# In-house Project
# Development of Technology for Detailed Investigation inside Primary Containment Vessel (PCV)
# (On-site Demonstration for Detailed Investigation inside PCV Through X-6 Penetration)

## Final Report for FY2023

July 2024

International Research Institute for
Nuclear Decommissioning（IRID)

無断複製･転載禁止　技術研究組合　国際廃炉研究開発機構
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# Table of Contents

1. Background and Purpose of the Project

2. Positioning of the Project

3. Project Organization and Implementation Schedule

4. Implementation Details and Results
   4.1 Access and investigation equipment
   4.2 Access route establishment related equipment
   4.3 Other ancillary system
   4.4 Fuel debris collection equipment
   4.5 On-site demonstration
   4.6 Other

5. Summary and Future Plans


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# 1. Background and Purpose of the Project



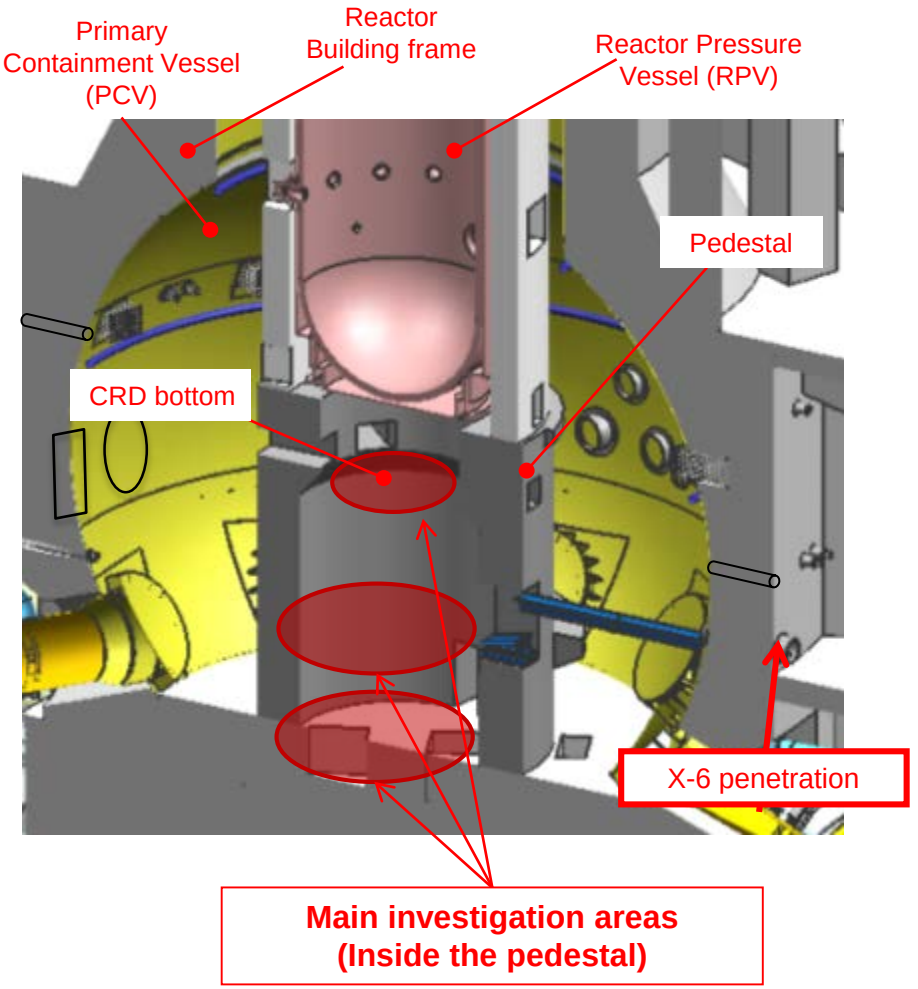
[Background]

As a result of the investigation inside Unit 2 PCV conducted in January 2018, pebble-like and clay-like deposits were found all over the bottom inside the pedestal.

Moreover, some of the fuel assemblies had fallen at the bottom, and the deposits found around them are assumed to be fuel debris.

**[Purpose]**

This project aims to confirm the validity of the developed investigation technology by enlarging the opening of the equipment insertion part of X-6 penetration used in past PCV internal investigations, and carrying out detailed investigation by inserting the access and investigation equipment and the investigation technology inside the PCV through that opening. In addition, the fuel debris collection equipment is installed to collect deposits from inside the PCV and to confirm the validity of these developed technology.




[PCV cross-section and overview of the areas to be investigated]



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# 2. Positioning of the Project

*This report is on the results of FY2023 of the colored .

FY2016-2017 Development of Technology for Investigation inside PCV

↓

FY2017-2018 Development of Technology for Detailed Investigation inside PCV

↓

FY2018-2019 Development of Technology for Detailed Investigation inside PCV
(On-site demonstration of the technology for detailed internal investigation using X-6 penetration)

Subsidized Projects

↓

FY2020-FY2024 Development of Technology for Detailed Investigation inside PCV*
(On-site demonstration of the technology for detailed internal investigation using X-6 penetration)

IRID In-house Project

↓

Development of Technology for Retrieval of Fuel Debris and Reactor Internal Structures

Development of Technology for Gradually Increasing the Scale of Fuel Debris Retrieval


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# 3. Project Organization and Implementation Schedule: Project Organization



**International Research Institute for Nuclear Decommissioning(IRID) (Headquarters)**

- ○ Development planning and technological management
- ○ Technological process control: Progress of technology and equipment development
- ○ Technology management for development phase

**Tokyo Electric Power Company (TEPCO) Holdings, Inc.**

- ○ Schedule management for on-site demonstration
- ○ Management of on-site demonstration phase
- ○ Administration work including communication with government

**Mitsubishi Heavy Industries, Ltd.**

→ Access and investigation equipment and other work training
→ On-site demonstration (detailed investigation inside PCV)

- ○ Access and investigation equipment
  - ① Mock-up tests considering site conditions
  - ② Work training
- ○ Access route establishment related equipment
  - ① Work training
- ○ Other ancillary system
  - ① Design and manufacturing
- ○ Small amount fuel debris collection equipment
  - ① Work training
- ○ On-site demonstration

**Toshiba Energy Systems & Solutions Corporation**

→ Work training for X-6 penetration hatch opening equipment
→ On-site demonstration (X-6 penetration hatch opening)

- ○ Overall planning of X-6 penetration hatch opening
- ○ Preparation for X-6 penetration hatch opening
- ○ On-site demonstration

**Tokyo Electric Power Company (TEPCO) Holdings, Inc.**

→ Work training for access and investigation equipment
→ On-site demonstration (access and investigation equipment operation)

- ○ Access and investigation equipment
  - ① Mock-up tests considering site conditions
  - ② Work training
- ○ Fuel debris collection equipment
  - ① Work training
- ○ On-site demonstration



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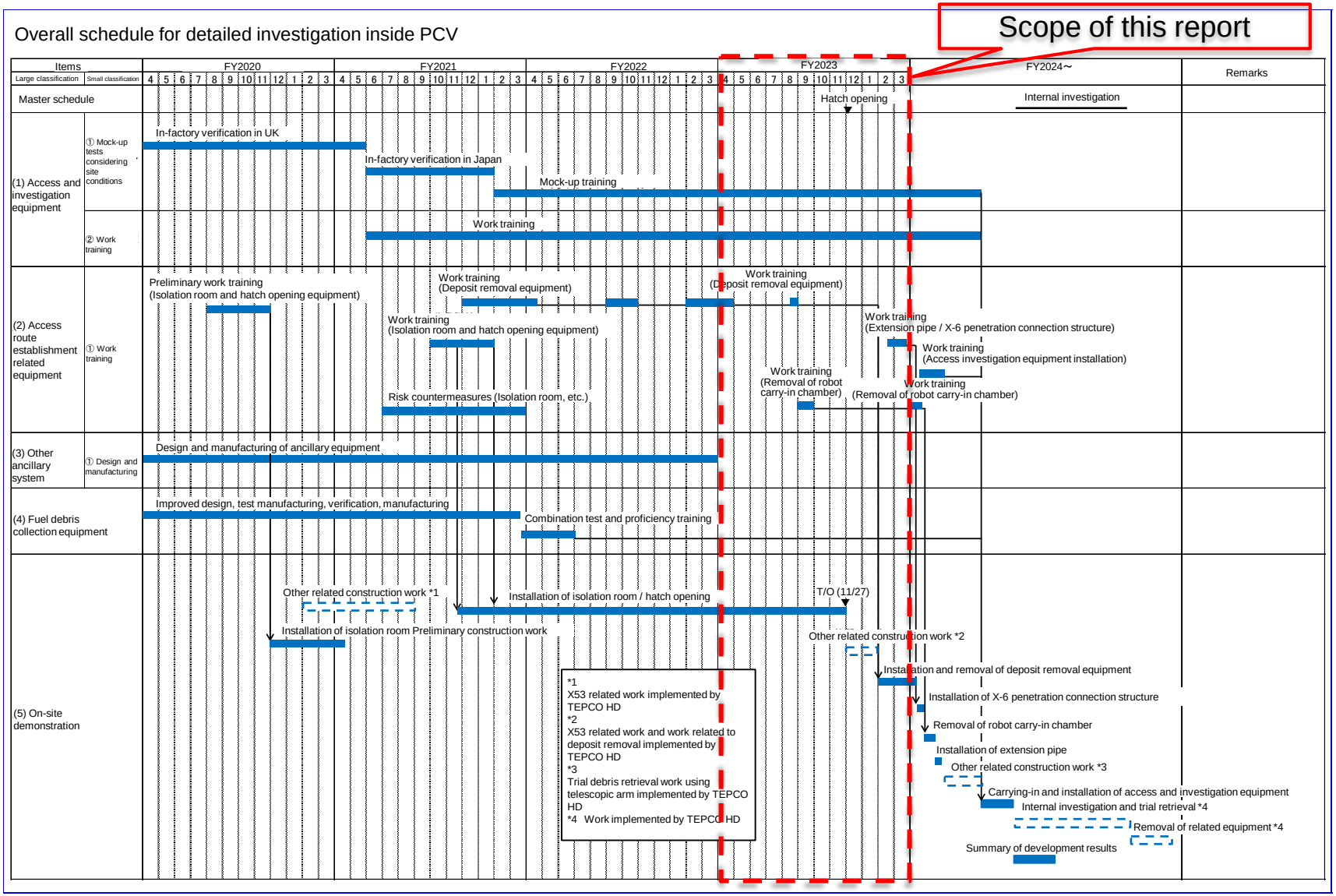
# 3. Project Organization and Implementation Schedule: Implementation Schedule



Overall schedule for detailed investigation inside PCV

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# 4. Implementation Details and Results

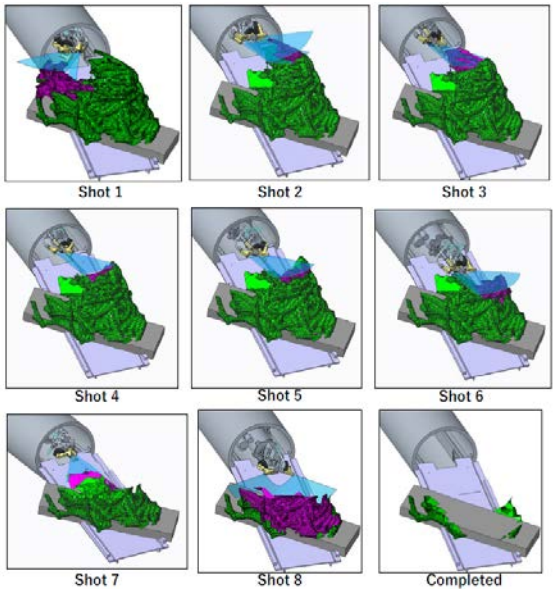
## 4.1 Access and investigation equipment

### (1) Mock-up tests considering site conditions (i) Arm verification test

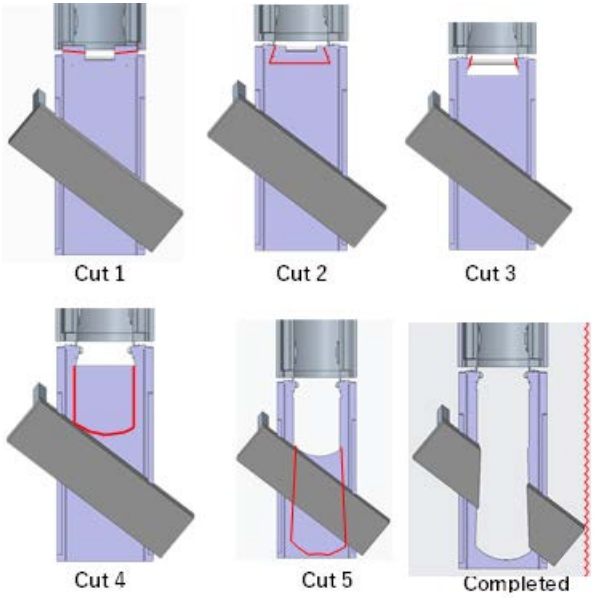
#### (a) AWJ cutting test

**Purpose**

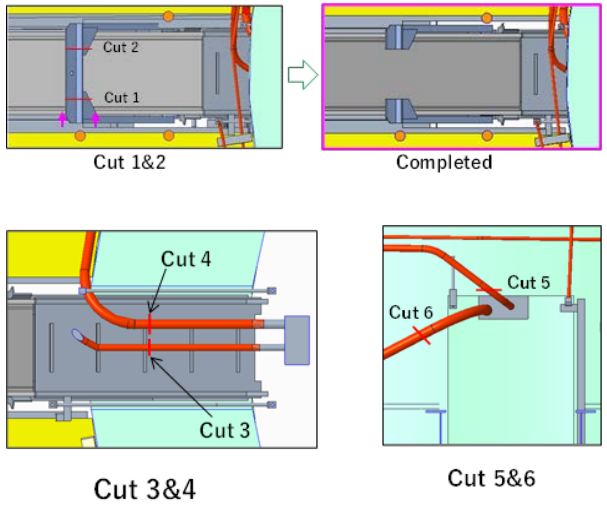
- This project plans to establish a route for the arm to access inside PCV (access route) by using AWJ (Abrasive Water Jet) to cut and remove remaining cables, CRD rail, hoisting attachment and conduits (obstacles).
- In order to establish the access route on-site, it is necessary to check whether obstacles can be cut and removed with AWJ and confirm and optimize cutting procedures before performing on-site work.
- AWJ cutting test was conducted at the Naraha Center for Remote Control Technology Development before the on-site work in order to establish an access route assuming the site.




**Remaining cable removal procedures**




**CRD rail cutting procedures**




**Hoisting attachment cutting procedures**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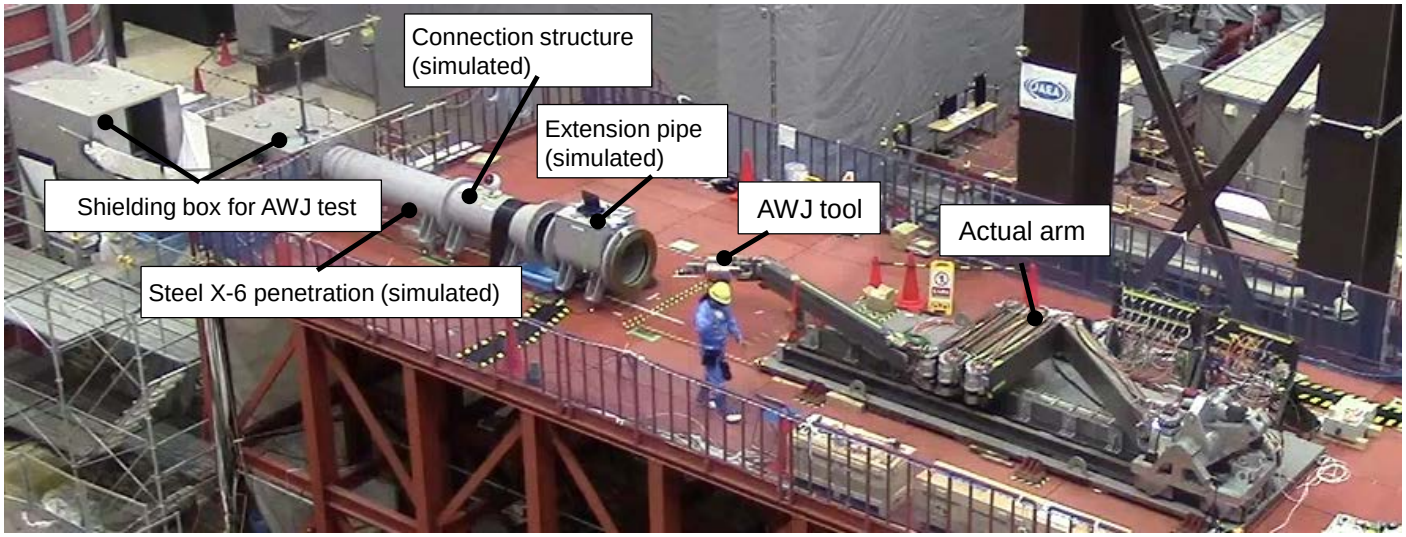
# 4.1 Access and investigation equipment

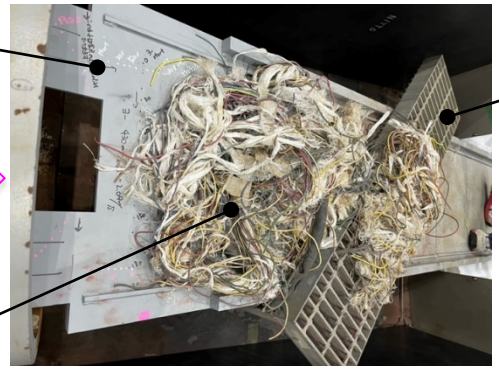
## (1) Mock-up tests considering site conditions (i) Arm verification test

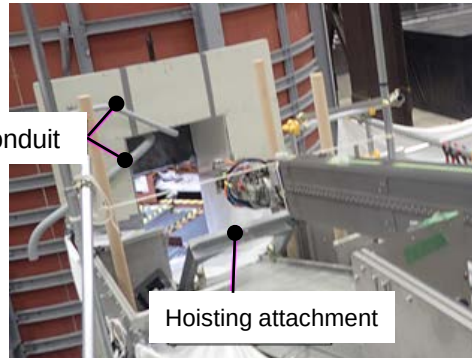
### (a) AWJ cutting test

Overview of test equipment and test pieces

- Simulated extension pipe, connection structure and X-6 penetration were used. The test was conducted with an actual AWJ tool mounted to an actual arm (below figure).
- CRD rail, remaining cables and hoisting attachment were installed in the shielding box for AWJ test in order to prevent abrasive grain from scattering (see below figure).





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# 4.1 Access and investigation equipment

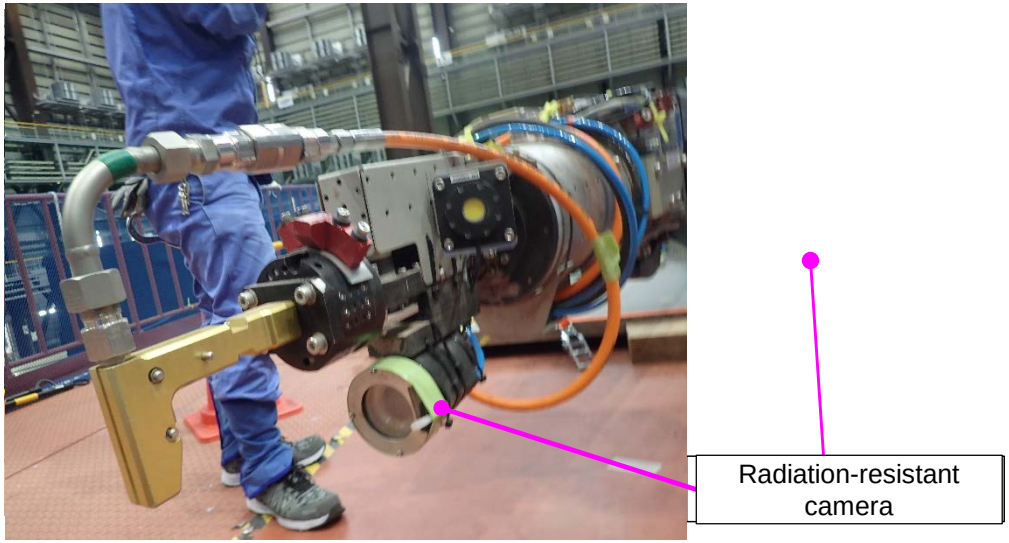
## (1) Mock-up tests considering site conditions (i) Arm verification test

### (a) AWJ cutting test

**Test conditions**

- Operating conditions of the AWJ unit are as shown in the below table.
- Assuming establishing the access route on-site, the AWJ unit is remotely operated from the control room, and the starting position for cutting with AWJ is set (positioned) by using the radiation-resistant camera of the arm tip and nozzle tip (no checks by workers near the arm).
- Cutting is not performed in the range where the camera field of view is not available. The tool axis is moved so that the camera field of view is available.
- Extension pipe camera is used to check the interference between the arm and X-6 penetration or remaining cables.
- Confirming cutting of CRD rail, hoisting attachment and conduits is also remotely checked using the above camera.

| Items | Conditions |
|---|---|
| Hydraulic pressure | 650 [bar] |
| Abrasive grain | GMA garnet #120 Classic Cut |
| Abrasive grain mixing rate | 13 [%] |
| Flow rate | 4 [L/min] |
| Water | Use industrial water |





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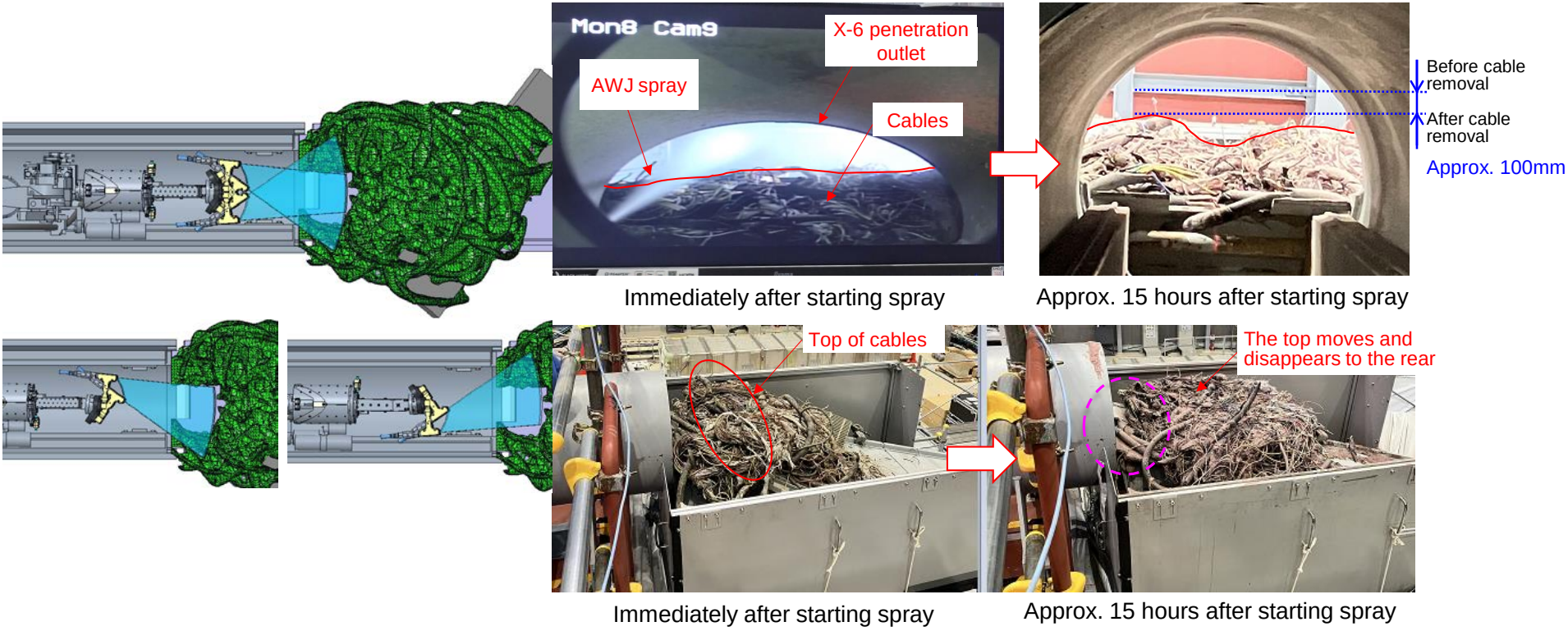
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test

### (a) AWJ cutting test

Summary of test results

- The test result of removal of remaining cables is as shown in the below figure. Spraying the AWJ for 15 hours exposed the CRD rail hidden beneath the remaining cables at the X-6 penetration outlet, and it was confirmed that the nozzle of the tool can be inserted. The deposited amount of remaining cables was conservatively estimated for this test.





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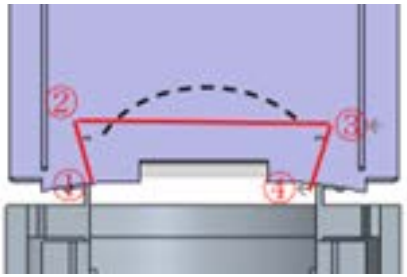
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test

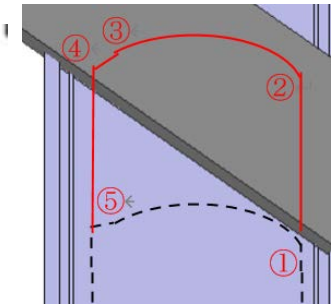
### (a) AWJ cutting test

Summary of test results

- The test result of cutting of the CRD rail is as shown in the below figure. As the figure shows, the CRD rail could be cut almost exactly as planned. However, Cut4 and Cut5 had to be cut in half due to securing the camera field of view and interference between the camera and the cutting targets. Additionally, it took around 35 hours for AWJ spray for grating cutting (Cut5).

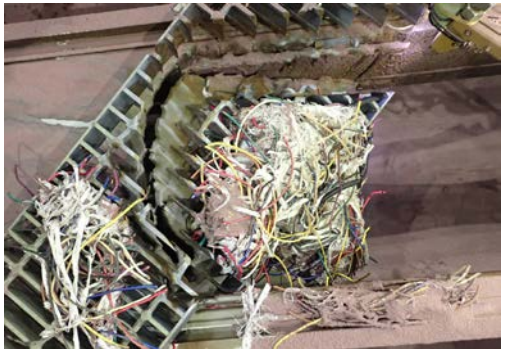



Cut2 cutting (plan)

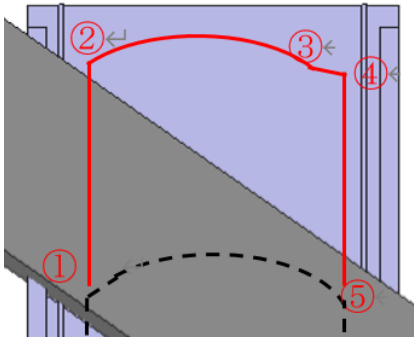



Cut5-1 cutting (plan)

Cut2 completed



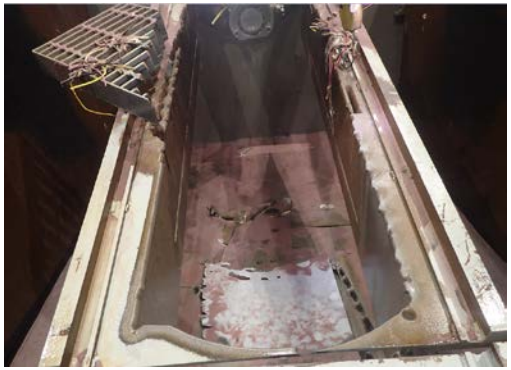
Cut5-1 completed




Cut4-2 cutting (plan)

Cut5-2 cutting (plan)

Cut4-2 completed



Cut5-2 completed



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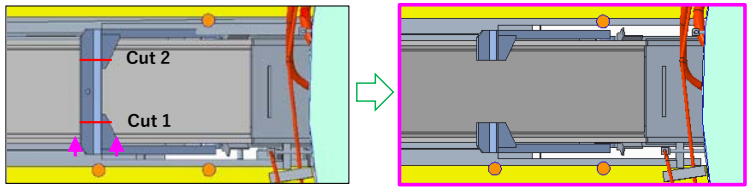
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test
### (a) AWJ cutting test

Summary of test results

- The test result of cutting of the hoisting attachment and conduits is as shown in the below figure. As the figure shows, they could be cut as planned. Additionally, it was confirmed that the camera field of view does not show any problem during cutting and when confirming cutting.
- However, the impact of the current conduit cutting method needs to be grasped since AWJ spray of the method damages the pedestal opening (see next section (b)).

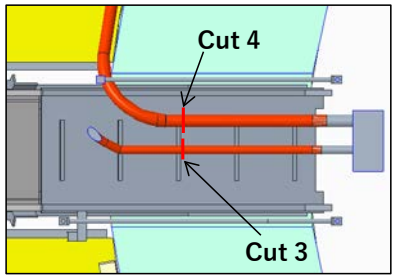



Cut 1&2

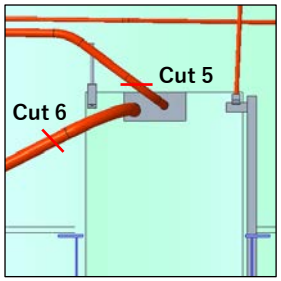


Completed

**Cut1 cutting (camera field of view)**




**Cut 3&4**




**Cut 5&6**

**Cut2 completed**

**Cut6 cutting (camera field of view)**

**Cut6 completed**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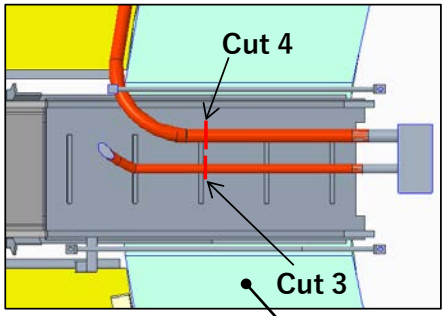
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test
## (b) Impact evaluation of pedestal damage

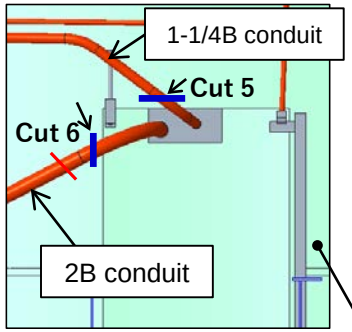
**Purpose**

- The plan is to cut obstacles using the AWJ (abrasive water jet) to secure the arm access route
- Conduits near the pedestal wall are also subject to cutting (Cut3-6 in below figure)
- Some AWJ is sprayed to the pedestal wall behind the conduits due to cutting the conduits
- Damage data is obtained by conducting the AWJ test for integrity evaluation (separately conducted) of the pedestal wall



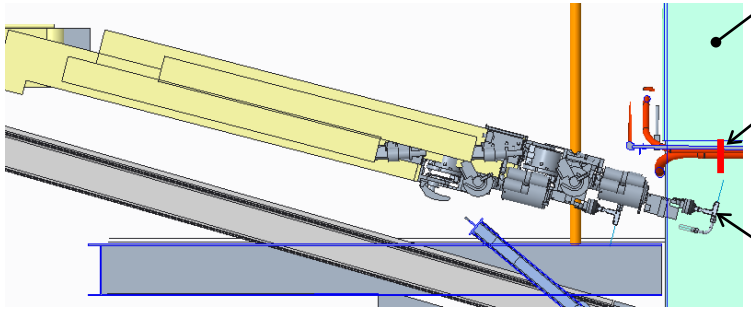

**Cut 3&4**

Pedestal




**Cut 5&6**

Pedestal




Arm posture when cutting Cut 3&4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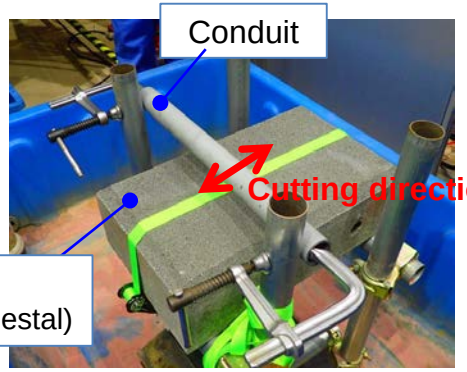
# 4.1 Access and investigation equipment

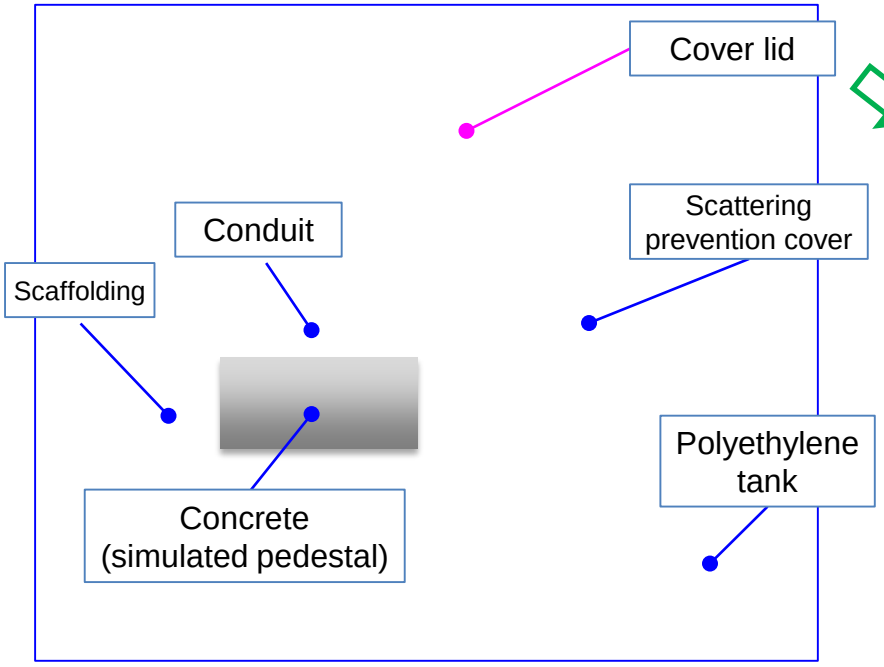
## (1) Mock-up tests considering site conditions (i) Arm verification test (b) Impact evaluation of pedestal damage

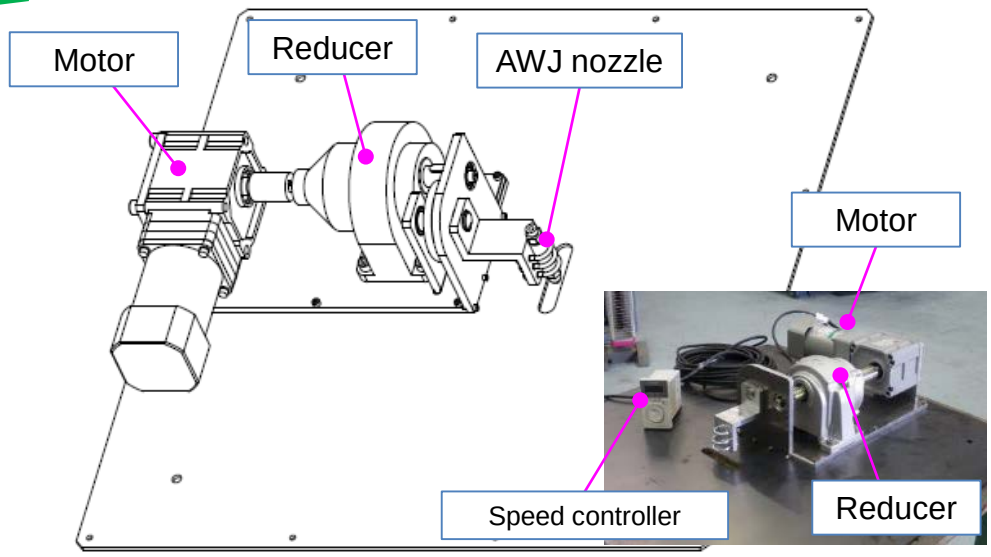
**Overview of test equipment**

- Conduits and concrete (simulated pedestal) are used
- AWJ is sprayed from the nozzle to cut the conduits, and range of concrete damage is checked after cutting




Installation status of concrete and conduits




Nozzle rotating equipment is installed to the cover lid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# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test (b) Impact evaluation of pedestal damage

Test conditions, parameters

- AWJ spray condition : Hydraulic pressure is 650[bar], same as the condition of actual equipment (flow rate is 4[l/min] and abrasive grain (garnet) content is 13%wt)
- Conduit size : 1-1/4B (outer diameter 43.5mm) or 2B (outer diameter 63.5mm)
- Concrete strength : Block (500x300xH150) with design basis strength (Fc) of 18N/mm$^2$ was used based on the strength assumed at Unit 2 after the accident. Block (180/205xH250xL600) of Fc=24N/mm$^2$ was also used for comparative evaluation. Additionally, the test was also conducted for rebars (test condition without installation of concrete blocks (conservative condition for rebar damage evaluation))
- Cutting speed : 0.02(1.1deg/min) or 0.05(2.75deg/min)

| Test case name | Conduit size | Concrete | Cutting speed | Remarks |
|---|---|---|---|---|
| Case 1 | 1-1/4B | Plain concrete (Fc=18) | 0.02 | Basic case of concrete strength |
| Case 2 | 2B | Plain concrete (Fc=18) | 0.02 | |
| Case 3 | 2B | Plain concrete (Fc=18) | 0.02 | Starting point of AWJ spray is changed from the edge to the center (reference case) |
| Case 4 | 2B | Plain concrete (Fc=18) | 0.05 | Impact evaluation of cutting speed |
| Case 5 | 2B | Plain concrete (Fc=24) | 0.02 | Impact evaluation of concrete strength |
| Case 6 | 2B | Rebar (D38) | 0.02 | Basic case of rebar case |
| Case 7 | 2B | Rebar (D38) | 0.05 | Impact evaluation of cutting speed |


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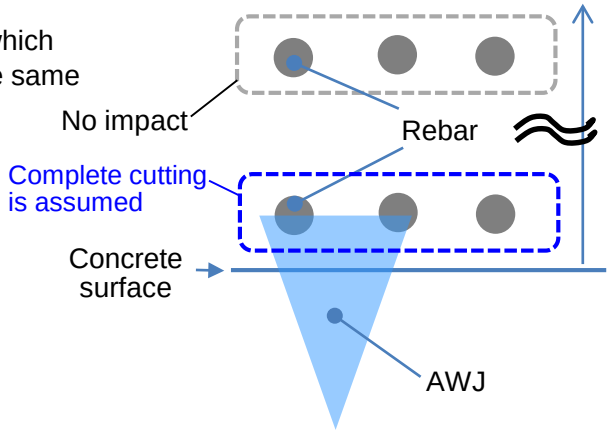
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test
## (b) Impact evaluation of pedestal damage

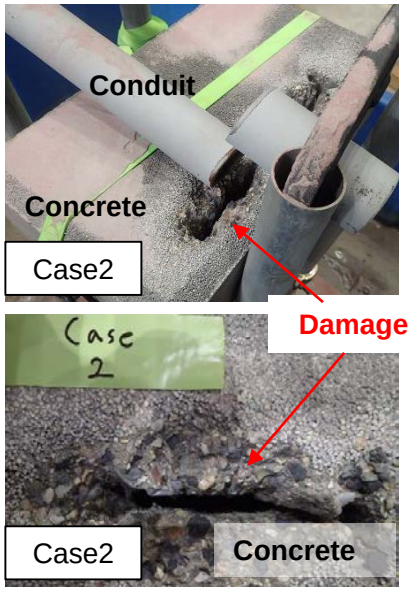
### Summary of test results

- In Case3, the starting point of AWJ spray was changed from the conduit edge to the center, which increased the damage. Therefore, actual cutting shall be performed from the conduit edge the same as before.
- When the cutting speed is increased from 0.02 to 0.05, damage depth of concrete and rebar becomes shallow.
- Although the rebar was damaged, it was not completely cut.
- Based on the above result, the following is proposed as the conditions of pedestal integrity evaluation.
  - Concrete damage depth : 140mm (result of Case2)
  - Rebar damage depth : 1 row is completely cut in the depth direction (assuming conservative side: see right figure)




Additional tests of cutting speed shall continue to minimize the range of pedestal damage.

| Test case name | Conduit size | Concrete | Cutting speed | Damage depth |
|---|---|---|---|---|
| Case 1 | 1-1/4B | Plain concrete (Fc=18) | 0.02 | 125mm |
| Case 2 | 2B | Plain concrete (Fc=18) | 0.02 | 140mm |
| Case 3 | 2B | Plain concrete (Fc=18) | 0.02 (starting point of AWJ spray is changed to the center) | More than 150mm (reference case) |
| Case 4 | 2B | Plain concrete (Fc=18) | 0.05 | 60mm |
| Case 5 | 2B | Plain concrete (Fc=24) | 0.02 | 65mm |
| Case 6 | 2B | Rebar (D38) | 0.02 | 20mm (rebar) |
| Case 7 | 2B | Rebar (D38) | 0.05 | 5mm (rebar) |





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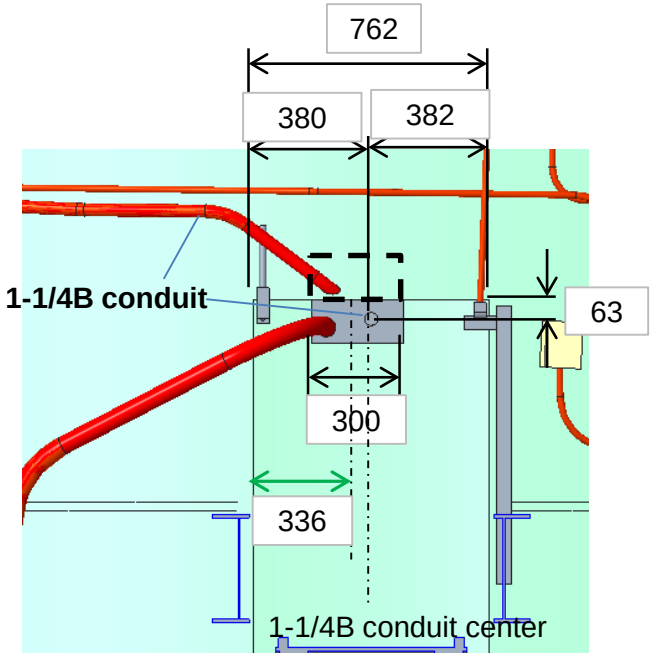
# 4.1 Access and investigation equipment

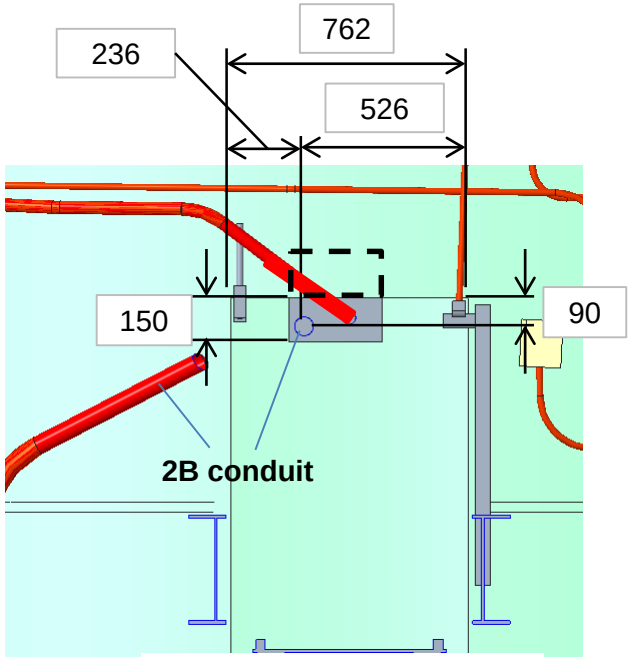
## (1) Mock-up tests considering site conditions (i) Arm verification test
## (b) Impact evaluation of pedestal damage

Condition of range of AWJ damage for pedestal integrity evaluation (draft)

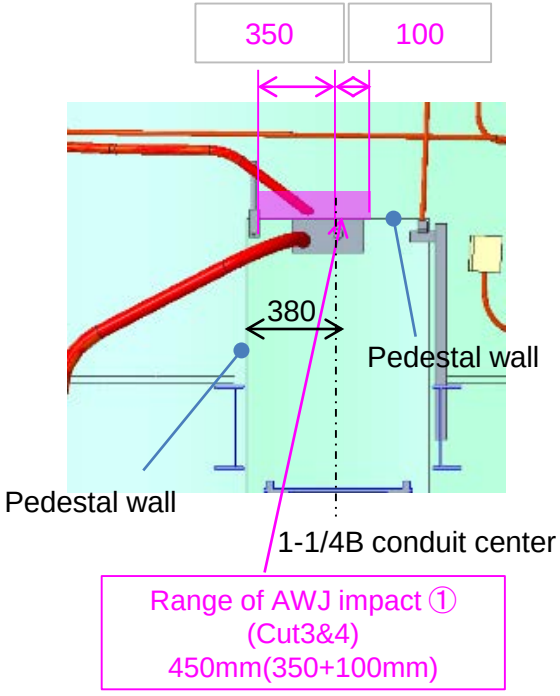
The condition of range of AWJ damage for pedestal integrity evaluation is as follows based on the AWJ test result.




**1-1/4B conduit position**




**2B conduit position**





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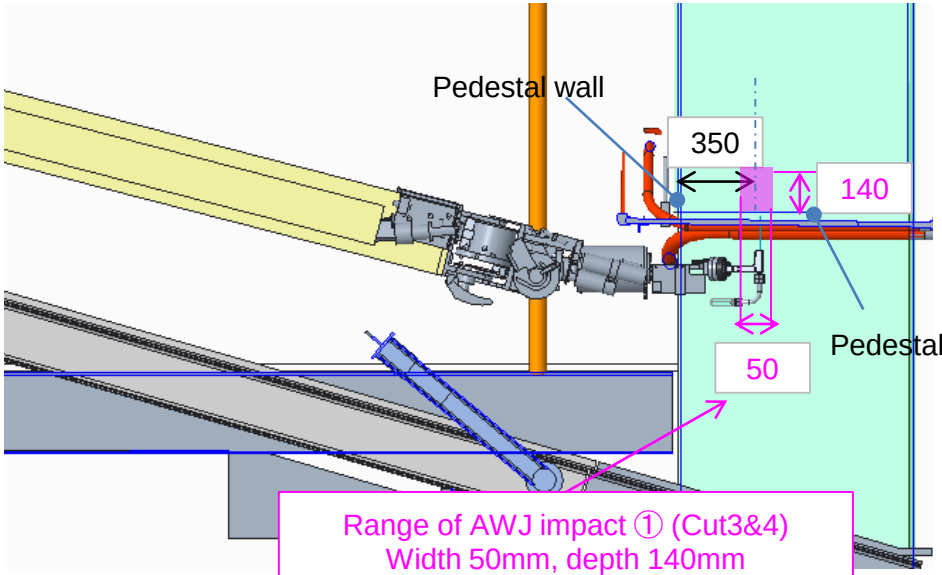
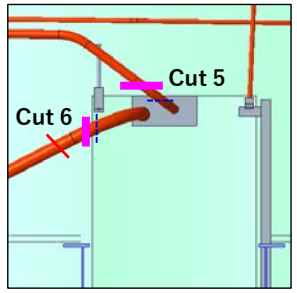
# 4.1 Access and investigation equipment

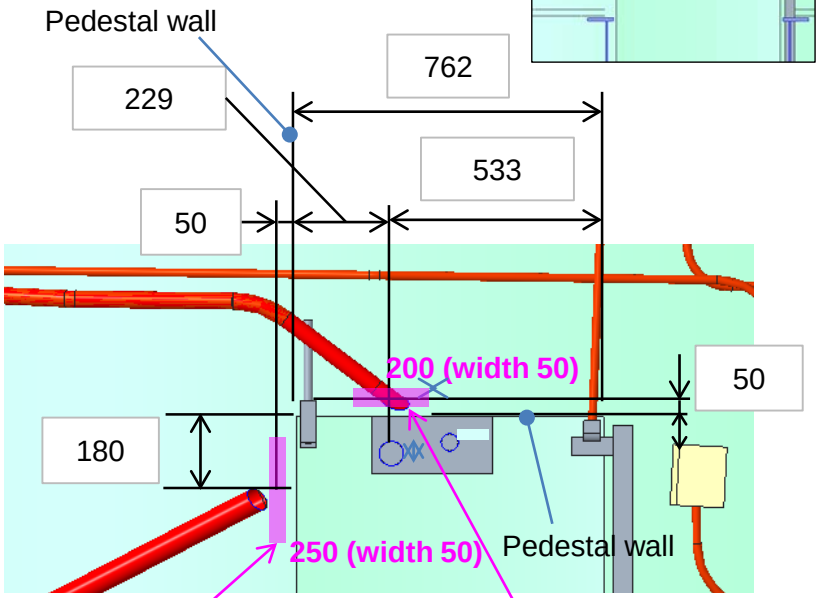
## (1) Mock-up tests considering site conditions (i) Arm verification test
## (b) Impact evaluation of pedestal damage

Condition of range of AWJ damage for pedestal integrity evaluation (draft)




Range of AWJ impact ① (Cut3&4)
Width 50mm, depth 140mm
(length 450mm: see previous page)




Range of AWJ impact ③ (Cut6)
Width 50mm, height 250mm, depth 140mm

Range of AWJ impact ② (Cut5)
Length 50mm, width 200mm, depth 140mm

- Concrete damage depth : 140mm
- Range of rebar damage : Rebar at 140mm depth is ruptured (loss of function)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# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test

### (c) Pedestal access test 1) VR accuracy confirmation test

[Test conditions]

A test was conducted focusing on “access of the arm to pedestal bottom through the platform opening (confined space)”, which is important and technically challenging, to determine arm function and applicability.

[Result overview]

Steps ①-④ below were conducted. It was confirmed that it can be determined with VR if there is arm interference when passing the platform which is confined space (see next page). This confirmed that the arm can access the pedestal bottom using VR.

<Test outline flow>

Step ①

・Arm access to pedestal bottom
・Create T&RF*

Step ②

Mount the laser scanner to the arm to collect data on the position and form of obstacles around the arm (point cloud data)

Step ③

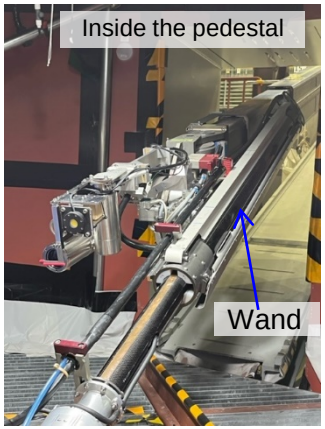
Incorporation of point cloud data to the VR system* of the arm

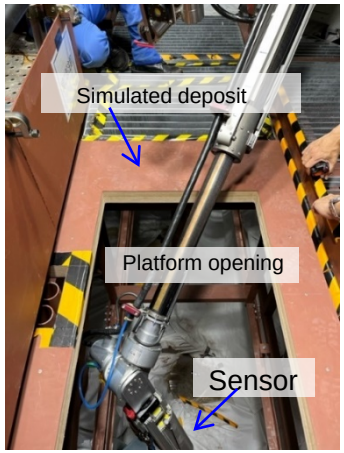
Step ④

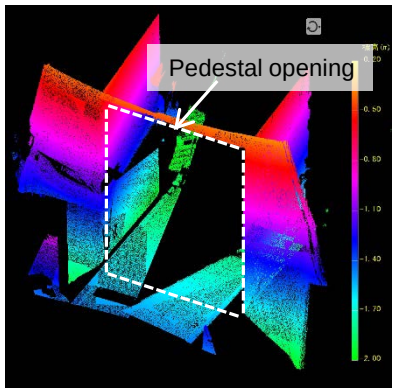
Access to pedestal bottom using T&RF, VR and camera

・Grasp VR accuracy
・Confirm camera visibility

*Teach and Repeat File: File setting the movement of each arm axis.
*VR system: Virtual Reality System. Allows checking for avoidance of arm interference by incorporating point cloud data of structures around the arm.



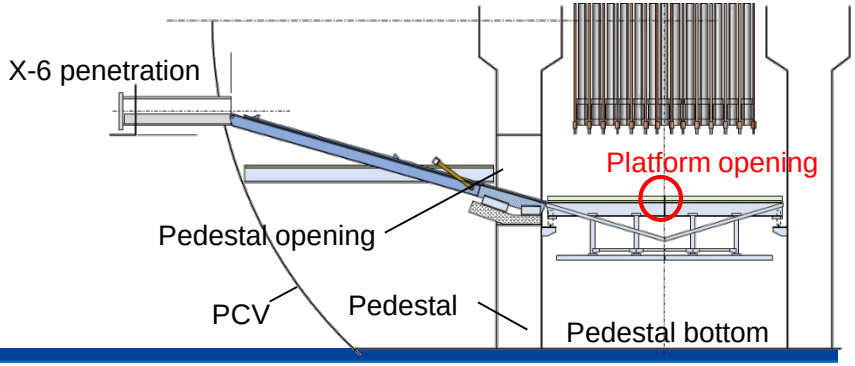




Laser scan data

Step ① Arm access to pedestal bottom

Step ② Collection of point cloud data

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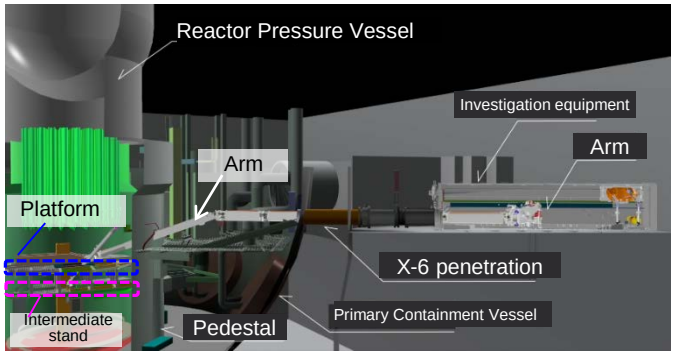
# 4.1 Access and investigation equipment

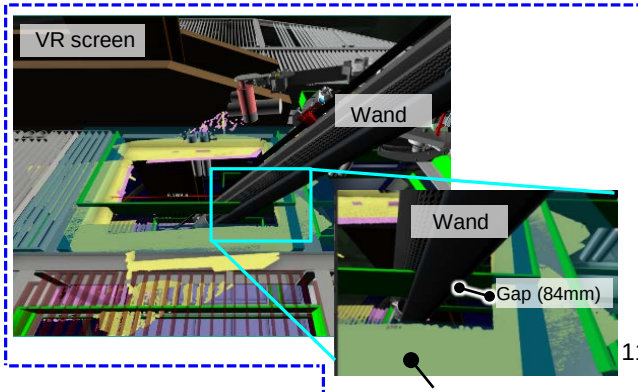
## (1) Mock-up tests considering site conditions (i) Arm verification test

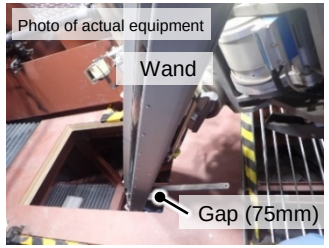
### (c) Pedestal access test 1) VR accuracy confirmation test

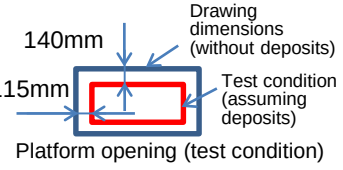
[Test result] There is VR accuracy capable of determining if there is any arm interference when passing the platform or intermediate stand which are confined spaces. It was confirmed that the arm can access the pedestal bottom using VR.

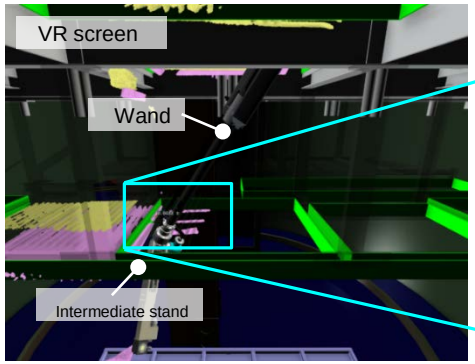
| Area (confined space) | Gap in VR | Actual measured gap | Error of measurement | Evaluation |
|---|---|---|---|---|
| Platform | 84mm | 75mm | 9mm < gap 75mm | Interference is avoidable with VR |
| Intermediate stand | 31mm | 71mm | 40mm < gap 71mm | Interference is avoidable with VR |

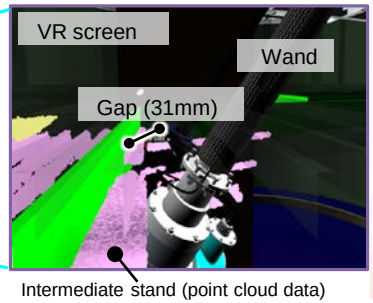


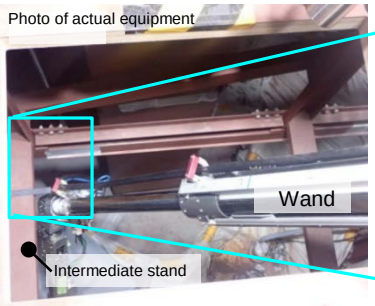



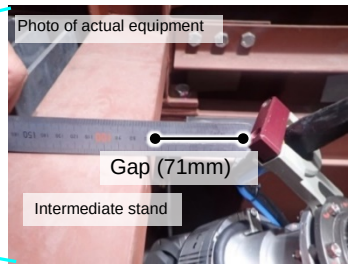





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# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test

### (c) Pedestal access test 2) Full remote access test

[Purpose / positioning]

In past tests, arm operation was done by remote operation where workers visually confirmed the arm position directly and called out to the operators when necessary. This test is conducted completely by full remote operation eliminating situations of workers calling out to operators, based on the situation at the 1F site.

[Test conditions]

| Items | Test conditions |
|---|---|
| Equipment | Mounting conditions of the arm, wand and laser scanner |
| Access route | Route from when the arm is folded (home position) to extension pipe / X-penetration connection structure / X-6 penetration ⇒ inside the pedestal ⇒ platform opening ⇒ pedestal bottom (round-trip) |
| X-6 penetration installation position | Offset 30mm to the left in the traveling direction and +30mm in the height direction (assuming discrepancies due to on-site installation accuracy on the conservative side. Operators are not notified of this offset amount) |
| Calling out by workers | None (operators perform full remote operation based on camera footage and VR display) |

[Operation policy]

| Location | Operation policy |
|---|---|
| From home position to passing X-6 penetration | Operate with camera footage. Determine the arm position compare with pre-created celluloid images* and actual camera field of view. |
| After passing X-6 penetration to pedestal bottom | Operate with VR display and camera footage. |



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*Celluloid images are pointed maximum camera field of view in the case of without the arm interference

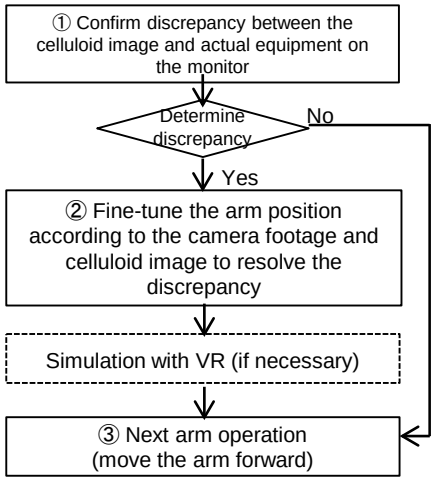
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test
## (c) Pedestal access test 2) Full remote access test

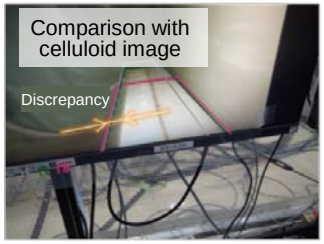
[Test result]

From home position to passing X-6 penetration

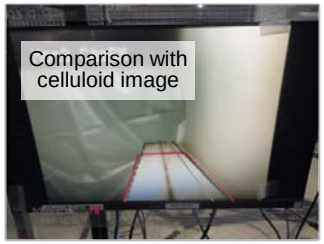
・The arm was operated with full remote operation based on camera footage and celluloid images. The arm could pass through X-6 penetration, but there was interference (minor contact) between the arm and X-6 penetration several times when passing through. Additionally, the arm traveling direction is to the rear side on the way back, but there was lack of camera field of view, which indicates that additional cameras are needed.



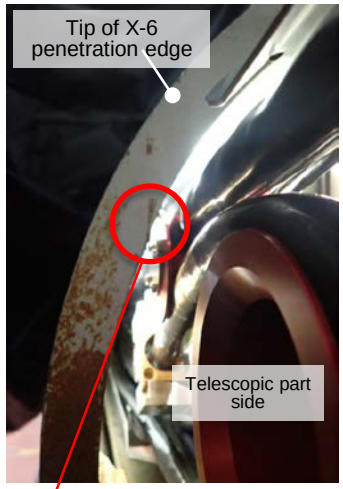

Operation flow



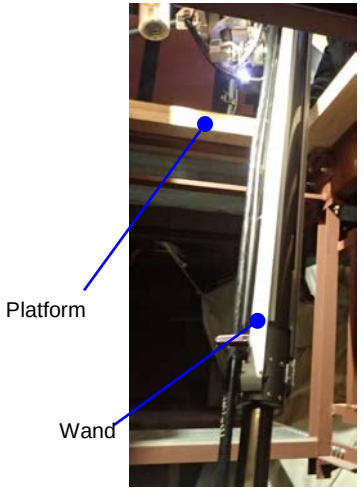

Not OK




OK




Contact between the X-6 penetration interior and metal cable support




Access to pedestal bottom (no interferences)

After passing X-6 penetration to pedestal bottom

・The arm was operated with full remote operation based on VR display and camera footage, and the arm could access the pedestal bottom without interference with obstacles. Additionally, the arm could be operated without any problems in the same manner on the way back.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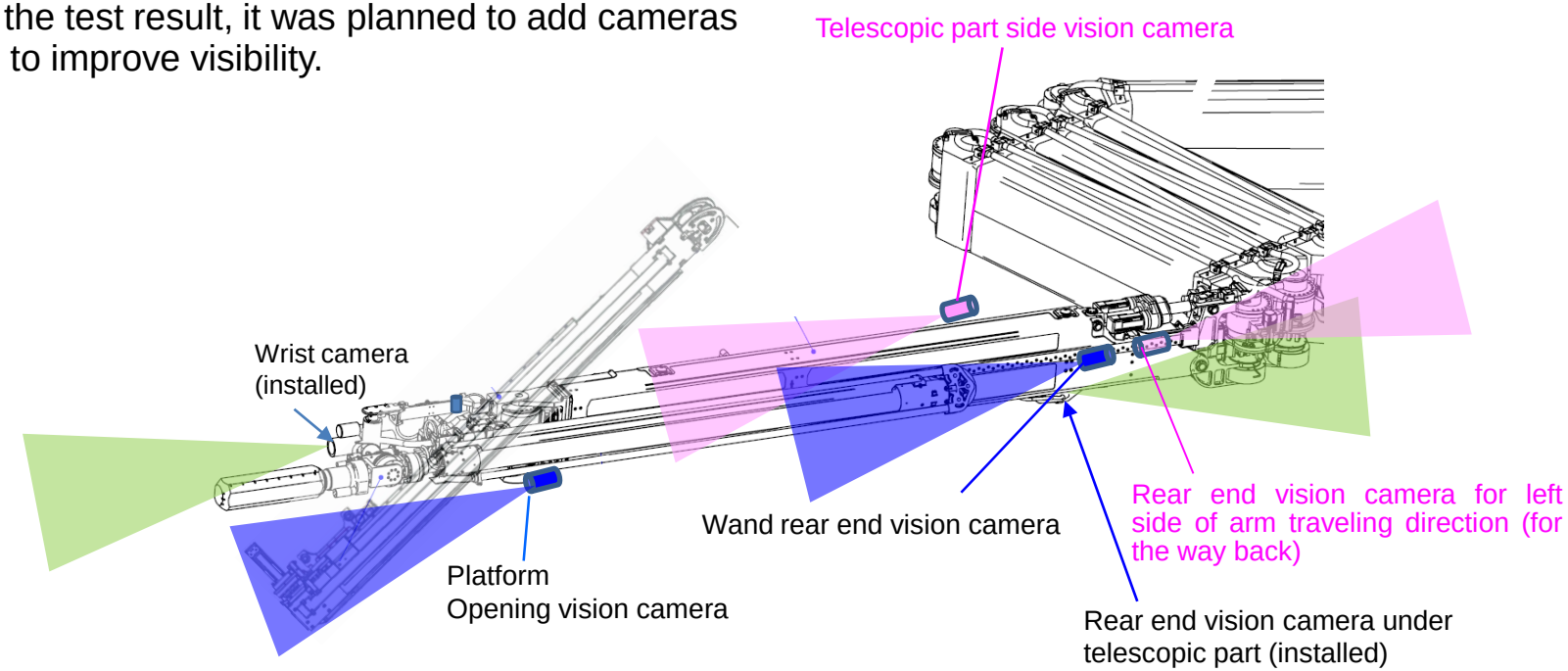
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test
## (c) Pedestal access test 2) Full remote access test

Based on the test result, it was planned to add cameras as follows to improve visibility.




: Installed during full remote access test

: Planned for additional installation based on the result of full remote access test

Additional camera installation plan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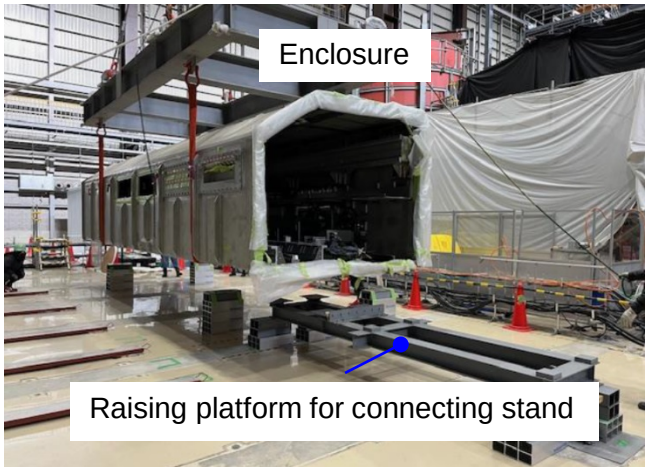
# 4.1 Access and investigation equipment

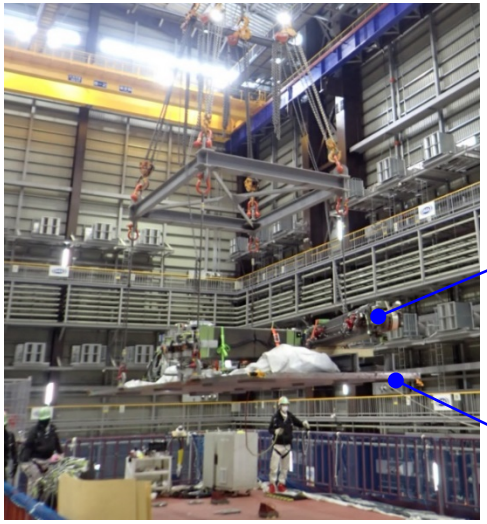
## (1) Mock-up tests considering site conditions (i) Arm verification test

### (d) Arm assembly

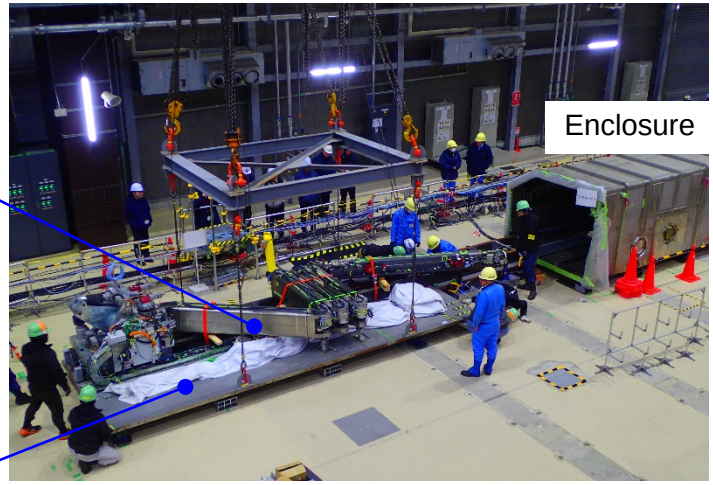
- Past tests were conducted with the arm alone, but in order to conduct tests with the arm assembled to the enclosure, the arm was assembled inside the enclosure.




Status of enclosure preparation work



Lifted from the mock-up stand




Temporarily placed behind the floor enclosure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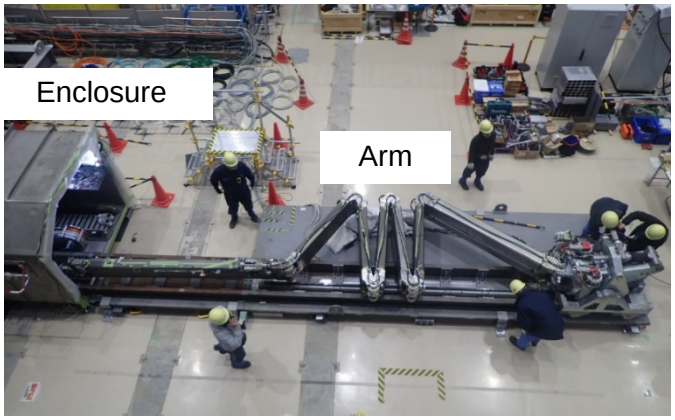
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (i) Arm verification test

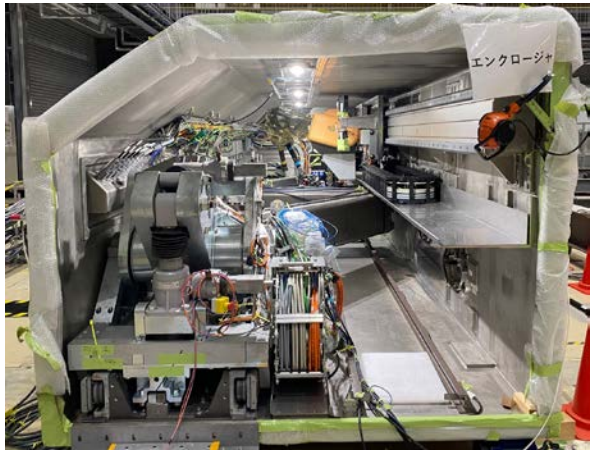
### (d) Arm assembly




Deformation completed before arm assembly

Status of arm assembly work

Status of arm assembly work



Arm assembly completed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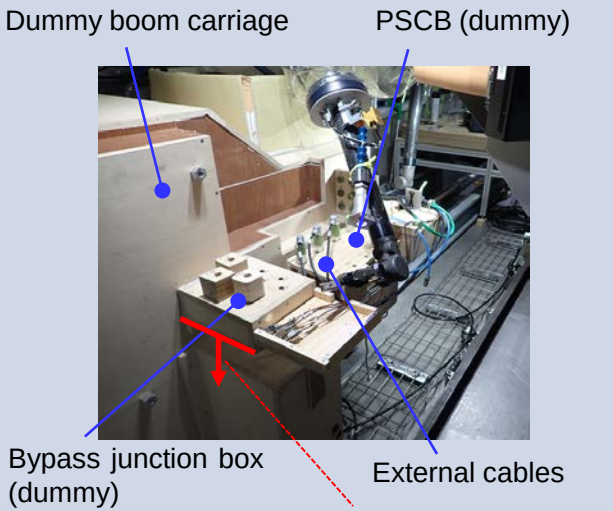
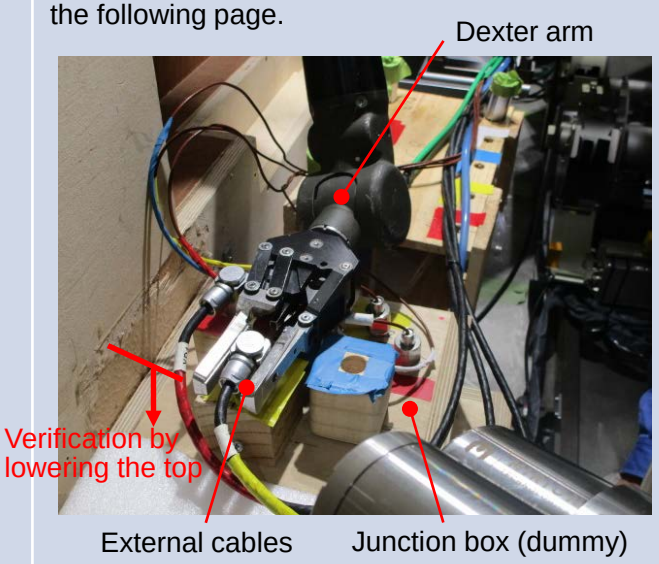
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (ii) Verification tests for the work efficiency of Dexter arm

### (a) Installation and removal of external cables for sensor

| Verification items | Verification result and areas for improvement of the mock-up tests at the Naraha center (FY2022) | Test result of the mock-up tests at the Naraha center (FY2023) |
|---|---|---|
| Installation of connector to bypass junction box | ・Workable outlook was obtained by confirming work efficiency of installation to bypass junction box / PSCB.<br>・The issue is that work efficiency is better if the bypass junction box is lowered. (improvement based on whether actual equipment can be improved) | ・Work efficiency was verified using mock-up equipment simulating the revised pedestal structure (lowered top) of the bypass junction box. It was confirmed that work efficiency is improved and work can be conducted without any problems.<br>・The actual arm was modified as shown on the following page. |





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# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (ii) Verification tests for the work efficiency of Dexter arm

### (a) Installation and removal of external cables for sensor

Improvement

・Pedestal structure of the installation part of the junction box of the actual arm was revised to lower the installation height of the junction box by 50mm and expand the work space above the junction box.

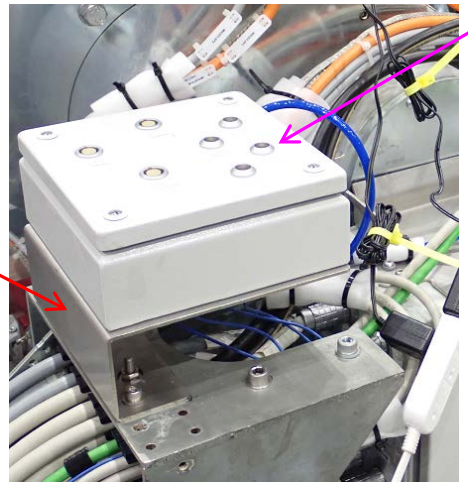
Test result

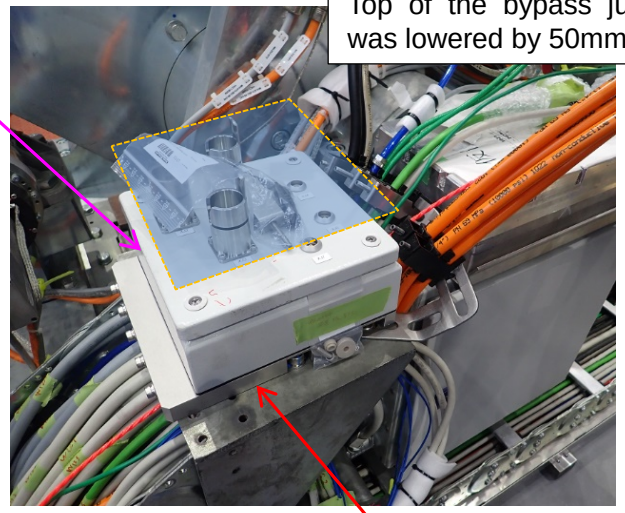
・Work efficiency of connector installation improved by securing enough height for connector fitting work below the upper limit of the movable area of the Dexter arm.

Junction box

Top of the bypass junction box was lowered by 50mm

Pedestal structure (height before improvement: 74mm)





Pedestal structure (height after improvement: 24mm)

**Have been incorporated to the actual arm after confirming the work efficiency of the Dexter arm with mock-up equipment.**



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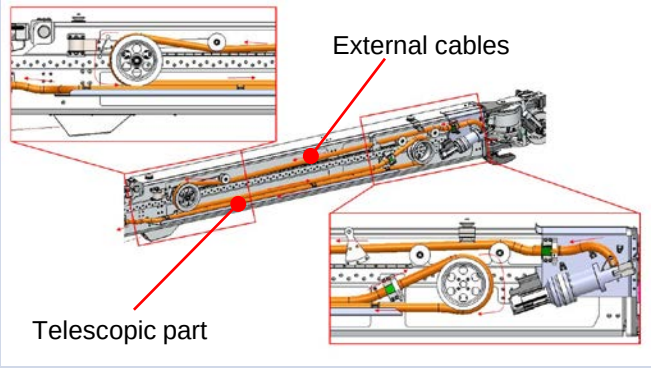
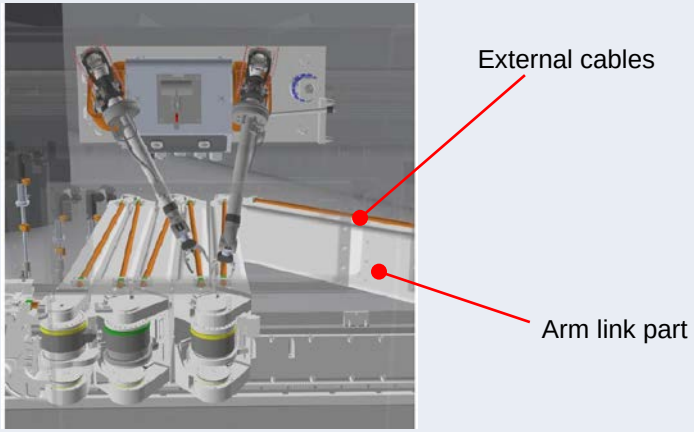
# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (ii) Verification tests for the work efficiency of Dexter arm

### (b) Installation and removal of external cables for tools

| Verification items | Areas for improvement | Result of mock-up tests at the Naraha center |
|---|---|---|
| Installation of external cables to the telescopic part<br>  | ・Although installation/removal with the Dexter arm was possible, it was necessary to align the orientation since the metal bracket for installation and cable collar to be fitted were trapezoidal. | ・It was confirmed that alignment of orientation is no longer needed for installation to the telescopic part by changing the fitting shape of the metal bracket for installation and collar of external cables to a conical shape.<br>(details on next page) |
| Installation of external cables to the link<br>  | ・In the initial design, external cables could not be installed to the metal bracket for installation under the cable tray due to interference between the Dexter arm and cable tray.<br>・Changing the structure of the metal bracket for installation allows access to said bracket, which enables installation/removal to the link, but this required aligning the orientation of installation. | ・It was confirmed that alignment of orientation is no longer needed for installation to the link part by changing the fitting shape of the metal bracket for installation and collar of external cables to a conical shape.<br>(details on next page) |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# 4.1 Access and investigation equipment

## (1) Mock-up tests considering site conditions (ii) Verification tests for the work efficiency of Dexter arm

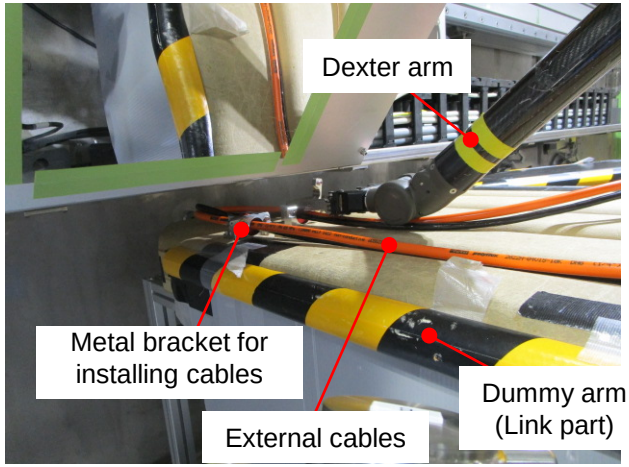
## (b) Installation and removal of external cables for tools

Focal points

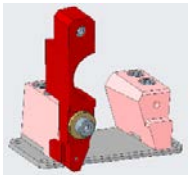
・Review of shape of cable collar (from trapezoidal to conical shape)

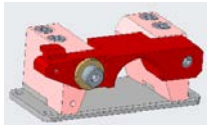
It was necessary to align the orientation to insert the trapezoidal cable collar into the metal bracket for installation. This required time for installation since the cable is stiff and hard to twist.

Additionally, since angled cable collars easily get caught on surrounding structures during installation, the shape of the cable collar was changed to a conical shape.



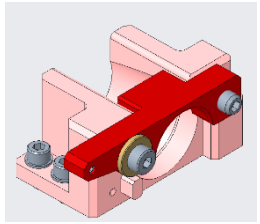

Metal fitting is locked by turning it with the Dexter arm after installing the cables (bolts unrequired)

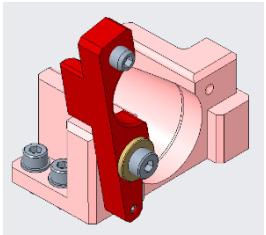




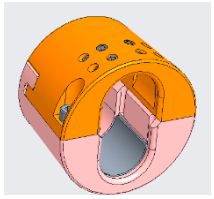
Cable collar for tools (trapezoidal)

Past metal fitting for installation (trapezoidal)



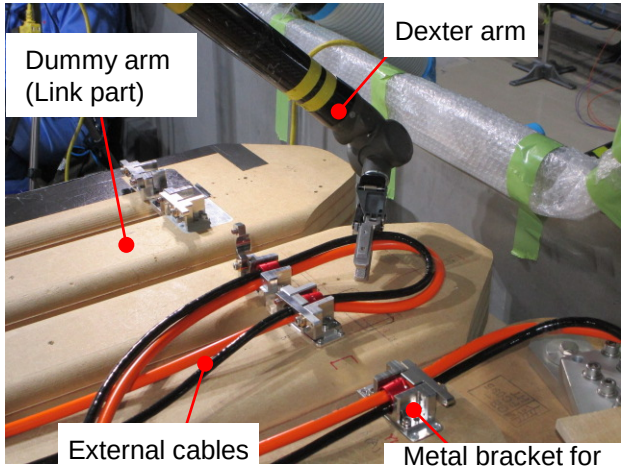


Metal bracket for installing external cables (cone-shaped)



Cable collar for tools (cone-shaped)

Metal fitting for installation with revised shape (from trapezoidal to conical shape)




Installation of the external cables for tools to the link part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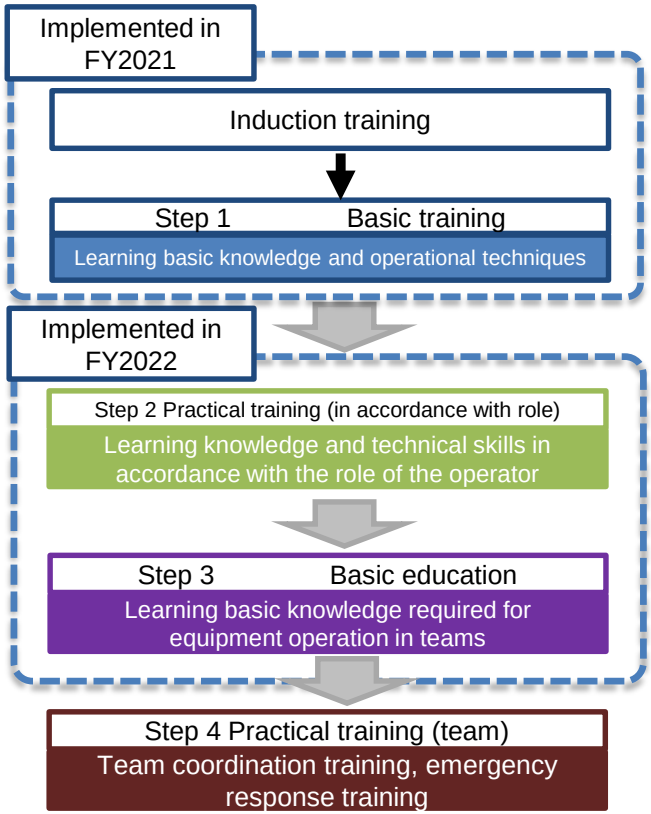
# 4.1 Access and investigation equipment

## (2) Work training

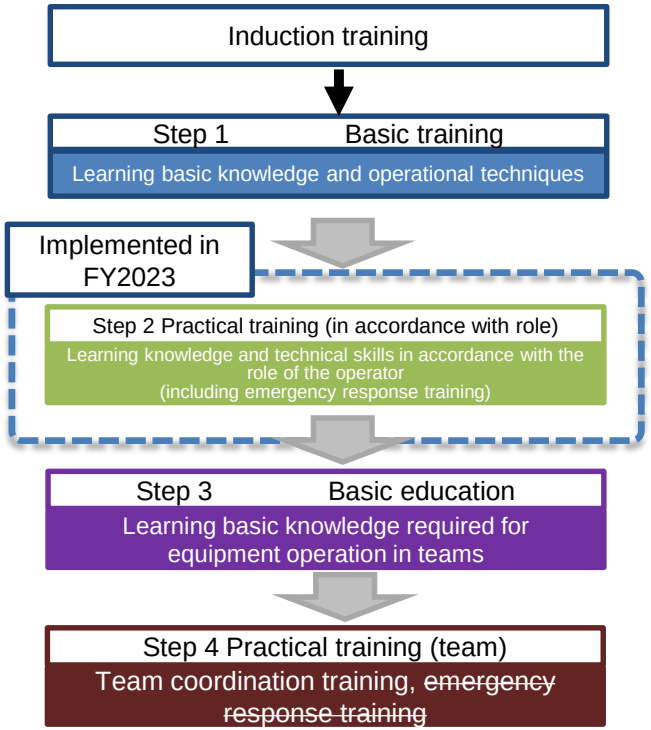
### i. Review of work training program, and work training results

- The work training program was reviewed based on the training status and operator needs, and practical training is ongoing accordingly. (Step 2 was conducted in this fiscal year, and Steps 2 and 4 will be conducted in the next fiscal year)

**[Initial plan]**




**[Plan after review]**

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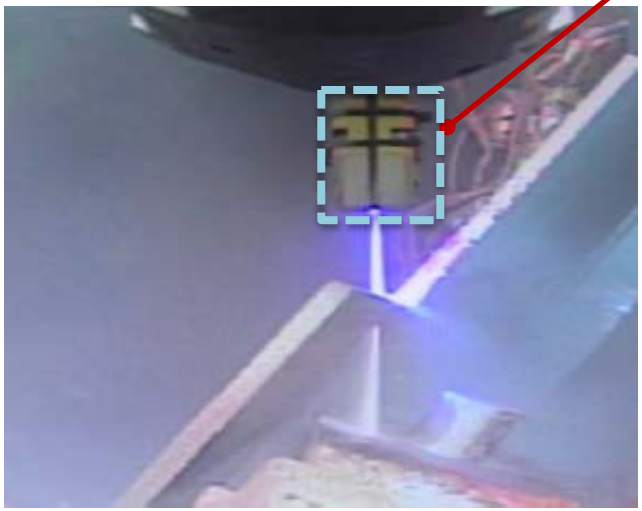
# 4.1 Access and investigation equipment

## (2) Work training

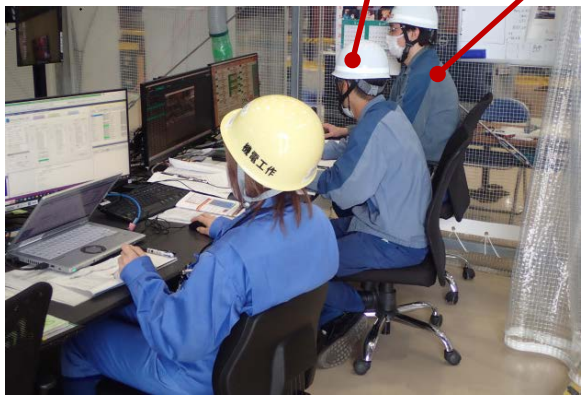
### ii. Result of practical training　BO*2 training

- Operators learned how to establish an access route, create and execute the Teach & Repeat File, and edit said file according to the situation in the field, from AWJ cutting test, boom access test and full remote test of practical training through boom verification.
- Practical training through boom verification and once-through verification will continue to be implemented in FY2024.




**Status of training through AWJ cutting test (operation)**

**Status of training through boom access test (creating celluloid images)**




**Status of training through full remote test (operation)**

*1 RO: operation leader　*2 BO: boom (arm) operator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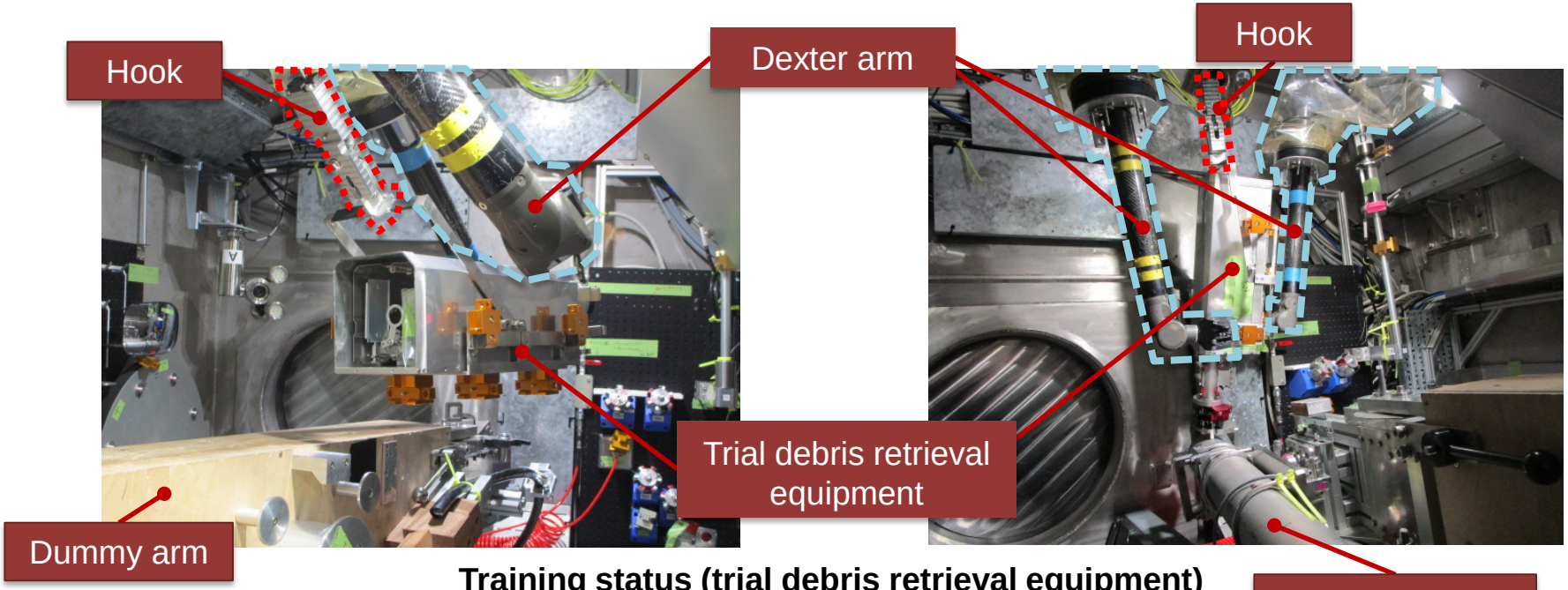
# 4.1 Access and investigation equipment

## (2) Work training

### iii. Result of practical training

MO[*1], camera operator training

- Operators learned how to handle and operate various accessories with the Dexter arm and operate the camera to secure field of view, from practical training through Dexter arm verification.
- Findings and procedures obtained through training are compiled as operation procedures. Training will continue in the next fiscal year for on-site demonstration, and its results will be incorporated in the procedures.
- Operation training for the camera attached to the boom will be conducted in FY2024 in line with handling and operation of the boom during the boom access test.




**Training status (trial debris retrieval equipment)**

*1 MO: Manipulator (Dexter arm) operator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# 4.2 Access route establishment related equipment

## (1) Work training

### i. Training plan

In FY2022, verification and once-through test of access route establishment related equipment was conducted at the JAEA Naraha Center for Remote Control Technology Development using full-scale mock-up equipment.
Feedback on cable laying arrangement, cable rack layout and shape, and hook installation areas was completed for the laying drawing for cables and hoses of enclosure ancillary equipment.

In FY2023, cable laying verification was conducted at JAEA Naraha Center for Remote Control Technology Development using actual-size mock-up of the cable laying area, upon reviewing on paper construction details, such as the order of laying cables and hoses of enclosure ancillary equipment, way of bundling (grouping) cables, and reduction of workers by using jigs, which were issues in the FY2022 verification, with business partners in advance.

- Verification item ① Reduction of laying workers by utilizing jigs as an alternative
- Verification item ② Optimization of way of bundling (grouping) approx. 180 cables and hoses and order of laying of each bundle
- Verification item ③ Improving work efficiency by improving the cable laying route [around arm and enclosure]
- Verification item ④ Optimization of isolation and alignment of cables [cable crossing area near watertight door]


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# 4.2 Access route establishment related equipment

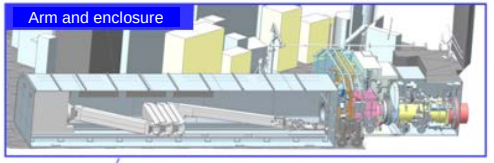
## (1) Work training

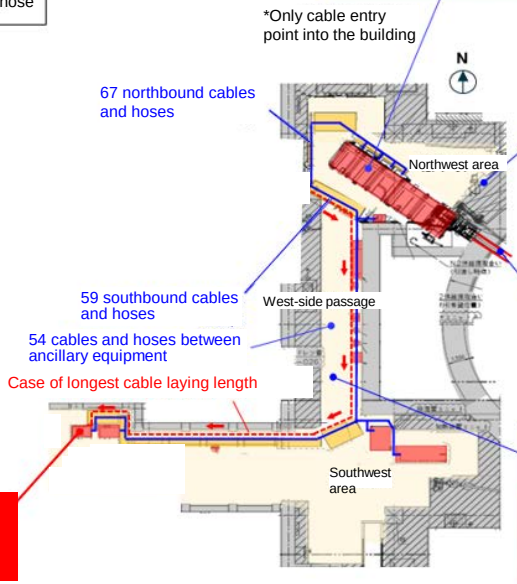
### ii. Overview of work to lay cables and hoses of ancillary equipment

Of the approx. 300 cables and hoses to be laid inside and outside the reactor building, it is necessary to safely lay 180 cables and hoses inside the reactor building under high dose without damaging them within the limited work time.

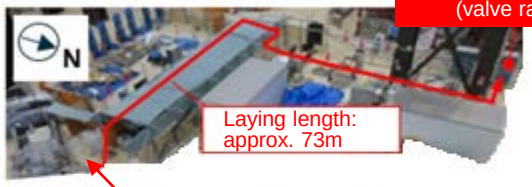
- Work time under high dose: approx. 15min. (①)
- Working with cables all over the place (②)
- Alignment work based on remote distance (③)
- Long-distance cable laying (④)

Legend *Quantity in ( )
- Arm-type equipment and ancillary equipment (12 units)
- Cable rack (14 units)
- Cables and hoses to be laid (180 cables and hoses) Power, signal, control, hose





Case of longest cable laying length




Signal cable (outer diameter: 11mm): 8 cables
Control cable (outer diameter: 12.5, 14.5mm): 2 cables
Grounding wire (outer diameter: 5mm): 1 wire

*It has been confirmed that there are no problems with the route laying cables and hoses from outside the reactor building through the watertight door regarding the cables and hoses laid this time.

Inside Fukushima Daiichi Nuclear Power Station Unit 2 Reactor Building

*Photo of full mock-up verification at JAEA Naraha center in 2022

**Overview of work to lay cables and hoses of ancillary equipment**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# 4.2 Access route establishment related equipment

## (1) Work training

### iii. Training results (verification of exposure reduction and quality maintenance)

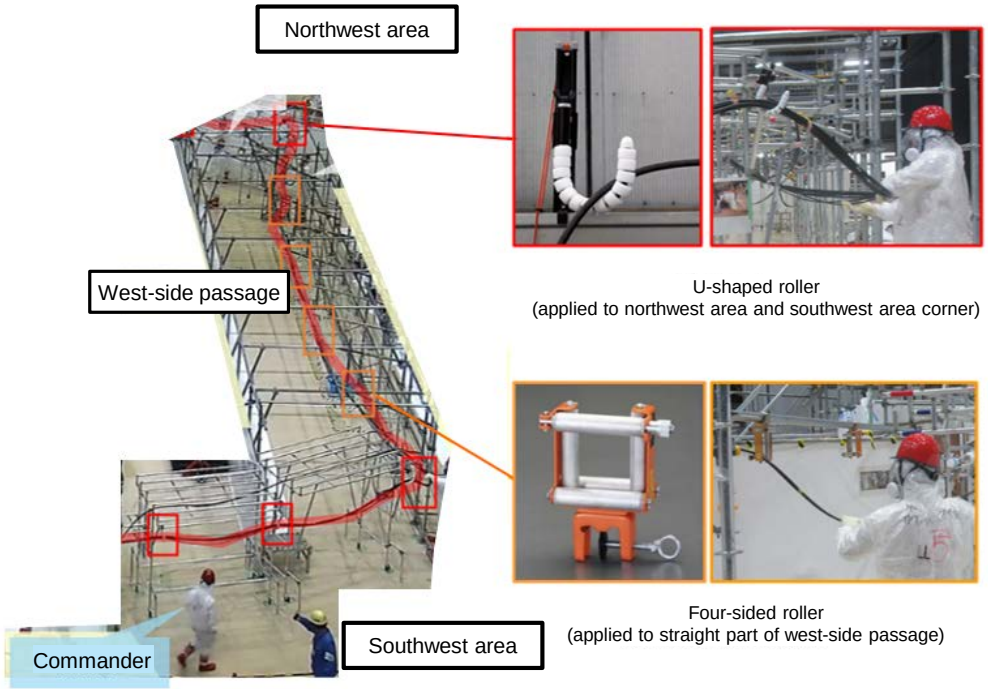
Verification item ① Reduction of laying workers by utilizing jigs as an alternative

Verification of application of the cable roller as an alternative to workers pulling cables was conducted.

⇒ **It was confirmed that workers can be reduced (exposure reduction) as intended in the preliminary study.**

⇒ **It was confirmed that it also contributes to reducing the load on cables during laying work (quality maintenance).**

**Laying workers are reduced by applying the roller**





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# 4.2 Access route establishment related equipment

## (1) Work training

### iii. Training results (verification of exposure reduction and quality maintenance)

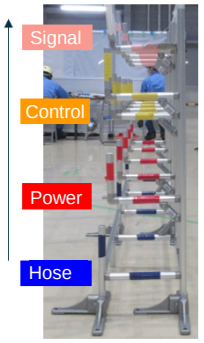
Verification item ② Review of optimization of way of bundling (grouping) approx. 180 cables and hoses and order of laying of each bundle

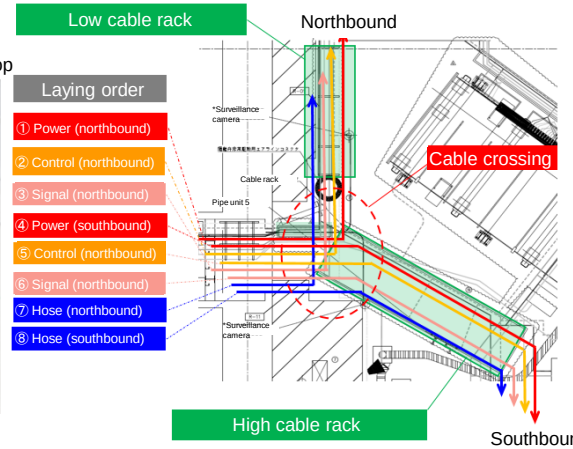
The laying order was reviewed determining the optimum cable bundle for laying and considering ease of laying at the crossing of cable racks and cables, in order to efficiently conduct laying work in a planned manner and reduce exposure.

**⇒ Feasibility was confirmed upon putting it into the schedule for each day and each work team.**

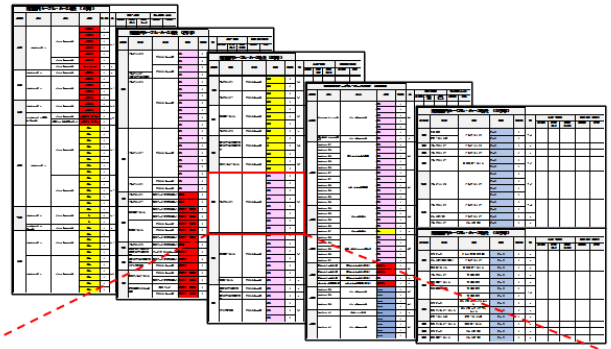
**Changed from 180 cables to 72 bundles due to grouping (▲60%)**

Review of optimum cable bundle for laying




Order of laying considering ease of laying at the crossing of cable racks and cables



Cable and hose laying inside reactor building (third day)

| Work team | End | Start | Type | Number | Bundle | People / time | | | Exposure dose (mSv) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Worker | Radiation control (people) | Time (sec) | Worker | Radiation control |
| Team 4- | Valve rack 1 | Plant room ⑥ _ | Signal | 1 | ○ | 9 | 2 | 594 | 4.10 | 0.02 |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |
| | | | Signal | 1 | | | | | | |

Laying schedule for each day and each work team

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# 4.2 Access route establishment related equipment

## (1) Work training

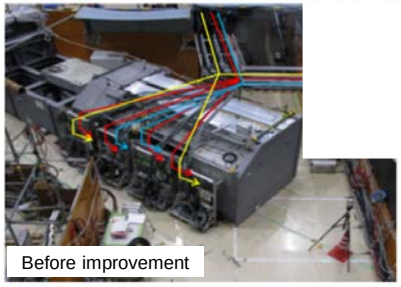
### iii. Training results (verification of exposure reduction and quality maintenance)

Verification item ③ Improving efficiency of laying work by improving the cable laying route

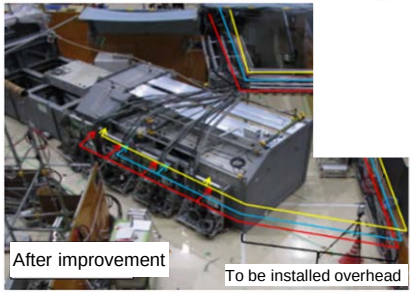
Verification of a new cable laying route that underwent preliminary study was conducted.

**⇒ Compared to before the improvement, effect of improvement of work efficiency was confirmed such as cable laying position becoming lower, cable isolation work becoming easier due to installation of cable racks and accessibility improving for connector connection.**

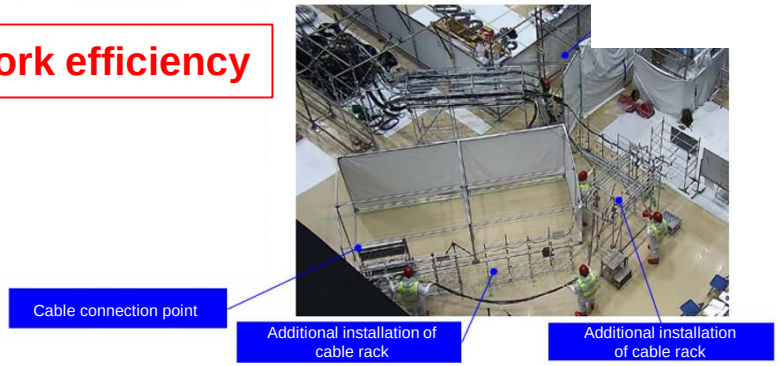
**Improvement of cable laying route ➡ improvement of work efficiency**




Before improvement of cable laying route

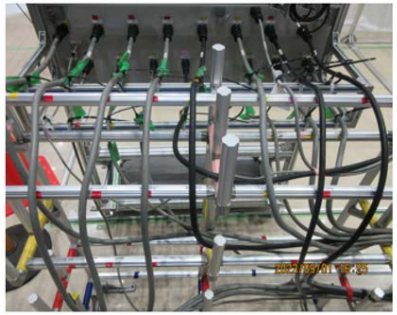



After improvement of cable laying route




Status of verification of new cable laying route

Confirmation of accessibility for cable connection



Additional installation of cable rack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# 4.2 Access route establishment related equipment

## (1) Work training

### iii. Training results (verification of exposure reduction and quality maintenance)

Verification item ④ Optimization of cable isolation and alignment

Cable racks were applied to all cable laying areas for isolation and alignment.

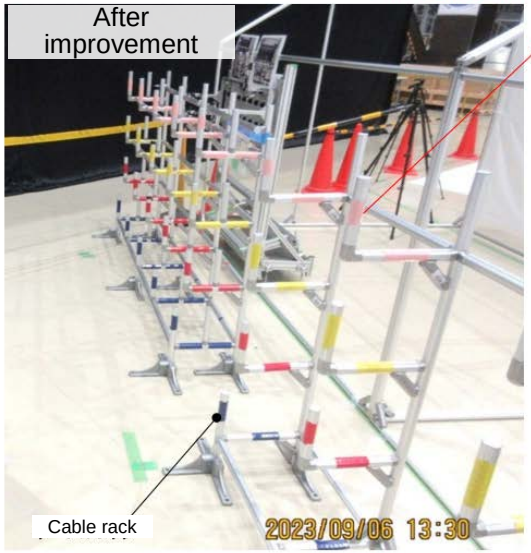
**⇒ Elimination of risks of cables being stepped on the floor (quality maintenance)**

Both cable racks and cables were color-coded to indicate the cable type.

**⇒ Elimination of unnecessary exposure of workers by preventing mistakes in the laying position during laying work and rework due to incorrect laying.**

Verification at JAEA Naraha Center in 2022

**Color-coding of both cable racks and cables to indicate the type**



Verification of laying this time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# 4.2 Access route establishment related equipment

## (1) Work training

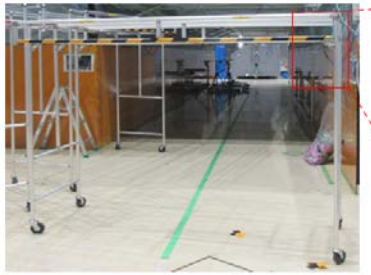
### iii. Training results (verification of exposure reduction and quality maintenance)

Verification item ④ Optimization of cable isolation and alignment

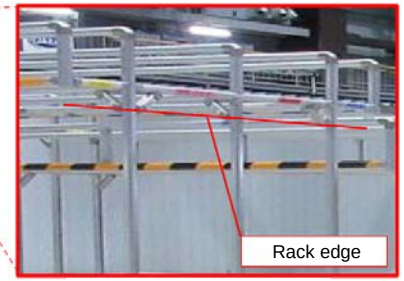
As an improvement of the cable racks, isolation distance was secured by making the length of the edges different and changing the starting point of cable hanging for each cable type.

**⇒ It was confirmed that quality is maintained by avoiding excessive pulling on the cables during laying work by eliminating cable congestion.**

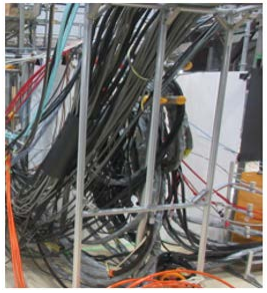
Before improvement



Cable rack




Cable rack edge

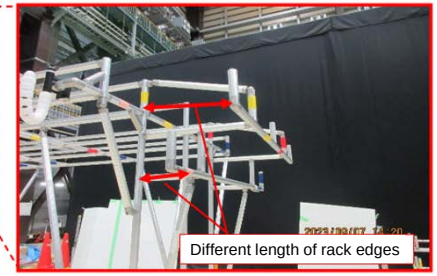


Cable laying state

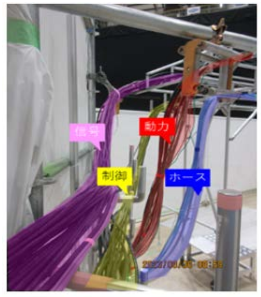
Verification at JAEA Naraha Center in 2022

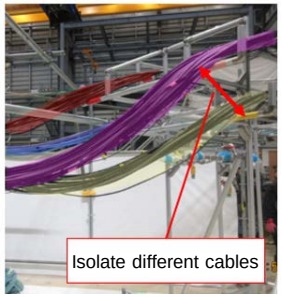
After improvement

Cable rack




Cable rack edge






Cable laying state

Verification of laying this time



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# 4.2 Access route establishment related equipment

## (1) Work training

### iv. Test results and future plans

"Exposure reduction"

Cable and hose laying work inside Unit 2 reactor building (high dose, confined space, dark area) Feasibility was verified using actual-size mock-up, and great results in "exposure reduction" (683→384 man-mSv) were achieved.

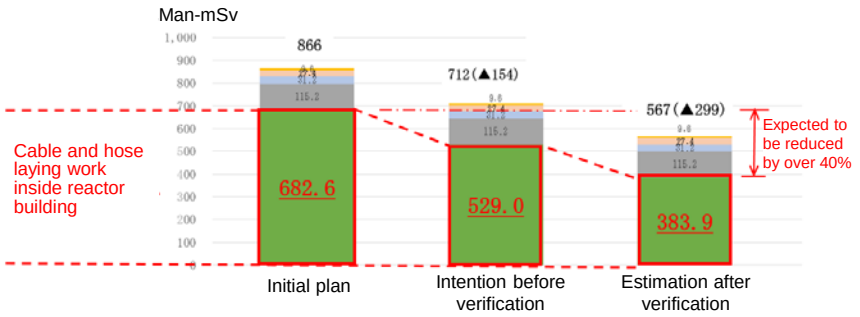
"Quality maintenance"

Quality maintenance was confirmed such as reduction of load on cables during laying work by applying the cable roller, and preventing cables from being stepped on and avoiding cable damage during laying work with cable congestion through cable laying, alignment and isolation using cable racks.

This mock-up verification result will be fed back to the training plan, and pre-site training will be conducted for worker proficiency before on-site construction work.

| | | Worker (people) | Commander (people) | Radiation control (people) | Number of teams (teams) | Cables (cables) | Exposure (man-mSv) |
|---|---|---|---|---|---|---|---|
| First day | Outside building ⇒ enclosure (power / control) | 60 (120) | 21 (16) | 21 (16) | 7 (8) | 43 (30) | 55.4 (113.8) |
| Second day | Outside building ⇒ enclosure (signal)<br>Outside building ⇒ ancillary equipment (power) | 69 (120) | 24 (16) | 24 (16) | 8 (8) | 35 (30) | 73.9 (113.8) |
| Third day | Outside building ⇒ ancillary equipment (control / signal) | 62 (120) | 21 (16) | 21 (16) | 7 (8) | 33 (30) | 65.2 (113.8) |
| Fourth day | Outside building ⇒ ancillary equipment (signal)<br>Outside building ⇒ hose<br>Cable between equipment inside building | 56 (120) | 24 (16) | 24 (16) | 8 (8) | 41 (30) | 58.6 (113.8) |
| Fifth day | Hose between equipment inside building | 77 (120) | 21 (16) | 21 (16) | 7 (8) | 14 (30) | 67.0 (113.8) |
| Sixth day | Hose between equipment inside building | 71 (120) | 21 (16) | 21 (16) | 7 (8) | 13 (29) | 63.8 (113.8) |
| | Total | 395 (720) | 132 (96) | 132 (96) | 44 (48) | 179 (179) | 383.9 (529.0) |

Work and expected exposure dose (estimated) *Planned values before verification of laying in ( )




Transition of exposure dose for ancillary equipment and cable laying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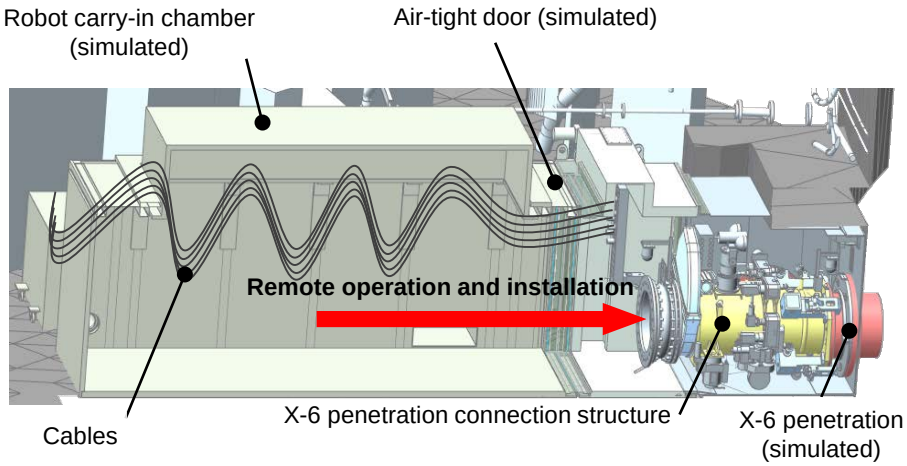
# 4.2 Access route establishment related equipment

## (1) Work training

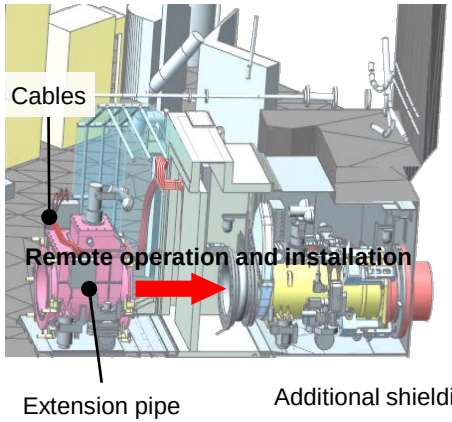
### v. On-site training

On-site training for X-6 penetration connection structure, extension pipe and additional shielding plate

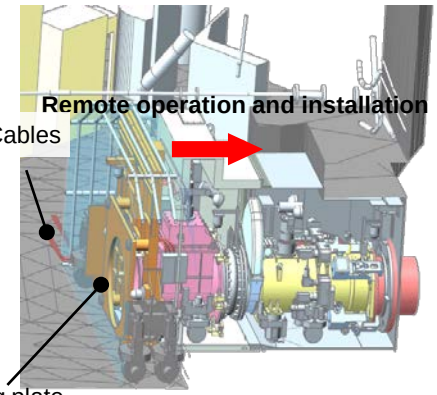
Worker proficiency training was conducted from January to March 2024 at JAEA Naraha Center for Remote Control Technology Development regarding installation of connection structure, extension pipe and additional shielding plate to X-6 penetration of access route establishment related equipment, for which on-site construction work will start in May 2024.
Upon establishing the procedures through previous verifications, six items were implemented in this training: "① preparation of actual-size mock-up", "②wearing actual radiation control protective gear", "③creating on-site construction work instructions in advance", "④preparation of actual equipment to be used on-site", "⑤summoning people who will conduct the actual construction on-site", "⑥reflection of strategies and lessons from prior construction work". The purpose of the training was to develop detailed procedures and obtain prospects for exposure reduction.




① Installation of X-6 penetration connection structure




② Installation of extension pipe




③ Installation of additional shielding plate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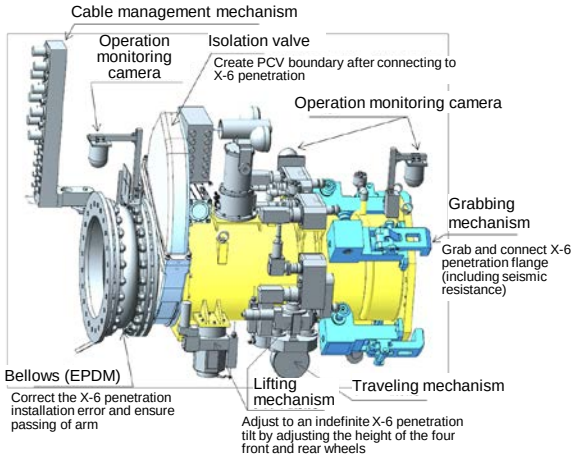
# 4.2 Access route establishment related equipment

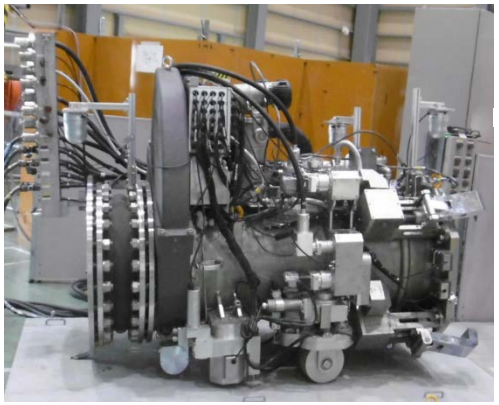
## (1) Work training

### v. On-site training

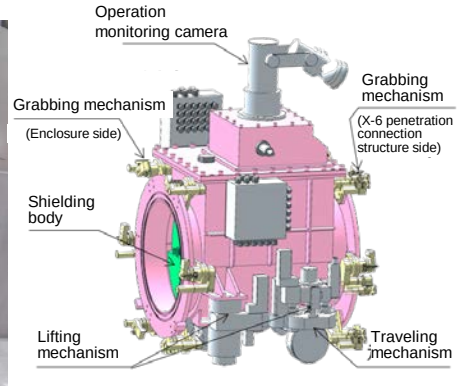
Actual connection structure, extension pipe, additional shielding plate and closing lid flange were used.

**① X-6 penetration connection structure**



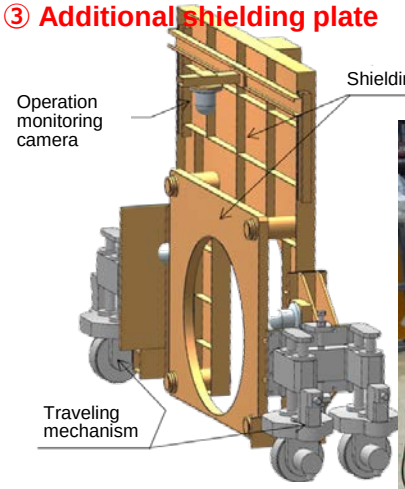



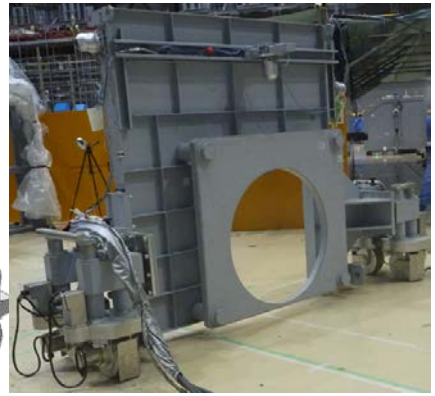
**② Extension pipe**




Extension pipe

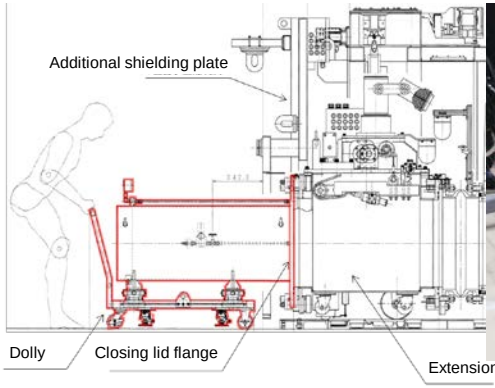
**③ Additional shielding plate**



Additional shielding plate

**④ Closing lid flange**



Closing lid flange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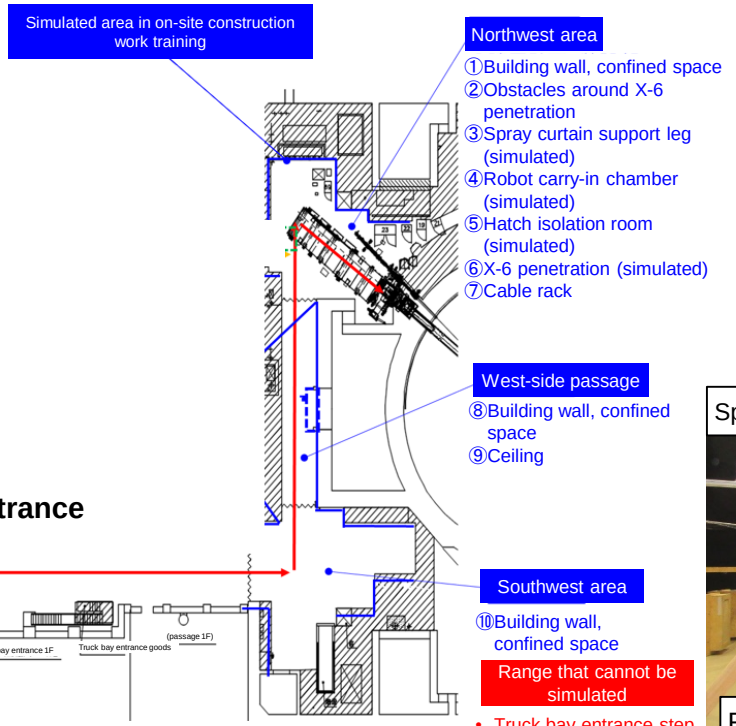
# 4.2 Access route establishment related equipment

## (1) Work training

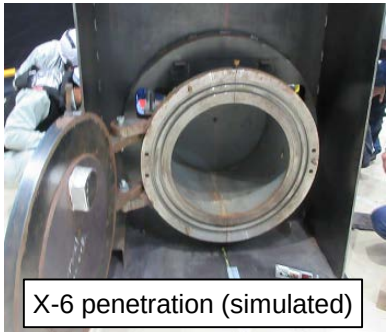
### v. On-site training

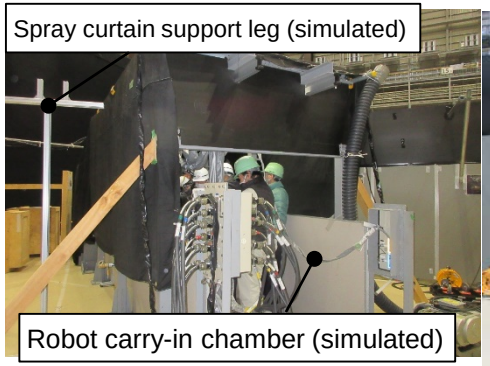
Conducted in 1/1 scale
Equipment is R equipment

Training simulation was conducted in 1/1 scale.
The same protective gear as equipment on-site was used during the training.



Hatch isolation room (simulated)


X-6 penetration (simulated)


Spray curtain support leg (simulated)
Robot carry-in chamber (simulated)

Building wall, ceiling

***Materials were carried into the building from Unit 2 outdoor yard via the truck bay entrance. Materials related to the connection structure, extension pipe and additional shielding plate that were verified this time were planned to be carried into the truck bay entrance by hand or with a forklift, and training was completed as planned.**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# 4.2 Access route establishment related equipment

## (1) Work training

### v. On-site training

Detailed procedures were created to clarify who does what in the entire process

| No. | Instructions number and classification | Work step | Work overview | Conditions for determining transition to the next process | Customer witness | Work location | Remarks |
|---|---|---|---|---|---|---|---|
| 3 | 6-4 | ・Stop position inside robot carry-in chamber<br>1m marking<br>・Marking of “slightly open” position of the airtight door | ・Mark the equipment stop position in the robot carry-in chamber<br>① A and E are to wear shoe covers, and mark the floor 1m from the airtight door inside the robot carry-in chamber as the connection structure stop position. (enter from the truck bay entrance)<br>・Mark the “slightly open” position of the airtight door inside the robot carry-in chamber.<br>② A and E are to wear shoe covers, and mark the floor at 230mm as the “slightly open” position of the airtight door. | ・The floor 1m from the edge of the airtight door in the robot carry-in chamber is marked, and camera footage can be checked from the operation panel.<br>・“Slightly open” position of the airtight door is marked | No | Inside R/B | |
| 4 | 7-1 | Cable connection from relay panel and storage panel to connection structure<br>Laying only | ・Connect cables from the relay panel and camera equipment storage panel to the cable management mechanism.<br>① At the signal of A, B and C are to transport mesh cage ① storing cables from the southwest area to the northwest area with the guidance of D and lock the foot stopper.<br>② B is to check and pull out the cables, and A, C and D are to lay two power cables*.<br>③ B is to check and pull out the cables, and A, C and D are to lay one camera cable* and one LAN cable*.<br>④ B, C and D are to align the cables at the signal of A. Align the zipper tube end not the cable end.<br>⑤ B, C and D are to place the cable end on the protective bag.<br>⑥ A and D are to transport the mesh cage from the northwest area to the southwest area for clean-up. | | No | Inside R/B | *Perform double checks (confirmation of connection location) after cable connection during work<br>(check whether cables are connected for sure after work) |
| 5 | 6-1 | Cable connection from relay panel and storage panel to connection structure | ・Connect cables from the relay panel and storage panel to the connection structure.<br>① Workers A and B are to perform cable connection on the panel side.<br>② Workers C and D are to perform cable connection on the equipment side.<br>③ After cable connection while checking the route, workers A and B are to align the cables on the panel side and workers C and D on the equipment side.<br>④ Worker D is to check that the hook for winch is hung. | ・Lay the following self-propelled cables to complete connector connection.<br>① Camera equipment storage panel to cable management mechanism: 4 cables<br>② Relay panel to cable management mechanism: 9 cables<br>・Make sure that the LAN cable is tightly bound with no load<br>・Make sure the cable bundle is fixed to the cable management handle | No | Inside R/B | *Perform double checks (confirmation of connection location) after cable connection during work<br>(check whether cables are connected for sure after work)<br><br>Collection of photos of check points when No.2 work step is completed |


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# 4.2 Access route establishment related equipment

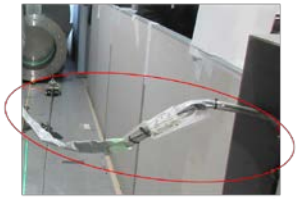
## (1) Work training

### v. On-site training

"Establishment of work procedures"
Improvements that were made better are added for on-site construction work

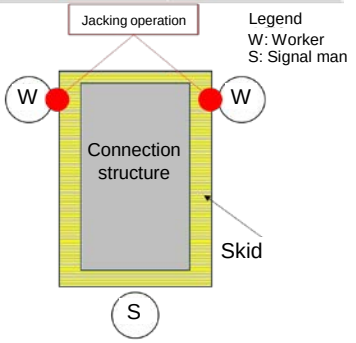
| Event | Cause | Measures | Implementation status |
|---|---|---|---|
| Of the six bundles of cables (three cables for robot carry-in chamber and three cables for outside the chamber) stored in the mesh pallet, when one cable to be laid outside the robot carry-in chamber was to be taken out and carried in, one cable to be laid inside was mistakenly taken out and laid. | It was not specified on cables whether they were for outside the chamber or inside the chamber (only color-coded). | Attach tags indicating outside the chamber or inside the chamber | Implemented on 3/6 |
| | Lack of recognition of color coding by workers | Re-educating workers about this event and review of labeling | Disseminated in the morning meeting and TBM on 3/7. Precautions shall also be added to the on-site work instructions, and thoroughly disseminated again during on-site construction work. |

Cable to be laid outside (black tape)

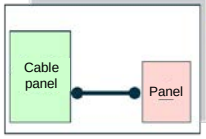


Cable to be laid inside (grey tape)

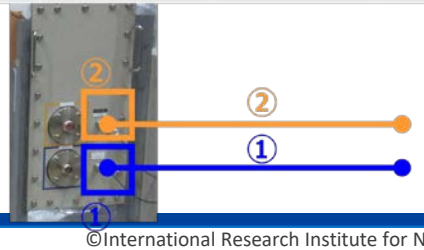
| Event | Cause | Measures | Implementation status |
|---|---|---|---|
| During jack down by two workers after installing the connection structure mounted with the skid, the timing of lowering varied. | The field team leader did not give out calls. | Clarify the division of roles among work supervisor, field team leader and workers, and ensure 3-way communication. | Disseminated in the morning meeting and TBM on 3/7. Precautions shall also be added to the on-site work instructions, and thoroughly disseminated again during on-site construction work. |
| | The workers also started work (only one worker) without instructions from the team leader. | | |




| Event | Cause | Measures | Implementation status |
|---|---|---|---|
| Cables were laid in the wrong direction on the connector panel side and panel side. | Although it was largely labeled connector side and panel side, work was conducted without looking at the labels. | Re-educating workers about this event and review of labeling | Disseminated in the morning meeting and TBM on 3/7. Precautions shall also be added to the on-site work instructions, and thoroughly disseminated again during on-site construction work. |
| | Lack of awareness of cable direction | | |
| | Lack of instructions from the work supervisor regarding cable direction | Thorough dissemination of work procedures and precautions before starting work | |
| | One-person work (environment where double checks cannot be performed) | Perform double checks in two-people work instead of one-person work | Team structure was revised to allow double checks |
| Work was not stopped even though it was not correctly connected and it felt out of place | There were not enough skills to recognize the right state and wrong state (could not be sure that "it was wrong") | Improve skills through additional training so that workers can be sure that work is complete in any work | Proficiency is improved in additional training from 3/8 |
| | Information was not communicated to the work supervisor even though it felt out of place. | The work supervisor or leader is to check with the workers if work was correctly completed after work ends. | Disseminated in the morning meeting and TBM on 3/7. Precautions shall also be added to the on-site work instructions, and thoroughly disseminated again during on-site construction work. |
| | | Foster a culture to immediately stop the work when things feel out of place and discuss with the parties concerned. | |




| Event | Cause | Measures | Implementation status |
|---|---|---|---|
| Cables were laid with the wrong top and bottom for the two slots (top and bottom) on the connector panel in the robot carry-in chamber. | Number tags were attached to each of the connector and cable (top: ②, bottom: ①), but other tags were also attached to the cable, which caused misidentification of the number (top-side cable read ① and also had a different number tag reading 1・2・3・・・) | Remove other misleading tags, and leave only number tags on each of the connector and cable (top: ②, bottom: ①) | Implemented on 3/6 |
| | There was a low level of understanding and sense of urgency regarding the fact that the cables can be connected even if the top and bottom are reversed and its degree of impact. | In addition to the above physical measures, the work supervisor should ensure that workers are alerted especially of high-impact work. | Disseminated in the morning meeting and TBM on 3/7. Precautions shall also be added to the on-site work instructions, and thoroughly disseminated again during on-site construction work. |





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# 4.2 Access route establishment related equipment

## (1) Work training

### v. On-site training

"Exposure reduction"

Training was completed for the installation and removal of the X-6 penetration connection structure, extension pipe and additional shielding plate. It was confirmed that the construction work can be conducted as initially planned by incorporating the improvements extracted from past mock-up verifications into the procedures and ensuring worker proficiency through training based on latest procedures.
The on-site construction work exposure plan was also revised based on the training results. By shortening the work time due to improvement of work procedures and proficiency of workers, results showed an expected exposure reduction of 10% compared to the initial plan. (395 man-mSv → 355 man-mSv)

Applications (customer comments during training, track record of response in on-site construction work, etc.) from prior construction work (deposit removal work) were reflected in the on-site construction work instructions to ensure thorough preparation.

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# 4.2 Access route establishment related equipment
## (2) Opening the X-6 penetration hatch (1/7)

State after opening the hatch

### [Progress of FY2023]

- At Fukushima Daiichi Nuclear Power Station Unit 2, bolts and nuts were removed with the hatch opening equipment after setting up the robot carry-in chamber, and X-6 penetration hatch was opened.
- After opening the hatch, the penetration flange surface was cleaned, the inside of the isolation room was cleaned, and hatch opening equipment was removed and cleaned. The site was handed over to the next work process (removal of deposits inside X-6 penetration) after this. (November 27, 2023)
- Major activities of FY2023 are as follows.

### [Setting up the robot carry-in chamber]

- After setting up the hatch isolation room, the robot carry-in chamber was carried into the R/B northwest area. After installing ancillary equipment such as rescue winder, collection box and camera equipment, the robot carry-in chamber was set up and a leak verification test was conducted for the entire isolation room.

Carrying-in the robot carry-in chamber

Installation of rescue winder

### [Installing the hatch opening equipment]

- Hatch opening equipment was carried into R/B northwest area, and installed in the robot carry-in chamber after aligning the cables and hoses. Later, operation was checked to confirm that it worked properly.

Carrying hatch opening equipment into R/B

Hatch opening equipment cable connection

Installation in the robot carry-in chamber


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# 4.2 Access route establishment related equipment

## (2) Opening the X-6 penetration hatch (2/7)

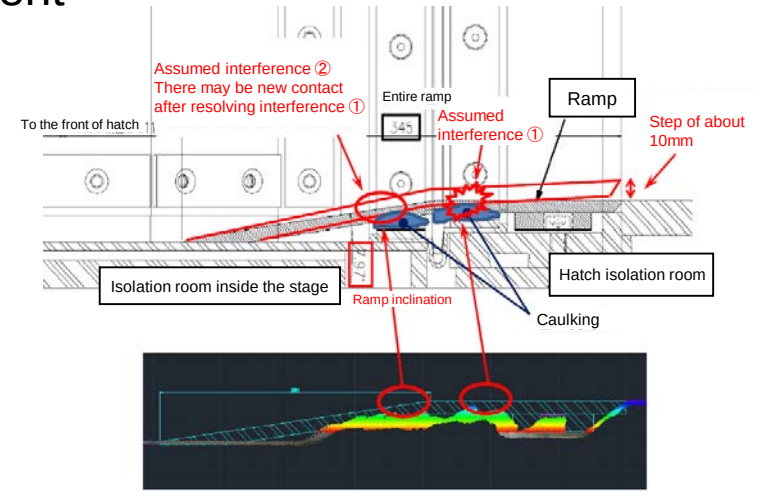
### [Ramp installation and response to lifting event]

- When installing the ramp* inside the isolation room with the hatch opening equipment, the ramp interfered with the caulking material** and lifted up to create a step.

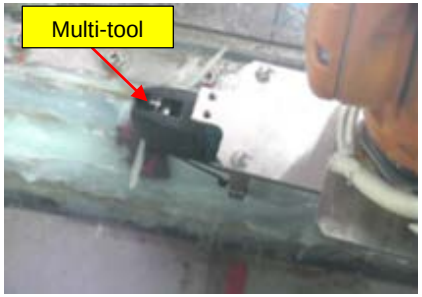
*Slope to absorb the step between isolation rooms when running equipment

**Additionally applied on-site to prevent foaming events near the bellows of the stage isolation room and hatch isolation room.

- As a countermeasure, an additionally developed multi-tool was attached to the hatch opening equipment to remove interfering caulking material.

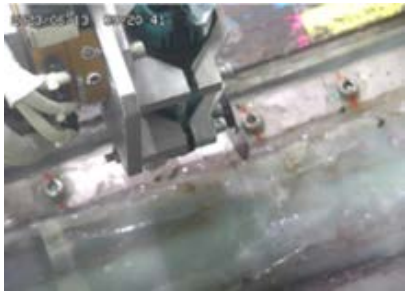



Lifted state after installation of ramp (cross-section)

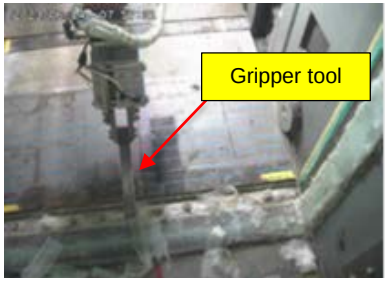



Horizontal cutting of horizontal plane

Horizontal cutting of inclined plane



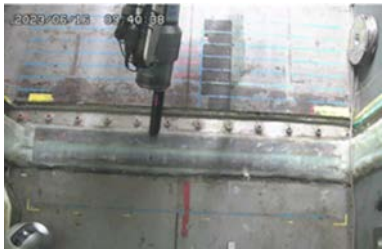
Vertical cutting



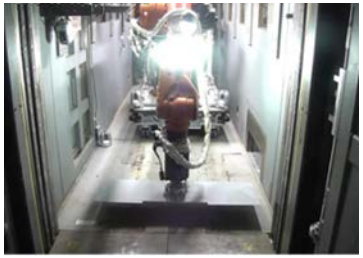

Collection of cut caulking pieces with the gripper tool

Cutting of caulking material with multi-tool

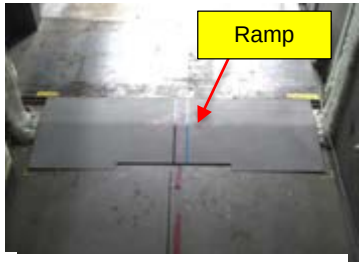
- After removing the caulking material, it was confirmed with 3D measurement that there is no interference of the ramp, and the ramp was re-installed with the hatch opening equipment.



Cleaning of ramp installation surface



Ramp installation with the hatch opening equipment




Ramp installation state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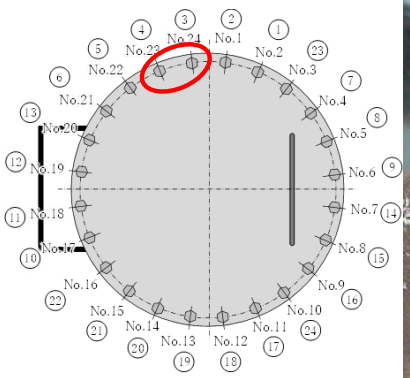
# 4.2 Access route establishment related equipment

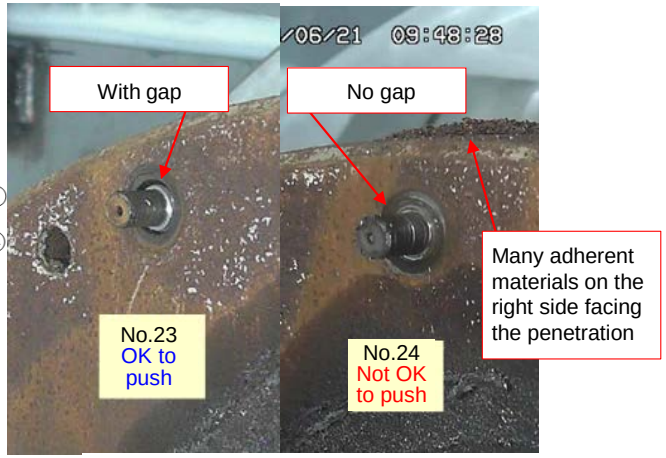
## (2) Opening the X-6 penetration hatch (3/7)

### [Release of fastening of hatch bolts and nuts]

- In order to open the hatch, fastening of the penetration hatch bolts and nuts (24 bolts and nuts) was released using the hole saw attached to the hatch opening equipment. Later, when the remaining bolts were attempted to be removed with a push rod, about half of the bolts were stuck and could not be removed due to foreign matter adhesion.

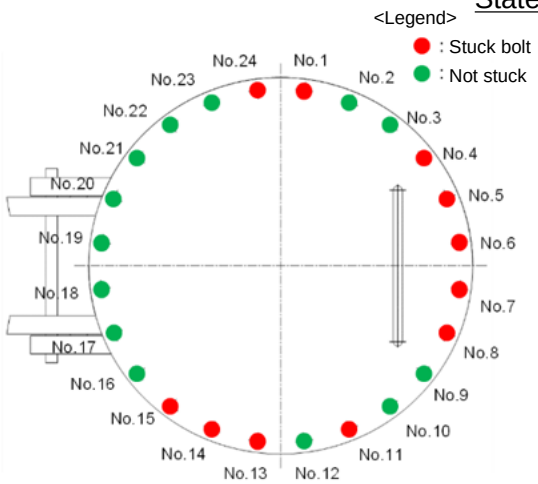
Nut removal processing by hole saw




State of stuck bolts after nut removal

Bolt pushing with push rod




Position of stuck bolts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# 4.2 Access route establishment related equipment

## (2) Opening the X-6 penetration hatch (4/7)

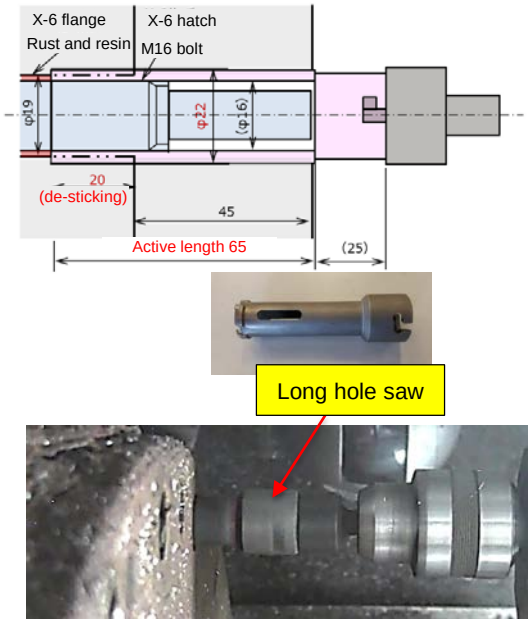
### [Response to stuck hatch bolts]

- To deal with the stuck bolts, the following de-sticking tool was additionally developed to remove the stuck bolts.
  - ・Additional processing of stuck part with long hole saw
  - ・Bolt pushing with air cylinder push-in jig
  - ・De-sticking of bolts and adherent material by drill cutting

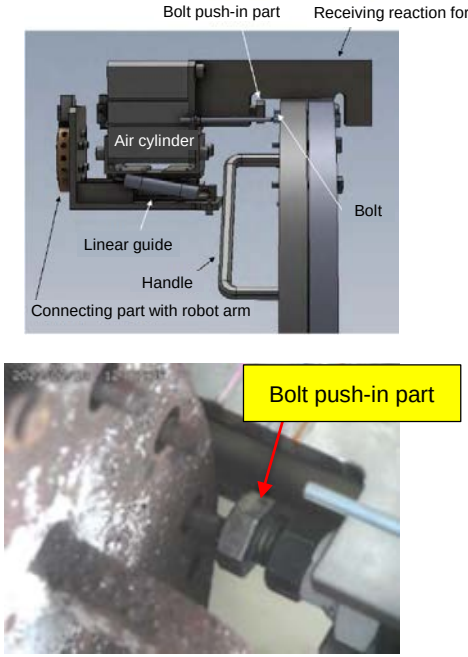
| Stuck bolt No. | Long hole saw | Air cylinder Push-in jig | Drill cutting |
|---|---|---|---|
| 1 | × | × | ○ |
| 4 | × | × | ○ |
| 5 | × | × | ○ |
| 6 | × | × | ○ |
| 7 | × | × | ○ |
| 8 | ○ | — | — |
| 11 | ○ | — | — |
| 13 | × | × | ○ |
| 14 | × | × | ○ |
| 15 | × | ○ | — |
| 24 | × | × | ○ |

<Legend>
○: Removed
×: Could not be removed
—: Not implemented

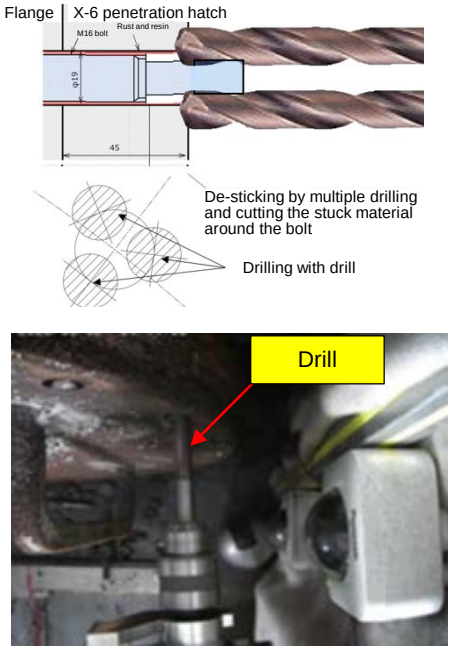
Result of applying the measure




Additional processing with long hole saw




Push-in with air cylinder push-in jig




De-sticking by drill cutting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# 4.2 Access route establishment related equipment

## (2) Opening the X-6 penetration hatch (5/7)

[Hatch opening]

- After removing all bolts and slightly opening the hatch by hooking the hook tool attached to the hatch opening equipment to the hatch handle, the hatch handle was cut. Later, the hatch was opened more than 90° using the hook tool.

Hooking the hook tool to the hatch

Hatch slightly opened

Hatch being opened

Right before fully opening the hatch

Hatch opened to 90°

State inside penetration

Status of opening the hatch with the hatch opening equipment

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# 4.2 Access route establishment related equipment

## (2) Opening the X-6 penetration hatch (6/7)

### [Cleaning of flange surface]

- After opening the hatch, the flange surface was cleaned with laser cleaning equipment and buffing tool. More adherent materials were stuck on the flange surface than expected, which could not be completely removed.

Flange surface before removing adherent materials

Before irradiation with laser cleaning equipment

Irradiation with laser cleaning equipment

Cleaning with buffing tool 1

Cleaning with buffing tool 2

Surface cleaning with laser cleaning equipment and buffing tool

Removing adherent materials with chisel (scraper)

Removing adherent materials with flat drill

Removing adherent materials with polishing disc

Removing adherent materials with cup wheel

Cleaning the surface with adherent material removal tools

### [Removal of stuck adherent materials]

- As a countermeasure, the following adherent material removal tools were additionally developed to remove adherent materials and perform final surface finishing.
  - ・Chisel
  - ・Flat drill
  - ・Polishing disc
  - ・Cup wheel


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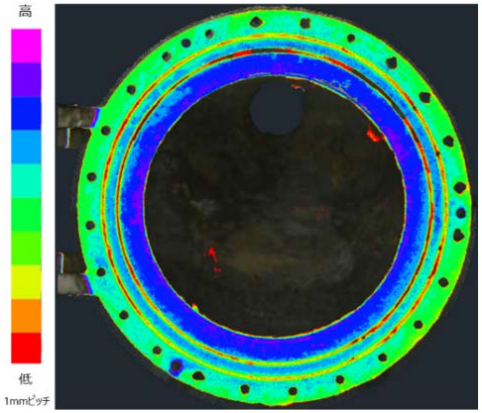
# 4.2 Access route establishment related equipment

## (2) Opening the X-6 penetration hatch (7/7)

### [Confirmation of flange surface after removing adherent materials]

- Flatness of the flange surface after removing adherent materials was visually checked and checked with the laser measurement equipment and laser scan.

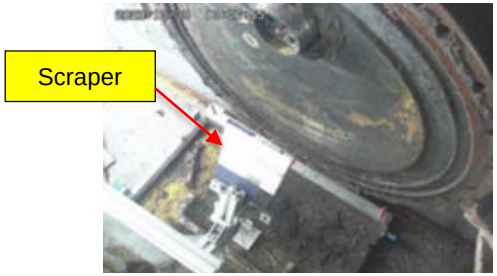
Flange surface after removing adherent materials




Confirmation of flatness of the flange surface with the laser scan

### [Cleaning of back side of hatch]

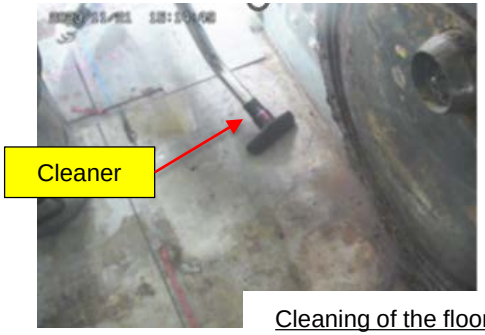
- Adherent materials on the back side of the hatch was cleaned and removed with a scraper.




Removing adherent materials from the back side of the hatch

### [Cleaning of floor of isolation room and removal of hatch opening equipment]

- The floor of the isolation room was cleaned with a cleaner.
- The hatch opening equipment was carried out from the robot carry-in chamber and the site was turned over for the next process.



Cleaning of the floor of isolation room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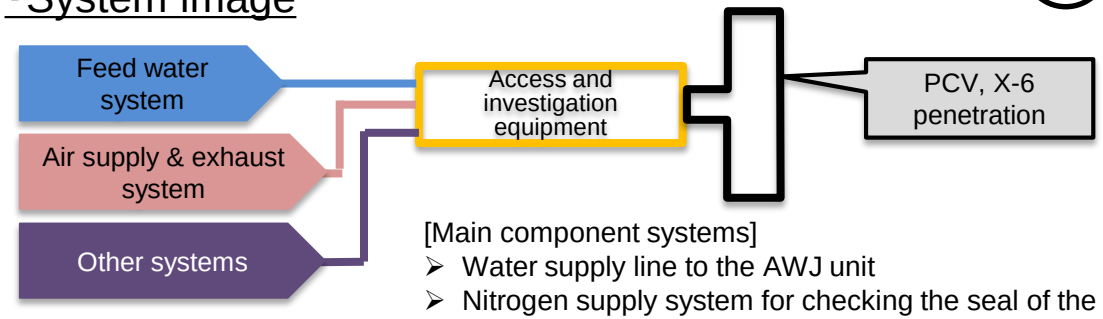
# 4.3 Other ancillary system

## (1) Design and manufacturing

### i. System plan

The system plan was mainly revised as shown in the right bottom table in view of the arrangement/laying plan on-site.

・System image




[Main component systems]

- Water supply line to the AWJ unit
- Nitrogen supply system for checking the seal of the X-6 penetration connection structure flange part
- Nitrogen purge system to the Dexter arm inside the enclosure
- Nitrogen supply system to the air operated valve
- Nitrogen (air) exhaust system
- Enclosure dehumidification and circulation system

・Actual system plan

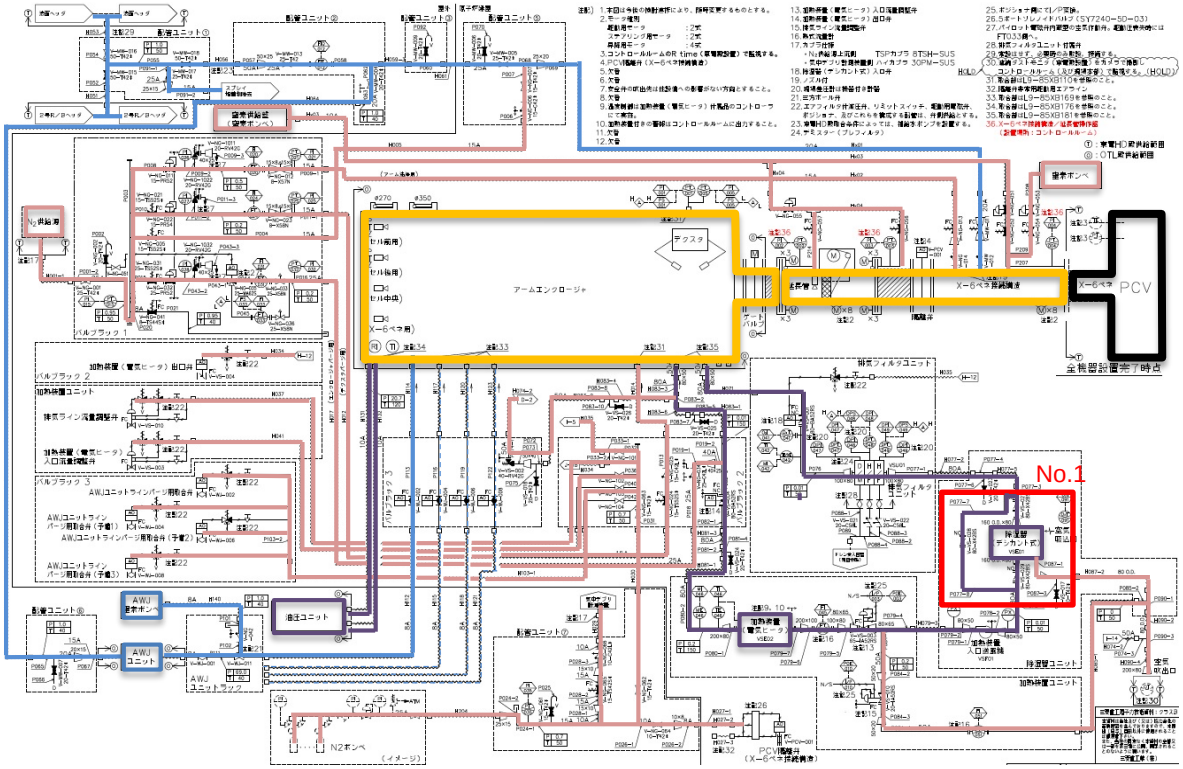



Table: Major revisions to the system diagram

| No. | Changes since FY2022 | Reason for change |
|---|---|---|
| 1 | Addition of line to bypass the humidifier | To improve operating efficiency during depressurization inside the system |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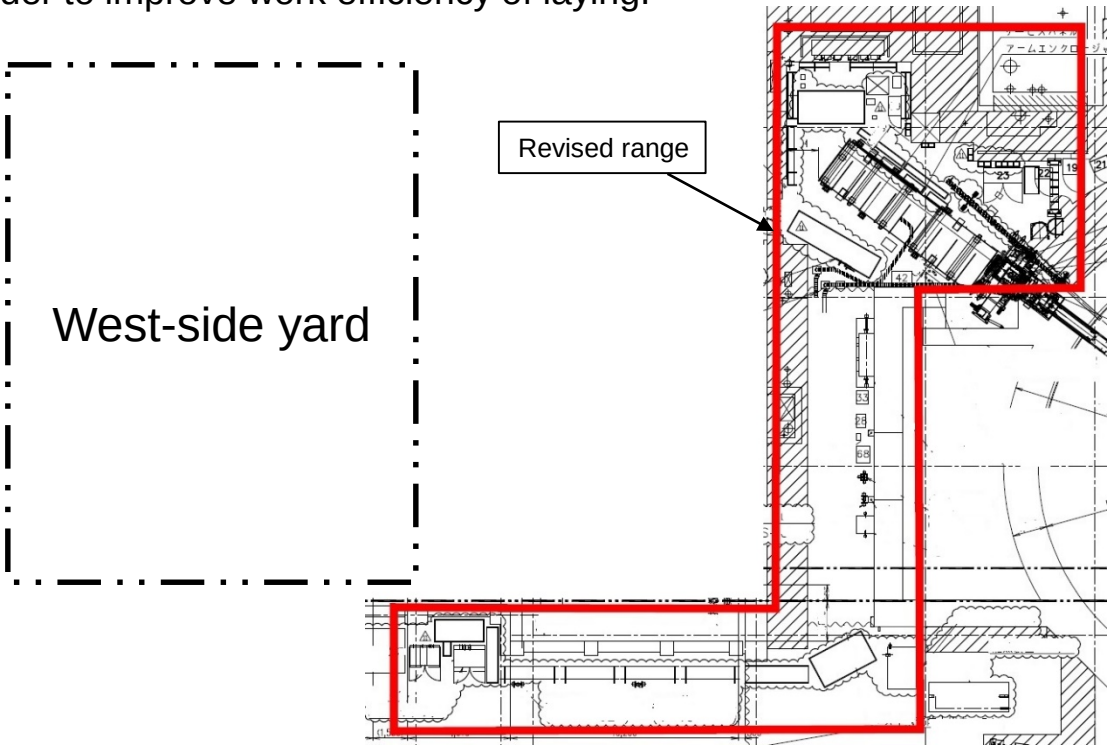
# 4.3 Other ancillary system

## (1) Design and manufacturing

### ii. On-site layout plan

・Based on the result of element test verification for cable and hose laying of ancillary equipment conducted in FY2023, the cable and hose laying route was revised and cable rack was improved in order to improve work efficiency of laying.




### iii. Manufacturing status

・Ancillary equipment was modified in accordance with the revised system design.

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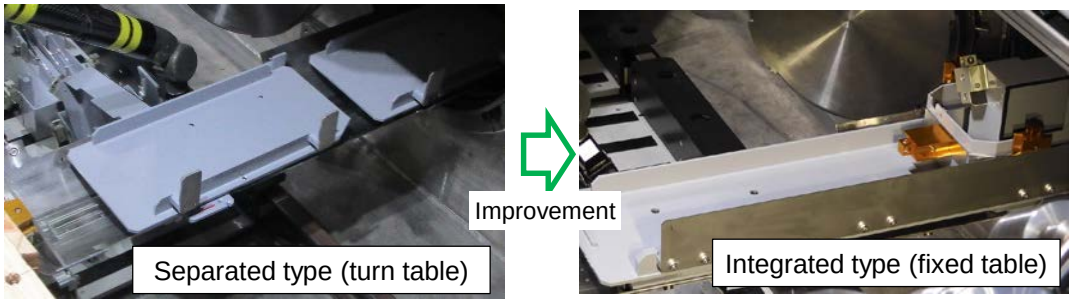
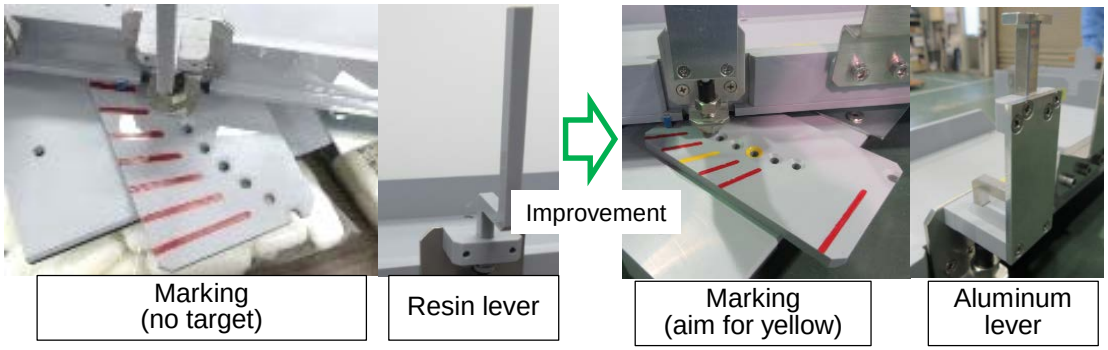
# 4.4 Fuel debris collection equipment

## (1) Dexter arm work verification

**Purpose**

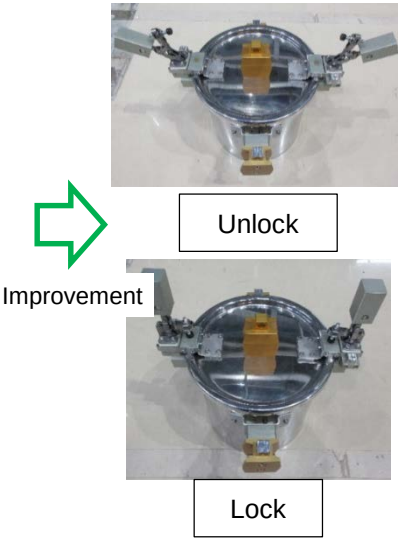
- Of fuel debris collection work, work conducted by the Dexter arm in the enclosure has been verified, and it was confirmed that the series of work are to be conducted by the Dexter arm.
- For work to carry in and carry out fuel debris collection equipment and jigs to and from DPTE port 350 and work to collect waste, efficiency of Dexter arm work can be improved by improving the jigs and waste collection containers.
- Therefore, a verification test was conducted to confirm improvement of Dexter arm work efficiency upon improving jigs and waste collection containers (see below figure).




Marking (no target) | Resin lever | Marking (aim for yellow) | Aluminum lever

**Improvement of jigs (top: integration of fixed table, bottom: turn table)**




Bolt-lock type | Lever-lock type

**Improvement of the waste collection container**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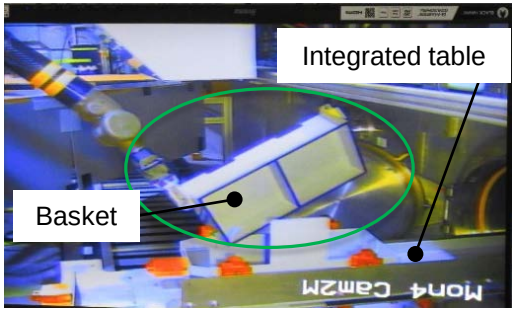
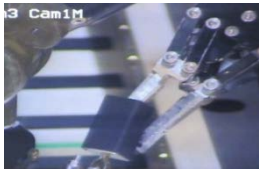
# 4.4 Fuel debris collection equipment

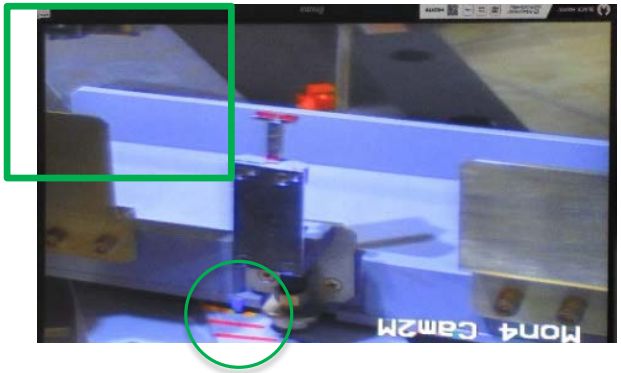
## (1) Dexter arm work verification

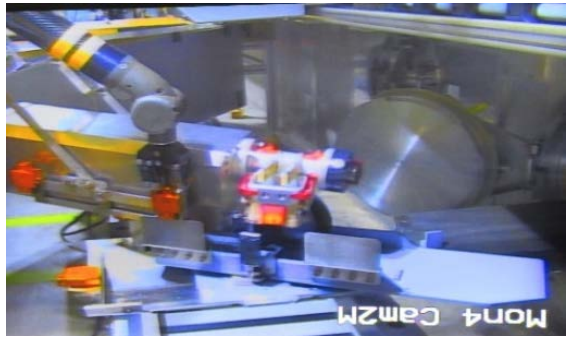
Verification result

- Man-hours related to the turn table was reduced by eliminating the turn table in the drawer for carrying in jigs and using a fixed integrated table, thereby improving work efficiency.
- The turn table in the drawer for carrying in jigs is a type that is turned and fixed with a lever, but it was confirmed that it can be turned to the target rotation angle and be easily locked.
- It was confirmed that the lever-lock type waste collection containers improve work efficiency more than with the bolt-fixed type.

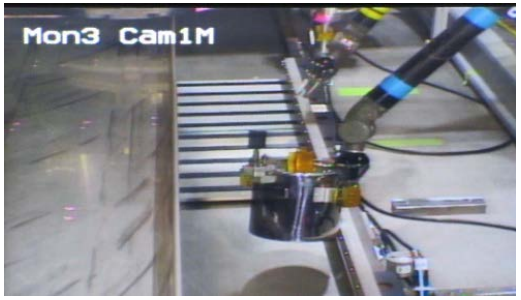







**Confirmation of handling of jigs (top: integrated table, bottom: turn table)**




**Confirmation of handling of waste collection containers**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# 4.4 Fuel debris collection equipment

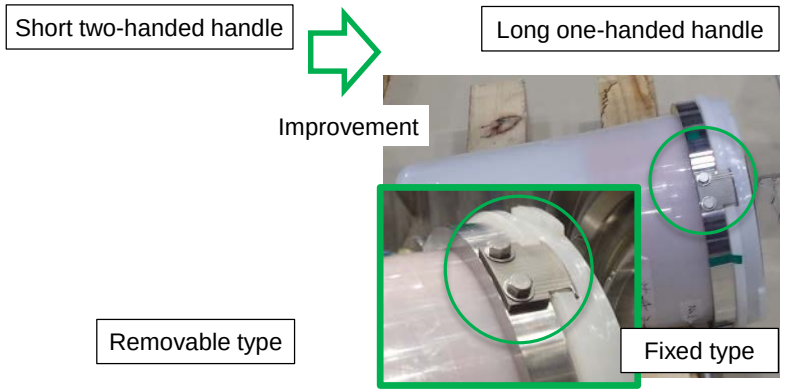
## (2) Improvement of handling of DPTE container 270

**Purpose**

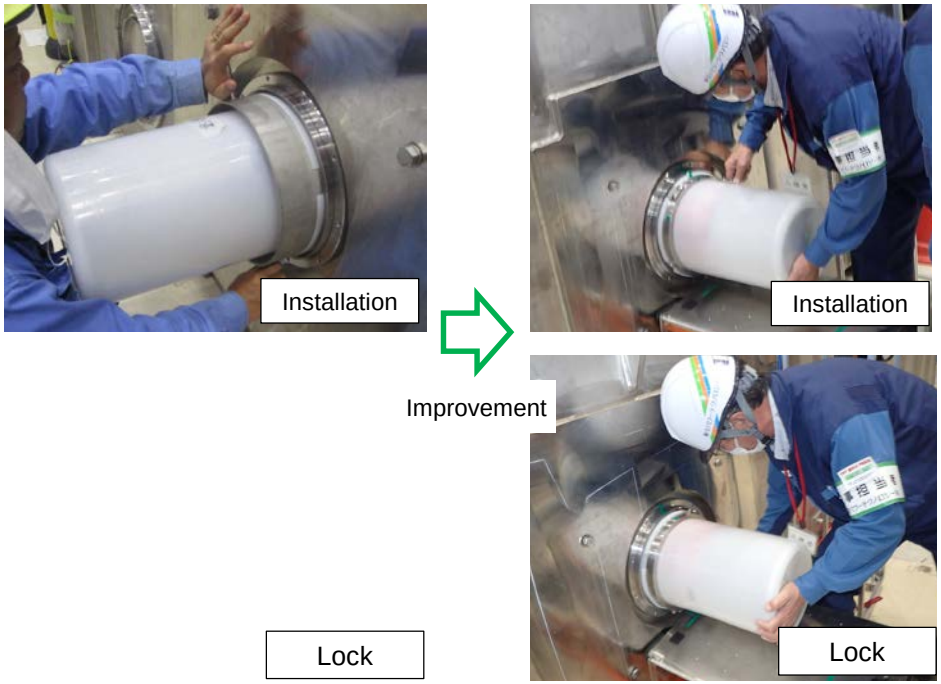
- Of fuel debris collection work, in order to reduce the time (exposure dose) for DPTE container 270 installation/removal work conducted by workers outside the enclosure, the installation handle was improved (see below figure).

**Verification result**

- The respective time required for installation and removal of DPTE container 270 is less than 30sec., and it was confirmed that more than 500mm is expected to be secured between the workers (chest) and debris.




**Improvement of DPTE container 270**




**Confirmation of handling of DPTE container 270**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# 4.4 Fuel debris collection equipment

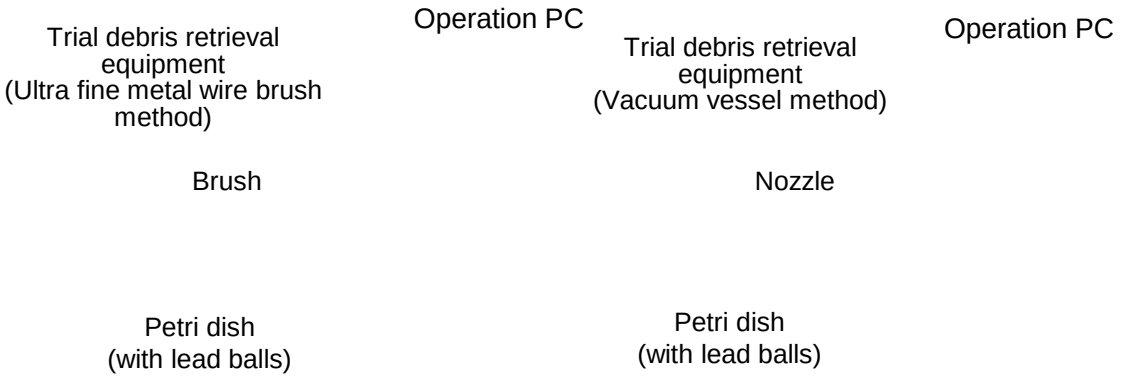
## (3) Collection test for simulated fuel debris (mixture of different diameters)

Purpose

- It is planned to collect around 1g of fuel debris in trial fuel debris collection. Past collection tests were conducted using lead balls simulating fuel debris, and the particle size of the lead balls had the same diameter in each test (single particle size R=0.35mm, 1mm and 2mm).
- The purpose of this test is to collect simulated fuel debris of a mixture of different diameters (gravimetric mixing ratio of R=0.35mm:1mm:2mm is 1:1:1) and confirm that around 1g can be collected.
- The test conditions and test equipment are as follows.

**Test conditions**

| Items | Conditions |
|---|---|
| Temperature | Room temperature |
| Atmosphere | Ambient air |
| Air pressure | Atmospheric pressure |
| Surface condition | Wet |
| Installation surface | Flat (petri dish) |
| Number of repetitions | N=3 (each equipment) |
| Equipment | Brush type and vacuum tube type |




**Test equipment**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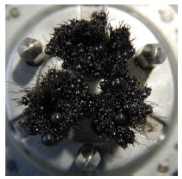
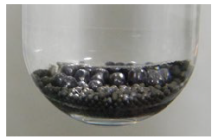
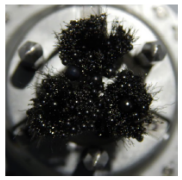
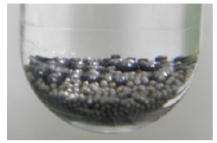
# 4.4 Fuel debris collection equipment

## (3) Collection test for simulated fuel debris (mixture of different diameters)

### Test result

- As a result of the test, the maximum amount of simulated debris collected was 0.67[g], while the planned value was around 1g (required amount is 0.5g). Therefore, it is unnecessary to change the debris collection plan according to this test result.
- The ultra fine metal wire brush method collection equipment was able to collect simulated debris of all particle sizes.
- The vacuum vessel method collection equipment was unable to collect simulated debris with particle size of 2mm. The vacuum vessel method equipment is suitable for collection of sandy debris.

| Equipment | | Collected amount (g) (after drying) | Number of balls collected | | |
|---|---|---|---|---|---|
| | | | Φ0.35 | Φ1.0 | Φ2.0 |
| Ultra fine metal wire brush method | First time | 0.648 | 275 | 71 | 5 |
| | Second time | 0.651 | 152 | 65 | 6 |
| | Third time | 0.529 | 208 | 45 | 5 |
| | Average | 0.609 | — | — | — |
| Vacuum vessel method | First time | 0.502 | Unmeasurable | 36 | 0 |
| | Second time | 0.435 | Unmeasurable | 19 | 0 |
| | Third time | 0.670 | Unmeasurable | 29 | 0 |
| | Average | 0.536 | — | — | — |

| | Brush adapter<br>Collected state of lead balls after the test (at brush tip) | | Vacuum suction tube<br>Collected state of lead balls after the test (bottom of suction tube) |
|---|---|---|---|
| First time | | First time | |
| Second time |  | Second time |  |
| Third time |  | Third time |  |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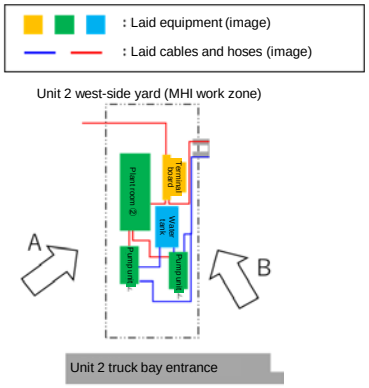
# 4.5 On-site demonstration

## (1) On-site installation and preparation work

The work plan and details of on-site work conducted in the FY2023 PCV internal investigation were organized.
In FY2023, access route establishment work for detailed investigation inside PCV began, and deposit removal work was conducted inside X-6 penetration using the installed deposit removal equipment.

### i. Preparation for deposit removal work

- ✓ Plant room ② containing the transformer, distribution board and connection panel was set up in the Unit 2 west-side yard as preparation for the construction work, and electric lines were additionally installed and connected to the cables installed in FY2022.
- ✓ Feed water tank and filtrate water sharing unit were installed for AWJ (abrasive water jet) work to remove deposits.
- ✓ They were connected to the nitrogen supply valve and filtrate water supply valve, which are building equipment, to enable water supply.
- ✓ Necessary cables and hoses for deposit removal work entered Unit 2 R/B from the Unit 2 west-side yard.




Arrangement in Unit 2 west-side yard

View A: State before work

View B: State after work

View A: State after work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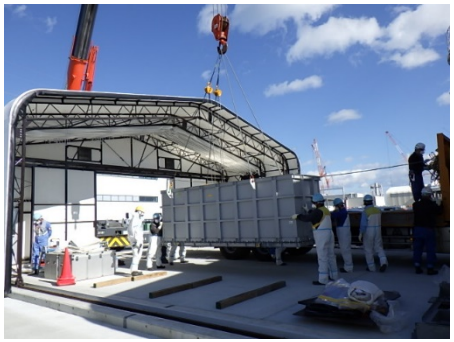
# 4.5 On-site demonstration

## (1) On-site installation and preparation work

**ii. Carrying-in of deposit removal equipment, confirmation of equipment leakage**

- ✓ Deposit removal equipment to be used for the construction work was transported from the MHI Kobe Factory on January 18, 2024 and carried into 1F.
- ✓ Carry-in skid was unpacked and stored in the tent house.
- ✓ On February 8, 2024, the equipment in storage was checked for acceptance condition and passed the leak check.
- ✓ The equipment was installed on the skid for Unit 2 carry-in



Situation at delivery

Installation on the skid for Unit 2 carry-in

Leak check of deposit removal equipment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# 4.5 On-site demonstration

## (1) On-site installation and preparation work

### iii. Carrying-in of deposit removal equipment into R/B and connection to X-6 penetration

- ✓ On February 12, 2024, the deposit removal equipment was transferred to the front of the Unit 2 building, and carried in from the truck bay entrance.
- ✓ Iron plate was laid for carrying-in from the truck bay entrance, and the iron plate was removed after carrying-in.
- ✓ The equipment was transported by hand from the truck bay entrance to the northwest area via the southwest area in the Unit 2 R/B.
- ✓ Later, the equipment was moved inside the robot carry-in chamber after connecting equipment traveling cables. After connecting the cables and hoses for equipment operation via the connector panel installed to the wall of the robot carry-in chamber, the equipment was connected to the X-6 penetration using a hydraulic cylinder.
- ✓ There is sealing function with double O-rings in order to ensure airtightness of the connecting part between the X-6 penetration and equipment. This leak check completes the connection.

Carry-in work from truck bay entrance

Transport inside Unit 2

Connection of cables and hoses for equipment operation

Transfer inside the robot carry-in chamber



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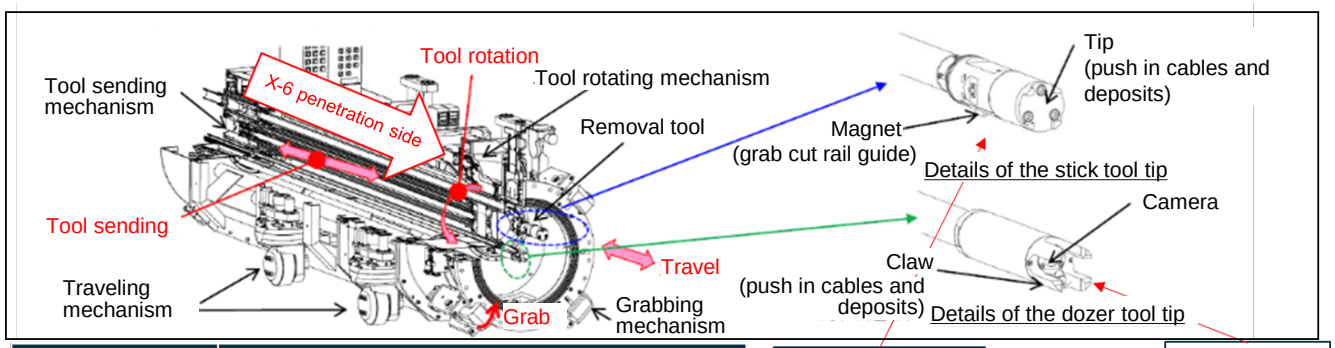
# 4.5 On-site demonstration

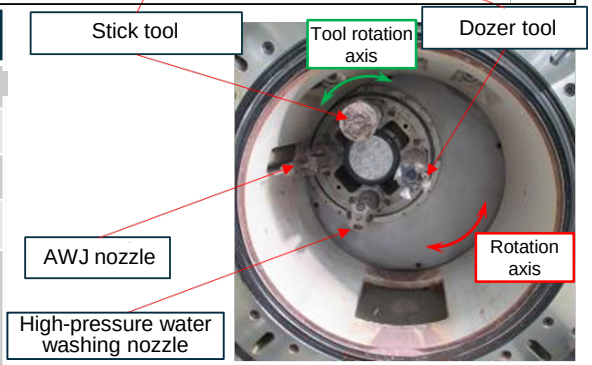
## (1) On-site installation and preparation work

### iv. Deposit removal work

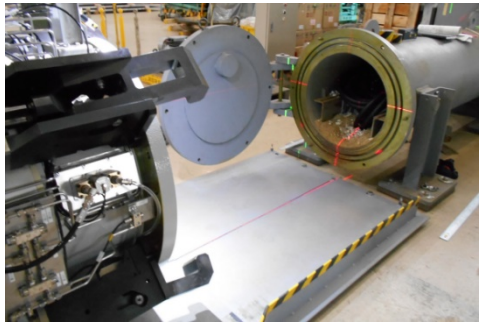
- ✓ The interior was checked after connecting the deposit removal equipment to the X-6 penetration.




| Items | Specifications |
|---|---|
| Dimensions, weight, material | Approx. 1000W × approx. 4100L × approx. 1200H (mm) |
| | Approx. 3.0t |
| | SUS304, SS400, aluminum alloy |
| Function | Deposit removal and structure removal inside X-6 penetration |
| Removal tool | ・AWJ<br>Pressure 245MPa, flow rate 4ℓ/min.<br>・High-pressure water washing<br>Pressure 30Mpa, flow rate 60ℓ/min.<br>・Dozer (attached with camera)<br>・Stick tool (magnet) |




Overview information of the deposit removal equipment, and state inside X-6 penetration after completing high-pressure water washing



Condition of connection of X-6 penetration with equipment at the Kobe Factory

Residual deposits inside X-6 penetration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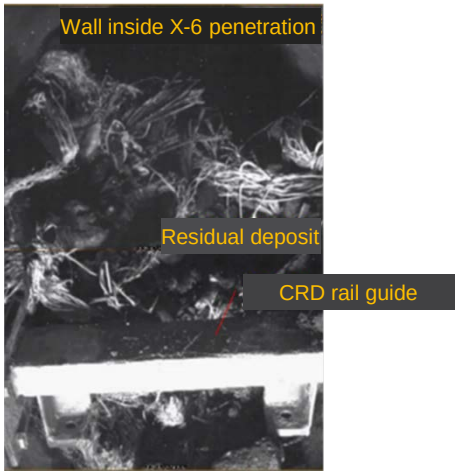
# 4.5 On-site demonstration

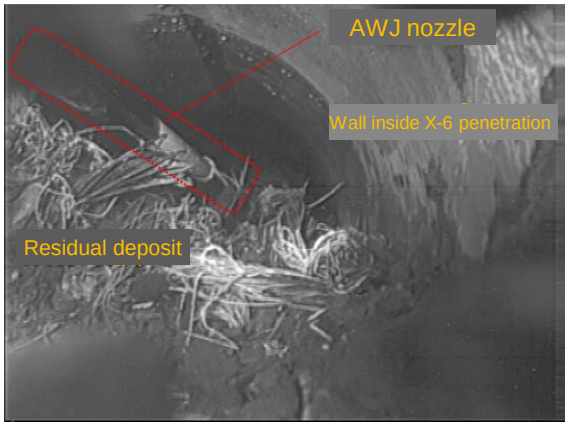
## (1) On-site installation and preparation work

### iv. Deposit removal work

- ✓ The interior of X-6 penetration where deposits remain was washed using the high-pressure water washing nozzle of the deposit removal equipment.
- ✓ Washing was performed after confirming the dust concentration inside PCV by preliminary trial spray.
- ✓ After performing high-pressure water washing, work was shifted to cutting and removing interfering objects such as cables and CRD rail guide remaining in the X-6 penetration with AWJ (abrasive water jet).
- ✓ On March 14, 2024 (at the time of writing this report), trial AWJ spray (8 times in total: trial spray time is 1-5min.) was performed to grasp dust behavior inside PCV due to washing work.
- ✓ It is planned to continue deposit removal work in FY2024 and shift to connection structure installation work after work is completed.




State inside X-6 penetration after completing high-pressure water washing




State inside X-6 penetration during trial AWJ spray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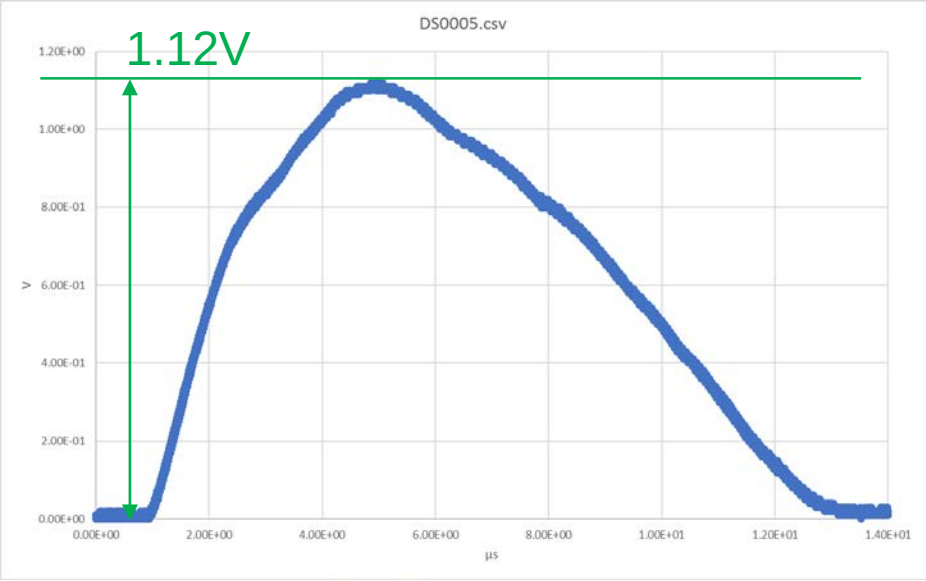
# 4.6 Other

## (1) Review of neutron sensor

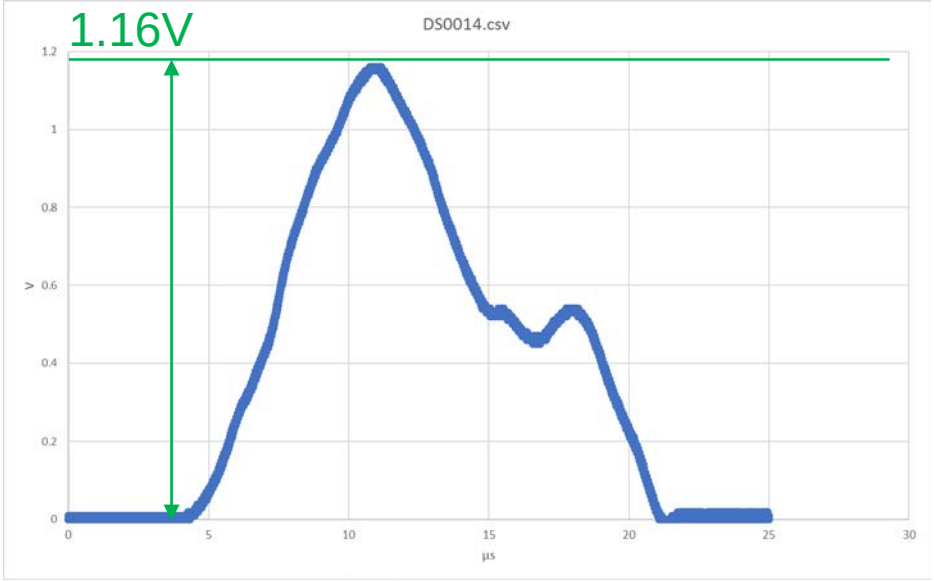
**Verification test in Japan (Nagoya University) (confirmation of pulse waveform)**

[Test overview]

- Pulse waveform due to neutrons was confirmed in a gamma ray environment, and it was confirmed that there are no abnormalities in the waveform (wave height around 2V).




No gamma irradiation




With gamma irradiation

Wave height of the pulse waveform due to neutrons was predicted to be around 2V based on past results, but it was only 1V in the test. It was decided to conduct the test again since it was possible that there were issues in the signal branching due to the test equipment configuration.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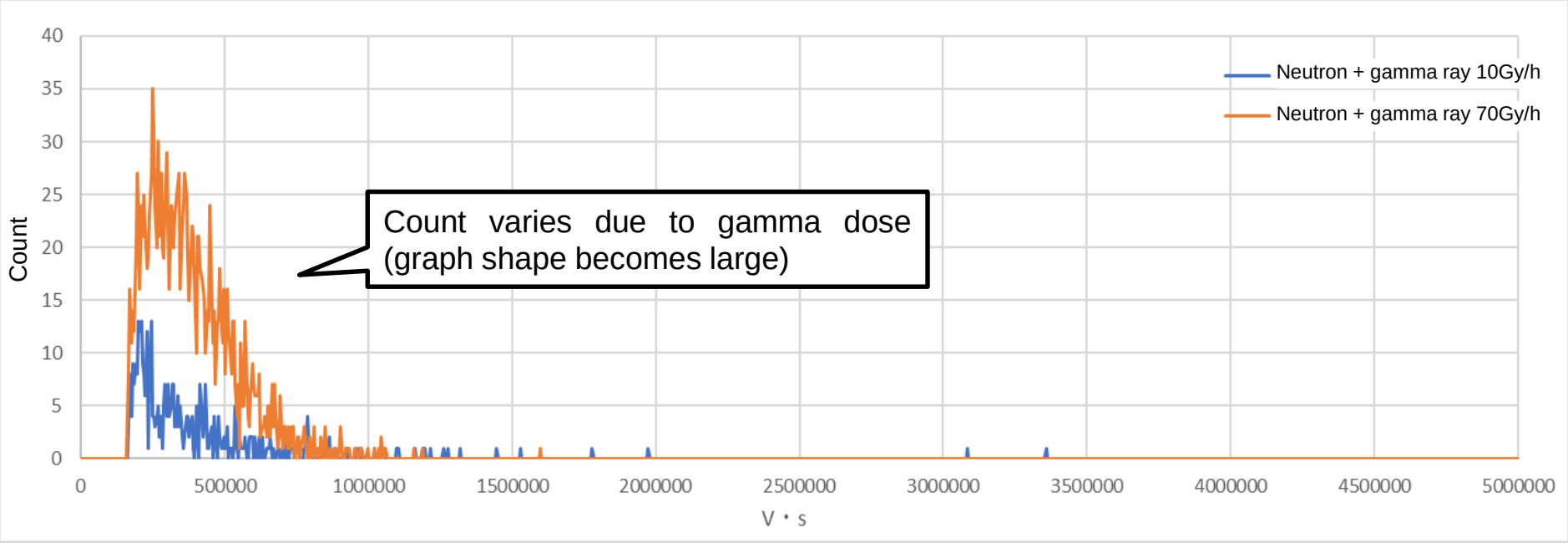
# 4.6 Other

## (1) Review of neutron sensor

**Verification test in Japan (Nagoya University) (confirmation of spectrum)**

[Test overview]

- Neutrons and gamma ray were irradiated at the same time to confirm that signals can be identified.




As a result of measuring neutron radiation with a neutron detection system by varying gamma dose, it was confirmed that the count depends on gamma dose (count will not vary even if gamma dose is changed, if neutrons and gamma rays are distinguished without any problem). However, all the pulses were accumulated in the system (server) at the time of the above spectrum acquisition, and it was confirmed that signals due to neutrons and noise including gamma rays can be distinguished using a different tool.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# 4.6 Other

## (2) Review of gamma sensor

The gamma sensor underwent a stand-alone operational test and operational test being connected to the arm-type access equipment (hereinafter “arm”) at JAEA Naraha Center for Remote Control Technology Development (hereinafter “JAEA Naraha Center”) in FY2022, and improvement work was conducted in the UK based on such results. Later, operation was checked after transportation at JAEA Naraha Center, and it was confirmed to work without any problems.

### Items and result of review of gamma sensor (1/2)

| Large category | Items | Overview and result |
|---|---|---|
| Improvement based on tests at the JAEA Naraha Center in FY2022 | Addition of user interface to operation PC<br>① Integration of gamma sensor rotation function<br>② Simplification of setting parameters during measurement<br>③ Addition of data download function | ① A function was added to easily adjust the rotation angle of the gamma sensor body, which is scheduled to be performed before the irradiation test and passing the X-6 penetration, and it was confirmed to work.<br>② The measurement precision selection function was changed to prevent setting errors (changed to select measurement precision High, Normal or Low), and it was confirmed to work.<br>③ A function to access measurement data was added to the user interface to improve accessibility to measurement data, and it was confirmed to work.<br> |
| | Improvement of measurement time of gamma sensor | • A program that is only used at the development stage was deleted for the radiation measurement time (measurement precision Normal).<br>It was confirmed that measurement time is shortened from approx. 180min. to approx. 120min. |


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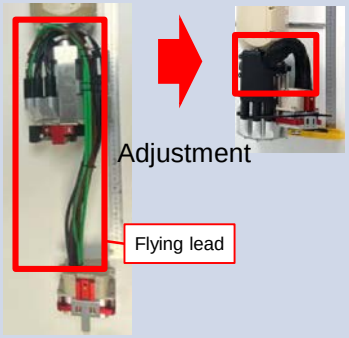
# Items and result of review of gamma sensor (2/2)

<table>
<tr><th>Large category</th><th>Items</th><th>Overview and result</th></tr>
<tr><td>Improvement based on tests at the JAEA Naraha Center in FY2022</td><td>Gamma sensor inspection and parts replacement<br>Since tests have been conducted in the UK and Japan since 2021 for a long period of time, there were concerns about aging degradation of internal parts. Therefore, the sensor was inspected and parts were replaced. In addition, the length of the flying lead connecting the gamma sensor body and connector was adjusted.</td><td>• Parts were replaced, and it was confirmed to work without any problems.<br> 

<br>Confirmation of combination with the arm</td></tr>
<tr><td>Defects of the relay (PSCB-W)<br>Since PSCB-W did not start up when PSCB-W was opened to improve the camera image quality of the gamma sensor, the cause was investigated in parallel with the image quality improvement work. The board failure was located, and the board was replaced for restoration.</td><td rowspan="2">• Operational test combined with the arm was conducted, and it was confirmed to work without any problems.<br> <br>Test combined with the arm</td></tr>
<tr><td>Operational verification test at JAEA Naraha Center<br>The gamma sensor body and PSCB-W were transported to JAEA Naraha Center after being handled in the UK, and operational verification test was conducted after transportation to confirm there are no problems.</td></tr>
</table>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# 5. Summary and Future Plans



(1) Summary of the FY2023 results

○ Access and investigation equipment:

- Tests were conducted with the AWJ tool, and it was confirmed that obstacles of the arm can be cut.
- Arm access to pedestal bottom was tested. It was confirmed that the arm can access the pedestal bottom using VR when passing the platform or intermediate stand which are confined spaces.
- Verification test was conducted for laying of cables and hoses considering order of laying, bundling method and use of cable roller, and worker exposure was reduced and construction work quality was improved for future on-site work.

○ Opening the X-6 penetration hatch:

- Robot carry-in chamber was set up and hatch opening equipment was carried in.
- Stuck bolts of the X-6 penetration lid were treated and hatch opening was completed.
- After opening the hatch, adherent materials on the flange surface were removed and final surface cleaning was performed.

(2) Plan for FY2024

- Mock-up tests and trainings on the access and investigation equipment will continue to be conducted at the Naraha Center for Remote Control Technology Development, and on-site demonstrations will be started afterwards.
- To establish the access route, deposits in X-6 penetration will continue to be removed and X-6 penetration connection structure and extension pipe will be installed.



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# Supplementary materials

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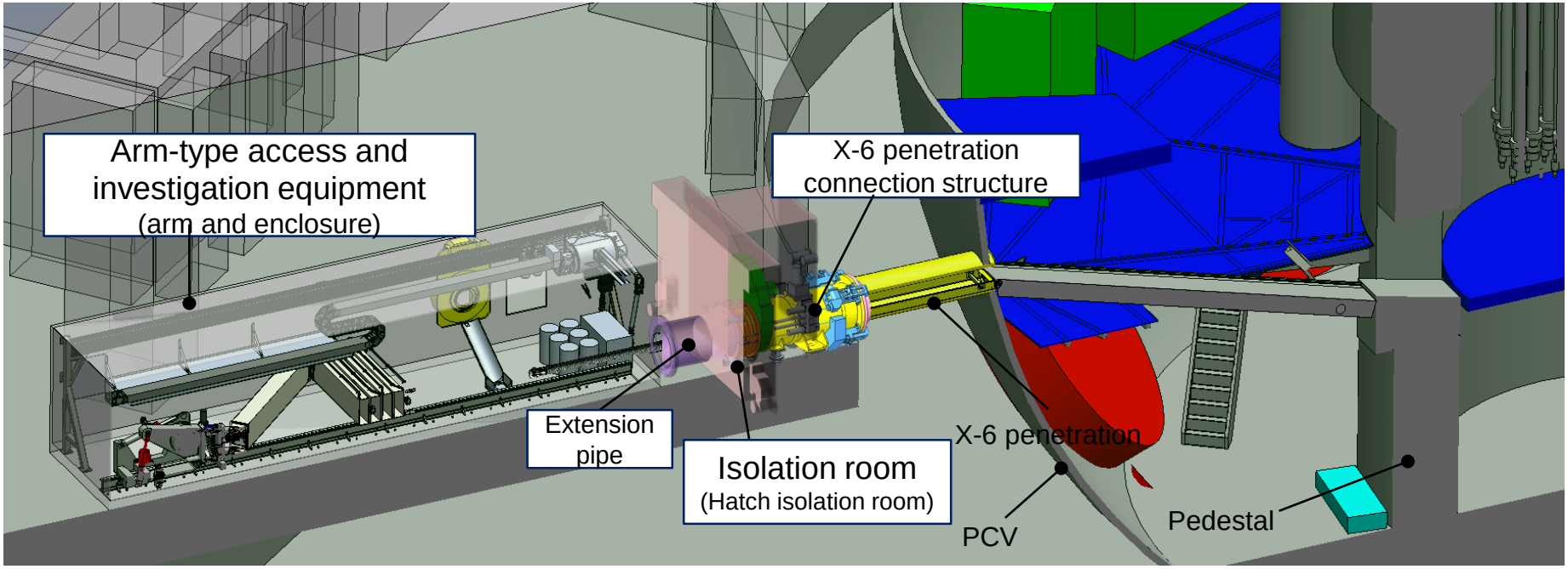
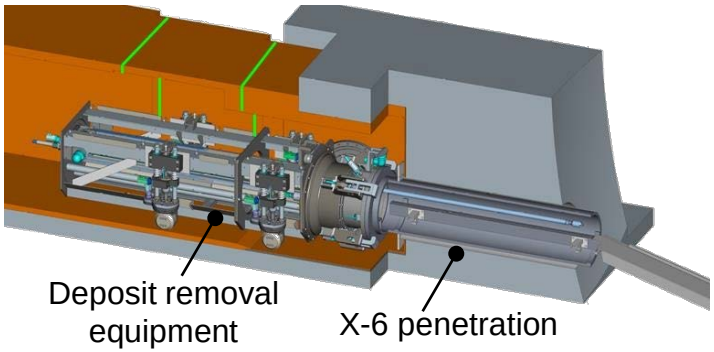
# Targets of development




| Equipment | Main purpose |
|---|---|
| Arm-type access and investigation equipment | Acquiring data about the inside of PCV (by mounting sensors), removing obstacles (by mounting tools) |
| X-6 penetration connection structure | Constructing PCV boundary and ensuring passing of arm (by mounting isolation valve) |
| Extension pipe | Ensuring shielding and passing of arm |
| Isolation room | Constructing the PCV boundary when the X-penetration lid is open (before installing the X-penetration connection structure), and shielding |
| Deposit removal equipment | Removing deposits from inside the X-6 penetration |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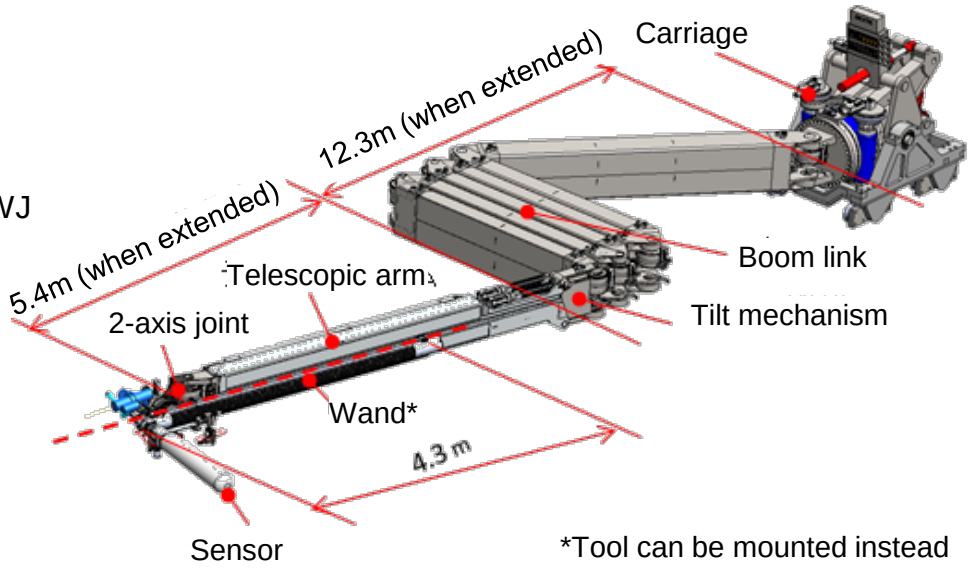
# Access and investigation equipment



[Specifications and structure of the arm-type equipment (hereinafter referred to as “arm”)]

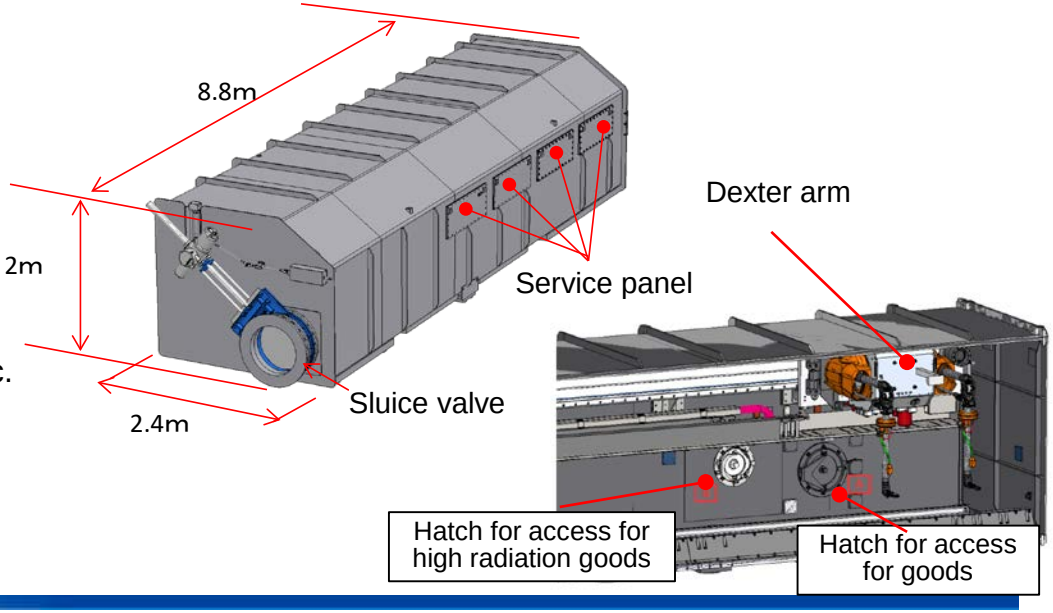
- ✓ Sensor that can be mounted: 10kg or less
- ✓ Tools to be mounted: Cutting and grabbing tool, AWJ tool
- ✓ Arm length: approx. 18m (excluding wand)
- ✓ Pressing force: 400N
- ✓ Positioning accuracy: ±100mm
- ✓ Accumulated dose: 1MGy
- ✓ Accessories
  Camera and lighting




*Tool can be mounted instead

[Arm enclosure specifications and structure]

- ✓ Outer plates Ceiling and lateral plate: thickness 10mm
  Bottom plate: thickness 25mm
- ✓ Mass: approx. 30t
- ✓ Main material: Stainless steel
- ✓ Design pressure: -5 to +10kPaG
- ✓ Accessories
  Dexter arm, sluice valve, camera, lighting, etc.



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