

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 FY2024

June 2025

International Research Institute for Nuclear Decommissioning (IRID)

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1. Background and Purpose of the Project

[Background]

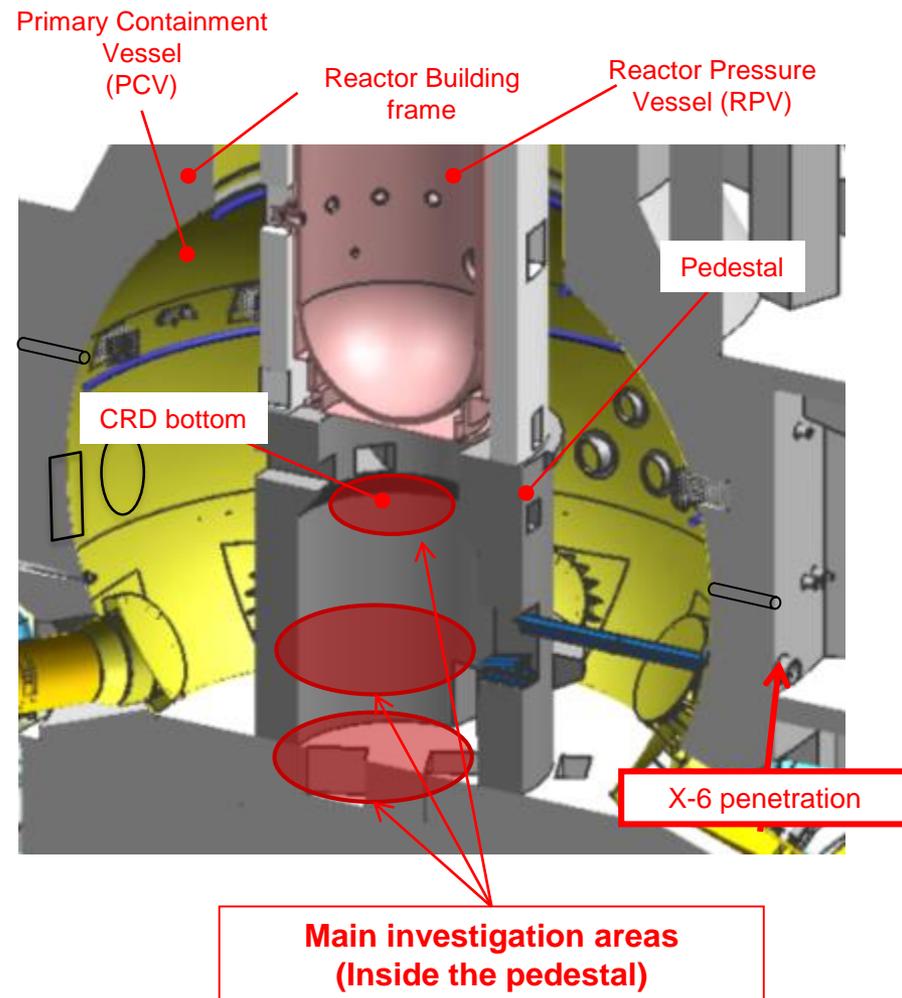
As a result of the investigation inside Unit 2 PCV conducted in January 2018, pebble-like and clay-like deposits were found all over the bottom inside the pedestal.

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



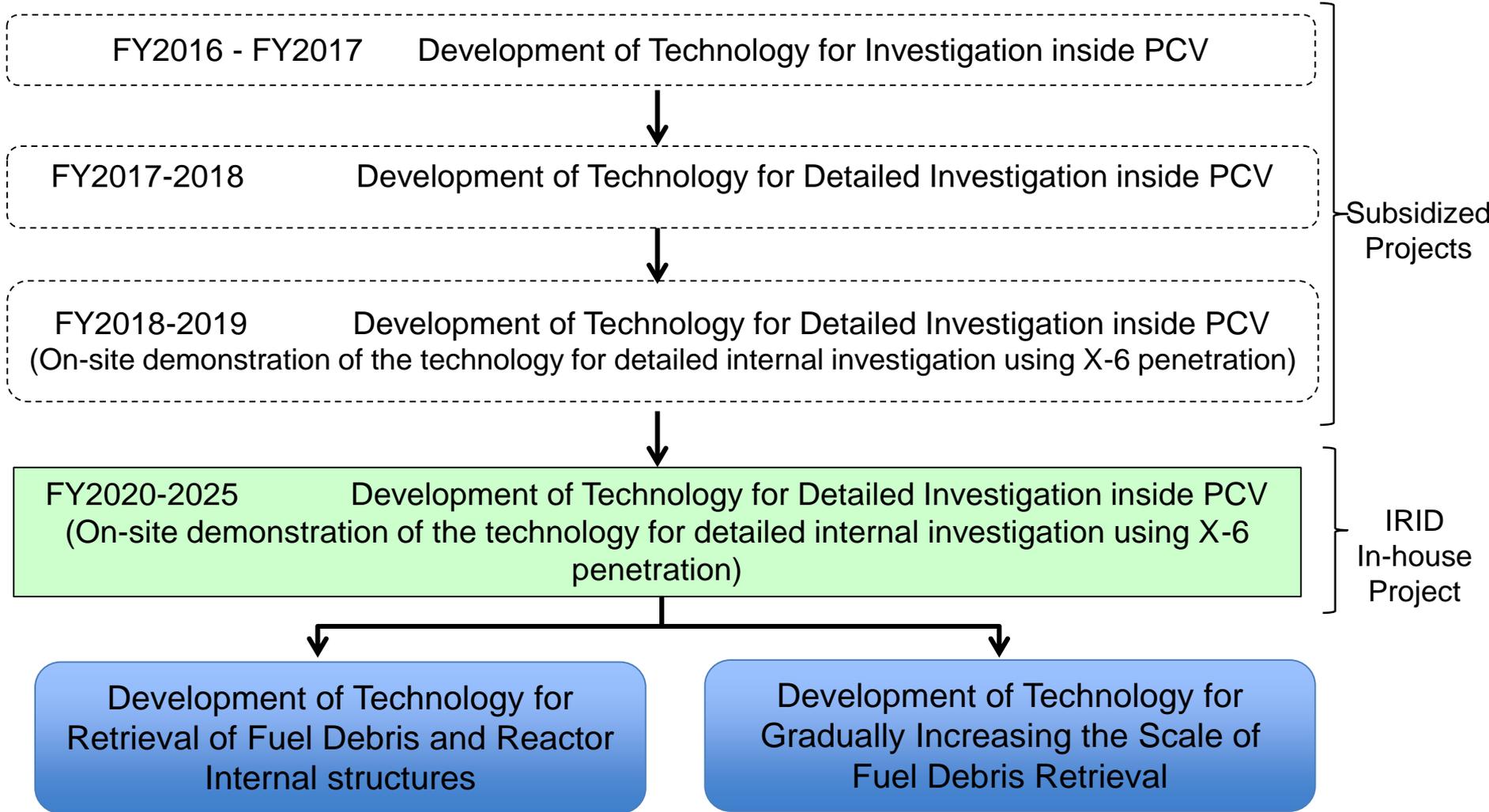
[Purpose]

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 the developed technology.

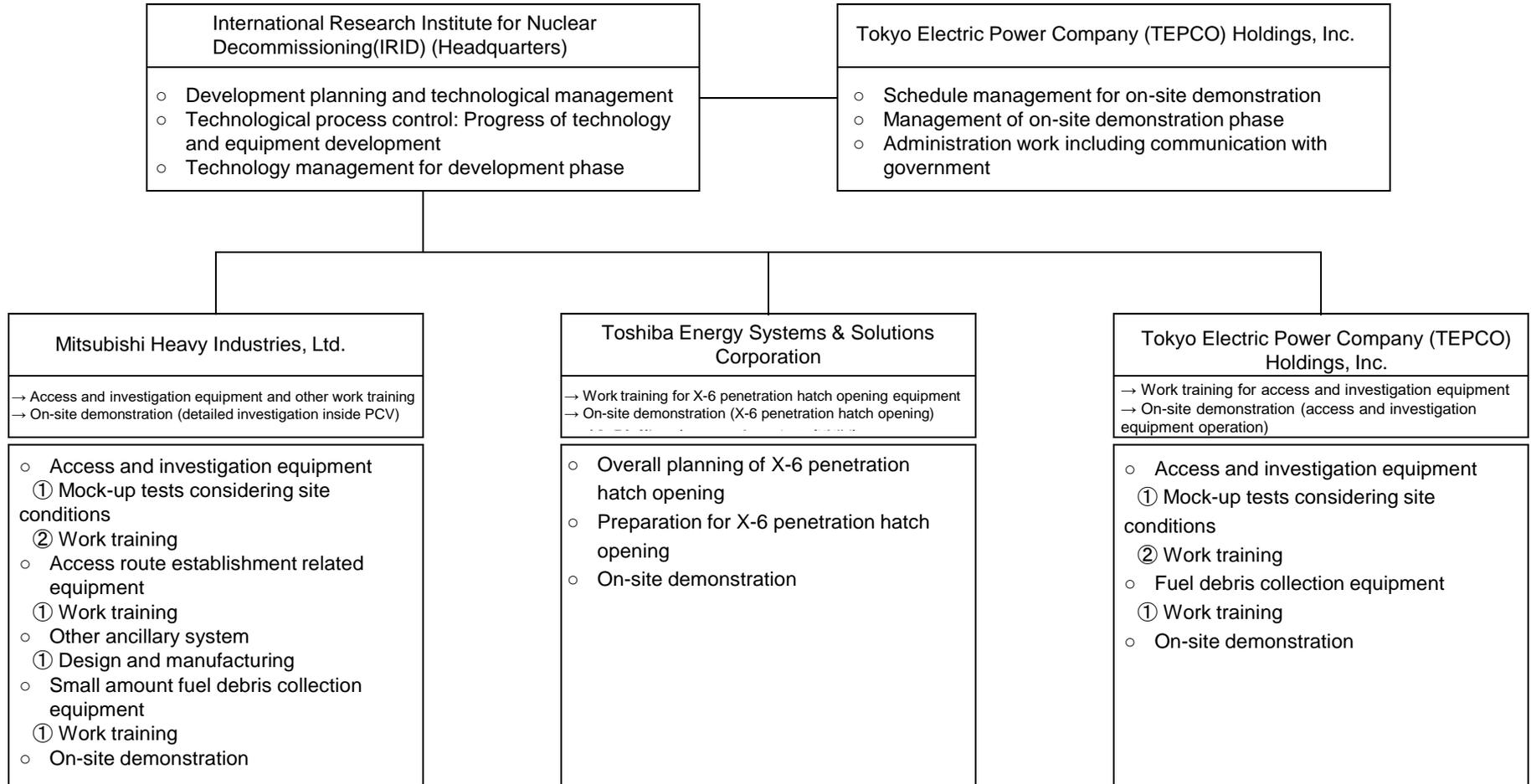


[PCV cross-section and overview of the areas to be investigated]

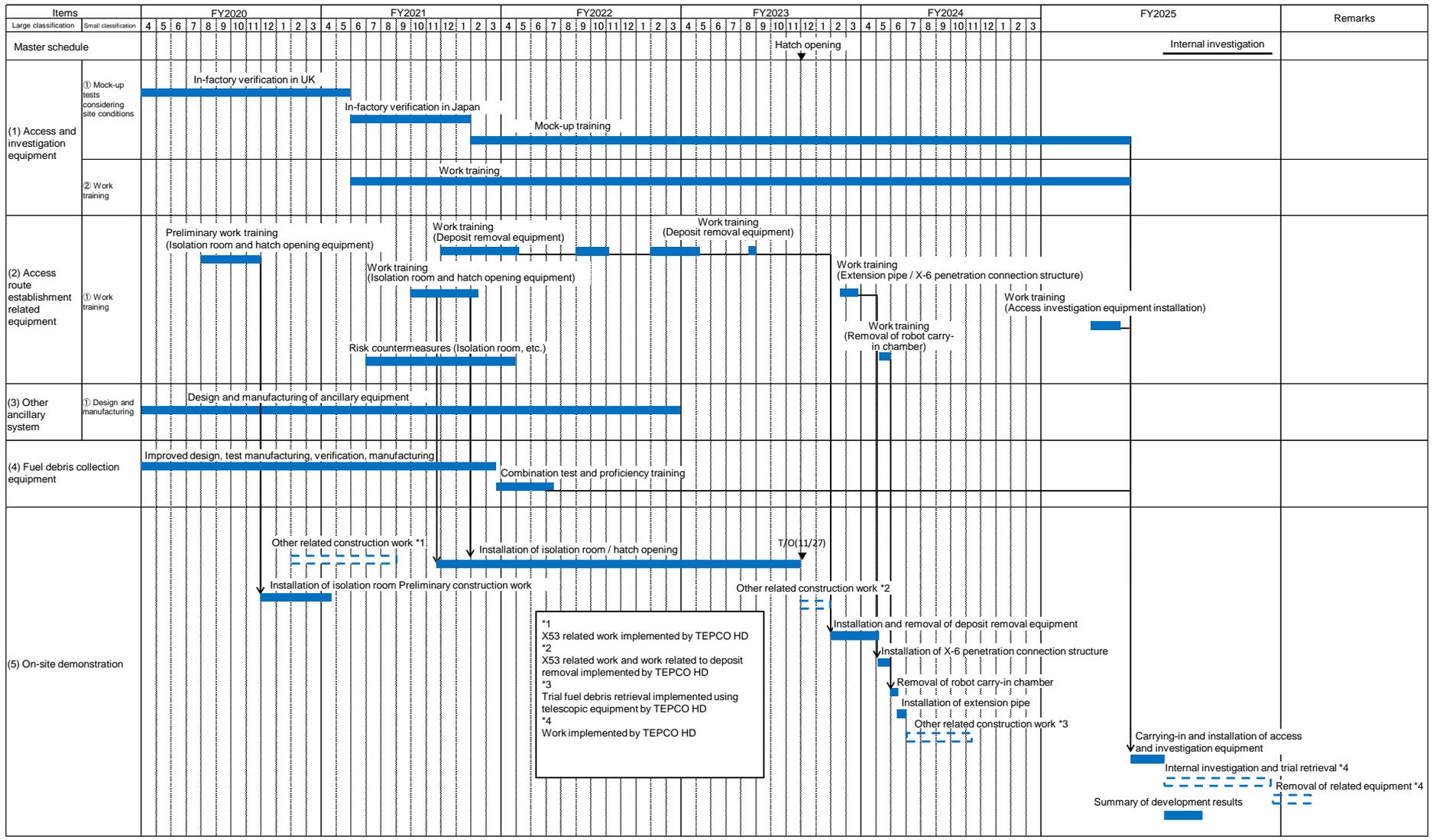
2. Positioning of the Project



3. Project Organization and Implementation Schedule: Project Organization



3. Project Organization and Implementation Schedule: Implementation Schedule



4. Implementation Details and Results

4.1 Access and investigation equipment

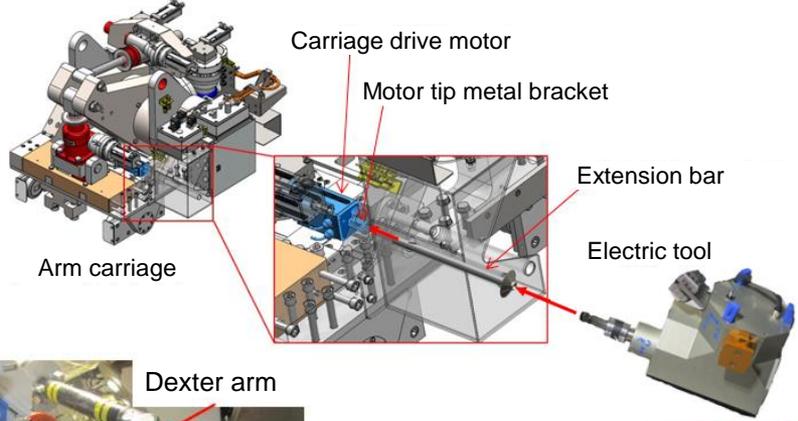
(1) Mock-up tests considering site conditions (i) Arm verification test

(a) Emergency arm retrieval test a. Carriage failure assumption test

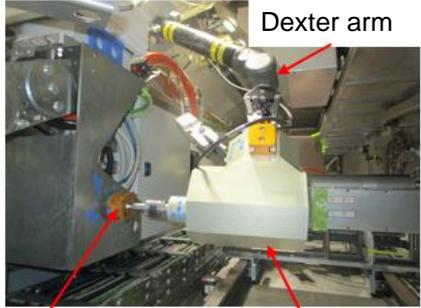
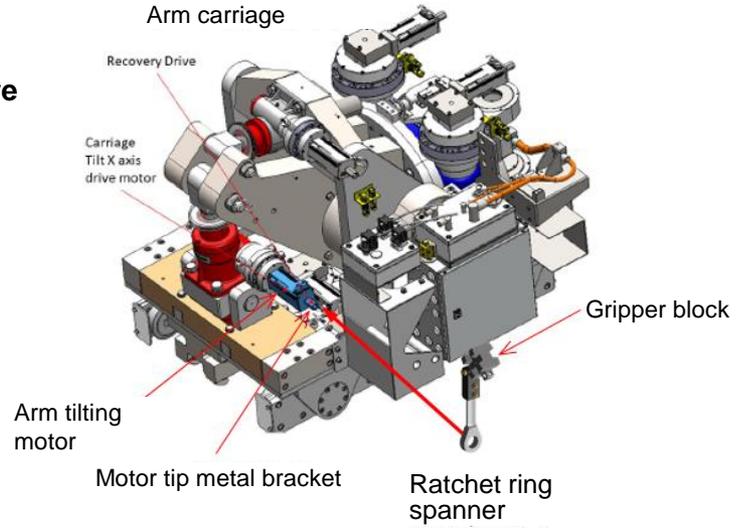
- Tests were conducted assuming cases of failure of the arm carriage drive motor or the tilt motor at the time of inserting the arm into the PCV.
- When the motor fails, a jig / tool is inserted into the metal bracket at the tip of the motor by means of remote operation of the dual arm type manipulator (hereinafter, "Dexter arm") and the motor shaft is rotated to start the motor.

Test result

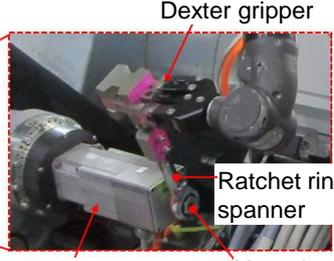
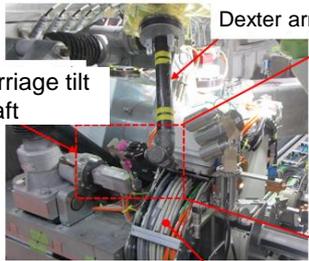
Drive motor (forward/reverse drive motor) failure



Tilt motor failure



The motor shaft was rotated with the help of an electric tool and it was confirmed that the carriage can travel



The ratchet ring spanner was inserted into the motor shaft and rotated, and it was confirmed that the carriage can tilt.

4.1 Access and investigation equipment

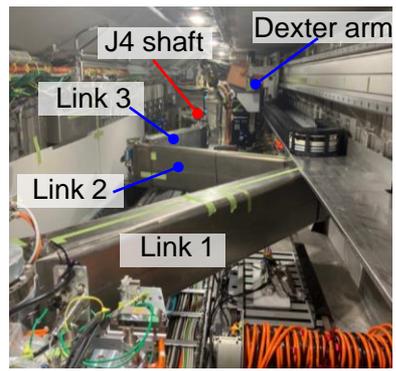
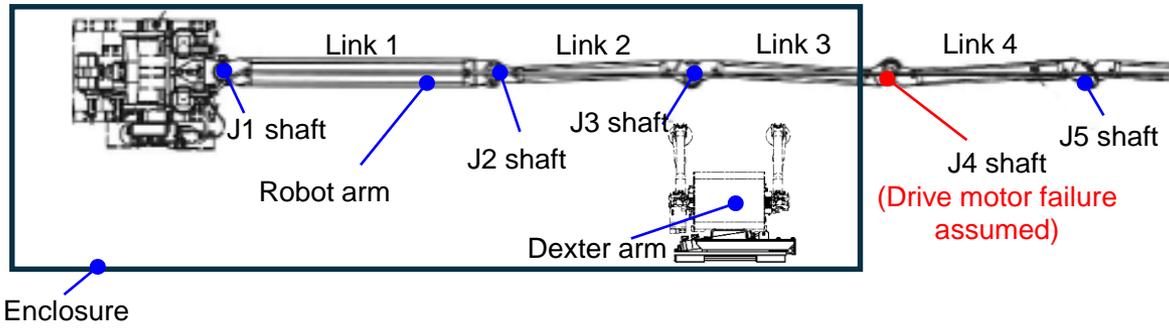
(1) Mock-up tests considering site conditions (i) Arm verification test

(a) Emergency arm retrieval test b. Link failure assumption test

- Tests were conducted assuming failure of the motor for the link joints section when the arm is deployed inside the PCV.
- After the motor fails, the joints are released (freed up), the arm is folded and retrieved.

| | Shafts without a clutch (Shafts J1 to J3) | Shafts with a clutch (Shafts J4 to J7) |
|--|--|---|
| Means for releasing the joints | Joints are released using the Dexter arm | Released by remotely operating the clutch |
| Means for folding and retrieving the arm (links) | The link part is folded and retrieved using the motor that is functioning normally and the Dexter arm. | |

Test results (Typical example)
Emergency retrieval test assuming link part (J4 shaft drive motor) failure



Retrieval status (Links being folded)

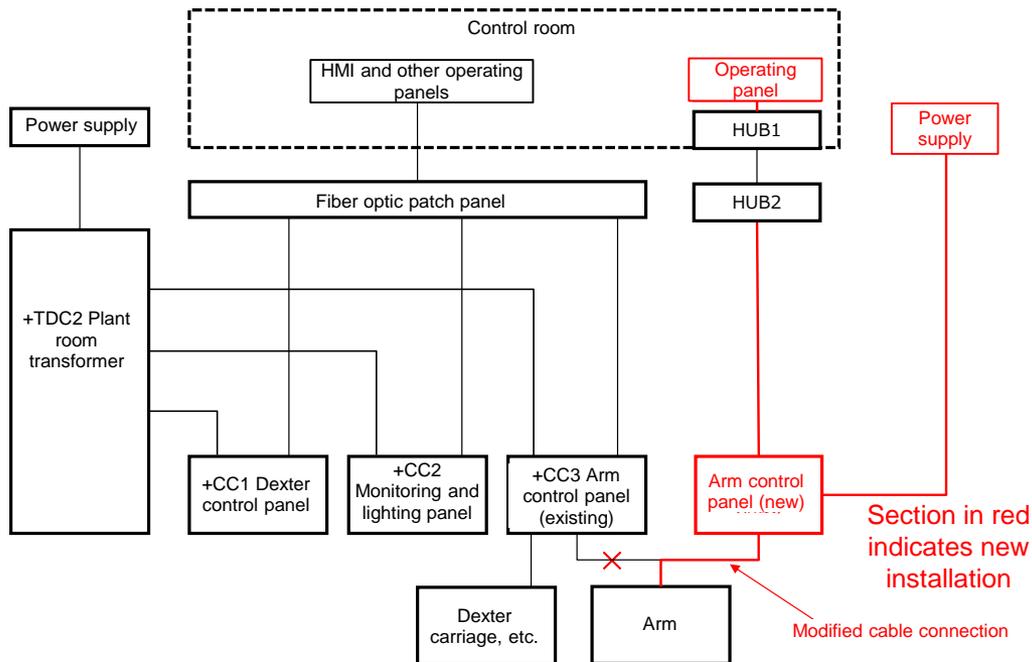
- It was verified that the arm can be retrieved into the enclosure by releasing the joints, and retracting (folding) the link part by remotely operating the shaft that is functioning properly and using the Dexter arm.

4.1 Access and investigation equipment

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

(b) Enhancement of arm positioning accuracy, etc. a. Panel installation, and verification of the operation of the shafts

- The control system was improved as part of risk reduction, so that a fault in the control panel at the site, etc. can be addressed promptly and restored.
- Only the control system for the arm was improved. The Dexter arm including the dexter arm carriage is still controlled using the existing control panel.
- In the improved system, the method for controlling the motor was changed from output shaft resolver control to motor shaft resolver control in order to enhance positioning accuracy of the tip of the arm.
- The operation of the shafts was verified by conducting a trial run of the control panel and adjusting the control parameters.



Control panel system configuration



Arm control panel

4.1 Access and Investigation Equipment

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

(b) Enhancement of the arm positioning accuracy, etc. b. Performance evaluation

- A comparative evaluation of the performance before and after the improvement was conducted.
- Evaluation items are provided in the table below.

| Items | Evaluation point | Comparison |
|---------------------------------|---|--|
| Performance | Positioning accuracy and repeatability | <ul style="list-style-type: none"> ● Measuring and comparing the position repeatability when the arm is deployed ● Measuring the amount of deviation of the arm tip from the reference line using laser during each Move (each step of arm movement), and checking repeatability by performing 3 back-and-forth cycles ● Measuring the actual equipment and the reference line, and the actual equipment and the VR display |
| | Repeatability of the HP | <ul style="list-style-type: none"> ● Measuring and comparing position repeatability when the arm returns to the HP (home position) ● Fitting the mastering jig and verifying whether it is at the mechanical zero position |
| | Erroneous operation | <ul style="list-style-type: none"> ● Comparing the presence of software bugs that hinder operation and the frequency of their occurrence |
| | Movement speed | <ul style="list-style-type: none"> ● Comparing the time required to move from HP to Pose2 (fully deployed position) |
| | Operability | <ul style="list-style-type: none"> ● Comparing the compatibility (ease of use) of the man-machine interface for the operator |
| Robustness (Troubleshooting) | Understanding the design philosophy, technical transparency | <ul style="list-style-type: none"> ● Comparing the extent of a black box element. In other words, ascertaining how far the design philosophy of the electrical hardware and software is understood, so as to be able to promptly address unforeseen issues. |
| | Availability of internal components of the control panel | <ul style="list-style-type: none"> ● Comparing the availability of the components of the control panel so as to be able to promptly address control panel failure |
| Risk | New errors caused by introduction of new systems | <ul style="list-style-type: none"> ● Verifying whether new errors occur in the control system after improvement. In particular, checking the following points <ul style="list-style-type: none"> • Impact of the motor shaft resolver control • Impact of the interlock with the existing control panel (Dexter arm control unit) |
| Running cost | Cost involved in dispatching SV | <ul style="list-style-type: none"> ● Comparing the cost (SV (Technical Support Engineer) dispatch cost (person / day)) involved in Naraha verifications and on-site construction works in the future |

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
- (b) Enhancement of the arm positioning accuracy, etc. b. Performance evaluation

■ Performance (Positioning accuracy and repeatability)

| After improvement | Deviation of the actual arm from the reference line | Deviation of the actual arm from the VR** | Before improvement | Deviation of the actual arm from the reference line | Deviation of the actual arm from the VR | Evaluation |
|------------------------|---|---|------------------------|---|---|---|
| POSE2 (Fully deployed) | 4mm (n=3) | 0mm | POSE2 (Fully deployed) | 75mm (n=8) | 60mm (n=8) | Performance enhancement through improvement |
| Maximum deviation | 15mm (n=3) | 6mm (Inside the penetration) | Maximum deviation | 92mm (n=8) | 98mm (n=8) | |

** Deviation is minimized through correction “n” stands for the number of tests

■ Performance (Repeatability of the HP)

| After improvement | Whether the jig fits | Shift in position if the jig doesn't fit | Whether the jig fits | Shift in position if the jig doesn't fit | Before improvement | Whether or not the jig fits | Shift in position if the jig doesn't fit | Evaluation |
|-------------------|-----------------------|--|-----------------------|--|--------------------|-----------------------------|--|---|
| | 1 st round | | 2 nd round | | | | | Performance enhancement through improvement |
| Y1 | ○ | — | ○ | — | Y1 | ○ | — | |
| Y2 | x | 16** | x* | 0.4 | Y2 | x | 47 | |
| Y3 | ○ | — | ○ | — | Y3 | x | -51 | |
| Y4 | x* | 4 | x* | 1 | Y4 | x | 1 | |
| Y5 | ○ | — | ○ | — | Y5 | x | -60 | |
| Y6 | ○ | — | x* | 2 | Y6 | x | -1 | |
| TY | ○ | — | ○ | — | TY | x | -9 | |

*The jig does not fit, but as the deviation is 10mu or less, it can be calibrated and used without any issues.
 **The output shaft resolver value (value of the resolver installed at a position not mediated by a reducer) is reproduced (error 2mu). The deviation of the motor resolver is presumed to have been caused by mechanical aging degradation of the Y2 shaft drive unit, and is planned to be verified during future maintenance.

The unit for shift in position is mu (motor unit)
 1mu=360/65536 ≈ 0.0055°

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
- (b) Enhancement of the arm positioning accuracy, etc. b. Performance evaluation

■ Performance (Erroneous operation)

| After improvement | Details | Before improvement | Details | Evaluation |
|-------------------|------------------------------------|--------------------|---|--------------------|
| Bug | There are no bugs during operation | Bug | The bug wherein 1 shaft does not operate during a 3-shaft operation is unresolved (Several times during Pose2 deployment). In addition, there are minor bugs that do not cause major hindrance to the operation | Bugs were resolved |

■ Performance (Movement speed)

| After improvement | Details | Before improvement | Details | Evaluation |
|-------------------|---------------------------------|--------------------|---------------------------------|------------|
| Speed | 61 minutes from the HP to Pose2 | Speed | 62 minutes from the HP to Pose2 | Equivalent |

■ Performance (Operability)

| After improvement | Details | Before improvement | Details | Evaluation |
|-------------------|----------------------------------|--------------------|--|------------|
| Operability | Equivalent to before improvement | Operability | Operation is possible without any major issues | Equivalent |

4.1 Access and investigation equipment

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

(b) Enhancement of the arm positioning accuracy, etc. b. Performance evaluation

■ Robustness

| After improvement | Details | Before improvement | Details | Evaluation |
|---|---|---|--|--|
| Understanding the design philosophy, technical transparency | Both, hardware and software, are domestically manufactured. Thus, there is no black box element with respect to technology. | Understanding the design philosophy, technical transparency | The supplier has disclosed information to a certain extent. But there are aspects of the design philosophy that are still unclear (black box). | Robustness was enhanced through improvement. |
| Availability of components | The components are manufactured in Japan and can be promptly acquired. | Availability of components | Some of the components (slot and driver) of the control panel are not available as they are no longer in production. | |

■ Risk

| After improvement | Details | Before improvement | Details | Evaluation |
|------------------------------|---|------------------------------|---|--------------------------------------|
| Motor shaft resolver control | No issues in the motor shaft resolver control | Motor shaft resolver control | Controlled by means of the output shaft resolver without any issues | Risk was lowered through improvement |
| Interlock | No critical errors | Interlock | No major interlock errors that would render the system inoperable | |
| Other | No critical errors, bugs | Other | No critical errors, bugs. (However, minor bugs still remain) | |

■ Running cost (Comparison of cost per month)

| After improvement | Details | Before improvement | Details | Evaluation |
|-------------------------------|---|-------------------------------|--|----------------------------------|
| Dispatching SV (Person / day) | 0.3 persons × 20 days / month = 6 persons / day / month | Dispatching SV (Person / day) | 1.5 persons × 20 days / month = 30 persons / day / month | Cost reduced through improvement |

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
 (b) Enhancement of the arm positioning accuracy, etc. b. Performance evaluation

■ Positioning accuracy, etc. was enhanced through improvement of the arm control system.

| Items | Evaluation point | Evaluation |
|---------------------------------|---|-------------------------|
| Performance | Positioning accuracy | Performance improvement |
| | Repeatability of the HP | Performance improvement |
| | Erroneous operation | Bugs were resolved |
| | Movement speed | Equivalent |
| | Operability | Equivalent |
| Robustness (Troubleshooting) | Understanding the design philosophy, technical transparency | Robustness improved |
| | Availability of components | Risk reduced |
| Risk | New errors caused by introduction of new systems | Risk reduced |
| Running cost | Cost involved in dispatching SV (person / day) | Cost reduced |

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test (c) One through test a. VT sensor* installation conditions

Test conditions

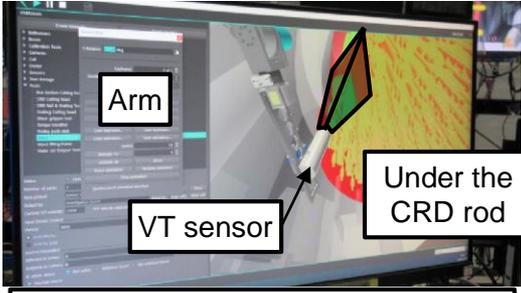
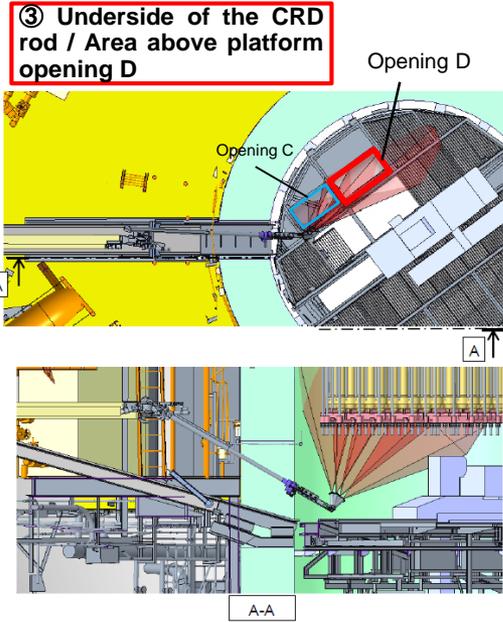
- > The internal area was accessed (the arm was moved to the inside of the pedestal and images were captured) by remote operation while adjusting the command values for moving the joints, based on the information on the field of view of the radiation resistant camera and the VR display.

Test results

- > Clear images of the top portion of the platform (CRD opening, underside of the CRD rod, etc.) and the bottom portion of the pedestal were obtained. The images of the underside of the CRD rod are provided in the table below as typical examples.

| Classification | Imaging target | Installed sensor |
|----------------------------------|---|--------------------------|
| Top portion of the platform (PF) | ① CRD opening entrance / Terminal box | For short- and mid-range |
| | ② Underside of the CRD rod / Area above PF opening C | |
| | ③ Underside of the CRD rod / Area above PF opening D | |
| | ④ Underside of the CRD rod / Area above slit opening | |
| | ⑤ Underside of the CRD rod / Area above the CRD exchanger | |
| Pedestal Bottom | ⑥ Vicinity of the center | For long-range |
| | ⑦ Opening for workers | |

Typical examples



Studying the pose based on VR

* Camera for imaging; The same applies hereinafter

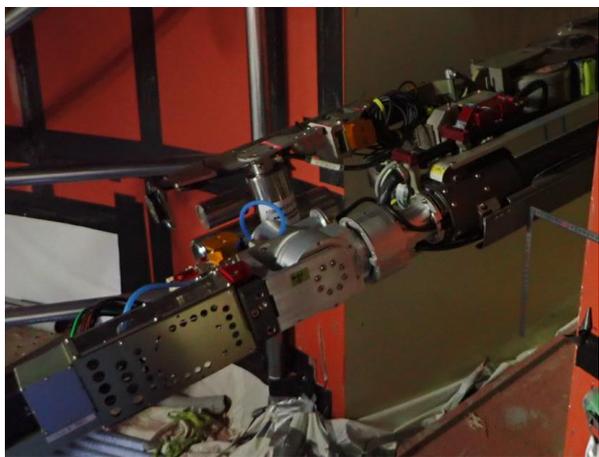
4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
- (c) One through test b. Laser scanner installation conditions

| |
|-----------------|
| Test conditions |
|-----------------|

- Laser scanning of the CRD hoisting jig after AWJ cutting, pedestal opening, platform opening and intermediate support frame was performed. Thereafter, the area up to the bottom of the pedestal was accessed by means of completely remote operation based on the results of the scans.
- Environment: Spray of water simulating core water injection inside PCV.
- Scanning position: The arm (mainly wand) axis value was adjusted based on the field of view of the camera equipped with laser scanner.
- Scanning target: As mentioned in the table below.

| No. | Scanning target | Scanner specifications | Scanning frequency* |
|-----|---------------------------------------|------------------------|---------------------|
| 1 | CRD hoisting jig | Downwards | 3 rounds |
| 2 | Overall pedestal opening | Downwards | 8 rounds |
| 3 | Top surface of the pedestal opening | Upwards | 4 rounds |
| 4 | Pedestal opening terminal box | Upwards | 1 time |
| 5 | Platform opening (CRD exchanger part) | Downwards | 6 rounds (2 rounds) |
| 6 | Middle frame | Downwards | 4 rounds |



*Final number of valid scans in which the contour shape is obtained

4.1 Access and investigation equipment

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

(c) One through test b. Laser scanner installation conditions

Test results

- For the clearance between the arm and the obstacle, the actual measured values were compared with the values in the VR environment displayed based on the results of the scans (point cloud data). The results of this comparison are provided in the table below, and typical examples are provided on the following page.
- It was verified based on the VR simulation and the field of view of the camera that completely remote access is possible.
 - ☞ A similar method of using the field of view of the camera and VR simulations based on the obtained point cloud data will be adopted for the 1F site as well.

Prospects of arm access up to the bottom of the pedestal were obtained, but further error reduction will continue to be studied.

| Accessed area (Obstacle) | Arm position | Clearance between the arm and the obstacle | | Error |
|-----------------------------|-----------------------------------|--|------------|--------|
| | | Actual measurement ^{Note} | VR display | |
| Pedestal opening | While passing through the opening | 60 mm | 17 mm * | 43 mm |
| Platform opening | While passing through the opening | 80 mm | 77 mm | 3 mm |
| Intermediate support frame | While passing through the opening | 270 mm | 125 mm | 145 mm |
| Pedestal opening | While accessing the bottom part | 65 mm | 10 mm * | 55 mm |
| Platform opening | While accessing the bottom part | 40 mm | 86 mm | 46 mm |
| CRD exchanger | While accessing the bottom part | 50 mm | 118 mm | 68 mm |
| Intermediate support frame | While accessing the bottom part | 240 mm | 0 mm * | 240 mm |

**Typical examples
(refer to the
following page)**

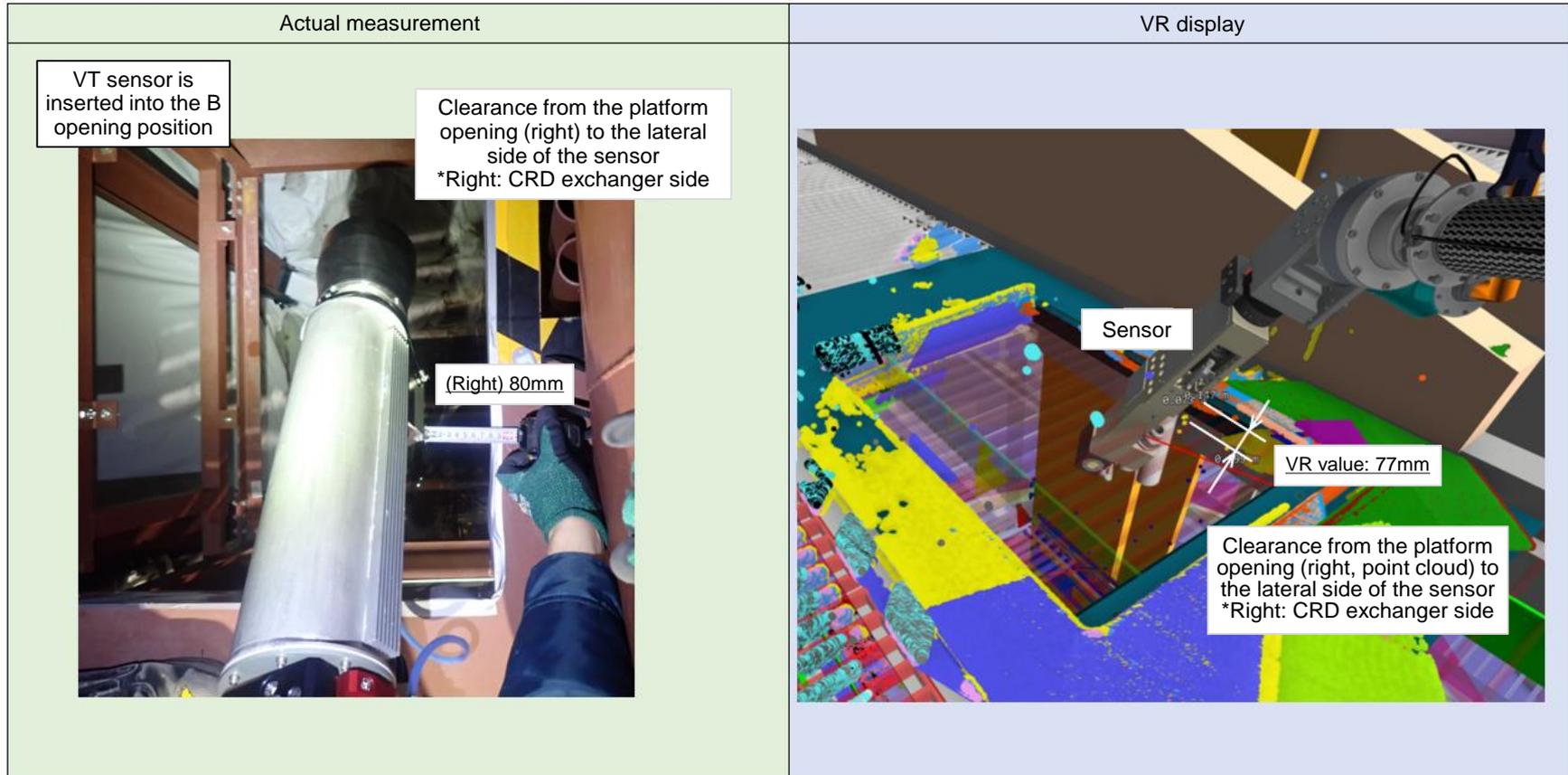
* In the VR environment, there was a narrow clearance, but the clearance was visually confirmed using the camera (it was determined that the arm can pass).

Note: During operation, the operator is not informed about the actual measured clearance.

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
(c) One through test b. Laser scanner installation conditions

Typical example: Arm access to the platform opening

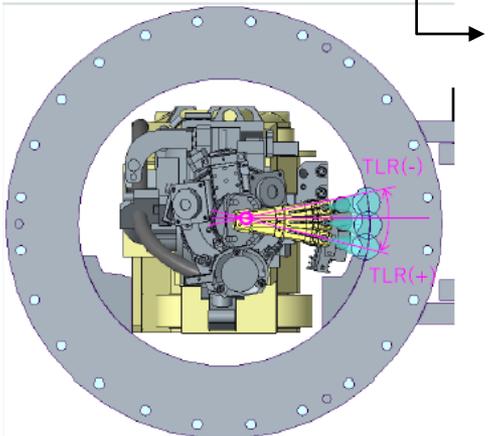
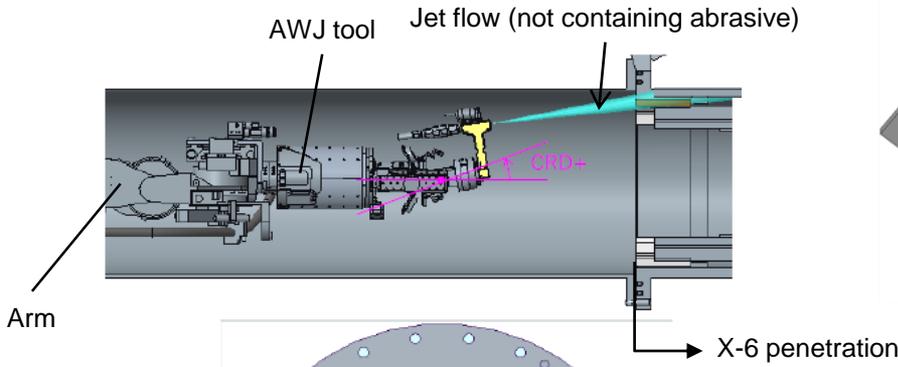


4.1 Access and investigation equipment

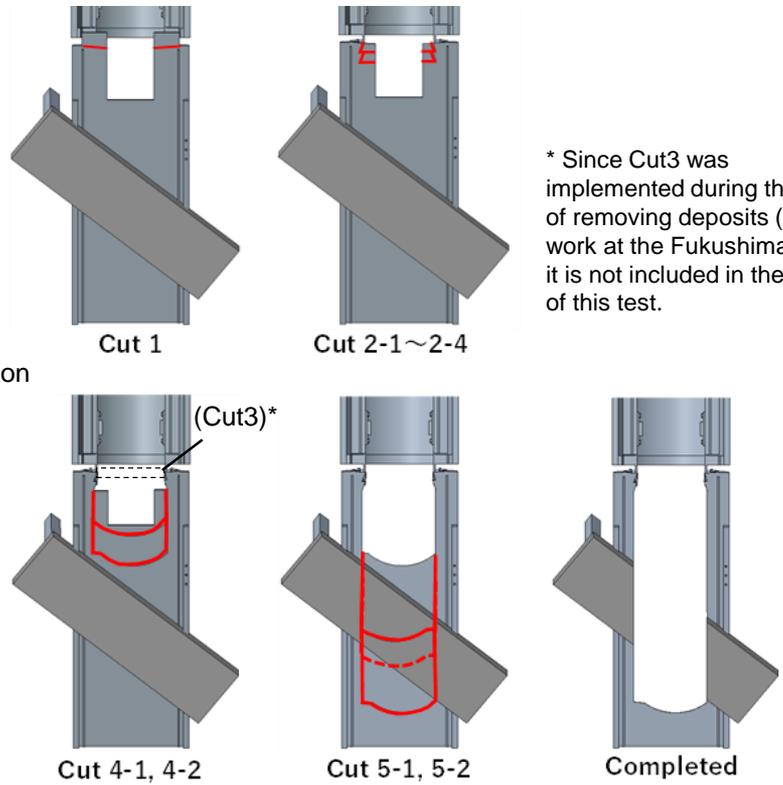
- (1) Mock-up tests considering site conditions (i) Arm verification test
- (c) One through test c. AWJ installation conditions

Test conditions

- A one-through test was conducted on access route construction by means of remote operation by installing the AWJ tool on to the arm with the arm enclosed in the enclosure.
- The deposits (remaining portion) at the entrance of the X-6 penetration were removed and the CRD rail was cut / removed according to the removal / cutting plan provided in the figure below.



Plan for removing the deposits (remaining portion) at the entrance of the X-6 penetration (Overview)



* Since Cut3 was implemented during the work of removing deposits (actual work at the Fukushima site), it is not included in the scope of this test.

CRD rail cutting plan (Overview)

4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (i) Arm verification test
(c) One through test c. AWJ installation conditions

Test results

- As shown in the figure below, the deposits at the entrance of the X-6 penetration were removed without any issues. The CRD rail was cut / removed as per the plan as well.



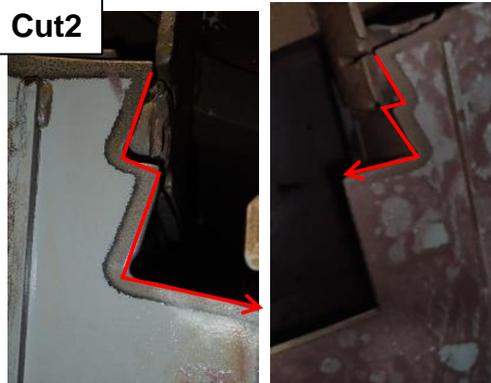
Cut1



Cut4-2



Cut2



Cut5-2



Before and after deposit removal

(Figure at the top: Front, Figure at the bottom: Back)

Results of cutting the CRD rail

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 of the wand and external cable (for the sensor)

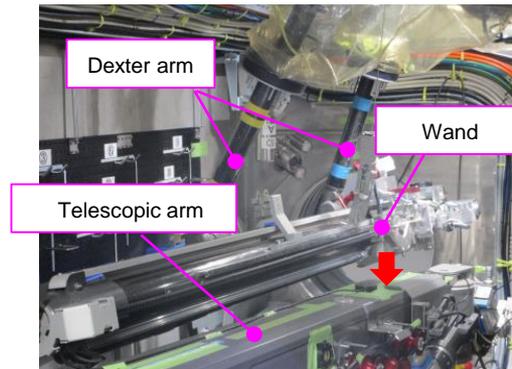
Test conditions

- In FY2024, the work efficiency in a series of operations including installation / removal of the wand and installation / removal of the external cable (for the sensor) using the actual arm was verified, based on the results of the mock-up tests performed using the dummy arm till FY2023 and the results of improvements made.

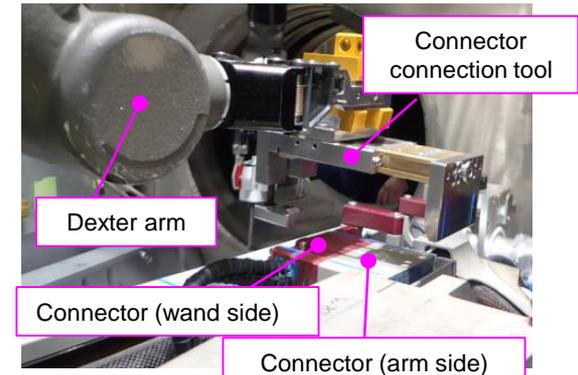
Test results

Tests were conducted using the actual arm and it was verified that the following operations can be conducted remotely.

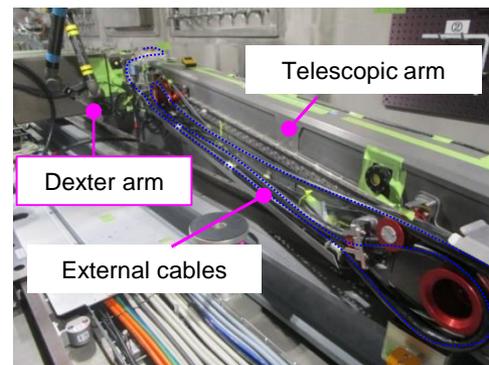
- Installation and removal of the wand
- ① Installation and removal of the main body of the wand
 - ② Connection and disconnection of the wand power connector
- Installation / removal of the external cable (for the sensor)
- ① Installation and removal of the external cable
 - ② Connection and disconnection of the connector



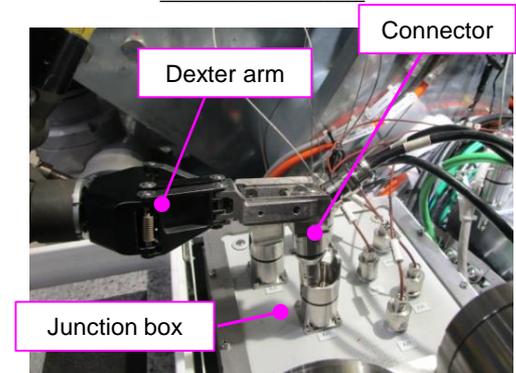
Wand installation and removal work



Wand power connector connection and disconnection work



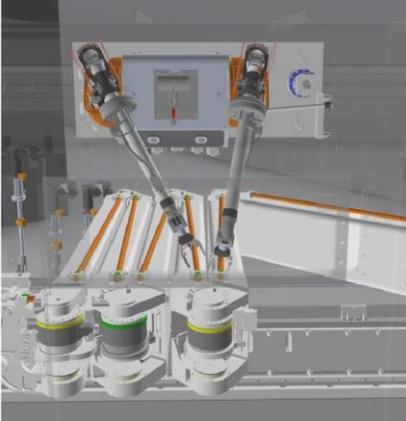
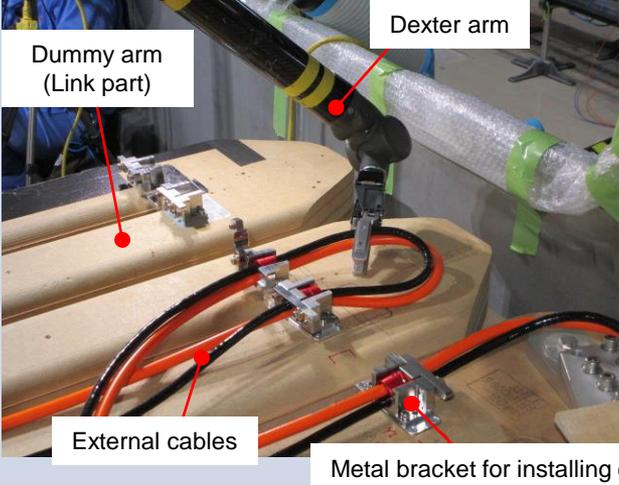
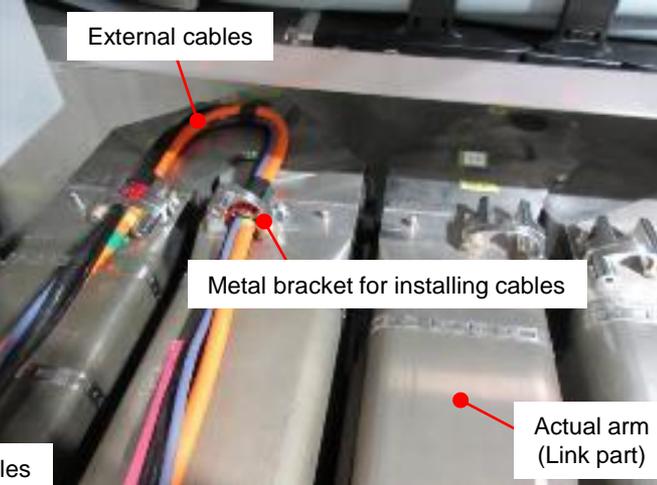
Installation and removal of the external cables



Connector connection and disconnection work

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 sensor

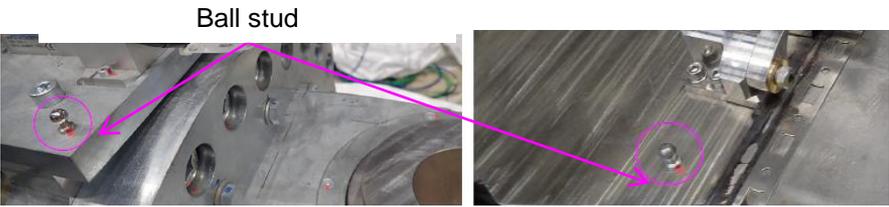
| Verification items | Verification result and areas for improvement of the mock-up tests at the Naraha center (FY2023) | Test result of the mock-up tests at the Naraha center (FY2024) |
|--|--|---|
| <p>Installation and removal of the external cables for tools onto the actual arm</p>  | <ul style="list-style-type: none"> The work efficiency in installing and removing external cables for tools onto the dummy arm was verified. Structural modifications in the collar and metal bracket for installing external cables were identified as areas for improvement. When tested using a dummy arm, it was found that work can be performed using the structurally modified metal bracket and collar.  | <ul style="list-style-type: none"> The collar and metal bracket for installing external cables which were tested using the dummy arm were transferred on to the actual arm and the work efficiency in installing / removing these onto the actual arm was verified. It was found that work can be performed without any issues, and that the external cables do not get lifted off after they are laid.  |

4.1 Access and investigation equipment

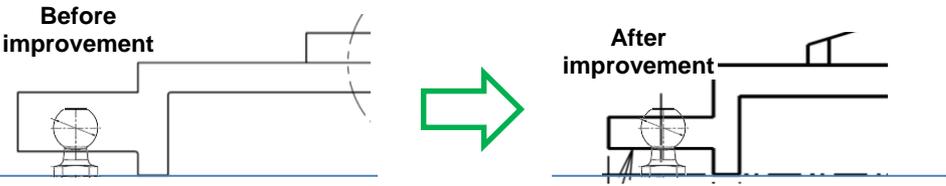
(1) Mock-up tests considering site conditions (ii) Verification tests for the work efficiency of Dexter arm

(c) Arm Mastering

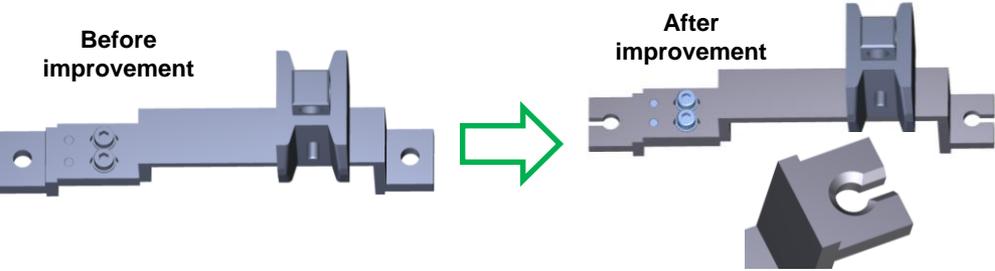
➤ Arm mastering (the work of verifying / correcting the initial position of the arm) is performed by engaging a calibration jig on the ball stud that is already installed. As it was difficult to perform mastering for the Dexter arm using the existing calibration jig, the improvement shown in the figure below was made and verified. As a result, it was confirmed that in the case of the Dexter arm, mastering can be performed by installing a calibration jig on the ball stud and engaging the calibration jig by means of the retraction motion of the arm.



Ball stud installed on the arm



(a) Engagement identification (Ball stud head)

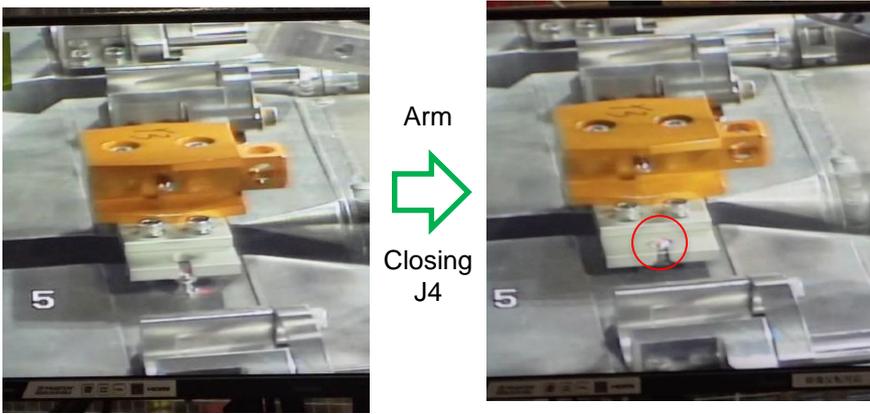


(b) Guiding the stud by means of a slit

Improvement of the mastering jig



(a) Mastering of Joint 2 (J2)



(b) Mastering of Joint 4 (J4)

Results of verification of mastering

4.1 Access and investigation equipment

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

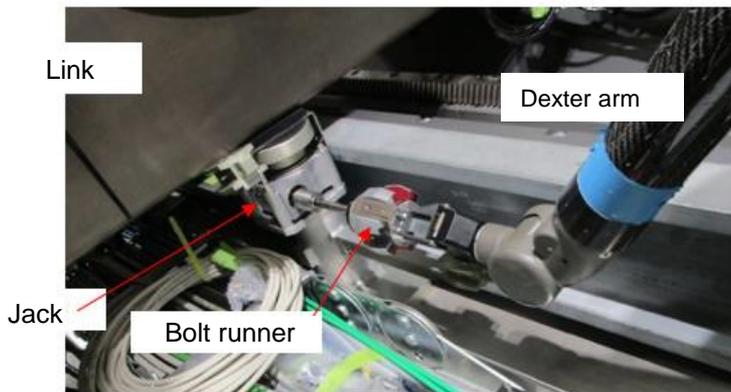
(d) Transportation jig removal

Test conditions

- Tests were conducted to verify whether the transportation jig that is installed for supporting the arm link part when the arm is transported inside the enclosure, can be removed by means of remote operation of Dexter arm and transported out from the DPTE port.

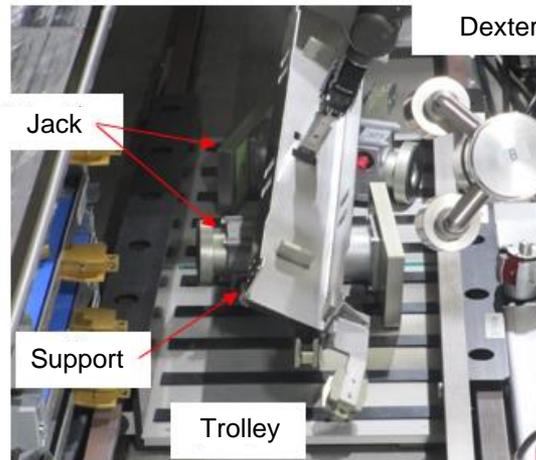
* Port for goods transportation on the lateral side of the enclosure

Test result



Lowering the jack

It was confirmed that the transportation jig can be removed, transported up to the DTPE port by means of remote operation of the Dexter arm and then transported out from the DTPE port without any issues.



Moving the fixing jig



Transporting out the fixing jig (manual)

Note:
Transportation will be carried out by the workers since it will be performed before the isolation valve is opened.

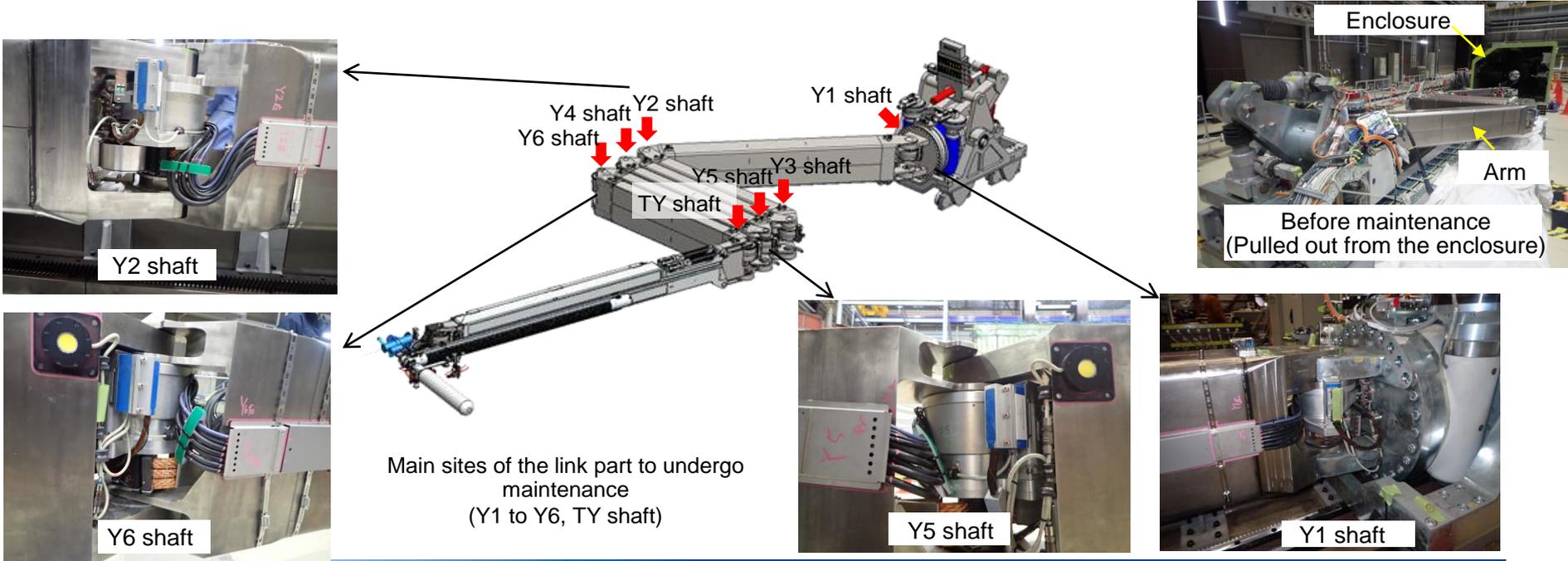
4.1 Access and investigation equipment

- (1) Mock-up tests considering site conditions (iii) Investigation equipment maintenance
- (a) Arm maintenance

Overview

➤ Arm maintenance is underway. The main tasks undertaken during maintenance are provided below.

| Parts to undergo maintenance | Maintenance overview |
|---|--|
| <ul style="list-style-type: none"> • Carriage • Link part • Telescope • Wrist • Wand | <ul style="list-style-type: none"> • Checking the assembly status of the drive mechanism (disassembly investigation) • Replacing the motor, obtaining operation data • Checking the output resolver assembly (disassembly investigation) • Lubricating, replacing seals • Replacing damaged parts (as required) |
| <ul style="list-style-type: none"> • Internal cables | <ul style="list-style-type: none"> • Replacing internal cables (including connectors) |



4.1 Access and investigation equipment

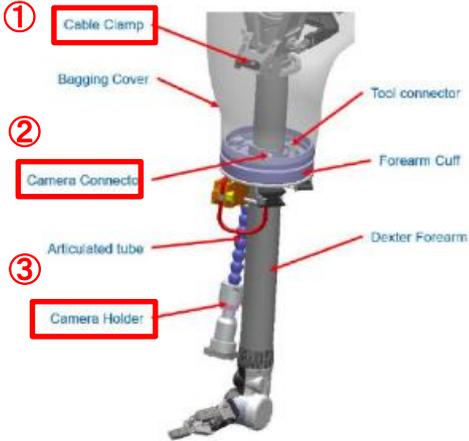
- (1) Mock-up tests considering site conditions
- (iii) Investigation equipment maintenance
- (b) Dexter arm maintenance

Overview

Dexter arm maintenance was carried out. The main tasks undertaken are provided below.

Major activities

- 1) Measures against disconnection of arm camera and tool power cables
 - ① Tight fitting elbow joint
 - Structural modification (loose fitting)
 - ② Cable bending load on the forearm connector section
 - Addition of a bend relief and support
 - ③ Common: Heavy camera holder
 - Using PEEK resin instead to make it lighter
- 2) Replacement of actuation wire and re-extension: Improvement of wire tension
 - Operation is planned to be checked in the future



- 3) Tuning: Tuning is underway to improve ease of handling (resistance, extent of vibrations)

| Left arm Tension of actuation wire | | | Right arm Tension of actuation wire | | |
|------------------------------------|--------------------|-------------------|-------------------------------------|--------------------|-------------------|
| Shaft | Before maintenance | After maintenance | Shaft | Before maintenance | After maintenance |
| 4 shaft A | 200 gf | 550 gf | 4 shaft A | 200 gf | 550 gf |
| 4 shaft B | 200 gf | 550 gf | 4 shaft B | 225 gf | 550 gf |
| 5 shaft A | 200 gf | 550 gf | 5 shaft A | 300 gf | 550 gf |
| 5 shaft B | 350 gf | 550 gf | 5 shaft B | 300 gf | 550 gf |
| 6 shaft A | 225 gf | 550 gf | 6 shaft A | 300 gf | 550 gf |
| 6 shaft B | 225 gf | 550 gf | 6 shaft B | 300 gf | 550 gf |

- Tension generated when a specified displacement is applied is measured.
- The gripper (7 shaft A) is not measured as significant tension is not generated.



Status of verification of the ease of handling

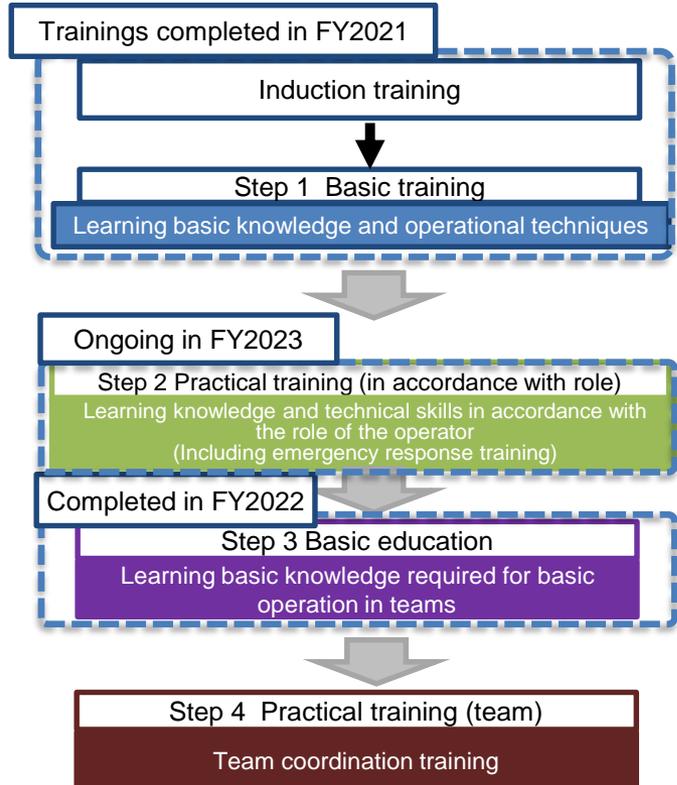
4.1 Access and investigation equipment

(2) Work training

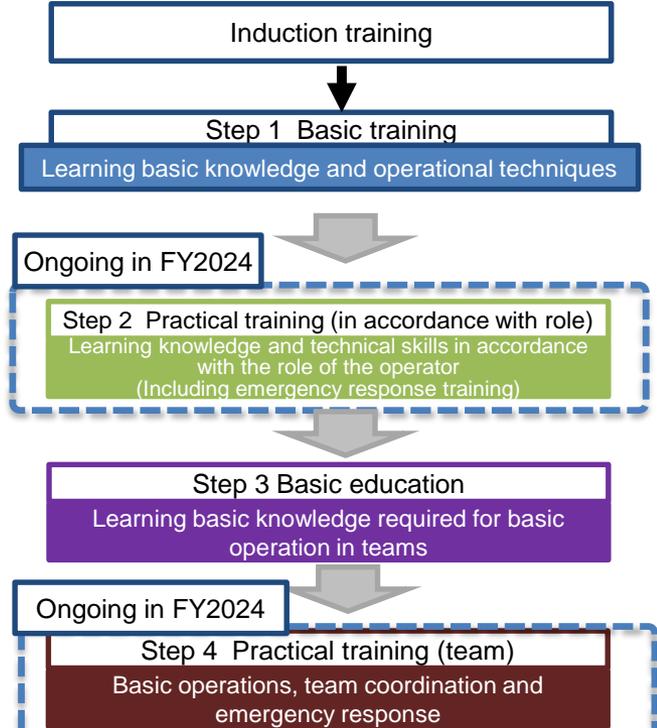
(i) Review of work training program, and work training results

- The progress of the work training program was reviewed based on the status of training and the feedback from the operators. Step 2 Practical training (in accordance with role) and Step 4 Practical training (team) continue to be implemented accordingly. (Step 1 and Step 3 have already been completed. Steps 2 and Step 4 were implemented in FY2024. Step 2 and Step 4 will continue to be implemented in FY2025.)

[Plan for FY2023]



[Plan after review in FY2024]



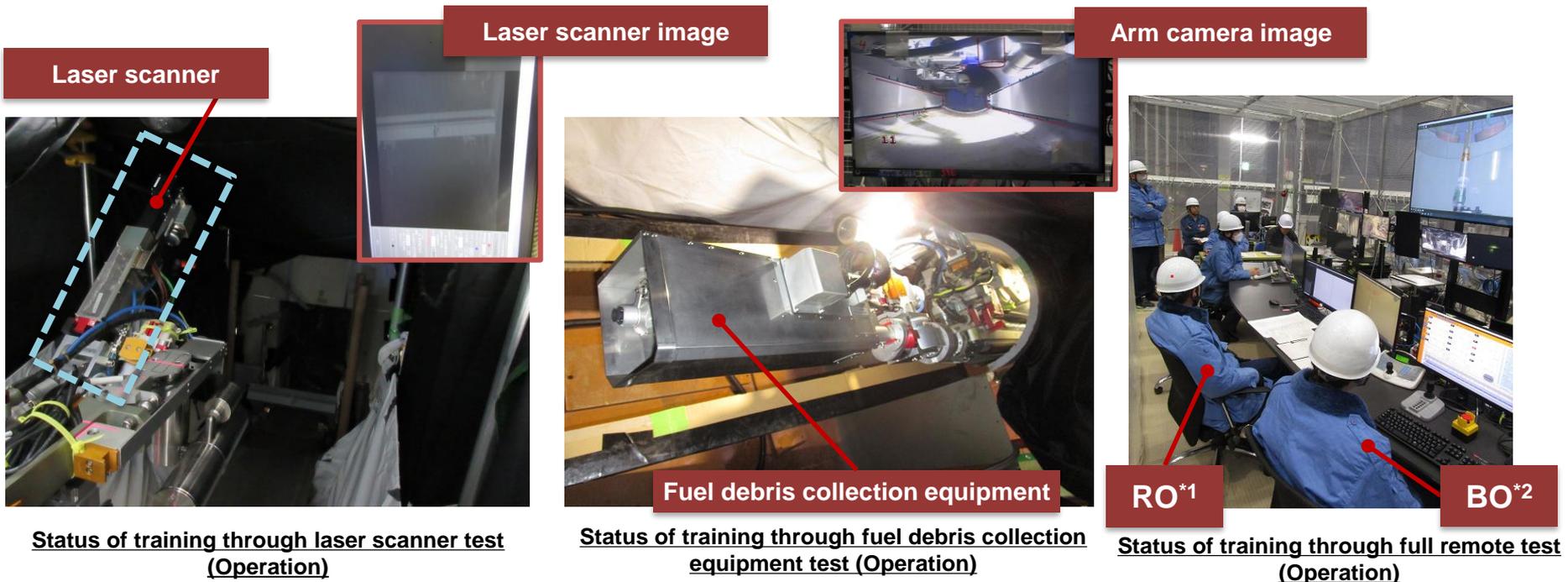
4.1 Access and investigation equipment

(2) Work training

(ii) Results of practical training (in accordance with role)

Training on BO*²

- From amongst the practical trainings (in accordance with role) through arm unit verification, proficiency in constructing the access route, creating and executing the Teach and Repeat File and editing said file depending on the site conditions, was achieved through arm access tests, full remote operation tests, and one-through verification conducted using the laser scanner, VT sensor, fuel debris collection equipment, and the AWJ tool.
- Practical trainings (in accordance with role) based on the one-through verification will continue to be conducted in FY2025 as well.



*1 RO: Operation leader *2 BO: Boom (arm) operator

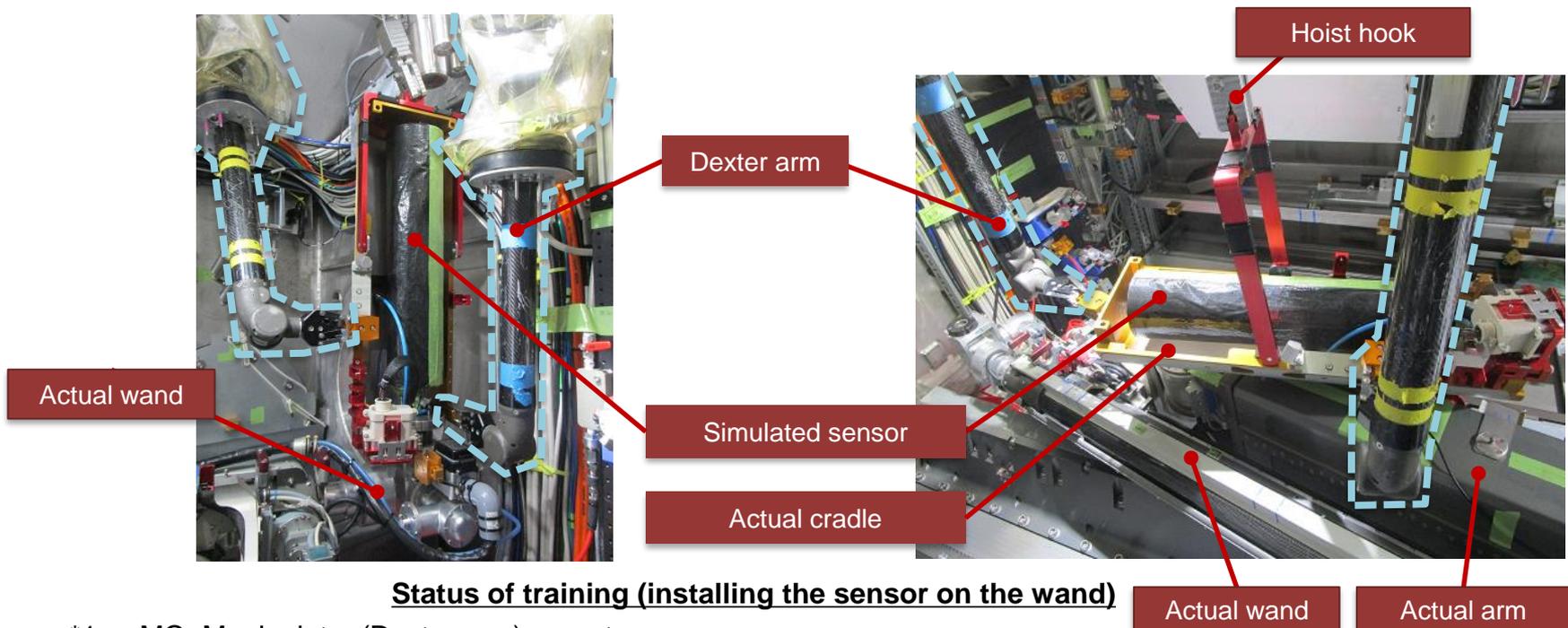
4.1 Access and investigation equipment

(2) Work training

(iii) Results of practical training (in accordance with role)

MO*1, camera operator training

- Proficiency in handling various auxiliary equipment and in operating the camera for securing the required field of view using the Dexter arm was achieved through practical training (in accordance with role) based on the verification in combination with the actual arm.
- The knowledge and procedures obtained through practical trainings (in accordance with role) have been compiled as the operation procedure manual. Practical trainings (in accordance with role) will continue to be conducted in FY2025 as well and the results are planned to be incorporated in the manual.
- The training on operating the camera that is attached to the arm is planned to be continued in FY2025 as well in tune with the handling and operation of the arm during the arm access test.



*1 MO: Manipulator (Dexter arm) operator

4.2 Other ancillary system

(1) Design and manufacturing

i. System plan

Revisions mentioned in the bottom right table were made based on the on-site status during other work.

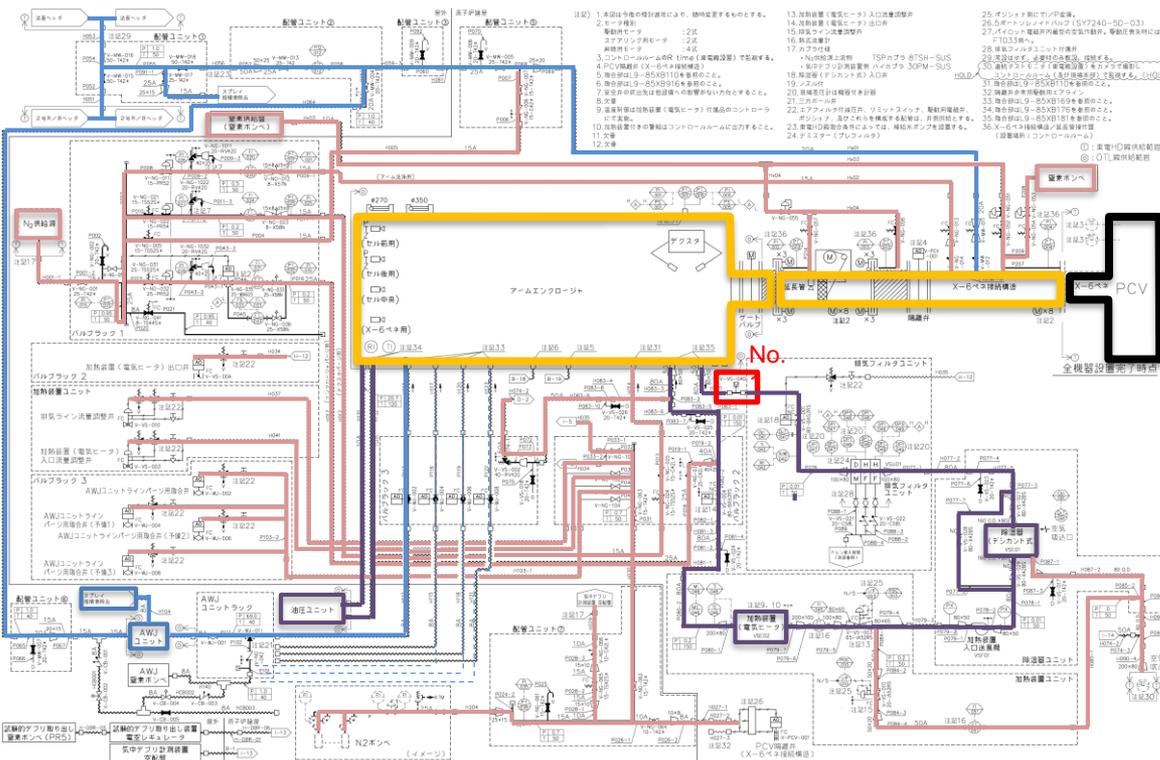
ii. On-site layout plan

In FY2024, the results of installation work at various stages were reflected based on the progress of on-site work, and the layout plan was reviewed based on the status of on-site work.

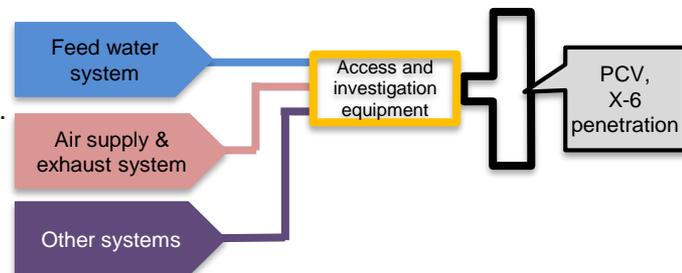
iii. Status of manufacturing

Ancillary system equipment was altered along with adding vacuum relief valve.

- Actual system plan



- System image



[Main component systems]

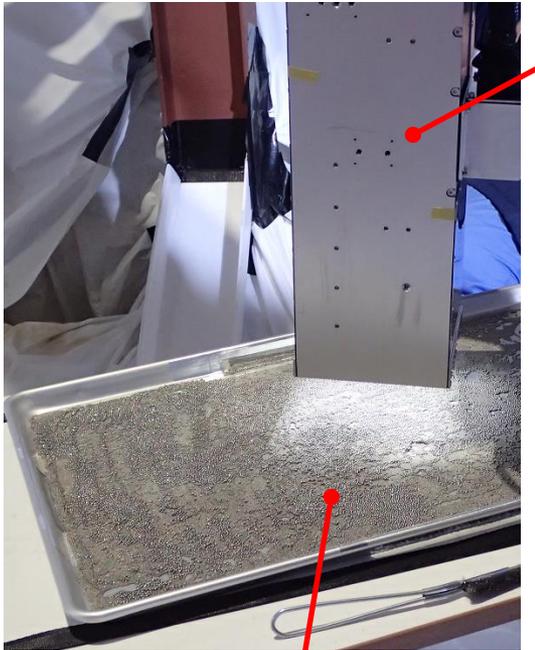
- Water supply line to the AWJ unit
- Nitrogen supply system for checking the seal of the X-6 penetration connection structure flange part
- Nitrogen purge system to the Dexter arm inside the enclosure
- Nitrogen supply system to the air operated valve
- Nitrogen (air) exhaust system
- Enclosure dehumidification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

Table Major revisions to the system diagram

| No | Changes since FY2023 | Reason for change |
|----|---------------------------------|--|
| 1 | Addition of vacuum relief valve | For preventing damage of the enclosure due to erroneous operation by the operator during negative pressure operation |

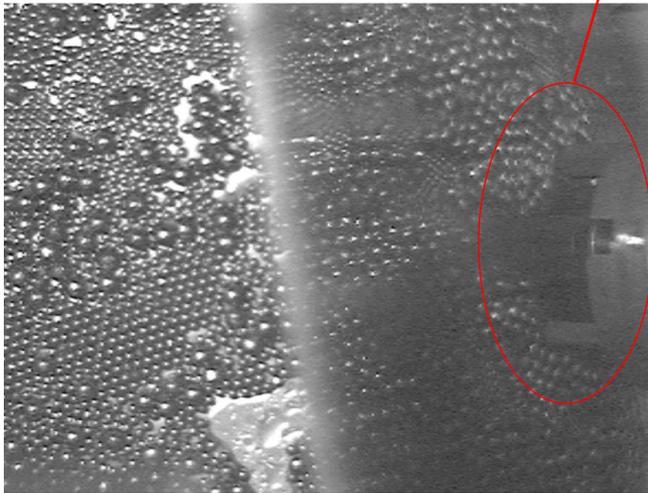
4.3 Fuel debris collection equipment

- A mock-up test (one-through test) was conducted wherein the fuel debris collection equipment was installed on the arm with the arm enclosed inside the enclosure, the arm was deployed, and debris was removed from under the pedestal inside the PCV.
- 0.436[g] of simulated fuel debris was collected with the help of metal brush type debris collection equipment through remote operation using VR and the camera installed on the equipment.
- Final position adjustment while collecting debris was carried out without any issues using the camera that was attached to the equipment and which was configured to have a focal length of 50mm.



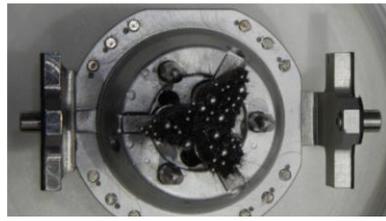
Debris collection equipment (metal brush type)

Simulated fuel debris (simulated PCV base)



Metal brush

Field of view of the equipment camera at the control room



Collected simulated debris

4.4 On-site demonstration

(1) On-site installation and preparation work

(i) Deposit removal work

Plant room ② was set up in the yard on the west side in Unit 2, electrical circuits were extended up to the cables that were laid in FY2022 and the cables were connected. A feed water tank and filtered water supply unit were installed, and cables and hoses were routed into the Unit 2 R/B (Reactor Building) from the yard on the west side in Unit 2 for AWJ operation.

Deposit removal equipment was transported from the Kobe plant, and brought into the 1F premises. The skid for transportation was unpacked, the status of the tent house with respect to receiving the equipment was checked, a leak check was performed, and the results were satisfactory.

The deposit removal equipment was transported to the area in front of the Unit 2 R/B, it was brought in through the truck bay entrance, and carried manually inside Unit 2 R/B to the north-western area via the south-western area. Thereafter, the cables for movement of the equipment were connected, the equipment was transferred into the robot carry-in chamber, and connected to the X-6 penetration.

[Yard on the west side in Unit 2]



[Tent house]



[Inside Unit 2 R/B]



4.4 On-site demonstration

(1) On-site installation and preparation work

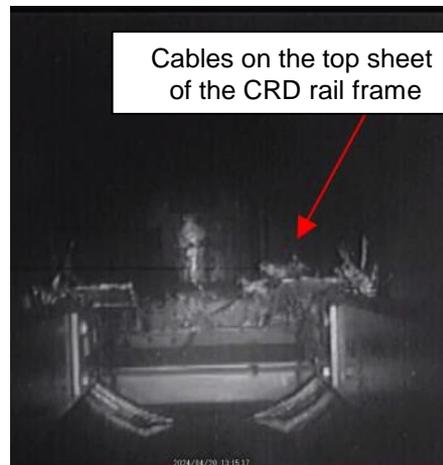
(i) Deposit removal work

After connecting the deposit removal equipment to the X-6 penetration, the condition inside was checked.

After checking the dust concentration inside PCV by means of preliminary tests, the remaining deposits were washed using a high pressure washing nozzle.

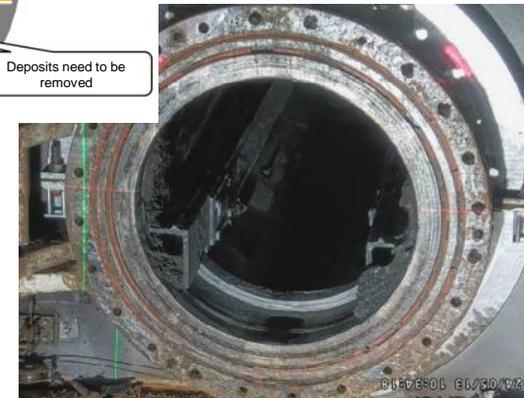
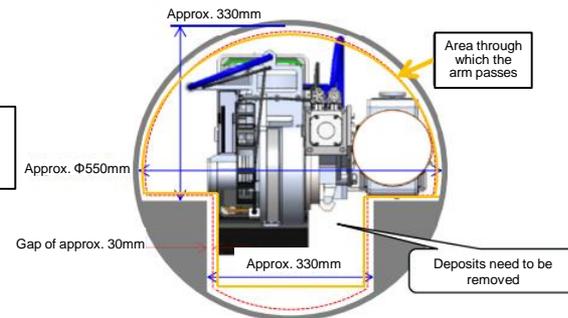
The cables were cut from the structures such as guide rails, etc. using AWJ, the fragments resulting from cutting of cables and deposits using dozer tools and WJ were pushed inside the PCV, and cleaning, washing down and removal was performed to the extent that subsequent work would not be affected. After starting the operation, the hose supplying abrasive got blocked. Training on replacement of the hose was conducted and thereafter the hose was replaced. And, since the dust concentration had not increased, the spray was discontinued halfway through cutting.

[State of the deposits remaining on the inner surface of the X-6 penetration]



[State of the top sheet of the CRD rail upon completion of high-pressure washing]

[Passing ability of the robot arm-type access and investigation equipment]



[Condition of X-6 penetration after the equipment is pulled back]

4.4 On-site demonstration

(1) On-site installation and preparation work

(i) Deposit removal work

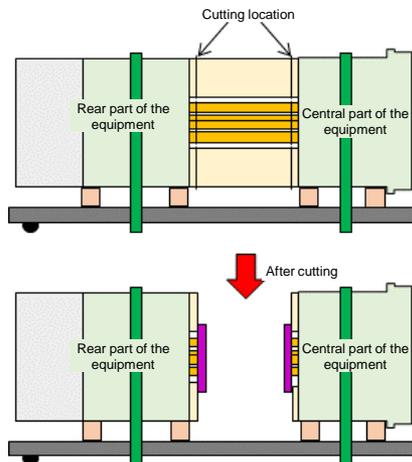
After completion of deposit removal, the hold of the X-6 penetration flange was released and the deposit removal equipment was pulled back, the air-tight door was closed and it was verified that there is no issue in the air-tightness of the isolation room. A lead shield was installed on the equipment and then it was covered. It was carried to the area in front of the truck bay entrance inside the Unit 2 R/B, and after bringing it out of the Unit 2 R/B, it was transported to the temporary storage inside the premises.

Other incidental equipment, hoses and cables were removed and transported outside the Unit 2 R/B, except for the condensed water collection equipment.

The plant room ② set up outdoors in the yard on the west side, pump unit and other equipment, cables and hoses were removed, leaving the water storage tank and certain other equipment.

Since the cleaning water remaining in the front part of the equipment could not be disposed of, the rear part of the equipment was cut off for removing the deposit removal equipment. The rear part that was cut off was cut further, enclosed in a 6m³ container and handed over to TEPCO HD.

In the future, the front part is planned to be enclosed in a special container and stored in Unit 2 R/B.



Cutting of equipment



Enclosing into 6m³ container



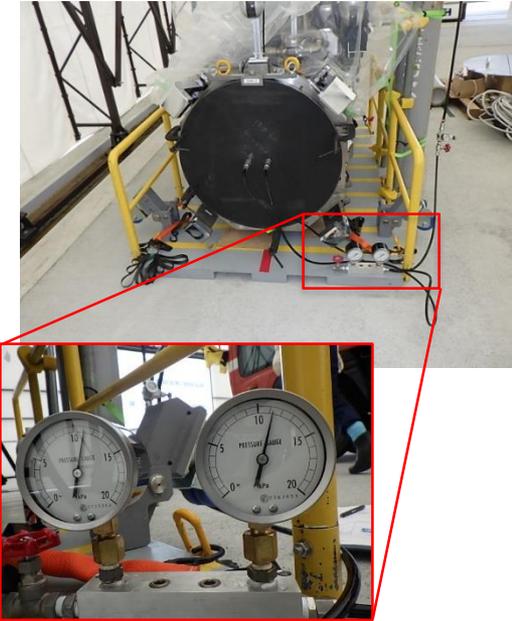
Temporary storage of the front part of the equipment

4.4 On-site demonstration

(1) On-site installation and preparation work

(ii) X-6 penetration connection structure installation

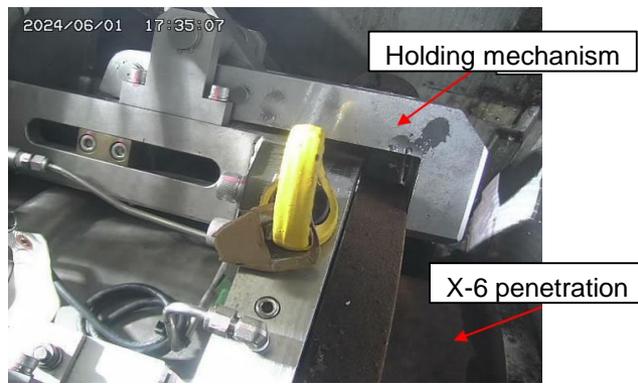
- The work of installing the connection structure was started in May 2024. On May 17, the air-tightness of the equipment was verified inside the tent house located within the 1F premises, and the results were satisfactory.
- The X-6 penetration connection structure equipment was transported to the area in front of the Unit 2 R/B on May 27, and brought in through the truck bay entrance. It was transported inside the R/B and on June 1 the equipment was connected to the X-6 penetration.
- On June 1, the connecting part between the X-6 penetration and the equipment was checked for leakages, and with that the connection was complete.



X-6 penetration connection structure equipment air-tightness verification



State of transportation in Unit 2



Holding of the connection structure

4.4 On-site demonstration

(1) On-site installation and preparation work

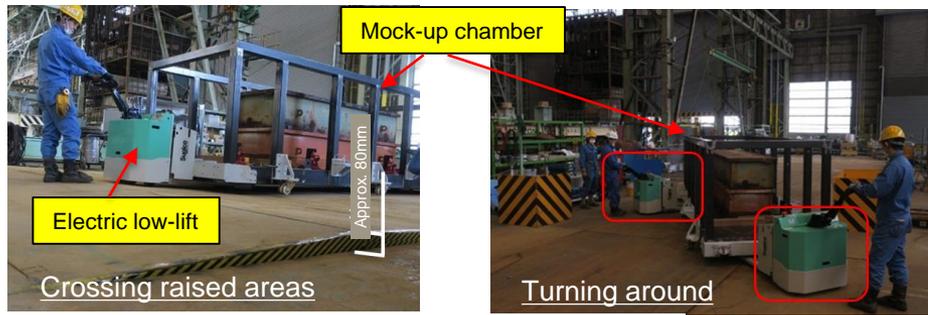
(iii) Removal of robot carry-in chamber (1/2)

Before installing the extension pipe for subsequent work, the robot carry-in chamber that was installed in order to access the X-6 penetration needs to be removed after installing the X-6 penetration connection structure that forms the boundary.

Implementation details related to the robot carry-in chamber removal carried out in FY2024 are given below.

[Operability verification test]

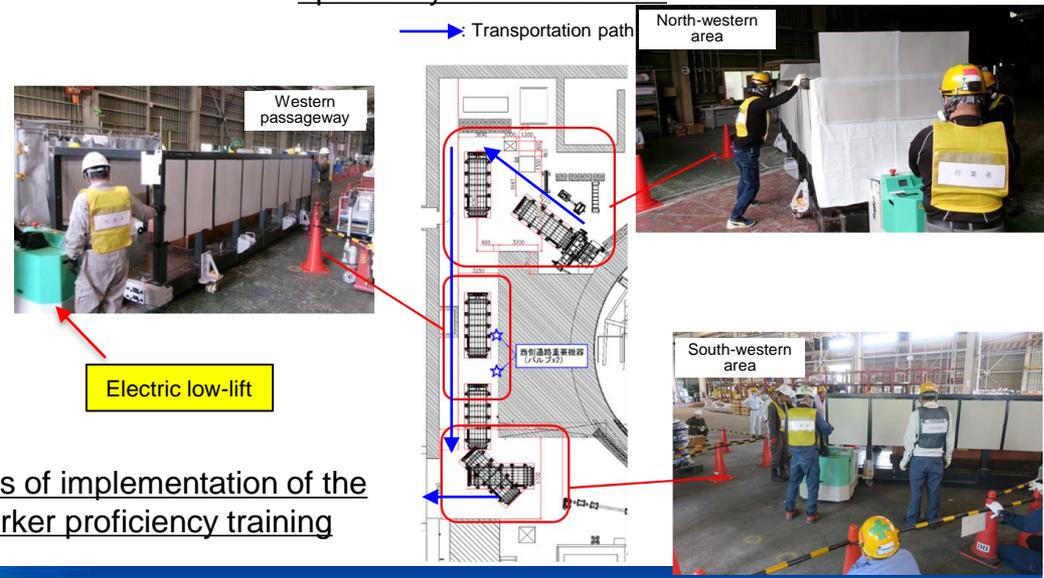
- In order to enhance work efficiency, the method of transporting the robot carry-in chamber was changed to one using an electric low-lift, and an operability verification test was conducted.
- The test was conducted using a mock-up chamber simulating the dimensions (except the overall height) and the weight of the robot carry-in chamber.



Status of implementation of the operability verification test

[Worker proficiency training]

- Worker proficiency training on the work of transporting the robot carry-in chamber using an electric low-lift was conducted.
- During the training, transportability was verified by setting up a transportation path simulating the dimensions of various areas inside R/B, in order to check and avoid interference with critical equipment and other equipment.



Status of implementation of the worker proficiency training

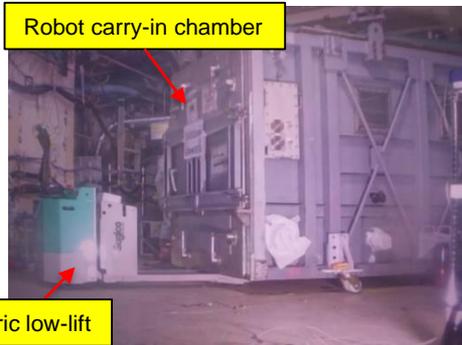
4.4 On-site demonstration

(1) On-site installation and preparation work

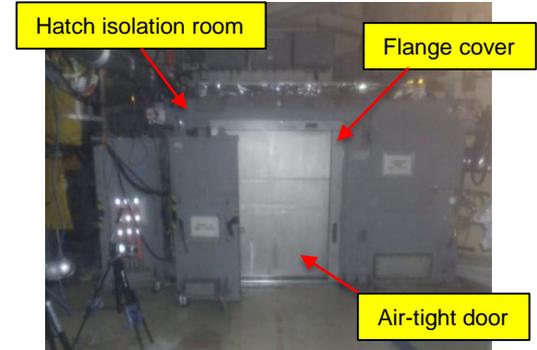
(iii) Removal of robot carry-in chamber (2/2)

[Removal of robot carry-in chamber]

- After completing installation of the X-6 penetration connection structure, the robot carry-in chamber was removed from the hatch isolation room, transported out of the R/B, transferred to the bellows-type tent in the storage area, thereby completing the work as scheduled. (June 2024)



North-western air lock side
Removing the robot carry-in chamber from the hatch isolation room
(R/B north-western area)



Hatch isolation room after removal
(Installation of flange cover)



Temporary storage at
the truck bay entrance



Loading on to the truck after covering



Transfer and set up in the bellows-type tent

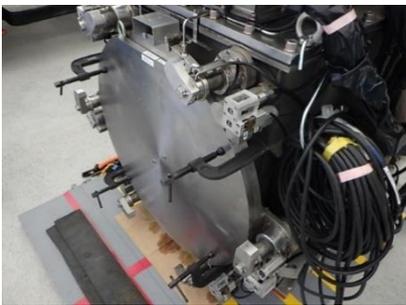
Status of removal of robot carry-in chamber

4.4 On-site demonstration

(1) On-site installation and preparation work

(iv) Installation of extension pipes and additional shielding plates

- The work of installing extension pipes and additional shielding plates was started in June 2024. On June 11, the air-tightness of the extension pipe equipment was verified inside the tent house located within the 1F premises, and the results were satisfactory.
- The extension pipe equipment and the additional shielding plates were transported to the area in front of the Unit 2 R/B on June 17 and June 21 respectively, and were then carried in through the truck bay entrance. After transporting inside the R/B, on June 26, the connection to the rear flange of the X-6 penetration connection structure equipment was completed. And, installation of the additional shielding plates was completed on the same day.
- On June 26, the connecting part between the X-6 penetration connection structure equipment rear flange and the extension pipe equipment was checked for leakages, and with that the connection was complete.



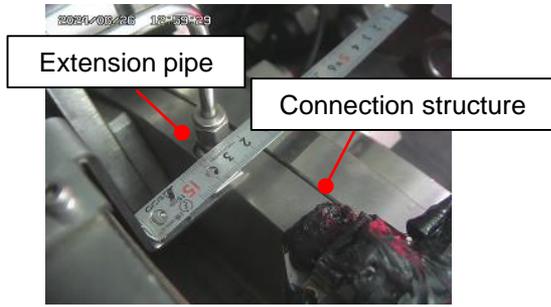
**Extension pipes equipment
Air-tightness verification**



**Remote transportation of the
additional shielding plates equipment**



Transportation of extension pipes equipment



Connection of extension pipe

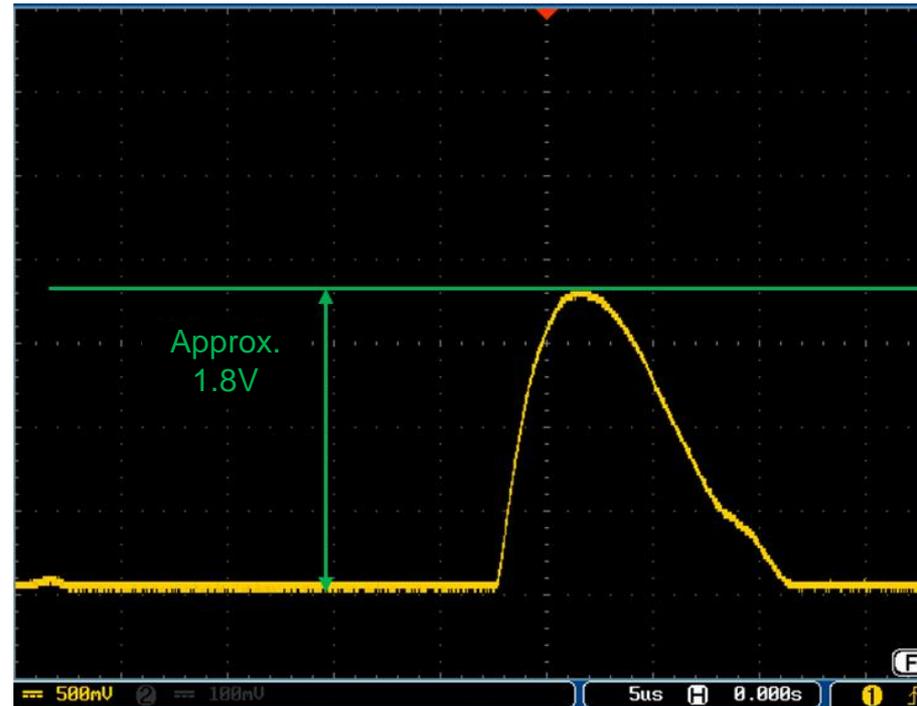
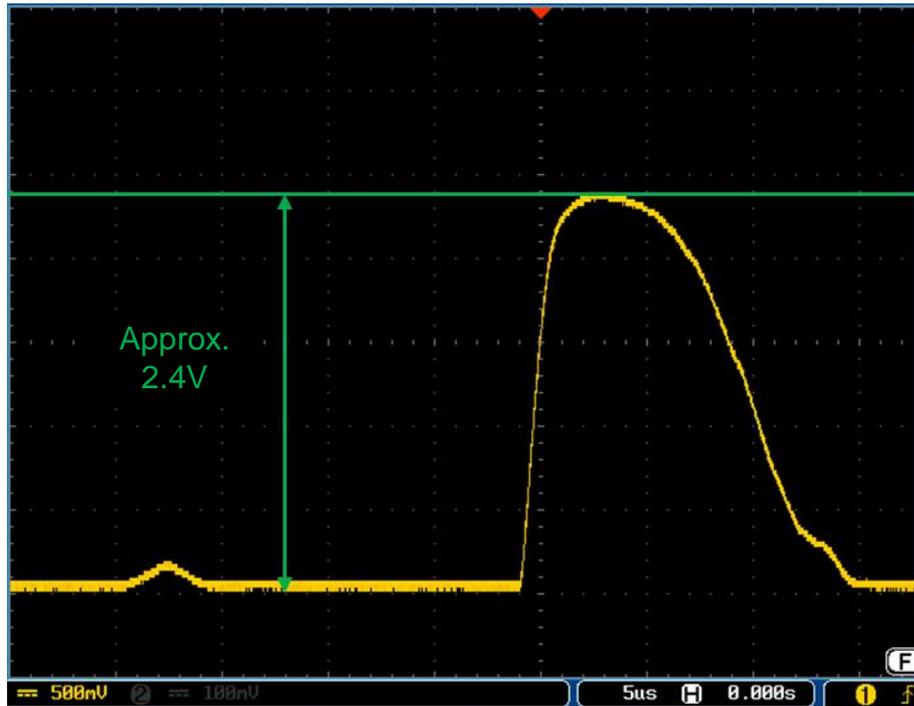


**Installation of the additional
shielding plates equipment**

4.5 Other

(1) Review of neutron sensor

Checking waveforms by means of neutrons (Modification of test equipment configuration)



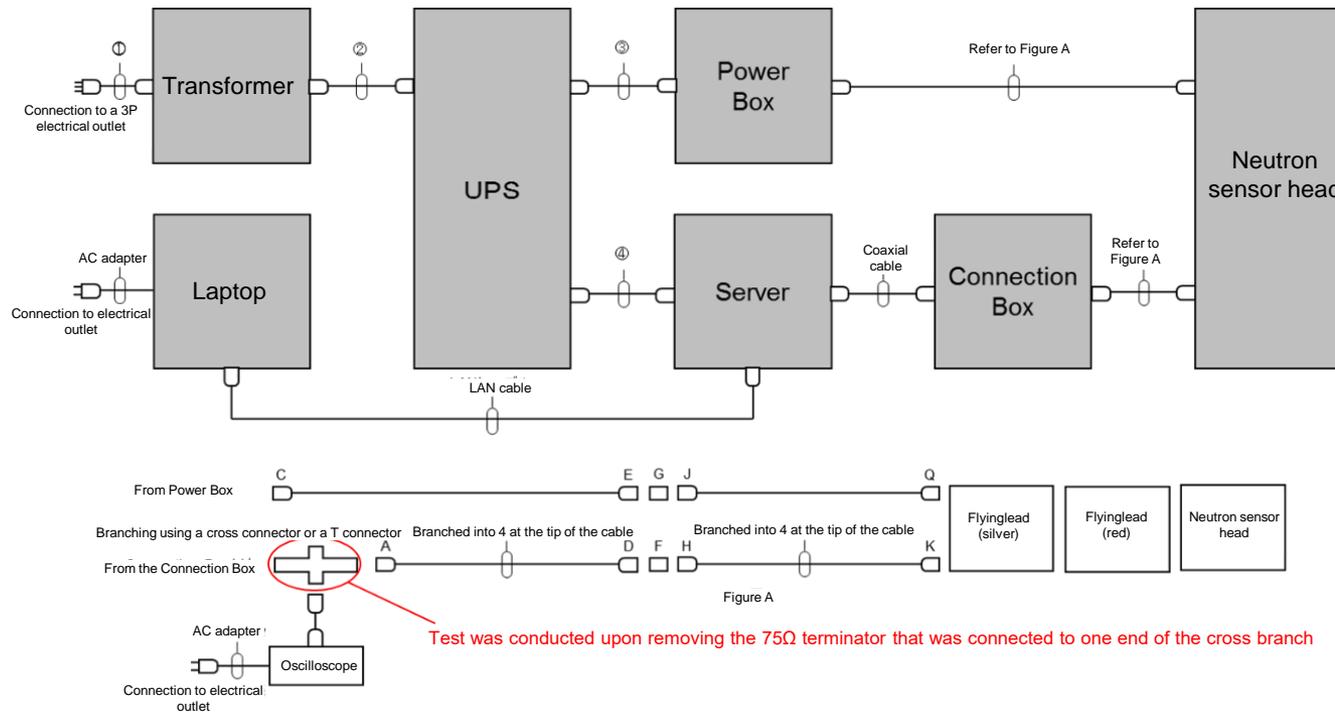
Pulse waveform caused by neutrons obtained using by the oscilloscope

Upon receiving results of the tests conducted in Nagoya University, the configuration of the test equipment was modified and in FY2023 pulse waveforms continued to be acquired. As a result, as anticipated in FY2023, waveforms of approximately 2V were obtained. Hence it was determined that there was some issue in the configuration of the test equipment. The specific modifications to the configuration of the test equipment are provided on the next page.

4.5 Other

(1) Review of neutron sensor

Checking waveforms by means of neutrons (Modification of test equipment configuration)

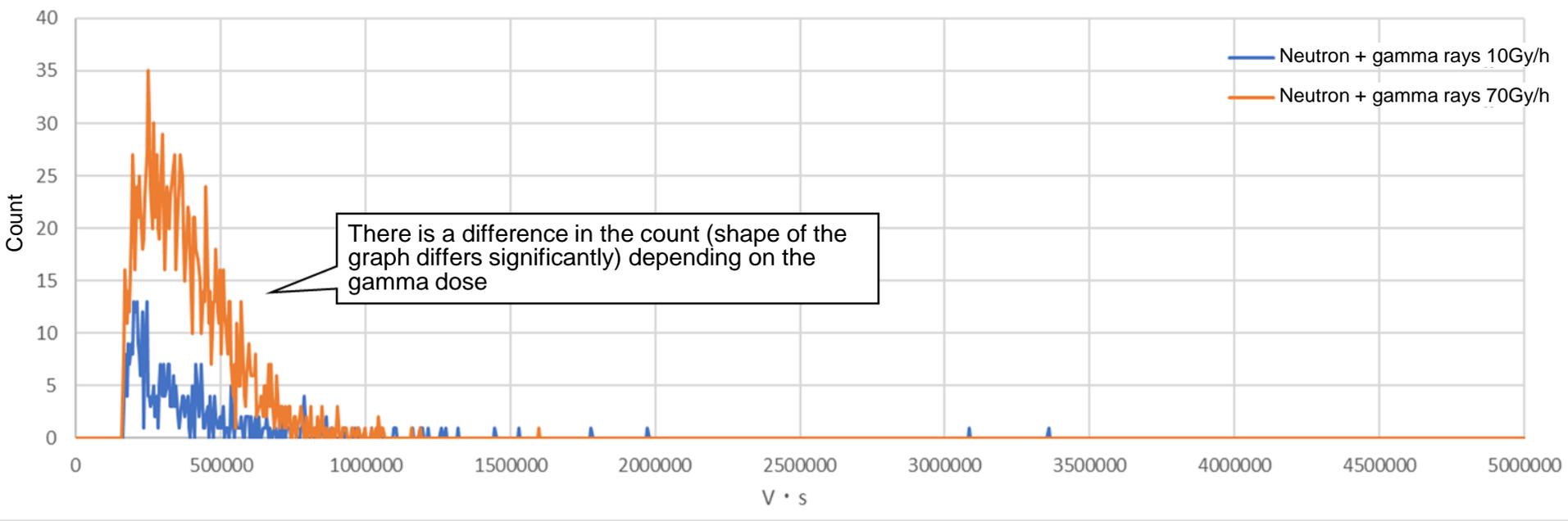


The modifications made to the test equipment configuration in FY2023 are as shown in the above figure (It was found that a terminator was installed on the detection system side, and hence the test was conducted once again after removing the terminator that was installed at the signal branch point to the oscilloscope. The terminator on the detection system side is embedded in the Connection Box). Due to additional resistance at said location, the voltage of the pulse waveform had decreased. However, upon removing said terminator, as mentioned on the previous page, the anticipated pulse waves of approximately 2V were obtained.

4.5 Other

(1) Review of neutron sensor

Differentiation of neutrons and gamma rays (The following spectrum is based on the FY2023 results)

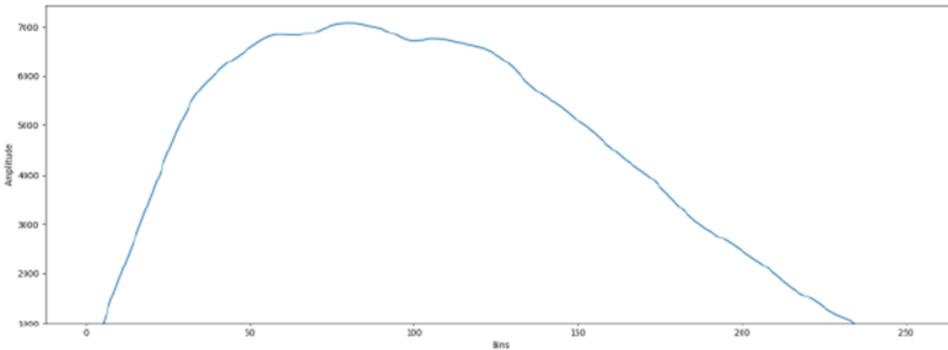


It was ascertained that the above-mentioned spectrum from the FY2023 report is a result from the state before the neutrons and gamma rays were differentiated. Basically, it was found that the pulse waveforms resulting from neutrons and those resulting from gamma rays can be differentiated by checking the pulse waveform stored in the system (server). A similar retest was being considered, but as it was confirmed that the differentiation can be done as mentioned above, it was decided to not conduct the retest. The analysis method is mentioned on the next page.

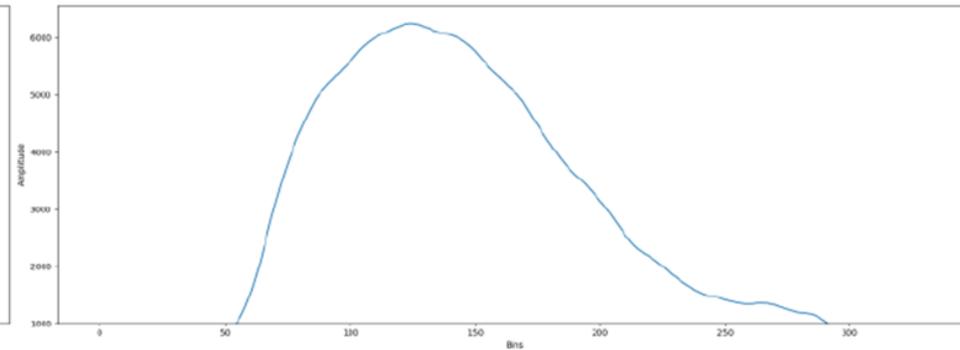
4.5 Other

(1) Review of neutron sensor

Differentiation of neutrons and gamma rays



Pulse waveform caused by neutrons



Pulse waveform caused by other sources

The figure above shows the pulse waveform obtained with the help of the neutron detector (Figure on the left: pulse waveform of neutrons, figure on the right: waveforms caused by other sources (gamma rays, etc.)). Following are the characteristics of waveforms caused by neutrons.

- Significant rising edge (slope)
- Flat central region
- Gradual falling edge (slope)

This waveform data is stored in the detection system. It was found that neutrons and other waveforms can be differentiated by selecting and counting the waveform data that has the above-mentioned characteristics from the stored waveform data.

4.5 Other

(2) Review of gamma sensor

Operation tests of the stand-alone gamma sensor and operation tests with the gamma sensor connected to the arm have been conducted at the JAEA Naraha Center for Remote Control Technology Development (hereinafter, "JAEA Naraha") until FY2023. Based on the results, the length of the cable connecting the maintenance gamma sensor and the connector was reduced in order to ensure that the specifications of the gamma sensor and the maintenance gamma sensor* are the same, and their operation verification test was conducted at JAEA Naraha.

Moreover, a control panel for testing to be used in the irradiation test and a relay for testing for conducting the operation test after transportation to the Fukushima Daiichi Nuclear Power Station were manufactured, and their operation verification was carried out at JAEA Naraha.

After that, the irradiation test was conducted on the gamma sensor and the maintenance gamma sensor.

* The sensor that will be used when the gamma sensor requires maintenance.

Items and result of review of gamma sensor (1/3)

| Large category | Items | Overview and result |
|---|---|--|
| Operation verification test of the maintenance gamma sensor | Operation was performed from the operating PC and basic operation was verified. | <p>It was verified that basic operations such as radiation measurement, etc. as per the operating instructions from the user interface of the operating PC can be performed using the maintenance gamma sensor.</p>  |

4.5 Other

(2) Review of gamma sensor

Items and result of review of gamma sensor (2/3)

| Large category | Items | Overview and result |
|---|---|--|
| <p>Operation verification test of the control panel for testing and the relay for testing</p> | <p>A control panel for testing to be used during the irradiation test was manufactured. A relay for testing to be used during the operation verification after transportation to 1F was manufactured. These operation verification tests were conducted at JAEA Naraha.</p> | <p>Upon conducting operation verification using the existing control panel and relay, the existing control panel and relay were replaced with those manufactured for testing and thereafter operation verification was conducted.</p> <div style="display: flex; justify-content: space-around;">    </div> <p style="text-align: center;">Control panel for testing (Server PC and control equipment)</p> <p style="text-align: right;">Relay for testing</p> |
| <p>Operation verification test of the remote power switch</p> | <p>The relay and the sensor need to be turned ON/OFF while connecting the gamma sensor to the arm. Devices that enable this operation to be performed from the control room were manufactured and their operation was verified at JAEA Naraha.</p> | <p>It was verified that the power to the relay and sensor can be turned ON/OFF through the control equipment on the control panel side, using the following devices installed inside the control room.</p> <div style="display: flex; justify-content: space-around;">   </div> <p style="text-align: center;">Devices installed inside the control room</p> <p style="text-align: right;">Control equipment on the control panel side</p> |

4.5 Other

(2) Review of gamma sensor

Items and result of review of gamma sensor (3/3)

| Large category | Items | Overview and result |
|------------------|--|---|
| Irradiation test | <p>This test was conducted to ensure that the radiation measurement function of the maintenance gamma sensor was sound after it was transported from UK. Measurements were performed at the gamma rays irradiation facility using the maintenance gamma sensor and the gamma sensor and it was verified whether the direction of the radiation source can be determined.</p> | <p>Radiation measurement test was conducted at the domestic irradiation facility. The 2-dimensional radiation dose rate distribution (Distribution indicating the direction in which radiation dose is high, x axis represents the horizontal position (rotation angle of the sensor) and the y axis represents the vertical position) obtained from the radiation measurement results is illustrated here. The validity of the results of this test is being verified.</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="840 549 1371 921"> </div> <div data-bbox="1391 564 1845 921"> </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div data-bbox="946 935 1294 963">Irradiation test environment</div> <div data-bbox="1420 928 1825 992">Radiation dose rate distribution (example)</div> </div> |

5. Summary and Future Plans

(1) Summary of the FY2024 results

○ Access and investigation equipment:

- The arm control system was modified and site applicability was verified by conducting one-through tests using full-scale mock-up facilities.
- And, trainings were conducted on operating the Dexter arm and the arm for investigation for achieving proficiency in operation.

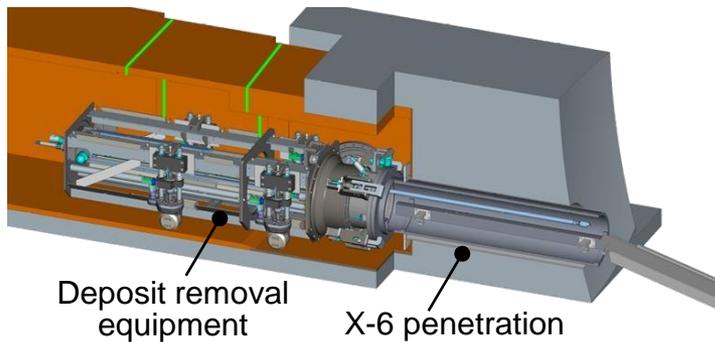
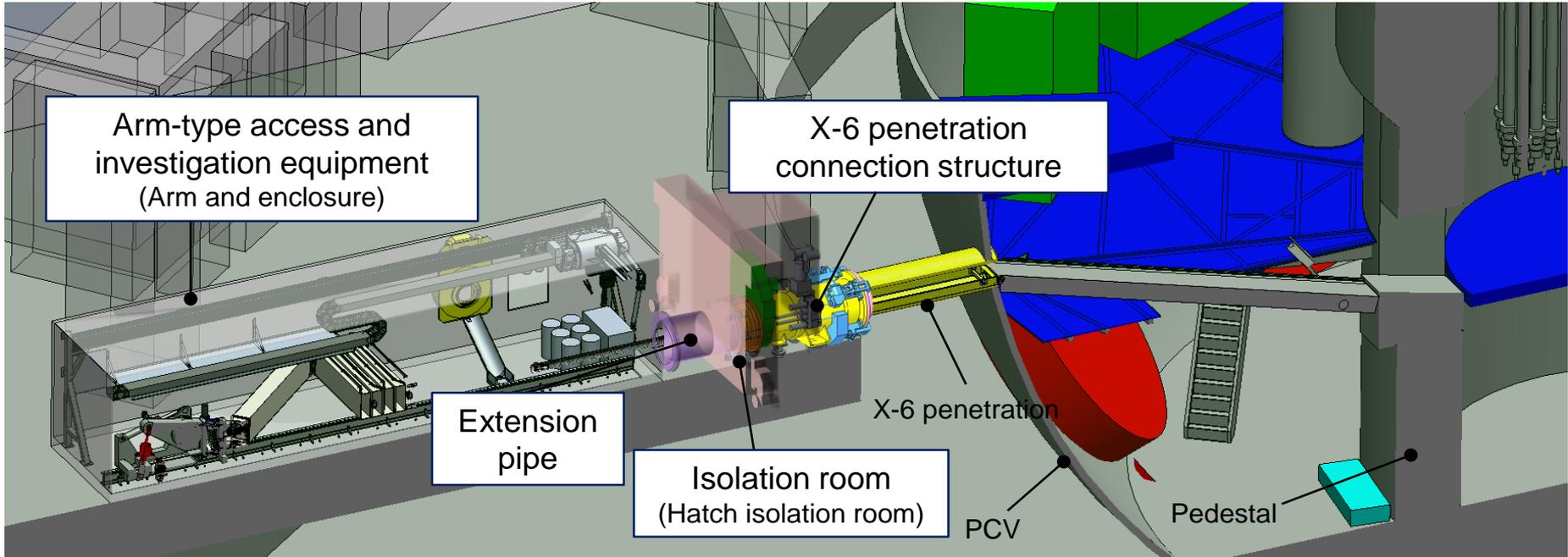
○ On-site demonstration:

- The work of removing deposits from inside the X-6 penetration was completed using the deposit removal equipment.
- Installation of the X-6 penetration connection structure and the extension pipe equipment was completed.
- Removal of the robot carry-in chamber was completed.

(2) Plan for FY2025

- The access and investigation equipment will be shipped to Fukushima Daiichi Nuclear Power Station after undergoing equipment maintenance, operation verification, etc.
- After being shipped to the Fukushima Daiichi Nuclear Power Station, the equipment will be transferred and installed, will undergo a trial run, which will be followed by a detailed internal investigation.

Supplementary materials

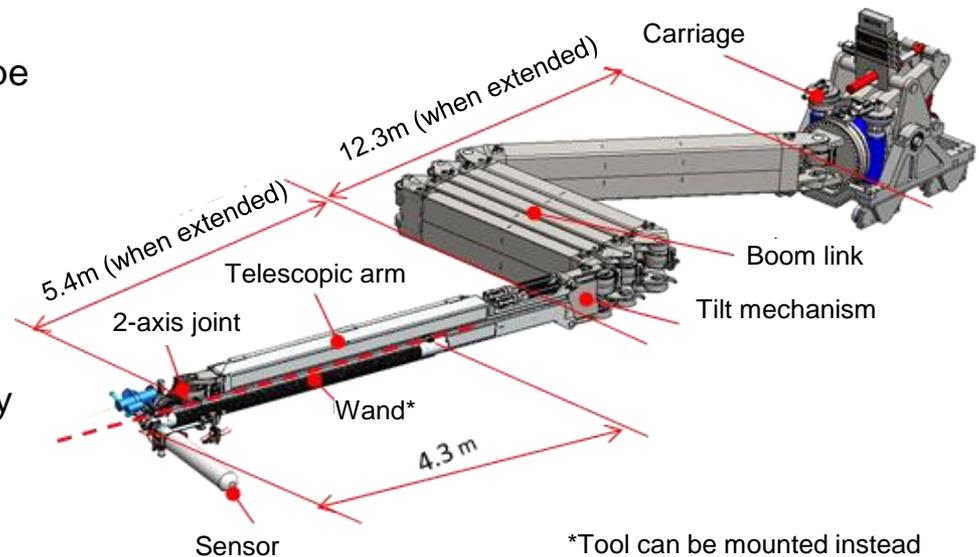


| Equipment | Main purpose |
|---|--|
| Arm-type access and investigation equipment | Acquiring data about the inside of PCV (by mounting sensors), removing obstacles (by mounting tools) |
| X-6 penetration connection structure | Constructing PCV boundary and ensuring passing of arm (by mounting isolation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

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
- ✓ radiation-resistant Accumulated dose: 1MGy
- ✓ Accessories
Camera and lighting



[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.

