

In-house Project

**Development of Technology for Detailed Investigation inside
Primary Containment Vessel (PCV)**

**(Onsite Demonstration for Detailed Investigation inside PCV
Through X-6 Penetration)**

Final Report for FY2021

May 2022

International Research Institute for Nuclear Decommissioning
(IRID)

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1. Background and Purpose of the Project

[Background]

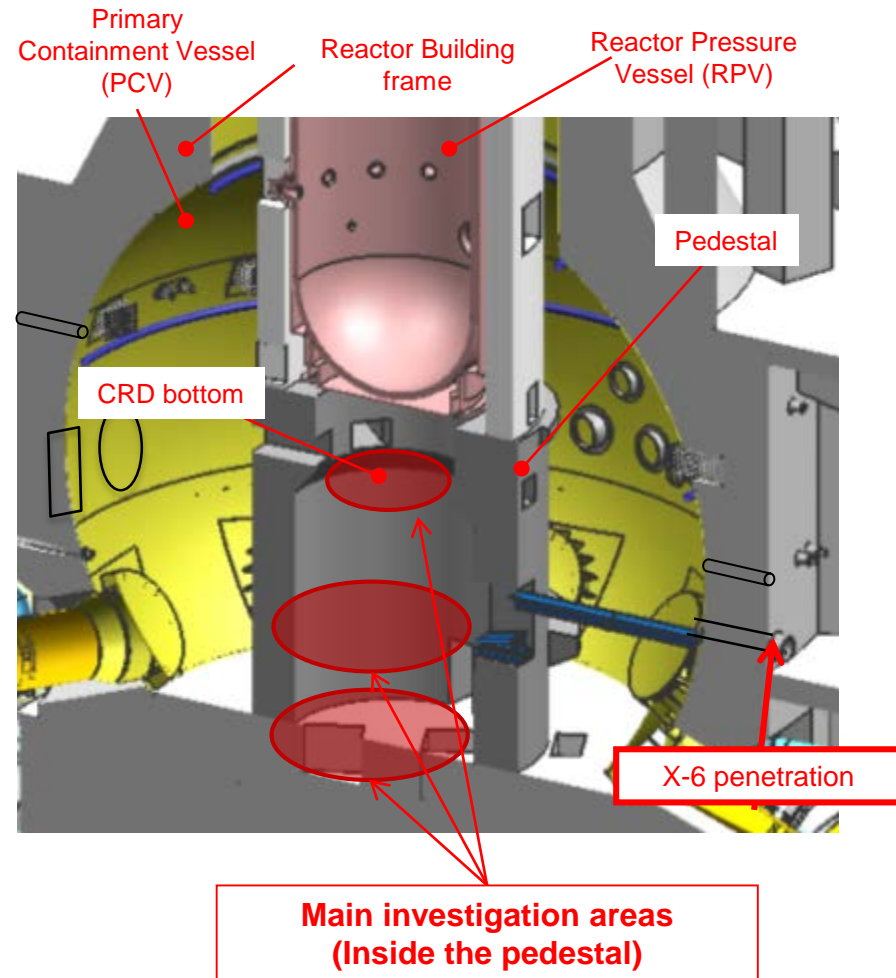
As a result of the investigation inside Unit 2 PCV conducted in January 2018, pebble-like and clay-like deposits were found all over the bottom inside the pedestal.

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



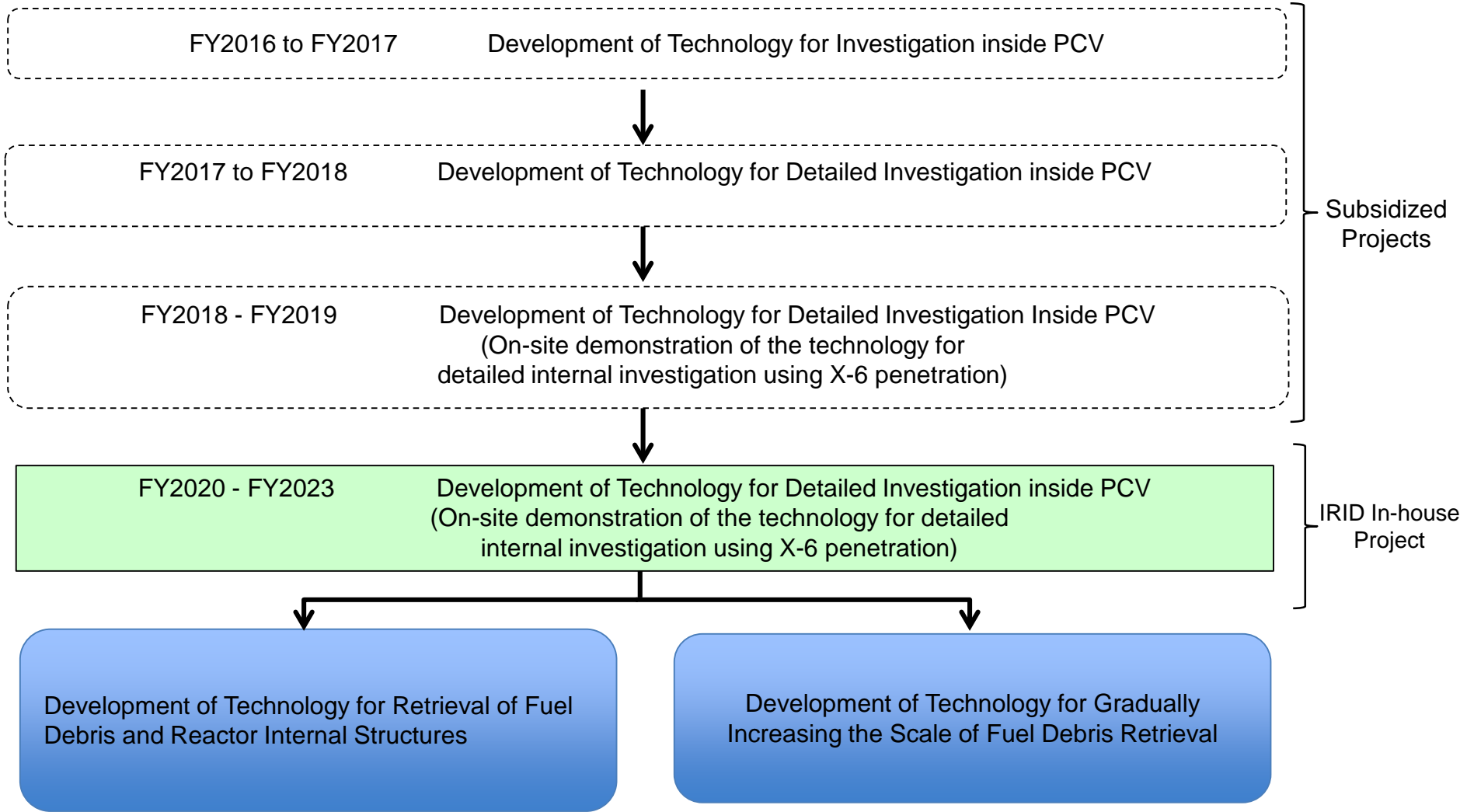
[Purpose]

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 said developed technology.

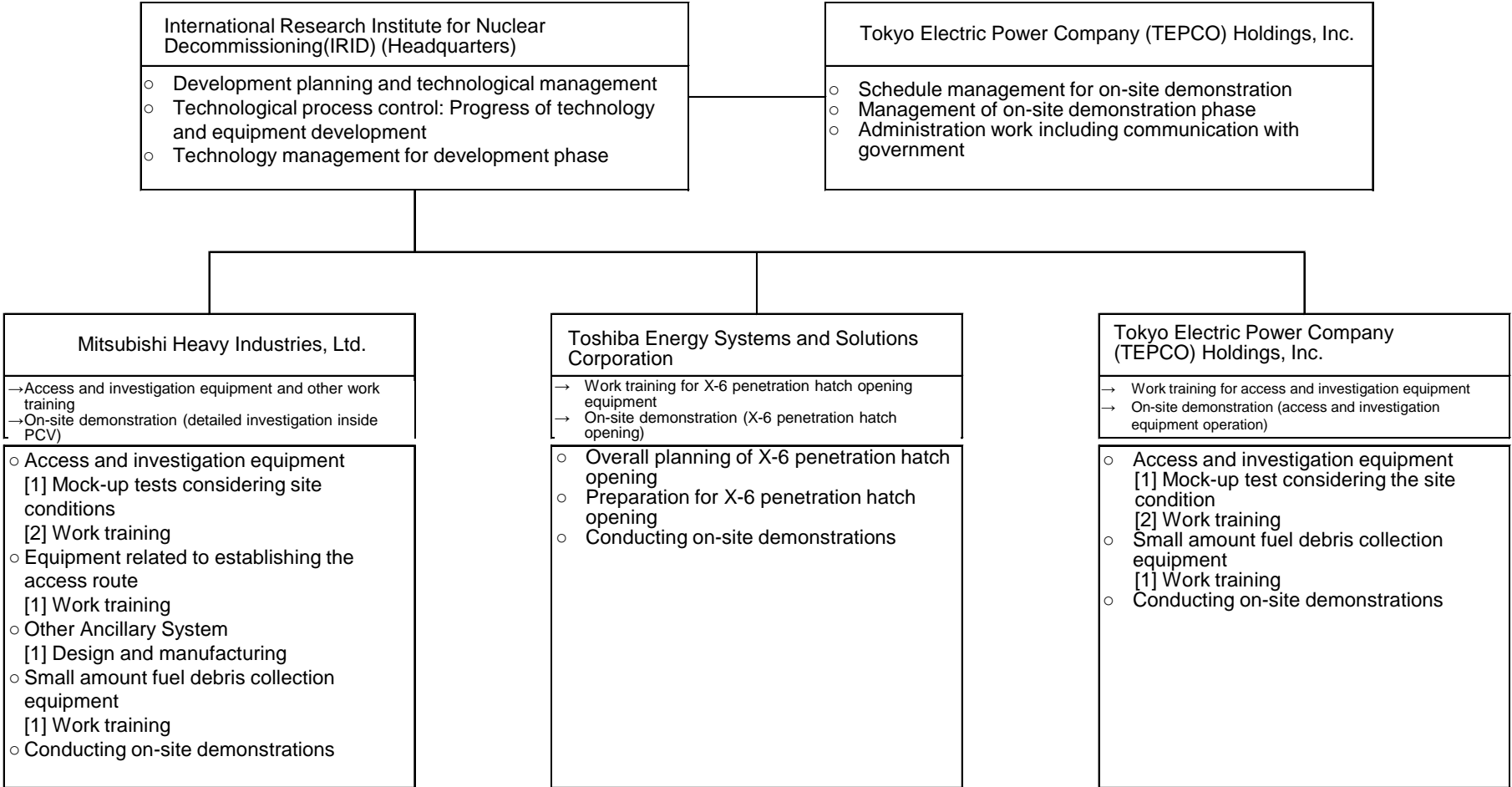


[PCV cross-section and overview of the sites to be investigated]

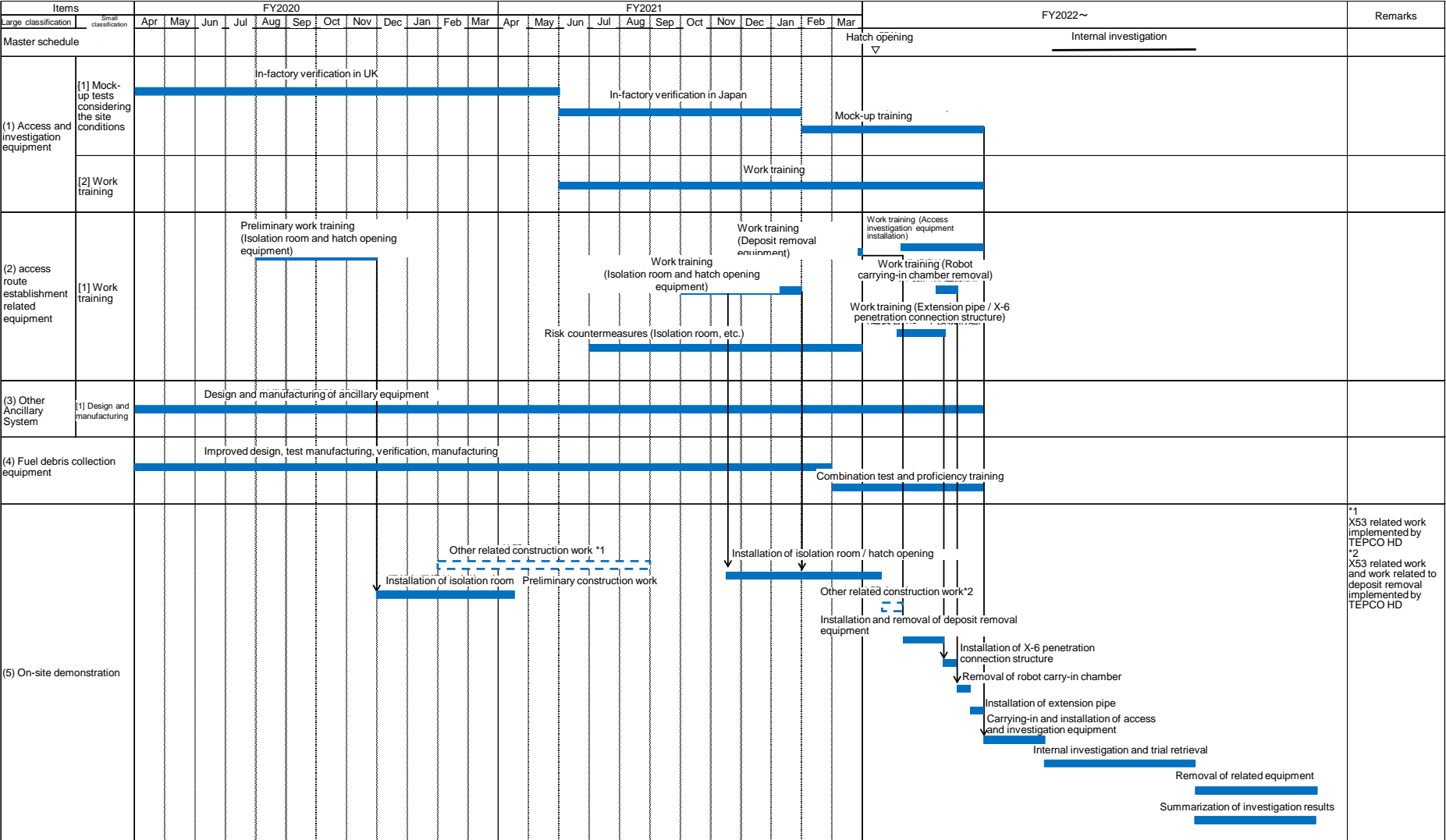
2. Positioning of the Project



3. Project Organization and Implementation Schedule: Project Organization



3. Project Organization and Implementation Schedule: Implementation Schedule



4. Implementation Details and Results

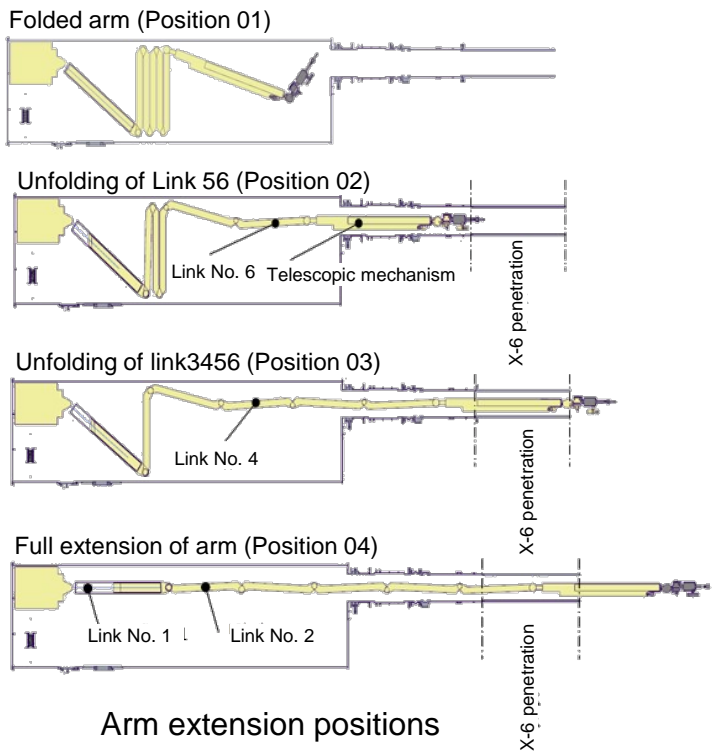
4.1 Access and Investigation Equipment

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

a. Comparative evaluation with deflection measurement and analysis

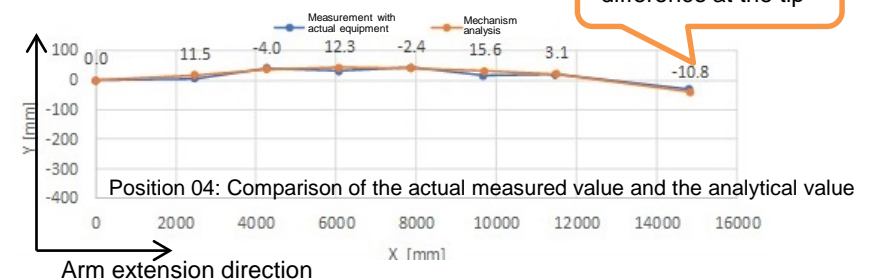
[Test overview]

- Acquisition of data on arm deflection in every position (Verifying that the actual measured value roughly matches the analytical value)
- The deflection data will be reflected in the arm operation and control program and is planned to be verified at the JAEA Naraha mock-up facility.



Onward motion of the arm

Vertical direction



4.1 Access and Investigation Equipment

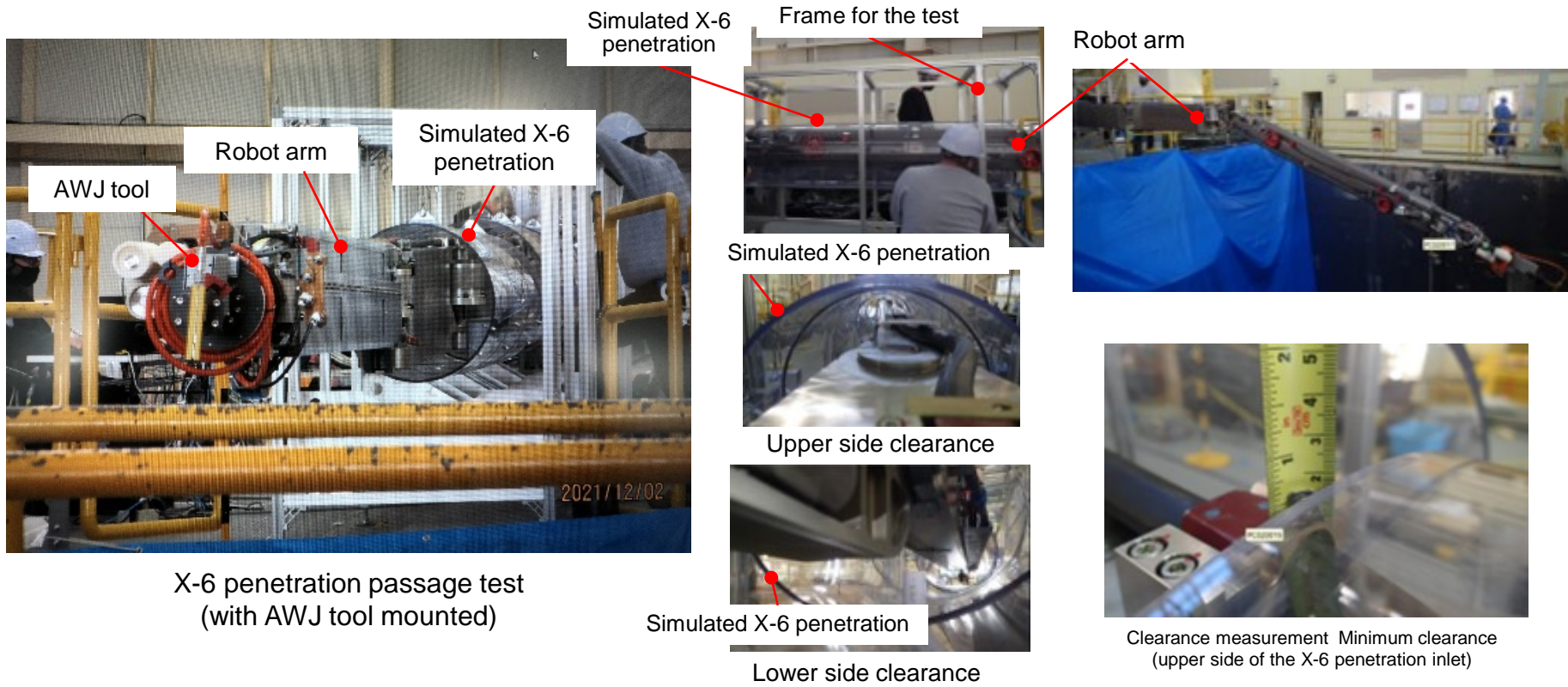
(1) Mock-up tests considering on-site conditions (i) Arm verification test

b. X-6 penetration passage test

*AWJ: Abrasive Water Jet

[Test overview]

- It was confirmed that the tip tool (AWJ)* installed on the arm can pass through the simulated X-6 penetration.
- Minimum clearance 15 mm (nominal dimensions are 25 mm)
- A program file (teach and repeat file) was created for the process up to arm extension ⇒ It will be used as the basic information for future arm operation



X-6 penetration passage test (with AWJ tool mounted)

Simulated X-6 penetration

Lower side clearance

Clearance measurement Minimum clearance (upper side of the X-6 penetration inlet)

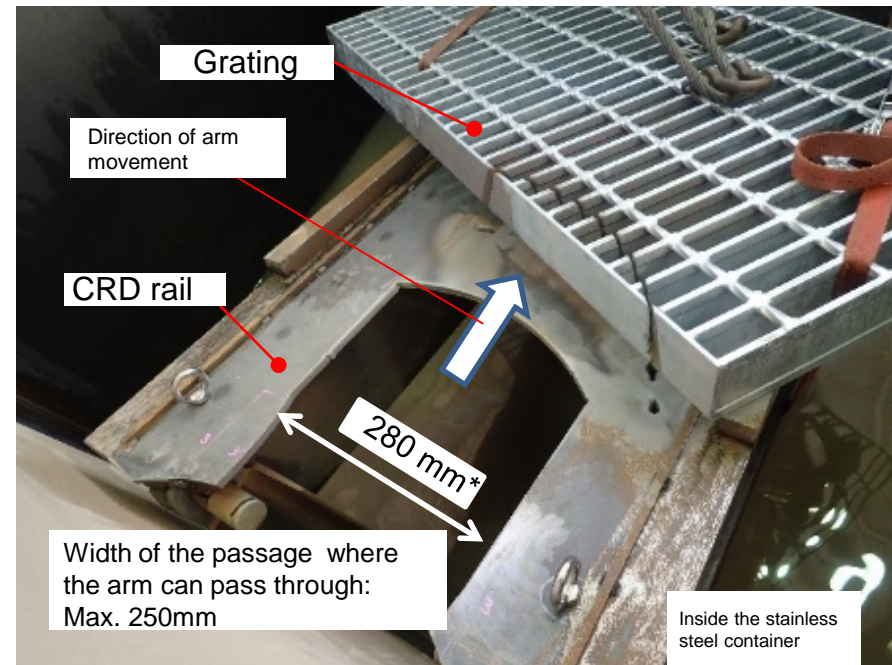
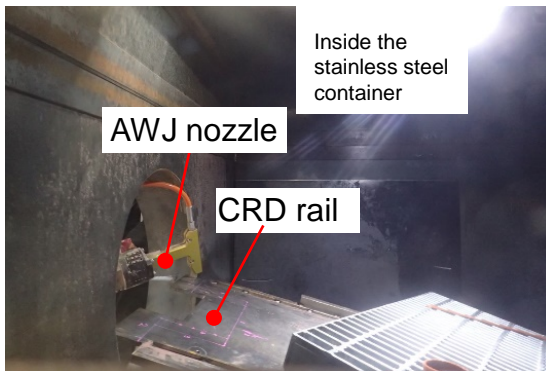
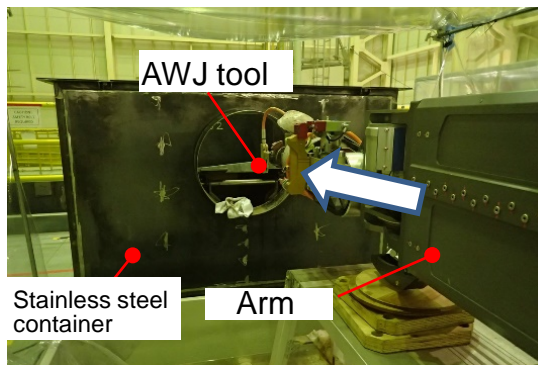
4.1 Access and Investigation Equipment

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

c. AWJ cutting test (1/2)

[Test overview]

- The tip tool (AWJ) installed on the arm cut the CRD rail and the grating (without the cables).
- The prospects of removing obstacles from the area through which the arm can pass through, were verified.



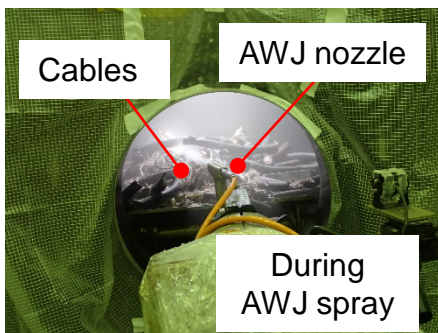
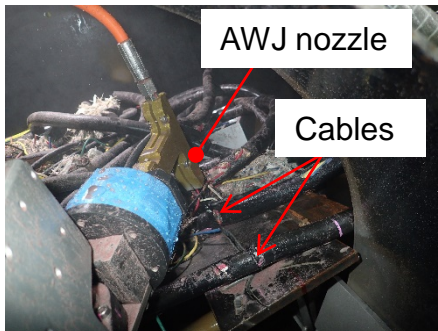
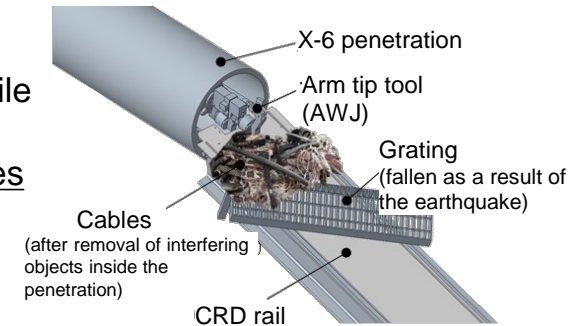
4.1 Access and Investigation Equipment

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

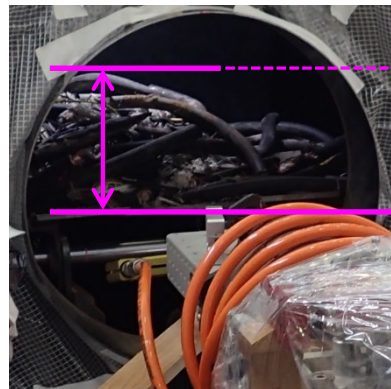
c. AWJ cutting test (2/2)

[Test overview]

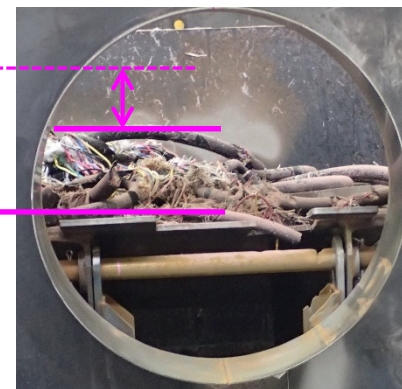
- The prospect of cutting and removing the cables on the CRD rail were verified while the tip tool (AWJ) was installed on the arm.
- From the viewpoint of reducing operating time, the detailed and revised procedures are needed such as the order of cutting the sites to be cut (CRD rail, cables, etc.) and direction of AWJ spray, etc. ⇒ Continued testing at the JAEA Naraha mock-up facility.



Test status



Before the test



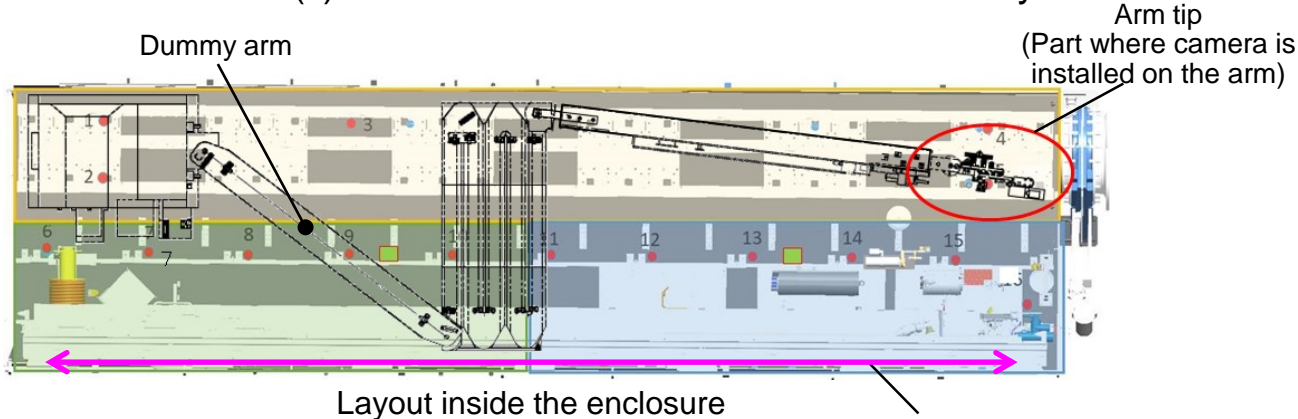
After the test

Verification that the cables can be cut and removed by the AWJ spray

4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

Overview of test conditions

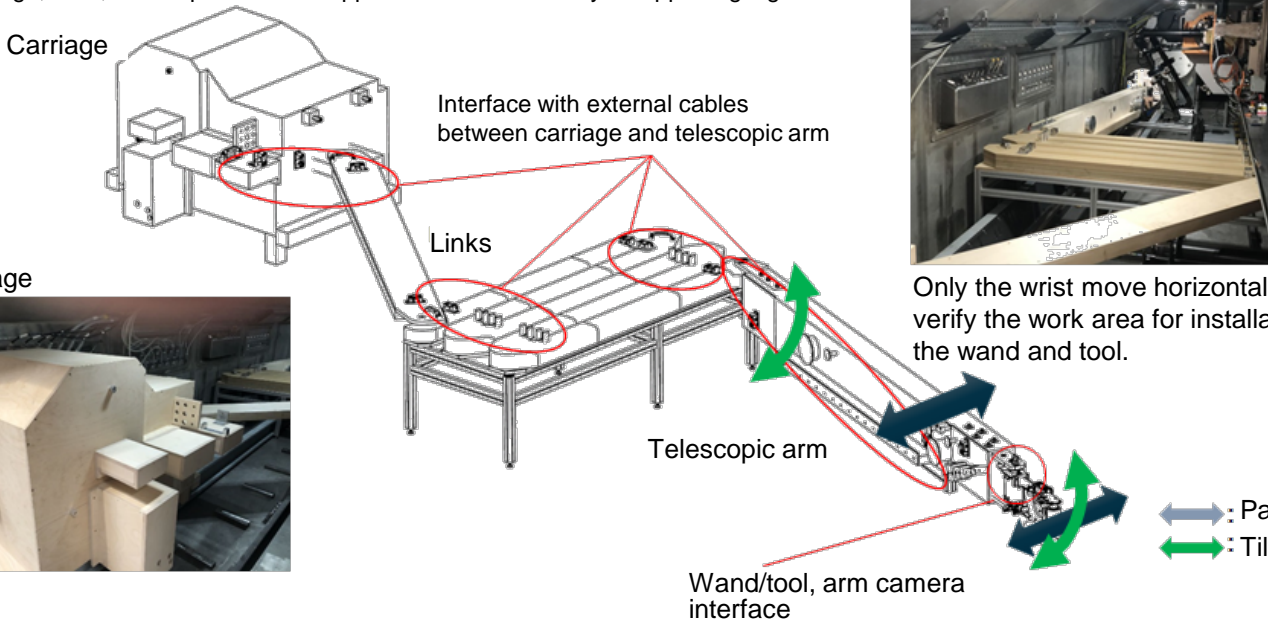


Overview of the dummy arm:

- The section from the arm carriage to the telescopic mechanism is simulated using wood
- The basic structure and the main measurements of the arm are simulated, but the rigidity, cantilever structure and mobility structure is not simulated except for some part. The carriage, links, telescopic arm are supported from the floor by a supporting leg.

Links and telescopic arm

Range of motion of the carriage for the manipulator for maintenance



Only the wrist move horizontally and vertically to verify the work area for installation and removal of the wand and tool.

4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

a. Replacement of arm camera/lighting

[Test overview]

- The dummy arm camera and lighting were replaced, and their viability was confirmed. The following improvements were identified.
- Slip prevention measures when holding the connector ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility.

Manipulator arm for maintenance

Gripper

Dummy arm

Lighting (dummy)

Arm camera (Dummy camera)

Brackets

Test status

Arm

Brackets

Lighting

Arm camera

Installation part

Boom Camera (Wand)

Installation/removal by holding with the gripper of the manipulator for maintenance

Camera side cable*

Arm side cable*

Connector*

*Dummy used for the test

When holding the connector, it can easily slip. Hence slip prevention measures are required.

Layout drawing of the inside of the enclosure

Dummy arm

Work area of the manipulator for maintenance

Arm camera/lighting replacement area (tip of arm)

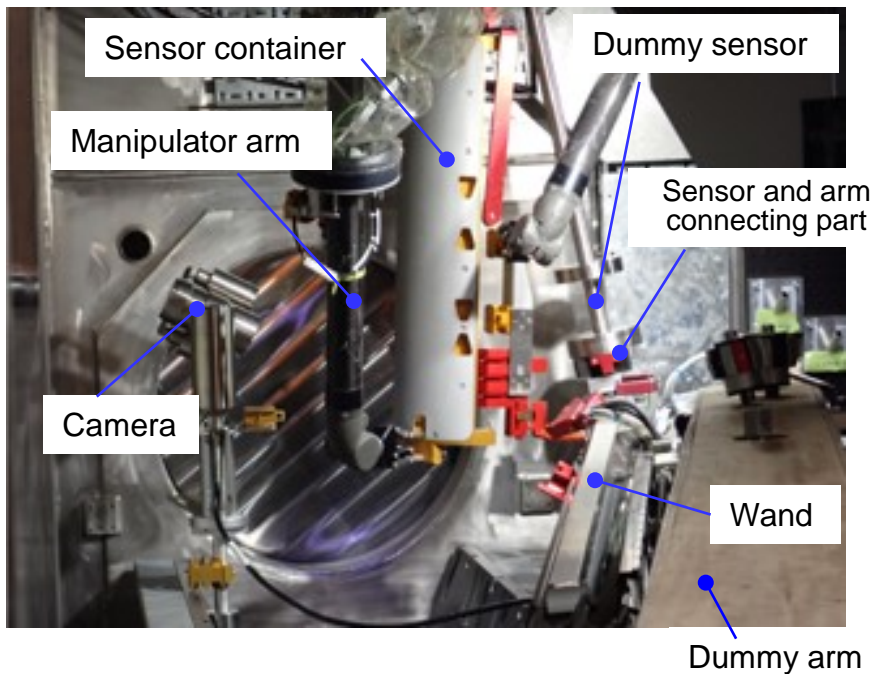
4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

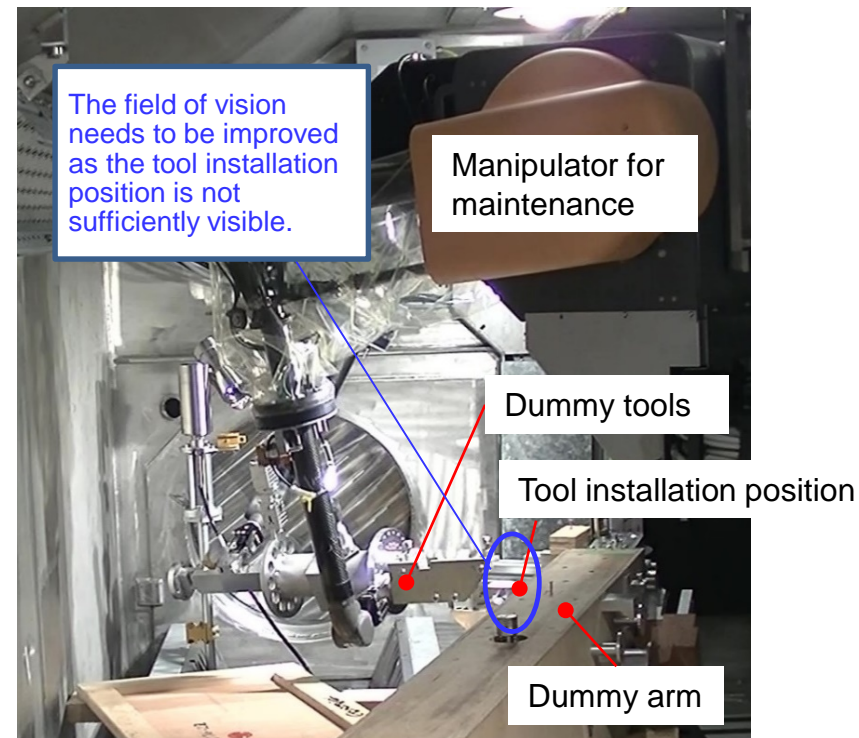
b. Installation of sensor and tool

[Test overview]

- The work of connecting with the dummy arm using the actual wand, a sensor container, a dummy sensor and a dummy tool was conducted and their viability was confirmed. The following improvements were identified.
- Improvement in the field of vision of the tool installation position ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility.



Connection of the sensor and arm (wand)



Connection of the tool and arm

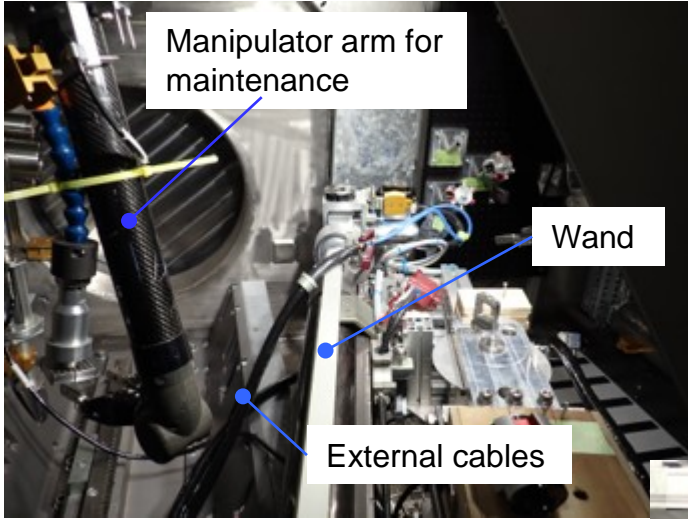
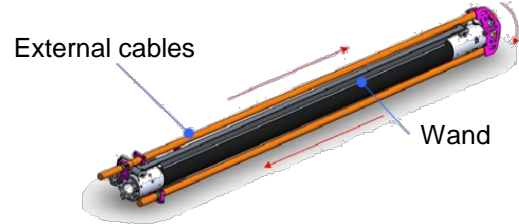
4.1 Access and Investigation Equipment

- (1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

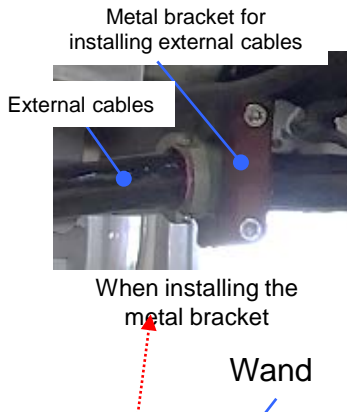
c. Installation of external cables (1/2)

[Test overview]

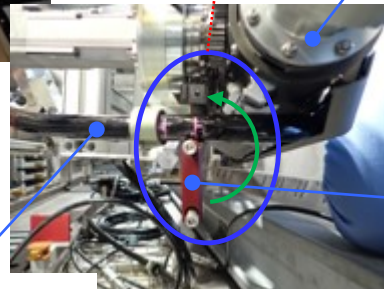
- The external cables on the wand was installed and their viability was confirmed. The following improvements were identified.
 - Modification of a part of the metal bracket structure for installing external cables in connection with drawing around the external cables to the wand
- ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility,



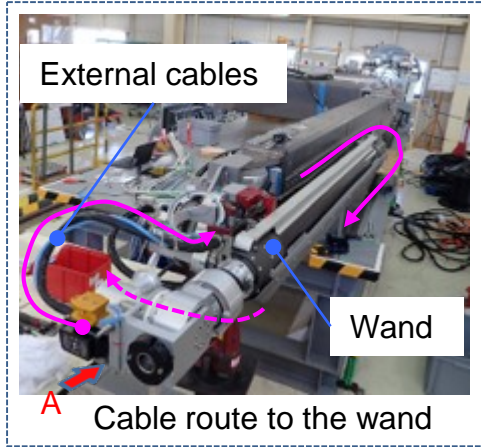
Work of drawing around cables to the wand



When installing the metal bracket



View A



The structure of the metal bracket needs to be modified as the work of installing the metal bracket for installing the cables will be done in limited space.

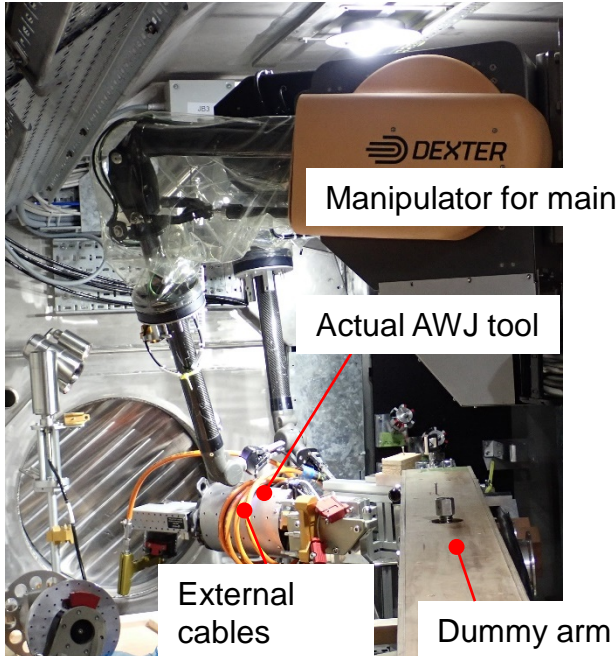
4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

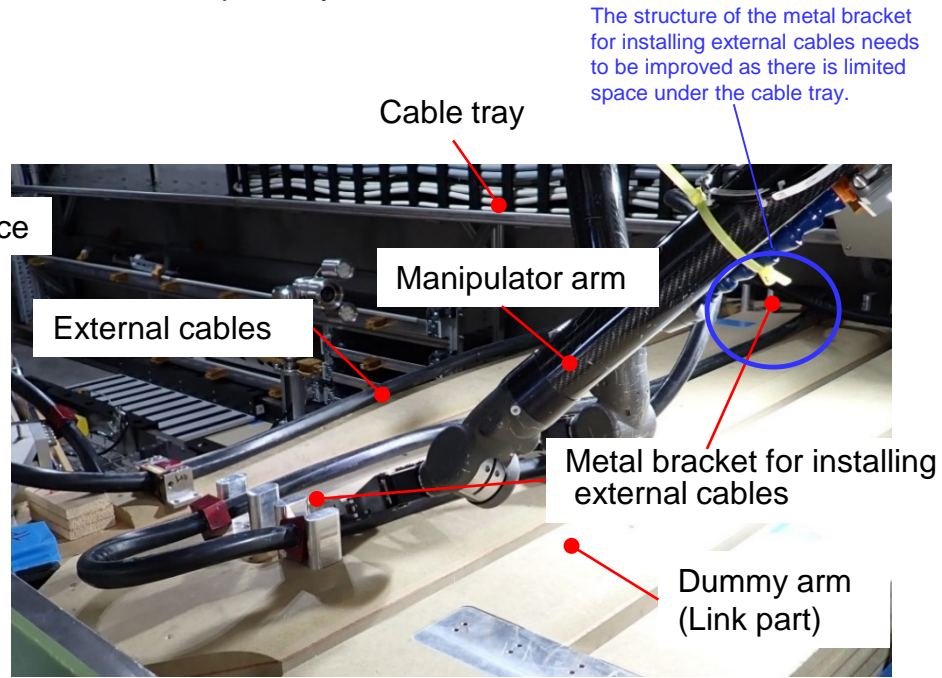
c. Installation of external cables (2/2)

[Test overview]

- The installation of the external cables with the dummy arm was conducted and their viability was confirmed. The following improvements were identified.
- Improvement of the metal bracket structure for installing external cables in connection with drawing around the external cables to the arm link part
 ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility.



Installation of external cables on to the tool



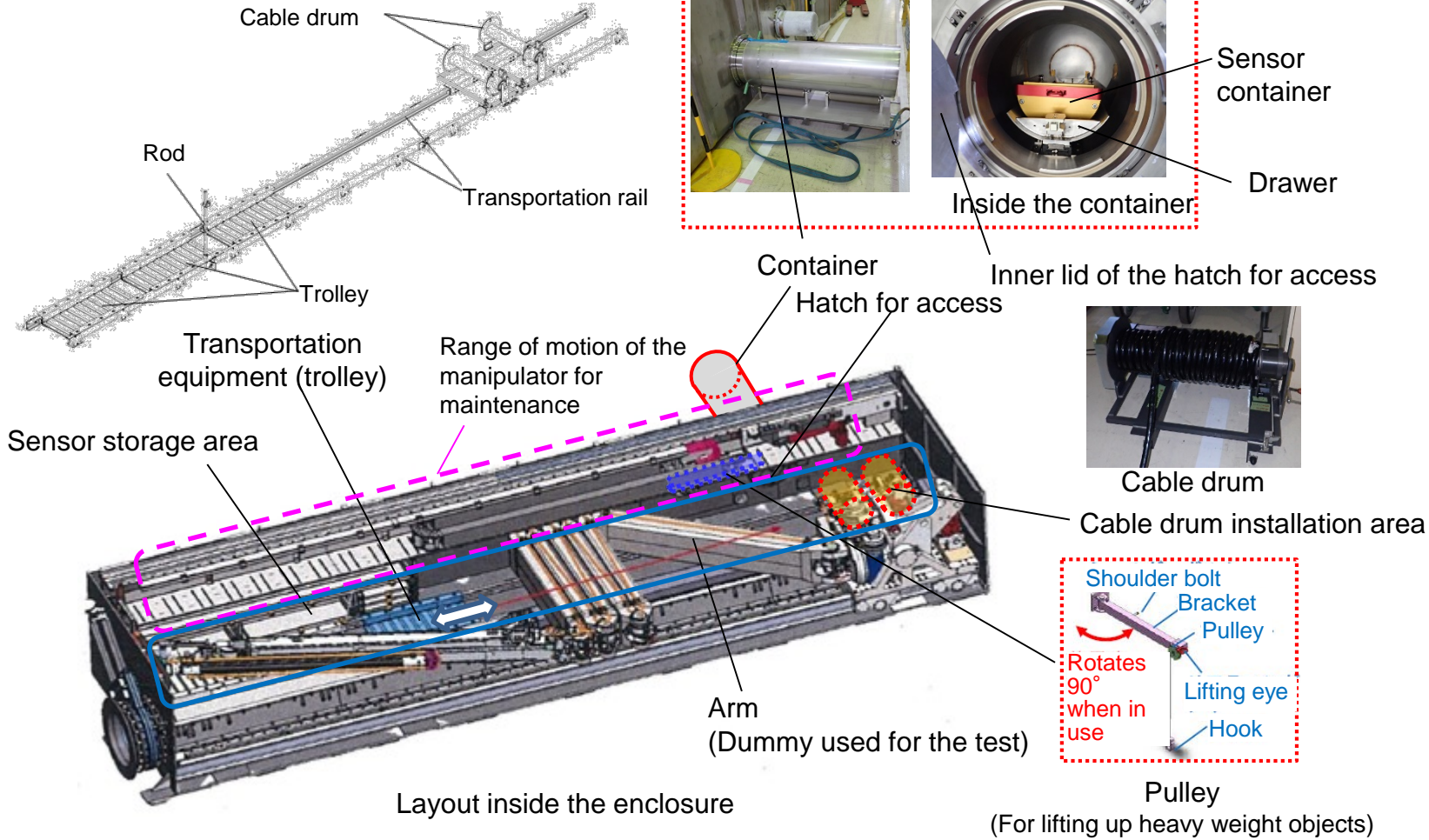
Installation of the external cables on to the arm link part

4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

d. Carrying-in/out of the sensor and tool (1/2)

[Overview of carrying-in/out]



4.1 Access and Investigation Equipment

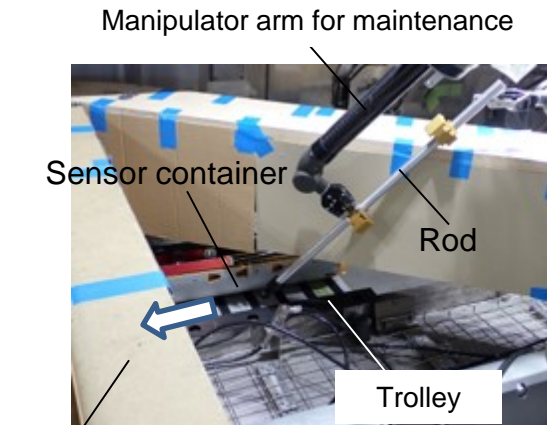
(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

d. Carrying-in/out of the sensor and tool (2/2)

[Test overview]

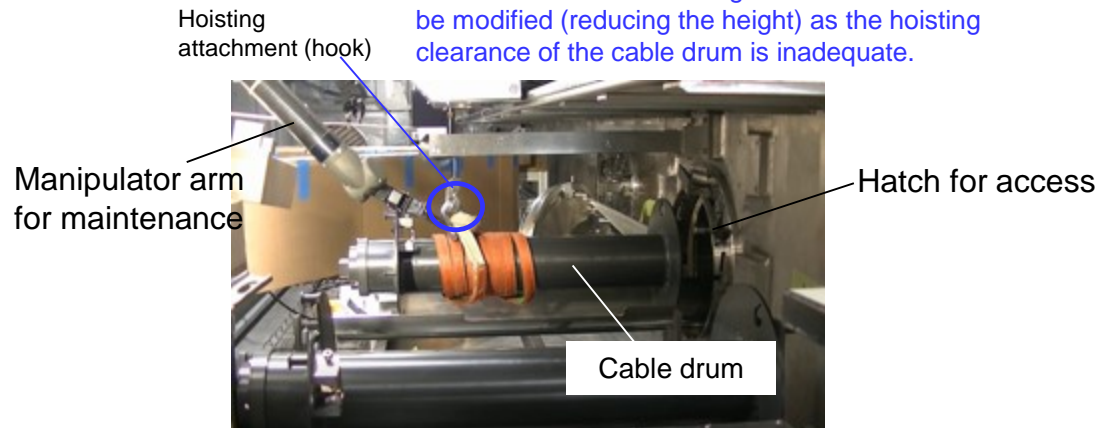
- The work of carrying-in the sensor container and cable drum was performed and their viability was confirmed. The following improvements were identified.
 - Streamlining of the method of transporting the sensor container inside the enclosure (method of transportation by trolley)
 - Modification of part of the structure of the hoisting attachment used at the time of carrying-in the cable drum, improvement in the field of vision for work while installing the cable drum
- ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility.

The structure of the hoisting attachment needs to be modified (reducing the height) as the hoisting clearance of the cable drum is inadequate.



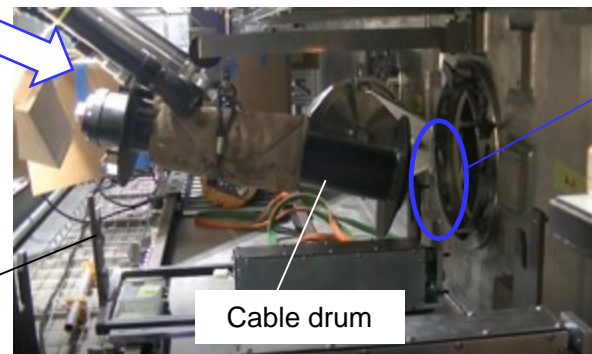
Dummy arm

Since transportation by means of a trolley using a rod requires time due to limited space, the transportation jig needs to be improved.



Direction of the view from camera

Trolley for installing the cable drum



The rear side of the cable drum is at a blind spot which affects work. The field of vision needs to be improved (securing an opening towards the cable drum, etc.).

4.1 Access and Investigation Equipment

(1) Mock-up tests considering on-site conditions (ii) Verification tests for the work efficiency of the maintenance manipulator

e. Changing of the position of the camera inside the enclosure

[Test overview]

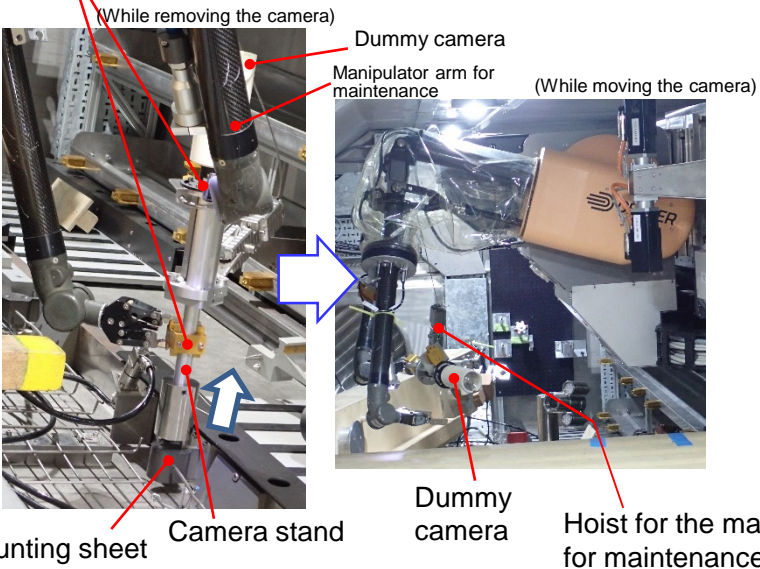
- The change of positioning the dummy camera and the carrying-out was performed and their viability prospects was confirmed. The following improvements were identified.
- Optimization of the installation position and direction of the manipulator gripper of the camera stand ⇒ Effects of improvement will be verified at the JAEA Naraha mock-up facility.

Changing of the position of the camera

The camera stand was removed, and the position of the dummy camera was changed (installed on the mounting eye at another location). The following improvements were identified.

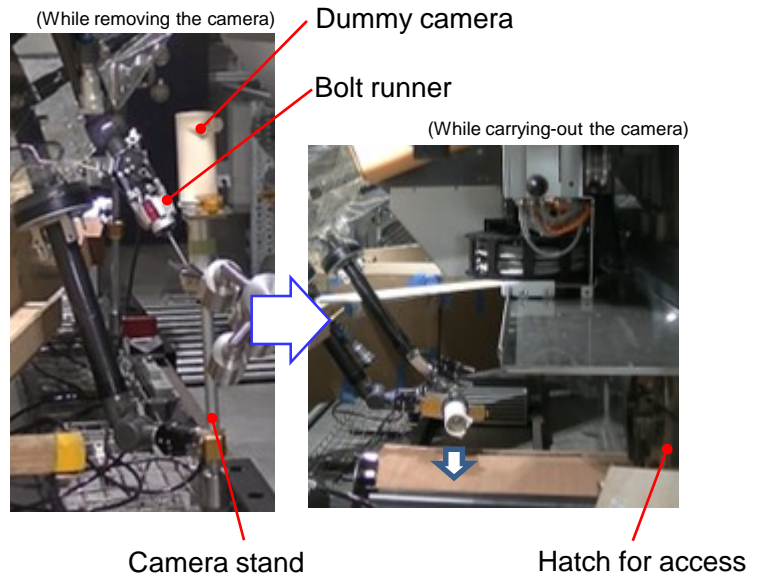
Gripper ⇒

Optimization of the gripper installation position and installation direction for enhancing installation work efficiency



Carrying-out the camera

The workability of carrying-out the dummy camera removed from the camera stand was verified.



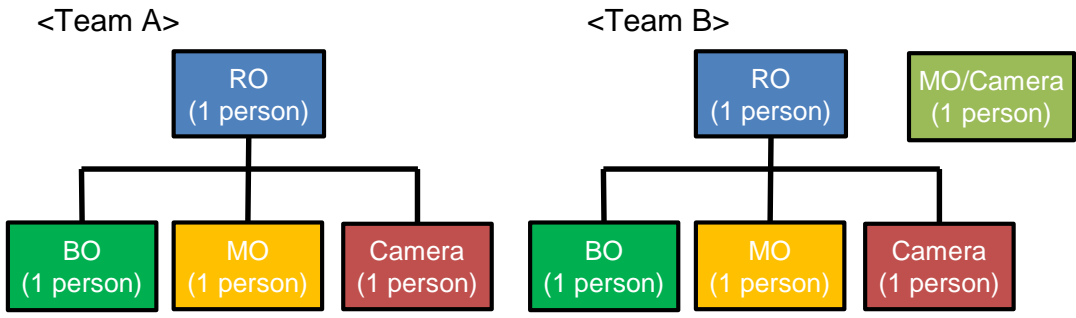
4.1 Access and Investigation Equipment

(2) Work training

i. Work training policy (organization and plan)

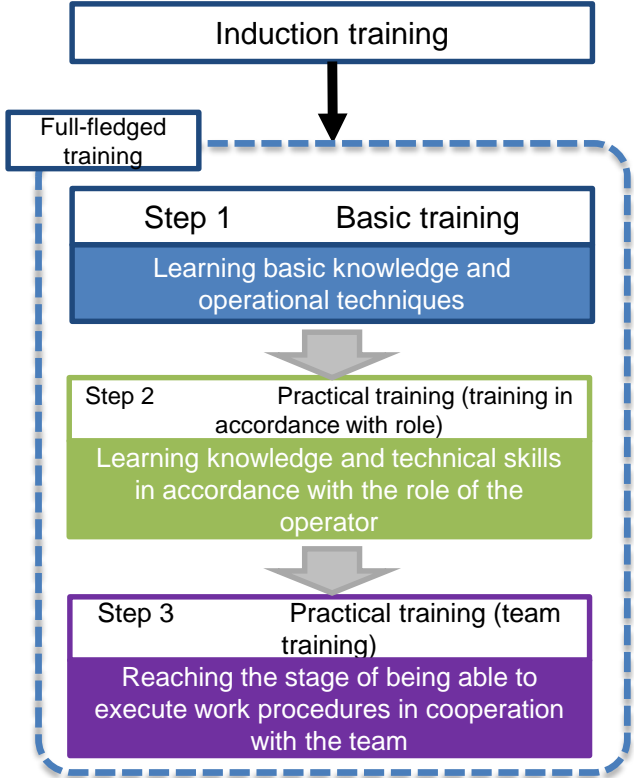
- Arm-type access equipment was operated by 4 persons / team.
- Based on the operating time using actual equipment, **two operator teams were formed** in this project and **nine operators were selected**. A training plan was created to facilitate stepwise and systematic learning of knowledge and skills required for the operation, and work training was conducted in accordance with the plan (completed up to Step 1 this year).

[Operator organization and roles]



	Role	Main required skills
RO	Leading a team	<ul style="list-style-type: none"> Team management skills Knowledge of work procedures and management skills
Camera	Operation of the camera, lighting, HMI	<ul style="list-style-type: none"> Camera operation techniques and HMI operation techniques from the standpoint of the operator
BO	Operation of the boom (arm)	<ul style="list-style-type: none"> Arm operation techniques VR system operation techniques
MO	Operation of the manipulator for maintenance	<ul style="list-style-type: none"> Operation techniques for the manipulator for maintenance

[Training flow]



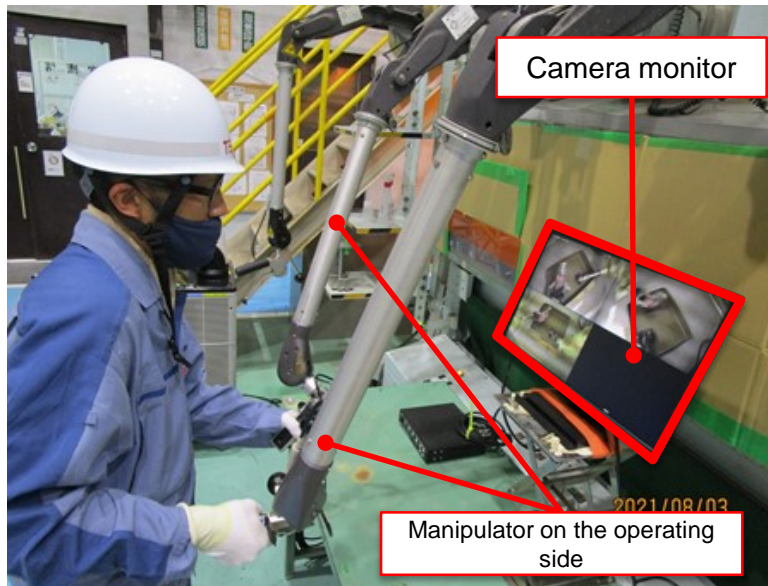
4.1 Access and Investigation Equipment

(2) Work training

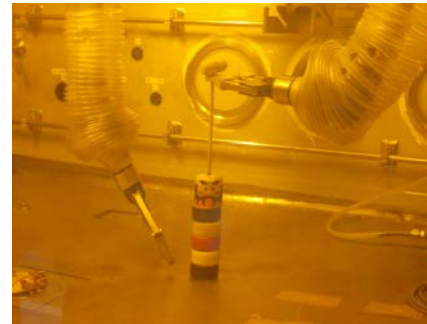
ii: Training results

Induction training

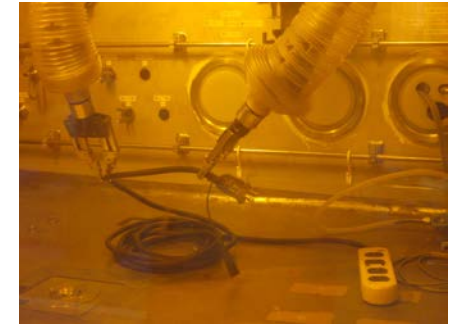
- Operation training was conducted using MHI manipulators as induction training at a stage prior to starting full-fledged work training.
- Through this training, the operators got a sense of operating the manipulator and got a hang of carrying out the operation over the camera monitor.



Manipulator operation training in progress



Assembling the daruma-otoshi (traditional Japanese game of stacking wooden blocks and hitting them)



Handling the cables



Assembling rings (stacking rings)

4.1 Access and Investigation Equipment

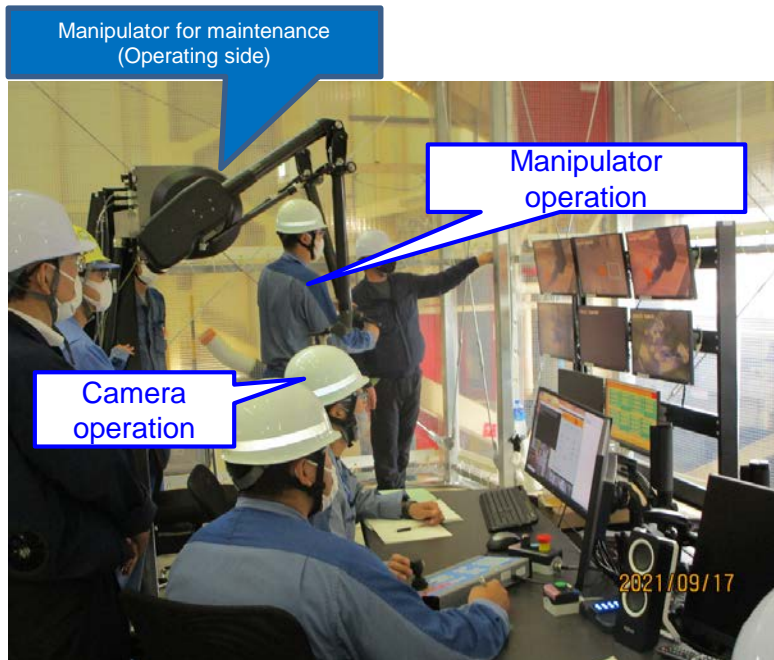
(2) Work training

ii: Training results

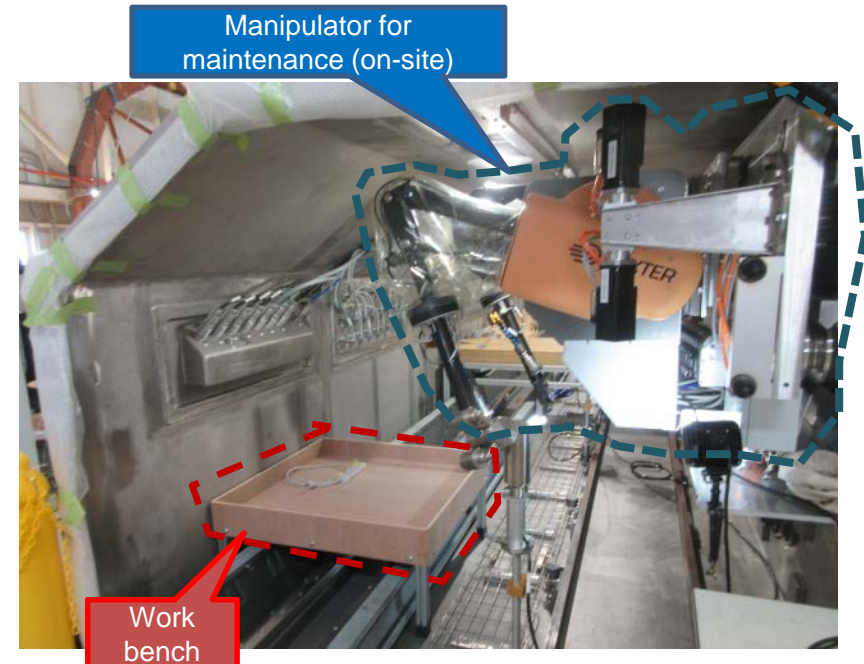
Step 1 Basic training (Manipulator for maintenance)

*HMI: Human Machine Interface

- Actual equipment operation training and training on basic knowledge (function, structure, etc.) concerning the manipulator for maintenance and the HMI* for the manipulator were conducted.
- During the training, a work bench was installed inside the enclosure, and various operations of the manipulator for maintenance were performed on the work bench.
- Eventually all operators learned the basic operating techniques pertaining to the manipulator for maintenance.



Control room



Inside the enclosure

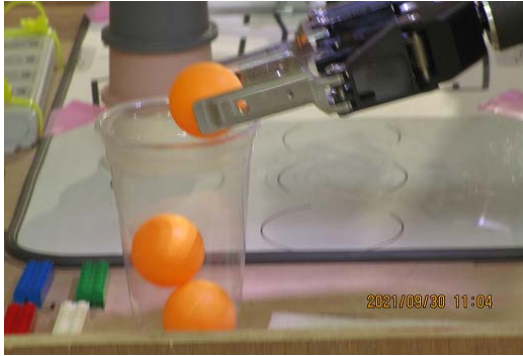
4.1 Access and Investigation Equipment

(2) Work training

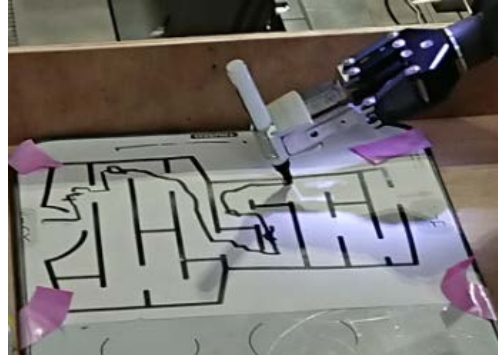
ii: Training results

Step 1 Basic training (Manipulator for maintenance)

Operation training using items of everyday use



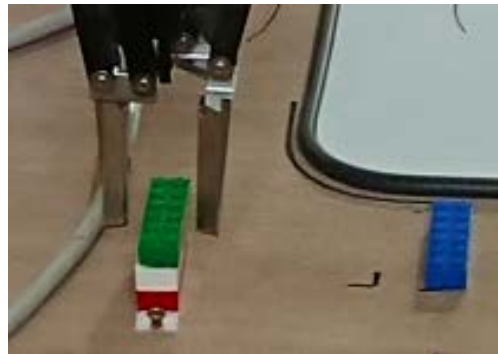
Holding a table tennis ball, and putting it in a cup



Tracing the maze



Stacking cups



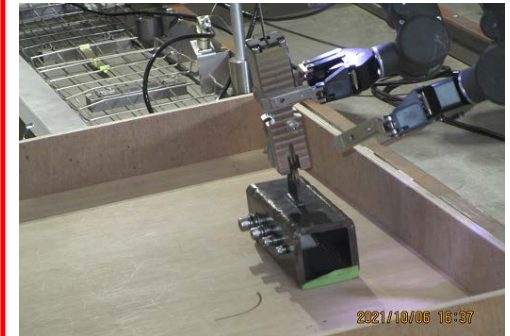
Assembling blocks

STEP UP
➔

Training using actual tools



Handling the screw runner



Operating the hoist

4.1 Access and Investigation Equipment

(2) Work training

ii: Training results

Step 1 Basic training (Arm operation control system)

- Education and operation trainings on VR simulator, method of starting up HMI, method of connecting the VR simulator and HMI, method of operation using joy stick, method of creating and editing the teach & repeat file were conducted.
- Education and operation training on OMS* functions and operation method were conducted.
- Eventually all operators learned the basic operating techniques pertaining to the operation control system.

*OMS: Operation Management System

Operation Control System PC



Education and training in progress

4.2 Access Route Establishment Related Equipment

(1) Work training

i. Work training policy (organization and plan)

- Work training was conducted in accordance with the actual site work plan.

Work procedures at the actual site		Training contents
Classification	Detailed contents	Whether implemented or not
Setting up of a plant room	Wiring from the plant room and control room	○
Carrying-in and installation of a lid for preventing spread of contamination	Carrying-in right to the front of the north-western area	○
	Installation at the operating location after installing in the north-western area	○
Carrying-in and connection of the main deposit removal equipment	Carrying-in right to the front of the north-western area	○
	Installation at the operating location after installing in the north-western area	○
Installation and connection of ancillary equipment (emergency winch, abrasive tank)	Installation of a board at the planned location after installing the equipment, and connection to the equipment	○
Operation verification	Verification of operation of equipment	○
Removal of low-pressure deposits	Removal of the hollowed out portion of the penetration hatch	○
	Cleaning inside the penetration	○
Removal of high-pressure deposits	Cutting and removal of cables	○
	Cutting and removal of rail guide	○
Retreating after completion of work	Remote retreating while the isolation room is closed	○
Carrying-out of the main deposit removal equipment	Covering to receding to skid mounting of the equipment inside the isolation room	○
	Retreating up to the truck bay entrance	○
Carrying-out the lid for preventing spread of contamination	Covering to receding inside the isolation room	○
	Retreating up to the truck bay entrance	○
Carrying-out of the ancillary equipment		○

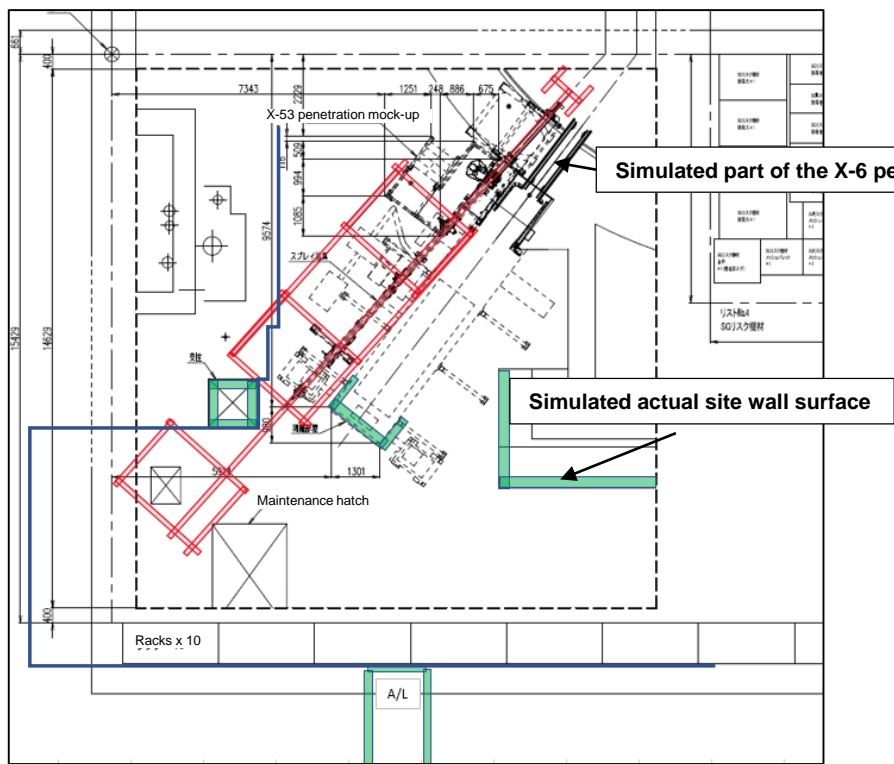
4.2 Access Route Establishment Related Equipment

(1) Work training

i. Work training policy (organization and plan)

During the transportation training, an environment was prepared simulating interference inside the building at the actual site, with layout dimensions of the ancillary equipment such as cables, control panel, etc. the same as that at the actual site.

The X-6 penetration and internal deposits to be removed were simulated for the operation training.



Status of simulation of the inside of X-6 penetration

4.2 Access Route Establishment Related Equipment

(1) Work training

ii: Training results (carrying-in the equipment)

Training of carrying-in the equipment was conducted. The work time initially planned was reduced, and training simulating the actual site was completed.

No.	Work procedures	Training contents/conditions	Items to become proficient in	Results and issues
1	Carrying-in (straight movement)	<ul style="list-style-type: none"> Carrying-in the equipment by pushing it by hands 	<ul style="list-style-type: none"> Traveling steadily Bringing the dolly back on track if it tilts away from the intended direction of travel 	The work of traveling was completed in the planned time with the assumed arrangement of workers. If by chance there is a level difference and the dolly gets caught in it, a crow bar is used to get out of it.
	Carrying-in (rotating and positioning)	<ul style="list-style-type: none"> Rotating and positioning the equipment by pushing it by hands Lifting up with a hydraulic jack 	<ul style="list-style-type: none"> Rotating to a predetermined position Positioning so as to be able to install a ramp 	The work of moving was completed in the planned time with the assumed arrangement of workers.
2	Carrying-in the robot Covering inside the room	<ul style="list-style-type: none"> Laying adhesive sheets (6 sheets) in the area on which the equipment will travel 	-	The covering sheets were prepared in advance at a low radiation dose area to reduce the exposure of the workers. They were prepared as a single sheet thereby reducing the actual work time, and the work was completed without any issues.
3	Carrying-in the lid for preventing spread of contamination	<ul style="list-style-type: none"> Carrying-in the lid into the robot carry-in chamber by pushing it by hands Laying of hoses and cables 	<ul style="list-style-type: none"> Bringing the dolly back on track if it tilts away from the intended direction of travel 	The moving was completed in the planned time with the assumed arrangement of workers.

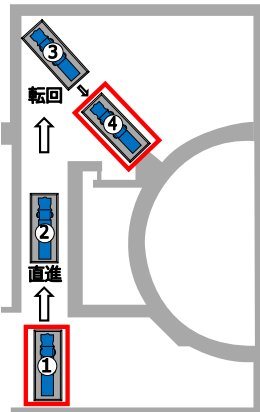


Figure showing the carrying-in route



Status of carrying-in of the equipment



Carrying-in of the lid for preventing spread of contamination

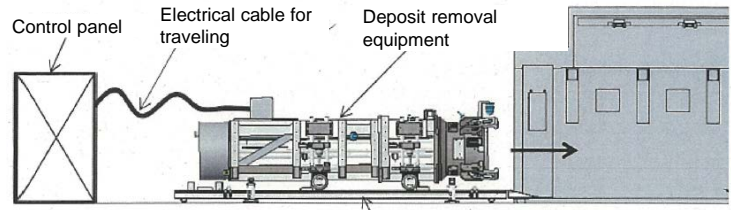
4.2 Access Route Establishment Related Equipment

(1) Work training

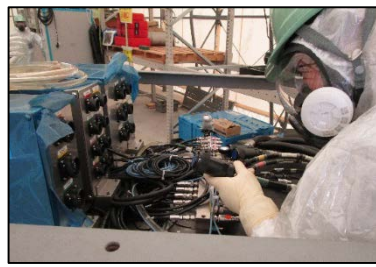
ii: Training results (carrying-in the equipment)

Training of carrying-in the equipment was conducted. The work time initially planned was reduced, and training simulating the actual site was completed.

No.	Work procedures	Training contents/conditions	Items to become proficient in	Results and issues	
4	Carrying-in the equipment for removing deposits from inside X-6 penetration	<ul style="list-style-type: none"> Carrying-in the equipment to the robot carry-in chamber by means of remote operation Directly connecting the control panel and the equipment 	Work efficiency of carrying-in	<ul style="list-style-type: none"> Making sure traveling is not hindered due to resistance of cables, etc. Carrying-in safely without damaging the equipment Carrying-in up to the designated location 	The work of connecting wires to the equipment was completed in the planned time with the assumed arrangement of workers. An additional cable support personnel will be made available to arrange the cables during remote operation of the equipment.
5	Unit installation	<ul style="list-style-type: none"> Installing the unit (abrasive tank, etc.) by pushing it by hands 	Work efficiency of carrying-in	<ul style="list-style-type: none"> Transporting and installing the equipment without damaging it Installing it horizontally using a level 	The work of installing the unit was completed in the planned time with the assumed arrangement of workers.
6	Laying of cables (Connector panel)	<ul style="list-style-type: none"> Laying cables as per the layout plan 	Work efficiency of laying	<ul style="list-style-type: none"> Connecting the connector without causing any damage Making sure there is no error in connecting the connector Wearing protective gear while connecting the connector 	Identity management of cables was carried out to enable connection by group, the work was performed while double checking so that cables were not laid incorrectly, and the work was completed without any issues.
7	Laying of cables (Control panel side)	<ul style="list-style-type: none"> Laying cables as per the layout plan 	Work efficiency of laying	<ul style="list-style-type: none"> Connecting the connector without causing any damage Making sure there is no error in connecting the connector Wearing protective gear while connecting the connector<!--</ul--> 	The work was completed in the planned time with the assumed arrangement of workers.
8	Laying of cables (Equipment)	<ul style="list-style-type: none"> Laying cables as per the layout plan 	Work efficiency of laying	<ul style="list-style-type: none"> Connecting the connector without causing any damage Making sure there is no error in connecting the connector Wearing protective gear while laying the cables Wearing protective gear while connecting the connector 	Identity management of cables was carried out to enable connection by group, the work was performed while double checking so that cables were not laid incorrectly, and the work was completed without any issues.



Layout plan for installing the deposit removal equipment



Status of wiring of the equipment



Status of wiring of the equipment

4.2 Access Route Establishment Related Equipment

(1) Work training

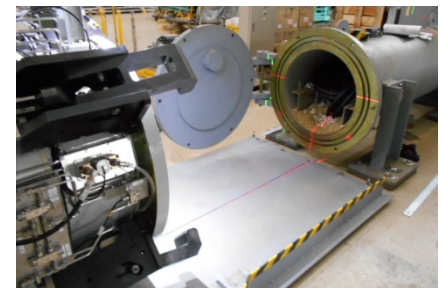
ii. Training results (Deposit removal operation)

Training of deposit removal operation was conducted. It was confirmed that the simulated deposits inside the penetration were removed successfully by the procedures that were initially planned, and the training was completed.

No.	Work procedures	Training contents/conditions	Items to become proficient in	Results	
9	Remote operation of the equipment for removing deposits from inside X-6 penetration	<ul style="list-style-type: none"> Moving the equipment up the ramp by means of remote operation Installation of cables Monitoring of confined spaces Understanding the position and location of the equipment Ability to pass through confined spaces 	Traveling efficiency Operating efficiency	<ul style="list-style-type: none"> Making the equipment travel without causing any damage 	Traveling of the equipment and installation of cables were completed as per the plan without causing any damage
			Interferences and monitoring	<ul style="list-style-type: none"> Recognizing whether or not something is drawing near or is coming in contact Recognizing when there is deviation from the reference line 	Traveling was completed as per the plan without anything coming in contact with the equipment.
10	Access and axis alignment	<ul style="list-style-type: none"> Alignment of the installation position of X-6 penetration Axis alignment and connection with the front wheel on a ramp Monitoring interferences between the hatch, flange and the grabbing mechanism 	Operating efficiency	<ul style="list-style-type: none"> Performing axis alignment and connection with the X-6 penetration by adjusting the elevating length, along with forward, backward and swivel motion on the ramp Performing the operation of accessing the penetration and grabbing without coming in contact with the x-6 penetration 	The operation of accessing and grabbing was completed without coming in contact, by adjusting the elevating length and steering, while checking the equipment camera.
			Monitoring and interferences		
11	Connection and grabbing	<ul style="list-style-type: none"> X-6 penetration hatch: With hexa plug 	Interferences	<ul style="list-style-type: none"> Grabbing without interfering with the hexa plug 	Grabbing was completed without interfering.
12	Verification of air-tightness	<ul style="list-style-type: none"> Pressure maintenance for longer than the specified time 	Verification of air-tightness	<ul style="list-style-type: none"> Ensuring air-tightness 	It was confirmed that air-tightness was ensured.
13	Deposit removal	<ul style="list-style-type: none"> Execution as per the operating procedures 	Procedures and operating efficiency	<ul style="list-style-type: none"> Understanding the procedures and the details of operation, and being able to remove deposits from inside the penetration 	Removal of deposits from inside the penetration was completed while checking the procedures and details of operation.
		<ul style="list-style-type: none"> Checking the status of deposit removal using the equipment camera 	Monitoring		
		<ul style="list-style-type: none"> Treatment of accumulated water 	Treatment of accumulated water	<ul style="list-style-type: none"> Discharging accumulated water to the PCV side 	Accumulated water was discharged to the PCV side as per the plan.



Status of system operation



Status of remote operation and grabbing of equipment

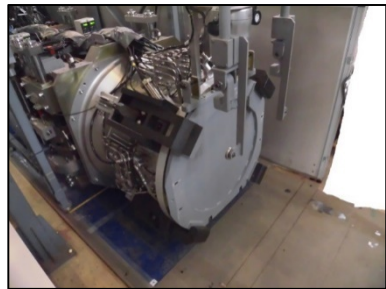
4.2 Access Route Establishment Related Equipment

(1) Work training

ii: Training results (Carrying-out the equipment and covering)

Training of carrying-out the equipment was conducted after completion of work. The work time initially planned was reduced, and training simulating the actual site was completed.

No.	Work procedures	Training contents/conditions	Items to become proficient in		Result
14	Withdrawal of the equipment for removing deposits from inside X-6 penetration	Verifying a series of procedures including grip release, withdrawal, and receding (going up the ramp), and their operating efficiency	Procedures and operating efficiency	<ul style="list-style-type: none"> Completing a series of operations without any interferences, etc. 	The work was completed in the planned time with the assumed arrangement of workers while checking the procedures and details of operation.
		Withdrawing the equipment using only the isolation room monitoring camera, assuming that the operation monitoring camera gets disabled (as a result of excessive radiation dose) during the period of installation	Monitoring	<ul style="list-style-type: none"> Being able to withdraw the equipment without any interference by monitoring the images on the monitoring camera inside the isolation room 	Withdrawal was completed without any interference by checking the images on the monitoring camera inside the isolation room.
		<ul style="list-style-type: none"> Cables being guided appropriately. 	Cable management	<ul style="list-style-type: none"> Making sure cables are guided appropriately without any backlash, kink, etc. 	Appropriate guiding of cables was completed.
15	Grabbing of the lid for preventing spread of contamination	<ul style="list-style-type: none"> Opening the lid for preventing spread of contamination Grabbing the lid for preventing spread of contamination 	Procedures and operating efficiency	<ul style="list-style-type: none"> Accessing and grabbing without coming in contact with the isolation room and the mechanism for moving the lid for preventing spread of contamination 	The operation of accessing and grabbing without coming in contact with the isolation room and the mechanism for moving the lid for preventing spread of contamination was completed.
		<ul style="list-style-type: none"> Monitoring interference with the lid for preventing spread of contamination Monitoring interference with the equipment and isolation room 	Monitoring and interfering		
16	Disconnection of cables	<ul style="list-style-type: none"> Work inside the isolation room / curtain rail, power, control and communication cables 	Work efficiency	<ul style="list-style-type: none"> Disconnecting the connectors without any damage Wearing protective gear while disconnecting the connector 	Disconnection of connectors was completed without any issue.



Status of installing the lid for preventing spread of contamination



Status of covering the equipment

4.2 Access Route Establishment Related Equipment

(1) Work training

ii: Training results (Carrying-out the equipment and covering)

Training of carrying-out the equipment was conducted on after completion of work. The work time initially planned was reduced, and training simulating the actual site was completed.

No.	Work procedures	Training contents/conditions	Items to become proficient in	Result	
17	Laying of cables	•Laying power, control and communication cables as per the layout plan	Work efficiency of laying	• Laying and connecting cables without causing any damage • Wearing protective gear while connecting the connector	Work was performed while double checking so that there is no mistake in the connection, and the work was completed without any issues.
18	Covering of the equipment for removing deposits from inside X-6 penetration	•Covering the equipment assuming there would be contamination (only the top surface)	Work efficiency	• Covering the equipment without damaging it • Wearing protective gear while performing the work of covering	The equipment was covered while wearing protective gear, and the work was completed in the planned time with the assumed arrangement of workers.
19	Carrying-out of the equipment for removing deposits from inside X-6 penetration	•Carrying out from the robot carry-in chamber by means of remote operation (cable support, remote operation of equipment, spreading the vinyl sheets for covering over the transportation stand)	Traveling efficiency and operating efficiency	• Making sure traveling is not hindered due to the covering sheets	The work was completed in the planned time with the assumed arrangement of workers.
20	Disconnection of cables	• Disconnecting the power, control and communication cables as per the layout plan	Work efficiency	• Disconnecting the connectors without any damage • Wearing protective gear while disconnecting the cables	Disconnection of connectors was completed without any issue.
21	Covering of the equipment for removing deposits from inside X-6 penetration (2 layers of covering)	• Covering the equipment (2 layers of covering) • Verifying the covering procedures	Work efficiency	• Covering without any gaps, tears • Wearing protective gear while performing the work of covering	The equipment was covered while wearing protective gear, and the work was completed in the planned time with the assumed arrangement of workers.



Status of covering the equipment



Status of covering the equipment

4.2 Access Route Establishment Related Equipment

(1) Work training

ii: Training results (Carrying-out the equipment and covering)

Training of carrying-out the equipment after completion of work was conducted. The work time initially planned was reduced, and training simulating the actual site was completed.

No.	Work procedures	Test details / test conditions	Items to become proficient in		Result
22	Carrying-out (withdrawal, rotation)	<ul style="list-style-type: none"> Withdrawal and rotation of the equipment by pushing it by hands Lowering to the ground with a hydraulic jack 	Work efficiency of carrying-out	<ul style="list-style-type: none"> Rotating to a predetermined position 	The work was completed in the planned time with the assumed arrangement of workers.
	Carrying-out (straight movement)	<ul style="list-style-type: none"> Carrying in the equipment by pushing it by hands Covering the caster wheels with tape 	Work efficiency of carrying-out	<ul style="list-style-type: none"> Ensuring stable traveling Bringing the dolly back on track, if it tilts away from the intended direction of travel 	The work was completed in the planned time with the assumed arrangement of workers.
23	Covering of the stand for the lid for preventing spread of contamination	<ul style="list-style-type: none"> Covering the stand Verifying the covering procedures 	Work efficiency	<ul style="list-style-type: none"> Covering without any gaps, tears Wearing protective gear while performing the work of covering 	The equipment was covered while wearing protective gear, and the work was completed in the planned time with the assumed arrangement of workers.
24	Carrying-out the stand for the lid for preventing spread of contamination	<ul style="list-style-type: none"> Carrying out from the robot carry-in chamber by pushing it by hands 	Work efficiency of carrying-in	<ul style="list-style-type: none"> Making sure there is no contact with the surroundings while carrying-out Bringing the skid back on track, if it tilts away from the intended direction of travel 	The work was completed in the planned time with the assumed arrangement of workers.
25	Covering of the stand for the lid for preventing spread of contamination	<ul style="list-style-type: none"> Covering the stand (2 layers of covering) Verifying the covering procedures 	Work efficiency	<ul style="list-style-type: none"> Covering without any gaps, tears Wearing protective gear while performing the work of covering 	The equipment was covered while wearing protective gear, and the work was completed in the planned time with the assumed arrangement of workers.



Status of the lid for preventing spread of contamination



Status of carrying-out the equipment

4.2 Access Route Establishment Related Equipment

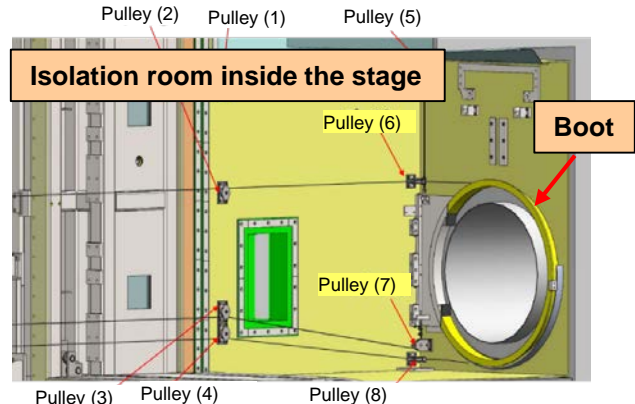
(2) Preparation for opening the X-6 penetration hatch

[Changing the method of setting up the isolation room inside the stage]

Changing the method of setting up the isolation room was considered so as to make it possible to remove the isolation room from inside the stage in the remote chance that it has to be removed after it is installed inside the stage.

[Modification of the isolation room, manufacturing the boot transportation equipment, and setting up the mock-up]

A method was developed in which a mechanism was provided for rotating the boot by means of wires and pulleys and installing it inside the isolation room, and in addition, a boot transportation equipment that can install the boot by means of remote operation was manufactured so that the isolation room can be removed from inside the stage in the remote chance that this needs to be done.



Layout of the wires and pulleys in the isolation room

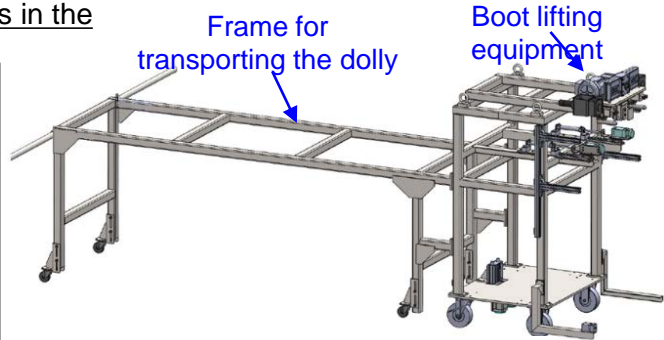
Installation of lower boot (Image captured without the boot transportation dolly)



Steps for installing the lower boot

Boot transportation equipment
 <Frame for transporting the dolly>
 Frame for handling the equipment, and installing the boot lifting equipment in the isolation room inside the stage

<Boot lifting equipment>
 Equipment for lifting and lowering the upper and lower boots over the penetration piping by means of remote operation



Boot transportation equipment



Mockup of the boot transportation equipment installation

4.2 Access Route Establishment Related Equipment

(2) Preparation for opening the X-6 penetration hatch

[Worker proficiency training]

Worker proficiency training was conducted at the plant following actual work procedures by simulating the actual site, for the purpose of on-site demonstration.



Polishing the penetration
(polishing equipment being installed)



Installing floor steel plates
(floor steel plates being installed)



Isolation room inside the stage
(being transported)



Setting up the hatch isolation room (being positioned)



Installing the boot (Boot transportation equipment (being installed))



Setting up the robot carry-in chamber
(being transported)



Installing the hatch opening equipment (being carried-in)



Removing the nuts and bolts of the penetration hatch



Collecting the deposit collection container

4.2 Access Route Establishment Related Equipment

(2) Preparation for opening the X-6 penetration hatch

[On-site demonstration]

Preparations for on-site demonstration began at Unit 2 of the Fukushima Daiichi Nuclear Power Station from November 15, 2021. Currently, on-site demonstration work directed towards hatch opening is being carried out.

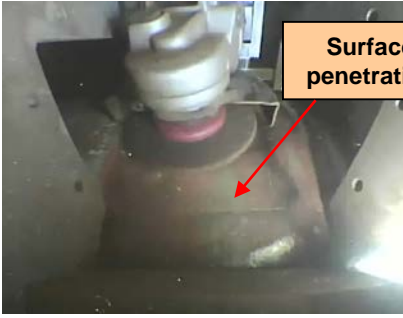
[State of progress]

- When the floor steel plates and the X-6 penetration isolation mechanism were removed, the floor was found to be rough. Hence the work of removing the roughness was carried out.
- The floor steel plates were installed after polishing X-6 penetration pipes.
- The isolation room inside the stage and the hatch isolation room were carried-in to the location of X-6 penetration and installed.



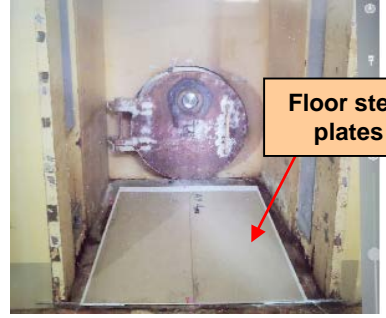
Concrete stage floor

Cleaning after removing the roughness of the floor



Surface of the penetration pipes

Status of penetration polishing

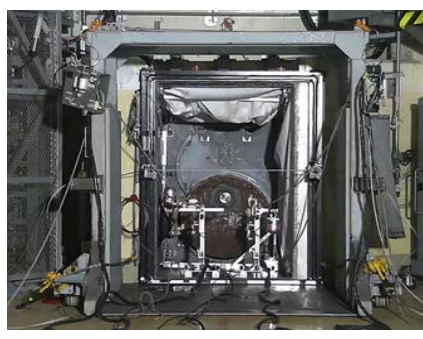


Floor steel plates

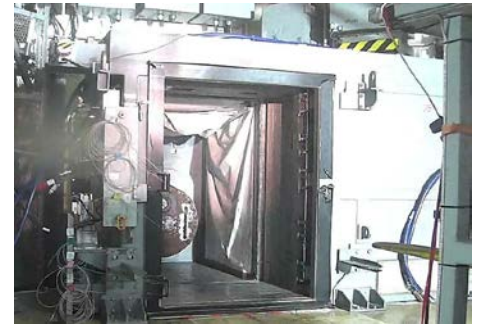
Status of installing floor steel plates



Work of installing the isolation room inside the stage



Status of installing the isolation room inside the stage



Status of installing the hatch isolation room (air-tight door open)

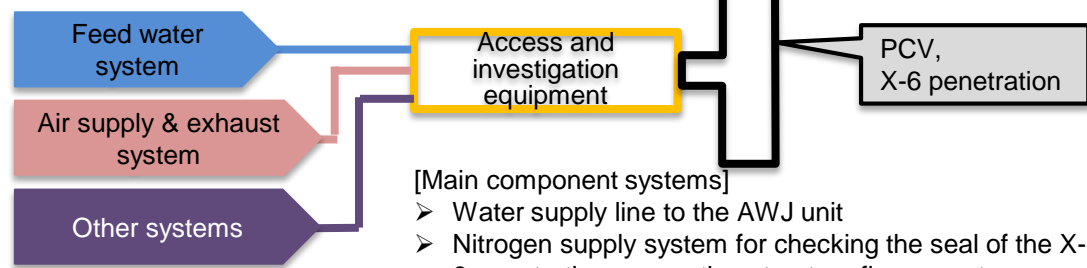
4.3 Other Ancillary System

(1) Design and manufacturing

i. System plan

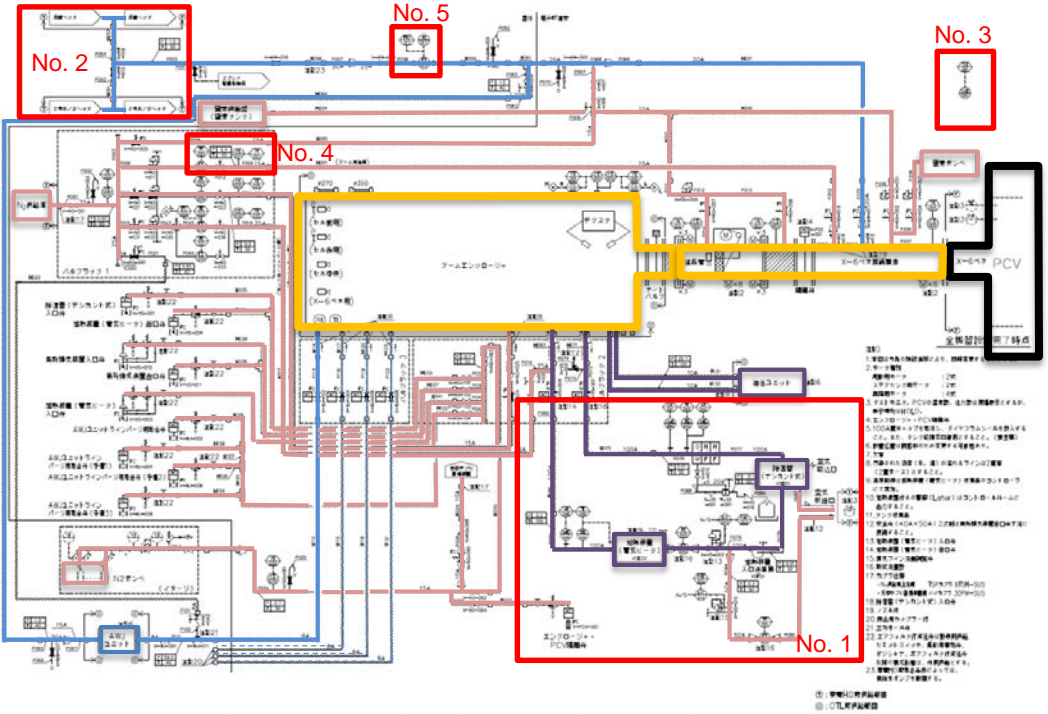
Part of the system plan was revised and refined for enhancing operation efficiency.

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 manipulator for maintenance inside the enclosure
 - Nitrogen supply system to the air operated valve
 - Nitrogen (air) exhaust system
 - Enclosure dehumidification and circulation system

Actual system plan



No	Changes since FY2020	Reason for change
1	Operation of the dehumidification system and review of the system along with that ① The operation of the dehumidification system was restricted to when the isolation valve is closed. ② Operation of the dehumidification system was made into a closed loop operation. The local exhaust ventilation was eliminated along with that, and the HEPA filter was changed to a 2 stage filter.	For suppressing release of radioactive materials
2	Change in source of water supply The source of water supply was changed from the make-up water tank to TEPCO's filtrate water tank	For simplifying and streamlining the operation
3	Installation of oxygen concentration meter inside R/B	For enhancing the monitoring efficiency (detecting nitrogen leakage)
4	Addition of flowmeter on the nitrogen line for arm cleaning	For understanding the flow rate of nitrogen gas flowing inside PCV
5	Addition of an integrating flowmeter on the water line for arm cleaning	For understanding the quantity of water flowing inside PCV

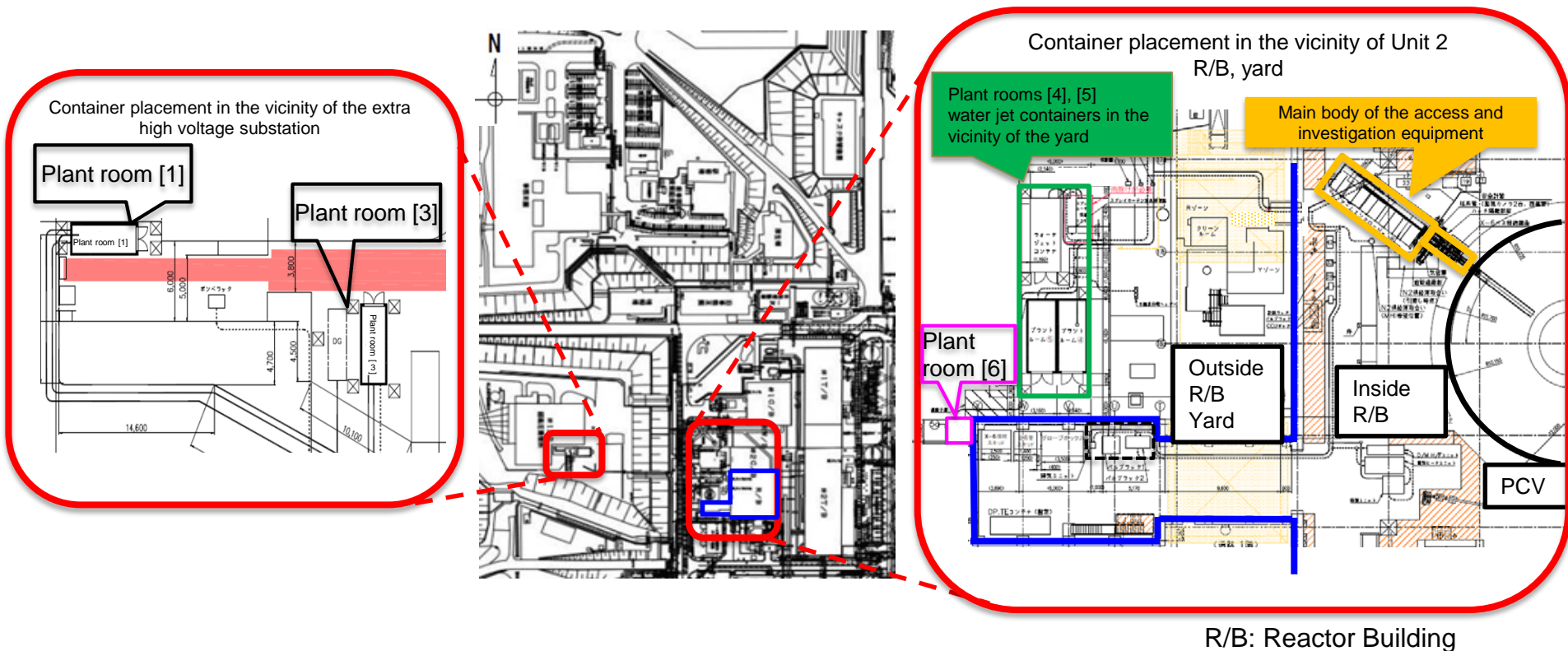
4.3 Other Ancillary System

(1) Design and manufacturing

ii . On-site layout plan

- The layout plan was reviewed and refined considering on-site layout conditions, constraints due to other engineering work, etc.

The plant room [6] which was located in the vicinity of the extra high voltage sub-station was moved to a location in the vicinity of Unit 2 R/B in order to reduce the quantity of cables passing through the trench.



4.3 Other Ancillary System

(1) Design and manufacturing

iii. Manufacturing status

- Control room

On-site installation work (foundation work, construction work and electrical work) was carried out.

- Plant room

The layout of the boards and equipment inside the container was reviewed, and the specifications of the accessories such as lighting, etc. were finalized. Some of the plant rooms were manufactured.



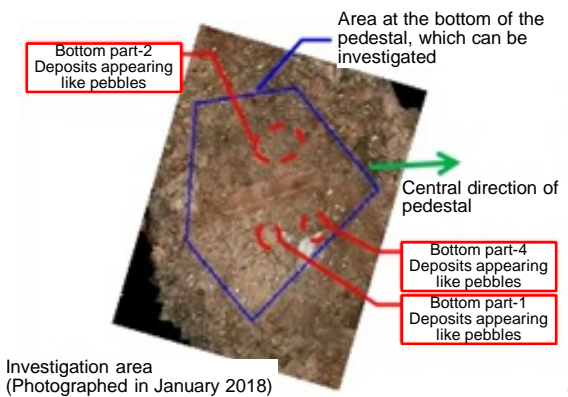
[Plant room]

4.4 Fuel Debris Collection Equipment

(1) Study of the scenario of on-site application of the trial debris retrieval equipment

- **PCV internal investigation conducted so far (A2d investigation)**
 - Deposits were adhered to the beams on the platform. Deposits appearing like pebbles were found although fewer as compared to those at the bottom.
 - The entire bottom was covered with deposits appearing like pebbles and clay. Deposits appearing like pebbles and accumulated water were found as well.
- **Approach towards the on-site application scenario**
 - Work of collecting the deposits on the platform is planned to be carried out in one round using the brush method.
 - Work of collecting the deposits at the bottom is planned to be carried out in 3 rounds in total, one round using the brush method, another using the vacuum vessel type method and one more round (using either one of the methods).
 - As for the specific collection areas, the area where small granular deposits are visible will be selected for the brush method, and the area with accumulated water (if there is such an area) will be selected for the vacuum vessel type method. However, the final decision will be made at the site based on the detailed investigation inside the pedestal, etc.

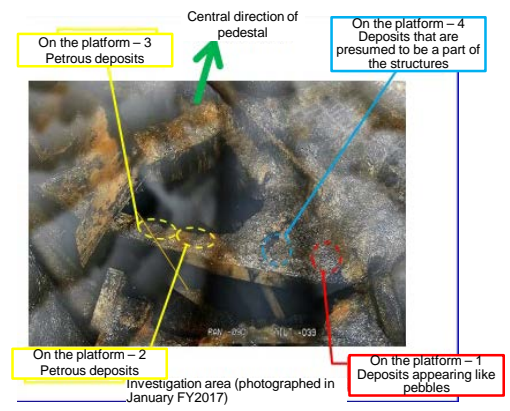
	A2d investigation results	Expected debris, etc.	Debris collection method		Proposed debris collection plan	Number of rounds
			Brush	Vacuum vessel		
Platform	Deposits were adhered to the beams. Deposits appearing like pebbles were present as well. (Fewer than those at the bottom)	Are the deposits adhered to the platform beams mainly solidified fuel debris?	If the deposits are granular, it is likely that they can be collected.	Collection is difficult.	1 round of collection using the brush method is planned as information different than the bottom is likely to be obtained.	1 round
Bottom	Deposits appearing like pebbles and accumulated water were found.	Are these debris pieces, fuel pieces, etc. that have fallen from MCCI, RV that have reacted with mortar? Information related to water quality is required.	Could be collected.	Could be collected (Accumulated water is desirable)	1 round each using the brush method and the vacuum vessel type method are planned based on the difference in obtained information. Another round is planned using either of the 2 methods.	3 rounds



Surface of debris at the PCV bottom



Status inside the pedestal (A2' investigation results)



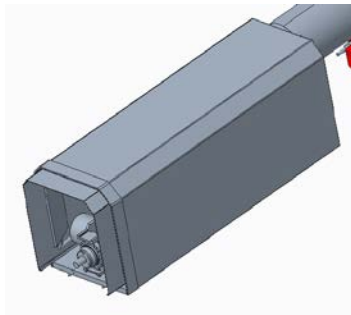
Deposits on the platform

4.4 Fuel Debris Collection Equipment

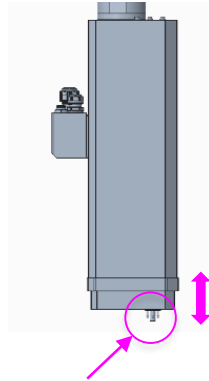
(2) Preparation for the arm assembly test

Study on access area and access position

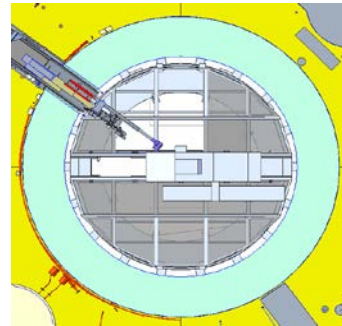
- The access location and position inside the pedestal was studied using a 3D-CAD model, as reference for the assembly test conducted by connecting the trial debris retrieval equipment to the tip of the arm type access equipment.
- The trial debris retrieval equipment extends the tip to get closer to the target object and collects it basically in a downward position.



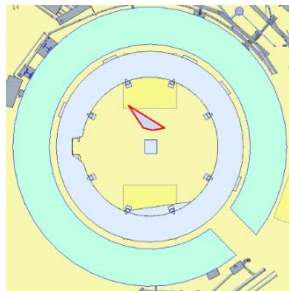
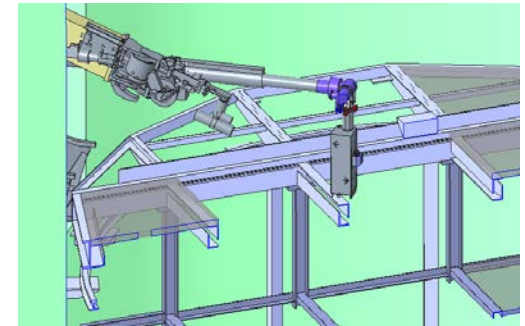
3D-CAD model (brush method) of the trial debris retrieval equipment



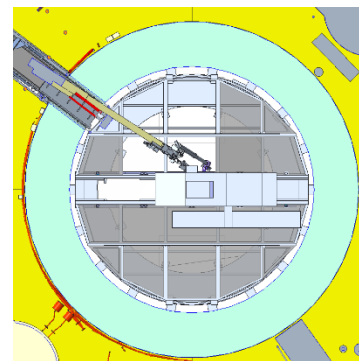
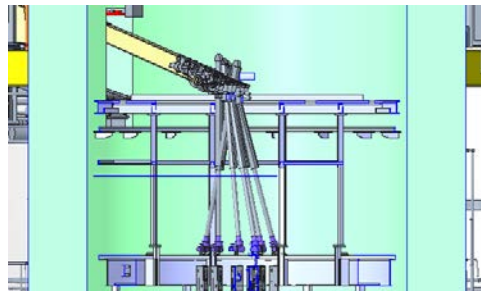
The tip extends to a maximum of 100mm



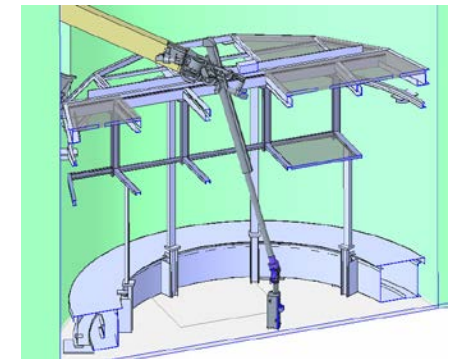
Example of the study on access location and position on the top surface of the platform



Results of studying the access area at the pedestal bottom



Example of the study on access location and position at the pedestal bottom

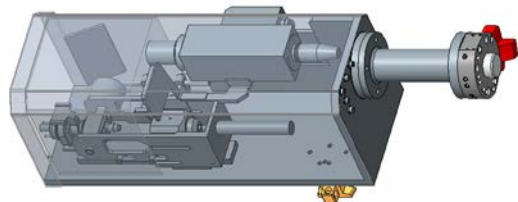


4.4 Fuel Debris Collection Equipment

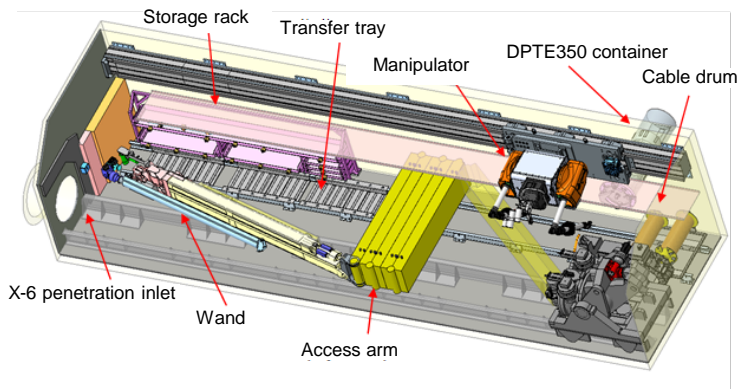
(3) Operation test of the manipulator for maintenance

[1] Study on the operation of the manipulator for maintenance

- The operation of the manipulator for maintenance was studied using 3D-CAD models of the trial debris retrieval equipment, enclosure, etc.



Trial debris retrieval equipment
(Brush method 3D-CAD model)



Arm enclosure and manipulator for maintenance
(3D-CAD model)

Manipulator operation flow

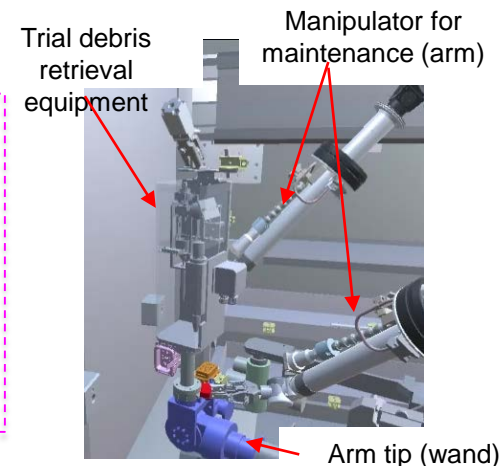
[Before debris retrieval work]

- ① Work of carrying-in from the DPT350 port
- ② Switching the trial debris retrieval equipment
- ③ Mounting on the arm, D-SUB connection, removal of hoisting attachment, etc.

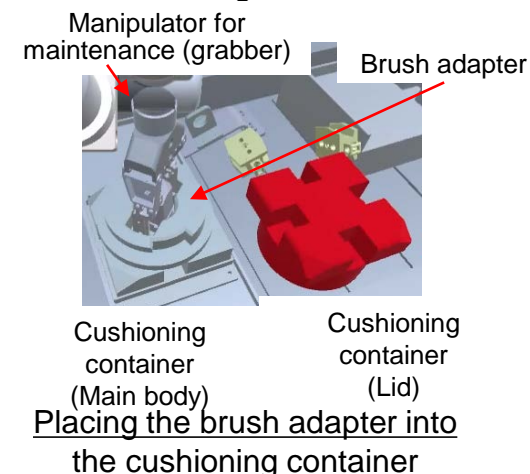


[After debris retrieval work]

- ④ Preparation of cushioning container
- ⑤ Removal of brush adapter/vacuum vessel
- ⑥ Placing the brush adapter/vacuum vessel into the cushioning container
- ⑦ Placing the cushioning container into the DPT270 container



Mounting on the arm



Placing the brush adapter into
the cushioning container

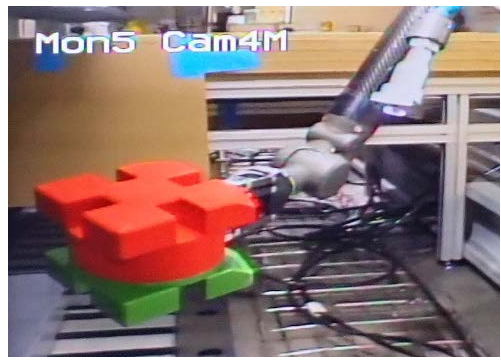
4.4 Fuel Debris Collection Equipment

(3) Operation test of the manipulator for maintenance

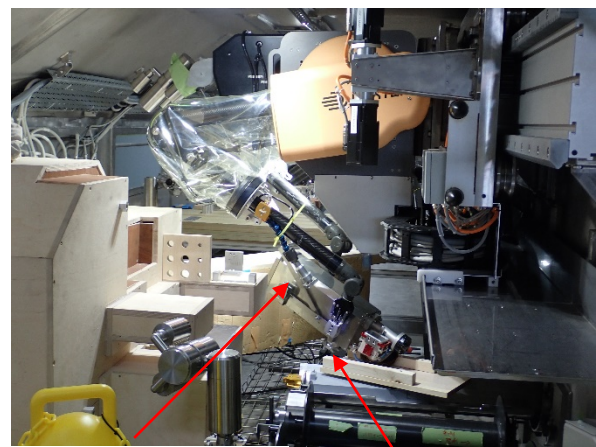
[2] Verification of the operation of the manipulator for maintenance

- Of the various operations that the manipulator for maintenance performs inside the enclosure, verification tests were conducted on the main operations.
- Improvements in jigs and tools, work procedures were identified. Verification tests are planned to be continued while making improvements.

Main operations	Improvements
Carrying-in from the DPTE3.50 port	Change in the structure of the hoisting attachment and table, improvement in the gripper, etc.
Changing the position of the equipment	Revision of work procedures
Mounting on the arm tip	Improvement in the equipment gripper and connector, etc. (improving work efficiency)
Removing the brush adapter/vacuum vessel	Review of work instructions such as the equipment position, wand location, etc.
Handling the cushioning container	Improvement in eye mark, lock lever, etc. (improving work efficiency)



Handling the cushioning container

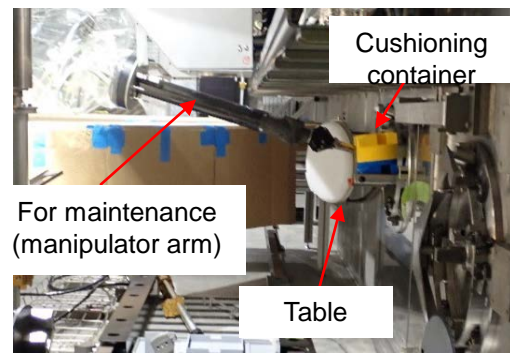


The rolling hanger to support the equipment Gripper added to the sides

Carrying-in from the DPTE350 port



Changing the position of the equipment



Withdrawal of cushioning container

4.5 On-site demonstration (Setting up the cable and control room)

(1) On-site installation and operation plan

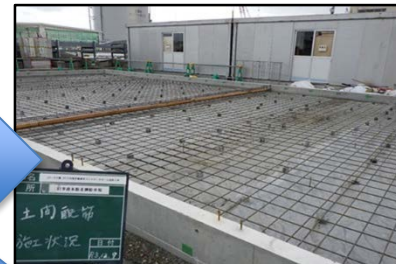
In FY2021, as advance preparations for detailed investigation inside PCV, a control room was installed for remote operation, and power cables required for various work and control cables required for remote operations were laid.

(i) Setting up of the control room

- Construction work related to the installation is planned to be carried out in the area outside the Seismic Isolated Building (parking lot) which was determined during the site investigation conducted last year.
- Since the purpose of this work was to install a control room for the equipment required for testing, research and development, and a break room for the workers, it did not fall under the category of the temporary structure built on site for executing work stipulated in Article 85 Paragraph 2 of the Building Standards Law, and hence a construction confirmation application was filed.
- According to the construction confirmation application, the control room was installed by performing foundation work on the floor.



b. Before performing foundation work



c. Foundation work
(placement of reinforcing bars)



b. Completion of foundation work

e. Installation of the control room

4.5 On-site demonstration (installation of the cable and control room)

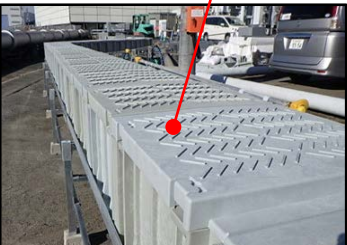
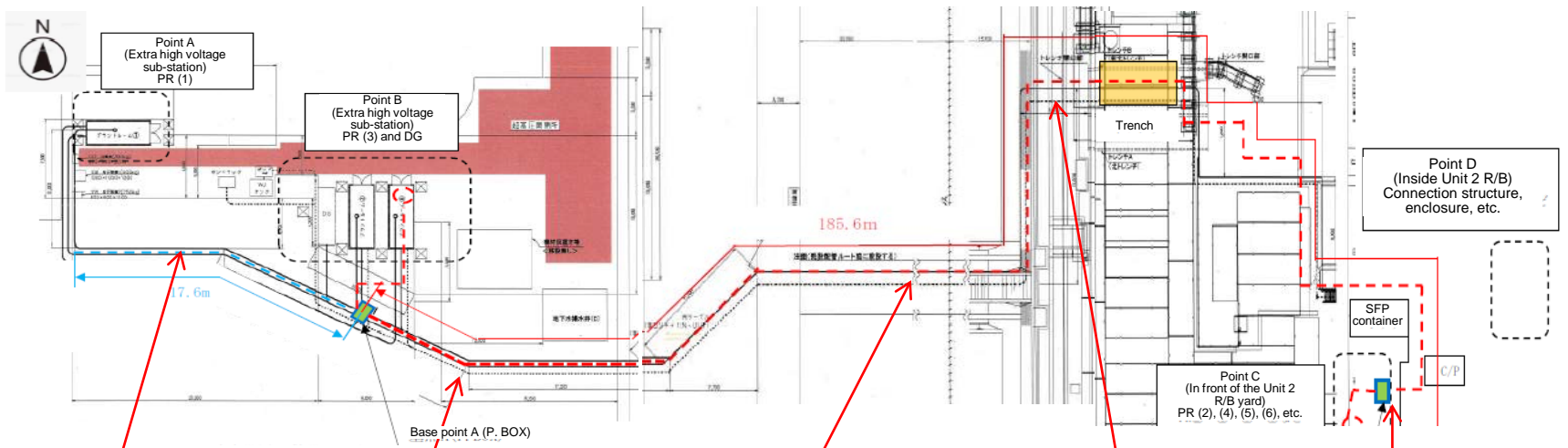
(1) On-site installation and operation plan

(ii) Utility installation work

It was decided that the power supply required for detailed investigation inside PCV would be provided by means of the outdoor D/G (diesel generator), and hence the diesel generator was placed in an extra high voltage sub-station.

Therefore, it was decided that cables would be laid for supplying electric power, from the extra high voltage sub-station to the slope and Unit 2 Reactor Building.

A cable run (trough and cable tray) was installed on the route for outdoor laying of cables and the power and control cables were placed in the cable run, following TEPCO's guidelines related to laying of cables.



a. Trough installation [1]



b. Trough installation [2]

c. Trough installation [3]



d. Cable duct installation [1]



e. Cable duct installation [2]

5. Summary and Future Plans

(1) Summary of the FY2021 results

This project is assessed to be progressing in accordance with the planned schedule.

[1] Access and investigation equipment

Verification test in Kobe

- Tests on passage of the arm for investigation through the X-6 penetration, and tests on removal of obstacles from the X-6 penetration outlet by means of AWJ were conducted, thereby confirming viability prospects as well as identifying areas for improvement.
- Tests for verifying the work efficiency of the manipulator for maintenance were conducted, thereby confirming viability prospects as well as identifying areas for improvement.

Mock-up tests at the Naraha center

- Mock-up tests of the arm for investigation and the manipulator for maintenance, in which the areas of improvements identified during the verification tests in Kobe have been reflected, are underway.

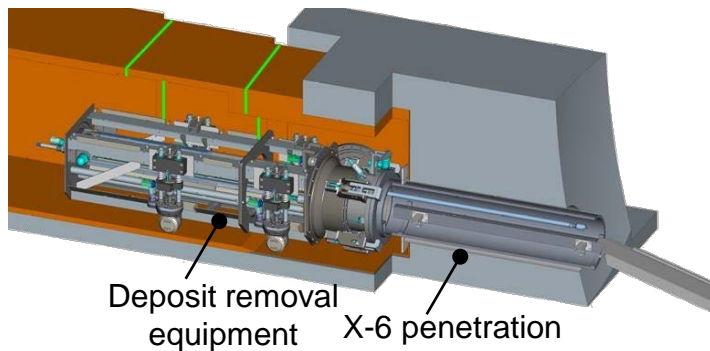
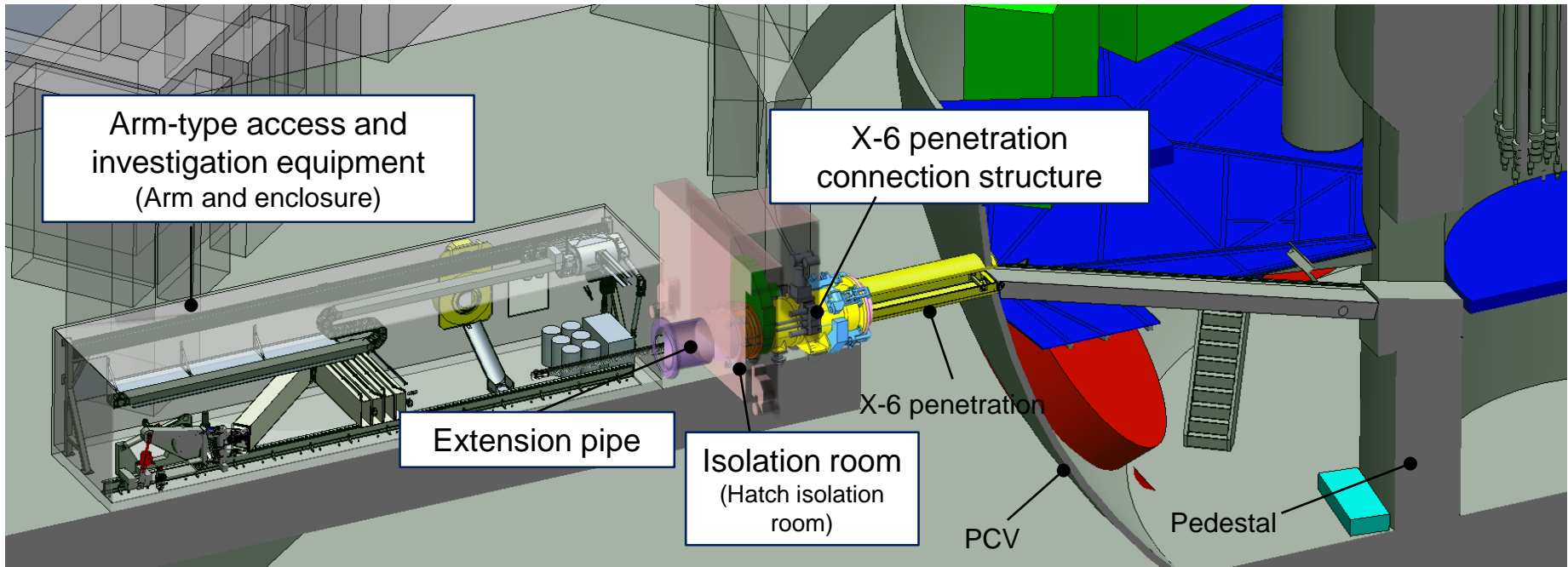
[2] Opening the X-6 penetration hatch

- The method of installing the isolation room inside the stage was changed in order to reduce risks, the installation of the isolation room inside the stage was modified, and the equipment that enables boot installation and removal was designed, fabricated, tested, etc.
- Moreover, worker proficiency training directed towards on-site demonstration was conducted, and on-site demonstration of opening the hatch was started.

(2) Plan for FY2022

- 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.
- After conducting trainings on access route establishment related equipment, on-site demonstrations will be started sequentially.

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-penetration lid is open (before installing the X-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, water jet cutting tool
- ✓ Arm length: approx. 18m (excluding wand)
- ✓ Pressing force: 400N
- ✓ Positioning accuracy: $\pm 100\text{mm}$
- ✓ 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
- ✓ Leakage rate: 0.05 vol%/h
- ✓ Accessories

Manipulator for maintenance, sluice valve, camera, lighting and etc.

