Subsidy Project of Decommissioning and Contaminated Water Management in the FY2017 Supplementary Budgets

Development of Technology for Detailed Investigation Inside the PCV (On-site Demonstration of Detailed Investigation Technology through the X-6 Penetration)

FY2019 Final Report

July 2020

International Research Institute for Nuclear Decommissioning (IRID)

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1. Research background and purpose

1.1 Reason why this research project is required

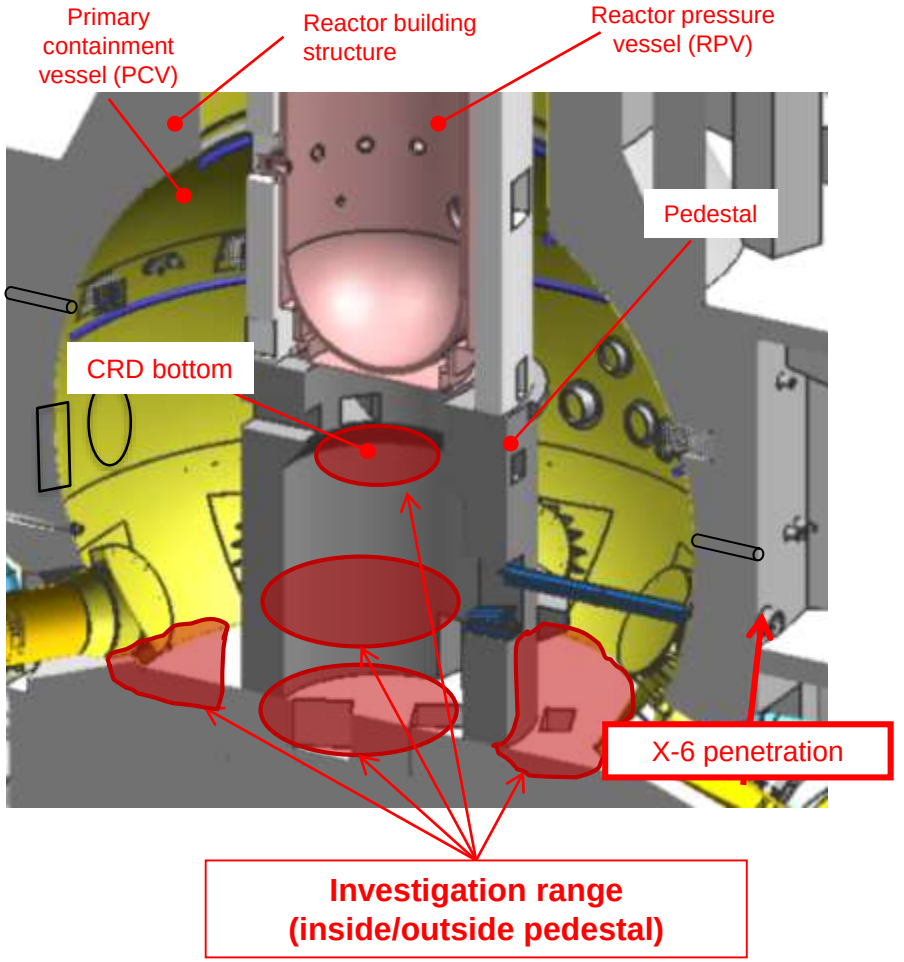
【Background】

As revealed by a result of investigation inside the PCV of Unit 2 conducted in January 2018, pebble- and clay-like deposits were confirmed on the whole pedestal bottom.

Moreover, part of fuel assemblies dropped on the bottom, in which deposits were confirmed to be fuel debris.

【**Purposes**】

The access and investigation equipment is intended to enter through the X-6 penetration that was used for the previous investigation inside the PCV after making a larger-diameter opening. For on-site demonstration and estimation of fuel debris distribution, detailed information regarding the conditions of inside/outside pedestal will be acquired to contribute to the clarification of the fuel debris retrieval method.



【Overview of the PCV cross section and investigation points】

1.2 Application and contribution of the results of research projects

FY2016–FY2017 Development of technology for investigation inside the PCV

↓

FY2017–FY2018 Development of Technology for Detailed Investigation Inside the PCV

- Development of access and investigation equipmer
- Applicability verification of element technologies
- Mock-up test plan

↓

This project

FY2018–FY2019 Development of Technology for Detailed Investigation Inside the PCV
(On-site validation of technology for detailed investigation inside the PCV through the X-6 penetration)

Development of investigation and development plans

Development of access and investigation equipment

↓

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

•Information for the determination of fuel debris retrieval method and the detailed design of fuel debris retrieval equipment, etc.

Development of Technology for Increasing the Scale of Retravel Debris in stages

Information necessary for the planning, etc.

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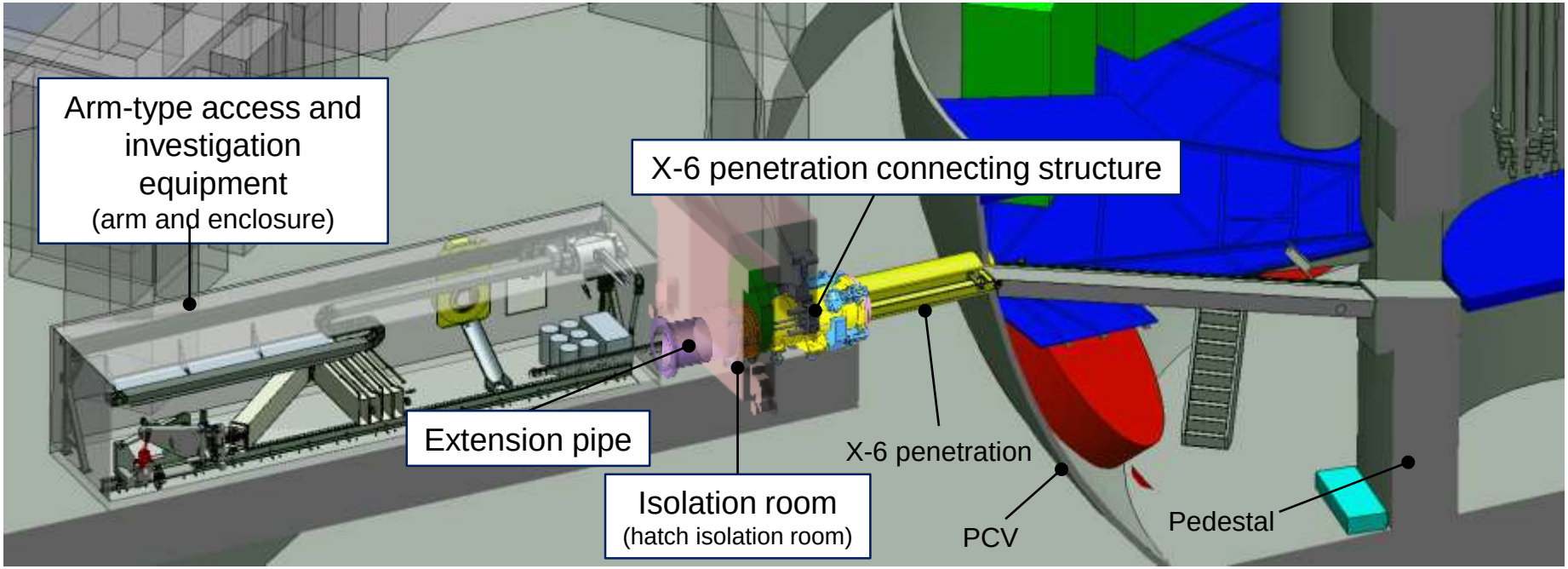
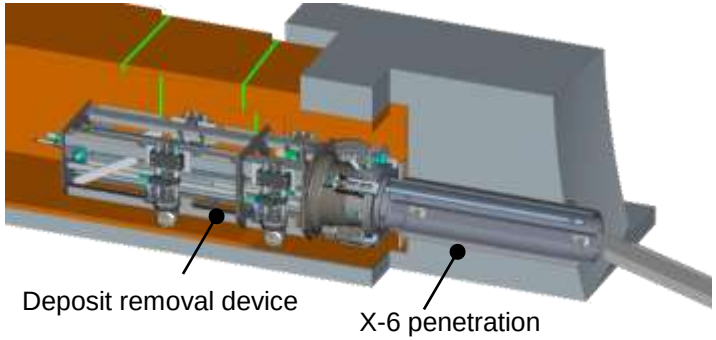
2. Implementation items, their correlations, and relations with other research

2.1 Subject of development and relations with other projects: configuration and the main purpose of equipment and structures





Equipment and structures	Main purpose
Arm-type access and investigation equipment	Acquisition of data on the inside of PCV (equipped with sensors), removal of obstacles (equipped with tools)
X-6 penetration connecting structure	Construction of PCV boundary and provision of access for arm (equipped with isolation valve)
Extension pipe	Shielding and provision of access for arm
Isolation room	Shielding and construction of PCV boundary while X-6 penetration lid is open (before X-6 penetration connecting structure is attached)
Deposit removal device	Removal of deposit, etc. from inside the X-6 penetration

2. Implementation items, their correlations, and relations with other research

2.1 Subject of development and relations with other projects

Subject of development		Design, manufacturing, and unit test	Mockup	Operation training	On-site verification (on-site investigation)
Access and investigation equipment	Arm-type access and investigation equipment		Installation of mockup facility, the concretization of test procedures	Operation of arm using simulation, the basic manipulator operation	Investigation plan/on-site layout
Equipment and structures for construction of access route	X-6 penetration connecting structure				
	Extension pipe		Mockup → Improvement/ functional verification		
	Isolation room				
	Hatch opening device		Mockup → Operability verification		
	Deposit removal device				
Research technology	Laser scanner		Concretization of test procedures, verification of connection of the access and investigation equipment		
	γ-ray sensor				
	Sonar				
	VT sensor				
	Neutron sensor				

: Development of technology for detailed investigation inside PCV (FY2017 to FY2018) (complete)

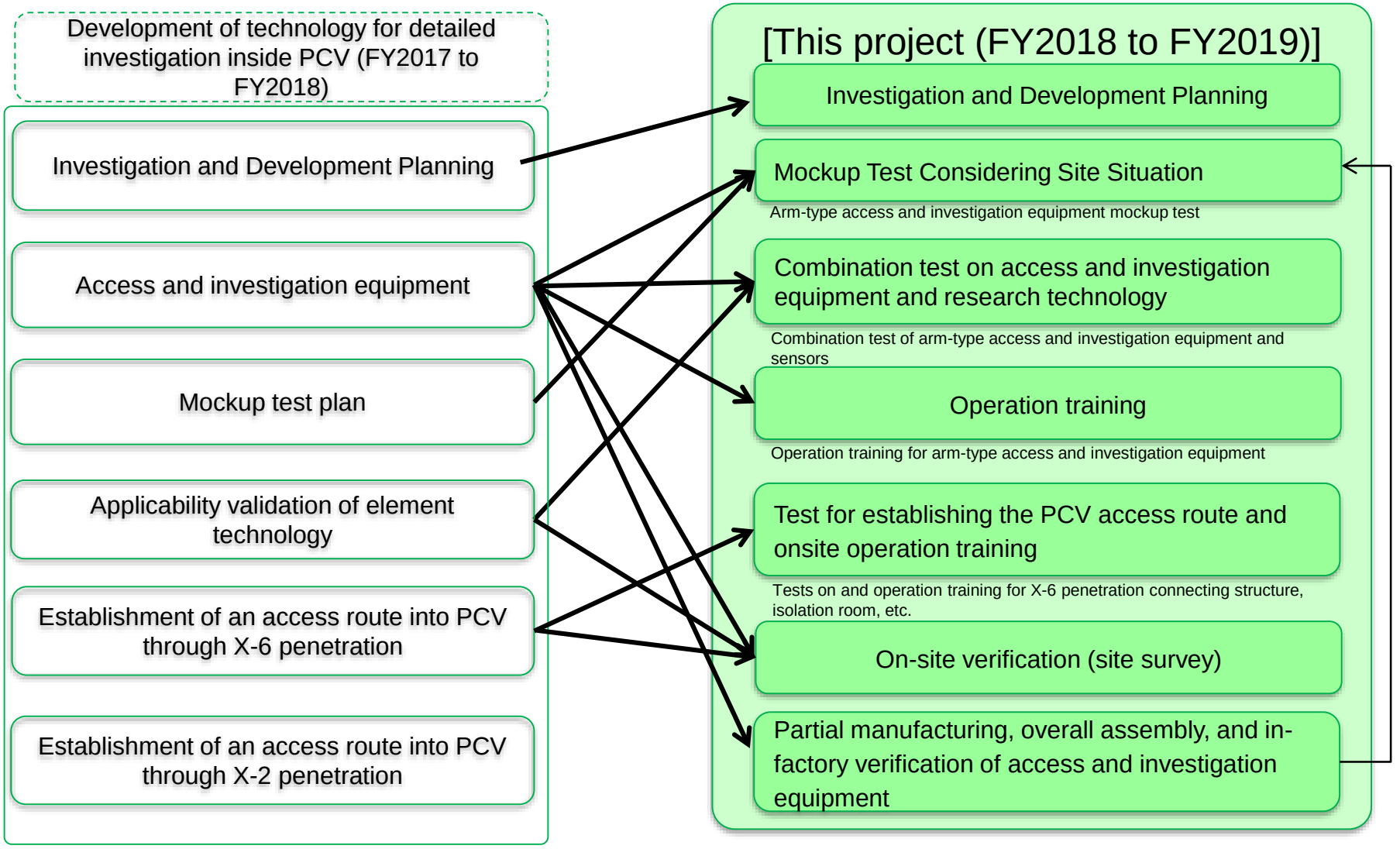
: This project

2. Implementation items, their correlations, and relations with other research

2.2 Implementation items of this project

Implementation items		Scope of implementation in FY2019
Investigation and Development Planning		Examination of investigation procedures
On-site verification of access equipment and investigation technology	Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment	Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment
	Mockup Test Considering Site Situation	- Assembly and installation of the facility for access and investigation equipment mockup test - Concretization of procedures for access and investigation equipment mockup test
	Combination test on access and investigation equipment and research technology	Verification of connection between access and investigation equipment and research technology
	Operation training	Access and investigation equipment operation training involving the use of a simulator, etc.
	Test for establishing the PCV access route and onsite operation training	- X-6 penetration connecting structure: structure upgrade, combination test, once-through verification test - Isolation room: structure upgrade, combination test - Deposit removal device: manufacturing, mockup test, once-through verification test - Extension pipe: manufacturing, mockup test, once-through verification test - Enclosure transportation device: mockup test, once-through verification test
	On-site verification (site survey)	- Manufacturing and verification of VT sensor and neutron sensor - On-site layout
	Mockup test in Japan	Manufacturing and installation of a facility for access and investigation equipment mockup test conducted in Japan
	Manufacturing of short-length wand	Design and manufacturing of short-length wand

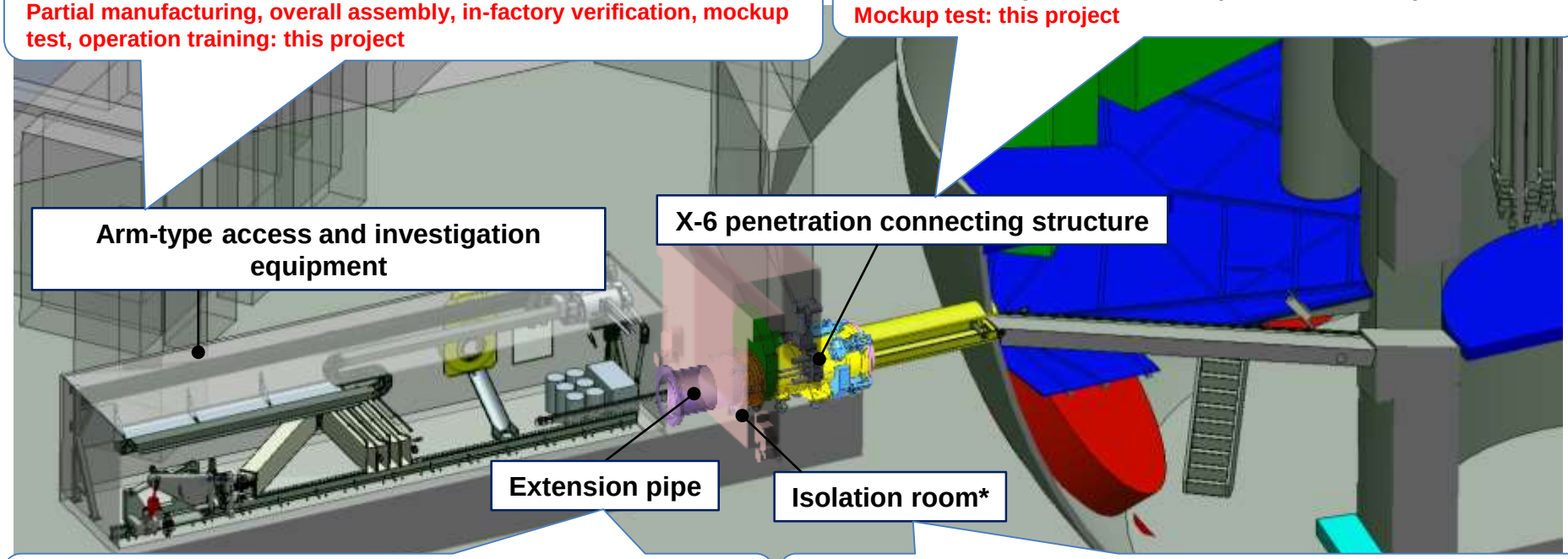
2.3 Relations between implementation items and relations with other projects (1/2)



2.3 Relations between implementation items and relations with other projects (2/2)

Design and manufacturing: Development of Technology for Detailed Investigation inside PCV (FY2017 to FY2018)
Partial manufacturing, overall assembly, in-factory verification, mockup test, operation training: this project

Design and manufacturing: Development of Technology for Detailed Investigation inside PCV (FY2017 to FY2018)
Mockup test: this project



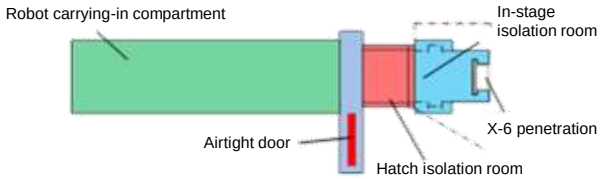
Basic plan: Development of Technology for Detailed Investigation inside PCV (FY2017 to FY2018)
Design, manufacturing and mockup test: this project

Design, manufacturing, test : Development of Technology for Detailed Investigation inside PCV (FY2017 to FY2018)
Equipment upgrade, verification of function and operability: this project

Deposit removal device, transportation device

Design, manufacturing and mockup test: this project

***The isolation room consists of the following.**
- **Robot carrying-in compartment**
- **Hatch isolation room (including airtight door)**
- **In-stage isolation room**



2.4 Objectives

Implementation items		Target achievement index (FY2018 to FY2019)
Investigation and Development Planning		The investigation and development plan are revised as necessary, reflecting the latest site situation and the investigation needs.
On-site verification of access equipment and investigation technology	Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment	The in-factory verification of the physical prototype of the access and investigation equipment is complete.
	Mockup test considering site situation	The mockup test facility is fully prepared.
	Combination test on access and investigation equipment and research technology	Verify the applicability of the combination of the access and investigation equipment and the research technology to the site.
	Operation training	Operation training using simulators, etc. to familiarize the access and investigation equipment among operators is conducted, and the workers are versed in the operation of the device.
	Test for establishing the PCV access route and onsite operation training	Conduct tests to examine the delivery and installation suitability of the structure that is connected to the opening of the X-6 penetration (hereinafter penetration opening) to create a boundary and on-site applicability is verified.
	On-site verification (site survey)	Plans for on-site operation and on-site investigation concerning access and investigation equipment, research technology, and structure that is connected to the penetration opening to create a boundary are formulated.
	Mockup test in Japan	The facility for mockup tests conducted in Japan is fully prepared.
	Manufacturing of short-length wand	The design and manufacturing of the short-length wand are complete.

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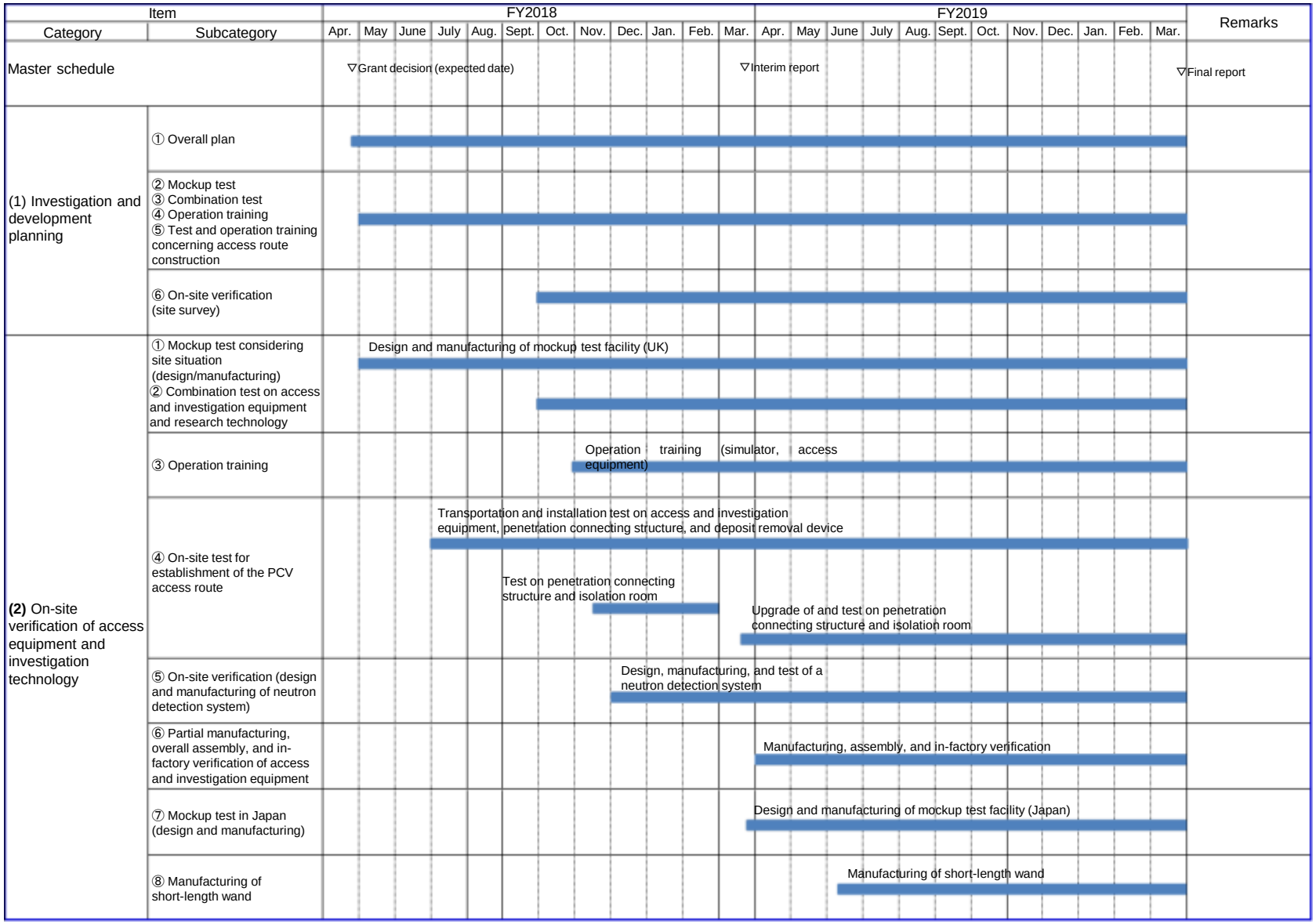
3. Implementation schedule and project organization (1/2)



3. Implementation schedule and project organization (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**

Mitsubishi Heavy Industries, Ltd.

1) Development of investigation and development plans

2) On-site demonstration of access and investigation equipment and investigation technology

①Mock-up test considering the site condition
②Combination test for access and investigation equipment and investigation technology
③Work training
④Test for the establishment of an access route into the PCV and work training
⑤On-site demonstration (site investigation)
⑥Partly manufacturing of access and investigation equipment, the whole assembly, and in-factory verification test
⑦Mock-up test in Japan
⑧Manufacturing of a short-length wand

Toshiba Energy Systems and Solutions Corporation

1) Development of investigation and development plans

2) On-site demonstration of access and investigation equipment and investigation technology

④Test for the establishment of an access route into the PCV and work training
⑤On-site demonstration (site investigation)

Contents

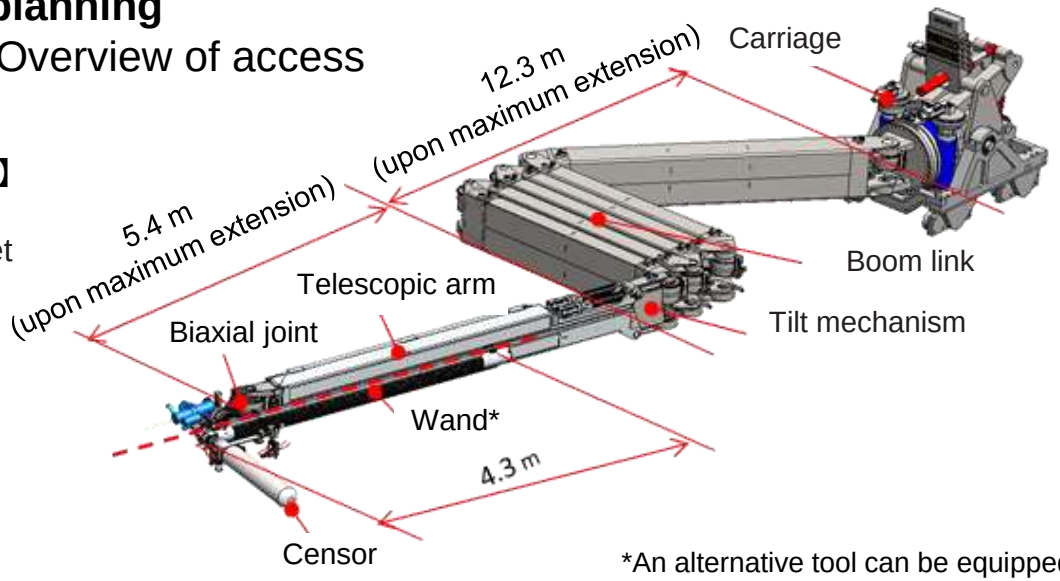
4.1 Implementation items and results

(1) Investigation and development planning

① Study on investigation procedure: Overview of access and investigation equipment

【 Specifications and structure of arm-type equipment 】

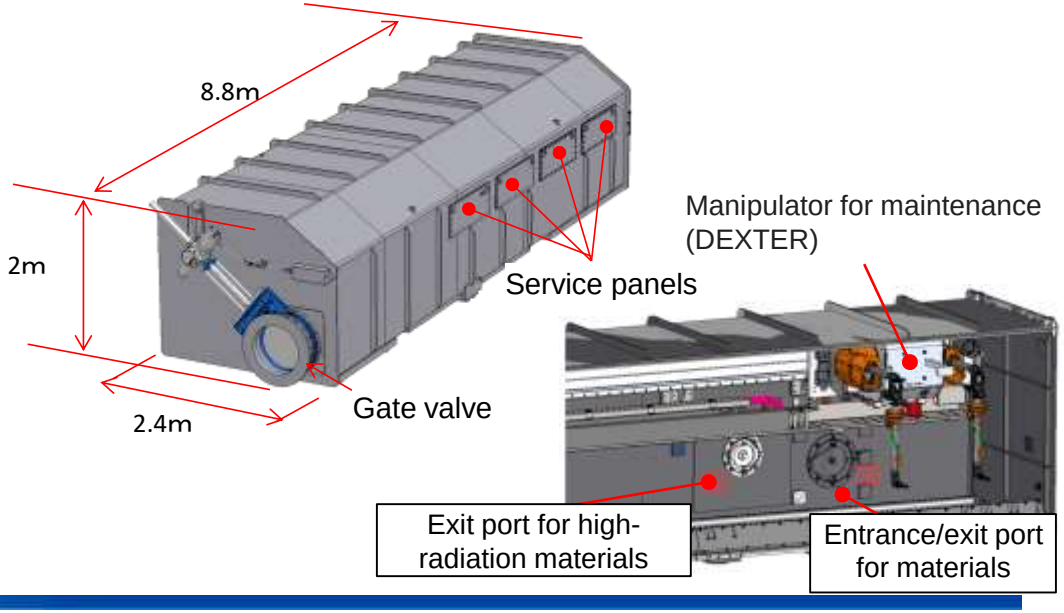
- ✓ Mountable sensor: 10 kg or less
- ✓ Mounted tools: Cutting and gripping tool and water jet cutting tool
- ✓ Arm length: Approximately 18 m (except wand)
- ✓ Pressing force: 400 N
- ✓ Positioning accuracy: ±100 mm
- ✓ Accumulated dose: 1 MGy
- ✓ Accessories: Camera and light



*An alternative tool can be equipped.

【 Specifications and structure of the arm enclosure 】

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



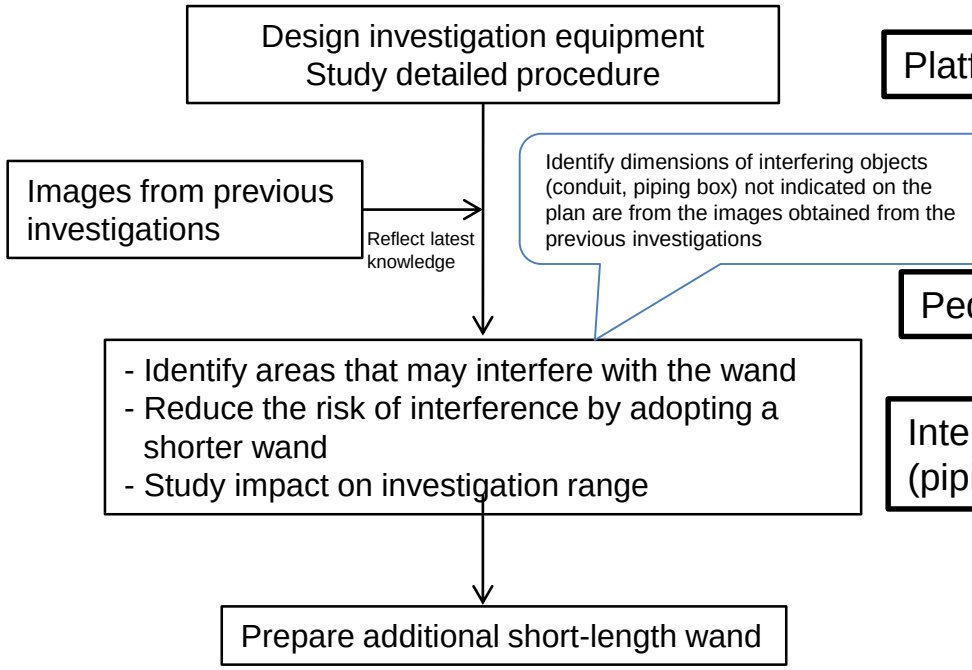
4.1 Implementation items and results

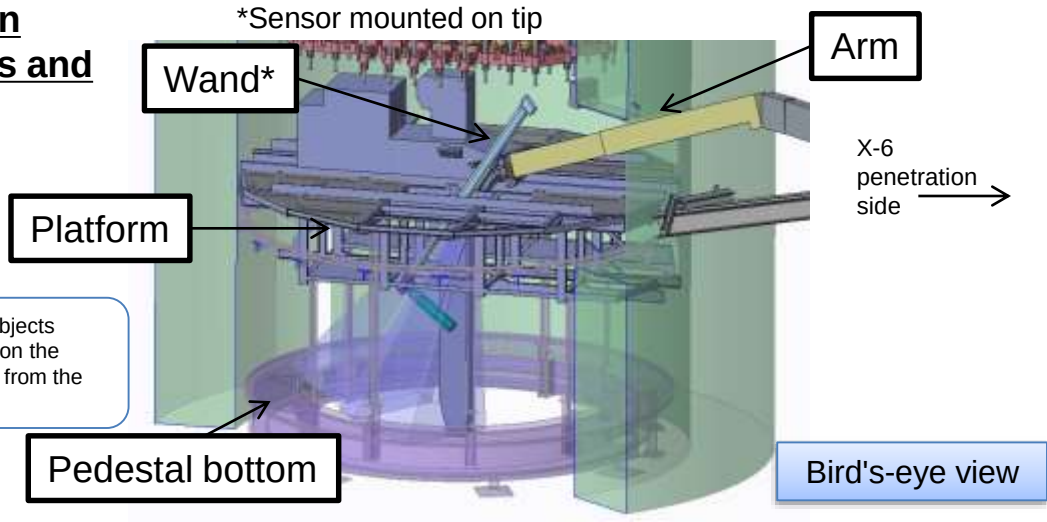
(1) Investigation and development planning

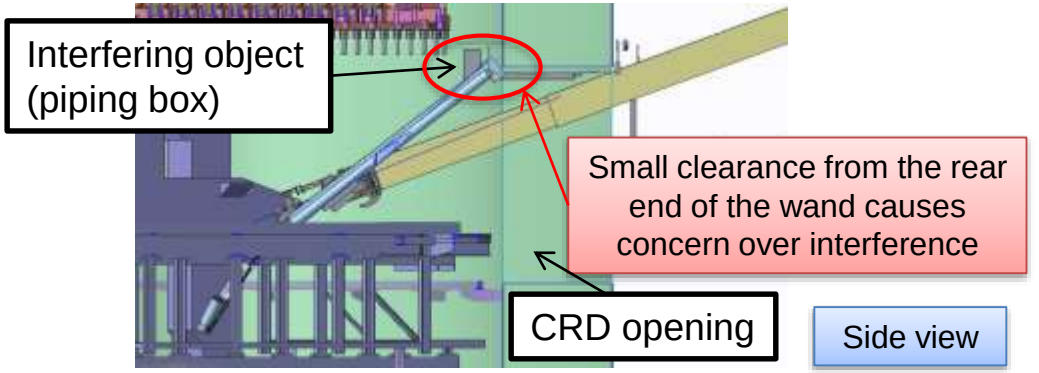
① Study on investigation procedure

Detailed procedures to establish an access route from the X-6 penetration to the pedestal's bottom and investigating the inside and outside of the pedestal are studied, and a flowchart consisting of approximately 100 steps is made.

Identify risks and work on measures based on images obtained from previous investigations and results of a study on detailed procedure







4.1 Implementation items and results

(1) Investigation and development planning

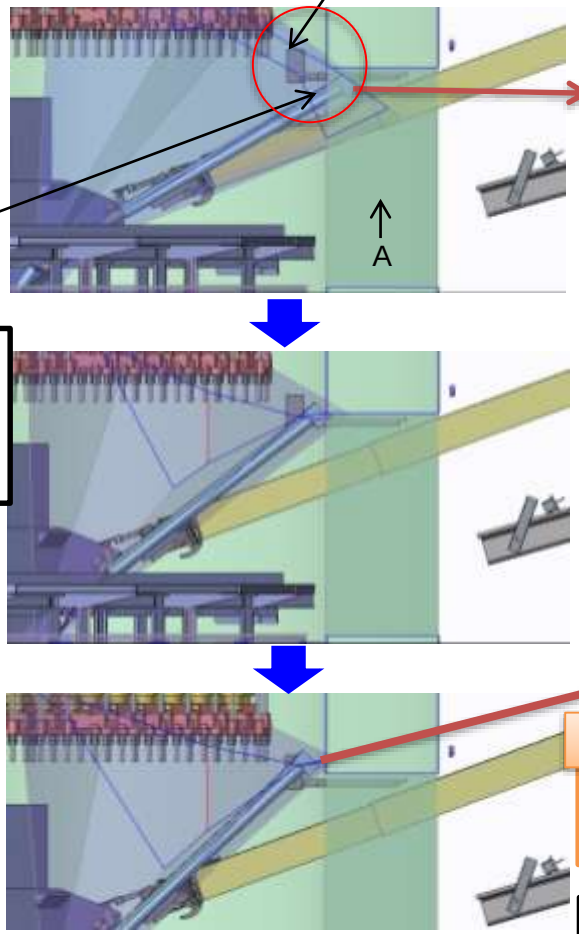
① Study on investigation procedure

A small gap between the rear end of the wand and the structure inside the pedestal

Detailed explanation about the passage through CRD opening

Tilt the wand while inserting it through the platform (lift the rear end)

Tilt the wand closer to an upright position while dodging the piping box (right diagram)



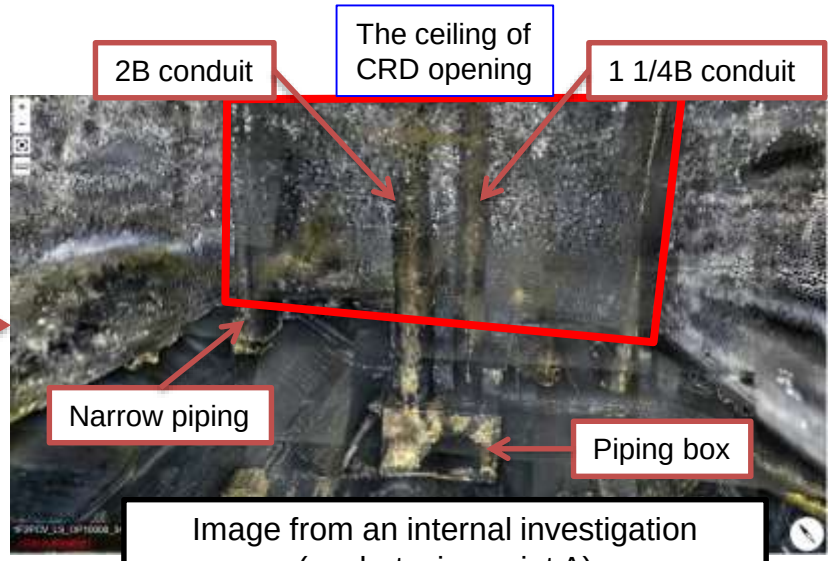
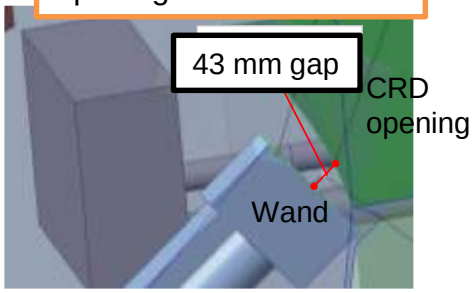


Image from an internal investigation (upshot: viewpoint A)

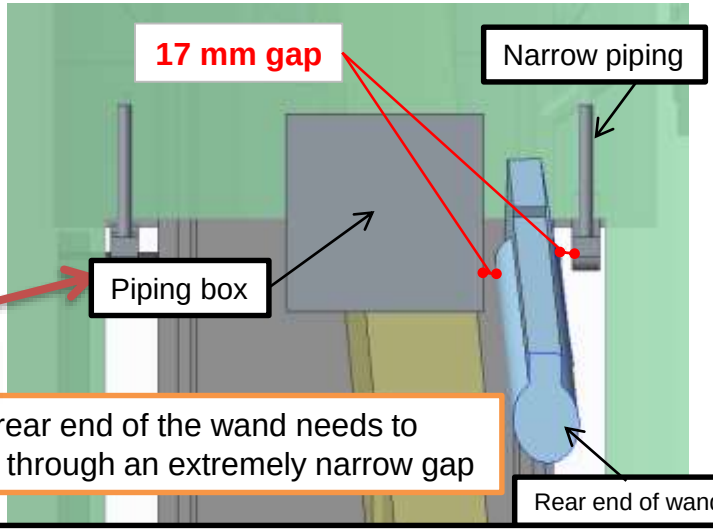
Risk

Clearance from the CRD opening is small



Risk

The rear end of the wand needs to pass through an extremely narrow gap



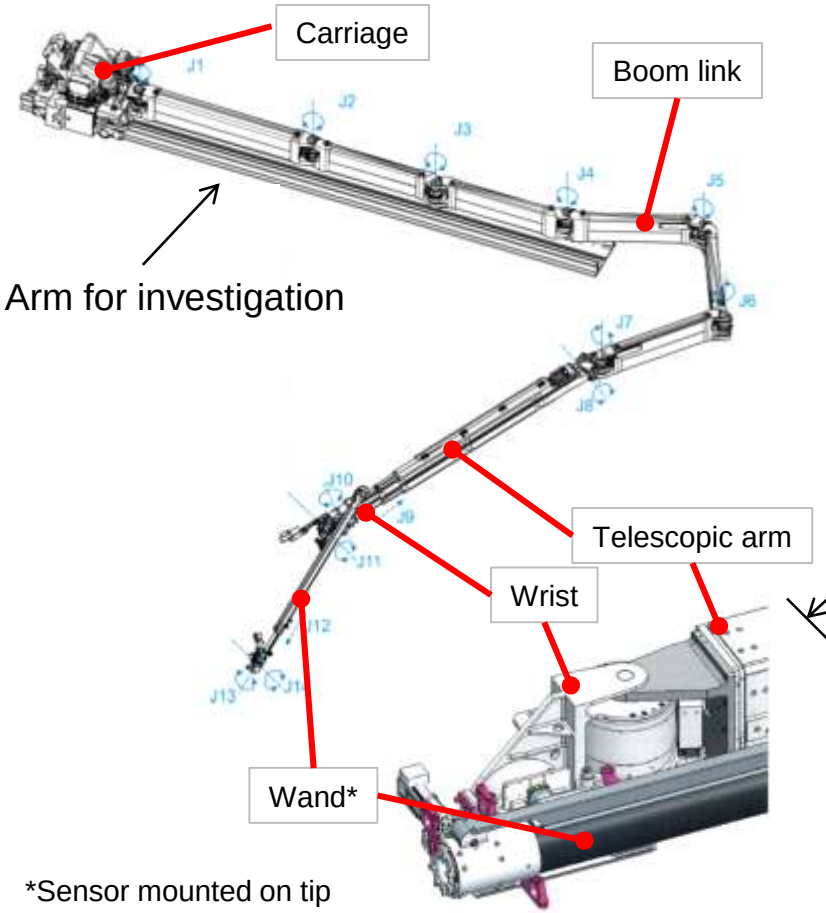
Conceptual drawing of image obtained from the VT sensor

4.1 Implementation items and results

(1) Investigation and development planning

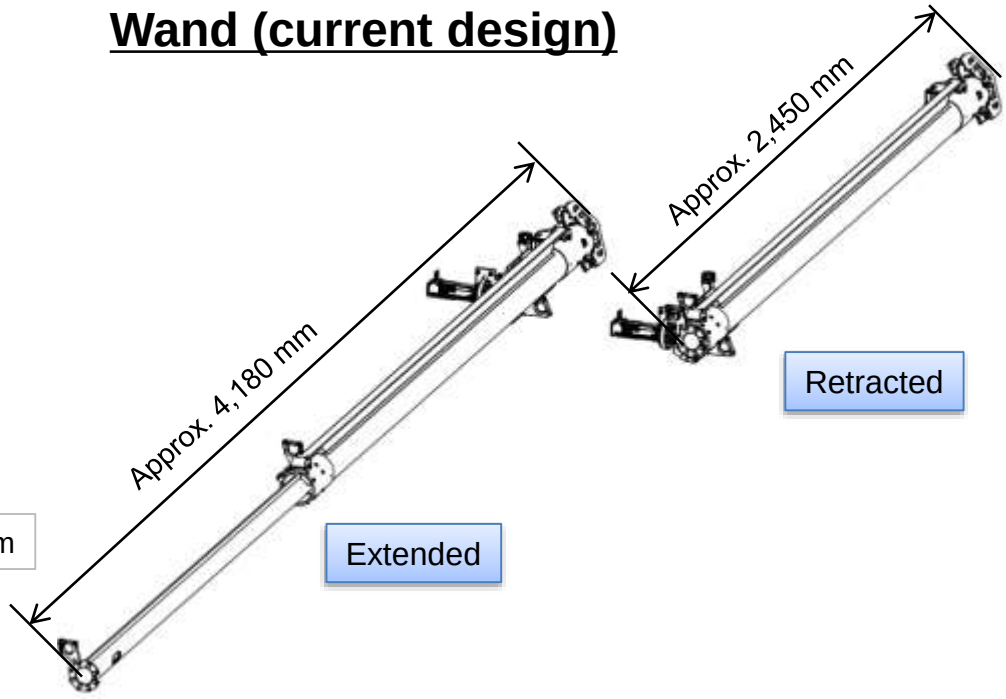
① Study on investigation procedure

Structure of arm for investigation and wand



*Sensor mounted on tip

Wand (current design)



4.1 Implementation items and results

(1) Investigation and development planning

① Study on investigation procedure

Procedure overview and camera view

Procedure overview of investigation inside the pedestal

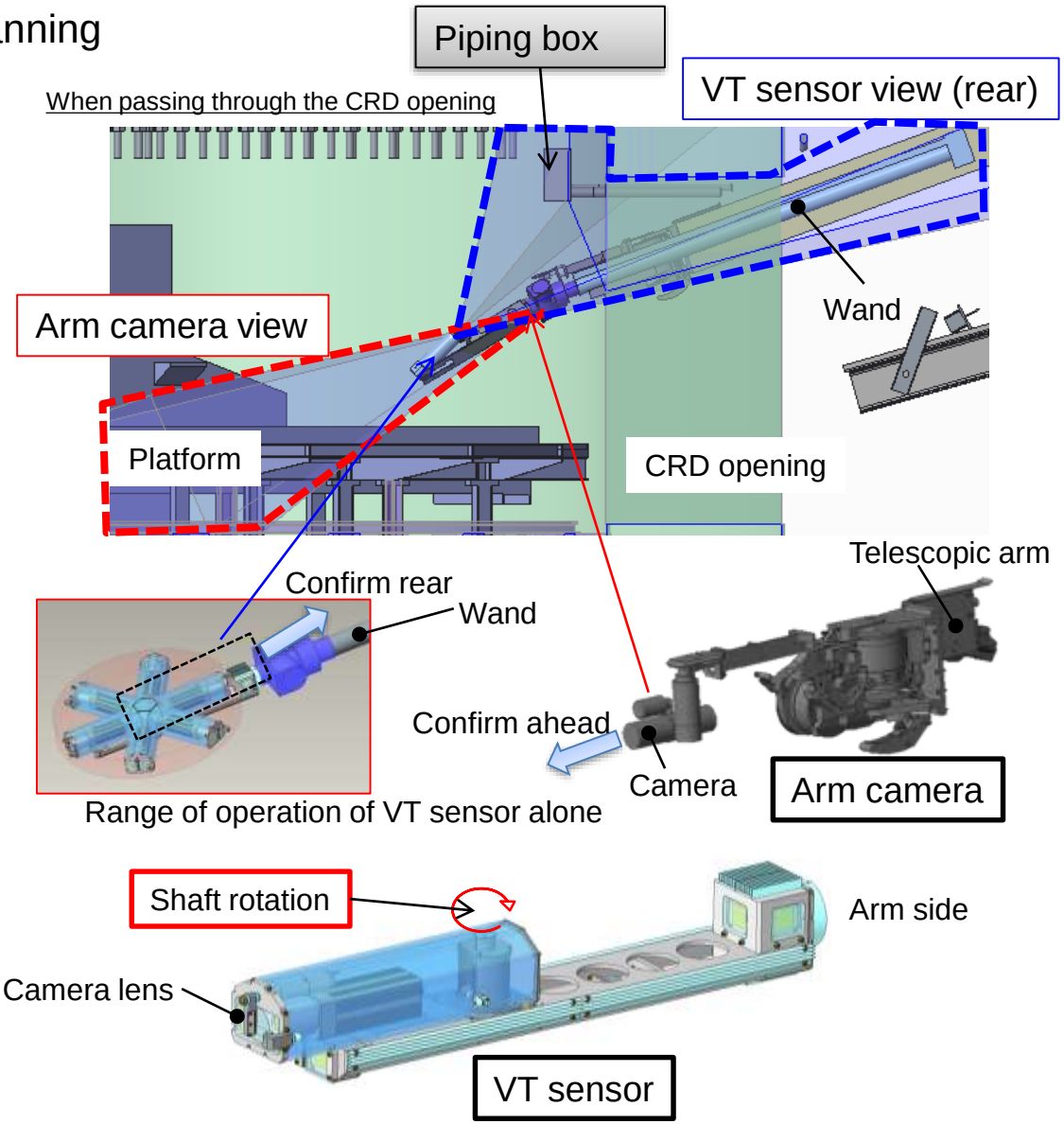
The tip of the wand (arm) reaches the inside of the pedestal

↓

Move the arm to the upper part of the platform opening

↓

Let the rear end of the wand pass through the CRD opening. Confirm the rear end of the wand with the VT sensor and ahead with the arm camera. Move the arm forward until the sensor on the tip of the wand reaches below the platform's opening.

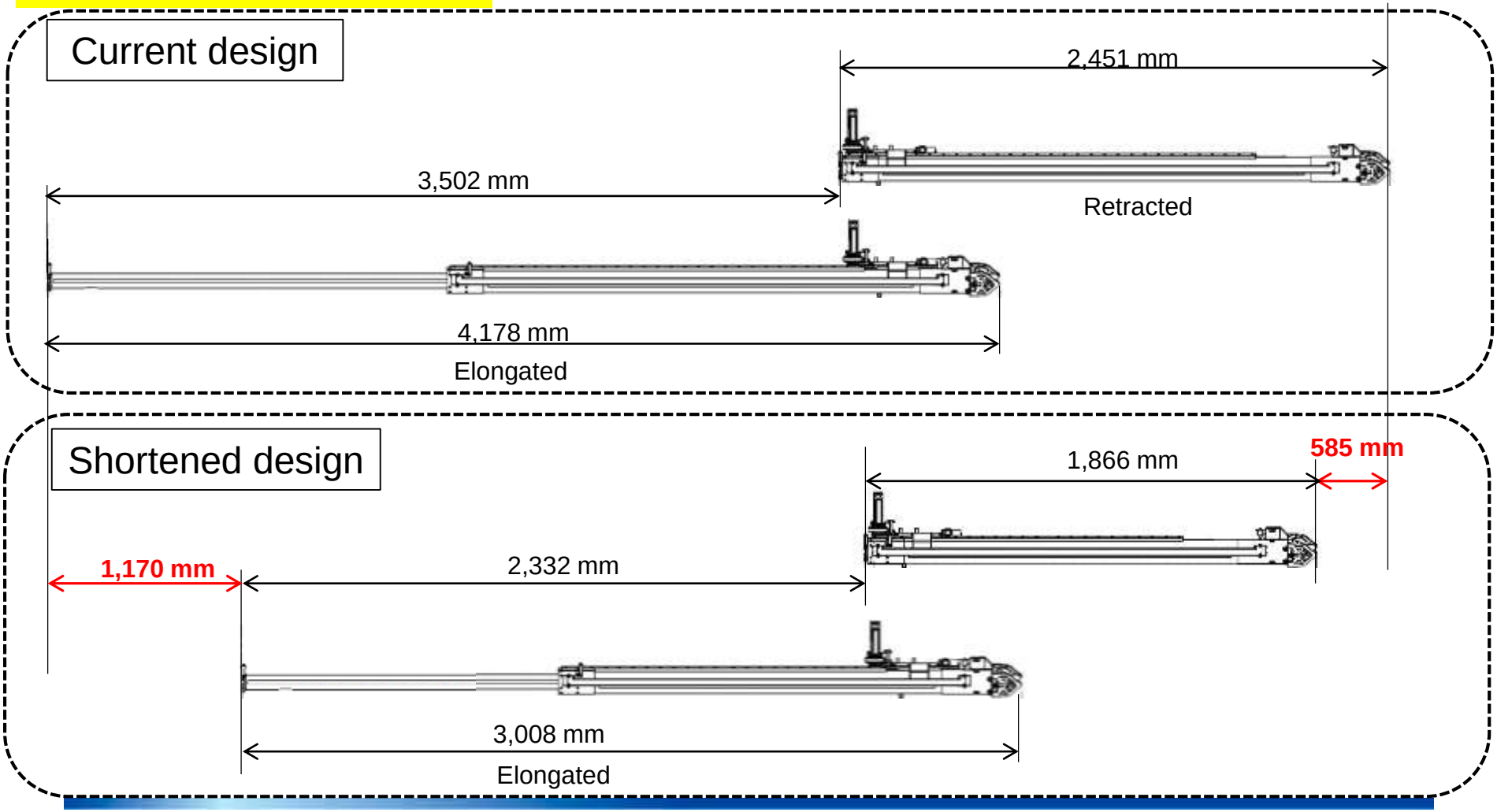


4.1 Implementation items and results

(1) Investigation and development planning

① Study on investigation procedure

Comparison of wand length

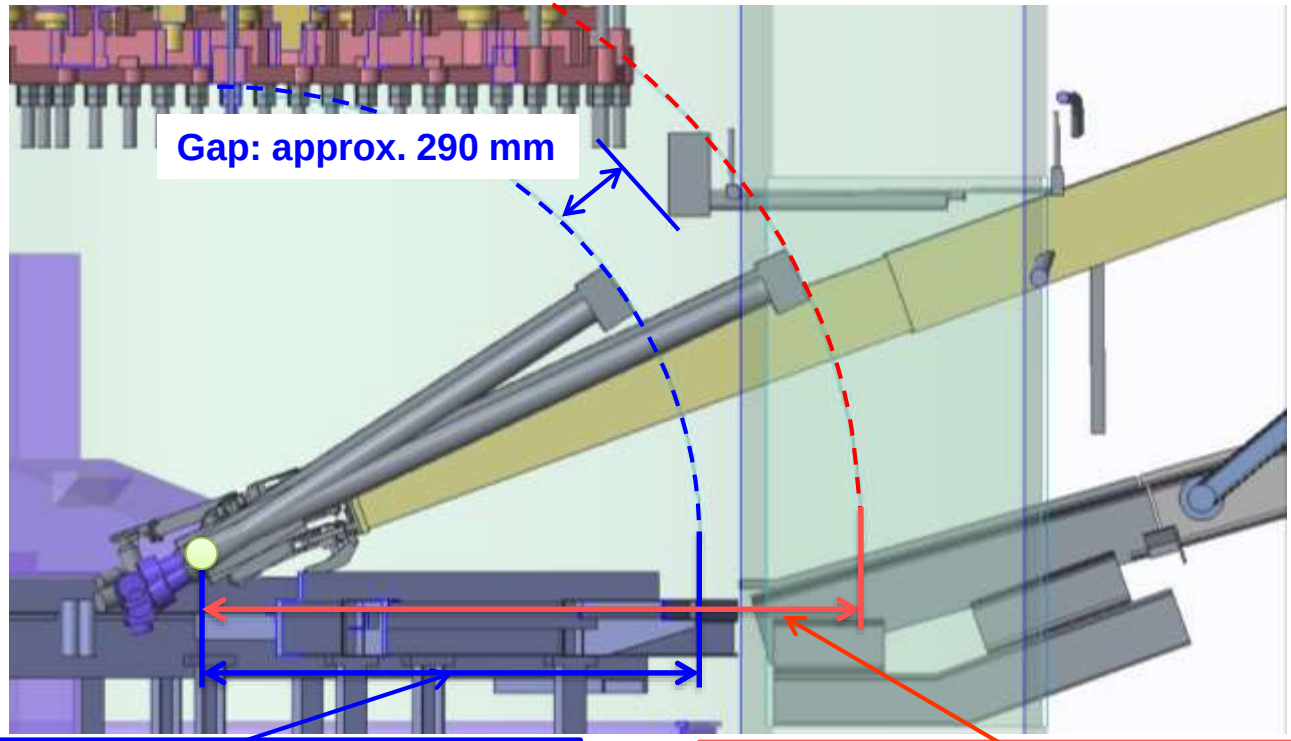


4.1 Implementation items and results

(1) Investigation and development planning

① Study on investigation procedure

- A short-length wand is prepared to reduce the risk of interference and increase the possibility of reaching the pedestal bottom
- Future mockup test will determine whether the current design or the shortened design will be adopted for on-site use



Shortened design: 1,866 mm

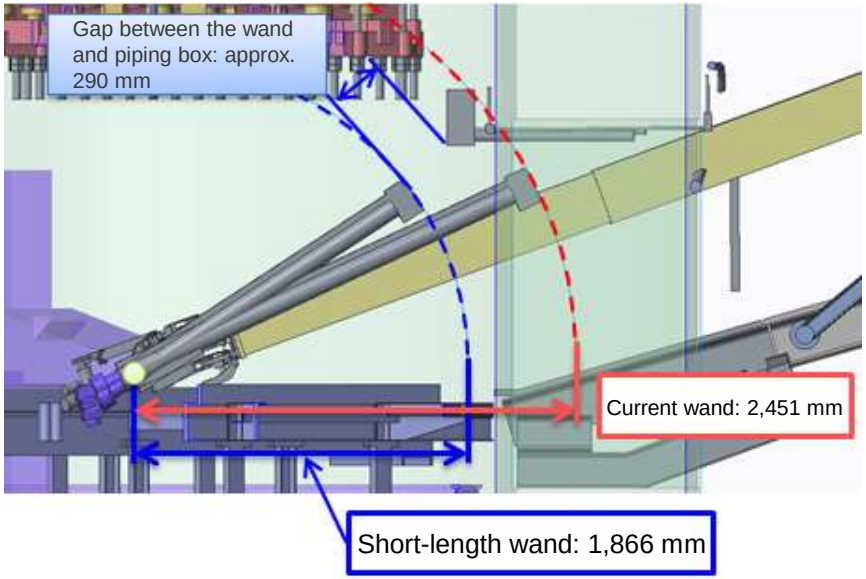
Current design: 2,451 mm

When the wand is shortened, it can pass in front of (below) the conduit box
--> The risk of interference with the piping box and narrow piping can be reduced.

4.1 Implementation items and results

(1) Investigation and development planning
② Manufacturing of short-length wand

- A detailed study on the investigation procedures revealed that there is a risk of the internal investigation arm interfering (coming into contact or colliding) with the structure inside the PCV in the access route (see p. 18).
- To reduce such risk and improve the accessibility of the internal investigation arm into the PCV, a wand shorter than the current design (short-length wand) was manufactured.



Avoid interference between the tip of wand and structure (piping box)

The manufactured short-length wand

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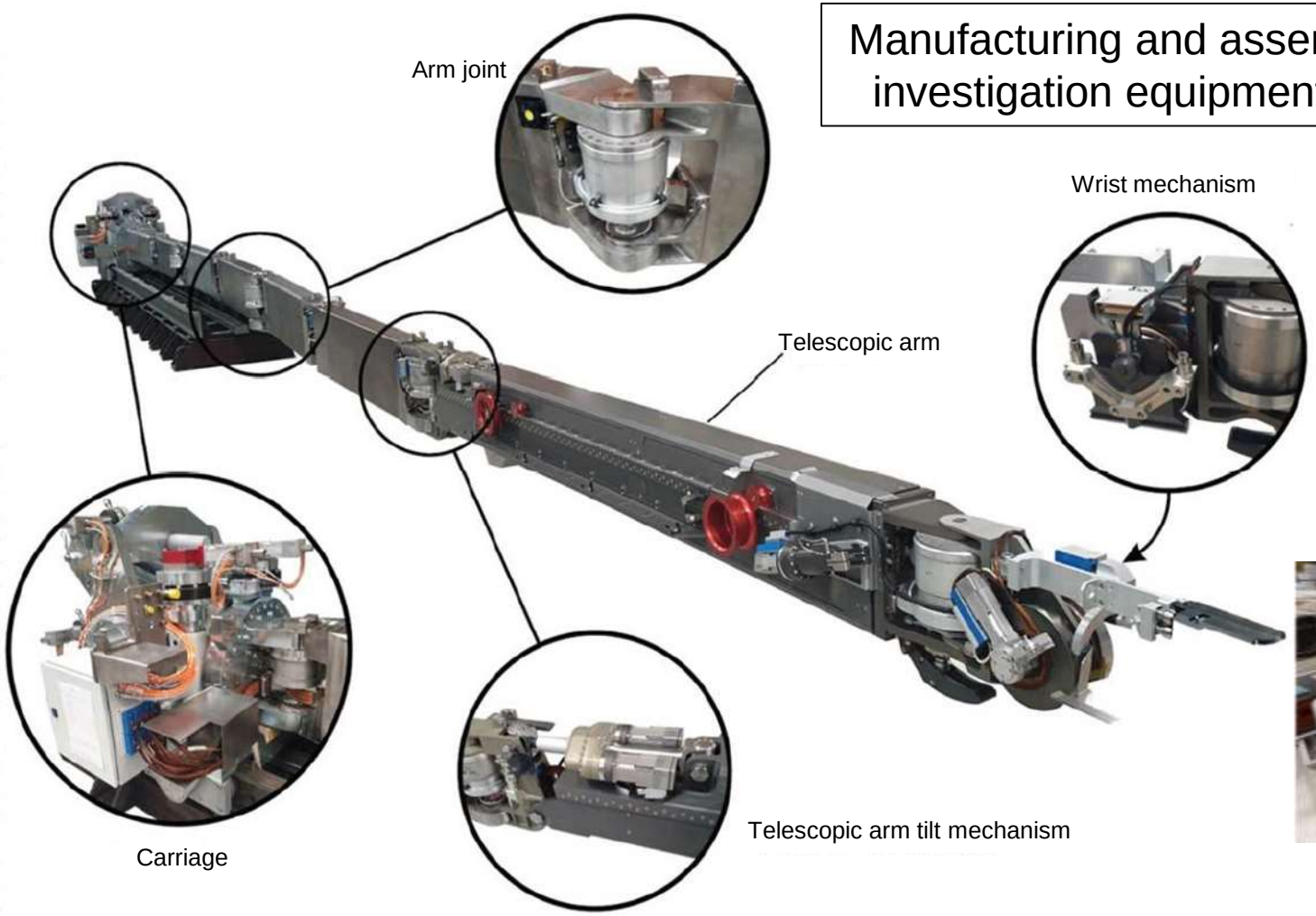
4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

① Assembly of access and investigation equipment

Manufacturing and assembly of access and investigation equipment have completed.



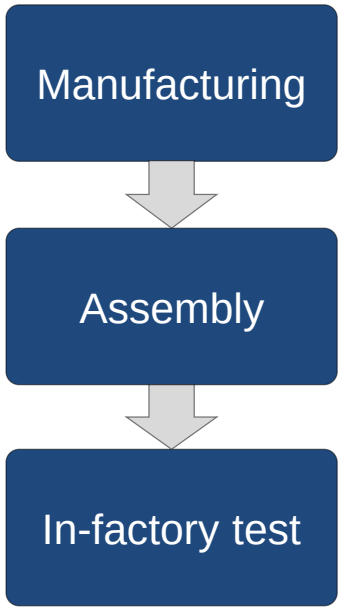
Wand

4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Assembly and test phase



Test details and items	
Tests and inspections	Visual inspection, dimensional inspection, non-destructive weld inspection, airtightness inspection, operation test, continuity, and insulation test
Assembly verification	Operation verification and tuning at the assembly stage
Functional test	In-factory function verification test after completion of assembly

The in-factory test (functional test) was completed after confirming the operation and tuning the device in the assembly stage.

4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Representative test results are shown below. Those in red will be explained in the following pages.

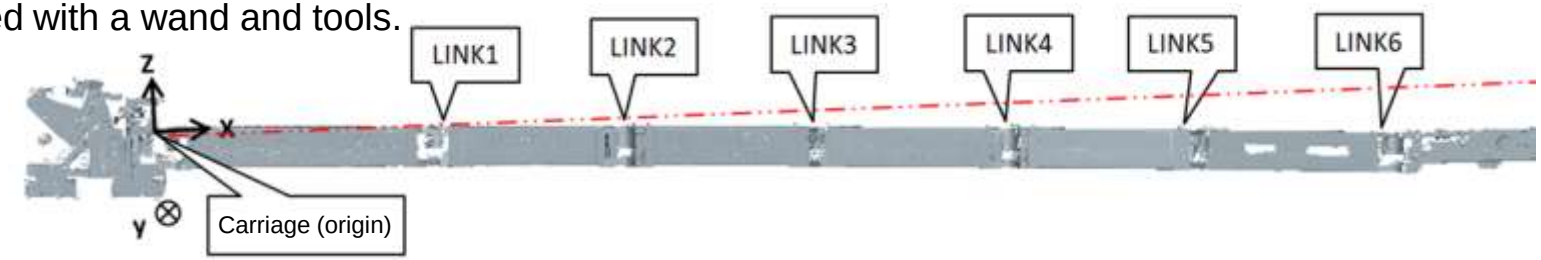
	No.	Test items	Confirmation items	Criteria	Test results
Arm	1	External appearance and dimensional inspection	Visual check of external appearance and measurement of main dimensions	No scratches or grime, dimensions in accordance with drawing	Pass
	2	Deflection test	Deflection of arm	Good prospect of accessibility through the X-6 penetration	Pass (pp. 28 to 29)
	3	Position accuracy verification test (repeatability)	Reproductivity of arm position	Within ±100 mm (target: within ±20 mm)	Pass ±12 mm
	4	Stability verification test	Shaking of arm tip	±10 mm (within 5 min.: target value)	Pass The arm stayed still within the range of the criteria during operation and when stopping
	5	Payload test	Operation while carrying load	Carried load (10 kg/moment 41 Nm)	Pass
Maintenance manipulator	1	External appearance and dimensional inspection	Visual check of external appearance and measurement of main dimensions	No scratches or grime, dimensions in accordance with drawing	Pass
	2	Operating range verification test	Operating range of arm	Range in accordance with design dimensions	Pass (p. 31)
	3	Payload test	Operation while carrying load	Load on the arm: 10 kg (equivalent to the weight of sensor) Load on hoist: 100 kg	Pass (p. 32)

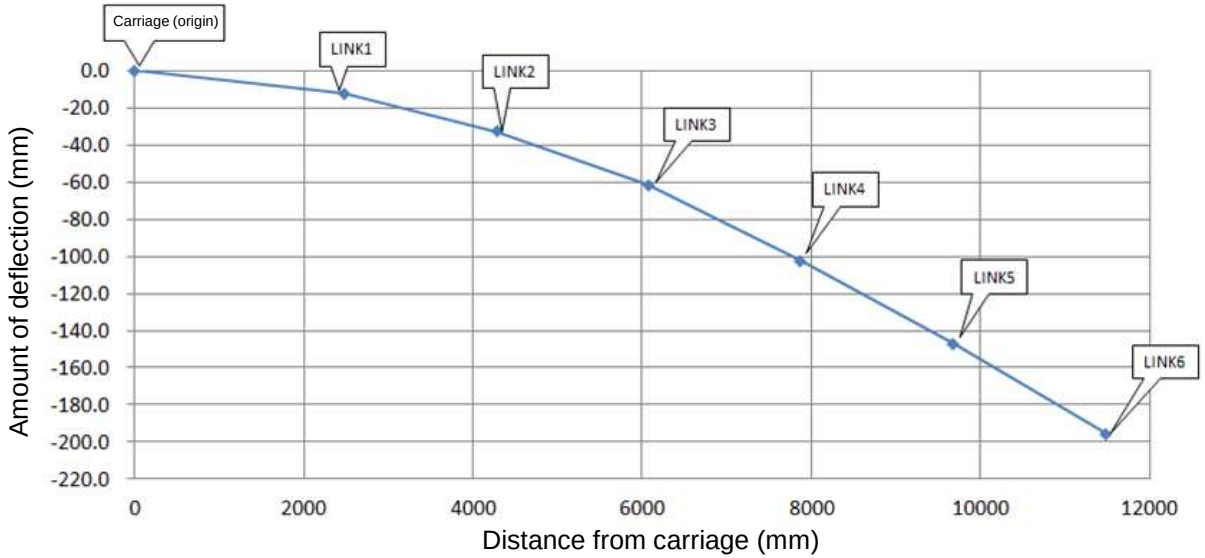
4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

After completing the arm assembly, measure the amount of deflection using a 3D laser scanner. The results were reflected in the structure analysis model, and the amount of deflection was evaluated when the arm is equipped with a wand and tools.





* The wand's weight differs between a long-length and short-length wand, resulting in a difference in the amount of deflection. The evaluation results shown above uses the weight of the heavier long-length wand. The same goes in p. 29.

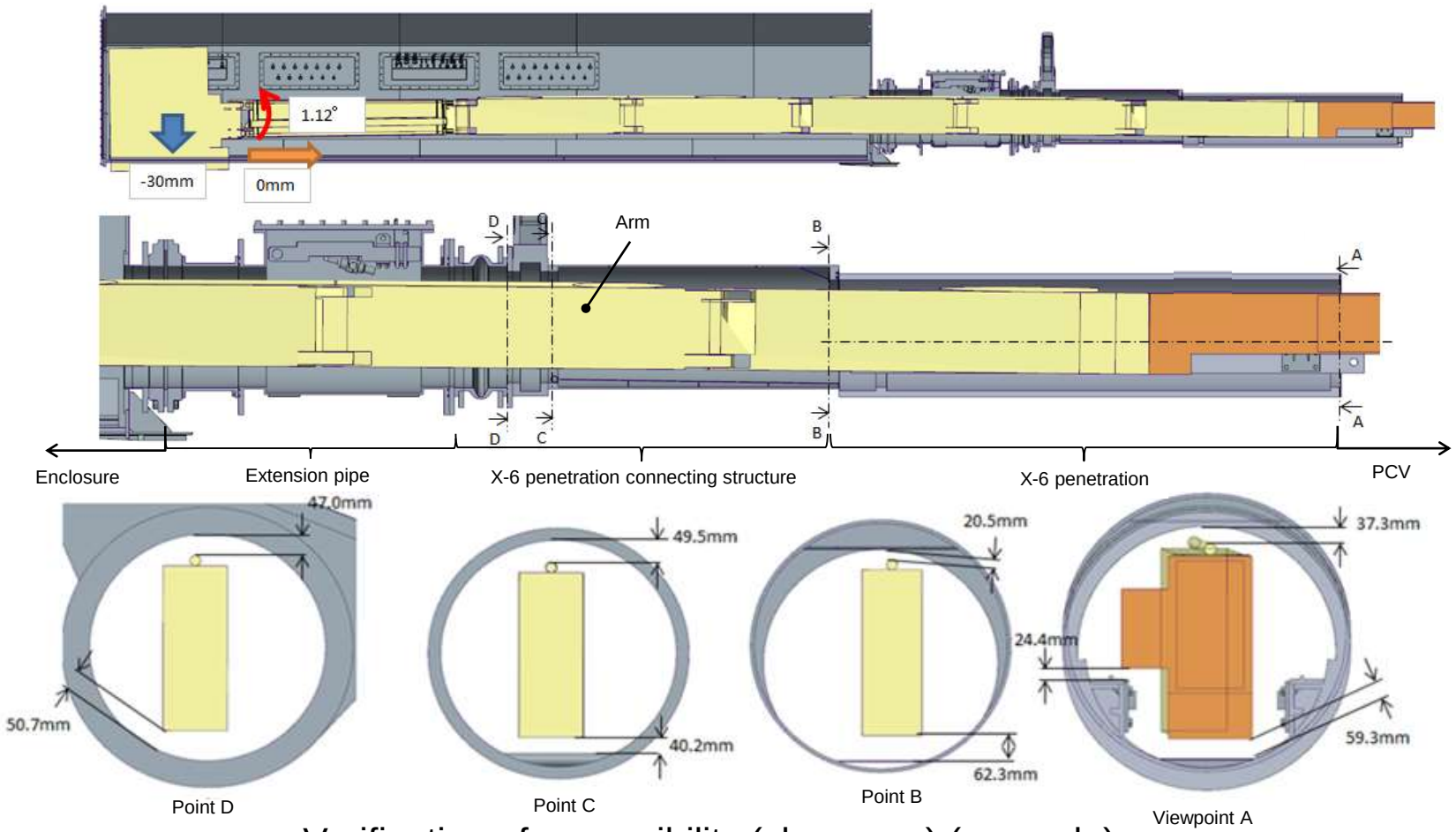
Results of the amount of deflection measured by a laser scanner (fully extended arm) (example)

4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Whether the arm can pass through the X-6 penetration was evaluated based on the actual amount of deflection measured, and it was confirmed that the arm could likely pass through.



Verification of accessibility (clearance) (example)

4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Dextre

Equipment that conducts various tasks by remote operation inside the enclosure

Master Dextre (control room)

Control monitor

Master-slave control (optical communications)

Slave Dextre (inside enclosure)

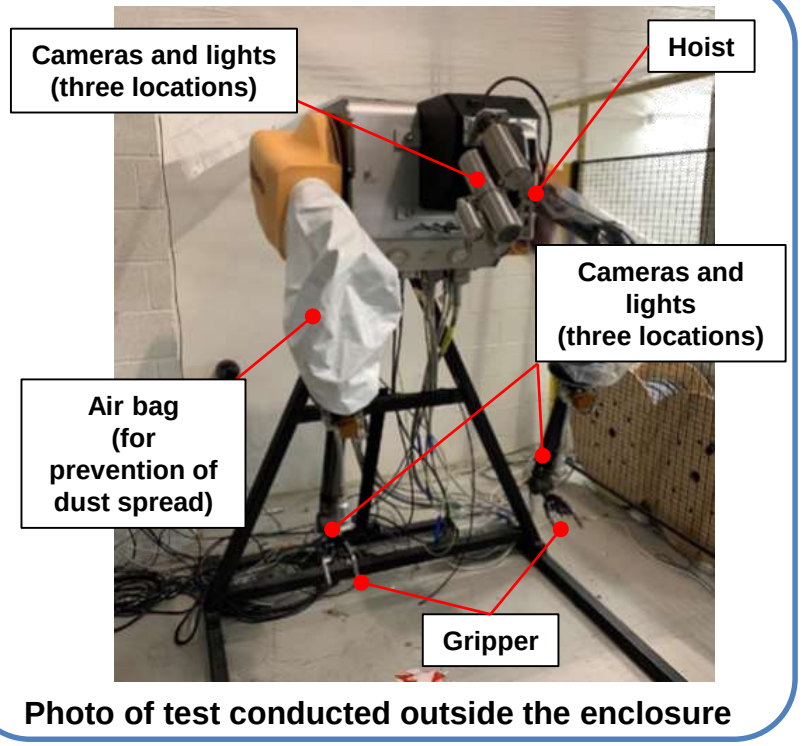


Photo of test conducted outside the enclosure

- The master-slave manipulator was developed by RACE*.
- An operator carries out tasks inside the enclosure by using the master Dextre set up in the control room to control the slave Dextre.
- The operator uses the control arms while checking multiple monitors.

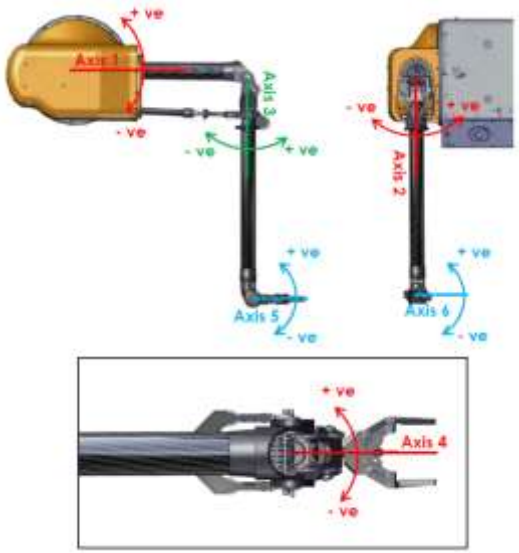
*RACE (Remote Applications in Challenging Environments): remote handling and robotics test facility operated by UK Atomic Energy Authority

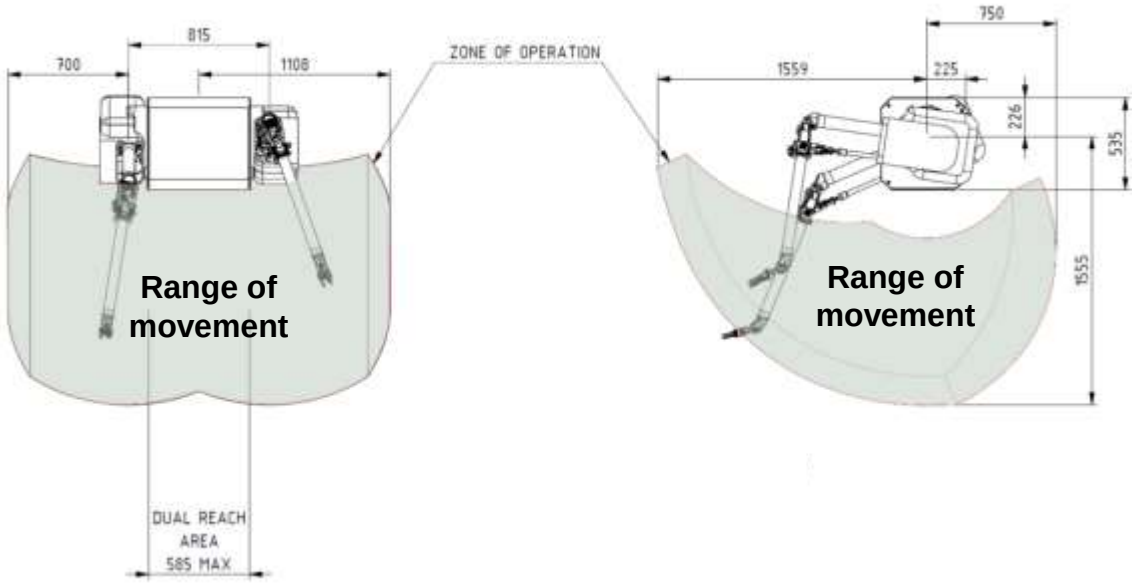
4.1 Implementation items and results

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Dextre: operating range verification test





Range of movement of Dextre arm and movable angle of joints

Axis	Movement	Range of movement
1	Up-and-down movements of shoulder	±45°
2	Left-and-right movements of shoulder	±45°
3	Back-and-forth movements of arm	±45°
4	Rotation of arm	±190°
5	Bending of wrist	-120°/+30°
6	Rotation of wrist	±340°
7	Open-and-close movements of gripper	0 to 80 mm

[Test condition]
- Grabbing weight: none, measurement method: angle meter

[Method for calculating the range of movement]
- Calculate the range of movement from the results of dimension measurement and the movable angle of joints measured in this test

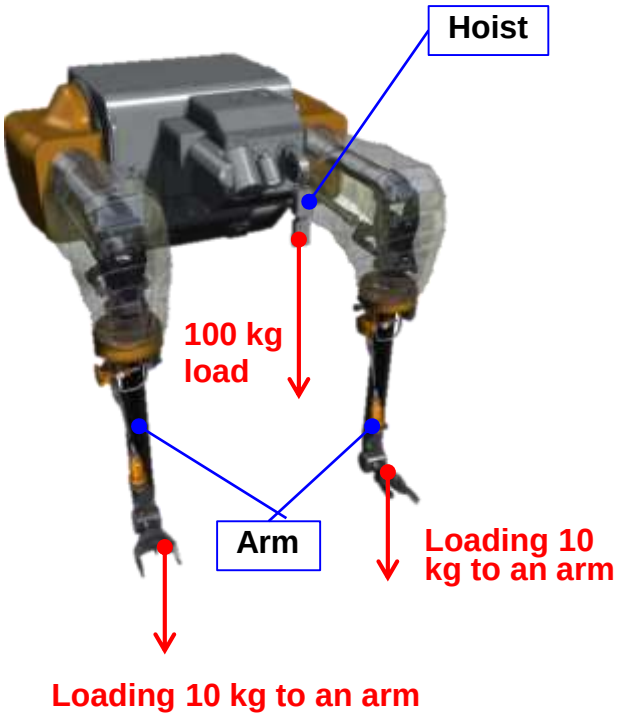
[Results]
- The test confirmed that the range of movement is in accordance with the design.

4.1 Implementation items and results

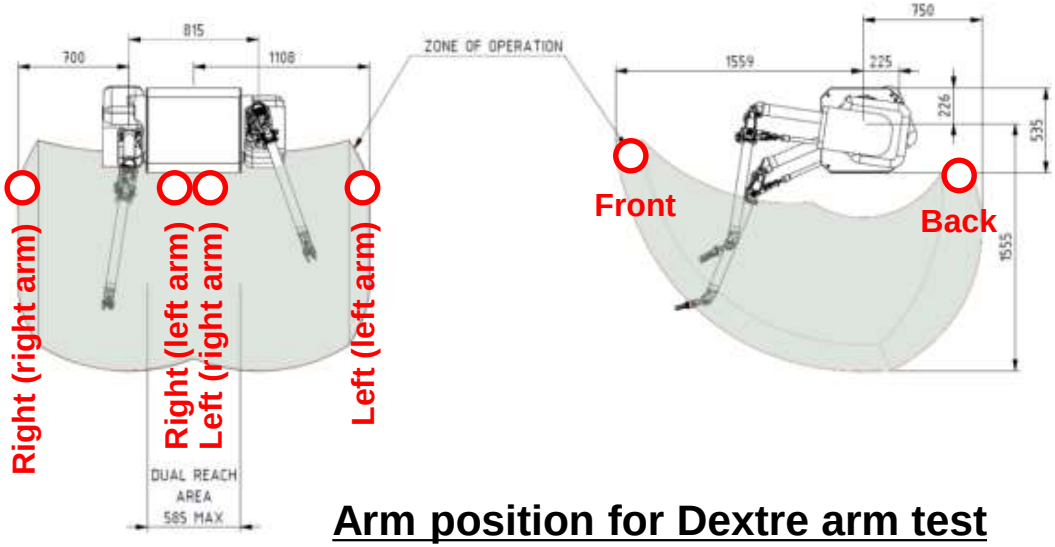
(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

② In-factory verification test

Dextre: payload test



The loads applied the arms and hoist



Arm position for Dextre arm test

[Test conditions (arm)]
- Arm position: five positions/arm (point zero (shown on the left), front, back, left and right)
- Loading weight: 10 kg (equivalent to weight of sensor)

[Test conditions (hoist)]
- Loading weight: 100 kg

[Results]
- The test confirmed that the arms could maintain their position while applying a load and can move while the hoist bears the load.

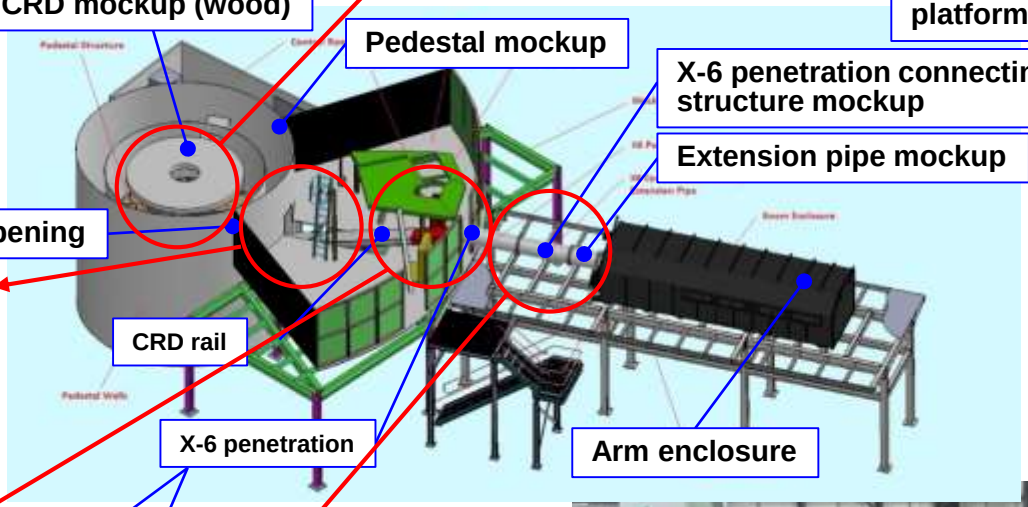
Contents

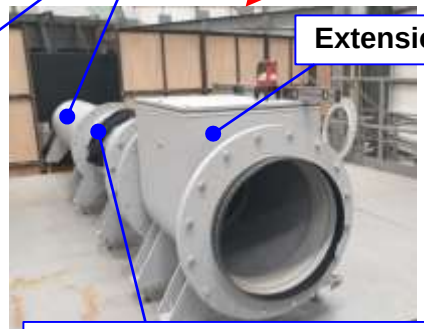
4.1 Implementation items and results

(3) Mockup test considering site situation

① Manufacturing of test facility

Manufacturing of test facility is complete





4.1 Implementation items and results

(3) Mockup test considering site situation

② Concretization of the mockup test plan

A mockup test was conducted based on the supposition of the actual method of use to verify conformity to functional requirements.

Functional requirements	Main mockup items
The arm can extend inside the PCV, and accessibility required for investigation can be secured	**- Calibration of arm positions** **- Accessibility through X-6 penetration** **- Removal of obstacles from the outlet of the X-6 penetration** **- Investigation of the inner lower and upper part of the pedestal**
Information necessary for remote control is obtained, and the device can be operated safely	**- Avoidance of interference using the arm operation system**
Sensors necessary for investigation can be mounted	**- Connection of sensors to arm** **- Connection/disconnection of external cables to arm**
Tools necessary for investigation can be mounted	**- Connection of tools to arm** **- Connection/disconnection of external cables to arm**
Cameras can be replaced and carried in and out of the enclosure	**- Remote-control maintenance of arm camera and lighting** **- Remote-control maintenance of enclosure camera** **- Carry-in and -out of sensors and tools**
The arm can be pulled out from the PCV in case it is damaged.	**- Recovery of the arm with Dextre** **- Forced extraction of arm**

Red text in table: explained in the next page onward

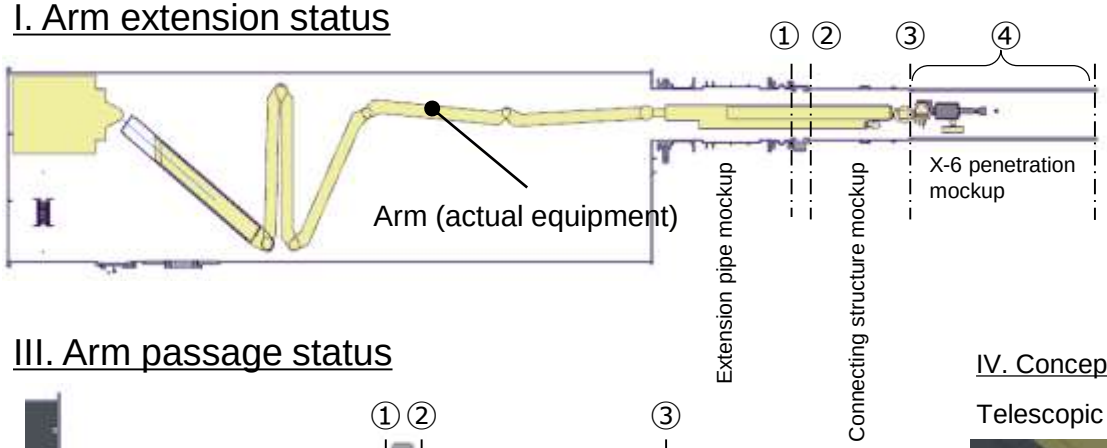
4.1 Implementation items and results

② Concretization of the mockup test plan: accessibility through the X-6 penetration

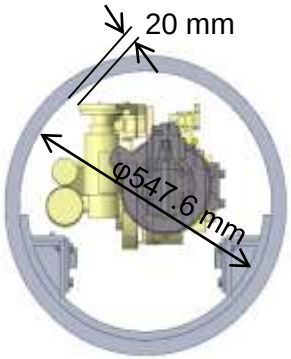
Focus of test

- **Verify accessibility of arm through the narrow X-6 penetration**
- **Verify the clearance as well as operability and controllability of the device, especially under the limited view of the camera**

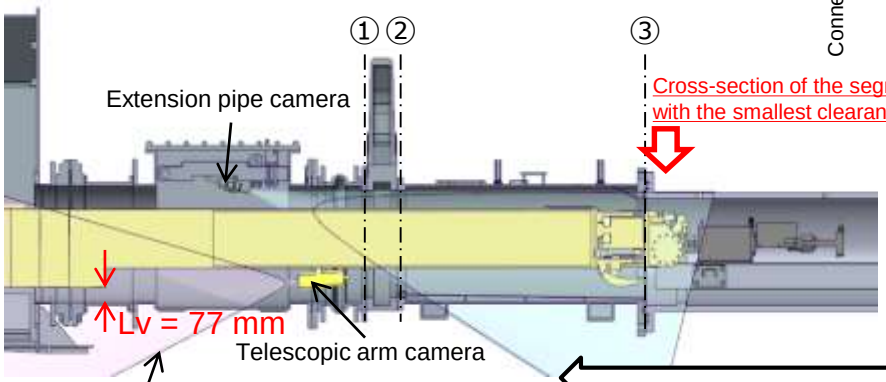
I. Arm extension status



II. Cross-section of the segment with the smallest clearance (④)



III. Arm passage status

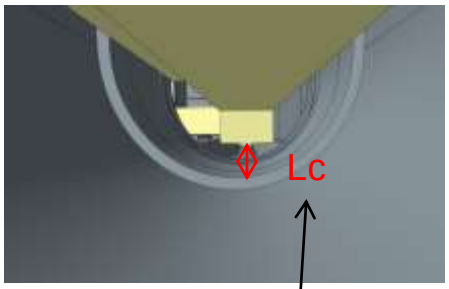


Design distance (with consideration to deflection): Lv

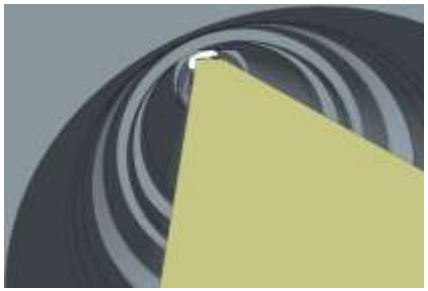
Move arm forward while comparing with design

IV. Conceptual image of camera view

Telescopic arm camera



Extension pipe camera



The distance that can be estimated with the telescopic arm camera: Lc

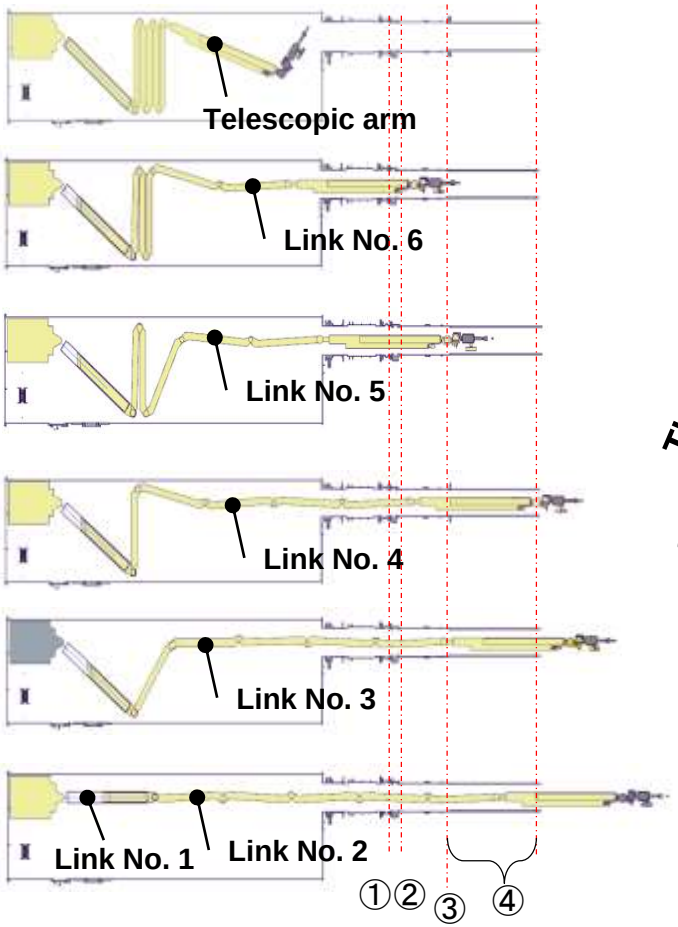
4.1 Implementation items and results

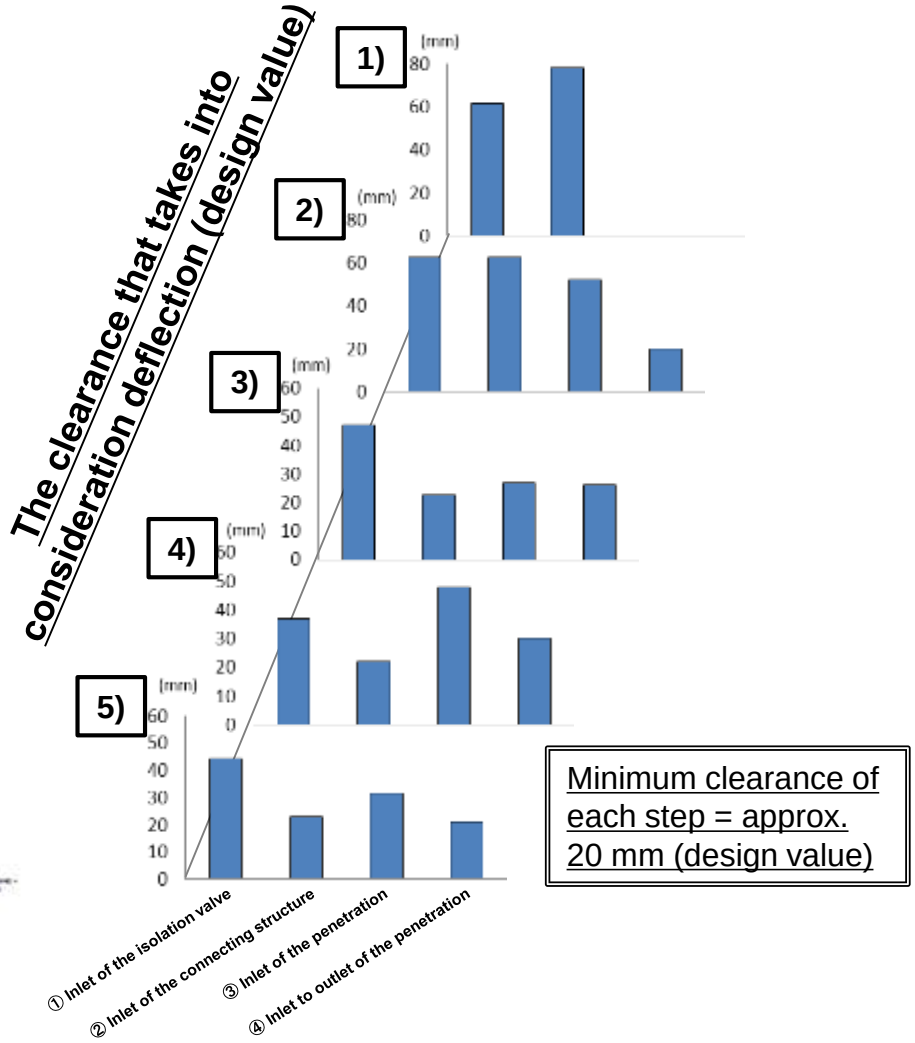
② Concretization of the mockup test plan: accessibility through the X-6 penetration

Test procedures and clearance

Arm: used actual equipment
X-6 penetration: used mockup that simulates the internal shape of the actual structure

- 0) All links folded
- 1) Extend link No. 6
- 2) Extend links No. 5 and 6
- 3) Extend links No. 4, 5, and 6
- 4) Extend links No. 3, 4, 5, and 6
- 5) Extend links No. 1, 2, 3, 4, 5, and 6





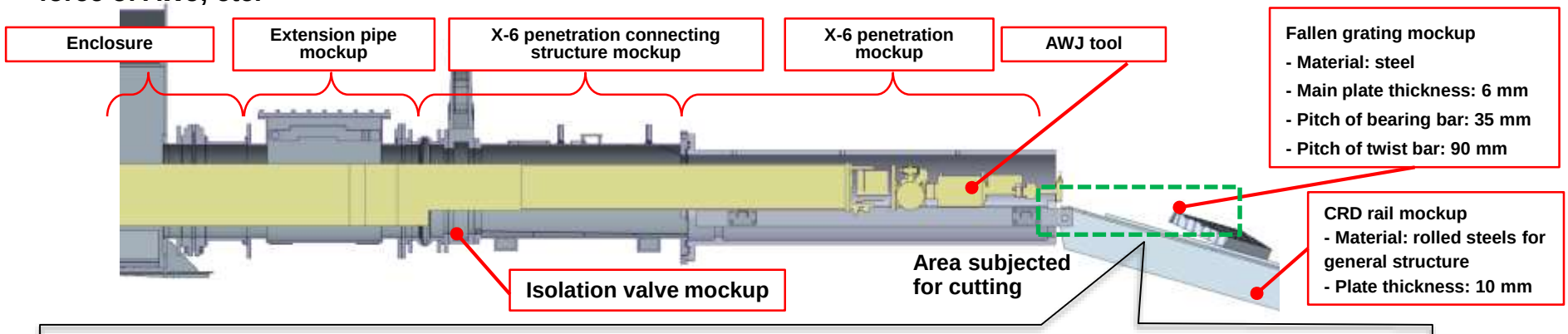
Minimum clearance of each step = approx. 20 mm (design value)

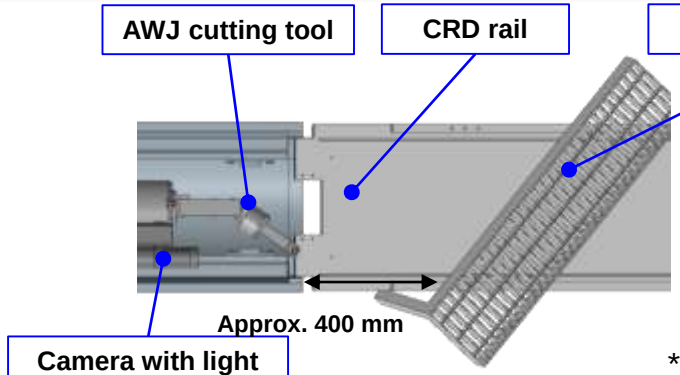
4.1 Implementation items and results

② Concretization of the mockup test plan: removal of obstacles from the outlet of the X-6 penetration

Focus of test

- **Cut obstacles (CRD rail, fallen grating) from the outlet of the X-6 penetration and verify the accessibility of the arm for investigation**
- **Especially verify the visibility of cut areas from the camera and impact of the shaking of the arm caused by the reaction force of AWJ, etc.**





*Specification, position, and dropped state of the fallen grating are uncertain. These factors are estimated in the mockup test based on the information obtained from images.

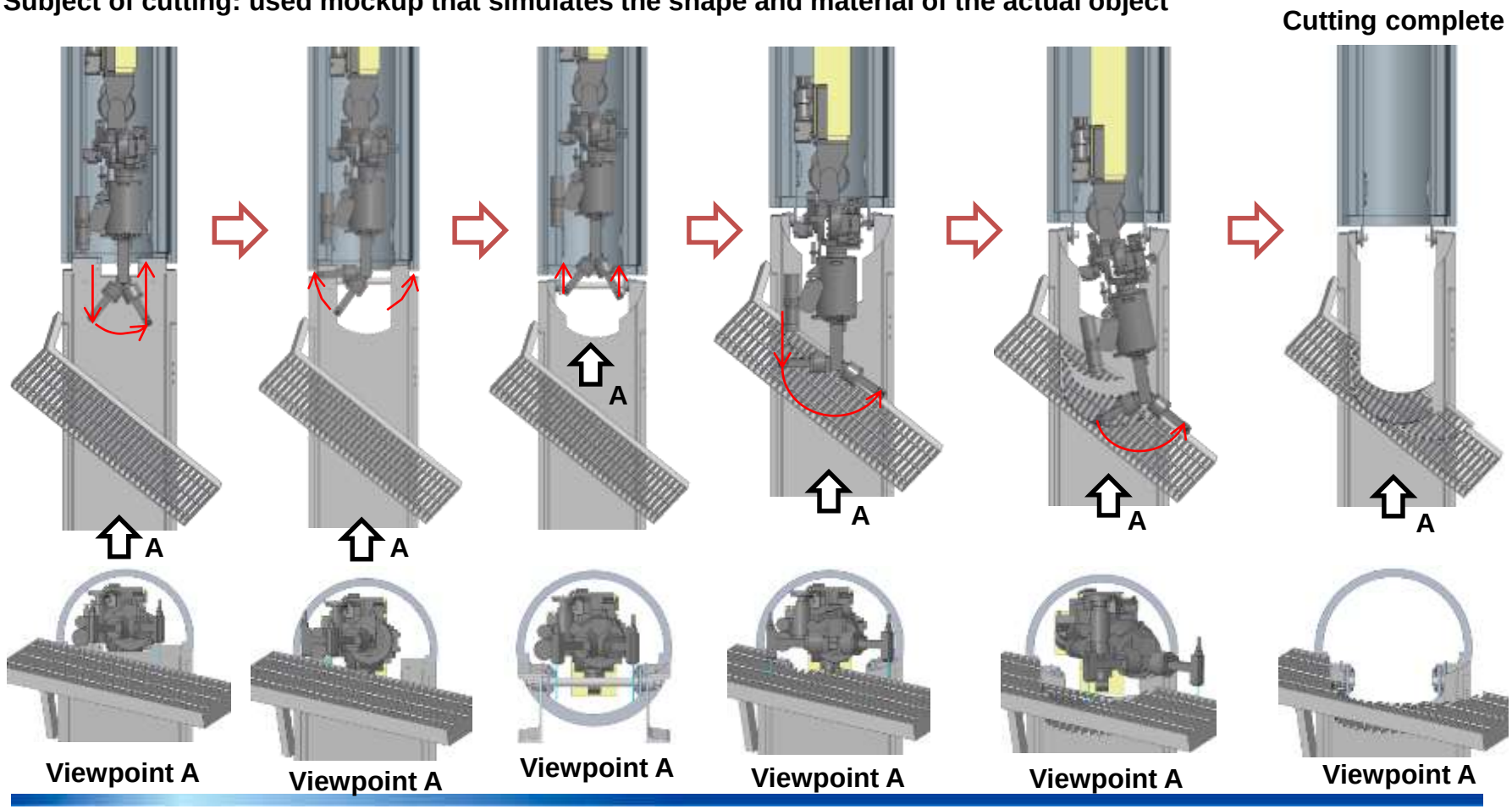
4.1 Implementation items and results

② Concretization of the mockup test plan: removal of obstacles from the outlet of the X-6 penetration

Test procedure (for cutting)

Arm: used actual equipment

Subject of cutting: used mockup that simulates the shape and material of the actual object



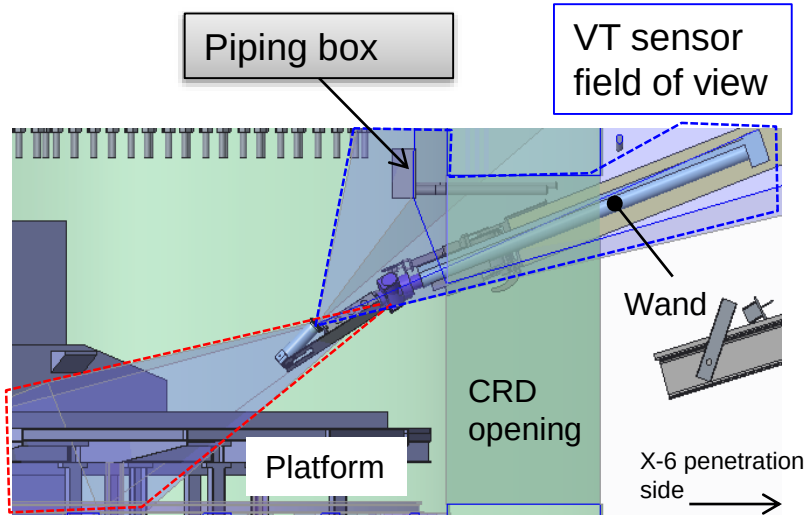
4.1 Implementation items and results

② Concretization of the mockup test plan: access to the bottom of the pedestal

Focus of test

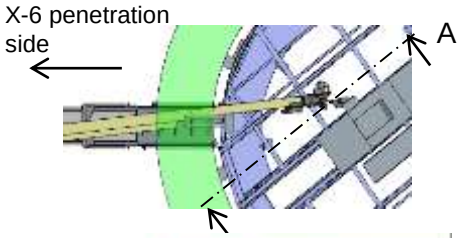
- **Verify the accessibility of the arm (wand and sensor) through the platform to the lower part of the pedestal**
- **Especially verify the visibility of the camera on the rear end of the wand, operability and controllability of the wand in narrow parts of the platform, and clearance**

I. Arm insertion status

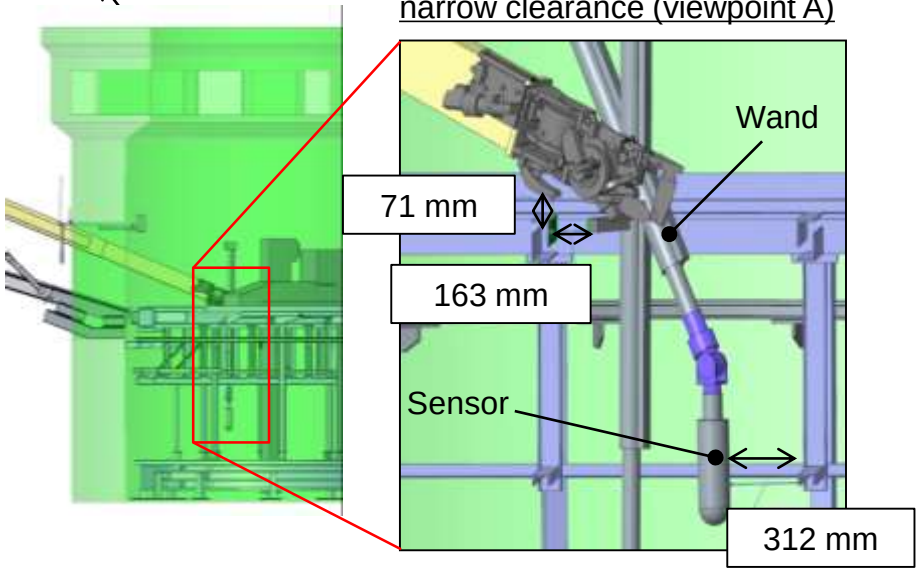


Arm camera view

II. Clearance in narrow section



Cross-section of the area with narrow clearance (viewpoint A)



Arm: used actual equipment
Structure inside PCV: used mockup that simulates the shape of the actual object

4.1 Implementation items and results

② Concretization of the mockup test plan: Dextre test

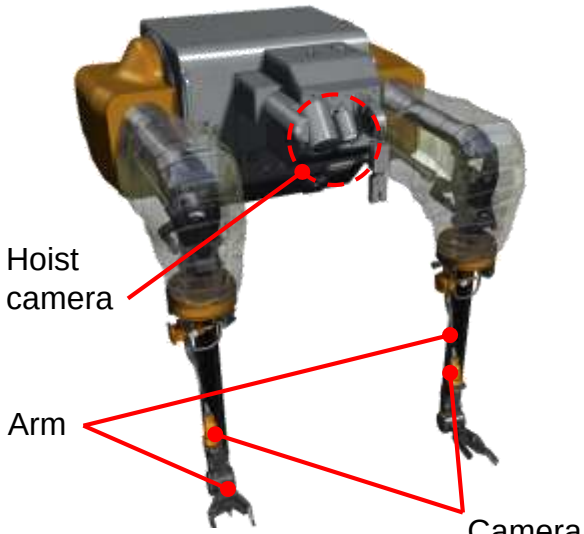
Maintenance of the arm will be conducted by remote control using Dextre. A detailed explanation will be given for tests (red text) that are difficult and conducted frequently.

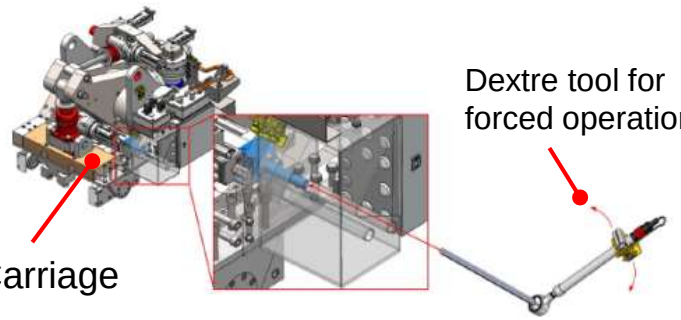
Tasks conducted by Dextre inside the enclosure
Connection of sensors and tools to the arm
Replacement of cables for sensors and tools
Replacement of the arm camera
Cleaning and decontamination of the arm
Replacement, shifting, and installation of the camera inside the enclosure
Carry-in and -out of sensors, etc. to and from the enclosure
Forced operation of the arm carriage*

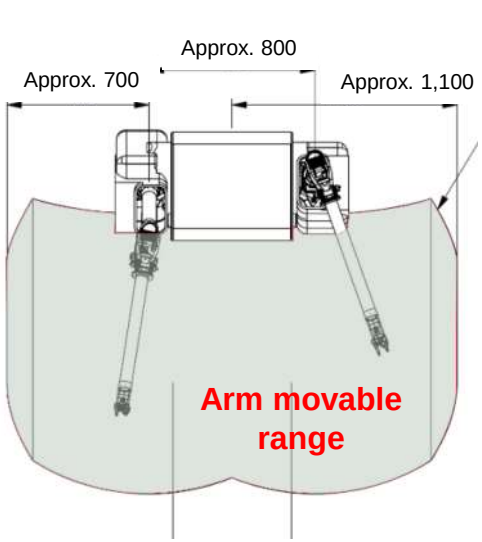
*When the carriage motor fails, the arm will be collected by forcibly operating the carriage

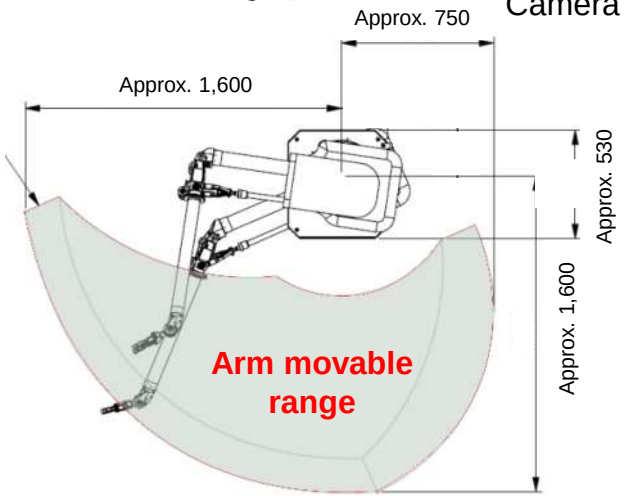
<Main specifications of Dextre>

- ✓ Payload
  - Each arm: 10 kg
  - Hoist: 100 kg
- ✓ Arm movable range
  - Refer to diagram below









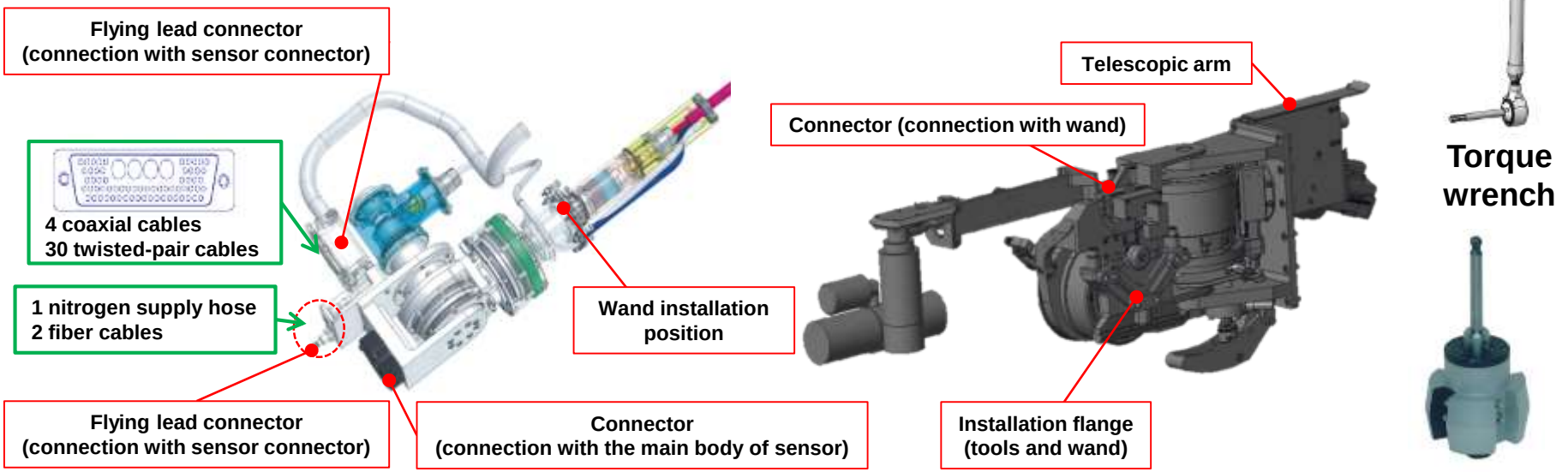
4.1 Implementation items and results

② Concretization of the mockup test plan: connection of sensors and tools to the arm using Dextre

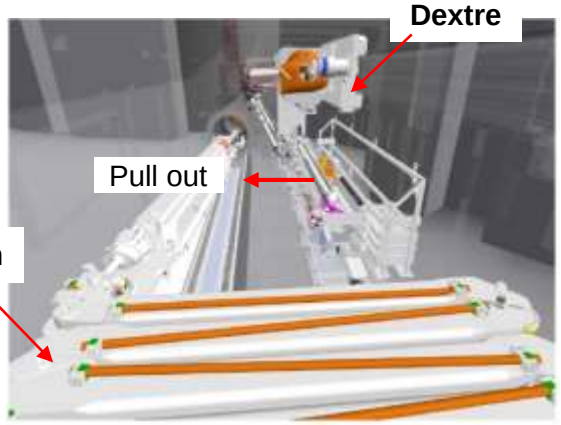
Confirm that sensors (including wand) and tools, as well as necessary cables and hose, can be attached and detached using Dextre.

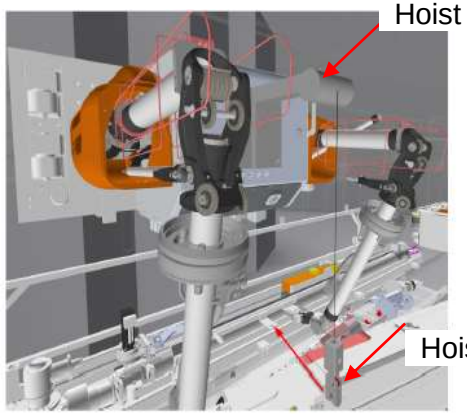
<Sensors, tools, and jigs used>

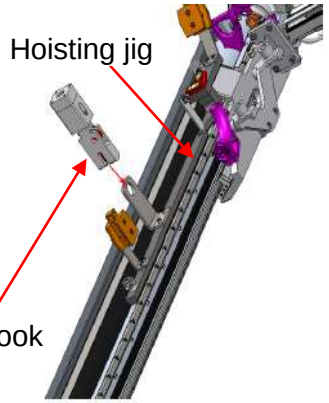
- Sensors (four types: γ-ray sensor, laser scanner, VT sensor, neutron sensor)
- Tools (three types: AWJ tool, AWJ gripper tool, gripper tool)
- Wand (including tool changer)
- Bolt runner (hex key, tools), torque wrench, cradle (sensor transportation jig)



② Concretization of the mockup test plan: Connection of sensors and tools to the arm using Dextre
Example of sensor connection

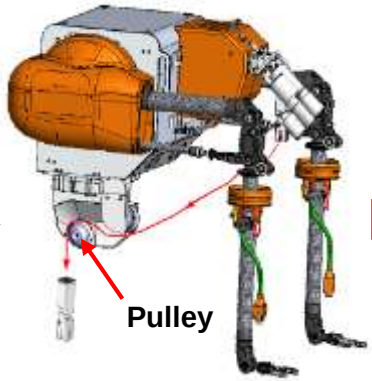






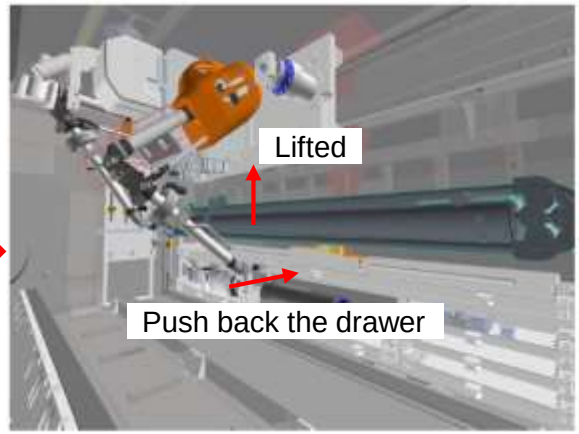
Pull out the drawer in which the wand is stored
<Confirmation items>
- **Confirm camera view when grabbing the drawer**
- **Confirm operator posture**

Attach the hoist hook
<Confirmation items>
- **Confirm camera view when attaching hook**
- **Confirm operator posture**



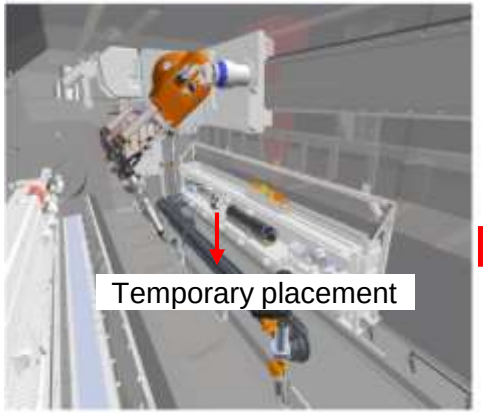
Hang the hoist wire on the pulley

<Confirmation items>
- **Verification of wire stability**
- **Confirm camera view when pulling the wire through**
- **Confirm operator posture**



Lift the wand and push back the drawer

<Confirmation items>
- **Confirm stability when lifting the wand**
- **Confirm view when grabbing the drawer**
- **Confirm interference of wand and Dextre**

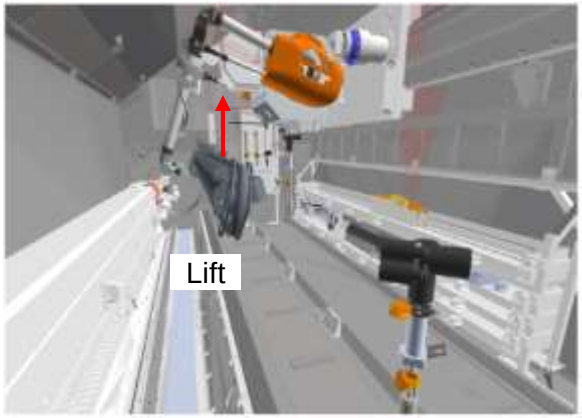


Temporarily place the wand and remove the wire from the pulley

<Confirmation items>
- **Confirm stability when hanging the wand**
- **Confirm stability when temporarily placing the wand**

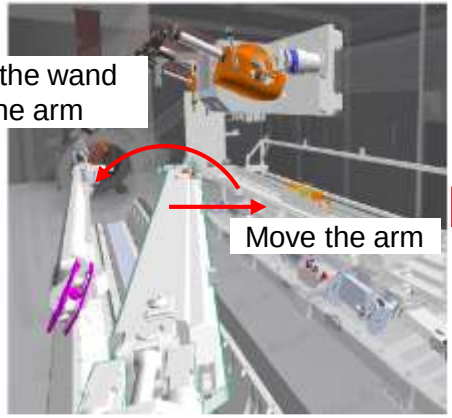
② Concretization of the mockup test plan: Connection of sensors and tools to the arm using Dextre

Example of sensor connection (Continued)



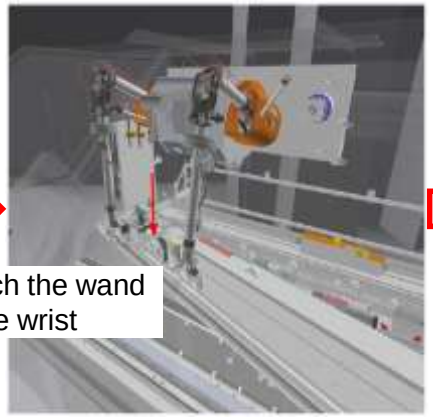
Remove the wire from the pulley and lift the wand

<Confirmation items>
- **Confirm view when grabbing the wand**
- **Confirm operator posture**
- **Confirm interference of wand**



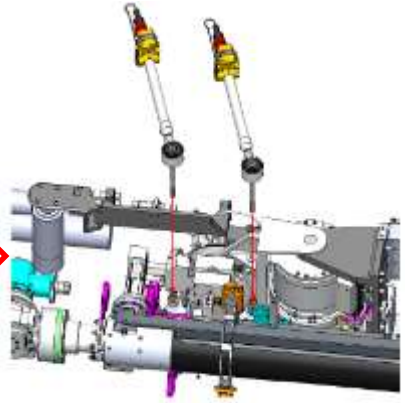
Move the wand over the arm to the installation position

<Confirmation items>
- **Confirm workability of wand in coordination with the arm**
- **Confirm interference of arm and wand**



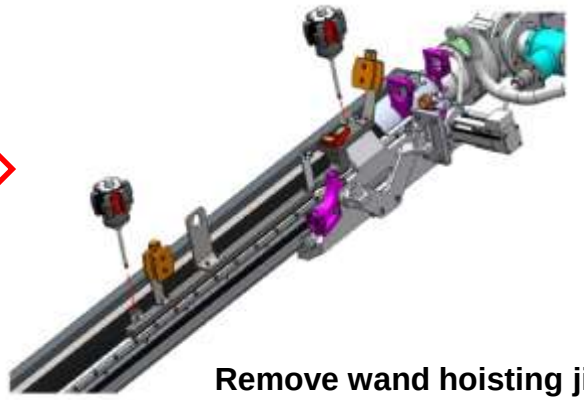
Install the wand

<Confirmation items>
- **Confirm view when attaching the wand**



Tighten bolt

<Confirmation items>
- **Use the torque wrench and bolt runner at the same time**

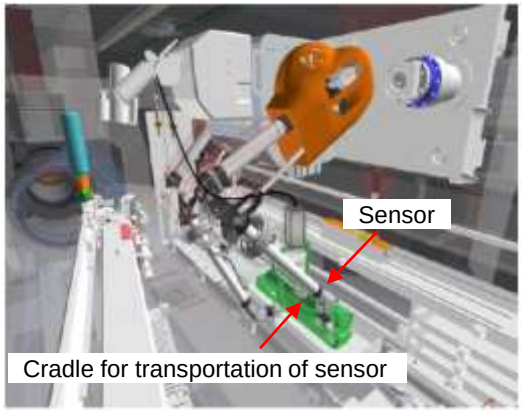


Remove wand hoisting jig

<Confirmation items>
- **Confirm view when working with the bolt runner**

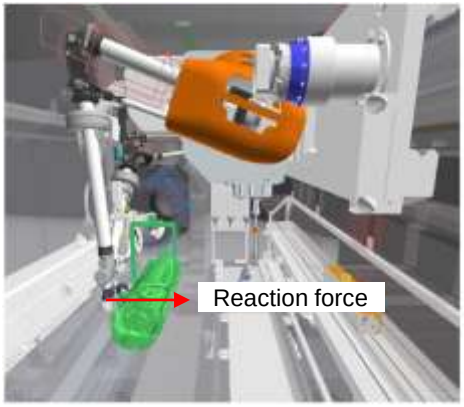
② Concretization of the mockup test plan: Connection of sensors and tools to the arm using Dextre

Example of sensor connection (Continued)



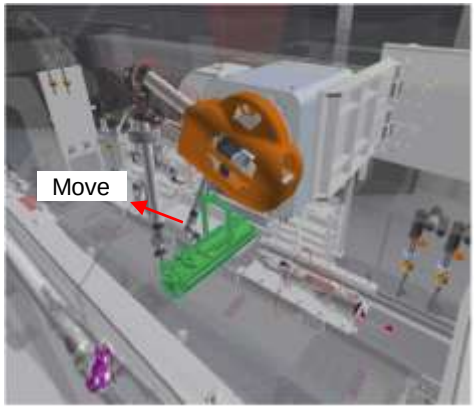
Attach the hoist hook and grab the cradle

<Confirmation items>
- **Confirm camera view when attaching hook**
- **Confirm operator posture**



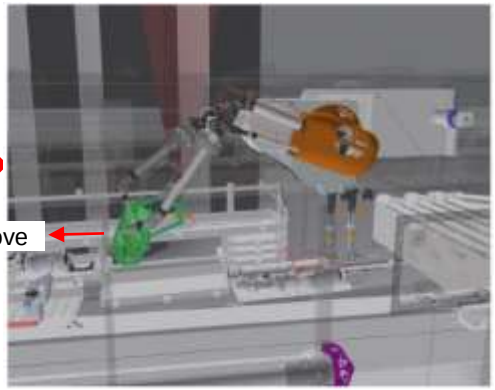
Lift the cradle

<Confirmation items>
- **Confirm the weight which the arm carries when lifting the cradle**
- **Work together with the hoist operator**



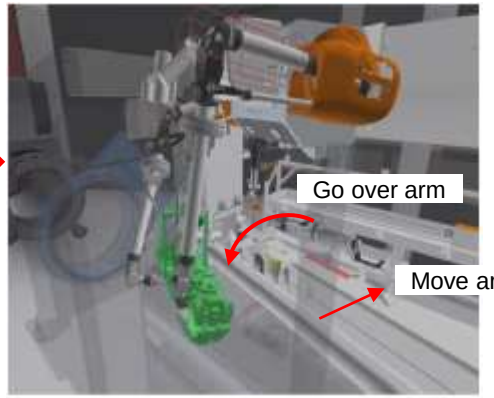
Move while grabbing the cradle

<Confirmation items>
- **Confirm interference during transportation**



Move while grabbing the cradle

<Confirmation items>
- **Confirm interference during transportation**



Go over the arm while grabbing the cradle

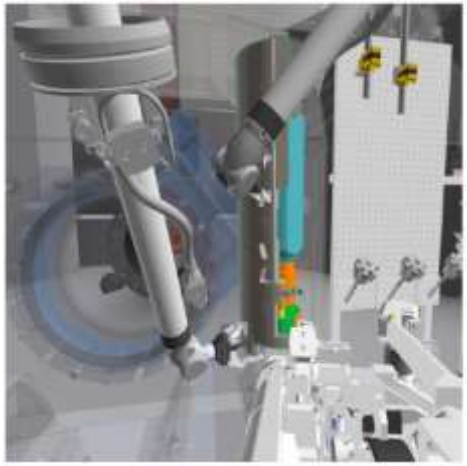
<Confirmation items>
- **Confirm interference with arm**
- **Work together with the arm operator**

Change the direction of the cradle

<Confirmation items>
- **Confirm behavior and stability when the sensor is rotating**

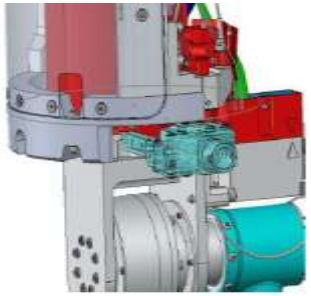
② Concretization of the mockup test plan: Connection of sensors and tools to the arm using Dextre

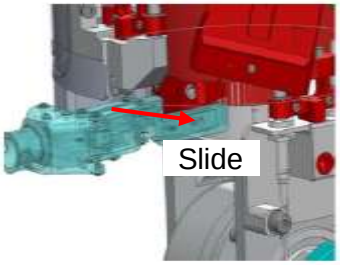
Example of sensor connection (Continued)



Grab the cradle and attach it to the tool changer

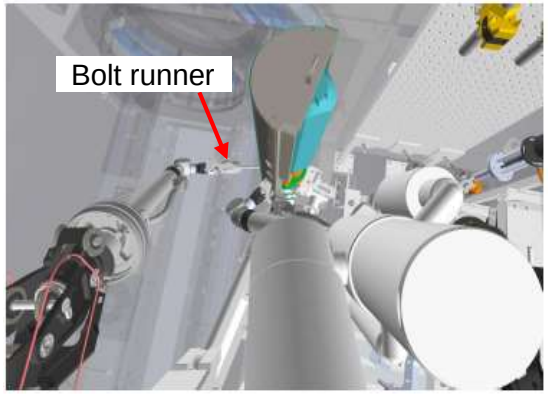
<Confirmation items>
- **Confirm operator posture**
- **Confirm view when grabbing the cradle**
- **Confirm view when attaching the sensor**





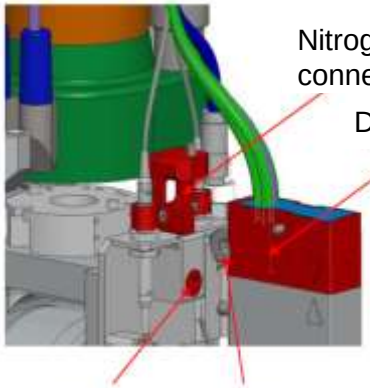
Install a sensor

<Confirmation items>
- **Confirm view when grabbing the lever**
- **Confirm sliding operation of the lock mechanism and locked state**



Install a sensor

<Confirmation items>
- **Confirm view when using the bolt runner**
- **Confirm the workability of the bolt runner**



Connect the connector

<Confirmation items>
- **Confirm view when attaching the connector**
- **Verification of connector stability**
- **Confirm the workability of the fixing bolt**

Contents

4.1 Implementation items and results

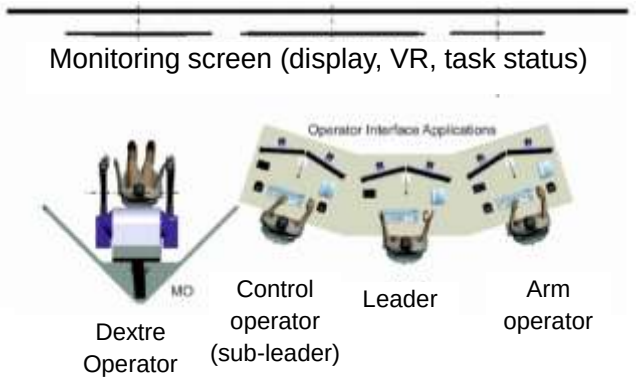
(4) Operation training

① Overall plan (1/2)

The arm-type access equipment is operated by building a team of several operators who manipulate the arm for investigation, Dextre, and various tools and sensors.

Operator	Role	Necessary skills
① Leader	Supervise the team and formulate the task procedures	- Understanding of procedures and ability to make good judgment - Attention to detail - Ability to use software and application
② Control operator	Operate display, lighting, and ancillary equipment (substitute of leader)	Same as above
③ Arm operator	Arm operation	- Attention to detail - Ability to use software and application
④ Dextre operator	Operate Dextre	- Spatial recognition ability - Attention to details

Conceptual image of control work station



Conceptual image of operator layout

4.1 Implementation items and results

(4) Operation training

① Overall plan (2/2)

Operators shall gain skills by increasing the difficulty level step by step as there is a wide range of skills they must acquire (operators obtain qualifications after confirming they have acquired all the necessary skills)

Broad classification		Details of training
1. Prior training		Get the feeling of operating a master-slave manipulator by practicing using a manipulator for training.
2. VR training	Part 1	Learn the basic operation of the arm using the VR system (prototype).
	Part 2	Master operation of the arm concerning all task procedures and method of correcting task procedures by using the VR system that is used with the actual equipment.
3. Training using the actual equipment	Phase 1	Understand the system configuration and details of remote-control tasks concerning the arm-type access equipment.
	Phase 2	Master the basic operation of Dextre.
	Phase 3	Master the basic operation of the operation and control system and the VR system.
	Phase 4	Conduct operation training in carrying out the basic tasks as a team.
	Phase 5	Revise the task as a team and conduct operation training in each system to formulate and verify the task.
	Phase 6	Master the practical use of command and control system for the robot arm and Dextre manipulator.
	Phase 7	Conduct intensive training for arm operators.
	Phase 8	Conduct an operator test (as a team) based on the training conducted so far. Those who pass shall be qualified as an operator.
	Phase 9	Final training. Foster teamwork and build confidence in operating the arm-type access equipment.

Practice using a manipulator for training

VR system training

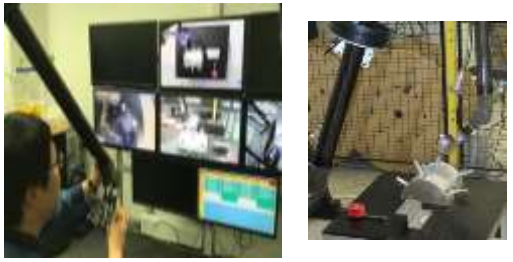
4.1 Implementation items and results

(4) Operation training

② Operation training

Conduct training using the actual equipment (Phases 1 and 2). The workers deepened their understanding of the specifications of Dextre (equipment and movable range) and obtained basic operation skills.

Operation of Dextre (actual equipment)

Item	Preconditions	Photos from the training
Basic motion	Conducted training to get used to the operation of Dextre, such as inserting and extracting connectors, transferring sand using cups, and tracing the way out of a maze	
Tool replacement	Conducted training of tasks such as grabbing a bolt runner and torque multiplier and tightening a bolt and nut	
Cabling	Conducted training in which operators loop a cable around bars to form a figure eight	

Contents

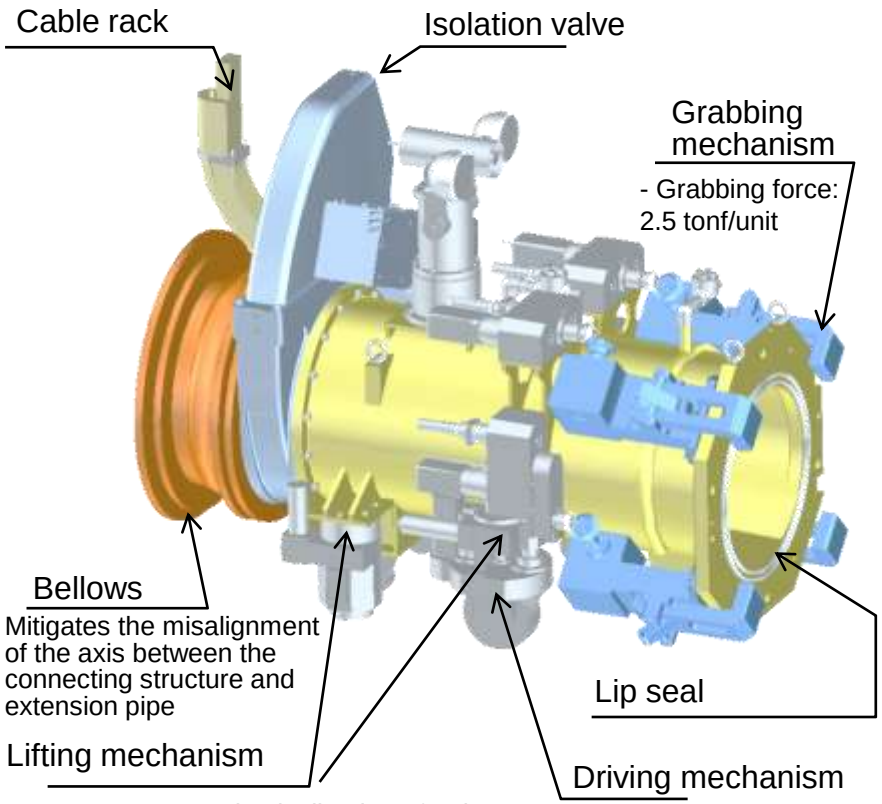
4.1 Implementation items and results

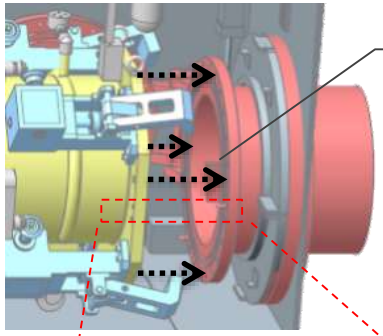
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

① X-6 penetration connecting structure

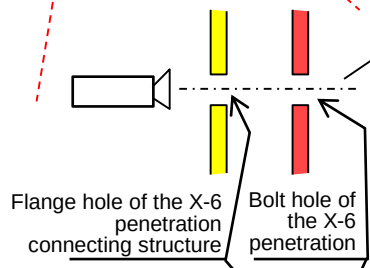
a) Function and specification of device (before modification)

Dimensions	L 1,850 mm × W 1,079 mm × H 1,466 mm
Weight	Approx 1.6 tons
Main material	SUS304, aluminum alloy
Main functions	Grabbing and connecting function, driving function, hoisting and lowering function (axis adjustment), PCV boundary (isolation valve)



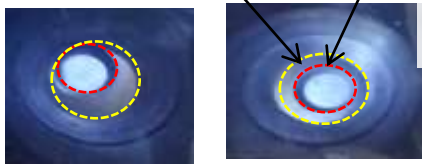


Laser distance meter (four locations around the circumference)
- Measurement accuracy: 0.2 mm
- Identifies the misalignment of the planar angle between the flanges of the X-6 penetration and X-6 penetration connecting structure

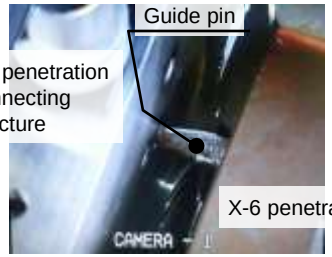


Flange camera (two along the circumference)

Determines the misalignment (amount of adjustment) with the axis of the X-6 penetration from the misalignment of the holes of the two structures



Before axis alignment | After axis alignment



4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

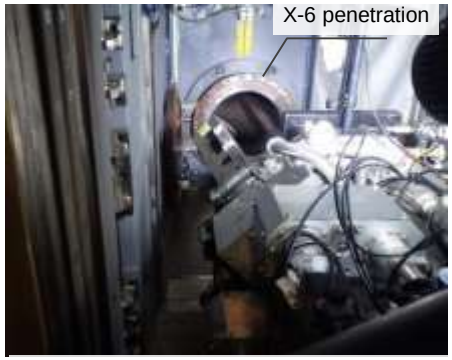
① X-6 penetration connecting structure

b) Overview of the combination test with the isolation room (Dec. 2018)

The test confirmed the prospects of the feasibility of the series of tasks, including self-driving, adjusting the axis, and grabbing operation by remote control, procedures for separation in an emergency, and tasks related to cables. Also, improvements that shall be made to the device were identified to enhance the task's reliability.

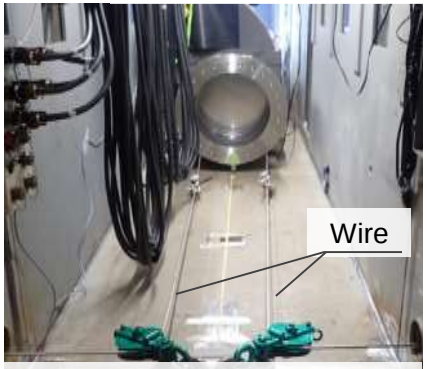
① Remote self-drive

Cable disconnection task

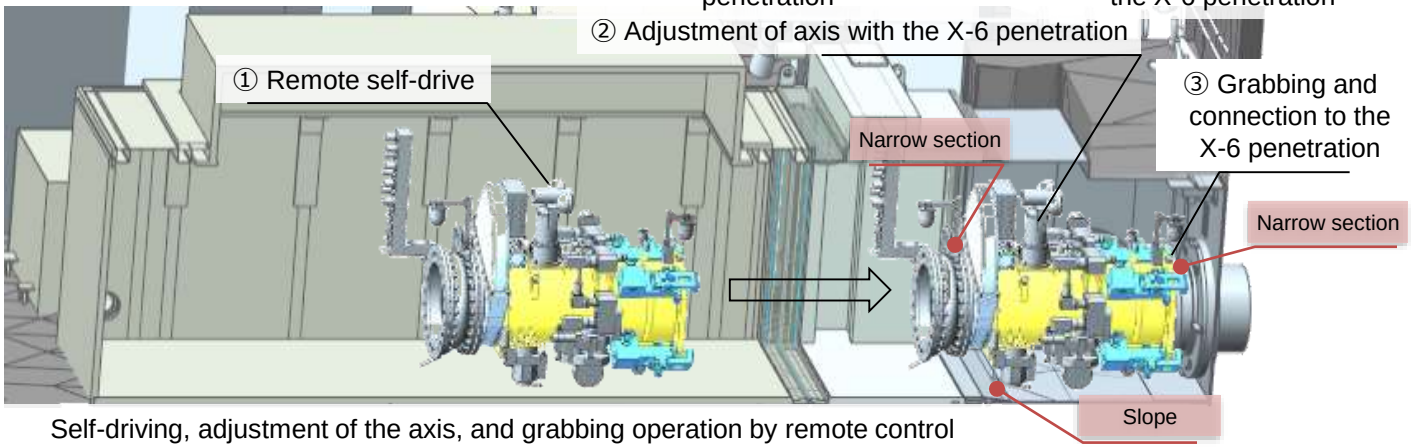


② Adjustment of axis with the X-6 penetration

③ Grabbing and connection to the X-6 penetration



Towing by winch in an emergency (failure of self-driving mechanism)



Self-driving, adjustment of the axis, and grabbing operation by remote control

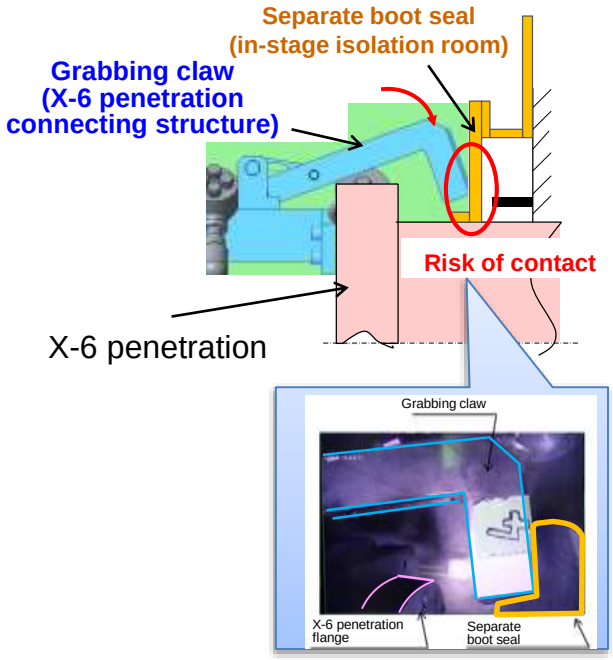
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

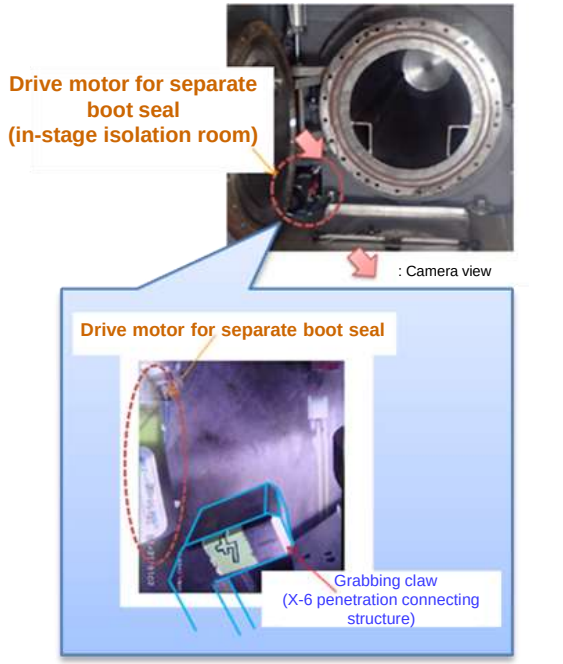
① X-6 penetration connecting structure

c) Details on modification of device (1/2)

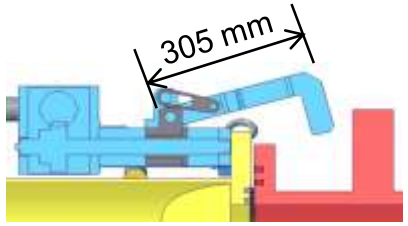
Modification items	Reason	Details
i) Shortening of grabbing claw and downsizing of course for grabbing	Secure clearance between the grabbing claw and the structures inside the narrow section of the isolation room (separate boot seal, drive motor) (avoid contact during adjustment of axis)	- Shorten grabbing claw from 335 mm to 305 mm - Downsize course for grabbing
ii) Additional operation monitoring camera	- Monitor device and narrow section of the isolation room - Improving the accuracy of grasping the posture and position of the device	- Install additional operation monitoring camera to the front, back, and side



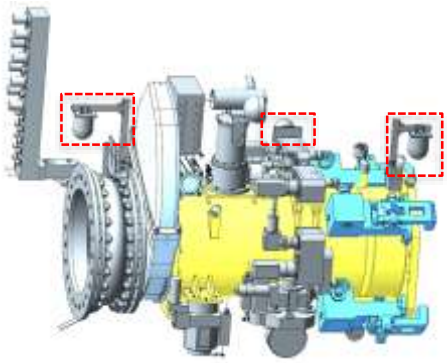
Risk of contact with separate boot seal



Risk of contact with a drive motor for separate boot seal



Shortening of grabbing claw



Additional operation monitoring camera

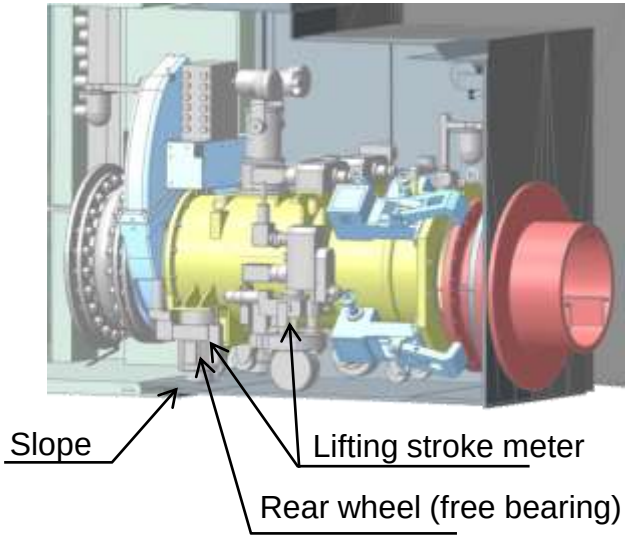
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

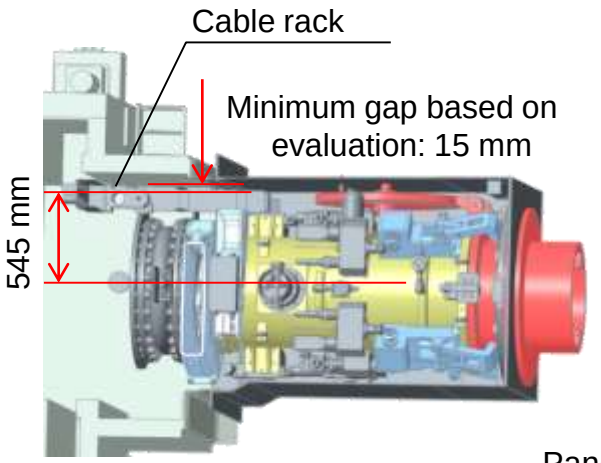
① X-6 penetration connecting structure

c) Details on modification of device (2/2)

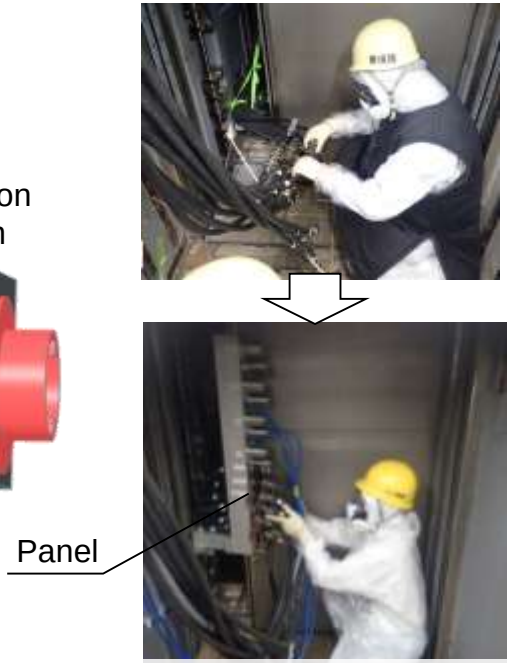
Modification items	Reason	Details
iii) Additional installation of lifting stroke meter	Enhance operability of axis adjustment on slope	Additional installation of lifting stroke meter: measurement accuracy 0.5 mm
iv) Downsizing of cable rack and arrangement into panel	Secure clearance in narrow section of the isolation room Enhance workability of disconnection and reconnection of cables	Downsize cable rack from 580 mm to 545 mm (dimension from center axis) Enhance workability by arranging connectors to make a panel



Additional installation of lifting stroke meter



Downsizing of cable rack



Modification of cable rack to a panel

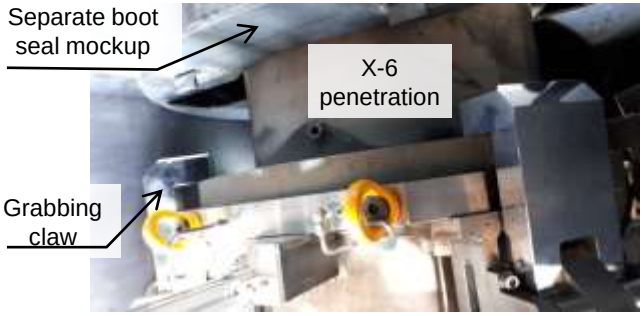
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

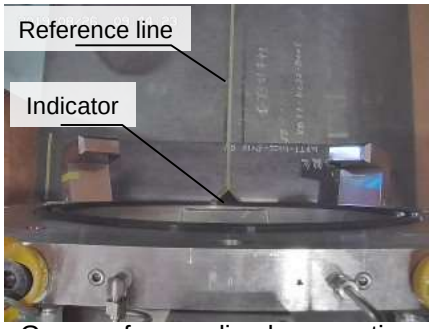
① X-6 penetration connecting structure

d) Results of unit test conducted after modifying the device

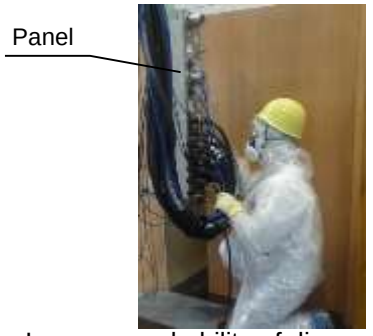
Verification items	Test details and conditions	Evaluation criteria	Results
i) Shortening of grabbing claw and downsizing of course for grabbing	- Installation position of X-6 penetration: (nominal) inclination ±1 deg., inclination ±0.5 deg. and height ±10 mm - Distance between the X-6 penetration and separate boot seal: 128 mm (worst (minimum) condition)	- The claw does not come into contact with the X-6 penetration or the separate boot seal and can approach and grab the X-6 penetration	Good: secured a clearance of approx. 10 mm (minimum condition) and completed the operation
ii) Monitoring performance by the operation monitoring camera	- Monitor device and narrow section of the isolation room - Grasping of the posture and position of the device	- The camera enables operators to know whether the connecting structure is approaching or in contact with other structures - The camera enables operators to recognize deviation from the reference line (standard: within 5 mm)	Good: confirmed that deviation of approximately 5 mm is recognizable
iii) Additional installation of lifting stroke meter	- Adjustment of axis and connection with the X-6 penetration while the rear wheel is on a slope - Installation position of X-6 penetration: (nominal) inclination ±1 deg., inclination ±0.5 deg. and height ±10 mm	- The connecting structure can adjust the axis and connect with the X-6 penetration while adjusting the ascend/descend stroke, in step with the back-and-forth movements and rotations on a slope	Good: completed connection without significant rubbing against guide pin
iv) Downsizing of cable rack and enhancement of workability	- Clearance between the inner wall of the isolation room and the cable rack: 15 mm (minimum condition)	- The connecting structure can approach and connect with the X-6 penetration without the cable rack coming into contact with the wall - Time required for disconnection: within 15 min. (target)	Good: no contact Time required for disconnection: approx. 8 min.



Grabbing complete



Grasp reference line by operation monitoring camera



Improve workability of disconnection of cables (arranged to make a panel)

4.1 Implementation items and results

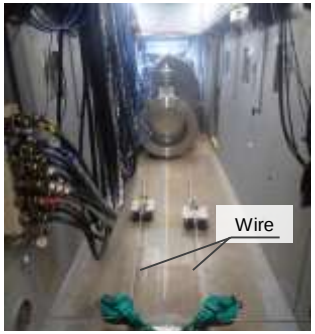
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

① X-6 penetration connecting structure

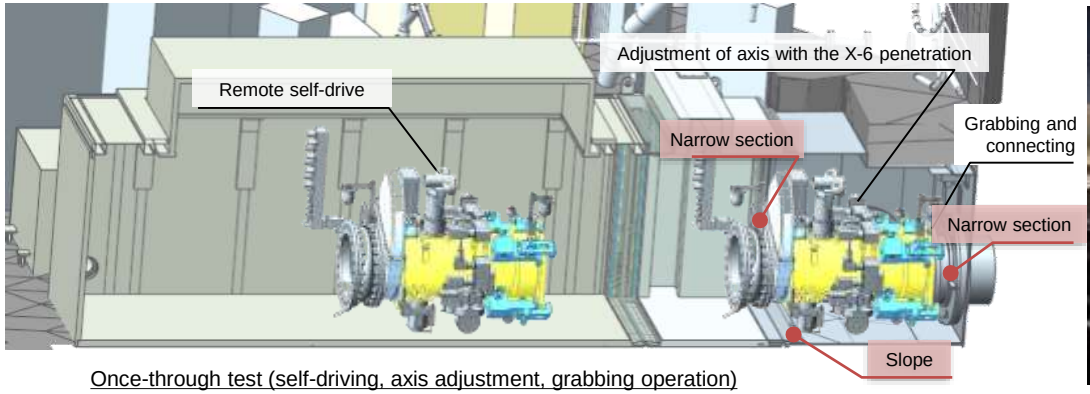
e) Results of the combination test with the isolation room after improving the device

Verification items	Modification items	Test details and conditions	Evaluation criteria	Results
Avoidance of interference at narrow section and monitoring	i, ii, iv	- Verification of monitoring performance and avoidance of interference at narrow sections by once-through test - Distance between penetration flange and separate boot seal: 132 mm	- Series of operation can be completed while monitoring the narrow section without the connecting structure coming into contact with the walls of and structures inside the isolation room - Condition of completion: complete grabbing operation*1 (grabbing force: 2.5 tonf/unit or greater, motor current: 3.5 A or greater)	Good: completed grabbing operation without unnecessary contact
Remote operation performance of axis adjustment	iii	- Verification of axis adjustment and operation performance by once-through test - Inclination of X-6 penetration: nominal	- The positioning pin does not wear, and connection (insertion) is conducted smoothly	Good: completed connection smoothly
Emergency escape by windup device for rescue	–*2	- Verification of ability to make an emergency escape without issue after modification - Open grabbing claws after connecting to X-6 penetration - Driving mechanism: power interruption	The connecting structure can return to the robot carrying-in compartment without colliding into or getting caught on the inner walls of the isolation room	Good: returns without colliding or getting caught

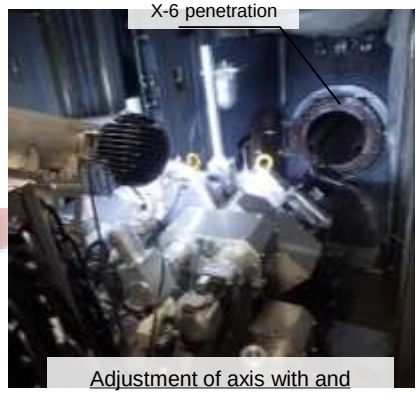
*1: Previous tests verified that the specified grabbing force and airtightness with the X-6 penetration flange could be achieved at a motor current of 3.5 A.
*2: Tests confirmed that emergency escape using a verified winch does not negatively impact the modification of the device.



Emergency escape by windup device for rescue



Once-through test (self-driving, axis adjustment, grabbing operation)



Adjustment of axis with and approach to X-6 penetration

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

② Isolation room (1/2)

[Overview] To establish a route for the investigation equipment to access inside the PCV from the X-6 penetration, the hatch of the X-6 penetration was opened by remote control while securing a PCV boundary with the isolation room*1.

[Progress in FY2019]

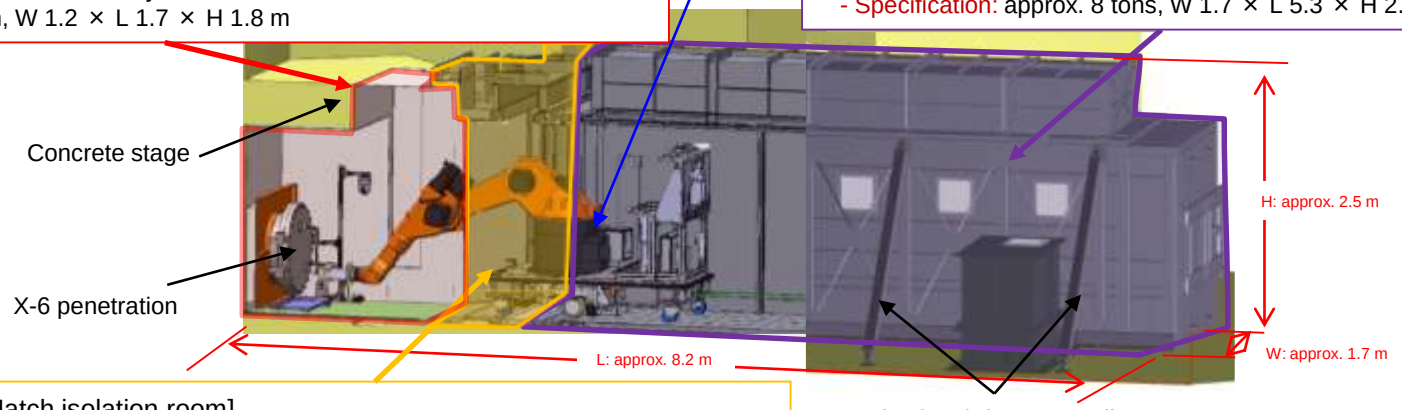
The in-stage isolation room (prototype) developed in the prior project*2 was modified (e.g., optimization of dimension) to improve the margin for on-site installation to the concrete stage, and a unit test, as well as a combination test, were completed.

[Specifications and structure of the isolation room]

[Hatch opening device]
- Function: opens X-6 penetration hatch
- Specification: approx. 2.3 tons, W 1 × L 2 × H 1.6 m

[In-stage isolation room]
- Function: provides the sealing ability to the concrete stage that connects the sleeve of the X-6 penetration with the hatch isolation compartment to maintain the soundness of the PCV boundary
- Specification: approx. 1 ton, W 1.2 × L 1.7 × H 1.8 m

[Robot carrying-in compartment]
- Function: forms part of the PCV boundary when the hatch is opened and serving as a facility to support the carrying in and out of equipment
- Specification: approx. 8 tons, W 1.7 × L 5.3 × H 2.5 m



[Hatch isolation room]
- Functions
  a. Forms part of the PCV boundary when the hatch opens
  b. Forms part of the PCV boundary and provides sealing ability by the airtight door when the hatch opens
- Specification: approx. 5.5 tons, W 1.7 × L 5.3 × H 2.5 m

[Specifications common to all isolation rooms]
- Withstand pressure: 6 kPag (control valve for the first floor of Unit 2 reactor shall be 5.5 kPaG or less)
- Main material: carbon steel

*1 Isolation room: an integrated structure consisting of the in-stage isolation room, hatch isolation room, and robot carrying-in compartment

*2 Prior project: Subsidy Project of Decommissioning and Contaminated Water Management in the FY2016 Supplementary Budgets “Development of Technology for Detailed Investigation Inside PCV”

4.1 Implementation items and results

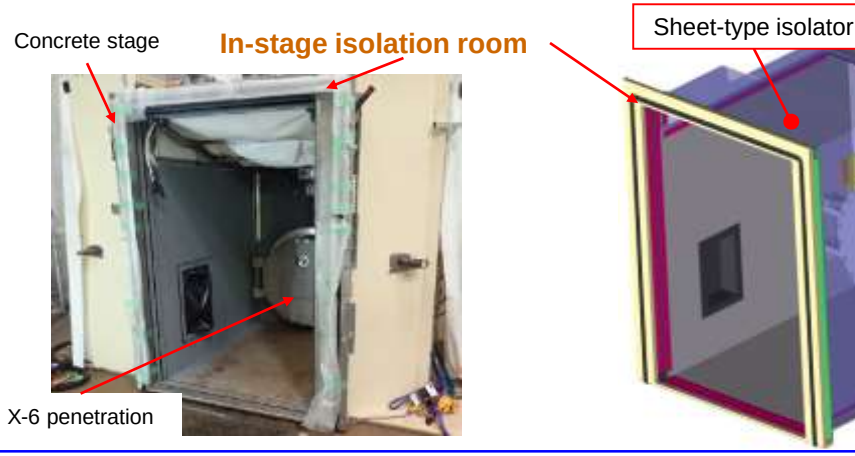
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

② Isolation room (2/2)

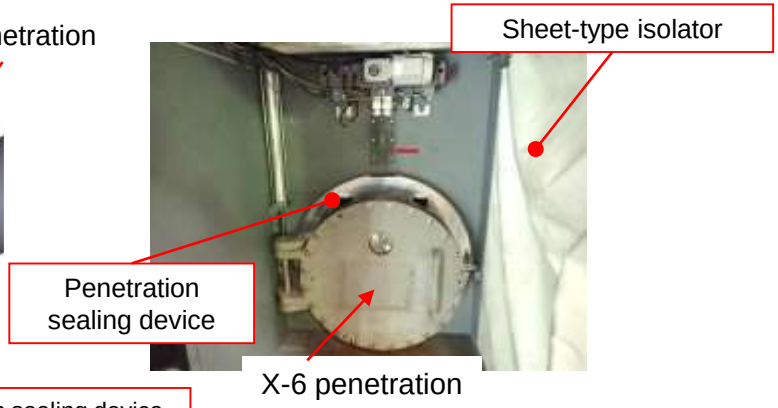
[Test situation] Using the improved in-stage isolation room, the following was conducted in the in-factory verification test. Also, a combination test of the isolation room and X-6 penetration connecting structure was completed.

- Confirmed that installation to the concrete stage is possible
- Confirm that the air leakage rate is lower than the target permissible rate in an airtightness test
- Confirm that the hatch opening device works properly in other isolation rooms

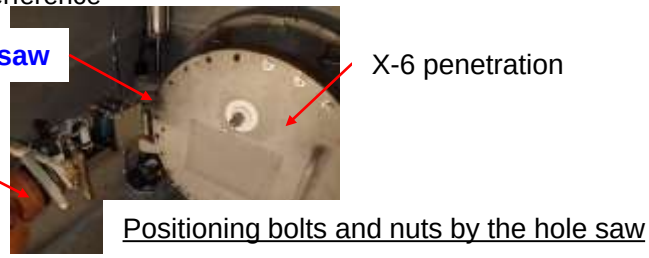
- Test overview 1: Confirmed feasibility of the installation of the in-stage isolation room to the concrete stage

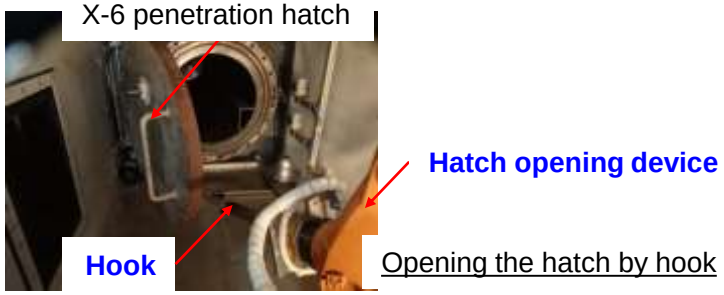


- Test overview 2: Confirmed feasibility of the installation of the penetration sealing device to the X-6 penetration by remote control



- Test overview 3: Confirmed feasibility of the operation of the hatch opening device without interference





4.1 Implementation items and results

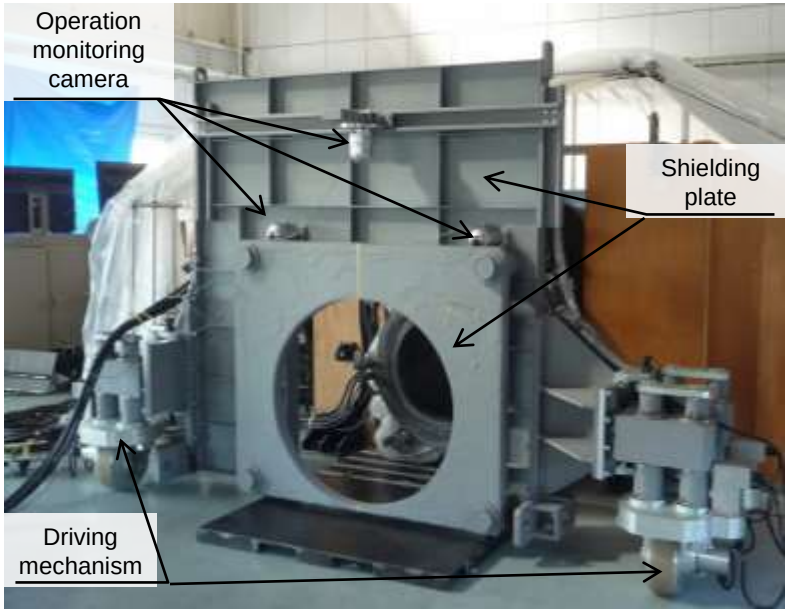
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

③ Extension pipe: manufacturing

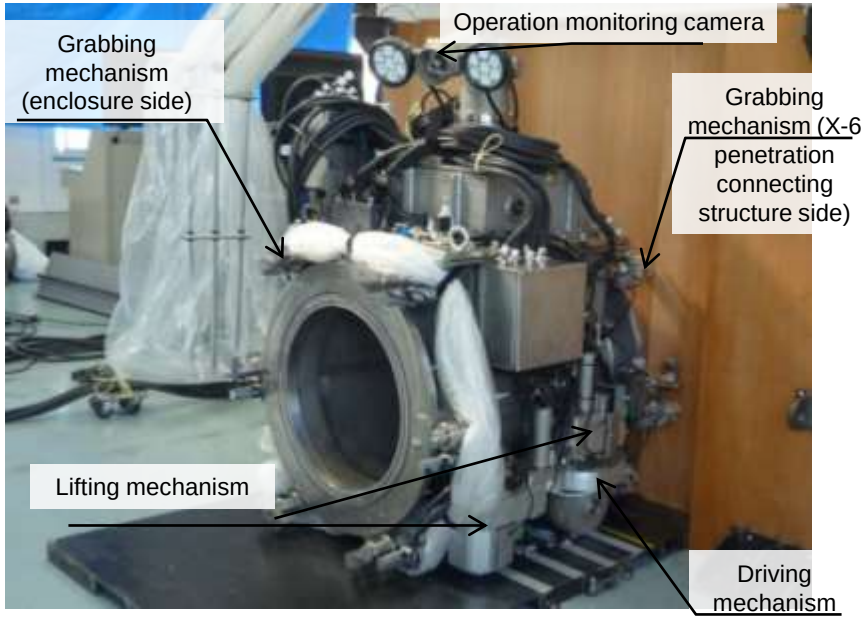
Completed the manufacturing of extension pipe and additional shielding plate based on the results of the design study conducted in 2018.

Dimensions	L 760 mm × W 3,589 mm × H 2,115 mm
Weight	Approx 3.5 tons
Main material	Lead, carbon steel
Function	Driving function, shielding

Dimensions	L 1,163 mm × W 1,110 mm × H 1,656 mm
Weight	Approx 1.2 tons
Main material	SUS304
Function	Grabbing and connecting function, driving function, hoisting and lowering function (axis adjustment), PCV boundary, shielding



Additional shielding plate



Extension pipe

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

③ Extension pipe: unit test

Confirmed the conformity to various requirements by conducting a design study and mockup test.
Assess the risks for each step of the task, and identify items to be verified in the mockup test.

Item	Required functions	Verification method	Requirements and evaluation criteria	Results
Maintaining of PCV boundaries (during the investigation)	Maintain boundaries during the investigation (amount of leakage shall be sufficiently small compared with the amount of leakage from PCV)	Leak test	Raise pressure to 11 kPa or greater and maintain the pressure for 10 minutes; there shall be no significant loss of pressure	Verified: No loss of pressure
Passage of arm	A route for the arm shall be established	Dimension inspection	Inner diameter (flange) 591.6 mm (±2 mm)	Verified: 592.0 mm
Shielding function	A level of shielding that shields direct ray from the penetration opening and enables a manned operation for the installation and removal of the investigation equipment shall be achieved (BG level)	Dimension inspection	Extension pipe shielding 70 mm or greater	Verified: 73 mm
			Additional shielding plate 50 mm or greater	Verified: 55 mm
Remote control	The extension pipe shall be able to approach and connect (create a boundary and arm passage route) to the X-6 penetration connecting structure by remote control after opening the airtight door	Operation test	Extension pipe Have grabbing force of 2,667 N/unit or greater	Verified: 2,773 N/unit or greater
			Extension pipe Can drive, rotate, ascend, and descend	Verified: Drivable, rotational, and ascendable/descendable
			Additional shielding plate Can drive and rotate	Verified: Drivable and rotational
Dimensions	Total length shall be 1 m or shorter due to limitations on routing space when installing an enclosure	Dimension inspection	Total length of extension pipe: 1000 mm (-4 to 0 mm)	Verified: 999 mm
Radiation resistance	Ensure radiation resistance during the installation period	Manufacturer guaranteed value, radiation resistance test	Based on the installation period and air dose rate at the installation location	Verified: Radiation resistant

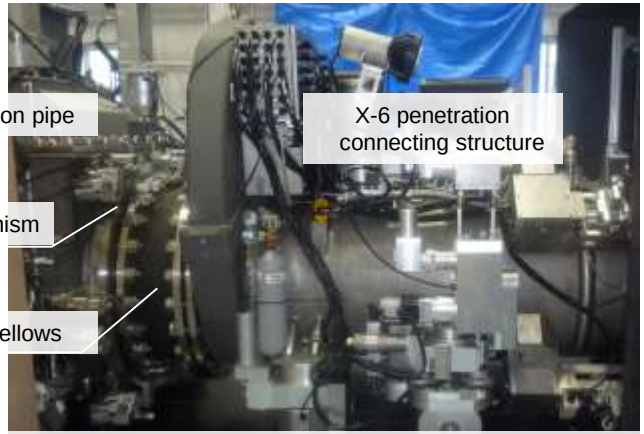
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

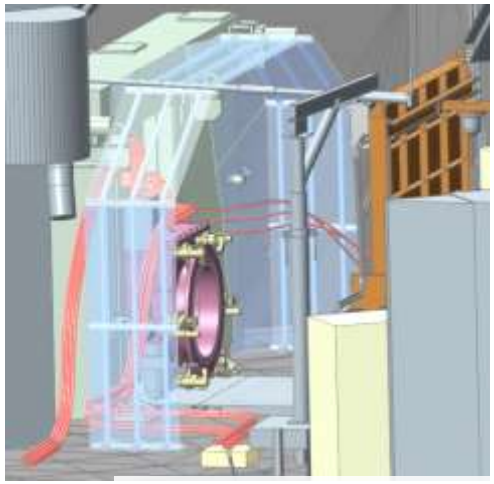
③ Extension pipe: mockup test <main body of extension pipe>

As a representative example of a mockup test that verifies the basic operation and workability, verification results of the remote control extension pipe installation test are shown below.

No.	Task procedure	Verification items	Test details and conditions	Evaluation criteria	Results
1-6	Self-driving, approaching, and adjustment of the extension pipe axis	- Ability to pass through narrow section (opening of airtight door), remote operation performance - Avoidance of interference with the cables of the X-6 penetration connecting structure (method for working with cable)	Clearance between the opening of airtight door and extension pipe - Nominal: 60 mm - Minimum: 28 mm (minimum condition for the horizontal deflection of the penetration (1 deg.) and accuracy of the installation of the isolation room)	Does not interfere with the airtight door and the cables of the X-6 penetration connecting structure	Satisfied: confirmed clearance of about 25 mm
		- Inspection of guidance performance and method of cable management (unmanned)	- Inspect guidance property of cable and optimal method for cable management	Does not inhibit remote operation of the extension pipe	Satisfied: confirmed that the cables are guided appropriately
		- Skidding, driving performance with regards to the groove width and step height of the isolation room	Groove width: 5 mm Step height: 2 mm	Can drive appropriately	Satisfied: confirmed that the extension pipe could drive the entire distance without any issues



Connection with the X-6 penetration connecting structure



Cable after installation (cable management)

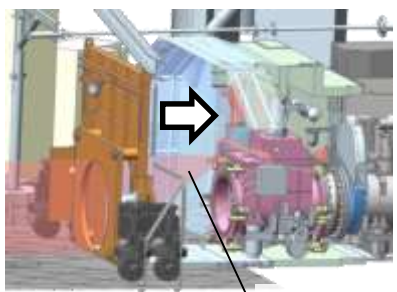
4.1 Implementation items and results

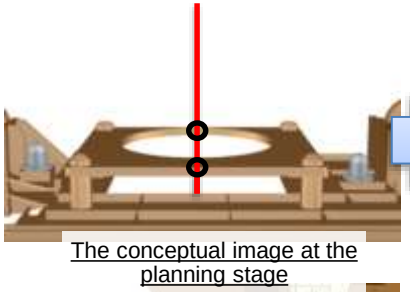
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

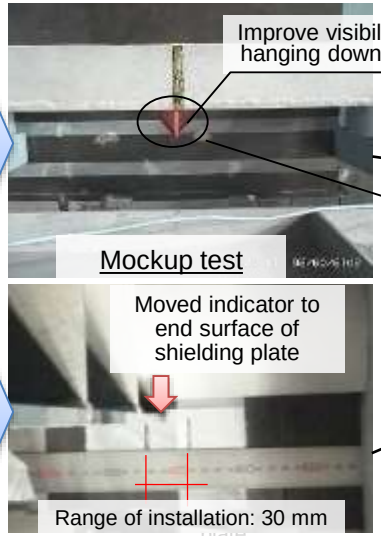
③ Extension pipe: mockup test <additional shielding plate>

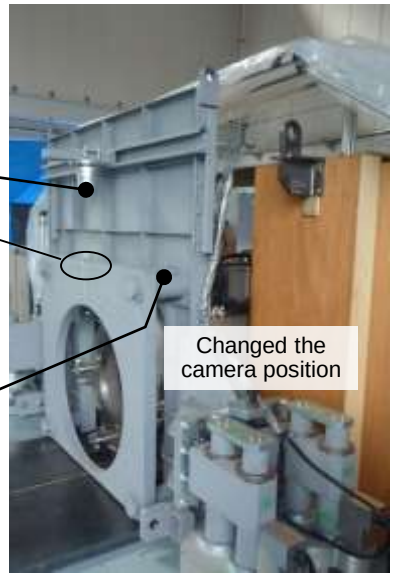
Below is the test's verification results on the installation of the additional shielding plate by remote control. The position of the indicator and camera was improved based on the test results.

Test No.	Task procedure	Verification items	Test details and conditions	Evaluation criteria	Results
1-8-1	Installation of additional shielding plate (approaching)	- Grasping of remote operation and position of the additional shielding plate	- Height of the extension pipe: nominal - Height of the extension pipe: -35 to +35 mm	- Can monitor how close the additional shielding plate is with the mobile camera and shielding plate camera - Laser and center marking matches	Satisfied: an indicator was added, improving the match visibility with the laser
		- Cable management		Does not inhibit remote operation of an additional shielding plate	Satisfied: does not inhibit remote operation
1-8-2	Installation of additional shielding plate	- Interference with extension pipe, airtight door, and cables - Method for verifying the installation position	- Installation position of the additional shielding plate: 289 mm to 259 mm	- Can be determined the position with the shielding plate camera - Can install additional plate to the specified position (30 mm range)	Satisfied: the camera position was changed and the indicator was moved to the end surface of the shielding plate









(5) Test for Establishing Access Route to PCV and Onsite Operation Training

④ Transfer carriage – implementation of mockup test (overview) –

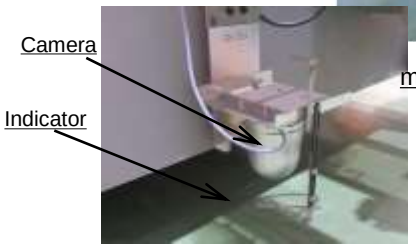
Transportation procedures that conforms to the actual equipment was established by conducting a basic performance verification of the remote control transportation system and verifying the coordinated operation of the entire system using the mockup transport route that mimics the actual facility (including mockup of enclosure). In addition, procedures for installation and removal of the enclosure was established.

[Purpose]

- Establishment of remote control transportation procedure
- Establishment of installation and removal procedures
- Response to emergencies and risks

Front of the enclosure (flange side)

Back of the enclosure



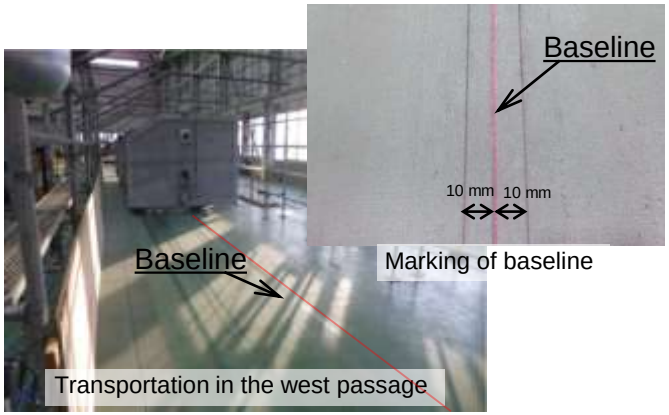
Core monitoring camera (placed in the front and back of the enclosure)

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

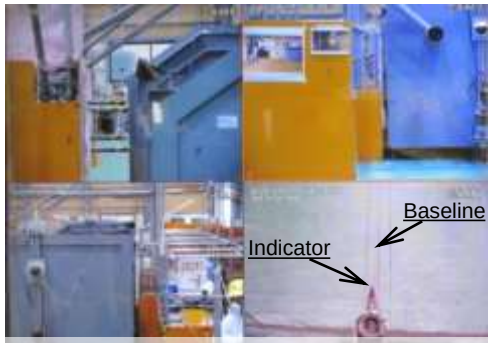
④ Transfer carriage – mockup test results (transportation) –

Procedure	Verification items	Test details and conditions	Evaluation criteria and check items	Results
Remote transportation	Visibility and placement of core monitoring camera	Confirm the visibility of the base line (core marking on west passage and installation reference line marking in the northwest area) and confirm that the device can run under the following conditions. - Marking width: 20 mm - Transportation speed: 35 mm/s	The indicator is visible while driving at 35 mm/s (operation speed) and the transfer carriage can run with the indicator staying within the 20 mm width range.	Verified: Drivable at operation speed.
	Visibility and placement of fixed camera	Confirm the visibility of the clearance at the narrow section in each of the transportation procedures and determine the placement and number of fixed cameras.	- The narrow section is visible in each of step of the driving procedure. - The placement of the fixed camera is determined.	Verified: Narrow sections confirmed to be visible. - Determined the placement of the fixed camera
	Verification of measurement range sensor responsivity	- Establish a method for confirming the position by a measurement range sensor - Verify the range of detection of the measurement range sensor	- Error between the distance (horizontal direction) measured by the measurement range sensor and the actual measurement is within 50 mm. - The measurement range sensor detects obstacles that are within a specified range in each step of the transportation procedures and the enclosure stops. - The sensor detects obstacles in the section of the east passage with a clearance of 37.5 mm. The installation angle and range of detection of the sensor which triggers the stop signal are determined.	Verified: The error (horizontal direction) from the actual measurement was within 50 mm. Verified: Assuming a mistake in operation in each step of the transportation procedure, the measurement range sensor detects obstacles which the enclosure approaches and stops the cart. Verified: The installation angle and range of detection of the measurement range sensor were determined based on the mockup drive test.

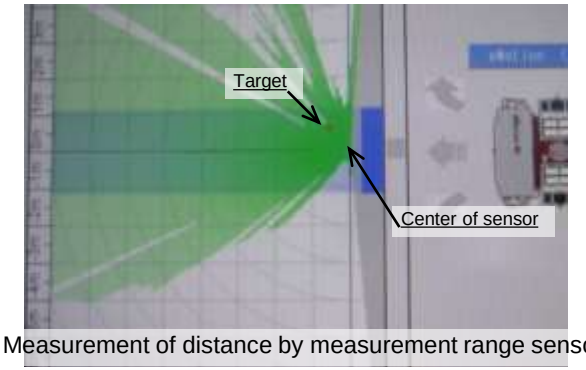


Marking of baseline

Transportation in the west passage



Verification of camera placement and visibility

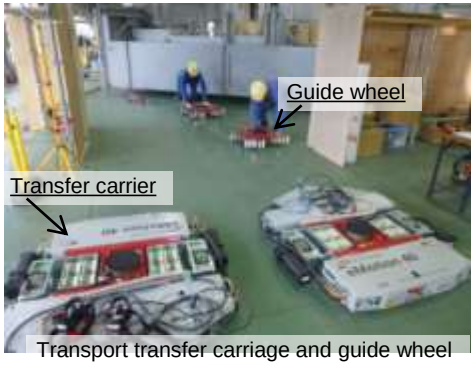


Measurement of distance by measurement range sensor

4.1 Implementation items and results

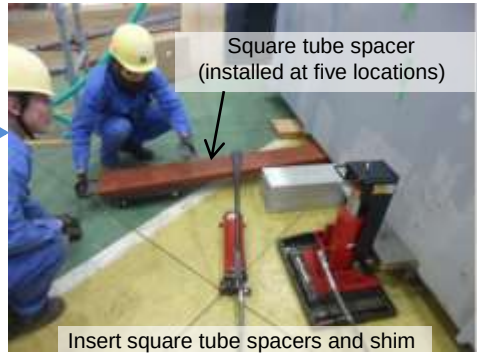
(5) Test for Establishing Access Route to PCV and Onsite Operation Training
④ Transfer carriage – mockup test results (installation and removal) –

Procedure	Verification items	Test details and conditions	Evaluation criteria and check items	Results
Installation	Feasibility of installation	Verify the feasibility of the enclosure installation procedure. - Operability of toe jack with slide table - Visibility of the flange surface with a camera	The basic procedure is feasible. - Error of flange surface: within ±2 mm (up-and-down direction, left-and-right direction) - Distance between flange: within 5 mm - Inclination of the main body of the enclosure (level of horizontal angle of enclosure): within 2 mm (left-and-right direction, back-and-forth direction) - The flange surface (marking) is visible by the additional shielding plate camera.	Verified: Feasibility of the basic procedure confirmed.



Transport transfer carriage and guide wheel

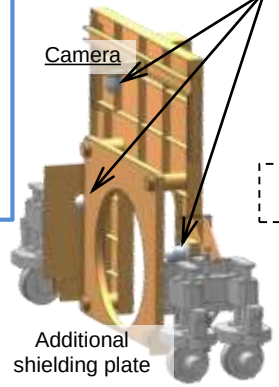
Set up toe jack with slide table

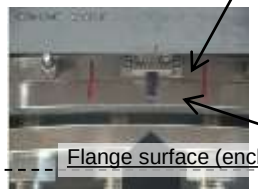


Insert square tube spacers and shim


Slide enclosure using toe jack with slide table


Install laser for level verification






Confirmation of flange surface by the additional shielding plate camera

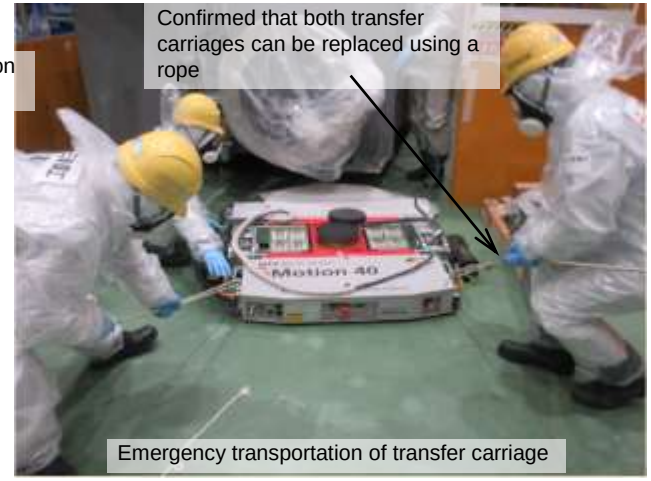
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

④ Transfer carriage – mockup test results (response to risks) –

Procedure	Verification items	Test details and conditions	Evaluation criteria	Results
Response to risks	Failure of transfer carriage	Confirm the feasibility of a transfer carriage replacement task assuming the risk of cart failure. (assume failure at the narrow part of the passage on the west)	The transfer carriage can be replaced using a jack at the narrow section of the west passage.	Feasible: Feasibility of replacement confirmed
	Dead transfer carriage battery	Confirm the feasibility of a transfer carriage replacement task assuming the risk of dead battery. (assume failure at the narrow part of the passage on the west)	The transfer carriage can be replaced using a jack at the narrow section of the west passage.	Feasible: Feasibility of replacement confirmed.
	Poor/no remote control wireless communication	Confirm the feasibility of switching to wireless/wired remote control operation assuming a poor or no remote control wireless communication. (*) (assume poor/no wireless connection at the narrow part of the passage on the west)	- Wireless/wired remote control can be installed. - Transfer carriage can be operated by wireless/wired remote control.	Feasible: Wireless/wired remote control confirmed to be installable. - It also confirmed that the transfer carriage can be operated by wireless/wired remote control.

*The transfer carriage is normally operated via wireless LAN repeater. As a backup plan, the cart switches to wireless or wired remote control by a changeover switch on the main body.



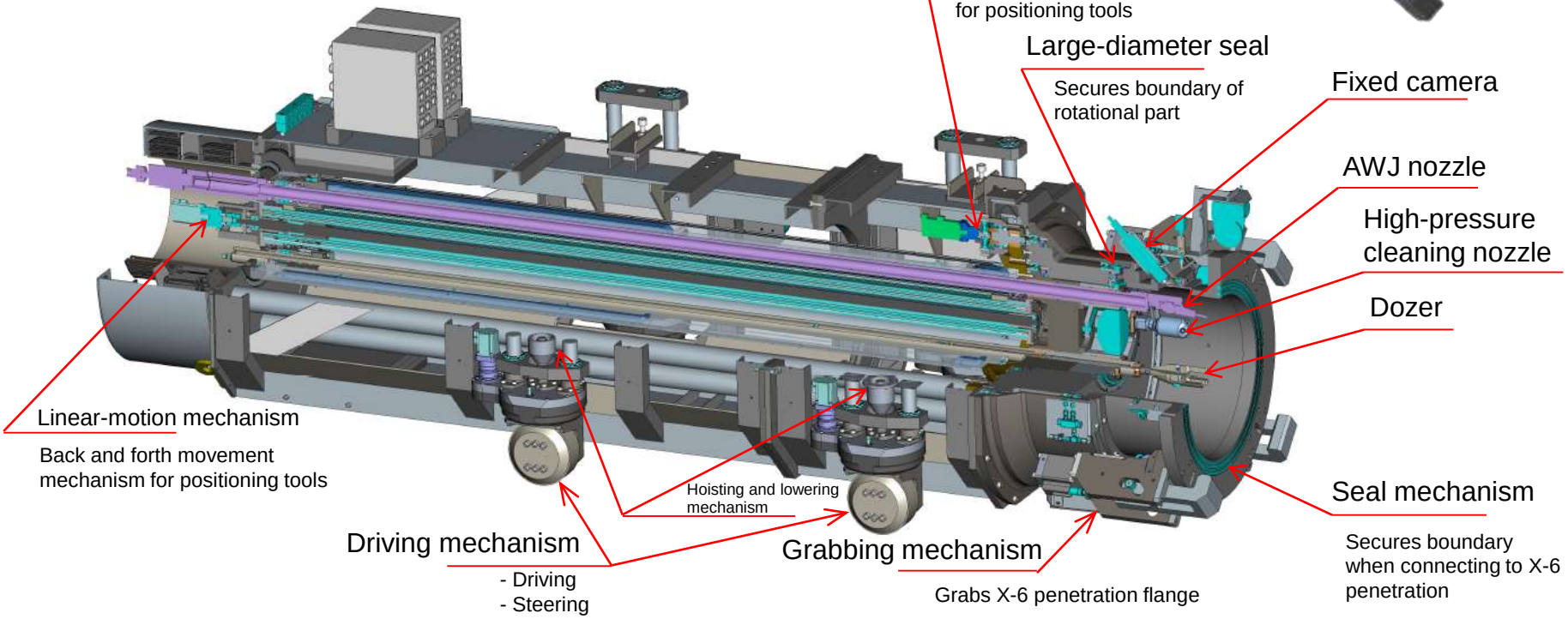
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑤ Deposit removal device: manufacturing

Completed the manufacturing of the deposit removal device based on the results of the design study conducted in 2018.

Dimensions	W 1,090 × L 3,975 × H 1,280 mm
Weight	Approx. 2.9 tons
Main material	: SUS304, aluminum alloy, carbon steel
Function	Grabbing and connecting function, driving function, hoisting and lowering function (axis adjustment), deposit removal function (high-pressure cleaning, AWJ, dozer)



4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

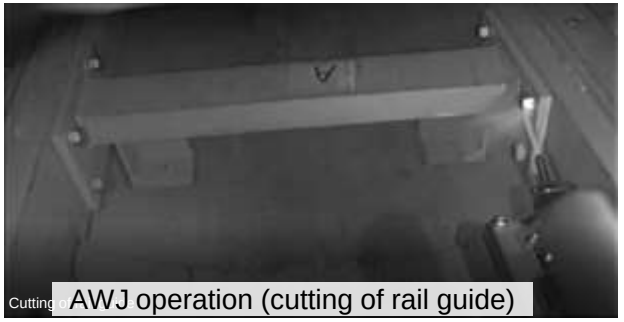
⑤ Deposit removal device: mockup test

As a representative example of a mockup test that verifies the basic operation and workability, the results of the deposit removal performance verification test are shown below.

Verification items	Details and conditions of test	Evaluation criteria	Results
Deposit removal function	- Confirm whether deposit can be removed by high-pressure cleaning	- Deposit can be removed	Verified: Removable
	- Confirm whether space through which the arm-type access equipment can pass can be secured	- Deposit can be removed to a degree in which the arm can pass through	Verified: Removable


Before high-pressure cleaning


Before high-pressure cleaning


AWJ operation (cutting of rail guide)


After high-pressure cleaning


After high-pressure cleaning


Secure space for passage
(bottom cable outside the range of passage is removed)

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑤ Deposit removal device: mockup test

Response to range outside the device specifications were confirmed as measures against risks.

Verification items	Details and conditions of test	Evaluation criteria	Results
Verification of range of response when conditions are outside the specification of the device	- Inclination of X-6 penetration flange: ±1 deg.	- Airtightness is ensured and connection operation can be conducted	Verified: Grabbed (connected) without problem and airtightness was ensured
	- Misalignment of X-6 penetration flange: ±10 mm	- Airtightness is ensured and connection operation can be conducted	Verified: Grabbed (connected) without problem and airtightness was ensured
	- Whether adherent mockup (silicone sealant, epoxy putty, etc.) can be removed	- Adherents can be removed	Verified: was able to remove adherents with WJ without abrasives
	- Place foreign object (wire) on the surface of the flange of the X-6 penetration and verify how much airtightness can be achieved	- Airtightness can be secured after connecting device	Verified: Airtightness up until φ0.3 mm achieved

Before removal of simulated adherent

After removal of simulated adherent

Verification of impact of foreign objects on airtightness

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑥ Once-through test: purpose and focus

In addition to the various task procedures verified by the mockup test, once-through verification test was conducted on the on-site workability including attendant tasks during the operation (laying of cables, installation of monitoring camera, etc.), the time required to complete the operation was measured, and points of improvement were identified.

The following were considered and simulated in conducting the workability verification test.

- Simulated interfering objects inside the R/B (reactor building) based on point cloud and actual measurements
- Team composition, worker positioning, and traffic lines
- Visibility due to it being remote control, connection and monitor
- Radiation management equipment, changing area
- Contamination spread prevention measures


Complete view of the once-through test


Team composition and worker positioning

Worker traffic line


Attendant task (organize cables)


Simulation based on actual measurements


Confirm placement and visibility of monitoring camera

Simulation of visibility

Contamination spread prevention measures


Covered during removal

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑥ Once-through test: construction workflow and scope of verification

① Begin construction

② Install isolation room

③ Open hatch

④ Remove deposit

Scope of verification

⑤ Install X-6 penetration connecting structure

Carry in and lay cables, etc.

Self-drive and connect

(⑥ Remove robot carrying-in compartment)

⑦ Install extension pipe and additional shielding plate

Carry in and lay cables, etc.

Self-drive, connect, and install

⑧ Install arm enclosure

Transfer passage of truck bay door

Transfer to the front of the X-6 penetration by remote control

Installation

Lay accessory cables

⑨ Conduct detailed internal investigation

Scope of verification

⑩ Remove arm enclosure

Remove accessory cables

Separate and remove

Transfer to southwest area by remote control

Carry out from truck bay door

⑪ Remove extension pipe and additional shielding plate

Separate

Cover and transfer

(⑫ Install robot carrying-in compartment)

⑬ Remove X-6 penetration connecting structure

Separate

Cover and transfer

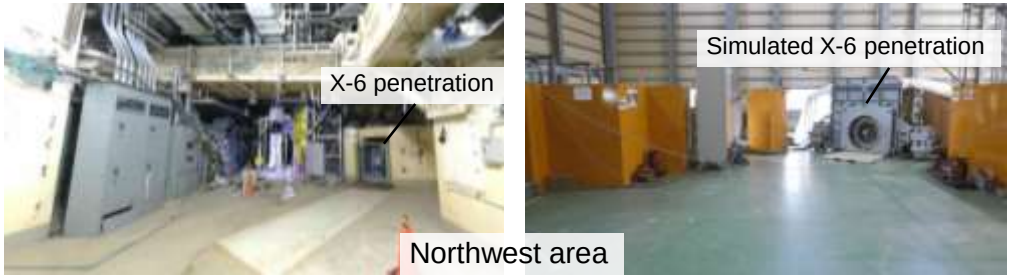
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑥ Once-through test: simulation of scope of task

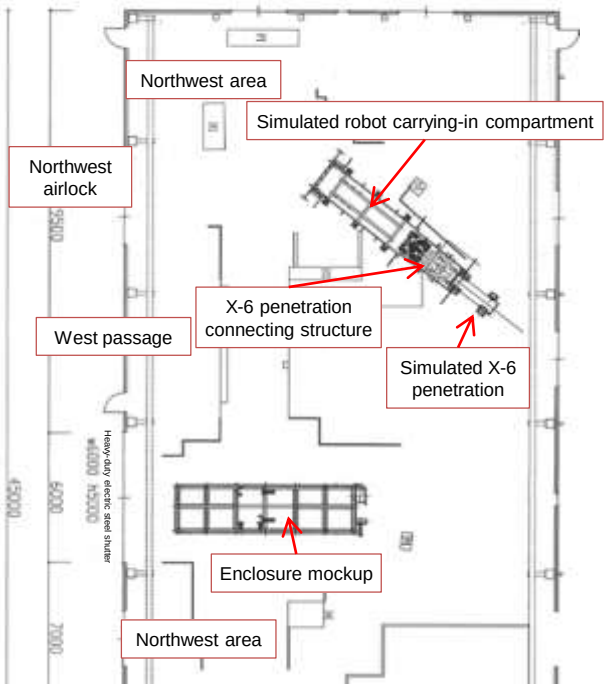
From the viewpoint of refining the plan dose, the range of R/B operation was simulated as it is conducted in an area with high radiation and where manned operation will be conducted. In addition, from the viewpoint of verifying the workability of attendant tasks such as transportation of equipment to and from the building, installation, removal, and laying of cables, necessary structures and dimensions were mimicked.

Northwest area to the west passage



Northwest area

West passage



4.1 Implementation items and results

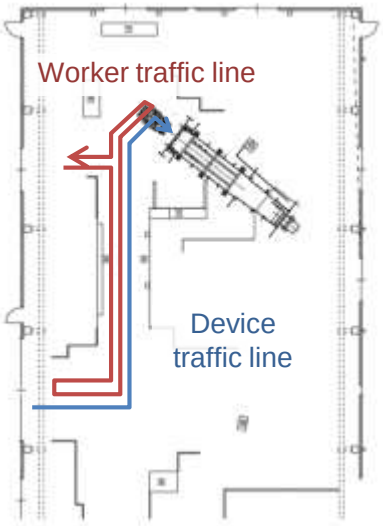
(5) Test for Establishing Access Route to PCV and Onsite Operation Training

⑥ Once-through test: results overview (X-6 penetration connecting structure)

*Measured time required for manned operation inside R/B

Install X-6 penetration connecting structure

- Carry in to northwest area
- Carry in to robot carrying-in compartment
- Lay and connect cables, etc.
- Close isolation room, replace nitrogen, open airtight door
- Self-drive, approach, and adjust axis
- Connect, grab, and confirm airtightness



Task procedure	Team composition	Duration*	Conditions for completion of task, check items, IF
Carry in to northwest area	Four people (Three for transportation, one for guidance)	① to ④: 3 min. 15 sec.	- The structure is carried to the front of the robot carrying-in compartment (rough estimate: 200 mm)

① Enter area from northwest airlock

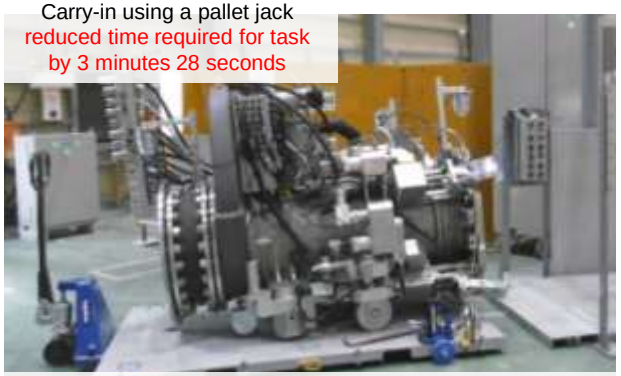
Compared to the forklift, a pallet jack requires less maneuvering at narrow spaces and can transport the structure more quickly

② Carry in attachment

Change fixed wheels to free-moving wheels to improve workability

③ Carry with a pallet jack

Carry-in using a pallet jack reduced time required for task by 3 minutes 28 seconds



④ Carry in to the front of the robot carrying-in compartment

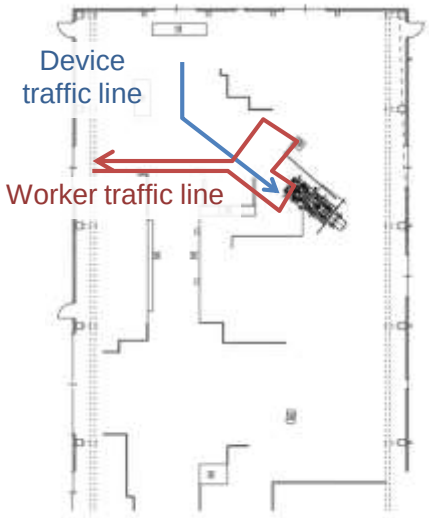
4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training

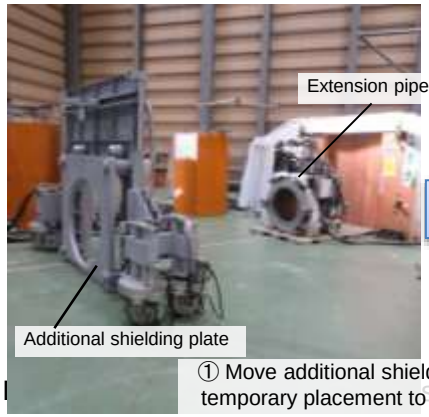
⑥ Once-through test: results overview (extension pipe)

*Measured time required for manned operation inside R/B

- Install extension pipe and additional shielding plate
  - Install green house
  - Carry in additional shielding plate
  - Carry in and set up extension pipe
  - Move additional shielding plate to initial position
  - Lay cables, etc. and check operation



Task procedure	Team composition	Duration*	Conditions for completion of task, check items, IF
Move additional shielding plate, lay cables, check operation	Four people	② to ④: 8 min. 09 sec.	- Cables are laid as planned - Images are obtained correctly and the device works normally (driving mechanism, hoisting and lowering mechanism, grabbing mechanism, opening and closing of isolation valve)



① Move additional shielding plate from position of temporary placement to initial installation position

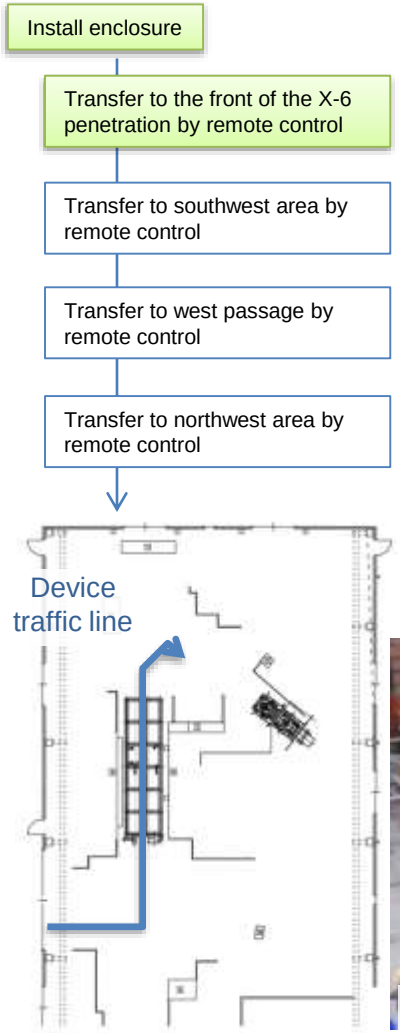
② Lay cables for extension pipe

④ Organize cables of additional shielding plate
⑤ Confirm operation of extension pipe

③ Lay cables for X-6 penetration connecting structure

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training
⑥ Once-through test: results overview (transportation of enclosure)



Task procedure	Team composition*1	Duration*2	Conditions for completion of task, check items, IF
Carry in to northwest area	Three people (remote control)	75 min.	Transfer the enclosure from the southwest area to the north west area through the west passage and to the location where the jack is set up (100 mm in front of the additional shielding plate).

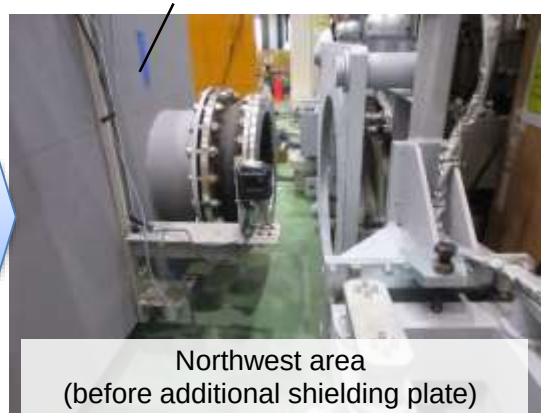

Verify visibility of monitoring camera on transportation route and determine position

*1: Verified that a three-person team at the operation headquarters (operator of controller, supervisor of monitoring camera, instructor) is optimal.

*2: time required for transportation by remote control


Transportation to southwest area


Transportation to west passage



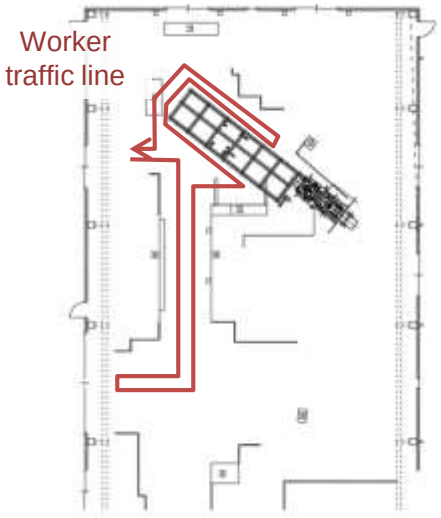
Northwest area (before additional shielding plate)

4.1 Implementation items and results

(5) Test for Establishing Access Route to PCV and Onsite Operation Training
⑥ Once-through test: results overview (installation of enclosure)

- Install enclosure
  - Installation
    - Transport transfer carriage and guide wheel
    - Set up toe jack with slide table
    - Insert square tube spacers and shim
    - Make minor adjustments using toe jack with slide table
    - Lower jack and adjust shim

Task procedure	Team composition	Duration	Conditions for completion of task, check items, IF
Install enclosure	Eight people	32 min. 30 sec.	- Make minor adjustments with a toe jack with slide table so that the surface of the enclosure touches the surface of the extension pipe flange Vertical direction, direction of axis: ±2 mm or greater (verify by camera) Direction of axis: 5 mm or less




Transfer and arrangement of toe jack with slide table in advance


Transport transfer carriage


Make minor adjustments using toe jack with slide table


Set up toe jack with slide table

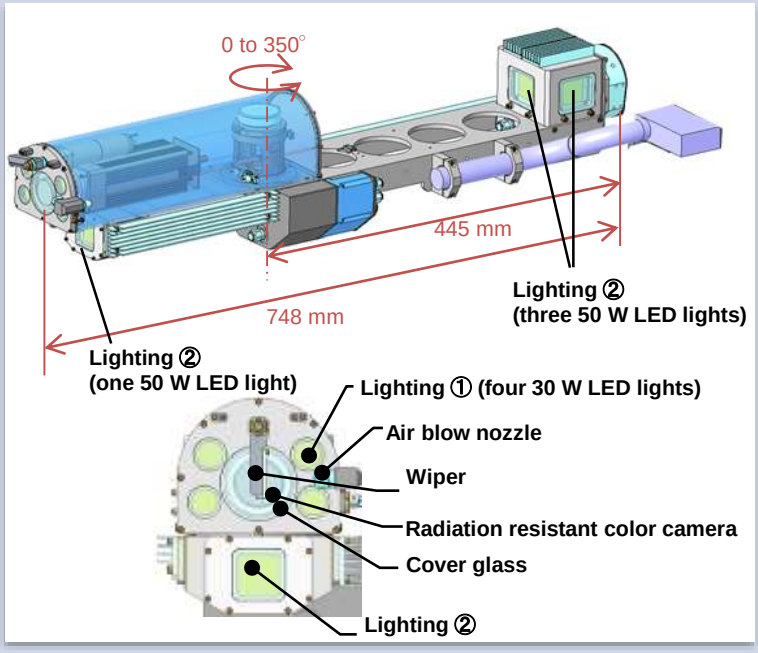
Contents

4.1 Implementation items and results

(6) On-site verification (site survey)

① Development of sensor applicable for on-site verification: (i) VT sensor (1/4)

➢ Completed the manufacturing of VT sensor (for short and medium distances)

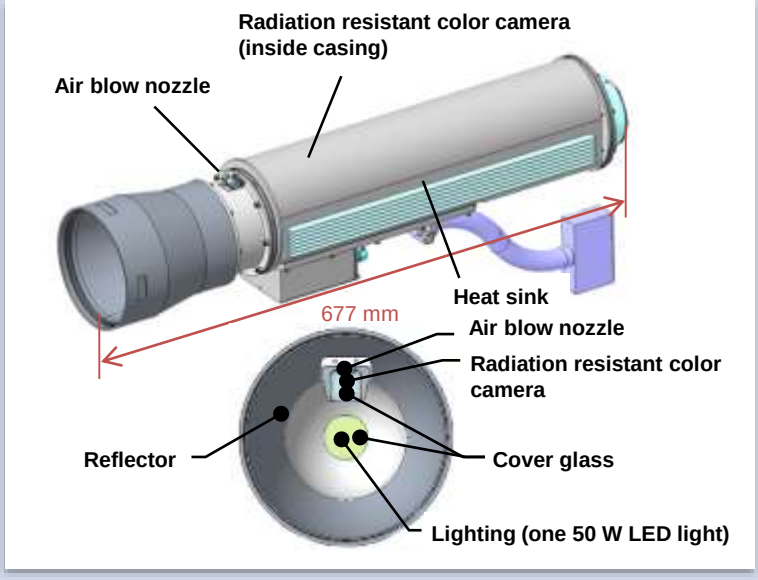
Item	Specifications		Shape and external appearance
External dimensions	φ140 × 678 mm (retracted) φ140 × 748 mm (extended)		
Weight	For short distance: 7.3 kg (excluding cables) For medium distance: 7.3 kg (excluding cables)		
Specifications of main body of camera	Radiation resistant color camera (up to 30 kGy) Number of effective pixels: 710 H × 484 V Anti-shake function: none		
Specifications of lens	<For short distance> Focus length: f = 12 mm Horizontal angle of view: approx. 57 deg. Focal distance: 1 m (fixed)	<For medium distance> Focus length: f = 25 mm Horizontal angle of view: approx. 29 deg. Focal distance: 3 m (fixed)	
Lighting	① Main lighting: four LED lights (adjustable from 0 to 30 W per light) ② Auxiliary lighting: four LED lights (adjustable from 0 to 50 W per light)		 
Waterproof, dust proof and waterfall measures	IP65 equivalent Gas blow, wiper, and water-repellent coating		

4.1 Implementation items and results

(6) On-site verification (site survey)

① Development of sensor applicable for on-site verification: (i) VT sensor (2/4)

➢ Completed the manufacturing of VT sensor (for remote control)

Item	Specifications	Shape and external appearance
External dimensions	φ140 × 677 mm	
Weight	7.0 kg (excluding cables)	
Specifications of main body of camera	Radiation resistant color camera (up to 30 kGy) Number of effective pixels: 710 H × 484 V Anti-shake function: none	
Specifications of lens	Focus length: f = 78 mm Horizontal angle of view: approx. 8 deg. Focal distance: 4 to 10 m (adjustable by remote control)	
Lighting	One LED light (adjustable from 0 to 50 W per light)	 
Waterproof, dust proof and waterfall measures	IP65 equivalent Gas blow and water-repellent coating	

4.1 Implementation items and results

(6) On-site verification (site survey)

① Development of sensor applicable for on-site verification: (i) VT sensor (3/4)

➢ In-factory test of VT sensor

Item	Test results	Details
① Visibility verification	Verified that the VT sensors focuses at the specified focal distance and sufficient visibility is ensured within the range of measurement --> focal distance: 1 m (for short distance), 4 m (for medium distance), adjustable between 4 and 10 m (for remote control)	 PC and panel for operation 
② Light-intensity verification	Verified that light intensity greater than the level necessary for visual recognition within the range of measurement (148.9 Lux) is achieved --> maximum of 1,440 Lux at 1 m (for short distance), 272 Lux at 4 m (for medium distance), and 189 Lux at 10 m (for remote control) Verified that light intensity of the lights (main lighting, auxiliary lighting) can be adjusted by remote control	 VT sensor 
③ Operation verification	Verified that camera pivot, wiper (for short and medium distances), and focus adjustment axis (for remote control) can be operated by remote control	 VT sensor (rotating) 
④ Dimension and mass verification	Verified that the external dimensions, mass, and moment satisfy the conditions for mounting on the arm-type access equipment	 Measuring of weight

4.1 Implementation items and results

(6) On-site verification (site survey)

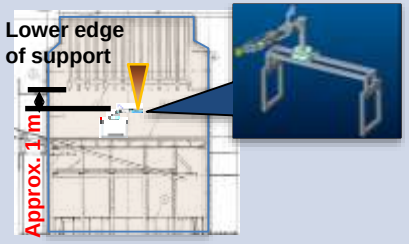
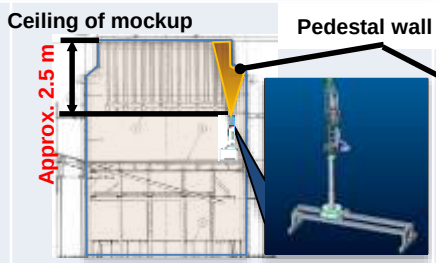
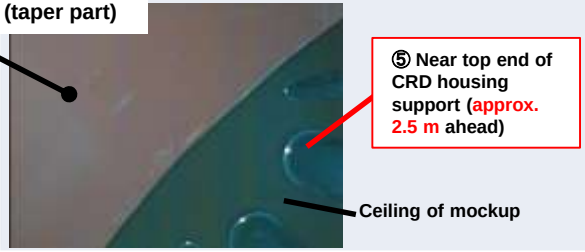
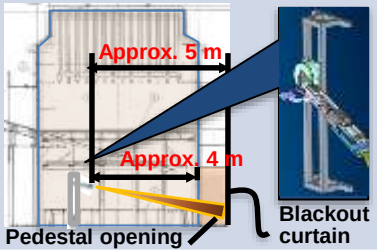
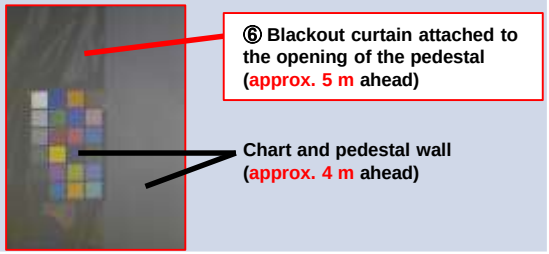
① Development of sensor applicable for on-site verification:

(i) VT sensor (4/4)

➢ Verification of sensor using the mockup facility in Japan

Mockup test facility

A blackout curtain was placed at the opening and the test was conducted in the dark.

Sensor	Verification details and evaluation criteria	Conceptual image of test	Verification results
Short-distance sensor	① Capable of checking for dropout of CRD housing or support ② Capable of recording close-up video that shows the accumulation of debris in the CRD housing ③ Capable of recording video when the arm passes through the CRD opening of the pedestal ④ Capable of collect image data of the top surface of the platform		
Medium-distance sensor	⑤ Capable of recording video of the joint between the CRD housing support and pedestal		
Sensor for remote control	⑥ Capable of recording video of the proximity of the personnel access port of the pedestal		

➢ Based on the above, it was confirmed that the sensor function (lighting, focus, etc.) satisfies the requirements.

4.1 Implementation items and results

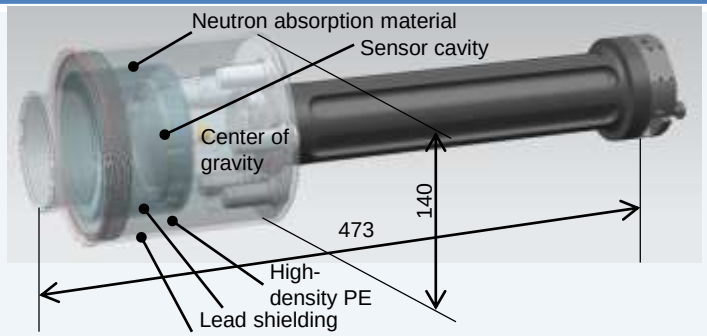
(6) On-site verification (site survey)

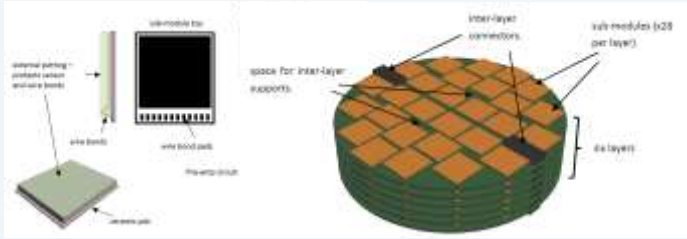
① Development of sensor applicable for on-site verification: (ii) neutron detection system (1/2)

➢ Manufacturing of neutron detection system

Item	Target specifications	Objectives achievement status
External dimensions	φ140 × 500 mm	Target achieved φ140 × 473 mm (excluding tool changer)
Weight	Less than 10 kg	Target achieved 8.33 kg (excluding tool changer)
Thermal neutron sensitivity	4.5 cps/nv	Achieved 5.7 cps/nv
γ-ray elimination rate	Level of γ-ray and neutron discrimination can be specified	Verified discrimination level can be specified
Neutron source directivity	Direction-dependent characteristic	System has direction-dependent characteristic

Shape and external appearance



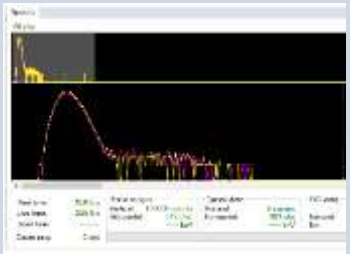
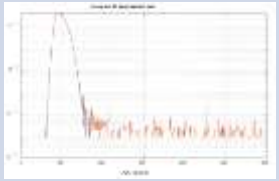


4.1 Implementation items and results

(6) On-site verification (site survey)

① Development of sensor applicable for on-site verification: (ii) neutron detection system (2/2)

➢ Neutron detector verification test

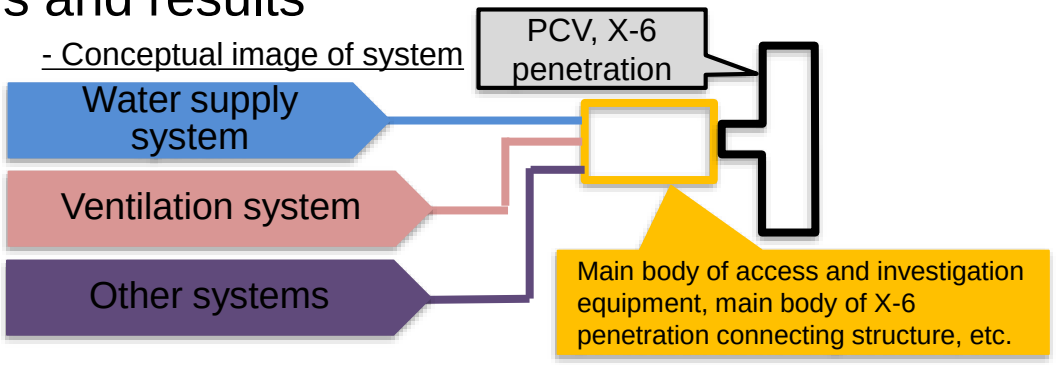
Item	Test details	Verification details and evaluation criteria	Results
Final acceptance test Full system	Confirmation of γ-ray elimination rate 	Specification of directory that can distinguish between γ-ray and neutron shall be possible	Verified that specification of directory that can distinguish between γ-ray and neutron is possible at the irradiation field which uses γ-ray source and neutron source
	Neutron sensitivity calibration test 	Target 4.5 cps/nv	Confirmed 5.7 cps/nv
	Direction-dependent characteristic verification test  	The materials and shape selected shall have a collimator function (has direction-dependent characteristic)	If the counting rate is 1 when the cylindrical center axis of the detector is at 0 degrees, the counting rate at 90 degrees is approximately 6% and is sufficiently small, therefore confirming directional dependence

➢ As shown above, a detector that mostly meets the target was manufactured.

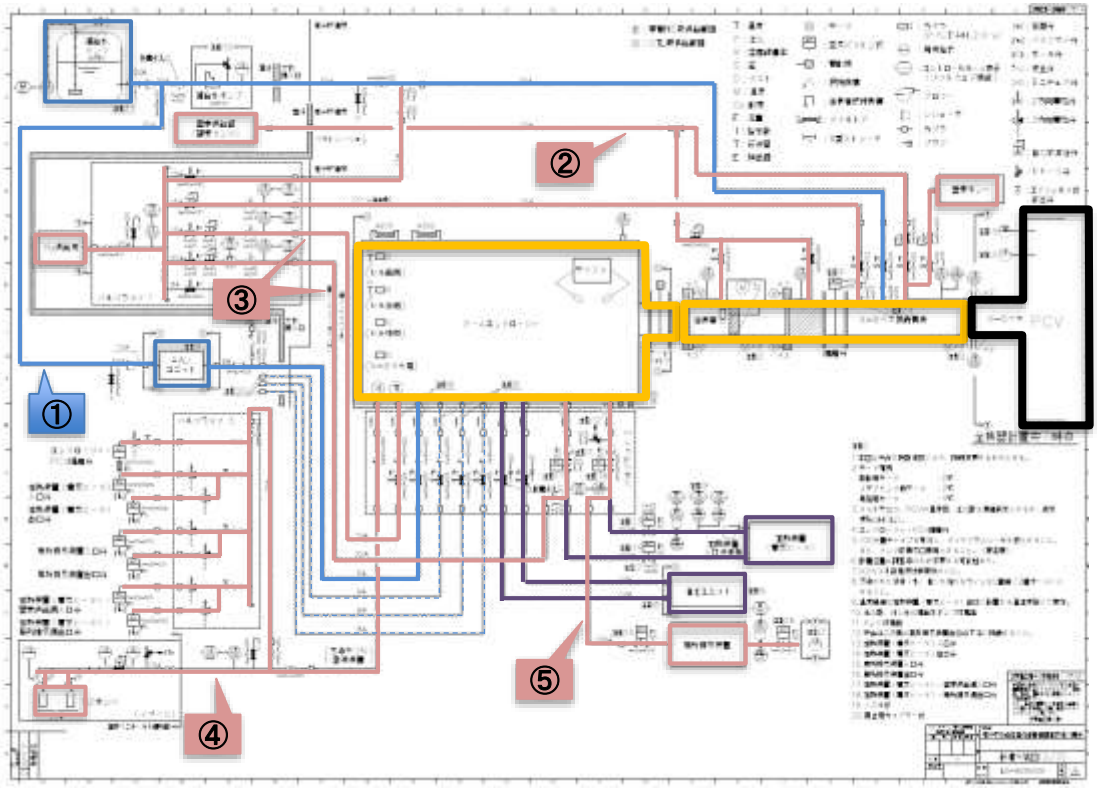
4.1 Implementation items and results

(6) On-site verification (site survey)
② On-site layout
i. System plan

- Conceptual image of system



- System plan of actual unit



[Main line]

① Water supply line for AWJ unit

② Nitrogen supply line for verifying seal of X-6 penetration connecting structure flange

③ Nitrogen purge line for Dextre inside enclosure

④ Nitrogen supply line connected to the air operated valve

⑤ Nitrogen (air) exhaust line

4.1 Implementation items and results

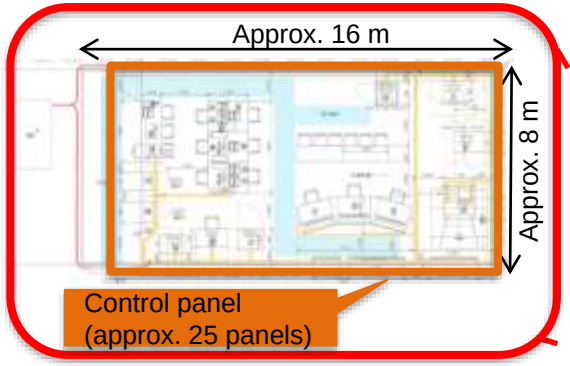
(6) On-site verification (site survey)

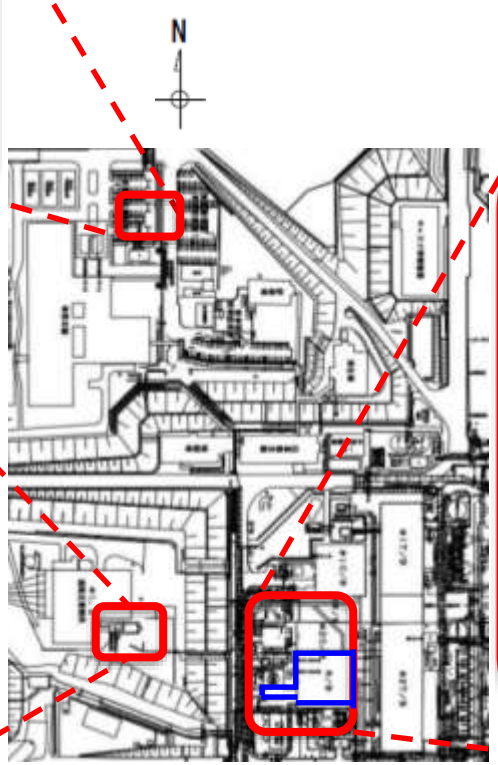
② On-site layout

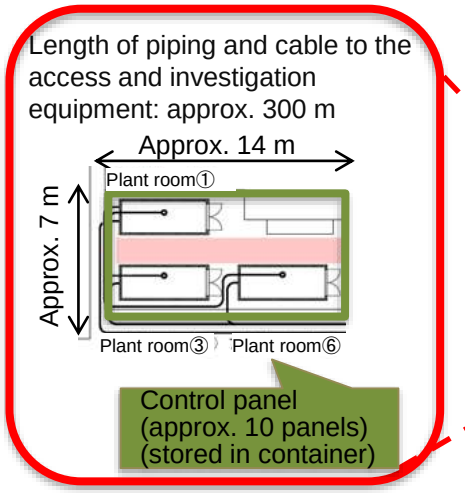
ii. Layout plan

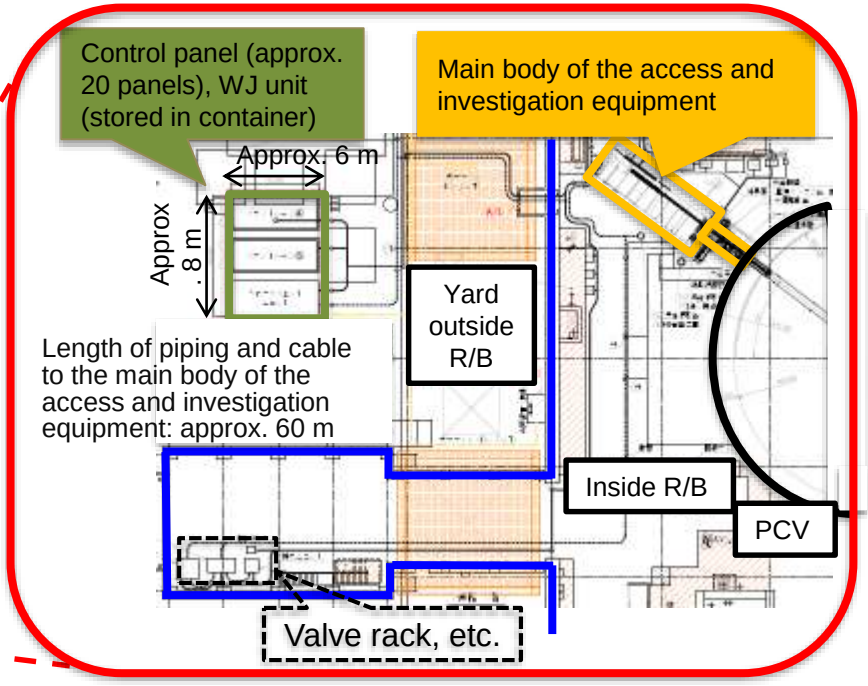
- An on-site investigation was conducted and a layout plan was devised with consideration given to the local environmental condition (dose, distance restriction*, congestion with other construction projects of TEPCO)

*There is a restriction in the distance from the main body of the access and investigation equipment to the control panel and abrasive waterjet unit from the viewpoint of voltage drop, noise, piping pressure drop, etc.









R/B: reactor building

Contents

4.1 Implementation items and results

(7) Mockup test in Japan

① Design and manufacturing of mockup facility

Design specification of mockup facility and concept of simulation

Items		Concepts of design specification and simulation
Facility configuration (scope of simulation*)	Platform for investigation equipment	Simulate the height of facility (e.g. arm-type access equipment, X-6 penetration)
	X-6 penetration, X-6 penetration connecting structure, extension pipe	Simulate internal shape and dimensions
	CRD replacement rail	Simulate shape and dimensions, taking into consideration the cutting test and assuming area around CRD replacement rail of the X-6 penetration and replacement of CRD rail hoisting jig
	Pedestal	Simulate internal shape and dimensions
	CRD	Simulate shape and dimensions
	CRD exchange equipment	Simulate shape and dimensions
	Obstacles (fallen grating, piping at inlet of pedestal)	Simulate shape and dimensions
Scale		1/1 scale
Main dimensions (overall)		Length: approx. 31,000 mm, width: approx. 8,000 mm, height: approx. 8,200 mm
Material (main component)		SS400
Location of installation		JAEA Naraha Center for Remote Control Technology Development
Ancillary equipment		Control room, various panels, abrasive waterjet unit, hydraulic unit, drain pump, drain tank, valve rack, waterjet countermeasure structure

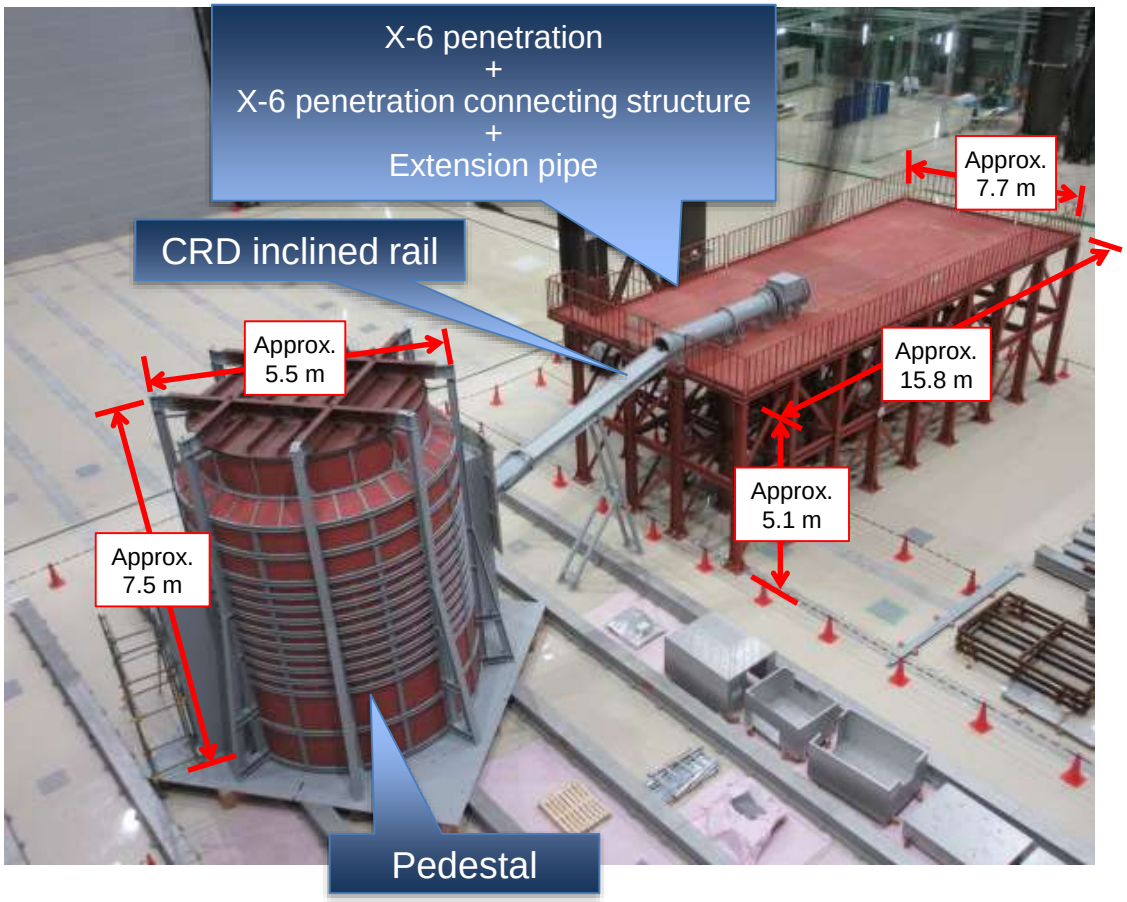
*Some of the shapes and dimensions have no information from the actual unit or are outline specifications that takes into consideration the manufacturability.

4.1 Implementation items and results

(7) Mockup test in Japan

② Installation of mockup facility

Mockup test facility was installed for the purpose of providing mastery training and conducting mockup test of access and investigation equipment at JAEA Naraha Center for Remote Control Technology Development. Installation was completed within tolerance.



Inside the pedestal

X-6 penetration (after connecting extension pipe to connecting structure)

Contents

4.2 Achievement of objectives

Implementation items		Achievement index (FY2019)	Achievement level
Investigation and Development Planning		The investigation and development plan are revised as necessary, reflecting the latest site situation and the investigation needs.	Achieved
On-site verification of access equipment and investigation technology	Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment	The in-factory verification of the physical prototype of the access and investigation equipment is complete.	Achieved
	Mockup Test Considering Site Situation	The mockup test facility is fully prepared.	Achieved
	Combination test on access and investigation equipment and research technology	Verify the applicability of the combination of the access and investigation equipment and the research technology to the site. (Target TRL upon completion: Level 4)	Achieved
	Operation training	Operation training using simulators, etc. for the purpose of familiarizing the access and investigation equipment among operators is conducted and the workers are versed in the operation of the device. (Target TRL upon completion: Level 4)	Achieved
	Test for establishing the PCV access route and onsite operation training	Tests are conducted to examine the delivery and installation suitability of the structure that is connected to the opening of the penetration to create a boundary and on-site applicability is verified. (Target TRL upon completion: Level 5)	Achieved
	On-site verification (site survey)	Plans for on-site operation and on-site investigation concerning access and investigation equipment, research technology, and structure that is connected to the penetration opening to create a boundary are formulated. (Target TRL upon completion: Level 4)	Achieved

Contents

5. Summary

(1) Investigation and development planning

- Completed study and manufacturing of short-length wand as a measure against the risk of interference based on images obtained from previous investigations and study results of detailed procedure of access and investigation equipment

(2) Partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment

- Completed partial manufacturing, overall assembly, and in-factory verification of access and investigation equipment
- Verified the prospect of accessibility through the X-6 penetration based on the arm deflection measurement results

(3) Mockup test considering the site situation

- Completed the installation of mockup test facility
- Concretized the test procedure

(4) Operation training

- Dextre: completed basic operation training using an actual equipment
- Arm for investigation: conducted operation training using simulation

(5) Test for establishing the access route to PCV and onsite operation training

① X-6 penetration connecting structure: completed device upgrade, mockup test, and combination test
② Isolation room: completed device upgrade and combination test
③ Extension pipe: completed device manufacturing and mockup test
④ Enclosure transportation device: completed mockup test
⑤ Deposit removal device: completed manufacturing and mockup test
⑥ Once-through test: completed test and verified materialization of on-site operation

(6) On-site verification (site survey)

- Devised layout with consideration given to the local environmental condition
- VT sensor: completed manufacturing and unit test; neutron detector: completed manufacturing and unit test

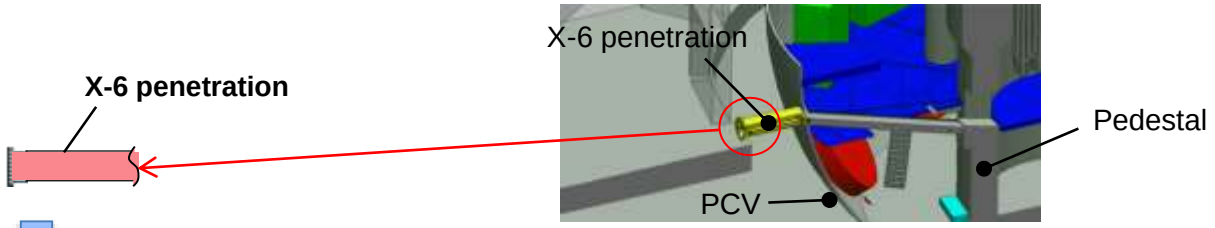
(7) Mockup test in Japan

- Completed installation of mockup test facility in Japan

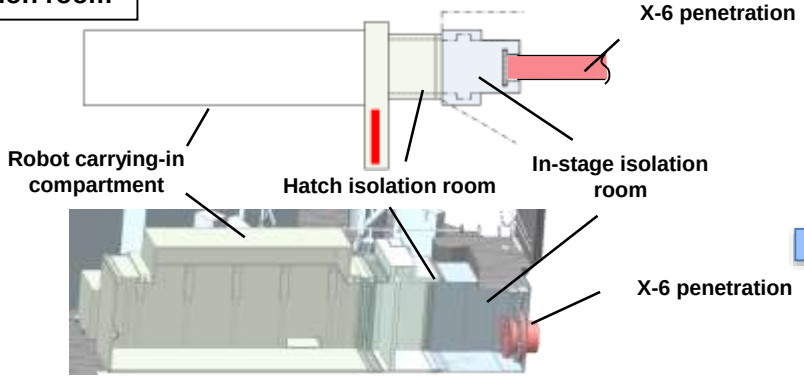
Appendix

Appendix-1: overview of the establishment of access route (1/2)

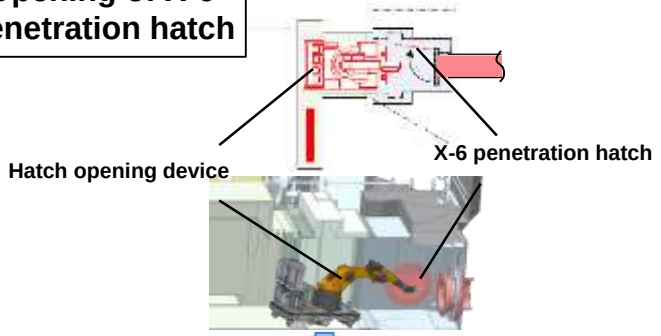
Initial condition



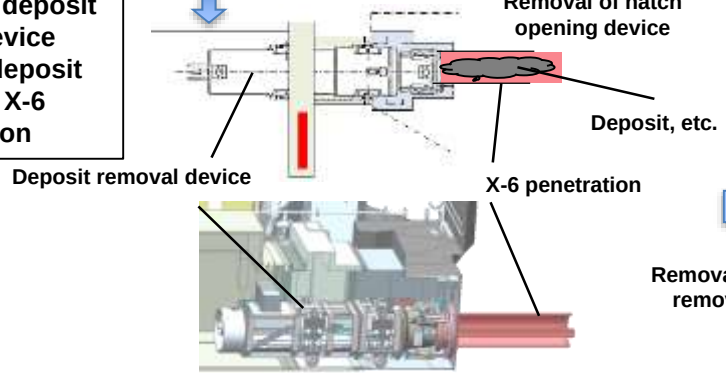
Installation of isolation room



Opening of X-6 penetration hatch

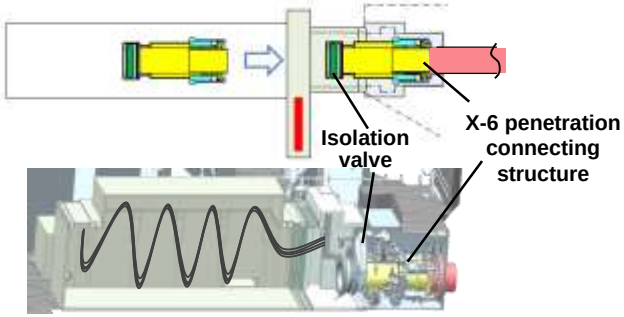


Installation of deposit removal device Removal of deposit inside the X-6 penetration



Removal of deposit removal device

Installation of X-6 penetration connecting structure



*(next page)

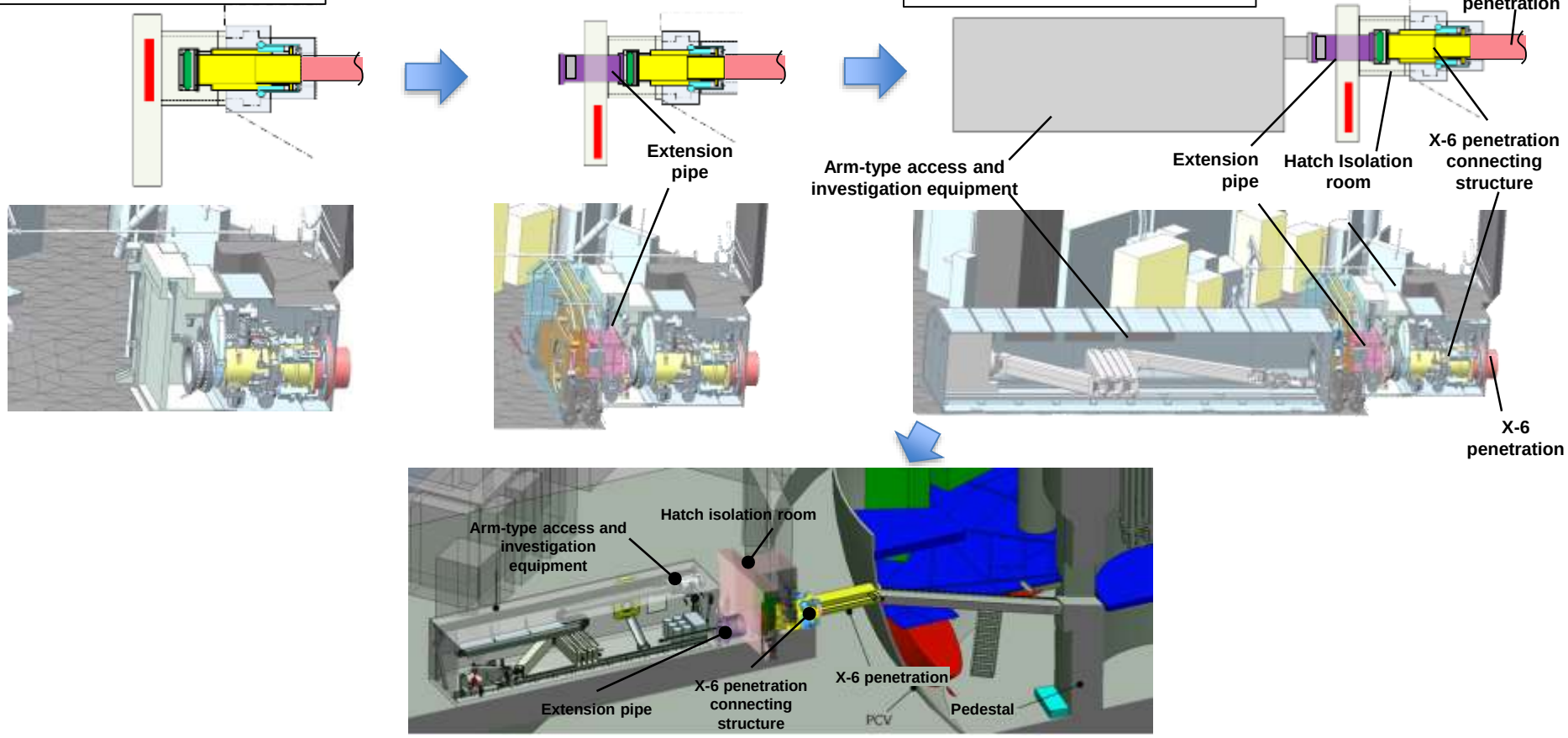
Appendix-1: overview of the establishment of access route (2/2)

*

Removal of robot carrying-in compartment

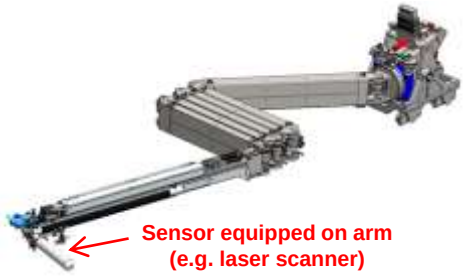
Installation of extension pipe

Installation of arm-type access and investigation equipment



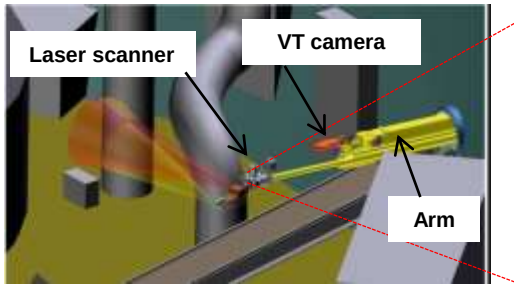
Appendix-2: arm operation policy (1/2)
[Reflect information of PCV internal in the arm operation system]

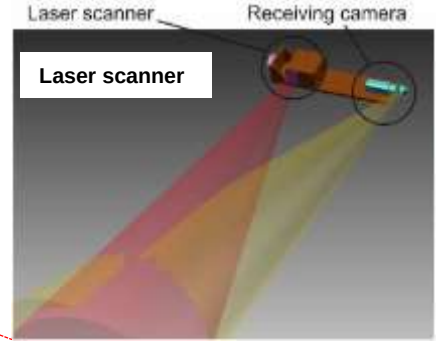
- **Obtain data on post-accident PCV internal using a laser scanner equipped on the arm tip and reflect it in the operation system (in the stage before the start of the investigation, a model of the PCV internal is made based on the pre-accident data)**
- **Simulate the arm movement using the operation system based on the PCV internal model that reflects the actual conditions (avoid interference)**



Arm for investigation

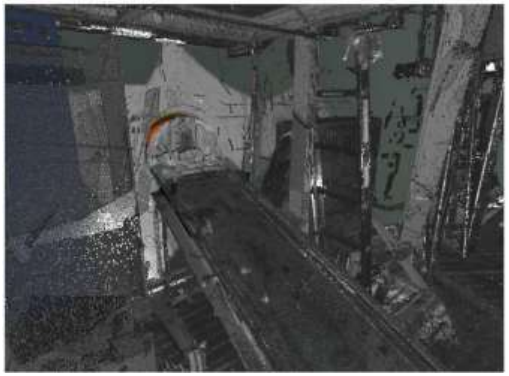
Provide information on position of laser scanner





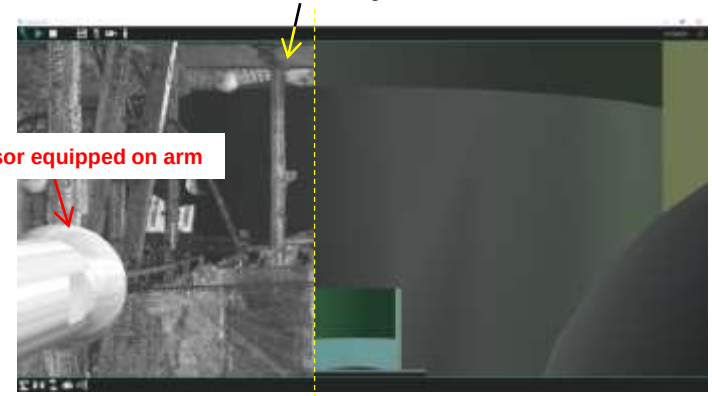
Obtain data (point cloud) on shape of PCV internal using a laser scanner

Integrate point cloud



Point cloud

Reflect point cloud to PCV shape in the operating system (update)



Conceptual image of the arm operating system screen

Appendix-2: arm operation policy (2/2)

[Operation policy]

<Basic flow>

Scan the shape of the PCV internal in the direction of travel with a laser scanner

⇩

Reflect scan data in operation system

⇩

Verify avoidance of collision between arm and obstacles by simulation

⇩

Visually verify the validity of the scan data (point cloud) by the images obtained from the arm camera*

⇩

Advance the arm

<Supplementary items>

<Area that can't be scanned by the laser scanner (inside the X-6 penetration, around the outlet of the X-6 penetration)>
Advance while observing with the camera on the arm.

<Areas with small clearance (opening of pedestal and platform)>
- Enter the area while observing with the arm camera or VT sensor.
- From the second time onward, enter the area without observation by taking the same route and making the same arm movement as the first time (reproductivity will be verified by mockup test).

<Obstacles (unavoidable)>
Cut by AWJ. Drop the cut parts to the bottom.

*Verify just in case as there is a risk of scan failures