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

Development of Technology for Detailed Investigation Inside PCV

FY2018 Accomplishment Report

July 2019

International Research Institute for Nuclear Decommissioning

Contents

1. Research Background and Purpose

1.1 Reason Why the Research Project is Needed

[Background]

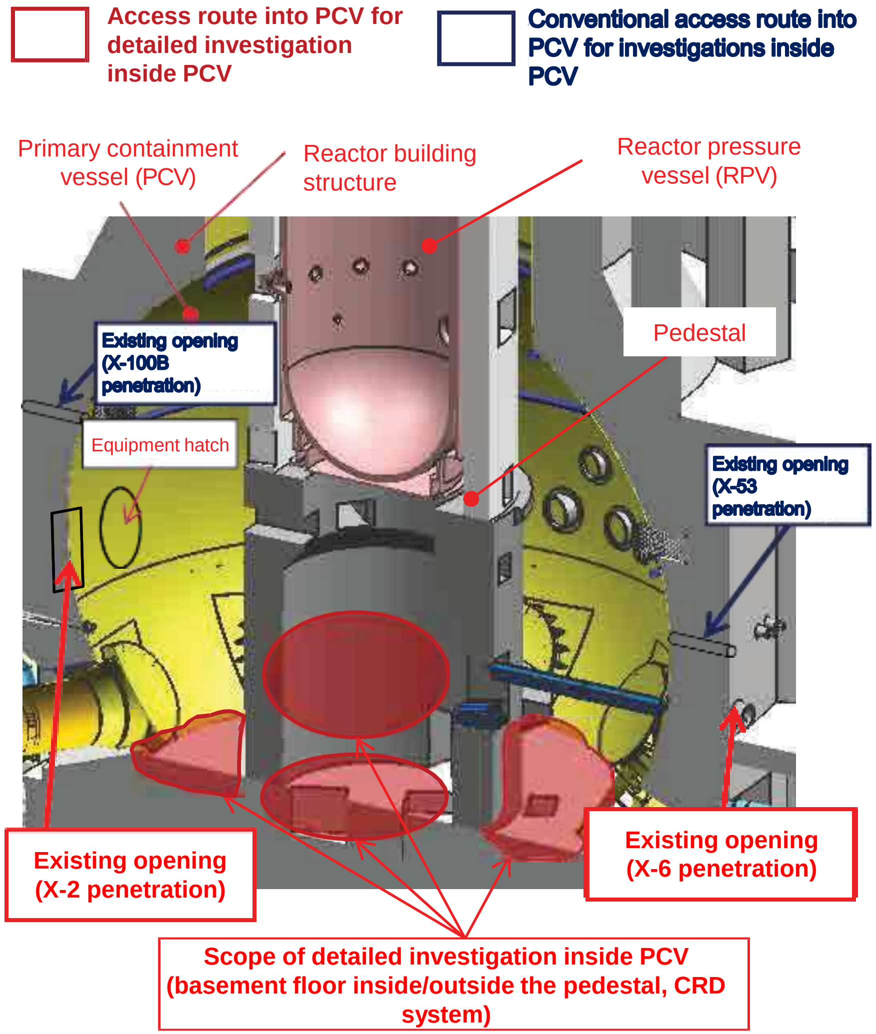
Investigations inside PCVs were performed in the following government-led projects in the past: B1/B2 Investigations (Unit 1), A1/A2/A2' Investigations (Unit 2), and Unit 3 Investigation using a small ROV.
While valuable information was obtained by these investigations, the size of the existing openings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

(Notes)
B1 investigation: Investigation of the top of the 1st floor grating outside the pedestal
B2 investigation: Investigation of the underground floor outside the pedestal
A1 investigation: Investigation of the condition of the rail of the control rod drive mechanism (hereinafter referred to as "CRD")
A2 investigation: Investigation of the top of the platform inside the pedestal
A2' investigation: Investigation under the platform inside the pedestal



[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 to FY2018 Development of Technology for Detailed Investigation Inside PCV (this project)

- Development of investigation and development plans
- Development of access and investigation equipment
- Applicability verification of element technologies

↓

FY2018 Development of Technology for Detailed Investigation inside PCV
(On-site validation of technology for detailed investigation inside PCV considering measures for deposit)
Unit 1

FY2018 Development of Technology for Detailed Investigation inside PCV
(On-site validation of technology for detailed investigation inside PCV through X-6 penetration)
Unit 2

↓

Research on the detailed design of methods and devices for fuel debris retrieval (including fuel debris retrieval work, earthquake resistance, repair, and criticality control)

Information for determination of fuel debris retrieval method and detailed design of fuel debris retrieval devices, etc.

Research on fuel debris sampling

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		Implementations to be accomplished in FY2018	Corresponding sections in this document
Development of investigation and development plans	Unit 2*	Based on the latest site conditions, the investigation plan shall be continuously reviewed, materialized, and updated	4.1
	Unit 3	Assessment of the applicability of the devices developed for Units 1 and 2 to Unit 3 and the clarification of whether there are any issues to be addressed in this regard	
Development of access and investigation equipment	Establishment of access route into PCV from existing pass-through hole (X-6 penetration)	Design, production and In-plant verification test of equipment pertaining to establishment of access route in PCV	4.2
	Establishment of access route into PCV from an existing pass-through hole (X-2 penetration)	In-plant verification test of the full-scale prototype of equipment pertaining to establishment of access route into PCV	4.3
	Production and verification of access and investigation equipment	Design, production and In-plant verification test of the full-scale prototype of access and investigation equipment	4.4
Applicability verification of element technologies		Verification test of measurement technologies to be incorporated in access and investigation equipment	4.5
Design and setup for mockup test facility		Completion of review of mockup test procedures of the arm type access equipment and design of the test facility, and commencement of the partial production	4.6

* The investigation and development plans for Unit 1 have clarified and updated in FY2017.

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

2.2 Relations between items and relations with other research (1/2)

[This project (FYs 2017-2018)]

Investigation and development planning
- Update and materialization of the plans based on the latest information on the inside of the PCVs

Establishment of access route into PCV through X-6 penetration
- In-plant verification test of the isolation room, hatch operating device, etc.
- Connection with investigation equipment: Steps from detailed design to in-plant verification

Establishment of access route into PCV through X-2 penetration
- Implementation of steps from detailed design to factory verification test for devices related to the establishment of access route into the PCV

Production and verification of access and investigation device
- Screening of access equipment
- Access and investigation equipment: Steps from detailed design to in-plant verification (Steps from detailed design to partial production are to be implemented for the arm type access and investigation equipment)

Applicability verification of element technologies
- Test of measurement technologies to be incorporated in access and investigation equipment

Design and setup for mockup test facility
- Development of test procedures and the design and partial production of the test facility for the mockup test of the arm type access equipment

FY2018 to FY2019 Development of Technology for Detailed Investigation inside PCV (On-site validation of technology for detailed investigation inside PCV considering measures for deposit) — Unit 1

Development of investigation and development plans
- Detailed plan for steps from mockup test to on-site validation

On-site validation of access and investigation equipment and investigation technology
- Preparation, mockup test and on-site validation of test facility

FY2018 to FY2019 Development of Technology for Detailed Investigation inside PCV (On-site validation of technology for Detailed Investigation inside PCV through X-6 penetration) — Unit 2

Development of investigation and development plans
- Detailed plan for steps from mockup test to on-site validation

On-site validation of access and investigation equipment and investigation technology
- Steps from partial production, full assembly, In-plant verification test, mockup test, to on-site validation of access and investigation equipment

(Above listed actions are planned to be started in FY2019)

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

2.2 Relations between items and relations with other research (2/2)

		Cooperation organization	Details of cooperation	Cooperation duration	Notes
Example		• Other projects (name of projects) • TEPCO • NDF, etc.	• What information was exchanged, and who were the providers and the receivers of the information? • What was discussed, considered, and decided, who was involved in the discussion and decision? • Things like the above-mentioned are to be described in detail.	Specific period, name and frequency of a meetings, etc.	Other information on details of cooperation, and issues
Achievements	1	Criticality Control, Debris Retrieval, and Reactor Inside Condition Identification Projects	Based on the results of internal PCV investigations of Unit 1 and 3, discussions were had about for updating the plan for detailed internal PCV investigations of Unit 1 and methods to avoid a risk of criticality during deposit removal in a limited area.	August 7, 2017 August 22, 2017	
	2	METI ANRE, NDF, and TEPCO HD	Based on the results of internal PCV investigations of Unit 1 and 3, discussions were had about updating the plan for detailed internal PCV investigations of Unit 1. Deposit sampling was requested	August 9, 2017	
	3	Debris Retrieval, Reactor Inside Condition Identification, and PCV Repair Projects, TEPCO HD, and NDF	Discussions were had on whether the results of the investigation met the needs for the implementation of a detailed investigation inside PCV as well as whether new needs had arisen based on the results of the A2' investigation. Needs of investigation were brought up such as the investigation of the conditions of deposit by direct contact.	Meeting to clarify specific needs for detailed investigation inside the PCV(February 9, 2018)	
	4	Debris Retrieval, PCV Repair, Seismic Evaluation, and Sampling Projects	Hearings were conducted with relevant project teams in order to reexamine the needs based on the results of investigations inside the PCVs conducted on Unit 1, 2 and 3 until FY2016.	Meeting for discussing needs for detailed investigation inside the PCV (1st session on February 20, 2018)	
	5	Criticality Control Project, TEPCO HD, and NDF	Hearings were conducted with relevant project teams in order to reexamine the needs based on the results of investigations inside the PCVs conducted on Unit 1, 2 and 3 until FY2016.	Meeting for discussing needs for detailed investigation inside the PCV (2nd session on February 22, 2018)	

Criticality Control Project: Development of fuel debris criticality control technology
Debris Retrieval Project: Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures
Reactor Inside Condition Identification Project: Upgrading the Comprehensive Identification of Conditions inside Reactor
PCV Repair Project: Full-Scale Test of Maintenance Technology for Leak Locations in PCV
Seismic Evaluation Project: Development of the method to evaluate the seismic resistance and the impact of earthquakes on the PCV and RPV
Sampling Project: Development of Sampling Technology for Retrieval of Fuel Debris and Internal Structure

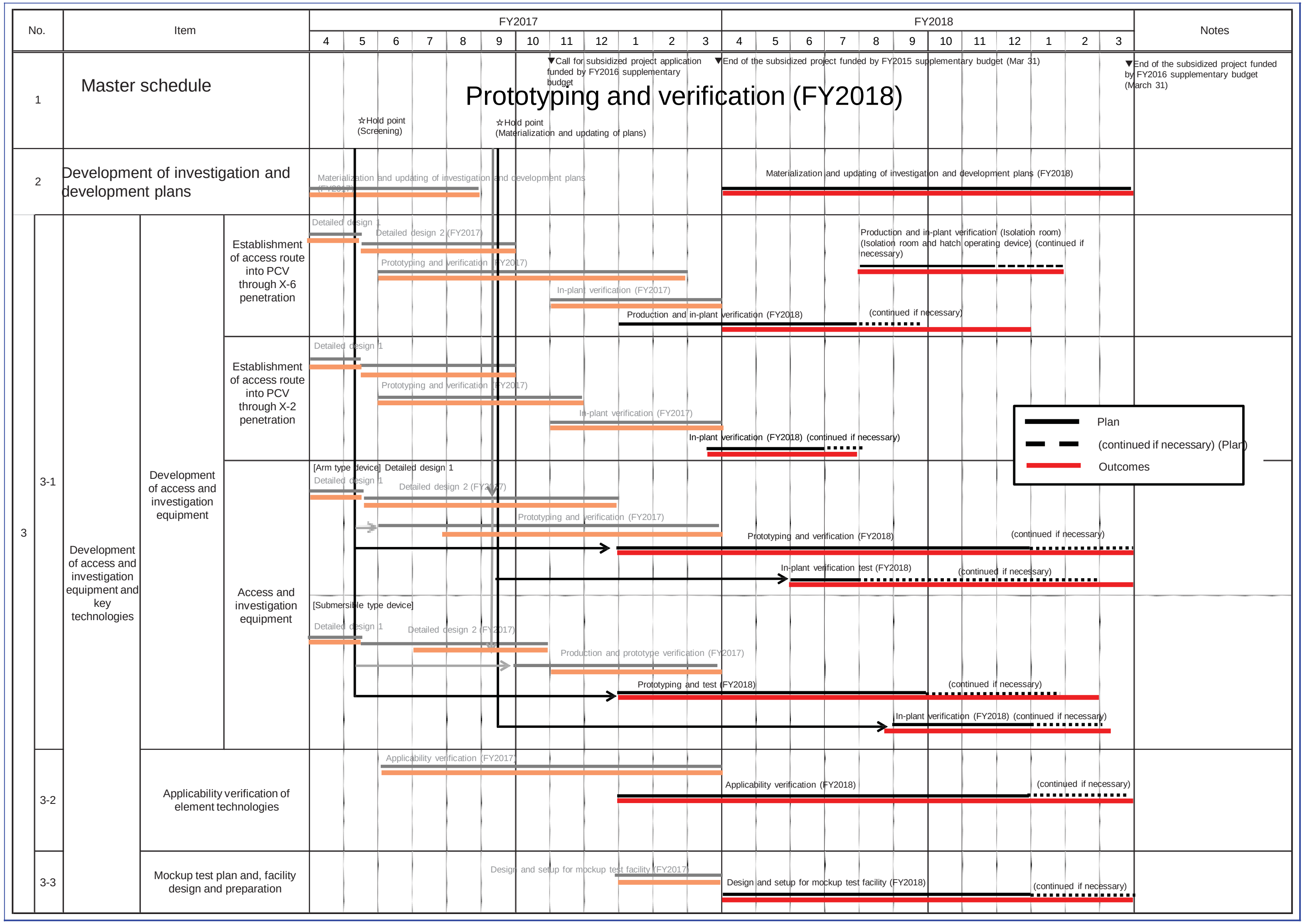
METI ANRE:
Ministry of Economy, Trade and Industry, Agency of Natural Resources and Energy
NDF: Nuclear Damage Compensation and Decommissioning Facilitation Corporation
TEPCO HD: Tokyo Electric Power Company Holdings, Inc.

2.3. Project Goals

Implementation Items and Results			Achievement index (FY2018)
Development of investigation and development plans		Unit 2*	Based on the latest site conditions, the investigation and development plans shall be reviewed, materialized, and updated
		Unit 3	The applicability of the devices developed for Units 1 and 2 to Unit 3 shall have been examined, and it shall have been made clear whether there are new issues to be addressed in this regard.
Development of access and investigation equipment	Establishment of access route into PCV through X-6 penetration	Opening of the hatch	Design/production and In-plant verification test of equipment pertaining to establishment of access route into PCV shall have been finished (Target TRL: Level 4 or 5)
		Development of new part of boundary by the connection joint	Production and In-plant verification test of a full-scale prototype structure connecting to X-6 penetration shall have been finished
	Establishment of access route into PCV through X-2 penetration		In-plant verification test shall have been completed for the access route into the PCV. (Target TRL: Level 4 or 5)
	Access and investigation equipment		Design, production, and In-plant verification test shall have been completed for a full-scale prototype of access and investigation equipment (Target TRL: Level 4 or 5)
Applicability verification of element technologies			The verification test of measurement technologies, to be incorporated in access and investigation equipment, shall have been completed. (Target TRL: Level 4 or 5)
Design and setup for mockup test facility			Review of the mockup test procedure of the arm type access equipment and design of the test facility completed, and setup started (not included in project goals)

* The materialization and update of the Unit 1 investigation plan and the development plan was done in FY2017.

3. Implementation Schedule and Organizational Framework (1/2)



3. Implementation Schedule and Organizational Framework (2/2)

International Research Institute for Nuclear Decommissioning (IRID)

- Development of overall plan and technical management
- Total management over all technical matters related to the project including development progress management

Hitachi-GE Nuclear Energy, Ltd.

(1) Development of investigation and development plans
(2) Development of access and investigation equipment as well as element technologies
  1) Development of access and investigation equipment
    b) Establishment of access route into PCV through X-2 penetration
    c) Production and verification of access and investigation equipment
  2) Applicability consideration of element technologies

Toshiba Energy Systems & Solutions Corporation

(1) Development of investigation and development plans
(2) Development of access and investigation equipment and element technologies
  1) Development of access and investigation equipment
    a) Establishment of access route into PCV through X-6 penetration

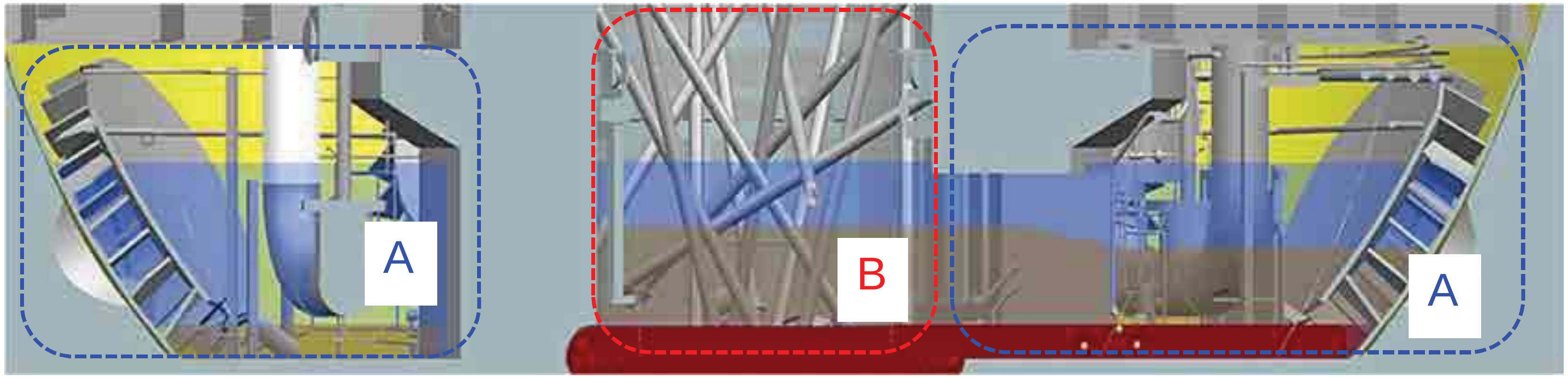
Mitsubishi Heavy Industries, Ltd.

(1) Development of investigation and development plans
(2) Development of access and investigation equipment as well as element technologies
  1) Development of access and investigation equipment
    a) Establishment of access route into PCV through X-6 penetration
    c) Production and verification of access and investigation equipment
  2) Applicability consideration of element technologies

4.1 Implementation Items and Results ― Development of Investigation and Development Plans (1/2)

(1) Materialization and update of the investigation plan for Unit 1 (Completed in FY2017)

- A large amount of deposit was found in Unit 1, which indicates the possibility of the collapse of the CRD housing and reactor internal structures.
- One of the important objectives of the on-site validation of the detailed investigation inside the Unit 1 PCV is to collect information required for the development of a deposit removal method and equipment, implementation of the debris removal, and planning for the dismantlement and removal of fallen objects, since the deposit and fallen objects need to be removed, before starting fuel debris retrieval work.



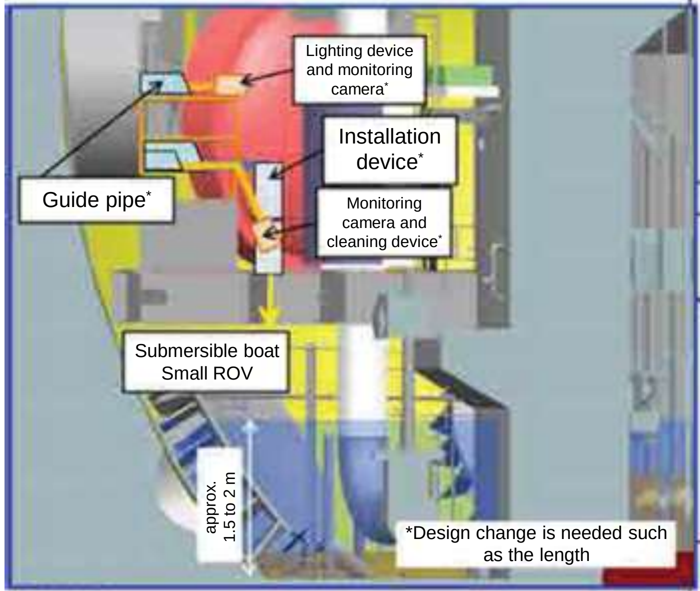
	Required priority information	Investigation methods
Outside pedestal - Workers access opening (A in the figure)	Information on the review of methods and facilities used for collecting deposit (such as the amount and the origins of the deposits) Information on the plans for deposit collection, dismantling and removal of fallen objects, etc. (such as the conditions under the deposit and the spread of fuel debris)	• Visual observation • Measurement* • Deposit sampling
Inside the pedestal (B in the figure)	Information on the planning of deposit collection, fallen object dismantlement and removal, etc. (Information on 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.)

*** Measurements here include the 3D mapping of the surface of deposit, measurement of the thickness of the deposit, and detection of fuel debris inside and under the deposits.**

4.1 Implementation Items and Results － Development of Investigation and Development Plans (2/2)

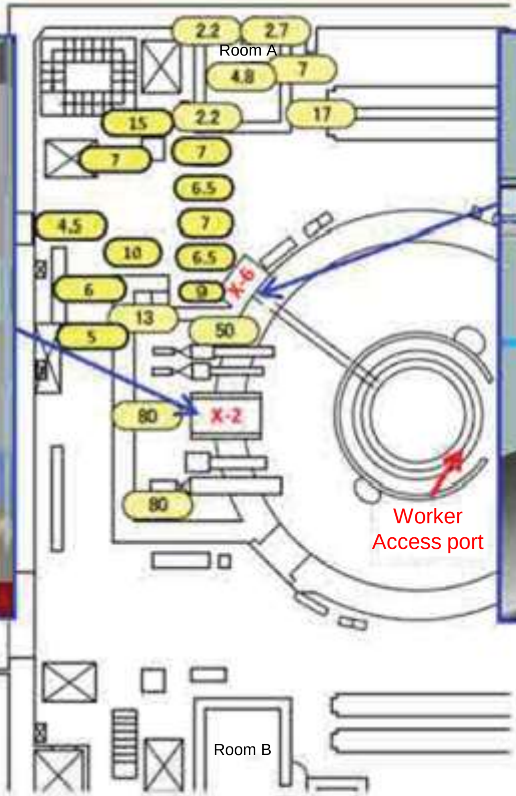
(2) Issues concerning applicability of devices developed for Unit 1 to be used for Unit 3

Investigation through X-2 penetration

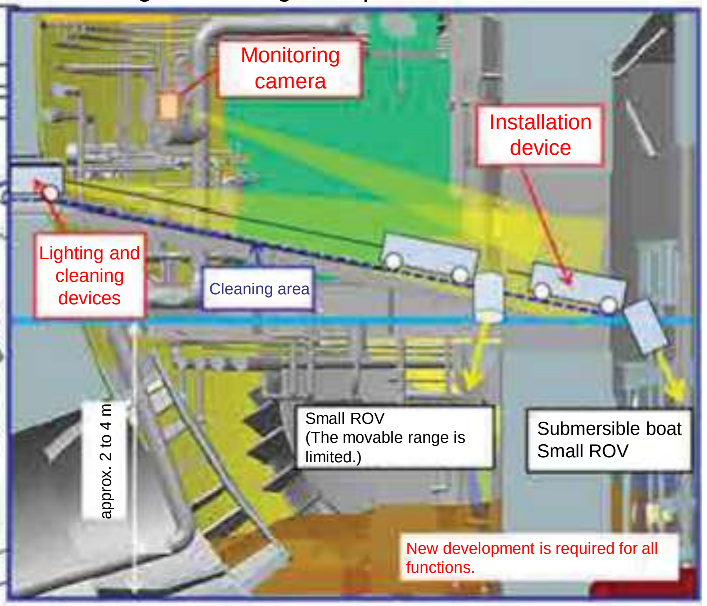


[Examples of new development]

(1) Intended area of investigation: Whole area outside the pedestal (a water depth of approx. 1.5-2 m)
(2) Investigation devices: Submersible boat and small ROV
(3) Things to be investigated: Same as Unit 1
(4) Issues: 1) reduction of radiation dose in the airlock room, and 2) design change (length change) for the opening machine, guide pipe installation machine and so on

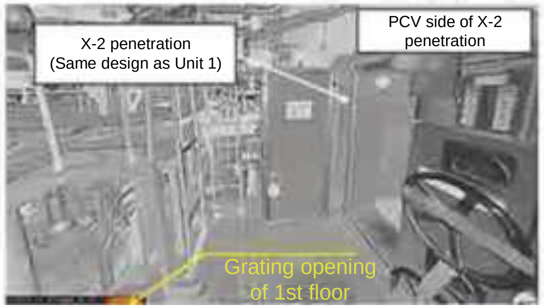


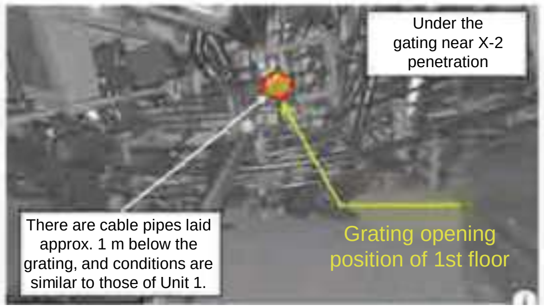
Investigation through X-6 penetration

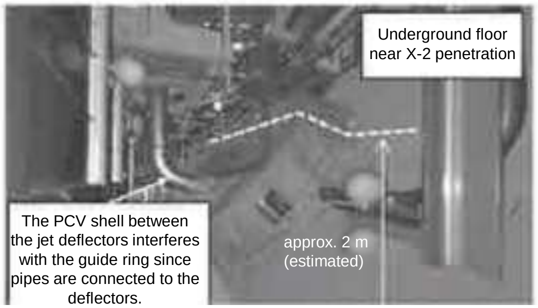


[Examples of new development]

(1) Intended area of investigation: Part of areas in and outside the pedestal (a water depth of approx. 2-4 m)
(2) Investigation devices: Submersible boat and small ROV
(3) Things to be investigated: Detailed visual inspection and measurement for the inside and detailed visual inspection for the outside
(4) Issues: Installation device, seal box, monitoring camera, cleaning device and so on should be newly developed







4.2 Implementation Items and Results
Establishment of Access Route into PCV through X-6 Penetration

(1) Opening of the Hatch (1/5) -- Isolation room design/production/in-plant verification test --

[Overview] In the on-site validation in Unit 2, the hatch of the X-6 penetration is opened by remote control to establish an access route into the PCV through the X-6 penetration for the investigation device while maintaining the PCV boundary.

[Progress in FY2018]

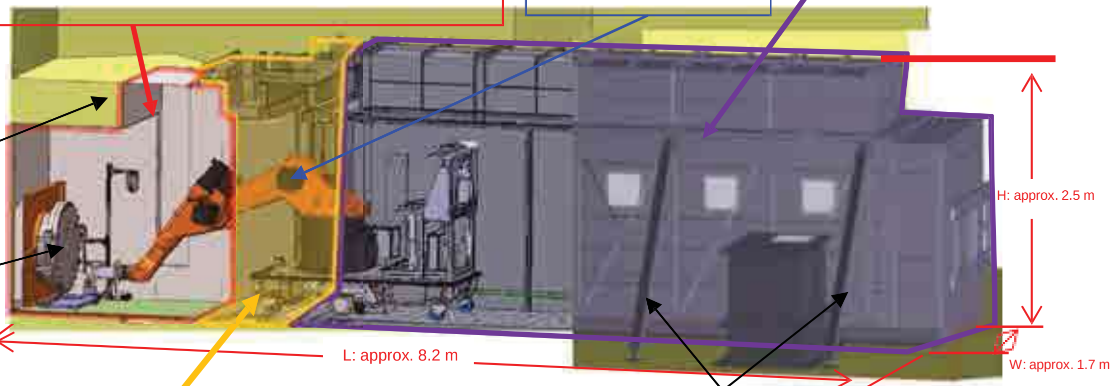
- In this project, the new isolation room with a downsizing and improved sealing performance and seismic resistance was designed and produced by reflecting the improvements achieved through the prototyping of the isolation room* in the project "Development of Technology for Detailed Investigation Inside PCV" in FY2017.

[Specifications and structure of the isolation room]

[Robot carrying-in compartment]
- Function: Establishing the PCV boundary when the hatch is opened and serving as a facility to carry in/out robots when the hatch is closed.
- Specifications: approx. 8 tons / W1.7 m x L5.3 m x H2.5 m

[In-stage isolation room]
- Function: Providing sealing ability from the sleeve of the X-6 penetration to the hatch isolation room in the concrete stage to maintain the soundness of the PCV boundary
- Specifications: approx. 1 ton / W1.2 m x L1.7 m x H1.8 m

Hatch opening device
(See the next page.)



[Hatch isolation room]
- Function:
  a. Establishment of the PCV boundary when the hatch is opened
  b. Establishment of the PCV boundary and providing sealing ability by the airtight door when the hatch is opened
- Specifications: approx. 5.5 tons / W1.7 m x L5.3 m x H2.5 m

[Specifications common to all isolation rooms]
- Withstand pressure: 6 kPaG (Control value for the Unit 2 reactor should be 5.5 kPaG or less)
- Main material: Carbon steel

[Robot carrying-in compartment]

<Prototype>

W2.7 x L5.9 x H2.7 m

Downsizing
(Reduced on-site assembly work)

<Improved version>

W1.7 x L5.3 x H2.5m

* The isolation room is the integrated structure of the in-stage isolation room, hatch isolation room, and robot carrying-in compartment.

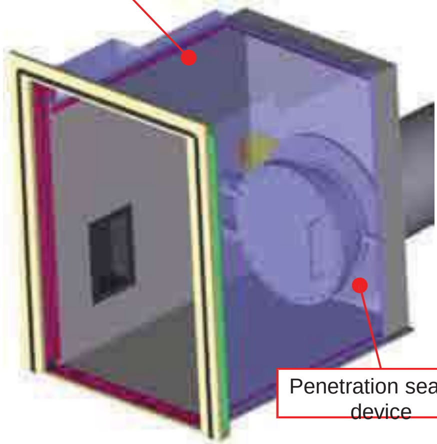
Establishment of Access Route into PCV through X-6 Penetration

(1) Opening of the Hatch (2/5) -- Isolation room design/production/in-plant verification test --

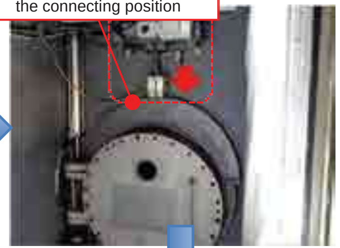
[Implementation items for FY2018] The in-plant verification test confirmed the feasibility of installing the isolation room, and proved that the air leakage rate is lower than the maximum permissible rate. In addition, issues of work procedures were identified for the on-site validation, and countermeasures for the identified issues were implemented.

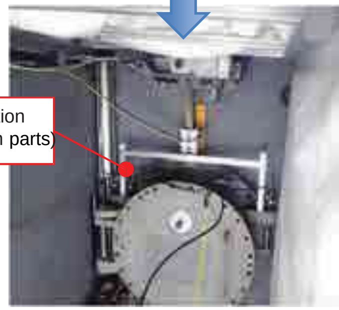
[In-stage isolation room]

- Test result 1: The remote-controlled transportation of the compartment was proved to be feasible.



- Test result 2: The installation of the penetration sealing device by remote control was proved to be feasible.

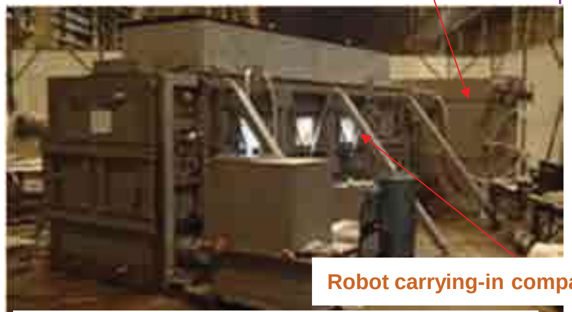




[Hatch isolation room and robot carrying-in compartment]

- Test result: The test confirmed the availability of installing and constructing the room and compartment by workers

After in-stage isolation room and hatch isolation room are connected



After hatch isolation room and robot carrying-in compartment are connected

(1) Opening of the Hatch (3/5) -- Hatch opening device: In-plant verification test --

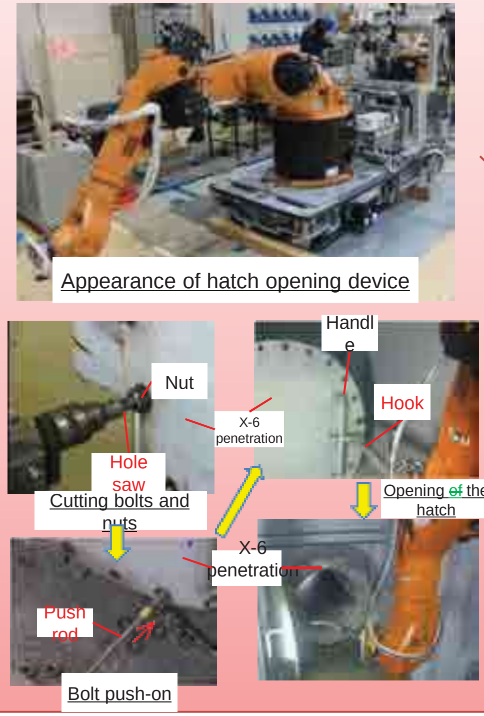
[Implementation items for FY2018]

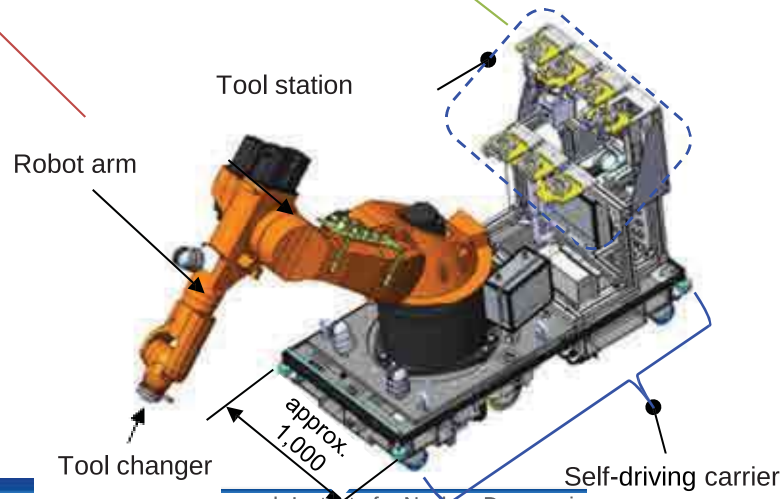
- The function test of the hatch opening device was completed in the project “Development of Technology for Detailed Investigation Inside PCV” in FY 2017. In this project, the hatch opening device was combined with the isolation room, and in-plant verification test was performed on the combined structures. (See the next page.) Through this test, issues that may arise in each work step of the hatch opening device carrying-in and installation operation, as well as hatch opening operation, were identified, and countermeasures for the identified issues were taken toward the on-site validation.

[Specification and structure of hatch opening device]

- Required functions
  The following types of work, all of which is essential to open the hatch of the X-6 penetration, shall be performed by remote control:
  - Cutting bolts and nuts
  - Bolt push-on
  - Collection of bolts and nuts
  - Opening the hatch
  - Cleaning flange surfaces
- Equipment specifications:
  - Dimensions (approx.):
    approx. W1 x L2 x H1.6 m
  - Weight:
    approx. 2.3 tons

Examples of tools attached to the tool changer





(1) Opening of the Hatch (4/5) -- Hatch opening device: In-plant verification test --

[Carrying-in and installation of Hatch opening device]

- Test result: The test confirmed the availability of the carrying-in and installation of the hatch opening device into the robot carrying-in compartment.

Robot carrying-in compartment

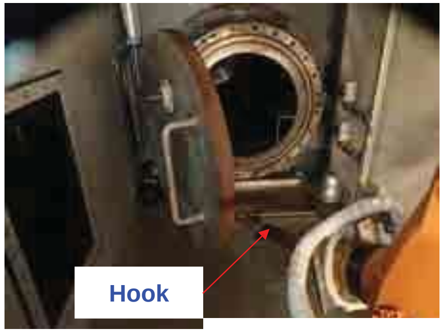
View A

[Hatch opening work]

- Test result: The test confirmed the availability of a remote operated work to open the hatch in the isolation room.

X-6 penetration

Cutting bolts and nuts by hole saw



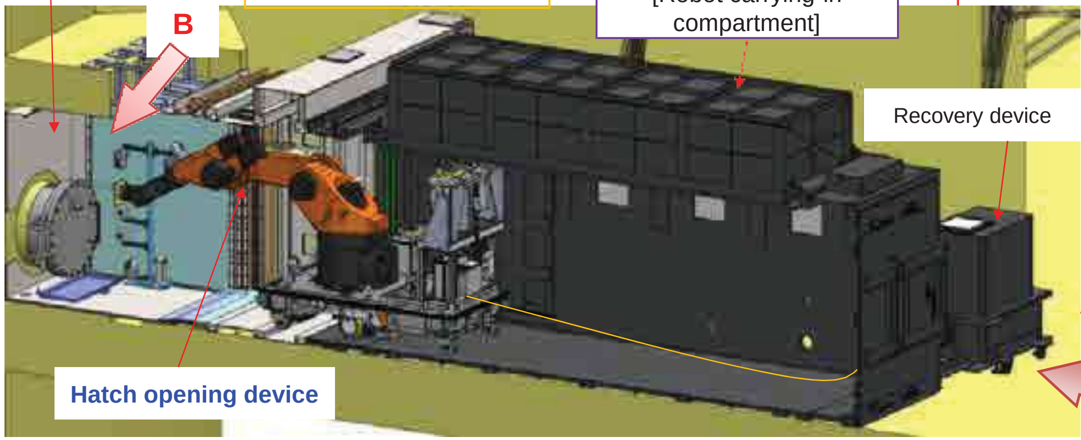
Opening the hatch by hook

View B

[In-stage isolation room]

[Hatch isolation room]

[Robot carrying-in compartment]



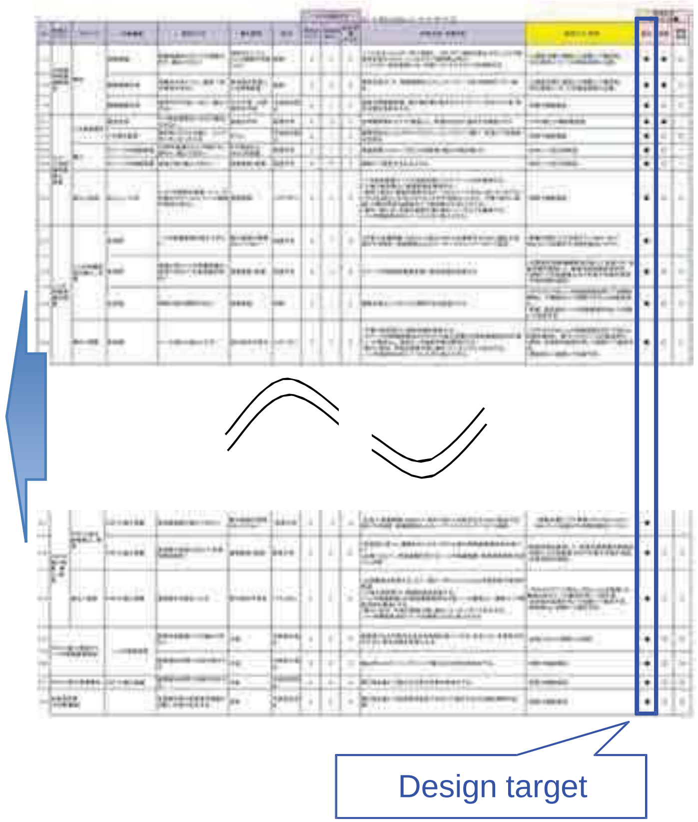
: Photographing direction

(1) Opening of the Hatch (5/5) -- Typical Examples of Risk Prevention (Reflected to Design) --

Devices and structures		Major risks (Possible problems)	Countermeasures (those reflected to design)
Isolation room	In-stage isolation room	Unable to carry-in due to high dose level	Use an air caster to carry in by remote control under a high radiation environment.
Isolation room	In-stage isolation room	The seam between the penetration and the in-stage isolation room cannot be sealed sufficiently due to the undulation of the outer surface of the penetration caused by rust or the like	Clean the outer surface of the penetration and remove rust on it before installing the in-stage isolation room to secure the quality of sealing.
Isolation room	Hatch isolation room	Unable to carry-in due to high dose level	Install a shield in the in-stage isolation room by remote control before installing the hatch isolation room to reduce radiation levels.
Isolation room	Hatch isolation room	The leak tight door cannot be operated due to the failure of the drive mechanism	The leak tight door is designed so that it can be operated manually from the outside of the isolation room.
Isolation room	Robot carrying-in compartment	Unable to carry-in due to high dose level	Install a shield in the in-stage isolation room by remote control before installing the hatch isolation room to reduce radiation levels.
Isolation room	Common	The seam between the compartments that is formed as the result of on-site work cannot be sealed sufficiently.	Apply a double-packing to the seam between the compartments, and perform a leak test on the side
Hatch opening device		The hatch opening device fails due to high radiation levels.	Use parts with high radiation resistance for the hatch opening device and install a shield when necessary
Hatch opening device		The hatch cannot be opened due to stuck bolts and nuts.	Cut the thread portion of the bolts and nuts with a hole saw and remove them.
Hatch opening device		The hatch cannot be opened due to stuck hatch.	Prepare a special wedge-shaped tool used to release the stuck hatch

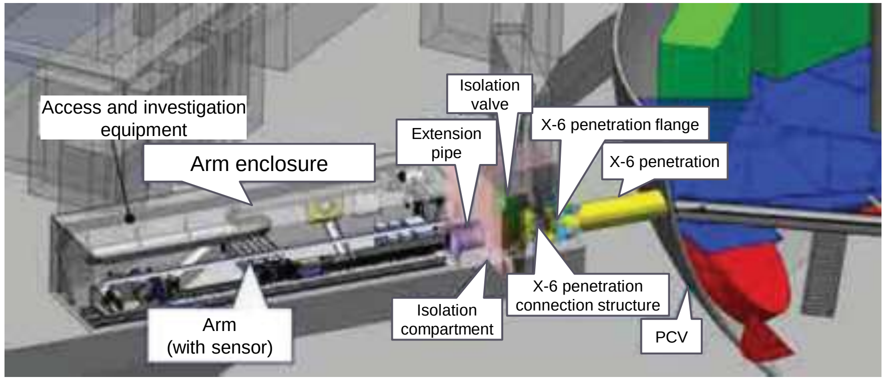
Risks were exhaustively analyzed for each work step, and the results were reflected in the design

Example of risk analysis (for route establishment)



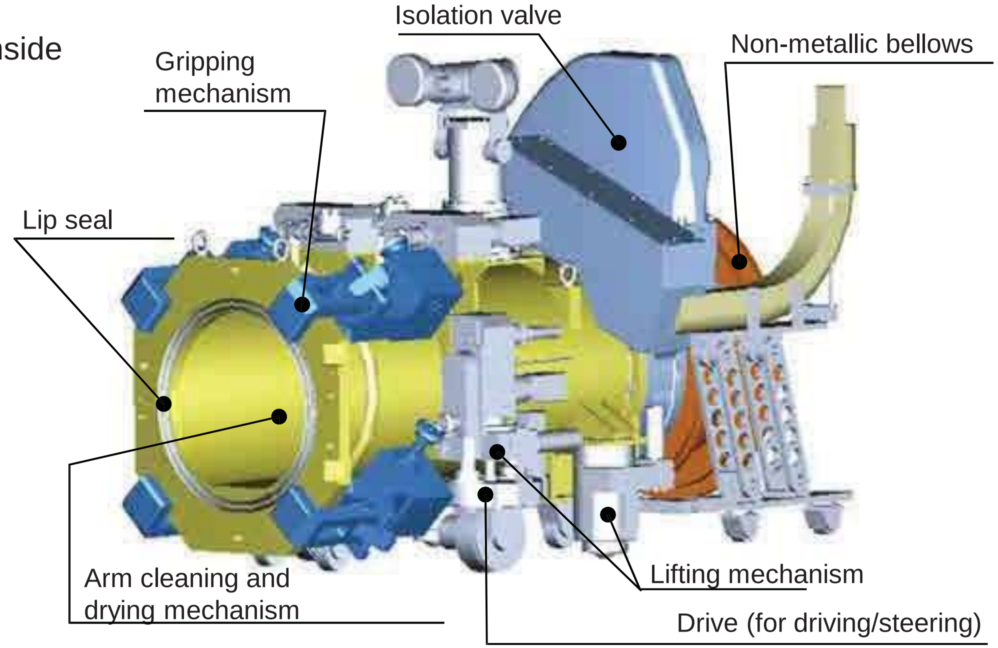
(2) X-6 Penetration Connection Structure (1/5) -- Design, manufacturing and in-plant verification test--

[Summary of results] The X-6 penetration connection structure, which establishes a new part of the PCV boundary after the opening of the hatch, was designed and produced, and the in-plant verification test (functional test) was completed for the on-site validation.



[Specification and structure of X-6 penetration connection structure]

- Dimensions: W1,065 x L1,850 × H1486 mm
- Weight: approx. 1,600 kg
- Main material: SUS304/aluminum alloy
- Function: Gripping, driving and steering, lifting, isolating, and arm cleaning and drying functions
- Isolation valve: Pneumatic pendulum valve with an inside diameter of 550 mm
- Withstand pressure: 10 kPaG



(2) X-6 Penetration Connection Structure (2/5) -- Design, production and In-plant verification test--

Required functions	In-service period	Mechanism/part	Required specifications	Results of verification tests	
Access route establishment	1 year	Gripping mechanism	Gripping force of 2.5 tons per clip	✓	Confirmed by verification test
	5 days	Drive and lifting mechanism	Shall be capable of moving the connection joint to the right position so that the axes of the X-6 penetration and the joint are aligned accurately and the flanges of them contact with each other properly.	✓	Confirmed by verification test
Fixation of access route and maintenance of PCV boundary	1 year	Main body of the connection joint, connecting flange and the seal of the flange	Welding and inspection shall be conducted in line with the requirements for class 3 equipment specified by the JSME standard.	✓	Confirmed by construction and inspection records
			Double seal	✓	Confirmed by verification test
		Isolation valve	Maximum permissible leakage rate shall be 0.05 vol%/hr.	✓	Confirmed by verification test
		Arm cleaning and drying mechanism	Cleaning and drying of the arm shall be performed properly. (Cleaning wastewater shall not be discharged into the enclosure side.)	✓	Confirmed by verification test
		Bellows	PCV boundary shall be maintained	✓	Confirmed by verification test
Dismantlement of access route	(to be used a year later)	Gripping mechanism	Gripping fingers shall be able to disengage in emergency situations.	✓	Confirmed by verification test
		Drive	Dismantlement of access route (All the parts of the access route shall be able to be disassembled and retrieved by remote control.)	✓	Verified by radiation resistance tests

* ✓: Compliance assurance made

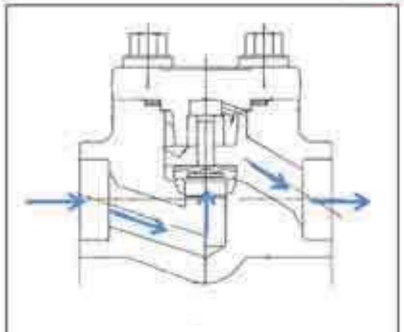
(2) X-6 Penetration Connection Structure (3/5) -- Design, production and In-plant verification test--

[Main connection structure]

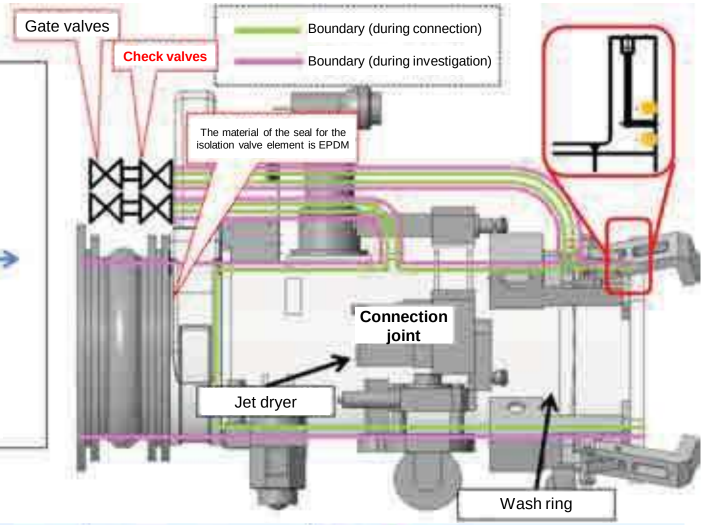
- It is designed in accordance with the requirements for class 3 equipment specified by the JSME standard.
- Check valves (JSME Class 2 valve) were installed in the pipe systems connected to the connection joint for cleaning water and nitrogen gas to form part of the PCV boundary.

[Sealing design]

- A lip seal is used due to its ability to fit with a given shape, taking into consideration that the surface condition (flatness) of the flange of the X-6 penetration is not known.



Check valve 20A
(JSME Class 2 valve)



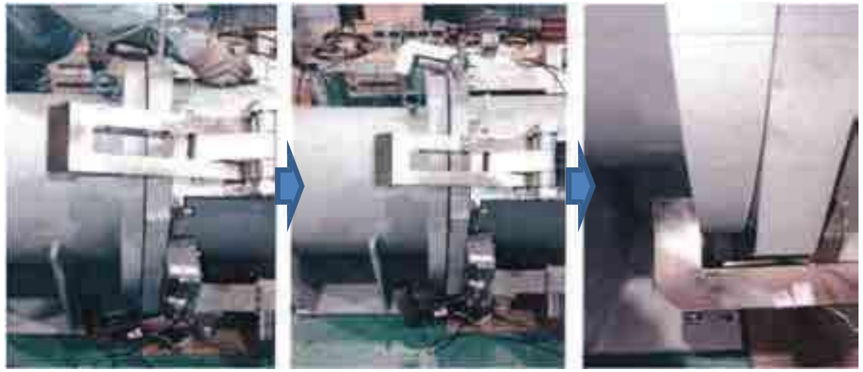
Lip seal (EPDM)

	O-ring	Lip seal	Inflatable seal	Liquid gasket
Illustration				
Advantages	–	• Margin of 2 mm applicable to undulation	• Margin of 2 mm applicable to undulation	Seal material follows the undulation of the surface well and provides good adhesion. (Applicable range of undulation is not known.)
Disadvantages	• Standard parts for sealing of machined surfaces have no margin applicable to the estimated undulation level	–	• Gas pressure needs to be applied continuously.	• Leak check cannot be performed (for seal material itself). • Difficult to control the amount of seal material to be applied as well as the cleanness of the surface • Peeled by shear force • Radiation resistance is not known.
Ability to deal with flaws	○ Seal material is pressurized into the gap	○ Seal material is pressurized into the gap	○ Seal material is pressurized into the gap	△
Assessment	△	◎	○	△ (Needs to be combined with one of the sealing methods listed on the left.)

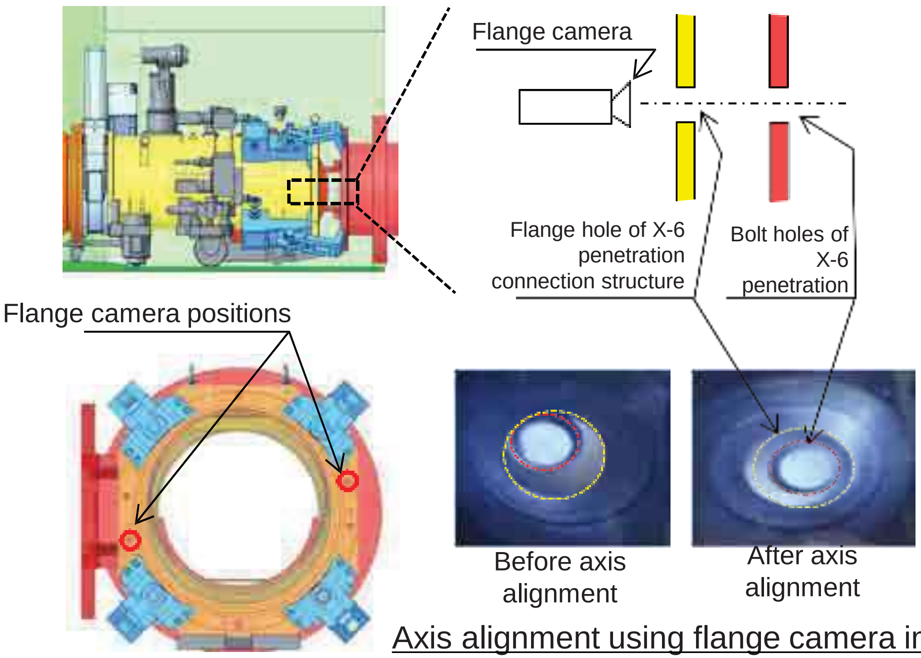
(2) X-6 Penetration Connection Structure (4/5) -- Design, production and In-plant verification test--

[Gripping mechanism and axis aligning mechanism]

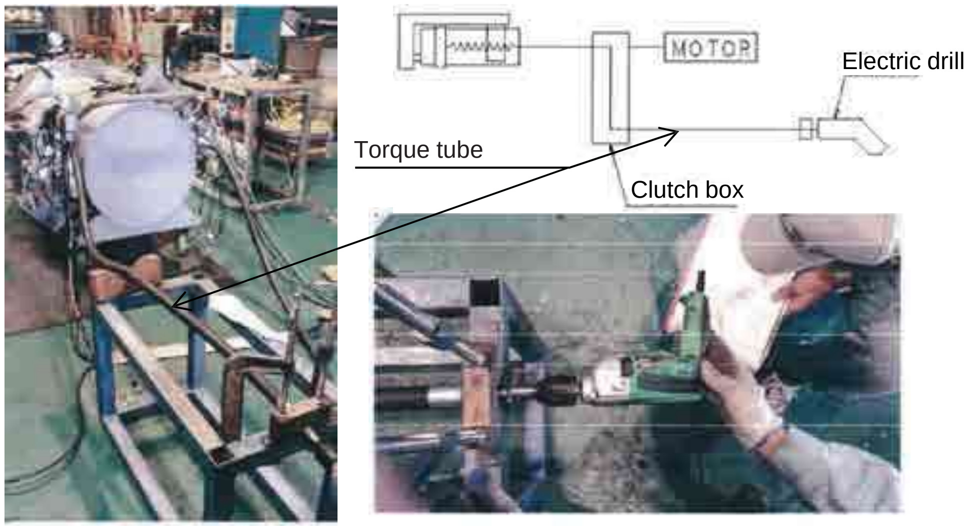
- The test confirmed that the gripping mechanism can grip the flange of the penetration with an intended gripping force (2.5 tons per clip)
- The test confirmed that the position and posture of the connection joint can be controlled as intended and the axes of the joint and the penetration were aligned accurately by using the data of the tilt angle of the X-6 penetration that was estimated based on the result of the point cloud analysis, etc., of the X-6 penetration and with the help of the flange camera image. (See the figure below.)
- The test confirmed that the gripping fingers can be disengaged by other means (torque tube) to prepare for the risk of the gripping mechanism failure.



Gripping mechanism Gripping operation



Axis alignment using flange camera images



Gripping finger release by torque tube

(2) X-6 Penetration Connection Structure (5/5) -- Design, production and In-plant verification test--

[Arm cleaning and drying mechanism]

- It was proved that a coin-type nozzle can provide decent cleaning performance with a pressure of 0.4 MPaG and a flow rate of 25 L/min.
- Outbound flow of the cleaning wastewater down the arm was suppressed to zero by two air nozzles, N_2 pressure of 0.06 MPaG, and N_2 flow rate of 90 L/min
- Additional tests are needed with a mockup of the arm that accurately simulates the shape of the actual arm.

Coin-type
CVVP908
0

Spray-type
NZRVFS1-2.0

Results of arm cleaning test

No.	Type of nozzle	Pressure [MPaG]	Flow rate [L/min]	Total volume (m^3) (for 20 minutes cleaning)	Cleaning result
1	Coin-type	0.4	25	0.5	Good
2	Spray-type	0.2	24	0.48	Cleaning residues in the area corresponding to between the nozzles
3	Spray-type	0.1	18	0.36	Incomplete cleaning

Arm cleaning operation

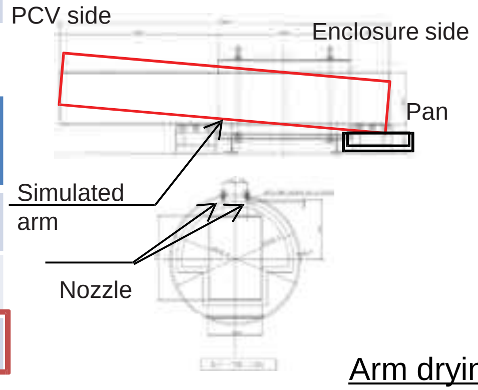
After cleaning test No. 1

After cleaning test No. 3

Arm cleaning test

Result of arm drying test

No.	Type of nozzle	N_2 pressure (MPaG)	N_2 flow rate (L/min)	Volume of outbound cleaning wastewater (L) (for 1 m length of the arm)	Total used N_2 volume (Nm^3/cycle)
1	6	0.3	200	9.8	15.9
2	2	0.2	150	0	9.0
3	2	0.06	90	0	2.9



Measurement of water inflow amount

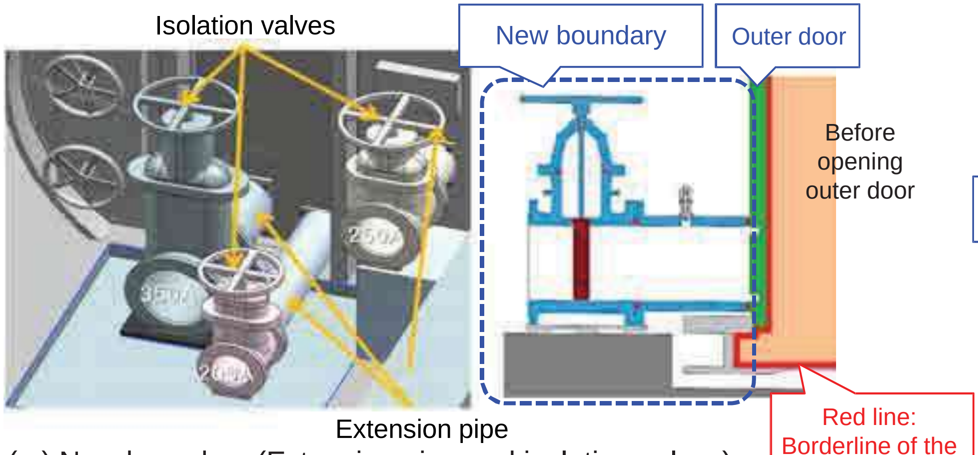
Arm drying test

4.3 Implementation Items and Results
Establishment of Access Route into PCV through X-2 Penetration (1/6)

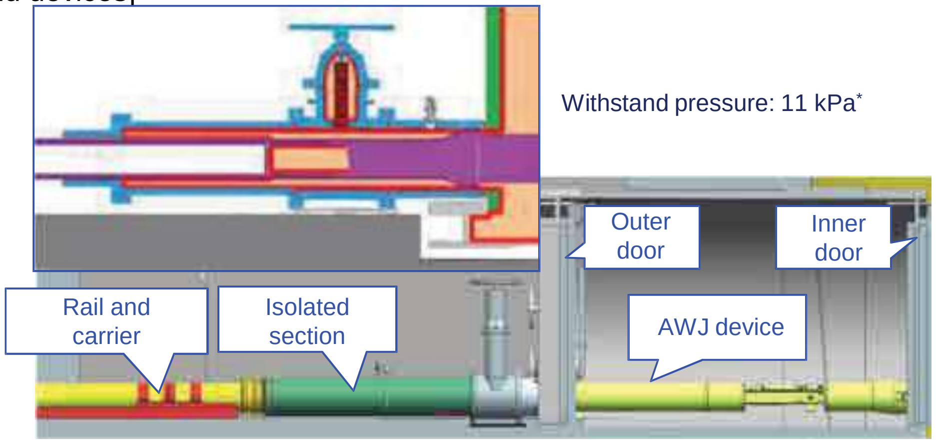
-- Design --

[Purpose] Final goal is to establish the access route into the Unit 1 PCV through the X-2 penetration. To achieve this goal, the following work is conducted while securing isolation from the inside of the PCV: installation of devices that form a new part of the PCV boundary, opening of the X-2 penetration, removal of internal structures in the PCV that may interfere with the establishment work, and the installation of the guide pipe.

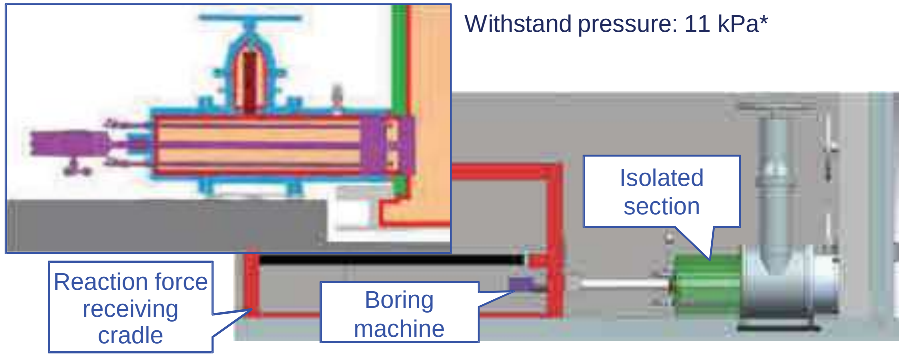
[Specifications and structure of the newly formed part of the boundary and devices]
Withstand pressure: 11 kPa (No leak shall be detected with bubble leak test.)



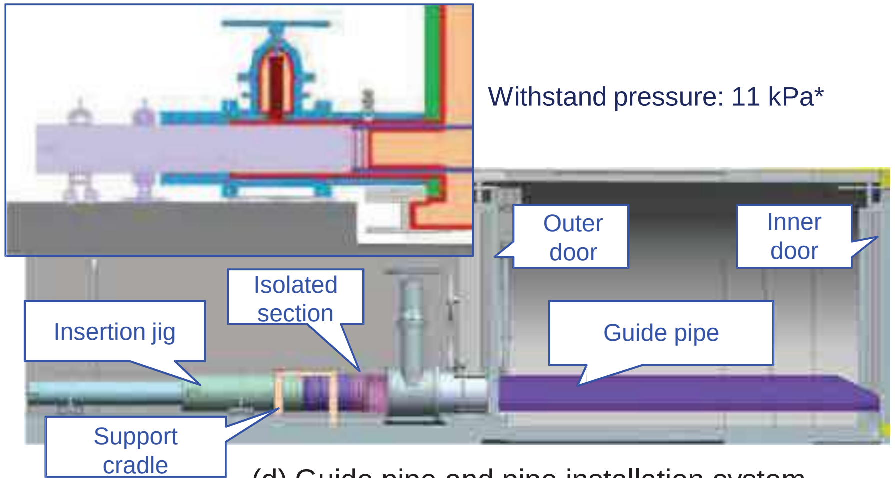
(a) New boundary (Extension pipe and isolation valves)



(c) Inner door opening device (AWJ device)



(b) Outer door opening system (Hole saw for metal)



(d) Guide pipe and pipe installation system

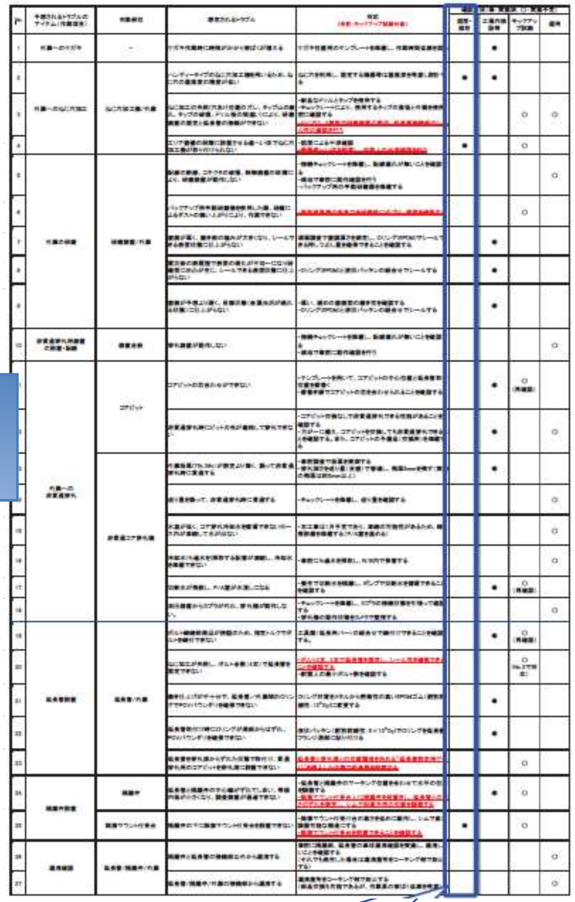
4.3 Implementation Items and Results
Establishment of Access Route into PCV through X-2 Penetration (2/6)
-- Risk Prevention (Reflected to Design) --

Category	Major risks (Possible issues)	Measures (those reflected to design)
New boundary connection	The perpendicularity of pilot screw holes is poor when they are drilled by using a handy drill machine	Consider the probable level of the perpendicularity of screw holes when designing devices that are fixed by screws
	An anti-vibration cradle cannot be installed under the isolation valves	Make the height of the cradle shorter and add a configuration that allows height adjustment by shims
Outer door opening	The O-ring on the extension pipe is damaged, and boundary performance is impaired.	Use a type of core bit (U-shaped groove bit) that doesn't contact the O-ring
Inner door opening, etc.	Garnet sand* deposits in the outer frame and rib, obstructs the rotation of the AWJ* head, and disturbs the drilling work	Change the design of the nozzle rotation mechanism to make it resistant to the deposit of the garnet sand
	Control of the AWJ head direction and expansion and contraction of the telescopic mechanism cannot be executed due to the absence of pressure applied to the cylinder	Use an anti-blowback hose coupler for the joints of the pressurized water pipe system
	AWJ cannot be retracted as its rotation shaft is deformed	Design the structure of the rotation shaft so that it is freed when it is forcibly pulled.
	Unable to retract the AWJ head as its telescopic mechanism is deformed	Increase the strength of the telescopic mechanism and add means to detect the contact of the AWJ head with other objects to prevent the telescopic mechanism from being subjected to abnormal loads
Others	The atmosphere dose rate in the airlock room increases due to the drilling of the inner and outer door, which disturbs the work	Analyze the atmosphere dose rate in the airlock room after a through hole is formed in the both doors and prepare a shield
	PCV gas that leaks through the sealing of the sliding contact surface spreads contamination	Enclose the airlock room with housing and provide a filtered local exhauster to prevent the spread of contamination outside the room
	The identification of individual pipes is not possible so it cannot be determined which pipe can be cut and which one cannot	Confirm that the pipes to be cut are cable pipes by reference to drawings and photos

* AWJ stands for abrasive water jet. Garnet sand is an abrasive used with an abrasive water jet machine

Risks were exhaustively analyzed for each work step, and the results were reflected in the design

Examples of risk analysis (New boundary connection)

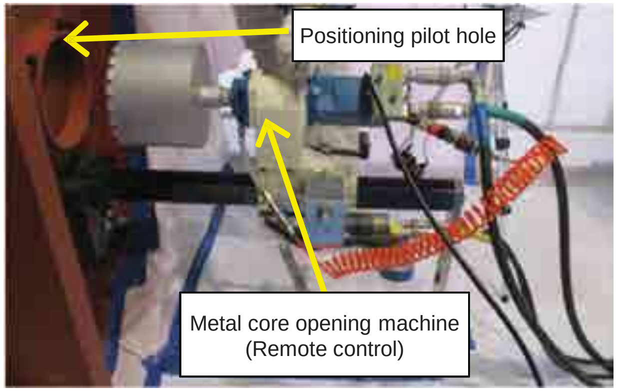


4.3 Implementation Items and Results
Establishment of Access Route into PCV through X-2 Penetration (3/6)
-- Production and In-plant validation (New Boundary Connection) --

- Issues associated with the construction method, devices, and procedures were identified through reviewing work procedures, and measures for the identified issues were taken
- It was proved that a bubble leak test can detect the leakage or non-leakage from the connecting part.

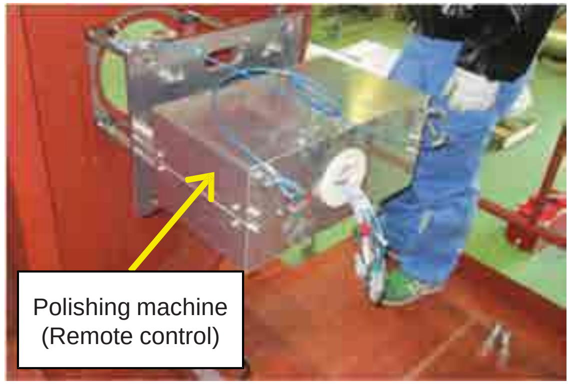
a) Bolt hole cutting

b) Blind hole opening



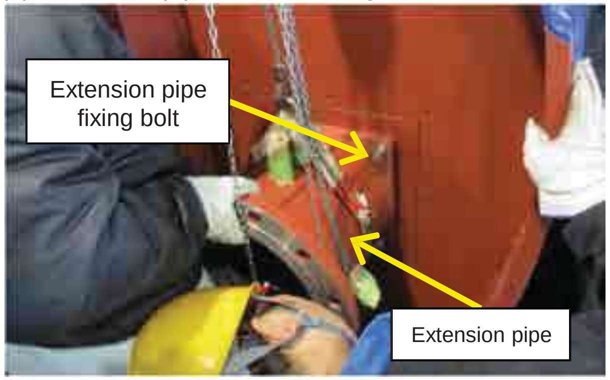
[Issue] Unable to pull out the core bit when drilling a positioning pilot hole
[Solution] Change opening method from using a positioning pilot hole to direct opening at a position marked by a scriber

c) Surface polishing (Coating removal)



[Issue] Unable to fix a device by bolts
[Solution] Devise the device mounting design taking into consideration the accuracy of bolt hole drilling

(d) Extension pipe bolt fastening



[Issue] Unstable sealing performance in repeated connection/disconnection work
[Solution] Change the material of the O-ring from metal to radiation-resistant rubber (EPDM) and the groove of the extension pipe from L-shaped to rectangular-shaped

(e) Isolation valve bolt fastening

After establishment of new boundary connection

Figure 4.3-1. Work Steps to Establish New Boundary Connection

4.3 Implementation Items and Results
Establishment of Access Route into PCV through X-2 Penetration (4/6)
-- Production and opening (Airlock Outer Door Pass-Through Drilling) --

- Issues associated with the construction method, devices, and procedures were identified through reviewing work procedures, and measures for the identified issues were taken.
- Conditions for the outer door opening work were verified, and the feasibility of the opening work in an isolated environment was confirmed.

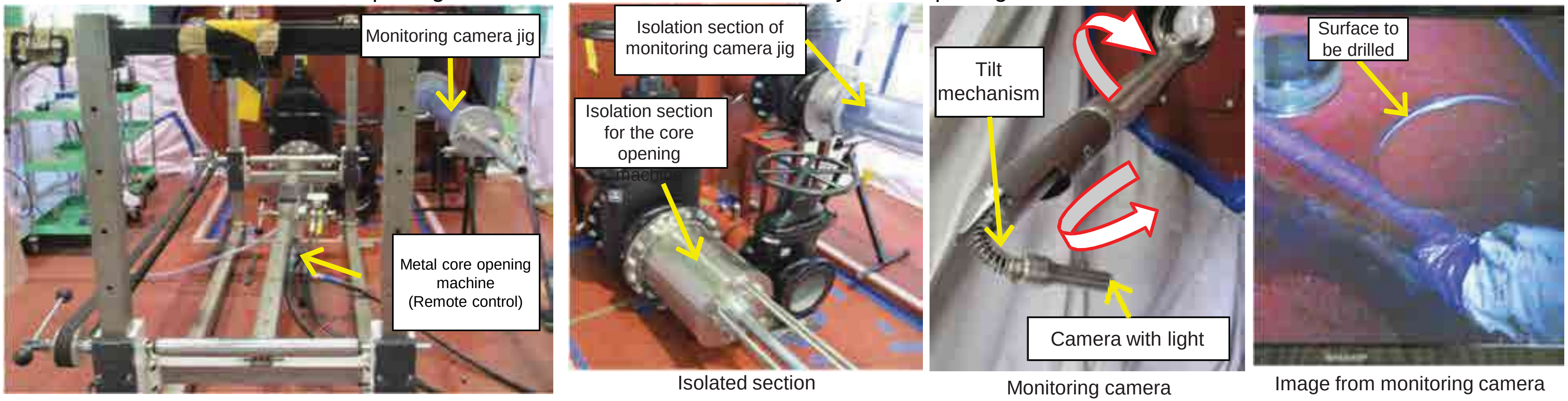
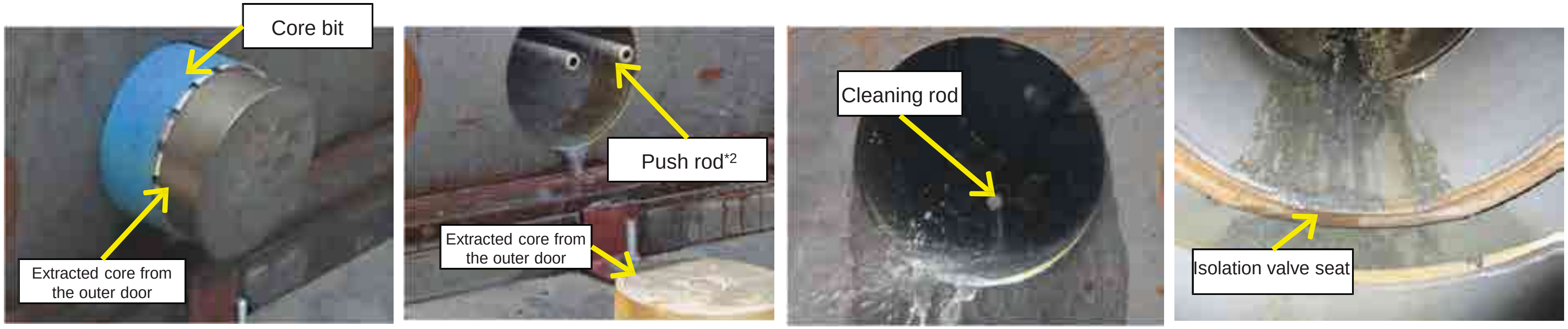


Figure 4.3-2. Outer Door Pass-Through Drilling Status



(a) Through hole opening *1 (b) Core extraction *1 (c) Grinding dust removal (Cleaning) (d) Grinding dust removal (Check) *2

*1: Check the condition of the inner surface of the drilled hole and extracted core, and check if anything noticeable occurred by using the monitoring camera.
*2: The observation of the condition of opening scrap removal is planned in the mockup test by installing an endoscope camera in the push rod.

[Issue] Boring scrap is moved to the isolation valve with the retraction of the core bit
[Solution] Change to a cleaning method (See the figure above.)

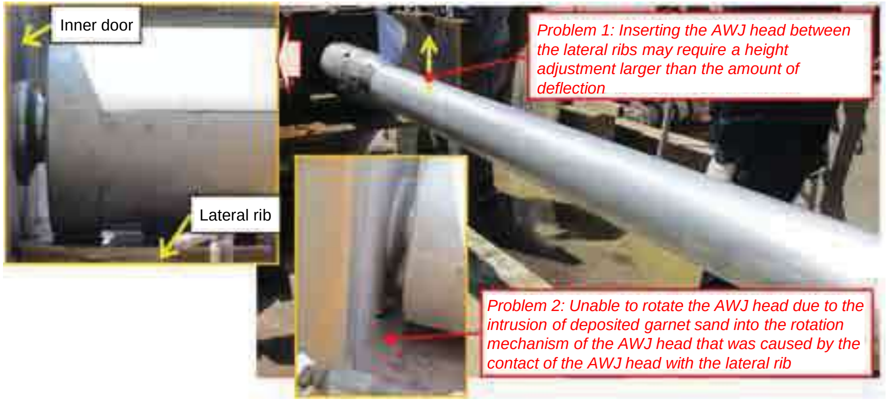
[Issue] Unable to remove grinding dust falling into the valve groove
[Solution] Change to a soft-seal valve

Figure 4.3-3. Main Steps after Pass-Through Drilling

4.3 Implementation Items and Results
Establishment of Access Route into PCV through X-2 Penetration (5/6)

-- Production and In-Plant Validation (Airlock Inner Door Opening) --

- Issues associated with the construction method, devices, and procedures were identified through reviewing work procedures, and measures for the identified issues were taken.
- Conditions for the inner door opening by the AWJ machine were verified, and the feasibility of the AWJ machine insertion work, without impairing the isolated condition of the work area, was confirmed.



[Solution 1] Add the function to adjust the height of the AWJ head
[Solution 2] Change the positional relationship between the AWJ head and the lateral rib so that more distance is provided between them

Figure 4.3-4. Inner Door Drilling Using AWJ for 250A

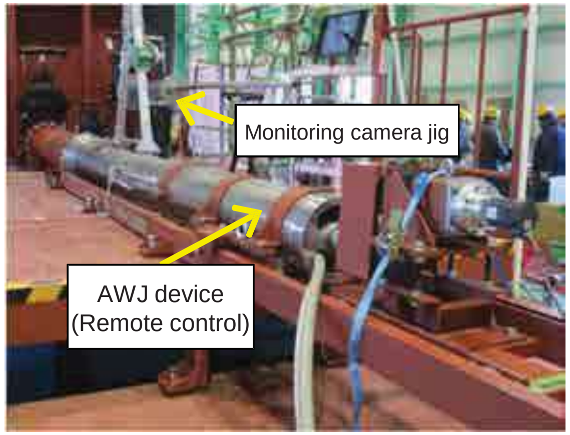


Image from monitoring camera

Figure 4.3-5. Inner Door Drilling Using AWJ for 350A

(a) Inner door drilling

(b) Handrail cutout

(c) Grating cutting out and interfering objects removal under the grating

[Issue] Excessive load is exerted to the high-pressure hose and other parts when the AWJ head is rotated
[Solution] Expand the outer diameter of the AWJ head to a size equal to that of its front edge to secure room to accommodate high-pressure hose and other parts

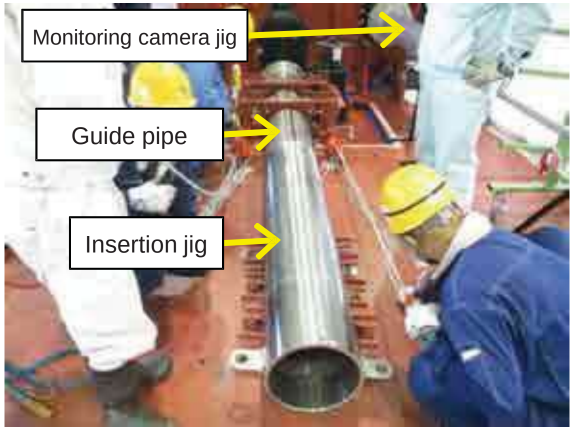
[Issue] Unable to check the setting condition of AWJ head from above the grating
[Solution] Add a monitoring camera on the telescopic mechanism

Figure 4.3-6. Examples of Verification Test Results of AWJ Installing Conditions (350A)

Establishment of Access Route into PCV through X-2 Penetration (6/6)

-- Production and In-Plant Validation (Guide pipe insertion) --

- It was demonstrated that the guide pipe can be inserted without impairing the isolated condition of the work area.
- Although there was no problem, the outer diameter of the 350A guide pipe for the AWJ head was changed according to a request from the investigation device team.



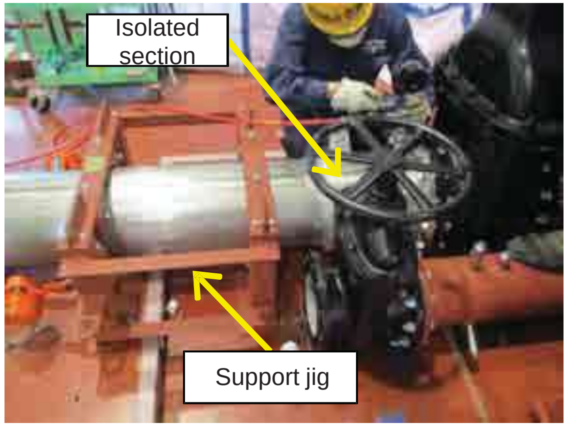


Figure 4.3-7. During Insertion of Guide Pipe for 350A

Figure 4.3-7. After Insertion of Guide Pipe

[Summary]

- Detailed design and production was carried out for the systems and devices that are needed to construct the access route into the PCV through the X-2 penetration for Unit 1, and the factory verification test (functional test) of them was performed
- In the factory verification test, the feasibility of pipe cutting work without impairing the isolated condition of the work area and conditions to realize such work were confirmed while reviewing the work procedures. At the same time, issues associated with the construction method, devices, and procedures were identified, and measures for the identified issues were taken

[Plan for the next step]

Measures developed in the above-mentioned activities are to be verified in the mockup test that will be performed as a part of the on-site validation of the project “Development of Technology for Detailed Investigation Inside PCV” (which is conducted taking into consideration measures for deposit). Based on the result of the verification, on-site validation is to be performed in Unit 1

4.4 Implementation Items and Results -- Access and Investigation Device --

(1) Arm-Type Device (1/8) --Overview--

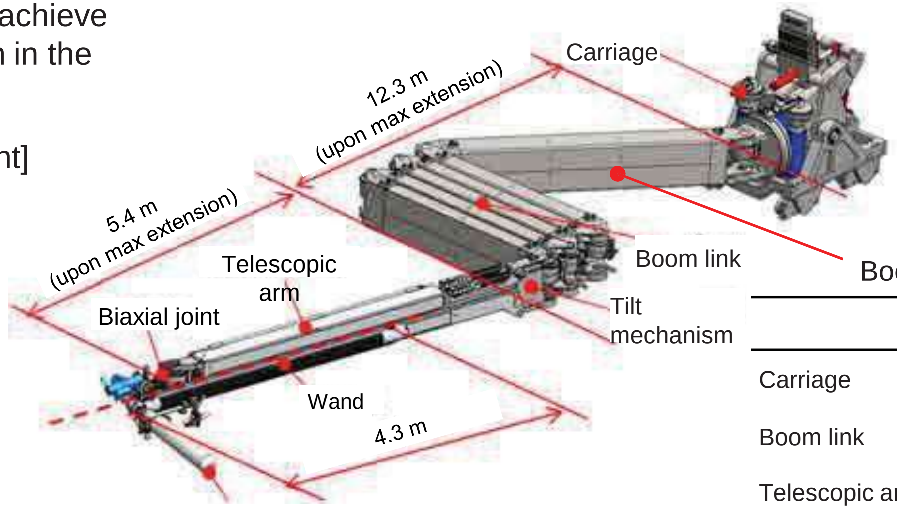
[Overview] The arm type device is a device used to achieve the access into the PCV through the X-6 penetration in the on-site validation in Unit 2

[Specifications and structure of arm-type equipment]

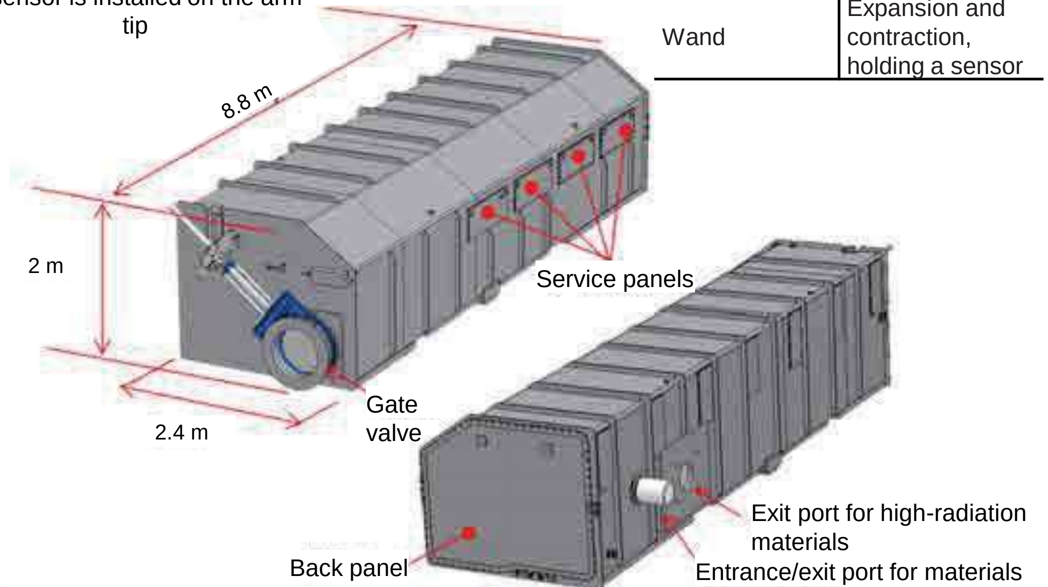
- ✓ Mountable sensor: 10 kg or less
- ✓ Mounted tools: Cutting and gripping tool, and water jet cutting tool
- ✓ Arm length: 22 m
- ✓ Pressing force: 400 N
- ✓ Positioning accuracy: ±100 mm
- ✓ Repetition accuracy: ±100 mm
- ✓ Cumulative dose: 1 MGy
- ✓ Accessories: Camera and light

[Specifications and structure of the arm enclosure]

- ✓ Thickness of outer panel:
  10 mm for top and side panels
  25 mm for bottom panel
- ✓ Weight: approx. 30 tons
- ✓ Main material: Stainless steel (SUS316L-equivalent)
- ✓ Designed to withstand pressure: From -5 to +10 kPaG
- ✓ Leakage rate: 0.05 vol%/h
- ✓ Accessories:
  Dual-arm manipulator for maintenance, gate valve, camera, light, and dosimeter



	Function
Carriage	Gripping and positioning
Boom link	Contraction and extension
Telescopic arm	Extension
Wand	Expansion and contraction, holding a sensor



4.4 Implementation Items and Results -- Access and Investigation Device --

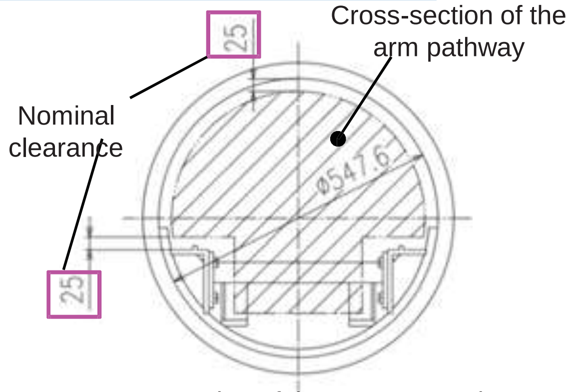
(1) Arm-Type Device (2/8) -- Typical Examples of Risk Prevention (Reflected in Design) --

Category	Major risks (Possible issues)	Measures (those reflected in design)
Carry-in of arm enclosure	Dimensions of the carry-in pathway are not large enough.	Conduct preliminary site survey, examine carry-in method, and downsize the arm enclosure
Installation of the arm enclosure and connection with the extension pipe	Inclination and offset of the arm enclosure occurs to the axis of the X-6 penetration	Install a flexible joint between the arm enclosure and the X-6 penetration to accommodate the inclination and offset
Arm manipulation in X-6 penetration	The arm contacts with the inner surface of the X-6 penetration	Install a camera on the arm as well as in the extension pipe to monitor the clearance to the inner surface.
	Water jet wastewater flows into the cell while cutting interfering objects	Install a dike in the X-6 penetration Connection Structure to force the wastewater to flow into the PCV.
Arm manipulation in PCV	The arm contacts with interfering objects.	Install an interlock to stop the driving motor immediately after detecting an abnormal motor torque.
	Cables are caught by interfering objects.	Run the cables inside the arm body or on the top of it, and minimize exposure to the outside of the arm.
	Loss of external power sources	Install a brake in the motor that kicks in when power is lost.
	Single failure of the arm drive mechanism (Everything else is fine.)	Make the system redundant by installing more than one motor, or installing a clutch between the motor and the arm. (Design the system so that the arm can be retracted automatically by using another motor.)
	The arm is caught by interfering objects	Install a mechanism to detach the wand.
Others	Hydrogen explosion	Replace the air in the arm enclosure with nitrogen.

4.4 Implementation Items and Results -- Access and Investigation Device --

(1) Arm-Type Device (3/8) -- Investigation arm design change --

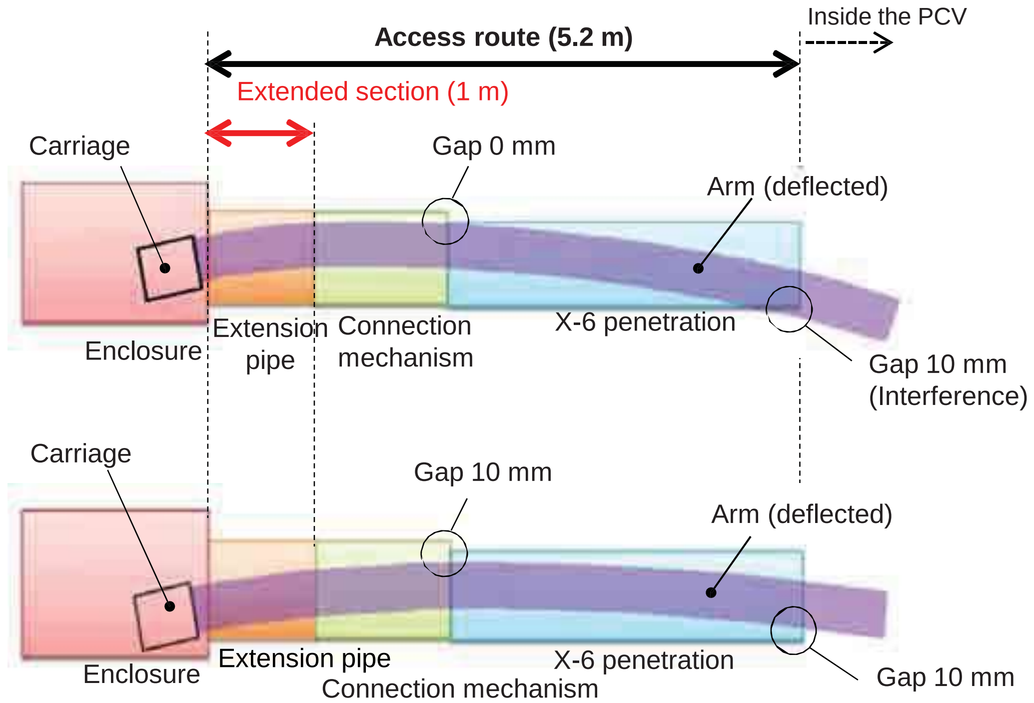
- The deflection of the arm needs be minimized due to very limited dimensions of the pathway allowed for the arm movement (especially inside the X-6 penetration).
- The total length of the access route was extended with the progress of detailed investigation concerning the access route establishment. Because of this, the maximum allowable deflection of the arm was decreased.
- High strength stainless steel (PH13-8Mo) was used for the boom links that constitutes the arm. In addition, the thickness of the box wall was reduced for weight saving, and machining tolerance was made stricter so that the deflection of the arm by its own weight was suppressed further.



Cross-section of the X-6 penetration

Before change
Original material:
17-4PH steel

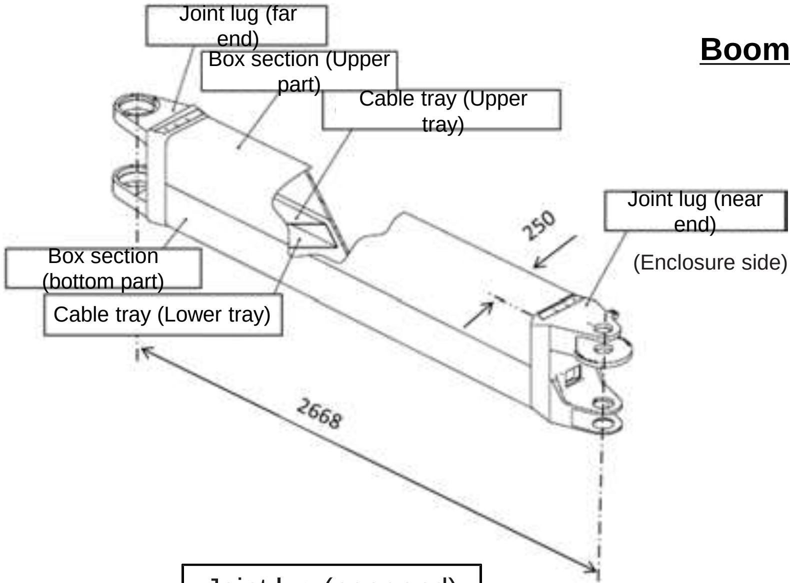
After change
Material:
PH13-8Mo
Weight saving by
wall thickness reduction



4.4 Implementation Items and Results -- Access and Investigation Device --

(1) Arm-Type Device (4/8) -- Production (Investigation arm boom link) --

Boom link



Boom link structure

- The box section of the boom links that constitute the arm, are made in a hollow rectangular pipe to reduce the weight and have cable trays inside to form pathways for cables
- The joint lugs provided on both ends of the box section are designed in shapes and strength so that they allow the boom link assembly to be folded compactly and support the weight of the arm with two connecting pins.
- The deflection of the arm will be measured after the completion of the arm with the final design. Correction shall be made if the measurement of the deflection of the final arm differs from what was estimated in the design.

Joint lug (far end)

Cut and shape a steel block

EBW joint

Box section

Bend a steel plate into a rectangular shape and form a rectangular pipe by welding the butted seam using electron beam welding (EBW)

EBW joint

Joint lug (near end)

Cut and shape a steel block

Connect the joint lugs on both ends of the box section by EBW, send it to heat treatment process, and perform finish machining to achieve dimensional accuracy

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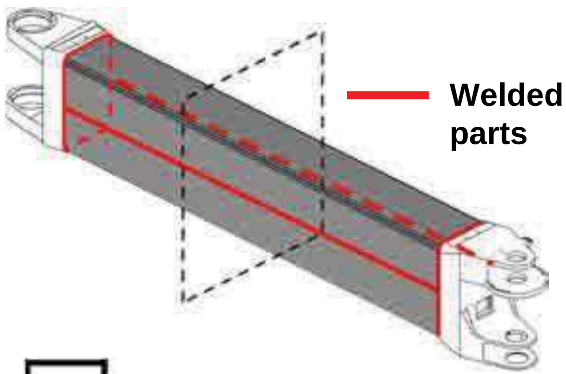
4.4 Implementation Items and Results -- Access and Investigation Device --

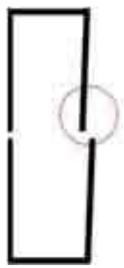
(1) Arm-Type Device (5/8) -- Production (Investigation arm boom link) --

Keys to successful boom link production

- Assurance of the bending accuracy of high strength stainless steel PH13-8Mo (installation of restraining jigs etc.)
- Assurance of the accuracy of weld groove cutting for welding to connect the joint lugs with the box section
- Assurance of the dimensional accuracy of final machining (Deformation due to heat treatment after welding must be considered.)

Issue (1): Assurance of bending accuracy and groove dimensions





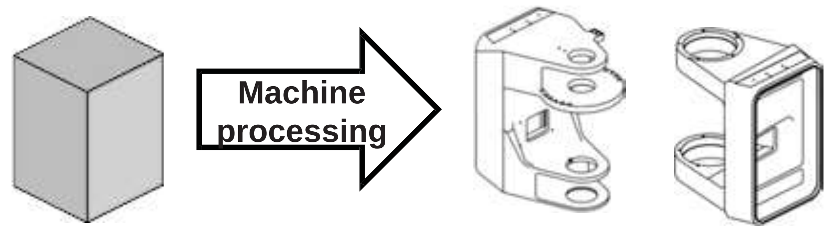
Cross-section of boom link

Since PH13-8Mo is a very strong and hard steel, it is not easy to achieve the required bending accuracy for the production of the top and bottom parts of the box section. Therefore, special methods need to be devised and new jigs need to be designed and built to position and fix the top and bottom parts at the right position (i.e., ensuring the accurate alignment of welding grooves) to perform butt welding with high dimensional accuracy.

Issue (2): Assurance of dimensional accuracy by machining

Forged steel block

Joint lug



Much machining work was required to produce thin-walled components for weight saving. In addition, the material was hard and shapes were complicated. For these reasons, the processing speed couldn't be increased, and it took longer to produce the components than expected.

(1) Arm-Type Device (6/8) -- Production (Investigation arm and enclosure) --

Production of arm components

- No. 1 boom link

- Telescopic arm

- Wand

- Enclosure

(1) Arm-Type Device (7/8) -- Verification Test --

Verification test of carriage

Purpose:

- Verify that the swivel joint, which connects the arm with the carriage in a swivel fashion, moves smoothly by testing the carriage test unit.

Test result:

- The test confirmed that the rotation angle of the swivel joint can be controlled smoothly with a resolution of 0.01 degrees under a cantilever load and axial torsional load being applied to the carriage test device.

Carriage specimen

Verification test of internal cables

Purpose:

- Conduct a test to verify the integrity of the internal cables against repeated bending stress by stretching and folding the simulated arm joint

Test result:

- The test confirmed that the internal cables have enough integrity without problems in electrical continuity and insulation against repeated bending stress by stretching and folding the simulated arm joint.

Cable test device

(1) Arm-Type Device (8/8) -- Verification Test --

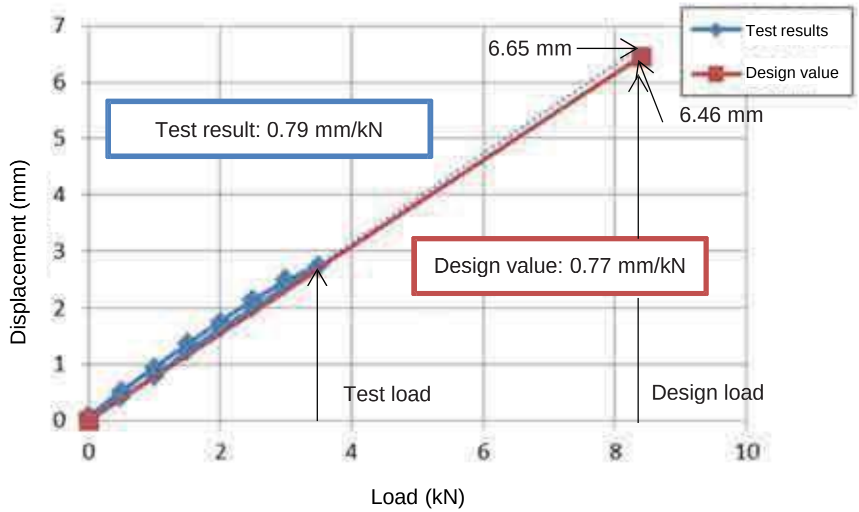
Boom link verification test

Purpose:

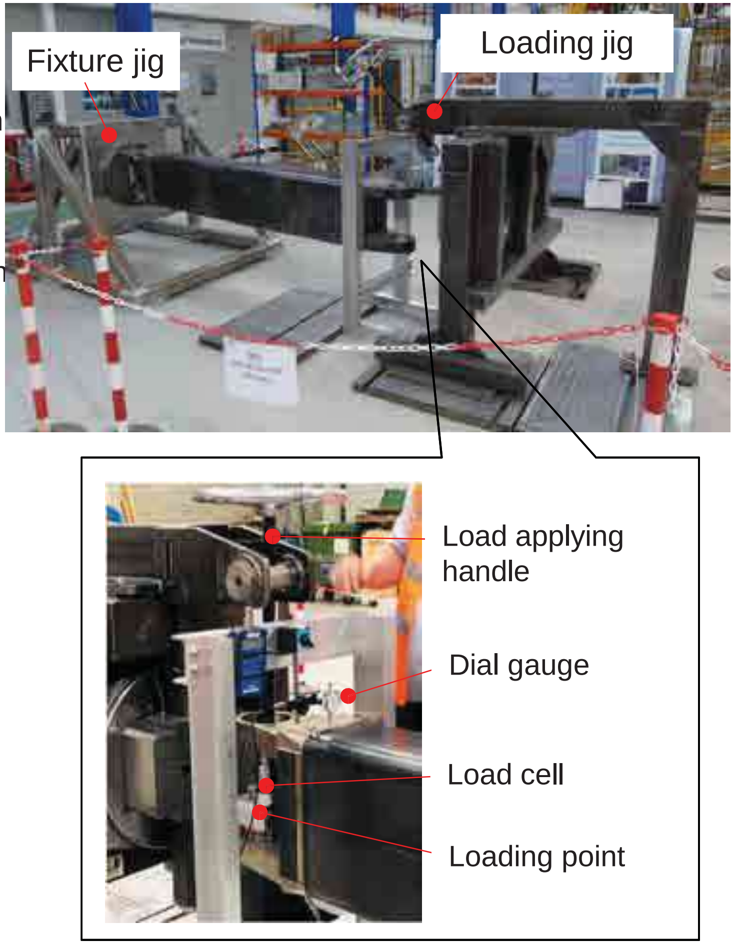
- In order to assess the technical feasibility of the arm type device, the deflection of boom link 1 was measured and its operation test was conducted.

Test result:

- The vertical load was applied to measure the deflection (see the figure on the right). In a result, the measured deflection was substantially equal to the design value (See the figure below). The operation test confirmed the motion range of the arm and the arm driving mechanism that the maximum driving torque of an actuator is sufficient to drive the arm driving torque.



Deflection test result



Deflection test setup

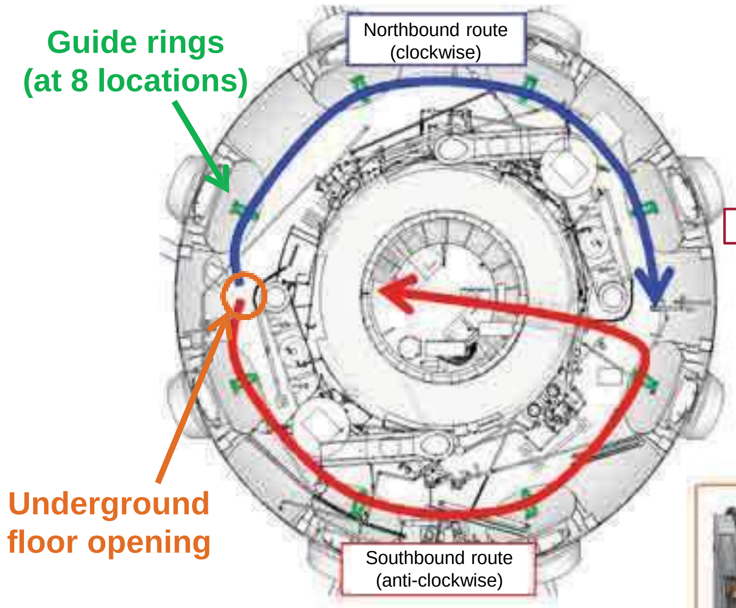
Part of the access and investigation devices were produced to confirm the productivity and verify technologies. The test results confirmed the feasibility of the device. From this result, this project was achieved the targeted results.

4.4 Implementation Items and Results -- Access and Investigation Device --

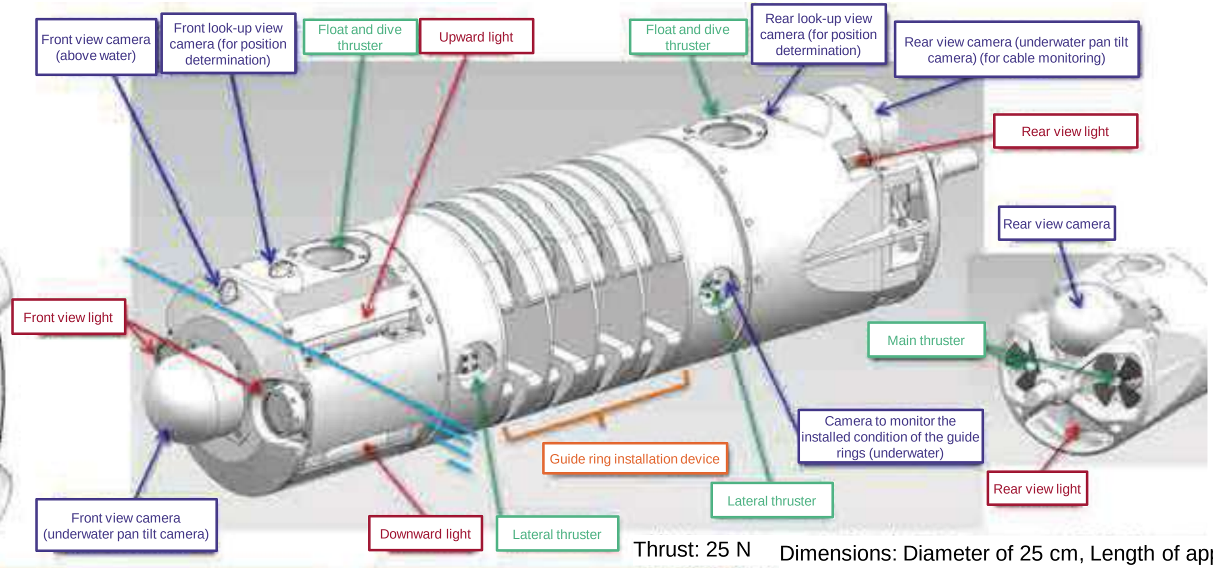
(2) Submersible Type Device (1/11) -- Design --

[Overview] The investigation device was inserted to the basement floor in the PCV through the X-2 penetration to investigate the condition over a wide area in the outer periphery of the pedestal as well as in the pedestal for Unit 1 on-site validation.

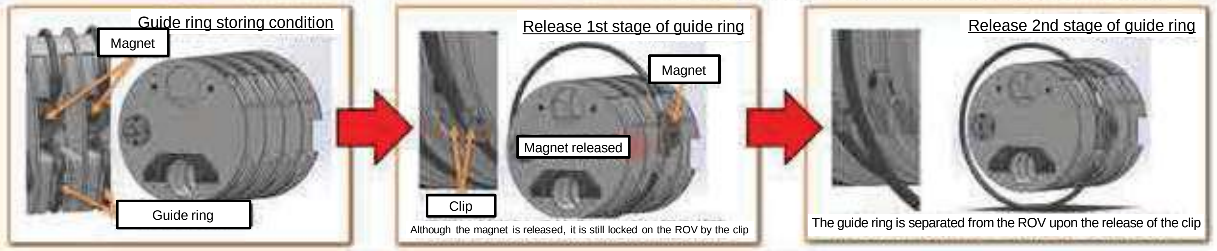
Investigation device	Measurement instrument	Intended use
ROV-A Guide ring installation	Fiber optic γ-ray dosimeter* (for ROV protection) * Same as that for B2	• To install the guide ring to the jet deflectors in order to prevent interference between cables and structures • To measure γ-ray dose rate in the traveling pathway of the ROV in order to assess the maximum operational time of the devices



Maneuvering route underwater



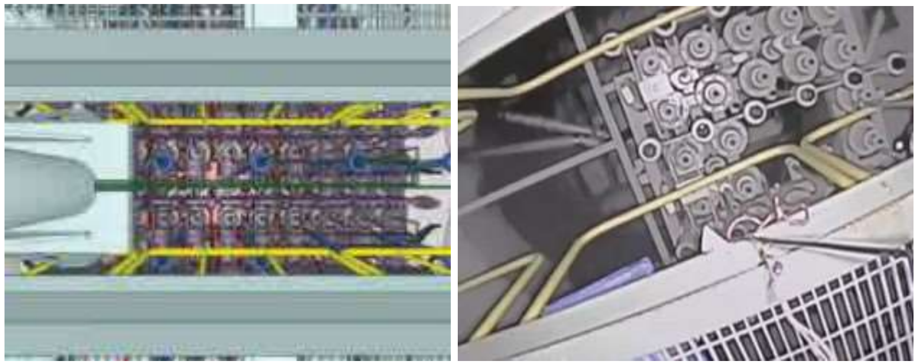
Thrust: 25 N Dimensions: Diameter of 25 cm, Length of approx. 110 cm



4.4 Implementation Items and Results -- Access and Investigation Device --

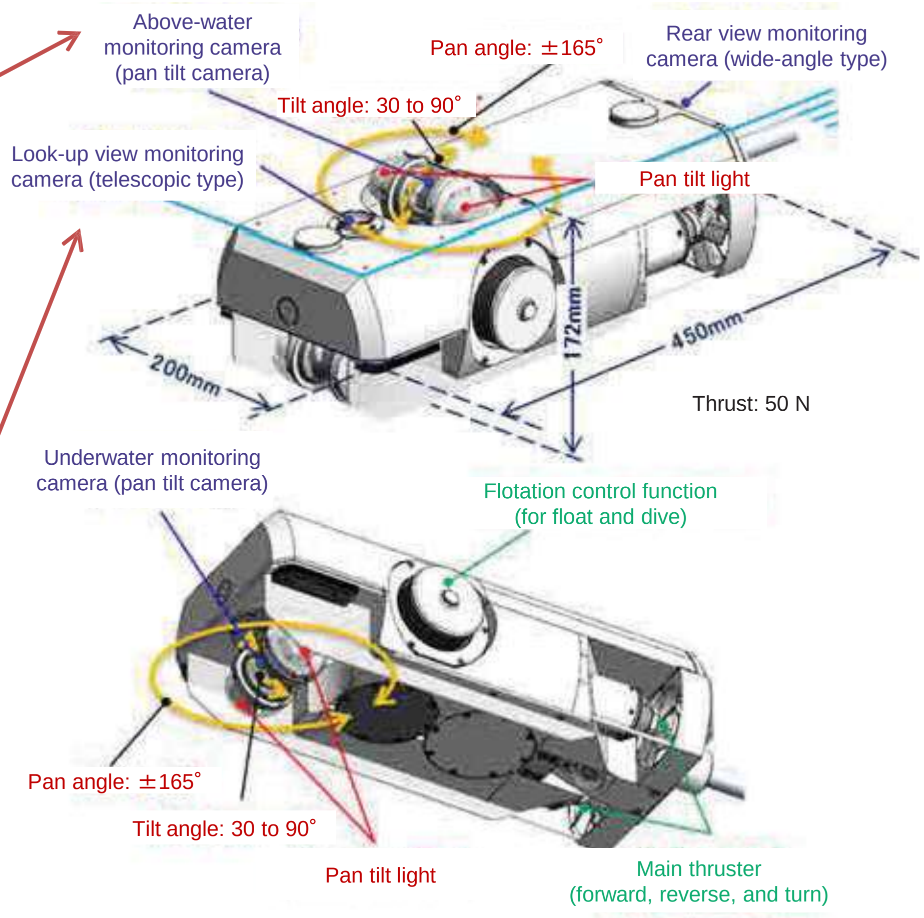
(2) Submersible Type Device (2/11) -- Design --

Investigation device	Measurement instrument * Same as those for B2	Intended use
ROV-A2 Detailed visual inspection	Fiber optic γ-ray dosimeter* and improved compact B-10 detector (for ROV protection)	To perform visual investigation over a wide area on the underground floor as well as in the pedestal in order to investigate the condition of the CRD housing collapse and so on



Images from the above-water monitoring camera (pan/tilt camera)

Images from the look-up view monitoring camera (telescopic type)

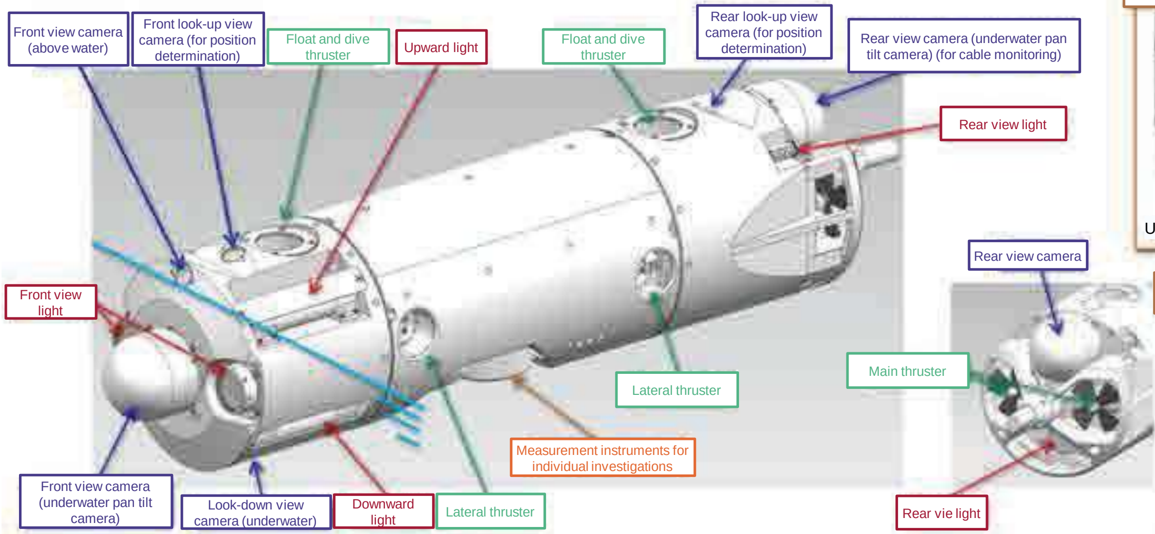


4.4 Implementation Items and Results -- Access and Investigation Device --

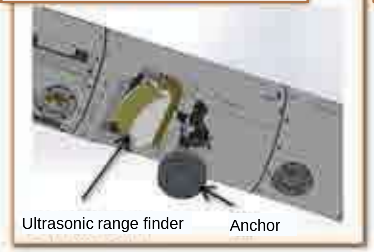
(2) Submersible Type Device (3/11) -- Design --

Investigation device	Measurement instrument	Implementation Items and Results
ROV-B Deposit 3D mapping	• Scanning ultrasonic range finder • Water temperature gauge	To measure the surface profile of deposit by the scanning ultrasonic range finder
ROV-C Deposit thickness measurement	• High-power ultrasonic sensor • Water temperature gauge	To estimate the height and distribution condition of debris by measuring the thickness of deposit and the condition of other materials under deposit using the high-power ultrasonic sensor
ROV-D Deposit debris detection	• CdTe semiconductor detector • Improved compact B-10 detector	To investigate the presence of fuel debris in deposit by analyzing nuclides and measuring neutron flux using the fuel debris detection sensor dropped on the surface of deposit
ROV-E Deposit sampling	• Suction-type sampling device	To sample deposit from the surface of the deposit by the deposit sampling device dropped on the surface of deposit

Thrust: 25 N Dimensions: Diameter of 25 cm, Length of approx. 110 cm

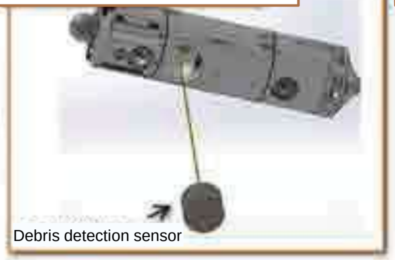


Deposit 3D mapping by ROV-B



Deposit thickness measurement by ROV-C

Fuel debris detection by ROV-D

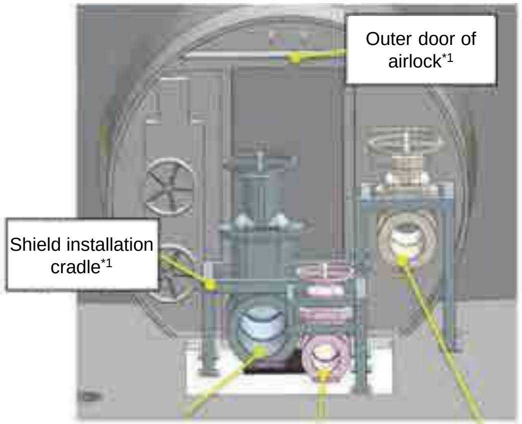


Deposit sampling by ROV-D

4.4 Implementation Items and Results -- Access and Investigation Device --

(2) Submersible Type Device (4/11) -- Design --

[Specification of investigation support system]



350A isolation valve for investigation equipment carrying in/out	200A isolation valve for insertion of monitoring camera and cleaning device	250A isolation valve for insertion of the light that illuminates inside the PCV

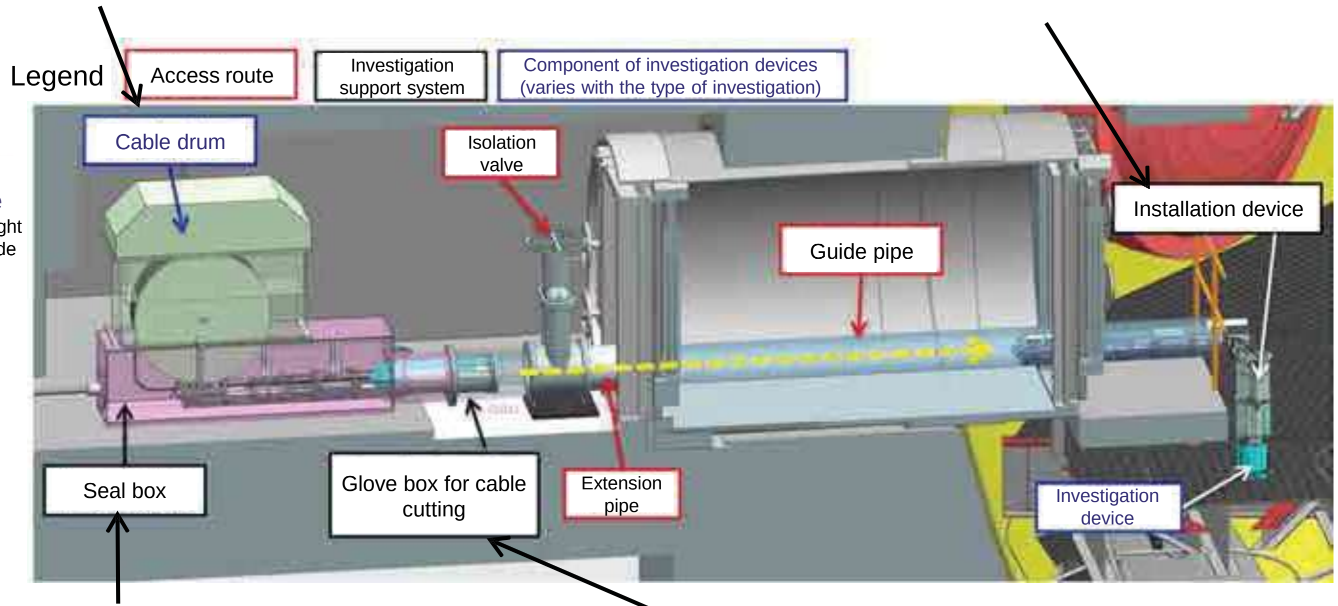
Main use of the penetrations for PCV inside detailed investigation

[Key functions]
- Maintaining isolation from the inside of the PCV (when the isolation valve is fully opened)
- Conveying and receiving the investigation devices to and from the seal box
- Feeding and winding cables (remote control)
- Manual cable winding*2
- Monitoring cables

*2 Although cables are taken up automatically by the motor in normal conditions, manual winding function is prepared in case of the motor failure.

[Key functions]
- carrying-in and carrying-out of investigation devices to and from the underground floor*1
- Cable feeding (Remote control)
- Lighting the underground floor
- Monitoring cables laid on the underground floor (only during the guide ring installation)
- Cleaning the investigation devices and cables

*1 Although the advance or retraction of the investigation device is driven by water-hydraulic power in normal condition, retraction is driven by the pole that is remotely controlled from outside the PCV in case of pump failure



[Specification of combined structure of cable drum and seal box]
1) Withstand pressure: 11 kPa
(No leak shall be detected with bubble leak test.)

[Key functions]
- Maintaining isolation from the inside of the PCV (when the isolation valve is fully opened)
- Conveying and receiving the investigation devices to and from the cable drum
- Guiding the installation device to the isolation valve
- Monitoring the cable

[Key functions]
- Maintaining isolation from the inside of the PCV (when the isolation valve is fully opened)
- Cable cutting (for emergent collection)
- Nitrogen injection and nitrogen substitution

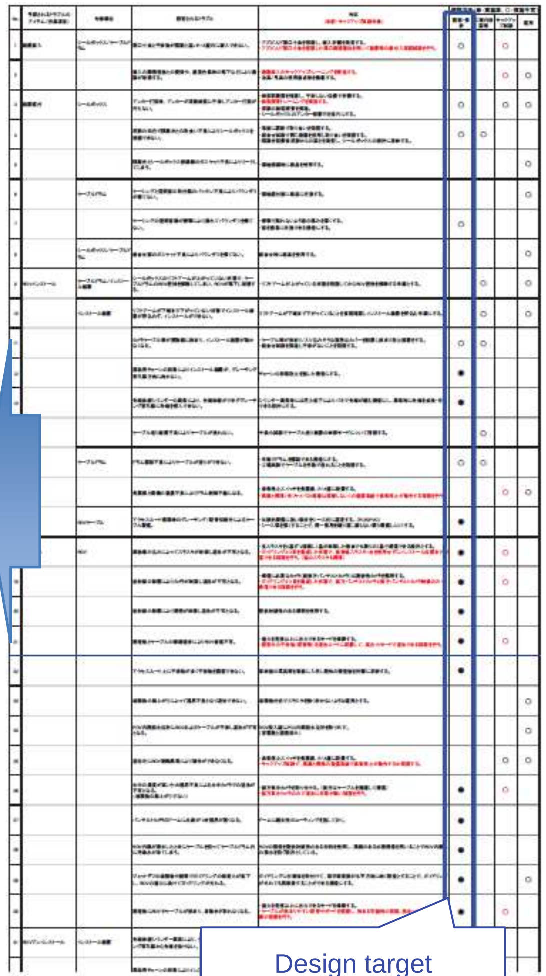
4.4 Implementation Items and Results -- Access and Investigation Device --

(2) Submersible Type Device (5/11) -- Risk Prevention Design --

Category	Major risks (Possible issues)	Main measures (those reflected on design)
Device installation	The sealing performance of the boundary is impaired by the fracture of the observation window for the seal box and cable drum due to impact.	Increase the thickness of the window glass. In addition, change the installation design of the window glass so that it can be replaced easily in case of fracture.
Installation	The installation device is stuck due to a cable such as a camera cable caught by a moving part of the device.	Install cable protection covers at locations where there is the risk of interference between cables and the moving parts of the installation device.
	The installation device does not turn its head to the opening of the grating due to the derailment of the head turn drive chain.	Change the chain drive mechanism to prevent chain derailment.
Submerging underwater	Cables may be damaged when it contacts with the cut end of an interference object under the grating in the access route establishment	Reduce the risk of cable cutting by using a stronger cable jacket (made of PUR or PVC) and increasing the thickness of the jacket.
	There is the risk of the thruster propeller being entangled by foreign objects and the thruster loses propellant force.	Provide two propellers for each thruster so that the other propeller provides sufficient propellant force for returning to the original point even when one propeller has failed.
	Maneuvering underwater may fail if radiation impacts on cameras or lights	Radiation resistance models shall be used for the front and rear view pan tilt cameras and lights that are essential for the return of the ROVs.
	Unexpected volume of structures and cable frictions prevent ROVs from moving forward	Prepare the ROV operation mode that enables the generation of propellant force exceeding the nominal thrust
	Water in the PCV may get cloudy due to deposits, which disturbs the maneuvering of the ROVs using underwater cameras.	Install the front above-water view camera. (Relying on the image of the cable captured by the rear view camera for reverse traveling to return to the original point.)
	The magnetic adhesion force of the guide ring to the jet deflector may be smaller than expected due to deposits on the deflector or rust so that it may come off by the tension of the cable generated by the advancement of the ROV.	Design the ROV and its controlling system so that the adhesion state of the guide ring can be checked and a fallen off guide ring can be reattached or abandoned.
Uninstallation	Due to insufficient water pressure, the head of installation device cannot be retracted and folded	Change the design of the mechanism to retract and bend the installation device head so that said motion can also be performed by the operation of the pole from outside the PCV.
	The cable cannot be wound up due to the failure of the cable drum drive motor or other devices.	Add a mechanism to allow manual cable winding.

Risks were exhaustively analyzed,* and measures for them were reflected to the design.

Examples of risk analysis



* The result of the exhaustive risk analysis will be introduced in the next report meeting of the government R&D project for the on-site validation that takes into consideration measures for deposit.

(2) Submersible Type Device (6/11) -- Production --

Total six types of submersible type investigation devices were produced, including submersible boats and compact ROVs

(a) For guide ring installation (ROV-A)

(b) For detailed visual inspection (ROV-A2)

(c) For deposit 3D mapping (ROV-B)

(d) For deposit thickness measurement (ROV-C)

(e) For fuel debris detection (ROV-D)

(f) For deposit sampling (ROV-E)

4.4 Implementation Items and Results -- Access and Investigation Device --

(2) Submersible Type Device (7/11) -- Production and In-Plant Validation --

The submersible boats and compact ROVs were designed and produced, and factory verification tests were performed on the produced devices including the test to evaluate the area coverage of the ROVs' mobility in the underground floor in the PCV and ability to go inside the pedestal, as well as the test of installation

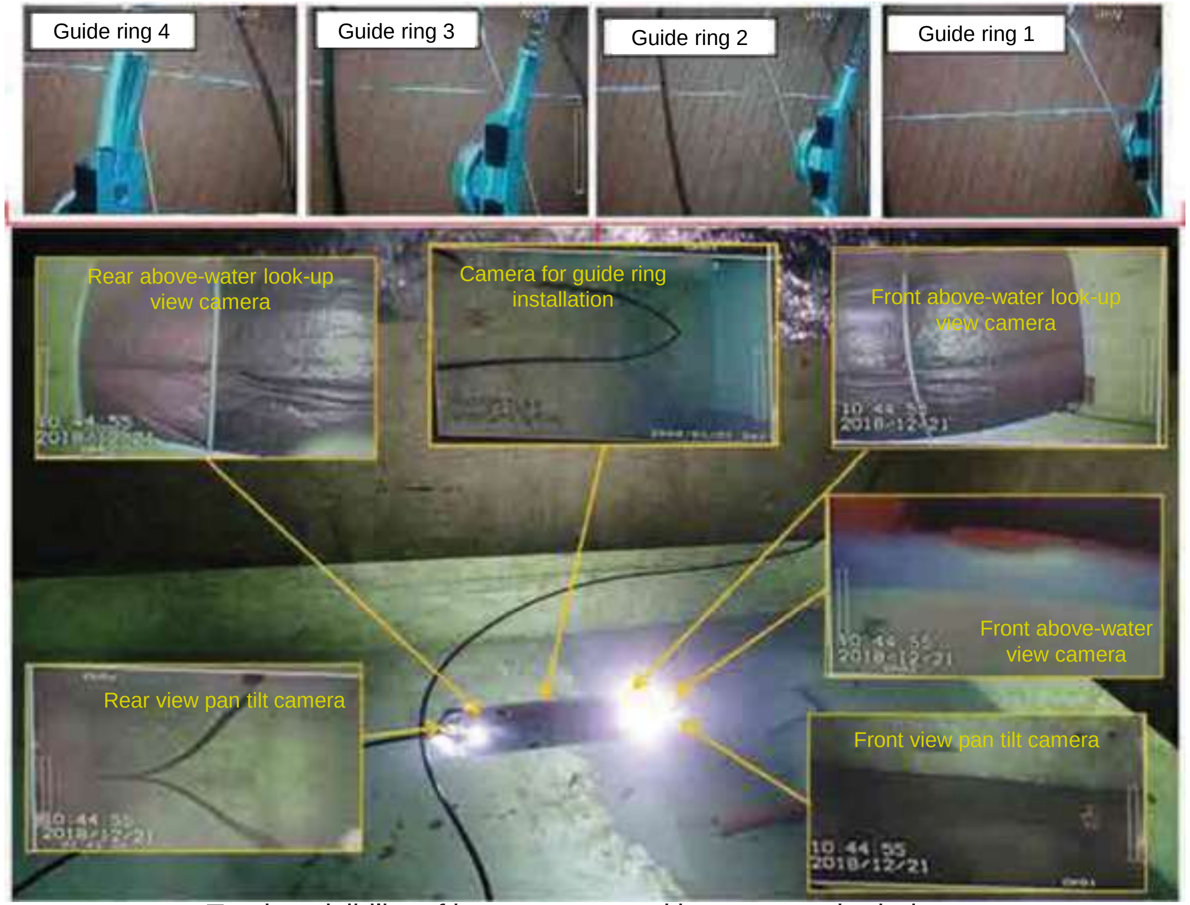
Device and equipment	Main check items in factory verification test (acceptance criteria)	Results of factory verification test	Section for detailed explanation
Investigation device (including cable drum)	Guide rings can be attached to jet deflectors	Prospect was confirmed*	4.4 (2) (7/10)
	ROV has mobility to cover a wide area outside the pedestal	Prospect was confirmed*	4.4 (2) (8/10)
	ROVs can go inside the pedestal	Prospect was confirmed*	
Installation device	Interlocking cable drum and feed mechanism of installation device can feed and retract cables	Prospect was confirmed*	4.4 (2) (10/10)
	Investigation device can be carried in to/out from the underground floor	Prospect was confirmed*	4.4 (2) (10/10)
	Investigation device and cables can be cleaned	Prospect was confirmed*	4.4 (2) (9/10)
Glove box for cable cutting	Investigation device cables can be disconnected in an emergency	Prospect was confirmed*	–
Seal box	Isolation from the inside of the PCV shall be maintained in the integrated state with the cable drum. (Withstand pressure: 11 kPa)	No problem	4.4 (2) (10/10)
Monitoring camera jig (200A)	The cable of investigation equipment under the grating opening can be monitored	Prospect was confirmed*	–
Lighting (250A)			

*Action required: Verification is required under a simulated on-site environment.

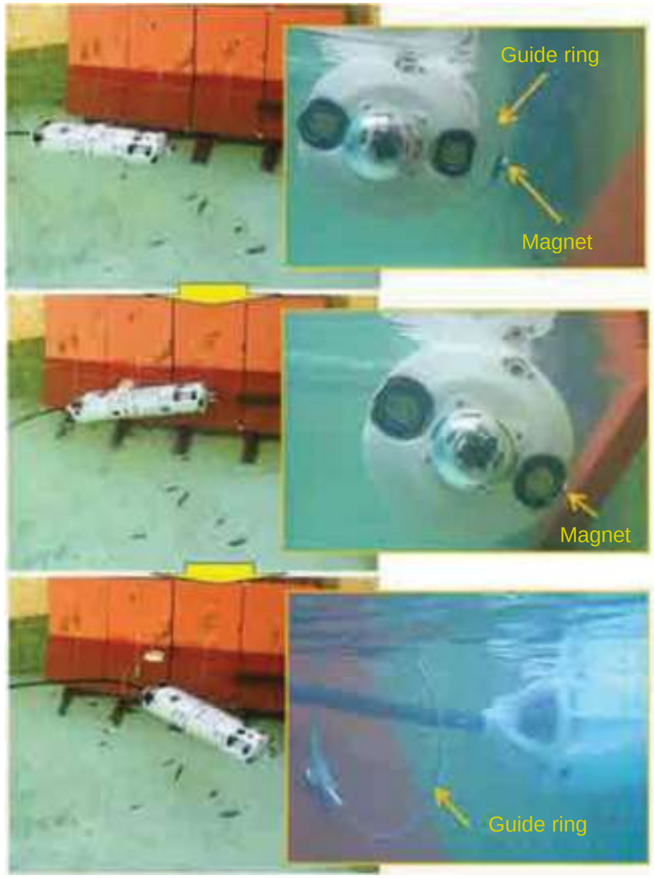
(2) Submersible Type Device (8/11) -- In-Plant Validation --

[Guide ring installation]

- The performance of the cameras in darkness was examined, and the feasibility of the operation to check the installed condition of the guide ring by the on-board cameras was confirmed.
- The feasibility of the operation to install the guide rings to the jet deflectors by relying only on the image captured by the on-board cameras was confirmed.



Testing visibility of images captured by cameras in darkness



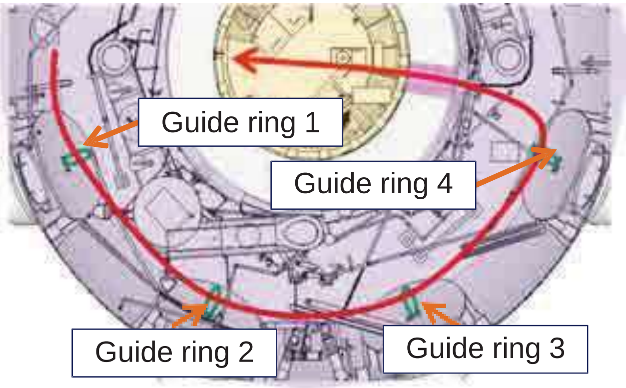
Guide ring installation

(2) Submersible Type Device (9/11) -- In-Plant Validation --

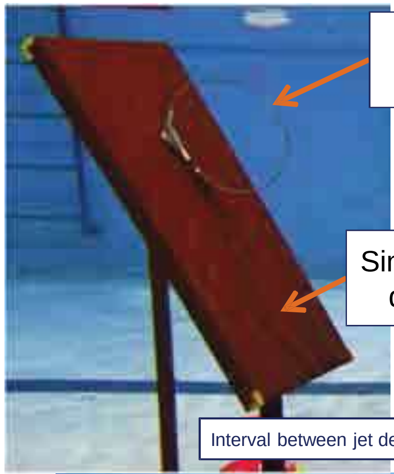
[Wide-range mobility of the device and entering the pedestal]

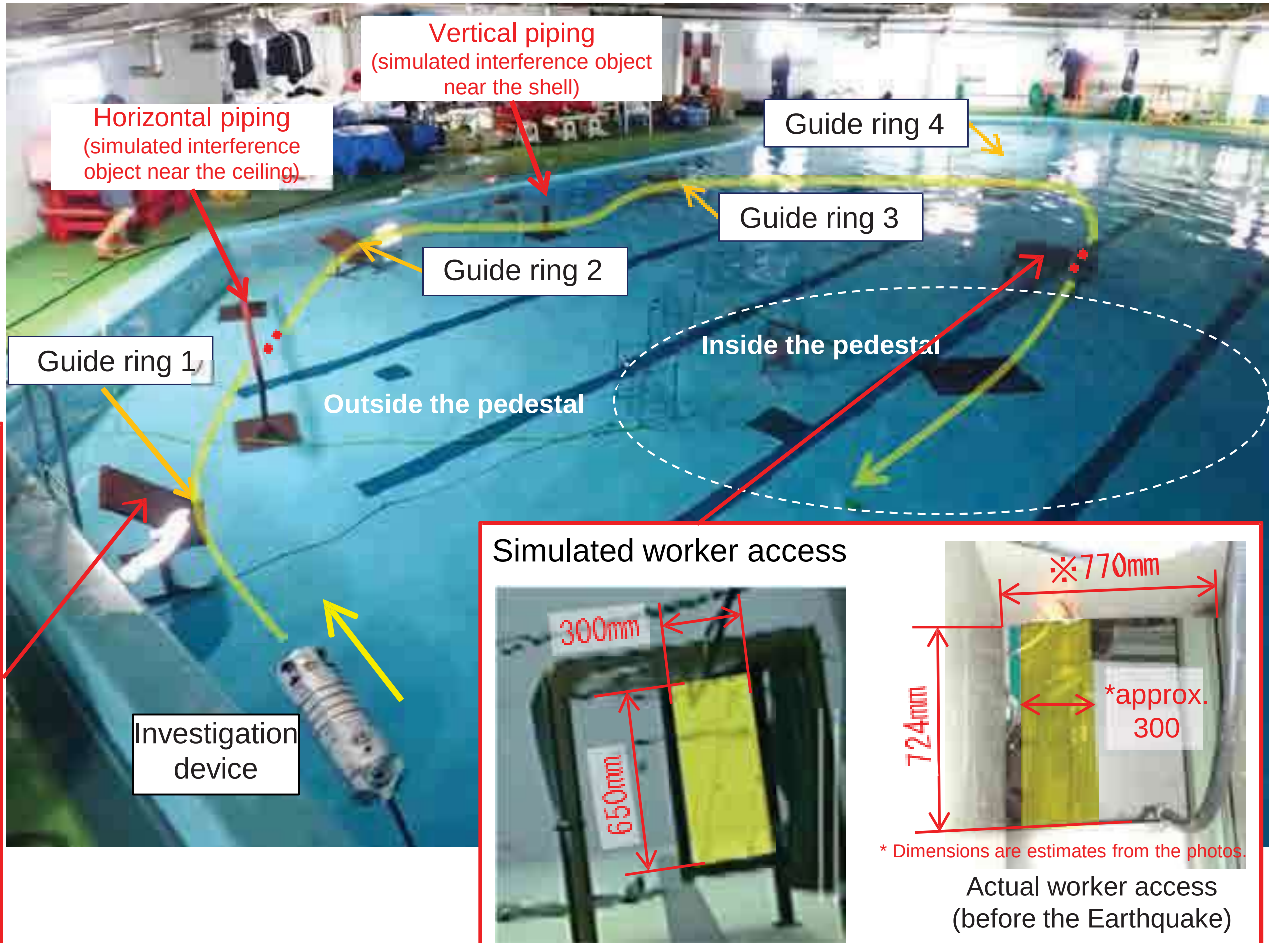
The test confirmed the feasibility of the device that can operate the investigation device by relying only on images captured by the on-board cameras, move a wide area of the space that is simulated the underground floor in the PCV of Unit 1, and enter inside the pedestal.

Example of access route into the pedestal



Simulated jet deflector





Simulated worker access

* Dimensions are estimates from the photos.

Actual worker access
(before the Earthquake)

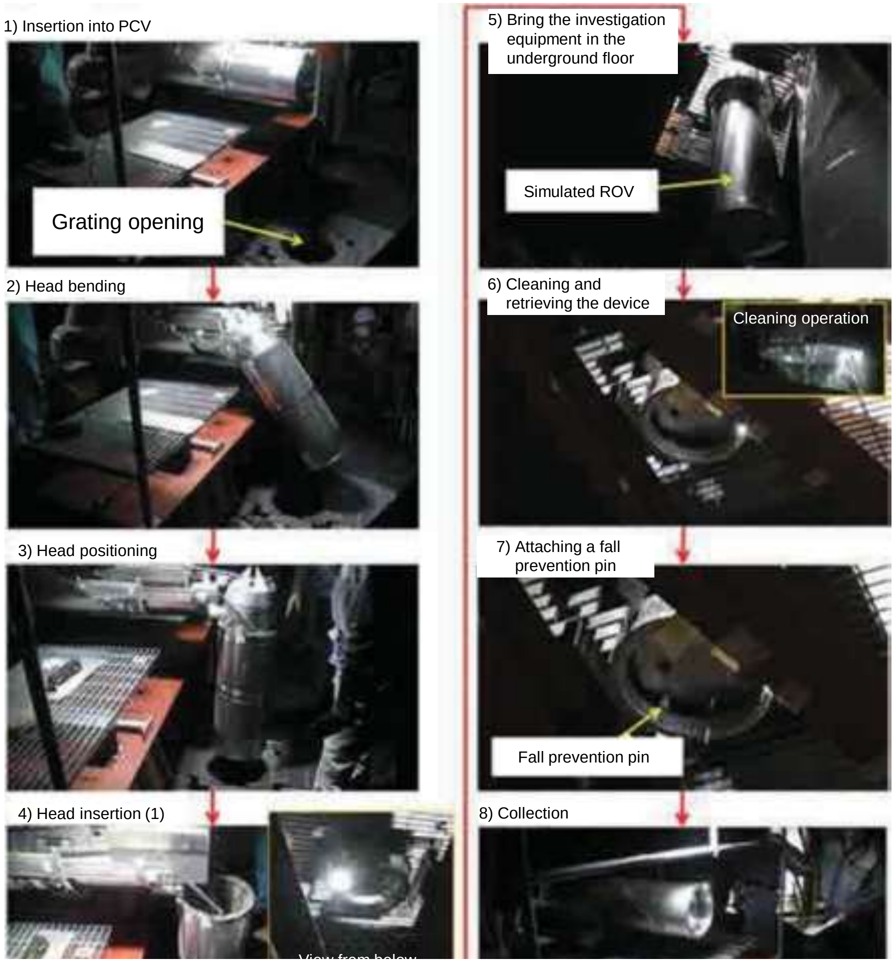
*** Test was performed using the test facility whose structural layout was horizontally flipped from that of the actual PCV due to constraints in constructing the facility so that the ROVs' traveling route was also flipped horizontally**

4.4 Implementation Items and Results -- Access and Investigation Device --

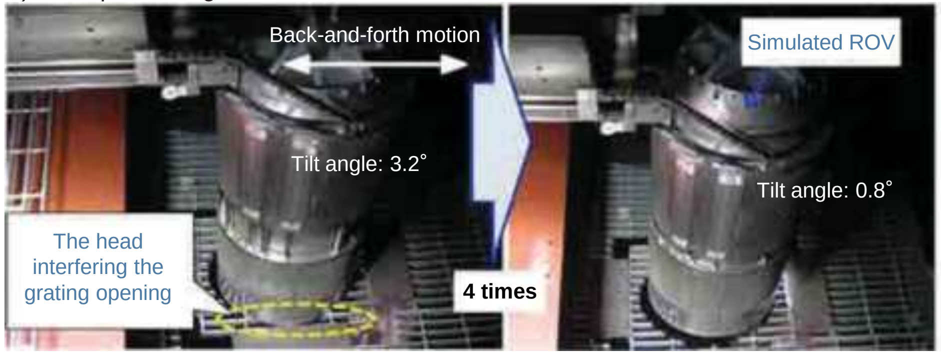
(2) Submersible Type Device (10/11) -- In-Plant Validation --

[Investigation devices carrying in/out into the basement floor (including cleaning)]

Investigation devices carrying in/out into the basement floor (including cleaning) was confirmed feasible by using the installation device.



a) Head positioning



[Issue] The head cannot be inserted into the opening as it cannot be set at a right angle to the grating
Solution: 1) enlarge the opening of the grating, or 2) move the installation device back-and-forth repeatedly to let its head point downward at a right angle by gravity (as shown in the figure above)

b) Cleaning

Test the performance of the cleaning device by applying chalk powder on the surface of the ROV mockup. No cleaning residue was found even in concave portion. The cleaning performance was confirmed satisfactorily.

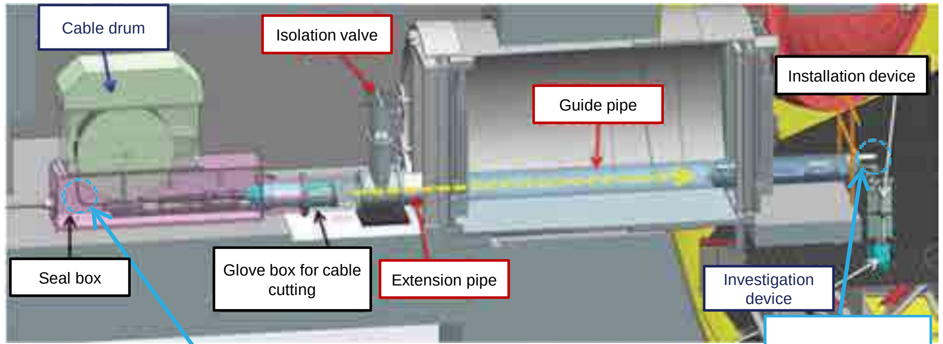
Before cleaning | After cleaning

4.4 Implementation Items and Results -- Access and Investigation Device --

(2) Submersible Type Device (11/11) -- In-Plant Validation --

[Interlock control]

A prospect was obtained that the cable can be fed and retracted to and from the underground floor by the interlock control of the cable drum, pinch roller, and the cable feed mechanism.



Pinch roller

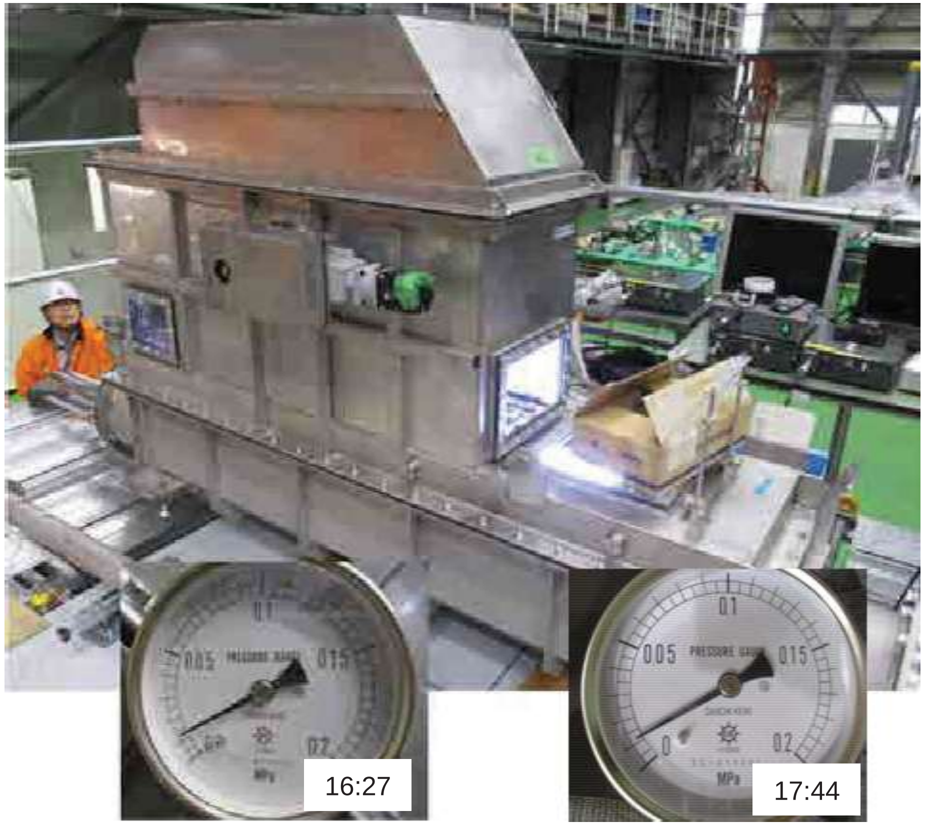
Cable feed mechanism

Cable feed mechanism controller

Cable drum pinch roller controller (with interlock control function)

[Withstand pressure of investigation device]

A pressurized leak test was performed on the combined structure of the cable drum and seal box, and no leakage was found



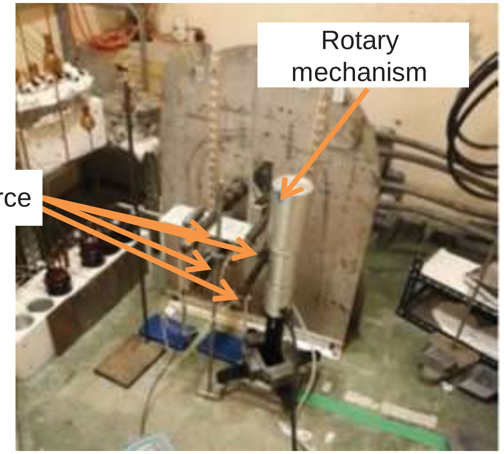
List of measurement technologies

	Measurement technologies	Purpose of measurement	Intended access equipment	Section for detailed explanation
Shape and dimension measurement technologies	Ultrasonic sonar	3D mapping of underwater fuel debris, etc.	Arm type (Unit 2)	4.5 (1) (i)
	Scanning ultrasonic range finder	3D mapping of deposit	Submersible type (Unit 1)	4.5 (1) (ii)
	Optical cutting method	3D mapping of structures, etc., above the water	Arm type (Unit 2)	4.5 (1) (iii)
	High-power ultrasonic sensor	Measurement of deposit thickness (Investigation of materials and objects under deposit)	Submersible type (Unit 1)	4.5 (1) (iv)
	Low-frequency ultrasonic sensor	Measurement of remained pedestal wall thickness	n/a (only for technology development)	4.5 (1) (v)
Radiation measurement technologies	γ-camera	γ-ray dose rate distribution (Estimation of fuel debris distribution)	Arm type (Unit 2)	4.5 (2) (i)
	CdTe semiconductor detector and improved compact B-10 detector	Identification of fuel debris in and under deposit	Submersible type (Unit 1)	4.5 (2) (ii)
Location technology	Monocular camera (Comparison of captured image with registered reference images)	Determination of the location of the investigation device	Submersible type (Unit 1)	4.5 (3)

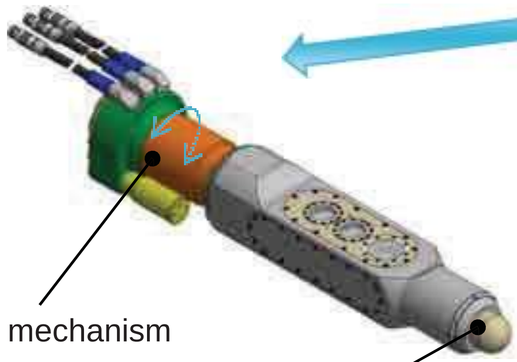
(1) Shape and dimension measurement technology (i) Ultrasonic sonar

- The sonar was designed and produced.
- The same pan mechanism design as that for the gamma camera was adopted.
- The pan mechanism, outer shell, and sonar head were produced. These components are currently being assembled. At the same time, performance of the pan mechanism and final weight are being evaluated.

Assembly of pan mechanism



Verification test of rotary mechanism performance characteristics under radiation environment



External view of ultrasonic sonar

Sonar head

Main functions and test results

Function	Verification results
Radiation resistance	All the parts of the sonar were confirmed resistant to a radiation dose of 10 kGy or more including the pan mechanism.
Measurement performance	The sonar was confirmed to have a resolution of 50 mm in underwater tests.
Water resistance	Use of seal material is planned to secure water resistance.

(1) Shape and dimension measurement technology (ii) Scanning ultrasonic distance measuring device(1/3)

The deposit 3D mapping system was designed and produced. Additionally, applicability of the produced system was verified (unit tests and combination tests). The test results confirmed the feasibility of the system installed on the Remote Operated Vehicle (ROV).

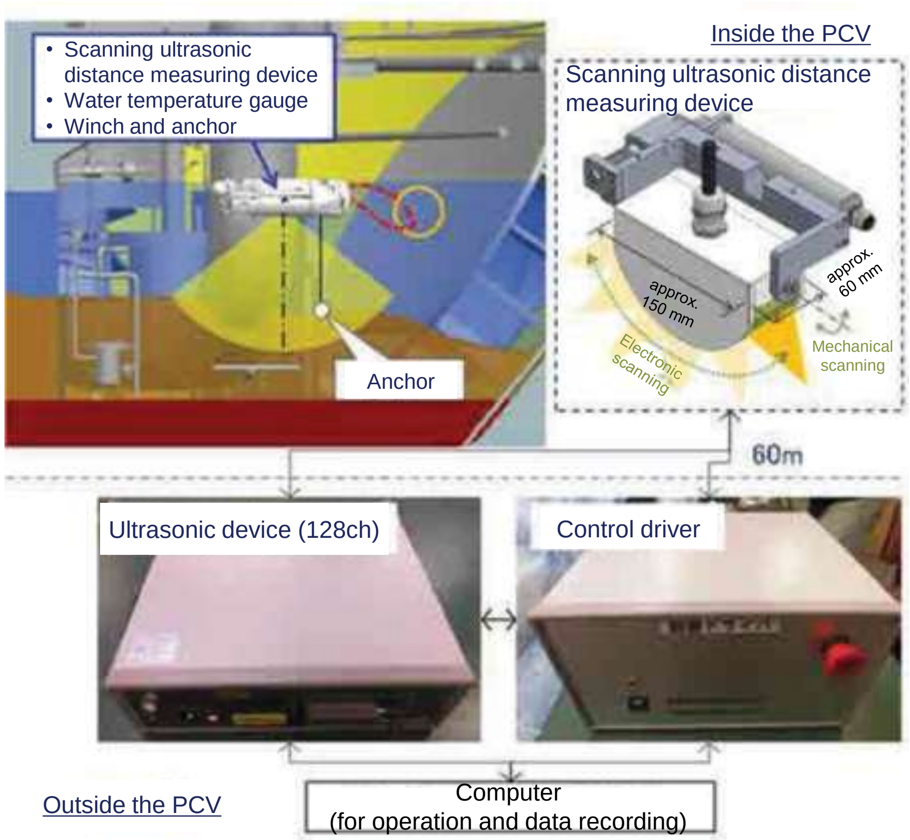


Figure 4.5 (1) (i)-1 Configuration of the deposit 3D mapping system

Compliance verification items

Test type	Check items	
Unit test 1 (Tests performed in a setup where sensors and measurement instruments used in the on-site validation and the cable used for the actual ROV [no redundant cabling] are connected to the produced system)	Measurable range	
	Measurement accuracy	
	Resolution	
	Effect of disturbance	Turbidity of water
		Electric noise
Unit test 2)	3D view function	
Combination test (Tests performed in a setup where sensors and measurement instruments used in the on-site validation are combined with an ROV)	Verification of measurement performance	
	Impact of ROV's posture	
	Effect of disturbance	Electric noise

(1) Shape and dimension measurement technology (ii) Scanning ultrasonic distance measuring device(2/3)

[Unit test 1 in FY2017]
The unit test confirmed basic characteristics of the measuring device to be required for measurement procedures of the deposit 3D mapping. As a result, the measurement accuracy was confirmed to satisfy the original requirements.

Unit test results (in FY2017)

Items (Original requirements)		Confirmed results
Measurable range	Distance	500 to 3000 mm
	Angle of incidence	From -50 to 50 degrees
Resolution		Horizontal resolution at 3 m is 50 mm or better. Ultrasonic beams are wrapped around between scanning pitch
Measurement accuracy	Vertical direction (± 50 mm)	Height: 1.2 mm (RMSE) Distance: 2.0 mm (RMSE)
	Horizontal direction (±200 mm)	6.2 mm (RMSE)
Effect of disturbance	Turbidity of water	Attenuation of −10 dB/m in turbid water with visibility of 6 cm*
	Electric noise	There was no electric noise in mechanical scanning with maximum sensitivity and maximum scanning speed.

*A measurable range of up to 2,200 mm can be achieved even in highly turbid water.

[Unit test 2) (3D view function)]
A new 3D view software (STL* compatible) was developed. It can display the 3D profile of deposit that is created using data from the scanning ultrasonic distance measuring device over the 3D drawing of the 1st floor of the dry well based on the location information from the investigation device

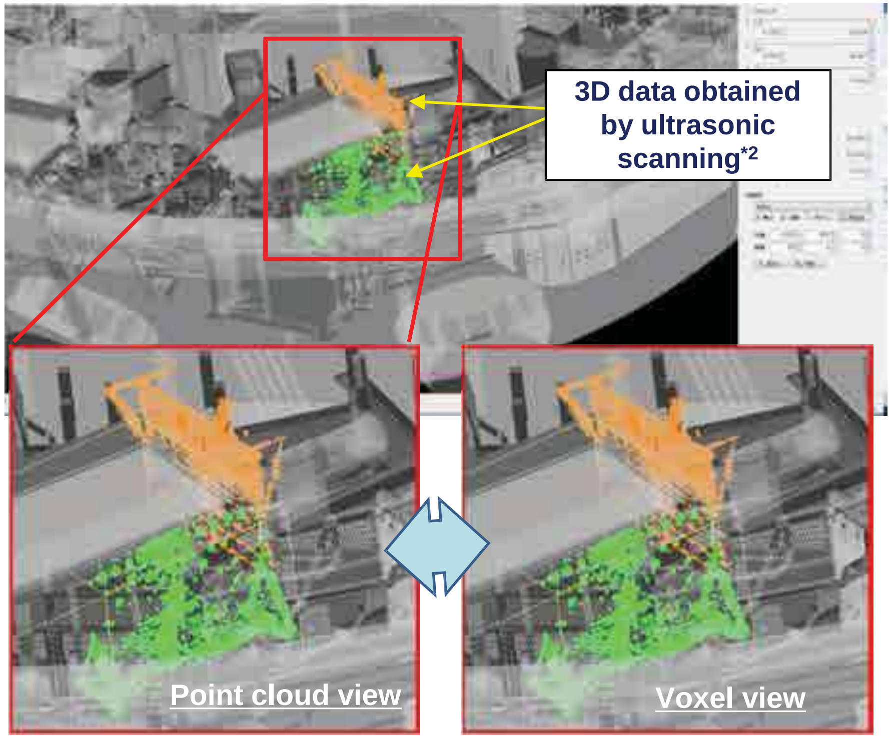


Figure 4.5 (1) (ii)-2. 3D View Function

*1: STL is an initialism of Standard Triangulated Language. It is a file format for saving 3D shape data.
*2: 3D profile of a flat plate with legs and a magnet attached obtained by ultrasonic 3D scanning

(1) Shape and dimension measurement technology (ii) Scanning ultrasonic distance measuring device(3/3)

[Combination test (in FY2018)]

The test confirmed that 3D data can be collected as the ROV posture and electric noise have less impact on data stability, that 3D software supports point and voxel view modes, and that measurement accuracy satisfies the original requirements.

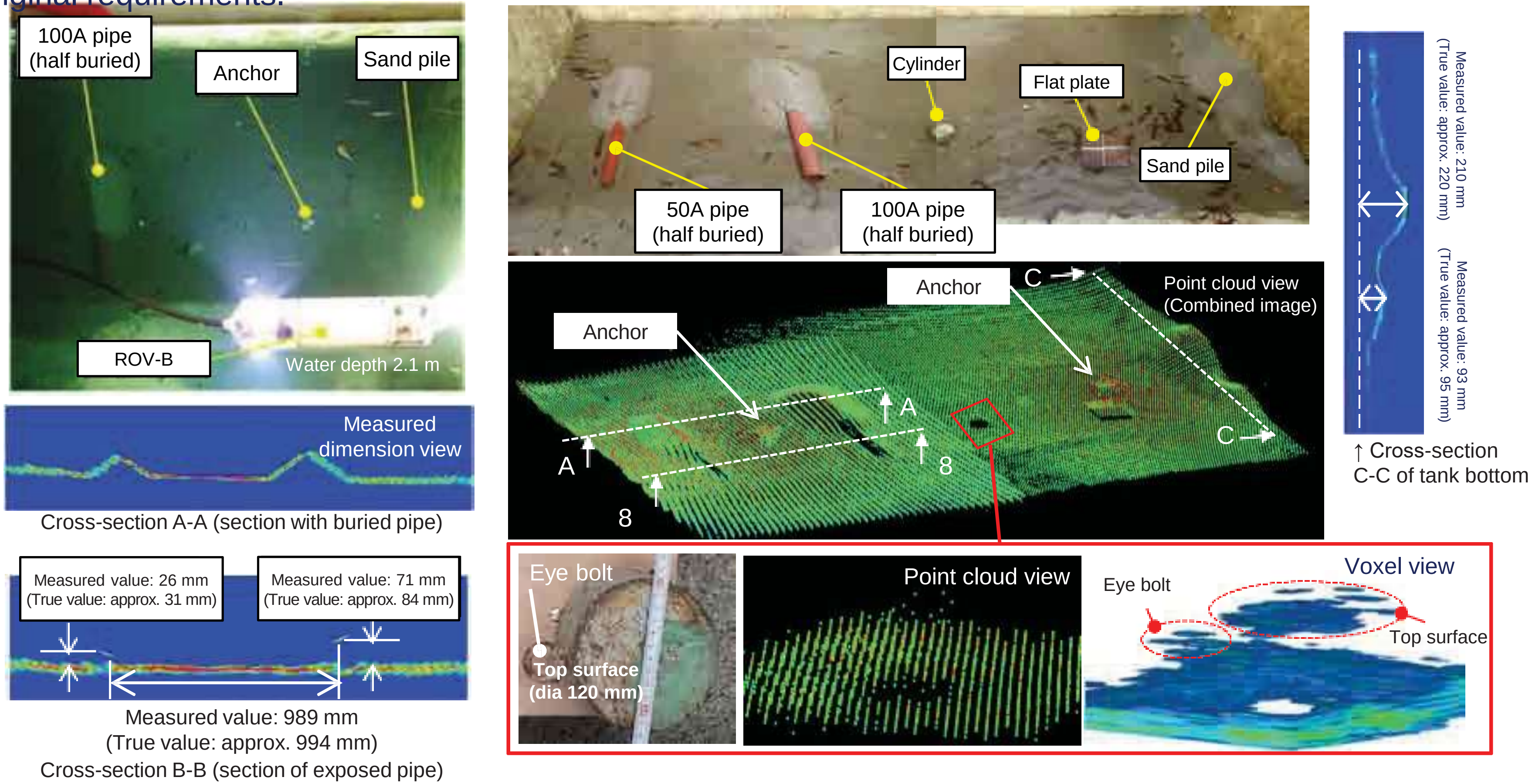


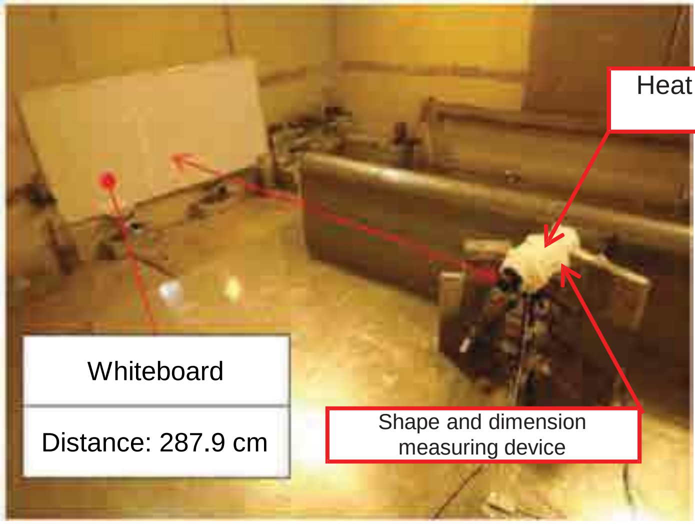
Figure 4.5 (1) (i)-3 Combination test result of the deposit 3D mapping system

Actions required: Verify that ROVs can perform measurements after passing through the guide rings, overlay 3D images on the actual PCV

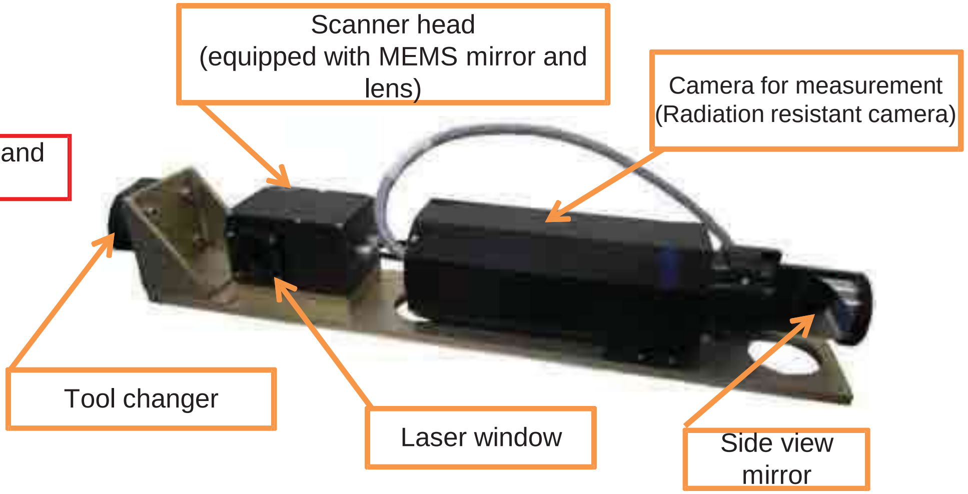
Action: Verify these in the combination test performed in the mockup test facility

(1) Shape and dimension measurement technology (iii) Light-section method

- A verification test was conducted to evaluate the applicability of a substitute camera (radiation resistance camera): verification of measurement accuracy under the radiation environment, to select a camera for measurement.
- Radiation resistance and the sliding tests of the optical fiber were conducted to select the optical fiber cover for the operating parts.
- Equipment and devices in the actual use were produced.



Testing measurement accuracy under radiation environment (in irradiation chamber)



Appearance of shape and dimension measuring device using light-section method


0.8 kGy/h
50°C

High noise
Low S/N ratio

Image captured by an unaccepted camera


1.0 kGy/h
50°C

Low noise
High S/N ratio

Image captured by the accepted camera


Optical fiber cable sliding wear test

(1) Shape and dimension measurement technology

(iv) High-power ultrasonic sensor (for deposit thickness measurement) (1/4)

A system of measuring deposit thickness was designed and produced. Additionally, the system was tested to verify the applicability (unit tests and combination tests). The tests confirmed the feasibility of the system installed on the ROV that can perform desired measurements.

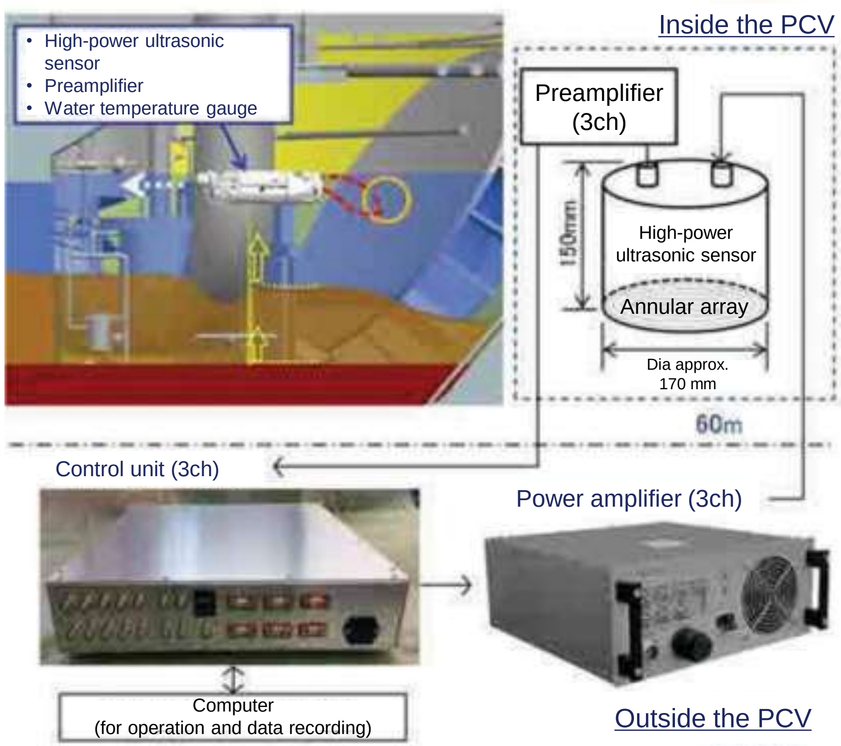


Figure 4.5 (1) (iv)-1Configuration of deposit thickness measurement system

Verification items

Test type	Check items	
Preliminary tests (Tests with equivalent sensors and evaluation by analysis)	Effect of the particle size of deposit	
	Effect of bubbles included in deposit (produced by radiolytic water splitting)	
	Effect of temperature gradient in deposit	
Unit test (Tests performed in a setup where sensors [including sensor elements] and measurement instruments used in the on-site validation and the cable used for the actual ROV [no redundant cabling] are connected to the produced system)	Effect of the material and mixed particle sizes of deposit	
	Radiation resistance	Preamplifier
		Sensor
	Measurable range of depth	
	Measurement accuracy	
	Resolution	
Combination test (Tests performed in a setup where sensors and measurement instruments used in the on-site validation are combined with an ROV)	Verification of measurement performance	
	Impact of ROV's posture	
	Effect of disturbance	Acoustic noise
		Electric noise

4.5 Implementation Items and Results -- Applicability Verification of Element Technologies (8/22) --
(1) Shape and dimension measurement technology
(iv) High-power ultrasonic sensor (for deposit thickness measurement) (2/4)

Unit test results (performed mainly in FY2017)

Check items		Confirmed results (Preliminary and unit tests)
Measurable range of deposit thickness		• With 100 kHz wave: From 0.04 to 0.5 m (Max. thickness increases to 1 m when particle size is 400 μm or larger.) • With 10 kHz parametric wave: Measurable range is wider than that with 100 kHz wave
Accuracy of deposit thickness measurement		Measurement accuracy is ± 7% when the particle size and temperature are within a typical range and sonic speed is applied (Effect of particle size and temperature gradient is included.)
Resolution		Lateral resolution: 56 mm, time resolution: 43 μs (approx. 40 mm) at 100kHz
Disturbing and environmental factors in measurement	Effect of the particle size of deposit	• Measurement error attributable to particle size (in a range of 45 to 1,700 μm) is approx. ±5%.* • The sensor was assessed capable of measuring the thickness of the layer of sand with mixed particle size like river sand. The thickness measurement system that will be used in the actual site is designed tentatively on a basis that sound speed in the debris pile is 1.15 times faster than in water (equivalent to a particle size of 900 μm), since sound speed in particle layer with uniform particle size is about 1.1 to 1.2 times faster (depending on particle size) than in water.
	Effect of bubbles included in deposit (produced by radiolytic water splitting)	There is no effect of bubbles produced by radiolytic water splitting in deposit as long as the γ-ray dose rate is between 10-100 Gy/h. (See figure 4.5 (1) (iv)-2.)
	Effect of temperature gradient in deposit	Measurement error attributable to temperature gradient is approx. ±2.3%. Variation of sound speed with temperature in a range of 10-40°C was taken into consideration based on the sound speed in approx. 20°C water.
	Electric noise	It was found that sufficient earthing was required for parametric measurement to suppress low-frequency noise.*
Radiation resistance	Preamplifier	Although noise (2 MHz) was added to the output wave (10 kHz) by irradiation, the noise was able to be removed by a low-pass filter, and the output wave before irradiation was able to be reproduced.(See figure 4.5 (1) (iv)-3)
	Sensor	The sensitivity was reduced by 14% due to irradiation. (This level of reduction does not affect the measurement.) (See Figure 4.5 (1) (iv)-3)

* Earth connection in front of the airlock room could be applicable.

(1) Shape and dimension measurement technology

(iv) High-power ultrasonic sensor (for deposit thickness measurement) (3/4)

[Effect of bubbles in deposit (produced by radiolytic water splitting)]

(1) Test conditions

a. Dose rate: 10 Gy/h (at deposit surface)
100 Gy/h (at fuel debris surface)

b. Irradiation duration: approx.: 8 days

(2) Test results

It was demonstrated that there is no effect of bubbles produced by radiolytic water splitting in deposit as long as the γ-ray dose rate was between 10-100 Gy/h.

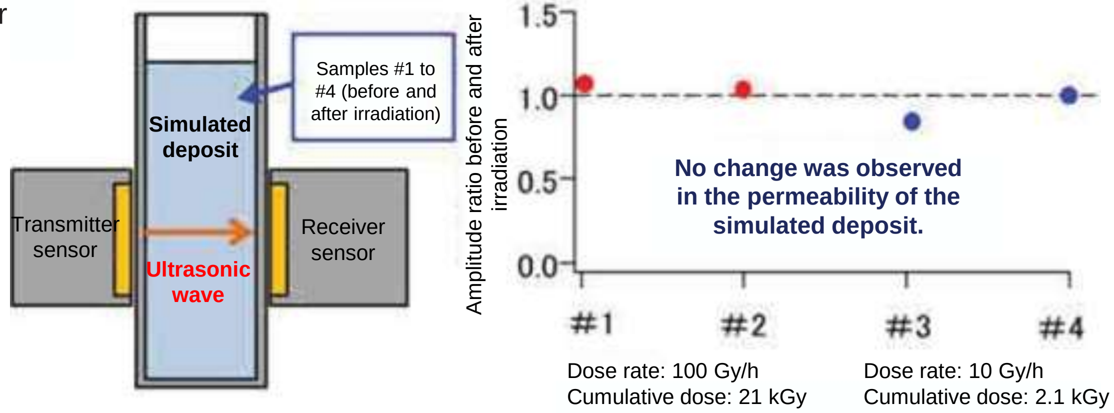


Figure 4.5 (1) (iv)-2 Effect of radiolytic water splitting on ultrasonic wave permeability

[Radiation resistance]

(1) Test conditions

a) Dose rate: 10 Gy/h (equivalent to a dose rate sensors are exposed to)

b) Cumulative dose: Max. 1 kGy or more

(2) Test results

Sensor

The sensitivity was reduced by 14% due to irradiation. (This level of reduction does not affect the measurement.)

Preamplifier

Although noise (2 MHz) was added to the output wave (10 kHz) by irradiation, the test confirmed that the noise was able to be removed by a low-pass filter, and the output wave before irradiation can be reproduced.

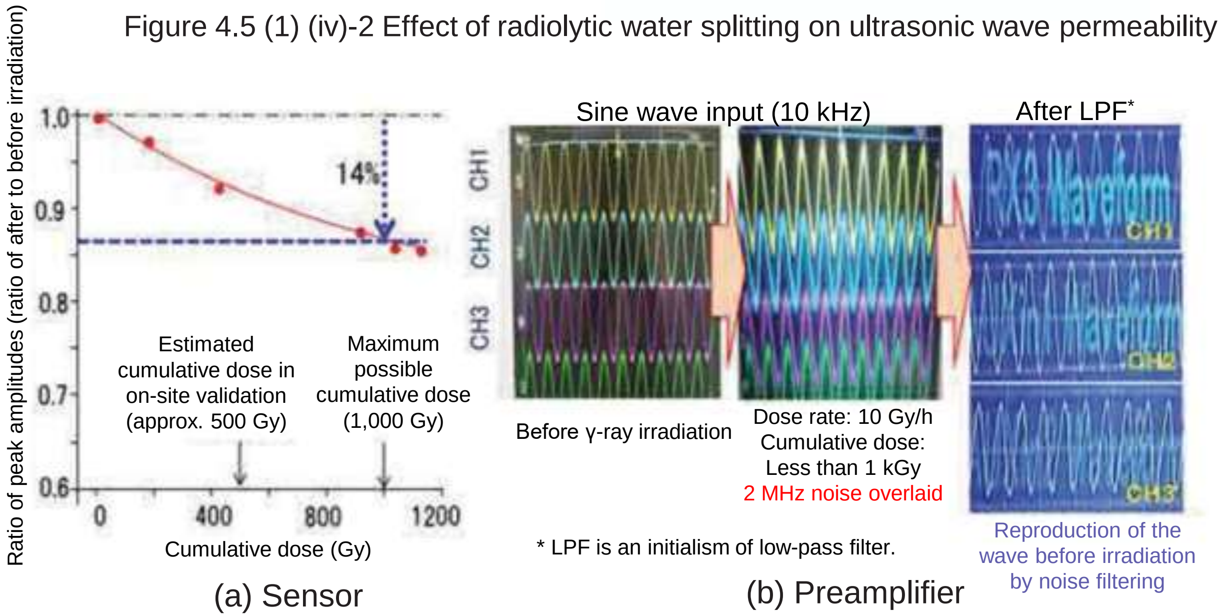


Figure 4.5 (1) (iv)-3. Effect of Cumulative Dose on Sensor and Preamplifier

(1) Shape and dimension measurement technology

(iv) High-power ultrasonic sensor (for deposit thickness measurement) (4/4)

[Combination test (in FY2018)]

- A deposit thickness measurement test was performed with 100 mm and 300 mm thick deposit simulants placed on the bottom of 2.1 m deep water pool. In this test, the high-power ultrasonic sensor was loaded on the ROV, and ultrasonic waves were irradiated in a manner where (a) 100 kHz basic measurement method and (b) parametric method were switched alternately at a high frequency while having the ROV keep on traveling (See Figure 4.5 (1) (iv)-4)
- It was demonstrated that the measurement method is less susceptible to the posture of the ROV and disturbing noise and can capture the image of the surface and bottom face of deposit as well as objects buried in deposit and also can measure deposit thickness (Figure 4.5 (1) (iv)-6))

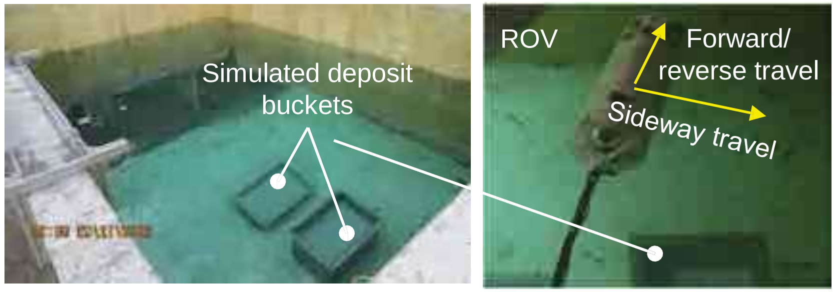


Figure 4.5 (1) (iv)-5. Schematic View of Test Preparation

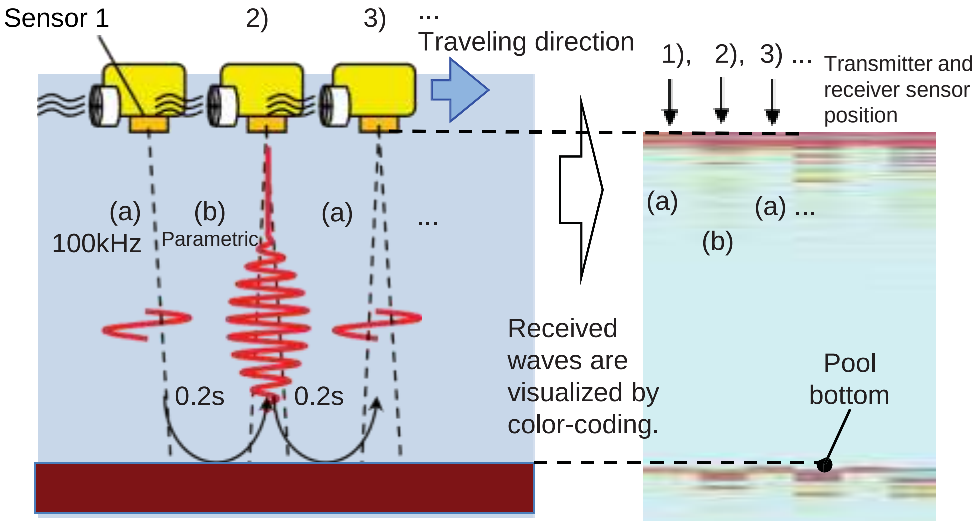


Figure 4.5 (1) (iv)-4 Ultrasonic image scanning method used in combination test

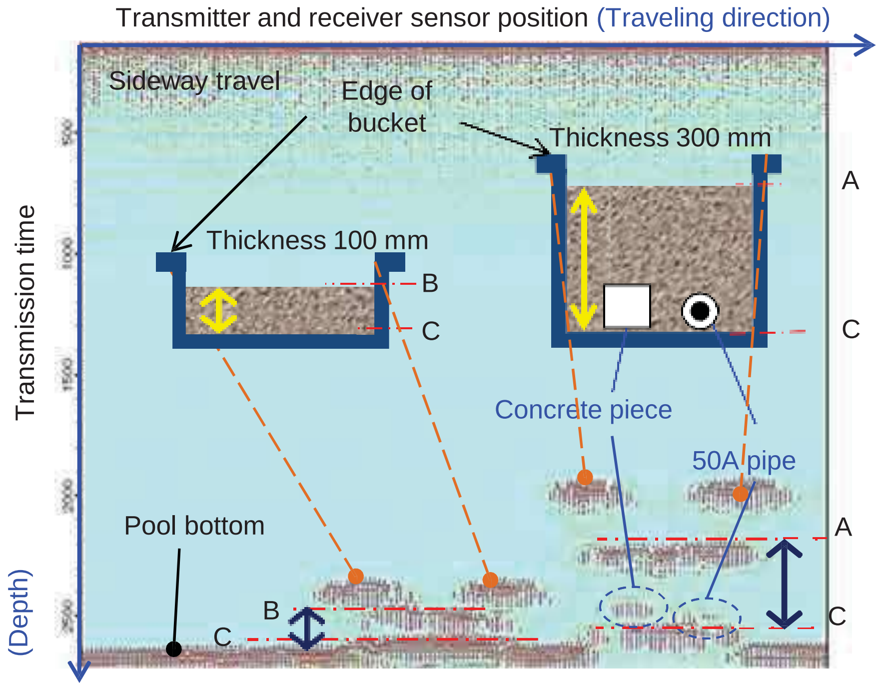


Figure 4.5 (1) (iv)-6 Example of ultrasonic scanned image for deposit thickness measurement

Actions required: Verify that ROVs can perform measurements after passing through the guide rings, etc.
Action: Verify these in the combination test performed in the mockup test facility

(1) Shape and dimension measurement technology

(v) Low-frequency ultrasonic sensor (for measurement of remained pedestal wall thickness) 1/4

Prototyping of a sensor to measure the thickness of the remaining pedestal wall and only the unit test of the prototype was performed as the result of the decision to lower the priority of developing the whole measurement system since it would be needed after the removal of deposit. In this test, measurement conditions were examined and measurement performance was evaluated.

Compliance verification items

Test type	Check items
Unit test (Tests performed in a setup where sensors and measurement instruments that simulate those that are used in the devices deployed for actual on-site operation and the cable used for the actual ROV [no redundant cabling] are connected to the produced system)	Sensor selection
	Radiation resistance of sensor
	Measurement conditions
	Measurable range of remained thickness
	Measurement accuracy
	Resolution

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

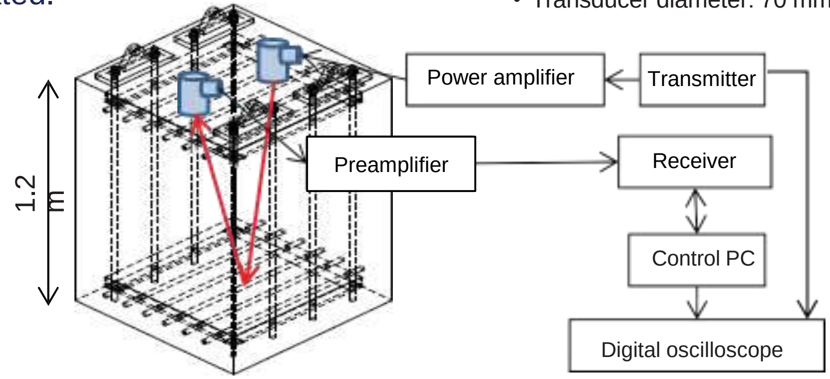


Figure 4.5 (1) (v)-1 Configuration of unit test system

[Measurement principle]

Determining the thickness of the remaining pedestal wall based on measured echo round-trip travel time between the sensor and the back side surface (bottom surface) of the concrete layer with a thickness equal to that of the remaining wall and sound speed (4 km/s)

[Issues in measurement]

To receive aggregate echo (maximum diameter of 20 mm) in addition to bottom echo, a method to discriminate the former from the latter needs to be developed

[Characteristics of waveform] (See Figure 4.5 (1) (v)-2.)

- High-frequency components (100 kHz and higher) of the received wave signal are mostly those of echo reflected by aggregate and don't include the wave signal of echo reflected by the bottom surface much
- Low-frequency components (50 kHz) include bottom echo signals

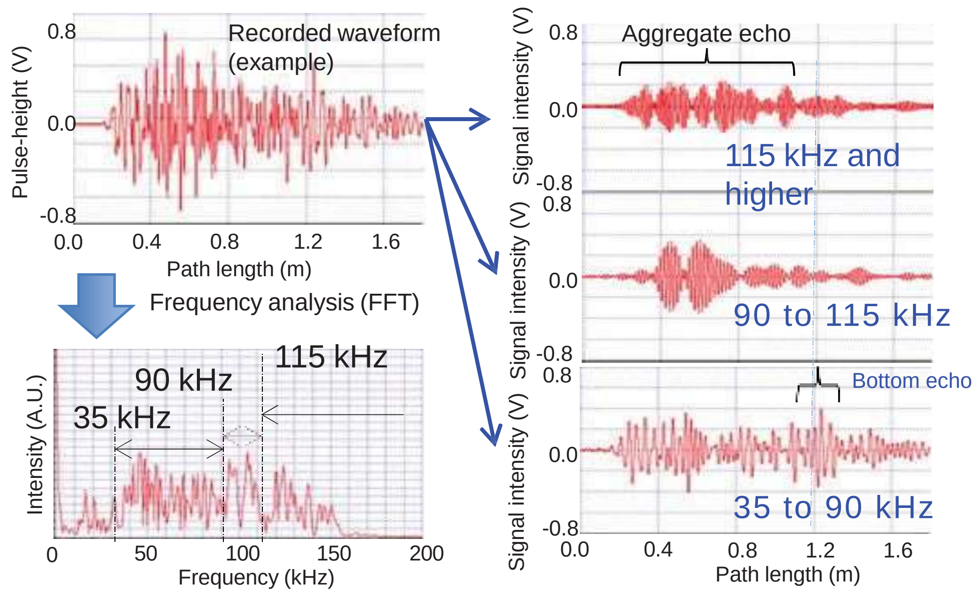


Figure 4.5 (1) (v)-2 Recorded waveforms and frequency analysis result (examples)

Unit test results (obtained in FY2017 to FY2018)

Check items (Targeted needs are parenthesized)		Summary of test results
Sensor specifications	Resonant frequency	100 kHz
	Transducer diameter	1) 70 mm (for transmitter and receiver)
	Radiation resistance	Resistant to the cumulative dose of 1 kGy or more (Figure 4.5 (1) (v)-3)
Measurement conditions	Excitation frequency	50 kHz
	Band-pass filter (BPF) frequency	Mean value of permeable frequency range: 50 kHz, attenuation rate: -14 dB/oct.
	Distance between transmitter and receiver sensors	450 mm (See Figure 4.5 (1) (v)-4)
	Sensor scanning method and recording interval	Scan the outer surface of the pedestal along the circumference direction and record waveform at an interval of 50 mm
	Signal processing	Averaging 9 or more waves (See Figure 4.5 (1) (v)-5)
Measurable range of remained wall thickness (Figure 4.5 (1) (v)-6)	Section without inner skirt	0.3 to 1.2 m
	Section with inner skirt	0.3 to 0.6 m* *Depth of inner skirt
Measurement accuracy (±100 mm)		100 mm
Resolution	Time resolution	200 mm
	Lateral resolution	400 mm

[Radiation resistance]

(1) Test conditions

a) Dose rate: 10 Gy/h (outside the pedestal

b) Cumulative dose: Max. 1 kGy or more

(2) Test results

No change was observed in the waveform after γ-ray irradiation at a dose rate of 10 Gy/h for 116 hours (approx. 5 days, cumulative dose of 1.16 kGy), which proved that the sensor had enough radiation resistance for investigation operation.

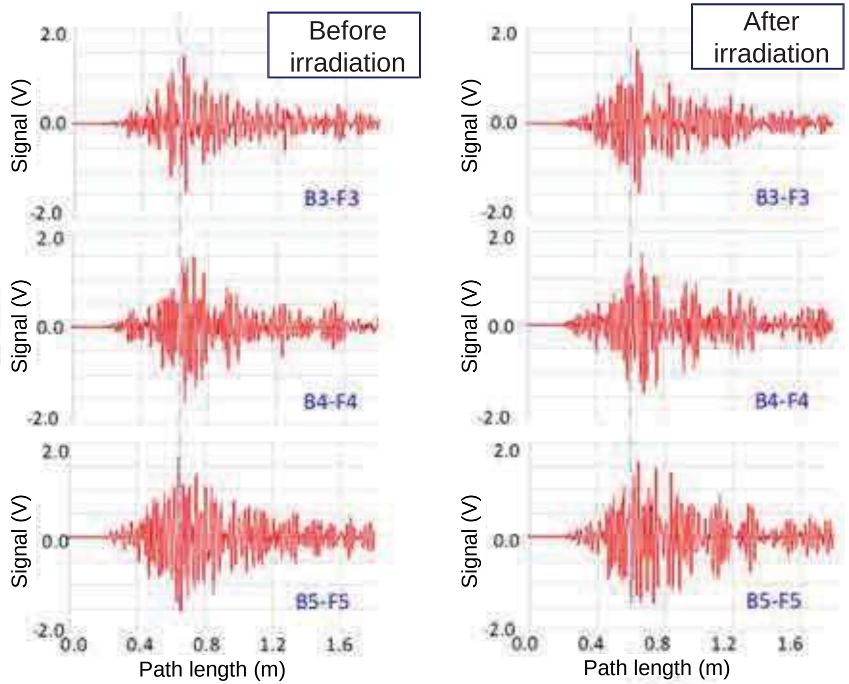


Figure 4.5 (1) (v)-3. Examples of Radiation Resistance Test Results

(1) Shape and dimension measurement technology

(v) Low-frequency ultrasonic sensor (for measurement of remained pedestal wall thickness) 3/4

[Consideration of distance L between transmitter and receiver]

Seek a measurement condition that more low-frequency components be included in the echo signal.

- Increase the distance L between the transmitter (transducer) and receiver (transducer) in order to excite the transmitter transducer with a lower-frequency (50 kHz) electric signal than the resonant frequency (100 kHz)

(It is to take advantage of the property that lower-frequency (thus longer wavelength) ultrasonic wave has a wider spread angle when the area of the wave transmission section is the same.)

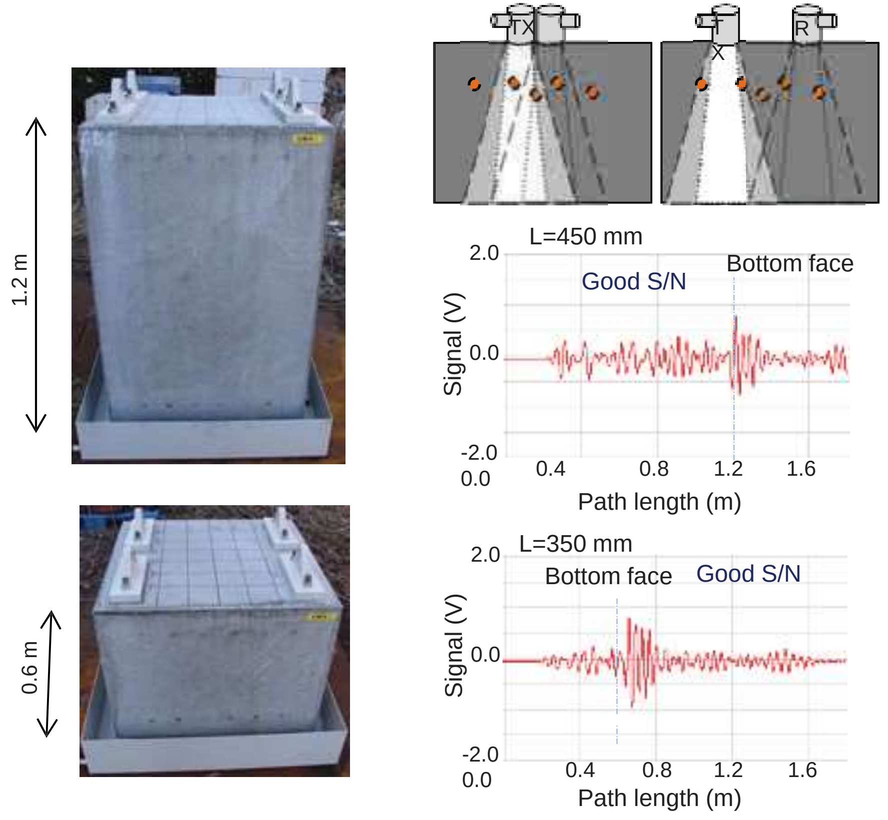


Figure 4.5 (1) (v)-4. Test of Distance between Transmitter and Receiver Sensors

[Improvement of S/N ratio]

Measure ultrasonic echo signals at different positions and average the recorded waveforms to improve the S/N ratio of the signal

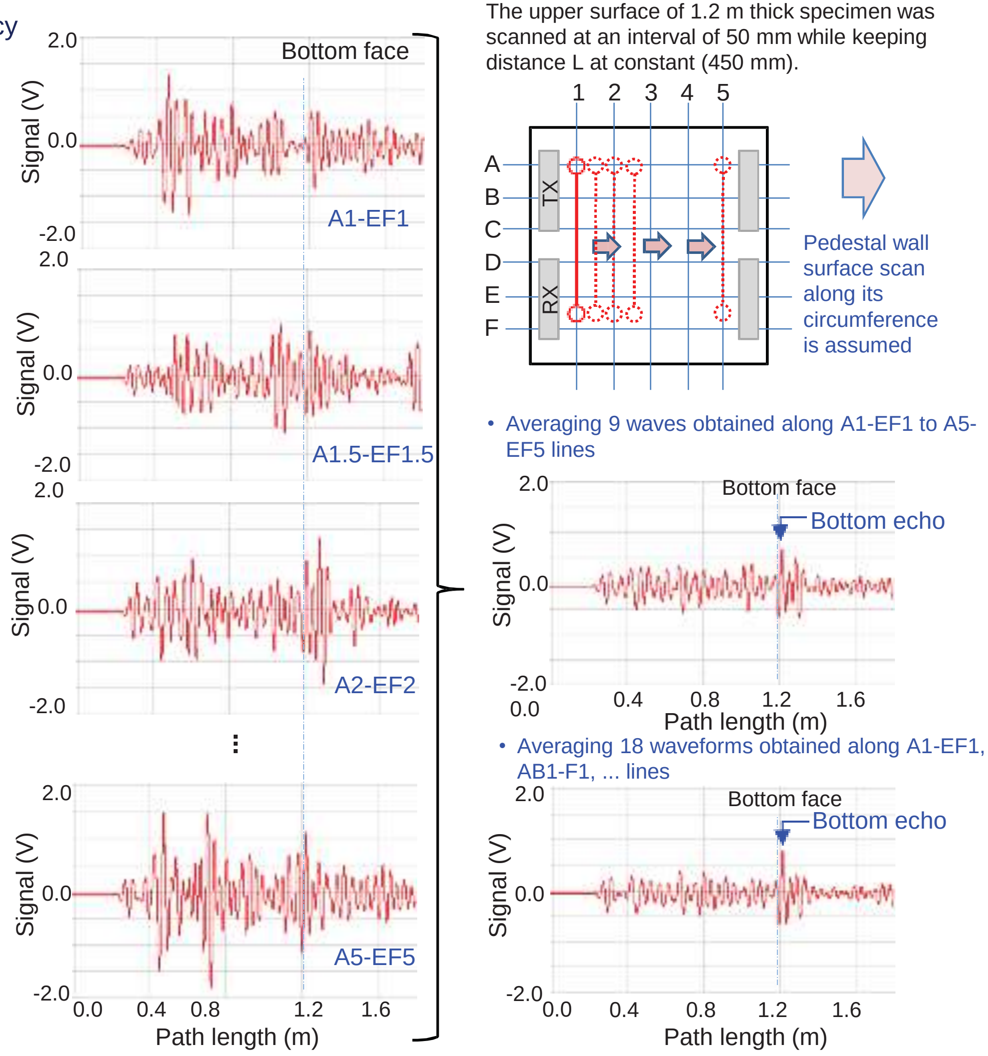


Figure 4.5 (1) (v)-5 Effects of waveform averaging

(1) Shape and dimension measurement technology

(v) Low-frequency ultrasonic sensor (for measurement of remained pedestal wall thickness) 4/4

[Measurable range of remained pedestal wall thickness]

- Bottom echo was received with both 0.6 m thick and 1.2 m thick test specimens.
- All waves were reflected by the simulated inner skirt, and bottom echo signal was not received.
- From the above results, the following judgment can be derived: corrosion of the inner surface of the pedestal has not reached the inner skirt when echo reflected from a point of 0.6 m path length is received in a height range of 1 m or less.
- Remaining thickness below 0.3 m cannot be measured due to dead band

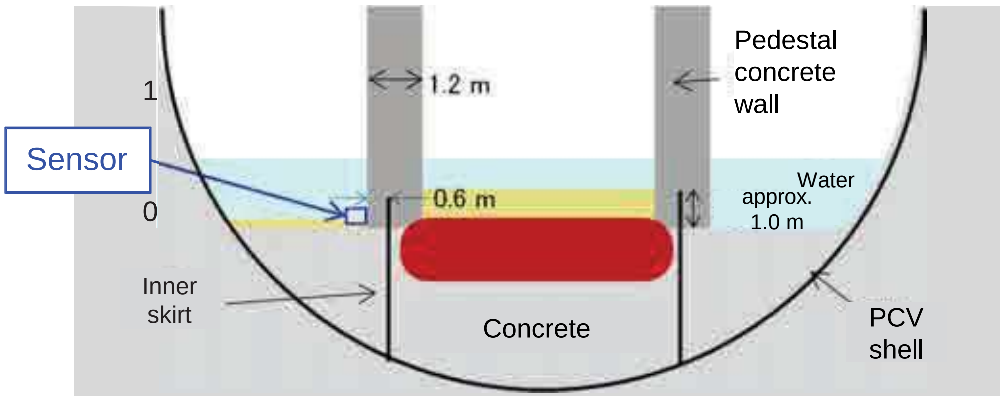
< Measurable range of remained thickness >

- Section without inner skirt: 0.3 to 1.3 m
- Section with inner skirt: 0.3 to 0.6 m

*** There is a possibility to be able to determine whether the pedestal inner surface corrosion has reached the inner skirt or not from this measurement.**

[Preconditions for application to the actual site]

Deposit and interfering objects in the outer periphery of the pedestal need to be removed prior to the measurement since the outer surface of the pedestal needs to be scanned along its circumference at different heights including the bottom part



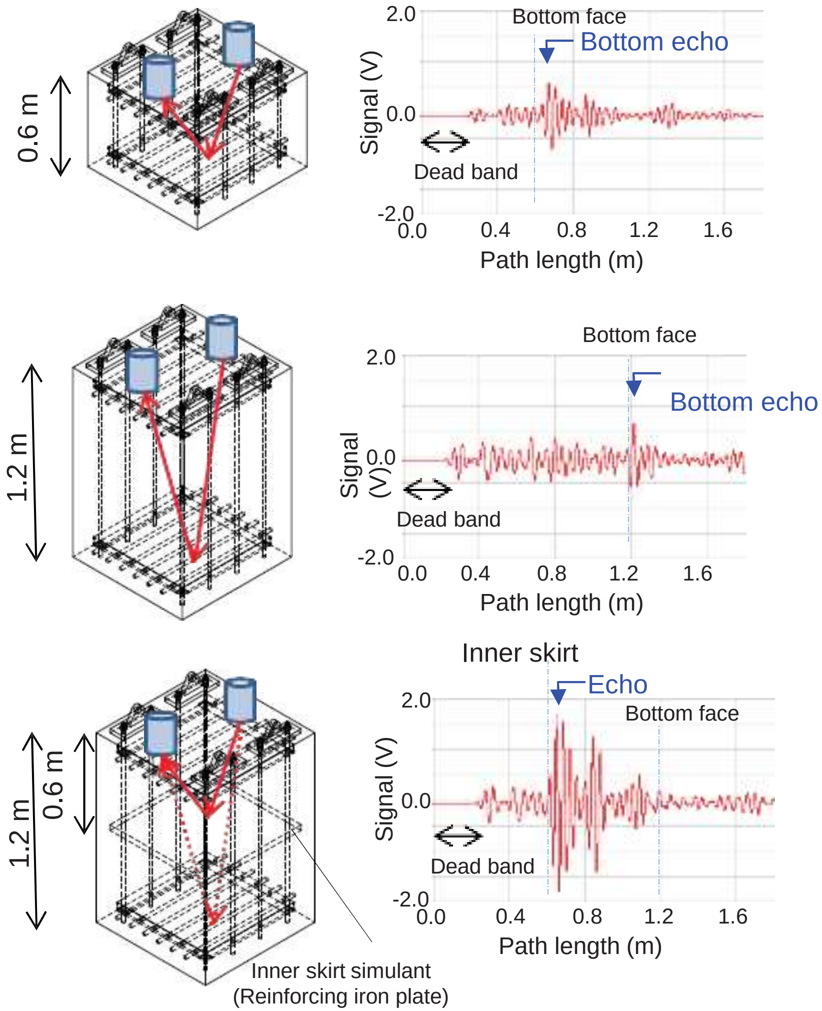


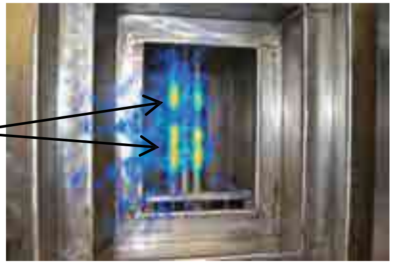
Figure 4.5 (1) (v)-6. Results of Remained Thickness Measurement

Action required: Applicability verification in the assumed concrete environment with the actual equipment including heat deterioration

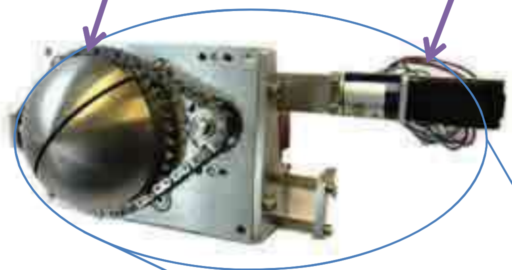
Action: Preparation and verification of measurement test conditions based on the result of detailed visual inspection planned in the detailed investigation inside the PCV of Unit 1

(2) Radiation measurement technologies (i) γ-camera

- A γ-camera was designed and produced.
- The same pan mechanism design as that for the ultrasonic sonar was adopted.
- The pan mechanism, outer shell, and γ-camera were produced. The produced components were assembled together and tested (pan mechanism and collimator operation tests and total weight measurement).



Dynamic range (high limit) evaluation

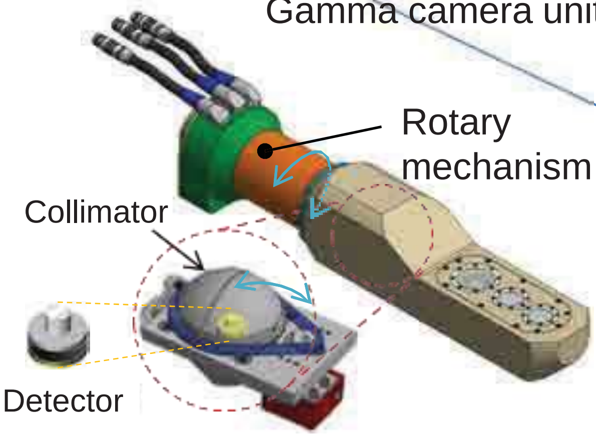


Gamma camera unit

Back side of pan mechanism

Main functions and test results

Function	Verification results
Radiation resistance	It was demonstrated that all components have a radiation resistance of 10 kGy or more
Measurement performance	It was demonstrated by irradiation test that a dynamic range of 1 to 1,000 Gy/h can be achieved
Water resistance	It is planned to test the effect of sealing material to secure water resistance



External view of γ-camera

Appearance of γ-camera

(2) Radiation measurement technologies

(ii) CdTe semiconductor detector and improved compact B-10 detector (for fuel debris detection) (1/4)

The applicability test of fuel debris detection system was performed (unit test and combination tests), and the test confirmed the feasibility of the system mounted on an ROV that is able to measure.

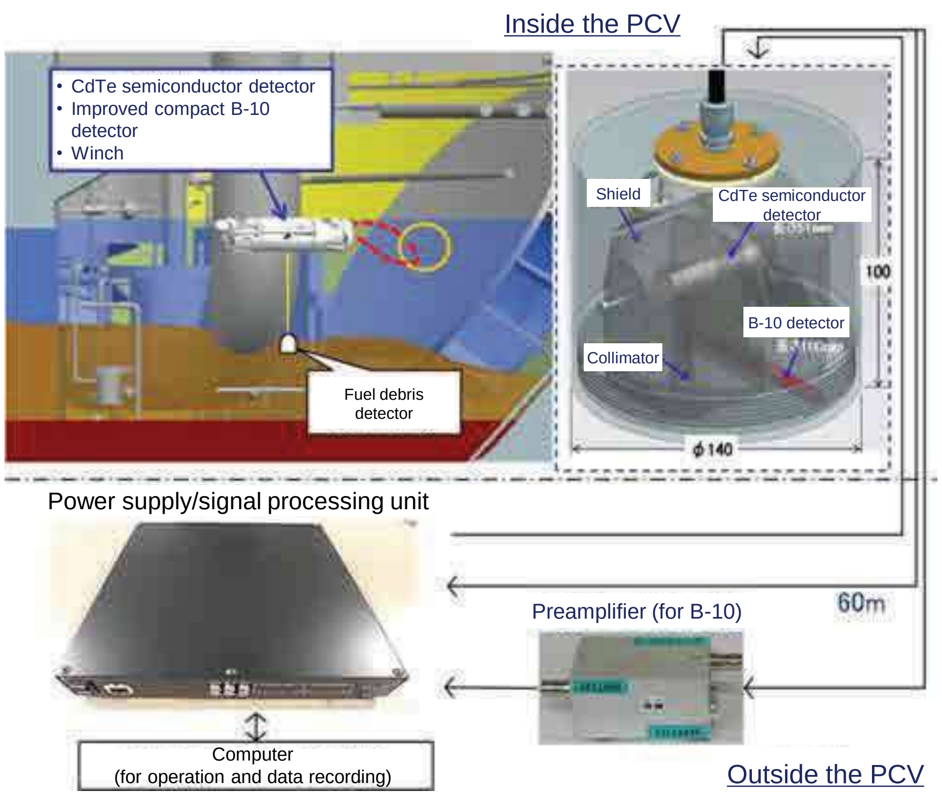


Figure 4.5(2)(ii)-1 Configuration of system to detect fuel debris in and under deposit

Verification items

Test type	Check items	
Unit test 1 (Tests performed in a setup where sensors and measurement instruments used in the on-site validation and the cable used for the actual ROV [no redundant cabling] are connected to the produced system)	Detection efficiency	
	Performance to analyze γ-ray nuclides	
	Neutron detection performance	
	Effect of disturbance	High dose-rate γ-ray
		Electric noise
		Polarizing action
Unit test 2)	Ability to measure radiation from spent fuel	
Combination test (Tests performed in a setup where sensors and measurement instruments used in the on-site validation are combined with an ROV)	Verification of measurement performance	
	Impact of ROV’s posture	
	Effect of disturbance	Electric noise

Unit test results (obtained in FY2017 to FY2018)

Check items		Verification results
Detection efficiency	Eu-154	2.2 X 10^{-4} cps/Bq (Error ±10%)
	Cs-137	1.6 X 10^{-3} cps/Bq (Error ±14%)
	Co-60	1.8 X 10^{-4} cps/Bq (Error ±26%)
	Thermal neutron	0.28 cps/nv (Figure 4.5 (2) (i)-5)
Discriminability between Co-60 peak and Eu-154 peak		Both are discriminable as the peak half-value width of Eu-154 is 33 keV or less (Figure 4.5 (2) (ii)-3)
Detection limit	CdTe	0.08 cps
	Improved B-10	0.03 cps
Effect of measurement disturbances	Polarizing action	No polarization after 1 hour from the start of measurement (Figure 4.5 (2) (i)-4)
	Effect of high dose-rate γ-ray	A prospect was obtained that γ-ray and neutron could be discriminated when a dose rate is about 120 Gy/h or less* (Figure 4.5 (2) (i)-6)
	Electric noise	A prospect was obtained that noise reduction methods (such as ferrite core and common earthing) could be effective to reduce noise when a 60 m long cable is used.
Ability to measure radiation from spent fuel		Eu-154 and neutron were detected. (Figure 4.5 (2) (ii)-7)

[CdTe detector unit test results]

The CdTe detector was installed in the collimator-equipped tungsten shield and connected to a 60 m cable, and γ-ray and neutron spectra of various radioactive nuclides were measured by the detector.

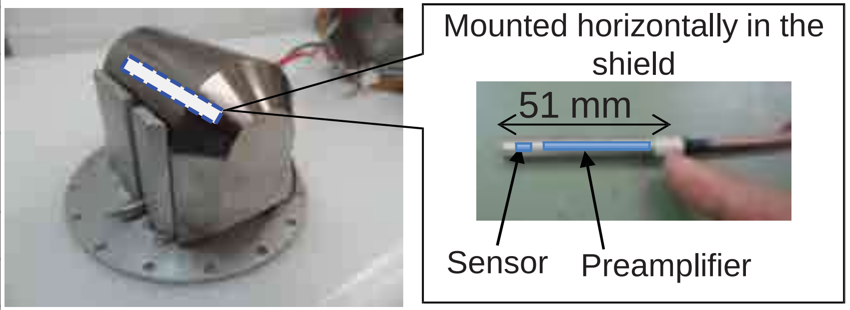


Figure 4.5 (2) (ii)-2. Appearance of tungsten shield and CdTe detector

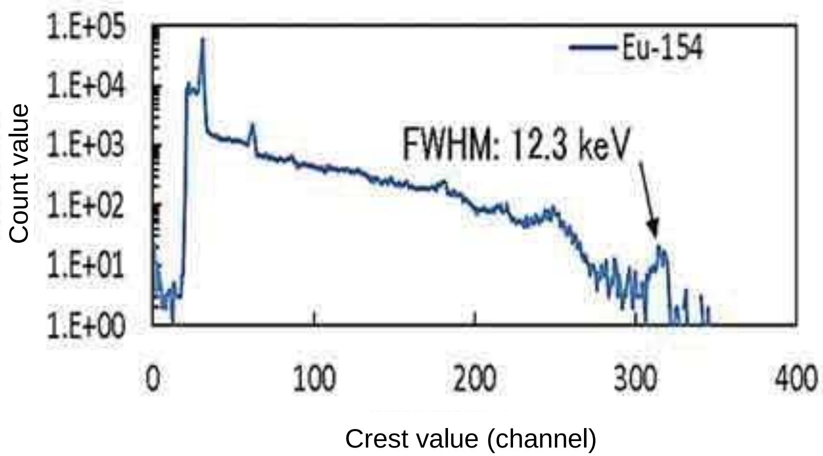


Figure 4.5 (2) (ii)-3 Result of Eu-154 γ-ray spectrum measurement

* A further test is necessary to evaluate the discriminability under higher dose-rate γ-ray than 120 Gy/h.

[CdTe detector unit test results (Continued)]

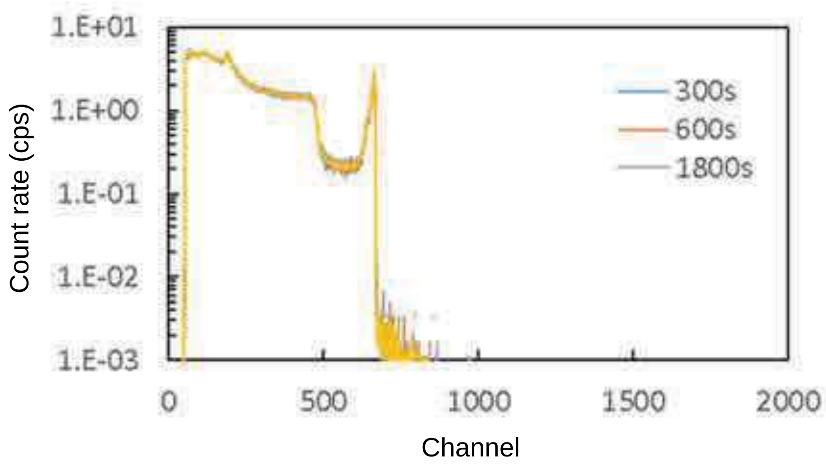


Figure 4.5 (2) (ii)-4. Result of Polarization Occurrence Check

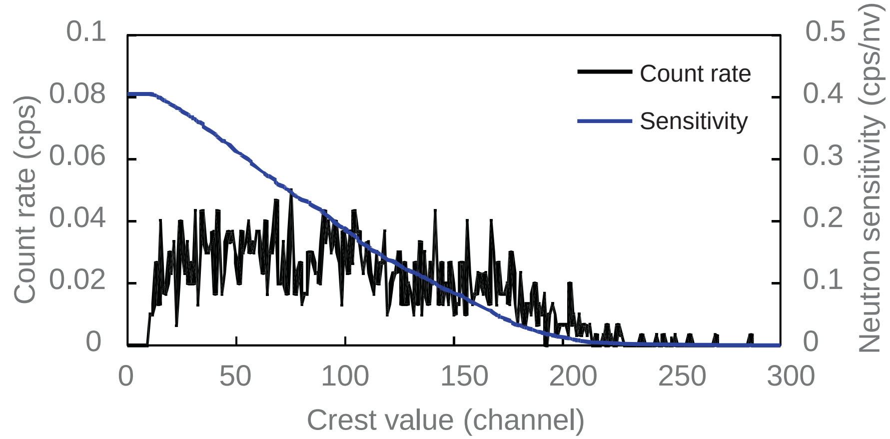


Figure 4.5 (2) (ii)-5. Result of Cf-252 Neutron Spectra Measurement

[Unit test results of improved compact B-10 detector]

- The improved compact B-10 detector was connected to a 60 m coaxial cable, and neutron spectra of various radioactive nuclides were measured by the detector.
- The pulse-height threshold dependence of thermal neutron sensitivity was obtained.
- Neutron spectra were obtained in a dose rate of higher than 100 Gy/h.

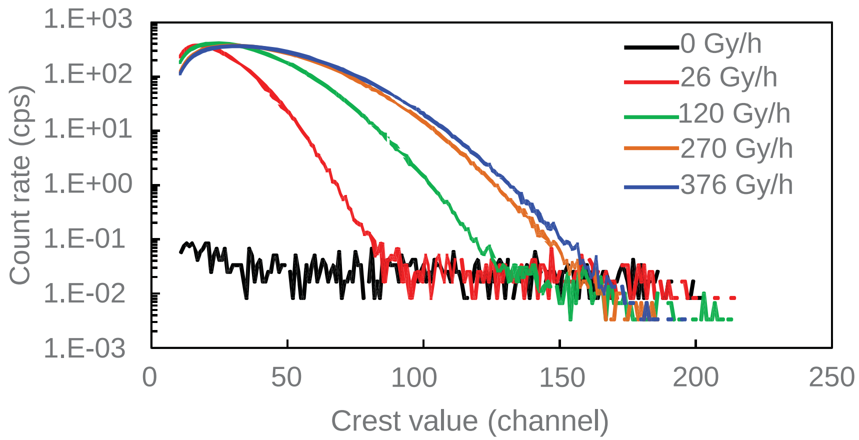


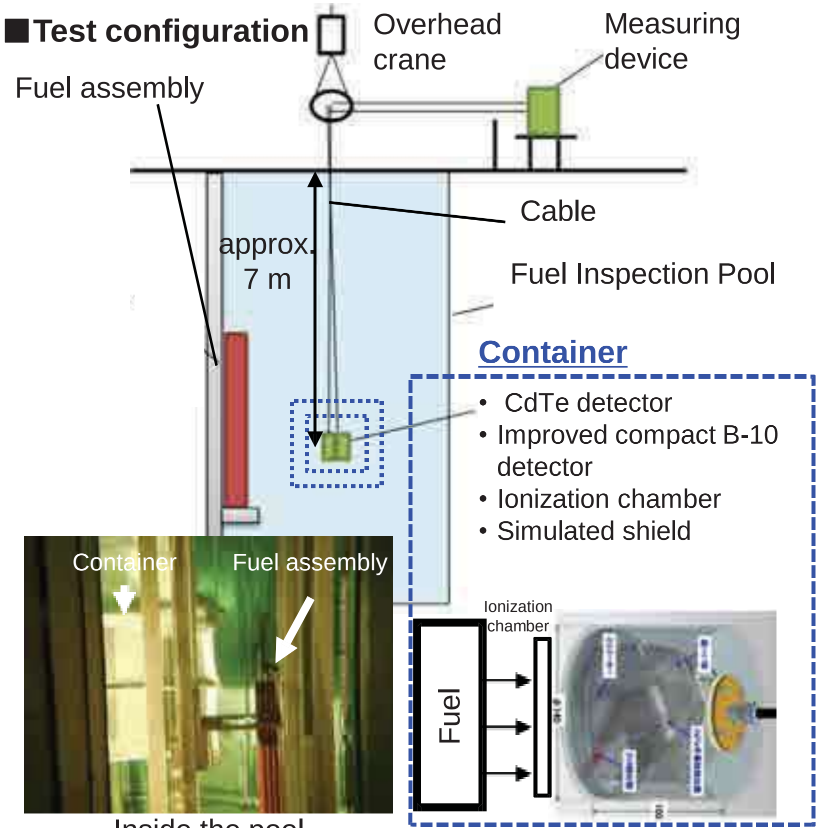
Figure 4.5 (2) (ii)-6 Result of neutron spectra measurement under high dose-rate Co-60

(2) Radiation measurement technologies

(ii) CdTe semiconductor detector and improved compact B-10 detector (for fuel debris detection) (4/4)

[Ability to measure radiation from spent fuel assembly]

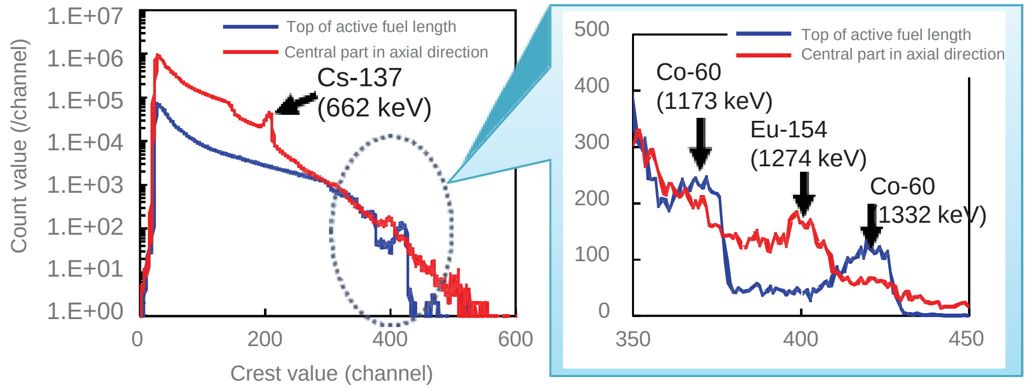
■Test configuration



Inside the pool
(viewed from lateral side)

■Measured data

[CdTe semiconductor detector] Succeeded in detecting Eu-154 even when dose rate was approx. 20 Gy/h or less.



[Improved compact B-10 detector] Succeeded in detecting neutron even when dose rate was approx. 20 Gy/h or less.

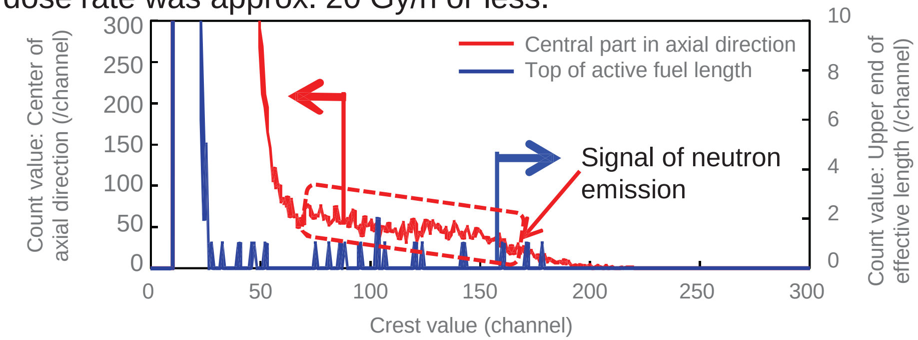


Figure 4.5 (2) (ii)-7. Results of detector performance test using spent fuel assembly

[Combination test with ROV]

There was no electric noise caused by the camera and LEDs mounted on the ROV. Meanwhile, noise was added when the cable drum motor was activated. It was determined that this noise would not cause any adverse effect since the ROV wouldn't be moved during measurement.

Further actions required: Setting of criteria to determine the sensor location point and measurement time that fits the condition of the site.

Action: Consider these items in the detailed plan for on-site validation

(3) Location technology (i) Monocular camera (1/3)

A location system was designed and produced, and the in-plant verification test (stand-alone test and combination test) was performed on the produced system. The test confirmed the feasibility of system that can determine the location with an accuracy of ±200 mm or better within the original requirements to satisfy the needs .

Compliance verification items

Test type	Check items	Verification results
Unit test	Location error	Figure 4.5 (3) (i)-3, 4
	Navigation mark visibility	
	Effect of ROV posture	
Combination test	ROV mounting position calibration	Figure 4.5 (3) (i)-5, 6
	Camera undistortion	

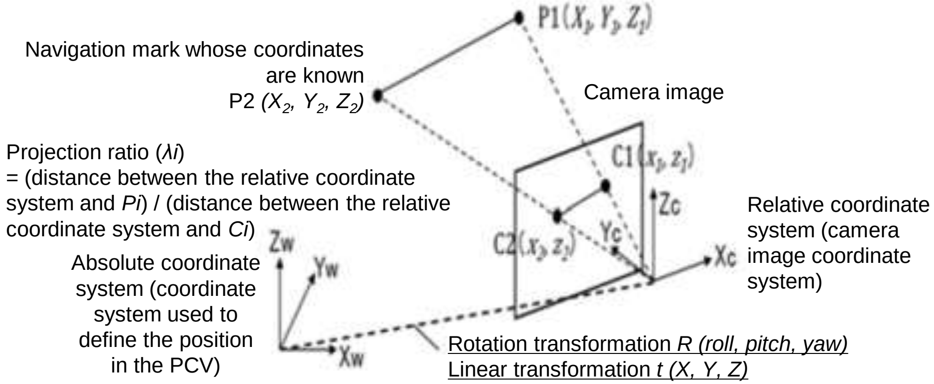


Figure 4.5 (3) (i)-1. Principle of Monocular Camera-Based Location Determination Method

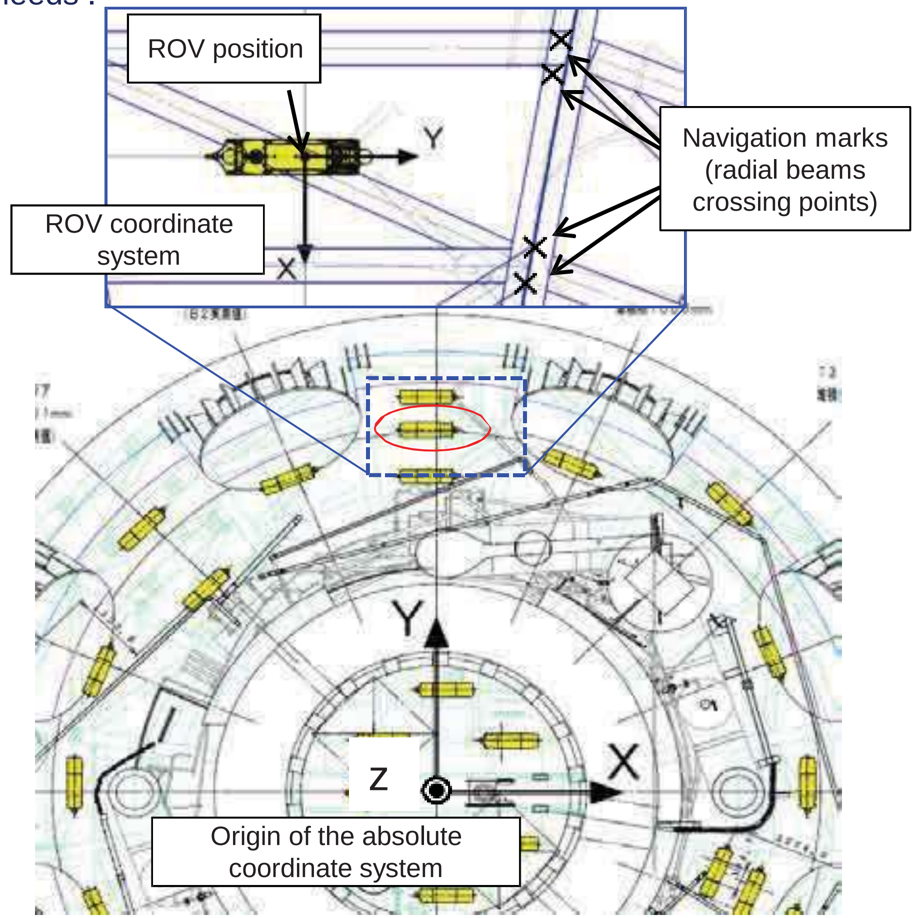
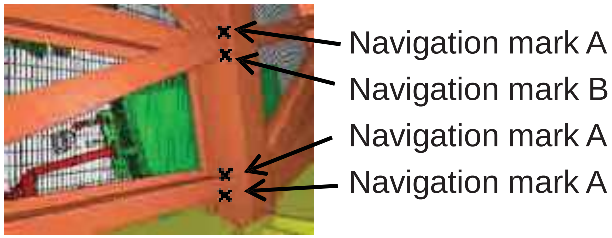


Figure 4.5 (3) (i)-2. ROV Location Method Using Characteristic Structures as Navigation Marks

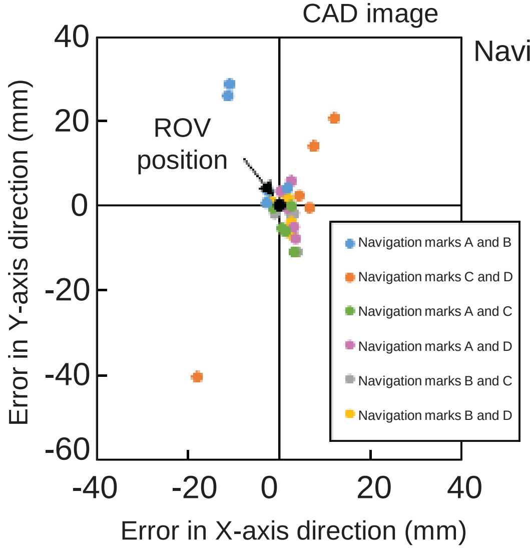
(3) Location technology (i) Monocular camera (2/3)

[Evaluation of location error by comparing with CAD drawings] (Unit test)

- Location error was evaluated by comparing the positions of navigation marks in the 3D CAD space and the positions of the same navigation marks determined from simulated camera images.
- The maximum measurement error was confirmed to be 40 mm based on a navigation mark pointing error in the image of ±1 pixel.



CAD image



Navigation mark pointing error in the image: ±1 pixel

Error in X-axis direction: -18.1 to +12.0 mm

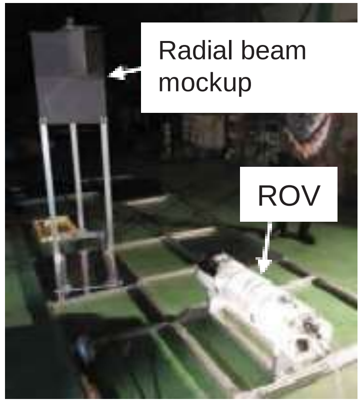
Error in Y-axis direction: from -40.4 to +28.8 mm

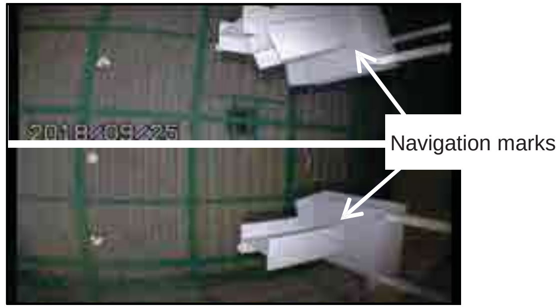
Angular error: -1.1 to +1.9 degrees

Figure 4.5 (3) (i)-3 Examples of ROV positioning errors

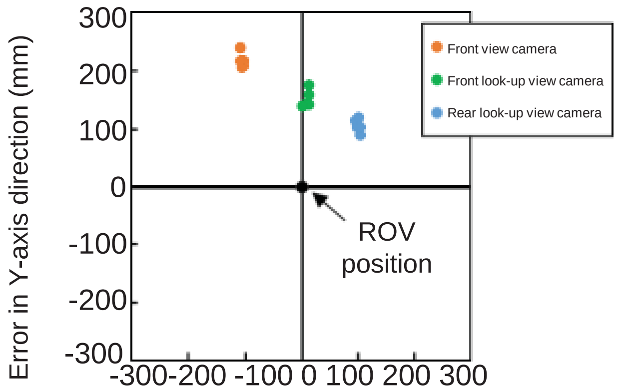
[Evaluation with simulated structure (Combination test)]

- The ROV and a mockup simulating the actual radial beam and having simulated navigation marks on it were arranged with a fixed relative position, and the image of the mockup was captured by the camera to evaluate the visibility of the navigation marks.
- An error of the ROV location derived from the captured image was maximum 242 mm.





Example of captured image



Error in X-axis direction: from -109.0 to +103.8 mm

Error in Y-axis direction: +89.5 to +242.2 mm

Angular error: -3.5 to +1.4 degrees

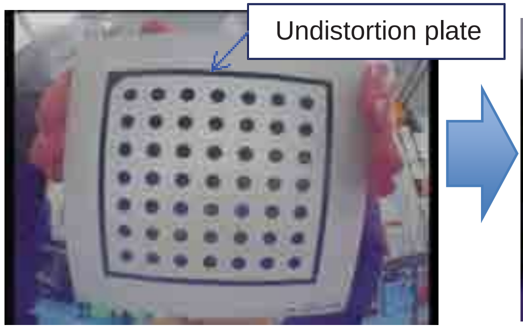
Figure 4.5 (3) (i)-4 Examples of ROV position errors with test mockups

Error in X-axis direction (mm)

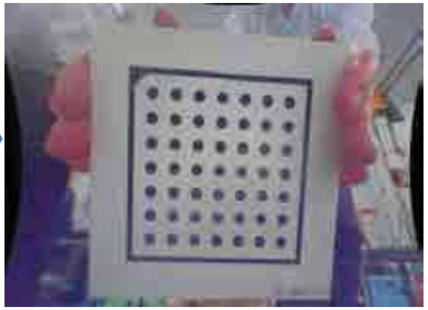
(3) Location technology (i) Monocular camera (3/3)

[Camera undistortion and ROV mounting position calibration] (Combination test)

- Correction of camera image distortion using the undistortion plate and correction of the position of the cameras using the calibration plate
- The maximum location error was reduced from 242 mm to 145 mm by these corrections.



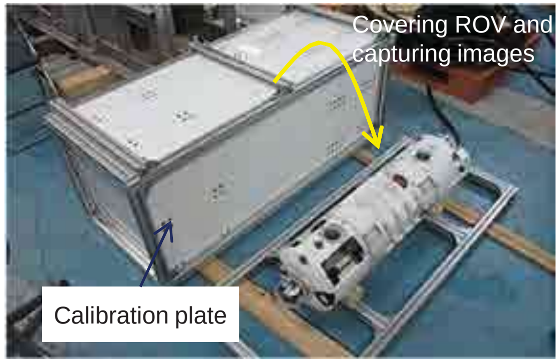
Before undistortion



After undistortion

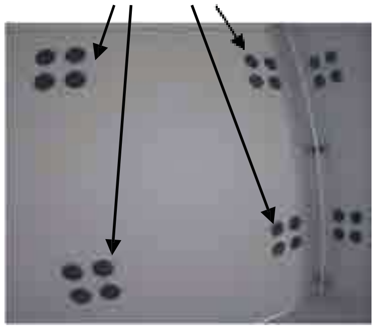
Captured image in stand-alone accuracy evaluation test

Corrections results reflected



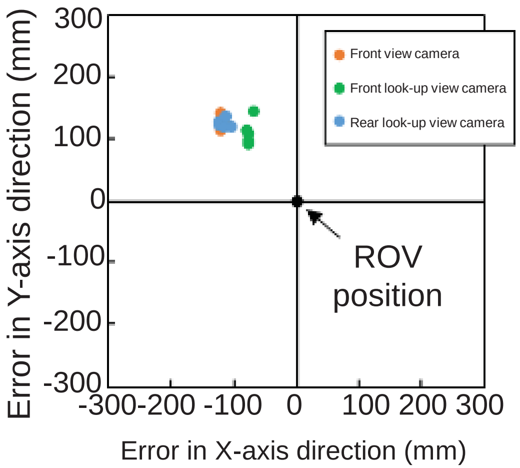
Camera positioning jig

Calibration reference points



Example of captured image

Figure 4.5 (3) (i)-5 Effect of camera distortion correction (top) and tools for camera mounting position calibration (bottom)



Error in X-axis direction: from -123.6 to -68.5 mm

Error in Y-axis direction: from +90.7 to +145.3 mm

Angular error: -4.6 to +1.5 degrees

Figure 4.5 (3) (i)-6 Examples of ROV position errors reflecting correction values

Further actions required: Figuring out how to deal with difficult cases, such as where navigation marks in the field of camera view are hidden by objects like a cable pipe

Plan: To examine the applicability of the following alternate location methods: extrapolating the location of a hidden navigation mark (intersection point) from the image of two beams, and determining location using underwater structures such as jet deflectors

4.6 Implementation Items and Results -- Design and Preparation for Mockup Test Facility (1/3) --

In order to increase the reliability of the Detailed Investigation, the verification of the arm type access device has been planned in a mockup test using a test facility that partly simulates the actual facility.
The following tasks were executed in this project:

[Determination of the specifications of the test facility and design of the test facility]

- The test items of the mockup test were reviewed, the specifications of the test facility were determined,* and the test facility was designed.
  * Scale, simulated sections, and accuracy level of simulation of the mockup (including dimensions and materials).

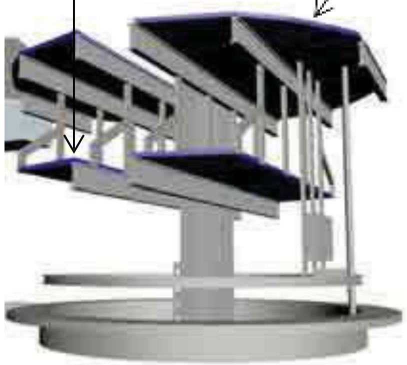
[Procurement of test materials]

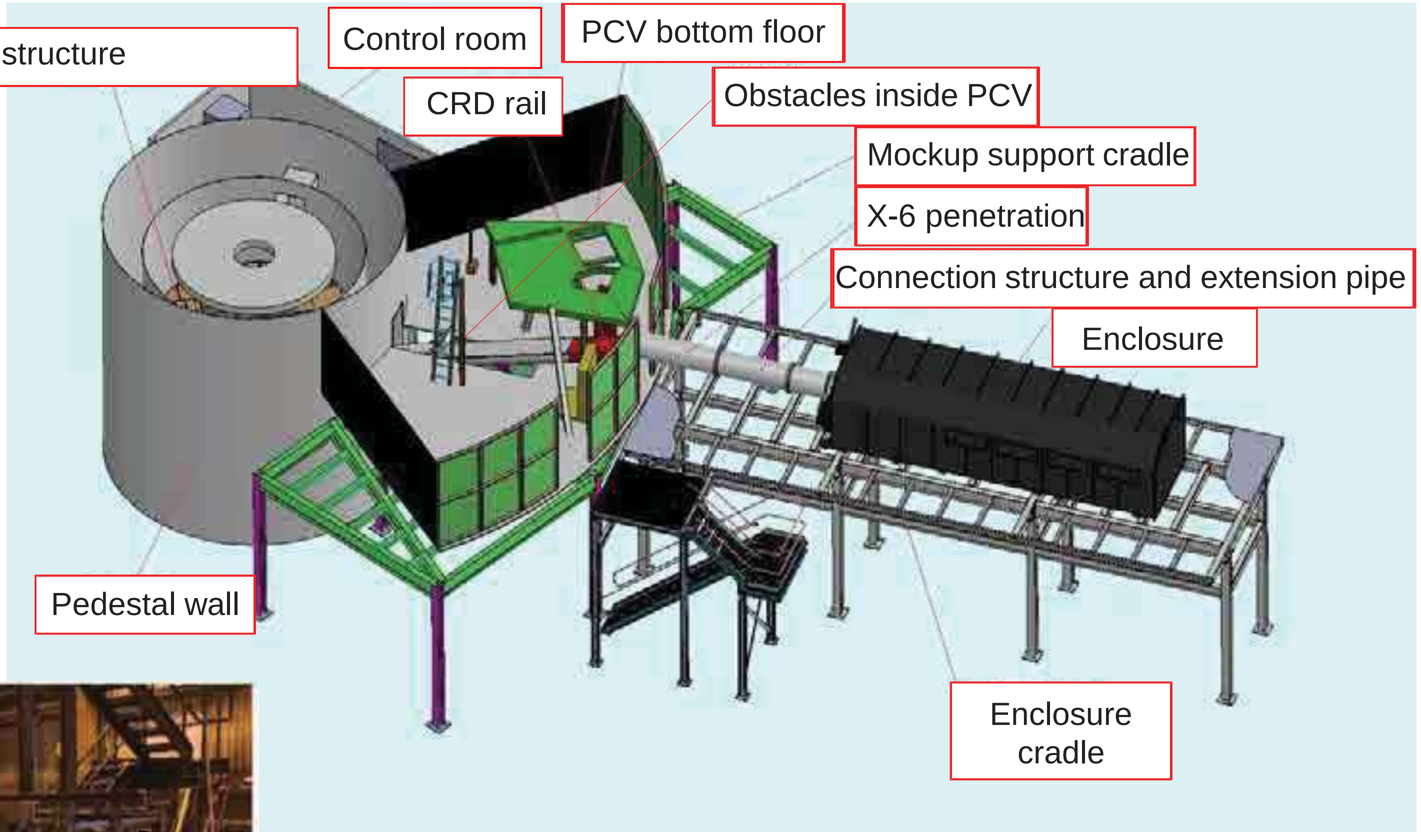
- Based on design of the mockup test facility, the production commenced (the materials were procured).

Main specificationss of mockup test facility (UK)

Items		Requirements
Scale		1/1 scale
Sections to be simulated and accuracy level of simulation	Inside the pedestal	• Design shall be according to the drawings of inside pedestal structures. • Not the whole structure of CRD but only its lower end shall be reproduced using flat plates. • The platform and intermediate work platform shall be reproduced. • A grating opening shall be reproduced based on the photograph taken after the accident. • The CRD exchange equipment shall be reproduced above the grating. • The lifting frame of the CRD exchange equipment shall be reproduced on the underground floor.
	Outside the pedestal	Pipes and ladders shall be reproduced on the wall of the simulated PCV wall around the inside end of the X-6 penetration as simulated objects for testing obstacles cutting method inside the PCV.
	X-6 penetration, connection structure, extension pipe, and CRD rail	The internal structure of the actual PCV shall be simulated in the mockup test facility as much as possible to ensure the reliability of the arm type device passing test through the X-6 penetration and inside PCV obstacles removal test, both of which are performed in relation to the construction of the access route through the X-6 penetration.
Sections to be simulated and accuracy level of simulation	Enclosure support cradle	The mockup test facility shall consist of a two-story structure with the first floor simulating the PCV underground floor and the second floor simulating the vertical position of the X-6 penetration and the enclosure. To enable this structure, a cradle shall be constructed to support the X-6 penetration, Connection Structure, and extension pipe.
Material		The X-6 penetration, Connection Structure, extension pipe, grating, and sections that receive reaction force and support loads shall be made of steel. Other sections that don't require high strength can be made of inexpensive materials (such as plastic and wood).

Overall view of mockup test facility





Overall view of the mockup test facility and the produced mockup of the structure in the pedestal (on the left)

* The mockup of the structure in the pedestal is flipped upside down in the photograph.

4.6 Project Achievements

Implementation Items and Results			Achievement index (FY2018)	Achievement level
Development and investigation planning		Unit 1	Based on the latest site condition, the investigation and development plans shall be reviewed, materialized, and updated.	Achieved (in FY2017)
		Unit 2		Achieved
		Unit 3	The applicability of the devices developed for Units 1 and 2 to Unit 3 shall be studied, and it shall be clarified whether a development issue exists.	Achieved
Development of access and investigation device	Establishment of access route into PCV through X-6 penetration	Opening the hatch	Design/production and in-plant verification test of equipment and devices for establishment of access route into PCV shall have been finished (Target TRL: Level 4 or 5).	Achieved
		New boundary connection	Production and in-plant verification test of a full-scale prototype structure connecting to X-6 penetration shall have been finished.	Achieved
	Establishment of access route into PCV through X-2 penetration		In-plant verification test of established access route into PCV shall have been finished (Target TRL: Level 4 or 5).	Achieved
	Access and investigation device		Design, production, and factory verification test shall have been completed for a full-scale prototype of access and investigation device (Target TRL: Level 4 or 5).	Achieved (The prospect of developing the arm type access and investigation equipment was obtained through the examination of the producibility and the technical feasibility of achieving the intended performance and functions that was conducted by prototyping part of the device.)
Applicability verification of element technologies			The verification test of measurement technologies to be incorporated in access and investigation device shall have been completed (Target TRL: Level 4 or 5).	Achieved
Mockup test plan			Review of the mockup test procedure of the arm type access device and design of the test facility completed, and the preparation started (not included in objectives).	Achieved

5. Overall Summary

(1) Development of investigation and development plans
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 were updated.

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

- The isolation room and hatch opening device were designed and produced to identify issues of the work procedures by in-plant validation test. Further, countermeasures for the identified issues were implemented.
- The Connection Structure to the X-6 penetration was designed and produced. A in-plant verification test of the structure was conducted.

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

- In-plant verification tests verified the workability and construction conditions for access route establishment isolated from the inside of the PCV and issues in relation to the construction method and devices, as well as procedures, were also identified in the same test. Further, countermeasures for the identified issues were implemented.

(3) Access and investigation equipment

- Part of the arm type access device was produced. The feasibility of the arm type access device was examined in terms of the producibility and technical prospects for achieving the intended performance and functions.
- The submersible type access device was designed and produced. Then, a in-plant validation test was performed on the produced device to identify issues in relation to the device and work procedures. Further, countermeasures for the identified issues were implemented.

(4) Applicability Verification of Element Technologies

- Measurement systems to be incorporated in the submersible type device were designed and produced, and a verification test was performed on the produced systems to evaluate the performance.
- Measurement systems to be incorporated in the arm type device were designed and produced, and a verification test was performed on the produced systems to evaluate the performance.
- As to the measurement of the thickness of the remaining pedestal wall, which will be performed after deposit removal, a sensor to be used for the measurement was selected, and a unit test was performed on the selected sensor, including the evaluation of measurable thickness range.

(5) Mockup test plan

- The design of the mockup test facility was completed, and then the construction was started.