IRID

Subsidy Project of Decommissioning and Contaminated Water Management for FY2021
Development of Fuel Debris Retrieval Method

FY2022 Final Report

June 2023

International Research Institute for Nuclear Decommissioning (IRID)

Table of Contents

1. Purpose and Goals of "**Development of Fuel Debris Retrieval Method**"

[Purpose of development of fuel debris retrieval method]

It is believed that the nuclear fuel has melted along with the core internals at Tokyo Electric Power Company Holdings, Inc. (TEPCO) Fukushima Daiichi Nuclear Power Station (1F) and exists in the Reactor Pressure Vessel (RPV) and the Primary Containment Vessel (PCV) as fuel debris.

Although it is believed that the fuel debris present inside the RPV and PCV is currently in a sub-critical state, since the Reactor Building (R/B), RPV, PCV, etc. have been damaged due to the accident, the plant itself is in an unstable condition unlike its initial design. In order to prevent diffusion of radioactive materials and bring the fuel debris to a stable condition, the fuel debris needs to be retrieved and its sub-critical state needs to be maintained.

Against this background, we will conduct studies in this project based on the "Mid-and-long-term Road-map Towards Decommissioning of Tokyo Electric Power Company Holdings, Inc.'s Fukushima Daiichi Nuclear Power Station" (hereinafter "Mid-and-Long-Term Road-map"), aiming towards the implementation of work for further increasing the scale of fuel debris retrieval in coordination with the engineering and project management activities undertaken by Tokyo Electric Power Company Holdings, Inc. (TEPCO). The development results of this project will be used in TEPCO's engineering activities.

The purpose of this project is to smoothly carry out decommissioning and contaminated water management at 1F by implementing projects that support technological development contributing to the decommissioning and contaminated water management at 1F based on the Mid-and-Long-Term Road-map and the "FY2021 Decommissioning Research & Development Plan" (Secretariat Meeting of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (86th), and in addition, to make efforts to enhance the standard of science and technology in Japan.

Under the project for "Development of Fuel Debris Retrieval Method", the elemental technologies required for securing retrieval work area for the technologies related to equipment, devices and systems required for increasing the retrieval scale of fuel debris and reactor internal structures, and for ensuring throughput, will be developed and tested based on research and development results obtained so far.

[Project goal]

The goal of the project is to conduct studies in order to accomplish work for further increasing the scale of fuel debris retrieval based on the Mid-and-Long Term Road-map.

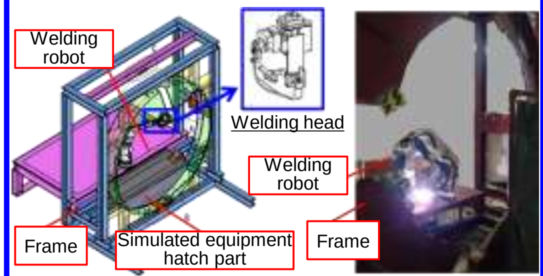
[Duration of Project] April 2021 to March 2023 (2 years)

2. Accomplishments of Related Projects Implemented in FY2019-20

The fuel debris retrieval method results related to this project are provided below.

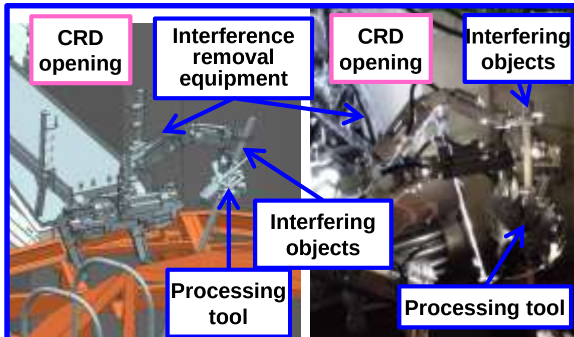
Details pertaining to (1) to (5) are provided in the following pages.

(2) Access tunnel

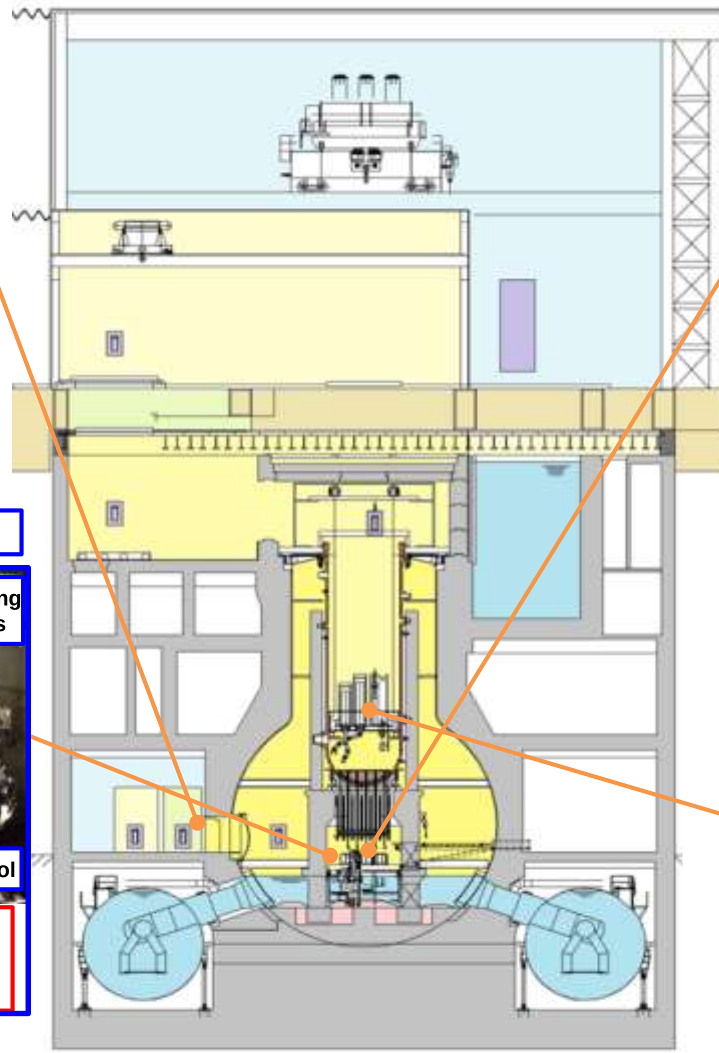


Result: Development of access tunnel installation (welding) technology

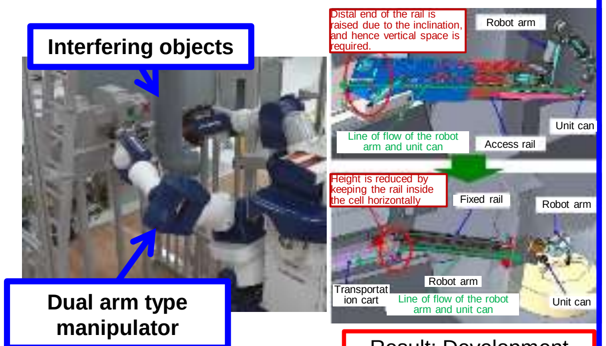
(3) Side access method using access tunnel



Result: Method for interference removal using fuel debris retrieval equipment when side access method



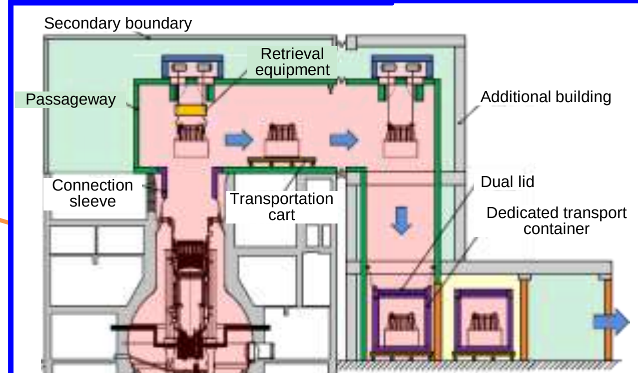
(1) Establishment of access route for installation of cells
(4) Access equipment



Result: Development of techniques for supporting remote operations

Result: Development of access route establishment technology related to installation of the cells

(5) Top access method



Result: Development of technology for removing interfering objects and reactor bottom

2. Accomplishments of Related Projects Implemented in FY2019-20

(1) Establishment of access route for installation of cells

[Overview of access route establishment for installation of the cells]

- A boundary is set up by means of cells and fuel debris is retrieved by accessing from the side of the PCV using a robot arm.
- Considering accessibility of the pedestal opening, the robot arm is carried in via the shortest linear route to access fuel debris.
- The cells are installed after reducing the load on the R/B floor because they are heavy.

[Items implemented until FY2020]

① Access equipment

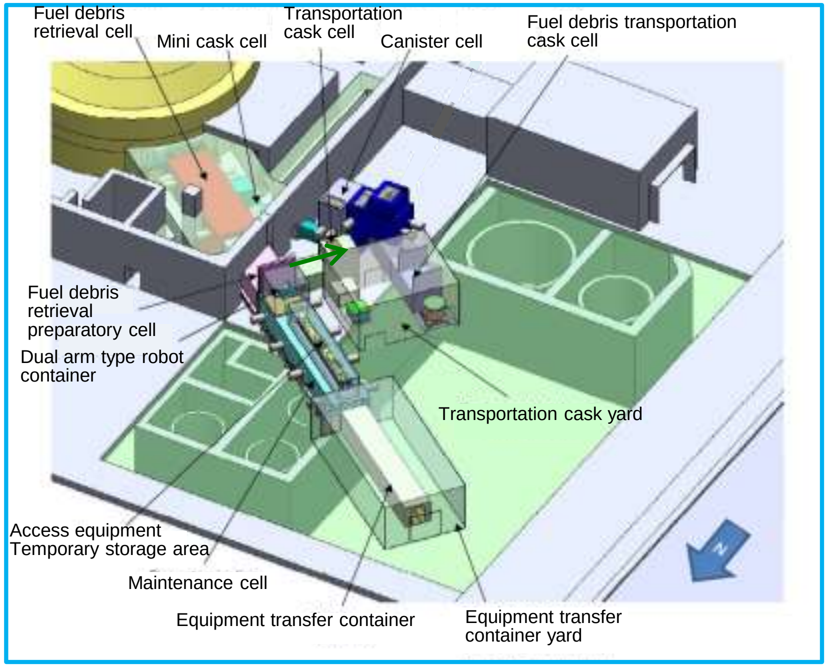
- The access equipment was modified from using the access rail method to fixed rail method, the required height and space were reduced, and conceptual study was completed.

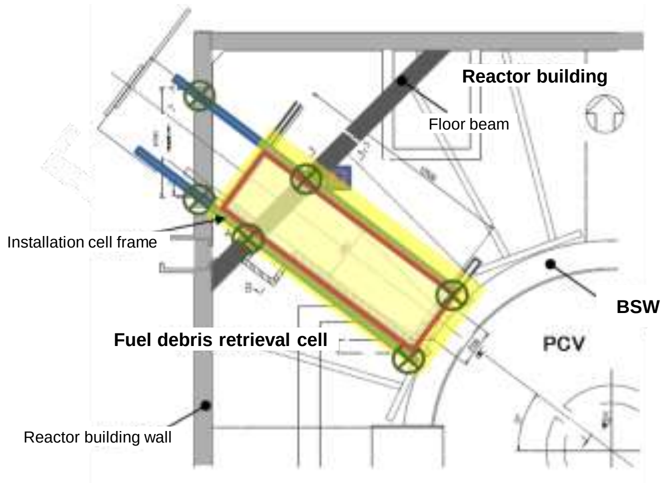
② Cell (Fuel debris retrieval cell established inside the R/B)

- The functions of the fuel debris retrieval cell were clearly specified, the equipment inside the cell were studied, the cell structure was substantiated and its size was reduced.
- The shielding thickness was streamlined to reduce the weight of the fuel debris retrieval cell.
- The method of installing the cell installation frame on the wall and floor beams, which are the strong members of the building, to support the weight of the cell was studied, and it was confirmed that the installation in that manner is possible from the perspective of allowable load at each R/B location.

③ Study of cell installation method

- The illustration showing the steps that are expected to be viable from preparatory works to installation was studied and technical issues were identified.





(1) Establishment of access route for installation of cells

- Issues in cell installation: Issues related to this project are excerpted from the Fuel Debris Retrieval FY2020 Final Report*1

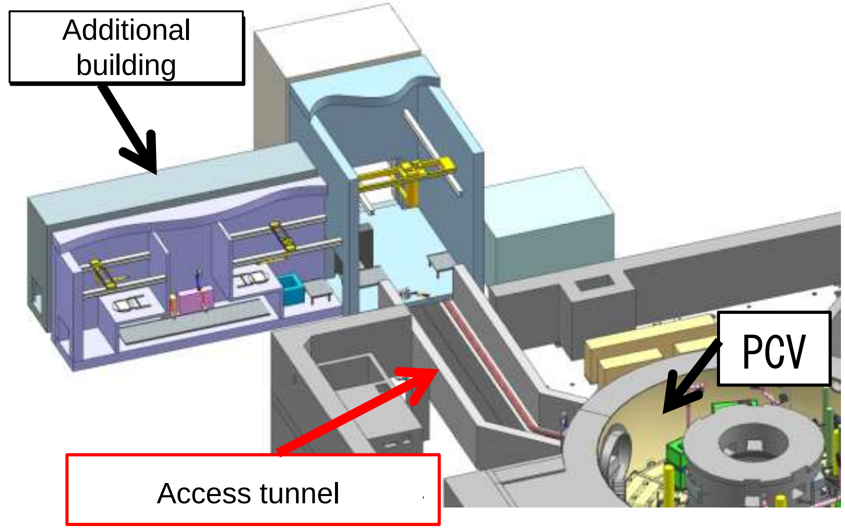
No.	Issue	Overview	This project
1	Detailing of the structure of the shielding door and the structure between cells	The partitioning structure of the shielding door for substantiating an efficient installation method so as to reduce the exposure of workers, and the structure of the connecting part between the cells will be detailed.	Refer to 6.1) (1) ①
2	Substantiation of the cell adapter structure	The structure of the cell adapter required for adopting the method of installing the cell adapter by remote operation will be substantiated.	Refer to 6.1) (1) ①
3	Substantiation of the method of carrying-in and installing the shielding door and the cell adapter	The steps involved in carrying-in and installation will be detailed, based on the detailed structures of the shielding door, cell adapter and cell; element tests pertaining to the method of installation by remote operation will be planned and implemented; and feasibility will be verified.	Refer to 6.1) (1) ①
4	Establishment of the reference marking method for cell installation	The method of measurement and marking performed in advance for determining the reference line from the pedestal opening or X-6 penetration, etc. required for installing the cell will be established.	Refer to 6.1) (1) ①

*1: "Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures" FY2020 Final Report (March 2021)

(2) Access tunnel

[Overview of access tunnel]

- The additional building outside the R/B and the PCV is connected with an access tunnel having a shielding function, to establish the carrying-in/out route.
- The load of the access tunnel will be borne by the outer wall of the R/B and the Biological Shield Wall (BSW), in order to maintain within the load limit for the floor surface on the first floor.
- The tunnel is assembled outside the R/B, and is inserted and installed by remote operation so as to reduce worker exposure.

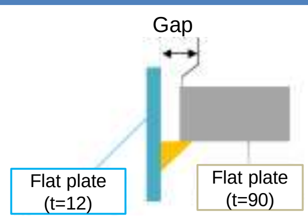


Overview of access tunnel

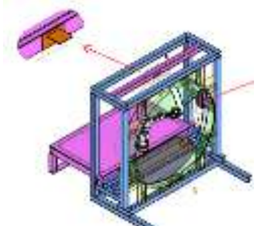
[Items implemented until FY2020]

- The work procedures from removing the shield in front of the equipment hatch to connecting the access tunnel to the PCV were drafted taking remote operation into consideration, and the exposure dose in the event of operations that are not carried out remotely was estimated.
- The structure of the connecting part between the PCV and sleeve, and the sleeve and access tunnel was studied, element tests related to connecting the PCV (equipment hatch) and the sleeve by means of welding were conducted, and it was verified that the 20mm gap can be welded.

Testing by setting conditions → **Element test**



- ✓ Stacking method
- ✓ Welding position
- ✓ Heat input for welding
- ✓ Welding gap



- ✓ Welding gap (Equipment similar to the actual facility)

Implemented

<While creating the arc> <Welding machine>

Welding test being conducted

2. Accomplishments of Related Projects Implemented in FY2019-20

(2) Access tunnel

■ Issues in the whole access tunnel: Items related to this project are excerpted from the Fuel Debris Retrieval FY2020 Final Report*1

No.	Issue	Overview	This project
1	Installation accuracy of access tunnel sleeve	The access tunnel sleeve is welded to the PCV equipment hatch shell. Although it was confirmed that the 20mm gap can be welded, the gap needs to be reduced as much as possible considering the on-site workability, thermal contraction effect at the time of welding, and quality.	**Refer to 6.1) (1) ②**
2	Reduction in the scale of delivery equipment by reducing the delivery weight of the main body of the access tunnel and shortening of the installation process	The delivery weight of the main body of the access tunnel is approx. 430 ton, and exceeds 1000 ton if the counterweight is included. Hence, the delivery equipment and the related provisions outside the R/B are large scale. This leads to issues such as not being able to start preparations around the R/B such as constructing the additional building, etc.	**Refer to 6.1) (1) ③**
3	Shield block (Unit 1) and BSW block out (Units 2, 3)	(Unit 1) After pulling out the existing shield plug, as it interferes with the access tunnel main body, it needs to be removed. (Units 2, 3) BSW needs to be blocked out.	**Refer to 6.1) (1) ④**

*1: "Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures" FY2020 Final Report (March 2021)

2. Accomplishments of Related Projects Implemented in FY2019-20

(3) Side access method using access tunnel

[Overview of side access method using access tunnel]

- ✓ The PCV and additional building are connected by means of a passage (access tunnel). The access tunnel is installed by delivering it remotely from outside the R/B.
- ✓ The work of removing interferences from inside PCV and the work of fuel debris retrieval is carried out using multiple equipment for remote operation. Equipment is assembled inside PCV as required.
- ✓ This method is applicable regardless of the unit and whether the interference is inside or outside the pedestal.

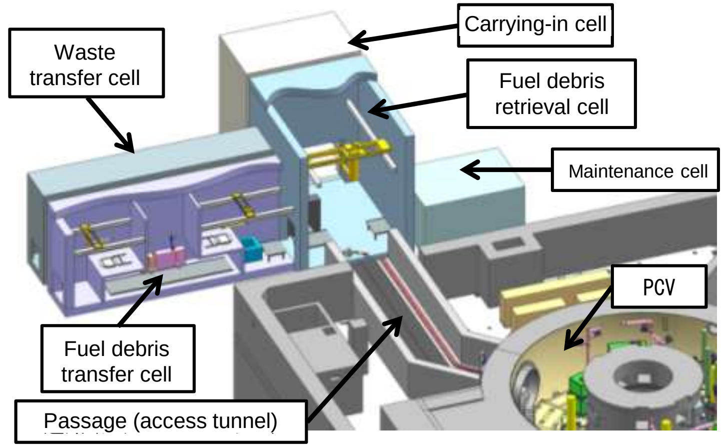


Illustration showing how the PCV and additional building are connected

[Items implemented until FY2020]

- ✓ The feasibility of the work of installing common utilities (assembling the stand, connecting the utility line) was verified.
- ✓ It was projected that comparatively smaller interfering objects such as fallen ICM (In-core monitor) housing can be removed by remote operation.
- ✓ It was projected that the work of routing cables, processing fuel debris, etc. can be carried out in parallel using multiple equipment

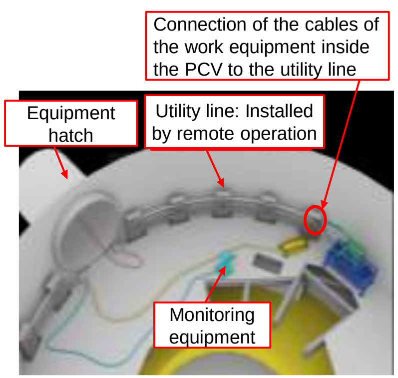
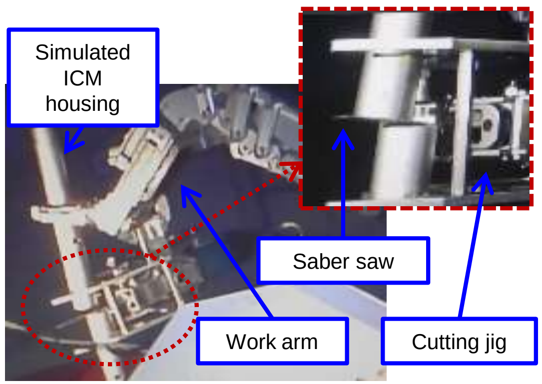


Illustration showing installation of utility line



Cutting of simulated ICM housing

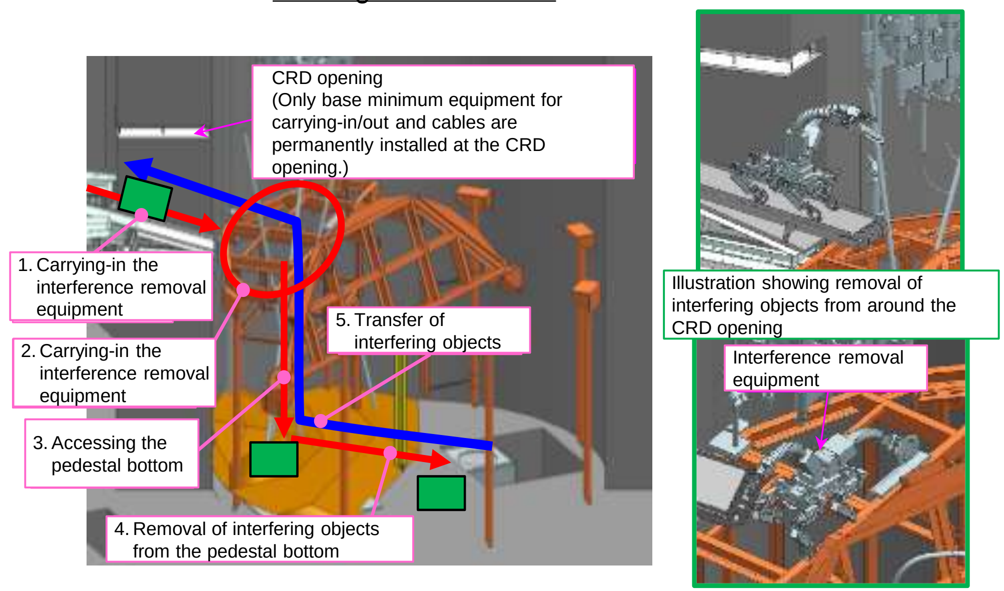


Illustration showing work inside the pedestal

(3) Side access method using access tunnel

■ Issues in side access method: Items related to this project are excerpted from the Fuel Debris Retrieval FY2020 Final Report*1

No.	Issue	Overview	This project
1	Method of removing large interfering objects	The method of removing large interfering objects such as CRD changer, which cause major hindrance in the fuel debris retrieval work, by remote operation, will be studied.	**Refer to 6.1) (2) ① to ③**

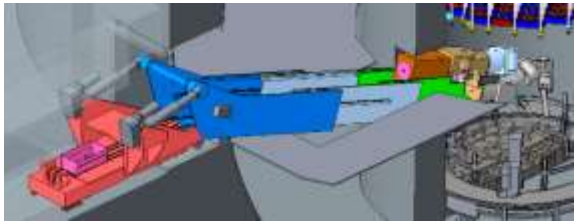
*1: “Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures” FY2020 Final Report (March 2021)

2. Accomplishments of Related Projects Implemented in FY2019-20

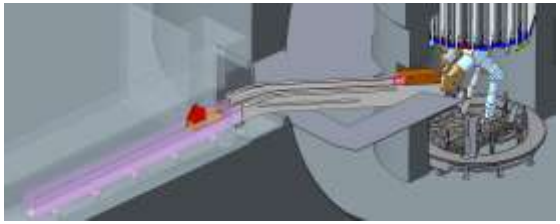
(4) Access equipment

[Overview of access equipment]

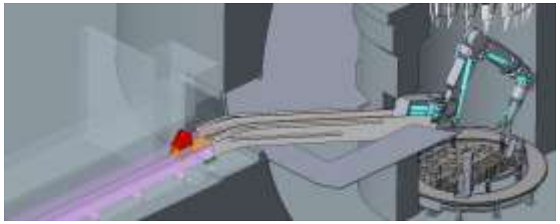
- The access equipment is carried-in in a straight line towards the pedestal opening in the PCV, and the interfering objects on the access route and fuel debris inside the pedestal are cut and collected.



Telescopic interference removal equipment (Dual motor-operated arms)



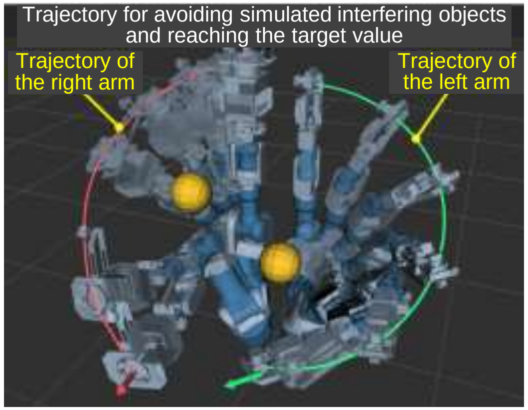
Fixed rail type dual motor-operated arms



Fixed rail type hydraulic arms

[Items implemented until FY2020]

- The following conceptual studies on the access equipment for accessing the interfering objects and fuel debris were completed.
  - ➢ Concept, structure and installation method of the fixed rail and telescopic guiding equipment.
  - ➢ Concept, structure, method of carrying-in, method of emergency withdrawal of the dual motor-operated arms.
  - ➢ Method of using the hydraulic arms with the fixed rail.
- The height of the access equipment was reduced from 3m to 2.2m.
- It was confirmed that the load of the access equipment does not cause any issues in the integrity of the pedestal CRD opening.
- The procedures for removing the interfering objects and retrieving fuel debris were brushed up and substantiated, technical issues were identified and the actions to be taken in response were studied.
- Methods supporting remote operation were studied for better work efficiency.



Generation of trajectory when methods supporting remote operation are adopted

(4) Access equipment

■ Issues in the access equipment: Items related to this project are excerpted from the Fuel Debris Retrieval FY2020 Final Report*1

No.	Issue	Overview	This project
1	Conceptual study of tip tool	The method for cutting the assumed interfering objects and fuel debris and the concept of the tip tool need to be studied although under certain pre-conditions to get an idea of the overall work including throughput.	**Refer to 6.1) (3) ①**
2	Dealing with deviations	Deviations during remote operation support by the manipulator, caused due to the difference in the 3D model and the actual objects on-site, and due to errors in installation by using the robot, need to be dealt with.	**Refer to 6.1) (3) ①**
3	Establishment of remote operation support required during the operation	Remote operation support needs to be established for operations such as cutting, grabbing and collection.	**Refer to 6.1) (3) ①**

*1: "Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures" FY2020 Final Report (March 2021)

2. Accomplishments of Related Projects Implemented in FY2019-20

(5) Top access method

[Concept of the new top access method (removing and transferring unitized structures)]

- ✓ Individual structures are unitized and transferred
- ✓ The reactor core is cut into multiple units, and the lower hemispherical dome at the reactor bottom is separated from the RPV as a single unit.
- ✓ The shielding and air tightness of the objects to be transferred is ensured by using dedicated transportation containers for transporting structures or access route or a combination of both.
- ✓ The work of finely cutting the structures that are retrieved and enclosing them in storage containers is carried out in a building that is at a distance from the R/B.

[Items implemented until FY2020]

- ✓ The retrieval plan and removal method pertaining to interfering objects, from removing the shield plug up to the reactor bottom, were consolidated and a draft of the steps involved in the access method was created.
- ✓ It was indicated that measures to reduce the weight of the shielding on the operation floor, the crane and the means of transportation are feasible, and the specifications such as dimensions, shield weight, etc. of the large transportation container were created.
- ✓ Element tests were conducted pertaining to the reactor bottom part which is difficult to access due to space constraints and for which the work procedures such as for fall prevention measures, etc. are complex, and the required time obtained from test results was reflected in the throughput estimation.

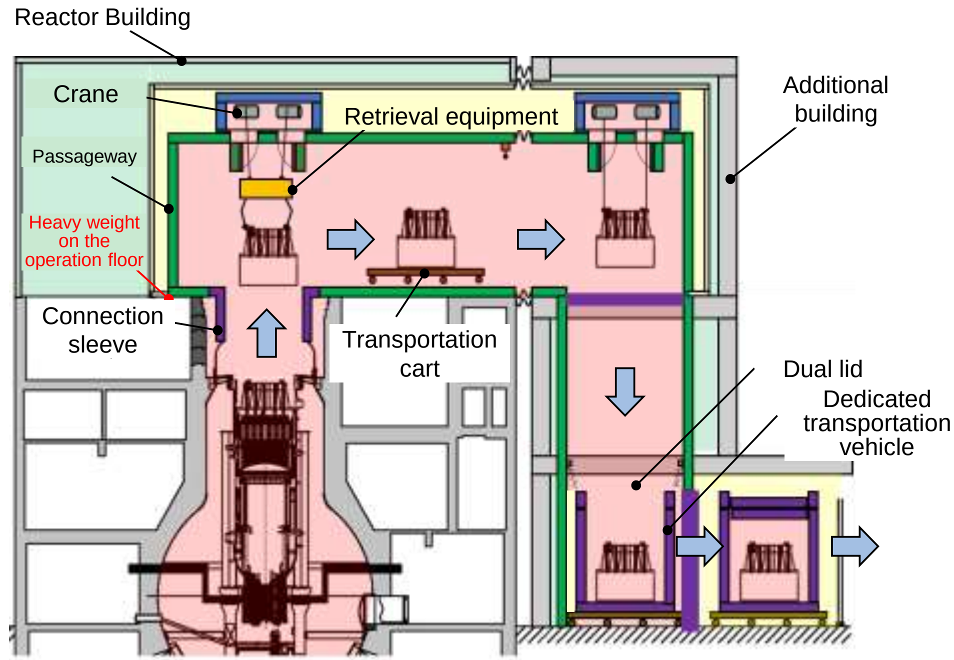


Illustration of the method of transferring unitized structures

(5) Top access method

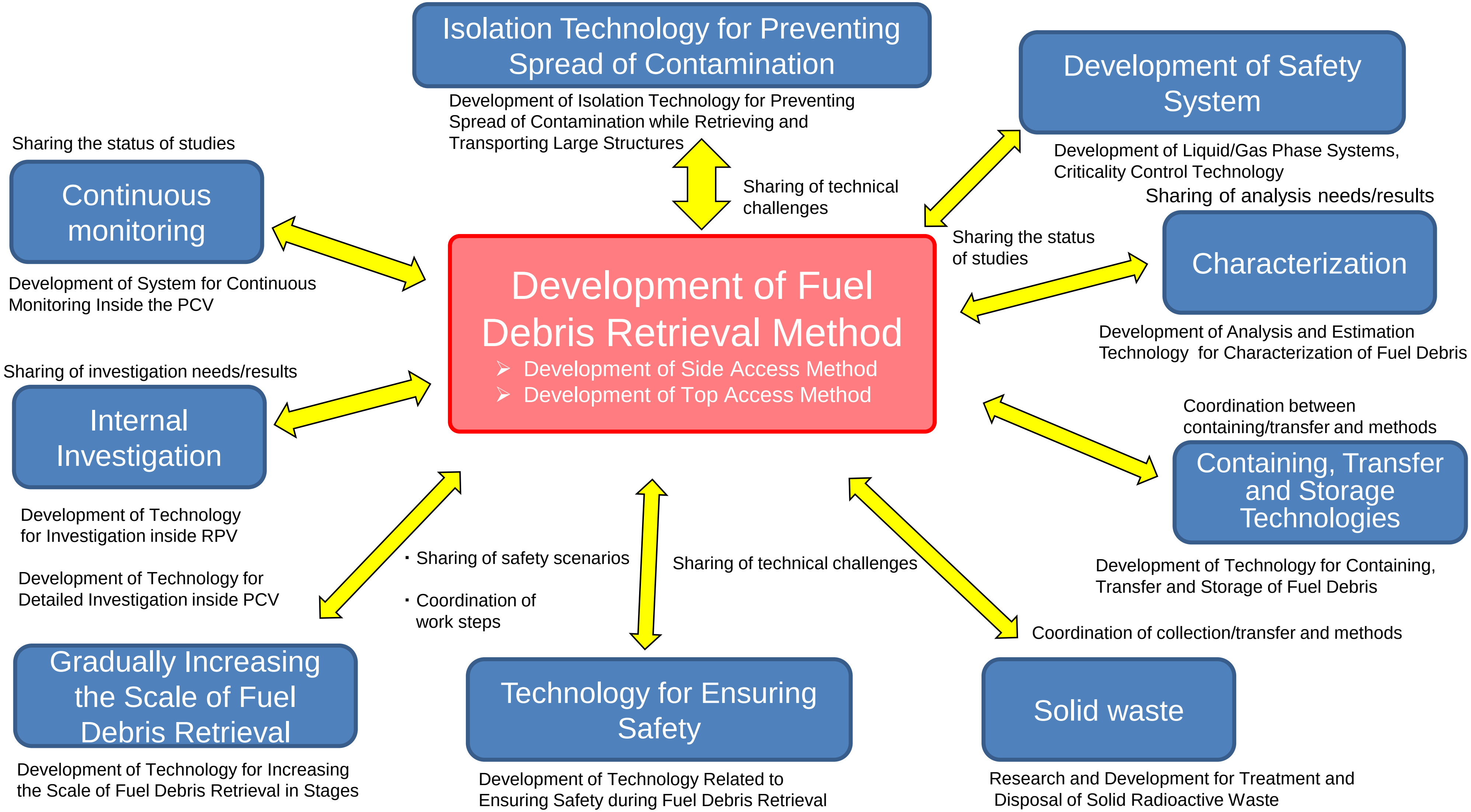
■ Issues in top access method: Items related to this project are excerpted from the Fuel Debris Retrieval FY2020 Final Report*1

No.	Issue	Overview	This project
1	Method for cutting structures other than the reactor bottom	During the conceptual study, cutting the shroud into upper and lower parts was considered as a work step. The method of cutting the reactor internal structures including the shroud will be re-examined and studies will be conducted on substantiation of the cutting method.	Refer to 6.2) (1) ①
2	Substantiation of the large transfer container	Conceptual studies were conducted on large transfer containers (dedicated transportation containers) for transferring structures up to the New building. In the future, the structure of large transfer containers will be substantiated, and studies will be conducted on the structural viability including manufacturing capability, etc.	Refer to 6.2) (1) ②
3	Substantiation of transportation equipment	Cutting structures that cannot be directly stored in large containers in the additional building was considered as a work step in the conceptual study. Also, localized shielding will be added for structures that have a high radiation dose rate. Hence, substantiation of the means for transporting the retrieved structures will be studied, and revision of the work steps will be considered in accordance with the workability at the additional building.	Refer to 6.2) (1) ③

*1: "Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures" FY2020 Final Report (March 2021)

3. Project Overview

3. 1. Collaboration with other projects



In this project, joint meetings will be conducted as required in coordination with the above-mentioned projects.

3. Project Overview

3. 2 **Development items involving solicitation and implementation policy**

1) Development of side access method

(1) Development of the method of installing access equipment

① Installation of large heavy structures

・Verification of the feasibility of detailing and installation method of the cell structure to be installed inside of the R/B or the structure of the access equipment

② PCV connection sleeve installation and welding by remote operation

・ Study/feasibility verification of methods for remote installation and welding, inspection, maintenance, etc. of the sleeve

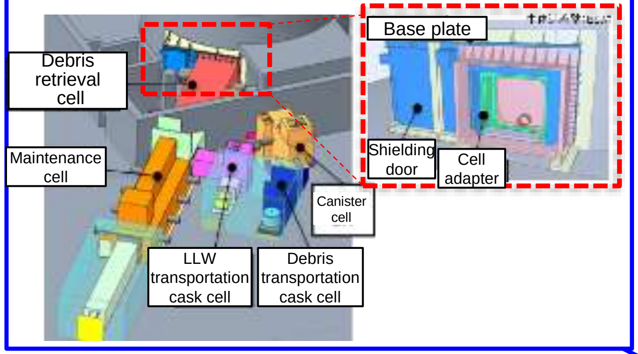
③ Installation of shield

Study/feasibility verification of the method of additional installation of access tunnel shield for reducing the load of the ancillary facilities

④ Disassembly of shield plug

・ Study/feasibility verification of technology related to remote disassembly of the shield plug, etc. (shield plug, block-out) which is a large and heavy object

① Installation of large heavy structures



② PCV connection sleeve installation and welding by remote operation

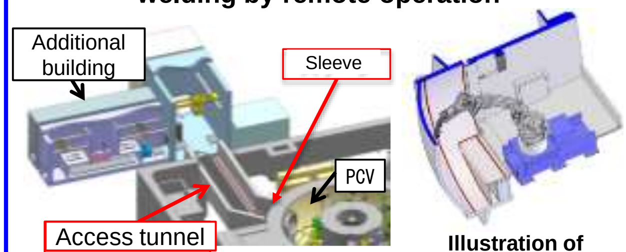
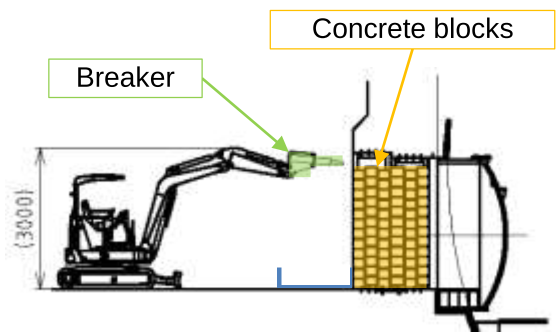
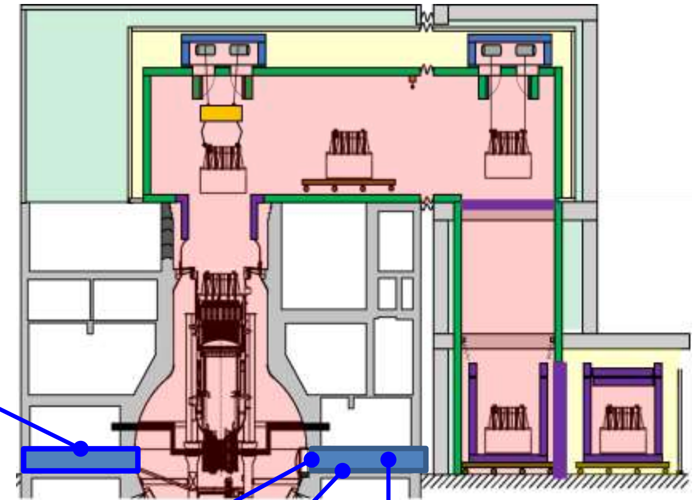
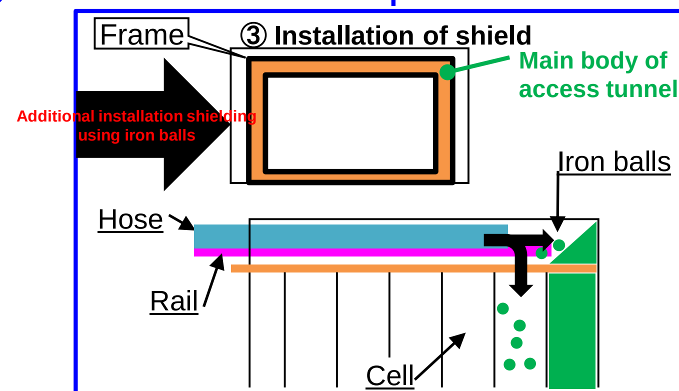


Illustration of sleeve welding

④ Disassembly of shield plug







3. Project Overview

3. 2 **Development items involving solicitation and implementation policy**

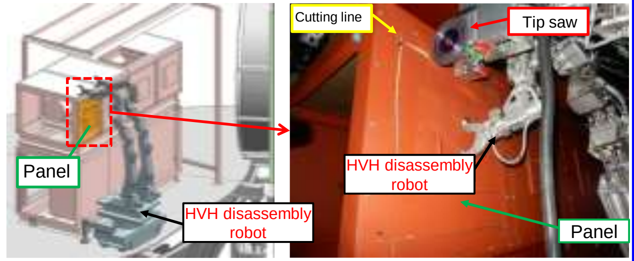
1) Development of side access method
(2) Development of disassembly and removal technology
① HVH disassembly
・Study/feasibility verification of the methods for HVH removal considering fall prevention and remote operation

② Disassembly of CRD exchanger
・Study/feasibility verification of the methods for disassembling and removing the CRD exchanger, which is a large structure, considering remote operation in limited space with limited equipment

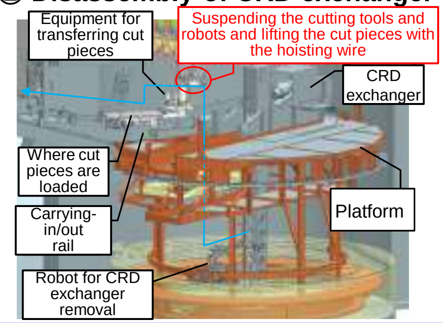
③ Interfering objects removal from pump pit
・Study/feasibility verification of the methods for remotely cutting and transferring interfering objects such as existing pumps, etc. from inside the pump pit

(3) Advancement and development of retrieval methods
① Remotely operated tip tool for retrieval
・ Verification of the methods for disassembly and removal of structures inside PCV, and the procedures for processing and collecting fuel debris.
・ Acquisition of data for throughput evaluation.

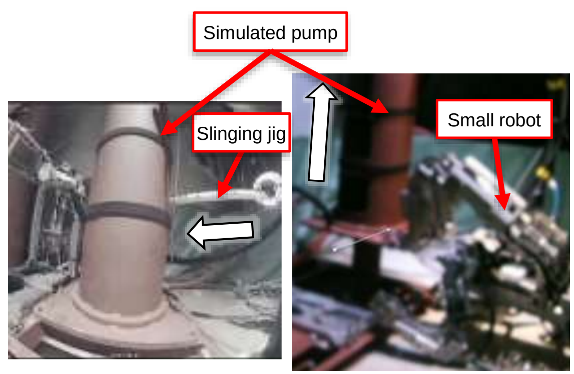
(2) ① HVH disassembly



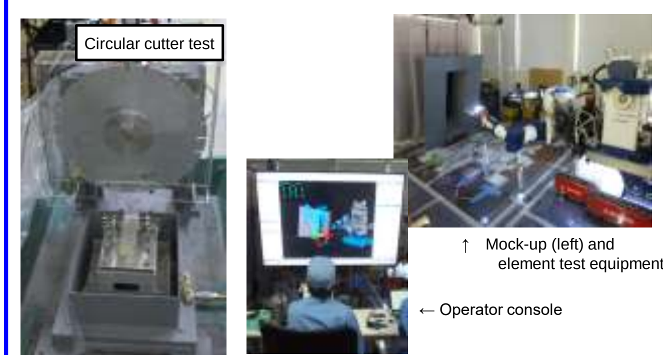
(2)② Disassembly of CRD exchanger



(2)③ Interfering objects removal from pump pit

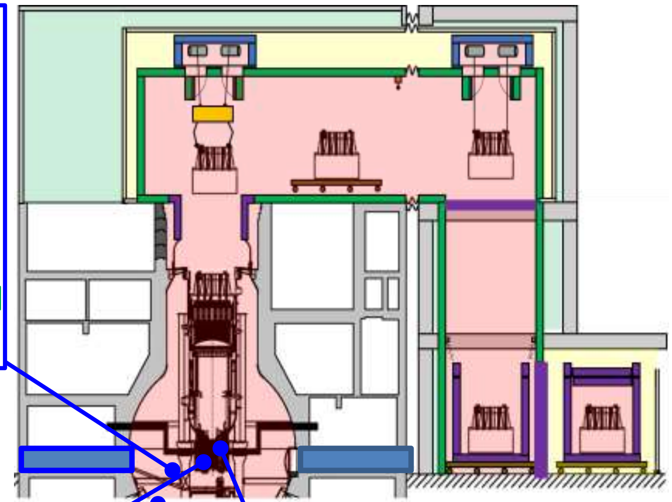


(3)① Remotely operated tip tool for retrieval



↑ Mock-up (left) and element test equipment

← Operator console



3. Project Overview

3. 2 **Development items involving solicitation and implementation policy**

2) Development of top access method

(1) Development of technology for realizing the concept of retrieving large structures

① Method of cutting large structures

・Study/feasibility verification of the methods for cutting and separating structures that are a mixture of metallic and ceramic material including the filler material

・Study/site applicability evaluation of the methods for transferring the structures after they have been cut, until the structures are loaded on to the large transportation equipment

② Large transfer container

・Development of the conceptual structure of the transfer system including the method of placing the structures in the large transfer container

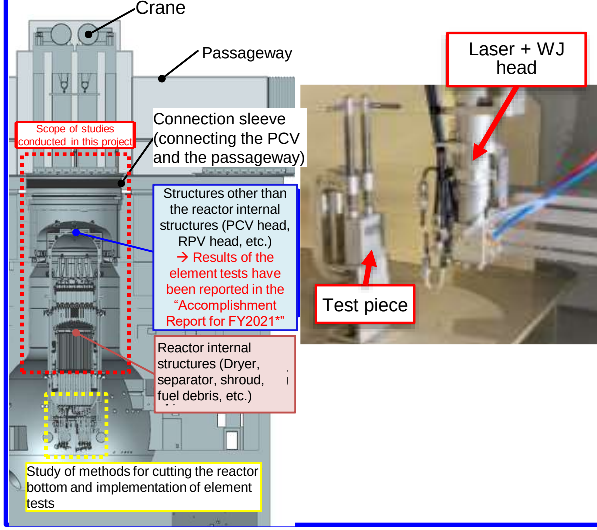
・Detailed study/feasibility verification related to the air-tight structure of the large transfer container as a whole, manufacturing procedures, etc.

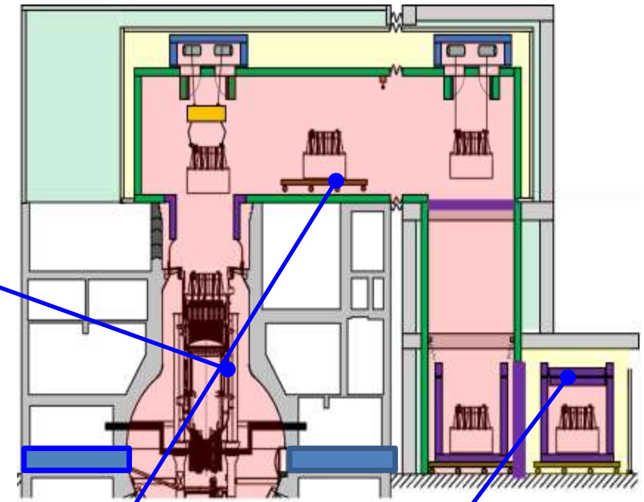
③ Large transportation equipment

・Investigation and studies related to the methods of transporting large and heavy contaminated structures in terms of the adaptability to the air-tight gate, etc.

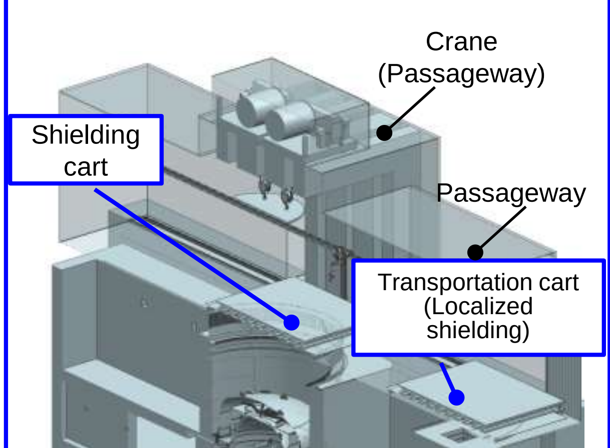
・Structural examination/on-site applicability evaluation of the transportation equipment including the drive mechanism

① Method of cutting large structures

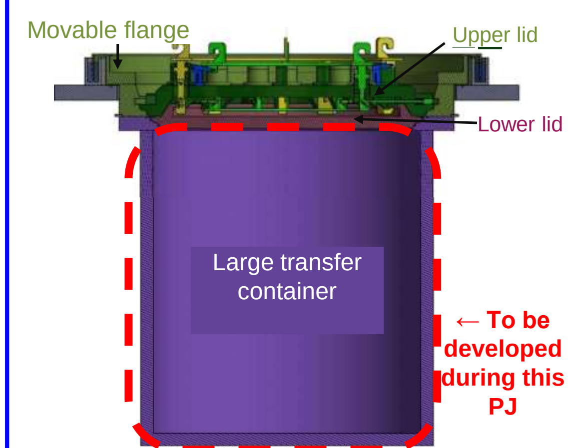




③ Large transportation equipment



② Large transfer container



*Accomplishment Report for FY2021: https://irid.or.jp/wp-content/uploads/2022/08/2022007_deburitoridashi.pdf

3. 2 **Development items involving solicitation and implementation policy**

Development items involving solicitation	Implementation policy	Reference pages
1) Development of side access method (1) Development of the method of installing access equipment	① Installation of large heavy structures The pre-conditions and required specifications will be clearly specified, the cell structure installed inside R/B and the structure of the access equipment will be detailed, the installation method will be studied, and the feasibility will be verified based on the on-site applicability of the method including the procedures, installation accuracy and efficiency of the overall method, by element tests using simulated test specimens, etc.	No. 27 to 152
	② PCV connection sleeve installation and welding by remote operation The requirements for installation of the sleeve, etc. connected to the PCV by remote operation will be consolidated, the method of installation by remote operation, the equipment and devices, and procedures will be studied, and feasibility of the requirements such as accuracy assessment, etc. will be verified by element tests using simulated test pieces. Also, the requirements pertaining to welding, inspection and maintenance of the sleeve, etc. as containment technology for the connection part will be consolidated, the method of implementing the series of operations including welding procedures, inspection and maintenance by remote operation will be studied, and the feasibility and workability of welding will be verified by means of verification tests using simulated test pieces.	No. 153 to 228
	③ Installation of shield In order to reduce the floor load of the ancillary facilities required for transportation to the inside of the R/B, the R/B, etc. streamlining the structure of the access tunnel shield, and the transportation / installation methods will be studied and development will be carried out.	No. 229 to 264
	④ Disassembly of shield plug As the shield plug, etc. (shield plug, block out) in front of the existing equipment hatch, which is a large and heavy object made of concrete, etc. needs to be removed, technology related to safe and efficient disassembly in confined spaces will be studied and developed.	No. 265 to 293
(2) Development of disassembly and removal technology	① HVH disassembly Upon studying and organizing the requirements for disassembling and removing HVH, element tests on disassembly and removal by means of remote disassembly equipment and devices developed so far using simulated test pieces will be planned and implemented considering remote operation in limited space, and the feasibility of specific cutting/collection methods will be verified.	No. 294 to 321
	② Disassembly of CRD exchanger Upon studying and organizing the requirements for disassembling and removing the CRD exchanger, element tests using simulated test pieces will be planned and implemented considering remote operation in limited space, and the feasibility of specific cutting/collection methods will be verified.	No. 322 to 381

3. 2 **Development items involving solicitation and implementation policy**

Development items involving solicitation	Implementation policy	Reference pages
1) Development of side access method (2) Development of disassembly and removal technology	③ Interfering objects removal from pump pit The gap between the inner surface of the pit and the pump is small, and it is not easy to access with tools, etc. Hence, the method of confirming the status of the target objects by means of images captured by the camera, and then cutting, etc. and transferring will be studied in detail, and feasibility will be verified by element tests.	No. 382 to 411
(3) Advancement and development of retrieval methods	① Remotely operated tip tool for retrieval The procedures for removing structures from inside the PCV, processing fuel debris and collecting in unit cans, operability, efficiency of the tip tools, etc. will be verified by studying the tip tools and operation systems and conducting element tests, etc., and the viability of the series of operations will be verified. Also, the actual data on the work procedures will be acquired and consolidated, and data for evaluating the throughput will be obtained.	No. 412 to 538
2) Development of top access method (1) Development of technology for realizing the concept of retrieving large structures	① Method of cutting large structures The method of cutting and separation taking metal in-core structures and ceramic fuel debris into consideration will be studied, and element tests will be conducted using simulated test pieces. Also, the method of transferring cut structures including PCV head, etc. until the structures are loaded on to the large transfer equipment, will be studied, and on-site applicability will be evaluated.	No. 539 to 614
	② Large transfer container Detailed study will be conducted on the conceptual structure of the transfer system including the method of placing the structures in the large transfer container, the air-tightness and shield structure of the large transfer container as a whole including the lid part, manufacturing procedures, etc. Also, the structure of the large transfer container will have to be such that it is easy to decontaminate the inside of the container assuming it will be re-used. Furthermore, full-scale transfer containers will be test manufactured, their performance will be verified by element tests, viability will be verified and issues in on-site application will be identified.	No. 615 to 648
	③ Large transportation equipment The preconditions of the large transportation equipment and the required development items will be studied and consolidated, the method for transporting large heavy contaminated structures with certainty will be investigated and studied in terms of the adaptability to the air-tight gate, etc., on-site applicability of the large transportation equipment will be evaluated by element tests and structural examination of the transportation equipment including the drive mechanism, and issues will be identified.	No. 649 to 669

3. 3 Points to be noted while executing this project

The points to be noted while executing the plans under this project are described below.

[Points to be noted]

During the study, fuel debris retrieval method will be developed while considering handling capability and maintenance methods of the equipment that will be handled remotely, in terms of the following.

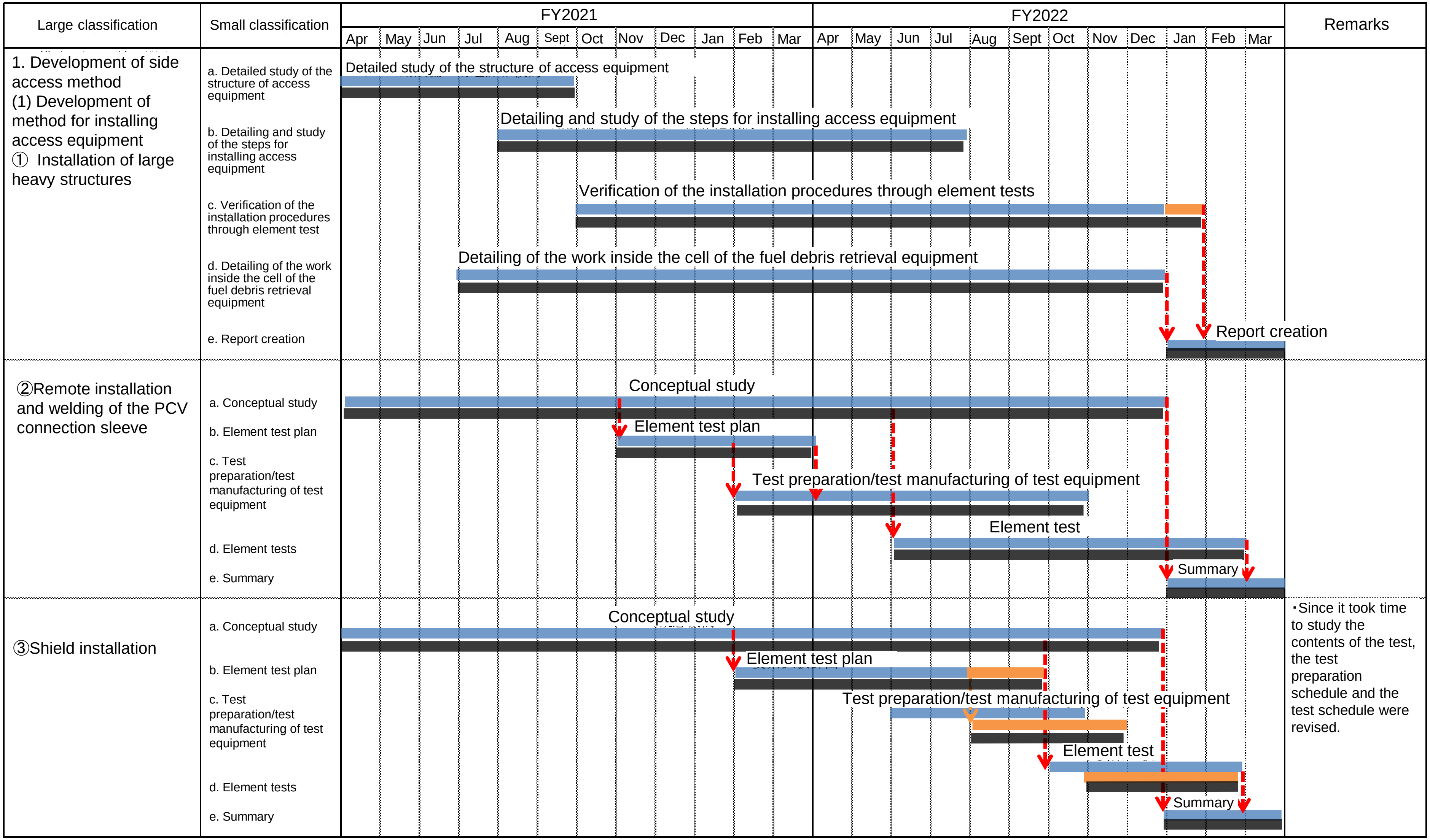
- **As the equipment will be installed in areas with high radiation, as a general rule, maintenance will be carried out remotely.**
- **The contamination of the equipment and the required decontamination will need to be taken into consideration.**
- **Limited work area will be available for maintenance work.**
- **Waste generated during maintenance work will need to be minimized as much as possible.**
- **Installation and handling of criticality monitoring equipment will need to be considered.**

4. Implementation schedule of this project

No.21

Development of fuel debris retrieval method Implementation schedule (1/4)

[Legend]
:Planned
:Revise
:Actual

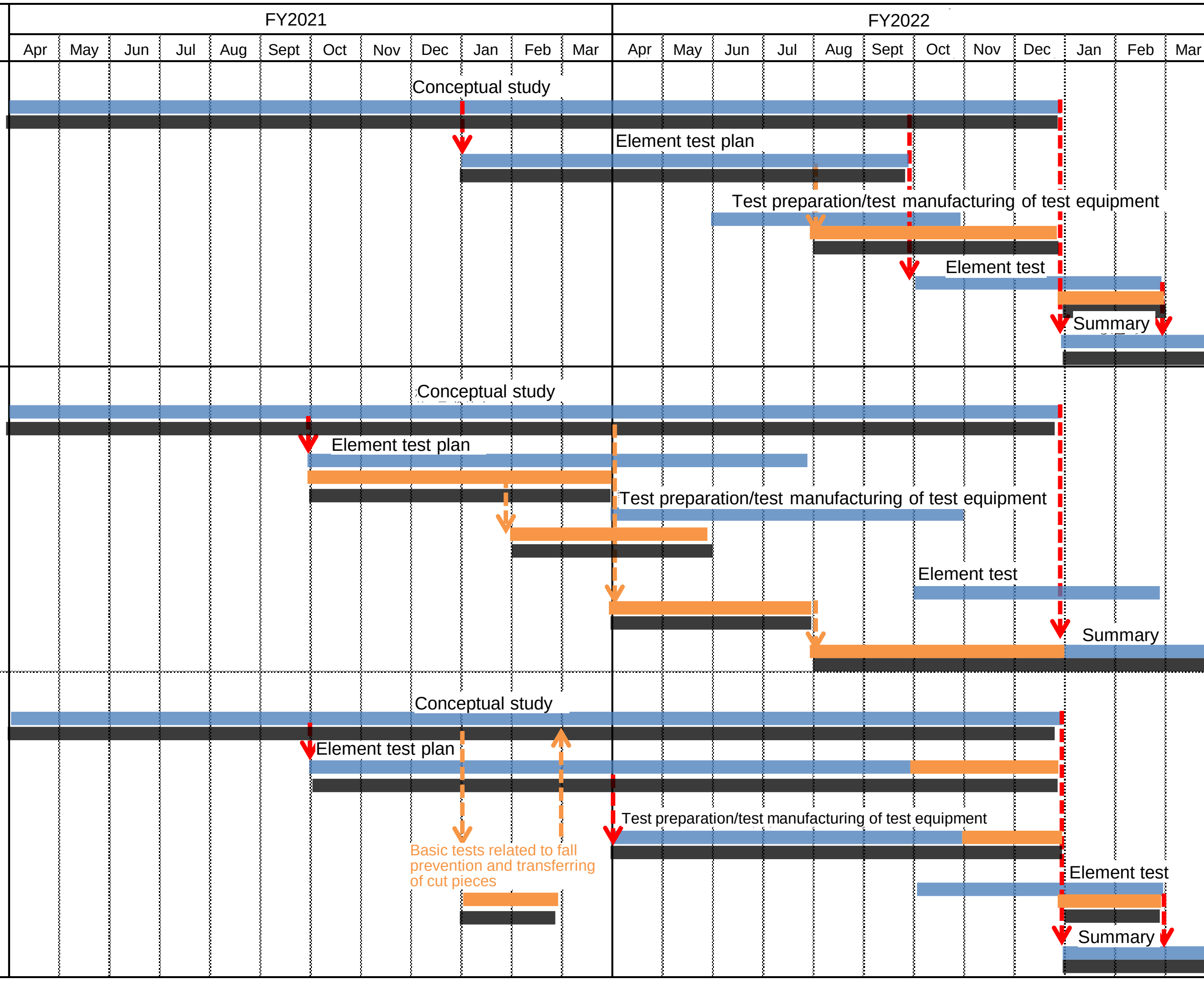


4. Implementation schedule of this project

[Legend]
- :Planned
- :Revised
- :Actual

Development of fuel debris retrieval method Implementation schedule (2/4)

Large classification	Small classification	Remarks
1. Development of side access method (1) Development of method for installing access equipment ④ Disassembly of shield plug	a. Conceptual study b. Element test plan c. Test preparation/test manufacturing of test equipment d. Element tests e. Summary	・Since it took time to draft the test plan (finalize the test items, etc.) and prepare the test pieces, the test preparation schedule and test schedule were revised.
(2) Development of disassembly and removal technology ① HVH disassembly	a. Conceptual study b. Element test plan c. Test preparation/test manufacturing of test equipment d. Element tests e. Summary	・Since the tests on HVH disassembly, CRD exchanger disassembly and interfering objects removal from the pump pit are conducted at the same location, the time of implementation was revised.
② Disassembly of CRD exchanger	a. Conceptual study b. Element test plan c. Test preparation/test manufacturing of test equipment d. Element tests e. Summary	・Basic tests are conducted in FY2021 based on matters indicated during the IRID internal review, etc. The results are reflected in the conceptual study and element test plan. ・Since it took time to plan the tests (studying the test contents) and prepare for them, the test schedule was revised.

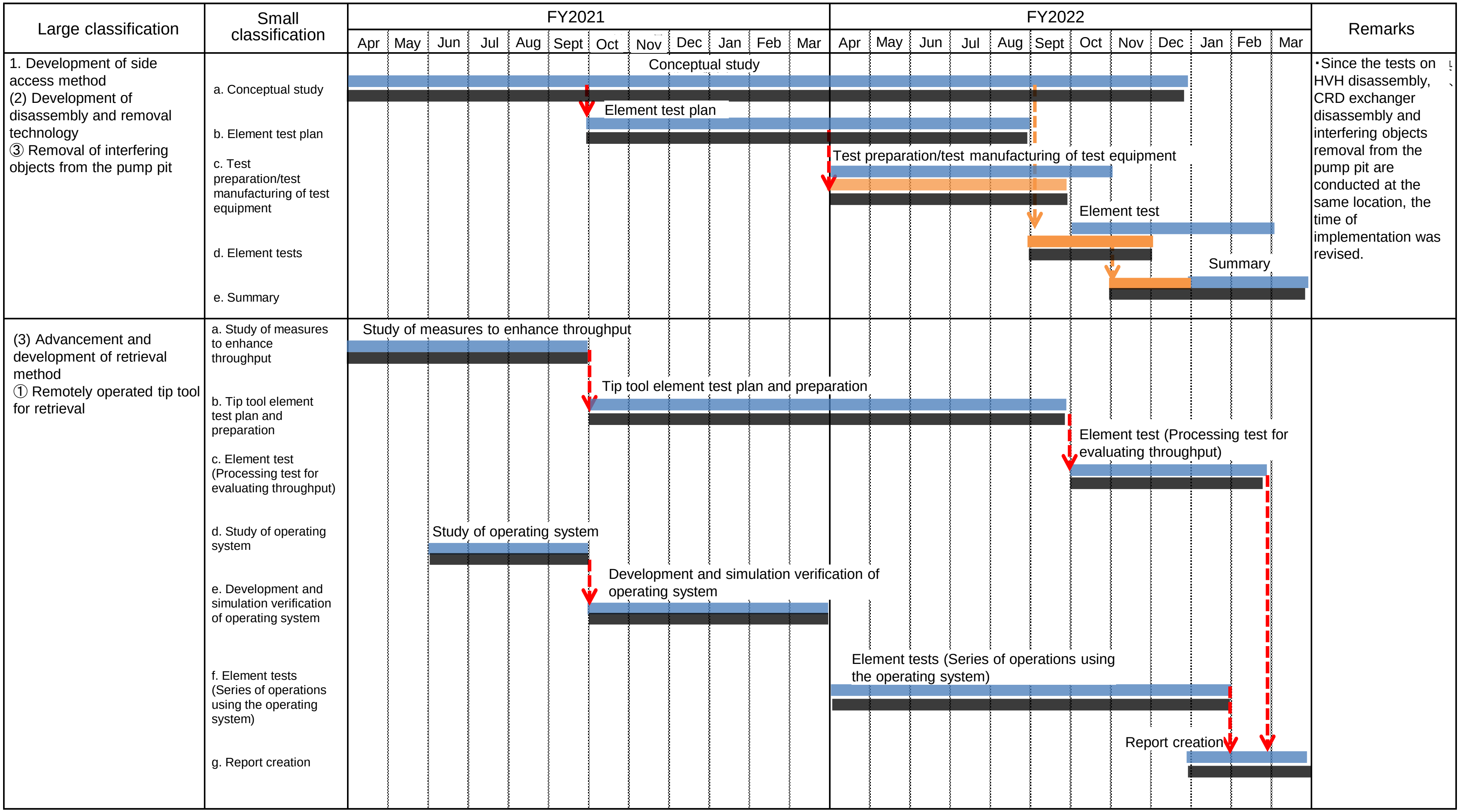


4. Implementation schedule of this project

No.23

[Legend]
:Planned
: Revised
:Actual

Development of fuel debris retrieval method Implementation schedule (3/4)



4. Implementation schedule of this project

[Legend] :Planned :Revised :Actual

Development of fuel debris retrieval method　Implementation schedule (4/4)

Large classification	Small classification	FY2021 (Apr–Mar) / FY2022 (Apr–Mar)	Remarks
2. Development of top access method (1) Development of technology for realizing the concept of retrieving large structures ① Method of cutting large structures	a. Conceptual study	Conceptual study	･As the time of the RPV head stud bolt cutting element test overlapped with the test time of other tests, test preparations were made assuming the element tests would be conducted in FY2021, and the element tests were conducted. They were completed in March 2021.
	b. Element test plan	Element test plan; Element test plan (Cutting reactor internal structures)	
	c. Test preparation/test manufacturing of test equipment	Test preparation/test manufacturing of test equipment	
	d. Element tests	Element tests (RPV head disassembly); Element test (Cutting reactor internal structures)	
	e. Summary	Summary	
② Large transfer container	a. Conceptual study	Conceptual study	Element tests were completed in December 2022
	b. Element test plan	Element test plan	
	c. Test preparation/test manufacturing of test equipment	Test preparation/test manufacturing of test equipment	
	d. Element tests	Element tests	
	e. Summary	Summary	
③ Large transfer containers	a. Conceptual study	Conceptual study	･After organizing the issues based on the steps for carrying in/out the work container and isolation sheet, element test items, etc. are identified and the element test plan is drafted. ･Since it took time to study the steps for carrying in/out and to organize the issues, the element test plan was drafted from FY2022.
	b. Element test plan	Element test plan	
	c. Test preparation/test manufacturing of test equipment	Test preparation/test manufacturing of test equipment	
	d. Element tests	Element tests	
	e. Summary	Summary	
Major milestones		Interim report (Nov FY2021); Annual report (May FY2022); Interim report (Oct FY2022); Final report (Feb FY2022); Presentation of results report (Mar FY2022)	

5. Project Organization

International Research Institute for Nuclear Decommissioning (IRID)
- Coordination of overall planning and technology management
- Coordination of technology administration including technology development progress management

Tokyo Electric Power Company Holdings, Inc.
- Various coordination for site application

Hitachi-GE Nuclear Energy, Ltd.

[Element tests, technical development]
1) Development for side retrieval method
   (1) Development of the method of installing access equipment
      ② PCV connection sleeve installation and welding by remote operation
      ③ Installation of shield
      ④ Disassembly of shield plug
   (2) Development of disassembly and removal technology
      ① HVH disassembly
      ② Disassembly of CRD exchanger
      ③ Interfering objects removal from pump pit
2) Development of top access method
   (1) Development of technology for realizing the concept of retrieving large structures
      ① Method of cutting large structures
      ② Large transfer container
      ③ Large transportation equipment

Mitsubishi Heavy Industries, Ltd.

[Element test, technical development]
1) Development for side access method
   (1) Development of the method of installing access equipment
      ① Installation of large heavy structures
   (3) Advancement and development of retrieval methods
      ① Remotely operated tip tool for retrieval

- Development of technology for detailed investigation inside PCV (Field validation of the technology for detailed internal investigation using X-6 penetration)
- Development of technology for detailed investigation inside PCV (On-site demonstration of technology for detailed investigation considering deposit measures)
- Development of technology supporting integrated management of decommissioning at Fukushima Daiichi Nuclear Power Station (Development of systems for continuous monitoring inside PCV)

Project teams to cooperate for technological development

- Development of Fuel Debris Retrieval Method (Development of Isolation Technology for Preventing Spread of Contamination while Retrieving and Transporting Large Structures）
- Development of technology for further increasing the scale of retrieval of fuel debris and reactor internals (Development of technology related to ensuring safety during fuel debris retrieval)
- Development of safety systems (Liquid/gas phase systems, criticality control technology)
- Development of analysis and estimation technology for characterization of fuel debris
- Development of technology for investigation inside RPV
- Development of technology for gradually increasing the retrieval scale of fuel debris
- Research and development for treatment and disposal of solid waste
- Development of technology for containing, transfer and storage of fuel debris

Main sub-contracting details

Hitachi-GE Nuclear Energy, Ltd.	Mitsubishi Heavy Industries, Ltd.
[Sub-contracting details] ・ PCV connection sleeve remote installation test, additional access tunnel shield installation test, HVH disassembly element test, CRD exchanger disassembly element test, pump pit interfering objects removal element test, large transportation equipment element test (Toko Corporation) ・ PCV connection sleeve remote welding test, element tests related to RPV head disassembly, test manufacturing of large transfer containers, air-tightness test (Mitsubishi Heavy Industries, Ltd. (Former Mitsubishi Power, Ltd.)) ・ Elemental test related to the method of cutting large reactor internal structures (Sugino Machine Limited) ・ Study related to filler material for the top access unitized large structures transfer method (University of Tokyo) ・ Design assistance related to the study of side access method, shield plug disassembly elemental test (Hitachi Plant Construction, Ltd.) ・ Design assistance related to the study of top access method (JTEC Corporation)	[Sub-contracting details] ・ Design assistance related to detailing of cell structure (MHI NS Engineering Co., Ltd.) ・ Design assistance related to detailing of the access equipment fitting method (MHI NS Engineering Co., Ltd.) ・ Cell adapter remote installability verification test （DIA F Engineering, Ltd., MHI NUSEC, LTD.) ・ Indoor and outdoor cell installation frame placement study (Nihon Kensetu Kogyo Co. Ltd.) ・ Installation position setting technology verification test （DIA F Engineering, Ltd., MHI NUSEC, LTD.) ・ Design assistance related to the method of processing structures and fuel debris (MHI NS Engineering Co., Ltd.) ・ Structures and fuel debris processing test (MHI NS Engineering Co., Ltd.) ・Evaluation of validity of the trajectory calculation logic for avoiding obstacles (Kobe University) ・Coding of the software for avoiding obstacles (MHI NS Engineering Co., Ltd.)

1) Development of side access method

(1) Development of the method for installing access equipment

① Installation of large heavy structures

The installation of cells, which are large heavy structures, has been studied to be used as access equipment for the side access method, with the purpose of further increasing the scale of retrieval of fuel debris and reactor internal structures. For precise cell installation inside the R/B, ensuring of installation accuracy and optimization of installation work need to be studied and related development needs to be carried out with respect to the cell structure and connection with the PCV.

In order to install the cell structure, which is a large heavy structure, on the PCV connecting part, the cell structure needs to be positioned accurately on the PCV connecting part while keeping within the load limit for the floor inside R/B, and the connection to the PCV opening needs to be accomplished remotely via the structure equipped with confinement function and a function for dealing with displacement caused by earthquakes. The method of installing the access equipment for the cell structure inside the R/B will be studied, verification tests will be conducted, and the efficiency of the method as a whole and feasibility of the procedures will be verified.

As the pedestal opening cannot be modified and changed easily, the cell structure needs to be installed accurately by remote operation while sufficiently considering the mutual correlation between the location of the X-6 penetration, which is where the access equipment is installed, and the location of the pedestal opening (axis joining both openings), when both openings are connected. As the access equipment is installed along the axis leading to the pedestal opening from the X-6 penetration, first, the method of carrying-in and remotely installing the cell structure meeting this requirement via the connection structure will be studied while taking earthquakes measures into consideration. Then, the viability will be verified based on the on-site applicability of the method including the procedures, installation accuracy and efficiency, by elemental tests using simulated test pieces, etc.

① Installation of large heavy structures

Table of Contents

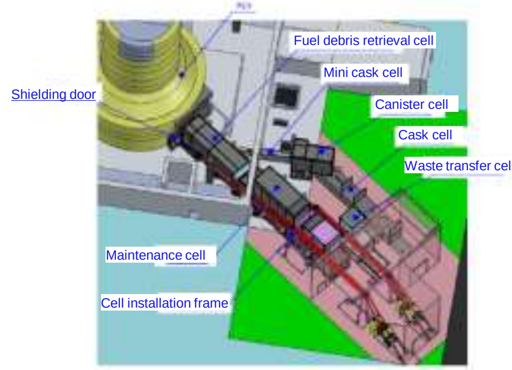
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

① Installation of large heavy structures

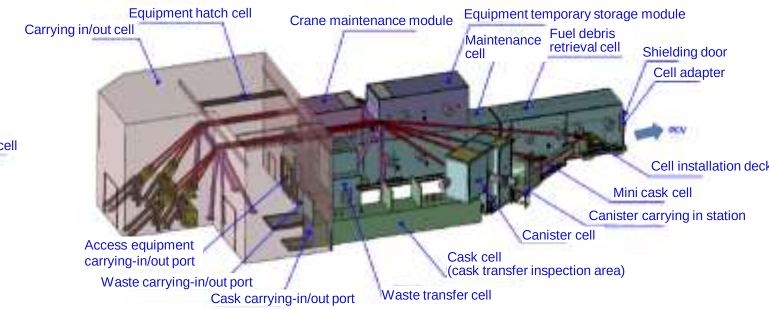
(1) Development results achieved so far and correlation with this project

[Upgrading of fundamental technology (FY2017-18)]

- **Study of the composition of fuel debris retrieval equipment and the proposed layout**
- **Study of the method of installing the suspension bridge type cell**



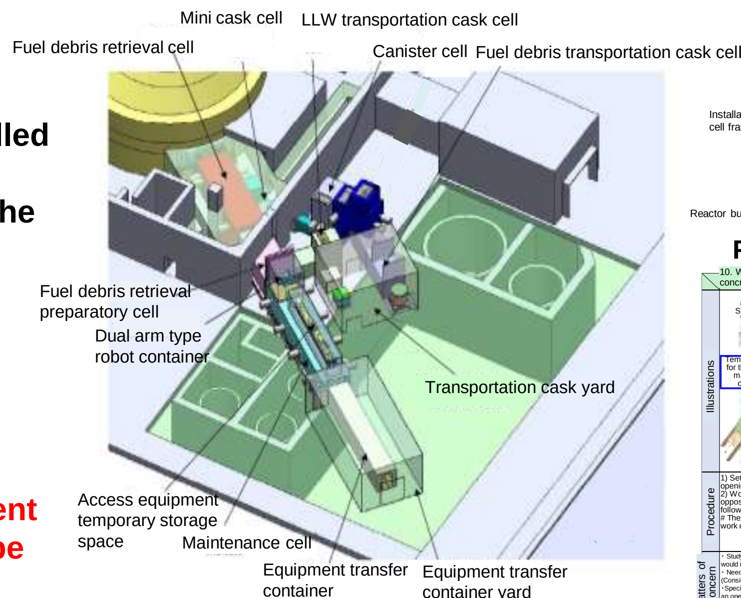
Layout of the fuel debris retrieval equipment



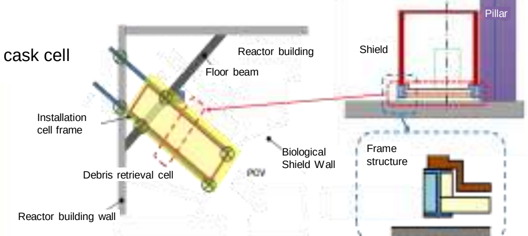
Composition of the fuel debris retrieval equipment (suspension bridge type cell)

[Further increasing the retrieval scale (FY2019-20)]

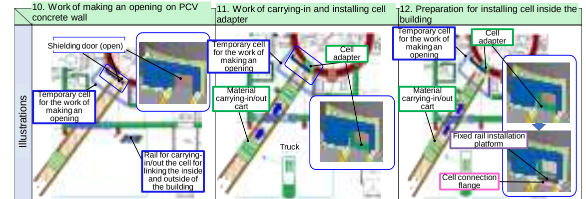
- **Study on downsizing the cells installed inside R/B**
- **Study of the method of supporting the load of the cells**
- **Study of the work steps involved in installing the fuel debris retrieval equipment**



Cell downsizing



Frame for supporting the load of the cell



	10. Work of making an opening on PCV concrete wall	11. Work of carrying-in and installing cell adapter	12. Preparation for installing cell inside the building
Procedure	1) Setting up the cell for the work of making an opening 2) Work of making an opening (Procedures opposite to those for carrying-in work are followed for debris, etc.) # The shielding door is gradually closed as the work of making the opening progresses.	1) Preliminary preparation for carrying-in cell adapter (PCV wall surface cleaning / 3D shape measurement / Cell adapter groove work) 2) Loading the carrying-in/out cart on the outdoor rail with the help of a yard building crane 3) Loading the cell adapter on the equipment carrying-in/out cart 4) Installing while adjusting the position in accordance with the layout markings	1) Carrying-in and installing the fixed rail installation platform 2) Loading the cell connection flange on to the equipment carrying-in/out cart 3) Installing while adjusting the position in accordance with the layout markings 4) Disassembling the temporary cell for the work of making an opening, after the shielding door is closed
Matters of concern	・Study of method of making an opening □ A method that would not damage the PCV steel plate ・Need for finishing the surface of the opening (Considering the impact on cell adapter installation) ・Specifications of the temporary cell for the work of making an opening and dust measures once the opening is made ・Method of removing the X-6 penetration and contamination control	・Installation of cell adapter (Installation of sling and roller for carrying-in at the opening)	・Need for cell connection flange, remote carrying-in and installation method ・Method of temporary shielding during work

Fuel debris retrieval equipment installation work steps

[Development of Retrieval Method (FY2021-22)]

- **Substantiation of the access equipment (cell adapter, shielding door, cell) to be connected to the PCV inside the R/B, study and verification of feasibility of installation method.**

① Installation of large heavy structures

(2) Background and purpose of this research

✓ **Reasons for this research**

- Studies have been conducted on the equipment for accessing the inside of the PCV pedestal, cell adapter for connection to the PCV and for confinement, and access equipment composed of the shielding door and cell, with respect to the side access method, in order to further increase the retrieval scale of fuel debris and reaction internal structures. In FY2020-21, the access equipment was studied in terms of downsizing the cells to be installed inside the R/B, method of supporting the load of the heavy cells, as also the work steps involved in installing the fuel debris retrieval equipment.
- The following requirements concerning the access equipment are addressed in this subsidy project.
  - ➢ In order to install the cell structure, which is a large heavy structure, on the PCV connection part, the cell structure needs to be positioned accurately on the PCV connection part while keeping within the load limit for the floor inside the R/B, and the connection to the PCV opening needs to be accomplished remotely via the structure equipped with confinement function and a function for dealing with displacement caused by earthquakes, and the structures and requirements to accomplish this need to be clearly specified.
  - ➢ As the pedestal opening cannot be modified and changed easily, while connecting the X-6 penetration, which is the location where the access equipment is installed, to the PCV opening, the mutual correlation between the locations of both openings (the axis joining the openings) is sufficiently considered, and the access equipment is installed along the axis leading to the pedestal opening from the X-6 penetration. Hence for remotely installing the cell structure, the procedures for carrying-in the cell structure and installing it accurately, while meeting these requirements, need to be established.
- Therefore, in order to install the access equipment accurately inside the R/B, ensuring installation accuracy and optimization of installation work need to be studied and related development needs to be carried out with respect to the cell structure and connection with the PCV.

✓ **Expected outcome of this research, reflection destination, and contribution of the outcome**

- Expected outcome: Development of the procedures for installing the access equipment, and establishment of the required specifications of the equipment for remote operation.
- Reflection destination and contribution of the outcome: Establishment of the method for installing the access equipment inside the R/B for the side access method.

① Installation of large heavy structures

(3) Project Goals

✓ **Requirements from the reflection destination**

- The access equipment is planned to enter from the pedestal opening of the PCV and retrieve fuel debris.
- An access route for the above-mentioned access equipment needs to be constructed in a straight line from the pedestal opening to the X-6 penetration.
- Hence, the shielding door or the cells, etc. which are large heavy structures, need to be installed accurately along that straight line.
- Also, the connection part between the cells installed on the first floor of the R/B and the PCV should use a cell adapter with a bellows structure to absorb the displacement in the event of an earthquake.
- Further, the cell adapter, shielding door and the cells need to have a confinement function.
- And, as BSW is installed after the opening is created, it means that the work of installing the cell adapter will have to be carried out under high radiation environment from the PCV. Hence installation by remote operation becomes necessary.

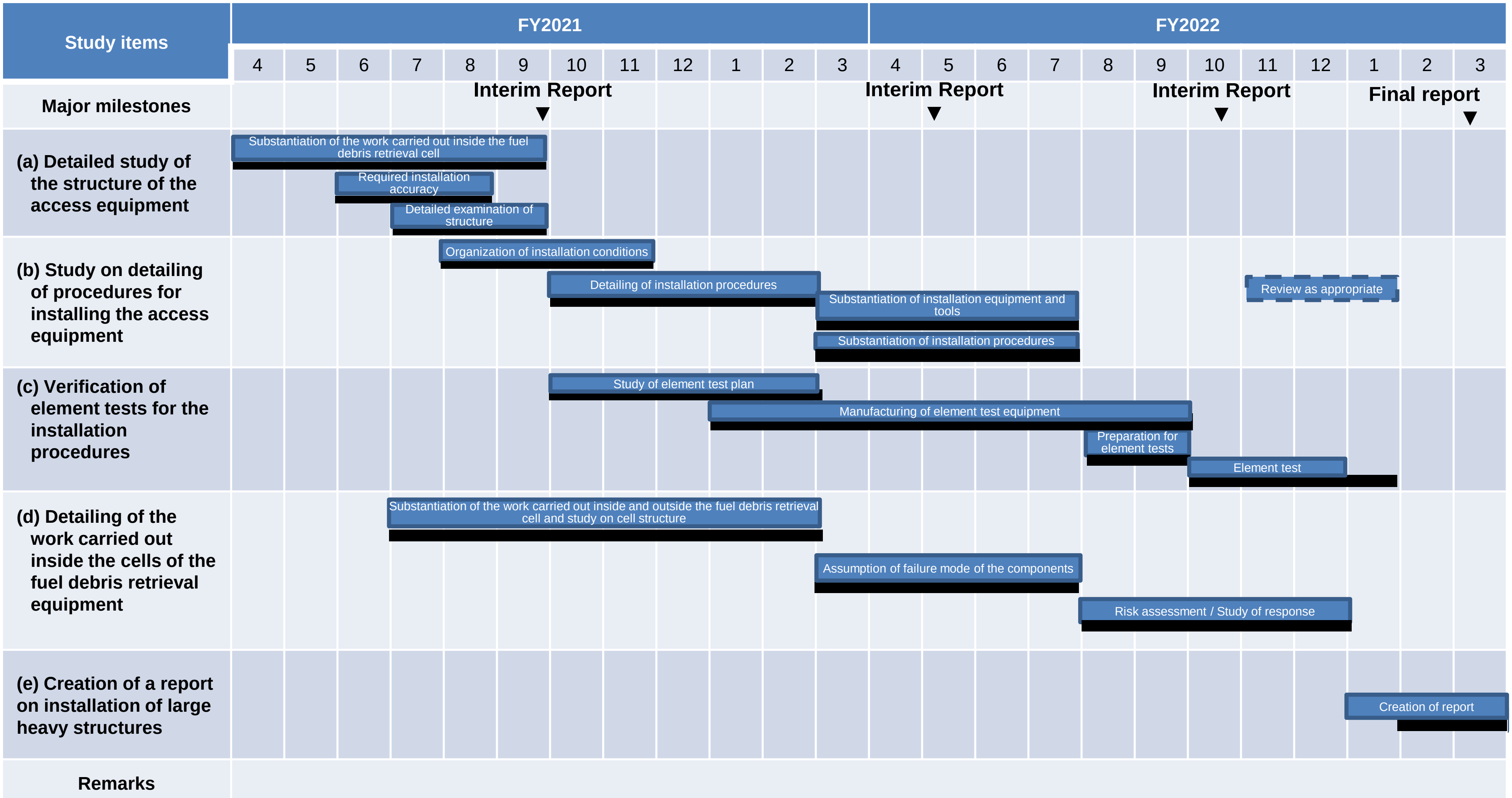
✓ **Goals based on the above-mentioned requirements**

- Studying the required fitting accuracy, adjustment method, etc. and substantiating the structure, in addition to functions such as the earthquake displacement absorption function, confinement function, etc. that are required of the access equipment which comprises large heavy structures.
- Detailing the procedures for installing the access equipment.
- Examining the installation procedures that must be verified, and verifying them by element tests.
- Organizing the required specifications of the equipment for remote installation, based on the results of element tests.

① Installation of large heavy structures

(4) Development schedule

[Legend] Planned: Actual:



6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

① Installation of large heavy structures

(5) Implementation items, their mutual correlation, and correlation with other research

✓ Implementation items and correlation between the implementation items

<Brief explanation>

a. Detailed study of the structure of the access equipment
Substantiation of the specifications of the access equipment and clear specification of installation requirements

b. Study on detailing of procedures for installing the access equipment
- Detailing of installation procedures
- Substantiation of installation tools

c. Verification of element tests for the installation procedures
- Designing and manufacturing of equipment for the element test
- Identification of issues in implementation of element tests and in the specifications of the equipment for remote installation

d. Detailing of the work carried out inside the fuel debris retrieval equipment cell
- Detailing of installation procedures
- Substantiation of installation tools

c. Verification of element tests for the installation procedures
- Identification of required specifications of the equipment based on the results of element tests

(Detailed explanation)

Verification by mock-up tests after completing basic designing (1/1 scale)

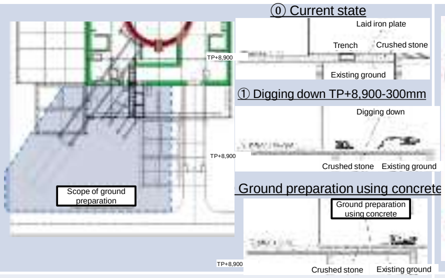
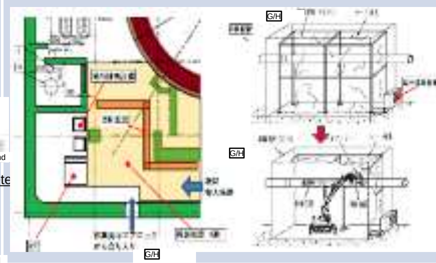
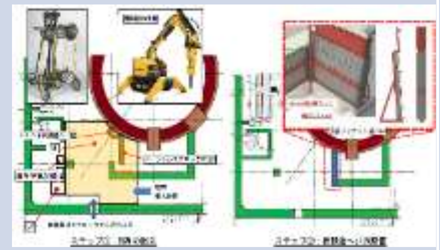
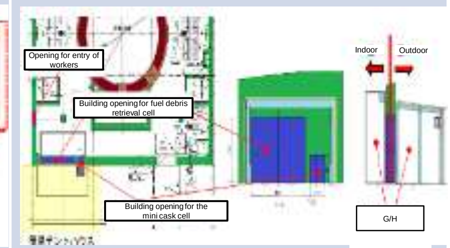
① Installation of large heavy structures

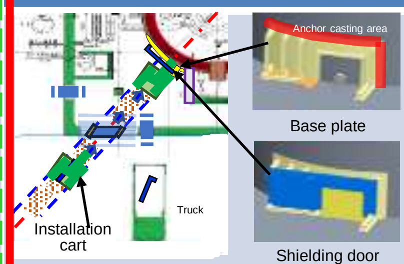
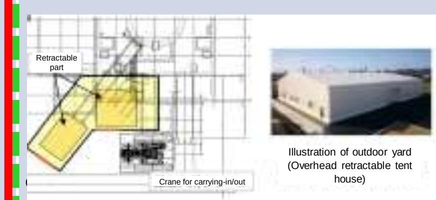
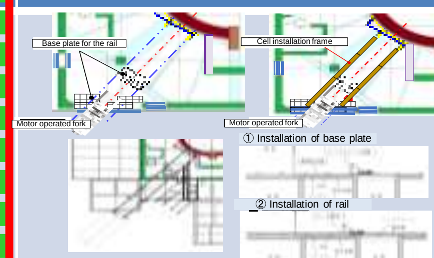
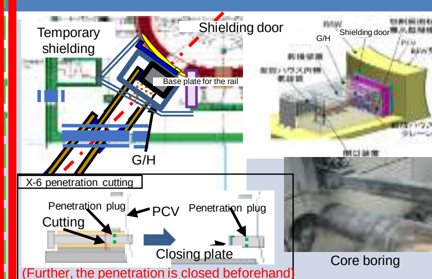
(5) Implementation items, their mutual correlation, and correlation with other research

✓ **Implementation items and correlation between the implementation items**

[Red box] : Items targeted during the installation of large structures in FY2021-2022

[Green dashed box] : Items studied particularly in FY2021-2022

Work step	Ground preparation in front of R/B	Removal of interfering objects inside the Reactor Building (Removal of RHR piping, etc.)	Removal of BSW in front of air lock and around X-6 penetration	Making of an opening in the R/B building wall
Illustration of work steps				
Remarks	• FY2019-2020: Implementation of conceptual study on the method		• FY2019-2020: Implementation of conceptual study on the method	• FY2017-2020: Implementation of conceptual study on the method

Work step	Shielding door base plate Shielding door installation	Setting up the outdoor yard	Setting up the cell installation frame	Making a hole in the BSW/Cutting the X-6 penetration
Illustration of work steps				
Remarks	• FY2017-2020: Implementation of conceptual study on the method • FY2021-2022: Implementation of study on substantiation of the structure of the base plate and shielding door, and on detailing of the installation method		• FY2019-2020: Implementation of conceptual study on the method • FY2021-2022: Implementation of study on the method of marking the reference line for installation	• FY2017-2018: Plan to use the method of making a hole in BSW developed by Toshiba (hole making method) • FY2021-2022: Implementation of study on the method of ascertaining the shape of the PCV steel plate through measurements using 3D scanner

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

① Installation of large heavy structures

(5) Implementation items, their mutual correlation, and correlation with other research

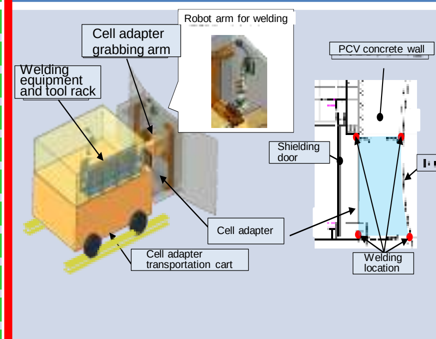
✓ **Implementation items and correlation between the implementation items**

[red box] : Items targeted during the installation of large structures in FY2021-2022

[green dashed box] : Items studied particularly in FY2021-2022

Work step: Carrying-in and installation of cell adapter

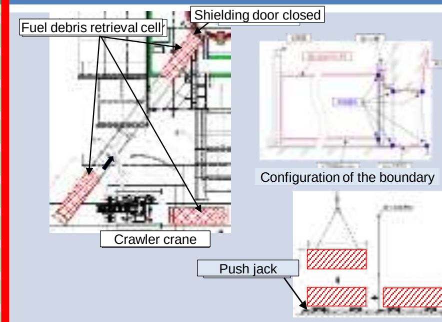
Illustration of work steps:



Remarks:
- FY2019-2020: Implementation of conceptual study on the method
- FY2021-2022: Cell adapter installation method, interfering objects verification and identification of required specifications for the installation equipment

Work step: Installation of fuel debris retrieval cell and other structures

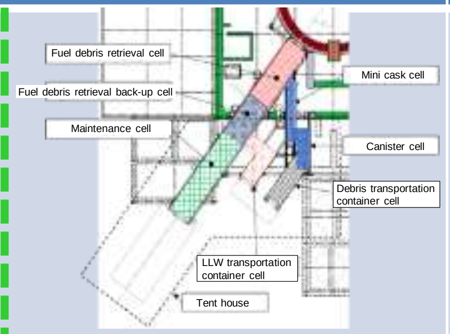
Illustration of work steps:



Remarks:
- FY2019-2020: Implementation of conceptual study on the method
- FY2021-2022: Overall structural verification (structural verification of boundary) using simulated bodies

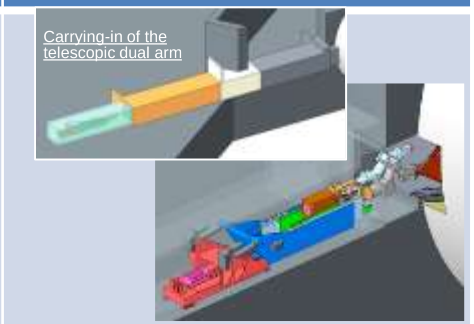
Work step: Pressure resistance test and trial run of the cell functions

Illustration of work steps:



Work step: Arm introduction and making of hole in PCV wall

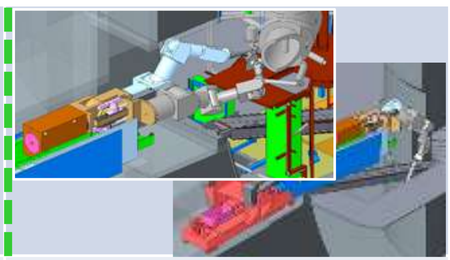
Illustration of work steps:



Remarks:
- FY2017-2020: Implementation of conceptual study on the method

Work step: Removal of interfering objects outside the pedestal (1) (Telescopic dual arm type robot)

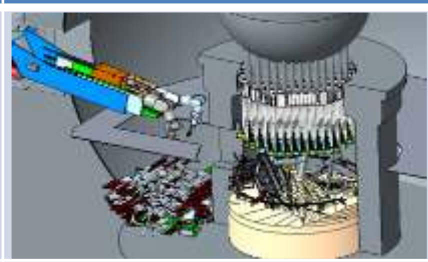
Illustration of work steps:



Remarks:
- FY2017-2020: Implementation of conceptual study on the method
- FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles

Work step: Removal of interfering objects outside the pedestal (2) (Telescopic dual arm type robot)

Illustration of work steps:



Remarks:
- FY2017-2020: Implementation of conceptual study on the method
- FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles

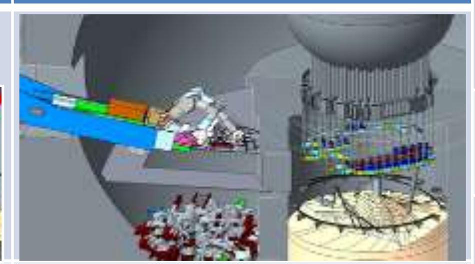
Work step: Removal of interfering objects from inside the pedestal (1) (Telescopic dual arm type robot)

Illustration of work steps:

Remarks:
- FY2017-2020: Implementation of conceptual study on the method
- FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles

Work step: Removal of interfering objects from inside the pedestal (2) (Telescopic dual arm type robot)

Illustration of work steps:



Remarks:
- FY2017-2020: Implementation of conceptual study on the method
- FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

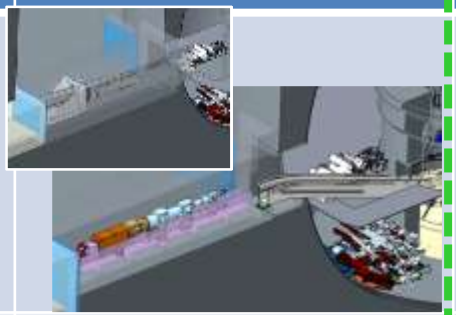
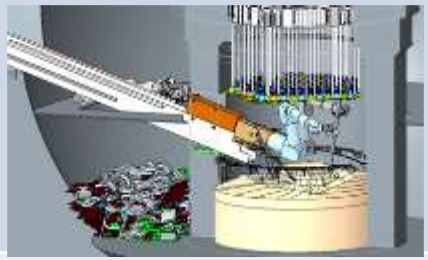
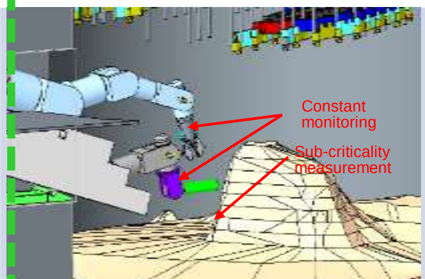
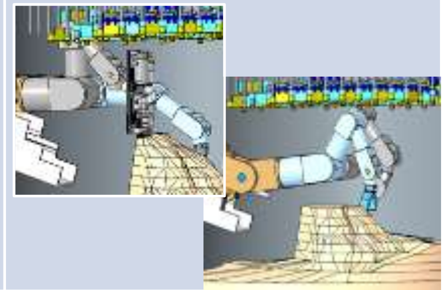
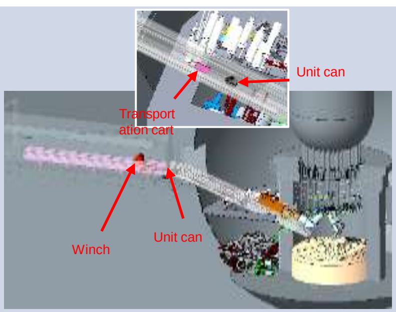
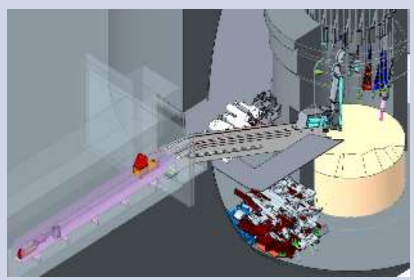
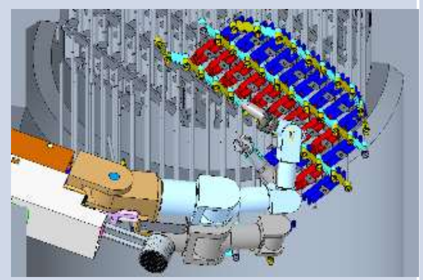
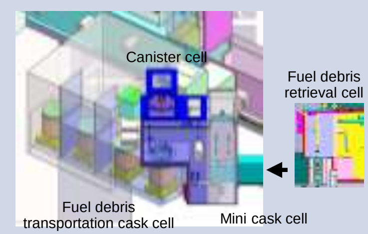
① Installation of large heavy structures

(5) Implementation items, their mutual correlation, and correlation with other research

✓ **Implementation items and correlation between the implementation items**

(red box) : Items targeted during the installation of large structures in FY2021-2022

(green dashed box) : Items studied particularly in FY2021-2022

Work step	Installation of fixed-type rail (Fixed rail type dual arms)	Removal of interfering objects from inside the pedestal (3) (Fixed rail type dual arms)	Sub-criticality measurement	Fuel debris retrieval (Fixed rail type dual arm type robot)
Illustration of work steps				
Remarks	• FY2017-2020: Implementation of conceptual study on the method	• FY2017-2020: Implementation of conceptual study on the method • FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles	• FY2017-2020: Implementation of conceptual study on the method	• FY2017-2020: Implementation of conceptual study on the method
Work step	**Fuel debris transfer**	**Fuel debris retrieval (Hydraulic arms)**	**CRD removal**	**Fuel debris delivery**
Illustration of work steps				
Remarks	• FY2017-2020: Implementation of conceptual study on the method	• FY2017-2020: Implementation of conceptual study on the method • FY2021-2022: Verification of cutting performance of the tip tool, and development of the function for automatically avoiding obstacles	• FY2017-2020: Implementation of conceptual study on the method	• FY2019-2020: Implementation of conceptual study on the method

① Installation of large heavy structures

(6) Implementation items

(6)-1: a. Detailed study of the structure of the access equipment

✓ **Objective**

- In order to install the cell structure, which is a large heavy structure, on the PCV connection part, the cell structure needs to be positioned accurately on the PCV connecting part while keeping within the load limit for the floor inside the R/B, and the connection to the PCV opening needs to be accomplished remotely via the structure equipped with confinement function and a function for dealing with displacement caused by earthquakes. The structures and requirements to accomplish this need to be clearly specified.
- The access equipment that is provided with a confinement function, etc. and conforms with the limitations on the floor load applicable to fuel debris retrieval equipment using the side access method, needs to be substantiated.

✓ **Project Goals**

- To substantiate the structure of the cell adapter, shielding door and cell that form the access equipment.
- To study the specifications of the confinement function and the earthquake displacement absorption function, and the structure.
- Also, to add the required installation accuracy and method of adjusting the position while installing, to the structural study.

✓ **Comparison with existing technologies**

- The cell adapter, shielding door and cell that are the components of the access equipment are technologies that are present in existing nuclear facilities.
- Since the access equipment, which comprises large and heavy structures, has to be installed accurately inside the existing R/B at the Fukushima Daiichi Nuclear Power Station, and the cell adapter has to be installed by remote operation, the requirements of the installation equipment need to be satisfied.

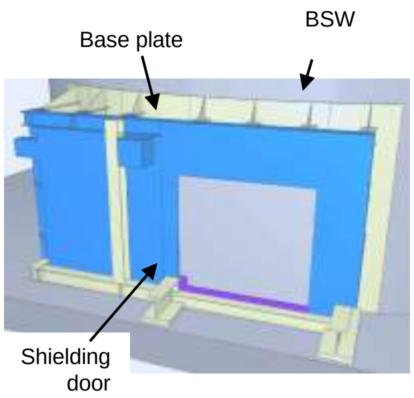
① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

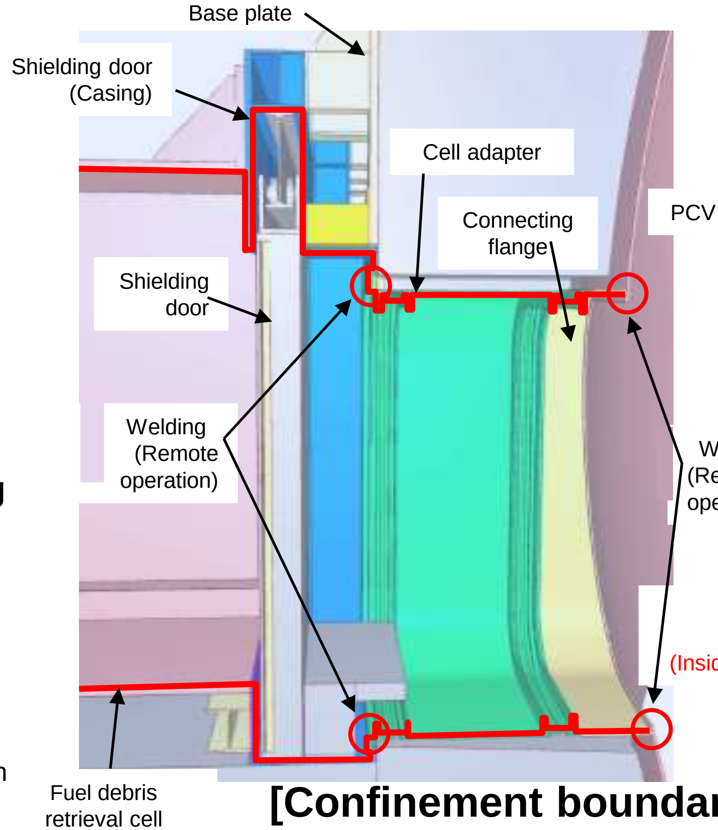
1) Connection structure of the boundary with the PCV (1/7)

- A base plate is installed to support the load of the BSW and then the shielding door is installed.
- The cell adapter is welded between the PCV and the shielding door.
- The shielding door and the fuel debris retrieval cell are welded/connected with bolts.
- The confinement boundary comprises the fuel debris retrieval cell, shielding door (casing) and the cell adapter.

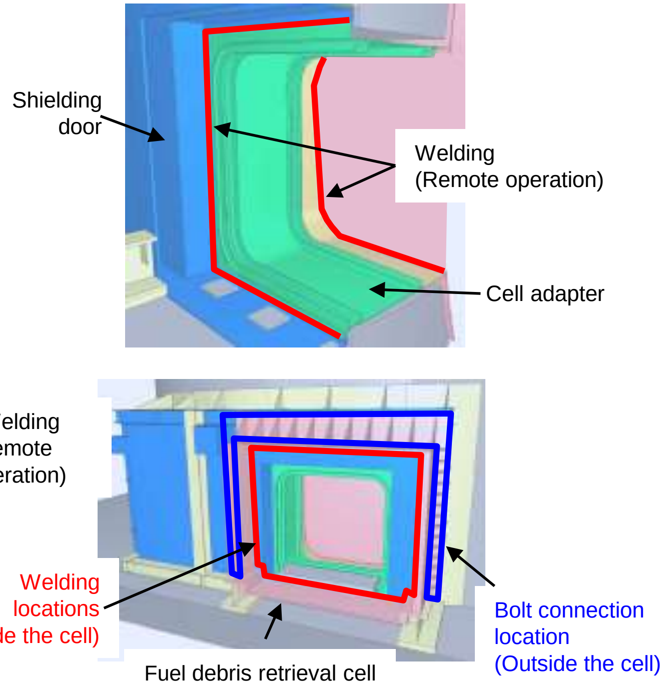


[Illustration of the shielding door installation]

[Mass of each component]
- Cell adapter: 3 ton
- Base plate: 70 ton
- Shielding door: 25 ton
- Fuel debris retrieval cell: 140 ton
- Equipment inside the cell/ancillary equipment (including the margin): 42ton



[Confinement boundary]



[Connection methods]

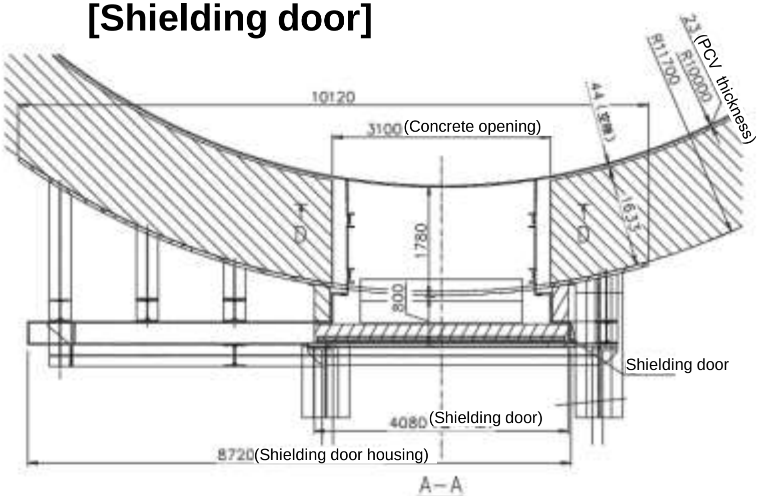
① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

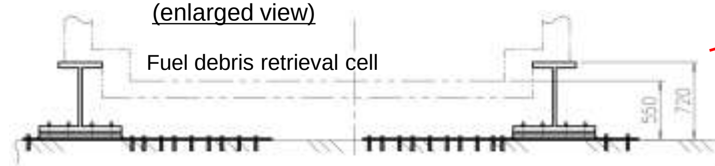
✓ **Implementation items and results**

1) Connection structure of the boundary with the PCV (2/7)

[Shielding door]

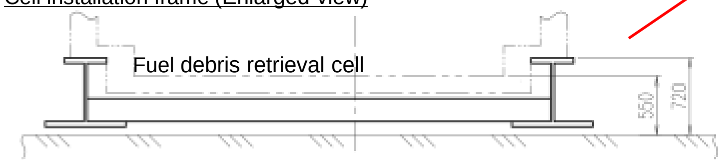


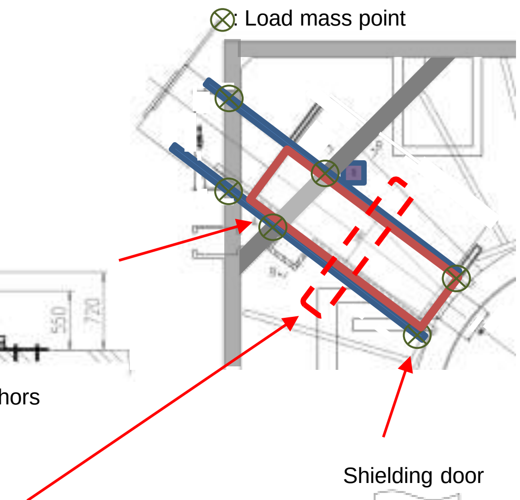
Cell installation frame and anchor casting part (enlarged view)

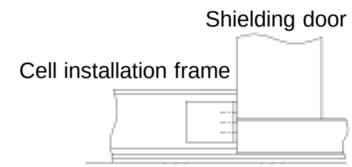


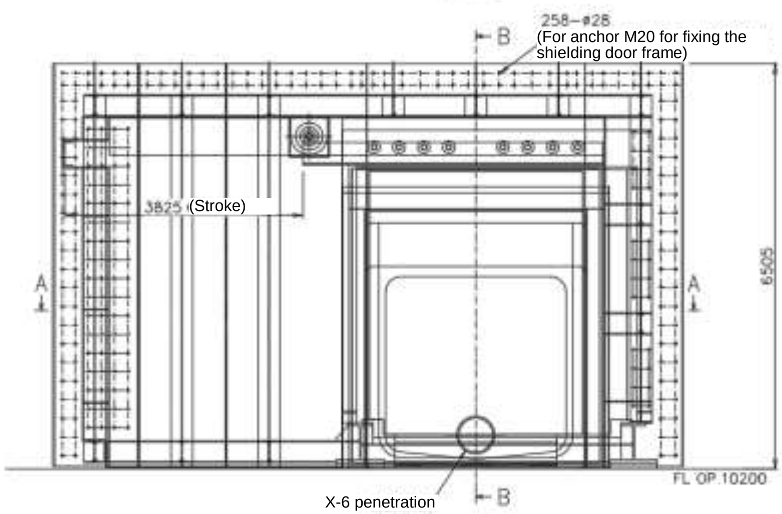
Fixed on the strong members using post installed anchors

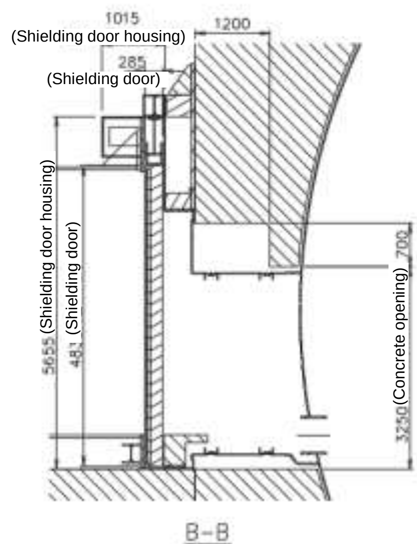
Cell installation frame (Enlarged view)



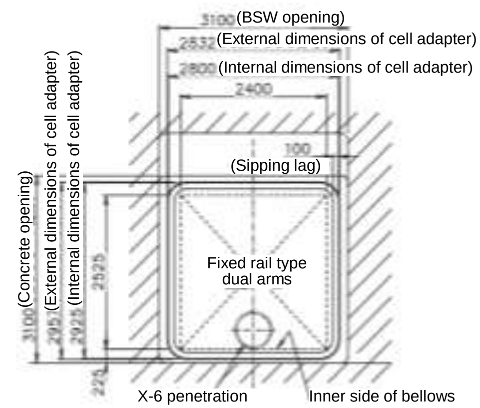








Connecting part of the shielding door and cell installation frame (Enlarged view)



① Installation of large heavy structures

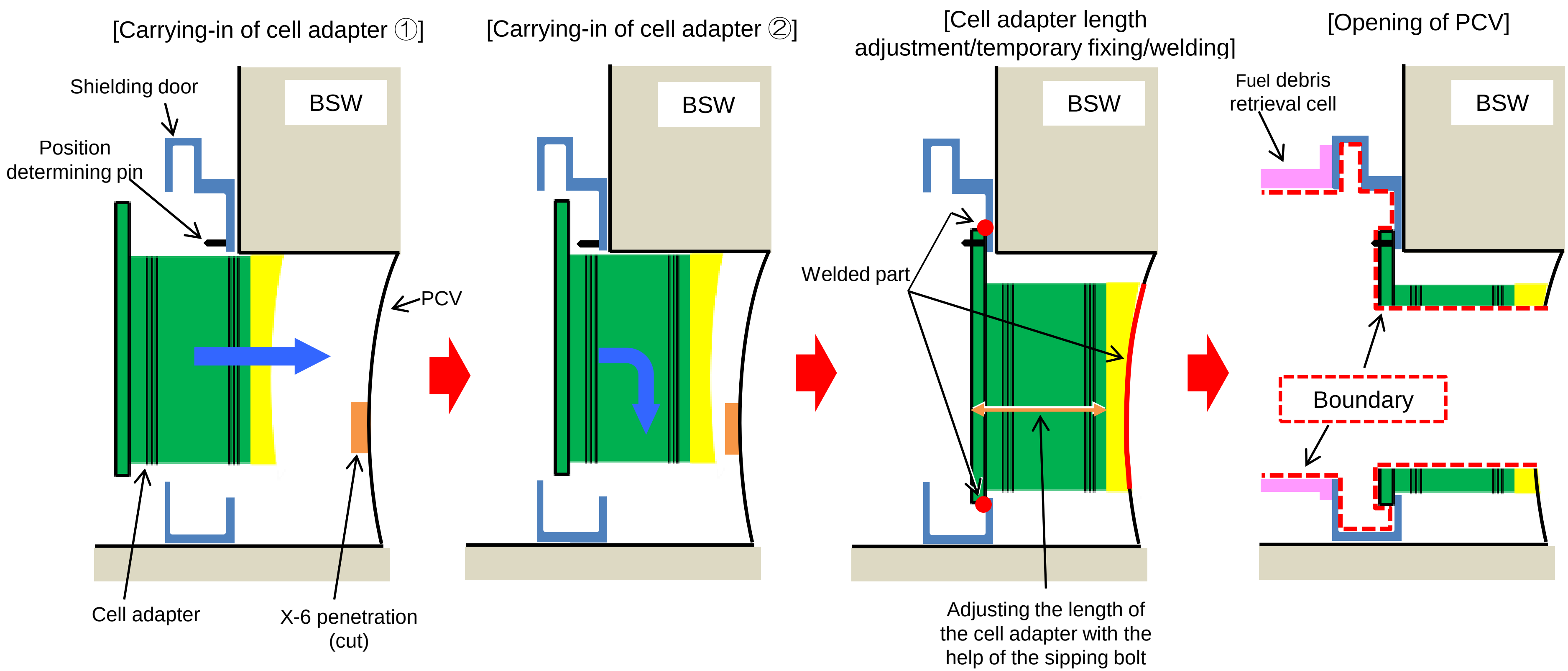
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

1) Connection structure of the boundary with the PCV (3/7)

[Boundary part]

A structure such that the cell adapter flange part can be hitched on the shielding door



① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

1) Connection structure of the boundary with the PCV (4/7)

The bases for establishing the dimensions of the cell adapter, BSW opening and shielding door are consolidated below.

<Width/Height> ⇒ The size of the BSW opening is established by keeping a 100mm# margin while inserting from an opening that is required based on the arm and rail size.

No.	Name	Width (mm)	Basis	Height (mm)	Basis
1	Required opening (Arm and rail)	2400	Arm and rail	2525 225	Arm and rail Height from the floor
2	Internal dimensions of cell adapter	2800	200mm (= sipping lug height 100mm+ margin 100mm) × 2 = 400mm	2925 (2525+400)	200mm (= sipping lug height 100mm + margin 100mm) × 2 = 400mm
3	Cell adapter dimensions	2832	Plate thickness 16mm × 2 = 32mm	2957	Plate thickness 16mm × 2 = 32mm
4	BSW opening	3032 ≒ 3100	External dimensions + margin 100mm × 2 (= 200mm)	3057	External dimensions + margin 100mm (External dimensions of cell adapter from the floor +100mm)

The margin is established based on the work of installing large heavy objects by the company in the past.

<Length/Depth> ⇒ Determined by measuring the distance from the PCV steel plate to the shielding door.

No.	Name	Length (mm)	Basis
1	Cell adapter	Approx. 1780 (In accordance with the actual measured value)	Gap between PCV and BSW (44mm), BSW thickness (1676mm), base plate thickness (60mm), 44 + 1676 + 60 = 1780mm
2	Depth of the shielding door	800	Frame for the fixed rail (350mm), shielding door thickness (285mm), shielding door plate thickness (45mm, 20mm), total gap (100mm) 350 + 285 + 45 + 20 + 100 = 800mm

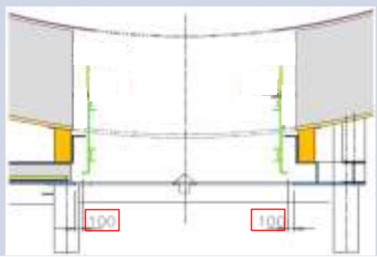
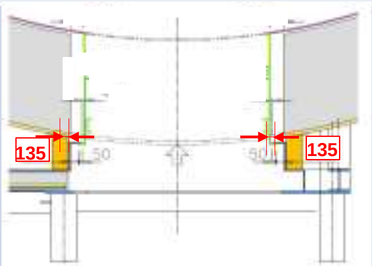
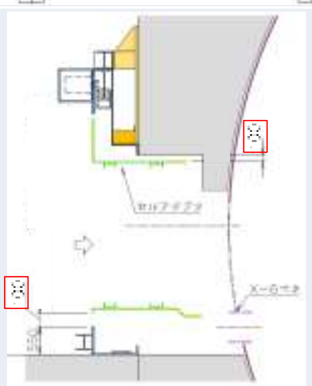
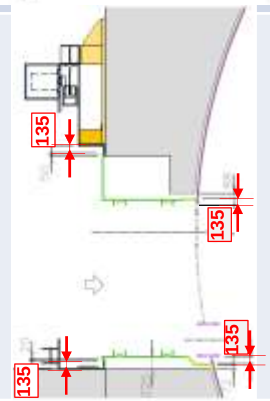
① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

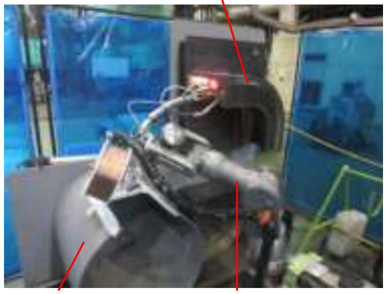
1) Connection structure of the boundary with the PCV (5/7)

Clearance with the shielding door and BSW opening while carrying-in the cell adapter ⇒ Established based on the dimensions required for the remotely operated welding robot

		Gap while installing and inserting (Step 1: Avoiding interfering objects)	When installation is complete (Step 2: Securing a clearance for welding)
Clearance	Width	200mm (100 + 100)	270mm (135 + 135)
	High	200mm (100 + 100)	270mm (135 + 135)
Flat surface			
Side			

Requirements from the remotely operated robot

Welding specimen

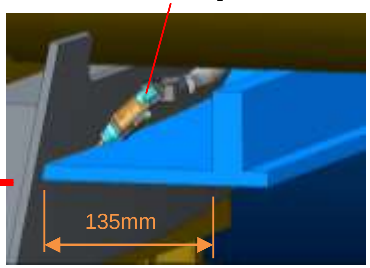


Simulated X-6 penetration

Manipulator (Property of IRID)

Illustration of welding in a confined space

Welding head



A clearance of at least **135mm** is required for the welding head to access the part to be welded.

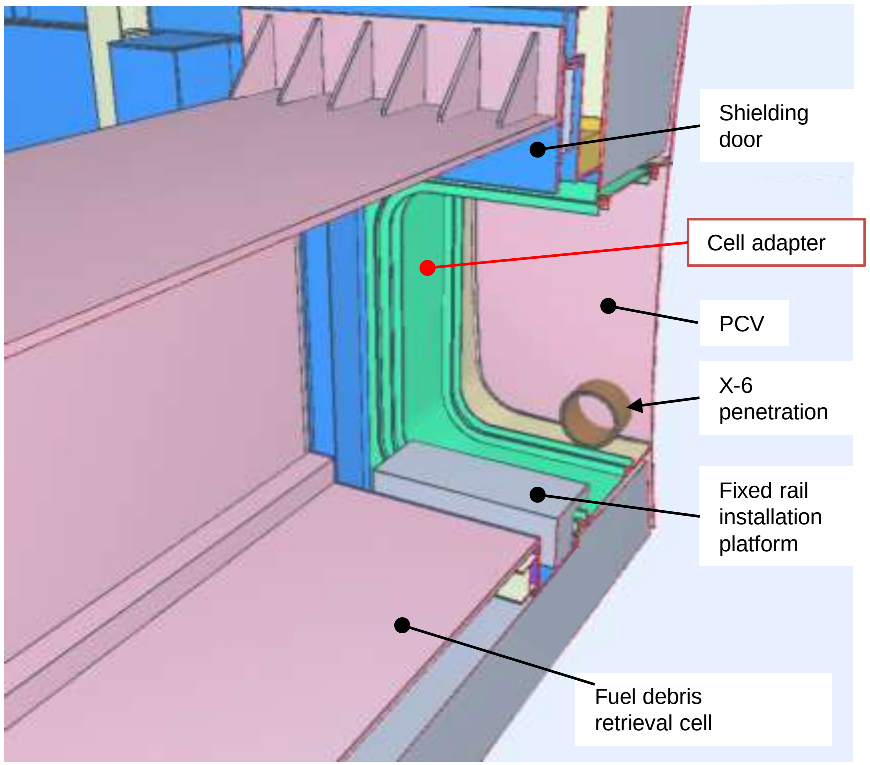
① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

1) Connection structure of the boundary with the PCV (6/7)

[3D-CAD of boundary structure]

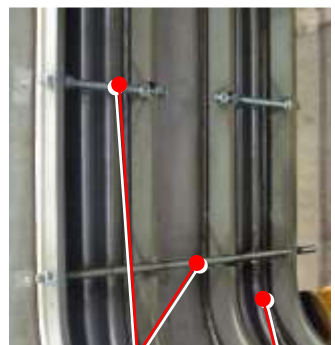


[Examples of operating performance of cell adapter (square shaped bellows) in nuclear facilities]

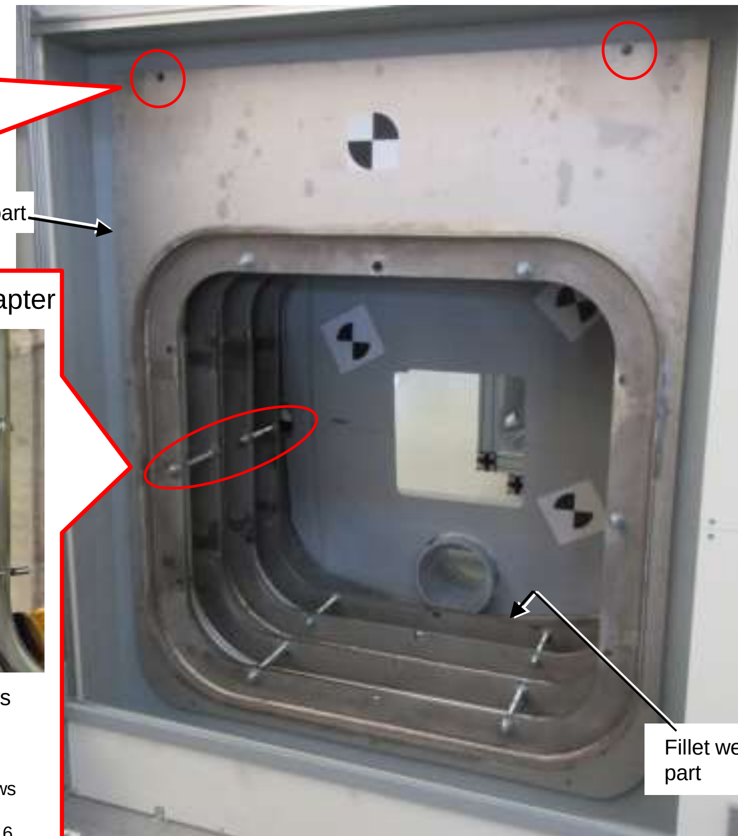
- Fast breeder experimental reactor main exhaust duct
- High-temperature incinerator exhaust gas treatment facility
- Connection between glove boxes

Position determining pin

Inner surface of cell adapter



<Sipping bolt>
・Restricts the retraction of bellows during transportation
・Size × number of bolts: M24 x 6 bolts
・Long bolts may be used as well



Cell adapter for element tests (1/2 scale)

① Installation of large heavy structures

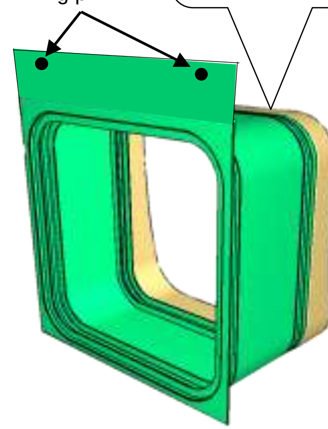
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

1) Connection structure of the boundary with the PCV (7/7)

[Design specifications of cell adapter]

№	Items	Unit	Numerical values
1	Size	mm	2800 x 2925
2	Entire length	mm	1500
3	Material	—	SUS
4	Design pressure	kPa	20.0
5	Design temperature	℃	40.0
6	Amount of displacement in the axial direction (horizontal)	mm	10.0 / -10.0
7	Amount of displacement in the direction perpendicular to the axis (vertical)	mm	5.0 / -5.0
8	Position determining pin (connecting hole)	Pins	2 pins



No. 4 Design pressure

- The design should be water pressure resistant so that even after the hole is made in the PCV steel plate it can be covered with water as required in order to ensure reversibility.
- The design pressure of the cell adapter is established based on the maximum water head pressure is applied to the cell adapter.
  Maximum water head pressure = TP10064 (Current water level) - TP8764(R/B1FL) = 1.3m (0.0127MPa(g) ≒ 0.02MPa(g))

No. 5 Design temperature

- Established based on the temperature inside PCV

No. 6, 7 Amount of displacement in the axial direction/amount of displacement in the direction perpendicular to the axis

- Established as followed based on the documents obtained from TEPCO on February 22, 2022.

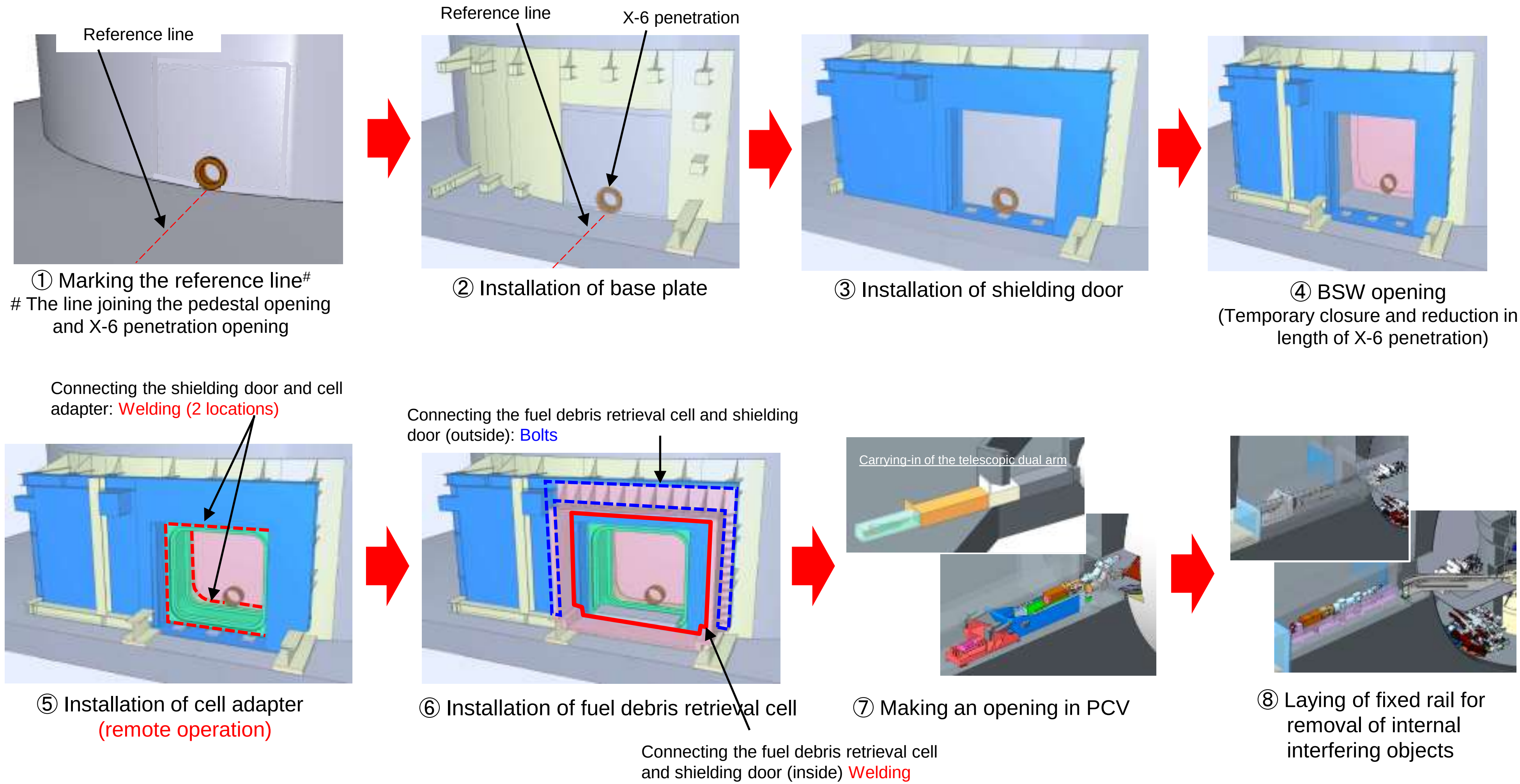
(1) Considering the case of 900gal, ±10mm while ensuring sufficient margin as against a maximum horizontal value of 1.2mm.
(2) Vertical value is half that of the horizontal value = ±5mm.

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

2) Procedures for connecting the boundary with the PCV (Proposed)



① Installation of large heavy structures

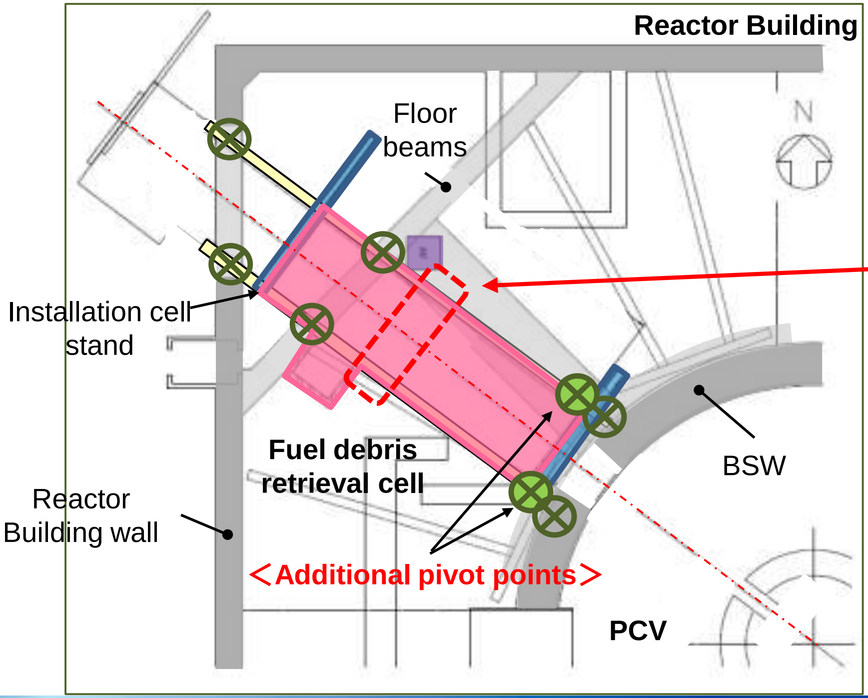
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

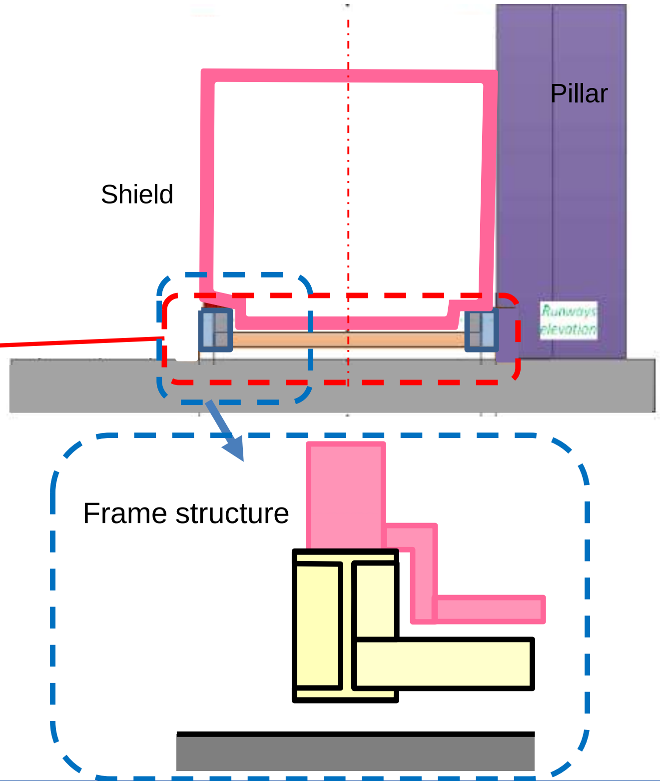
✓ **Implementation items and results**

3-1) Study of the strength of the access equipment ～ Distribution of the load on the floor because of the installation stand

- The cell weight is 270 ton after streamlining the shield as well.
- The structure is such that the weight of the cell does not get distributed directly on the R/B floor, but is supported by strength members such as the floor beams and wall of the R/B.
- Based on the site investigation results, etc., in addition to BSW since the nearby floor is expected to be used as a strength member as well, the evaluation was revised (⊗: load pivot point / ⊗ : additional pivot point).
- As a result, workability improved and the exposure of the workers reduced as well.

[Structure of the load on the R/B]





① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

3-2) Study of the strength of the access equipment ～ Evaluation of the anchor bolt for fixing the cell installation frame

Purpose: It was determined that the BSW anchor casting performance needs to be improved from the perspective of reducing worker exposure.

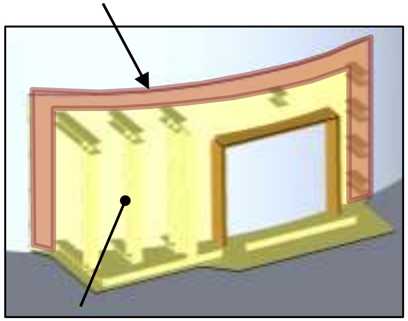
The shape of the installation stand described in the Accomplishment Report for FY2021*, which had a larger BSW anchor casting area was modified.

[Case 1: **Main Proposal**] BSW and floor support proposal

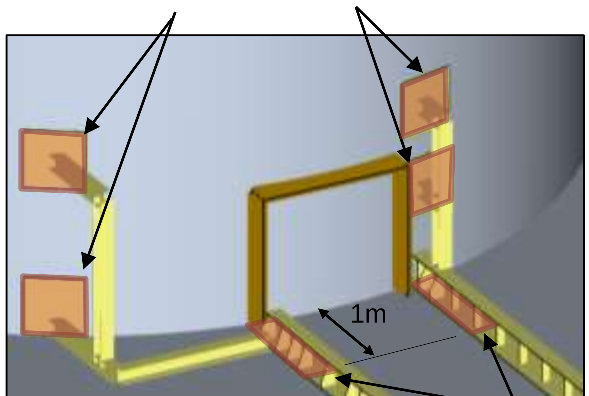
- The anchor casting area of the cell installation frame should be decentralized from only the BSW to include the BSW, the area under its floor and some of the floor beams as well.

[Case 2: Additional study] Proposal to support the entire floor surface

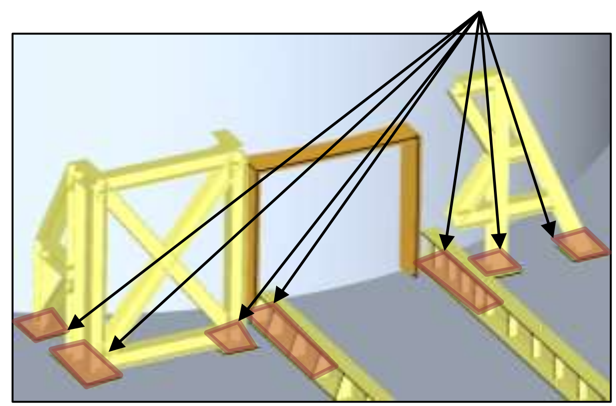
- The extreme case wherein the BSW anchor casting in Case 1 is eliminated should be studied for further reducing exposure.
- The anchor casting area of the cell installation frame should be decentralized from only the BSW to include the BSW, the area under its floor and some of the floor beams as well, and the stand should be reinforced.



Accomplishment Report for FY2021 (*)
Fuel debris retrieval cell structure



Case 1: Main Proposal



[Case 2: Additional study]

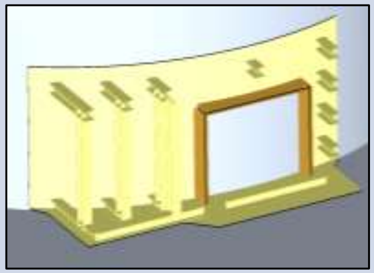
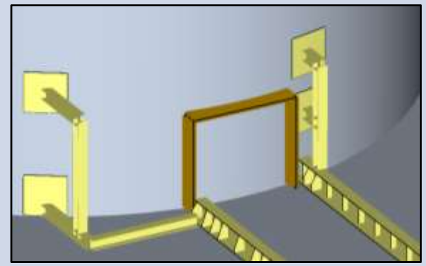
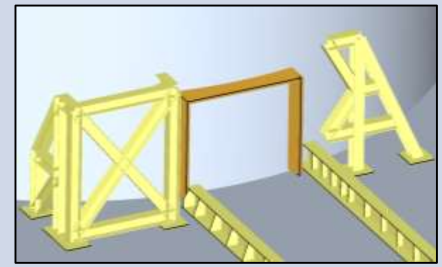
(*) https://irid.or.jp/wp-content/uploads/2022/08/2022007_deburitoridashi.pdf

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

3-2) Study of the strength of the access equipment ～ Evaluation of the anchor bolt for fixing the cell installation frame

Items		Previously reported	Case 1: Main Proposal	[Case 2: Additional study]
BSW wall surface structure				
Number of bolts	BSW wall surface	130 bolts	32 bolts	0 bolts
	Area under BSW floor	0 bolts	48 bolts	46 bolts
	Cell installation frame part	277 bolts	148 bolts	62 bolts
	Total	407 bolts	228 bolts	108 bolts
Merits		• Simple structure which does not have diagonal bracing for supporting the BSW wall surface and the building wall surface	• Reduced number of BSW wall surface anchor casting bolts • Reduced number of overall anchor casting bolts	• Reduced number of BSW wall surface anchor casting bolts • Reduced number of overall anchor casting bolts
Demerits		• Comparatively larger number of BSW wall surface anchor casting bolts • Comparatively larger number of overall anchor casting bolts	• Diagonal bracing is required to support the cell for seismic resistance or the rigidity of the cell needs to be enhanced.	• A frame is required to support the shielding door. • Diagonal bracing is required to support the cell for seismic resistance or the rigidity of the cell needs to be enhanced.

① Installation of large heavy structures

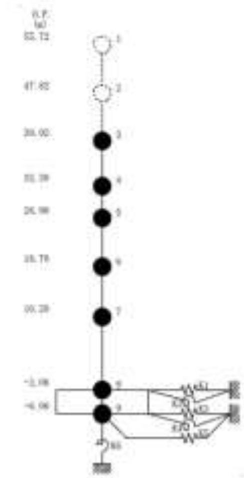
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

3-3) Study of the strength of the access equipment ～ Evaluation of the strength of the Reactor Building

(Brief strength evaluation by modeling the BSW and Reactor Building wall surface openings)

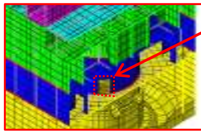
- Analysis model: A multi-mass model in which the BSW and Reactor Building wall surface openings required for installing the access equipment are made in a model of the current Unit 3 Reactor Building and which is provided with heavy load conditions considering side access retrieval method (Building-ground interaction system model).
- Seismic ground motion: Seismic response analysis is conducted with respect to a seismic ground motion of Ss 900 that is used for the study as a severe value on the safer side.
- Seismic response analysis result: It was verified that there is sufficient margin between the shear strain on the seismic wall (0.19×10^{-3}) and the evaluation criteria （4.0×10^{-3}）.



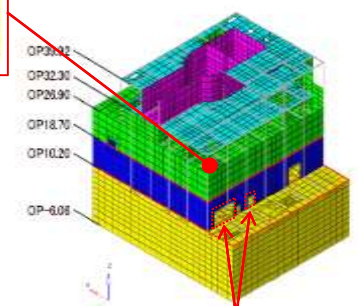
Seismic response analysis model

(Detailed strength evaluation by modeling the openings)

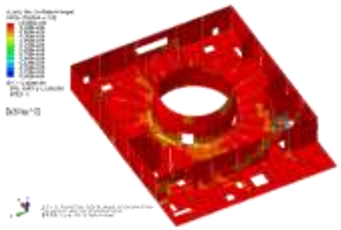
- Studies were conducted on functional maintenance of the seismic wall of the Reactor Building with respect to long-term vertical load (self weight) and seismic load using a three dimensional elasto-plasticity FEM analysis model.
- As a result of the evaluation, it was verified that the compressive strain (957μ) of concrete and the tensile strain (673μ) of the rebars is below the evaluation criteria (compressive strain: 3000μ, tensile strain: 5000μ).

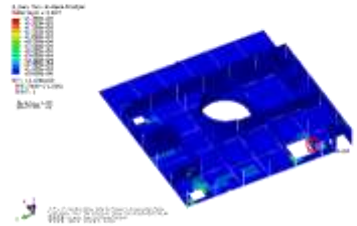


Cross section of the analysis model



Three dimensional elasto-plasticity FEM analysis model





① Installation of large heavy structures

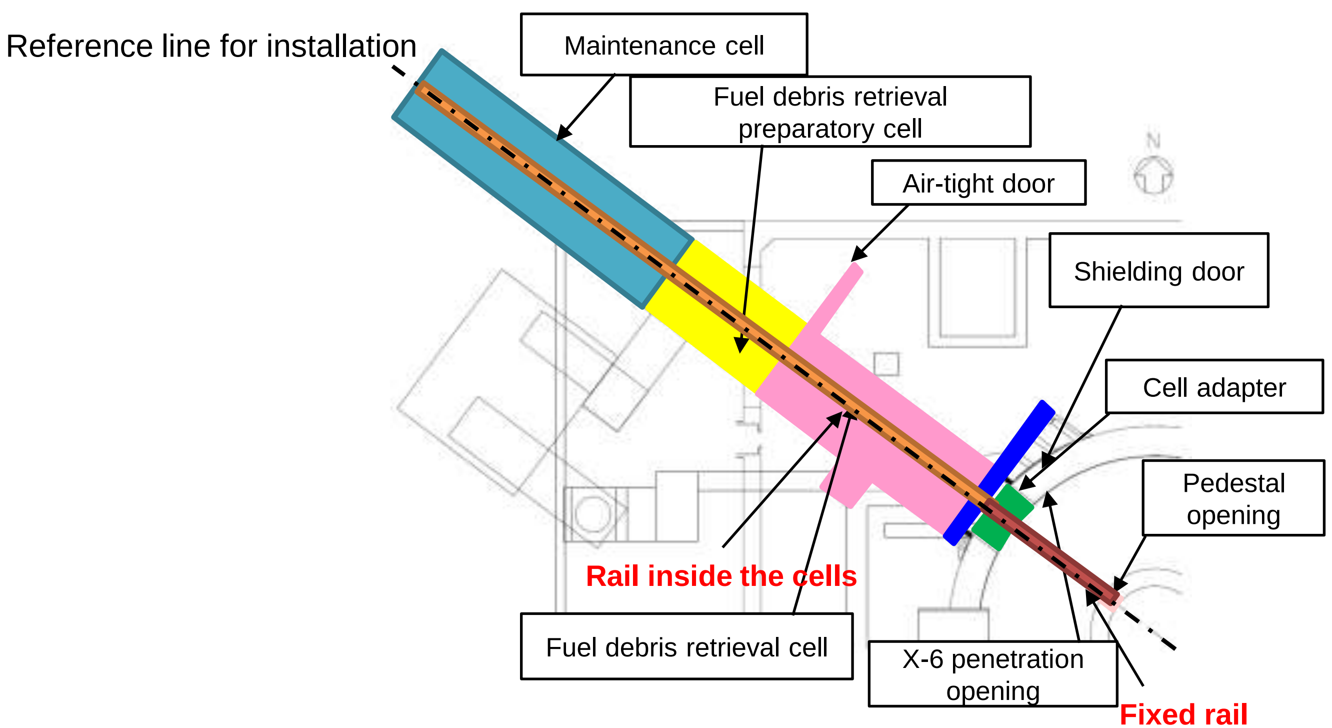
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (1/7)

a) Requirements at the time of installation

- A route that would enable the robot arm to access the pedestal opening from the X-6 penetration opening in a straight line needs to be established.
- In other words, the fixed rail and the rail inside the cells need to be installed along the straight axis joining the pedestal opening and the X-6 penetration opening.



① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ Implementation items and results

4) Study on required installation accuracy for the access equipment (2/7)

b) Deviation occurred during installation

[2] Rotational direction
(Direction of angular deviation from a certain line heading towards a center) (Angle of deviation from the reference line)

The greater the distance from the center, larger is the angle of deviation.

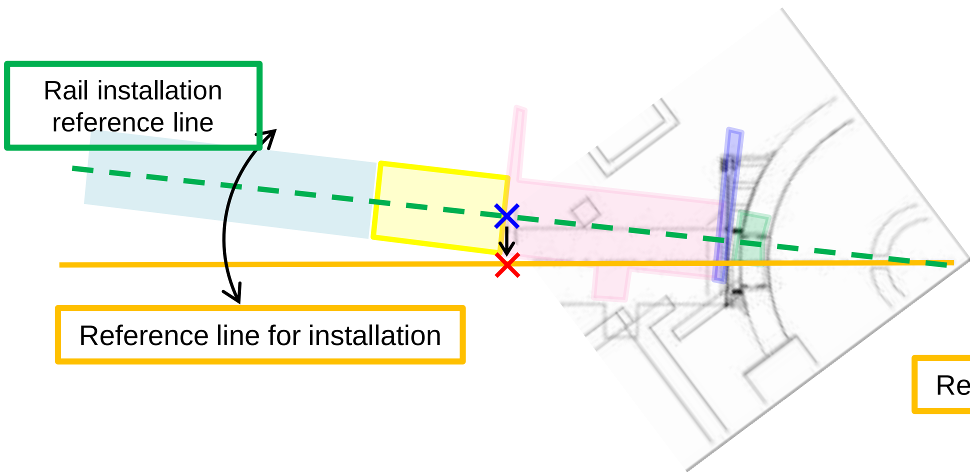
→ The extent of deviation can be controlled by positioning the installation reference line and the rail installation position reference line at a location that is as distant as possible from the center.

[2] Horizontal direction

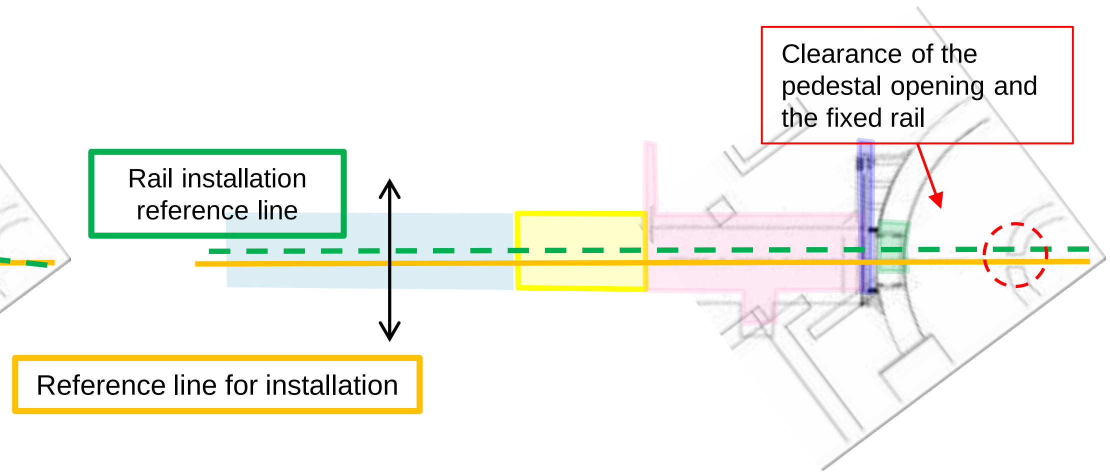
The extent of deviation during installation can be controlled within the clearance of the pedestal opening and fixed rail.

→ At other sites, for example in the case of the clearance of BSW and cell adapter, there is sufficient margin for deviation and it can thus be dealt with.

Further, deviation in the vertical (height) direction can be adjusted when installing the fixed rail.



[1] Rotational direction



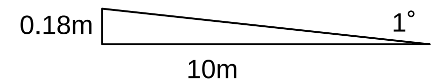
[2] Horizontal direction

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (3/7)



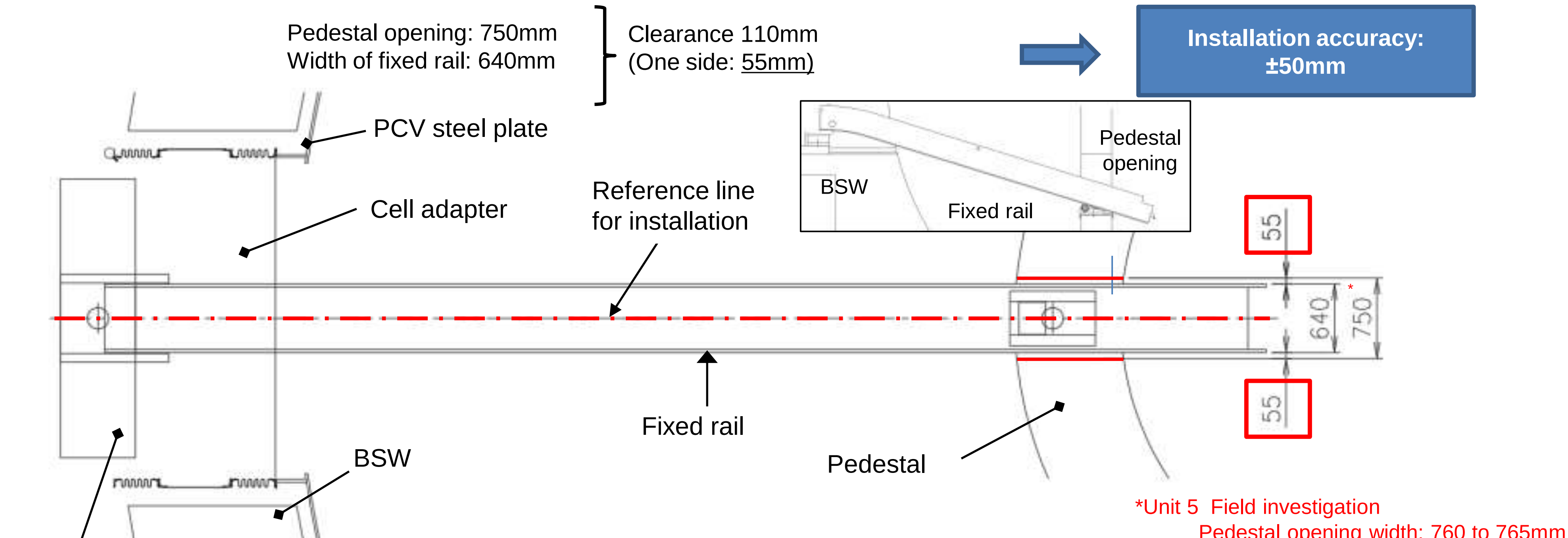
c) Setting the installation accuracy for the rotational direction

➢ Set to less than 1° . (Tentatively: apportioned to the horizontal accuracy mentioned below.)

d) Setting the installation accuracy for the horizontal direction

➢ Needs to be installed within the clearance of the pedestal opening and the fixed rail.

➢ Installation accuracy is set as given below.



Clearance of the pedestal opening and the fixed rail

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (4/7)

e) Other: Installation accuracy of cell adapter

If the central axis deviates horizontally or vertically during the installation of the cell adapter, its impact on the groove gap is evaluated.

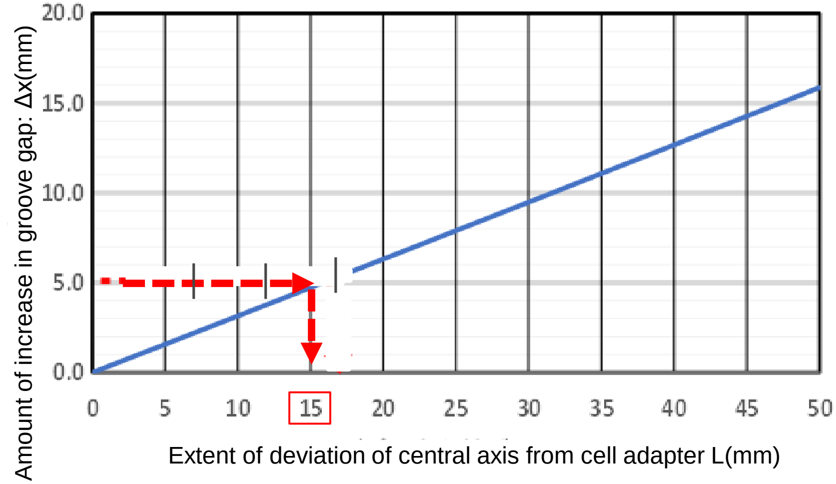
【 Evaluation conditions】

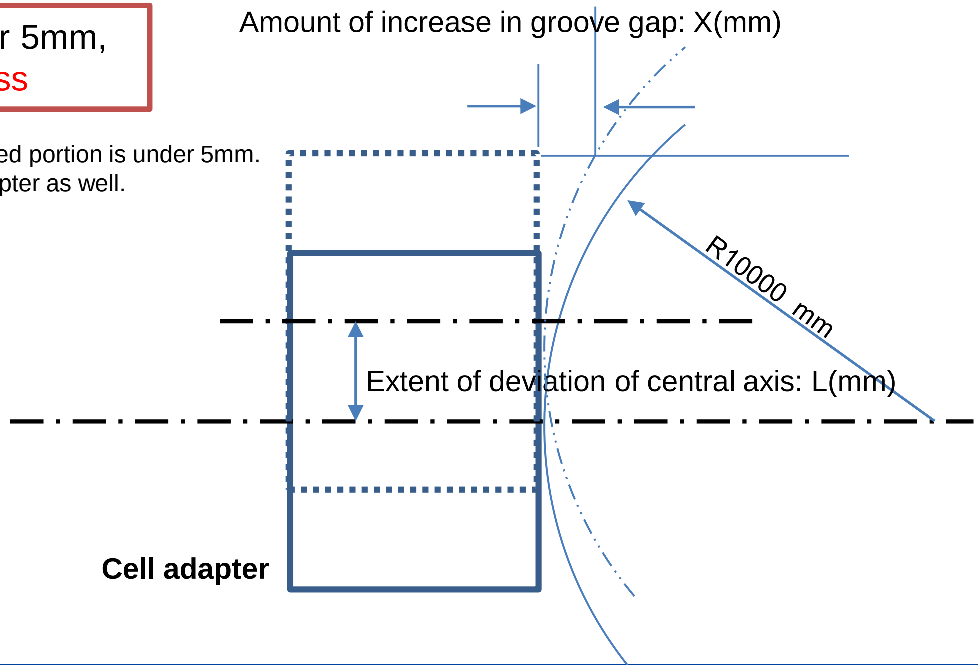
PCV outer diameter = 20,000mm

Cell adapter dimensions = 3,000mm

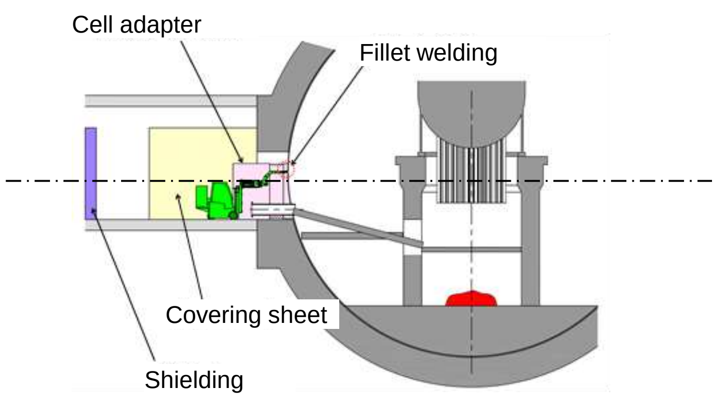
The center of the cell adapter is assumed to be the center of the PCV spherical shell.

As the gap with the welding portion needs to be under 5mm,
Installation accuracy of cell adapter: 15mm or less





The installation position of the cell adapter is adjusted so that the gap with the welded portion is under 5mm. Further, it may be possible to eliminate the gap as required by pressing the cell adapter as well.

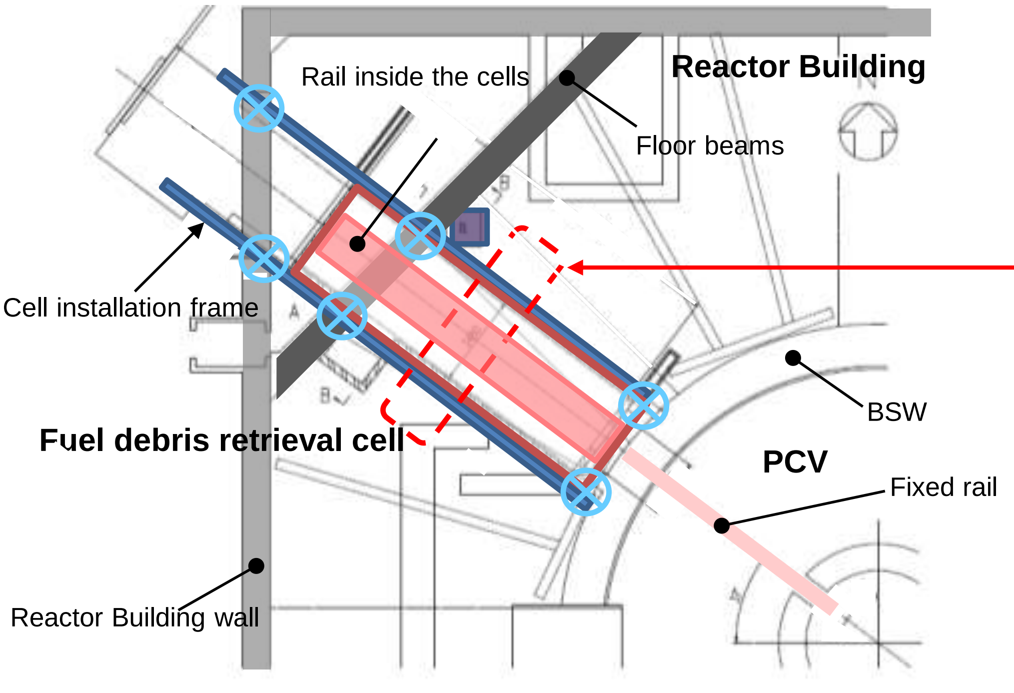


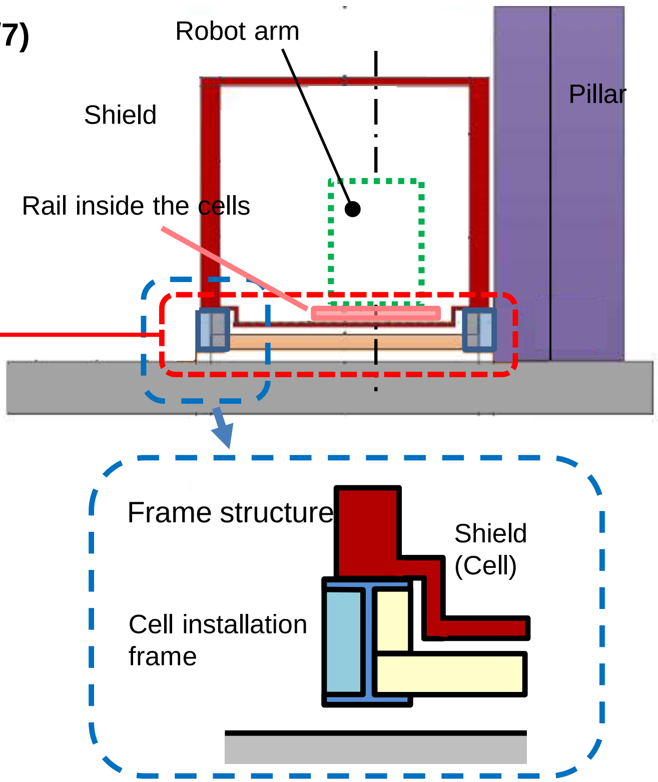
① Installation of large heavy structures

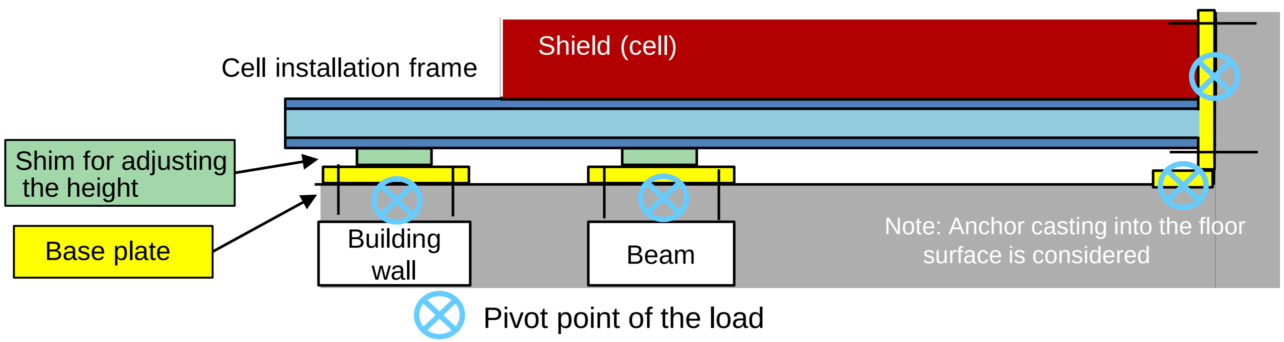
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (5/7)







- The structure is such that the weight of the cell does not get distributed directly on the R/B floor, but is supported by strength members such as the floor beams and wall of the R/B.
- Method of fixing the cell installation frame on to the Reactor Building floor surface.

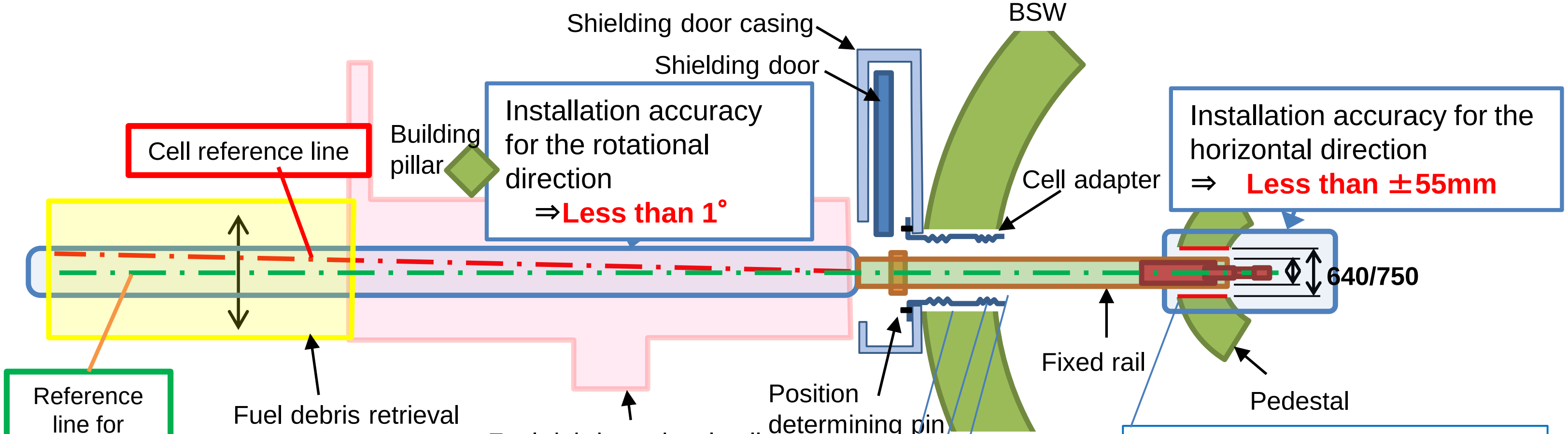
- The base plate is installed on the Reactor Building floor surface
- The cell installation frame is welded and fixed on to the base plate (The height is adjusted with the shim plate)

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (5/7) - Installation method

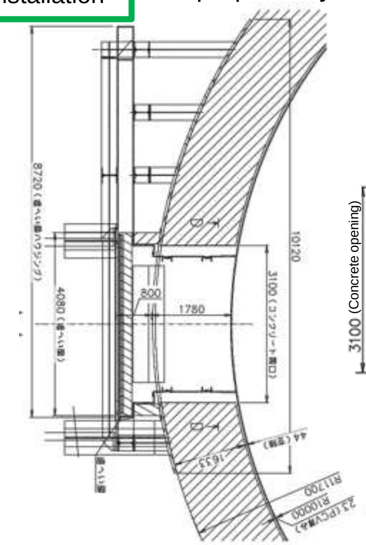


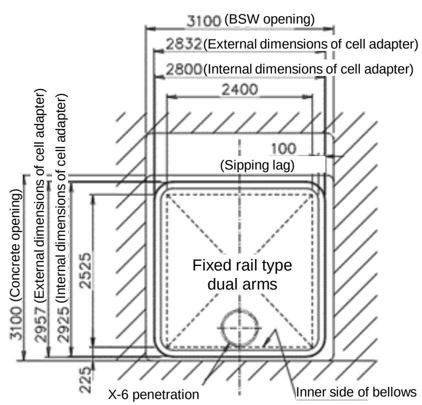
① The central axis is established by leaving a gap of 55mm on the left and right sides to make room for the large hydraulic arm* to pass.

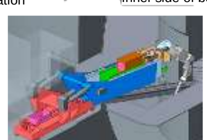
② The “required opening size” is established by leaving a margin of 100mm on the left and right sides in accordance with the telescopic type guiding equipment* or the fixed rail that passes through, whichever is wider.

③ The outer diameter of the cell adapter is established considering the unevenness* of the bellows in addition to the “required opening size”.

④ The “BSW opening width” is established by considering the unevenness* of the core in addition to the outer diameter of the cell adapter.







(Telescopic type guiding equipment)

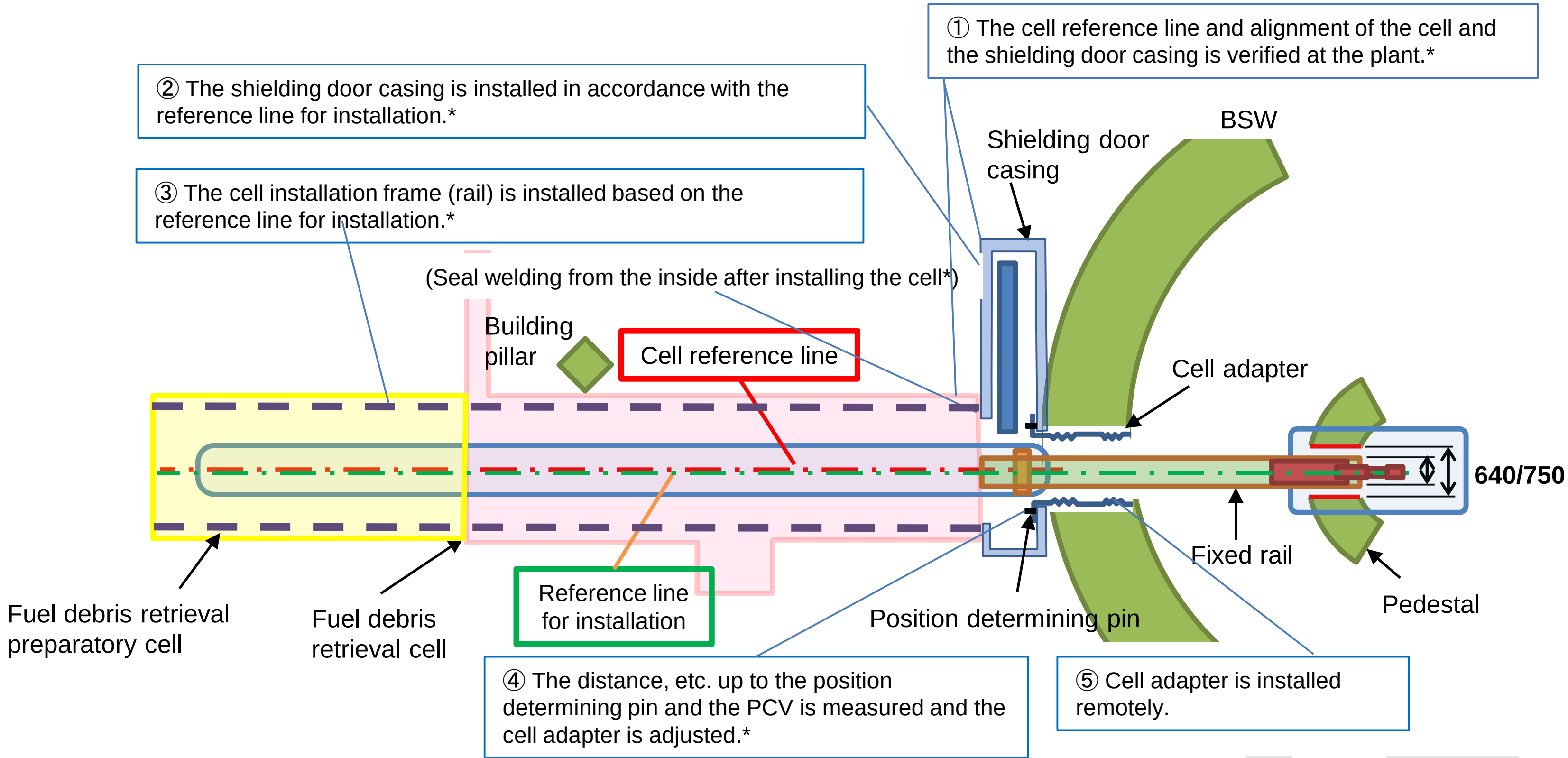
[There is room for modifying the size of the BSW opening part.
Also, changes can be made by modifying the dimensions of “*”.]

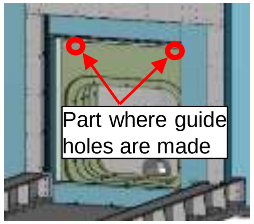
① Installation of large heavy structures

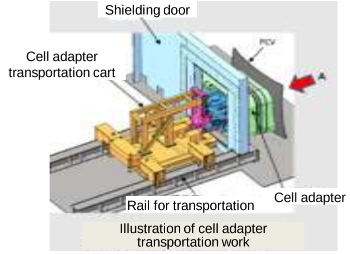
(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (5/7) - Installation method







[*: Can be implemented manually using the shielding door, etc.]

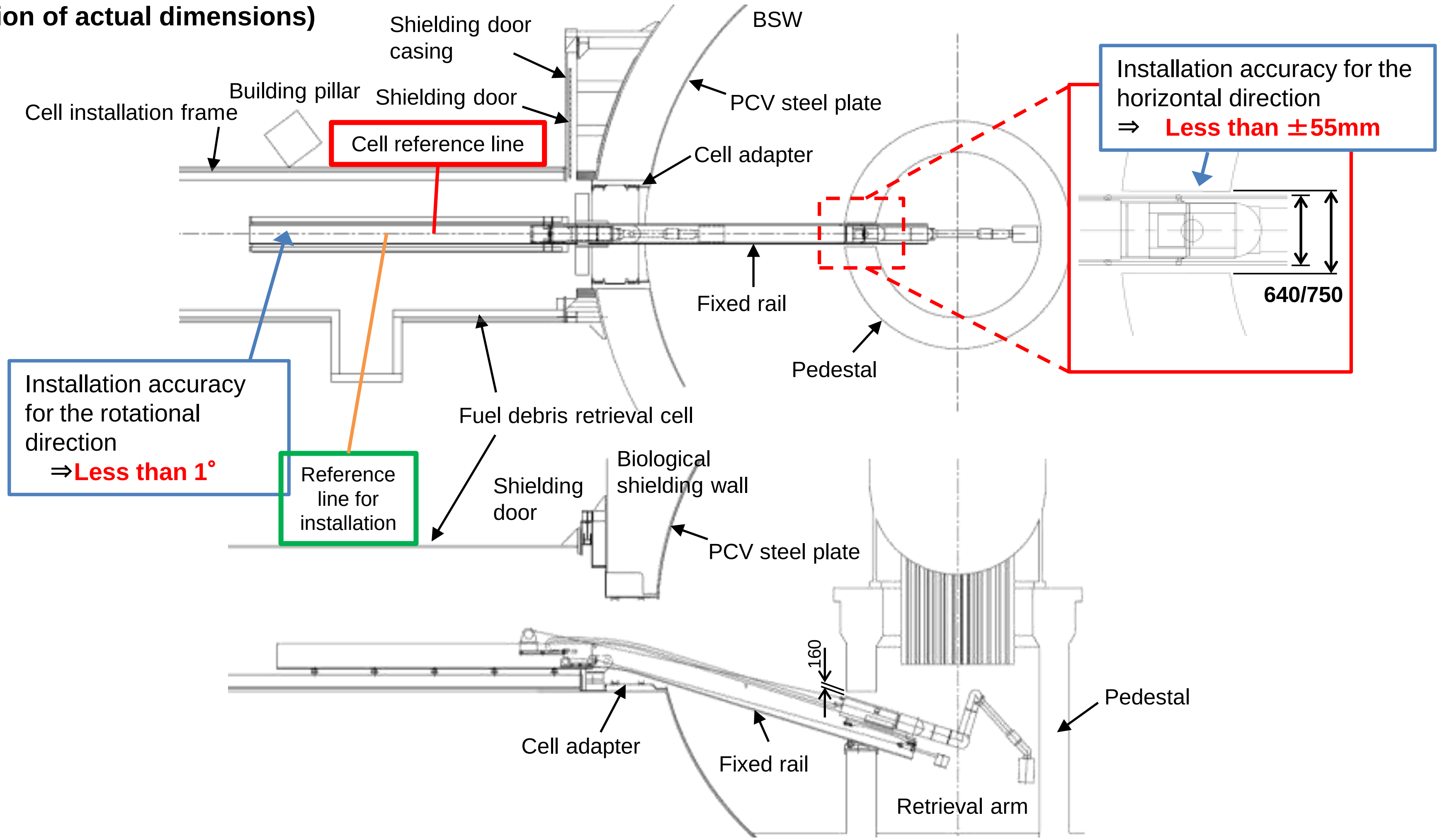
① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (5/7) - Installation method

(Illustration of actual dimensions)



① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (6/7)

f) Other: Actions to be taken in the event of an earthquake during installation

Even through the duration of installation is about 1 year, which is short, earthquakes are likely to occur during work. Actions to be taken in the worst case that an earthquake should occur, are listed here.

[1] Maintenance of confinement function

- The work of making an opening in the PCV wall surface is carried out by means of a robot arm, while maintaining negative pressure inside, after conducting the pressure resistance test once the installation of access equipment (cells) is completed.
  Hence, even if an earthquake occurs during the work of making an opening, a boundary is secured by means of PCV - cell adapter - shielding door - cell.

- During the work of making an opening in the BSW or the outer wall of the Reactor Building, G/H is installed as a measure to prevent dispersion of dust produced during the work into the surroundings.

[2] Actions to be taken in response to deviation in the installation position caused by the earthquake

- In the event of a major earthquake, it is confirmed if there is any deviation from the coordinates that are set for marking the installation reference line and the reference points* that are marked on the R/B and PCV.
  *: If X-6 penetration is present, X-6 is the reference point.
  When the X-6 penetration is removed, new reference points are marked on the R/B and PCV.

- If there are any deviations, the installation reference line is set again and the installation position is adjusted accordingly.

① Installation of large heavy structures

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (7/7)

g) Summary (1/2)

1 Required installation accuracy

1) Cell installation accuracy

① Within 1° in the rotational direction, within ±50mm in the horizontal direction with respect to the reference line

2) Cell adapter

① Within ±15mm from the installation reference line

3) Actions to be taken in the event of an earthquake during installation

① Confirming for deviation from the installation reference line and the reference points marked on the R/B and PCV

2 Structure formation

1) Establishment of the boundary from PCV - cell adapter - shielding door casing - cells

① Verification of viability including that of installing the casing, work in confined spaces, and welding work

② Indication of specifications for the equipment for remote operation (Mentioned in No. 116)

① **Installation of large heavy structures**

(6) Implementation items (6)-1: a. Detailed study of the structure of the access equipment

✓ **Implementation items and results**

4) Study on required installation accuracy for the access equipment (7/7)

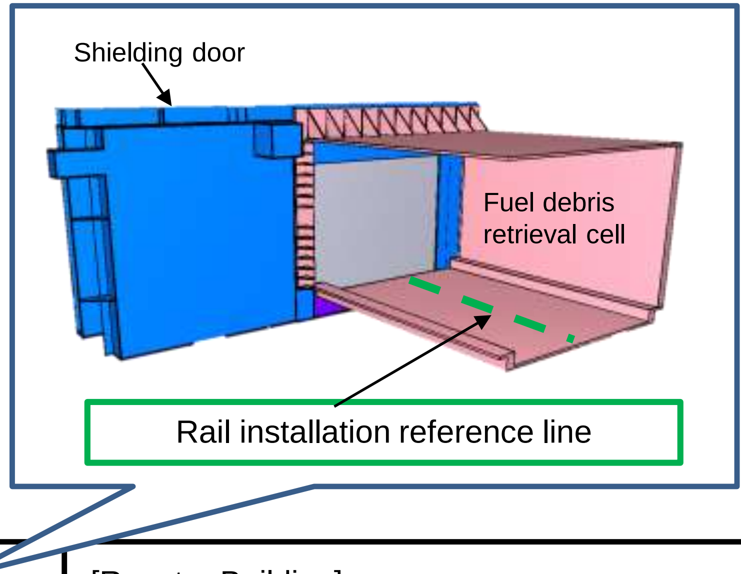
g) Summary (2/2)

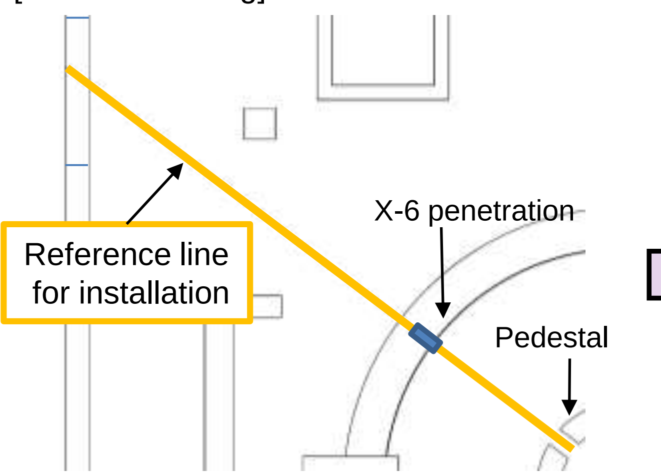
3 Plan pertaining to the installation method

[1] The reference line for installation joining the pedestal opening and the X-6 penetration opening will be established .

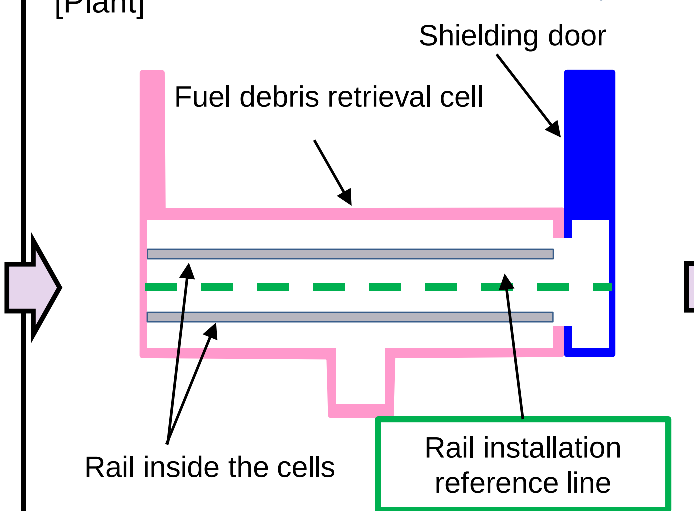
[2] The rail installation position reference line will be established on the cell (including the shielding door, etc.) after the cell is built at the plant.

[3] The cell will be installed where the rail installation position reference line coincides with the reference line for installation.

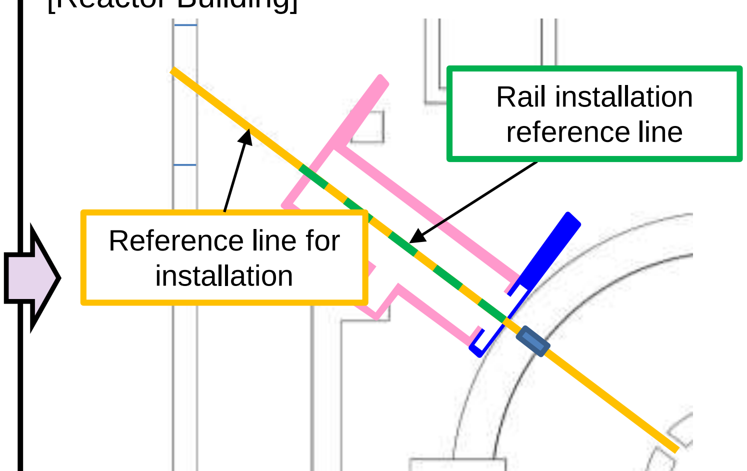




[1] Establishing the reference line for installation



[2] Establishing the rail installation reference line



[3] The cell will be installed where the rail installation position reference line coincides with the reference line for installation.

① Installation of large heavy structures

(6) Implementation items

(6)-1: a. Detailed study of the structure of the access equipment

✓ **Contribution of the results towards the reflection destination**

- Specific access equipment for establishing the access route for retrieving fuel debris present inside the pedestal opening can be provided for fuel debris retrieval equipment used in the side access method.
- The access equipment can be equipped with a confinement function and the function of absorbing displacements in the event of an earthquake.
- The method of installing the cell adapter by remote operation can be established in order to reduce the exposure of workers during installation.

✓ **Analysis from the viewpoint of on-site applicability**

- As the cell adapter has to be installed under high radiation environment from the PCV after the opening in the BSW is made, installation (dimensions, required accuracy) by means of equipment for remote operation is considered. (Reference: No. 35 to 40, 42)
- A structure that requires minimal on-site welding work is used. (Reference: No. 35 to 42)
- Closing the shielding door in accordance with the work procedures, etc. after the opening in the BSW is made, is considered for reducing worker exposure. Further, considering the rare possibility that this gets reversed, a structure that enables complete sealing by installing a closing plate on the shielding door is used. (Reference: No. 35, 36)

✓ **Issues**

- For the shielding door or the cells, the base plate is planned to be installed on the BSW using post installed anchors. The structure of the fixed part of the base plate needs to be studied and determined upon conducting site investigation, confirming the status of the arrangement of reinforcement bars, and considering their placement.

① Installation of large heavy structures

(6) Implementation items
(6)-1: a. Detailed study of the structure of the access equipment

✓ **Level of achievement compared to the goals**

- The specifications and structure of the access equipment with confinement function and displacement absorption function for dealing with an earthquake, were substantiated. (Reference: No. 35 to 40, 42)
- As part of the substantiation mentioned above, the installation accuracy and adjustment method during installation were studied and the results were reflected in the structure.

✓ **Future plans**

- In order to make it more feasible, results of verification by element tests will be provided as feedback and the specifications and structure of the access equipment will be revised accordingly.
- The impact of dust dispersion when the opening in the BSW is made will be studied.

① Installation of large heavy structures

(6) Implementation items

(6)-2: b. Study on detailing of procedures for installing the access equipment

[Purpose]: Verification of feasibility of the side access method for large scale fuel debris retrieval based on on-site application.

[Objective]: Detailing of procedures for installing the access equipment related to fuel debris retrieval
Study of the method of identification and resolution of issues in implementing the procedures

✓ **Comparison with existing technologies**

- The “existing technologies” are used or combined for the installation method.
Along with using general technologies and results of past research, practical studies are conducted while comparing with the environment (reduction in personnel exposure, prevention of spread of contamination, dust reduction, etc.) specific to the stabilization of Fukushima.

✓ **Implementation items and results**

- Studies on the method and detailing of procedures concerning installation of access equipment (shielding door, cell adapter, large cells) installed inside the R/B.

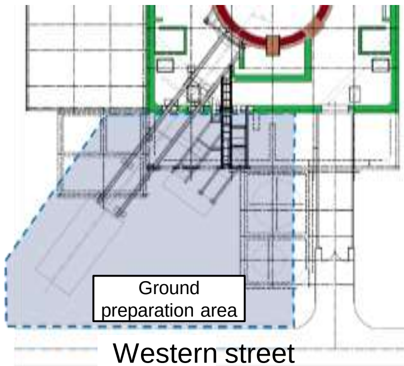
[Results]: ① Detailing of the overall procedures concerning the access equipment (installation steps)
② Detailing of installation procedures of the cell adapter, which are believed to be technically highly difficult (installation steps)

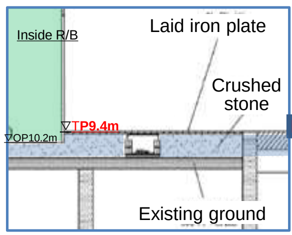
③ Clear specification of the method of identification and resolution of issues in the installation procedures

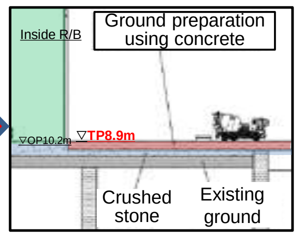
① Installation of large heavy structures

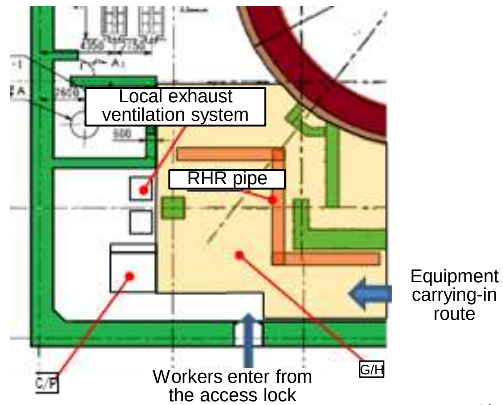
(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

[Result]: Overall step diagram

<table>
<tr><td></td><td>1. Work of ground preparation outside the R/B</td><td>2. Removal of RHR pipes inside the R/B</td><td>3. Removal of BSW in front of air lock and around X-6 penetration</td></tr>
<tr><td>Conceptual drawing</td>
<td>



Current state of the outdoor area


After ground preparation work</td>
<td>

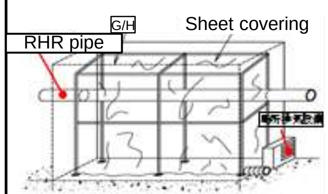


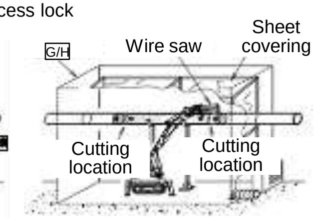
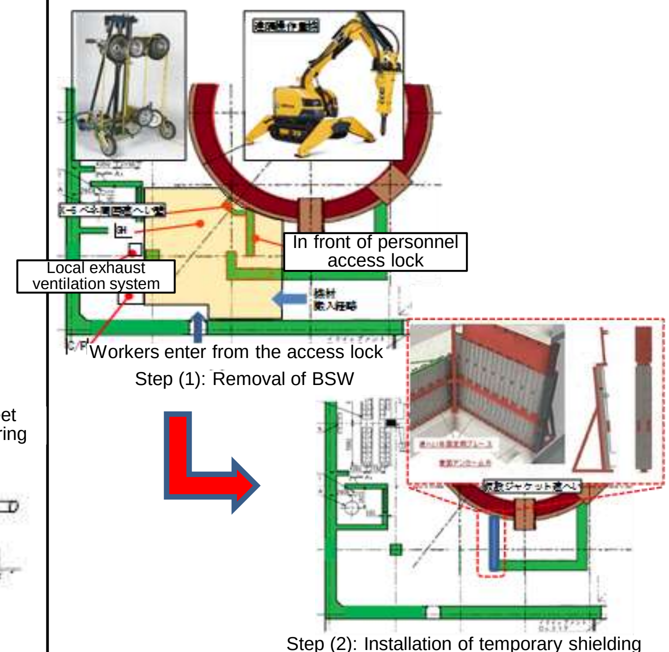
Illustration of isolation room


Illustration of cutting the RHR pipes</td>
<td>
</td></tr>
<tr><td>Procedure</td>
<td>The embankment in the area on the west side outside the R/B is flattened so that its floor level is the same as the floor of the R/B.
・ Inside R/B： TP.8.9m
・ Outside R/B： TP.9.4m ⇒ TP.8.9m</td>
<td>After the dose around the RHR pipes and the residual material inside the pipes is verified, the shielding material and support are removed.
G/H is installed for cutting the pipes, a pipe balloon plug is installed on both sides of the section of the pipes to be removed, and after a blowing agent is filled, the pipes are cut and the opening is closed.</td>
<td>The shield wall around the X-6 penetration and the BSW in front of the personnel access lock and on the western passageway are removed using an electric crane, and a temporary shield is installed in front of the personnel access lock. Thereafter, 3D measurement of the form of the surface of the BSW is performed.</td></tr>
<tr><td>Issues</td>
<td>If there are any objects to be buried, burying those objects, etc.</td>
<td>Dust control measures during work
Method of filling the blowing agent while cutting the RHR pipes, etc.</td>
<td>Method of removing the BSW in front of the personal access lock (remotely operated heavy machinery)
Substantiation of additional temporary shielding</td></tr>
</table>

① Installation of large heavy structures

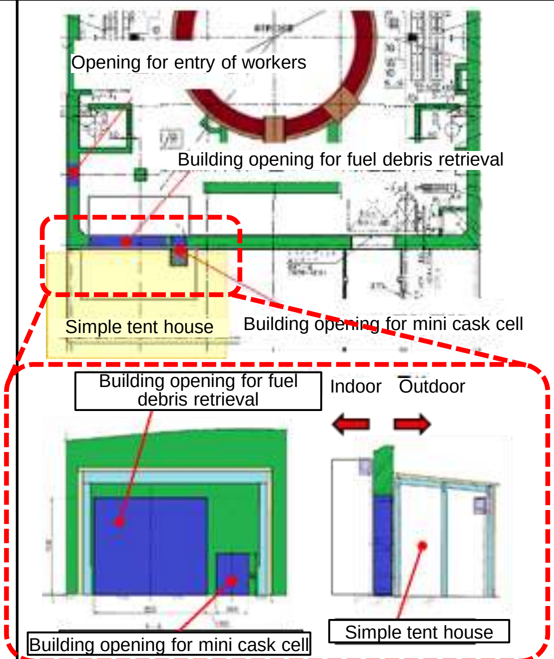
(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

[Result]: Overall step diagram

(Red box / Blue box): Target to be studied this time

4. Making an opening in the R/B wall

Conceptual drawing



Procedure: Indoor G/H, vinyl covering, simple outdoor tent house are installed as dispersion prevention measures, measures to prevent exposure (temporary shielding installation) are taken and then openings are made in the building wall at 3 locations using a wire saw.

Issues:
- Structure of the greenhouse
- Dispersion prevention measures while making openings

Issue: Layout marking accuracy

5. Centering (reference line for installation) and layout marking inside and outside the building

Conceptual drawing

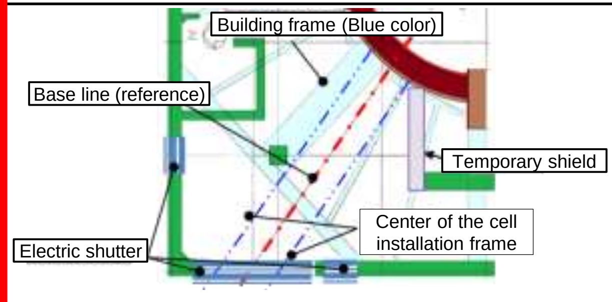


Illustration of layout marking inside R/B

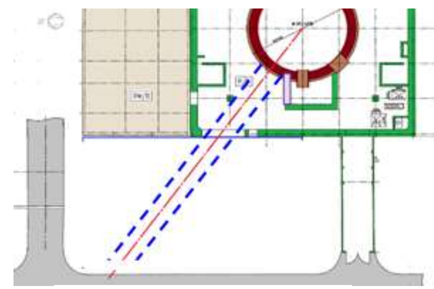


Illustration of the layout marking outside the R/B

Procedure: After marking the locations on the BSW (opening) inside the R/B, the installation location of shielding door base plate, and the location for laying the cell installation frame, etc., the markings are extended on the floor of the outdoor yard.

Issues:
- Method of ascertaining the reference location for installation
- Floor surface level adjustment method (required accuracy)

Issue: Substantiation of the structure

6. Installation of shielding door base plate

Conceptual drawing

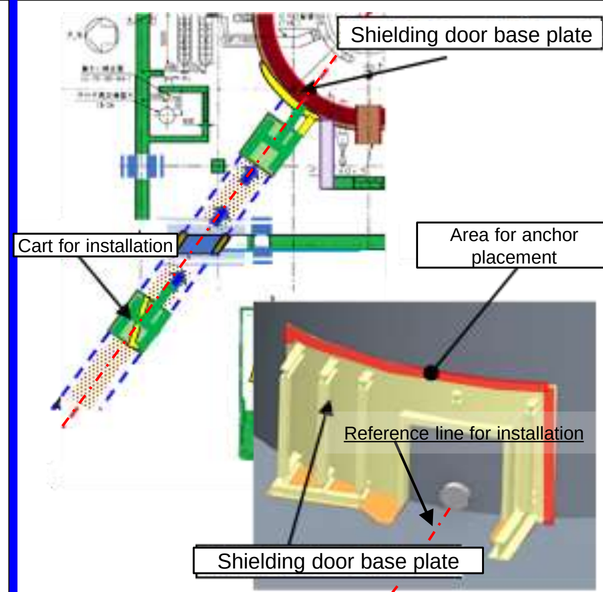


Illustration of the shielding door base installation

Procedure: After searching for the rebars, the shielding door base plate is fixed by placing anchors.

Issues:
- Handling of objects to be burried (rebars, etc.)
- Study of transportation and installation methods

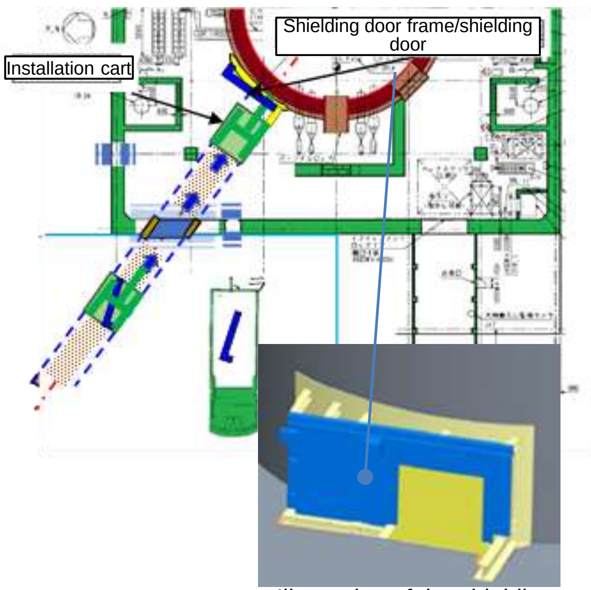
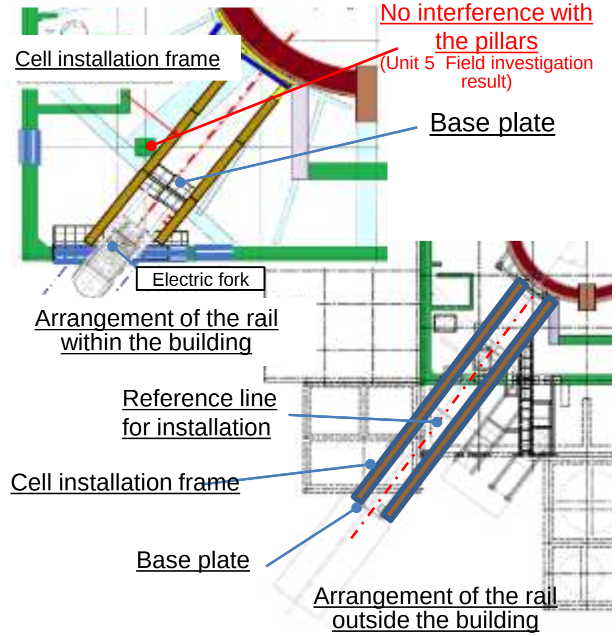
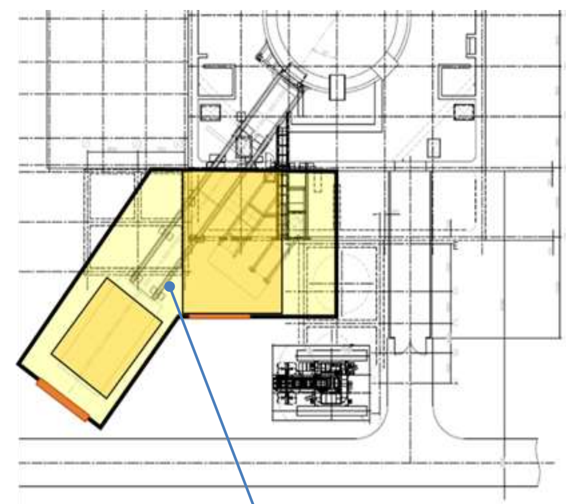
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

① Installation of large heavy structures

(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

[Result]: Overall step diagram

(red box) (blue box) : Target to be studied this time

	issue: Study of installation methods	Issue: Layout marking accuracy	
	7. Shielding door installation	8. Laying of the cell installation frame	9. Installation of outdoor tent house
Conceptual drawing	 Illustration of the shielding door installation		
Procedure	The shielding door frame / shielding door is carried in by means of the installation cart and bolted.	The cell installation frame is installed inside the R/B and the base plate and the cell installation frame is installed outside the R/B by means of a crane, etc.After laying the cell installation frame, the work of centering and leveling the rail is carried out inside and outside the building.	Tent house is installed at the ground preparation location outside the R/B. The ancillary facilities and utilities are set up.
Issues	・ Substantiation of the transportation, alignment and installation method	・ Method of ascertaining the reference location for installation ・ Cell installation frame connection method ・ Method of fixing the cell installation frame outside the R/B	・ Dimensions of the outdoor tent house (required size)

① Installation of large heavy structures

(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

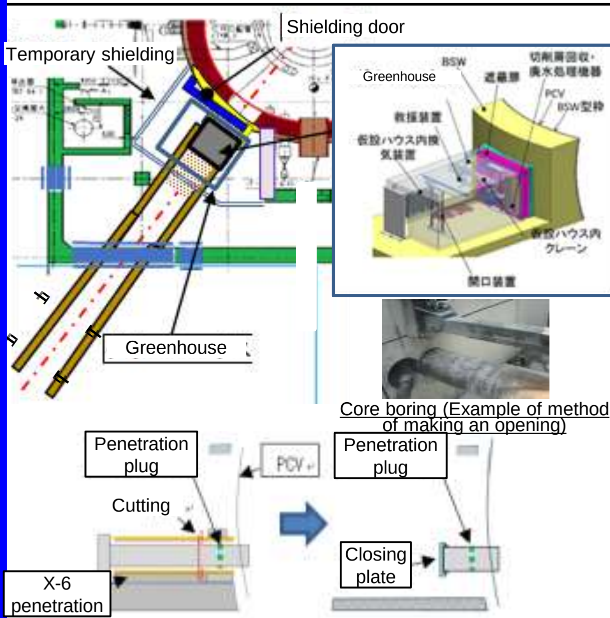
[Result]: Overall step diagram

(Red box / blue box): Target to be studied this time

Issue: Dust control

10. Making a hole in the BSW and cutting the X-6 penetration

Conceptual drawing:



(It is assumed that the penetration plug (seal) is installed after the internal investigation or after internal 3D measurement.)

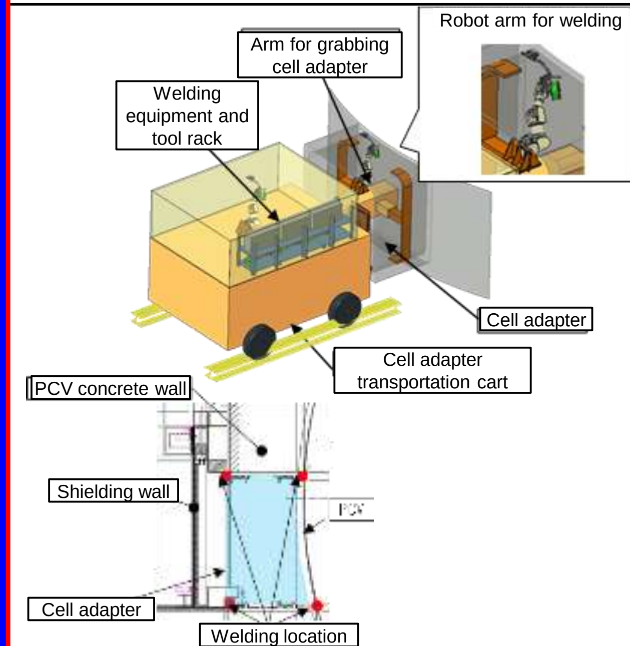
Procedure: The cell for making the hole is installed, and an opening is made in the BSW.
Also, the length of the X-6 penetration is reduced and a closing plate is installed.

Issues:
- Tentative cell specifications for the work of making the opening
- ~~Removal of X-6 penetration and contamination control~~ Note)
- Measures against outflow of dust into the gap between the BSW and the PCV

Issue: Processes concerning establishment of the boundary

11. Carrying-in and installation of cell adapter

Conceptual drawing:

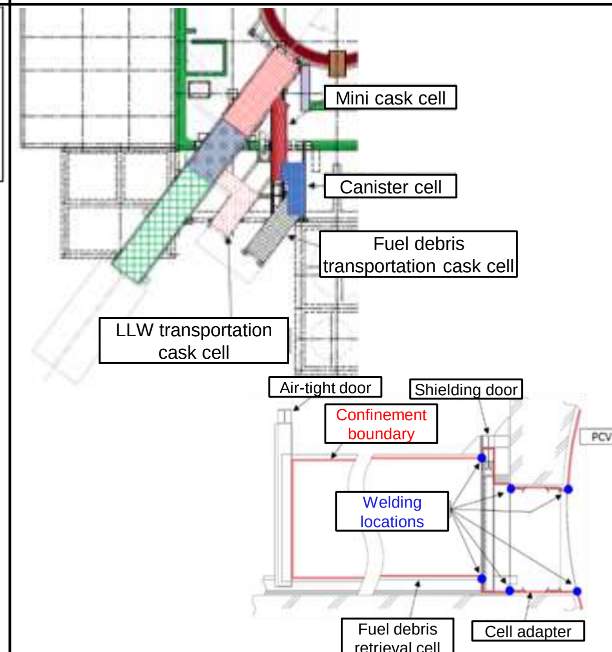


Procedure: After carrying out the work of cleaning the PCV wall surface, conducting 3D measurement and making the cell adapter groove, the cell adapter is carried in by means of the cell adapter transportation cart and installed. PCV steel plate and the shielding door are welded on to the cell adapter.

Issues:
- Reflection of the PCV surface finishing and measurement into manufacturing
- Installation of cell adapter by carrying it in remotely (Position determination and detailing of installation method)
- Study of the required equipment specifications in association with use of equipment for remote operation

12. Installation of the device/equipment transfer system cell

Conceptual drawing:



Procedure: After closing the shielding door, the cell is temporarily placed on the cell installation frame with a crawler crane, and then is carried in and joined (welded).
After the cell is joined, a pressure resistance test of the inside of the cell is conducted.
Similarly all cells are carried in and installed.

Issues:
- Cell fixing method

Note: Deliberately crossed out as this is outside the cope of studies conducted in the PJ.

① Installation of large heavy structures

(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

[Result]: Issues in the cell adapter installation procedures and response measures

[Legend]
- Element test ①
- Element test ②
- Element test ③
- Overall verification test
- Unit 5 Field investigation

Work step	Issue	Method of resolving the issue	Test plan	Classification into manual operation and remote operation		Remarks
				Element test	Actual facility	
1. Advanced preparation						
(1) Measuring and marking the cell installation location	Establishment of the method of scanning from the X-6 penetration location to the CRD opening and the method of making the marking for the cells	• Desk study of the scanning method and marking technique will be conducted. • Feasibility of the studied methods will be verified using simulated bodies.	[Element test ①] • 1/1 scale simulation • Ascertaining the coordinates by means of 3D measurement	Manual operation	Manual operation	• Status at Unit 5 will be verified (FY2022)
2. Installation of shielding door						
(1) Installing the shielding door base plate	Checking of the status of BSW rebars for placing post installed anchors Strength of BSW is unknown	• It will be confirmed that the rebars are inserted at 200mm pitch and the work has been carried out as per the manufacturing drawings (Unit 5 Field investigation)	-	-	Manual operation	• Rebars in Unit 5 will be investigated (FY2022)
(2) Installing the shielding door	Method of carrying-in, transportation and installation of shielding door	• Desk study	-	-	Manual operation	-
(3) Making an opening in the PCV concrete wall and cutting the X-6 penetration	① Making an opening in the concrete ② Method of cutting x-6 penetration ③ Dust behavior when the opening in concrete is made	① Subsidy projects that have been implemented in the past are planned to be utilized. ② Desk study will be conducted ③ Circumstances will be estimated through analysis	-	-	Remote operation	③ Dust behavior is planned to be analyzed
3. Cell adapter processing						
(1) Polishing the surface adjoining the PCV wall surface	Study of method of polishing the surface by means of remote operation	• Desk study (Identification of specifications required for remote operation)	-	-	Remote operation	-
(2) Performing 3D measurement of the surface adjoining the PCV wall surface	Study of 3D scanning method for the PCV steel plate with the marking location of the fitting reference line as a guideline	• Desk study will be conducted on the method. Feasibility of the studied methods will be verified using simulated bodies	[Element test ②] • 1/2 scale simulation • Ascertaining the form by means of 3D scanning • Manufacturing of simulated cell adapter • Comparative verification with the form in the drawings	Manual operation	Remote operation	-
(3) Carrying out work at the plant: Manufacturing the cell adapter	Advisability of processing the PCV connecting surface based on the results of 3D measurement	• The cell adapter will be manufactured on a trial basis using the results of the 3D measurement performed in (2), feasibility of processing using 3D measurement will be verified.		Manual operation	Manual operation	-
(4) Carrying out work at the plant: Processing the cell adapter connecting flange				Manual operation	Manual operation	-
(5) Carrying out work at the plant: Connecting the cell adapter and flange				Manual operation	Manual operation	-

① Installation of large heavy structures

[Legend]
Element test ① / Overall verification test / Element test ② / Unit 5 Field investigation / Element test ③

(6) Implementation items (6)-2: b. Study on detailing of procedures for installing the access equipment

[Result]: Cell adapter installation procedure

Work step	Issue	Method of resolving the issue	Test plan	Classification into manual operation and remote operation: Element test stage	Classification into manual operation and remote operation: Actual facility stage	Remarks
4. Cell adapter connection work						
(1) Inserting the cell adapter in the BSW	Interference of shielding door and BSW concrete with the machined surface	• Checking for interfering objects by inserting simulated bodies • Identification of specifications required for remote operation	[Element test ③] • 1/2 scale simulation (Part which will be checked for interfering objects will be at 1/1 scale) • Checking for interfering objects • Verification of positioning (Accuracy ±7.5mm or less) • Verification of gap measurement	Manual operation	Remote operation	
(2) Aligning, welding and inspecting the cell adapter						
① Aligning the cell adapter on the PCV side	Establishment of the method of positioning the cell adapter on the PCV steel plate	• Desk study of the method (position with the help of the guide pin) • Verification of feasibility of the studied methods using simulated bodies • Identification of specifications required for remote operation		Manual operation	Remote operation	
② Aligning the cell adapter on the shielding door side	Establishment of the method of positioning the cell adapter on the shielding door side	• Desk study of the method (Positioning with the help of the guide pin) • Verification of feasibility of the studied methods using simulated bodies • Identification of specifications required for remote operation		Manual operation	Remote operation	
③ Measuring the gap between the cell adapter and the PCV surface	Establishment of a method of gap measurement by remote operation	• Study using simulated bodies • Identification of specifications required for remote operation		Manual operation	Remote operation	
④ Measuring the gap between the cell adapter and the shielding door frame	Establishment of a method of gap measurement by remote operation	• Study using simulated bodies • Identification of specifications required for remote operation		Manual operation	Remote operation	
⑤ Welding the cell adapter to the PCV wall surface	Establishment of a method of welding the cell adapter and the PCV steel plate by remote operation	• Desk study • Identification of specifications required for remote operation (Results of existing subsidy projects will be used)	-	-	Remote operation	-
⑥ Welding the cell adapter to the shielding door side	Establishment of a method of welding the cell adapter and the shielding door by remote operation	• Desk study • Identification of specifications required for remote operation	-	-	Remote operation	-
5. Cell installation						
(1) Closing the shielding door			-	-	Remote operation	-
(2) Carrying-in the cell	Establishment of the boundary formation from the PCV steel plate to the cell	• Final verification of the boundary formation after carrying- in by means of usual methods (TIR roller, etc.) using simulated bodies (including cell installation frame)	[Overall verification test] • 1/2 scale simulation (Cell length about 2m)	Manual operation	Manual operation	-
6. Boundary inspection						
(1) Pressure resistance test	-	-	-	-	Remote operation	-

① Installation of large heavy structures

(6) Implementation items
(6)-2: b. Study on detailing of procedures for installing the access equipment

✓ **Contribution of the results towards the reflection destination**

- Contributes to substantiation of the procedures for installing access equipment inside the R/B for the side access method.

✓ **Analysis from the viewpoint of on-site applicability**

- Procedures were studied based on the structures inside Unit 3 Reactor Building, and the methods were studied considering on-site applicability.
- Each method required for installation is a combination of general technology and considers on-site applicability to the extent possible.

✓ **Issues**

Work through the X-6 penetration and work after removing BSW is highly difficult and is carried out under high-dose radiation environment. Hence it is carried out by remote operation (Carrying out the following work, in particular, is challenging.)

- Ascertaining the reference location required for installing access equipment and the method of marking the layout.
- Method of ascertaining the shape of the cell adapter and the PCV steel plate at the time of connection.
- Method of positioning the cell adapter on the BSW by remote operation.

① Installation of large heavy structures

(6) Implementation items

(6)-2: b. Study on detailing of procedures for installing the access equipment

✓ **Level of achievement compared to the goals**

[Objective]: Detailing of procedures for installing the access equipment related to fuel debris retrieval
Study of the method of identification and resolution of issues in implementing the procedures

[Achievement status]

① Detailing of the overall procedures concerning the access equipment
: Study of all the steps was completed.
The detailed study on the method of establishing the reference line has been completed as well.

② Detailing of installation procedures of the cell adapter, which are believed to be technically highly difficult
: The study of procedures for carrying-in and installing the cell adapter has been completed.

③ Clear specification of the method of identification and resolution of issues in the installation procedures
: The following issues have been identified in the installation procedures. The methods for resolving the issues has been clearly specified.
1) Ascertaining the reference location using a laser scanner and the method of marking the layout
2) Method of aligning the cell adapter with the PCV steel plate
3) Method of remotely checking the position at the time of carrying-in and fitting the cell adapter

① Installation of large heavy structures

(6) Implementation items

(6)-3-1: c. Verification of element test for the installation procedures

[Purpose]: Verification of feasibility of the side access method for large scale fuel debris retrieval based on on-site application.

[Objective]: Verification of viability of the following issues identified in (6)-2 by element tests.
And, verification of workability if the operation needs to be performed remotely.
1) Ascertaining the reference location using a laser scanner and the method of marking the layout
2) Method of aligning the cell adapter with the PCV steel plate
3) Method of remotely checking the position at the time of carrying-in and fitting the cell adapter
Remote operations are not to be performed during the test. The scope of the test is to perform simple carrying-in and installation and to clearly specify the specifications required of the remotely controlled equipment.

✓ **Comparison with existing technologies**

- The “existing technologies” are used or combined for the installation method.
  Along with using general technologies and results of past research, practical studies are conducted while comparing with the environment (reduction in personnel exposure, prevention of spread of contamination, dust reduction, etc.) specific to the stabilization of Fukushima.

✓ **Implementation items and results**

- Element tests have been conducted concerning the following issues identified in (6)-2 using test pieces and the feasibility of the method has been verified.

[Results]: ① Element test plan (Completed)
② Study of the element test details and test pieces, and arrangement of the test pieces (Completed)
③ Implementation of element tests, provision of the results as feedback for the study on detailing of each method (Completed)

① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Elemental test plan ①-2 Establishment of the method of marking the reference line for installation

(Aim)

- **The central axis of the pedestal opening and the reference line for installation needs to coincide so that the robot arm can access the pedestal opening in a straight line.**
- **Hence the procedure for extending the central axis of the pedestal opening to the floor surface where the cell will be installed will be substantiated and verification tests will be carried out.**

(Expected outcome)

- **Establishment of the method of marking the reference line for installation (using 3D scanning), verification of the marking accuracy, and points of improvement.**

➢ **The R/B wall surface, X-6 penetration, and pedestal opening were measured by 3D scanning to obtain coordinates, and the method for marking the reference line for cell installation was adopted to verify the following.**

- **3D measurement using the 3D scanning procedure studied, and ascertaining of the coordinate position by integrating the measurement results.**
- **Marking of the reference line for installation on the building floor based on the coordinate data, and verification of its accuracy.**

⇒ Feasibility of the method for ascertaining the reference line for installation by 3D scanning measurement is verified.

3D scanning while the back hatch of the isolation chamber is open (Acquisition of Data A pertaining to Target ①, ②)

↓

Closing the back hatch of the isolation chamber, and releasing the air-tight door

↓

3D scanning while the air-tight door is open (Acquisition of Data B pertaining to Target ②, ③ and X-6 penetration)

↓

Moving the 3D scanner up to the area in the vicinity of x-6 penetration, and performing 3D scanning (Acquisition of Data C pertaining to Target ③ and from inside the X-6 penetration)

↓

Inserting the 3D scanner inside x-6 penetration, and performing 3D scanning (Acquisition of Data D from inside the X-6 penetration)

↓

Inserting the scanner inside PCV, and performing 3D scanning inside PCV (Acquisition of Data E pertaining to X-6 penetration and the pedestal opening part)

↓

The relationship between the R/B wall surface, x-6 penetration and pedestal opening part is ascertained in terms of coordinates based on the measurement Data A to E, and the reference line for installation is marked on the R/B floor after the isolation chamber is removed (for verifying accuracy)

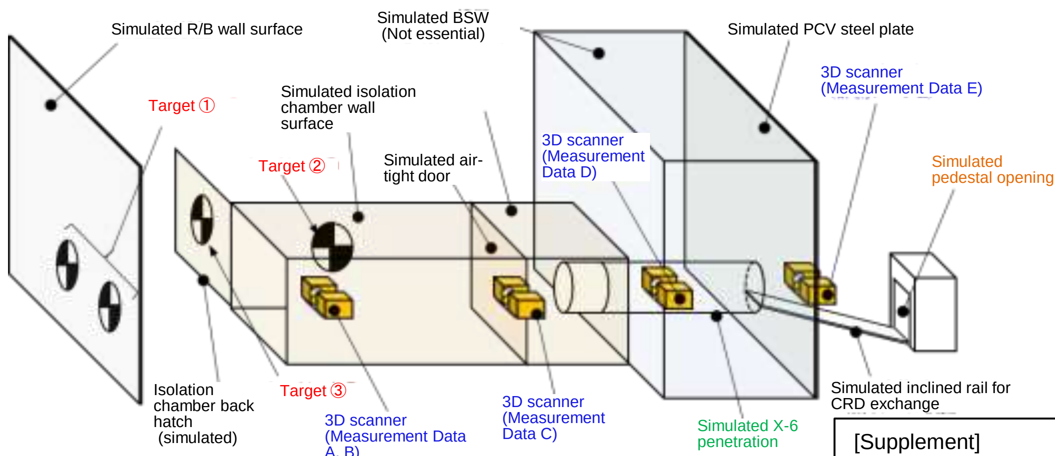


Illustration of 3D scanning

[Supplement]
- It is assumed that the isolation chamber is set up based on the assumption that measurement can be performed during the “Detailed Investigation Inside PCV” in Unit 3.
- 1/1 scale simulation
- 3D scanner is the type equipped with a laser tracker

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment] **No.74**

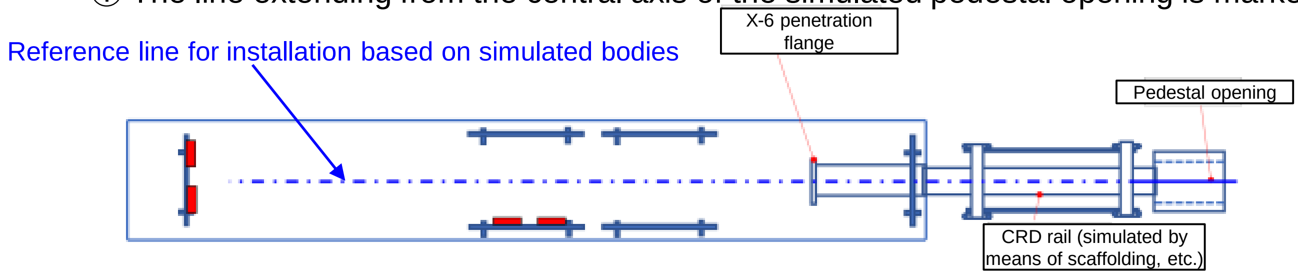
① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Element test plan ①-2 Establishment of the method of marking the reference line for installation

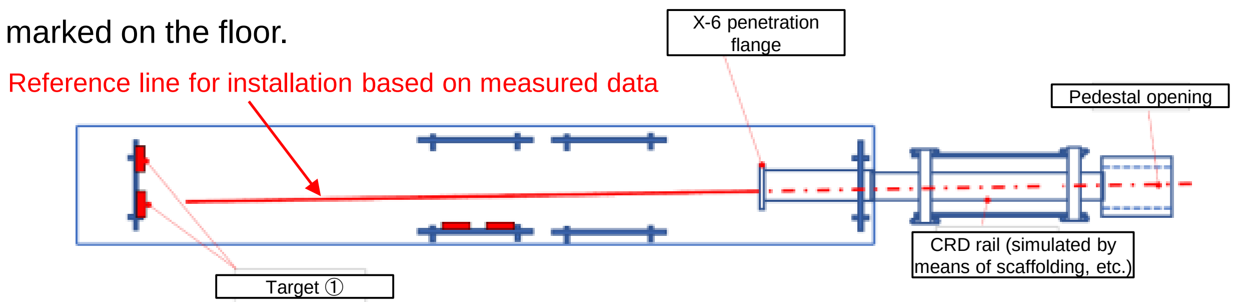
・ Verification of marking accuracy

① The line extending from the central axis of the simulated pedestal opening is marked on the floor.



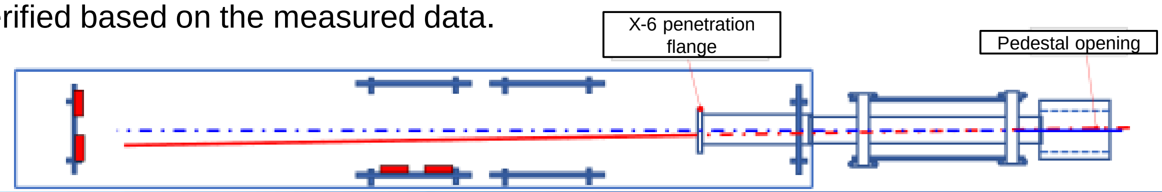
② The 3D measurement Data A - E are integrated and the coordinates of the line extending from the central axis of the pedestal are obtained based on the measured data.

③ With the Target ① and X-6 penetration flange as the reference points, the line extending from ① is marked on the floor.



Marking using the laser marking instrument

④ The reference line for installation of ② and ③ are compared and the marking accuracy is verified based on the measured data.



[Approach towards accuracy verification]
The actual value is verified considering whether or not the reference line for installation is within the installation accuracy (±50mm) required for the pedestal opening as the primary condition.

Exc

① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ①-2 Establishment of the method of marking the reference line for installation

- Time of implementation : Mid October 2022 onwards (Tests completed)
- Location: In the premises of the Mitsubishi Heavy Industries, Kobe Shipyard
- Test piece : 1/1 scale

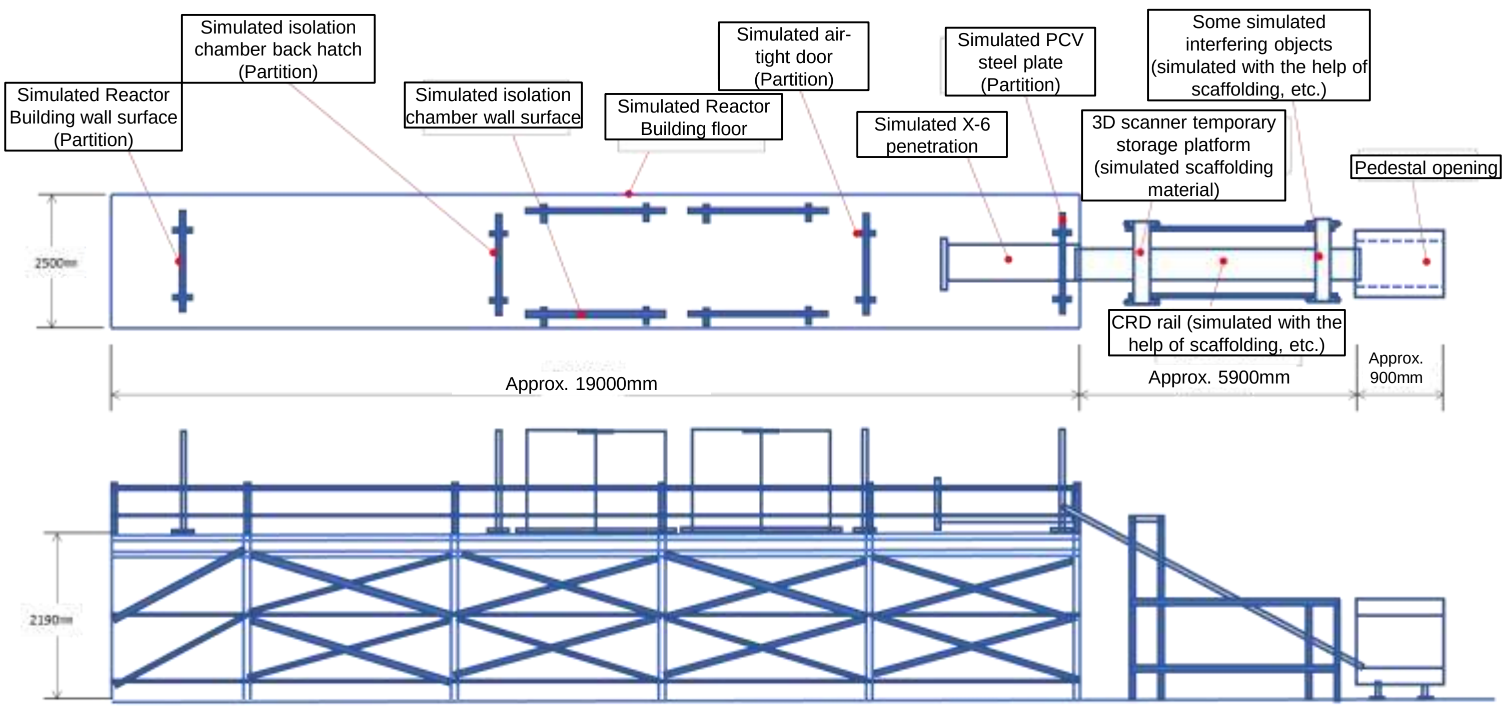


Illustration of the test piece (Total length approx. 26m * width approx. 2.5m * height approx. 2.5m)

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-2 Establishment of the method of marking the reference line for installation

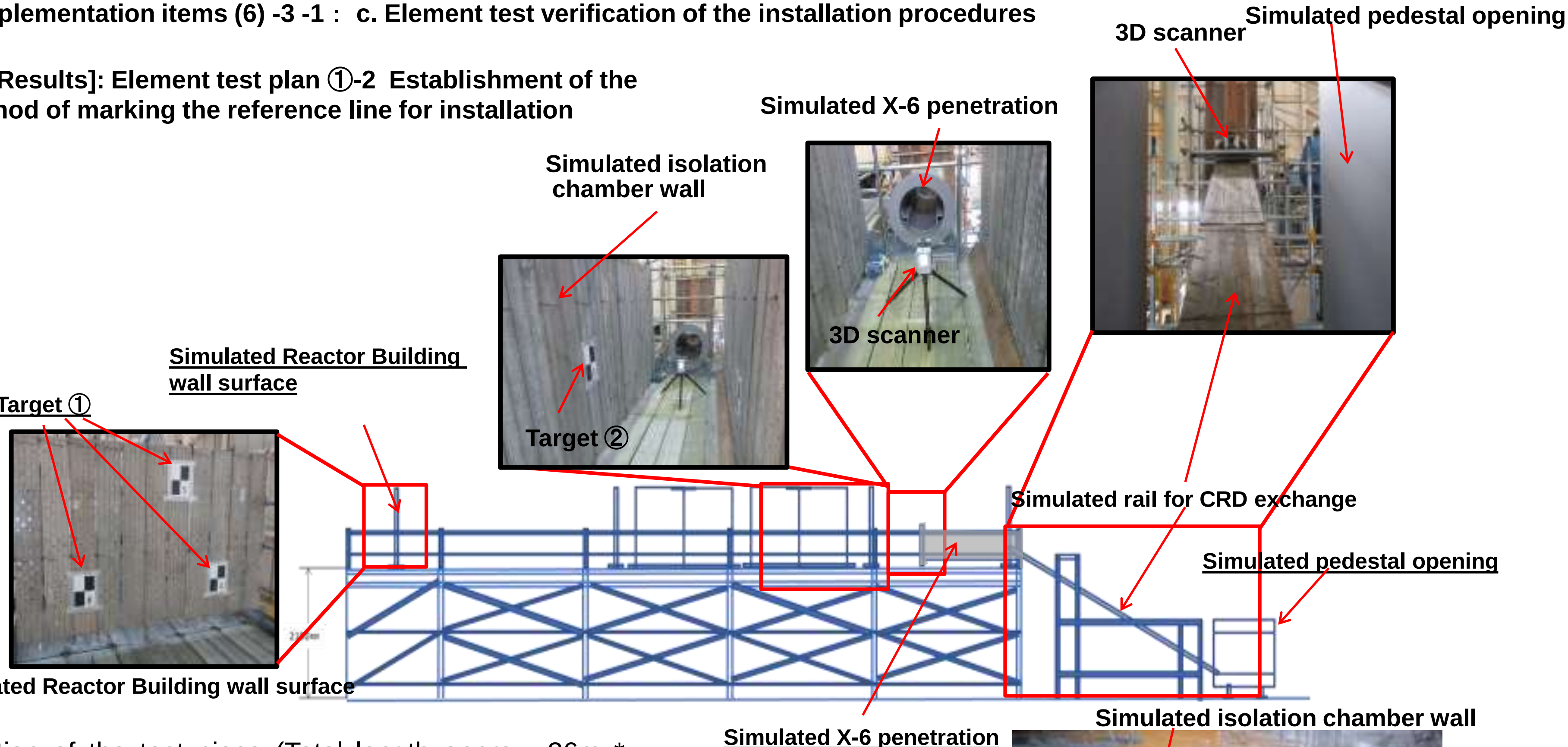
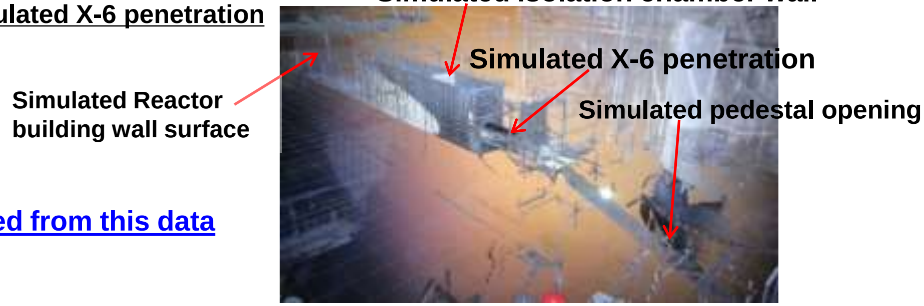


Illustration of the test piece (Total length approx. 26m * width approx. 2.5m * height approx. 2.5m)



<<Reference>> 3D measurement output
Verification of the accuracy of the reference line for installation obtained from this data

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

・ Method of integrating the measured data A - E

The Measured data A - E is integrated by overlapping **each 3D measurement data using common measurement targets.**

- Measured data A, B are integrated using Target ② ⇒ Integrated data ①
- Measured data B, C are integrated using Target ③ and X-6 penetration flange ⇒ Integrated data ②
- Measured data C, D are integrated using the Inside of the X-6 penetration ⇒ Integrated data ③

Measured data	Measurement target (○: Relevant part)					
	Target ①	Target ②	Target ③	X-6 penetration flange	Inside of the X-6 penetration	Pedestal opening
A	○	○				
B		○	○	○		
C			○	○	○ (RB side)	
D					○ (RB/PCV side)	
E					○ (PCV side)	○

- Integrated data ① and ② are integrated using Measured data B ⇒ Integrated data ④
- Integrated data ② and ③ are integrated using Measured data C ⇒ Integrated data ⑤

Integrated data	Source measured data to be integrated				
	A	B	C	D	E
①	○	○			
②		○	○		
③			○	○	○

Integrated data	Source measured data to be integrated		
	①	②	③
④	○	○	
⑤		○	○

Integrated data ④ and ⑤ are integrated using integrated data ② and hereby the integration of measured data A-E is complete.

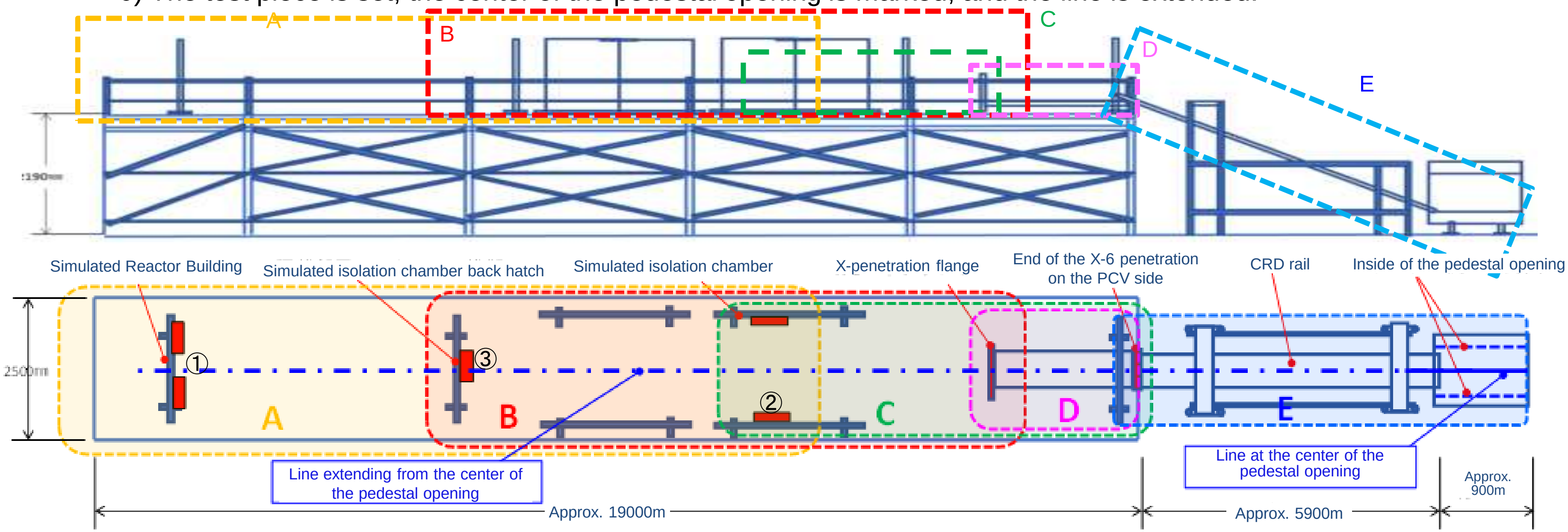
The correlation between the central axis of the pedestal opening and Target ① is accomplished.

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures
[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

〇 Test method

0) The test piece is set, the center of the pedestal opening is marked, and the line is extended.



Region	Measurement section						Remarks
A	Target ①	T ③	T ②				• Efforts are made to improve accuracy by setting the target.
B		T ③	T ②	X-6 flange			• Many points are measured in all the sections and the data is evaluated as 3D.
C			T ②	X-6 flange	X-6 end		• Measurement is carried out in detail as it is based on the structural shape.
D				X-6 flange	X-6 end		• The pedestal opening is evaluated as a surface and the central axis is obtained.
E					X-6 end	Pedestal opening	

(Coordinates are obtained by overlapping)

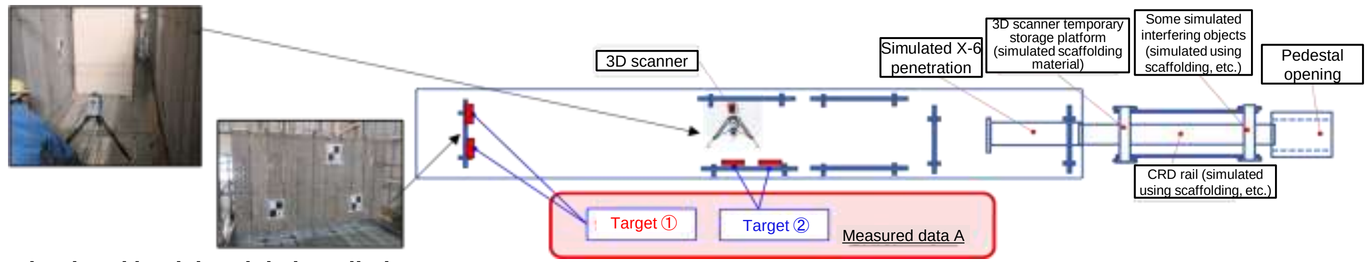
① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

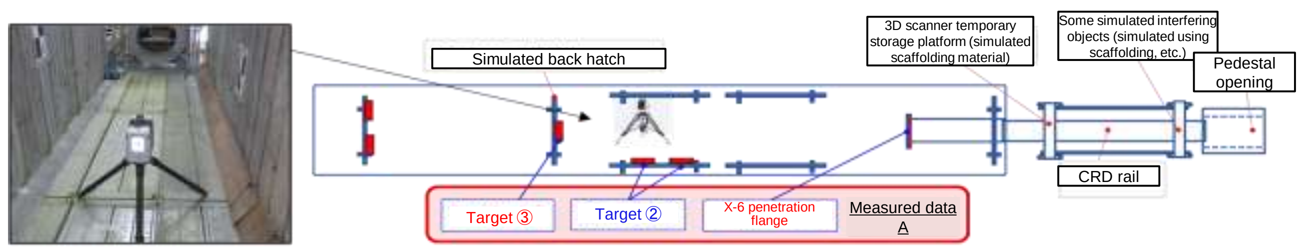
[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

○ Test method

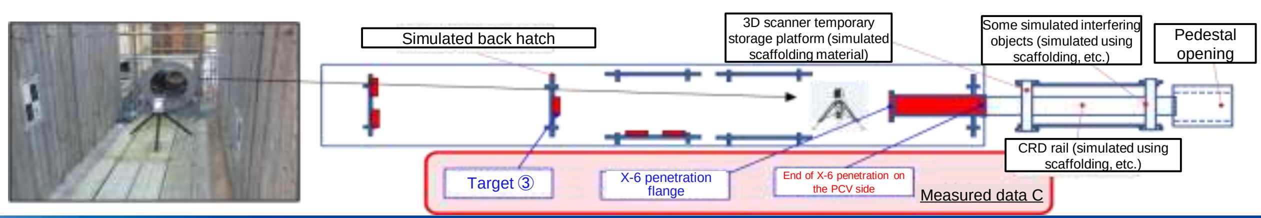
1) Target ① and ② are installed on the simulated Reactor Building wall surface and the simulated isolation chamber wall surface of the mock-up.
2) Correlation data between ① and ② is collected by 3D scanning (Measured data A).



3) The simulated air-tight door is removed, and the simulated back hatch is installed.
4) Target ③ is installed on the simulated back hatch on the inside of the isolation chamber.
5) Correlation data between Target ②, ③ and X-6 penetration flange is collected by 3D scanning (Measured data B).



6) The 3D scanner is moved to the vicinity of the X-6 penetration flange.
7) Correlation data between Target ③ and the area from X-6 penetration flange to the end of the X-6 penetration on the PCV side is collected by 3D scanning (Measured data C).

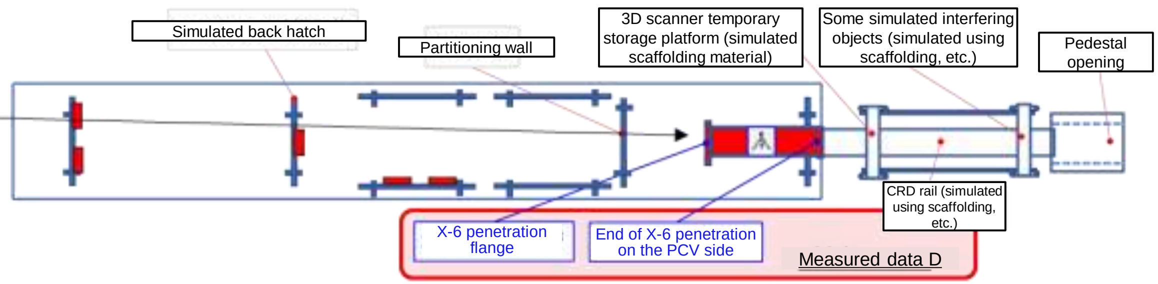


① Installation of large heavy structures

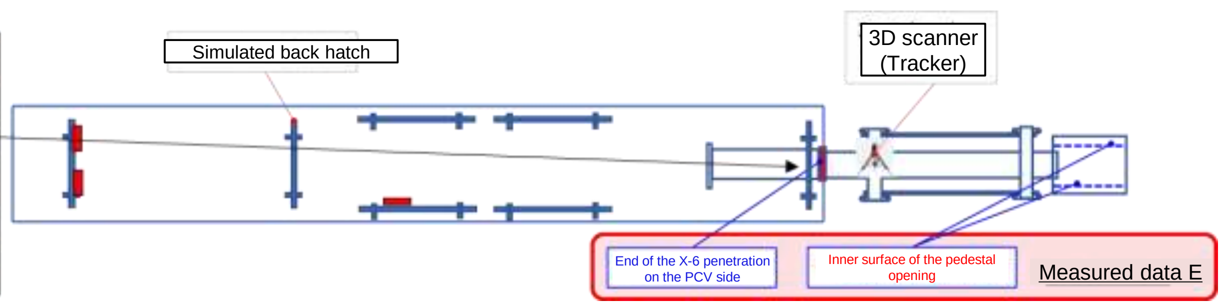
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

8) The 3D scanner is moved to the central part inside the X-6 penetration.
9) A partitioning wall is installed between Target ③ and the X-6 penetration flange.
10) Correlation data between Target ③ and the area from X-6 penetration flange to the end of the X-6 penetration on the PCV side is collected by 3D scanning (**Measured data D)**.



11) The 3D scanner is installed on the temporary storage platform for the simulated CRD rail part.
12) Correlation data between the pedestal opening and the end of the X-6 penetration on the PCV side is collected by 3D scanning (**Measured data E)**



① Installation of large heavy structures

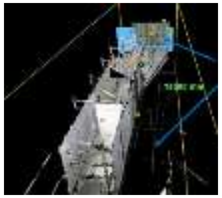
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

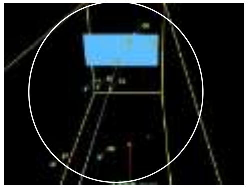
13) The Measured data A-E is integrated (No. 78 sheet), and **coordinates (1) (Target ①), coordinates (3) and coordinates (4) (pedestal opening) are acquired.**

The point cloud data obtained from the 3D scanner is converted to coordinates

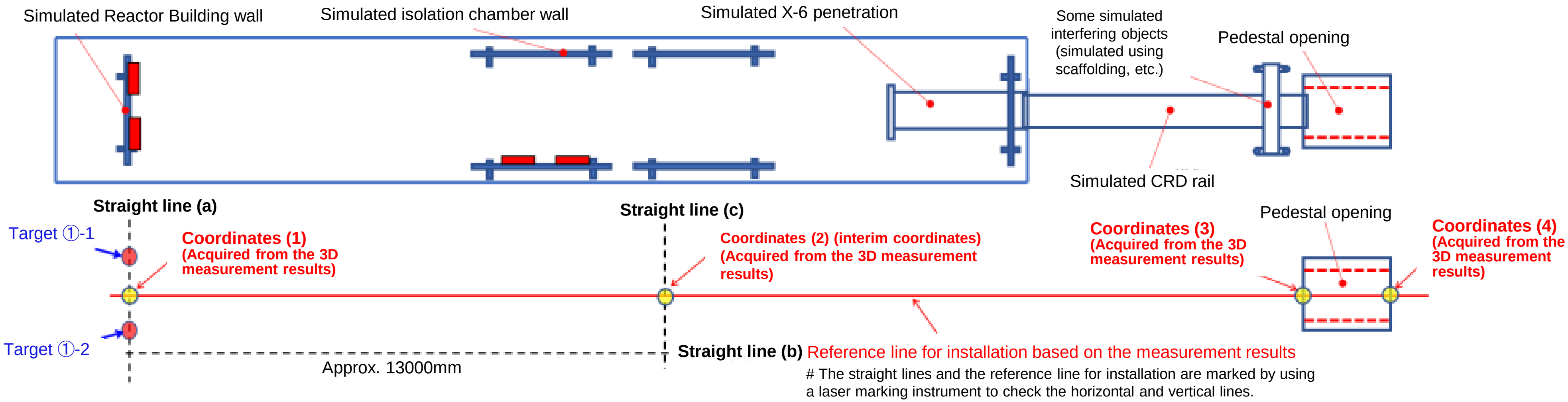
① Integration of point cloud data



② Acquisition of coordinates from the integrated data



③ Acquisition of coordinates to be used



14) The pedestal opening and the simulated part of the Reactor Building wall surface are at a distance and hence interim coordinates are established from the viewpoint of making marking easier. Therefore a laser marking instrument is used to mark straight lines (a), (b) and (c).

Coordinates (2) of the point where straight line (c) intersects are obtained.

15) A straight line passing through the coordinates ascertained from the integrated data obtained after 3D measurement is marked.

(This straight line becomes the reference line for installation.)

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

〇 Classification of the collected data

3D measurement is conducted 3 times and the data obtained is said to be N-1, N-2 and N-3 respectively.
Also, the following 3 cases were implemented for the method of integrating the measured data A - E.

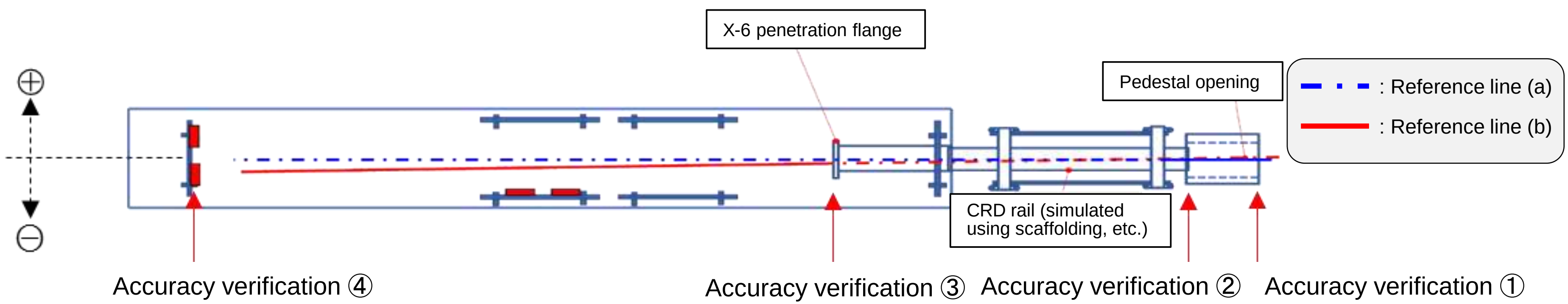
◆ Case 1
- The measured data (A-C) is integrated using only the targets.
- Since there are no targets for measured data (D and E), data is integrated using the test piece structure.

◆ Case 2
- The measured data (A-C) is integrated not only using the targets but also using the test piece structure.
- Since there are no targets for measured data (D and E), data is integrated using the test piece structure.

◆ Case 3
- Measured data (A-E) is integrated using all available data (Targets, test piece structure, building, etc.)

〇 Accuracy verification method

The reference line for installation (a) while assembling the test piece and the reference line (b) based on the measured data were actually measured and errors were verified.
The following 4 locations were verified.



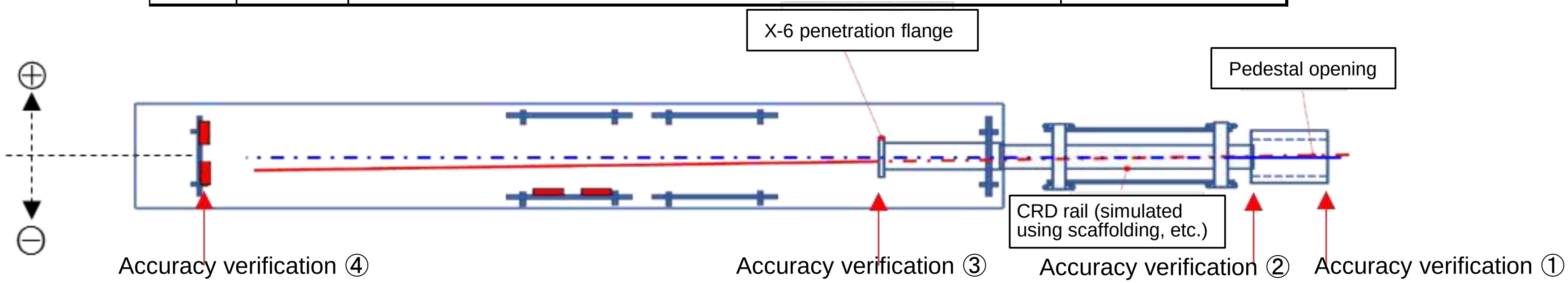
① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

○ Test results

Data	Measurement items	Case 1	Case 2	Case 3	Remarks
N-1	①	-8.1 mm	7.8 mm	4.2 mm	Reference: ≦50mm
	②	-8.1 mm	7.8 mm	4.8 mm	
	③	-1.8 mm	4.8 mm	8.5 mm	
	④	8.1 mm	-0.9 mm	16.1 mm	
	Angle misalignment	-0.04°	0.02°	-0.03°	Reference value (calculated value)
N-2	①	Maximum value 25.0 mm	21.2 mm	1.8 mm	Reference: ≦50mm
	②	24.9 mm	21.2 mm	2.5 mm	
	③	17.3 mm	17.5 mm	4.9 mm	
	④	4.1 mm	12.1 mm	10.1 mm	
	Angle misalignment	0.05°	0.02°	-0.02°	Reference value (calculated value)
N-3	①	-19.0 mm	-8.1 mm	-1.6 mm	Reference: ≦50mm
	②	-18.0 mm	-8.0 mm	-0.5 mm	
	③	-3.5 mm	0.5 mm	1.6 mm	
	④	23.1 mm	15.1 mm	8.1 mm	
	Angle misalignment	-0.10°	-0.06°	-0.02°	Reference value (calculated value)
Common	⑤	23920 mm			For calculating the angle



① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ①-3 Establishment of the method of marking the reference line for installation

〇 Test results and considerations

1) **In case 1 the maximum error was 25.0mm**, **in case 2 the maximum error was 21.2mm** and **in case 3 the maximum error was 16.1mm**.
The error in the pedestal opening was less than 50mm (acceptable error). **Thus the errors in all the cases were within the margin of error.**
2) It was confirmed that the reference line for installation can be obtained by ascertaining the relative positional relationship from the pedestal opening to the R/B wall surface by 3D scanning measurement.

3) The error in case 3, which has the most data to be integrated, is the least. It was found that accuracy improves furthermore if all available data is used while integrating the measured data.

The results of the tests conducted at actual scale (1/1) **showed that an error accuracy of less than 25mm can be ensured for the central axis of the pedestal opening when the cell is installed in accordance with the reference line for installation obtained using the 3D scanner, and that it will be possible to insert the robot arm even in its current size**.

〇 Future challenges

It is determined that the following will need to be considered in the future for securing a risk margin assuming 1) the impact of environmental factors inside the PCV (scanner being under high radiation environment), and 2) impact of the status inside the PCV (dust, etc.).

① Confirming the impact of the 3D scanner being under high radiation environment

② Increasing the installation risk margin by modifying the structure

- Trying to increase the risk margin by making it possible to adjust (movable) rail used for inserting the arm into the cell.
- Reducing (appropriately) the size of arm, particularly the actuator to increase risk margin.
- Extending the internal wall of the cell which is likely to interfere with the cell if the actuator of the arm shifts laterally,

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

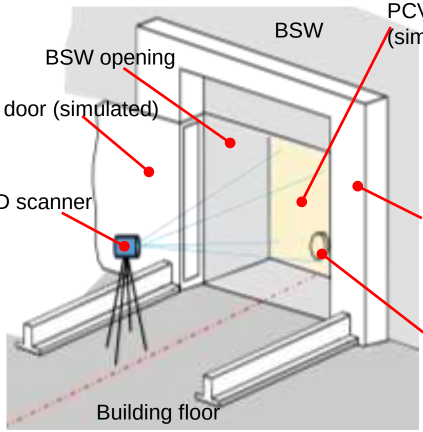
[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

(Aim)
- **A gap of 5mm or less needs to be provided for the welded connection surface between the cell adapter and the PCV.**
- **Hence, not just the installation accuracy but also the accuracy of the PCV connection surface of the cell adapter needs to be good.**
- **Therefore, the method of acquiring data will be substantiated and verification test will be conducted assuming that the three dimensional data on the PCV surface will be obtained and 3D processing will be carried out.**

(Expected outcome)
- **Establishment of the method of acquiring 3D processed data using a 3D scanner and verification of the processing accuracy of cell adapter.**

➢ The PCV connection surface of the cell adapter is processed based on the data obtained by 3D scanning the simulated PCV steel plate, and it is verified whether or not the finishing is according to the design shape based on the measured data.
- 3D scanning of the simulated PCV steel plate is performed, and the data required for designing the shape of the PCV connection surface is acquired.
- The cell adapter processing model is created using the 3D scan data.
- The PCV connection surface of the cell adapter is processed based on the processing model, and the finished state is verified.

⇒ Verification of the feasibility of 3D scanning of the lower part of the X-6 penetration (confined space) (Verification of whether or not PCV connection surfaces with complex shapes can be processed)



3D scanning was performed at a prescribed location and PCV connection surface was manufactured based on those results.

Illustration of the scanning test of the PCV steel plate surface

1. 3D scanning of the simulated PCV steel plate surface including the X-6 penetration is performed (Acquisition of multiple data)
2. Creating a 3D model of the PCV steel plate surface by integrating multiple data
3. Designing (processing model) and processing of the cell adapter PCV connection surface shape
4. 3D scanning and creating a 3D model of the cell adapter (finished product)
5. Verifying the finished state by comparing with the cell adapter (finished product) and the 3D model of the PCV steel plate shape

[Supplement]
Lower part of the X-6 penetration (confined space)
Verification of feasibility of 3D scanning

[Data acquired by means of 3D scanning]
・PCV steel plate shape
・Required length of the cell adapter
・Position of the guide pin

[Supplement]

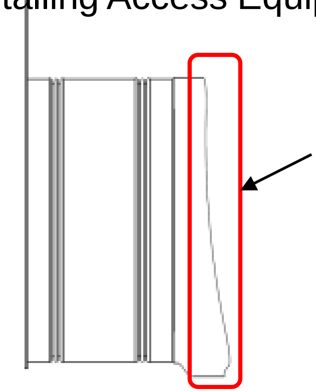
1/2 scale simulation (Considering work efficiency during the test)

① Installation of large heavy structures

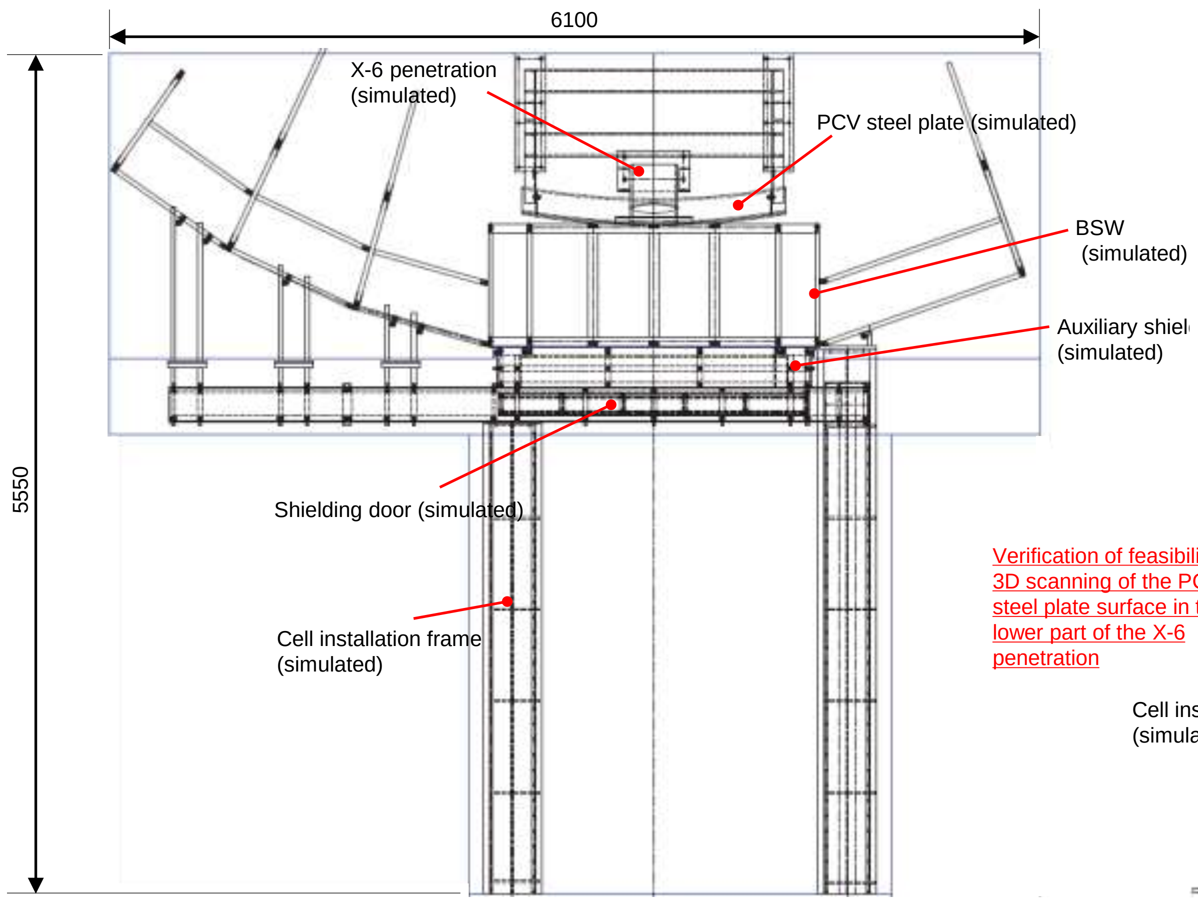
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

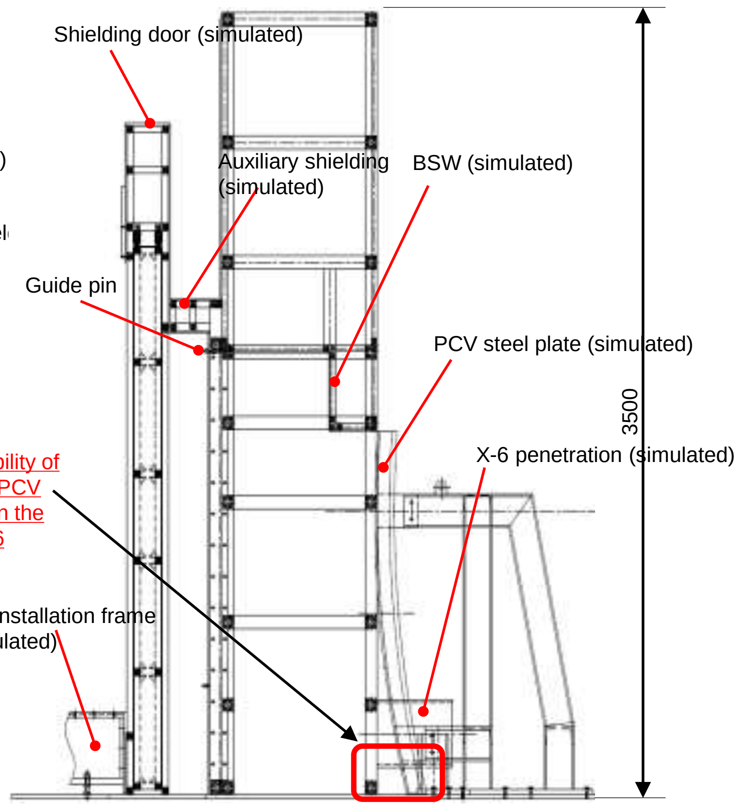
- Time of implementation： Early October 2022 onwards (Tests completed)
- Location: In the premises of the Mitsubishi Heavy Industries, Kobe Shipyard
- Test piece: 1/2 scale (Element test ③, used for the overall verification test as well)



Drawing of the inner surface of cell adapter



Test piece Floor plan



Test piece Cross-section

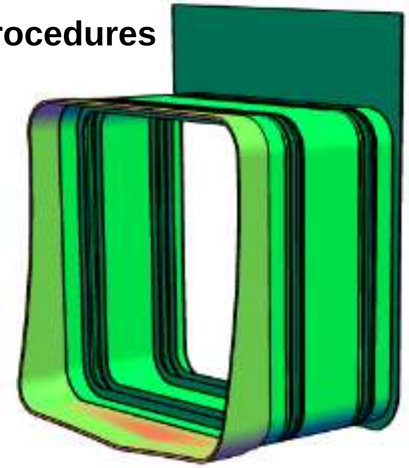
① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

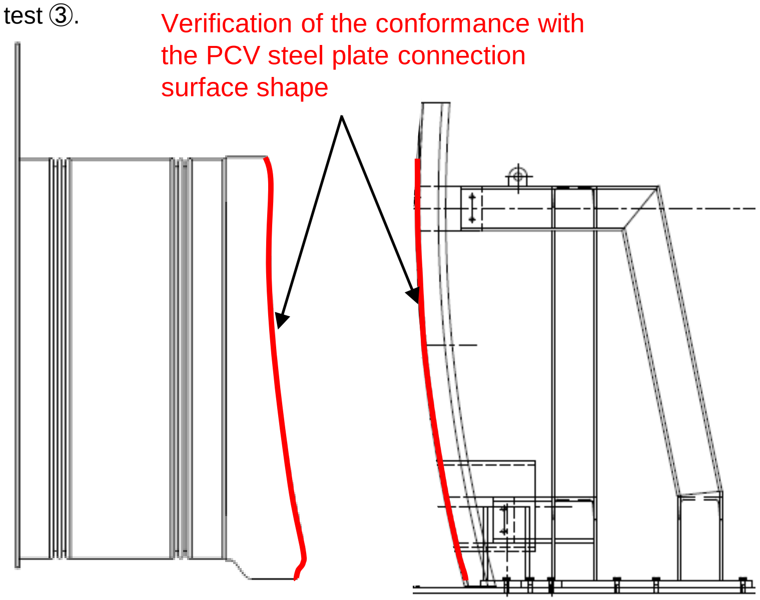
- Verification of the finished state of the cell adapter

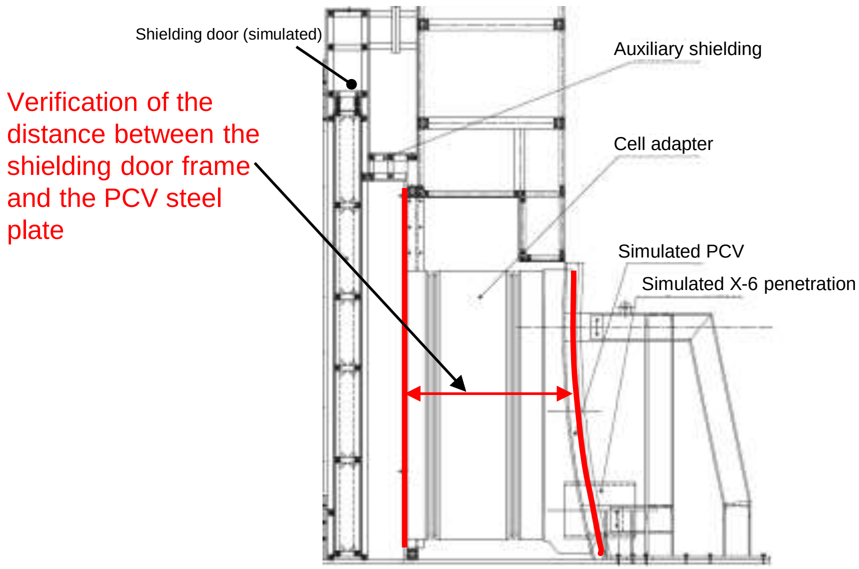
① A 3D model of the cell adapter is created by 3D scanning the cell adapter for which the connection surface with the PCV steel plate has been processed.
② The finished state of the PCV connecting surface of the cell adapter is verified by comparing the 3D model of the cell adapter after processing and the 3D model of the PCV steel plate surface shape.



Cell adapter 3D model after processing (Illustration)

[Approach towards determining processibility]
The finished state is verified as reference, and the final determination is based on the results of verifying the gap after inserting the cell adapter during element test ③.





① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

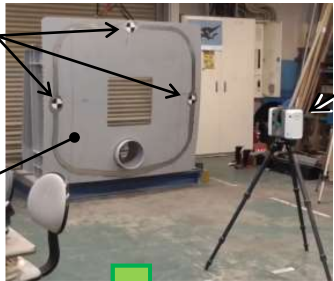
[Result]: Element test plan ② Verification of whether or not the PCV connection surface of the cell adapter can be processed]

・ The cell adapter is manufactured based on the data obtained from the 3D scan of the simulated PCV steel plate.

・ Three dimensional verification of the finished state of the PCV connecting surface of the cell adapter.

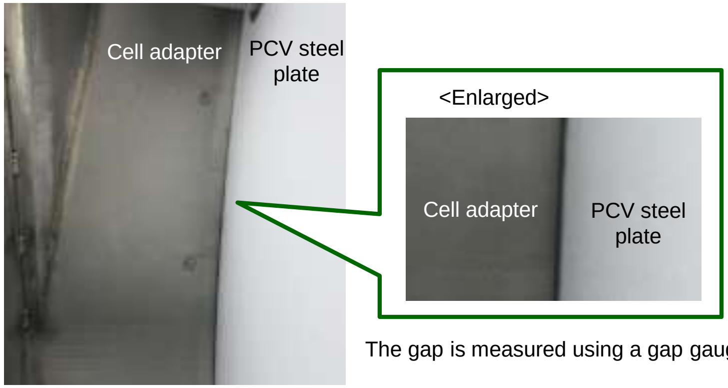
⇒ It was found that there is a gap of about 4mm in the model. (The results of actual measurement were equivalent.)
Fine adjustments are made to the connecting part from there so that the dimensions of the finished product are within the criteria.
(Criteria : 2.5mm > Result 2.4mm)

3D measurement of the simulated PCV

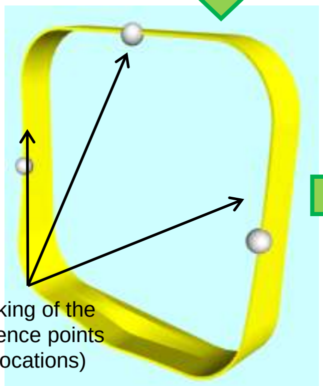


3D measurement of the PCV connecting surface of the cell adapter

Cell adapter and PCV connecting part

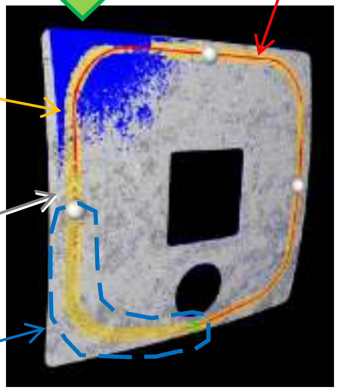


The gap is measured using a gap gauge

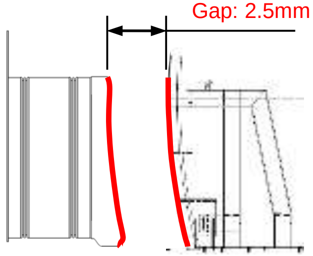


Cell adapter connecting part in the 3D model

Finished cell adapter



Result of overlapping the edges in the 3D model



Criteria: Basis of less than 2.5mm
⇒ Required dimensions from the remotely operated welding equipment Since the actual gap is 5mm, here it is set to 2.5mm which is 1/2.

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

〇 Test method

1) A simulated PCV steel plate part is set up, and a 3D scanner is installed at a location that is 2500mm from the X-6 penetration on the reference line for installation (approx. 1000mm from the shielding door frame) and at a height of 880mm.
Data from 3D scanning of the front surface of the PCV steel plate is obtained using the 3D scanner.
(Measured data A).

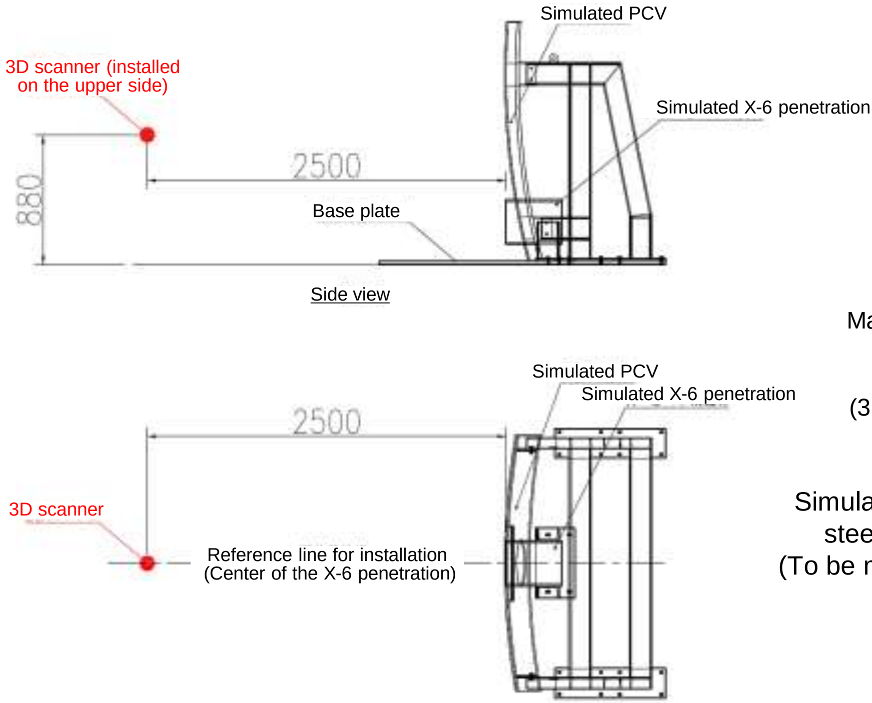
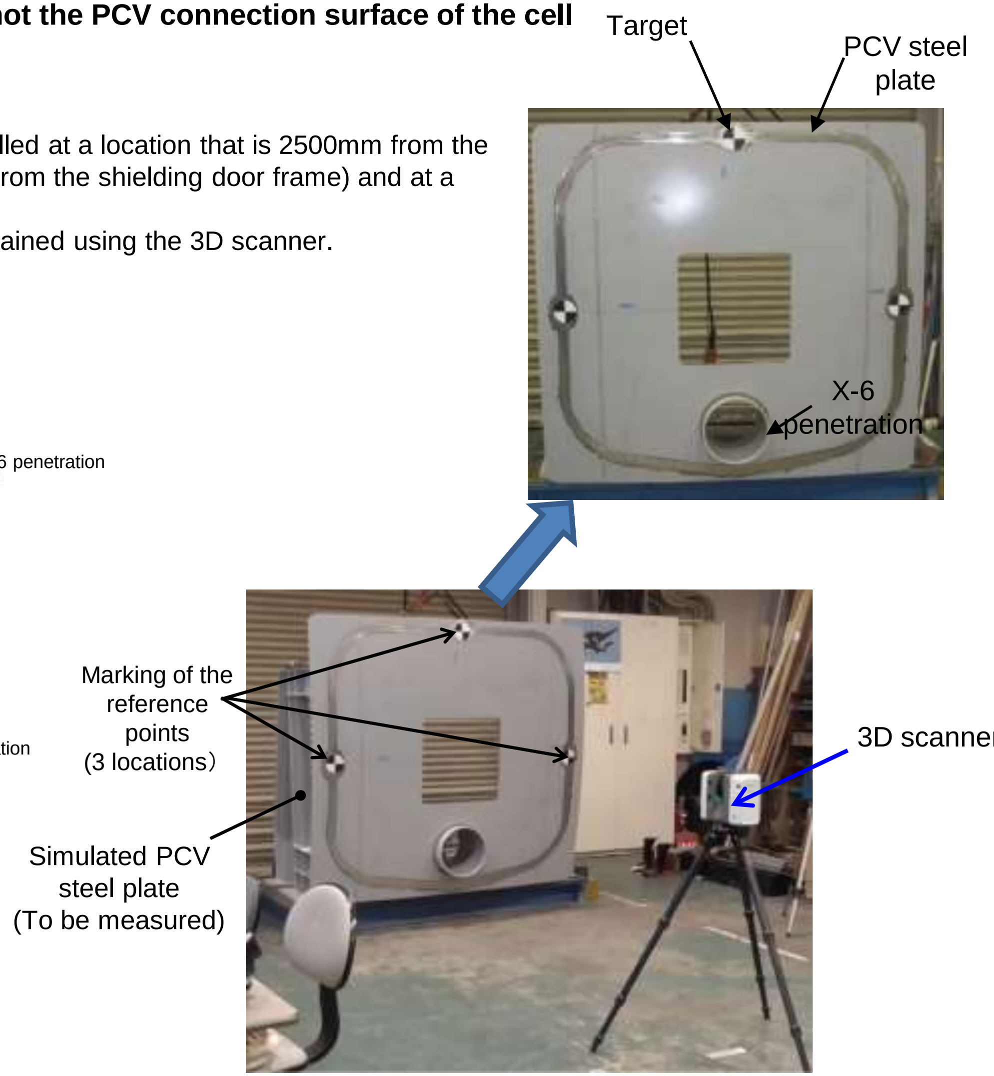


Illustration of the 3D scanner installation location (on the reference line for installation)



3D measurement of the simulated PCV

① Installation of large heavy structures

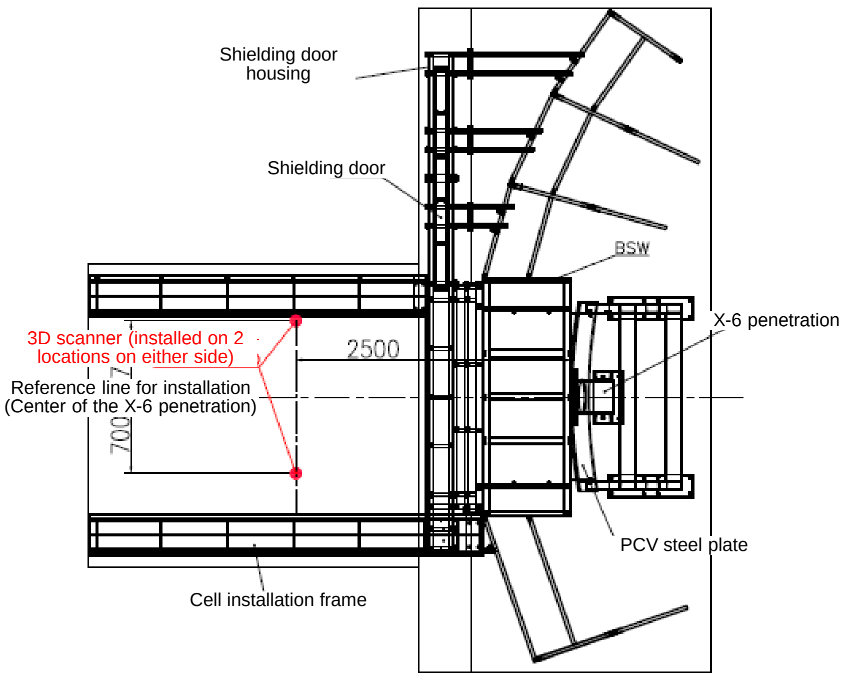
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

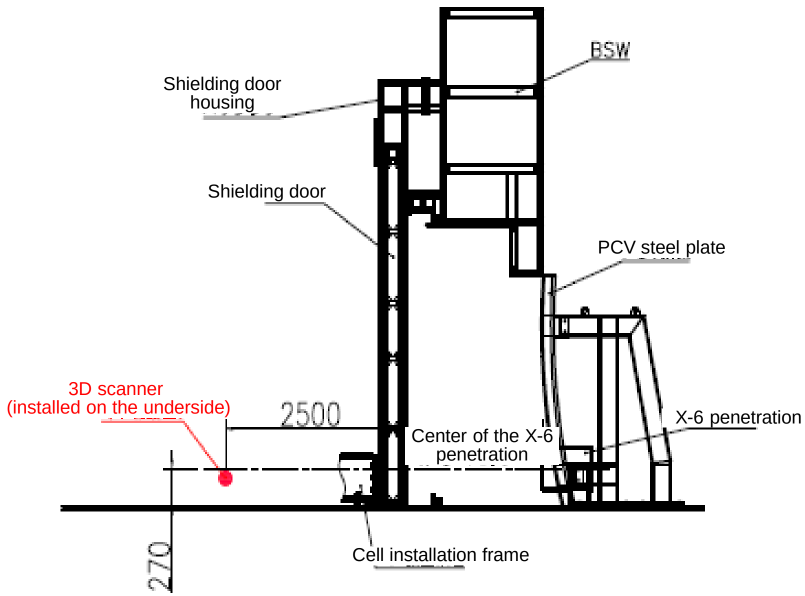
○ Test method

3) The 3D scanners are installed at 2 locations that are 700mm on either side of a location that is 2500mm from the X-6 penetration end of the reference line for installation and at a height of 270mm or less.

4) Data from 3D scanning of the PCV steel plate is obtained from the 3D scanners on both sides respectively. (Measured data B, C)



Layout drawing



Side view

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

○ Test method

5) Measured data A - C is integrated to ascertain the shape of the PCV steel plate.

6) A 3D-CAD model of the PCV steel plate is created.

7) A 3D-CAD model of the shape of the cell adapter edge that connects to the PCV is created based on the 3D-CAD data on the PCV steel plate.

8) The processing data of the distal end of the cell adapter is processed and the cell adapter is processed using a machine processor.

3D point cloud data (sample)

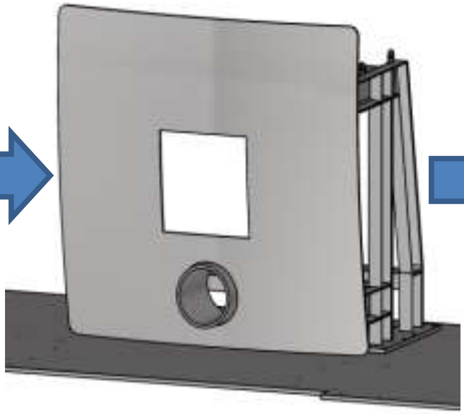
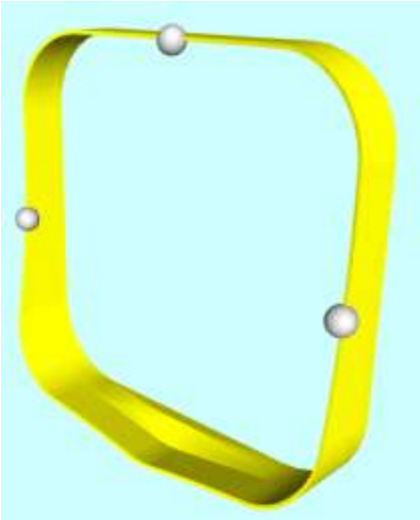
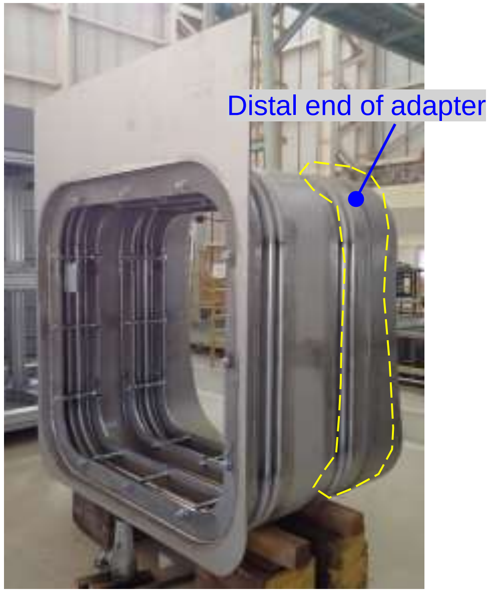


Illustration of the 3D model of the PCV steel plate



3D-CAD data on the distal end of the cell adapter



Cell adapter distal end processing

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

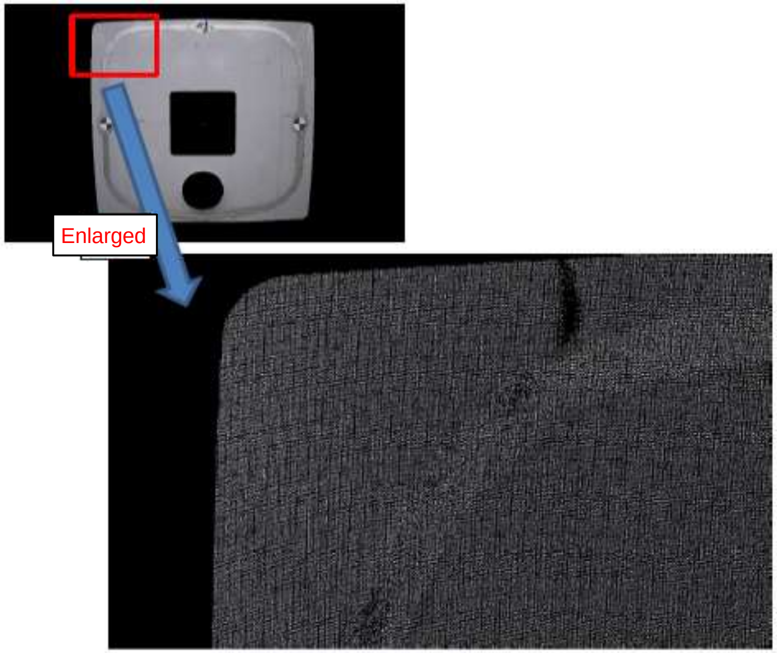
○ Test results

[Feasibility of 3D scan measurement including that of the gap under the X-6 penetration]

1) In order to collect data pertaining to the location on the PCV steel plate front surface at the lower end of the X-6 penetration at a height of approx. 850mm above the reference line for installation, 3D scanners were installed at 3 locations (A, B and C) including the location on the reference line for installation and 2 locations on either side of the line (left side 550mm, right side 700mm) at a height of approx. 250mm, and measurements were performed. It was thus verified that data pertaining to the cell adapter connection part of the PCV steel plate including the gap on the underside of the X-6 penetration can be collected without any issues.

To be measured (picture)

3D scan



Point cloud data

PCV steel plate 3D scanning results (point cloud data)

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

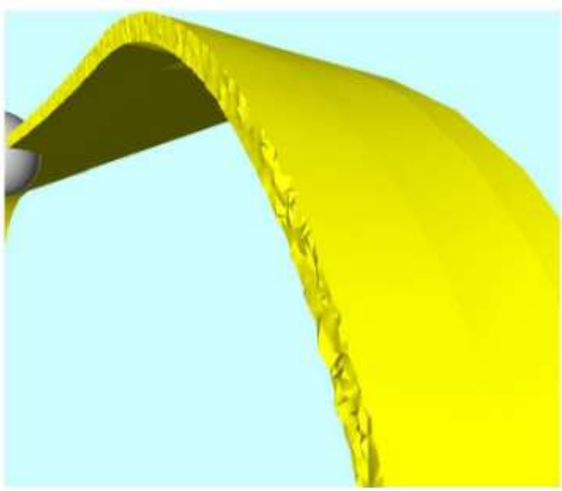
[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

〇 Test results

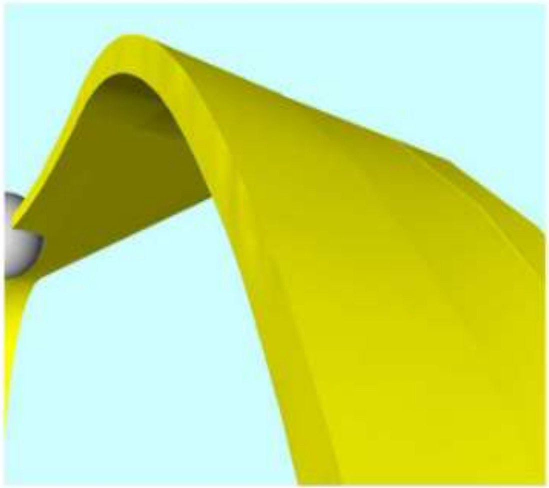
[Processed shape of the cell adapter based on the 3D scanning data]

・ The shape of the PCV connecting surface of the cell adapter is specified based on the results of 3D measurement of the PCV steel plate.
When the adjacent point cloud data is connected by straight lines, due to measurement error in 3D scanning the surface becomes uneven. The surface is smoothened# before processing the cell adapter.

Fine smoothening to the extent that data which is clearly noise, does not have an impact on the removal and connection.



Smoothening process



Shape before processing (3D-CAD)

Shape after processing (3D-CAD)

Exc

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

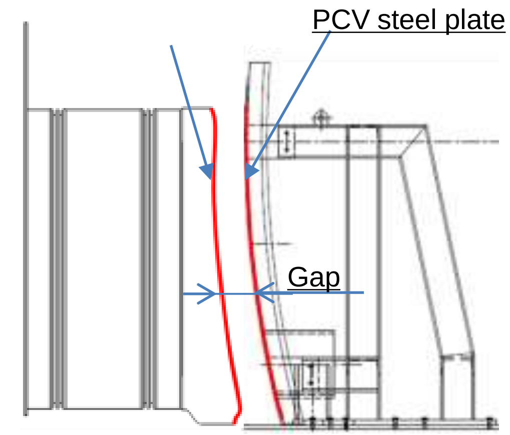
[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

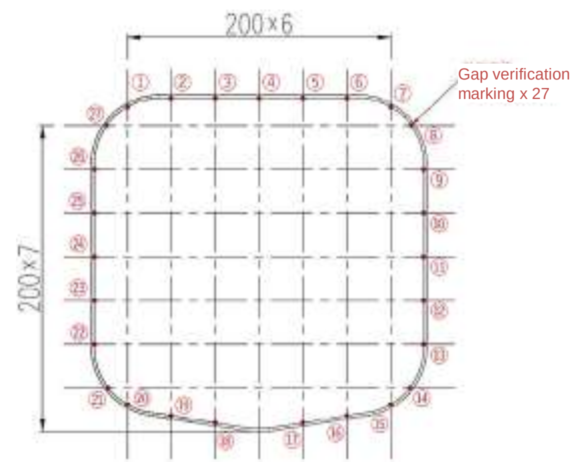
○ Test results

[Processing of the cell adapter and PCV steel plate connection surface, and verification of the finished state]

1) According to the initial results of measurement there was a maximum gap of 4.0mm as against the allowable gap of 2.5mm or less.
2) The distal end of the cell adapter was adjusted and processed based on the initial results, and the gap was checked about re-inserting.
3) By making adjustments it was possible **to reduce the gap to a maximum of 2.4mm as against the allowable gap of 2.5mm or less.**
4) Based on the above, even though after the initial installation adjustments were necessary, adequate installation became possible by making adjustments and processing once again based on the data pertaining to the initial installation gap.
5) Moreover, by adopting the method in which the guide pin is used for insertion, installation within the gap between the pin and the pin hole became possible, and reproducibility (re-adjustment) became easier as well.

[The test was conducted at 1/2 scale this time, but the shape, curvature, allowable gap were matched and hence the results are applicable to the actual facility as well.]





Cell adapter distal end gap measurement location

Measurement location	Measurement results (before adjustment)	Measurement results (after adjustment)	Measurement location	Measurement results (before adjustment)	Measurement results (after adjustment)
①	2.0	0.7	⑯	2.0	0.9
②	1.5	0.7	⑰	1.5	1.2
③	2.0	0.7	⑱	2.0	0.0
④	2.5	1.6	⑲	3.5	1.5
⑤	3.0	1.3	⑳	4.0	1.7
⑥	3.0	1.5	㉑	4.0	2.3
⑦	4.0	1.8	㉒	3.5	2.0
⑧	4.0	2.2	㉓	3.0	1.7
⑨	4.0	2.4	㉔	2.0	1.0
⑩	4.0	2.0	㉕	2.0	1.0
⑪	3.0	1.4	㉖	2.0	0.9
⑫	3.0	0.4	㉗	1.5	0.8
⑬	2.0	0.9	Maximum	4.0	2.3
⑭	1.0	0.0	Minimum	1.0	0.0
⑮	1.0	0.7	Evaluation criteria:	：≦2.5mm	

Cell adapter distal end gap measurement results

① Installation of large heavy structures

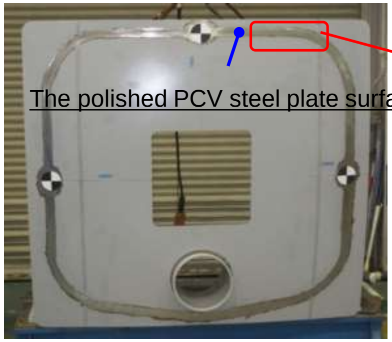
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Result]: Element test plan ②-1 Verification of whether or not the PCV connection surface of the cell adapter can be processed]

○ Test results and considerations

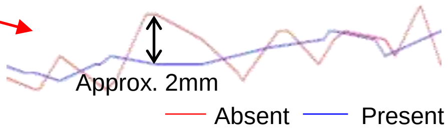
1) **The mirror surface (polished) condition of the PCV surface** is likely to have caused the 4mm error in the initial gap measurement results.

2) Since the work of removing the coating from the PCV steel plate before performing 3D scanning measurement was initially assumed to be part of the work procedure, the picture was taken in the polished condition.
While performing the measurement at the actual facility, a laser scanner will be used and a polish removing spray#, etc. will be used so that the shining surface does not have an impact.



Picture of the PCV steel plate

Effect of the polish removal spray



The reduction in noise (unevenness) was verified by comparing the measurement results before and after application of the polish removal spray.

Name: HELLING 3-D Anti Glare Spray
Color: White

Based on the measurement results obtained from the additional test after using the polish removal spray, when the cell adapter end was manufactured once again, **the maximum gap was 1.6mm**.

[Operation at the actual facility]

The procedure while using the actual facility was revised, so that **a rigid template member processed based on the results of measurement performed** using the 3D scanner is first inserted, the gap after insertion is confirmed and the template is pulled out, **the PCV steel plate connecting surface is processed further, the shape with which the gap can remain within the allowable value is finalized,** and then the cell adapter is processed.Thereafter the cell adapter is processed and installed. This revised procedure further improves accuracy.

Exce

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-1 Verification of the method of installing the cell adapter by remote operation

(Aim)

- **As the cell adapter is a high-dose radiation environment, it is required to be transported and installed by remote operation, and a gap of 5mm or less needs to be provided for the welded connection surface between the cell adapter and the PCV in order to ensure welding integrity.**
- **Hence the transportation method and installation method of the cell adapter are substantiated, the validity of the studied structure is confirmed by verifying the insertion procedure through tests and the required specifications if the operation has to be performed remotely are identified.**

(Expected outcome)

- **Establishment of cell adapter transportation and installation methods, verification of installation accuracy, validation of the boundary structure and clear specification of required specifications of the equipment for remote operation.**

➢ The cell adapter (manufactured during the element test ②) is inserted in the simulated body, and the interference risk, positioning and workability are verified.
- The cell adapter is loaded on a simple cart and is inserted into the BSW opening along the cell installation frame.
- The risk margin of interference with the shielding door, BSW opening and the X-6 penetration when the work of inserting the cell adapter is being performed is verified.
- It is verified that the gap between the shielding door frame/PCV steel plate frame and the cell adapter is within the allowable range.

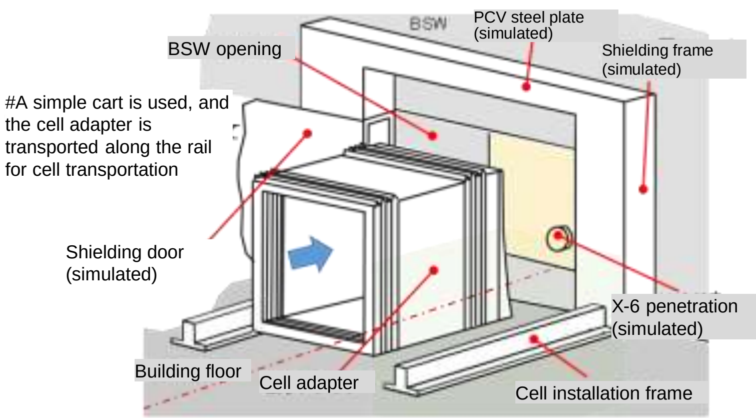


Illustration of the work of transporting the cell adapter
#The simulated body used in element test ② is used.

The simple cart on which the cell adapter is loaded is installed on the cell installation frame
↓
The height of the cell adapter is adjusted (Height ①)
↓
The cell adapter is moved forward towards the PCV until it completely enters the shielding door frame
↓
The height of the cell adapter is adjusted (Height ②)
↓
The cell adapter is inserted completely into the PCV (positioned using a guide pin)
↓
Accuracy of the installation position (Top and bottom, left and right: error ± 7.5mm or less)
↓
Verification of the gap with the PCV steel plate/shielding door frame (2.5mm or less)

[Supplement]
The risk margin of interfering during insertion and the workability are verified, and the required specifications for remote operation are identified.

[Supplement]
The method of remotely verifying the gap is considered.

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-2 Verification of the method of installing the cell adapter by remote operation

Cell adapter insertion workflow

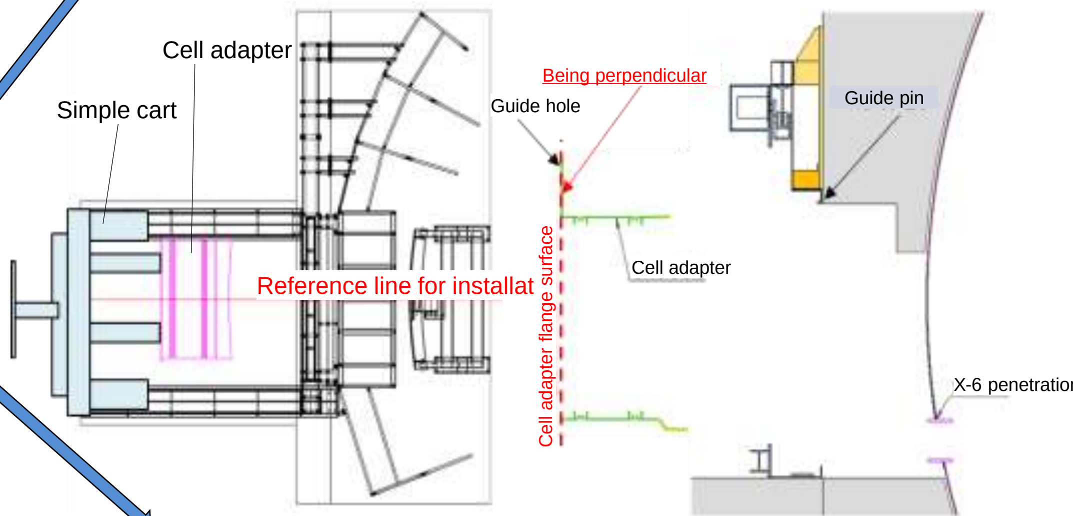
- **The simple cart on which the cell adapter will be loaded is installed on the cell installation frame.**
  - **The cell adapter is loaded on the simple cart.**
  - ↓ **The position of the cell adapter on the simple cart is adjusted. (Centering, leveling)**
  - ↓ **Change in shape (vertical) of the cell adapter in its installed state is checked.**
  - ↓ **The simple cart is moved forward along the cell installation frame up to the shielding door.**
- ↓ **Height of the cell adapter is adjusted (Height ①)**
- ↓ **The cell adapter is moved forward towards the PCV until it is completely inside the shielding door frame.**
- ↓ **Height of the cell adapter is adjusted (Height ②)**
- ↓ **The cell adapter is inserted completely on the PCV side. (Positioning with the help of the guide pin)**
- ↓ **Verification of the gap with the PCV and verification of the cell adapter installation position**

The feasibility of positioning the cell adapter with the guide pin method is verified in this element test.

Important points related to positioning the cell adapter

・ Horizontal adjustment of the cell adapter (making sure the cell adapter flange surface is perpendicular)

・ Centering of the cell adapter with respect to the reference line for installation



・ Change in shape of the cell adapter when it is loaded on to the simple cart (vertical direction)
Since the cell adapter is held in place by the sipping bolts, the bellows part does not sag, but this is verified for reference.

・ It is ensured that the cell adapter can be moved forward without any shift in its position and after moving forward the position of the cell adapter is checked once again.

・ The guide pin is centered with respect to the guide hole (fine vertical adjustments)

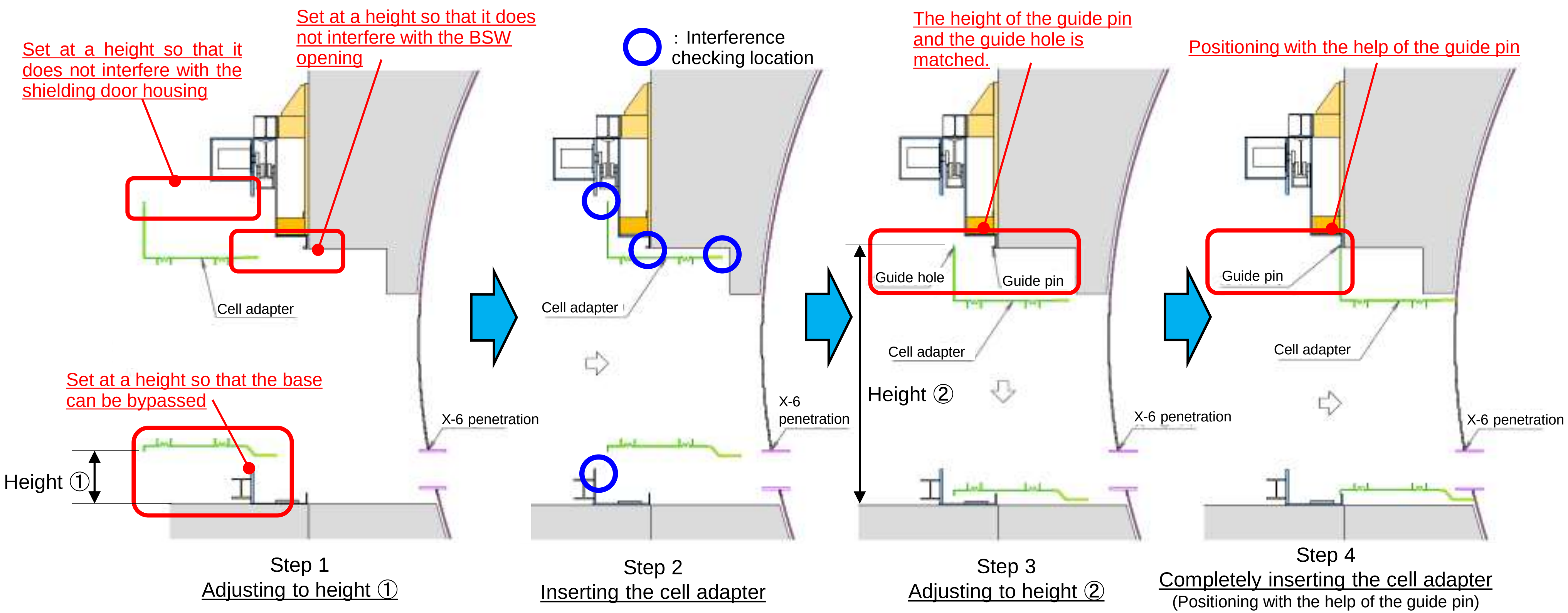
[Actions to be taken if the position needs to be corrected] If the gap exceeds the permissible value
The guide hole should be provided with a clearance of ±2.5mm*, and the position of the cell adapter should be finely adjusted so that the gap is 2.5mm or less (the cart should be provided with an adjustment function).
* Set conservatively as against a ±7.5mm (provisional value) lateral slip margin

① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Element test plan ③-3 Verification of the method of installing the cell adapter by remote operation

Process	Verification items	Remarks (Dimensions are based on ½ scale)
Step 1	Cell adapter height ①	Design value: 360 - 460mm
Step 2	Risk margin of each interference checking location	—
Step 3	Cell adapter height ②	Design value: 2000mm
Step 4	Deviation of installation position	Details on the following page
	Gap between cell adapter/shielding door frame	Details on the following page
	Gap between the cell adapter/PCV steel plate surface	Details on the following page



① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Element test plan ③-4 Verification of the method of installing the cell adapter by remote operation

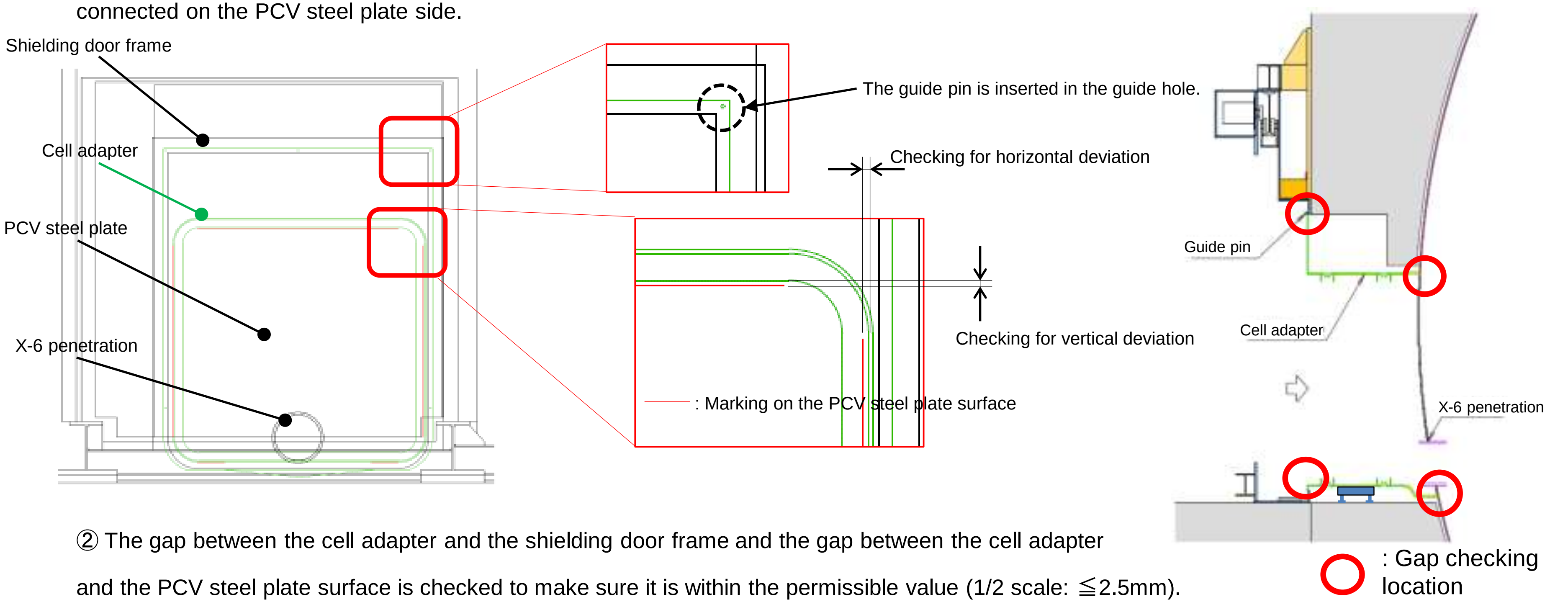
・ Verification after inserting the cell adapter

① It is verified whether the accuracy of installation position is within the permissible value (1/2 scale: ≦±7.5mm).

[Verification method]

・ Shielding door frame side: The guide pin is inserted in the guide hole.

・ PCV steel plate side: Checking for shift in the position of the cell adapter from the marking of position where the cell adapter is planned to be connected on the PCV steel plate side.



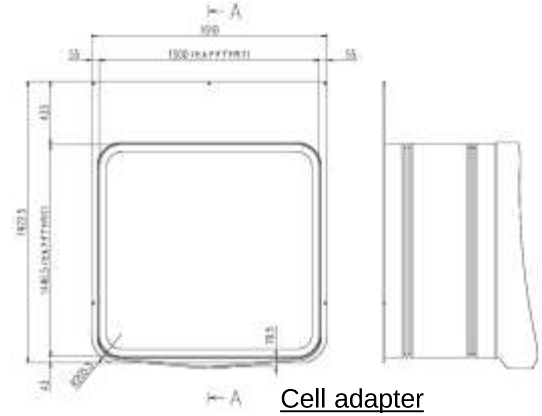
② The gap between the cell adapter and the shielding door frame and the gap between the cell adapter and the PCV steel plate surface is checked to make sure it is within the permissible value (1/2 scale: ≦2.5mm).

① Installation of large heavy structures

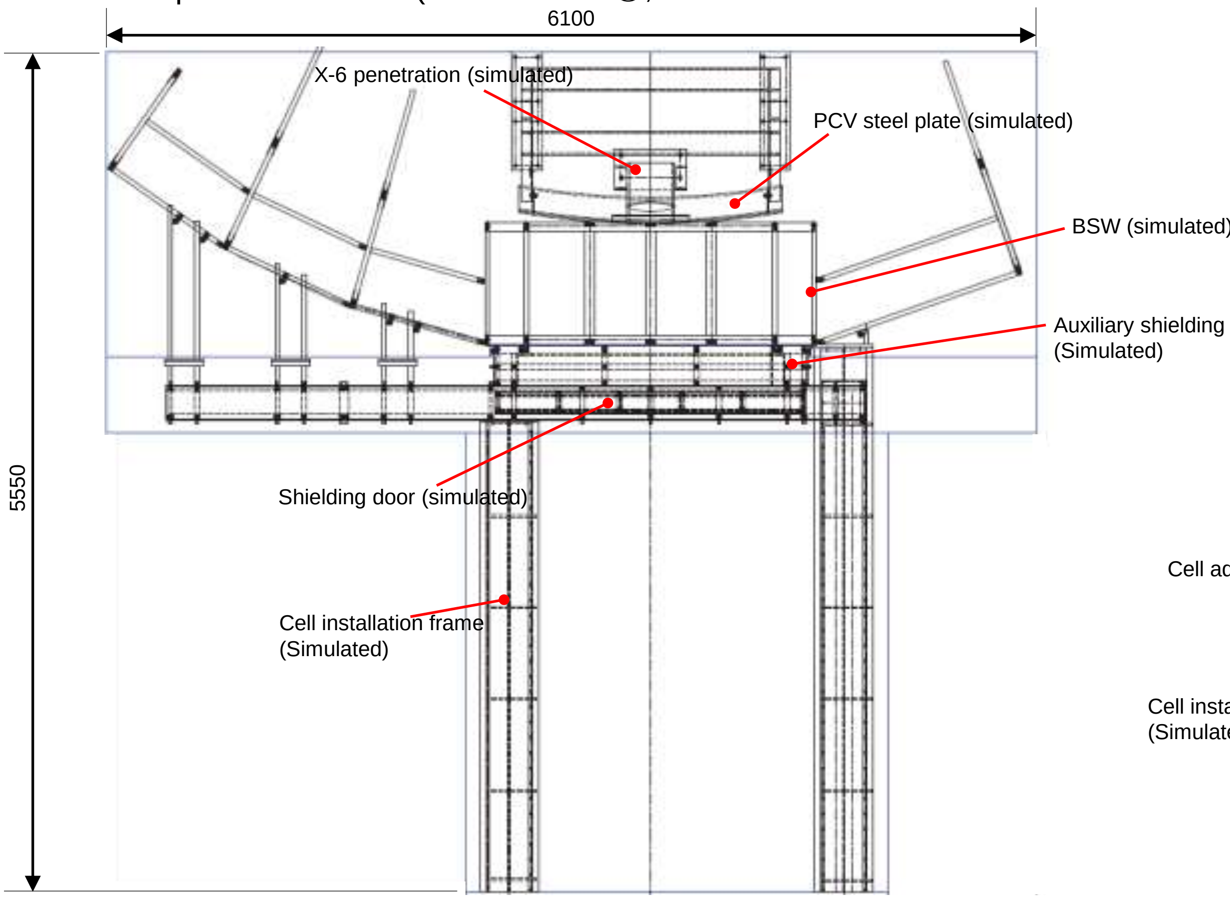
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

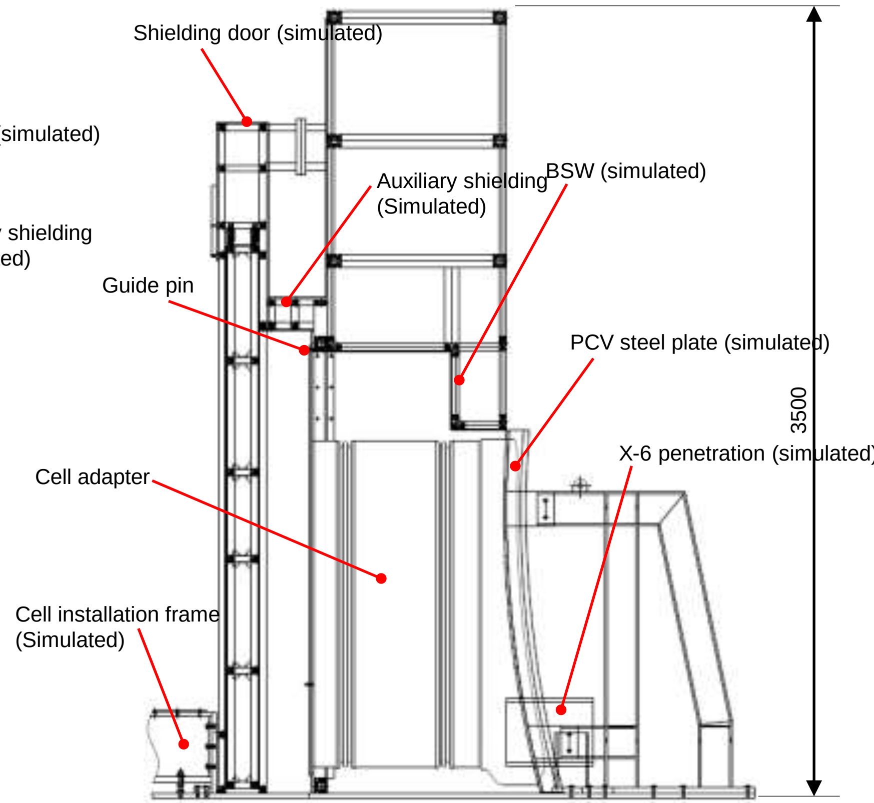
- Time of implementation： Early December 2022 onwards (Tests completed)
- Location: In the premises of the Mitsubishi Heavy Industries, Kobe Shipyard
- Test piece: 1/2 scale (Element test ②, used for the overall verification test as well)



Cell adapter



Test piece Layout drawing

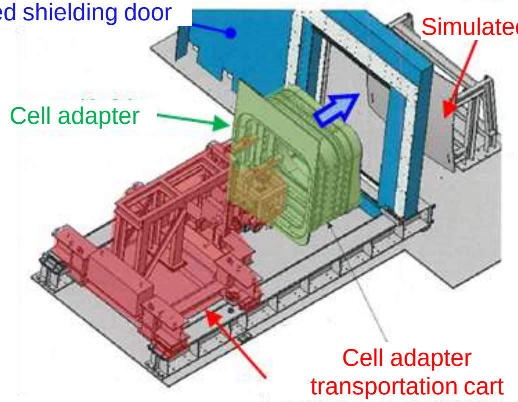


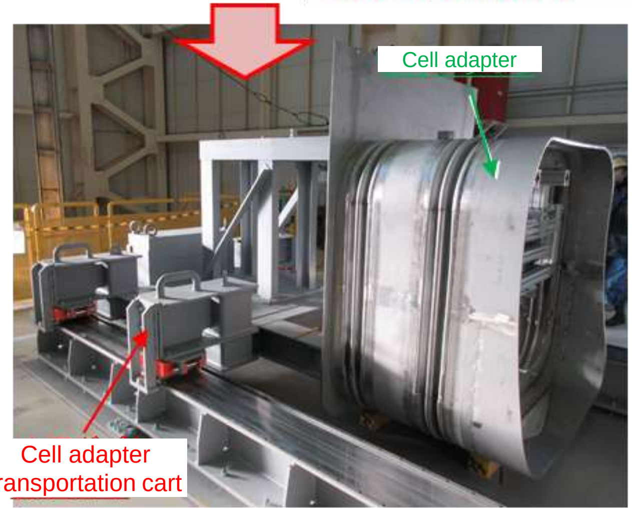
Test piece Cross-section

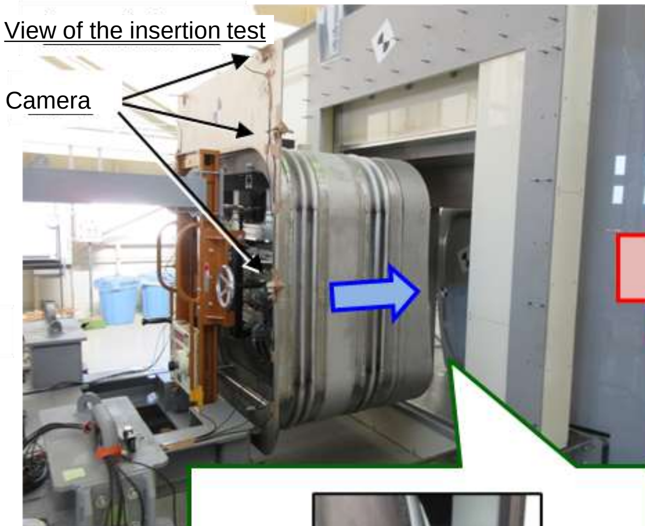
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment] No.101

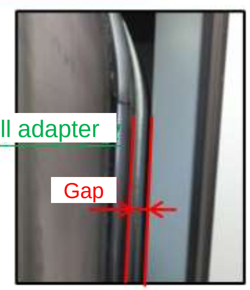
① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation









Verification of gap with the shielding door while inserting

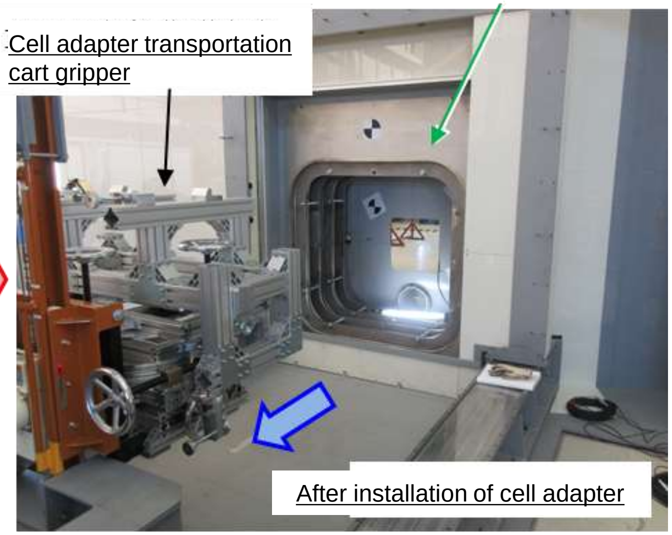


Image captured by the camera installed on the cell adapter

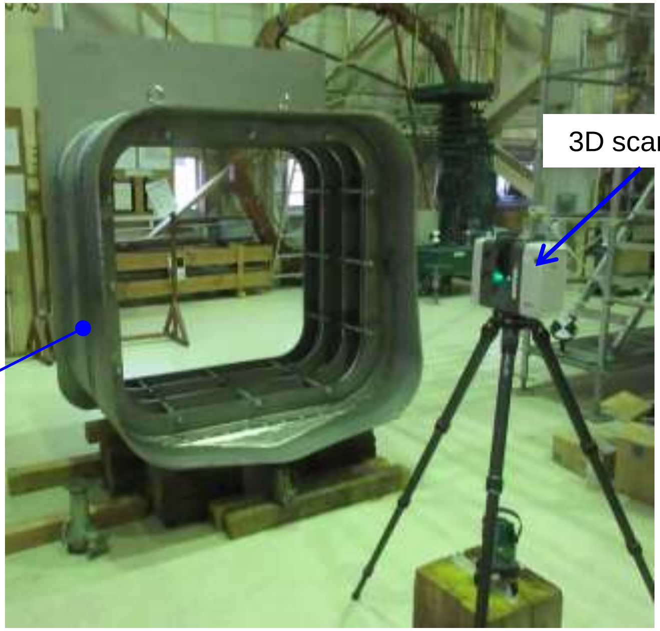
① **Installation of large heavy structures**

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test method

1) A 3D model of the cell adapter is created by 3D scanning the cell adapter for which the connection surface with the PCV steel plate has been processed.

Finished cell adapter



3D measurement of the PCV connecting surface of the cell adapter

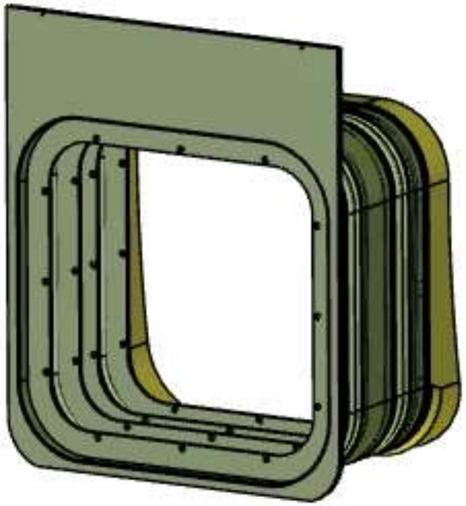


Illustration of the 3D model of the cell adapter after processing

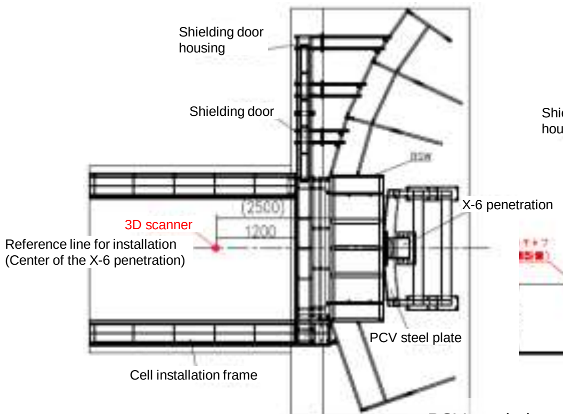
① Installation of large heavy structures

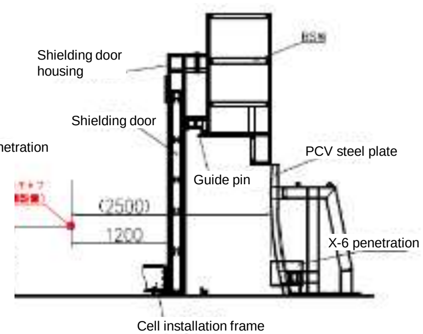
(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

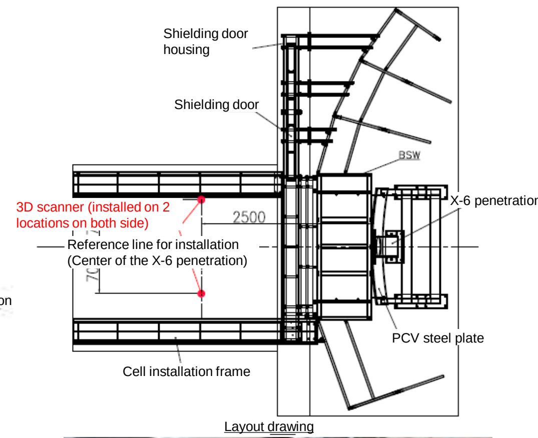
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

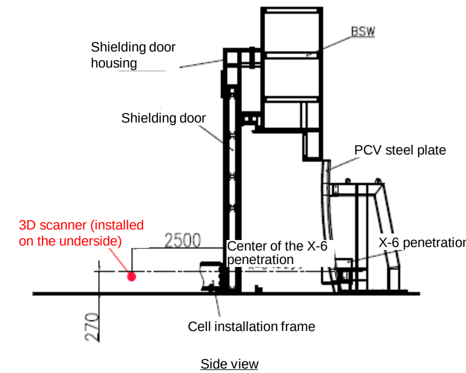
○ Test method

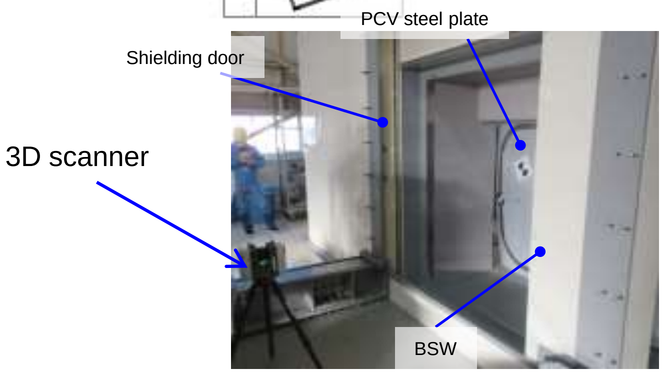
2) 3D measurement data is acquired while the PCV steel plate, X-6 penetration, BSW and shielding door are assembled.



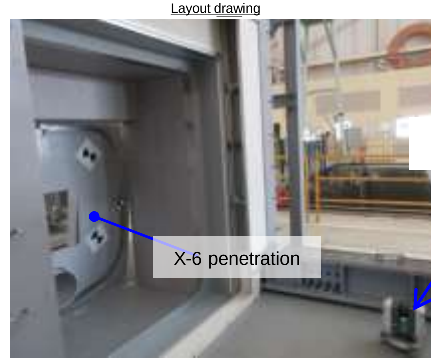








3D scanner at the center of the test piece



3D scanner on the right side of the test piece

3D scanner on the left side of the test piece

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

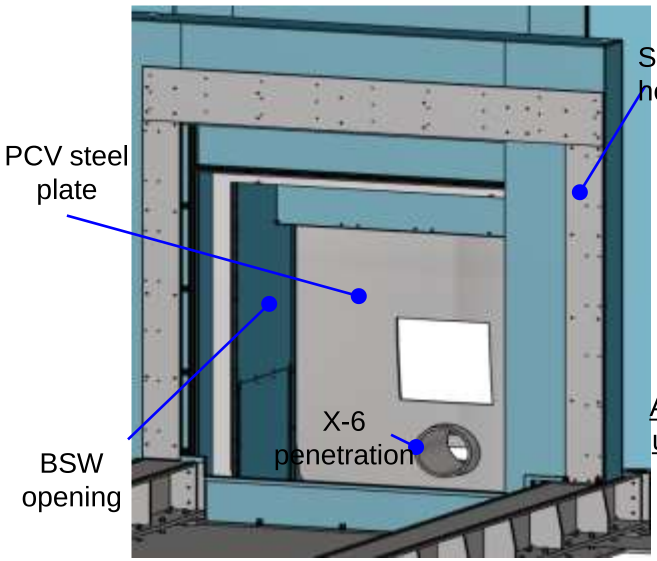
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test method

3) The measured data mentioned earlier is combined and the following items are verified.

(a.) Specification of the guide pin hole position on the cell adapter flange

(b.) Ascertaining the planned gap when the cell adapter is inserted



Mock-up side 3D model

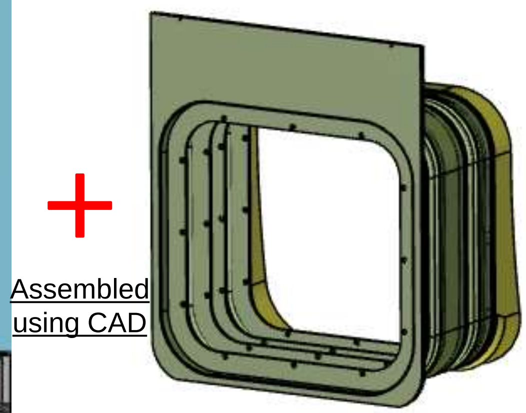
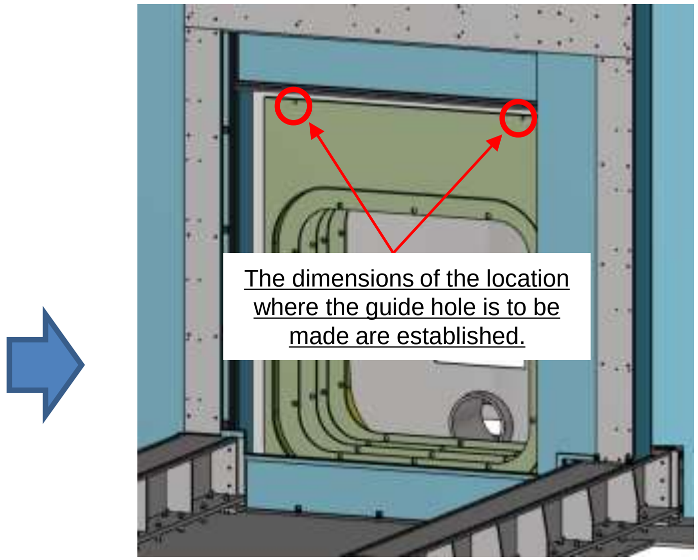


Illustration of the 3D model of the cell adapter after processing



Assembled using 3D CAD (Ascertaining the location on the part where the guide hole is to be made)

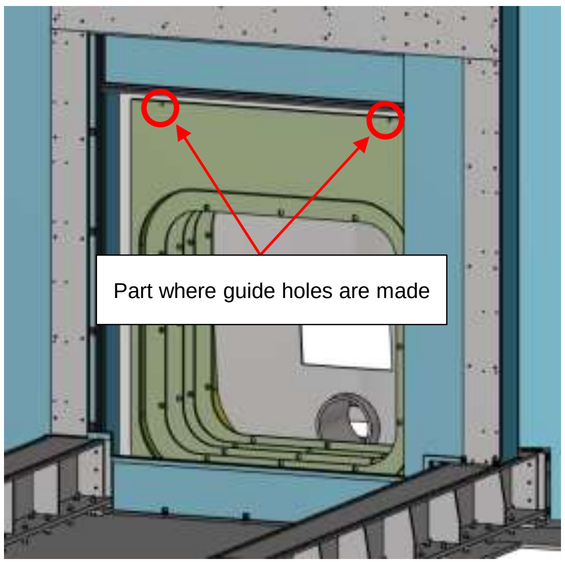
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test method

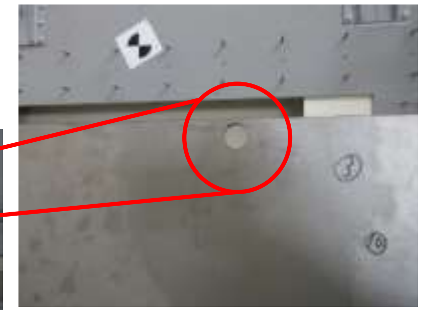
4) The cell adapter guide pin holes are made based on the positional dimensions confirmed using 3DCAD.



Location on the part where the guide hole is to be made indicated using 3D CAD

Guide pin hole on the right side

Making the cell adapter guide pin hole



Guide pin hole on the right side

① Installation of large heavy structures

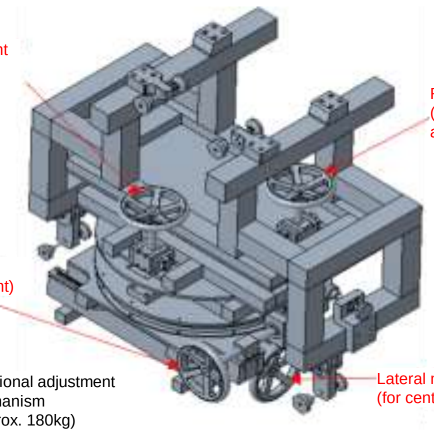
(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

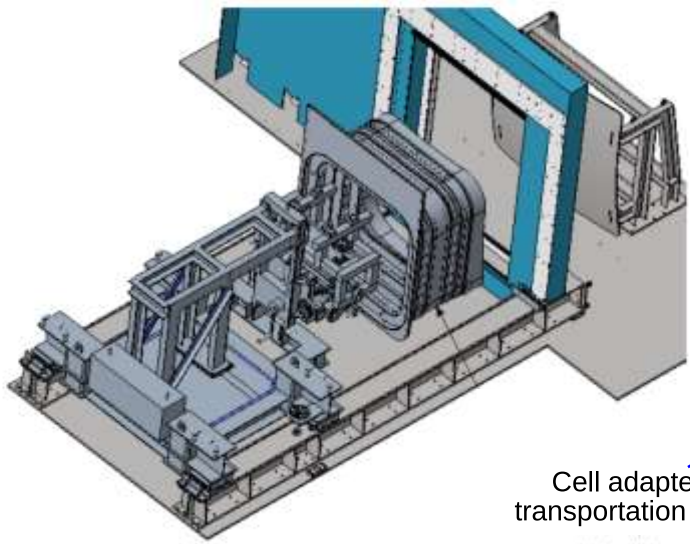
〇 Test method

5) The cell adapter is loaded on the simple cart.
6) The cell adapter is positioned before starting to insert it.
- Leveling of the cell adapter
- Making sure that the central axis of the cell adapter coincides with the reference line for installation
- Verifying the extent of change in shape (vertical sagging) of the cell adapter

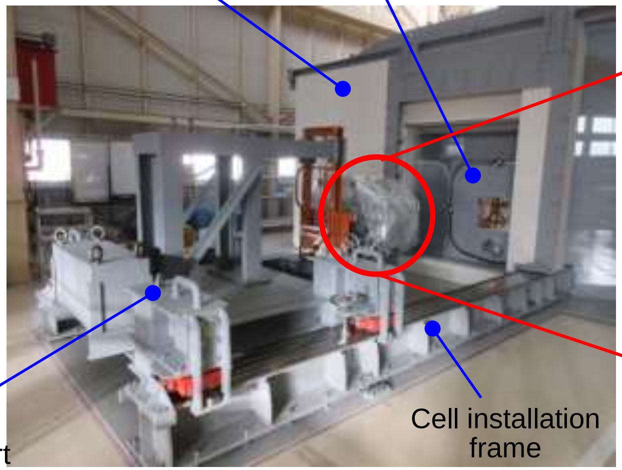
7) The shielding door is completely opened.



Cell adapter position adjustment mechanism



Cell adapter transportation cart installation status （3D CAD）



Cell adapter transportation cart installation status (photo)

State of the cell adapter when loaded (photo)

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

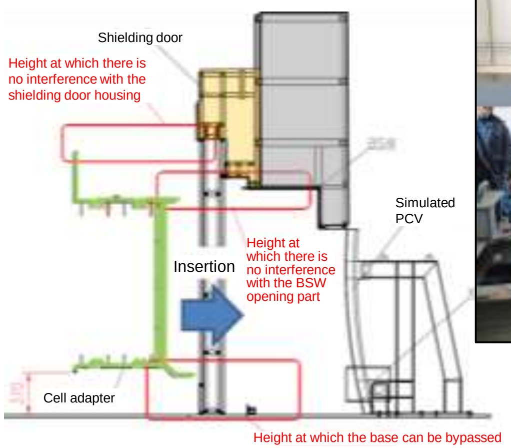
Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface

○ Test method

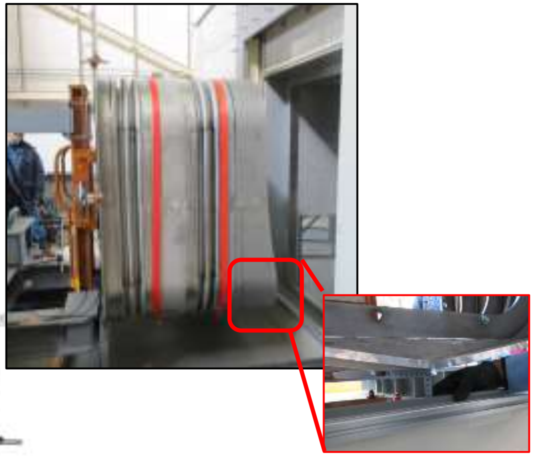
8）The cell adapter is inserted.

a) The height of the cell adapter is adjusted so that it can pass through the shielding door frame of the shielding door and the BSW opening (Each height is verified).

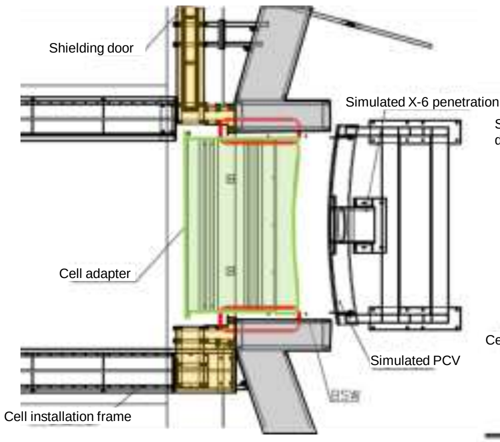
b) The cell adapter flange part is moved forward until it enters on the PCV side from the end of the shielding door frame while checking for interfering objects (The margin for interference and the heights of the positions are verified).



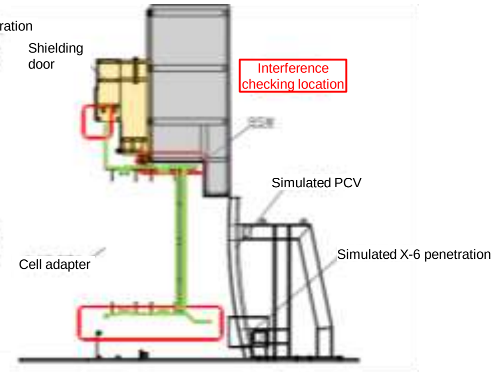
Cross-section of Step 1



Status at Step 1 (photo)



Step 2 from the top



Cross-section of Step 2

① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface

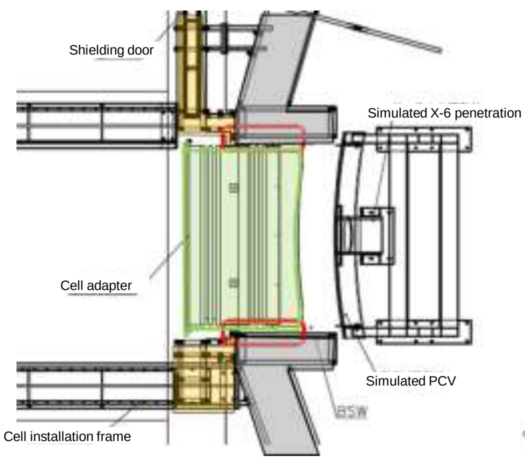
○ Test method

8) The cell adapter is inserted.

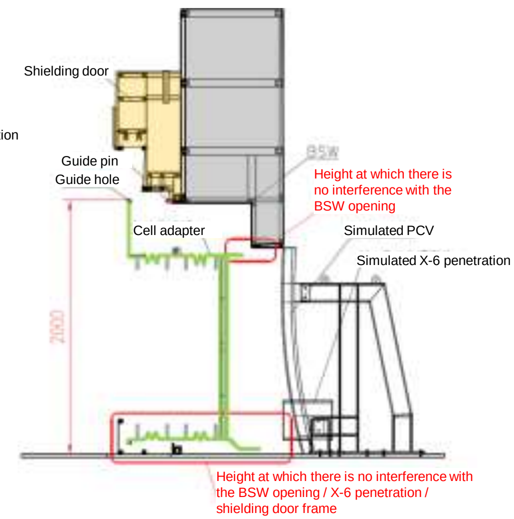
c.) The height of the cell adapter is reduced so that the height of the guide pin on the shielding door frame side and that of the guide hole of the cell adapter coincide (The margin for interference and the heights of the positions are verified).

d.) The cell adapter is moved forward until the tip of the cell adapter comes in contact with the PCV steel plate surface while checking the margin for interference and making sure that the guide pin on the shielding door frame side enters the cell adapter guide hole.

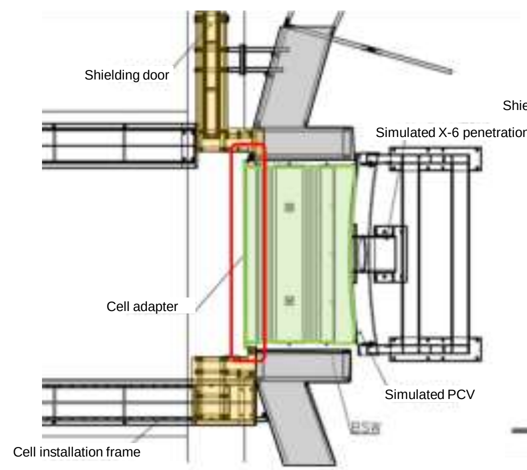
Fine adjustments are made as required in the position of the cell adapter (The margin for interference and the heights of the positions are verified).



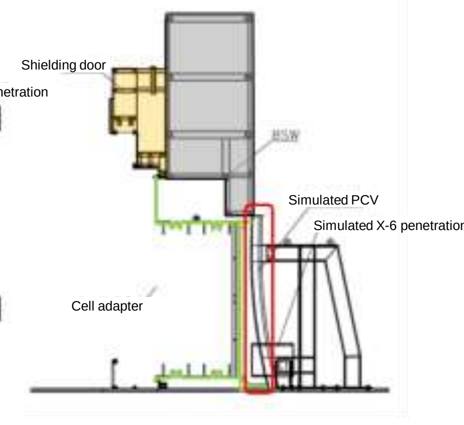
Step 3 from the top



Cross-section of Step 3



Step 4 from the top



Cross-section of Step 4

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

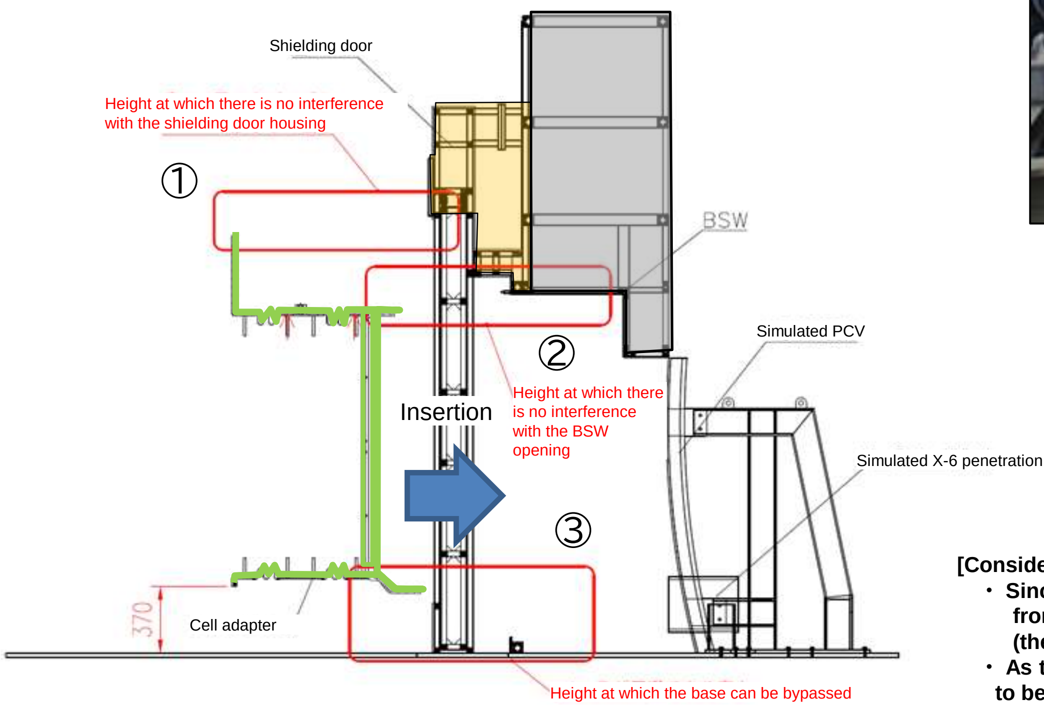
Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface

○ Test method

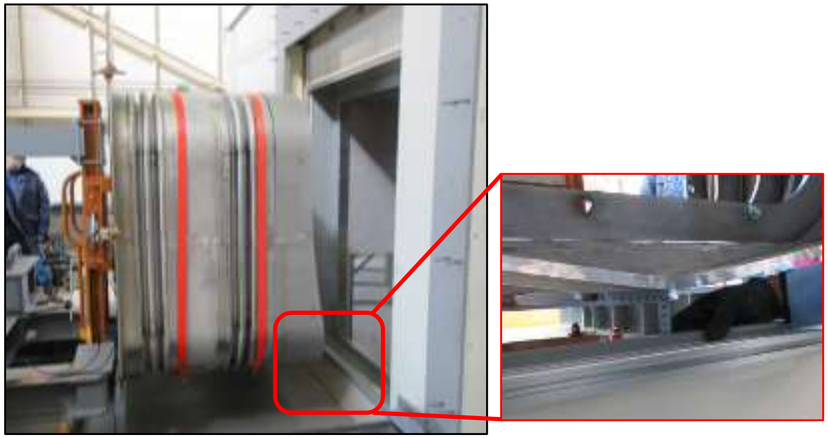
[Verification of the margin of interference with the shielding door and the BSW opening when the cell adapter is inserted]

a.) Verification of margin of interference in Step 1

・Only the position is set, as the cell adapter is in its initial state before transportation.



Cross-section of Step 1



Status at Step 1 (Picture)

No.	Verification site		Actual measured value (mm)	Design value (mm)
	Cell adapter side	Item with which there is interference		
①	Top of the tip	Top of BSW opening	100	95
②	Upper end of the flange part	Shielding door housing	91	71
③	Bottom of the tip	Shielding door housing	51	71

[Considerations and evaluation]

- **Since the difference between ② and ③ is the cell adapter flange, a broader area is set from the perspective of making the gap between the upper end and the BSW visible (the lower end is visible).**
- **As the cell adapter is in its initial state before insertion, similar settings are planned to be made when working with the actual cell adapter or improvements are planned to be made using a camera.**

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

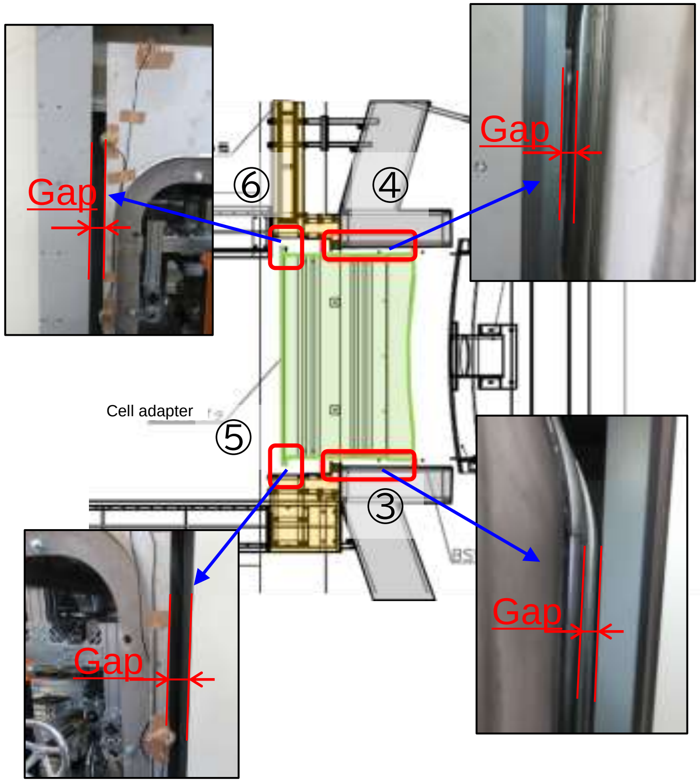
Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface

○ Test method

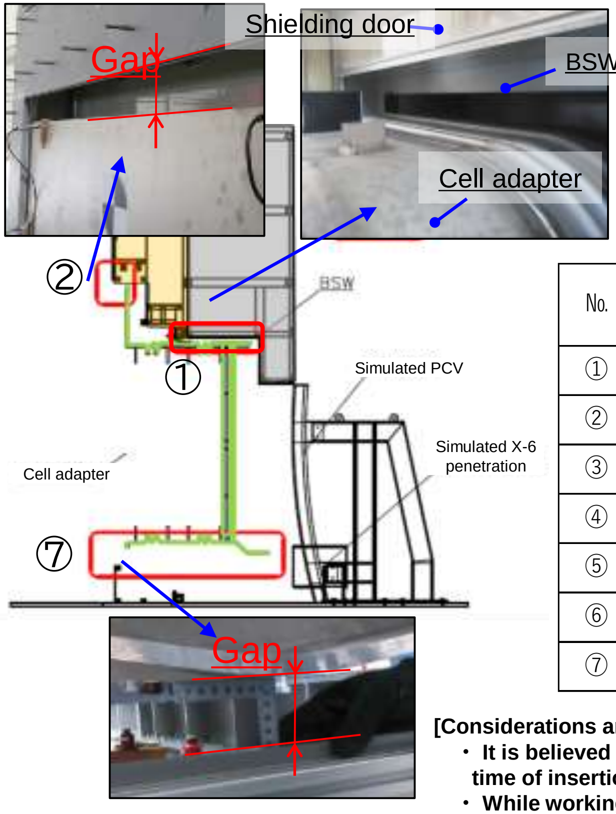
[Verification of the margin of interference with the shielding door and the BSW opening when the cell adapter is inserted]

b.) Verification of margin of interference in Step 2

- **It is determined that as the BSW opening is small it would be advisable to increase the margin on both sides of the tip.**



Step 2 from the top



Cross-section of Step 2

No.	Verification site		Actual measured value (mm)	Design value (mm)
	Cell adapter side	Item with which there is interference		
①	Top of the tip	Top of the BSW opening	100	95
②	Upper end of the flange part	Shielding door housing	91	77
③	Right surface of the tip	Right surface of the BSW opening	8	16
④	Left surface of the tip	Left surface of the BSW opening	23	16
⑤	Right tip of the flange part	Shielding door housing	62	77
⑥	Left tip of the flange part	Shielding door housing	59	77
⑦	Bottom of the tip	Shielding door housing	51	71

[Considerations and evaluation]

- **It is believed that the difference in ③ and ④ is caused by the shift at the time of insertion.**
- **While working at the actual facility improvements are planned to be made by constantly monitoring with a camera.**

① Installation of large heavy structures

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

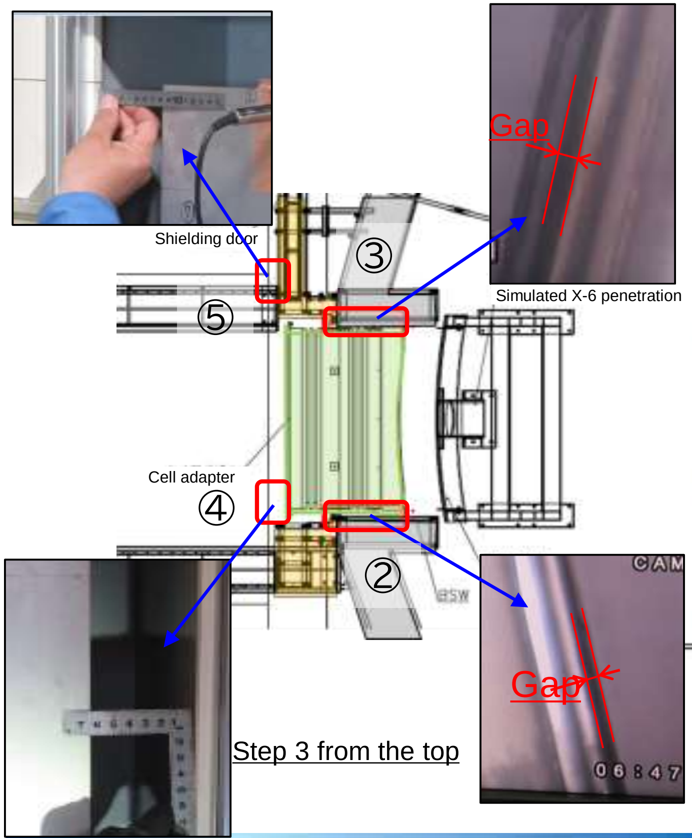
○ Test method

[Verification of the margin of interference with the shielding door and the BSW opening when the cell adapter is inserted]

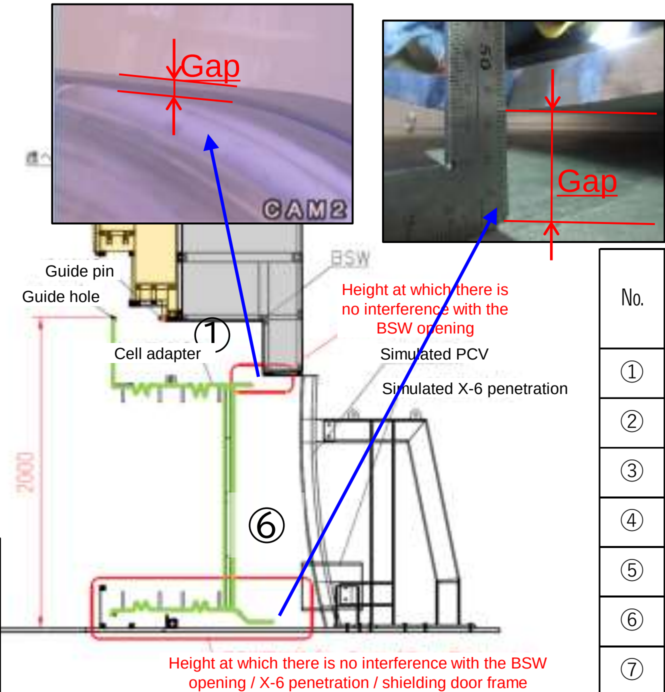
c.) Verification of margin of interference in Step 3

- **As the tip of the cell adapter flange part is not visible during insertion, verification is performed using a camera, etc.**

Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface



Step 3 from the top



Cross-section of Step 3

No.	Verification site: Cell adapter side	Verification site: Item with which there is interference	Actual measured value (mm)	Design value (mm)
①	Top of the tip	Top of the BSW opening	51	47
②	Right side of the tip	Right side of the BSW opening	25	30
③	Left side of the tip	Left side of the BSW opening	35	30
④	Right end of the flange part	Shielding door housing	62	67
⑤	Left end of the flange part	Shielding door housing	77	67
⑥	Bottom of the tip	Lower end of the X-6 penetration	72	64
⑦	Bottom of the tip	Bottom of the BSW opening	34	39

[Considerations and evaluation]

- **The numbers when installation is half way through can be used for the difference with the design value without any problems.**
- **Visibility is good. While working at the actual facility insertion is planned to be performed by constantly monitoring with a camera.**

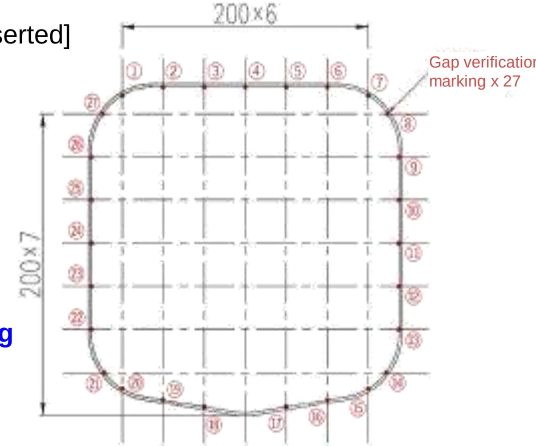
① Installation of large heavy structures

Process	Verification items
Step 1	Cell adapter height ①
Step 2	Risk margin of the interference checking locations
Step 3	Cell adapter height ②
Step 4	Deviation of installation position
	Gap between cell adapter / shielding door frame
	Gap between cell adapter / PCV steel plate surface

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

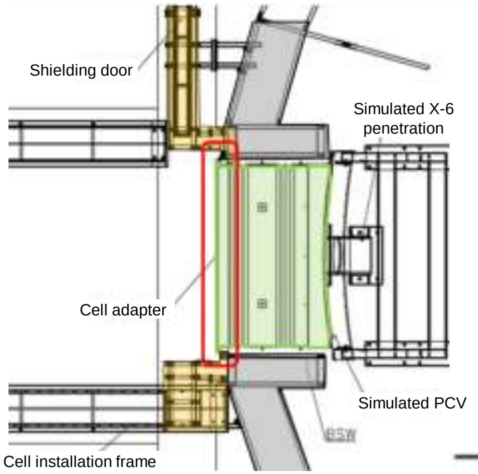
○ Test results

[Verification of the margin of interference with the shielding door and the BSW opening when the cell adapter is inserted]

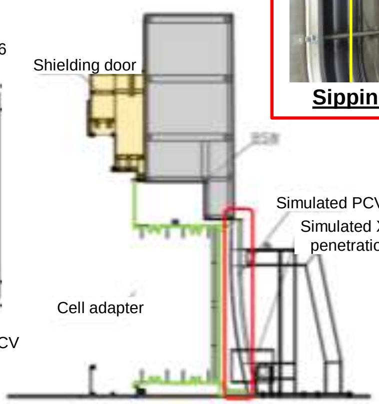


[Considerations and evaluation]

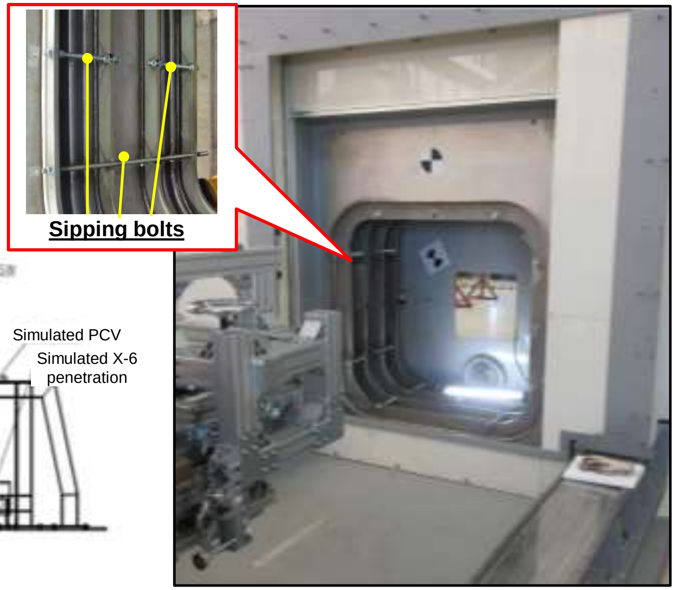
1) **After insertion, when the gap with the opening part was verified, it was found that an almost sufficient gap was secured, and thus the cell adapter can be favorably installed.**
2) **It was possible to keep a gap of maximum 2.4mm with the cell adapter after insertion as against the allowable gap of 2.5mm or less.**
3) **While positioning the cell adapter its entire length needs to be adjusted. The adjustment can be performed using the sipping bolts in between the bellows (The effectiveness of adjustments made using the sipping bolts is verified.)**



Step 4 from the top



Cross-section of Step 4



Status after installation

[Gap measurement results] Evaluation criteria: ≦2.5mm

Measurement location	Gap measurement result (mm)	Measurement location	Gap measurement result (mm)	Measurement location	Gap measurement result (mm)
①	0.7	⑪	1.4	㉑	2.3
②	0.7	⑫	0.4	㉒	2.0
③	0.7	⑬	0.9	㉓	1.7
④	1.6	⑭	0.0	㉔	1.0
⑤	1.3	⑮	0.7	㉕	1.0
⑥	1.5	⑯	0.9	㉖	0.9
⑦	1.8	⑰	1.2	㉗	0.8
⑧	2.2	⑱	0.0		
⑨	2.4	⑲	1.5		
⑩	2.0	⑳	1.7		

Results of verifying the gap between the cell adapter and PCV steel plate after installation

① **Installation of large heavy structures**

(6) Implementation items (6) -3 -1 : c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test results

[Verification of the margin of interference with the shielding door and the BSW opening when the cell adapter is inserted]

1) The gap with the opening part was verified when the cell adapter was inserted and it was found that an almost sufficient gap was secured, and thus it became possible to install the cell adapter favorably.

2) However, there was a deviation of 8mm and 23mm in the gap between the distal end of the cell adapter and the shielding door frame.
(This is assumed to have been caused by the deviation at the time of insertion).

3) It is determined that there are no issues while working at the actual facility as continuous monitoring is performed using a camera, etc., but in an effort to increase the risk margin (including visibility, etc, while verifying the gaps), increasing the gap to about 50mm (1/1 scale) with respect to the dimensions (horizontal) of the opening in the lateral direction of the shielding door housing and the cell adapter flange connecting plate part is considered as well.

Further, the test was conducted at 1/2 scale this time, but the shape, curvature, allowable gap were matched and hence the results from the following page onwards can be applied to the actual facility of 1/1 scale. Moreover, during the test the rigidity of the bellows is maintained by the sipping bolts and thus it does not pose any issues in measuring the interference and gap during insertion.
Further, it was confirmed that the length can be adjusted with the help of sipping bolts.

① Installation of large heavy structures

(6) Implementation items (6) -3 -1： c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test results

[Validity of the guide pin and the guide hole position/size]

1) The cell adapter was inserted while positioning with the help of the guide pin, with pin size φ12mm and hole size φ22mm.
(Since the gap between the BSW and the cell adapter was approx. 25mm, the size of pin hole was kept at approx 22mm.)
Also, the location of the guide hole made on the cell adapter was finalized by verifying the connecting surface between the PCV steel plate and the cell adapter using 3D scanning data.
2) When the cell adapter was completely inserted, **it was confirmed that the guide pin was inserted into the guide hole without any issues, and that there was a gap of 1mm or more between the guide pin and the guide hole.**
(While working at the actual facility as well, the guide pin will be observed with the camera on the cell adapter transportation cart, and based on that the position can be adjusted.)
Also, the insertion position can be replicated within the scope of the guide pin.
3) It was confirmed that the installation method using the guide pin can be implemented without any issues.

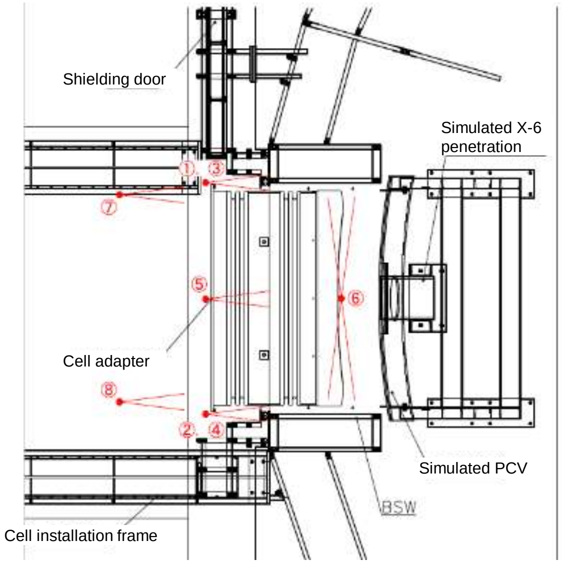
① Installation of large heavy structures

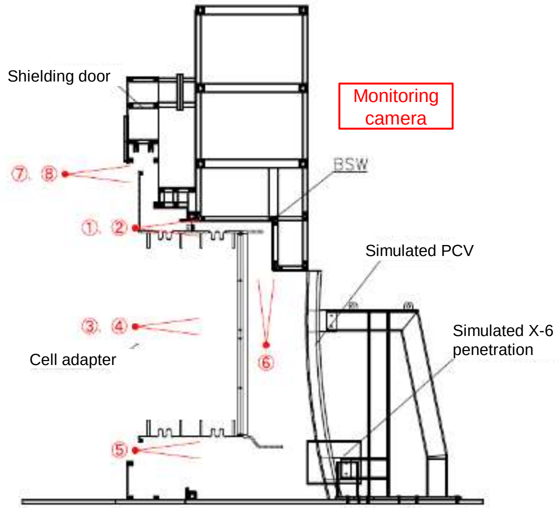
(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

○ Test results

[The points to be remotely monitored while inserting the cell adapter]

1) The interference with the shielding door housing or the BSW opening, and the positioning of the guide pin were verified with the help of a remotely operated camera.
2) In this test as well, the points to be remotely monitored while inserting were verified by installing a monitoring camera.
3) Moreover, the points that were monitored visually were identified as points to be remotely monitored.
Based on the above, it was determined that the cell adapter can be inserted while visually checking the status of the gaps remotely by installing cameras at the following points.
In the future, the method of fixing the cell adapter and the method of cable routing will be studied in detail.





- **Monitoring camera ①, ②**
  : For checking for interferences on the upper side of the cell adapter
- **Monitoring camera ③, ④**
  : For checking for interferences on the side of the cell adapter
- **Monitoring camera ⑤**
  : For checking for interferences on the lower side of the cell adapter
- **Monitoring camera ⑥**
  : For checking for interferences on the top of the cell adapter
- **Monitoring camera ⑦, ⑧**
  : For checking the guide pin / guide hole

① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures

[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

Consolidation of requirements concerning the cell adapter transportation cart

The required specifications and required functions of the equipment for remote transportation of cell adapter were noted.
Further, the work to be performed remotely on said part was planned to be divided among the equipment required for remote operation in the surrounding.

№	Required equipment	Requirements	Required functions
1	BSW drilling equipment	Making an opening in the BSW	Drilling the required opening (□3100mm) Detecting the PCV steel plate
2	X-6 penetration cutting equipment	Cutting the X-6 penetration plug and X-6 penetration	Verifying (camera), cutting and removing the X-6 penetration plug Verifying (camera), cutting and removing the X-6 penetration
3	Equipment for finishing the PCV steel plate	Removing the coating of the PCV steel plate, removing existing weld beads	Verifying the PCV steel plate (camera) Surface treatment by means of buffing
4	Cell adapter transportation cart	Grabbing, inserting, positioning, tack welding and gap measurement of the cell adapter	Grabbing mechanism of the cell adapter ・Mechanism for carrying-in (2 shafts: forward movement, up and down movement) ・Positioning mechanism (4 shafts: horizontal, yaw, pitch, roll) ・Movement pitch (Axis of rotation: 0.5°, lift travel: 5mm/rotation) Monitoring the gap between the cell adapter and the shielding door (camera, clearance gauge) Cell adapter gap measurement Monitoring the gap between the cell adapter and PCV steel plate (camera) Temporary fixing and welding of cell adapter and PCV steel plate Temporary fixing and welding of cell adapter and shielding door
5	Equipment for welding the cell adapter and PCV	Welding, inspection of external appearance	Welding and inspection of external appearance after welding (camera)
6	Equipment for welding the cell adapter and shielding door	Welding, inspection of external appearance	Welding and inspection of external appearance after welding (camera)
7	Equipment for removing the sipping bolts	Removing the sipping bolts (cutting)	Cutting and removing the sipping bolts Verifying the position of the sipping bolts, verifying after cutting (camera)

The test was conducted at 1/2 scale this time, the shape, gap, etc. were matched to present the requirements concerning the equipment for remote operation. Although the weight and rigidity were different than the actual facility, the rigidity of the bellows was maintained by means of sipping bolts and did not pose any issues. Thus the requirements can be applied as they are. However, handling the weight of the actual facility needs to be considered.

① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

Design concept of the transportation cart for the actual facility

1) The work of transporting and positioning the cell adapter and the work of tack welding shall be carried out using the same cart.
2) The cart shall be equipped with the following functions based on cell adapter transportation and position adjustment mechanism.
   (a.) Groove gap visual verification function (quantification of gap dimensions by image processing)
   (b.) Cell adapter tack welding function
      (Equipped with welding torch operation mechanism, wire feeding mechanism)

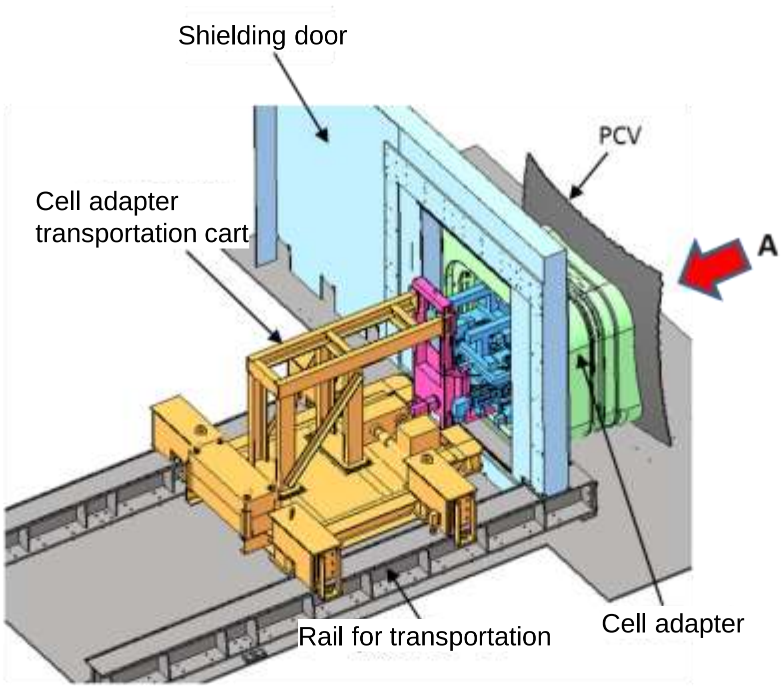


Illustration of cell adapter transportation work

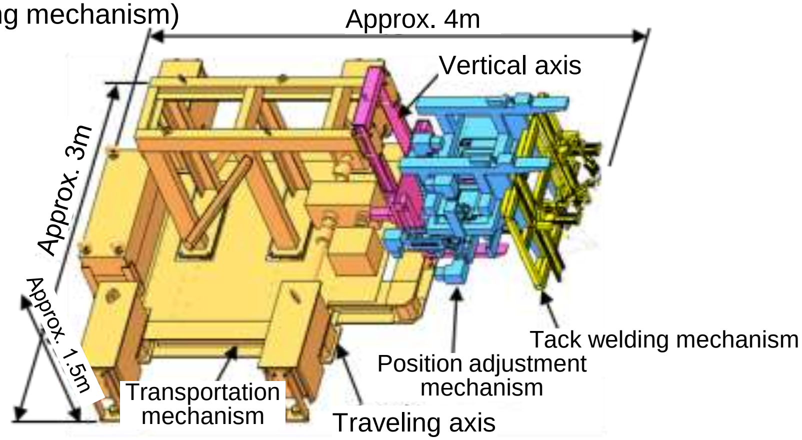
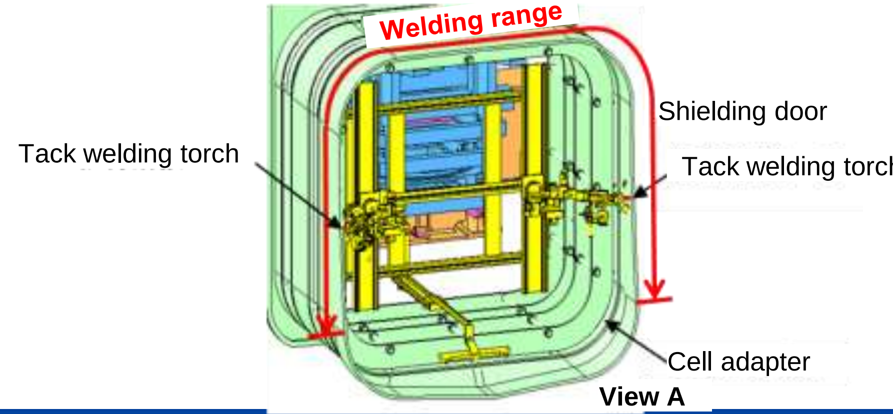


Illustration of the overall cell adapter transportation cart



View A

① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]: Element test plan ③-5 Verification of the method of installing the cell adapter by remote operation

Equipment specifications

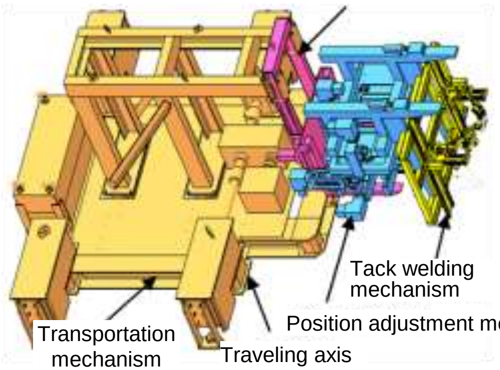


Illustration of the overall cell adapter transportation cart

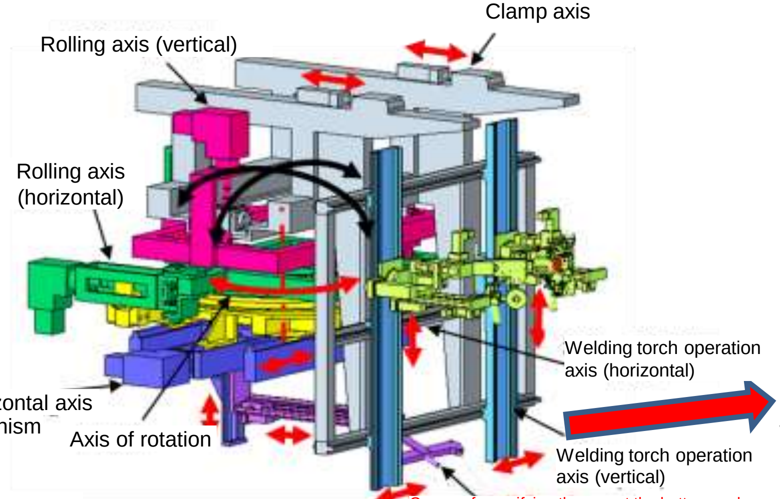
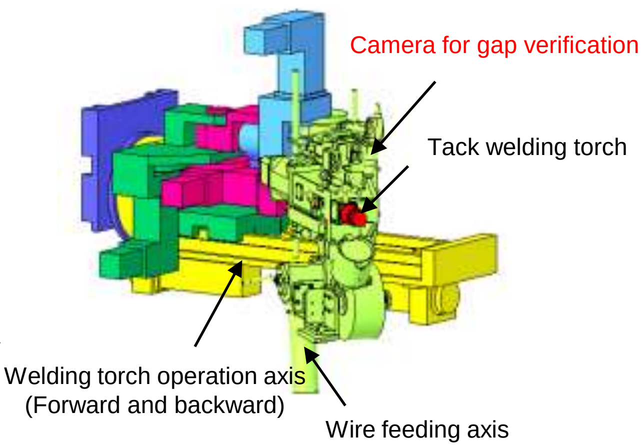


Illustration of the position adjustment mechanism and the temporary welding mechanism



Ilustration of the area around the temporary welding torch diagram

Items		Specifications
Main material		SS400, SUS304, Aluminum alloy
Function		Cell adapter transportation, positioning, groove gap verification, tack welding function (Tig welding) *Simultaneous welding at 2 locations possible
Transportation mechanism	Axial configuration	Traveling axis, vertical axis
	Actuator	Hydraulic cylinder, electric motor
Position adjustment mechanism	Axial configuration	Clamp axis, horizontal axis, axis of rotation, rolling axis (vertical, horizontal)
	Actuator	Electric motor
Tack welding mechanism	Axial configuration	Welding torch operation axis (forward and backward, vertical, horizontal), wire feeding axis
	Actuator	Electric motor

① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]: Element test plan ④ (Overall verification test)-1 Verification of viability of the boundary components

(Aim)
- **The method of installing the overall components (shielding door, cell adapter, cell installation frame) including the cell will be substantiated and the boundary components will be verified.**

(Expected outcome)
- **Establishment of the method of carrying-in and installing the overall components and verification of viability of the boundary components.**

➢ **The simulated fuel debris retrieval cell (partially simulated) is installed in the test equipment used in element tests ②, ③ and the boundary components are verified.**
- **The simulated cell is mounted on the cell installation frame and is moved along the cell installation frame up to the shieding door side.**
- **The simulated cell and the shielding door connecting plate are fastened.**
- **The boundary part is verified.**

⇒ **It is verified that the boundary has been formed.**

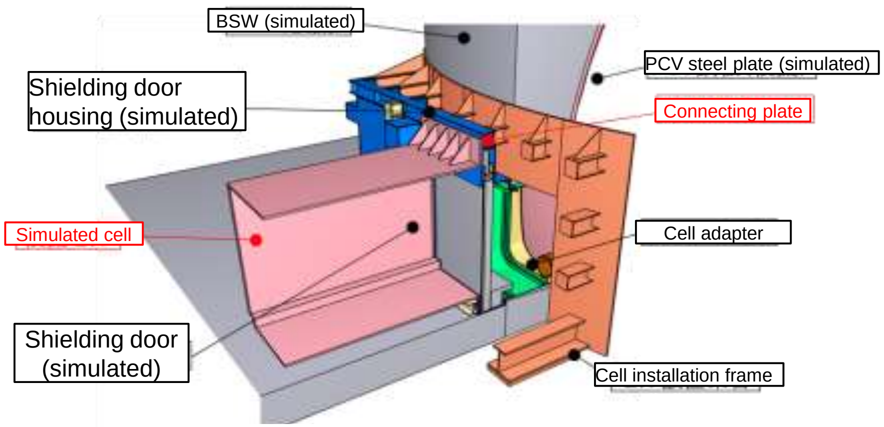


Illustration of simulated cell installation
#Simulated body is shared between element tests (2) and (3)

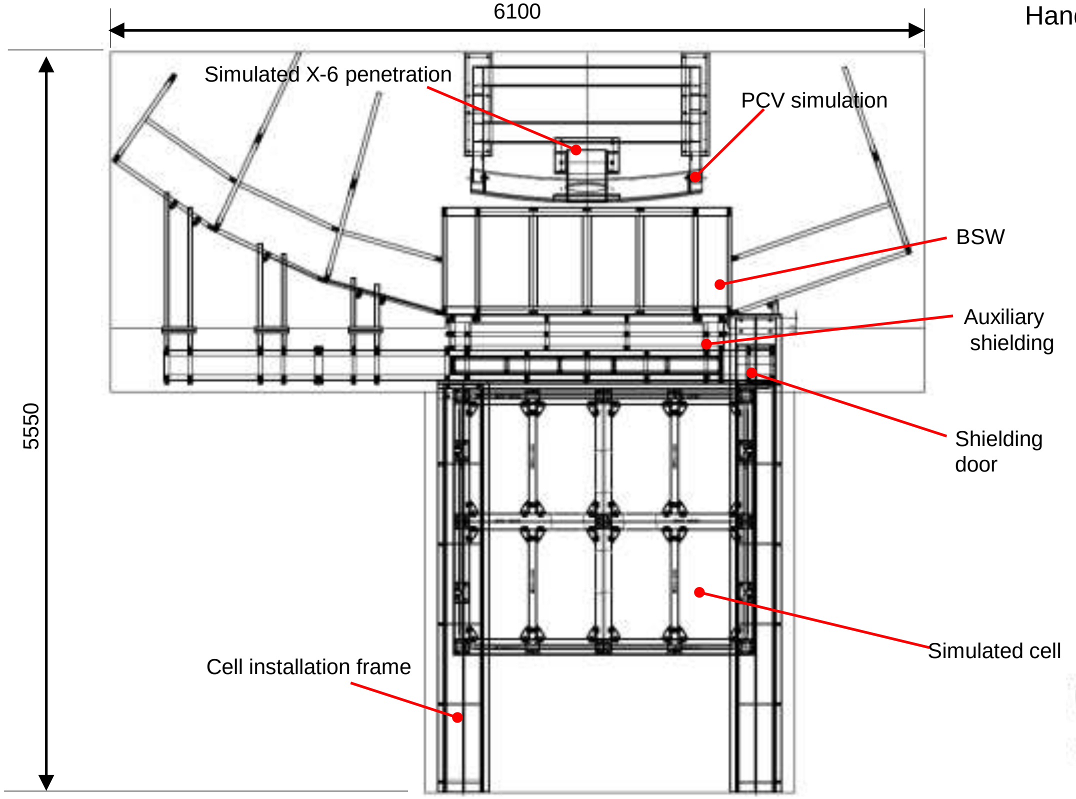
Preparing for simulated cell installation (Verifying that the shielding door is "closed")
↓
Mounting the simulated cell on the cell installation frame
↓
Moving the simulate cell up to the shielding door frame along the cell installation frame
↓
Fastening the flange for connecting simulated cell to the shielding door frame
↓
Verifying the housing part from inside (The shielding door should be "Open")

[Supplement]
The simulated body is at ½ scale.

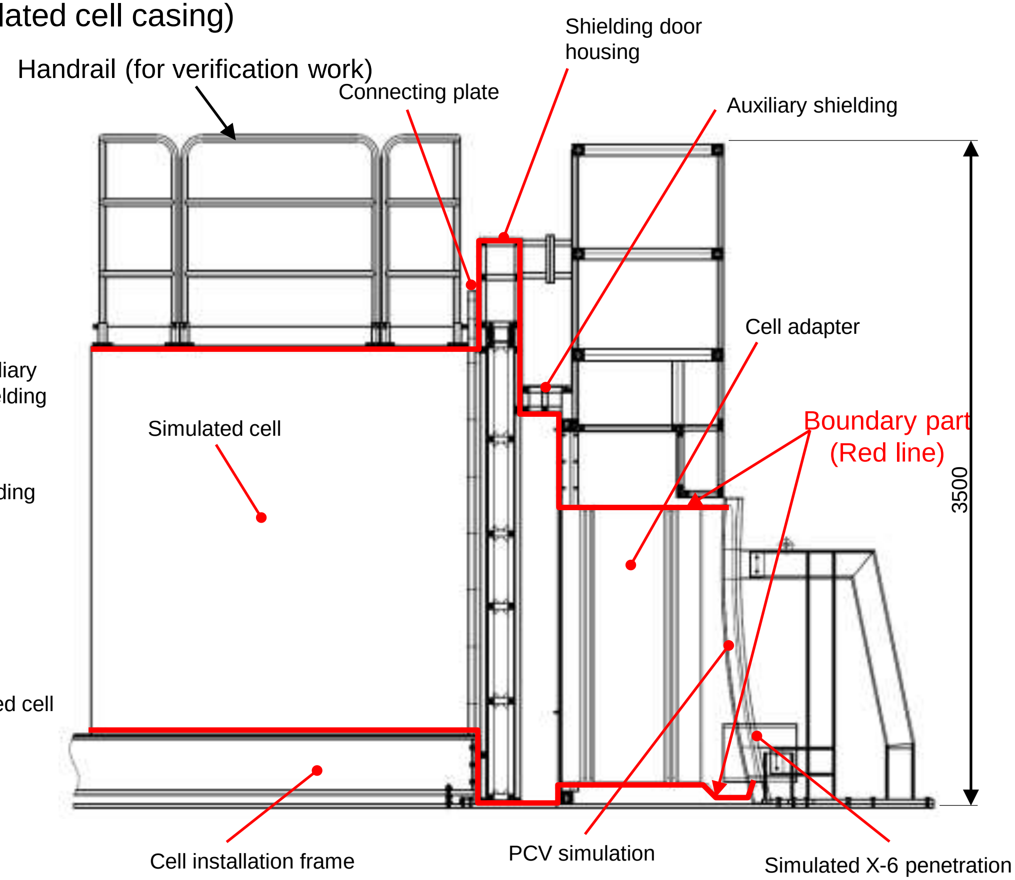
① **Installation of large heavy structures**

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]: Element test plan ④ (Overall verification test)-2　Verification of viability of the boundary components

- Time of implementation: Mid December 2022 onwards (Tests completed)
- Location: In the premises of the Mitsubishi Heavy Industries, Kobe Shipyard
- Test piece: 1/2 scale (Used in element tests ② and ③ ＋ simulated cell casing)



Test piece　　Layout drawing



Test piece　　Lateral view

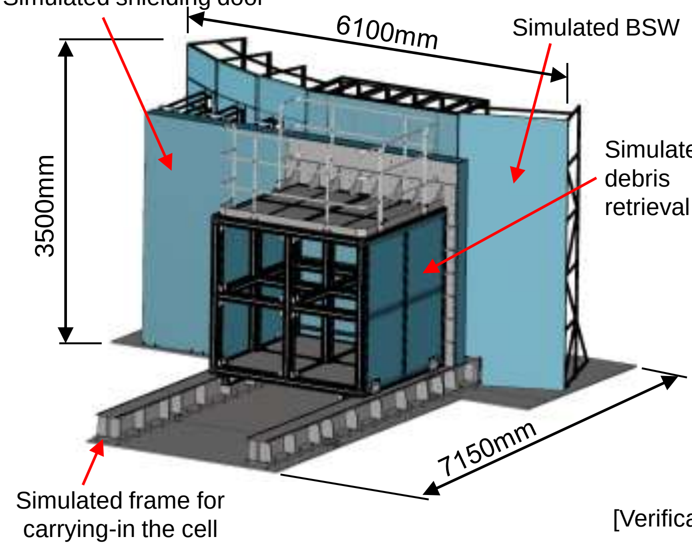
① Installation of large heavy structures

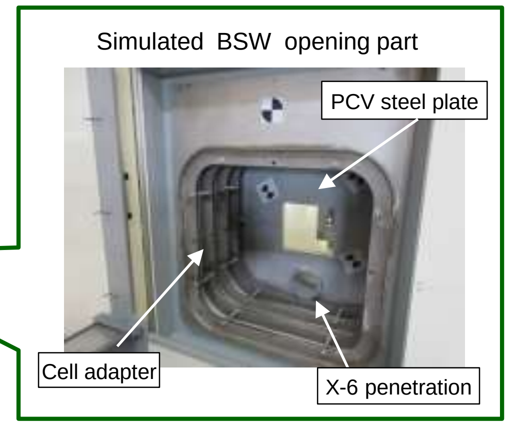
(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures

[Results]: Element test plan ④ (Overall verification test)-2 Verification of viability of the boundary components

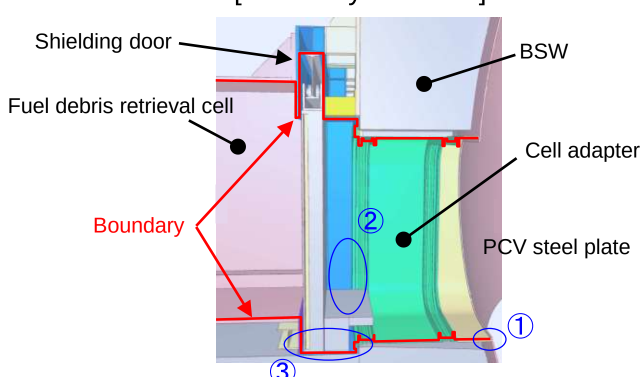
・The simulated fuel debris retrieval cell is installed and whether the boundary from the cell to the PCV steel plate has been formed is verified.

[Further, the test was conducted at 1/2 scale this time, but the shape, gap and curvature of the boundary part were matched and hence the results are applicable to the actual facility of 1/1 scale.
(Since the test is conducted at 1/2 scale, the rigidity of the flange part, etc. is higher, but to an extent that can be sufficiently taken into consideration while designing.)]

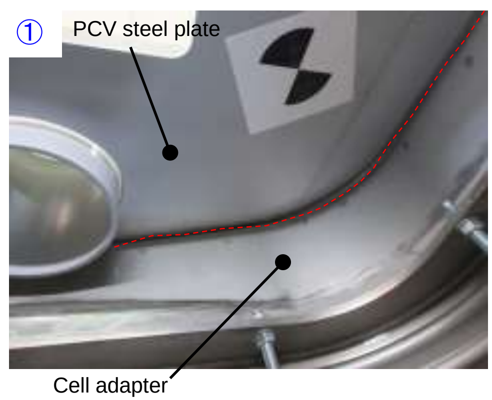


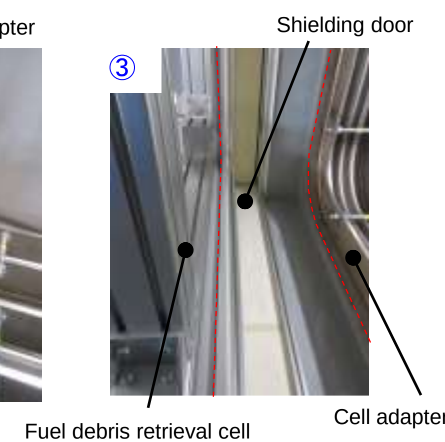


[Boundary structure]



[Verification of the boundary at the connecting part (part with the red dotted line)]





① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures
[Results]： Elemental test plan　Main verification items

[Key results]

Test	Verification items	Verification method	Evaluation criteria	Results	Scale of simulated body	Future examination	Technical viability / feasibility
Element test ①	Method of marking the reference line for installation	Verifying the actual value of the reference line for installation obtained by means of the 3D scanner by simulating the length based on the actual facility	Allowable error ≦±50㎜	Maximum error 25mm	1/1	Impact of radiation resistance of 3D scanner	Expected to materialize based on the prospects of studying the shielding structure
						Ensuring further margin for error (Study of margin of the cell arm)	Expected to be accomplished based on the detailed design in the future
Element test ②	Whether of not the cell adapter can be processed	Comparison of the shape of the cell adapter and the shape of the PCV steel plate after processing	Gap between the PCV steel plate and the cell adapter: ≦2.5mm	Initial measurement: 4mm (Impact of the metallic luster of the PCV steel plate）After adjustment: 2.4mm (The error improves to 2mm upon using the luster removal spray)	1/2	Reflecting adjustment and use of luster removal spray into the procedures for the actual facility	Expected to be implemented by revising the operation procedures of the actual facility
						Study of template for verifying the gap	Expected to be accomplished through detailed designing in the future
Element test ③ (Verification of ease of insertion)	Risk margin of interference during insertion	Interference between the cell adapter and shielding door frame	There is no interference during insertion	Gap that is almost according to the design is ensured and thus insertion is possible. (Should be inserted by shifting the position from the perspective of visibility in some parts)		Study of BSW opening part dimensions considering interference margin	Expected to be accomplished through detailed designing in the future
		Interference between the cell adapter and BSW					
		Visual confirmation of passing through X-6 penetration					
	Verifying viability of positioning with the help of the guide pin	Effectiveness of the guide pin insertion method	Positioning should be possible within the range of the guide pin and it should be possible to reproduce the phenomenon	・ It is possible to position and insert without any issues ・ Can be reinserted within the range of the guide pin gap		—	The guide pin method has been used at our company and hence is expected to materialize.
Element test ③ (Identification of required specifications)	Verification of the operation of inserting the cell adapter and the method of positioning it	Verifying the direction related to position adjustment	Verification of number of working shafts	・ Mechanism for carrying-in: 2 shafts (forward movement and vertical movement) ・ Positioning mechanism: 4 shafts (horizontal, yaw, pitch, roll)		Concept of the equipment for remote operation and the conceptual study	Expected to be accomplished through detailed designing in the future
		Verifying the pitch for position adjustment	Verifying the movement pitch	Axis of rotation: 0.5° Movement stroke: 5mm			
		Verification of speed of insertion	Speed verification	Approx. 10mm/second			
		Identification of items to be verified pertaining to position adjustment	Identification of monitoring position	Can be inserted at the monitoring point			
Overall verification test	Verification of boundary formation	Visual confirmation	Visual confirmation of the boundary	Confirmed that there is no gap in the boundary part		Complete full scale mock-up tests	Expected to be accomplished through detailed designing in the future

① Installation of large heavy structures

(6) Implementation items
(6)-3-1: c. Verification of element test for the installation procedures

✓ **Contribution of the results towards the reflection destination**

・ Contributes to substantiation of the procedures for installing access equipment inside the R/B for the side access method.

✓ **Analysis from the viewpoint of on-site applicability**

・ The shape, etc. of the BSW opening / PCV steel plate is simulated to the extent possible as required in the test piece and the structure inside the Reactor Building in Unit 3, and on-site applicability is considered.

1) Ascertaining the reference location using a laser scanner and the method of marking the layout

As the pedestal opening, the X-6 penetration and the distance between buildings need to be simulated to actual scale, 1/1 scale simulation is performed. **(Reference: No. 73 - 84)**

2) Confirmation test on alignment of the cell adapter and PCV steel plate, method of confirming the position at the time of carrying-in and installation, and verification of installation procedures of the cells, etc.

PCV and BSW around the X-6 penetration inside R/B are partially simulated, and the cell adapter, shielding door and fuel debris retrieval cell are simulated (Approximately 2m of the length of the fuel debris retrieval cell on the PCV connection side is simulated).

The size of the test piece is 1/2 scale based on the margin of error in the measurement accuracy and the workability. **(Reference: No. 85 to 122)**

・ Each method required for installation is a combination of general technology and considers on-site applicability to the extent possible.

① Installation of large heavy structures

(6) Implementation items (6)-3-1: c. Element test verification of the installation procedures

✓ **Level of achievement compared to the goals**

[Objective]: To verify the viability of the following issues identified in (6)-2 by element tests.

1) Ascertaining the reference location using a laser scanner and the method of marking the layout
2) Method of positioning the cell adapter with the PCV steel plate
3) Method of remotely confirming the position at the time of carrying-in and installing the cell adapter
The scope of the test is to perform simple carrying-in and installation and to clearly specify the specifications required of the remotely controlled equipment.

[Achievement status]

1) Establishment of the method of marking the reference line for installation
   - Study on the method of ascertaining the reference location has been completed (The layout will be marked by means of regular marking.).
   - Element tests have been conducted to verify feasibility (Confirmed that the error is ≦25mm as against the error range of ≦50mm).
2) Verification of whether or not the PCV connection surface of the cell adapter can be processed
   - Study on the method of ascertaining the shape by means of laser scanning has been completed.
   - Element tests were conducted on machining the shape of the tip of the cell adapter based on the scanner results and its feasibility was confirmed. （≦2.4mm as compared to the error range of ≦2.5mm),
3) Verification of the method of installing the cell adapter by remote operation
   - Study on the method of insertion and installation with respect to the PCV steel plate at the time of carrying-in the cell adapter has been completed.
   - Element tests were conducted on carrying-in and installation with the structure that is being studied , and it was confirmed that there are no issues. Also, the specifications required for remote operation (equipment for remote operation) were clearly specified.
4) Verification of feasibility of the boundary components
   - Element tests were conducted on carrying-in and installation with the structure that is being studied , and it was confirmed that there are no issues in the structure.

① Installation of large heavy structures

(6) Implementation items

(6)-3-2: c. Elemental test verification of installation procedures (Organizing the required specifications of the equipment for remote installation)

[Purpose]: Verification of feasibility of the side access method for large scale fuel debris retrieval based on on-site application.

[Objective]: To clearly specify the specifications required of the equipment needed for remote operation based on the results of the element tests at the time of carrying-in and installing the cell adapter.

Clear specification of required specifications of the equipment

1) Clear specification of the cell adapter carrying-in and installation procedures
2) Consolidating the requirements concerning the equipment with respect to the carrying-in and installation procedures
3) Clear specification of the requirements concerning the equipment based on the results of element tests

✓ **Comparison with existing technologies**

・ As far as possible, existing technologies are combined for the installation method.

✓ **Implementation items and results**

Clarification of the specifications required of the equipment based on the results of the element tests at the time of carrying-in and installing the cell adapter has been completed.

① Installation of large heavy structures

(6) Implementation items

(6)-3-2: c. Elemental test verification of installation procedures (Organizing the required specifications of the equipment for remote installation)

- ✓ **Contribution of the results towards the reflection destination**

  ・ Contributes to substantiation of the procedures for installing access equipment inside the R/B for the side access method.

- ✓ **Analysis from the viewpoint of on-site applicability**

  ・ When the structure inside the R/B of Unit 3 and test piece were simulated, although the scale was reduced to 1/2 and the weight was not simulated, the small size made handling easier, and as the environmental conditions (shape of the BSW opening / PCV steel plate, etc.) that are required for installation were simulated, it became easier to verify workability at the site.

  ・ The on-site work procedures were studied, and the results were reflected when the on-site work was considered.

① Installation of large heavy structures

(6) Implementation items

(6)-3-2: c. Elemental test verification of installation procedures (Organizing the required specifications of the equipment for remote installation)

- ✓ **Level of achievement compared to the goals**

[Objective]: To clearly specify the specifications required of the equipment needed for remote operation based on the results of the element tests at the time of carrying-in and installing the cell adapter.

1) Clear specification of the cell adapter carrying-in and installation procedures
2) Consolidating the requirements concerning the equipment with respect to the carrying-in and installation procedures
3) Clear specification of the requirements concerning the equipment based on the results of element tests

[Achievement status]

1) The cell adapter carrying-in and installation procedures have been clearly specified.
2) The requirements concerning the equipment with respect to the carrying-in and installation procedures have been consolidated.
3) The requirements concerning the equipment have been clearly specified based on the results of element tests.

① Installation of large heavy structures

(6) Implementation items
(6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment
Other: Detailing of the work carried out inside the cells

a) Purpose of the study

- **Time required for the work such as handling the unit can inside the cells, etc. is relevant to throughput calculation.**
- **In order to enhance throughput, the work carried out inside the cells at the time of fuel debris retrieval work is detailed in an attempt to enhance the accuracy of the throughput calculation results.**

Further, in order to be able to stably carry out fuel debris retrieval work on an ongoing basis, if any of the components of the fuel debris retrieval equipment fails, it needs to be exchanged early on or maintenance needs to be carried out at the earliest, so as to be able to resume retrieval work. Therefore, the following studies are conducted as well, as risk assessment of the fuel debris retrieval equipment.

〇 Assumption of failure mode of the components inside the cells

〇 Assessment of the extent of impact on retrieval work

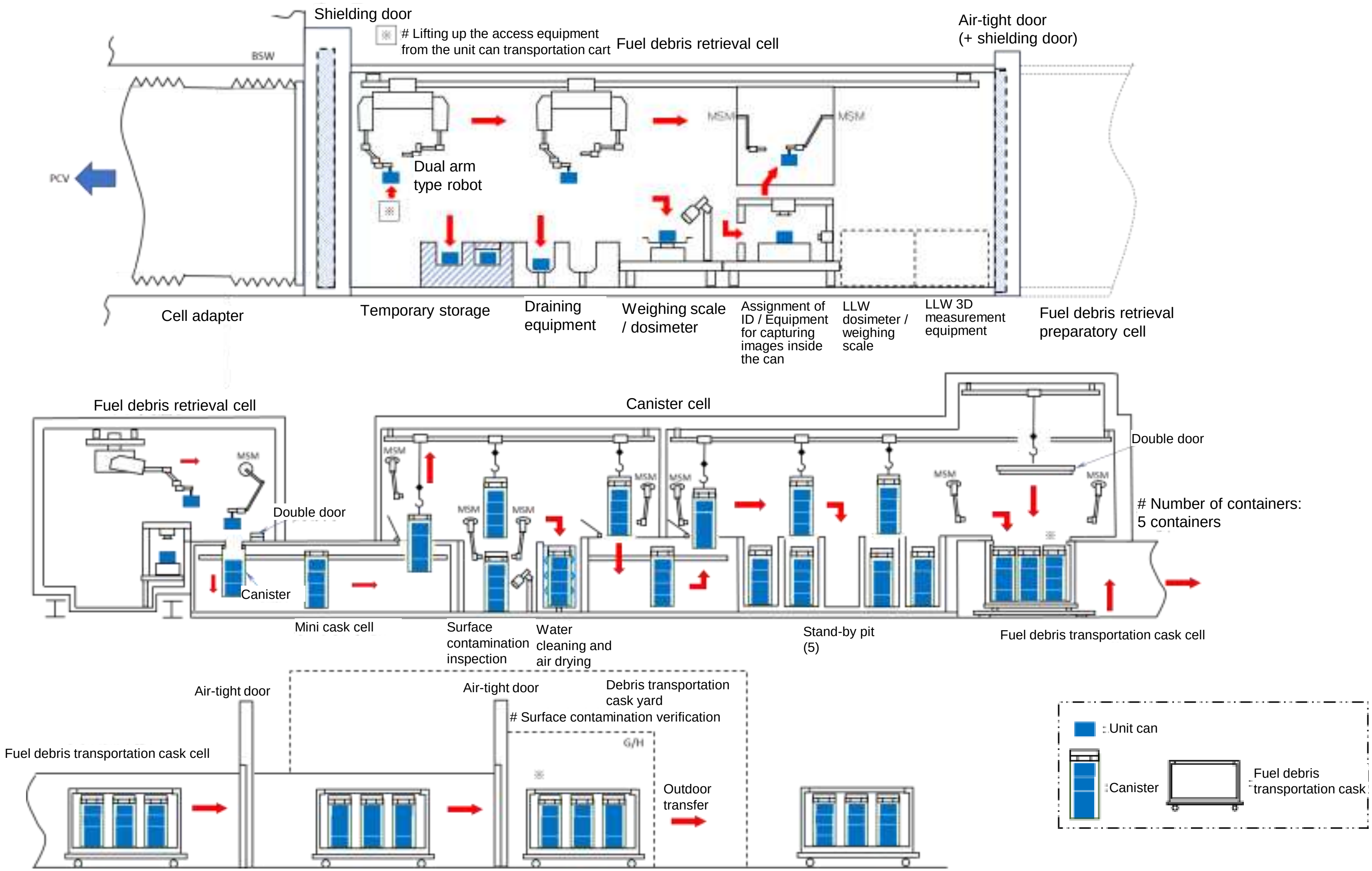
〇 Study of measures to prevent long-term shutdown of operation

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-1 Material handling flow (Fuel debris handling line)



① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-1 Material handling flow (Fuel debris handling line)

Fuel debris retrieval cell	①	The unit can containing fuel debris is transported from inside the PCV by means of a transportation cart.
	②	The unit can is grabbed by means of the dual arm type robot and is stored temporarily in a temporary storage container with a shield.
	③	The unit can is removed from the temporary storage container by means of the dual arm type robot, and is placed inside the draining equipment to drain.
	④	The unit can is removed from the draining equipment by means of the dual arm type robot, and the weight and dose of the unit can are measured.
	⑤	The unit can is lifted up by means of the dual arm type robot, the images of the inside of the unit can are captured and an ID is assigned.
	⑥	The unit can is lifted up by means of the overhead crane, and is placed inside the canister via the double door.
	⑦	The double door of the canister is closed by means of the MSM on the wall surface.
Mini cask cell	⑧	The canister is transported up to the opening of the connection with the canister cell by means of the transportation mechanism.
Canister cell	⑨	The canister is received by lifting it up from the mini cask cell by means of the overhead crane.
	⑩	The second lid of the dual lid is attached to the canister and surface contamination inspection is conducted.
	⑪	The canister is washed with water and air dried as required based on the results of the surface contamination inspection.
	⑫	The canister is lifted up from the transportation route by means of the overhead crane and placed in the stand-by pit.
	⑬	After removing the lid of the fuel debris transportation cask by means of the overhead crane, the canister is placed inside the fuel debris transportation cask.
	⑭	The lid of the fuel debris transportation cask is closed by means of a dedicated crane and the MSM.
Fuel debris transportation cask cell	⑮	The fuel debris transportation cask is transported up to the fuel debris transportation cask yard.
Fuel debris transportation cask yard	⑯	The fuel debris transportation cask undergoes various inspections to be conducted before transporting out such as inspection of external appearance, air-tightness test, surface contamination inspection, etc.
	⑰	The fuel debris transportation cask is transported to the storage preparation facility by means of the transportation vehicle.

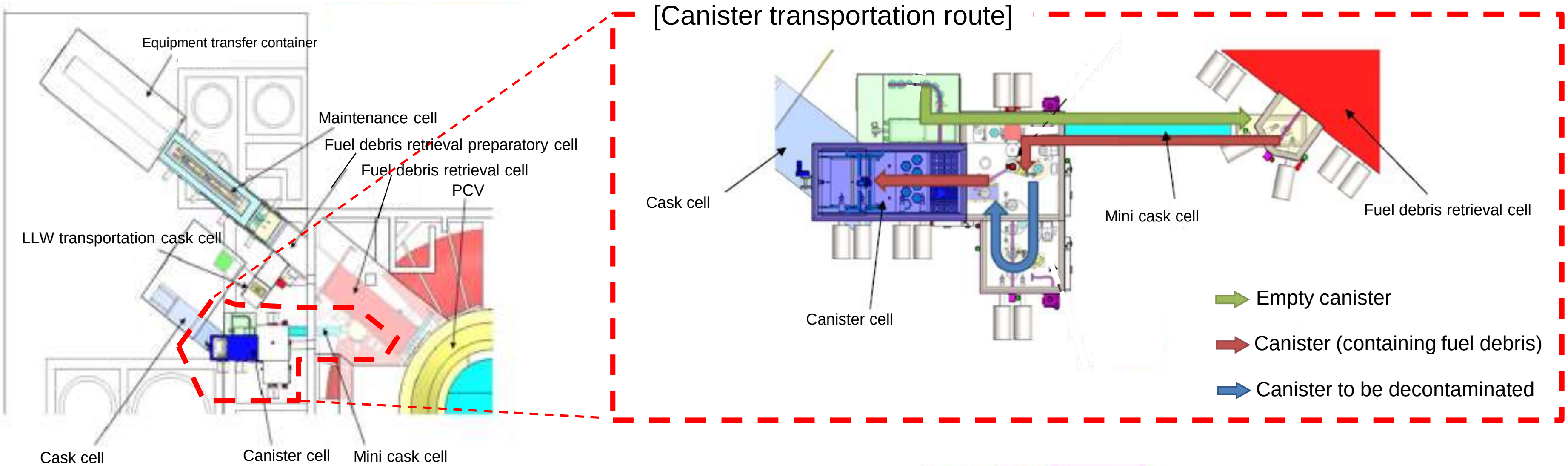
① **Installation of large heavy structures**

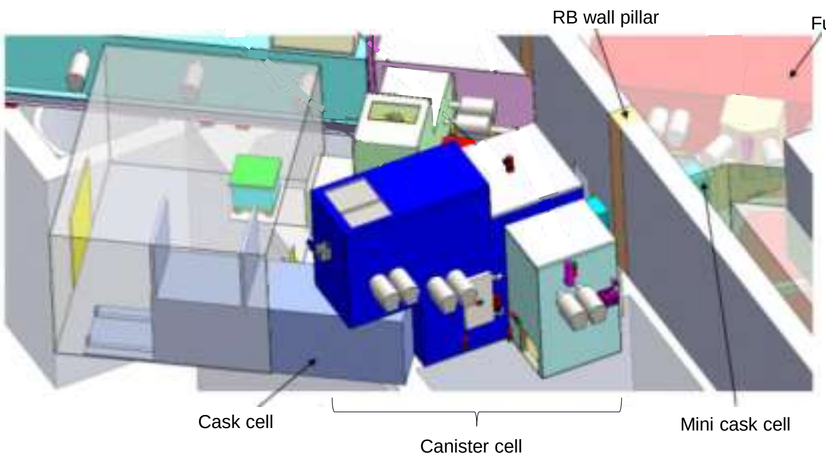
(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

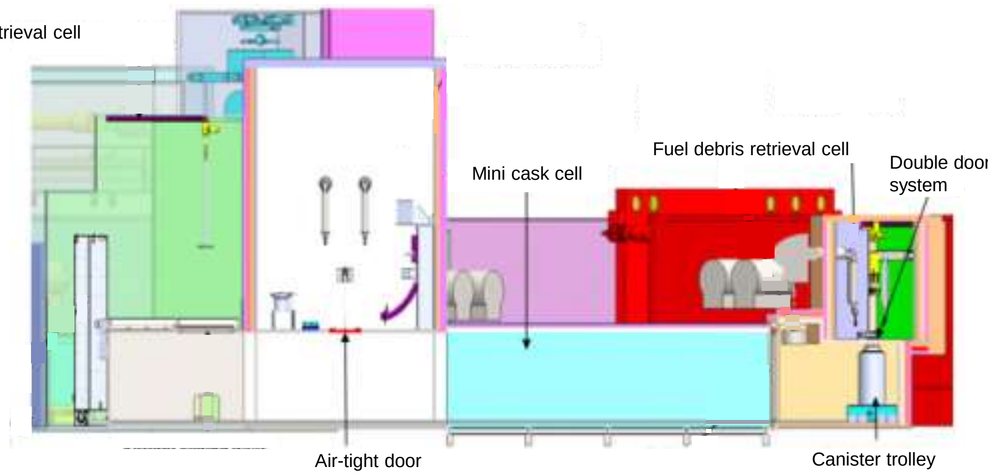
✓ **Other: Detailing of the work carried out inside the cells**

b)-1 Material handling flow (Fuel debris handling line）

・**Placement of equipment inside and outside the cell (Part 1)**







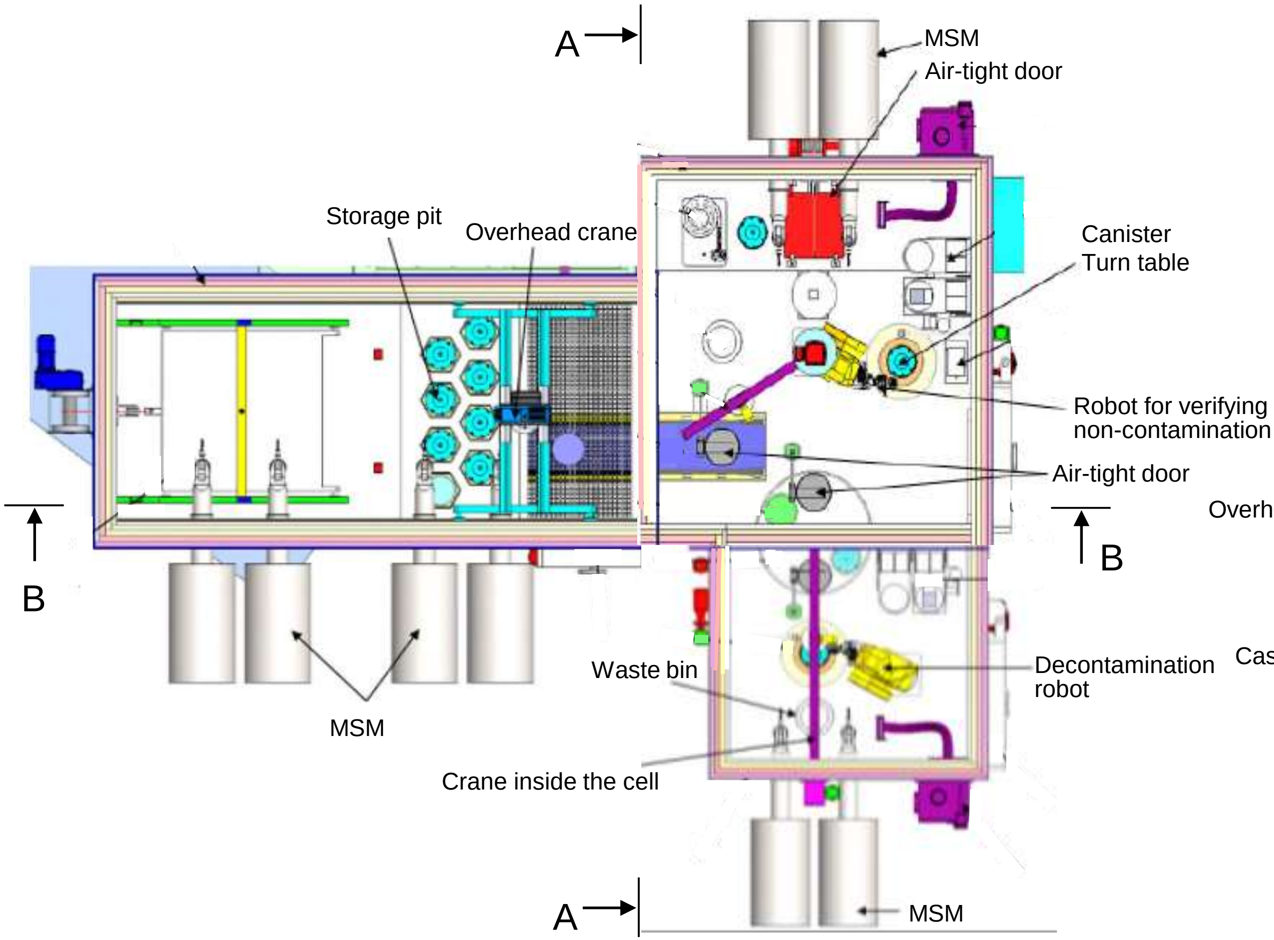
① **Installation of large heavy structures**

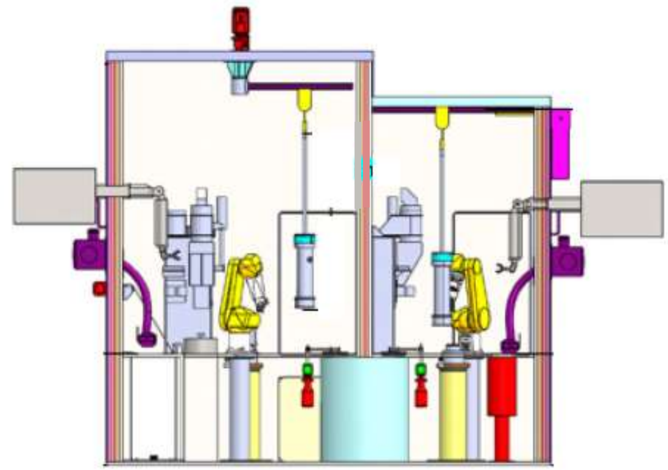
(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

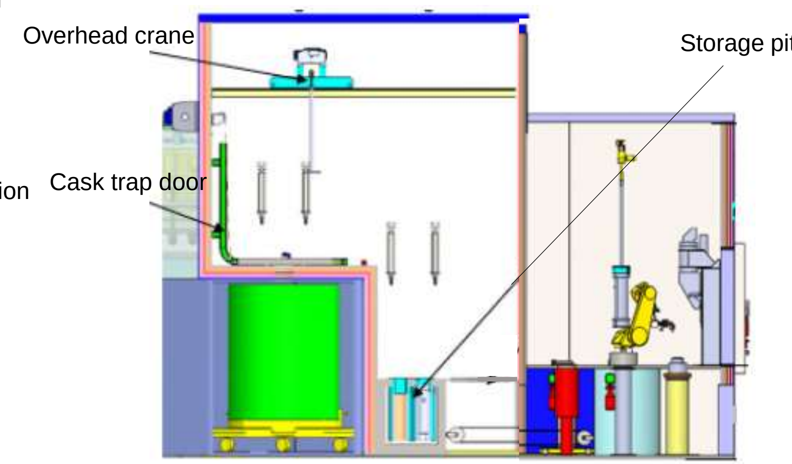
b)-1 Material handling flow (Fuel debris handling line)

- **Placement of equipment inside and outside the cell (Part 2)**





A-A (Reduced drawing)



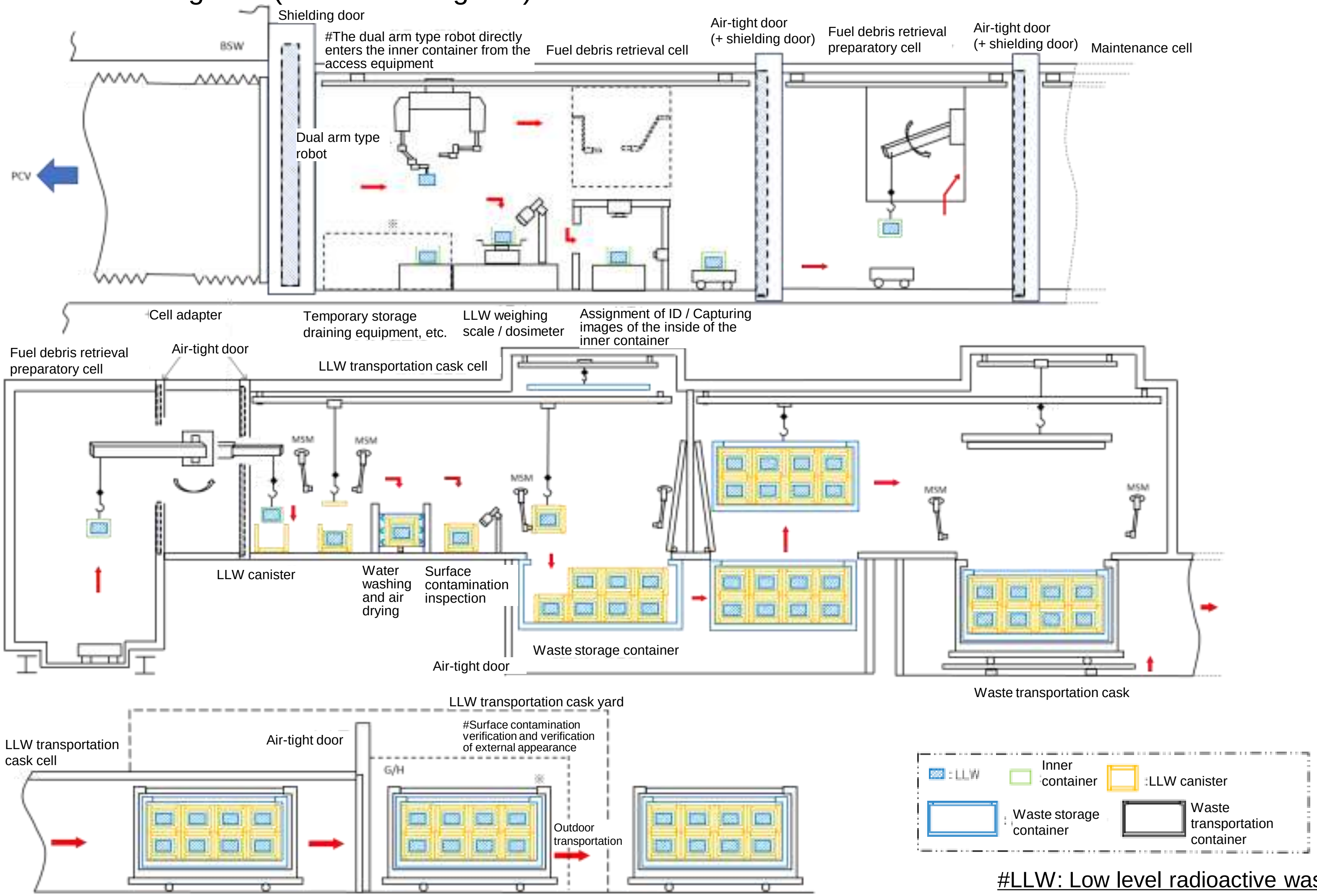
B-B (Reduced drawing)

① **Installation of large heavy structures**

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-2 Material handling flow (LLW# handling line)



#LLW: Low level radioactive waste

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-2 Material handling flow (LLW handling line)

Fuel debris retrieval cell

① The inner container containing LLW is transported from inside the PCV by means of a transportation cart.

② The inner container is lifted up by means of the dual arm type robot, and its weight and dose are measured.

③ The inner container is lifted up by means of the dual arm type robot, the images of the inside of the unit can are captured and an ID is assigned.

④ The inner container is loaded on the transportation cart by means of the dual arm type robot, and transported to the fuel debris retrieval preparatory cell.

Fuel debris retrieval preparatory cell

⑤ The inner container is hoisted by means of a jib crane, and delivered to the LLW transportation cask cell.

⑥ The LLW that is hoisted by means of the jib crane is received in the LLW transportation cask cell.

LLW transportation cask cell

⑦ The inner container is placed in the LLW canister by means of the jib crane.

⑧ The lid of the LLW canister is closed by means of an overhead crane and MSM.

⑨ The LLW canister is hoisted by means of the overhead crane, and the contamination on its surface is inspected.

⑩ The LLW canister is washed with water and air dried at the LLW canister washing area as required based on the results of the surface contamination inspection.

⑪ After the lid of the waste storage container is opened by means of a dedicated crane, the LLW canister is placed inside the waste storage container by means of the overhead crane.

⑫ The lid of the waste storage container is closed by means of a dedicated overhead crane.

LLW transportation cask yard

⑬ The waste transportation cask is transported to the LLW transportation cask yard by means of the transportation cart.

⑭ The waste transportation cask undergoes various inspections to be conducted before transporting out such as inspection of external appearance, surface contamination inspection, etc.

⑮ The waste transportation cask is loaded onto the transportation vehicle.

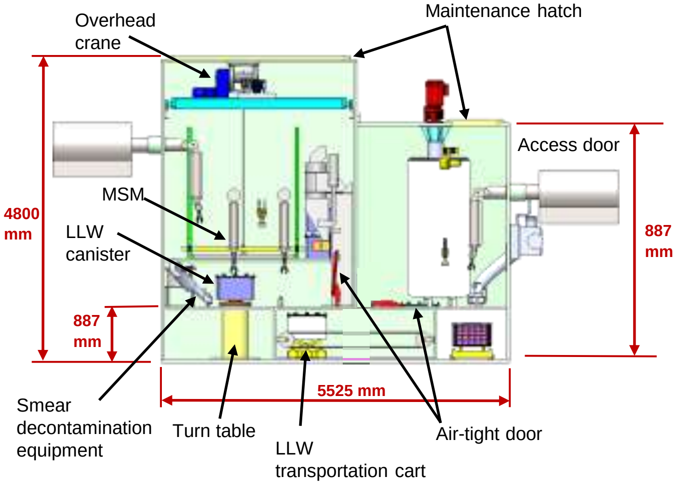
⑯ The waste transportation cask is transported to the solid waste storage facility, etc. by means of the transportation vehicle.

① Installation of large heavy structures

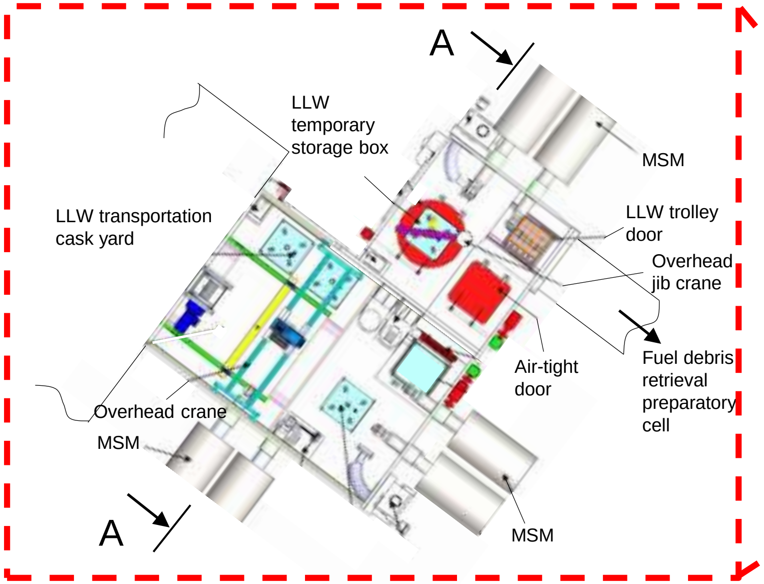
(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

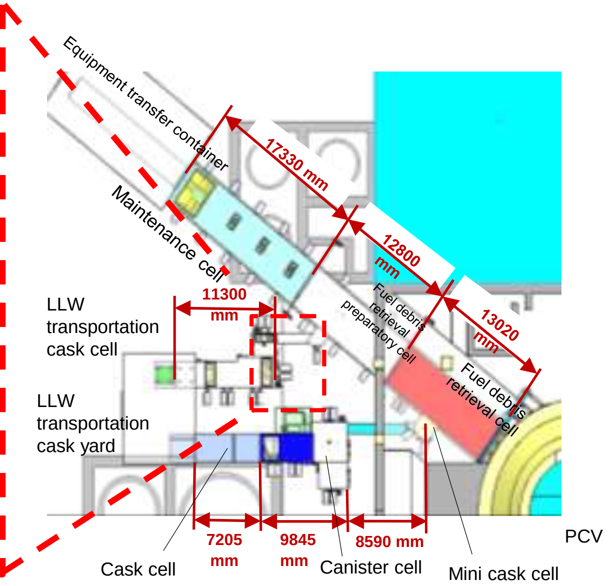
✓ **Other: Detailing of the work carried out inside the cells**

b)-2 Material handling flow (LLW handling line)

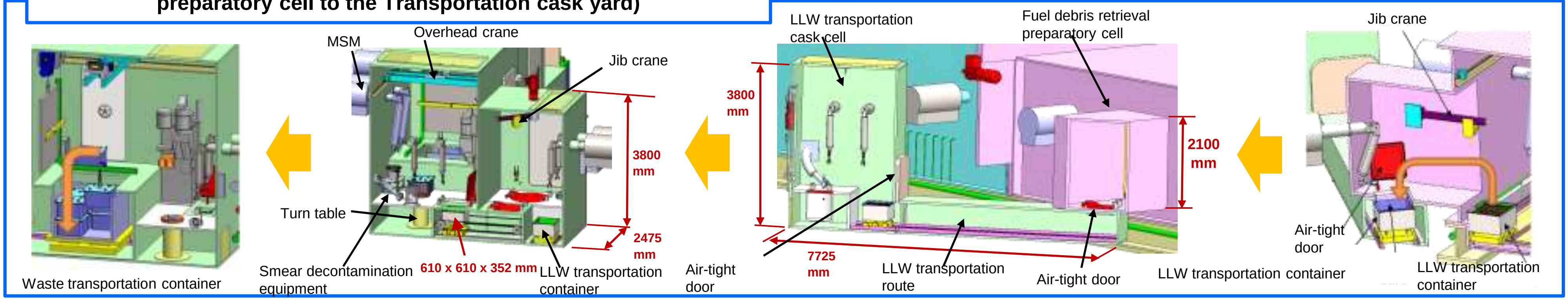


A-A (Reduced drawing)





LLW transportation route (from the Fuel debris retrieval preparatory cell to the Transportation cask yard)

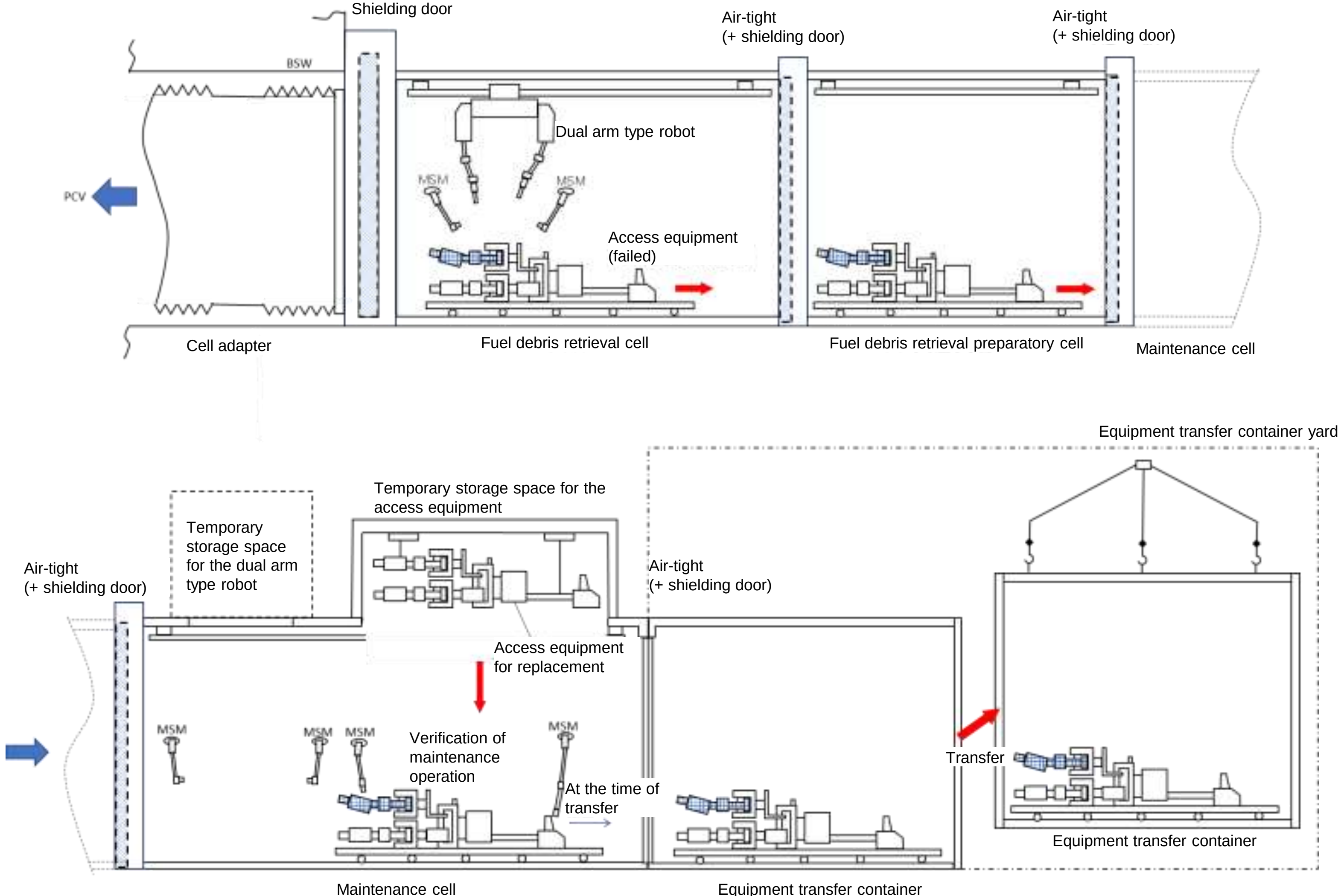


① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-3 Material handling flow (Fuel debris retrieval robot arm handling line)



① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-3 Material handling flow (Fuel debris retrieval robot arm handling line)

At the time of carrying-out

Fuel debris retrieval cell	①	Access equipment pulled up from inside the PCV is received.
	②	The access equipment is washed with water and decontaminated.
	③	The power supply cables, etc. are separated from the access equipment.
	④	The access equipment is moved to the fuel debris retrieval preparatory cell by means of the remotely operated transportation equipment.
Fuel debris retrieval preparatory cell	⑤	The access equipment is moved to the maintenance cell by means of the remotely operated transportation equipment.
Maintenance cell	⑥	The access equipment is washed with water and decontaminated once again.
	⑦	The access equipment is placed in the equipment transfer container connected to the maintenance cell.
Equipment transfer container yard	⑧	Equipment transfer container is separated from the maintenance cell.
	⑨	The equipment transfer container undergoes various inspections to be conducted before transporting out such as inspection of external appearance, surface contamination inspection, etc.
	⑩	Equipment transfer container is loaded on to the transportation vehicle.
	⑪	Equipment transfer container is transported to the maintenance facility by means of the transportation vehicle.

At the time of carrying-in

The procedures are the opposite of those mentioned above except for the following.

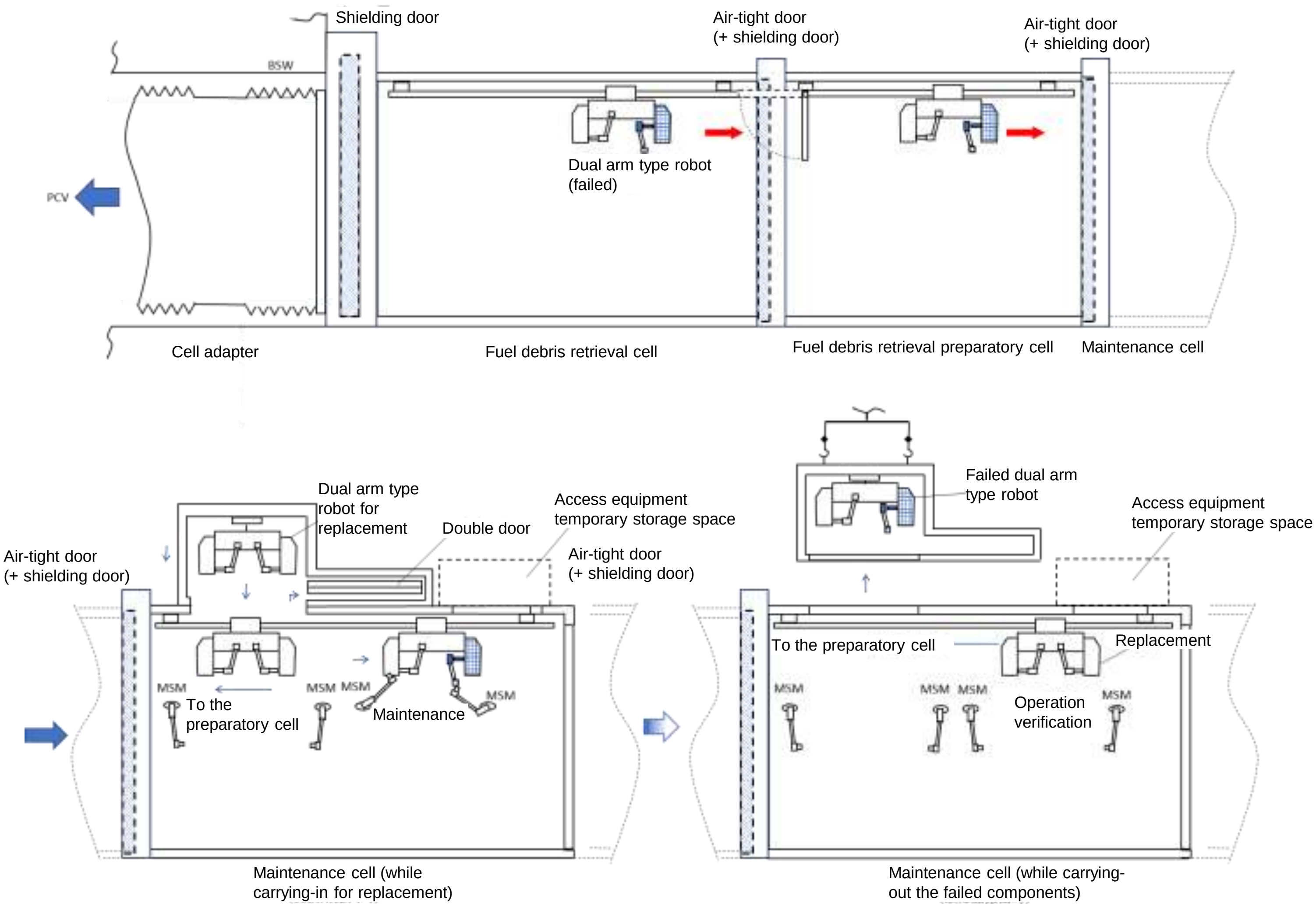
・ After receiving the transportation vehicle in which the required equipment transfer container is loaded, it is temporarily stored if required in the access equipment temporary storage space in the maintenance cell.

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-4 Material handling flow (Overhead traveling dual arm type robot handling line)



① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

b)-4 Material handling flow (Overhead traveling dual arm type robot handling line)

At the time of carrying-out

Fuel debris retrieval cell

① The failed dual arm type robot is decontaminated to the extent possible.

② The dual arm type robot is moved to the fuel debris retrieval preparatory cell.

Fuel debris retrieval preparatory cell

③ The dual arm type robot is moved to the maintenance cell.

Maintenance cell

④ The dual arm type robot is washed with water and decontaminated once again.

⑤ The dual arm type robot is placed in the dedicated container connected to the maintenance cell.

⑥ The dedicated container is separated from the maintenance cell.

⑦ The dedicated container undergoes various inspections to be conducted before transporting out such as inspection of external appearance, surface contamination inspection, etc.

⑧ The dedicated container is loaded on to the transportation vehicle.

⑨ The dedicated container is transported to the maintenance facility by means of the transportation vehicle.

At the time of carrying-in

The above-mentioned process is reversed and the replacement dual arm type robot is brought into the fuel debris retrieval cell.

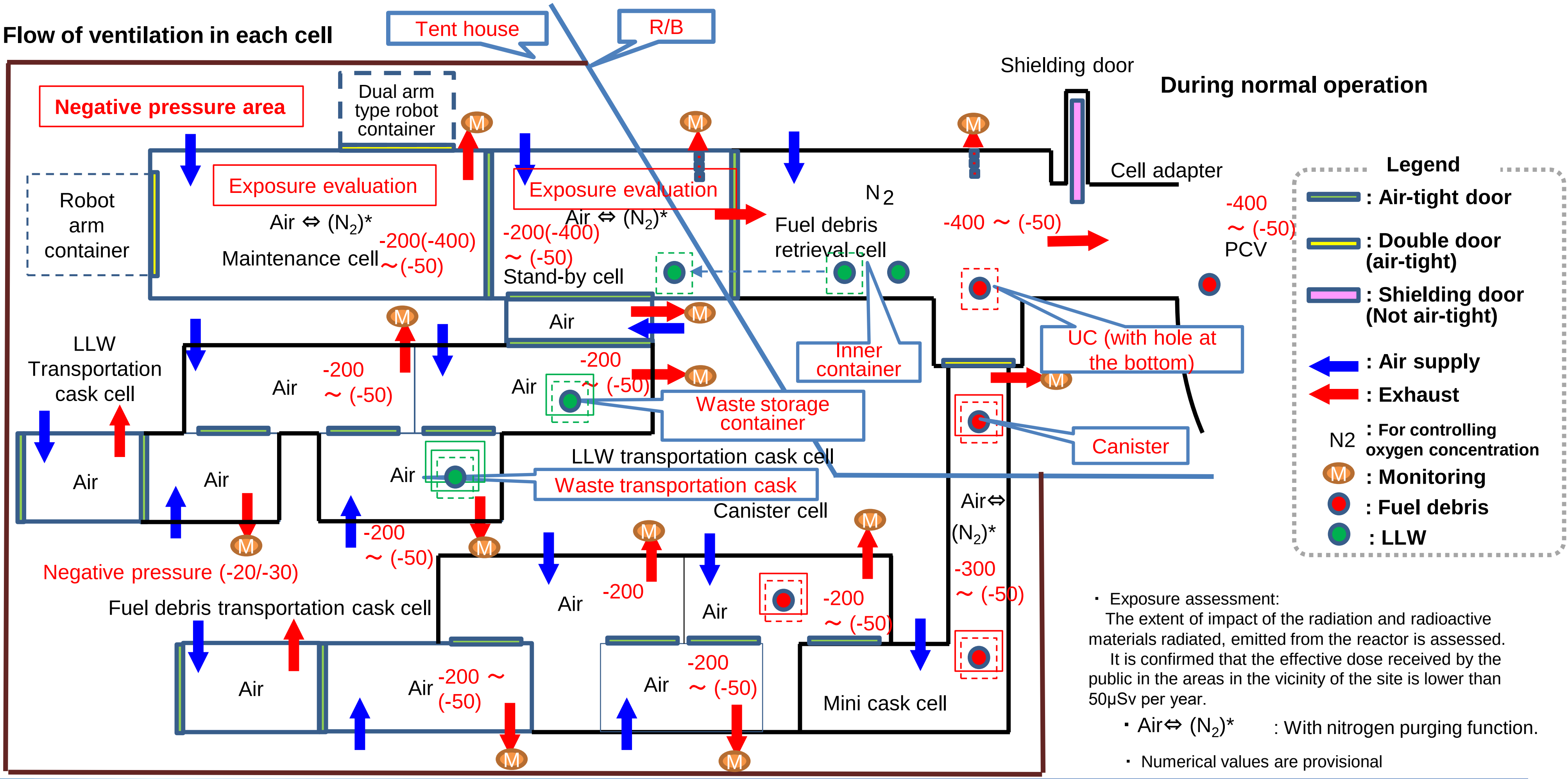
① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

c) Heating, Ventilating and Air Conditioning System for each cell

Flow of ventilation in each cell



- Exposure assessment: The extent of impact of the radiation and radioactive materials radiated, emitted from the reactor is assessed. It is confirmed that the effective dose received by the public in the areas in the vicinity of the site is lower than 50μSv per year.
- Air⇔ (N_2)* : With nitrogen purging function.
- Numerical values are provisional

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

d) Risk assessment (1/4)

➢ The risks assumed in each cell are identified, and their exposure impact and impact on the work schedule are studied. Also, their countermeasures are studied.

(light blue) : Probability / impact is low (pink) : Probability / impact is high

Risk												Initiatives in response to the risks	
Assumed events and causes		Target area (✓: Applicable, ー : Not applicable)					Probability of occurrence (Reasons)	Exposure impact (Public)	Exposure impact (Workers)	Impact on work schedule		Prevention	Mitigation of the impact upon occurrence
		FDR Cell	Mini cask cell	Canister cell	Fuel debris transportation cask cell	Fuel debris transportation cask yard							
Risks during normal operation	Dispersion of dust from the surface contamination of the vessel or fuel debris while handling unit cans or canisters	✓	✓	✓	ー	ー	ー (Generated due to normal work)	Small (The impact is small as a confinement effect is expected due to the cell boundary)	Same as on the left	ー (Due to normal operation)		ー	Controlling negative pressure inside the cell
	Dispersion of dust associated with draining the fuel debris or canister	✓	ー	✓	ー	ー	ー (Generated due to normal work)	Small (The impact is small as a confinement effect is expected due to the cell boundary)	Same as on the left	ー (Due to normal operation)		ー	Controlling negative pressure inside the cell, collecting dust by installing a local exhauster in the periphery of the draining equipment
Loss of dynamic confinement function	Leakage of dust from a route that does not go through a filter, as the negative pressure inside the cell is lost when the exhaust fan stops.	✓	✓	✓	ー	ー	Low (The probability of occurrence is low as failure of the exhaust fan or loss of power supply, etc. are causes and thus multiple preventive measures are conceivable)	Large (If events associated with dust dispersion such as falling of the unit can or canister, etc. overlap, dusk is likely to leak from a route that does not go through a filter due to shutdown of the exhaust fan.)	Large (If events associated with dust dispersion such as falling of the unit can or canister, etc. overlap, dusk is likely to leak from a route that does not go through a filter due to shutdown of the exhaust fan.)	Large (The impact is small if the equipment can be restored by remote operation or by manner operation outside the cell. If large scale work such as equipment replacement, etc. due to equipment failure, etc. needs to be carried out, a major delay in schedule is expected.)		Using a design in which multiple exhaust fan systems are installed and in the event of an emergency, nitrogen supply stops by means of an interlock, etc.	Stopping nitrogen supply to the cell
Loss of static confinement function	Leakage of dust from a route that does not go through a filter, as a part of the boundary is damaged due to aging degradation of the seal part	✓	✓	✓	ー	ー	Low (There is no leakage as long as the static confinement function is not lost, since it is caused by aging degradation due to long-term use)	Large (If events associated with dust dispersion such as falling of the unit can or canister, etc. overlap, dusk is likely to leak from a route that does not go through a filter due to shutdown of the exhaust fan.)	Large (If events associated with dust dispersion such as falling of the unit can or canister, etc. overlap, dusk is likely to leak from a route that does not go through a filter due to shutdown of the exhaust fan.)	Large (The impact is small if the equipment can be restored by simple operations such as replacement of components, etc. If large scale work needs to be carried out due to failure of the seal part, etc., a major delay in schedule is expected.)		Retaining the confinement function by increasing the quantity of exhaust or reinforcing the boundary, if a drop in air-tightness is detected when the extent of negative pressure in the cell is monitored.	ー

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

d) Risk assessment (2/4)

: Probability / impact is low : Probability / impact is high

Risk													Initiatives in response to the risks	
Assumed events and causes		Target area (✓: Applicable, ー : Not applicable)					Probability of occurrence (Reasons)	Exposure impact (Public)	Exposure impact (Workers)	Impact on work schedule			Prevention	Mitigation of the impact upon occurrence
		FDR Cell	Mini cask cell	Canister cell	Fuel debris transportation cask cell	Fuel debris transportation cask yard								
Leakage of contaminated water	Contaminated water leaks due to inadequate draining after washing the canister with water leading to spread of contamination	✓	ー	✓	ー	ー	Low (The effect of the method of draining is verified by means of mock-up tests, etc.)	Small (Since this is mostly after draining, it can almost be ignored, and hence the impact is small)	Large (If the abnormality needs to be restored by manned operation, the exposure impact on the personnel is likely to be significant.)	Small (Large quantity of radioactive material is unlikely to be released.)			Studying methods, etc. for adequately draining the canister	Controlling negative pressure inside the cell
	The pipes or containers in which contaminated water resulting from washing the canister is collected get damaged, leading to leakage of contaminated water.	✓	ー	✓	ー	ー	Low (Large quantities of contaminated water being generated and the container or pipes getting damaged due to it is a rare occurrence.)	Small (The impact is small since the quantity of contaminated water generated as a result of draining is believed to be small.)	Large (If the abnormality needs to be restored by manned operation, the exposure impact on the personnel is likely to be significant.)	Large (The impact is small if the equipment can be restored by remote operation or by manned operation outside the cell. The impact is large if large scale work such as equipment replacement, etc. due to equipment failure, etc. needs to be carried out.)			Regularly verifying the integrity of the pipes or containers for collecting contaminated water	Controlling negative pressure inside the cell
Loss of shielding function	The shielding door is stuck open thus making restoration impossible.	✓	ー	ー	ー	ー	High (This is an event that would occur due to failure of stand-alone equipment constantly used during the fuel debris retrieval period. Hence the probability of occurrence is comparatively high.)	Small (The impact is small as the public is at a sufficient distance from the site boundary.)	Large (If the abnormality needs to be restored by manned operation inside the cell, the personnel is likely to get exposed.)	Large (If the equipment cannot be restored from outside the cell, methods for restoring the equipment need to be studied. Hence a major delay in schedule is expected.)			Adopting a design that enables collection of fuel debris without entering the cell in the event of abnormal shutdown of equipment, and developing procedures for remotely restoring the abnormality	ー
	The lid of the container which is expected to shield fails to close, and hence the unit can, etc. cannot be appropriately contained leaving it exposed.	✓	ー	✓	ー	ー	High (This is an operation that is repeatedly carried out during the fuel debris retrieval period. Hence the probability of occurrence is high.)	Small (The impact of external dose is small as the public is at a sufficient distance from the site boundary.)	Large (Personnel present in the vicinity of the cell is likely to get exposed.)	Large (The impact is small if the equipment can be restored by simple operations. If the container gets damaged and cannot be restored, a major delay in schedule is expected.)			Studying means to remotely verify whether the lid of the container is held securely	Installing auxiliary shielding

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

d) Risk assessment (3/4)

(Light blue box) : Probability / impact is low (Pink box) : Probability / impact is high

Risk											Initiatives in response to the risks	
Assumed events and causes		Target area (✓: Applicable, ー : Not applicable)					Probability of occurrence (Reasons)	Exposure impact (Public)	Exposure impact (Workers)	Impact on work schedule	Prevention	Mitigation of the impact upon occurrence
		FDR Cell	Mini cask cell	Canister cell	Fuel debris transportation cask cell	Fuel debris transportation cask yard						
Increase in activity concentration (dust dispersion)	Dispersion of the contents and adhered contaminants when the unit can, etc. falls or tumbles	✓	✓	✓	–	–	High (This is an operation that is repeatedly carried out during the fuel debris retrieval period. Hence the probability of occurrence is high.)	Small (The impact is small as the negative pressure inside the cell is controlled and confinement is expected from the cell boundary.)	Small (Since the negative pressure inside the cell is controlled, the personnel in the area around the cell hardly get exposed.)	Large (If the fuel debris that has fallen from outside the cell cannot be collected, methods for restoring the equipment need to be studied. Hence a major delay in schedule is expected.)	Studying means to remotely verify whether the unit can, etc. is held securely	Controlling negative pressure inside the cell
	Heavy weight objects fall on top of fuel debris and the impact causes dust dispersion	✓	–	✓	–	–	High (This is an operation that is repeatedly carried out during the fuel debris retrieval period. Hence the probability of occurrence is high.)	Small (The impact is small as the negative pressure inside the cell is controlled and confinement is expected from the cell boundary.)	Small (Since the negative pressure inside the cell is controlled, the personnel in the area around the cell hardly get exposed.)	Large (If the fuel debris that has fallen from outside the cell cannot be collected, methods for restoring the equipment need to be studied. Hence a major delay in schedule is expected.)	Studying means to remotely verify whether the heavy weight object is held securely	Controlling negative pressure inside the cell
	Dispersion of contents of the fuel debris transportation cask when it falls as a result of coming in contact with surrounding structures, etc.	–	–	–	✓	✓	High (This is an operation that is repeatedly carried out during the fuel debris retrieval period. Hence the probability of occurrence is high.)	Large (If the transportation cask gets damaged due to the impact, a large amount of dust is likely to get dispersed, but if the cask remains intact it can be expected to provide confinement.)	Same as on the left	Large (If the transportation cask gets damaged due to the impact, methods for restoring it need to be studied. Hence a major delay in schedule is expected.)	Setting a limit to the rate of acceleration of the transportation cask for preventing collision and fall	–
Occurrence of criticality	– (The shape of the container is controlled and hence the possibility of criticality is ruled out.)	–	–	–	–	–	–	–	–	–	–	–
Abnormality in fuel debris cooling function	– (Forced cooling is not in the scope of assumptions for a unit can or canister)	–	–	–	–	–	–	–	–	–	–	–

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ Other: Detailing of the work carried out inside the cells

d) Risk assessment (4/4)

(light blue) : Probability / impact is low (pink) : Probability / impact is high

Risk											Initiatives in response to the risks	
Assumed events and causes		Target area (✓: Applicable, ー : Not applicable)					Probability of occurrence (Reasons)	Exposure impact (Public)	Exposure impact (Workers)	Impact on work schedule	Prevention	Mitigation of the impact upon occurrence
		FDR Cell	Mini cask cell	Canister cell	Fuel debris transportation cask cell	Fuel debris transportation cask yard						
Stopping of nitrogen supply (Fire and explosion inside the cell)	Maintaining the nitrogen atmosphere is unsuccessful, leading to hydrogen combustion and metallic fire	✓	✓	✓	ー	ー	Low (The probability of occurrence is low because the event can be prevented by stopping acceptance of fuel debris from the PCV when an abnormality is detected and transferring the fuel debris from inside the cell to the outside)	Large (If the boundary gets damaged due to the fire / explosion, the radioactivity inside the cell is likely to get dispersed to the outside.)	Same as on the left	Large (A major delay in the work schedule is expected due to restoration of the damaged cells or equipment, investigation of cause, recurrence prevention, etc.)	Adopting a design in which multiple nitrogen supply systems that stop working until restoration are installed so as to enable switching over to stand-by systems, etc. in the event of an emergency	Extinguishing fire by means of firefighting equipment in the event of a fire
Fire and explosion inside the container	The container continues to remain sealed due to insufficient drying of fuel debris, and the concentration of hydrogen inside the container reaches the inflammability limit (4%) leading to hydrogen combustion.	ー	✓	✓	✓	✓	Low (The probability of occurrence is low as this occurs when there is an overlap of insufficient drying and loss of hydrogen emission function on the container side.)	Large (If the boundary gets damaged due to the fire / explosion, the radioactivity inside the cell is likely to get dispersed to the outside.)	Same as on the left	Large (A major delay in the work schedule is expected due to restoration of the damaged cells or equipment, investigation of cause, recurrence prevention, etc.)	Sufficiently drying the fuel debris and verifying it	Extinguishing fire by means of firefighting equipment in the event of a fire
Unrestorable due to equipment shutdown	The equipment related to material handling such as dual arm type robot, crane, transportation cart, etc. cannot be restored as they have shutdown abnormally	✓	✓	✓	ー	ー	High (This is an event that would occur due to failure of stand-alone equipment constantly used during the fuel debris retrieval period. Hence the probability of occurrence is comparatively high.)	ー	Large (If the abnormality needs to be restored by manned operation inside the cell, the personnel is likely to get exposed.)	Large (If the equipment cannot be restored from outside the cell, a major delay in schedule is expected.)	Adopting a design that enables collection of fuel debris in the event of abnormal shutdown of equipment, and developing procedures for remotely restoring the abnormality	ー
	Failure of other equipment	✓	ー	✓	ー	ー	High (This is an event that would occur due to failure of stand-alone equipment constantly used during the fuel debris retrieval period. Hence the probability of occurrence is comparatively high.)	ー	Small (Restoration by means of manned operations inside the cell is likely to become necessary, but personnel exposure can be kept adequately down by entering after the inside of the cell is decontaminated.)	Small (Since manned operation can be carried out inside the cell by transferring fuel debris from the cell and decontaminating the inside of the cell, it is believed that there is little impact on work schedule.)	Periodic integrity verification of the equipment	ー

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

e) Restoration when the equipment is shutdown (mini cask cell and canister cell)

(1) Maintenance and repairs (inside the cell)

Cell	№	Equipment name	Failure mode	Maintenance method	Equipment used	
					Remote MSM	Overhead crane
Mini cask cell	1	Canister trolley	Failure of actuator Etc.	・ Separating the actuator installed outside the cell ・ Moving it to the maintenance facility and carrying out maintenance	—	—
	2	Canister hoisting equipment	Failure of actuator Etc.	・ Moving up to the collection location and transferring using the external drive shaft (There are 2 actuators)	—	—
	3	Double door system	Regular replacement	・ Replacing the door by means of the remote MSM on the fuel debris retrieval cell side	✓	#
Canister cell	4	Overhead crane (Storage pit area)	—	—	—	—
	5	Crane inside the cell (Decontaminated area)	—	—	—	—
	6	Remote MSM	Slave arm failure	・ Removing the slave arm from the cell wall surface	#	✓
	7	Air-tight door (Between the storage pit area and the decontaminated area)	Regular replacement	・ Replacing the door by means of the remote MSM (replacing the packing)	✓	#
	8	Canister turn table	—	—	—	—
	9	Robot for verifying non-contamination	Failure of detector	・ Removing the cable connector of the detector	✓	#
	10	Decontamination robot	Failure of decontaminator	・ Removing the decontaminator	✓	#
	11	Cask trap door	Regular replacement	・ Replacing the sealant	✓	#

# indicates that providing support as required from the perspective of improving work efficiency is considered.

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

e) Restoration when the equipment is shutdown (mini cask cell and canister cell)

(2) Maintenance and repairs (outside the cell)

Cell	№	Equipment name	Failure mode	Maintenance method
Mini cask cell	1	Canister trolley		—
	2	Canister hoisting equipment	—	—
	3	Double door system	—	—
Canister cell	4	Overhead crane (Storage pit area)	Failure of actuator	・Replacing the actuator from the ceiling (There are 2 actuators)
	5	Crane inside the cell (Decontaminated area)	Failure of actuator	・Replacing the actuator from the ceiling (There are 2 actuators)
	6	Remote MSM	Failure of drive module	・Separating the arm connecting part from the suspension arm of the drive module using the hoist ・Loading on the dedicated cart ・Moving it to the maintenance facility and carrying out maintenance
	7	Air-tight door (Between the storage pit area and the decontaminated area)	—	—
	8	Canister turn table	Failure of rotary actuator	・Removing and replacing the actuator (There are 2 actuators)
	9	Robot for verifying non-contamination	Failure of actuator Etc.	・Removing and replacing the actuator (There are 2 actuators)
	10	Decontamination robot	Failure of actuator Etc.	・Removing and replacing the actuator (There are 2 actuators)
	11	Cask trap door	Replacement of the drive wire	・Replacing the external actuator (There are 2 actuators)

In principle, maintenance and repair work is carried out by workers.

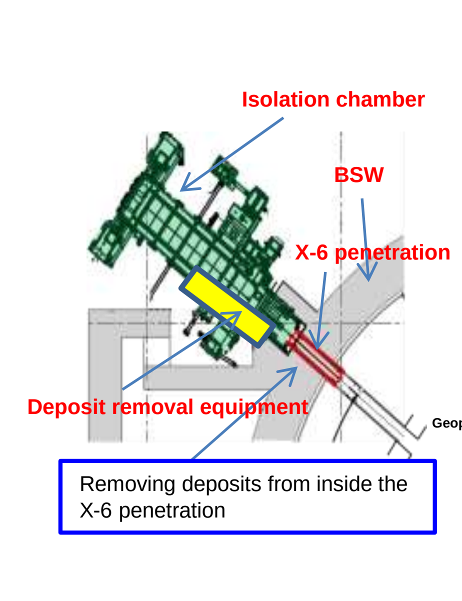
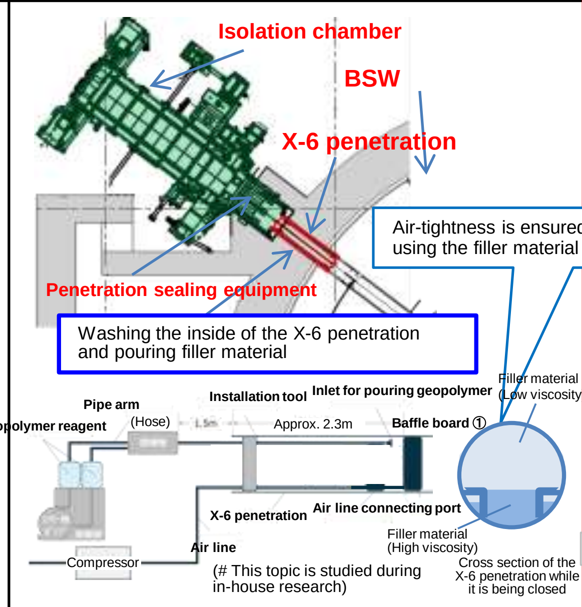
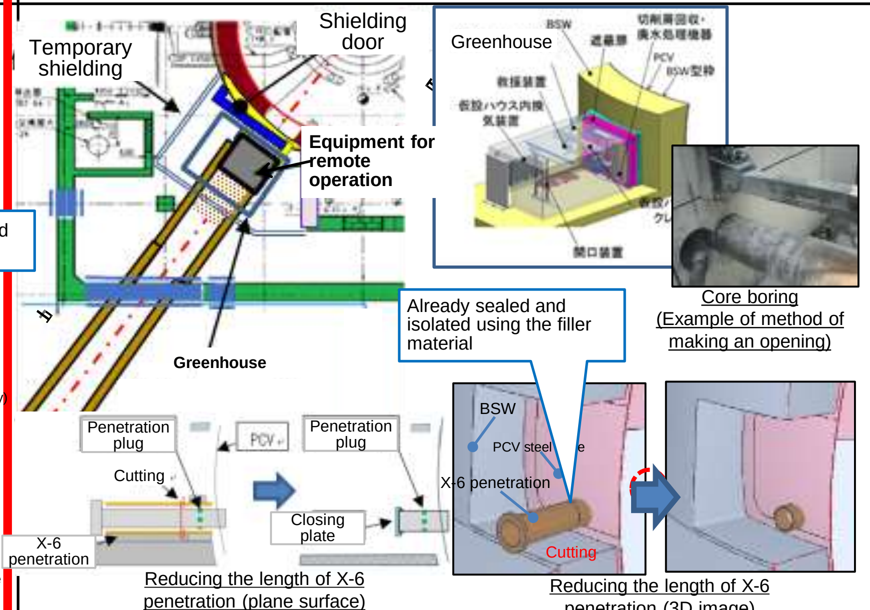
① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipmen

✓ Other: Detailing of the work carried out inside the cells

f) Dust evaluation (1/3)

A conceptual study on the method of making an opening in the BSW concrete and the method of cutting the X-6 penetration has been conducted, but **since dust is likely to flow into the gap between the BSW and the PCV steel plate while making an opening in the BSW concrete, the inflow of dust is evaluated**.

<table>
<tr><td></td><td>[During the PCV internal investigation]
Releasing the X-6 penetration flange and removing deposits (Work inside the isolation chamber)</td><td>[After internal investigation or after installing the shielding door]
① Releasing the X-6 penetration flange and sealing the penetration
(Work inside the isolation chamber)</td><td>10. Making an opening in BSW concrete
(Work inside the isolation facility for making the opening)</td></tr>
<tr><td>Conceptual drawing</td><td>
</td><td>
</td><td>

Core boring (Example of method of making an opening)
Reducing the length of X-6 penetration (plane surface)
Reducing the length of X-6 penetration (3D image)</td></tr>
<tr><td>Procedure</td><td>An isolation chamber is set up and if any deposits (cables, etc.) remain inside the penetration, they are removed.</td><td>An isolation chamber is set up for sealing the X-6 penetration, and the inside of the penetration is washed.
After washing, the X-6 penetration and the inside of the PCV are isolated by pouring filler material (Geopolymer, etc.).</td><td>The cell for making the opening is installed, and an opening is made in the BSW.
Also, the length of the X-6 penetration is reduced and a closing plate is installed.</td></tr>
<tr><td>Issues</td><td>・ Study of substantiation of the timing of the PCV internal investigation and the contents of the investigation</td><td>・ Substantiation of the method of sealing the X-6 penetration using filler material
・ Contamination control during work</td><td>Tentative cell specifications for the work of making the opening
・ Measures against outflow of dust into the gap between the BSW and the PCV</td></tr>
</table>

① Installation of large heavy structures

(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

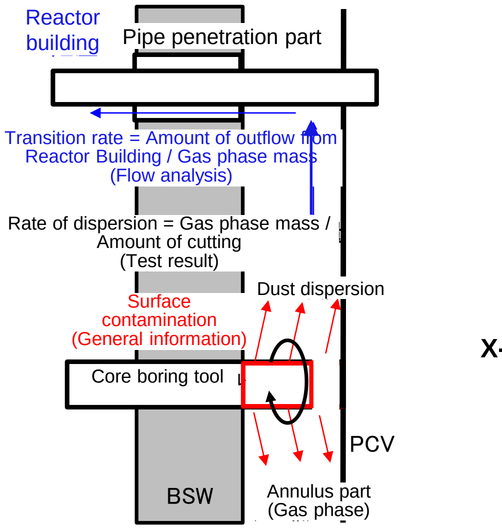
f) Dust evaluation (2/3)

In order to evaluate the exposure impact on workers due to generation of dust during the work of making an opening in the BSW, the quantity of dust outflow from the Reactor Building was evaluated and the amount of worker exposure was evaluated.

① Flow analysis Evaluation of gas flow and dust trajectory

(Dust behavior)

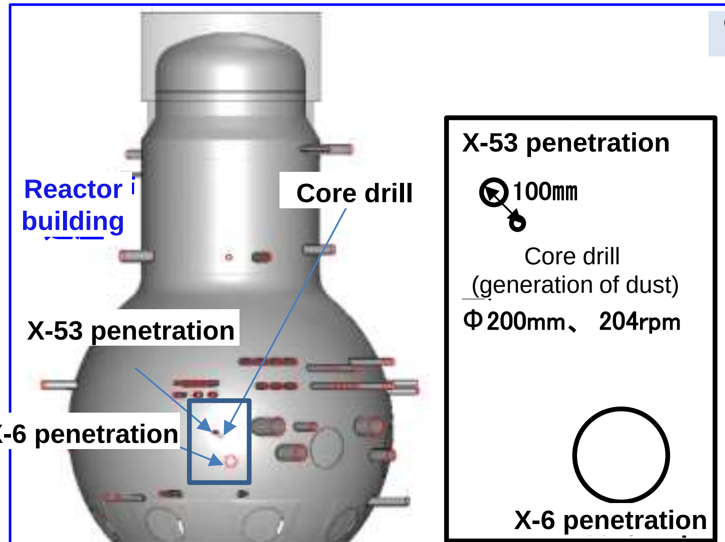
Amount of outflow of dust from the Reactor Building
＝ Amount of cutting x rate of dispersion ＊ x gas phase transition rate



＊: Dust dispersion rate (From the outcome of the Subsidy Project of Upgrading of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures under the "Subsidy Project of Decommissioning and Contaminated Water Management" in the FY2016 Supplementary Budgets)

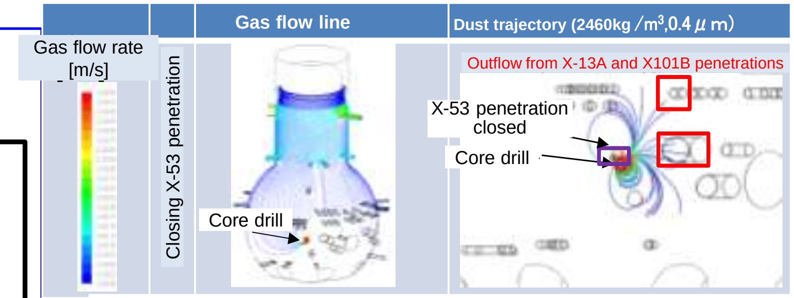
		Collected dust (mg)	Rate of dispersion (%)
Stand-alone hole	Surface part	47.7	0.028%
	Intermediate part	3.0	0.0028%
	Posterior part (PCV side)	0.2	0.00003%
Connecting holes	Surface part	6.1	0.0072%
	Intermediate part	13.8	0.0019%
	Posterior part (PCV side)	39.2	0.013%

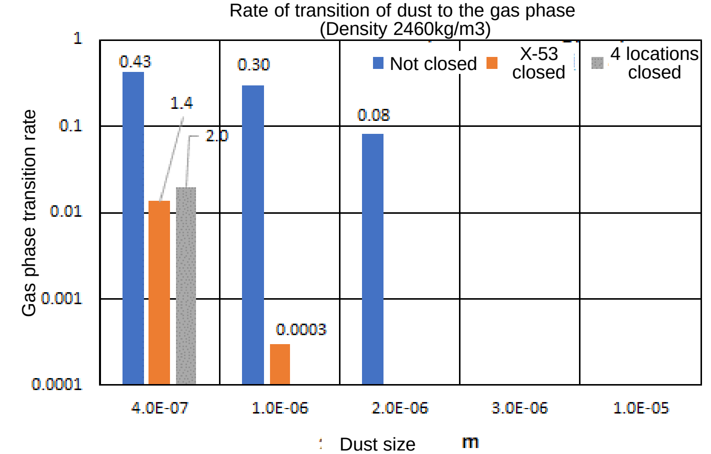
(Flow analysis model)



Analysis method
- The penetration part is simulated up to the Reactor Building side in the Analysis model
- The initial work of making an opening is assumed
- The core drill is rotated until it completely passes through the annulus part
- The gas flow field induced by the core drill is calculated
- Dust having density and size is generated from the core drilled surface and its trajectory is calculated
- The transition rate of the dust flowing out from the Reactor Building is evaluated

(Flow analysis results)





① Installation of large heavy structures

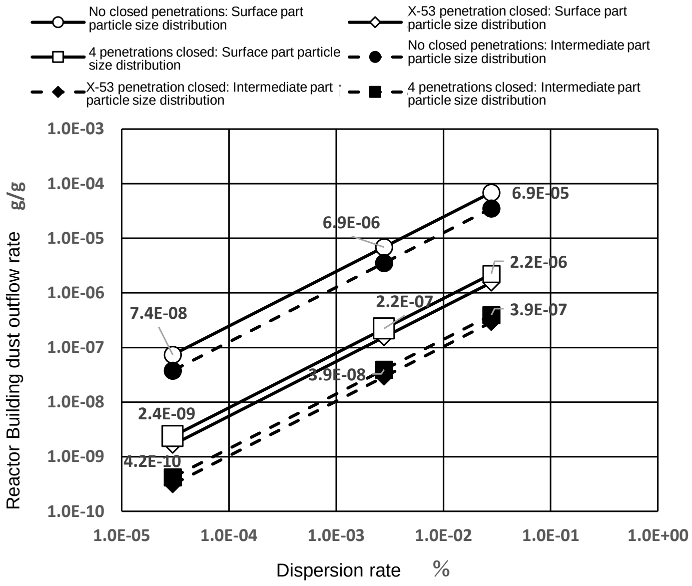
(6) Implementation items (6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

f) Dust evaluation (3/3)

② Reactor Building dust outflow rate evaluation

- ✓ **The Reactor Building dust outflow rate (g/g) is evaluated based on the dust dispersion rate, particle size distribution, and the gas phase transition rate for each particle size, when 1g BSW is scraped.**
- ✓ **There are 2 kinds of particle size distributions and many kinds of dispersion rates, but large, medium and small dispersion rates are identified, and the Reactor Building dust outflow is evaluated.**
- ✓ **The Reactor Building dust outflow rate is the maximum at approx. 1×10^{-4} when the penetrations are not closed, and it is equivalent to 2×10^{-6} when the penetration parts are closed.**



③ Reactor Building dust exposure evaluation

[Exposure evaluation method and conditions]

- **Based on the CFD analysis results, the Reactor Building outflow rate of radioactive dust generated while making an opening in the BSW (= Quantity of radioactive dust that has dispersed from the opening and flown into the R/B / Amount of radioactive material present within the range of the opening) is set at 1.0E-03 % assuming the case when the X-53 penetration is closed.**
- **Other conditions are set while referring to the Fukushima Daiichi Nuclear Power Station Specified Nuclear Facilities Implementation Plan [1] (hereinafter "Implementation Plan") and the "Hand-book on Environmental Impact Assessment for Decommissioning Work (Third Edition)"[2] (hereinafter , "Decommissioning hand-book), etc.**

Item	Unit	Value	Remarks
Contamination density (1)	Bq/cm^2	Cs :8.5E+06 Pu :2.1E+05	Set based on the Subsidy Project Report
Opening space	cm^2	314.2	Area corresponding to the diameter (20 cm) of the core cutter according to the Subsidy Project Report
Rate of outflow of radioactive waste into the R/B (2)	%	1.0E-03	Set based on the CFD analysis result
Volume of the work area in R/B	m^3	825	Volume of the work area in R/B as assumed in the Unit 2 Implementation Plan [1] (1/4 area on the first floor)
Gamma rays effective energy	MeV	Cs :5.97E-01 Pu :1.73E-03	From the Decommissioning Hand-book [2]
Internal exposure dose conversion coefficient	mSv/Bq	Cs :3.9E-05 Pu :1.2E-01	From the Decommissioning Hand-book [2]
Rate of respiration	m^3/h	1.2	Rate of respiration during activities undertaken by an adult
Exposure reduction effect due to the mask (DF)	–	50	Assuming that a full face mask is worn

【Evaluation results】

- **The exposure is 2.3E-03 mSv/h with a mask and 1.2E-01 mSv/h without a mask. Thus it is believed that the exposure impact on workers resulting from outflow of radioactive dust into the R/B during the work of making an opening in the BSW is small.**

	Unit	Dose rate (with mask)	Dose rate (without mask)
External exposure	mSv/h	1.4E-07	Same as the left
Internal exposure	mSv/h	2.3E-03	1.2E-01
Total	mSv/h	2.3E-03	1.2E-01

① Installation of large heavy structures

(6) Implementation items

[Tests related to PCV welding equipment for remotely welding the flange part]

Approach towards ensuring functional requirements

Equipment class, safety functions

○ **Non-class (Set based on the current conditions when there is no power generation facility)**

○ **Air-tightness for maintaining negative pressure (During normal times, in the event of an earthquake)**

Studies are conducted taking into account ensuring and maintaining safety functions by remote welding operations

- Structure that enables work **under restricted conditions such as confined spaces, remote operation, etc.**
- Ensuring air-tightness

[Structure]
○ Fillet welding on one of the inner sides
・ TIG welding
○ Structural evaluation by means of stress analysis
・ Self weight + pressure + seismic force

Ensuring welding quality
- Appropriate installation conditions
- Strength properties of the materials
- Improvement in welding skills

[Welding]
○ Verification of welding conditions
Full-scale partial model test
Considering confined space, groove gap, PCV curve, position, etc.
PCV material and welding joint test
Considering the impact of heat on PCV
○ Establishment of welding repair methods
○ Welding verification (full size)
○Improvement in welding skills through welding tests

- **Verification** of welding quality
- **Verification** of air-tightness
- **Verification** of the strength for withstanding load

[Inspection]
○ Before welding
・ Inspection of external appearance
・ Inspection of the groove (gap inspection)
○ After welding
・ Inspection of external appearance
(・ Leak test (air-tightness))
・ Pressure resistance test (strength)
[Other]
○ During welding: Work management

Reduction and **elimination of risks through long-term use**

[In-service monitoring]
○ Pressure inside the cell adapter
・ Maintenance of negative pressure
・ Detection of defect in air-tightness
○ Veriication of external appearance
・ Corrosion leading to defect in air-tightness

① Installation of large heavy structures

(6) Implementation items

(6)-4: d. Detailing of the work carried out inside the cells of the fuel debris retrieval equipment

✓ **Other: Detailing of the work carried out inside the cells**

✓ **Level of achievement compared to the goals**

- The work, equipment and work flow for each of the following items to be handled during the work inside the cells in the fuel debris retrieval equipment has been consolidated in the material handling flow diagrams.
  ○ Fuel debris
  ○ LLW
  ○ Robot arms for fuel debris retrieval
  ○ Overhead traveling dual arm type robot
- The heating, ventilating and air conditioning system inside the cell was studied based on the items to be handled inside the cells and their form, and considering that the inside of the cell needs to basically have negative pressure from the viewpoint of confinement, that spread of contamination needs to be prevented, that the atmosphere and environment inside the cells is the same as the PCV as the cells are connected to the PCV, etc. Specifically, the flow of air supply/exhaust, type of atmospheric gas inside the cells and the monitoring position were studied.

① Installation of large heavy structures

(7) Summary

- The structure was detailed focusing on the boundary (connected parts, assembled parts and installed parts) of the cell adapter, shielding door and fuel debris retrieval cell that form the access equipment.

- The access equipment and other fuel debris retrieval equipment cells need to be installed accurately in a straight line between the pedestal opening and the X-6 penetration opening, in order to establish the shortest access route.

Hence, the installation procedures and structure were studied, and proposals on the structure and installation feasible on the whole were developed considering the fitting accuracy.

- As a part of the study for enhancing throughput, the work carried out inside the cells was detailed for improving the accuracy of the results of calculating throughput.

- The work steps involved in installing large heavy structures were detailed and revised, issues in each step were identified, and element tests (establishment of the installation reference location, verification of the 3D processing technique for the cell adapter flange, verification of whether or not insertion is possible, and overall structure) for determining the policy for responding to the issues and for verifying it were designed and conducted.

- Since the work of installation will be carried out under high radiation dose environment, the cell adapter will need to be installed by remote operations. Hence the detailed steps involved in the installation procedure were organized and related isuues were consolidated. Also, a test plan for clarifying the required conditions for the remotely controlled equipment was created based on a structure that was substantiated and the tests were conducted.

② PCV connection sleeve installation and welding by remote operation

Studies have been conducted related to ensuring air-tightness of the connected parts for accessing the inside of the PCV for the purpose of further increasing the scale of retrieval of fuel debris and reactor internal structures. Technology is required that enables accurate installation of equipment such as the sleeve, etc connected to the PCV, by remote operation under work environment and installation conditions that include high radiation and confined spaces, etc., thereby securing the confinement function of the connected parts.

The requirements for installation of the sleeve, etc. connected to the PCV by remote operation will be consolidated, the method of installation by remote operation, the equipment and devices, and procedures will be studied, and element tests will be planned and implemented using simulated test pieces, and feasibility of the requirements such as accuracy assessment, etc. will be verified. The connection method considering the possibility of the PCV side being deformed will be studied. Also, the study will take into consideration the acceptable maximum load on the R/B floor.

The requirements for welding, inspecting and maintaining the sleeve, etc, as the technology for confining the connected parts will be consolidated, and the method of implementing a series of operations such as welding procedures, inspection and maintenance by remote operation, including the development of methods considering accuracy of installation by remote operation, remote welding equipment and required tools, pre-processing such as polishing before welding, will be studied. Thereafter, verification tests using simulated test pieces will be planned and implemented, and the welding efficiency and viability of the requirements will be verified.

② PCV connection sleeve installation and welding by remote operation

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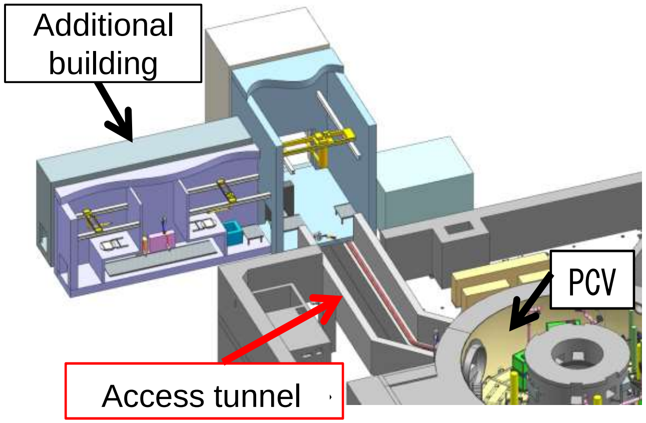
② PCV connection sleeve installation and welding by remote operation



Overview of access tunnel is provided below.

[Concept of the method]

- A method that does not apply any load on the R/B floor considering the load capacity of the R/B floor

[Overview of the method]

① The access tunnel is installed by delivering it from outside the R/B.
② The load is supported by the R/B wall and the floor surface of the BSW opening.
(Note) Connecting the access tunnel to the equipment hatch is being planned (common for Units 1 - 3)
(Note) Load bearing of the R/B wall and the floor surface of the BSW opening: 750ton/m^2, load bearing of the R/B_1F floor surface: Approx.4.9ton/m^2

[Developmental challenges]

① Feasibility of the delivery method
→ Verification of the feasibility of the delivery method by simulating the shape (Implemented in FY2018)
Verification of feasibility of the rotating part by simulating the mass (Implemented in FY2020-21: Ensuring Safety PJ)

② With 1800mm thick BSW, the load needs to be supported and displacement in the event of an earthquake needs to be absorbed.
→ Verification of feasibility of displacement absorption mechanism (Implementation in FY2020-21: Ensuring Safety PJ)
Study of installing and welding the sleeve, etc. (This project)

② PCV connection sleeve installation and welding by remote operation

Development results related to the access tunnel achieved so far and correlation with this project are indicated below.

Method & Systems Upgrade (Implemented in FY2017-18)

[Verification of the feasibility of the method (conducting element tests related to shape, dimensions, scale)]

- Delivery of tunnel path
- Delivery of the curved surface tunnel through the narrow opening
- Remote work monitoring, positioning accuracy

Further Increasing the Scale of Retrieval (Implemented in FY2019- 20)

[Verification of the connection method]

- Study of issues identified above
- Method of connecting to the BSW (sleeve welding test)
- Study of sleeve (displacement absorption mechanism) structure

Implemented in this project

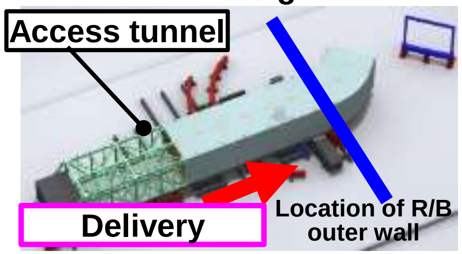
[Verification of feasibility looking ahead at the actual facility]

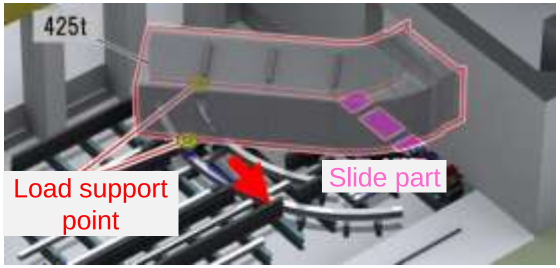
- Study of the method of remotely installing and welding the sleeve (Verification at full scale)
- Addition of shield and disassembly of shield plug

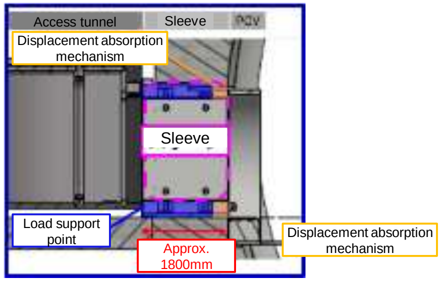
Items to be studied in future

- Study of developmental challenges identified during engineering and technical development, etc.

Biological shield opening







Ensuring Safety (Implementation in FY2020-21)

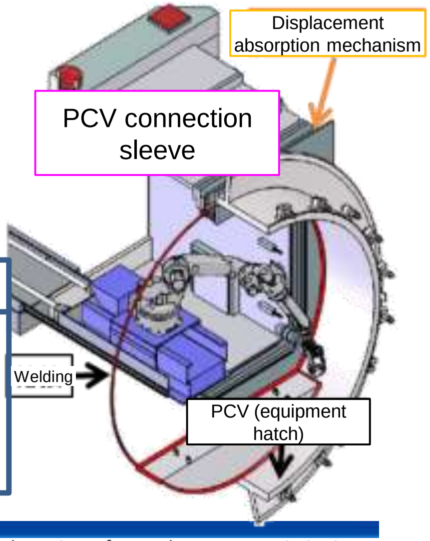
[Verification of feasibility through testing]

- Delivering heavy weight objects (Verification of the slide part)
- Displacement absorption mechanism (Verification of quantity of leakage)]

Outsourced to TEPCO HD (Implemented in FY2020-21)

[Study of the concept of the equipment for remotely installing the PCV connection sleeve]

- Selection of proposal for remote installation of sleeve
- Conceptual design and identification of issues



② PCV connection sleeve installation and welding by remote operation

[Status of studies conducted up to FY2020]

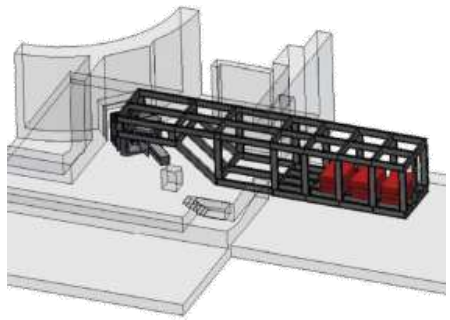


Illustration of the PCV connection sleeve installation (Unit 3)

<PCV connection sleeve welding>

- Consolidation of welding conditions of equipment hatch shell and PCV connection sleeve
- Welding element test (Verification of gap that can be welded)
- Selection of abrasive
- Study of grinder (Implementation of prior verification test)

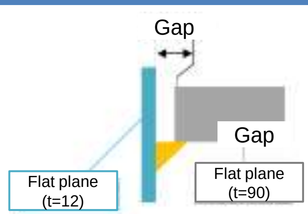
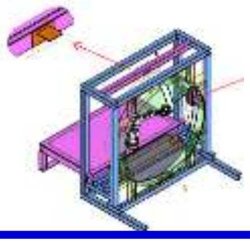
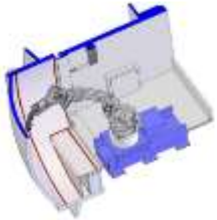
⇒ It was confirmed through the element test on welding that a gap of 20mm can be welded as well.

Full scale welding test (full scale mock-up test) is implemented based on the welding element tests conducted up to FY2020.

Further, the gap needs to be reduced as much as possible considering the on-site workability, thermal contraction effect at the time of welding, and quality.

A prototype of the installation equipment will be manufactured to verify the accuracy of full scale remote installation of the sleeve connected to the PCV.

Implemented in this project

Testing by setting conditions	Element test	Full scale mock-up tests
 ✓ Stacking method ✓ Welding position ✓ Heat input for welding ✓ Welding gap	 ✓ Welding gap (Equipment similar to the actual facility) Implemented	 ✓ Series of procedures ✓ Process management ✓ Inspection (Fluorescent PT) ✓ Verification of welding strain ✓ Cold crack measures

② PCV connection sleeve installation and welding by remote operation

[Issues]

- Considering the on-site workability and quality of welding, the gap between the PCV and the sleeve has to be reduced as much as possible. Accurately installing the PCV connection sleeve by remote operation is a challenge, based on the work environment (radiation dose, etc.).
- Also, establishing the method of remote welding considering the remote installation accuracy (gap) is a challenge.

[Implementation details]

- The pre-conditions related to the study are consolidated.
- The requirements for installation of the sleeve, etc. connected to the PCV by remote operation are organized, and the method of installation by remote operation, the equipment and devices, and procedures are studied.
 (The connection method considering the possibility of the PCV side being deformed, the acceptable maximum load on the R/B floor, etc. are considered.)
- The requirements for welding, repairing, inspecting and maintaining the sleeve are consolidated, and the method of implementing a series of operations such as welding procedures, inspection and maintenance by remote operation, including the development of methods considering accuracy of installation by remote operation, remote welding equipment and required tools, pre-processing such as polishing before welding, are studied.
- Element tests on the remote sleeve installation method and the welding procedures are planned and implemented to verify feasibility.

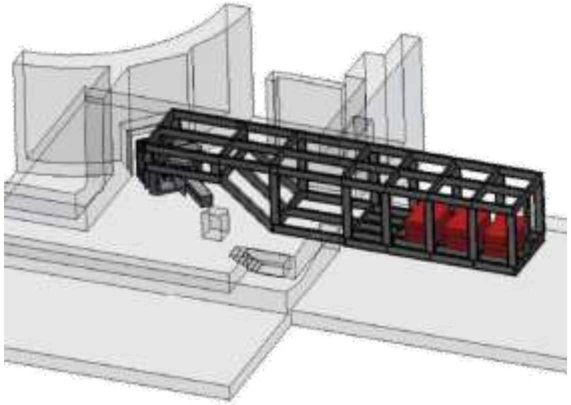


Illustration of the PCV connection sleeve remote installation (Unit 3)

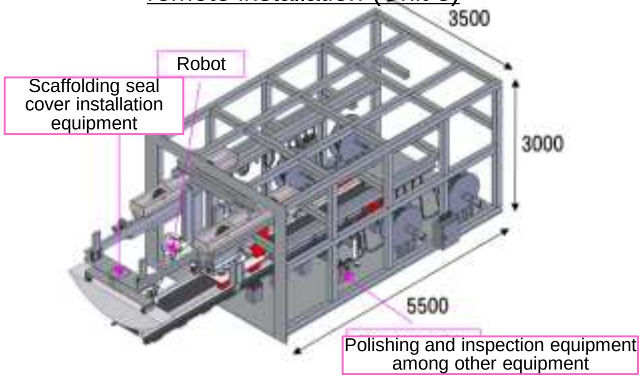


Illustration of PCV connection sleeve welding equipment

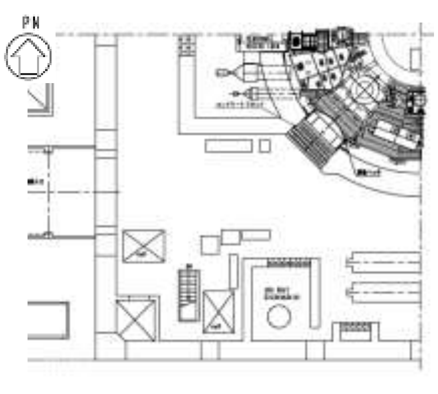
[Expected outcome]

- Presentation of a method for remotely installing the sleeve.
- Presentation of a series of remote welding procedures and remote maintenance methods related to the sleeve.

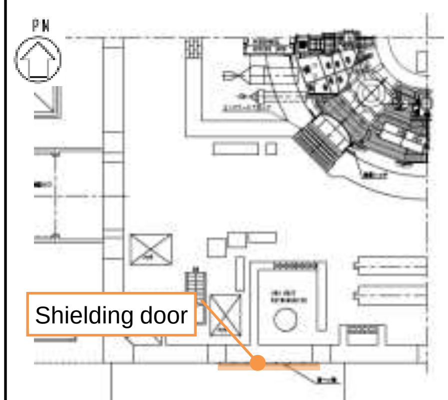
② PCV connection sleeve installation and welding by remote operation

[Outline of procedures while using the actual facility (1/2)]

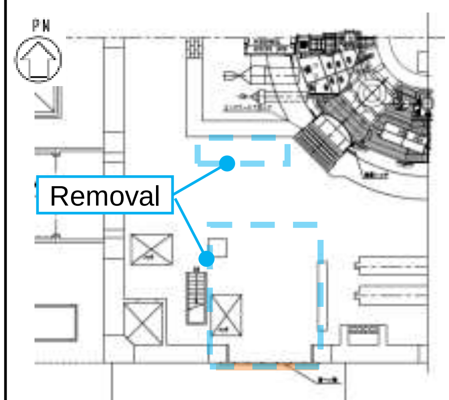
1. Before installing the access tunnel



2. Shielding door installation

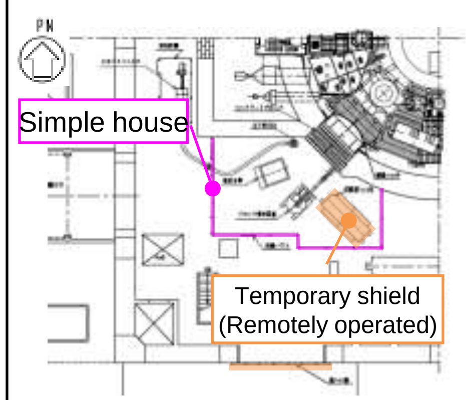


3. Removal of R/B wall and interfering objects



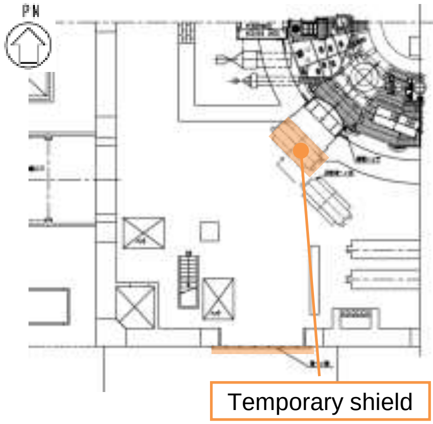
Removal of interfering objects such as RHR, etc.

4. BSW opening (Block-out)



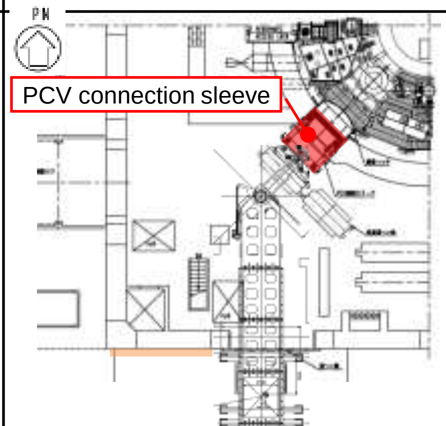
Simple house (Prevention of dust dispersion)

5. Temporary shield installation



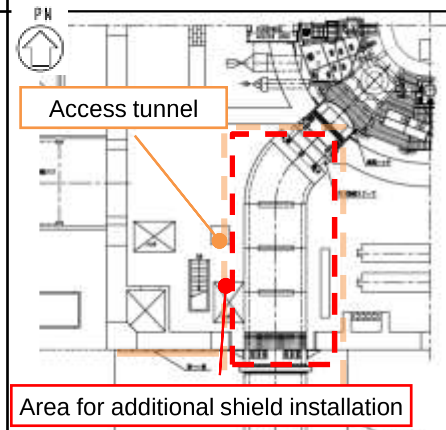
Measures against dose from inside the PCV

6. PCV connection sleeve installation



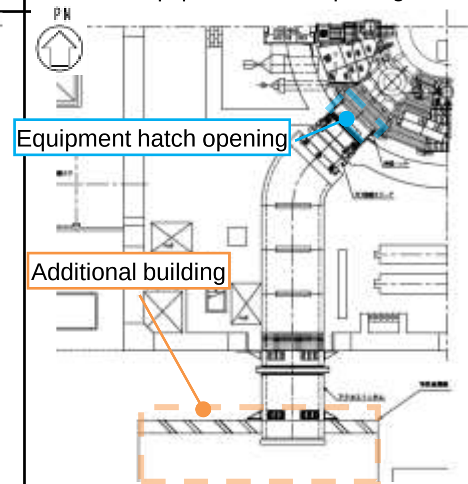
(Refer to the following page for detailed explanation)

7. Access tunnel Installation



Installation of additional shielding as required

8. Equipment hatch opening

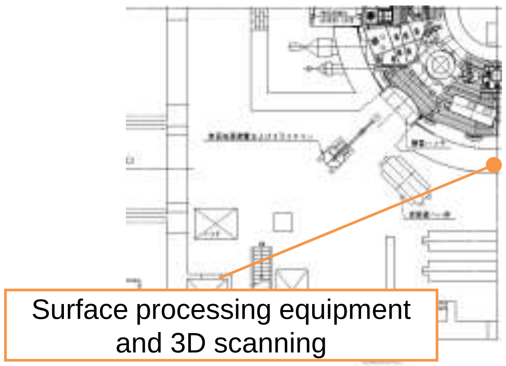


② PCV connection sleeve installation and welding by remote operation

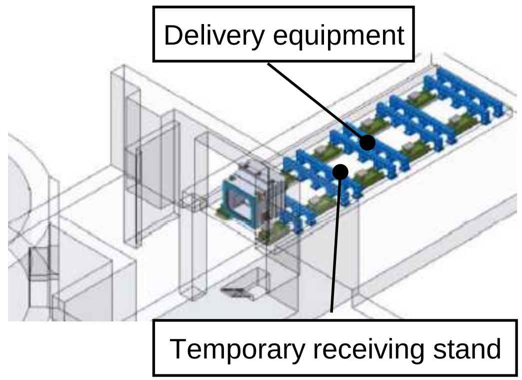
[Outline of procedures while using the actual facility (2/2)]

6. PCV connection sleeve installation

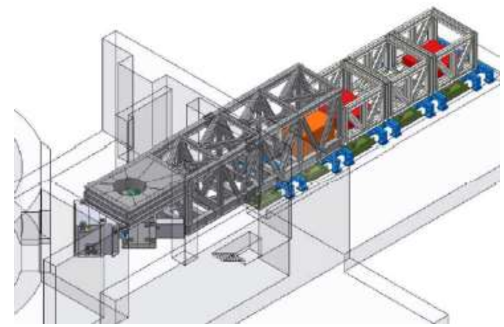
6.1 Surface processing and opening investigation (3D scanning etc.) → Reflection of shape into the PCV connection sleeve



6.2 Installation of remote installation equipment

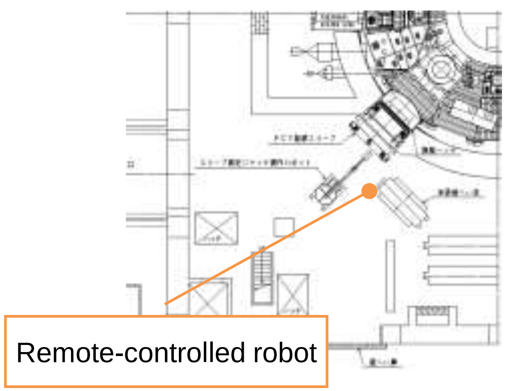


6.3 Installation of PCV connection sleeve

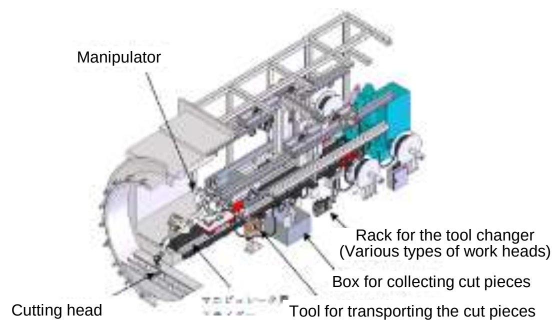


6. PCV connection sleeve installation

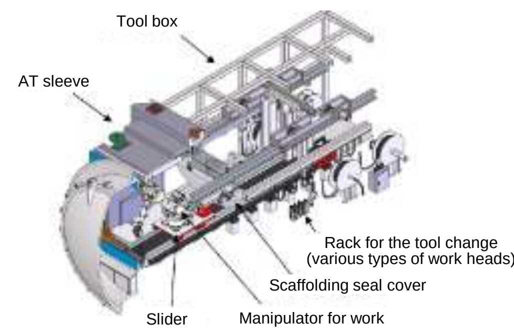
6.4 Fixing of PCV connection sleeve



6.5 Carrying-in of the scaffolding removal equipment / Removal of scaffolding



6.6 Carrying-in of the welding equipment / Welding / Inspection



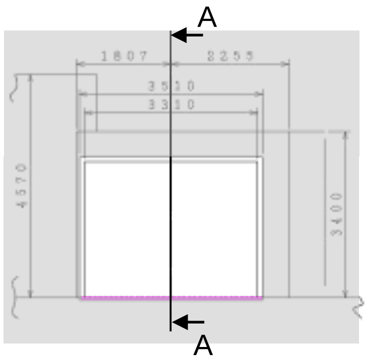
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

Table of Contents

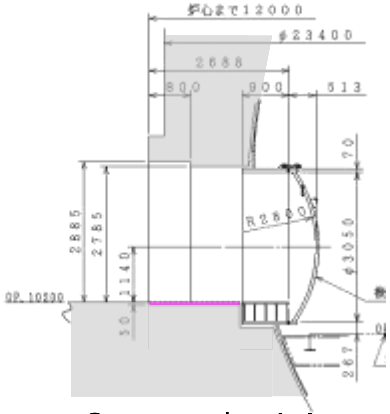
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Requirement (Consolidation of preconditions)]

No	Items	Pre-conditions	Remarks
1	Target	Unit 1: Installed from the northern side Unit 2: Installed from the southern side Unit 3: Installed from the southern side	Installed from the same opening as the access tunnel main body in all units
2	Permissible load on the R/B floor	Approx. 4.9 ton/m^2	The permissible load on the floor after making the BSW opening and the R/B wall opening is 750ton/m^2.
3	Dimensions of the assumed R/B opening	Unit 1: W5060×H6000mm Unit 2: W6300×H6100mm Unit 3: W6100×H6100mm	
4	Distance from the R/B wall to the equipment hatch	Unit 1: Approx. 16m Unit 2: Approx. 18m Unit 3: Approx. 18m	
5	Interfering objects inside and outside the Reactor Building	All must be removed.	
6	BSW opening (floor surface)	Must be flat and at the same level as the first floor	
7	Equipment hatch shell	Rust, etc. must be removed.	

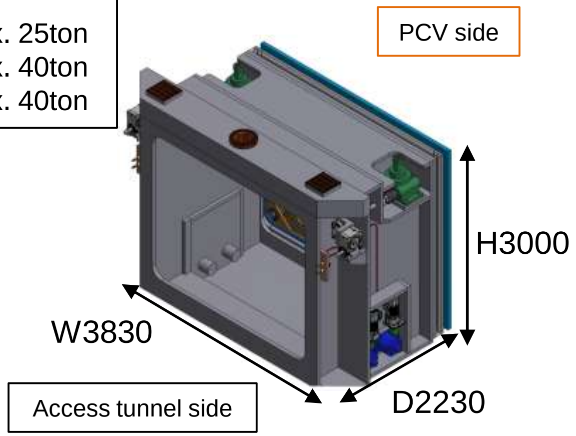


BSW opening (front view)



Cross-section A-A

PCV connection sleeve weight
Unit 1: Approx. 25ton
Unit 2: Approx. 40ton
Unit 3: Approx. 40ton



Bird's eye view of the PCV connection diagram (Unit 1)

Required accuracy	Remarks
The gap between the PCV connection sleeve and the equipment hatch shell is 7.5 mm or less (Target value)	During the FY2019-20 Subsidy Project it was confirmed that a gap of 20mm or less can be welded, but considering the on-site workability, as it is desirable to have a gap of 7.5mm or less, the target value is set at 7.5mm.

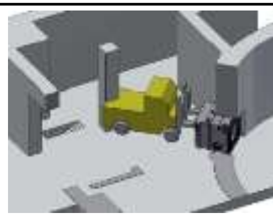
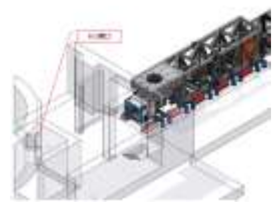
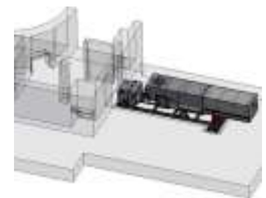
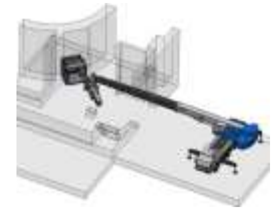
Note: The contents of this slide are cited from the results of the studies on the PCV connection sleeve remote installation equipment concept outsourced to TEPCO HD (Implemented in FY2020-21).

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Selection of remote installation equipment]

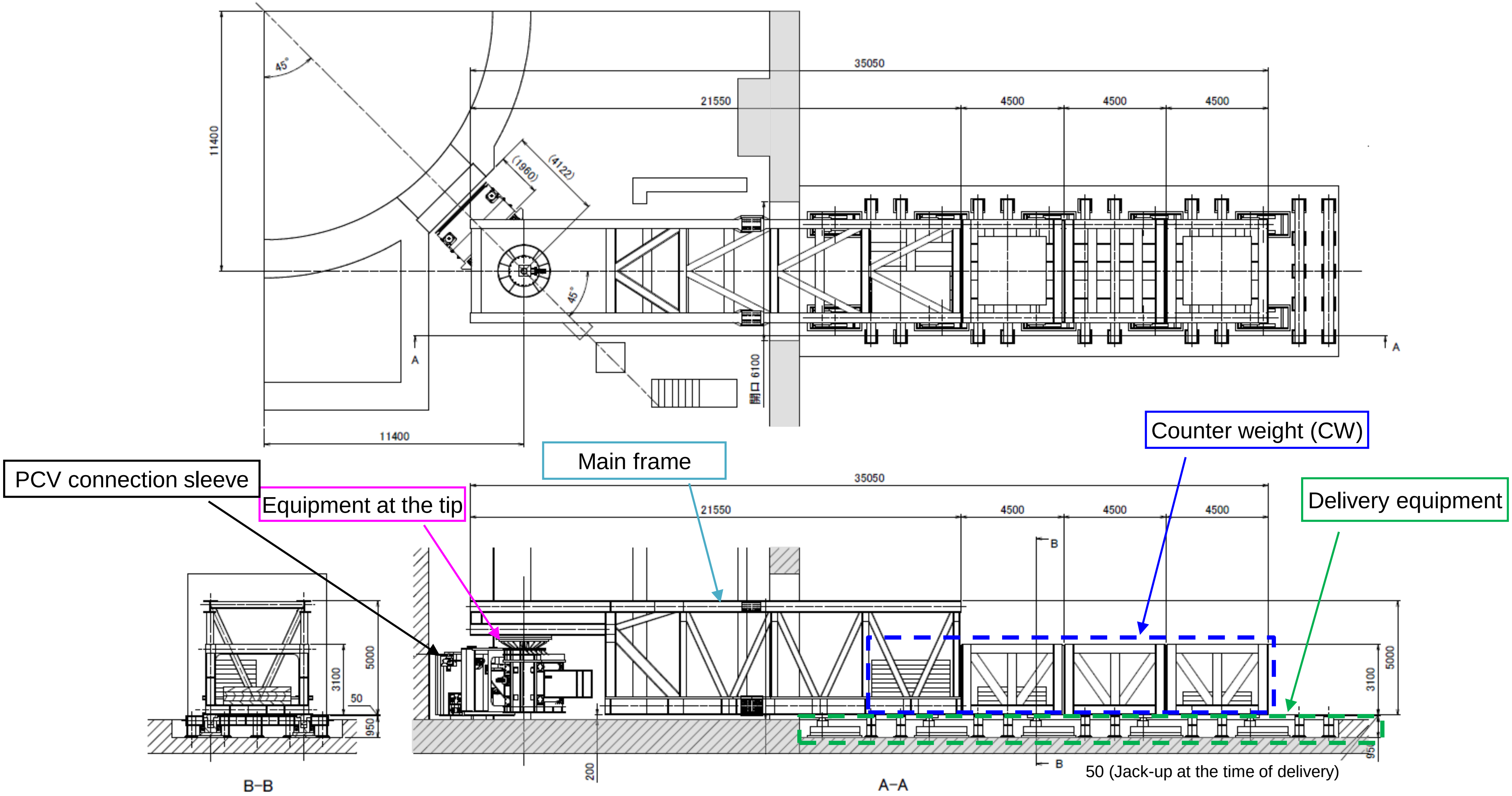
Proposal 3 and 4 are rated as "✓". Since proposal 3 is delivered using the same delivery method as access tunnel main body, it already has a proven track record. Also, since the same equipment is used, it is superior over other proposals in terms of the schedule as well. → Proposal 3 indicated by the red frame in the table below is selected.

	(Proposal 1) Forklift method	(Proposal 2) Traveling rail method	(Proposal 3) Integrated delivery method	(Proposal 4) Rail delivery method	(Proposal 5) Boom method
					
Permissible load on building floor (Unit 3: 4.9tm^2)	△ (Needs to be analyzed)	x (Tip foot part load capacity x)	✓ (As it is cantilevered it does not come in contact with the floor surface)		△ Load from an air caster
Equipment scale	Small	Large	Large	Large	Medium
Excavation outside the R/B	Absent	Small scale (or absent)	Present	Present	Small scale (or absent)
Track record	Present	Absent	Present (Access tunnel main body mock-up)	Absent Regular machine elements	Absent (Track record of retracting of boom is present)
Feasibility	x	x	✓	✓	△
	(Manufacturing) Possible. (Method) Since there is momentum at the tip, it is difficult to reduce the size, and interference cannot be avoided.	(Manufacturing) Although complex, it is possible. (Method) It is difficult to reduce the load on the floor when inserted through the opening, and hence the floor load capacity cannot be met.	(Manufacturing) Possible. (Method) Possible. Mock-up of the delivery has been implemented. The preceding and subsequent processes need to be considered.	(Manufacturing) Possible. (Method) Possible. Load bearing points need to be studied.	(Manufacturing) Possible. (Method) Unknown. Viability of the air casters needs to be verified, and measures to prevent spread of contamination due to wind pressure are required.
Grave issues	Present (Interference with the pillars)	Present (Load capacity)	Absent	Absent	Present (Continuous air supply in the event of an emergency)
Applicability to other units	x (Interference with the pillars)	✓ (Except building floor load capacity)	✓	✓	✓ (Except building floor load capacity)
Impact on schedule	Minor	Major	Medium	Major	Minor
Evaluation	x	x	✓	✓	x

Note: The contents of this slide are cited from the results of the studies on the PCV connection sleeve remote installation equipment concept outsourced to TEPCO HD (Implemented in FY2020-21).

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

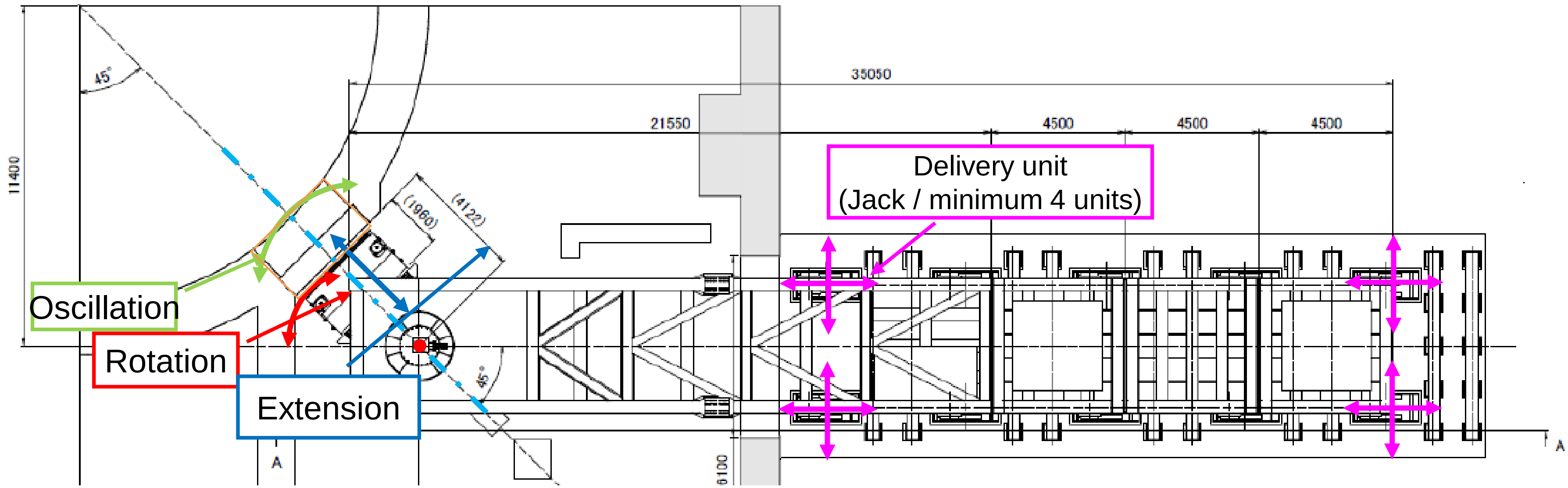
[Conceptual design_full view (Proposal 3)] Note) The figure illustrates Unit 3



Note: The contents of this slide are cited from the results of the studies on the PCV connection sleeve remote installation equipment concept outsourced to TEPCO HD (Implemented in FY2020-21).

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Operation axis]



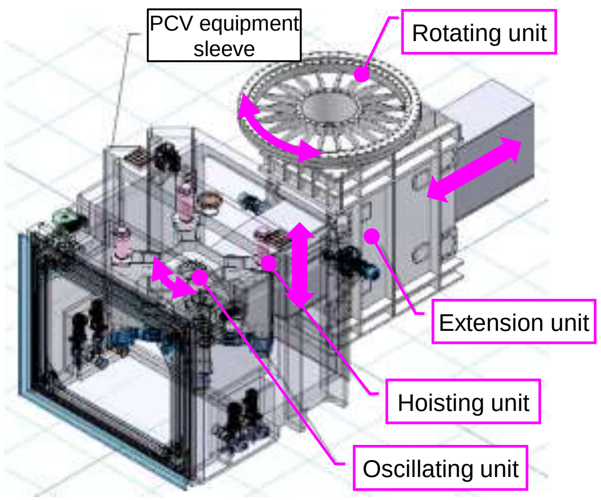


Illustration of equipment at the tip

Unit	Composition	Use applications
Delivery	XYZ Jack: 4 units (Can be operated on a single shaft)	Positioning up to the front of the BSW opening
Rotation	Rotation motor: 1 unit	Positioning up to the front of the BSW opening
Extension	Extension motor: 1 unit	Insertion into the BSW opening / Final fine adjustments
Oscillation	Rotation motor: 1 unit	Final fine adjustments (Aligning the surface with the equipment hatch end face
Hoisting	Hoisting motor: 4 units (Stand-alone operation of the 4 units is possible)	Final fine adjustments, seating / deflection compensation (leveling)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Conceptual design_outline of installation steps]

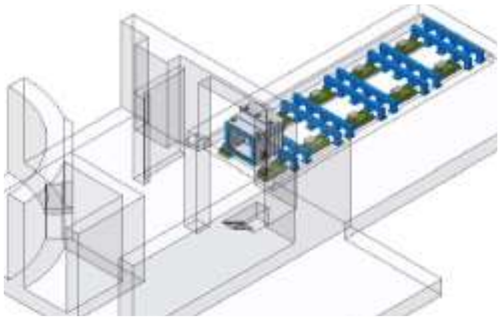
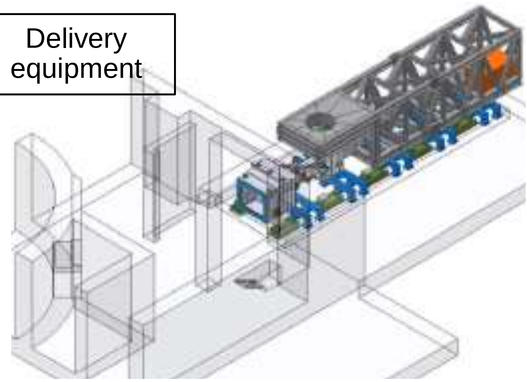
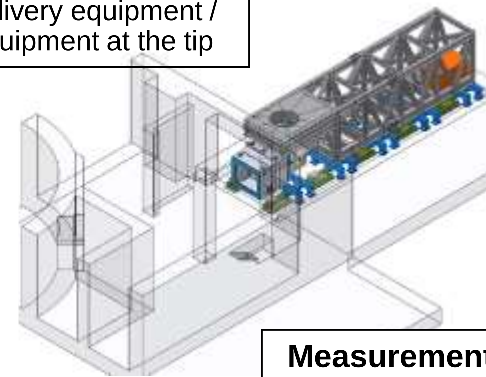
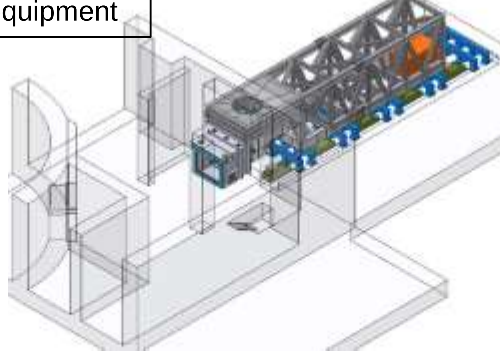
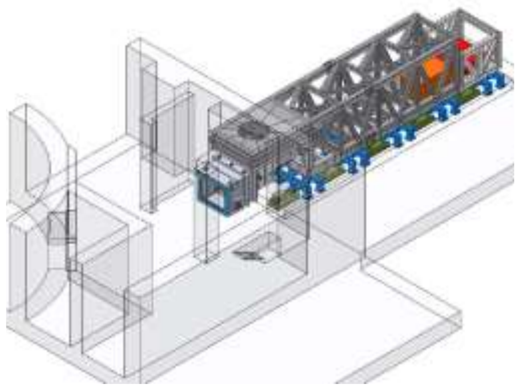
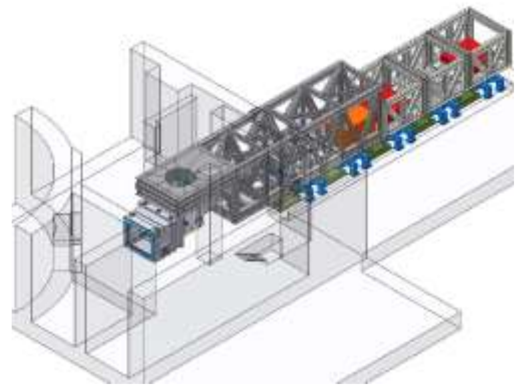
- Advanced preparations and equipment installation are tasks carried out directly by humans (not remote operations). Delivery is a remote operation.
- The auxiliary lines and other markings play an ancillary role in delivery. Final verification is carried out using camera or measuring instruments.

Step	Items	Overview	Work
1	Advanced preparations	The required auxiliary lines or markings are done before installing the delivery equipment.	Not a remote operation
2	Equipment installation	The delivery equipment is installed including ground improvement.	Not a remote operation
3	Delivery (1)	The sleeve is delivered up to right in front of the BSW opening.	Remote operation
4	Delivery (2)	It is delivered up to right in front of the equipment hatch shell by means of the equipment at the tip, and fine adjustments are made while confirming the gaps in the entire periphery by means of a camera, etc.	Remote operation
5	Positioning	It is seated on the BSW floor surface using the hoisting unit.	Remote operation
6	Fixing	Reaction force jack (Fixing jack) is operated to fix it on to the BSW.	Remote operation
7	Withdrawal	The delivery equipment is withdrawn.	Remote operation

Note: The contents of this slide are cited from the results of the studies on the PCV connection sleeve remote installation equipment concept outsourced to TEPCO HD (Implemented in FY2020-21).

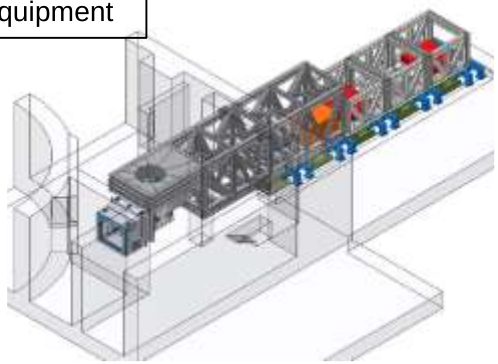
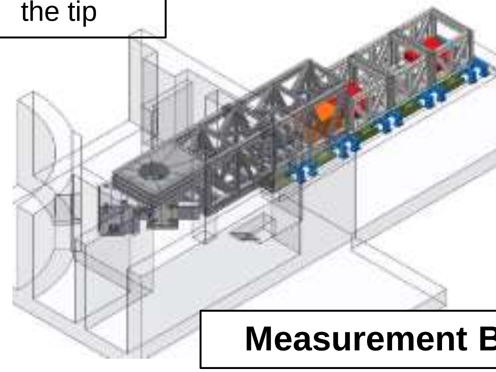
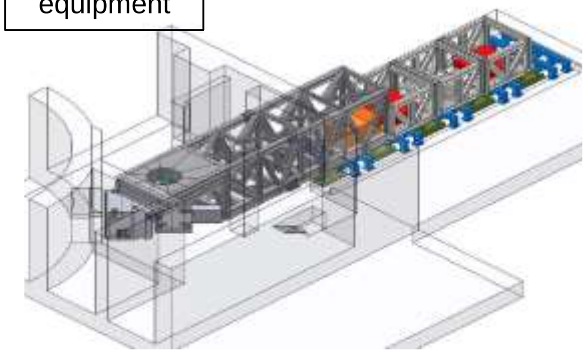
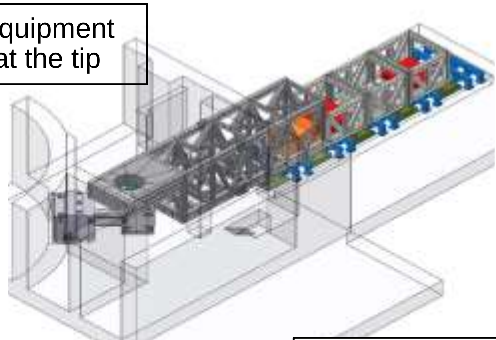
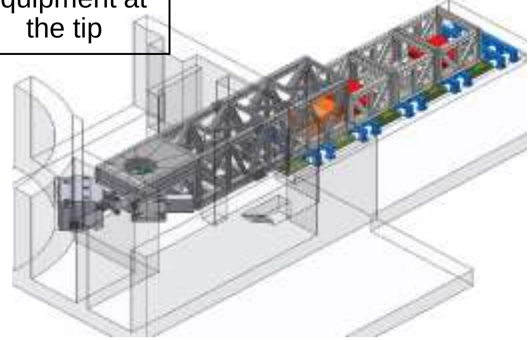
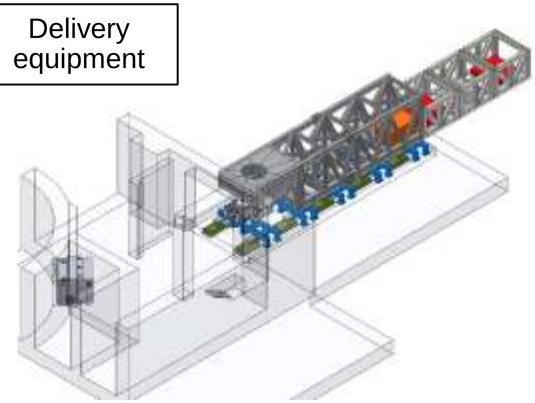
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Installation procedure: (1/2)]

1. Delivery equipment / PCV connection sleeve installation	2. Main boom / CW1 installation	3. 3m forward movement of main boom / holding of the PCV connection sleeve
 # Including excavation before installing the delivery equipment		
4. 4m forward movement of main boom	5. Connection of CW2	6. Completion of CW installation
	 Connection of CW3, 4 just like CW2	

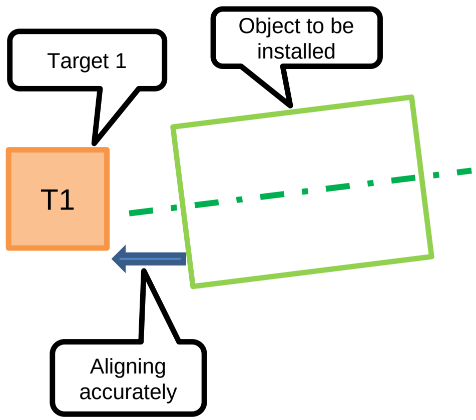
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

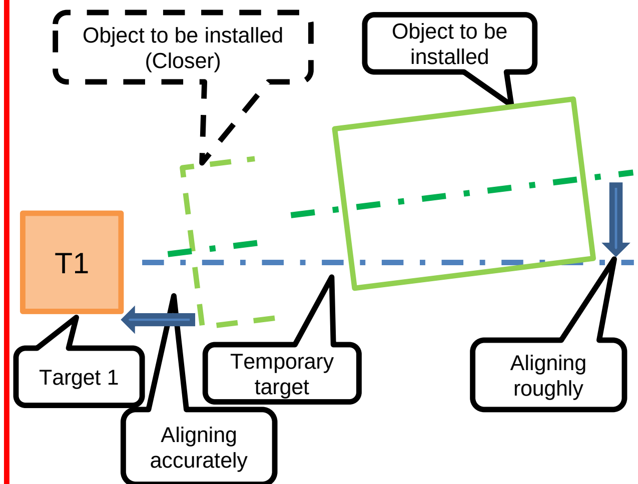
[Installation procedure: (2/2)]

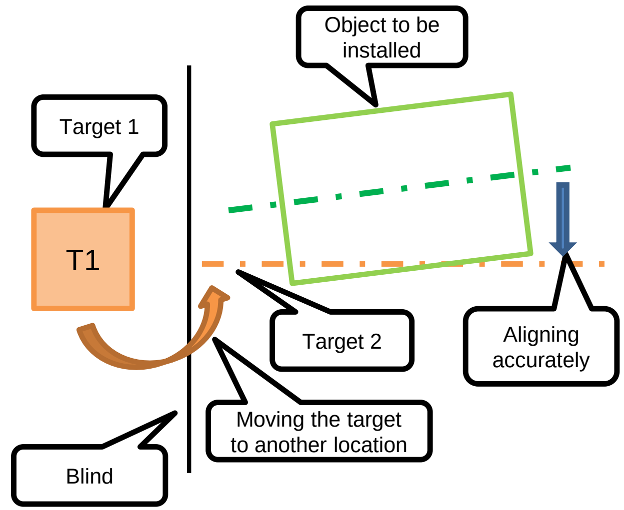
7. 2.4m forward movement of main boom	8. 45° rotation	9. Forward movement of main boom
		
10. PCV connection sleeve positioning / insertion / seating	11. Withdrawal of boom (extension unit)	12. Forward movement of main boom
		

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Approach towards installation]
The content in red frame indicates the approach towards the present method (Remote installation of PCV connection sleeve)







If the target can be verified directly		If the target cannot be verified directly
# When the target and object to be installed are near	# When the target and object to be installed are far	
If the target can be verified directly, positioning is carried out while directly verifying the target. (The following is carried out in the above case) ① Positioning of the object to be installed while directly verifying Target 1.	If the target can be directly verified but is far, a temporary target is set up, and until the target gets closer, positioning is carried out roughly using the temporary target as the guide. After getting closer to the target, positioning is carried out while directly verifying the target. (Outline of procedures) ① Setting up the temporary target. ② Roughly aligning the object to be installed with respect to the temporary target ③ Positioning the object to be installed while directly verifying Target 1, after getting closer to Target 1	If the target cannot be directly verified or if the verification is difficult, the target is moved to another location, positioning is carried out considering the target after relocation as the correct target. (Outline of procedures) ① Moving Target 1 to another location, and considering Target 2 as the correct target ②Positioning the object to be installed with respect to Target 2 (Note) ・Since Target 2 is considered as the correct target, positioning needs to be correctly carried out with respect to Target 2. ・Accuracy of moving the target to another location is needed as well.

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Scope of simulation]

The portion indicated by the red frame is simulated, and a verification test is conducted.

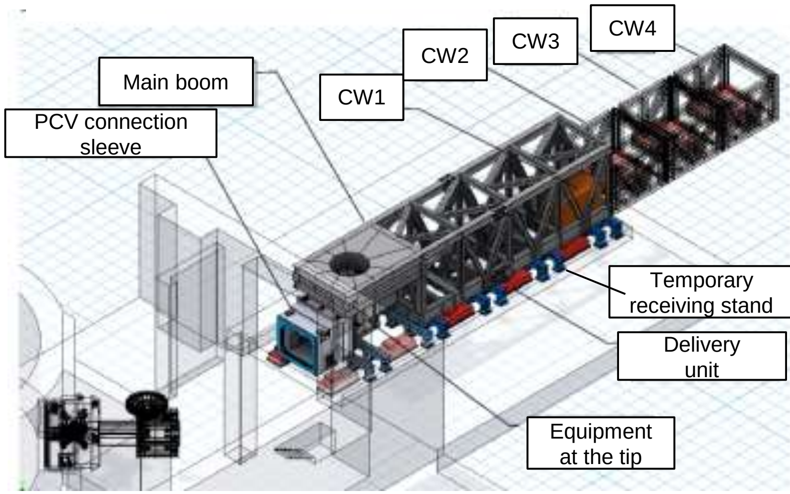


Illustration of entire actual facility (Before delivery)

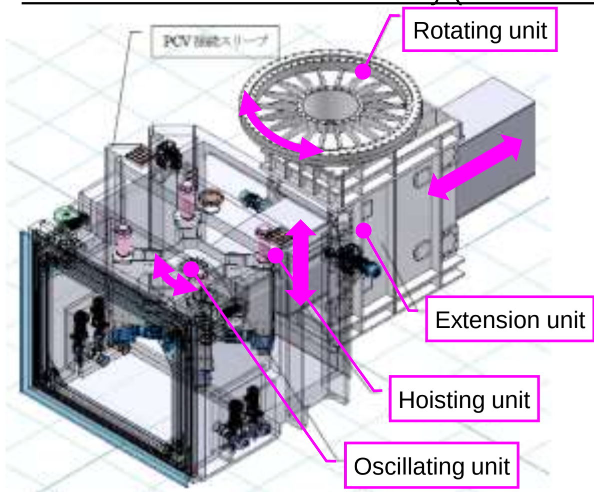
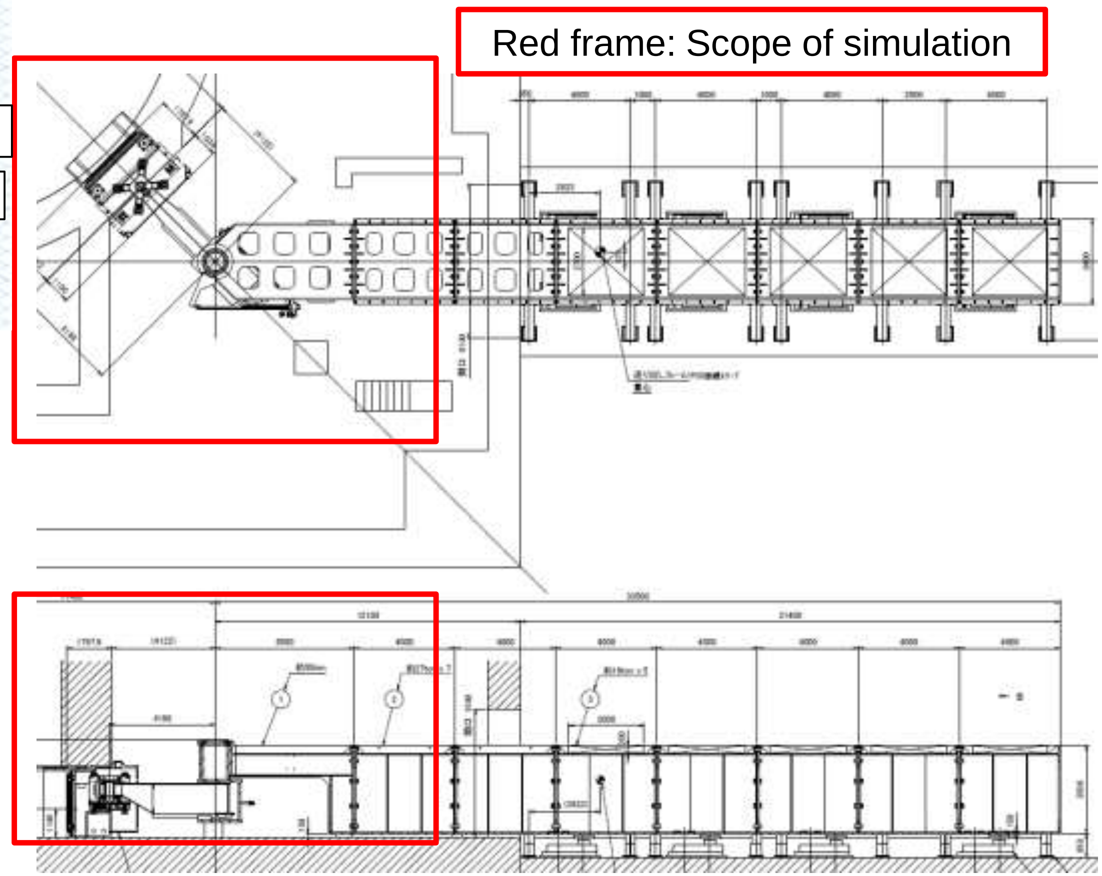
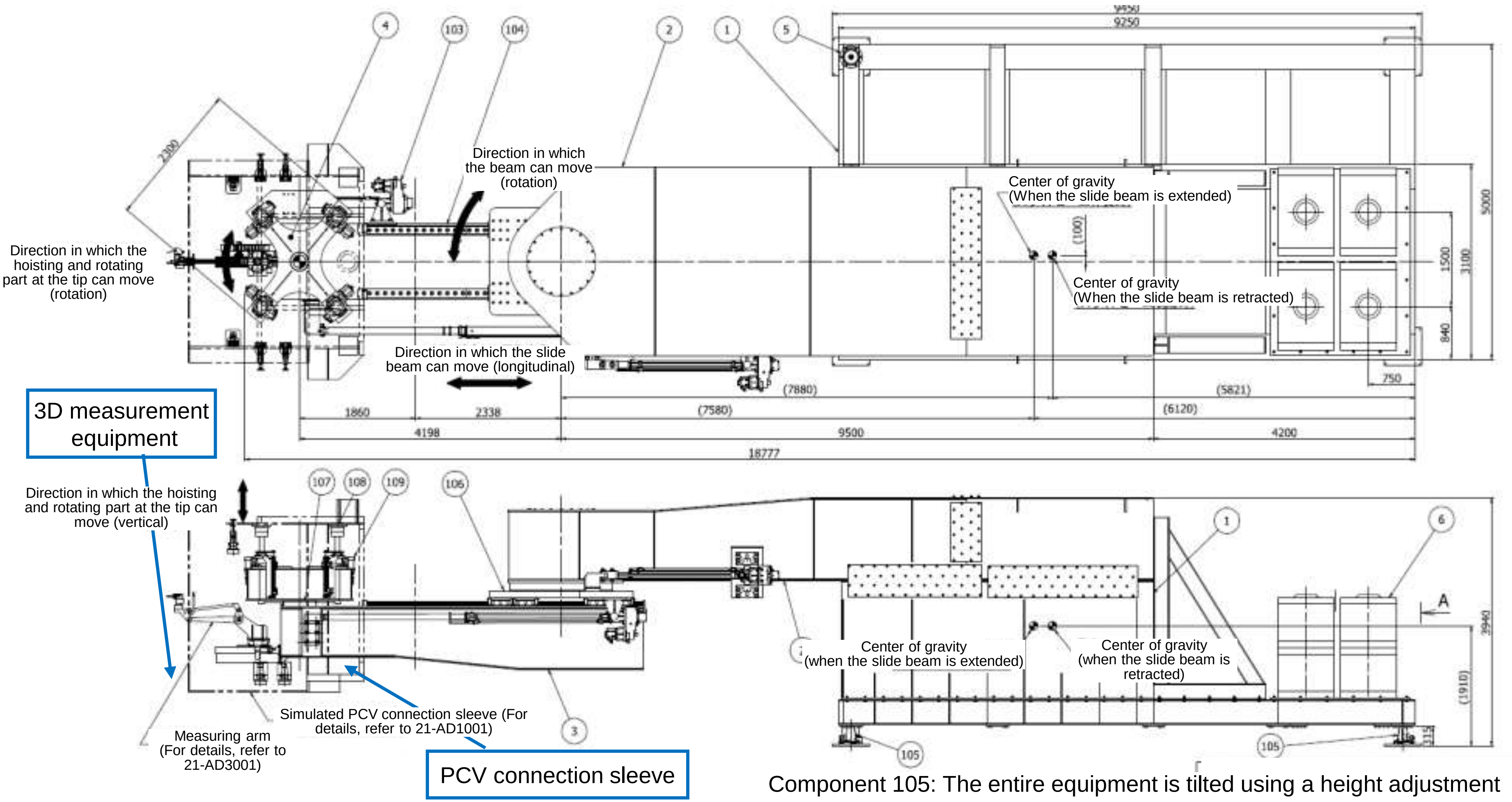


Illustration of equipment at the tip



② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Structure of the mock-up equipment]



Component 105: The entire equipment is tilted using a height adjustment mechanism in order to simulate maximum deflection.

② PCV connection sleeve installation and welding by remote operation

[Comparison with actual facility] Remote installation equipment specifications (1/2)

No.	Items		Actual facility (assumed)	Mock-up
0	Entire equipment	Composition of operation axis	Delivery unit: 3 axes (X, Y, Z)	Not simulated (Substituted by moving the simulated opening)
			Equipment at the tip: 7 axes (Rotation, retraction, oscillation, hoisting x 4)	Same as on the left
1	Delivery unit	Composition	Hydraulic jacks × 4 units	Not simulated (Substituted by moving the simulated opening)
		Installation accuracy (Resolution)	20mm or less	
2	Rotating unit (Equipment at the tip)	Composition	Power cylinder	Same as on the left
		Scope of movement	0 to 45° (Maximum 50°)	
		Speed	Rated: 0.03 rpm (Approx. 4.2min @ 45° Rotation) Maximum: 0.05 rpm (Approx. 2.5min @ 45° Rotation)	
		Resolution	0.0014° / rev (1.5mm/rev @ PCV connection sleeve tip)	
3	Extension unit (Equipment at the tip)	Composition	Power cylinder	Same as on the left
		Scope of movement	0 to 1900 mm (+10mm/-100mm)	
		Speed	Rated: 0.24 m/min (4.0 mm/s) Maximum: 0.60 m/min (10.0 mm/s)	
		Resolution	0.4 mm/rev	

② PCV connection sleeve installation and welding by remote operation

[Comparison with actual facility] Remote installation equipment specifications (2/2)

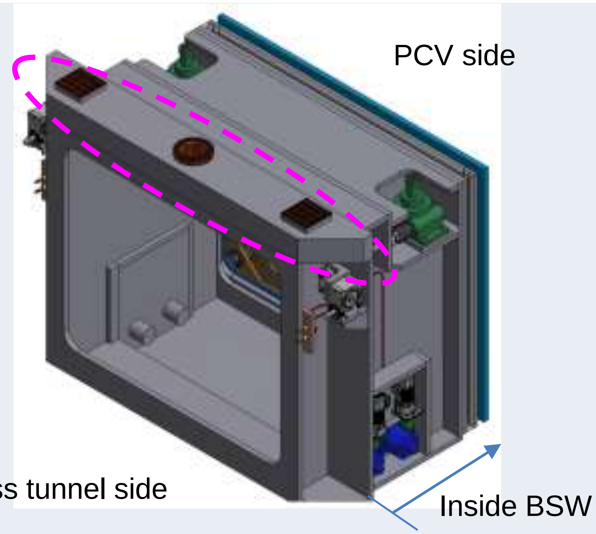
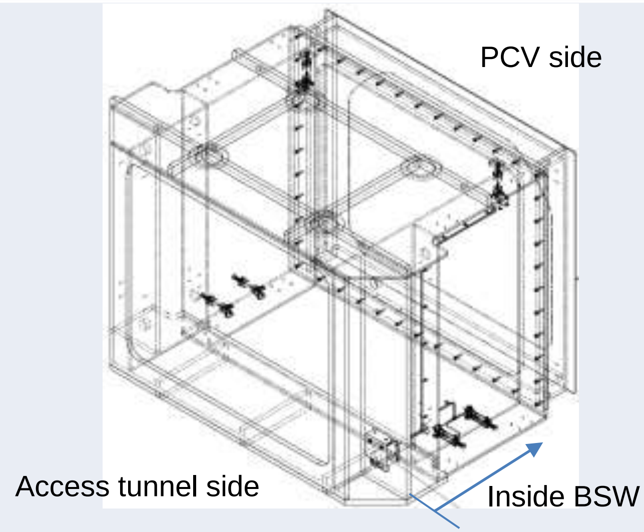
No.	Items		Actual facility (assumed)	Mock-up
4	Oscillation unit (Equipment at the tip)	Composition	Power cylinder	Same as on the left
		Scope of movement	± 5° (Maximum 31.5°)	
		Speed	Rated: 0.03 rpm (Approx. 28sec @ 5° Rotation) Maximum: 0.05 rpm (Approx. 17sec @ 5° Rotation)	
		Resolution	0.025° /rev (0.75mm/rev @ PCV connection sleeve tip)	
5	Hoisting unit (Equipment at the tip)	Composition	Servo motor + trapezoidal screw	Same as on the left
		Scope of movement	Maximum St.500mm	
		Speed	Rated: 0.06 m/min (1.0 mm/s) Maximum: 0.075 m/min (1.25 mm/s)	
		Resolution	0.025 mm/rev	
		Capacity	20 ton/unit	

Remarks

- An encoder (26bit) is used for detecting the position of each unit of the equipment at the tip.
- The optimum speed is confirmed through tests.
- The end point of the movement is detected using a limit switch.

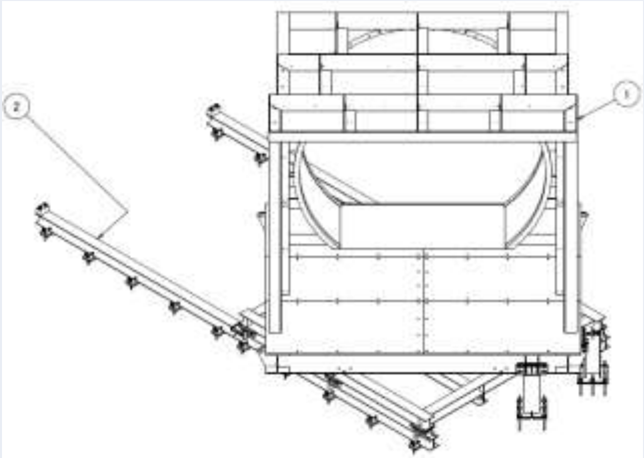
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Comparison with actual facility] PCV connection sleeve

Items	Actual facility (assumed)	Mock-up
Specifications	Target equipment: 1F-3 External dimensions: W3730 × L2812 × H3025 (mm) Weight: Approx. 40 ton	Target equipment: 1F-3 External dimensions: W3730 x L2812 x H2785(mm) Weight: Approx. 12 ton
Image		
Remarks	Height: Not simulated as there is no interference on the outer side of the BSW (When installation is complete / portion indicated by dotted line), and there is no impact on ease of installation. The actual facility external dimensions were simulated for the dimensions inside the BSW.	

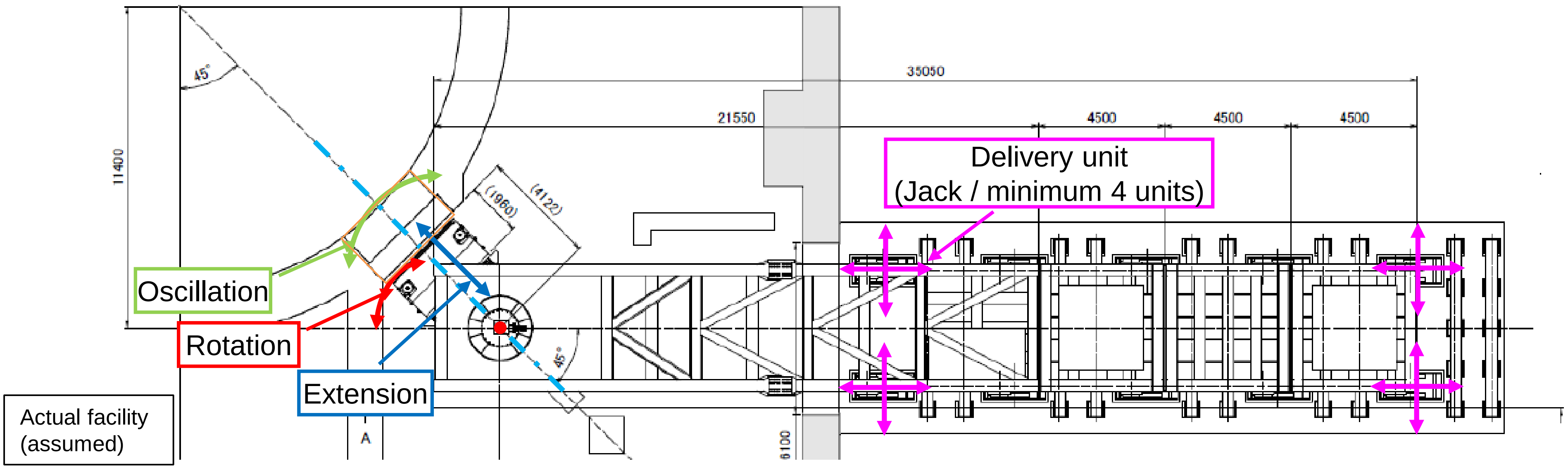
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

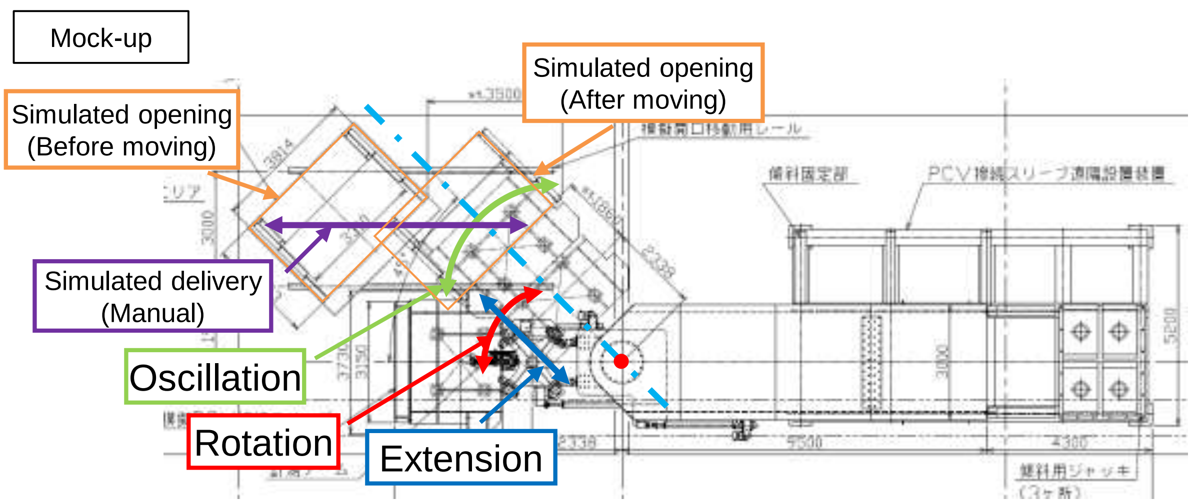
[Comparison with actual facility] BSW opening / Equipment hatch

Items	Actual facility (assumed)	Mock-up
Specifications	Target equipment: 1F-3 ・BSW opening Internal dimensions (narrower side): W3310 x D998 x H2785(mm) Internal dimensions (broader side): W3510 x D800 x H2885(mm) ・Equipment hatch Shell: φ3050 x t70mm	Target equipment: 1F-3 ・BSW opening Internal dimensions (narrower side): W3310 x D998 x H2785(mm) Internal dimensions (broader side): W3510 x D800 x H2885(mm) ・Equipment hatch Shell: φ3050 x t70mm
Image		
Remarks	—	

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Comparison with actual facility] Operation axis and rough outline of the steps involved





Procedure	Outline of procedures while using the actual facility	Outline of procedures while using mock-up
1	Delivery (Approx. 10m)	— (Not simulated)
2	40° rotation	Same as on the left
3	Delivery (Approx. 2.8m)	Simulated delivery (Approx. 2.8m)
4	Delivery (Approx. 0.7M/Measurement value) + Rotation (Approx. 5° /Measurement value)	Simulated delivery (Approx. 0.7m/Measurement value) + Rotation (Approx. 5° /Measurement value)
5	Extension (Approx. 1.8m)	Same as on the left
6	Fine adjustments (Extension / Oscillation / Hoisting)	Same as on the left
7	Seating (hoisting)	Same as on the left

② PCV connection sleeve installation and welding by means of remote operation: (a) Remote installation

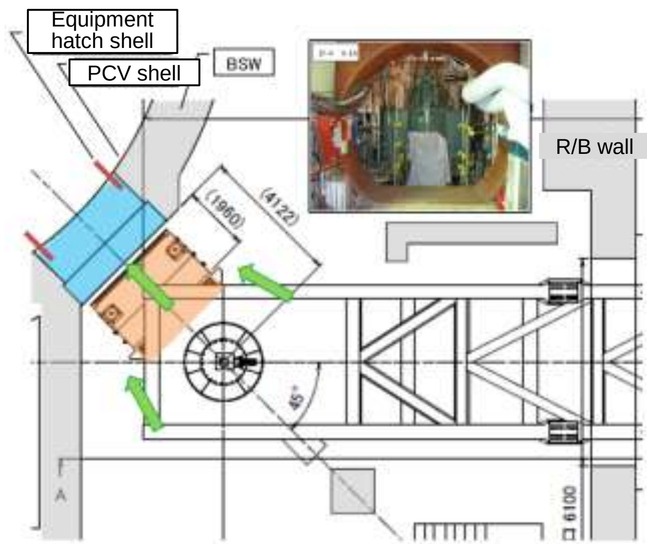
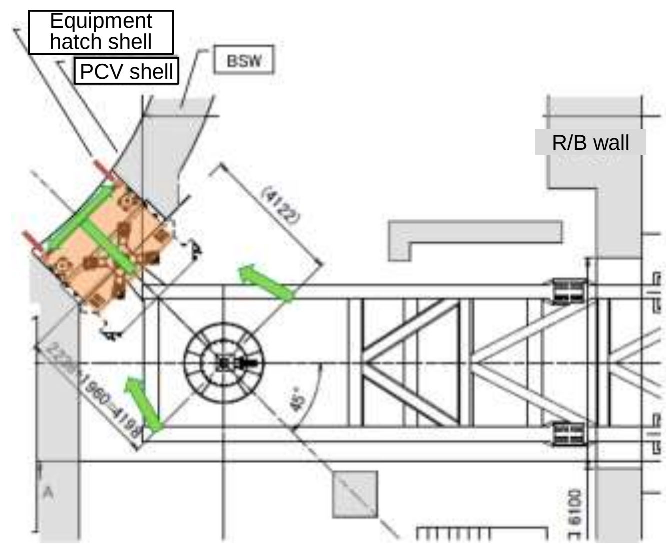
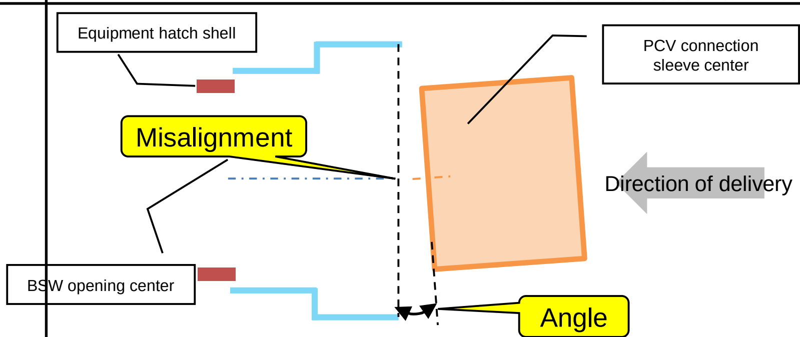
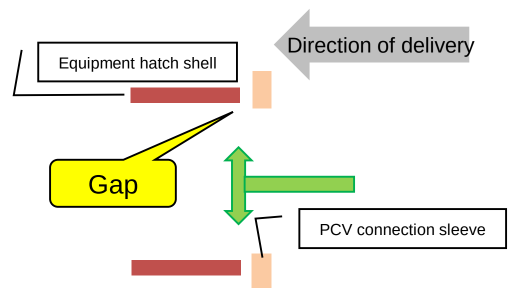
[Test plan (1/2)]

Items to be verified	Implementation details	Items to be monitored, measured and recorded	Criteria
Verification through studies and tests			
Verification of visibility of cameras, etc.	The installation location and visibility of the cameras at each step are studied and verified.	➢ Camera image	➢ Remote work should be possible based on the images from the camera.
Verification of detailed procedures	The installation procedures are studied in detail, the criteria for moving on to the subsequent step are compiled and verified by tests.	➢ Equipment operation data	➢ Remote work should be possible by following the procedures studied. ➢ The criteria should be met at every hold point (Refer to the following page).
Installation accuracy	Installation accuracy is verified using a simulated PCV connection sleeve.	➢ Installation accuracy	➢ 20mm or less (Target: 7.5mm or less)
Verification through studies			
Verification of object to be installed	The method of verifying the current status of the equipment hatch shell and BSW, and the method of reflecting the shape after verification are studied.	–	
Verification of final gap	The method of verifying the final gap is studied. ① Verifying that the gap is 20mm or less (target: 7.5mm or less) ② Estimating the gap		
Method of detecting seating	The method of detecting that the PCV connection sleeve has been seated on the BSW is studied, and verified.		
Verification of the fixing method	The procedures for fixing the PCV connection sleeve on to the BSW are studied in detail		

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

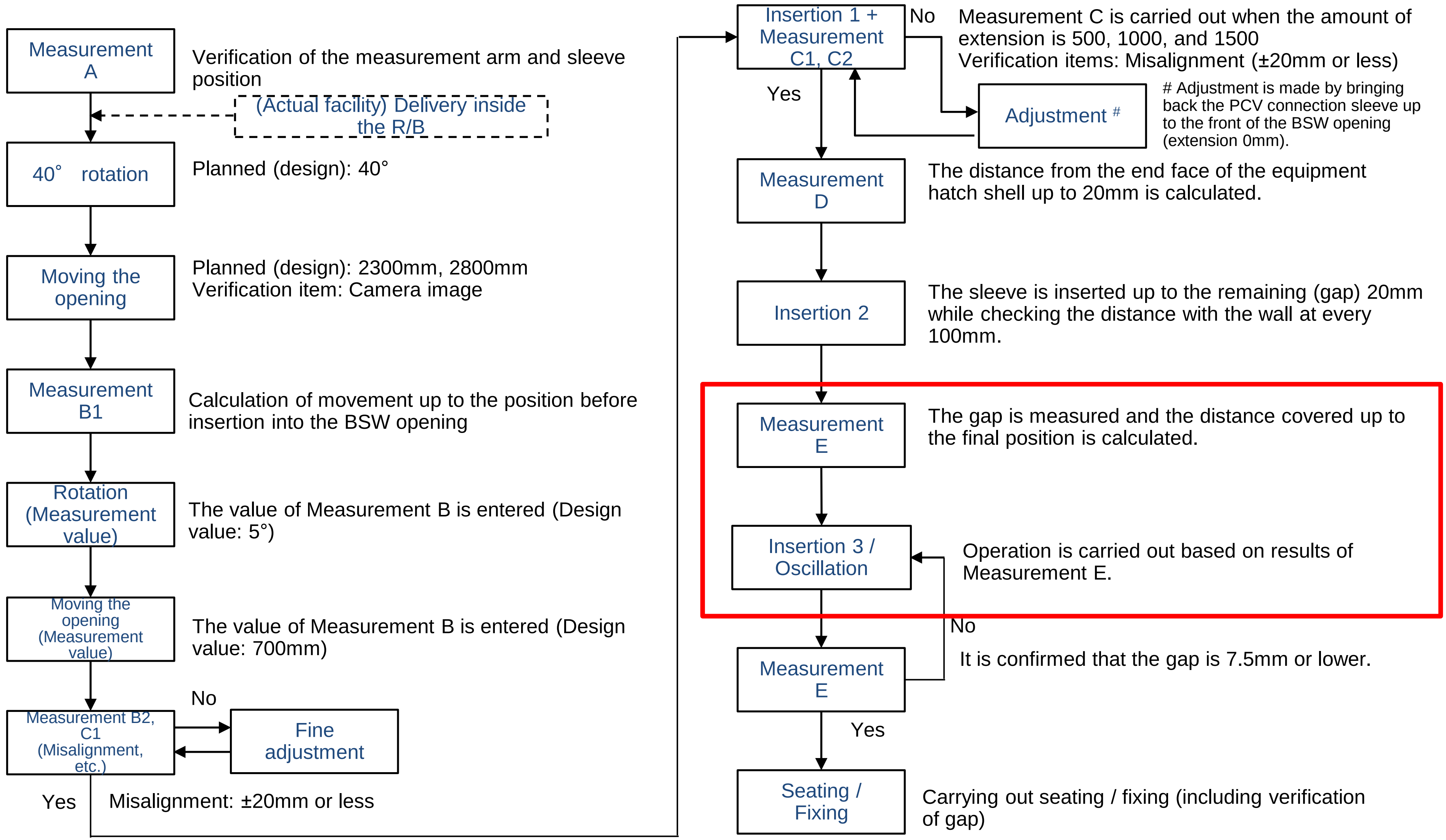
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Test plan (2/2)] Criteria for moving on to the subsequent steps

Items	Before making the BSW opening	Final location
Hold point (HP)		
Measurement		
Criteria	Misalignment: 20mm or less The angle between the BSW opening and the PCV connection sleeve surface: 1° or less	Gap: 20mm or less (target ±7.5mm or less)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

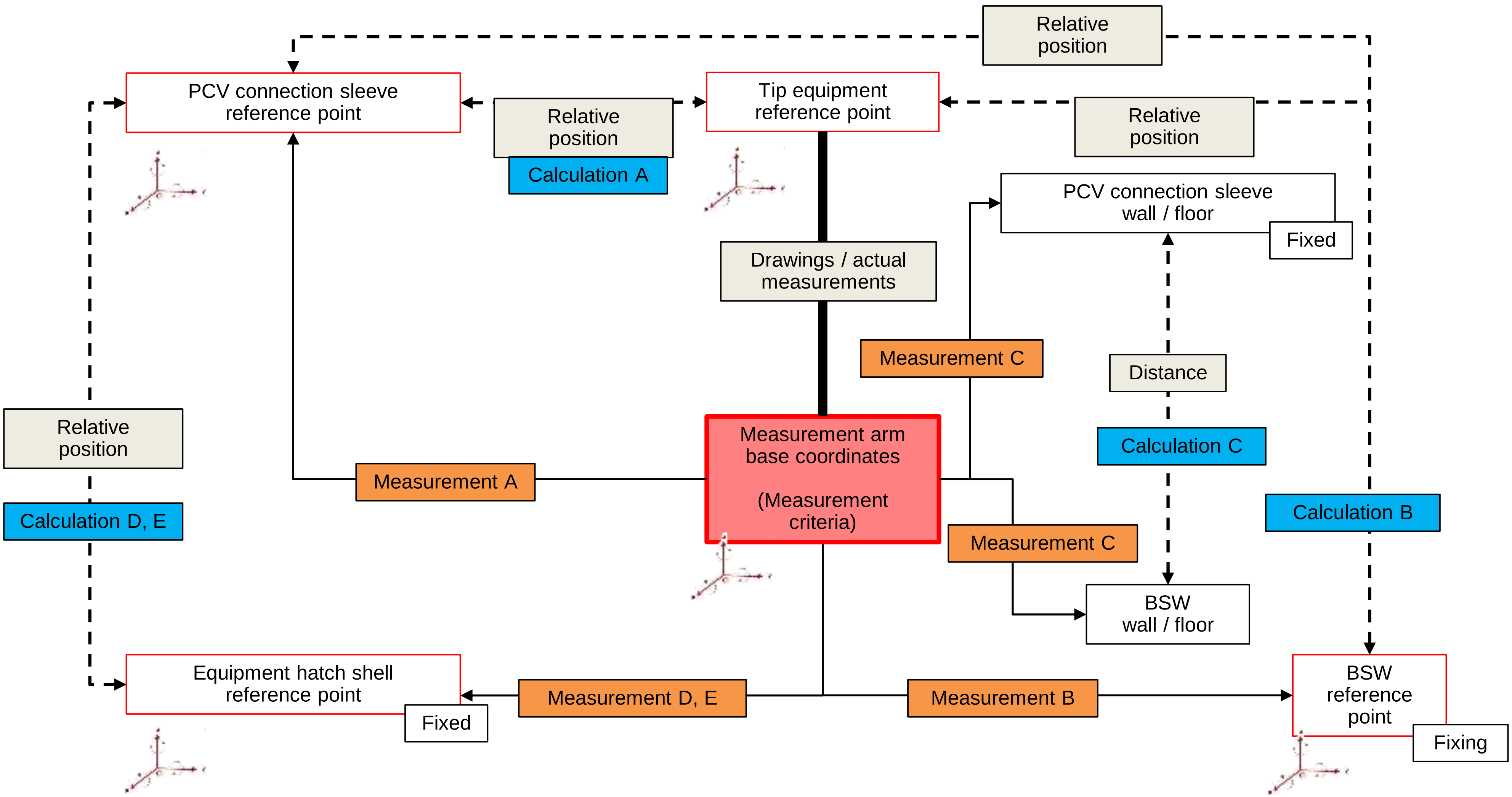
[Test flow]



② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Measurement correlation diagram]

Note) Since the measurement arm base moves, it is equivalent to what is called as the tool coordinate system in robotics.

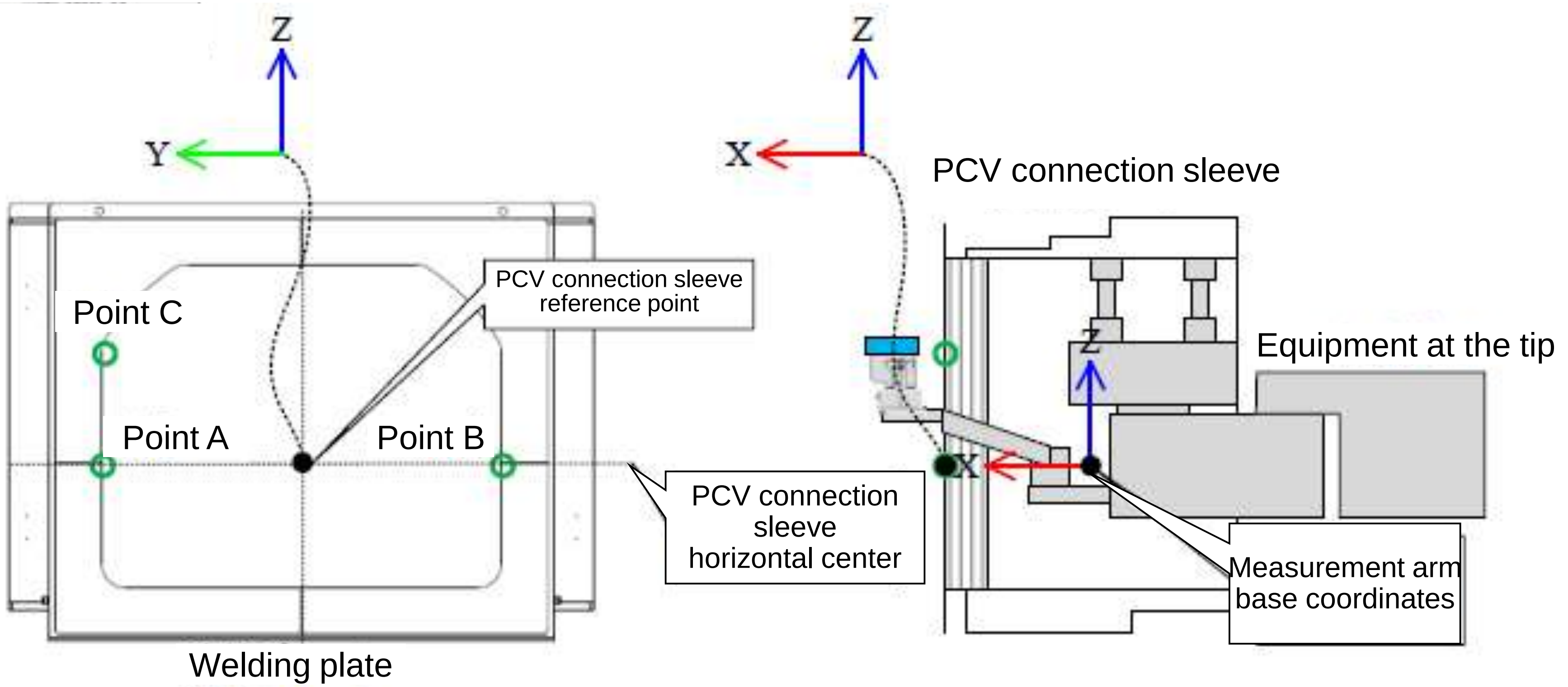


② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

Measurement A

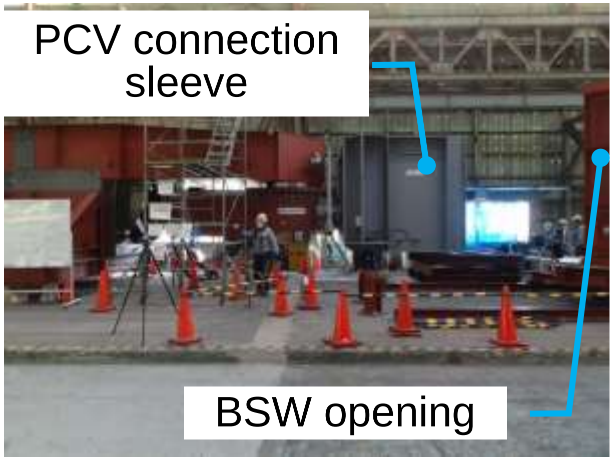
The 3 end faces of the PCV connection sleeve are measured, and the relative position of the measurement arm base coordinates and the PCV connection sleeve reference point is verified. The center position is verified by measuring points A and B, and the reference plane (reference point) is created by measuring any point C.



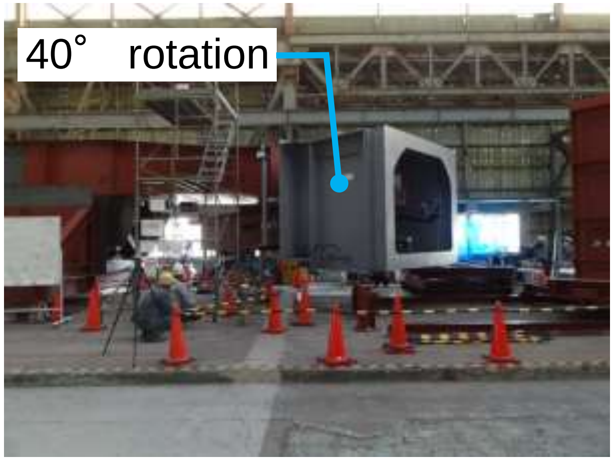
② PCV connection sleeve installation and welding by means of remote operation: (a) Remote installation

[Explanation of the procedures]

40° Rotation



Before rotation (0°)



Rotation (40°)

Moving the opening

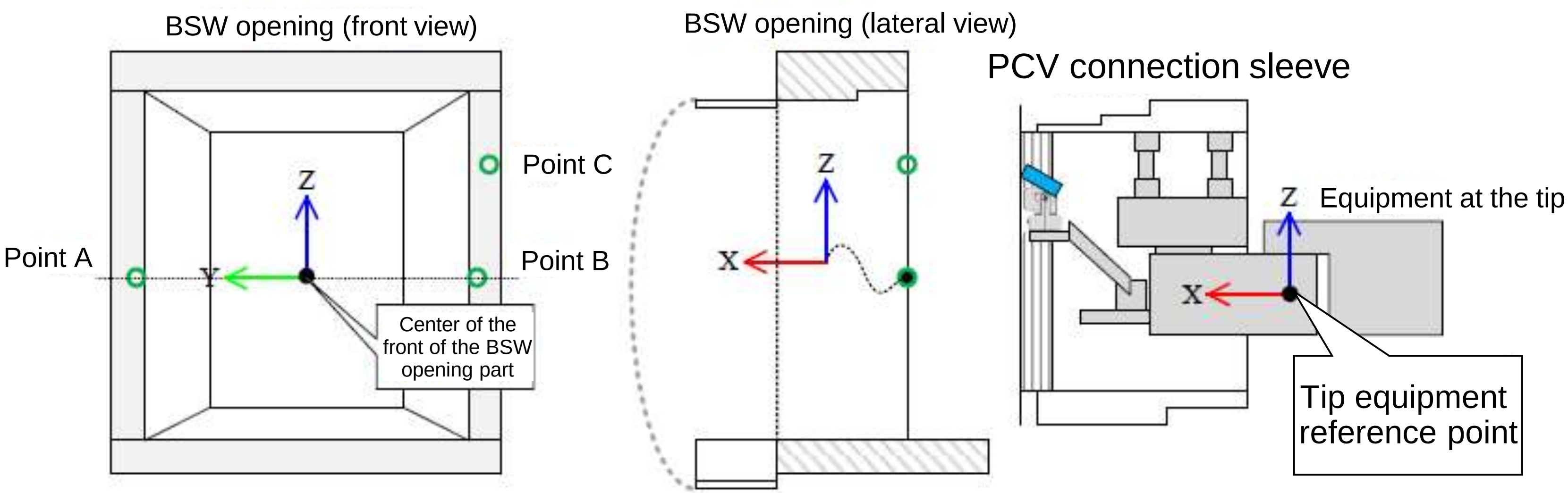
Moving the opening (2300mm)

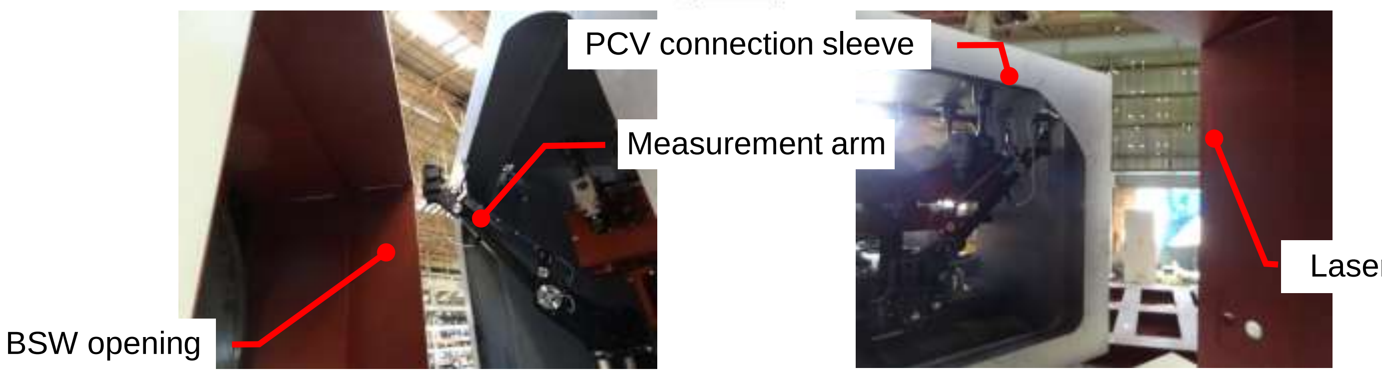
Moving the opening (2800mm)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

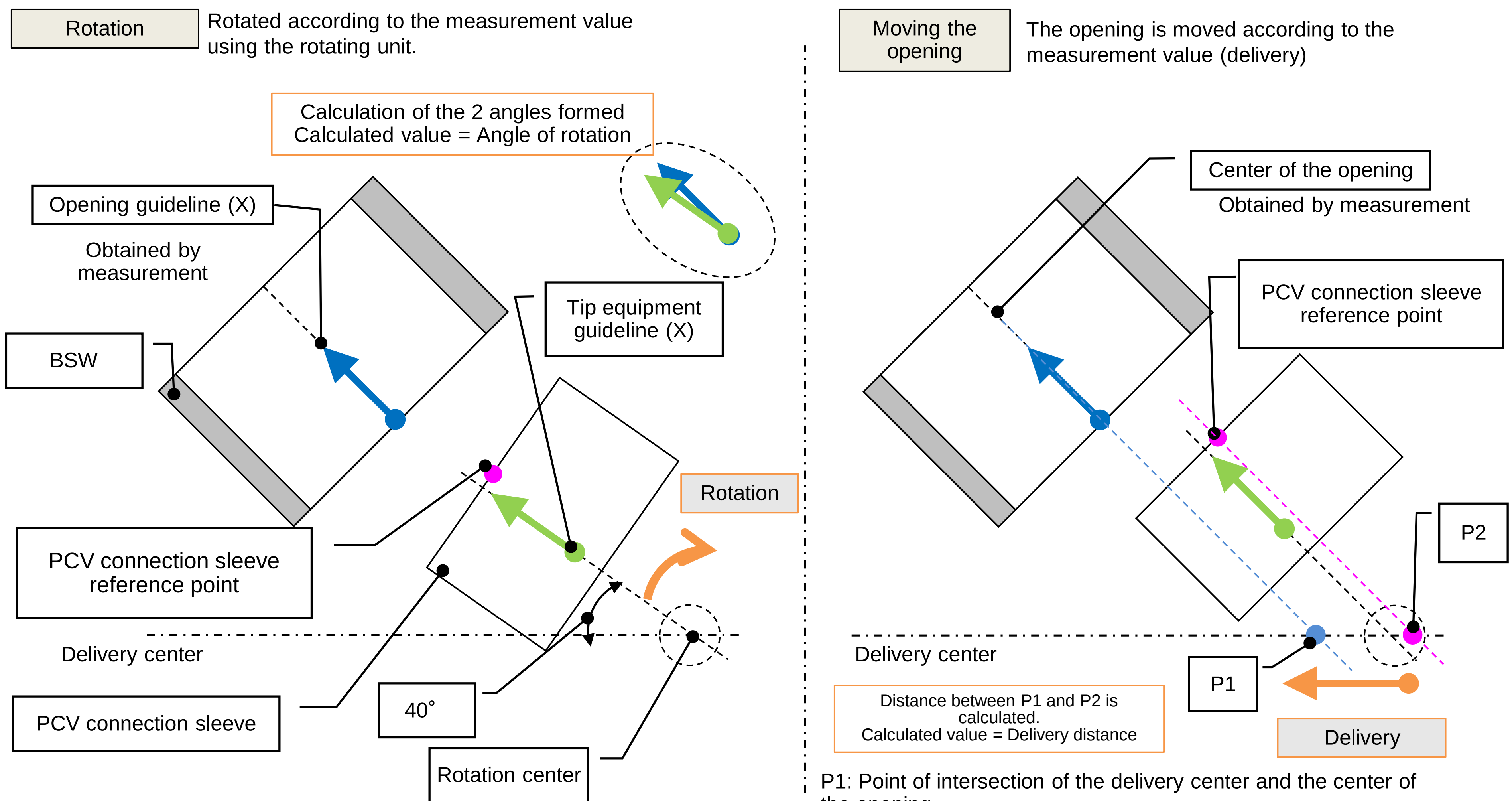
Measurement B1	The 3 end faces of the BSW opening are measured, and the angle of rotation and the delivery distance is calculated. The approximate center position is verified by measuring points A and B, and the reference plane (reference point) is created by measuring any point C.





② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]



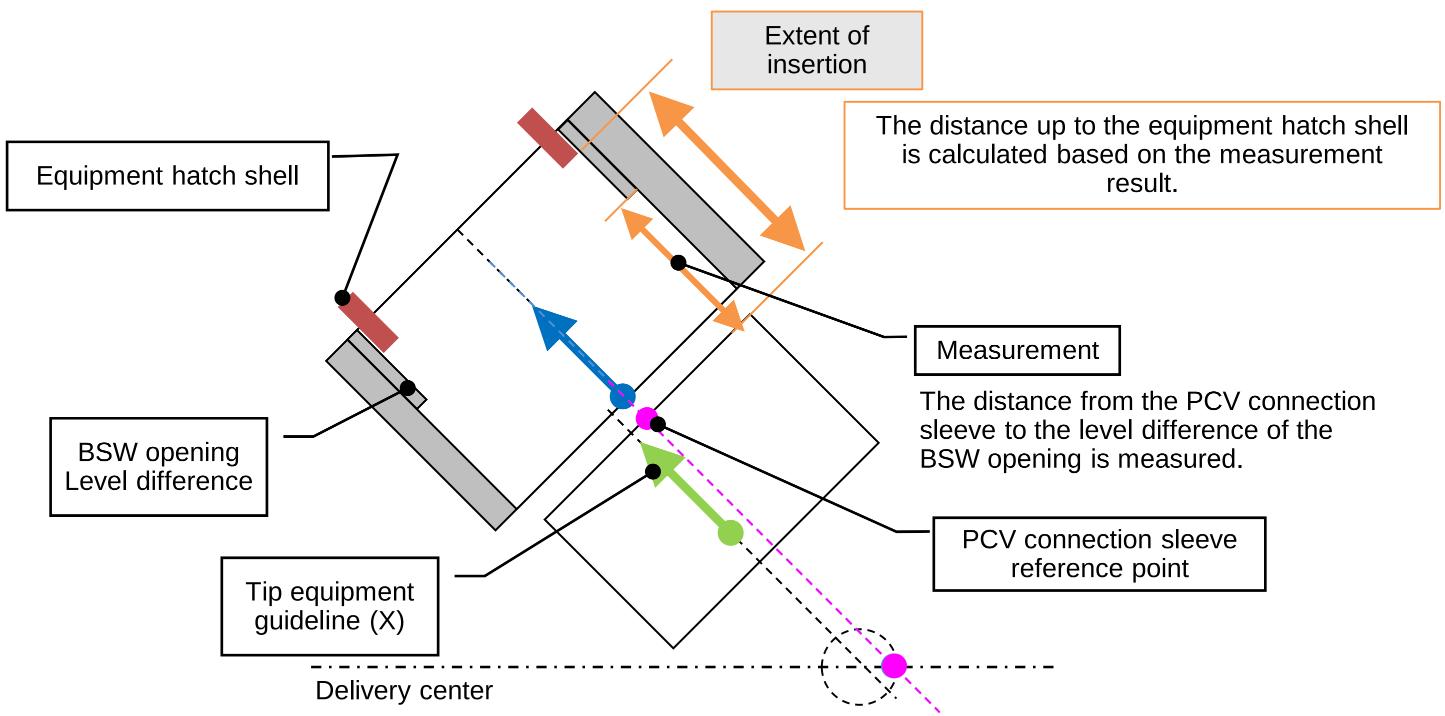
P1: Point of intersection of the delivery center and the center of the opening
P2: Point of intersection of the delivery center and PCV connection sleeve reference point

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

Measurement B2

The level difference of the BSW opening is measured, and the distance between the PCV connection sleeve and the equipment hatch shell is calculated. It is confirmed that the result of calculation is lower than the stroke (1900mm) of the extension unit.



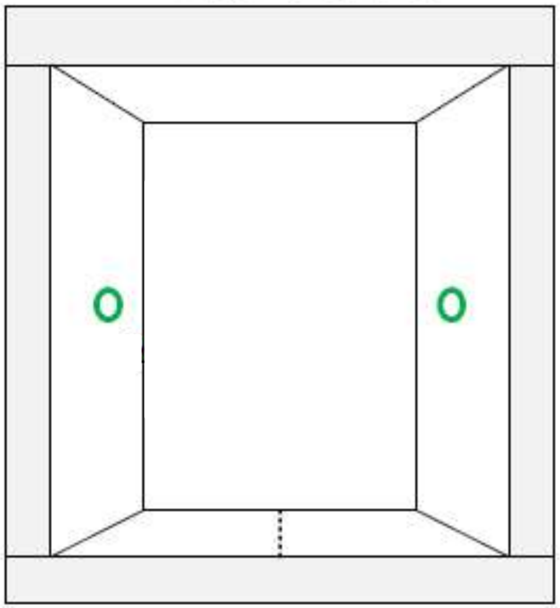
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

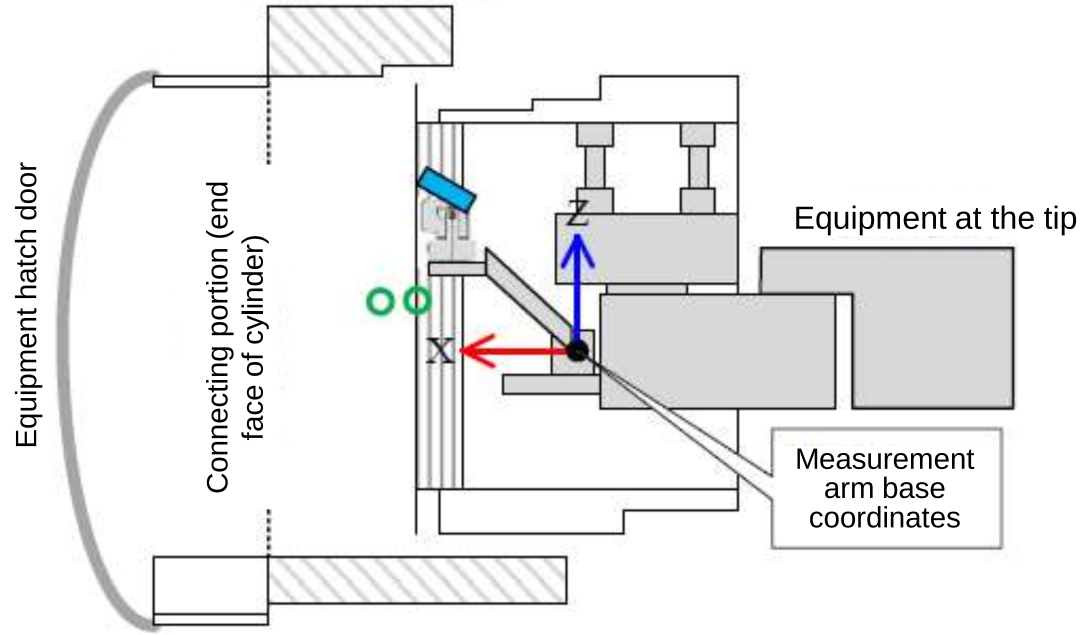
Measurement C1

The distance between the BSW opening wall surfaces (1 location on each side / Total 2 locations) and the PCV connection sleeve wall surfaces (1 location on each side / Total 2 locations) is measured, and it is confirmed that the misalignment is below the permissible value of ±20mm. If misalignment exceeds the permissible value, adjustments are made by “Rotation” and “Delivery (Moving the opening)”

BSW opening (front view)



BSW opening (lateral view)



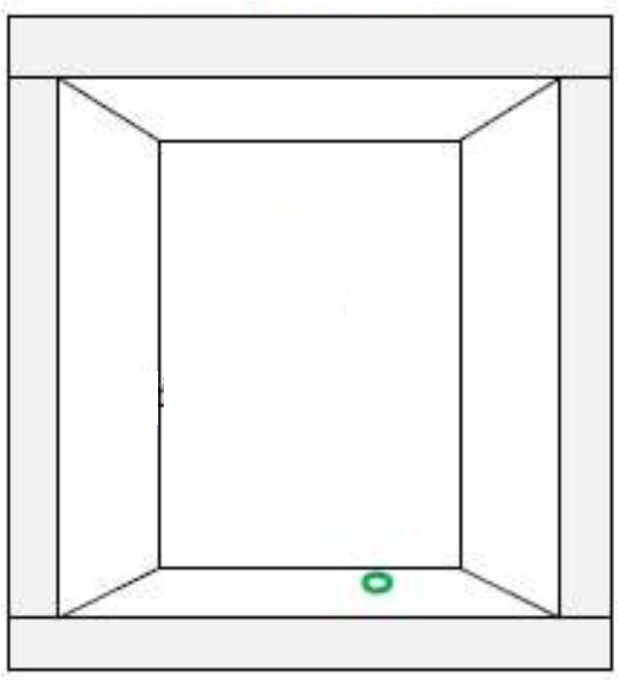
(Note)

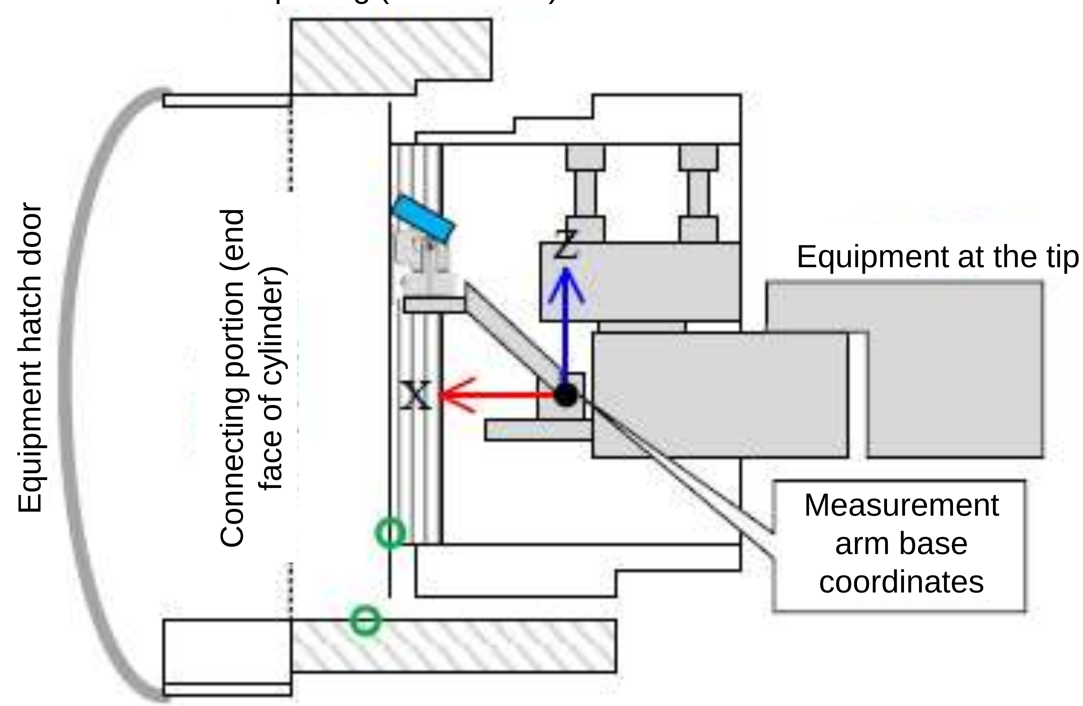
- Implemented at an extension stroke of 500mm pitch
- The minimum gap between the inner surface of the BSW and the outer surface of the PCV connection sleeve is 45mm on one side.

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

Measurement C2 The distance between the BSW opening floor surface (1 location) and the PCV connection sleeve floor surface (1 location) is measured and the height from the BSW opening floor surface is verified.





Note) Implemented at an extension stroke of 500mm pitch

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

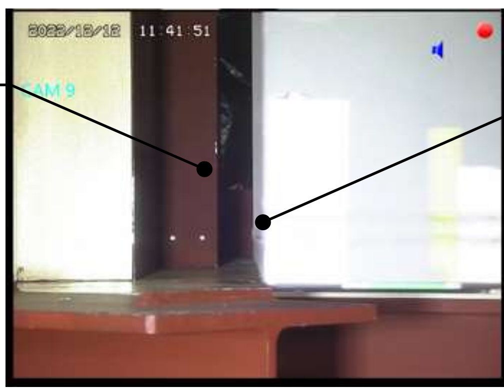
[Explanation of the procedures]

Insertion 1 The PCV connection sleeve is inserted while confirming the gap between the BSW wall and the PCV connection sleeve with a camera.

Before insertion (Extension stroke: 0mm)

Insertion (Extension stroke: 500mm)

Insertion (Extension stroke: 1500mm)



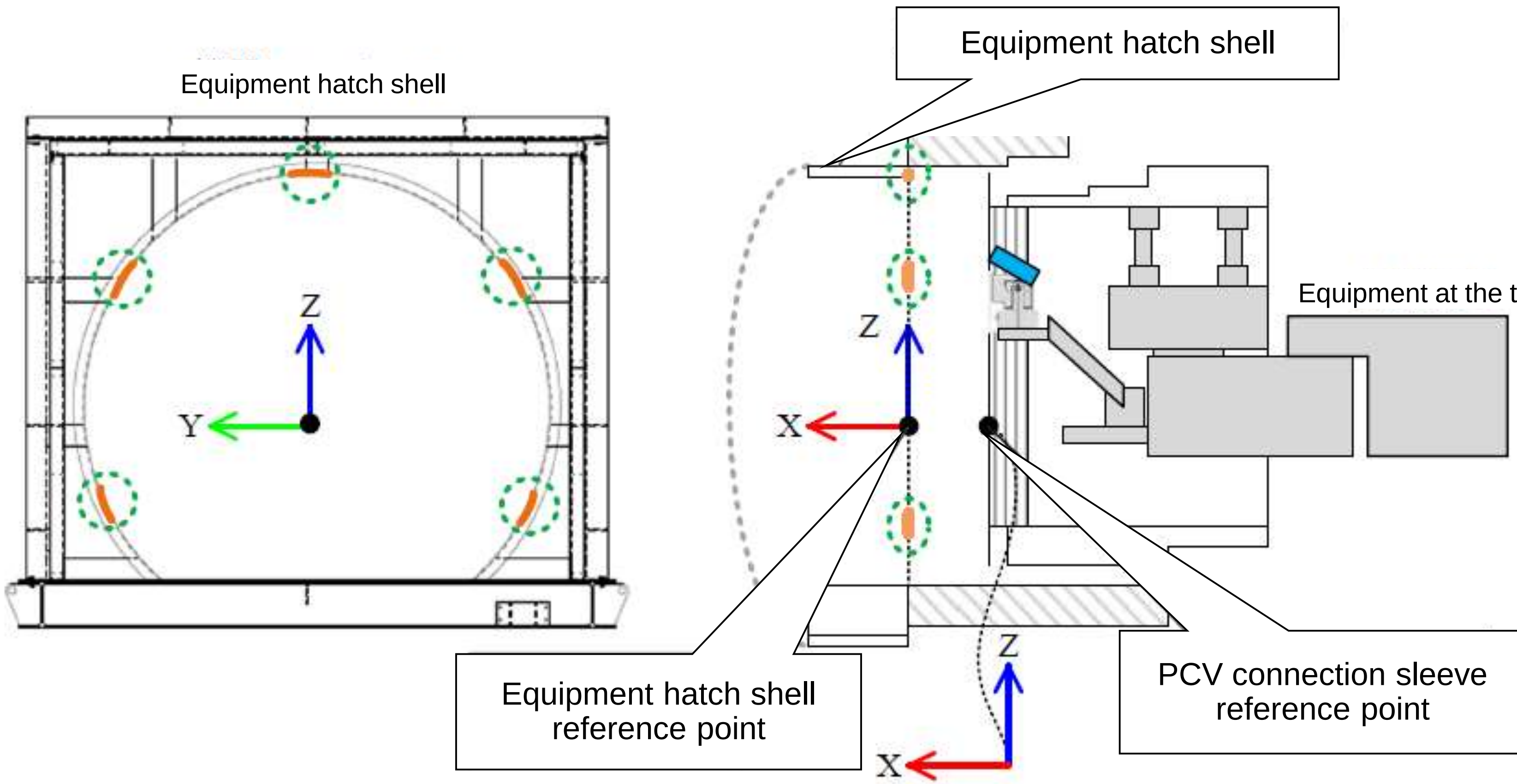
Insertion (Extension stroke: 500mm) / Image from rear camera / left side

Insertion (Extension stroke: 500mm) / Image from rear camera / right side

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

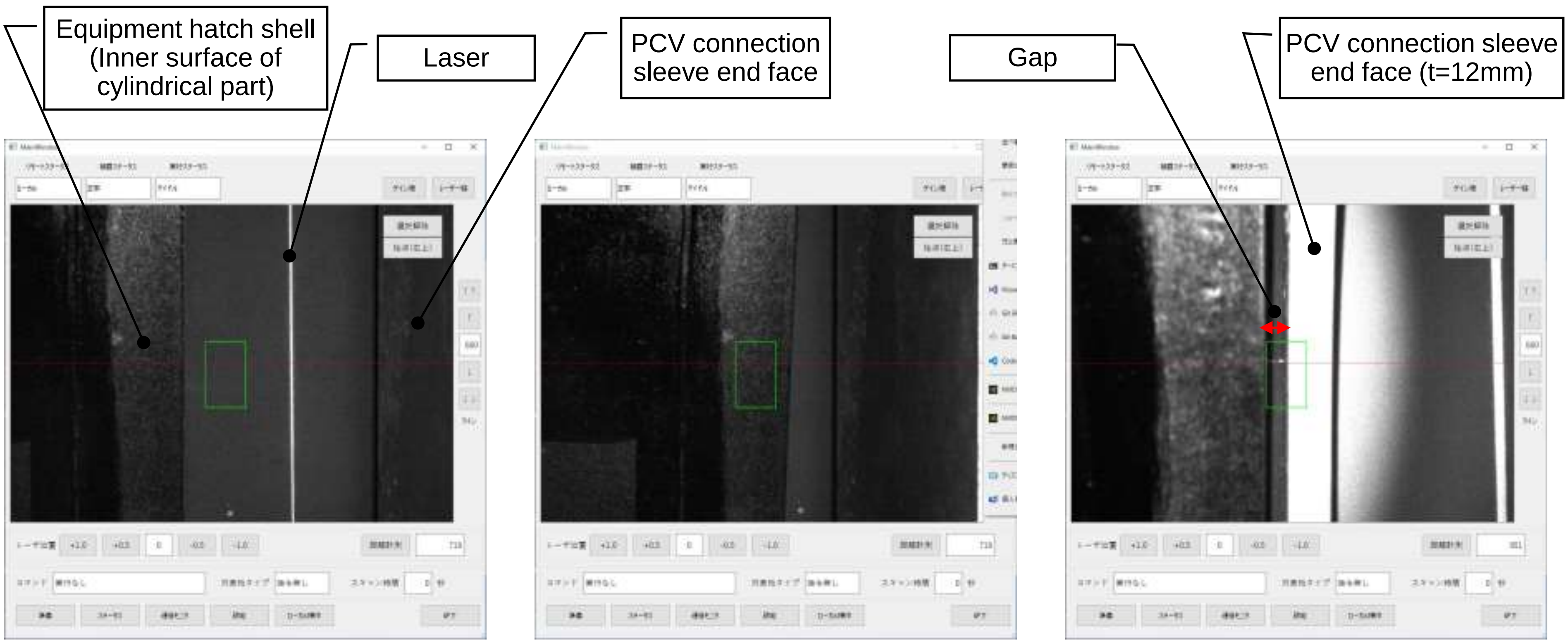
Measurement D	The distance up to the end face of the equipment hatch shell is measured at the position where the extension stroke is 1500mm, and the extent of movement up to the position approx 20mm in front of the equipment hatch shell is calculated.



② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

Insertion 2 After inserting up to 1800mm, the PCV connection sleeve is inserted approx. 20mm in front while checking the position of the equipment hatch shell and the PCV connection sleeve with the camera of the 3D measurement equipment.

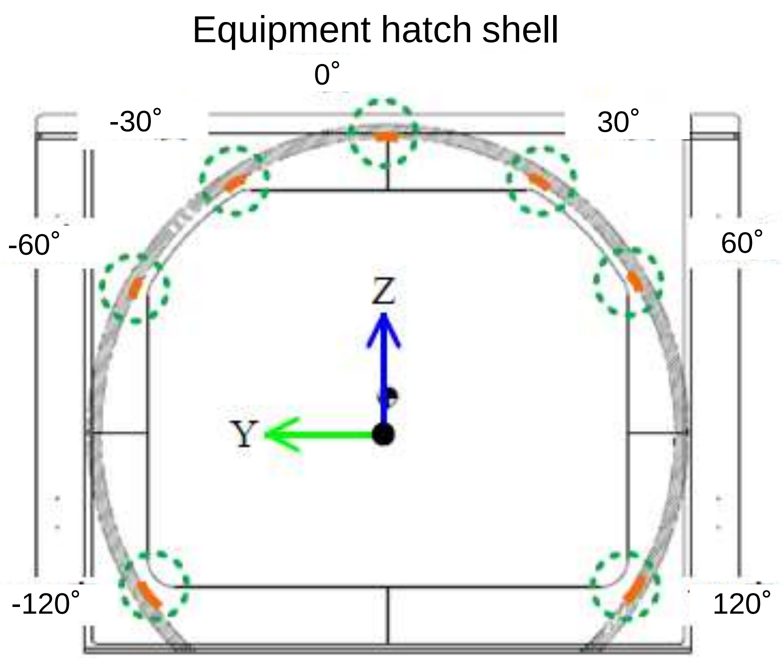


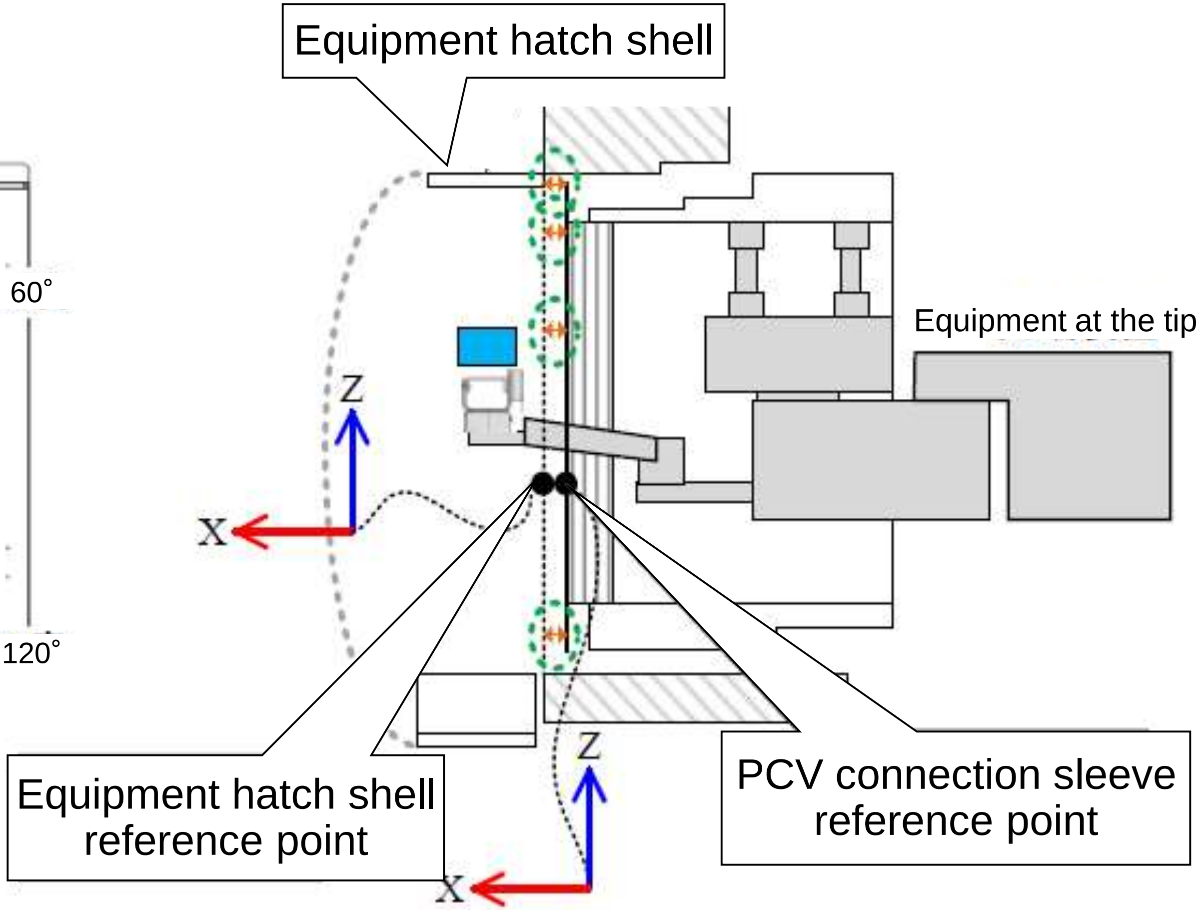
Insertion (Extension stroke: 1600mm) | Insertion (Extension stroke: 1800mm) | Insertion (Extension stroke: 1850mm)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures] Position up to approx. 20mm until the final target

Measurement E	The gap between the equipment hatch shell end face and the PCV connection sleeve is measured at 7 points (0°, ±30°, ±60°, ±120°), the final extent of movement is calculated.

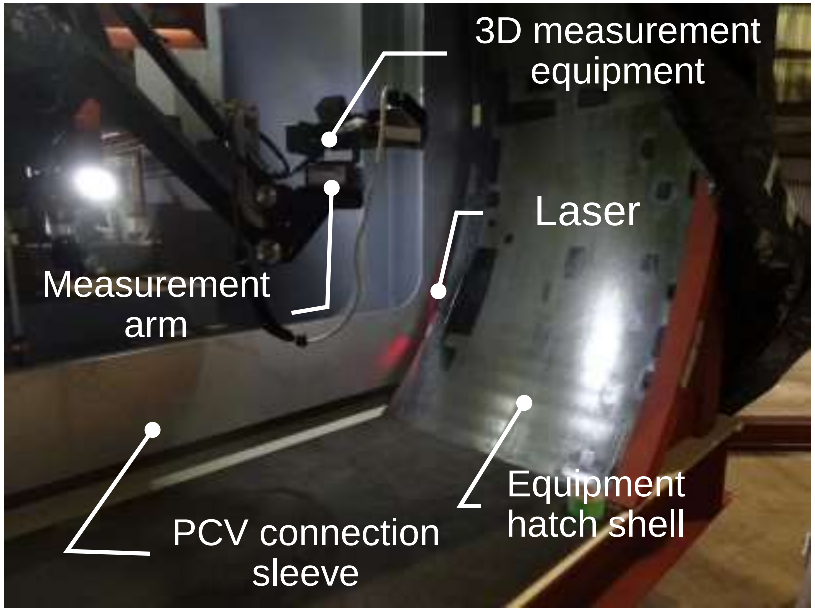




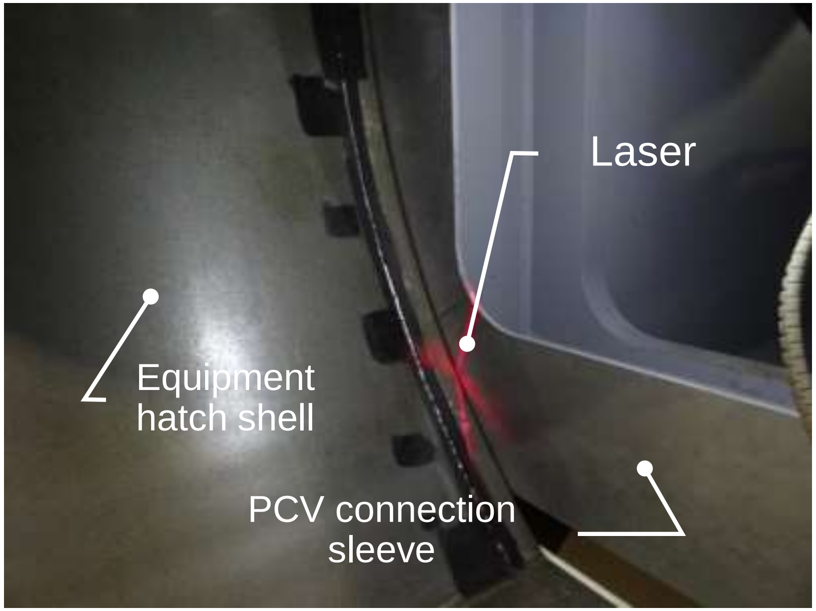
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures] Position up to approx. 20mm until the final target

Measurement E	The gap between the equipment hatch shell end face and the PCV connection sleeve is measured at 7 points (0°, ±30°, ±60°, ±120°), the final extent of movement is calculated.



Measurement position -120°

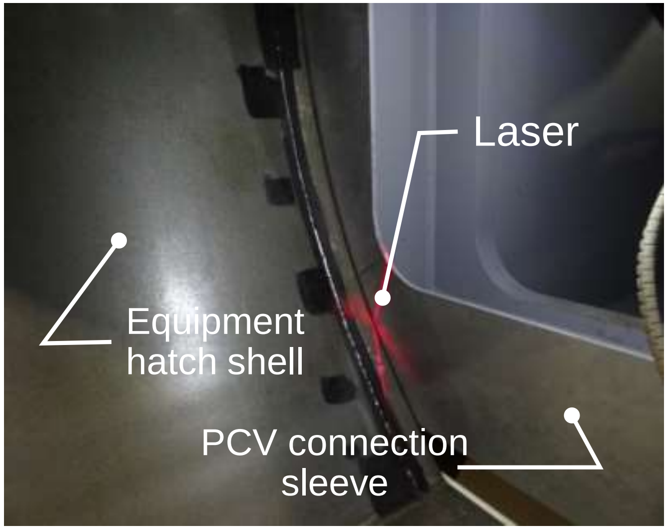


Measurement position 120°

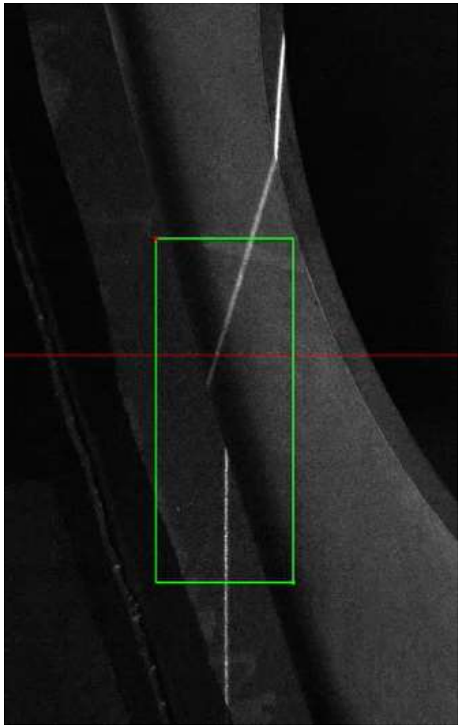
② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures] Position up to approx. 20mm until the final target

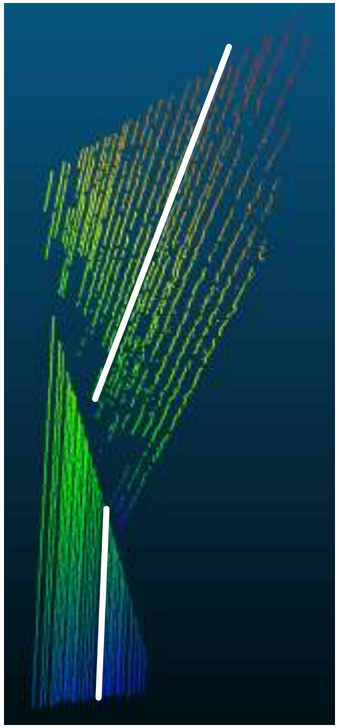
Measurement E	The gap between the equipment hatch shell end face and the PCV connection sleeve is measured at 7 points (0°, ±30°, ±60°, ±120°), the final extent of movement is calculated.



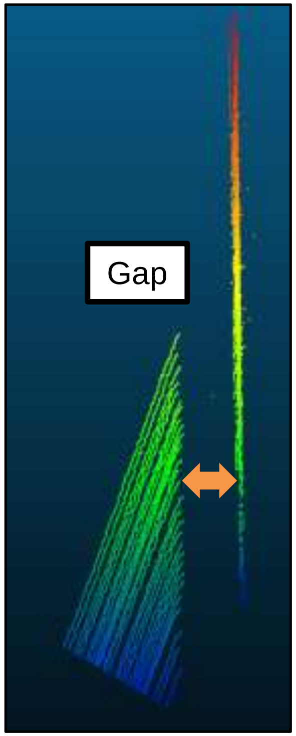
Measurement position 120°
(Digital camera image)



Measurement position 120°
(3D measurement camera image)



Point cloud data
(Same angle as the image)



Point cloud data
(For verifying the gap)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Explanation of the procedures]

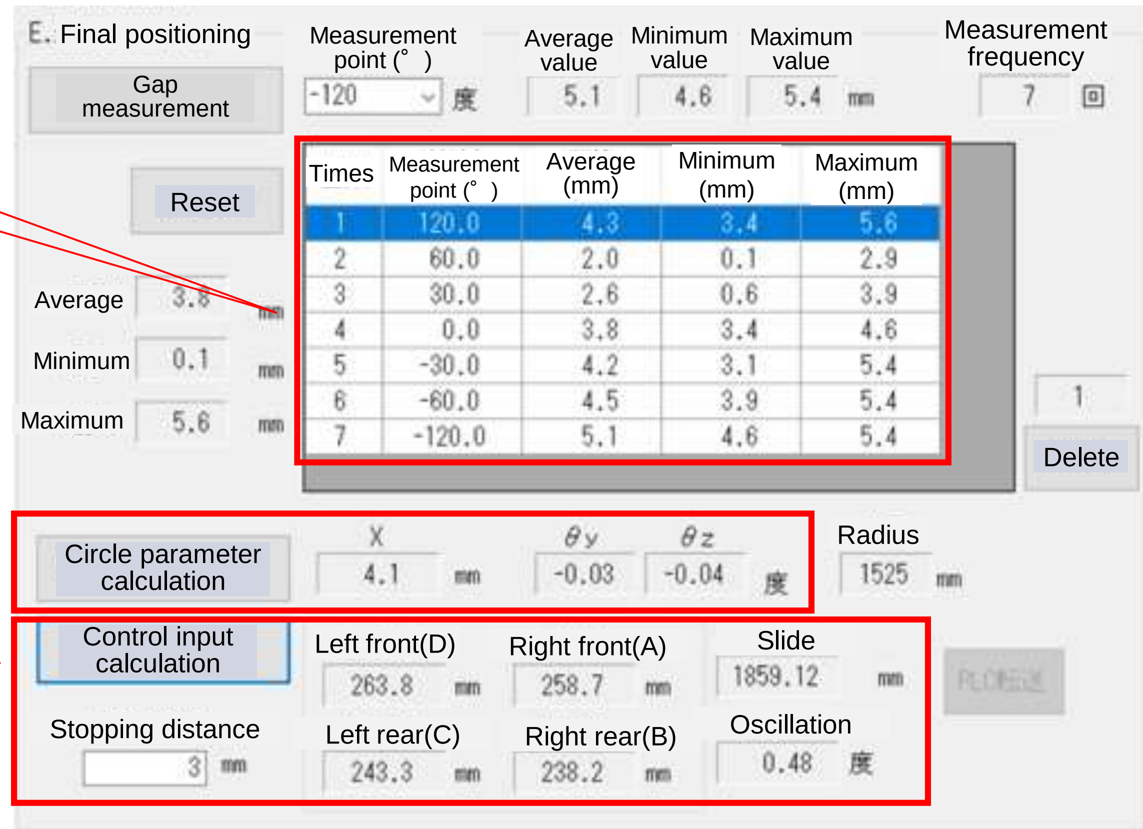
Insertion 3 / Oscillation

The equipment is operated in the order of hoisting, oscillation and extension based on the results of Measurement E, and is moved to its final position. The stopping distance from the equipment hatch end face is established.

Results of Measurement E

Deviation from the equipment hatch shell reference point and the PCV connection sleeve reference point

The extent of movement up to the final position is calculated.



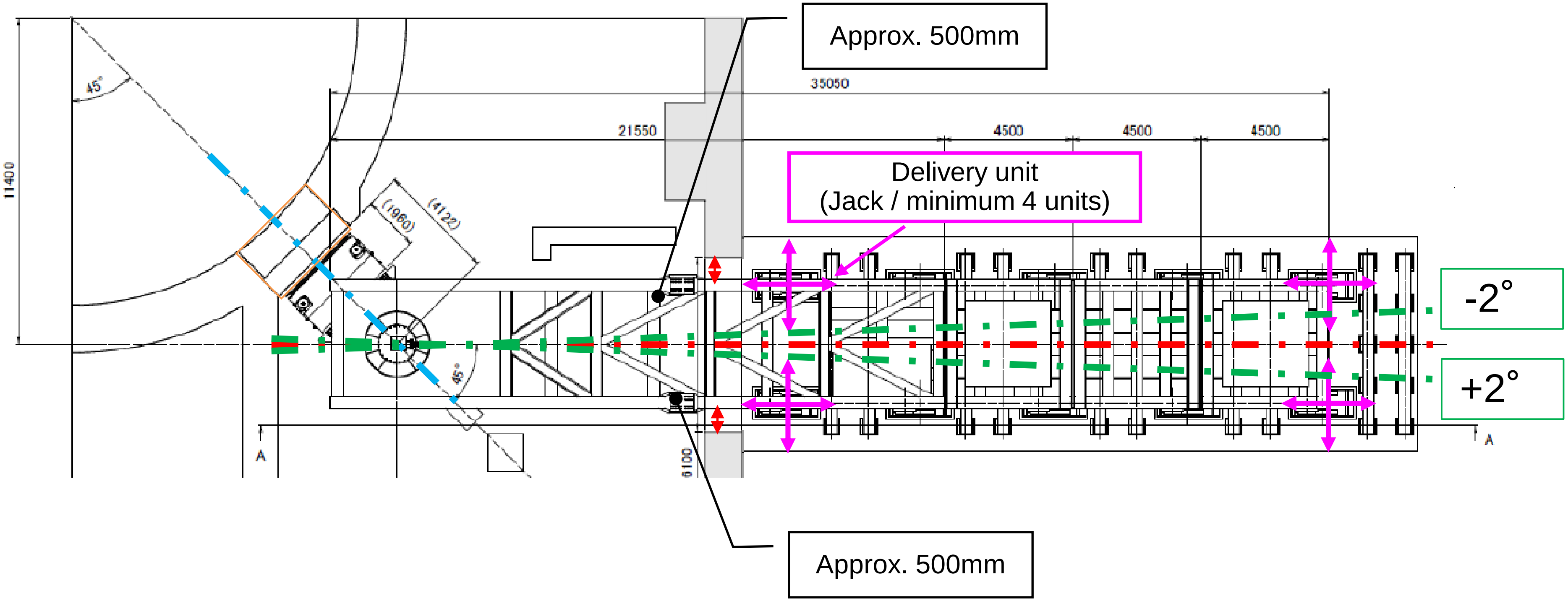
Times	Measurement point (°)	Average (mm)	Minimum (mm)	Maximum (mm)
1	120.0	4.3	3.4	5.6
2	60.0	2.0	0.1	2.9
3	30.0	2.6	0.6	3.9
4	0.0	3.8	3.4	4.6
5	-30.0	4.2	3.1	5.4
6	-60.0	4.5	3.9	5.4
7	-120.0	5.1	4.6	5.4

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Selection of test conditions ①]

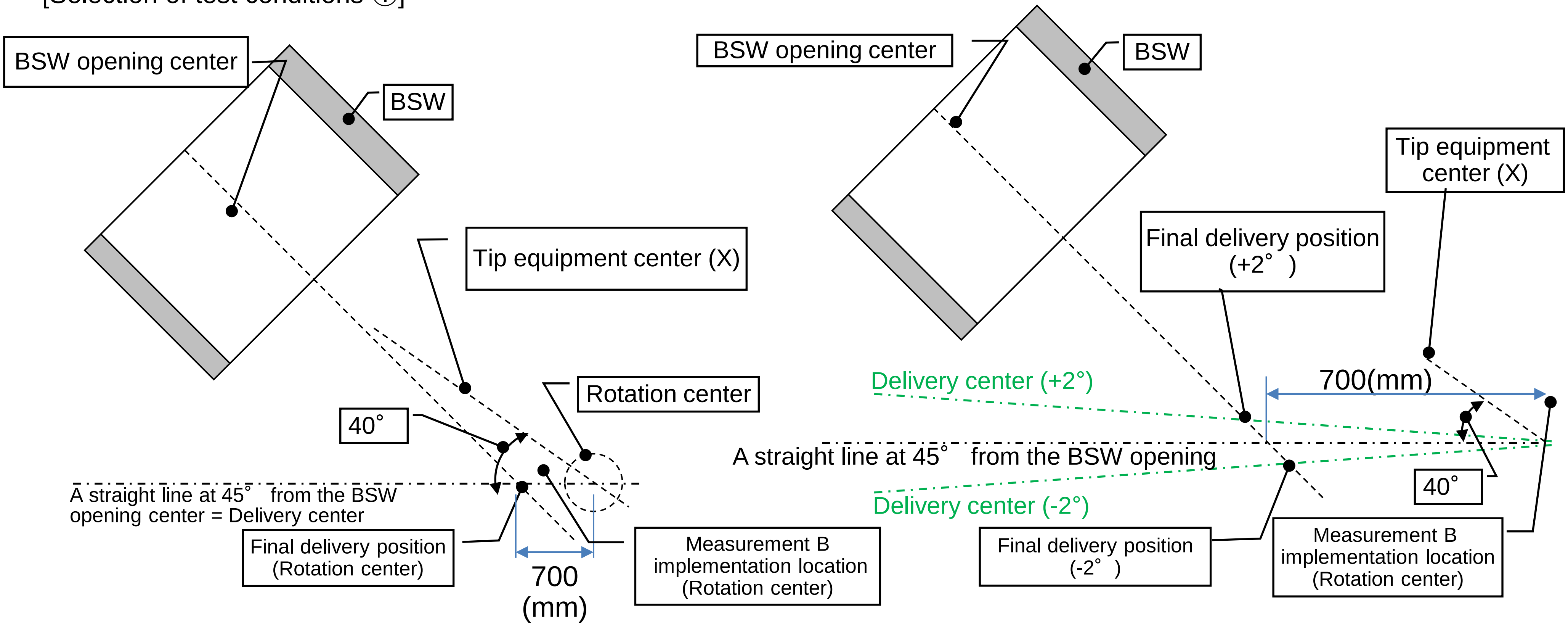
The clearance with the PCV connection sleeve remote installation equipment and the R/B opening part is approx. 600mm on one side. If the insertion angle deviates by ±2°, it gives rise to a deviation of approx. 500mm in the vicinity of the R/B opening. Hence tests for verifying whether measurement and calculation is possible if there is a deviation of ±2°were conducted.

Further, since the mock-up equipment cannot be moved, tests were conducted keeping the angle of the rotating unit at 40°±2° during Measurement B.



② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Selection of test conditions ①]

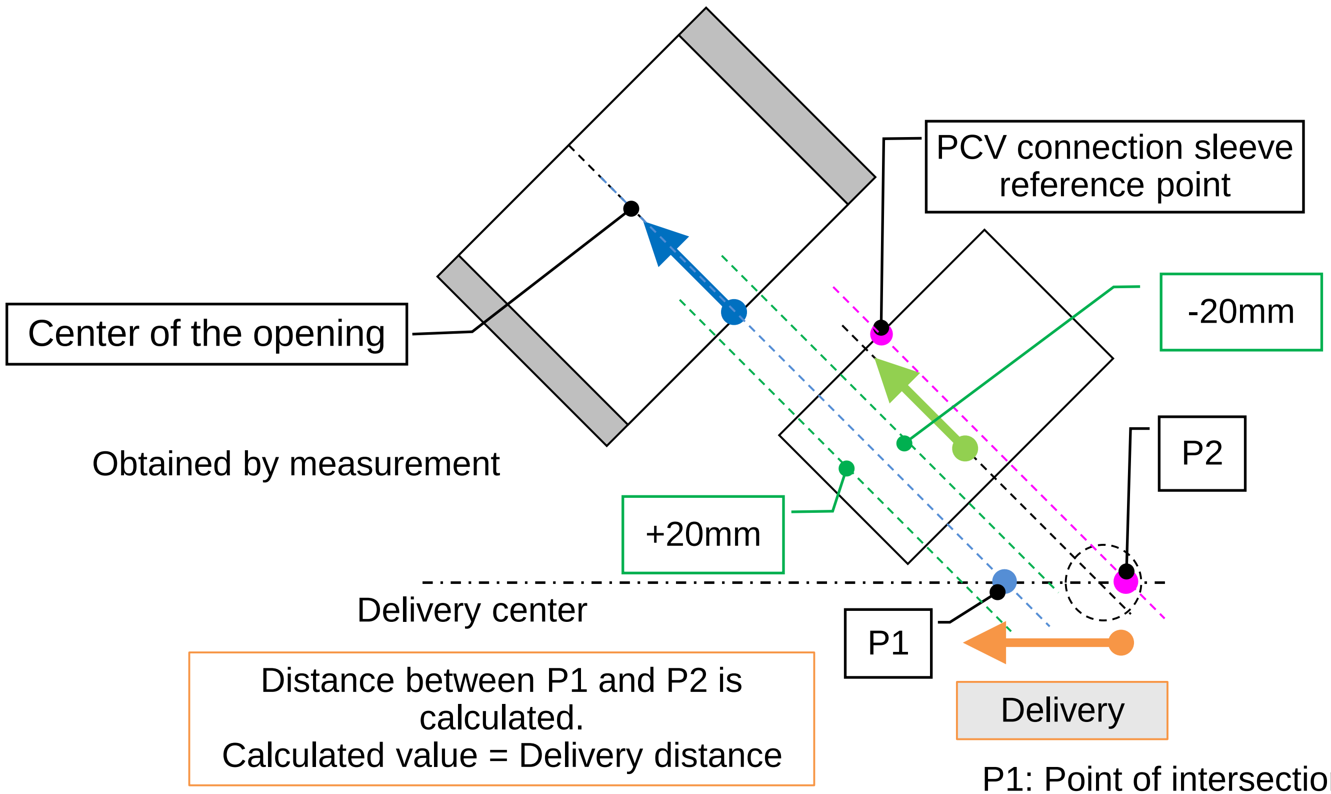


- The point of intersection of the “BSW opening center” and “the straight line at 45° from the BSW opening center becomes the final delivery position at the rotation center in the drawing.
- The position that is 700mm in front (outside R/B) of the above mentioned rotation center becomes the position for carrying out Measurement B.
- Considering the range of movement of the measurement arm and the range in which measurement is possible (measurement range), as long as the rotation center is in the 100mm diameter of the position for carrying out Measurement B, Measurement B is possible. Adjustment can be made with the help of the delivery unit (accuracy ±20mm). The measurement position is marked beforehand as required, and is verified with a camera.
- It was confirmed that since the rotation angle is mechanically set at 40° during measurement, even if the “straight line at 45° from the BSW opening center” and “delivery center” shift, measurement (calculation) is possible.

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Selection of test conditions ②]

The delivery distance is calculated based on Measurement B, and the opening is moved using the delivery equipment. Since the accuracy of the delivery equipment is ±20mm, the test on moving the simulated opening is conducted for the delivery distance calculated based on Measurement B ±20mm.



P1: Point of intersection of the delivery center and the center of the opening
P2: Point of intersection of the delivery center and PCV connection sleeve reference point

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

[Test results]

- The results under all conditions satisfied a “gap of 7.5mm or less” which is the required specification.
- The error in the calculated measurement and actual measurement was approx. ±2mm or less. The error in the calculated measurement value and the actual measured value was 2mm or more at 120° in Test number 2, 5. Refer to the following page for the reasons.

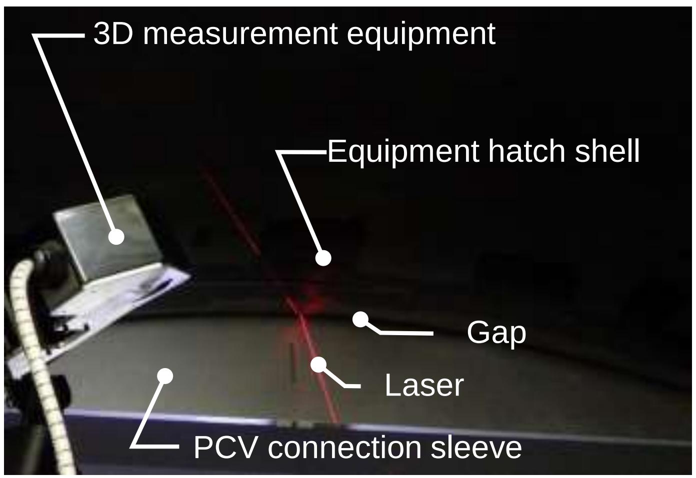
No.	Testing conditions	Initial rotation (°)	Measurement B		Actual delivery distance (mm)	Measurement C1 (Misalignment)		Measurement E (Final) (mm)							Actual measurement (Final) (mm)						
			Angle of rotation (°)	Delivery distance (mm)		Measurement (mm)	Actual measurement (mm)	0°	30°	60°	120°	-30°	-60°	-120°	0°	30°	60°	120°	-30°	-60°	-120°
1	No error	40	44.8	683.1	684	0.1	0.5	2.4	2	0.4	4.1	2.7	3.9	4.6	3	3	2	4	2	3	3
2	Angle misalignment - 2°	38	44.6	671.1	672	-2.3	-2	2.4	1.8	1.9	0.4	1.5	2.5	3.1	2	3	3	6	1	1	2
3	Angle misalignment + 2°	42	44.6	662.2	662	-1.5	-3	2.5	2.1	2	4.7	2.1	-	3.5	3	3	3	6	2	1	2
4	Delivery error +20mm	40	44.8	684.6	705	18	20	4.8	3.9	3	5	4.6	4.4	4.7	4	4	4	6	4	4	4
5	Delivery error -20mm	40	44.8	675	655	-20.2	-20	2	1.1	0.7	0.8	2.6	4.4	3.2	2	1	0	3	2	3	2

Note: Results of measurement before seating (before making the opening)

② PCV connection sleeve installation and welding by remote operation: (a) Remote installation

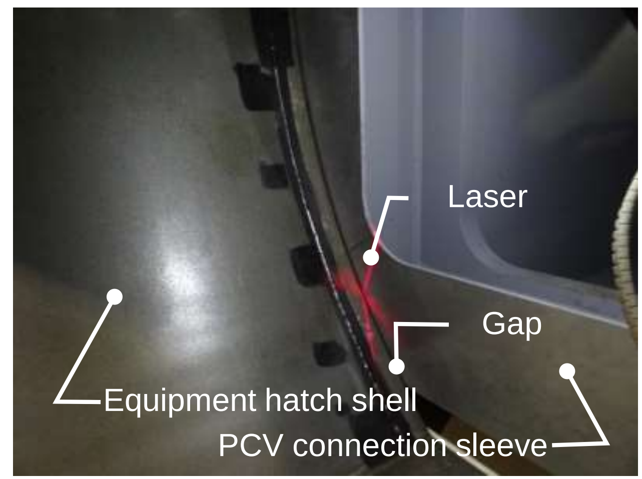
[Issues] Measurement precision

Measurement E is carried out by obtaining point cloud data by means of the light section method and measuring the gap. It is desirable for the laser to be perpendicular to the gap. However, at the ±120° position, the laser becomes almost parallel to the gap. Hence it becomes difficult to obtain the point cloud data. As a result, there are cases in which accuracy is poor. This phenomenon can be addressed by increasing the number of shafts of the measurement arm (positioning equipment of the 3D measurement equipment) to 6 shafts from the current 5 shafts. Studies will be conducted on such an addition in the actual facility in accordance with the required specifications.



Good example:
Measurement position 0°

Photo from the PCV side



Measurement position 120°

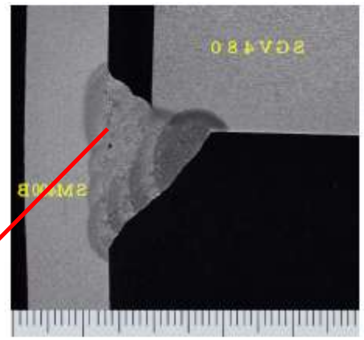
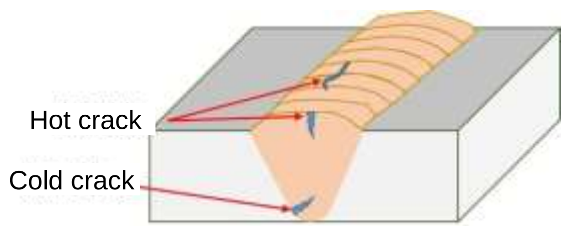
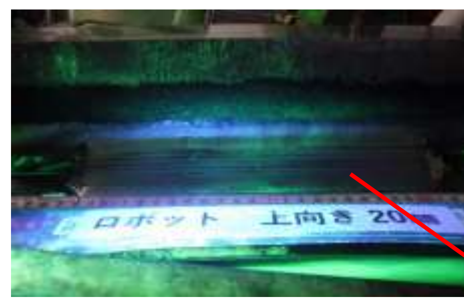
② PCV connection sleeve remote installation and welding: (b) Welding

Table of Contents

② PCV connection sleeve remote installation and welding: (b) Welding

[Results up to FY2020]

It was verified during the element tests conducted in FY2019-20 that a gap of 20mm or less can be welded. In addition, issues were identified considering remote operation as well.

Issue ① Joining defects	Issue ② Formation of oxides
From the results of tests conducted as part of the FY2019-2020 subsidy projects  Example of joining defects	 From the results of tests conducted as part of the FY2019-2020 subsidy projects Oxides
Issue ③ Concerns about cold cracks	**Issue ④ Need for remote inspection method**
 Welding of thick plates (Concerns about cold cracks)	 From the results of tests conducted as part of the FY2019-2020 subsidy projects Fluorescent PT

These issues were studied and full-scale simulated tests were conducted to verify remote operability.

② PCV connection sleeve remote installation and welding: (b) Welding

[Results up to FY2020]

No.	Source studied and verified (Issues identified during the FY2019-2020 subsidy projects)	Study/verification items	Overview of studies
①	**Joining defects**	Specification of process management	The actual work will be carried out remotely, and the camera visibility will be limited. Hence torch positioning, angle, etc. need to be verified by means of a mock-up. What exactly needs to be verified needs to be specified.
②	**Formation of oxides**	Study of small welding head (Improving shielding capabilities)	Formation of oxides was not observed in tests conducted by setting conditions. The formation of oxides needs to be controlled and the frequency of polishing needs to be reduced as much as possible by optimizing the gas nozzle.
③－1	**Concerns about cold cracks**	Study of tests on cold cracks	Methods of verifying prevention of cold cracks when there is no pre-heating and welding methods will be studied by conducting tests (T shaped coupling, etc.).
③－2	**Concerns about cold cracks**	Method of pre-heating	The method of pr-heating the equipment hatch (partial or full) will be studied. (Not applicable if ③-1 can be implemented.)
④	**Need for remote inspection method**	Study of inspection method other than Fluorescent PT	Methods for remote inspection will continue to be studied.
⑤	**Vertical downward welding** (Items that are not issues but need to be studied in response to test results)	Details of welding procedures, etc. (Order of tack welding or welding)	In the FY2019-20 subsidy projects, welding conditions up to a gap of 7.5mm were considered verified since vertical downward welding can be substituted by vertical upward welding. However, it is believed that the work efficiency is better in the case of vertical downward welding depending on the welding procedures. Firstly, the need for vertical downward welding will be clarified by studying the procedures, etc.
⑥	**Occurrence of false defects** (Items that are not issues but need to be studied in response to test results)	Applicability of the selected abrasive to actual environment	The applicability to actual environment needs to be studied and evaluated based on the data obtained during this subsidy project.

② PCV connection sleeve remote installation and welding: (b) Welding

[Issues and items that need to be studied]

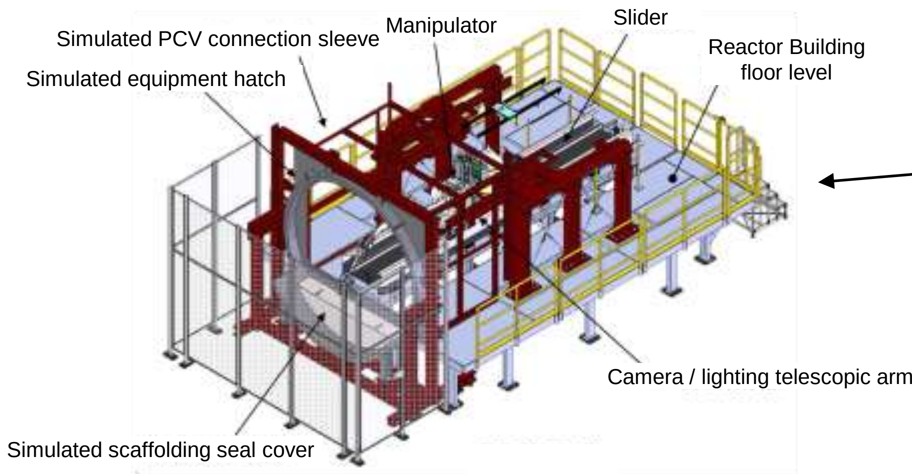
Step	Items	Issues and items that need to be studied	Study	Testing /Verification
1	Advanced preparations	Method of removing scaffolding considering post-processing (welding)	—	—
		Study of rust removal equipment (blast)	—#	—
		Study of scaffolding seal cover installation equipment	—#	—
2	Welding	(1) Specification of process management	✓	✓
		(2) Improving shielding capabilities and downsizing	✓	✓
		(3) Study of pre-heating method and working method	✓	✓
		(4) Study of welding procedures (stacking procedures, etc. for irregular gaps)	✓	✓
3	Polishing	Study on polishing machine and on the polishing guidelines	✓	✓
4	Inspection	(1) Study of fluorescent PT equipment and on inspection conditions (fluorescent agent blast pressure, etc.)	✓	✓
		(2) Study of inspection method other than Fluorescent PT (including organizing the required inspections)	✓	✓
		(3) Verification of the accuracy of dimension measurement (by means of the touch sensor of a robot)	✓	✓
5	Repairs	Study of repairing equipment and method	—#	—
6	Pressure resistance test	Study of pressure resistance testing method (after connecting the access tunnel main body)	—	—

Note) The items with "—" will be implemented during actual facility engineering
Studies conducted up to FY2020

Tests pertaining to welding, polishing and inspection indicated by the red frame in response to issues identified until FY2020, will be designed and implemented in FY2021-22.

② PCV connection sleeve remote installation and welding: (b) Welding

A series of welding procedures are verified using a full scale simulated equipment hatch shell and power manipulator (robot).



Testing facility

Verification contents	Items to be verified	Items to be monitored, measured and recorded	Criteria
Welding test	・Establishment of uneven gap welding ・Verification of welding deformation (strain) ・Verification of remote work efficiency	① Process management items such as welding conditions, etc. ② Amount of welding deformation ③ Results of non-destructive test (Dye PT, VT)	✓ Welded portion should be in a sound state ・Should pass the non-destructive test ・Required throat thickness should be secured
Abrasion test	・Verification of polishing work carried out by means of remote operation	① Selection of polishing tool ② Polishing guidelines	✓ Polishing that does not hinder the fluorescent PT should be possible
Fluorescent PT test	・Verification of applicability to actual facility	① Blasting conditions of the penetrant ② Surplus liquid washing conditions ③ Identification of indication	✓ It should be possible to detect the defect ✓ Remote operation should be possible
Dimension measurement	・Verification of guidelines for remote dimension measurement	① Dimension measurement guidelines ② Cross-sectional observation	✓ Ascertaining of the accuracy of dimension measurement

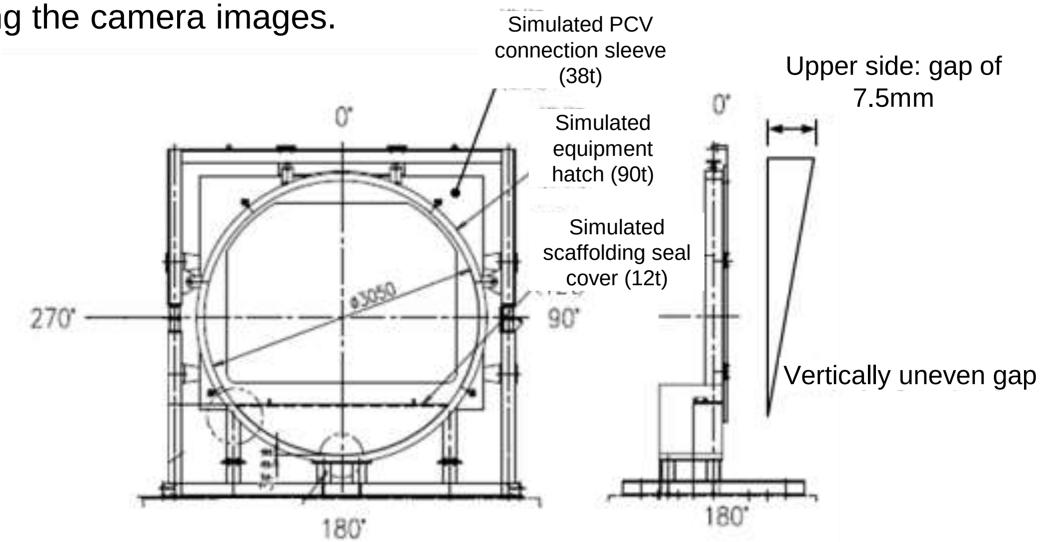
② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

Items to be verified	Items to be monitored, measured and recorded	Criteria
･Establishment of uneven gap welding ･Verification of welding deformation (strain) ･Verification of remote work efficiency	① Results of non-destructive test (Dye PT, VT) ② Dimension measurement results (required throat thickness) ③ Amount of welding deformation ④ Process management items such as welding conditions, etc.	✓ Welded portion should be in a sound state ･Should pass the non-destructive test ･Required throat thickness should be secured

- During the remote MU test welding is carried out using the camera images.

[Combination test]



[Remote MU test piece]

Test	Gap	Material	Objective
Combination test	Uniform gap of 7.5mm	SS400	Identification of remote work management items
Remote MU test	Vertically uneven gap of 7.5mm	SGV480/SM400B	Verification of a series of welding procedures

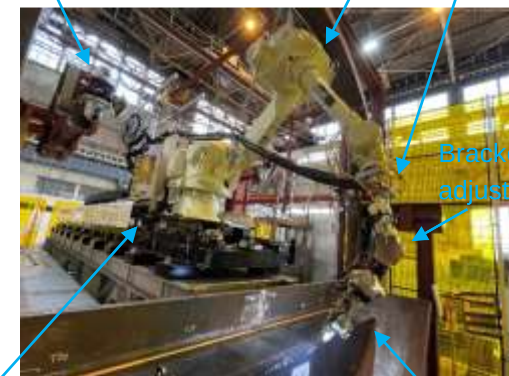
② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

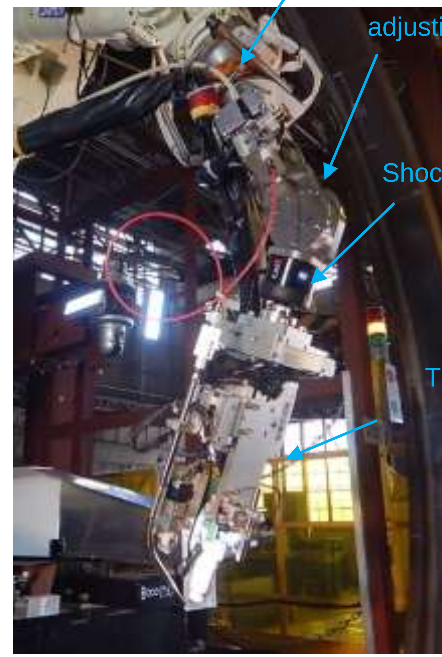
① Establishment of uneven gap welding

○ Welding equipment

Slider from the back



Slider from the front



TIG welding head
With AVC, OSC mechanism

Control equipment (robot, polishing machine, long shot camera) & welding power supply

Remote control for the welding operation

② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

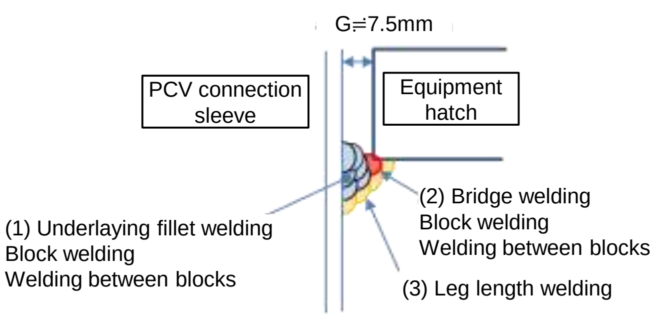
① Establishment of uneven gap welding

〇 Welding procedures

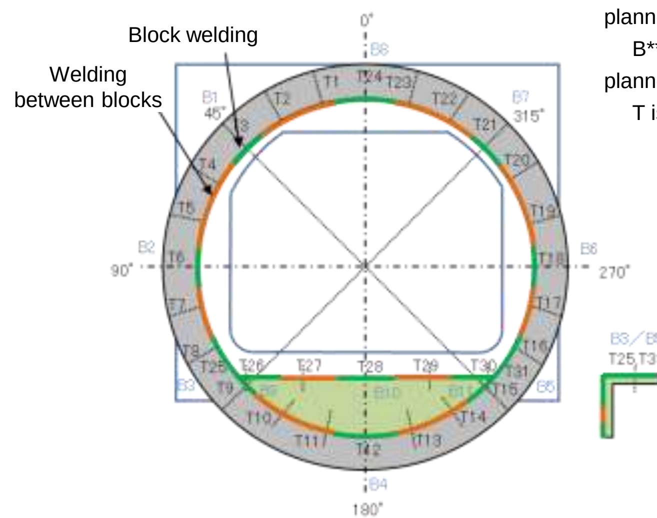
Tack welding → Block welding → Welding between blocks → Leg length welding




1. Gap measurement
2. Tack welding of gaps that are 2mm or less
3. Welding is carried out by segmenting it in the circumferential direction* *: Block welding
   (Underlaying fillet welding to bridge welding)
4. Welding between blocks (Underlaying fillet welding to bridge welding)
   (All-around seal welding completed)
5. Leg length welding（welding until the required [throat thickness (4.3mm)] is achieved)



Stacking where there are gaps



T**: Location where tack welding is planned
B**: Location where block welding is planned
T is 15° pitch and B is 45° pitch

〇 Block welding procedures
B3→B5→ B8→B4→B10→B11→B9→B6→B7→B2→B1

〇 Procedures for welding between blocks
B4～B3→B10～B9→B11～B10→B2～B1→B4～B5→B6～B7→B7～B8→B11～B6→B1～B8→B9～B2

Segmented locations for underlaying fillet welding and bridge welding

② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

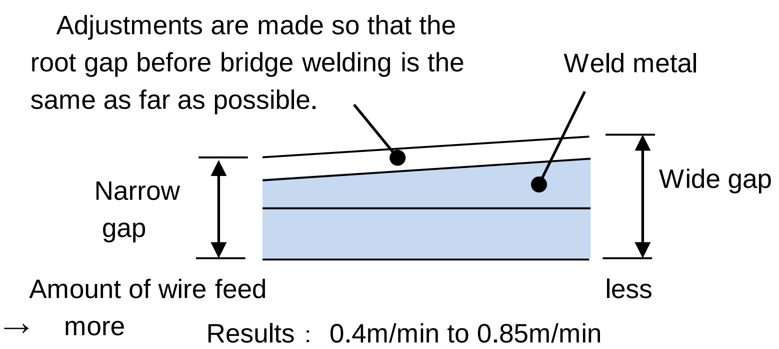
① Establishment of uneven gap welding

○ Welding conditions

① TIG welding that results in comparatively good shaped beads is used as the welding method taking the non-destructive inspection into consideration.
② Welding including tack welding is carried out under basic welding conditions
③ The amount of deposition in between uneven gaps (change in gap) is adjusted by changing the amount of wire feed
④ Number of block welding passes are matched with the number of weld passes for the location where the gap is the largest. Even if the gap varies depending on the welding location (orientation), the number of block welding passes does not change (taking welding between blocks into consideration)

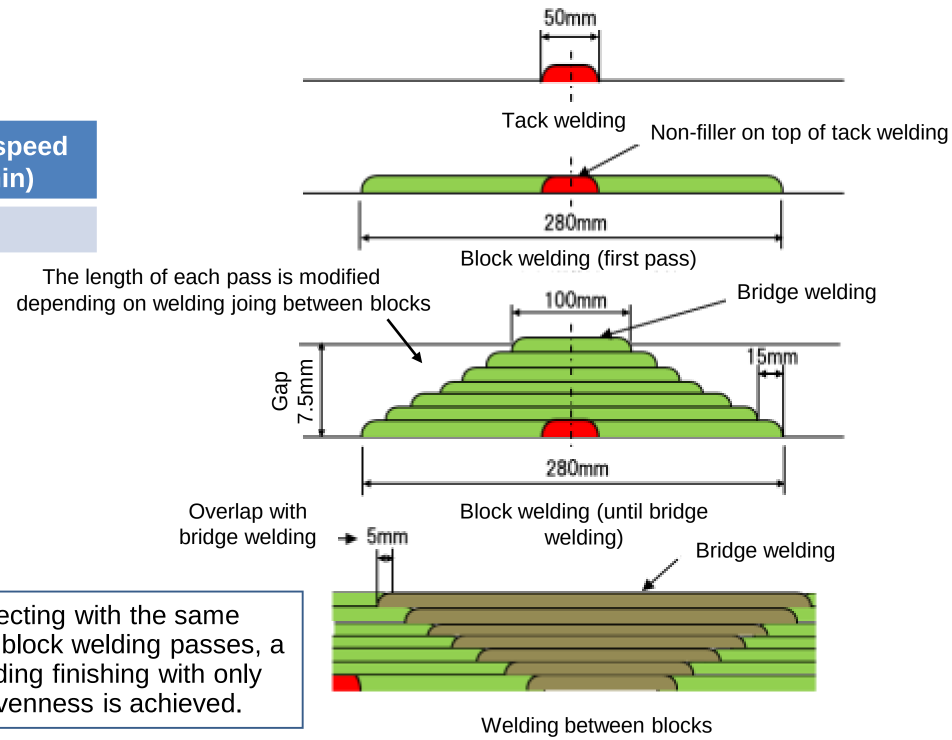
Basic welding conditions

Current P(A)	Current B(A)	Voltage (V)	Wire feed (m/min)	Welding speed (mm/min)
200	160	11	0.85	80



Results： 0.4m/min to 0.85m/min

Illustration of welding between uneven gaps



By connecting with the same number of block welding passes, a gentle welding finishing with only a little unevenness is achieved.

Tack welding to welding between blocks

② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

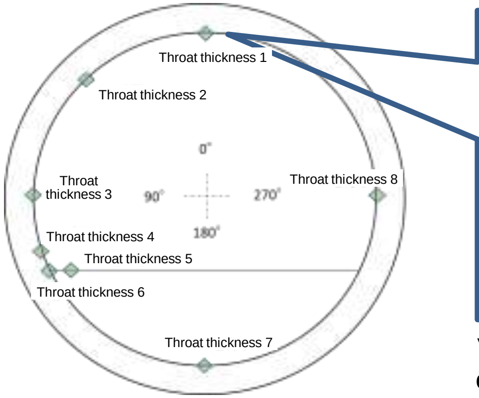
① Establishment of uneven gap welding

〇 Test results

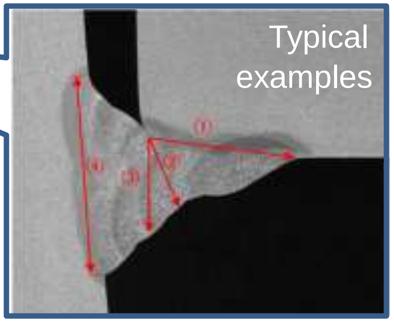
Criteria	Test results
✓ Welded portion should be in a sound state ① Should pass the non-destructive test ② Required throat thickness should be secured	Remote welding was carried out with the help of a manipulator for uneven gaps, and it wad confirmed that the welded portion was in a sound state. ① Dye PT was conducted after all-around welding. No defects were found. ② Throat thickness (4.3mm or more) was ensured through cross-sectional macro observation.

Status of remote welding using the manipulator

① Dye PT conducted after all-around welding



Throat thickness measurement locations



Verification of dimensions through cross-sectional macro observation

Measurement locations	1	2	3	4	5	6	7	8
Measured value (mm)	7.3	10.8	11.5	9.4	8.1	8.2	8.1	11.1

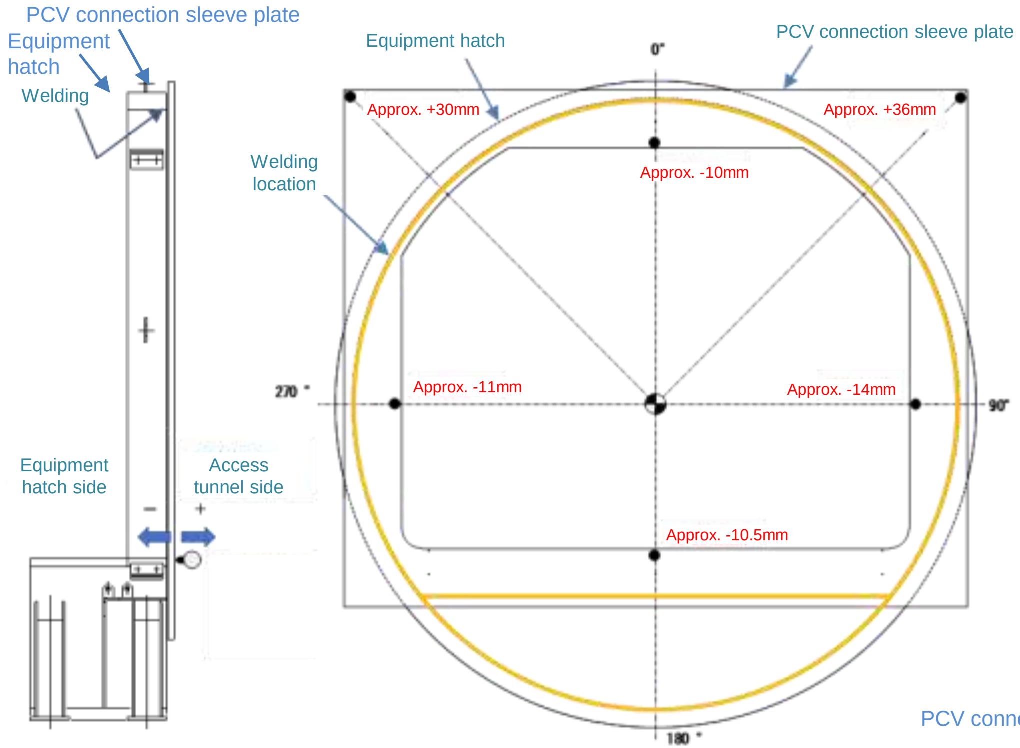
② Results of measuring the throat thickness (Determination: ≧4.3mm) through cross-sectional macro observation

② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

② Verification of welding deformation (strain)

The amount of welding deformation is measured while welding and after welding the entire layer to verify the amount of displacement.



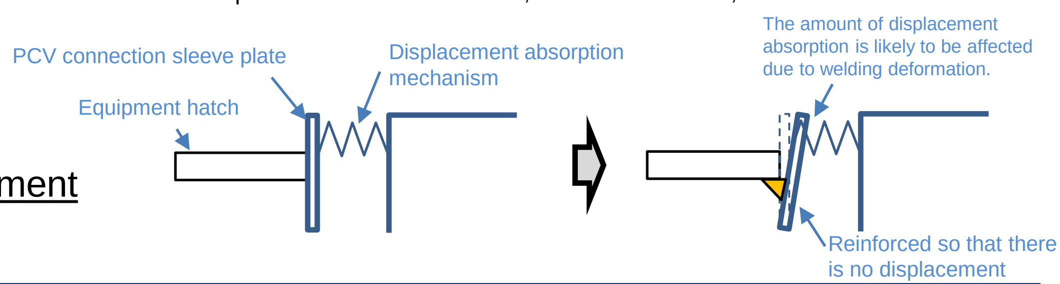
Results of measuring the amount of displacement after welding (representative locations)

<Results of measuring the amount of displacement>

1. While welding, the gap tends to change in the case of bridge welding and the displacement of the PCV connection sleeve plate tends to increase in the case of leg length welding.
2. On the inner side of the equipment hatch, deformation takes place on the "-" side (equipment hatch side). The deformation is at most approx. 14mm.
   (The measurement point is located 10mm from the PCV connection sleeve plate opening.)
3. On the outer side of the equipment hatch, deformation takes place on the "+" side (access tunnel side). The deformation is at most approx. 36mm.
   (The measurement point is located 20mm from the PCV connection sleeve plate distal end)

<Items to be reflected in the actual facility>

- While welding, the gap changes in the case of bridge welding. The gap should be verified before welding between blocks and the welding program should be adjusted accordingly.
  ⇒ Reflection into the work steps
- The amount of displacement obtained through the tests should be reflected into the design of the PCV connection sleeve so that the function of the displacement absorption mechanism is not lost, and reinforcement, etc. should be considered.



② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

③ Verification of remote work efficiency

No.	Verification contents / Improvements	Proposed countermeasures directed towards installation of actual facility	Improvement Items
1	Welding was possible by remote operation using the camera on the welding head. (2 cameras on the front and back in the direction of travel)	Enhancing visibility by increasing the number of cameras, etc. should be studied as further improvement.	Visibility ①
2	Teaching pertaining to the welding trajectory needs to be conducted, but it is difficult to conduct direct teaching using the images from the camera (directly touching by determining the position of the arm with respect to the teaching point). Direct teaching was conducted while the worker confirmed with their own eyes.	Offline program should be used. Offline program refers to creating the welding trajectory and the work position of the manipulator on a computer and installing it on the manipulator. If there are any differences in the installed program and the actual conditions, corrections are made remotely using the camera on the welding head.	Operating efficiency ①
3	Multi-layer filling programs available on the market are used for welding. The change in length from the initial pass can be specified for each weld pass, but there is a upper limit (99.9mm) to the change. If the upper limit was exceeded, programs needed to be added.	Even if the upper limit of change in length is exceeded, it is possible to deal with it as long as programs are added based on the bead length before the upper limit is exceeded. However, attempts should be made to enhance work efficiency by developing multi-layer filling programs in which there is no limit to the length.	Operating efficiency ②
4	It was possible to measure the gap using the welding head. (Using oscillation)	This should be reflected into the work procedure. In order to further enhance accuracy, introduction of a touch sensor in the welding head should be studied.	Operating efficiency ③
5	Welding was possible between uneven gaps when the worker adjusted the amount of wire feed while verifying with the camera.	Managing the numerical values of the wire adjustment timing by introducing up-slope control and down-slope control functions should be studied for further improvement.	Operating efficiency ④
6	Since long shot cameras were placed on both sides of the manipulator, the images captured were from the back of the manipulator thus leading to a blind spot while monitoring work.	The placement of the long shot cameras and the number of cameras should be adjusted. (Capturing images from the equipment hatch side)	Visibility ②
7	With long shot cameras, it was not possible to ascertain the correct work location (correct orientation, distance), such as at which location the beads were in a bad state, etc.	As it is difficult to put a mark on the existing equipment hatch, improvisation is required that would make it possible to acquire locational information with the help of a camera (visual), such as putting a mark on the PCV connection sleeve that is newly made available. Also, an encoder should be installed on the long shot camera thereby making it possible to acquire information on the location of the images.	Operating efficiency ⑤
8	Tungsten needed to be replaced (Replaced manually by the worker)	A tungsten replacement equipment should be made available. The welding head should be remodeled such that it can handle remote replacement.	Equipment ①
9	The welding material (wire) was likely to shift from the target location of the torch while welding when the direction of the welding head is changed (clockwise to anti-clockwise) or while welding after the welding head is stowed.	The method of fixing the wire on the welding head (adjustment) should be changed and the wire feed route should be improved.	Equipment ②

Improvement items were verified with respect to Visibility: 2 cases / Operating efficiency: 5 cases, Equipment: 2 cases.

② PCV connection sleeve remote installation and welding: (b) Welding

1) Welding test

Summary

No.	Results
1	Sound welding was achieved by remotely welding the uneven gap of 7.5mm. The required work management items such as work procedures, welding conditions, stacking method, etc. were verified.
2	The tendency of the PCV connection sleeve to get deformed due to welding was ascertained.
3	Remote work efficiency was verified, and issues in installing the actual facility were identified.

It is believed that welding is possible up to the 7.5mm gap with the work management achieved through this test. However, it is believed that revision of the stacking method and welding conditions pertaining to the 20mm gap is likely to be needed.

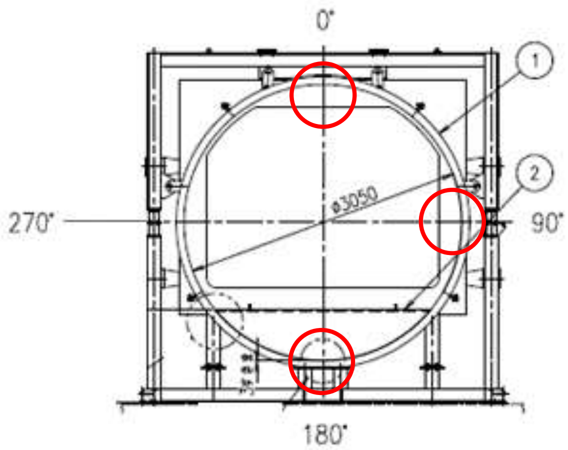
For executing the installation of actual facility ・・・

No.	Issue	Response	Response deadline
1	The structure should be such that the tendency to deform due to welding is provided as feedback while designing the PCV connection sleeve, so that there is no impact on the displacement absorption mechanism (deformation prevention elements such as ribs, etc. should be introduced as required).	Study	Until installation of actual facility
2	The issues identified during verification of remote work efficiency should be resolved (Equipment suitable for remote operation should be made available).	Study	Until installation of actual facility

② PCV connection sleeve remote installation and welding: (b) Welding

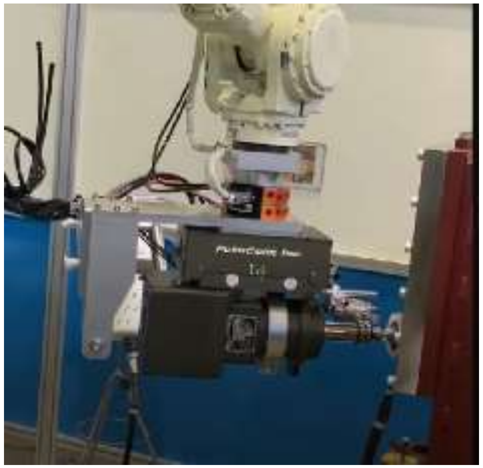
2) Abrasion test

Items to be verified	Items to be monitored, measured and recorded	Criteria
・Verification of polishing work carried out by means of remote operation	① Selection of polishing tool ② Polishing guidelines	✓ Polishing that does not hinder the fluorescent PT should be possible

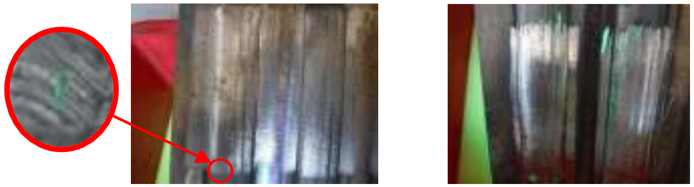


Location for verifying polishing work
Verified at typical positions
(downward, sideways, upwards)

(Location enclosed by the red circle)

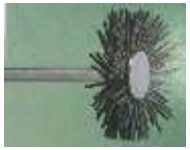


Verification of polishing work
- Polishing position
- Rotational speed
- Pressing force
- Progression speed



Examples of false defects due to areas left unpolished

<Polishing tools using which the results of the fluorescent PT were good>



Nippon unit
Diamond
Nylon brush

Nippon unit
Metal brush
(Thistle type)

3M
Radial bristles
Margaret disc

Selection of polishing tool suitable for the shape of the actual facility
Considering the approach towards the welded part, a polishing tool selected in FY2020 or a tool that is suitable for the approach is selected.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

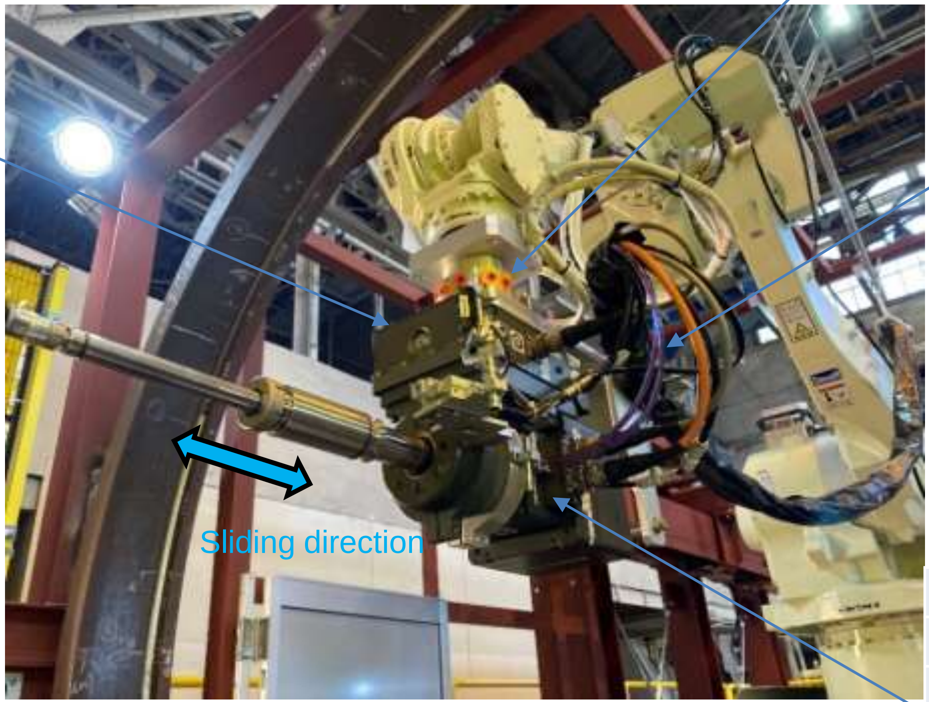
② PCV connection sleeve remote installation and welding: (b) Welding

2) Abrasion test

○ Polishing head

Active compliance equipment
(1) Model: AFD310-2
(2) Output: 267N(MAX.)
(3) Maximum payload: 27.2kg
(4) Sliding section: 20mm
(5) Mass: 5.5kg

Detects reaction force along with supporting the water cooling spindle motor, and automatically slides the spindle motor so that the magnitude of reaction force becomes constant.
This prevents the manipulator overload.



Polishing head (Manufactured by Push Corp Reaction force buffering equipment)

Water cooling spindle motor
(1) Model: STC1503-BT30
(2) Output: 2.2kW
(3) Torque: 3.5N.m
(4) Rotational speed: 60 to 15000rpm
(5) Mass: 12.7kg

② PCV connection sleeve remote installation and welding: (b) Welding

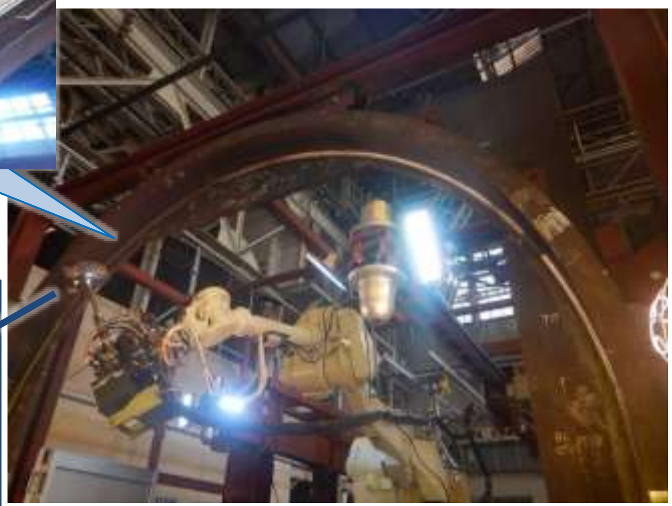
2) Abrasion test

○ Test results

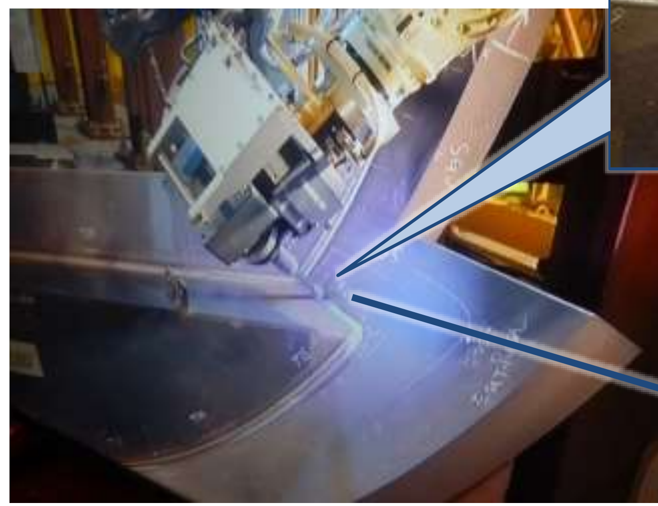
Criteria	Test results
✓ Polishing that does not hinder the fluorescent PT should be possible	It was confirmed that polishing is possible using the manipulator without hindering the fluorescent PT.

External appearance of the bead after polishing

Bevel brush
・External diameter: φ200/wire diameter: 0.3mm



Status of polishing ①



Status of polishing ②

External appearance of the bead after polishing

Metal brush
・External diameter: φ30/wire diameter: 0.3mm

<Polishing conditions>

Polishing conditions	Rotational speed (rpm)	Feeding speed	Pressing force	Range of access
Bevel brush	500	100mm/min	20N	Area excluding the scaffolding seal cover side
Metal brush	2000	100mm/min	20N	Complete periphery can be polished

② PCV connection sleeve remote installation and welding: (b) Welding

2) Abrasion test

Summary

No.	Results
1	The polishing tools were selected, polishing conditions for each tool were verified, and it was confirmed that the entire welded portion can be polished. Also, it was verified that the finishing achieved after polishing does not hinder fluorescent PT.

2 types of polishing tools were selected, but the consumption of the metal brush was large and it needed to be replaced frequently. Hence in the actual facility, polishing will be carried out mainly using the bevel brush and the metal brush will be used only in areas where the bevel brush cannot be used.

For installation of actual facility ...

No.	Issue	Response	Response deadline
1	Visibility during work needs to be ensured. The placement of the camera that can verify the tool tip at an appropriate location and placement of the long shot camera need to be studied.	Study	Until installation of actual facility
2	Whether offline program is applicable to polishing tools that have a soft tip needs to be verified (Development of polishing work steps).	Study	Until installation of actual facility
3	Introduction of equipment for automatic replacement of polishing tools	Study	Until installation of actual facility
4	Covering as a countermeasure for polishing dust generated while polishing, and collection of polishing dust	Study	Until installation of actual facility

② PCV connection sleeve remote installation and welding: (b) Welding

3) Fluorescent PT test

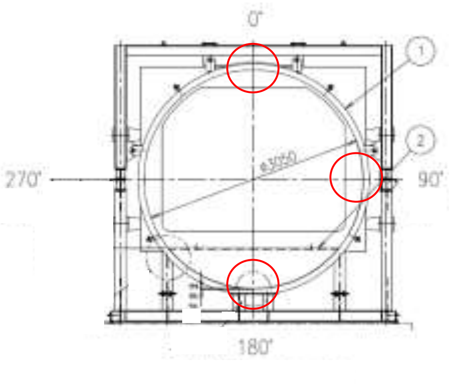
Items to be verified	Items to be monitored, measured and recorded	Criteria
・Verification of applicability to actual facility	① Blasting conditions of the penetrant (Pressure, distance, blasting time) ② Surplus liquid washing conditions (Pressure, distance, blasting time) ③ Identification of indication	✓It should be possible to detect the defect (Implemented using the test piece#) ✓Remote operation should be possible (Implemented through full-scale test)

・ Penetrant and cleaning water is blasted by means of a spray

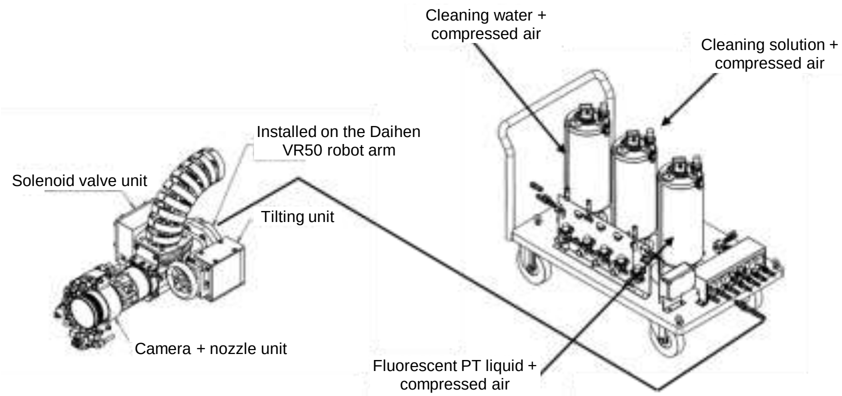
・ Parametric study of the blasting time and the distance from the specimen while blasting the penetrant and cleaning water is conducted to verify the test conditions.

・ The status of the fluorescent PT is conducted on the full scale test piece under the verified test conditions (verified for the typical position)

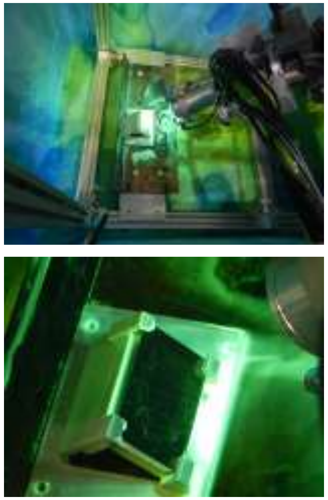
If defects are detected by means of the full-scale dye PT, it is verified whether similar defects can be detected by means of the fluorescent PT.



Fluorescent PT verification locations
(Locations enclosed by the red circle)



Inspection equipment



Testing by setting conditions

② PCV connection sleeve remote installation and welding: (b) Welding

3) Fluorescent PT test

○ Test results

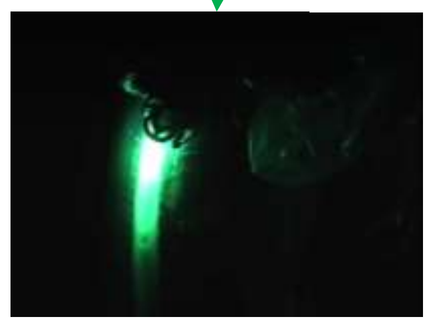
Criteria	Test results
✓It should be possible to detect the defect (Implemented using the test piece) ✓Remote operation should be possible	・Conditions under which defects can be detected were verified using the test piece ・It was verified that observation is possible during the fluorescent PT by remotely operating the manipulator

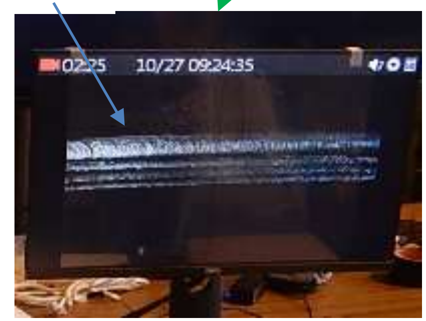
○ Fluorescent PT procedures

Polishing → Washing → Drying → Fluorescent penetrant → Surplus liquid removal → Drying → Observation

External appearance of the testing facility


Status of blasting fluorescent penetrant


Surplus liquid removal (UV radiation)



Observation (Camera image of the fluorescent PT head)

<Main working conditions (conditions established based on the results of testing by setting conditions)>

Work Items	Washing	Drying air	Penetrant blasting	Surplus liquid removal	Drying air	Observation
Working conditions	Movement: 30mm pitch Blast pressure: 0.2MPa Blasting time: 0.3s/cycle	Moving speed: 10mm/s Blast pressure: 0.1MPa	Movement: 30mm pitch Blast pressure: 0.2MPa Blasting time: 0.3s/cycle	Moving speed: 10mm/s Blast pressure: 0.25MPa	Moving speed: 10mm/s Blast pressure: 0.1MPa	Movement: 30mm pitch Observation: 30s/location

② PCV connection sleeve remote installation and welding: (b) Welding

3) Fluorescent PT test

Summary

No.	Results
1	Conditions under which defects can be detected were verified.
2	It was verified that the fluorescent PT using the typical position can be observed by remotely operating the manipulator.

It was verified that remote operation is possible using the manipulator and the working conditions for the Fluorescent PT were verified as well. However, reasonable options will be studied at the stage when the safety requirements pertaining to tool welding are determined, including the option of using only VT that does not generate any liquid waste.

In order to use the fluorescent PT in the actual facility

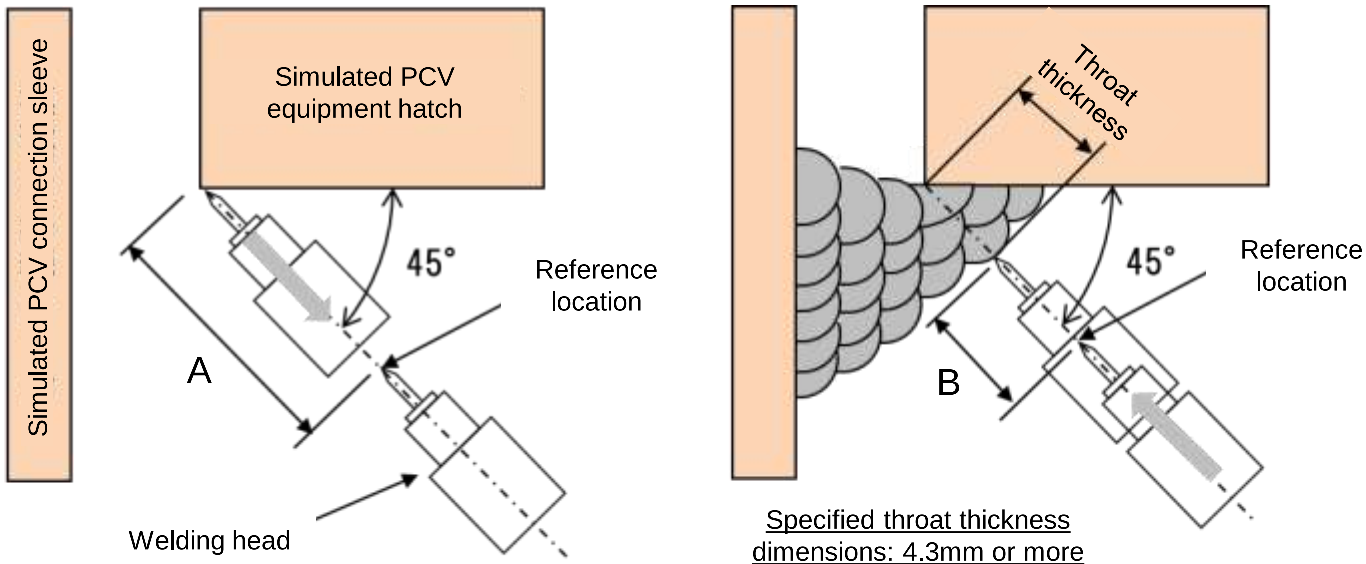
No.	Issue	Response	Response deadline
1	Establishment of the installation procedures including the method of waste liquid treatment to be used	Study	Until installation of actual facility
2	Development of inspection head for installation of actual facility (remodeling of the test head)	Development	Until installation of actual facility
3	Method of judging (determining acceptance/rejection) the magnitude of the indication and specification and recording of the location of detection	Study	Until installation of actual facility
4	Prevention of rust after fluorescent PT (Verification of the effect of cleaning water consisting of an anti-rusting agent)	Study	Until installation of actual facility

② PCV connection sleeve remote installation and welding: (b) Welding

4) Dimension measurement

Items to be verified	Items to be monitored, measured and recorded	Criteria
･Verification of guidelines for remote dimension measurement	･Dimension measurement guidelines ･Cross-sectional observation	✓ Accuracy of dimension measurement should be ascertained

- The "throat thickness" is measured by letting the welding head touch the electrode.
- After welding, cross-sectional observation is carried out to verify the accuracy of the dimension measurement by means of electrode touch.



Remembering the reference location before welding

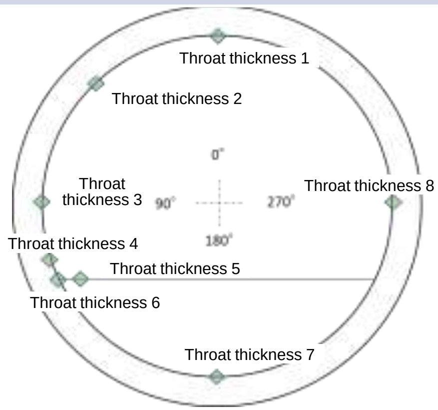
The movement of the tip from the reference location before welding is measured.
The throat thickness is calculated from the movement of the electrode tip (A-B).

② PCV connection sleeve remote installation and welding: (b) Welding

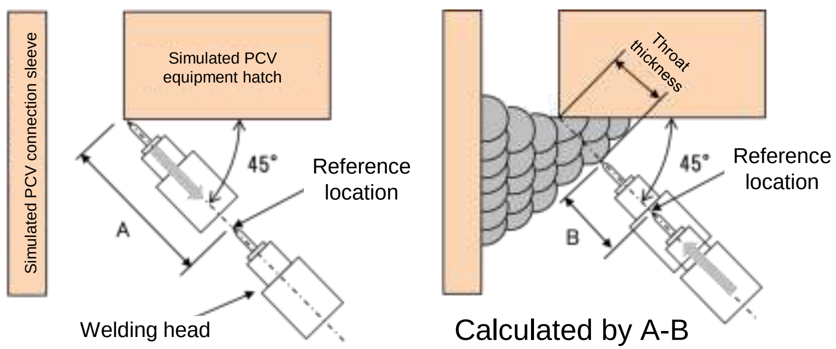
4) Dimension measurement

○ Test results

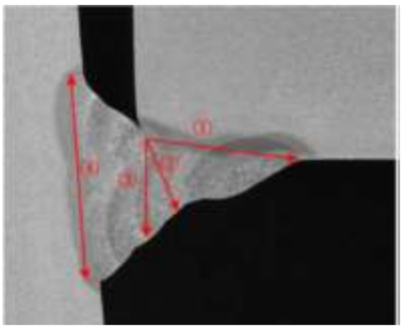
Criteria	Test results
✓ Accuracy of dimension measurement should be ascertained	・The error is -2.0 to 1.3. The welding head is almost underestimated, but as the cross-sectional macro includes weld penetration, it is believed to have roughly the same value. ・In the case of throat thickness 4, it is believed that the error in measurement was larger since the measurement position at the welding head was not from the central axis direction of the equipment hatch.



Measurement locations



Measurement based on the stroke of the welding head



Measurement by means of the cross-sectional macro

<Comparison of the dimension measurement results of the welding head and during cross-sectional observation> Unit : mm

Measurement locations	1	2	3	4	5	6	7	8
Welding head	6.2	8.8	11.3	10.7	8.1	8.4	7.2	10
Cross-sectional observation	7.3	10.8	11.5	9.4	8.1	8.2	8.1	11.1
Error	-0.9	-2.0	-0.2	1.3	0	0.2	-0.9	-1.1

② PCV connection sleeve remote installation and welding: (b) Welding

4) Dimension measurement

Summary

No.	Results
1	The measurement accuracy of the throat thickness was verified in the case of fillet welding using the welding head.

As the throat thickness turned out to be larger than the specified dimensions if manufactured according to the present stacking procedures, it is believed that the throat thickness achieved using the welding head can be controlled (determination of minimum dimensions) in the actual facility as well if the measurement position is controlled.

For installation of actual facility ...

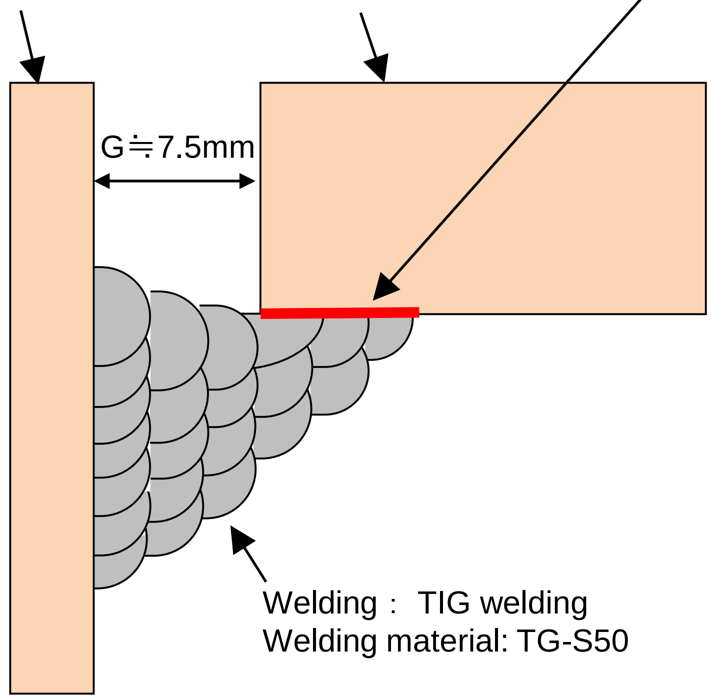
No.	Issue	Response	Response deadline
1	Controlling the measurement position (Particularly when the welding position is not perpendicular to welding)	Study	Until installation of actual facility
2	Introduction of the tungsten replacement equipment (Is replaced with new tungsten before measurement)	Development	Until installation of actual facility

② PCV connection sleeve remote installation and welding: (b) Welding

5) Cold crack test

PCV connection sleeve
Material： SM400 (P1)
Sheet thickness: 36t

PCV equipment hatch
Material： SGV480 (P1)
Sheet thickness： 90t (1F-1)



Welding： TIG welding
Welding material: TG-S50

Concerns about cold cracks

Verification of the formation of cold cracks

Items	Verification test	Verification contents
Verification test	Lap joint welding test (JIS Z 3154)	Short bead test (Bead-on-plate test)
Verification contents	Verification of formation of cold cracks due to fillet welding	Verification of formation of cold cracks assuming there are interruptions in welding
Plate thickness	40t	40t
External appearance of test piece (After welding)		
Verification method	Surface PT, Cross-sectional observation	Surface PT, Cross-sectional observation
Cross-sectional picture		

<Test results>
Cracks were not found in any of the tests

② PCV connection sleeve remote installation and welding: (b) Welding

5) Cold crack test

Summary

No.	Results
1	No cracks were found during the test for verifying formation of cold cracks using material equivalent to the actual facility.

The material of the test piece was equivalent to the actual facility and the test was conducted without pre-heating or thermal processing. But cracks were not formed. It is believed that cracks were not formed because the method of fillet welding was used due to which the binding force was comparatively small. But the condition of the material at the actual facility is unknown. It is believed that if the characteristics of the material in the actual facility can be ascertained, even if the actual facility is installed without pre-heating, the risk of cold cracks will be low.

For installation of actual facility ...

No.	Issue	Response	Response deadline
1	Ascertaining the characteristics of of the materials, such as verifying the Mill Test Report pertaining to the existing equipment hatch in each unit	Verification	Until installation of actual facility

② PCV connection sleeve remote installation and welding: (b) Welding

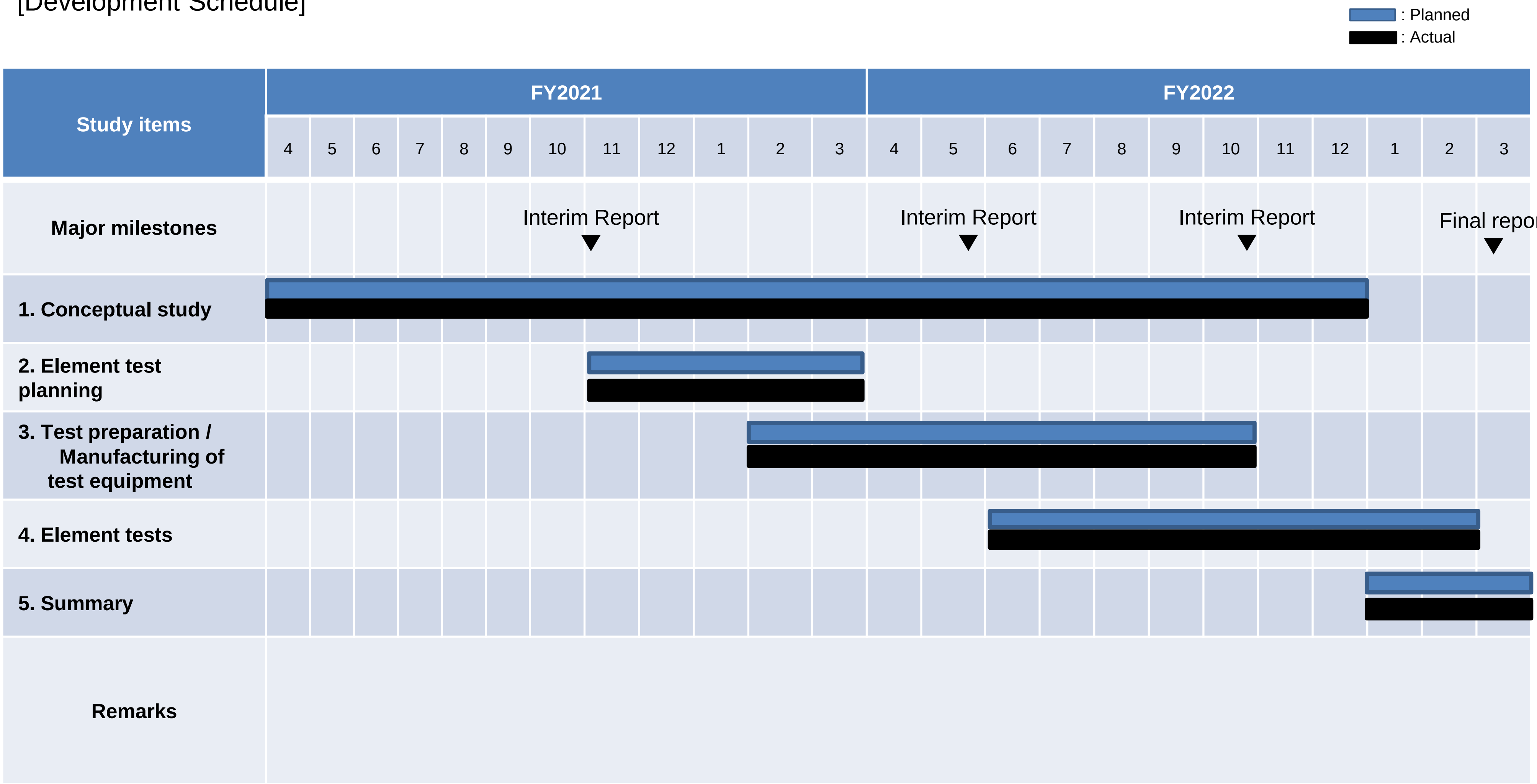
(6) Summary of test results

- **The feasibility of remote welding, polishing, fluorescent PT, dimension measurement (throat thickness control) was verified for a welding gap of 7.5mm or less by conducting full-scale tests.**
- **As a result of conducting tests for verifying the formation of cold cracks, it was confirmed that cold cracks do not form even if there is no pre-heating or thermal processing. It is believed that the risk of forming cold cracks is low while installing the actual facility even if the installation is carried out without pre-heating, but as the properties of material in the actual facility is unknown, if pre-heating has to be omitted while installing the actual facility, the characteristics of the material in the actual facility need to be verified such as by checking the Mill Test Report pertaining to the existing equipment hatch, etc.**
- **Issues in actual facility application were identified from the test results and consolidated. The identified issues including the work efficiency of remote operation need to be studied and resolved before the actual facility installation work.**

Further, technical verification such as pertaining to welding work, inspection method, etc. is being carried out, but for application to the actual facility, coordination and discussions (determination of pre-conditions) need to be carried out pertaining to compliance with technical standards (equipment class, applicability of the Operator's inspection on welding (including witnessed inspection), etc.).

② PCV connection sleeve installation and welding by remote operation

[Development Schedule]



② PCV connection sleeve installation and welding by remote operation: (a) Remote installation summary

- **In FY2021, the requirements (pre-conditions) for remote installation of the sleeve, results of studying the concerned delivery method and equipment were consolidated. "The method of delivering the unit in its entirety" which is the same as the method used for delivering the main access tunnel was selected, and the issues and items that need to be verified through tests, etc. were consolidated.**

- **Based on the results consolidated as mentioned above, the specifications pertaining to the remote sleeve installation equipment, sleeve structure, opening part, installation procedures, etc. were studied using mock-ups. The actual facility (assumed) and the mock-up equipment were compared and the results were compiled. Test plans including sensing were created, and a gap of 20mm or less (target 7.5mm or less) was established as the judgment criteria.**

- **Preparations were made for a full-scale test equipment and facility for remote installation of the sleeve, and tests for verifying the feasibility related to the procedures for remote installation of the sleeve and the equipment were conducted.**

- **As a result of the tests, it was verified that the target of 7.5mm or less is met. Also, issues in application to actual facility were identified and consolidated.**

② PCV connection sleeve remote installation and welding: (b) Remote welding summary

- **The methods of responding to the issues pertaining to remote welding of the sleeve consolidated during the FY2019-20 subsidy project were studied in FY2021, and issues as well as items that need to be verified through tests, etc. were consolidated.**

- **Items to be verified, monitored, measured and recorded were substantiated through the welding, polishing and fluorescent PT (inspection) tests, and judgment criteria were established.**

- **Preparations were made for element test equipment and facility for remote welding of the sleeve, and element tests were conducted for verifying the feasibility related to the procedures for remote welding of the sleeve and the equipment.**

- **Feasibility of remote welding for a welding gap of 7.5mm or less was verified by conducting full-scale tests. However, there is a possibility that the welding conditions for a welding gap of 7.5mm to 20mm will need to be revised. Also, maintenance was studied to verify applicability to the actual facility.**

- **Issues in application to the actual facility were identified from the test results and consolidated.**

③ **Installation of shield**

Studies on access equipment, such as the access tunnel (a tunnel type structure for accessing the inside of the PCV), to be used when the side access method is adopted, have been carried out for further increasing the retrieval scale of fuel debris and reactor internal structures. The retrieved fuel debris, etc. will be temporarily placed inside the access equipment. Considering that the area around the structures being installed will be used as the work environment, it is necessary to reduce the radiation dose. Thus, the access equipment becomes a large and heavy object with shielding functionality. Hence, in order to reduce the load on the floor of the R/B, ancillary facilities, etc. required for transportation to the inside of the R/B, etc., streamlining of the structure of the shield of the access equipment, and the transportation / installation methods need be studied, and development needs to be carried out as needed.

In order to safely and efficiently carry out the work of establishing the shield under high radiation dose by remote operation, first, the pre-conditions required for assessing the shielding functionality including the state of existence, the type of radiation source, etc. of the inside of the PCV and of the retrieved fuel debris, etc. will be studied and compiled. Next, studies including exposure dose evaluation will be carried out pertaining to the procedures, the transportation and installation method, including the shielding structure, addition of shield, etc. based on the strength of the R/B structure and the on-site workability. Subsequently, a simulated test piece of the access equipment on which the shield will be installed, will be manufactured, and viability will be verified and evaluated through verification tests for verifying the feasibility such as a manufacturing capability, etc., and thereafter the technology required for reasonably installing the shield on the access equipment will be developed.

③ Installation of shield

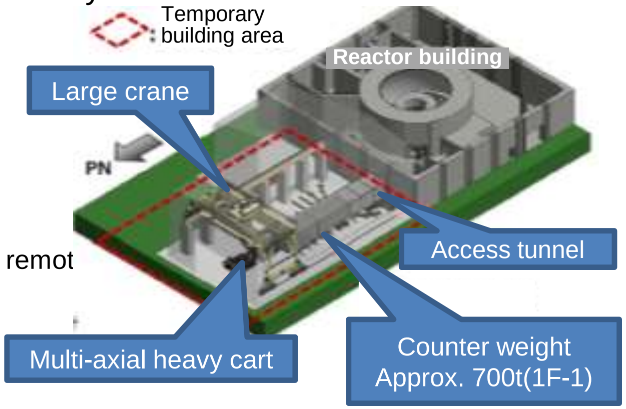
Table of Contents

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Status of studies conducted up to FY2020]

- Some of the conditions for studying the shield thickness were revised and a simple study of the shield thickness was conducted.
- Conceptual study of the frame structure was conducted.



Total delivery weight at present: Approx. 1100ton(1F-1)

[Issues]

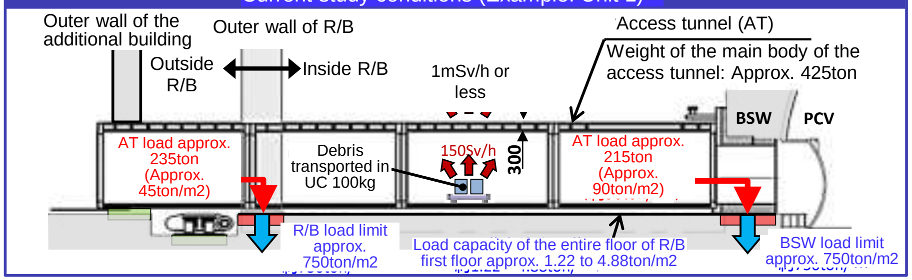
Large ancillary facilities, since the mass to be delivered is large. Interference during post-processing.
(Access tunnel weight (large) → Delivery weight including CW (large) → Ancillary facilities (large))

- Feasibility of the method for additional installation of shield by complete remote operation or partial remot operation.
- Structure with minimal defects and assurance of shielding performance (method of verification at completion)
- The structure of the access tunnel shield, the transportation and installation method need to be streamlined.
- Reduction in weight while maintaining rigidity of the delivery frame

[Implementation details]

- The preconditions required for assessing the shielding functionality including the state of existence, the type, etc. of the radiation source such as the inside of the PCV, the retrieved fuel debris, etc. are studied and compiled.
- The transportation and installation method and procedures including the additional installation of shield, etc., the shielding structure, etc. based on the strength of the R/B structure and on-site workability are studied including exposure dose evaluation.
- A simulated test piece of the access tunnel on which the shield will be installed, is manufactured, the element plan is created, and feasibility such as manufacturing capability, etc. is verified.

Current study conditions (Example: Unit 1)



[Expected outcome]

- Presentation of a reasonable method for installing the access tunnel shield.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Consolidation of preconditions]

The pre-conditions for calculating the shielding thickness were consolidated. The source strength for evaluation was calculated by back calculating based on the actual measured value.

Further, as the work to be performed in the R/B is unknown, this study was conducted assuming workers will enter inside the R/B.

Items		Conditions	Remarks
Target plants		1F-1, 2, 3	
Entry inside R/B	While transporting fuel debris inside the access tunnel	No (People are cleared out)	
	During regular times (Other than those mentioned above)	Yes	
Radiation source	Inside PCV	Source strength is calculated for evaluation	Data from Unit 1 is used
	Inside AT	Fuel debris inside the Φ200 unit can	Evaluation carried out with 30kg/can x 2
Material density	Concrete	2.15 (g/cm^3)	
	Iron	7.8 (g/cm^3)	
	Polyethylene (PE)	0.92(g/cm^3)	
Target dose rate on the access tunnel surface	Inside R/B	1.0mSv/h (During regular times)	
Evaluation points	Height	10cm, 120cm above the floor	

(Note)

・ The target dose rate was tentatively considered to be 1.0mSv/h. It needs to be finalized eventually while comparing with the quantity of fuel debris transported (dose rate), shielding thickness, and air dose rate inside the R/B.

・ As the impact of neutrons from inside the PCV is smaller than that of the gamma rays, the impact was verified using the actual measured value. The neutrons when the fuel debris passes through the access tunnel were evaluated.

The shielding thickness of the access tunnel was determined based on the above conditions, and the additional installation method and installation equipment were studied.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Consolidation of preconditions]

Shielding evaluation was carried out under the following conditions.

Items	Unit	1F-1	1F-2	1F-3	Shielding evaluation conditions
Initial concentration	wt%	3.7	←	←	3.7
Burn-up	GWd/tHM	40.172	40.557	40.499	41
Specific output:	MW/tHM	20.0	25.3	←	20.0 Note)
Cooling period	years	20	←	←	20
Fuel debris composition (weight)	—	UO_2 (Weight calculated assuming UO_2=1t)	←	←	UO_2 (Weight calculated assuming UO_2=1t)

Note) Studied based on Unit 1, as there is almost no impact.

The following was used for calculating burn-up.

- Calculation code: ORIGEN2.2 UPJ
- Cross-sectional area library: BS340J33
- DECAY library: JNDECAY33.LIB
- Photon library: gxuo2brm.lib

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

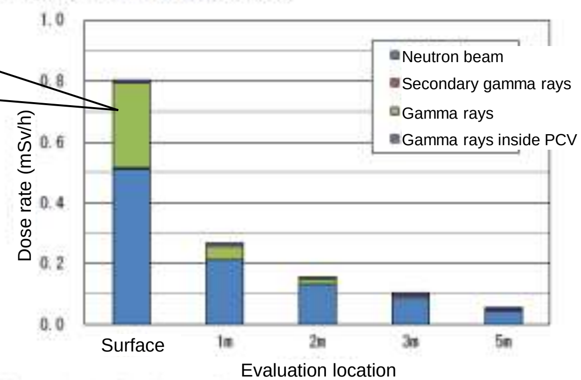
③ Installation of shield

[Evaluation results] Shielding thickness: Wall/Ceiling 300mm, Floor 110mm (Quantity of fuel debris 30kg × 2)

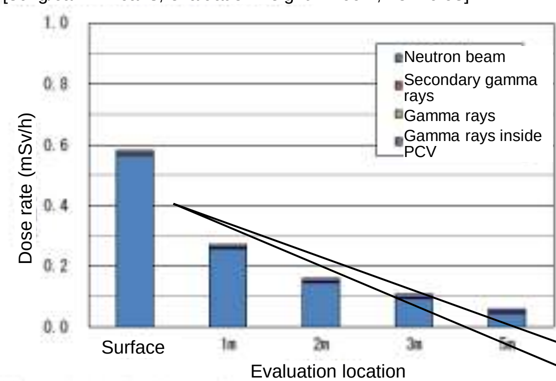
High γ radiation dose in the vicinity of the floor

Addition of shielding

[30kg/can x 2 cans, evaluation height: 10cm, keff=0.95]



[30kg/can x 2 cans, evaluation height: 120cm, keff=0.95]



Shielding thickness:
- Wall/Ceiling 300mm is the shielding thickness obtained through simple calculations when the study of the access tunnel began.
- The floor surface thickness is an approximate thickness calculated from the structural design

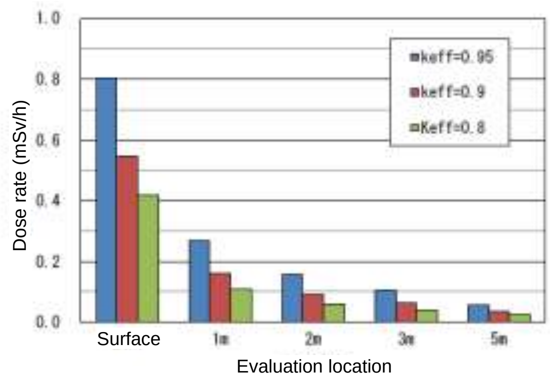
High neutron beam dose

Addition of neutron shielding

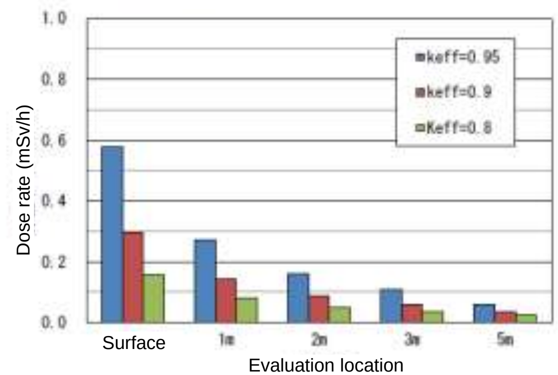
Evaluation height:
The position of the ADP during work is assumed.
- 10cm: During work on the floor surface (while laying on the floor)
- 120cm: During regular work

Evaluation location:
- Distance from the access tunnel surface

[30kg/can x 2 cans, evaluation height: 10cm]



[30kg/can x 2 cans, evaluation height 120cm]



1mSv/h or less is met even with a shielding thickness of 250mm.

Based on the results of dose comparison between shielding thickness 300mm/250mm, it is expected that by shielding neutrons, 1mSv/h will be met even if the access tunnel wall and ceiling are 200mm and the floor is 110mm.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

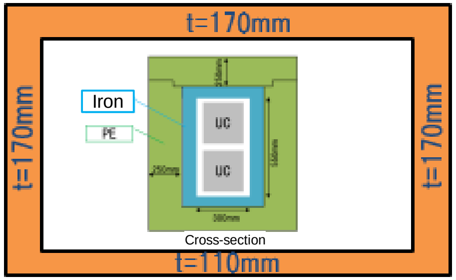
[Shielding thickness between the access tunnel and the cart]

The shielding thickness required for the access tunnel considering the thickness (75mm) of shielding that can be installed on the cart inside the access tunnel, is given below (red frame).

No.	Radiation source		Required shielding capability calculated based on the dose	Shielding capability required for the main body of access tunnel
①	Dose from inside the PCV (Regular times)		Floor: 110mm (@ iron)	Floor: 110mm (Not affected by the cart shielding)
			Other than floor: 170mm (@ iron)	Other than floor: 170mm (Not affected by the cart shielding)
②	Dose from fuel debris that is being transported (Temporary)	γ rays	Floor: 110 + αmm (@ iron)	Floor: 35 + αmm (Considering 75mm of cart shielding)
			Other than floor: 200mm (@ iron)	Other than floor: 125mm (Considering 75mm of cart shielding)
		Neutron beam	250mm (@ Polyethylene)	Perimeter: 0mm

Based on the above, the shielding thickness of the access tunnel is assumed to be 110mm for the floor and 170mm for areas other than the floor. The cart is assumed to bear the load of 30mm thick iron shielding and 250mm thick polyethylene shielding.

(At present) Cross-section of the access tunnel



(After modifications) Cross-section of the access tunnel

Shielding of the transportation cart inside the access tunnel
PE: 250mm
Iron: 30mm

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

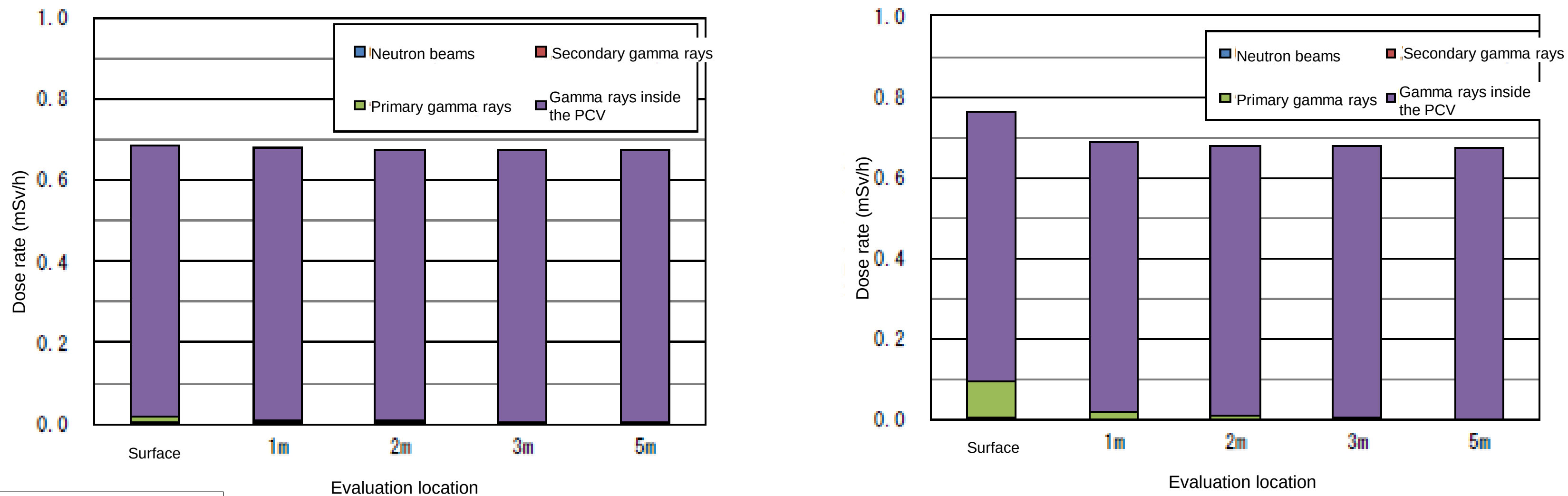
[Evaluation results]

Shielding thickness (Access tunnel): Wall/Ceiling 170mm (Iron), Floor 110mm (Iron)

Shielding thickness (Cart inside the access tunnel): Perimeter 30mm (Iron), Perimeter 250mm (PE)

- γrays from inside the PCV are dominant.
- The dose from the fuel debris passing from inside the access tunnel is extremely small.

Note) The dose from inside the PCV has been briefly studied. Hence attenuation of the distance has not been included.



(a) 10cm above the floor

(b) 120cm above the floor

Evaluation height:
The position of the ADP during work is assumed.

- 10cm: During work on the floor surface (while laying on the floor)
- 120cm: During regular work

Evaluation location:

- Distance from the access tunnel surface

<u>Evaluation conditions: Fuel debris: 30kg/can × 2 cans, keff: 0.95</u>

It was verified that the target dose of 1.0 mSv/h or less is met.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Organization of the purposes of additional installation of shield]

Purpose of the method for additional installation of shield

Avoiding interference with the work of constructing the additional building (Reducing the load of ancillary equipment)

① Simplification of hoisting equipment
② Reduction of counter weight

Addition (Comments during deliberations, etc. at IRID)

Additional shielding is installed as required after ascertaining the status inside the PCV

Study / Results

Implementation of shielding evaluation
→ Total weight approx. 260ton, maximum weight of the unit approx. 74ton

Study of the structure of the additionally installed shield
→ Maximum weight of the unit approx. 45ton

Hoisting equipment weighing 50ton or more is required
→ Ground improvement, etc. is necessary.

Maximum weight 115ton → 74ton
→ As this was 2/3 of the original maximum weight, the hoisting equipment was modified once again

Modification of the hoisting equipment
→80 to 90ton can be handled using CC#

#Crawler crane

Prospects of feasibility were obtained.

Examination of method of additional installation

Access tunnel construction schedule

Consolidation of design conditions → Designing of actual equipment (Structure that enables additional installation) → Manufacturing → Installation → Operation

Investigation: It was found that the dose was higher than the design conditions.

Installation of additional shielding to compensate for lack of shielding capability after installation

The design, etc. will not be reworked.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

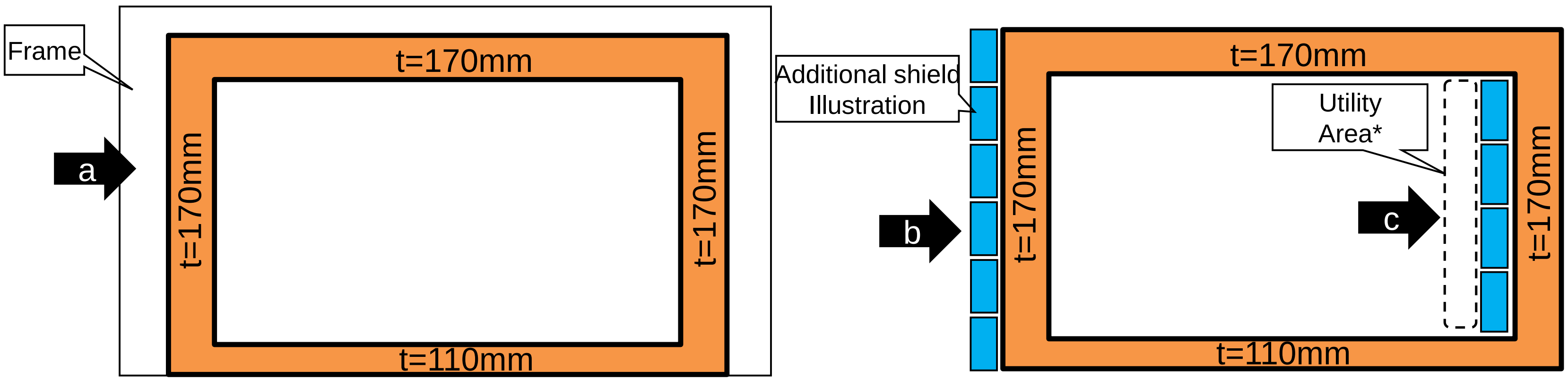
[Study of the methods for additional installation of shield]

The methods for additional installation can be classified into a. Method of inserting inside the frame, b. Method of installing from the outside, and c. Method of installing from the inside.

a. The proposal to insert a shield inside the frame. The method of inserting steel balls or iron plates inside the frame can be considered.

b. The proposal to add a shield from the outside. The method of placing load on the main body of the access tunnel or on the floor surface of the R/B first floor can be considered.

c. The proposal to install blocks from the inside. Installing blocks, etc. is being assumed, but as the shield needs to be installed around the utility, the size of the blocks needs to be reduced. As the blocks are expected to be large in number, c. will be exluded from the study.



* Same on the other side

As "c" is believed to have many issues, a and b will be studied.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

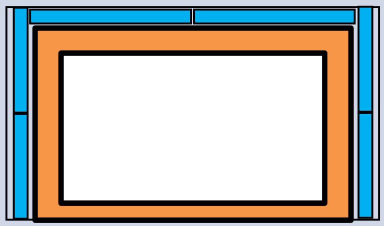
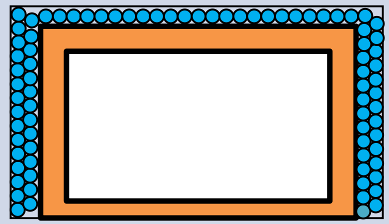
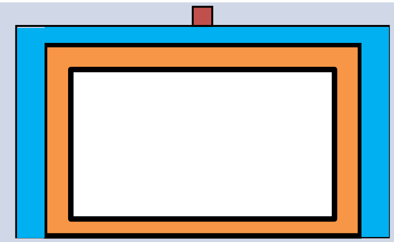
③ Installation of shield

[Study of the methods for additional installation of shield]

a. Proposal to insert the shield

● ▬ Additional shield ■ Spout

○ : Feasible
△ : There are issues
× : Not feasible

	Proposal to deliver a planar shielding	Proposal to fill spherical shielding	Proposal to cast
Illustration			
Overview	Proposal to deliver a planar shielding from the additional building side. For the curved part, reducing the length of the shielding for delivery is considered.	Proposal to pump spherical shields and fill them into small chambers separated by iron plates, etc. The spherical shields are filled in the chambers by using technologies such as shot blasting, etc.	Proposal to cast (pour) melted shielding material.
Issue	● Connection accuracy of the units of the access tunnel (Transfer of the additionally installed shield) ● Delivery of the curved part ● Emergency response (Difficult to handle if it gets stuck in the middle)	● Pumping method ● Verification of the filling rate (Shielding performance)	● Decline in shielding performance due to formation of cavities (Shielding performance cannot be ensured) ● Deformation due to heat ● The casting equipment is large
Evaluation	x	△	x

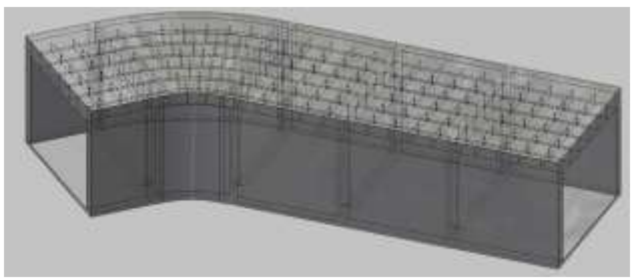
The proposal to fill spherical shielding / blocks proposal / curtain proposal were evaluated as "△"
As there are many unknowns such as the filling rate, etc. in the case of the proposal to additionally install spherical shields, its feasibility needs to be verified by conducting element tests.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Illustration of actual facility / Proposal to fill spherical shielding]

An illustration of the actual facility is indicated. The method of setting up several cells for additional installation of shields, and pumping spherical shields was studied. Although cells are not indicated on the wall surface in the bird's eye view (it has been shown as a single unit), in reality, the plan is to divide the area into multiple cells. The hose for pumping the shields is sent in up to the prescibed location by sliding it on a rail.



Bird's eye view

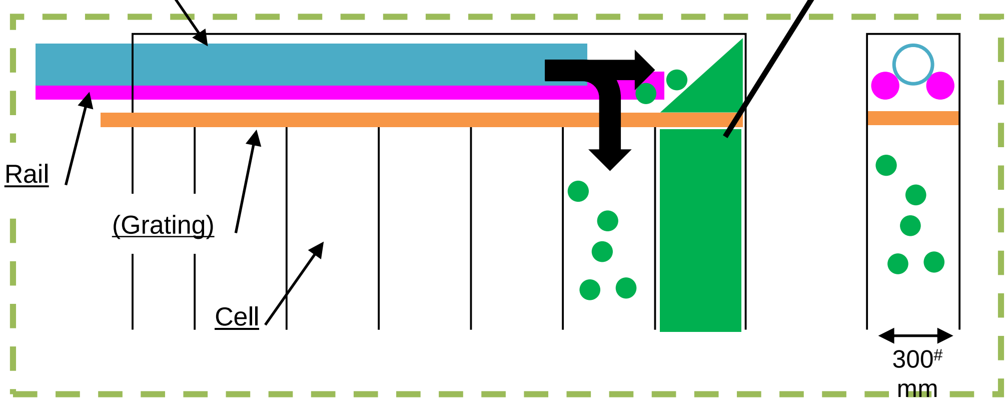
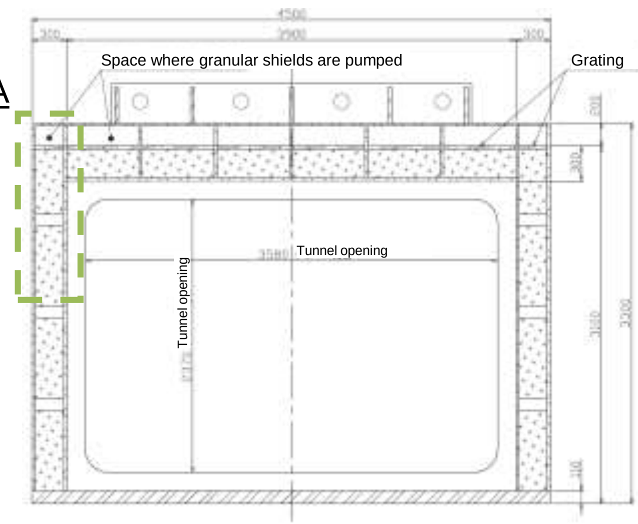


Illustration of the pumping of the shields



Cross-section

Although a thickness of 300mm is shown in the drawing, in this study the shield to be additionally installed is considered to be about 130mm thick.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test plan]

The following items to be verified are verified by conducting tests.

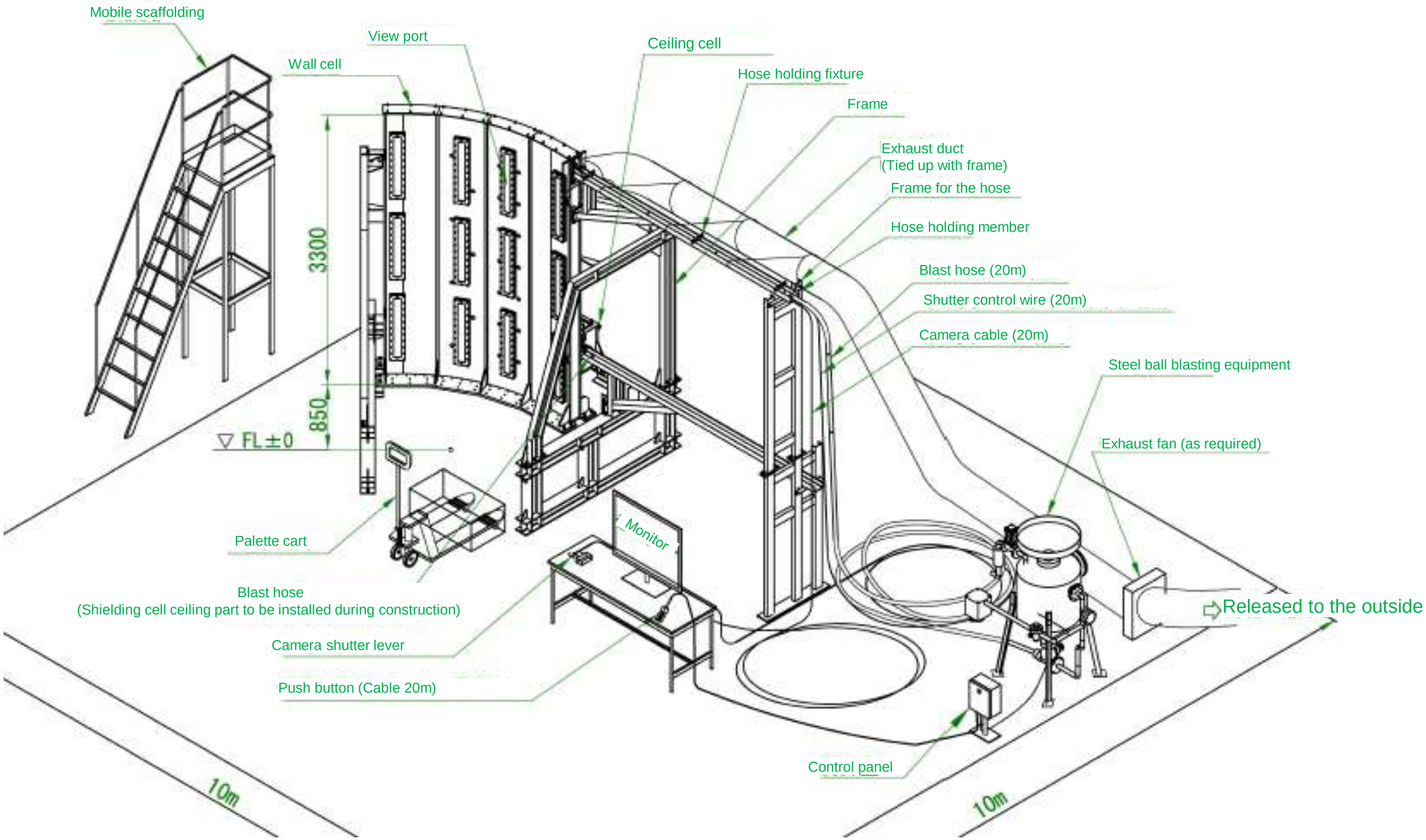
Items to be verified	Implementation details	Items to be monitored, measured and recorded	Criteria (Target value)
Filling rate	The rate of filling the spherical shields into the test cell is verified. Further, the volume of the test cell is measured by filling water into it.	➢ Volume of the test cell ➢ Weight of the filled shielding material	Target filling rate: 60% (Before operations such as tapping, etc.)
Filling status (Wall cell)	The status of filling the shields is verified from the windows provided alongside the cell. Windows for verification are provided at 3 locations: top, middle and bottom.	➢ Filling status	―
Filling status (Ceiling cell)	The status of filling the shields is verified from the window provided on top of the cell.	➢ Filling status	―
Filling status (Wall cell, Ceiling cell)	The status of the top portion of the filled shielding material (formation of the heap) is verified.	➢ Angle of repose	― (Reference measurement)

Remarks
・Target value 60%: Considering that the required shielding thickness is 300mm based on the studies conducted so far, the configuration used was: Access tunnel 170mm + Cart 75mm (Maximum) + Additionally installed shield approx. 75mm (130 × 0.6) (Total 320mm).
・Angle of repose: The (maximum) angle of an inclined plane at which accumulated particles and granular material (coal powder, etc.) remain stable and do not collapse of their own accord.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test equipment (Illustration)]

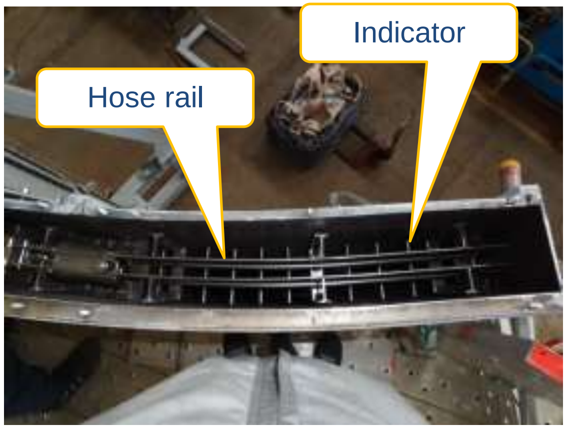


6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

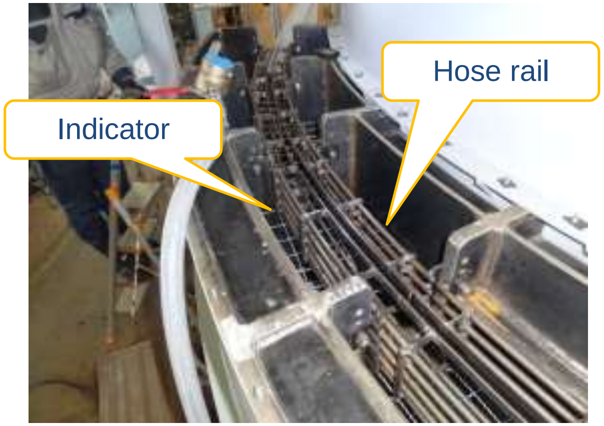
③ Installation of shield

[Complete view of the equipment and volume of each cell]

Complete view of the equipment



Wall cell



Ceiling cell

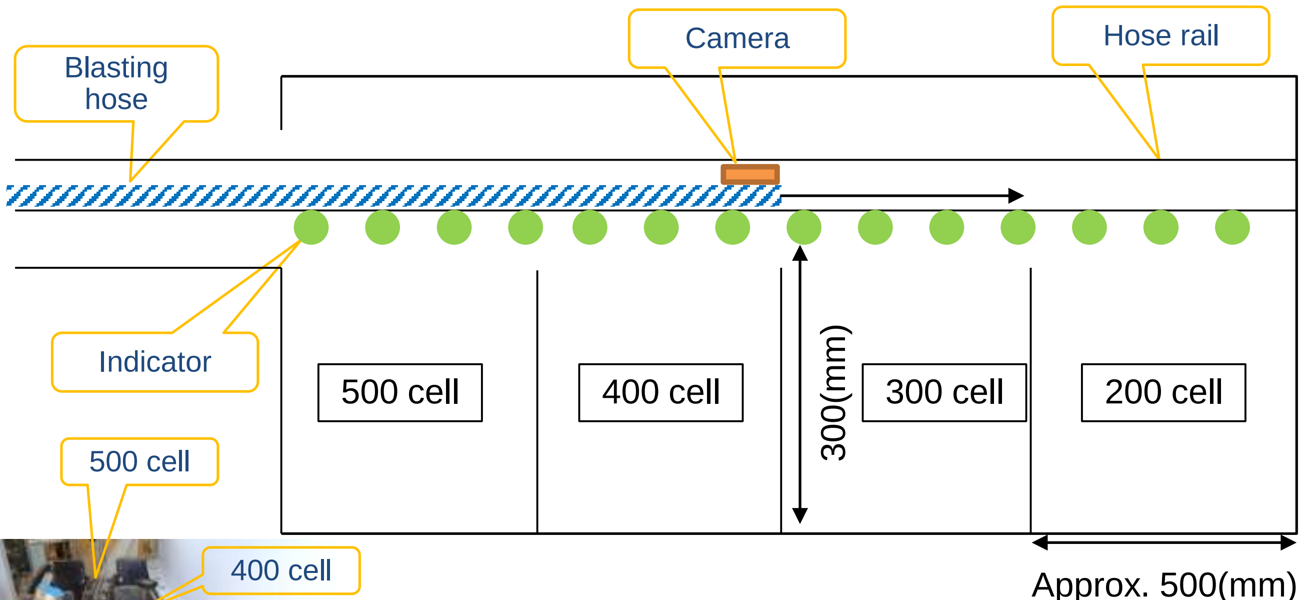
Cell name	Ceiling cell (Parameter: width)				Wall cell (Parameter: reinforcement)			
	200	300	400	500	Absent	Zigzag	Paralle l rows	Single row
Volume (L)	27	39	51.5	63.5	176	166	165	177.5

Note) Verified using a volume flowmeter by filling the cell with water.

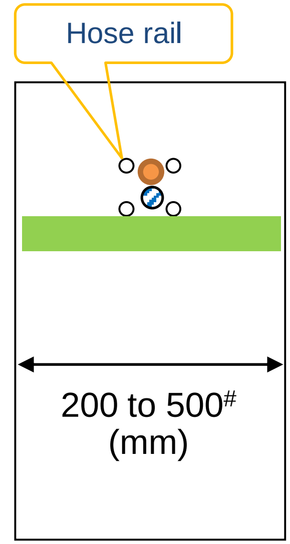
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test equipment (Outline drawing of ceiling cell)] Test is conducted using the width direction as the parameter (200 to 500mm)

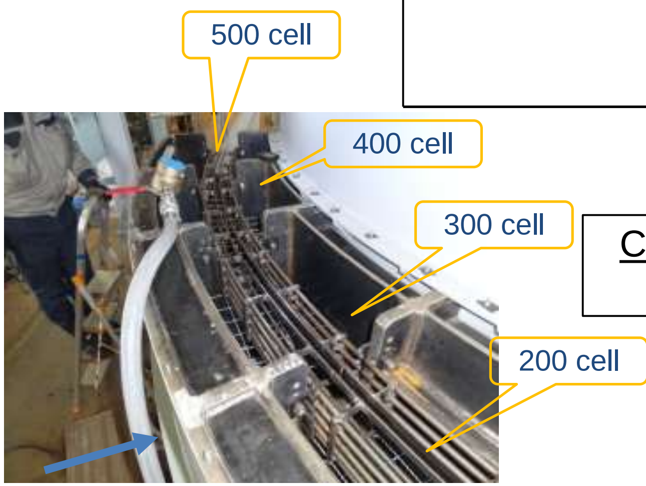


Cross-section (Lateral surface of equipment)



Cross-section (Front surface of the equipment)

Width of each cell is as follows
200 cell: 200mm
300 cell: 300mm
400 cell: 400mm
500 cell: 500mm



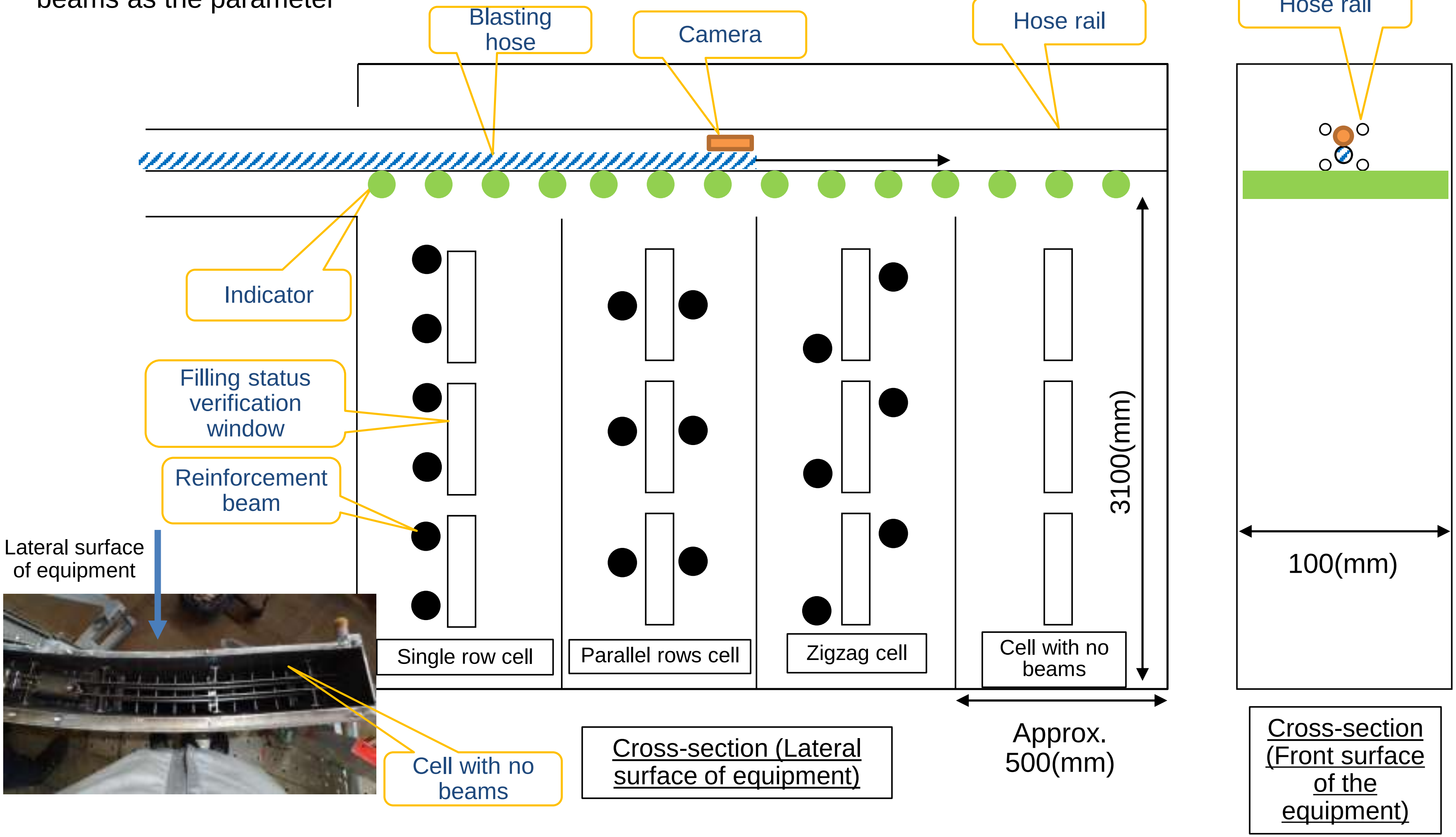
Lateral surface of equipment

Outline drawing of ceiling cell

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test equipment (Outline drawing of wall cell)] Test is conducted using the position of the reinforcement beams as the parameter

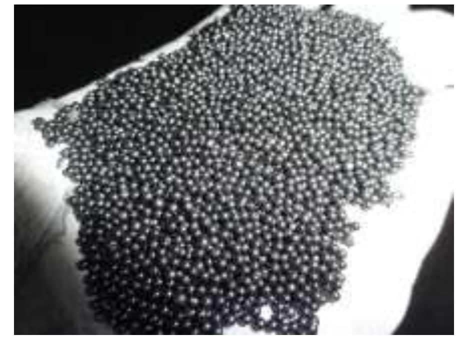


6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test equipment (Steel ball blasting equipment)]

Manipulator



Steel balls (Φ1.7mm)

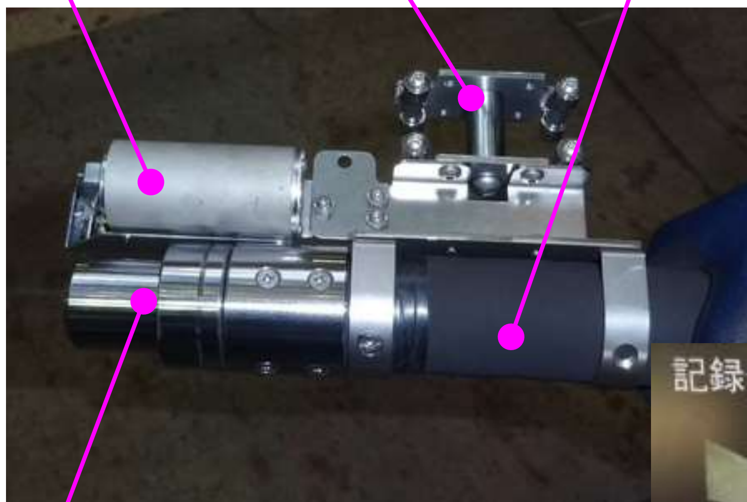
0.2MPa

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

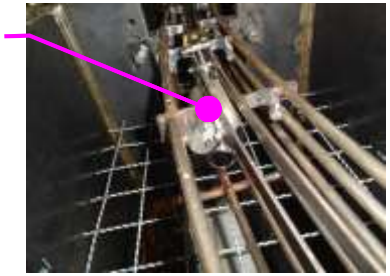
③ Installation of shield

[Test equipment (Blasting nozzle)]

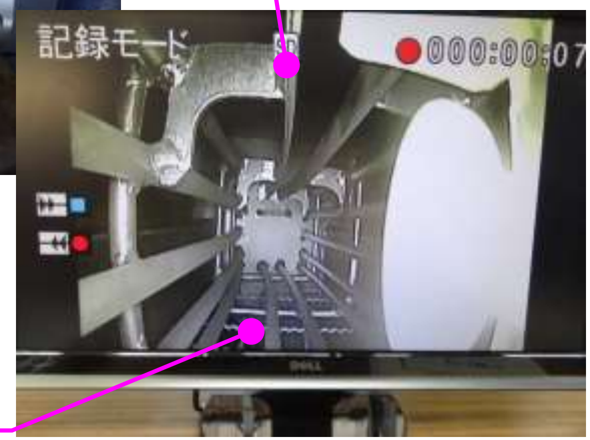
Elbow nozzle



Distal end of the blasting hose



Installation status



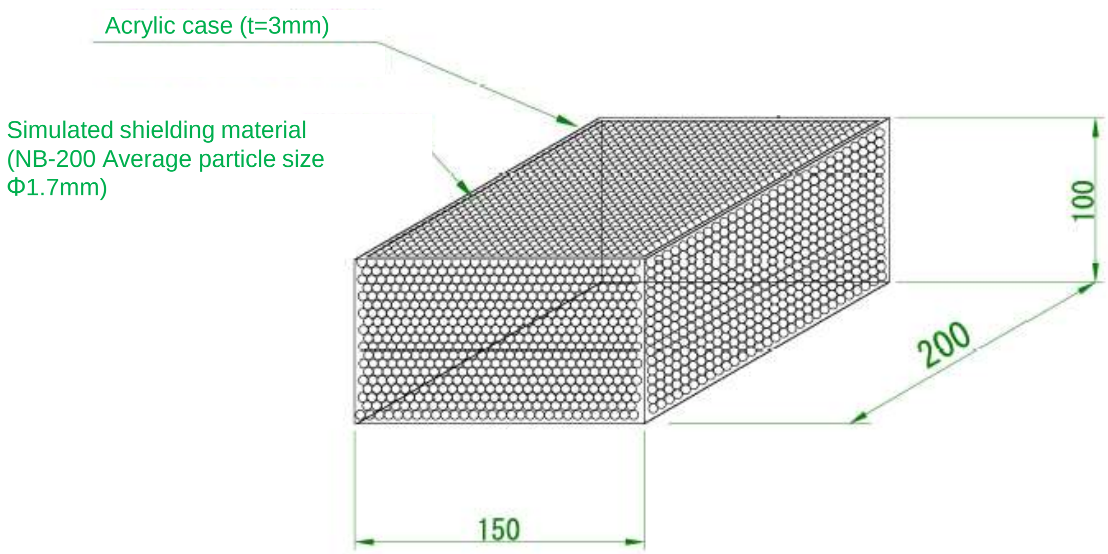
Camera image

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Fundamental test (1) Filling rate verification test]

Test guidelines: Fill (manually) the acrylic case with filler material, and measure the weight of the filling material. Verify the filling rate.



Filling status

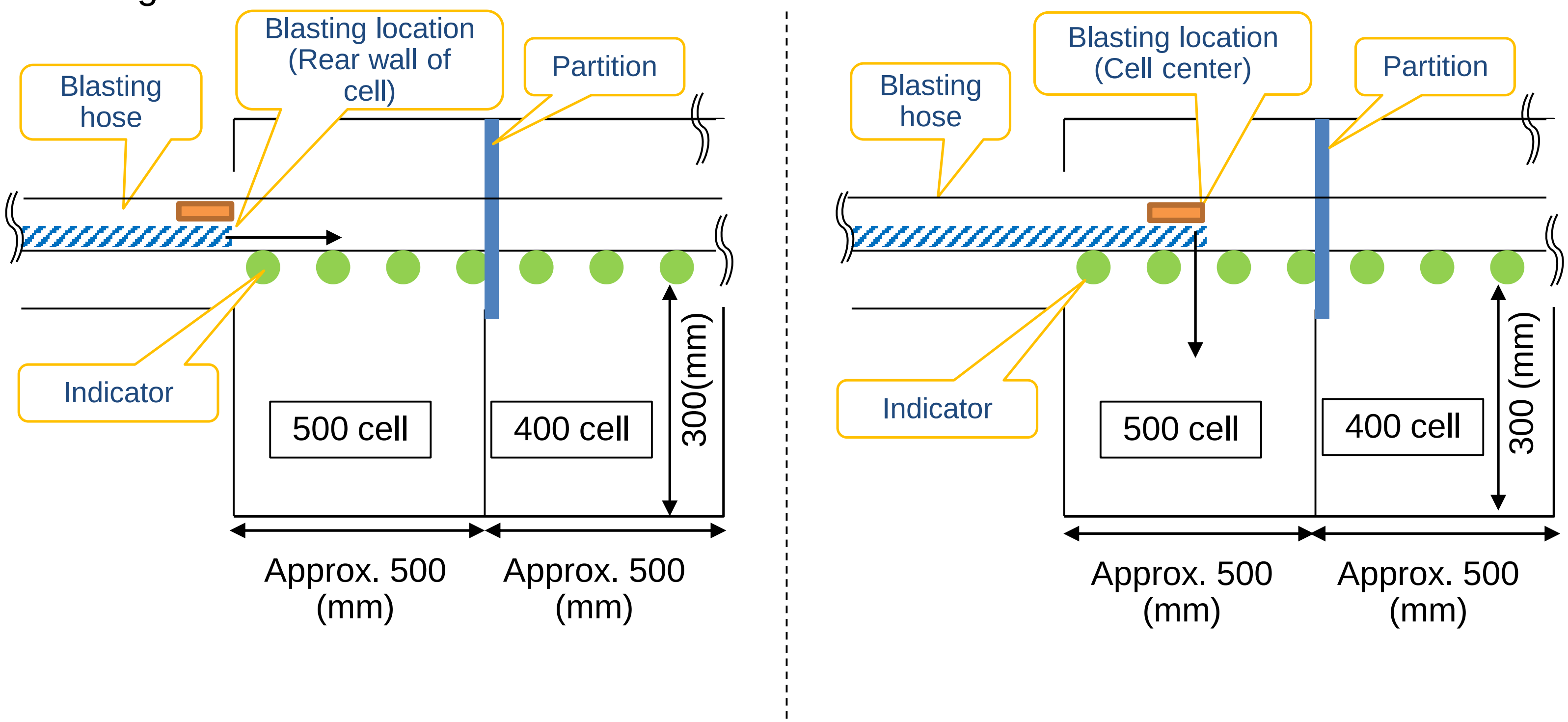
Items	Measurements	Apparent density	Filling rate	Remarks
Volume of acrylic case	2.73L	—		Calculated based on internal dimensions
Weight before tapping	12.34kg	4.52g/cm^3	57%	
Weight after tapping	13.08kg	4.79g/cm^3	61%	

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Fundamental test (2) Filling rate verification test]

Test guidelines: Fill with each nozzle until the indicator for verifying the height is covered, and once the top surface of the filling settles, weigh the filling material. Verify the filling rate when the equipment is used. Further, manually add filling material in case its level is lower than the water level during volume verification.



If the 500 cell is being filled (Left: straight nozzle, Right: elbow nozzle)

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Fundamental test (2) Filling rate verification test]

Test guidelines: Fill with each nozzle until the indicator for verifying the height is covered, and once the top surface of the filling settles, weigh the filling material. Verify the filling rate when the equipment is used. Further, manually add filling material in case its level is lower than the water level during volume verification.

Filling status (Ceiling cell / 500m width)

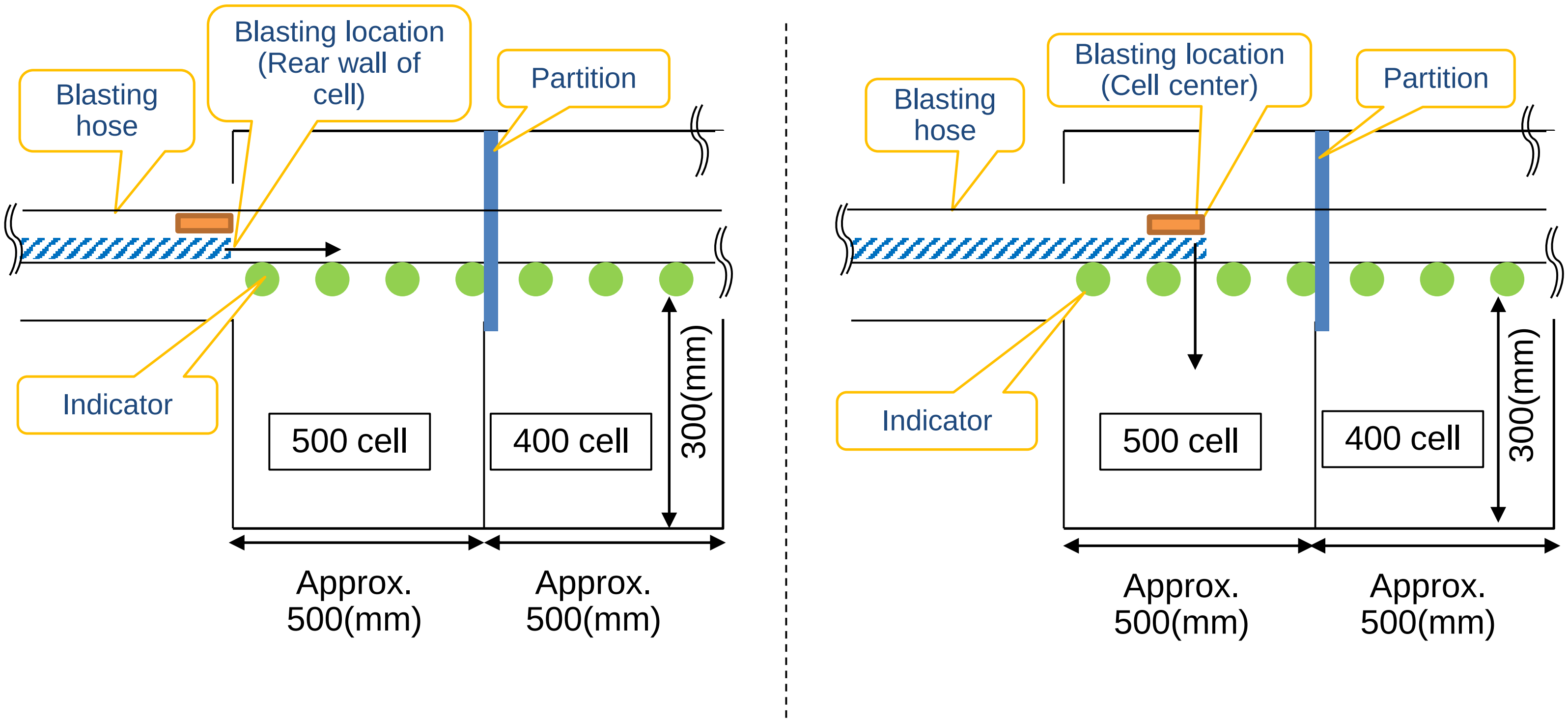
Apparent density (Filling rate)	Straight nozzle	Elbow nozzle
Ceiling cell (500 cell)	4.94g/cm^3 (63%)	4.83g/cm^3 (62%)
Wall cell (Cell with no beams)	4.94g/cm^3 (63%)	4.97g/cm^3 (64%)

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] (Verified with the help of the ceiling cell)

Test guidelines: Blast the filling material until the indicator for verifying the height is completely covered. Verify the blasting time, quantity filled (target cell/other) and the status of filling.

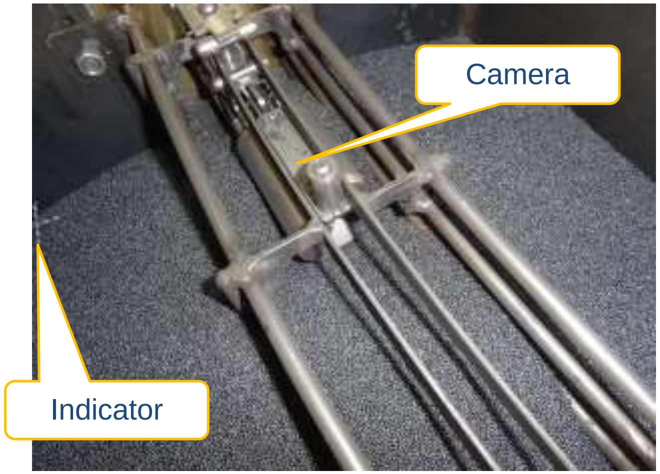


If the 500 cell is being filled (Left: straight nozzle, Right: elbow nozzle)

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ① (Ceiling cell)



500 cell / elbow / nozzle initial position

200 cell / elbow / camera image

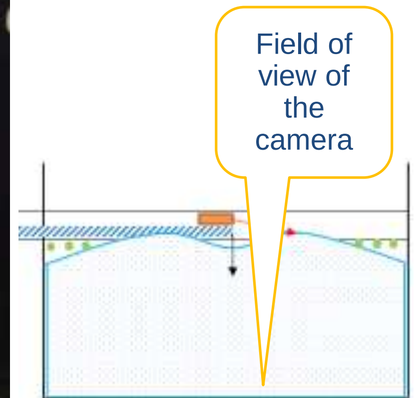


Illustration of the filling

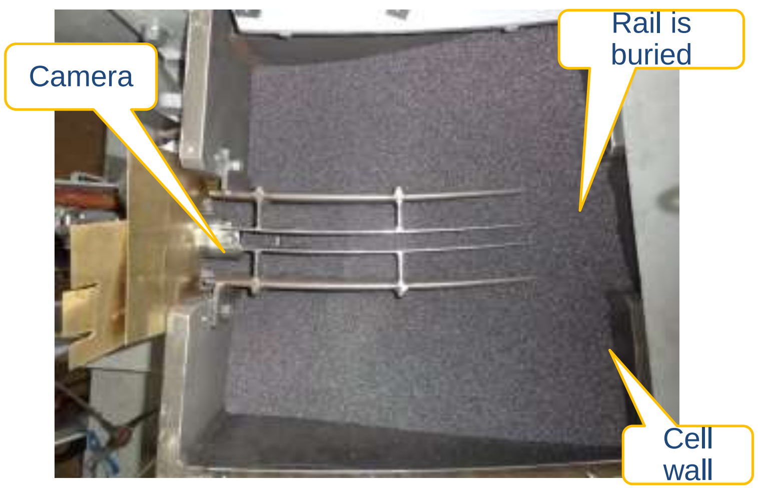
- As the elbow nozzle blasts right below, filling results in a mound with its apex right below the nozzle. Hence, the nozzle got buried in the filling material before the filling material spread up to the corners of the cell. Thus blasting became difficult (500 cell). The rail needs to be installed at a higher location and the distance between the indicator and the nozzle needs to be increased. The angle of repose at the time was approx. 28°.

- As indicated above, as the filling material gets filled in the shape of a mound in the case of an elbow nozzle, and further since craters are formed due to the blast pressure, bumps are formed in front of the camera. Due to these bumps, it was difficult to verify the filling status on the back side with the camera made available this time.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ②
(Ceiling cell)



500 cell / straight

500 cell / straight / camera image

- In the case of the straight nozzle, since the steel balls directly hit the cell wall, a large quantity of steel balls bounce back. As a result, a large quantity of filling material comes out of the target cell from the sides of the rail.
- A cell with 500mm width as well can be filled up to the top portion of the rail.
- In the case of the straight nozzle, since the cell is filled from the back side, it is easier to ascertain the status of filling.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ③ (Ceiling cell)

Ceiling cell	Nozzle	Volume	Estimation #1		Filling time		Quantity of filling			Filling speed kg/min
			Quantity of filling kg	Filling time min	Actual time min	Estimated rate	Target cell kg	Other kg	Estimated rate #2	
200	Straight	27	126.4	3.6	4.5	1.2	147	16.78	1.2	36.4
	Elbow				3.5	1.0	135	2.86	1.1	39.4
300	Straight	39	182.5	5.2	7	1.3	226	35.3	1.2	37.3
	Elbow				6	1.2	219	6.04	1.2	37.5
400	Straight	51.5	241.0	6.9	9	1.3	310	16.7	1.3	36.3
	Elbow				7.5	1.1	280	2.04	1.2	37.6
500	Straight	63.5	297.2	8.5	11	1.3	402	4.98	1.4	37.0
	Elbow #3				11	1.3	375	2.2	1.3	34.3

#1 Value calculated based on filling rate 60% and filing speed 35kg/min.
#2 Value obtained by dividing the quantity filled in the target cell by the estimated quantity of filling.
#3 Blasting was not possible because the nozzle was buried in steel balls before the indicator got covered. These are results of the test conducted by setting the position of the nozzle approx. 20mm in the upward direction.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ④ (Ceiling cell)

- The quantity of filling material required to fill the cell up to the indicator for verifying that the filling height is completely covered is 1.1 to 1.4 times the estimated quantity. Since dispersion to other cells is less in the case of elbow nozzle as compared to the straight nozzle, less quantity of filling is needed to fill the cell up to the required height.
- In the case of the 500 cell/elbow nozzle, the nozzle got buried in the filling material before the filling material spread up to the corners of the cell. Thus blasting became difficult. Hence, if wider cells are to be used, the cells need to be taller. As a result, the weight of the main body of the access tunnel would increase.
- In the case of the straight nozzle, since the cell is filled from the back side, it is easier to ascertain the status of filling. Meanwhile, it is difficult to ascertain the status on the back side using an elbow nozzle.

	Elbow	Straight
Required quantity of filling (Comparison with the target value)	1.1 to 1.3 times	1.2 to 1.4 times
Dispersion to other cells	Small amount	Large amount
Ease of filling (on top of the rail)	Not possible	Possible
Visibility with the camera	Bad	Good

The straight nozzle is selected based on the above-mentioned results.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ⑤ (Wall cell)

Wall cell	Nozzle	Volume	Estimation #1		Filling time		Quantity of filling			Filling speed kg/min
			Quantity of filling kg	Filling time min	Actual time min	Estimated rate	Target cell kg	Other kg	Estimated rate #2	
No beams	Straight	176	823.7	23.5	28	1.2	895.3	88.96	1.1	35.2
	Elbow				25	1.1	897.3	7.04	1.1	36.2
Zigzag	Straight	166	776.9	22.2	29	1.3	840.3	125.92	1.1	33.3
	Elbow				24	1.1	874.3	13.34	1.1	37.0
Parallel rows	Straight	165	772.2	22.1	28	1.3	831.3	106.72	1.1	33.5
	Elbow				23.5	1.1	825.3	8.84	1.1	35.5
Single row	Straight	177.5	830.7	23.7	30	1.3	898.3	115.08	1.1	33.8
	Elbow				25	1.1	892.3	22.04	1.1	36.6

#1 Value calculated based on filling rate 60% and filing speed 35kg/min.
#2 Value obtained by dividing the quantity filled in the target cell by the estimated quantity of filling.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (1) Selection of nozzle] Test results ⑥ (Wall cell)

- The quantity of filling material required to fill the cell until the indicator for verifying the filling height is completely covered is 1.1 times the estimated quantity. The wall cell is 100mm wide which is narrower than the ceiling cell. Hence it is believed that the indicators at the 4 corners would be covered with a small quantity of filling.

- The dispersion to other cells is extremely low in the case of elbow nozzle as compared to the straight nozzle (1/5 to 1/10). This large difference is believed to be because the filling time is longer as compared to the ceiling cell.

- The results pertaining to ease of filling and visibility with a camera were similar to the ceiling cell.

- The status of filling into the vicinity of the reinforcement beams is verified through the window for verification. It is verified that there has been sufficient filling into the area around the reinforcement beams. As it is believed that the reinforcement beams have almost no impact, there is enhanced freedom of design while designing the actual facility.

	Elbow	Straight
Required quantity of filling (Comparison with the target value)	1.1 times	1.1 times
Dispersion to other cells	Small amount	Extremely large amount
Ease of filling (on top of the rail)	Not possible	Possible
Visibility with the camera	Bad	Good

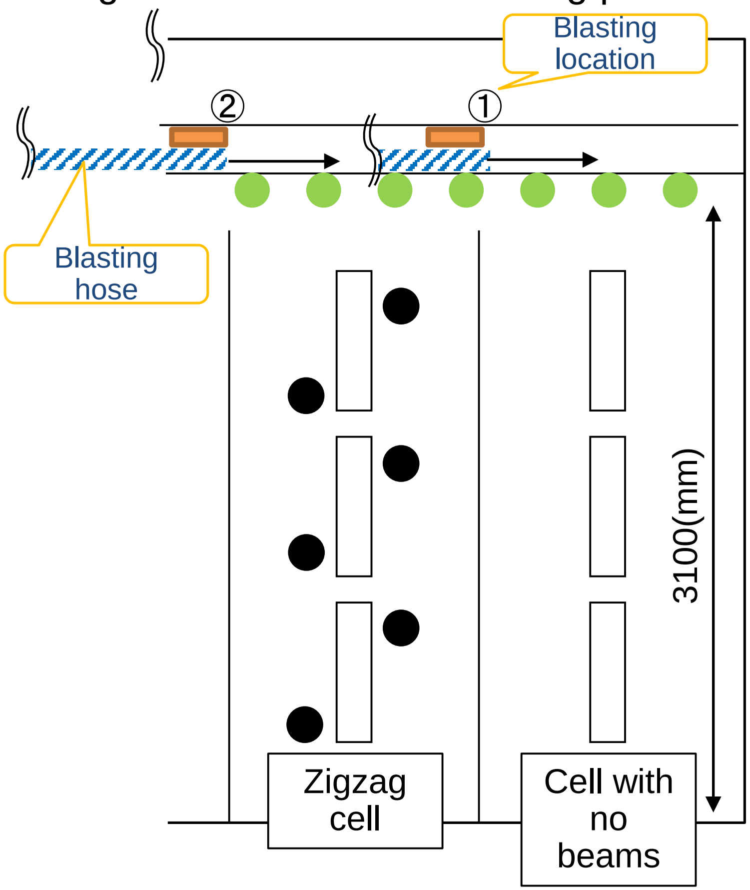
Based on the above-mentioned results, the straight nozzle is selected for the wall cell as well.

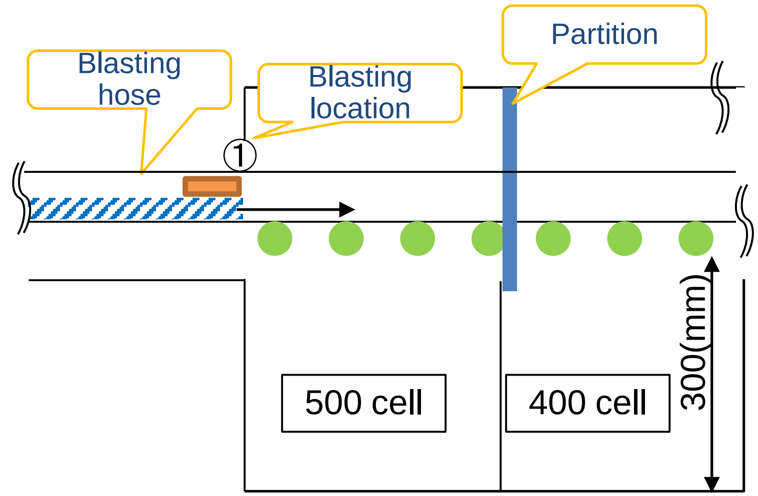
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (2) Filling method verification test]

Test guidelines: Blasting was carried out at position ① for the duration until the indicators for verifying the filling height were covered, which was verified during Test (1), and thereafter blasting was carried out at blasting position ②.





Remarks:
Wall cell: Since the width of all cells is the same (100mm), the cells without beams were tested.
Ceiling cell: As blasting cannot be carried out at position ② in the case of 500 cell, a 400 cell was tested.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (2) Filling method verification test] Test results ①

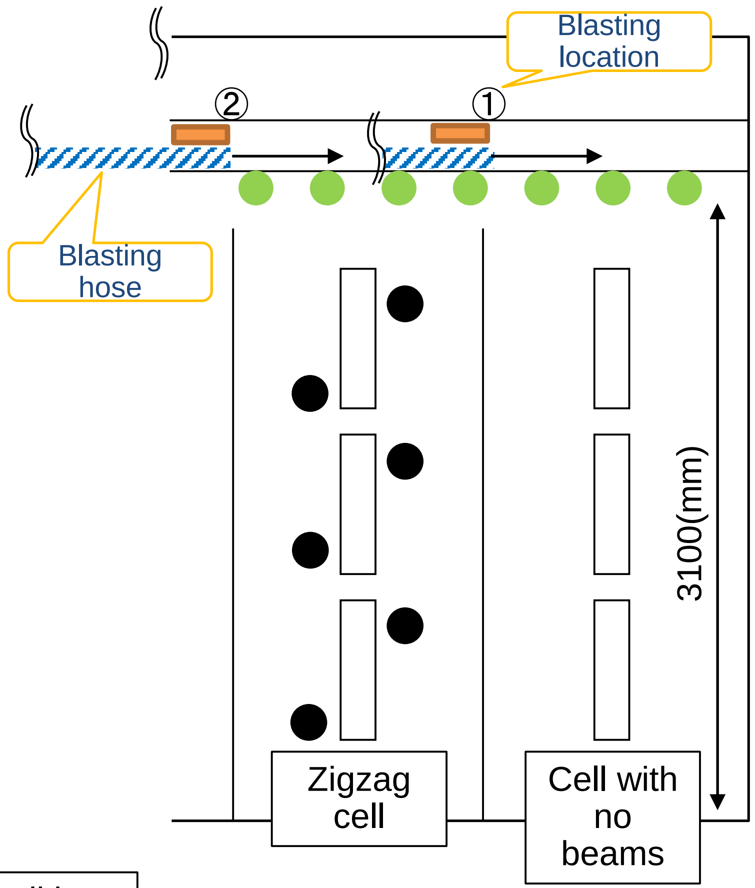


Image captured from the blasting location (28 min)

Image captured from above the cell (28 min)

Camera image (28 min)

Image captured from above the cell (28 min + 2 min)

The cell has been sufficiently filled up to the top (top of the nozzle). It was verified that filling is possible by this method.

Conditions

Blast pressure: 0.2MPa
Blasting time ① 28 min ② 2 min

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (2) Filling method verification test] Test results ②

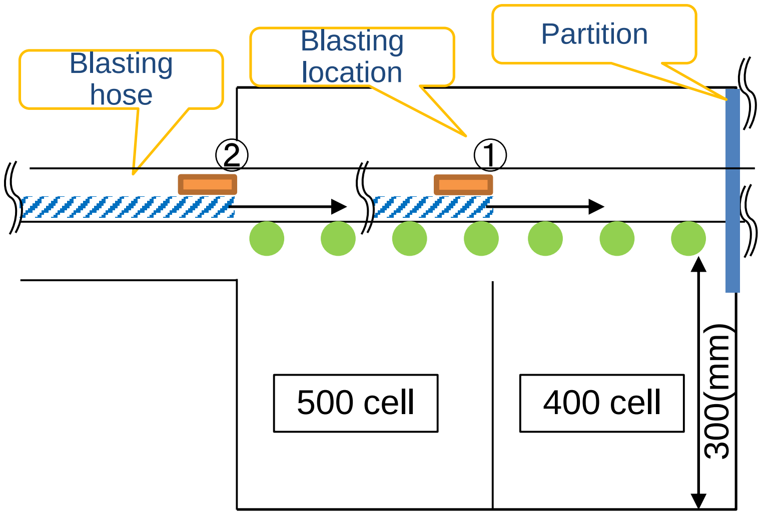


Image captured from above the cell (9 min)

Camera image (9 min)

Image captured from above the cell (25.5 min)

Camera image (25.5 min)

Conditions	Blast pressure: 0.2MPa Blasting time ① 9 min ② 16.5 min

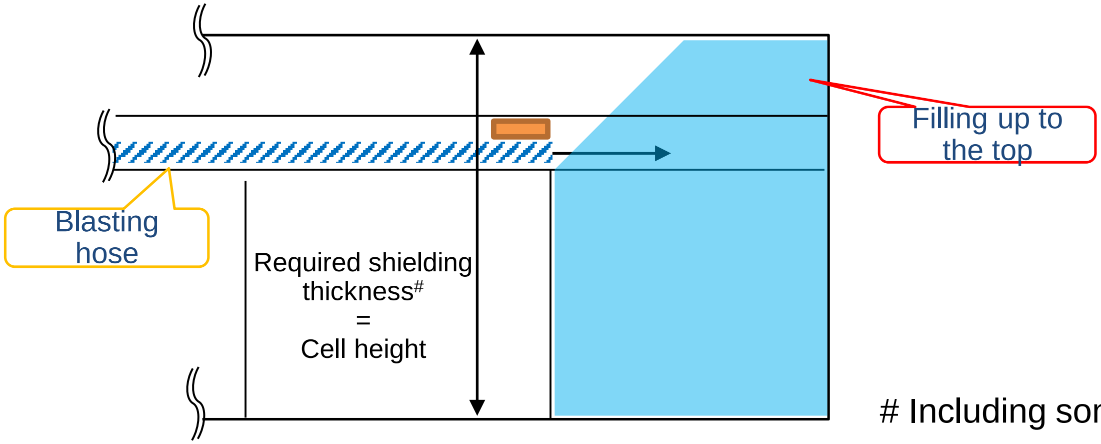
The cell has been sufficiently filled up to the top (top of the nozzle). Combined with the results of Test (1) on the 500 cell, it is expected that this method of filling can be used in the case of the 500 cell as well.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Test (2) Filling method verification test] Test results ③

- It was verified that filling is possible up to the top of the rail in a wall cell which has cell height.
- It is expected that a ceiling 400 cell can be filled up to the top of the rail, and based on the results of Test (1) on the 500 cell, it is expected that a cell with a width of 500mm can be filled up to the top of the rail as well.
- With a straight nozzle, since the cell can be filled up to the top of the rail, the required shielding thickness does not need to be added while setting the height of the rail part. This is effective in reducing the height of the cell.



Including some margin

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Issues]

✓ Structure

- Although it is expected that filling material can be filled sequentially from the back side of the cell, as it will not be possible to fill the last cell (assuming it to be outside the R/B) all the way, measures such as provision of auxiliary cells, filling from the top of the cell, etc. are needed.

- In this test a fiber camera was used to verify filling. In the case of the straight nozzle, a large number of steel balls bounce back. These steel balls are likely to damage the lens. Hence a lens cover was installed. The cover opened and closed due to the movement of the hinge structure brought about by pulling the wire. However, an event occurred wherein the filling material got stuck in the hinge structure and the cover did not be opened or closed. Measures such as modifying the structure, etc. need to be studied in preparation for installing the actual equipment.

- It was difficult to verify the status of filling on top of the rail with the camera and lights used this time. Selection of the camera, lights, etc. need to be studied considering application to the actual equipment.

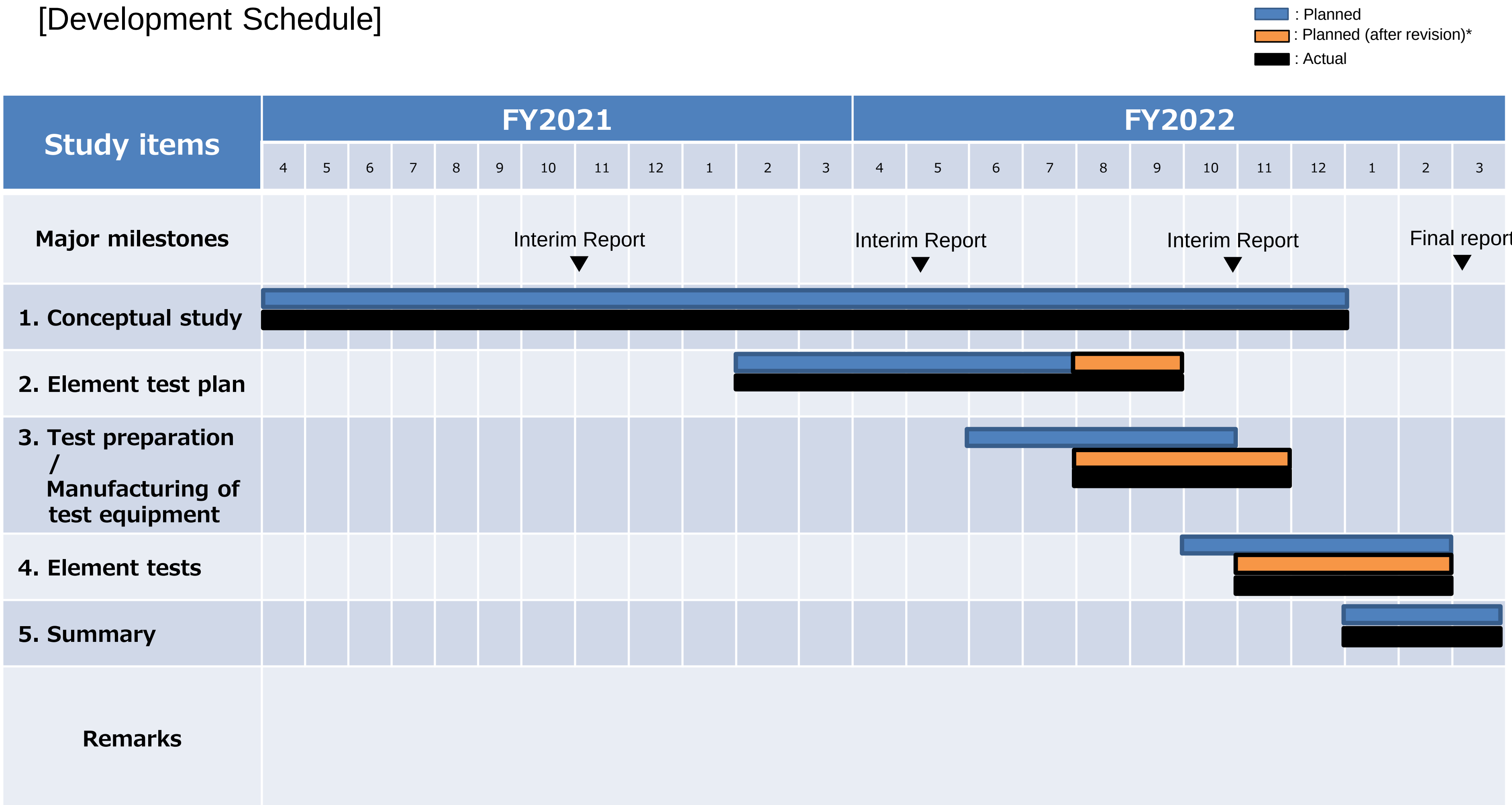
✓ Shielding performance evaluation method

- As the filling rate cannot be determined from the quantity of filling (delivered quantity) because there is dispersion to other cells, it is difficult to evaluate the shielding performance after filling the inside of the cell for each cell. The shielding performance is expected to be evaluated using the filling rate verified beforehand, but the evaluation including reproducibility of the status of filling, needs to be carried out by the time the method is used in the actual equipment.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield

[Development Schedule]



* The plan was revised to reflect the progress status of the studies.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

③ Installation of shield: Summary

- In FY2021, the study plan and the preconditions were consolidated and thereafter shielding was evaluated, for studying the method for additional installation of shield. It was found that as the radiation dose from neutron beams is high, neutron shielding needs to be installed to reduce the shielding thickness.

- Interference with the work of constructing the additional building is expected to be avoided (the access tunnel unit is expected to be pulled over with a crawler crane) by revising the required shielding thickness from 300mm wall (iron) to 200mm (iron) (part of it added to the cart inside the access tunnel). The method for additional installation of shield continued to be studied as additional shielding will be installed as required after ascertaining the status inside the PCV.

- It was determined that feasibility of the proposal to additionally install spherical shields needs to be verified through element tests. The items to be verified, and items to be monitored, measured and recorded during the filling test were studied, a filling rate of 60% was planned as the criteria and the test was conducted.

- As a result of the element test, it was verified that the spherical shielding material can be filled up to 20m ahead by using the blast equipment and the straight nozzle. Also, it was found that filling is possible up to a cell width of 500mm, and that the structures inside the cell (reinforcement material) do not have an impact on filling.

- Since spherical shielding material can be filled up to 20m ahead, it was verified that the operation can be performed from outside the R/B and thus worker exposure can be reduced.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

Studies on installation of access equipment, such as the access tunnel method, to be used as access equipment for the side access method, have been carried out for further increasing the retrieval scale of fuel debris and reactor internal structures. As the shield plug, etc. (shield plug, block out) in front of the existing equipment hatch, which is a large and heavy object made of concrete, etc., needs to be removed before installing access equipment on to the PCV connection part, technology related to safe and efficient disassembly in confined spaces needs to be studied and developed.

Studies will be conducted on the method and procedures for cutting, disassembling and removing the shield plug, etc. safely and with certainty in the confined space inside the R/B, transferring the disassembled structures and storing them in waste containers by remote operation, considering that this work is carried out in a high dose environment; considering prevention of dust dispersion, removal of structures required for strength such as intermediate posts, smoothening the cut parts, etc. after removal, and load restriction on the floor inside R/B.

Subsequently, the equipment for cutting, disassembly and removal will be test manufactured, and their viability will be verified by element tests using simulated test pieces for confirming feasibility.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

Table of Contents

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Status of studies conducted up to FY2020]

- Rough procedures for the Unit 1 shield plug removal method were developed, conceptual study and evaluation of the roughly estimated exposure dose were carried out.

[Issues]

<Common to Units 1 to 3>

- As the shield plug is large and heavy and hence difficult to remove, removal technology needs to be developed.
- Feasibility of the disassembly equipment, etc. considering the load on the floor surface of the building.
- Method of disassembling considering prevention of dust dispersion under a high dose environment.
- Increase in exposure dose due to increase in the amount of work carried out on-site for finely cutting large and heavy objects.

<Unit 1>

- Method of pulling out the shield plug considering anchoring, etc. of the drive wheel.
- Method of finely cutting considering the lining material (16mm).

<Units 2, 3>

- Method of removing concrete blocks (including intermediate posts, etc.)
- Method of smoothening the floor surface (surface on which the PCV connection sleeve is installed).

Unit 1 (Shield plug)	Units 2, 3 (Concrete blocks)
 (Steel plate + Concrete)	 (Reinforcement + Concrete)

Illustration of the method of disassembling

After removing concrete blocks, the intermediate posts need to be removed or mortar needs to be shaved off to make the surface smooth.

Illustration of the floor surface of Units 2 and 3

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Implementation details]

<Common to Units 1 to 3>

- Consolidating pre-conditions related to the study.
- Studying the method and procedures for cutting, disassembling, and removing the shield plug, etc. and transferring the disassembled structures and storing them into waste containers by remote operation. Studying the method for preventing dust dispersion, method for disassembling and transferring considering the load bearing capacity of the floor (approx. 4.9 ton/m^2), etc.
- Test manufacturing the required equipment such as cutting, disassembly and removal equipment, etc., planning and implementing element tests to verify feasibility of the method for removing the shield plug, etc.

<Unit 1>

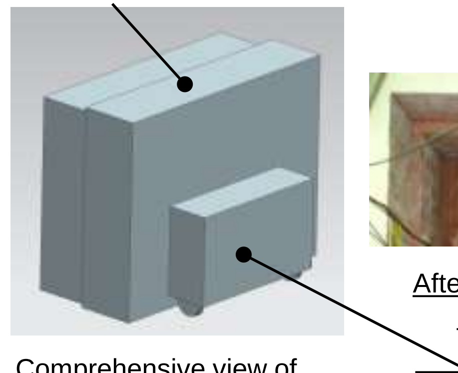
- Study of method of pulling out the shield plug
- Study of equipment for cutting the shield plug by remote operation
- Study of the method of transferring unitized structures (Removal using a cantilever)

<Units 2, 3>

- Study of remotely operated block-out equipment
- Study of method for smoothening the floor surface

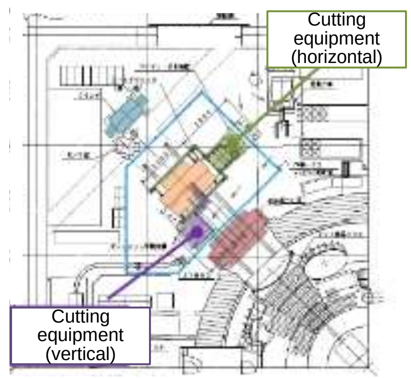
[Expected outcome]

- Presentation of the method of removing the shield plug, etc.

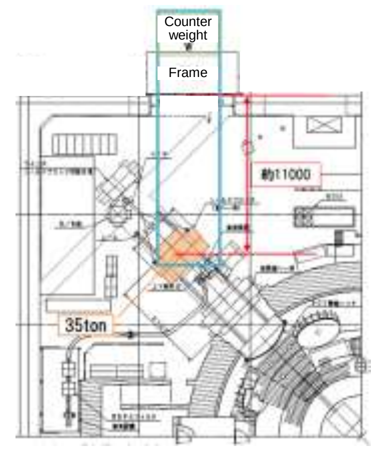


Comprehensive view of the Unit 1 shield plug

After removing the concrete blocks (1F-4　X-1B)



Method of fine cutting



Method of transferring unitized structures

Illustration of Unit 1 shield plug removal

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Study procedures (policy)]

Disassembly of Unit 1 shield plug

Disassembly of Unit 2, 3 concrete blocks

1. Consolidation of input, study conditions, environmental conditions of work area
2. Consolidation of work requirements (functional requirements) and study of action plan
3. Creation of conceptual diagram illustrating the disassembly work based on the action plan

↓

Consolidation of conditions required for substantiation of the study

↓

Evaluation and selection of applicable disassembly tools

↓

Verification of feasibility of the selected disassembly tools (Element tests)

↓

Study of means for smoothening / hatch protection

↓

Development of work steps and identification of issues in each step / worker exposure evaluation

↓

Presentation of action plan in response to the issues and establishment of development plan

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

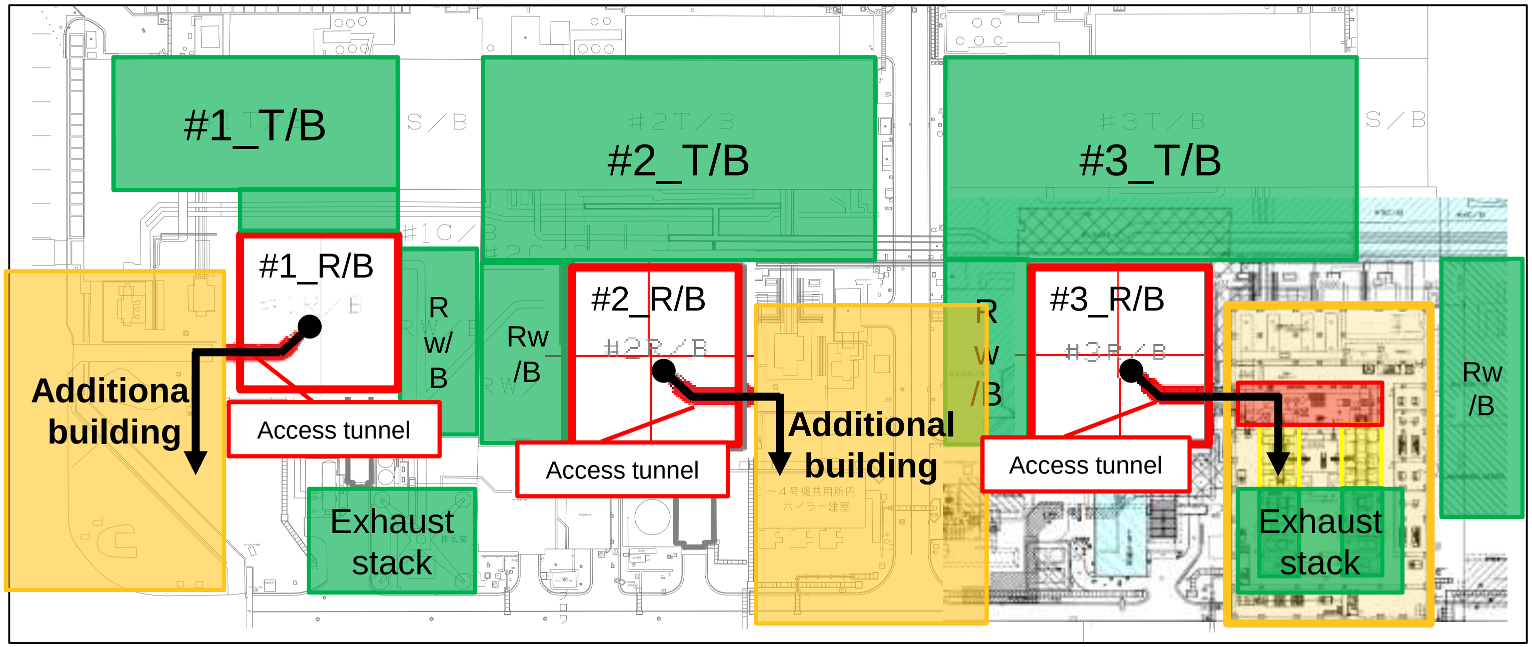
④ Disassembly of shield plug

[Consolidation of pre-conditions]

In Unit 1 shield is planned to be installed on the northern side of R/B, and in Units 2 and 3 it is planned to be installed on the southern side. All shields are to be installed on the equipment hatch, but in Unit 1 it will be on the shield plug, and in Units 2 and 3 it will be on the block wall.

Proposal for installing the access tunnel in Units 1 to 3

N Legend: R/B Existing structures New structures



Unit 1: Shield plug

Units 2, 3: Concrete blocks (Image)

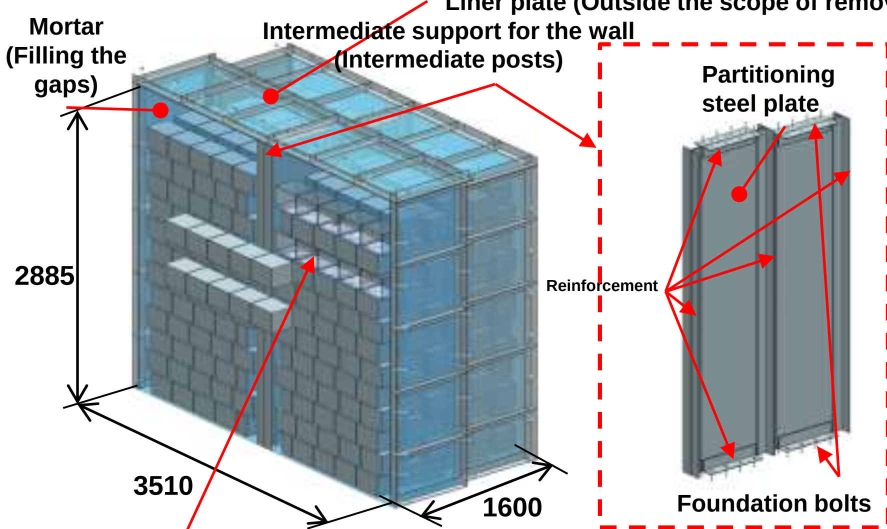
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

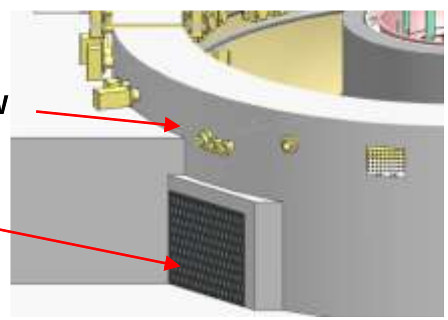
④ Disassembly of shield plug

[Consolidation of pre-conditions (Unit 3)]

➢ Objects to be removed (Concrete blocks) #1

Concrete blocks (Enlarged view)



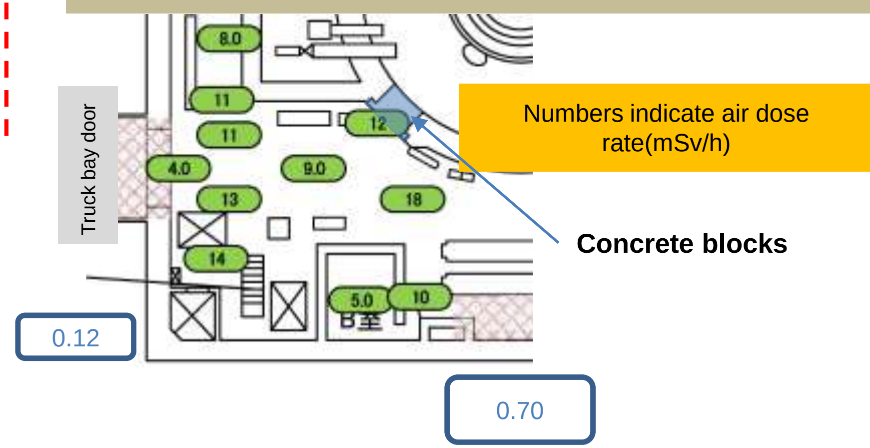


#1: The structures and dimensions include those from drawings from other units that were used as reference and hence include estimates as well.
#2: As it gets embedded into BSW

➢ Environmental conditions #1

Items	Specifications
Target	Unit 3 Concrete blocks
External dimensions	W 3510 × D 1600 × H 2885 (mm)
Mass	Approx. 36 ton
Composition	Concrete blocks + band plate + wire torus + intermediate support for the wall, mortar finishing of gaps
Air dose rate	Approx. 18 mSv/h
Floor load bearing capacity	Approx. 4.9 ton/m^2
Carrying-in/out	Western side of R/B (Truck bay door (W4900 × H4900mm))
Height at which work is carried out	Approx. 4m or less

Air dose rate on the southwestern side (work area) of the R/B first floor in Unit 3



: Data collection period: April 1, 2020 to March 31, 2021
: Measured on November 24, 2021

6. Implementation Items of This Project [1] (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Work of making openings (before the accident) and the removal policy in this project]

Content in the red frame: Items to undergo the mock-up test this time

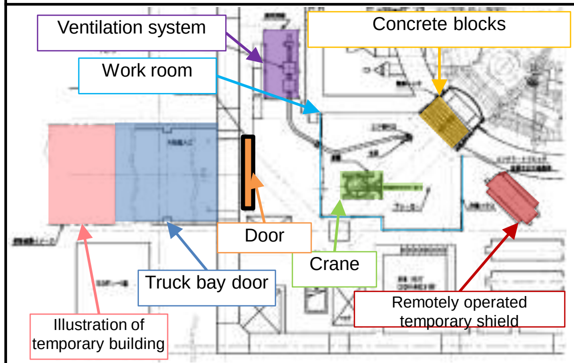
Items	Unit 1: Shield plug	Unit 2, 3 Concrete blocks
Overview of the target	Mainly entire blocks of concrete that normally travel over the rail on electricity.	Blocks are stacked like bricks and some of the gaps are filled with mortar.
Main procedures (Prior to the accident#) # Prior to the accident at the Fukushima Daiichi Nuclear Power Station associated with the Great East Japan Earthquake that occurred on March 11, 2011.	● (Measure 1) Pulling out by moving with the help of electricity. ● (Measure 2) Pulling out by rotating the shaft (external drive shaft) connected to a motor, etc. The external drive shaft is powered, has breaks and clutch (being verified), and a wheel clamp (being verified). ● (Measure 3) Pulling using a winch, etc.	① Shaving off the upper mortar using a breaker. (The mortar between the BSW and the block is shaved off as needed) ② Removing the block while making sure it does not get damaged. ③ Removing the intermediate support. ④ Removing the L shaped steel at the top and bottom.
Removal policy in this PJ	It should be confirmed whether or not the external drive shaft can be used. If it can be used, the shield plug should be pulled out using the external drive shaft. If it cannot be used, it should be pulled out using a winch. (Note) ・Before pulling, it should be made sure that there is no foreign material (including the rail cover) on the rail. ・Rust should be removed from the rail to the extent possible. ・It should be assumed that electricity cannot be used.	It should mainly be disassembled using a breaker. (Note) ・Prior to the accident, since the blocks (approx. 800 blocks) were re-used, they were removed carefully to ensure there is no damage, but this time they do not need to be restored. ・Cutting with the help of wire saw, etc. was considered, but it was determined that using a wire saw would be difficult because of the depth.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

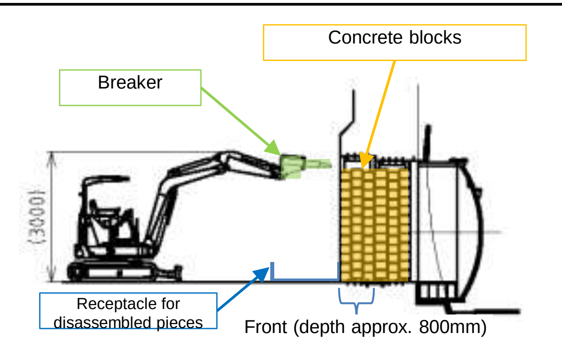
[Study of disassembly method (Unit 3)] Study of disassembly procedures (1/2)

1. Work of carrying-in the equipment



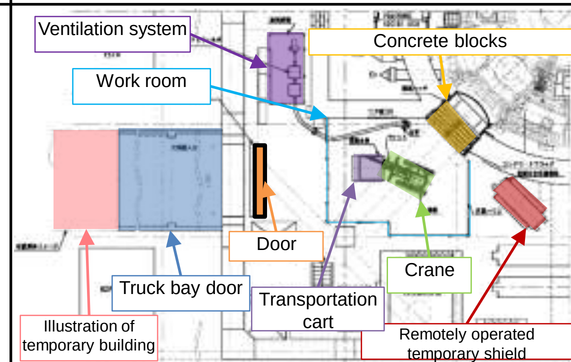
Additional information: Interfering objects are removed, temporary building set up is completed

2. Disassembly of concrete blocks from the front side



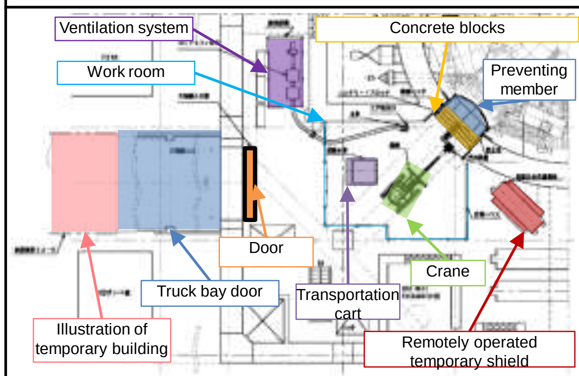
Additional information: Intermediate posts are cut with the cutting equipment. The disassembled pieces are collected using a bucket and a lifting magnet. While disassembling concrete blocks, the mortar joints are shaved so that the size of the disassembled pieces is as large as possible.

3. Collection of concrete blocks



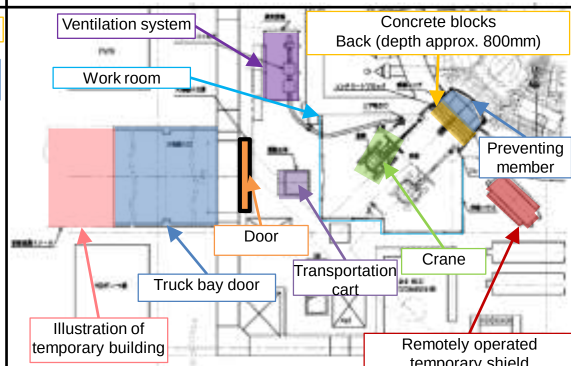
Additional information: If collecting with the bucket is possible, collection is done using the grabbing equipment

4. Installation of preventing member



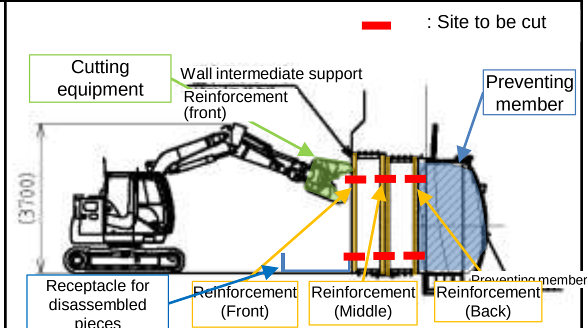
Additional information: Being planned for preventing debris from falling inside the equipment hatch

5. Disassembly of concrete blocks from the back side



Additional information: Implemented in the same manner as No. 2 and 3

6. Removal of reinforcement (front, middle, back)



Additional information: Disassembled and removed in the order of Reinforcement (front) ⇒ Partitioning steel plates ⇒ Reinforcement (middle) ⇒ Partitioning steel plates ⇒ Reinforcement (back)

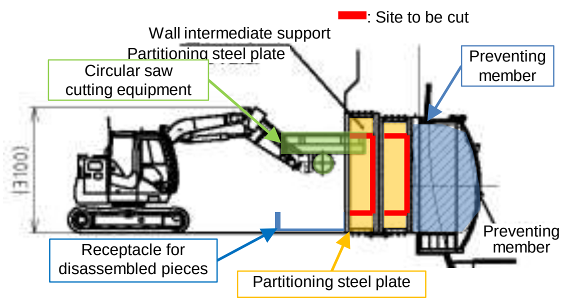
Preventing member: Planned to be installed by opening a through hole into the block by means of core boring, etc. The purpose of installing it is to prevent disassembled pieces from falling in between the PCV and BSW and preventing the equipment hatch from getting damaged, but its necessity needs to be discussed further.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

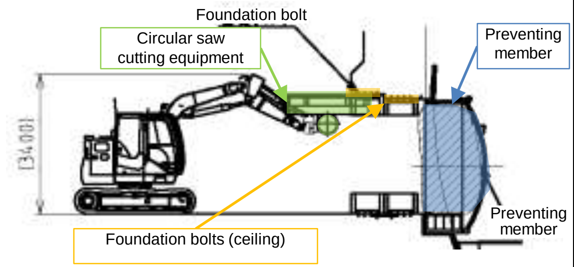
[Study of disassembly method (Unit 3)] Study of disassembly procedures (2/2)

7. Removal of partitioning steel plates



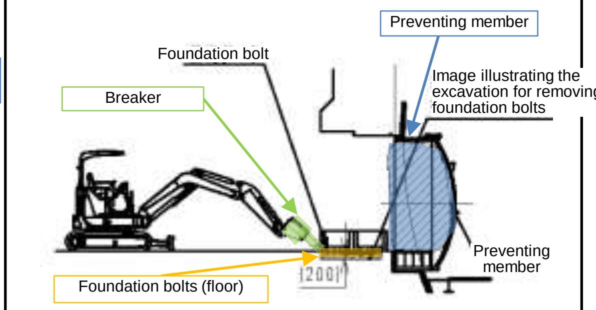
Additional information: Disassembled and removed in the order of Reinforcement (front) ⇒ Partitioning steel plates ⇒ Reinforcement (middle) ⇒ Partitioning steel plates ⇒ Reinforcement (back)

8. Removal of foundation bolts (ceiling)



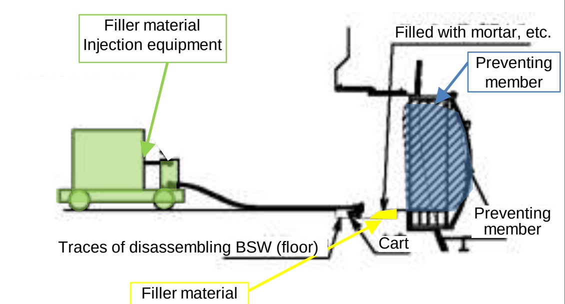
Additional information: Reinforcement (ceiling) can be removed along with the removal of foundation bolts (ceiling)

9. Removal of foundation bolts (floor)



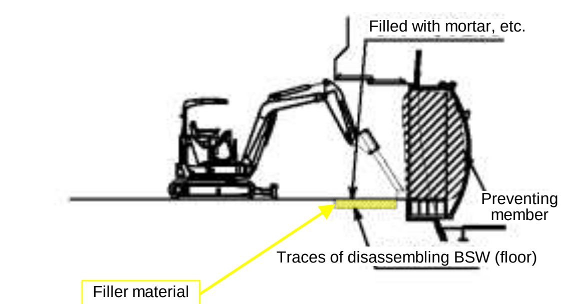
Additional information:Foundation bolts (floor) and reinforcement (floor) can be removed by shaving the floor surface or with the help of a polisher.

10. Pouring of mortar



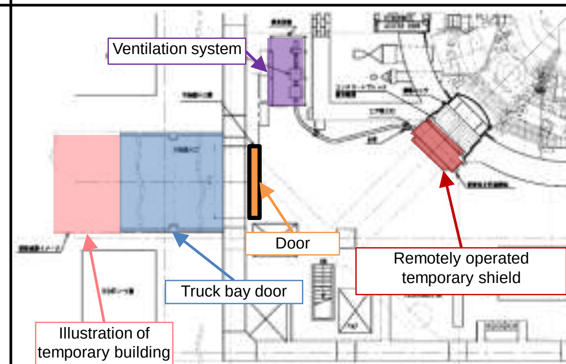
Additional information: In this step, filler material such as self leveling material, etc. is injected depending on the status of the floor surface.

11. Smoothening



Additional information: If smoothening has not been achieved in No. 10, the filler material is polished using a polisher.

12. Clearing



Additional information: Removing the equipment and moving the remotely operated temporary shield

Note) The status (dose / condition) of the target object is verified at every work step (1 to 12), and then work is continued.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Exposure evaluation (Unit 3)]

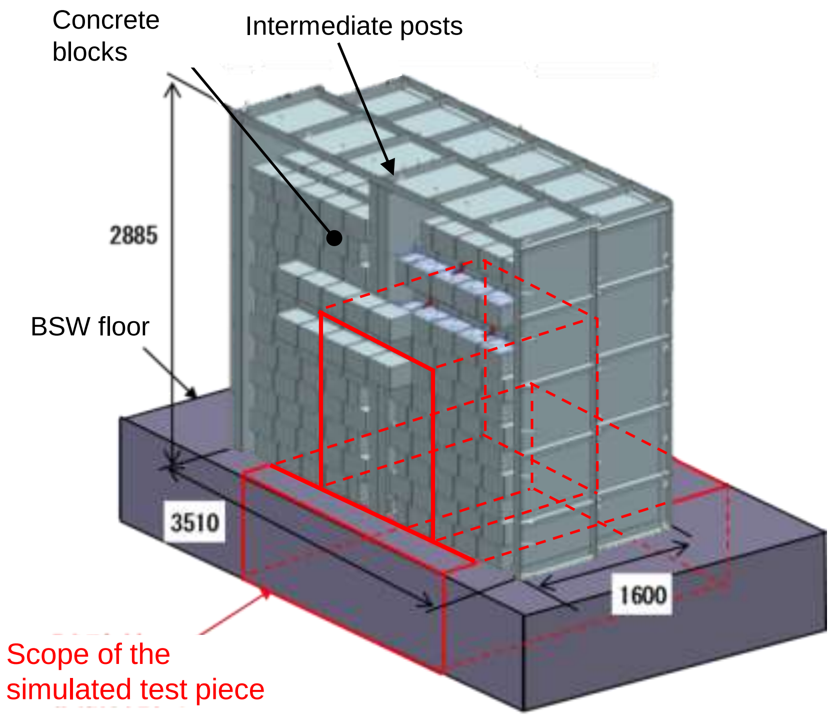
Disassembling procedures No.	Assumed human work	Work place	Total time required for work	Environmental radiation dose	Exposure dose	No. of persons	Exposure dose
			(hr)	(mSv/h)	(mSv/person)		(mSv)
1	Carrying-in and assembling the ventilation equipment and work room, carrying-in the remotely operated temporary shield	Inside R/B	21	11 to 18	350	4 to 5	1462
2	Replacing the processing and finishing tools (Breaker, cutting equipment)	Temporary building	11	0.12	1.32	2	2.64
3	Replacing the processing and finishing tools (Bucket, grabbing equipment)		12	0.12	1.44	2	2.88
4	Replacing the processing and finishing tools (Equipment for making holes, grabbing equipment)		2	0.12	0.24	2	0.48
5	Replacing the processing and finishing tools (Breaker, cutting equipment, bucket, grabbing equipment)		20	0.12	2.4	2	4.8
6	Replacing the processing and finishing tools (Cutting equipment)		3	0.12	0.36	2	0.72
7	Replacing the processing and finishing tools (Circular saw cutting equipment, grabbing equipment), replacing the disc when it becomes blunt		7	0.12	0.84	2	1.68
8	Replacing the processing and finishing tools (Circular saw cutting equipment)		1	0.12	0.12	2	0.24
9	Replacing the processing and finishing tools (Breaker, grabbing equipment)		2	0.12	0.24	2	0.48
10	Replacing the processing and finishing tools (Breaker, grabbing equipment)		2	0.12	0.24	2	0.48
11	Replacing the processing and finishing tools (Smoothening tool)		1	0.12	0.12	2	0.24
12	Replacing the processing and finishing tools (Grabbing equipment, cutting equipment)		2	0.12	0.24	2	0.48
						Total	1477.12

Note) Since the dose rate inside the R/B is high, the overall exposure dose increases → If the exposure dose does not reduce even after decontamination, shield needs to be installed at a location such that it does not interfere with removal work.

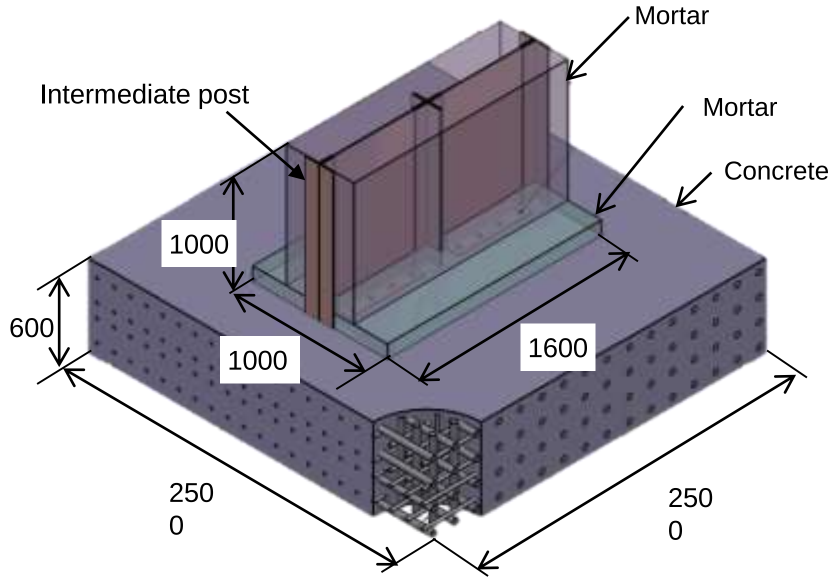
④ Disassembly of shield plug

[Structure of shield plug]

The structure of the Unit 3 shield plug is shown.
As mentioned in the previous pages, in Unit 1 unitized concrete blocks are pulled out with the help of electricity.
And, in Units 2 and 3, a large number of concrete blocks are piled. Further amongst these units, since there are intermediate posts made of steel in the middle of the shield plug in Unit 3, it is believed that disassembly and removal are more difficult in Unit 3 as compared to Unit 2. Hence it was determined that disassembly and removal of the Unit 3 shield plug would be undertaken during the MU test this time.



Unit 3 concrete blocks



Test piece

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

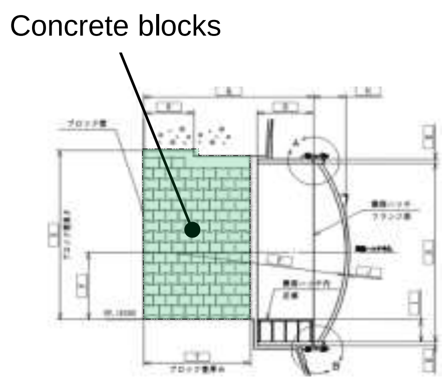
④ Disassembly of shield plug

[Study of smoothening methods]

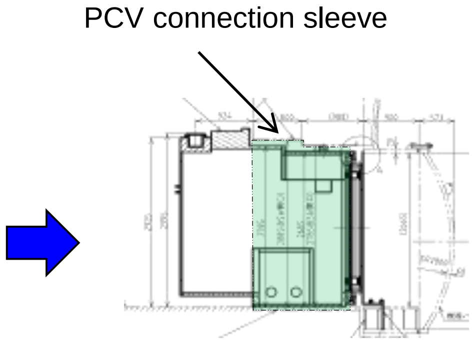
After removing the concrete blocks, the PCV connection sleeve is installed on the floor surface which becomes the load bearing point for the access tunnel. Also, the wall surface becomes the measurement point for 3D scanning for installing the PCV connection sleeve. Therefore, the methods for smoothening (#1) the floor surface and the wall surface were studied.
(#1: Smoothening: To level and create a flat surface)

Study flow of smoothening methods

Study of smoothening methods	
Smoothening test	The method that is feasible and provides higher smoothness is selected from multiple proposals and tested.
Measurement of smoothness	Multiple tests are conducted, and smoothness (flatness and level) is measured.
Selection of smoothening method	Based on the results of the measurement carried out during the test, the method that provides good smoothness is selected.
Reflection into the PCV connection sleeve design and structure	Reflected into the design and structure as a condition for remote installation of PCV connection sleeve



Before removing concrete blocks



After removing concrete blocks (Installation of PCV connection sleeve completed)

The existing concrete blocks need to be removed for installing the PCV connection sleeve.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Purpose of the element tests]

The element test has the following two purposes: ① Disassembling and removing the shield plug (including smoothening of the wall surface) and ② Smoothening the floor surface after disassembling and removing the shield plug. The test items are indicated below.

① Disassembly and removal of shield plug

The test items are indicated in the table below. It is believed that concrete can be removed by common methods. In this test, since the extent of adhesion of mortar to the intermediate posts and the smoothening# of the adhered mortar will be verified, it was decided that the mortar wall should be simulated rather than concrete blocks. Further, the floor surface has been simulated as a concrete surface.

Removing the mortar that has adhered to the wall surface of the opening that serves as reference while installing the PCV connection sleeve. In this test, the wall surface is replaced by intermediate posts.

Test Item (To be processed)	Processing and finishing tools	Verification contents	Criteria (Measurement and confirmation items)
Removal of concrete blocks (During the test mortar was simulated instead of concrete blocks in order to verify adhesion of mortar to the metal surface.)	Breaker	① Verifying whether or not it is possible to smoothen the mortar stuck on the lining plate	The mortar should not be significantly adhered on to the wall surface. (Height at which it is adhered)
		② Verifying the impact when the breaker collides with the partitioning steel plates or reinforcement	There should not be any significant deformation. (Condition of damage/deformation)
		③ Verifying whether concrete is shaved to an extent that it does not come in contact with the floor rebars (Thickness of concrete cover approx. 40mm)	・Should not come in contact with the rebars. ・There should not be any significant deformation.
Intermediate posts (L100 x 100 x 7)	Guzzilla cutter Breaker	Verifying the status after cutting with the Guzzilla cutter and shaving with the breaker. (It is believed that shaving is possible, but it is performed considering method selection.)	There should not be any remnants (L type beam) and shaving should be possible. (Maximum depth, maximum width)
Foundation bolts	Breaker	Checking the status after shaving#. It is believed that shaving is possible, but it is performed considering method selection.	There should not be any remnants (foundation bolts) and shaving should be possible. (Maximum depth, maximum width)

② Smoothening of the floor surface after disassembling and removing the shield plug

Test Item	Finishing method	Verification contents	Criteria (Measurement and confirmation items)
Shaving of floor surface	Laying self leveling material	Laying self leveling material on the test piece (floor surface) that is shaved with a breaker, and checking for gradient, etc. after laying.	・Floor surface gradient ・Unevenness of floor surface
	Laying non-shrink mortar	Laying non-shrink mortar on the test piece (floor surface) that is shaved with a breaker, and checking for gradient, etc. after laying.	・Floor surface gradient ・Unevenness of floor surface
Floor surface polishing	Polishing with the help of a polisher	Polishing on top of test piece shaved up to the floor surface, using a polisher.	・Unevenness of floor surface ・Amount of polishing of anchor bolt

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Test flow]

Test No. 1

- Disassembly and removal of concrete blocks (mortar part)
  - ・Mortar is removed under various conditions, and the attachment is selected.
- Removal of mortar adhered to the intermediate posts
  - ・ The extent of adhesion of mortar is verified.
  - ・ The adhered mortar is removed, and the attachment is selected.

Test No. 2

- Cutting of intermediate posts
  - ・ The intermediate posts are cut, and the cutting method is determined.

Test No. 3

- Removal of anchor bolts
  - ・ The anchor bolts are removed (manned, grinder)
  - Cutting of bolts using a crane
  - Cutting with a grinder (manned)

Test No. 4

- Removal of remains of the intermediate posts
  - ・ After removing the anchor bolts, the remains of the intermediate posts are removed.

- Removal of anchor bolts
  - ・ After removing the remains of the intermediate posts, the remains of the anchor bolt are removed.
    In order to install the PCV connection sleeve, the anchor bolts are removed to an extent that they are at the same level or lower than the existing floor surface.
  - Floor surface is shaved → **Test No. 6**: Filling of filling material → Smoothening of filled surface
  - Floor surface not shaved → **Test No. 5**: Removal of anchor bolts with a polisher

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Crane used]

	Test at actual facility, MU Test	Stand-by
	3 ton class	8 ton class
Photograph	 Hitachi Construction Machinery Co., Ltd. ZAXIS30U-5B Short reach specifications	 Hitachi Construction Machinery Co., Ltd. ZAXS75US-5B Short reach specifications
Dimensions	W 1650 x D 4050 x H 2540 (mm)	W 2320 x D 4820 x H 2820 (mm)
Specifications	Equipment mass: 3840kg	Equipment mass: 7430kg
	Mountable attachment mass: 450kg	Mountable attachment mass: 1430kg
	Maximum height at which work is carried out: 4240mm	Maximum height at which work is carried out: 5590mm
	Average ground contact weight: 3.0ton/m^2	Average ground contact weight: 3.8 ton/m^2
Use applications	Disassembly and removal of concrete blocks, band plate, wire torus, mortar Disassembly and removal of intermediate support for the wall	Same as described on the left. Arranged as stand-by in case disassembly and removal cannot be accomplished with the 3 ton class.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Tools used]

Details about the attachments installed at the tip of the crane are indicated below.

No.	Attachment	Figure	Use applications	To be processed/handled	Rough specifications (general)
1	Breaker (Moil point)		For crushing concrete	Concrete blocks, BSW (Floor)	Concrete, bedrock, hard floor, road work
2	Breaker (Flat end)		For crushing concrete	Concrete blocks, BSW (Floor)	Concrete, bedrock, hard floor, road work
3	Bucket		For collecting pieces, etc. of concrete	All disassembled pieces	Capacity (m^3): 0.11
4	Large concrete crusher (Guzzilla cutter)		For cutting/ grabbing and collecting steel plates	Wire torus, reinforcement (L100 x 100 x 7mm), partitioning steel plate (6mm)	Target: Iron frame, reinforced concrete

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Smoothening materials / tools]

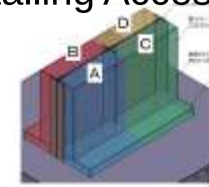
Details about the materials and tools used for smoothening are indicated below.

No.	Tool	Figure	Use applications	To be processed/handled	Rough specifications
1	Self leveling material		For smoothening BSW (floor)	BSW (floor)	Has better fluidity as compared to non-shrink mortar, but is not as strong. (Can bear the load of the PCV connection sleeve and AT) The surface on which the material is to be placed needs to be coated with a primer before placement.
2	Non-shrink mortar		For smoothening BSW (floor)	BSW (floor)	Fluidity is not as good as the self leveling material, but strength is better. The surface on which the material is to be placed needs to be moistened with water before placement.
3	Polisher		For smoothening BSW (floor)	BSW (floor)	Ordinary concrete
4	Breaker (Flat end)		For crushing concrete	Concrete blocks, BSW (Floor)	Concrete, bedrock, hard floor, road work

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Element test results Test No. 1-1 to 1-4]



Division of the test piece

The results of tests on disassembly and removal of shield plug are indicated.
The shield plug portion of the test piece is divided into 4 parts (Part A to Part D). Disassembly and removal, wall surface smoothening, and collection of disassembled pieces was carried out using different cranes and attchments on each of these parts respectively.

No.	To be processed	Crane	Work	Attachment	Results	Remarks
1-1	Shield plug Part A (Mortar)	3 ton class crane	Disassembly and removal	Breaker (Moil point)	Can be disassembled and removed. Disassembled pieces of a certain size can be collected, but disassembled pieces in powdered form cannot be collected with a bucket. (Same for No. 1-2 to 1-4)	Mortar of length 5cm x width 1cm x height 1cm remains
			Wall surface smoothening	–		
			Collection of disassembled pieces	Bucket		
1-2	Shield plug Part C (Mortar)	3 ton class crane	Disassembly and removal	Breaker (Moil point)	Can be disassembled and removed.	The mortar got peeled off from the intermediate posts and the floor surface.
			Wall surface smoothening	Bucket		
			Collection of disassembled pieces	Bucket		
1-3	Shield plug Part B (Mortar)	3 ton class crane	Disassembly and removal	Large concrete crusher	Disassembly is possible to a certain extent, but complete disassembly and removal is not possible as the blade does not get lodged.	
			Wall surface smoothening	Bucket		
			Collection of disassembled pieces	Bucket		
1-4	Shield plug Part D (Mortar)	8 ton class crane	Disassembly and removal	Breaker (Moil point)	Can be disassembled and removed. Smoothing can be accomplished using a bucket.	The mortar got peeled off from the intermediate posts and the floor surface.
			Wall surface smoothening	Bucket		
			Collection of disassembled pieces	Bucket (3 ton crane)		

As the intermediate posts have anti-rust coating, mortar did not adhere. Also, it is believed that mortar did not adhere since laitance treatment of the floor surface was not carried out at the time of mortar jointing. (With regards to Laitance# treatment, excavation was not carried out on the underside of the shield plug to see the smoothening of the floor surface.)
#Laitence treatment: The treatment of removing the thin layer accumulated on the surface at the time of mortar jointing.

In some cases the mortar got peeled off from the intermediate posts and the floor surface, but disassembly and removal were possible even when the mortar did not get peeled off.
In the actual equipment as well, the area on which mortar is adhered is expected to be small, either because the surfaces are made of metal (wall surface) or because mortar has not adhered.
Also, it was verified that smoothening can be achieved using a bucket even if mortar is adhered. (Test results are indicated on the following pages.)

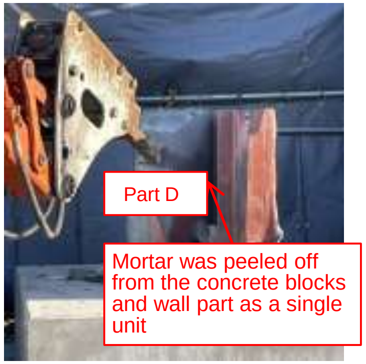
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Element test results Test No. 1-4]

No.	To be processed	Crane	Work	Attachment	Results	Remarks
1-4	Shield plug Part D (Mortar)	8 ton class crane	Disassembling and removal	Breaker (Moil point)	Can be disassembled and removed. Smoothing can be accomplished using a bucket.	The mortar got peeled off from the intermediate posts and the floor surface.
			Wall surface smoothening	Bucket		
			Collection of disassembled pieces	Bucket (3 ton crane)		


8 ton crane



While disassembling

Top portion of the test piece

After completing disassembly of the side of the test piece


Mortar removal using a bucket


Mortar removal completed

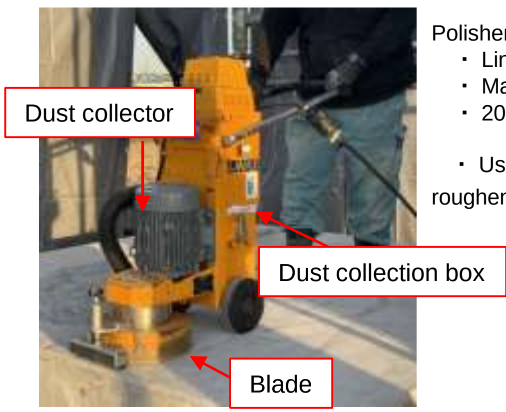
6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Element test results Test No. 5 Floor surface smoothening]

It was verified whether the anchor bolts can be cut using only the polisher without shaving the floor surface.

No.	To be processed	Height of the bolts from the floor surface	Cutter	Results	Criteria	Remarks
5-1	Anchor bolts	1mm	Polisher	Can be cut	The height of the anchor bolts should become the same as that of the floor surface	
5-2		2mm		Can be cut		
5-3		3mm		Can be cut		
5-4		4mm		Cannot be cut		As smoothening took time, the floor surface around the bolt got shaved. However, if it takes time, cutting itself becomes possible.



Compete view of polisher

Polisher specifications
- Linax KLX-38
- Mass approx. 100kg
- 200V

- Used for grinding or roughening concrete, mortar.


Smoothening work using a polisher


Polisher (blade surface)


Before processing No. 5-4


After processing No. 5-4

It was verified that the bolts that are 3mm or less from the floor surface can be cut using the polisher.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Element test results Test No. 6 Floor surface smoothening]

The floor surface was shaved using a breaker in preparation for filling filling material for smoothening, and the shaved surface was filled with filling material. Results of smoothening are indicated on the following page.

No.	To be smoothened	Crane	Work	Filling material
5-1	Concrete floor surface (Approx. 900mm x 900mm x Depth 40mm)	3 ton class Crane	Shaving of floor surface	Self leveling material
5-2	Concrete floor surface (Approx. 1200mm x 600mm x Depth 40mm)	3 ton class Crane	Shaving of floor surface	Non-shrink mortar

Before shaving the floor surface

After shaving the floor surface (Before removing the disassembled piece)

After shaving the floor surface (After removing the disassembled pieces)

While filling non-shrink mortar

Filling completed (Right after filling)

Filling completed (After 1 week of drying)

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

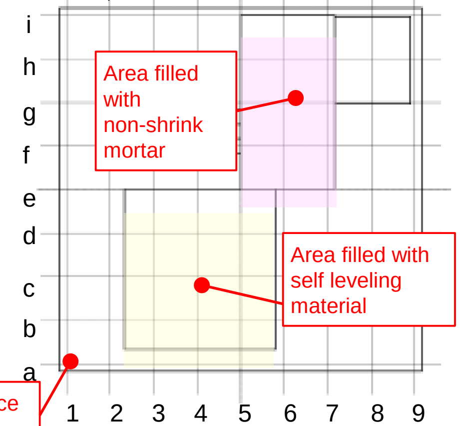
④ Disassembly of shield plug

[Element test results Test No. 6 Floor surface smoothening]

The test piece was measured with the 300mm pitch (81 points). It was measured 3 times in all. The intersection points shown in the figure below are the measurement points. After filling the filling material, measurement was carried out after providing 1 week of drying period. Thereafter, the area that was filled with filling material was polished with a polisher, and after ensuring that the area appeared to be smooth, measurement was carried out.

After smoothening using a polisher

Status of measurement



After smoothening using a polisher (Lateral surface)

	1	2	3	4	5	6	7	8	9
i	−3.1	−2.8	−2.5	−3.1	−3.3	−4.1	−4.3	−1.7	−4.1
h	−2.3	2.1	2.3	−0.2	−1.9	−3.0	2.7	1.9	−1.8
g	−2.5	2.4	3.4	0.4	−2.4	0.2	−0.6	3.2	−1.0
f	−2.2	2.2	4.7	0.3	−2.5	0.0	3.6	3.5	−1.7
e	−0.5	3.1	5.1	4.7	5.4	2.2	4.4	4.8	−1.1
d	−0.9	3.8	6.0	5.8	5.7	1.5	5.6	5.9	−0.7
c	−1.4	4.1	6.1	6.0	5.6	0.9	3.0	4.8	−0.9
b	−0.7	2.4	6.1	6.0	5.7	2.9	2.9	2.9	−0.8
a	0.0	1.2	2.5	2.0	2.5	1.6	1.6	3.3	−0.5

Results of measurement before smoothening

	1	2	3	4	5	6	7	8	9
i	−1.6	−1.2	−0.7	−1.2	−1.5	−1.8	−2.0	0.8	−1.6
h	−1.0	3.5	3.7	1.1	−1.3	−1.9	−0.7	2.8	−0.3
g	−1.4	3.5	4.6	1.3	−1.6	0.4	0.0	3.5	0.6
f	−1.2	3.2	5.8	1.0	−3.1	0.8	3.1	4.3	−0.3
e	0.3	3.8	4.3	0.4	0.9	2.2	5.2	6.1	0.3
d	−0.3	3.9	3.0	1.1	2.0	2.2	6.5	7.1	0.4
c	−1.0	2.3	3.2	2.2	1.6	1.3	3.9	5.8	0.3
b	−0.5	1.5	0.8	0.6	0.7	2.9	3.8	3.9	0.2
a	0.0	1.3	2.7	2.2	2.8	1.9	2.1	3.9	0.1

Results of measurement after smoothening

Filling material	Only filling material				Filling material + Polisher				Results
	Average value	Maximum	Minimum	Maximum - Minimum	Average value	Maximum	Minimum	Maximum - Minimum	
Self-check Self leveling material	+5.7mm	+6.1mm	+4.7mm	+1.4mm	+1.7mm	+4.3mm	+0.7mm	+3.6mm	・There is little variation in the case of only filling material. (Uniformly spread) ・When the polisher is used to smoothen the filling material and the edges of the existing floor surface, the existing floor surface gets polished as well. ⇒ A smoother surface is expected to be achieved, if there is a mechanism to adjust the polishing height of the polisher.
Non-shrink mortar	-1.3mm	+3.6mm	-4.3mm	+7.9mm	-0.8mm	+3.1mm	-3.1mm	+6.2mm	・The filled surface is uneven before as well as after polishing with the polisher and hence the measurement results are varied. (Not uniformly spread) ・Similar to the self leveling material, issues at the time of polishing the edges are present in this case as well.

The self leveling material that spreads uniformly and has a smoothening effect even before polishing with the help of a polisher, is expected to be used. Also, it is expected that further smoothening effect can be achieved by providing the polisher with a height adjustment feature. For reflection into the structure of the PCV connection sleeve, 3D measurement is carried out before installation to ascertain the shape of the floor surface and adjust the shim, etc.

2. Development of the method of installing access equipment

2. 3 Disassembly of shield plug

[Summary of test results]

Test No. 1: Disassembly and removal of concrete blocks (mortar)

- Removal of concrete blocks (mortar) is expected to be possible by combining the methods tested this time.
  ⇒ Disassembly with 3 ton class crane + breaker will be primarily considered.

- Mortar and metal did not adhere even as much as was expected.
  ⇒ As it was possible to remove the sites to which mortar adhered using the bucket, even if the extent of adhesion is larger in the actual equipment, it is believed that the mortar can be removed.

- With regards to adhesion of mortar and concrete, the extent of adhesion changed depending on whether laitance treatment was carried out.
  ⇒ Smoothening will be carried out using the polisher depending on the extent of adhesion of mortar. If mortar has not adhered and the surface is smooth, polishing is not required.

- Large blocks of disassembled mortar pieces can be collected using the bucket, which is the tool made available during this test.

  ⇒ Disassembled pieces that are small or in powder form will be collected by means of suction.

2. Development of the method of installing access equipment

2. 3 Disassembly of shield plug

[Summary of test results]

Test No. 2: Disassembly and removal of intermediate posts

・ Intermediate posts can be cut using a large concrete crusher either by means of the horizontal cutting method or the triangular cutting method.
⇒ Since the triangular cutting method offers better cutting efficiency, the triangular cutting method will be primarily considered. However, while cutting the upper portion of the intermediate posts, sites where the triangular cutting method cannot be used are expected to arise from the perspective of the access range and the position of the crane. In such cases, the horizontal cutting method will be used in combination.

・ It was difficult to cut the L steel parts of 6mm thickness installed in front, in the middle, and behind the intermediate posts, but upon repeated cutting, the welded portion of the L steel part broke, and was possible to be disassembled and removed.
⇒ The welded portion of the L steel is assumed to be pitch welded, but the welding method in the actual equipment is unknown. An attachment with a larger output than the current attachment needs to be arranged for.

・ It was possible to collect large disassembled pieces (L steel, etc.) resulting from the cutting using the bucket, but the smaller disassembled pieces (metal about several cm large) were impossible to be collected.

⇒ Lifting magnets, etc. may be used for collecting small disassembled pieces.

2. Development of the method of installing access equipment

2. 3 Disassembly of shield plug

[Summary of test results]

Test No. 3: Cutting of anchor bolts

・ A grinder or a chip saw is being considered for cutting the anchor bolts, but a breaker or a large concrete crusher was able to be used as well.

⇒ If a grinder or a chip saw is used, measures against fire should be taken.

Test No. 4: Removal of remains of the intermediate posts

・ It was verified that for the bottom part of the intermediate posts the anchor bolts can be cut and can be grabbed and removed by means of the large concrete crusher.

Test No. 5: Smoothening of floor surface and cutting of anchor bolts

・ The remaining parts of the anchor bolts that are 3mm or less can be cut using a polisher.
⇒ A generic polisher was used in this test, but it may be possible to increase the allowance for height of the remaining parts by changing the blade.

2. Development of the method of installing access equipment

2. 3 Disassembly of shield plug

[Summary of test results]

Test No. 6: Floor surface smoothening

・ It is expected that the floor surface can be smoothened by combining the self leveling material and the polisher.

⇒ The non-shrink mortar is highly viscous and work involving it requires practice. Hence it is not suitable for remote operation. Also, if floor surface mortar can be easily peeled off and hence does not require much shaving work, it is believed that smoothening can be achieved with only the polisher.

⇒ This time a generic polisher was used for the test. Hence there was no control at locations at a height. In the actual equipment, the height of the surface being polished by the polisher will be controlled by means of tools, etc.

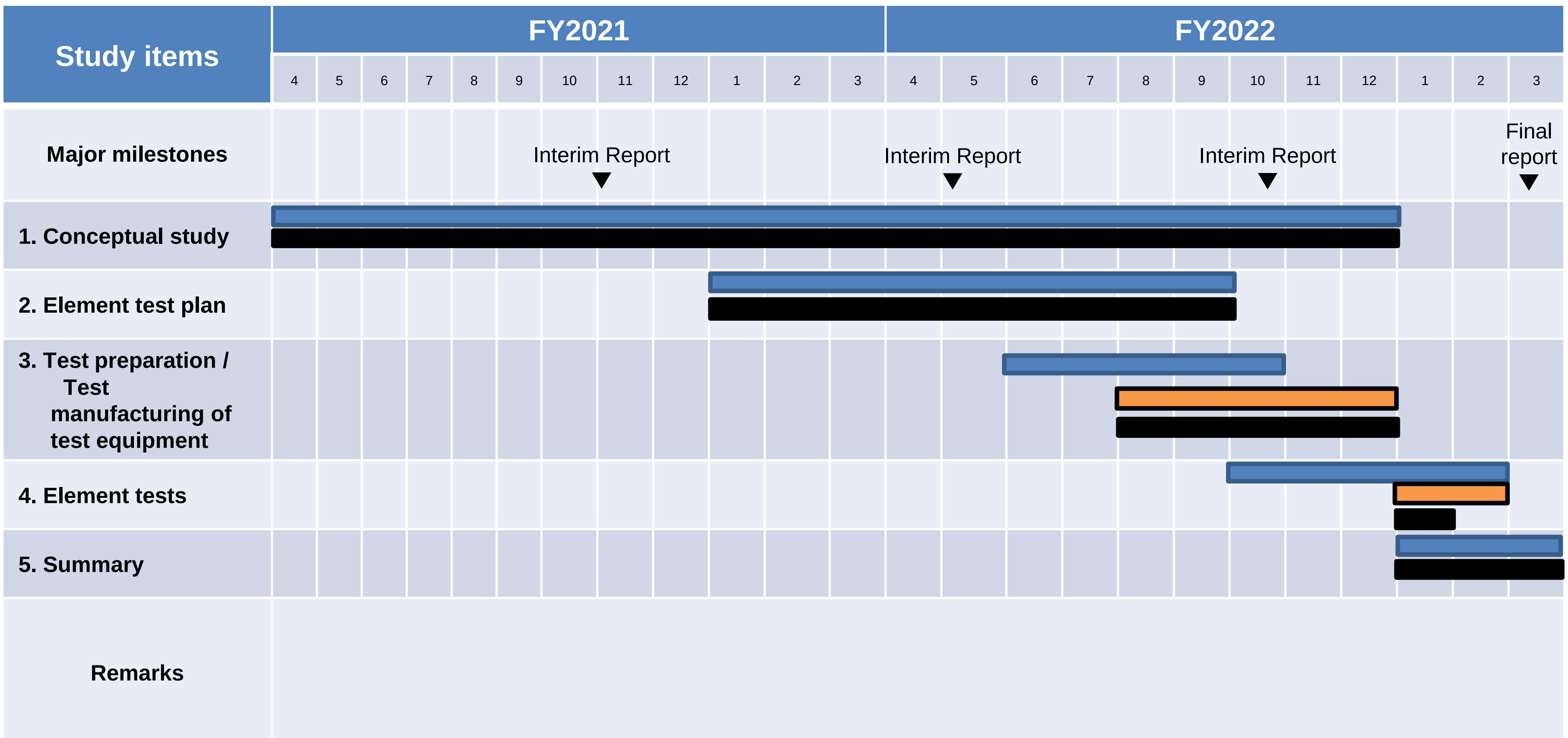
Further, after smoothening the floor surface, the gradient or unevenness of the floor surface is planned to be measured by means of 3D scanning, and the results are planned to be reflected while making prior adjustments to the seating surface of the PCV connection sleeve. (Example of the method of adjustment: Installing a shim, etc. at the bottom surface of the PCV connection sleeve)

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

[Development Schedule]

: Planned
: Planned (after revision)*
: Actual



* The plan was revised to reflect the progress status of the studies.

6. Implementation Items of This Project [1) (1) Development of the Method for Installing Access Equipment]

④ Disassembly of shield plug

- **The course of study and preconditions pertaining to the method of disassembling the shield plug in Unit 1 and concrete blocks in Units 2, 3 were consolidated in FY2021, and the disassembly and removal procedures were studied briefly. The disassembly procedures were consolidated. Issues in the methods were identified and a rough exposure dose evaluation was carried out.**

- **The cranes and tools to be used were substantiated, and whether or not the items to be processed such as concrete blocks, etc. can be processed was studied. The necessity of the test including the study of smoothening methods was evaluated, and the test plan was formulated (test items, verification contents and judgment criteria were consolidated).**

- **Element tests were conducted based on the above-mentioned test plan, and it was thus anticipated that it will be possible to remove concrete blocks in Unit 3 by combining the methods tested this time (3 ton class crane + breaker). Also, issues in application to the actual equipment were identified from the test results and consolidated.**

6. Implementation Items of This Project

1) Development of side access method

(2) Development of Disassembling and Removal Technology

① HVH disassembly

Development is being carried out concerning disassembly, removal, etc. of interfering objects for further increasing the scale of retrieval of fuel debris and reactor internal structures. Technology for verifying the feasibility of the work of cutting pipes, installing utilities (hose, etc.), etc. which is carried out outside the pedestal inside the PCV using equipment for remote operation, was developed so far.

This development will enhance fuel debris retrieval throughout by securing a work area by removing large HVH from among the equipment installed outside the pedestal, as also will enhance the work efficiency of removing fuel debris and deposits from the basement floor of the pedestal. Also, as heavy motor (several hundred kilos) is placed on top of the HVH, technology for disassembling while ensuring it does not fall, is required. Upon studying and consolidating the requirements for disassembling and removing HVH, considering the impact of obstacles such as grating and other equipment, etc. present outside the pedestal, element tests on disassembly and removal by means of remote disassembly equipment developed so far will be planned and implemented using simulated test pieces considering remote operation in limited space, and the feasibility of specific cutting/collection methods will be verified.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

Table of Contents

- Development results related to the side access method achieved so far and correlation with this project
- Issues, implementation details and results

- Main specifications of the HVH disassembly robot
- Robots and equipment associated with the work of disassembling and removing the HVH
- Blades associated with the work of disassembling and removing the HVH
- Scope of simulation in the element tests associated with the work of disassembling and removing the HVH
- Contents to be verified during the element tests
- Element test results
- Issues

- Development schedule
- Summary

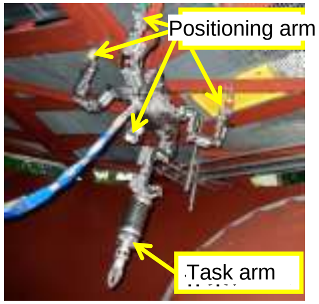
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

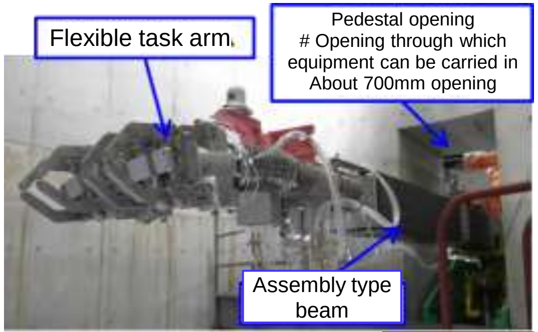
① HVH disassembly

Development results related to the side access method achieved so far and correlation with this project are indicated below.

Fundamental technology upgrade (Implemented in FY2017-18)

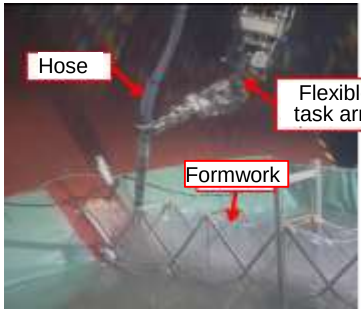
[Verification of feasibility of the fundamental work of cutting, collecting, etc.]
- ➢ Method of removing interfering objects from the basement floor inside PCV (outside the pedestal)
- ➢ Method of removing interfering objects from inside the pedestal (Assembly type beam method)
- ➢ Method for preventing spread of contamination to the S/C (Method of setting up dikes was selected)

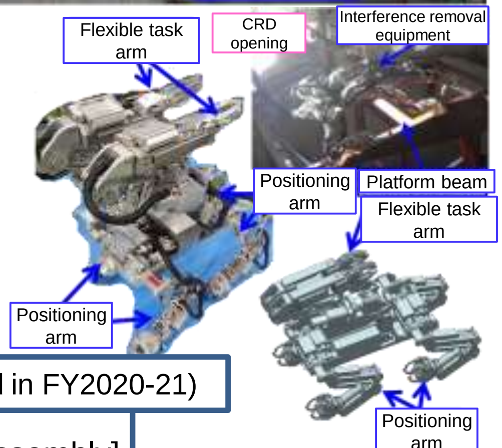




Further Increasing the Scale of Retrieval (Implemented in FY2019-20)

[Study of response measures based on the issues]
- ➢ Method of constructing the utility line inside PCV
- ➢ Method of removing interfering objects from inside the pedestal (Small equipment method)
- ➢ <u>Method of setting up dikes for preventing spread of contamination (Formwork and partition carrying-in method)</u>



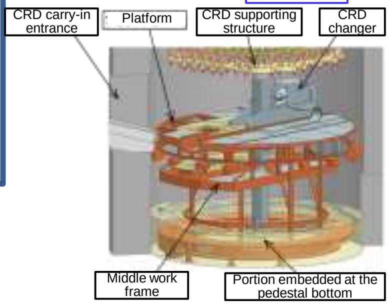


Implemented in this project

[Verification of feasibility looking ahead at the actual equipment]
- ➢ <u>Disassembly of large interfering objects (HVH) outside the pedestal</u>
- ➢ <u>Disassembly of large interfering objects (HVH) inside the pedestal (CRD changer)</u>
- ➢ <u>Method of removing interfering objects from inside the pump pit</u>

Outsourced to TEPCO HD (Implemented in FY2020-21)

[Conceptual study of HVH disassembly]
- ➢ Consolidation of pre-conditions
- ➢ Conceptual study of HVH disassembly methods
- ➢ <u>Identification of issues</u>



Items to be studied in the future

- ➢ <u>Study of developmental challenges identified during engineering and technical development, etc.</u>

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

[Issues]

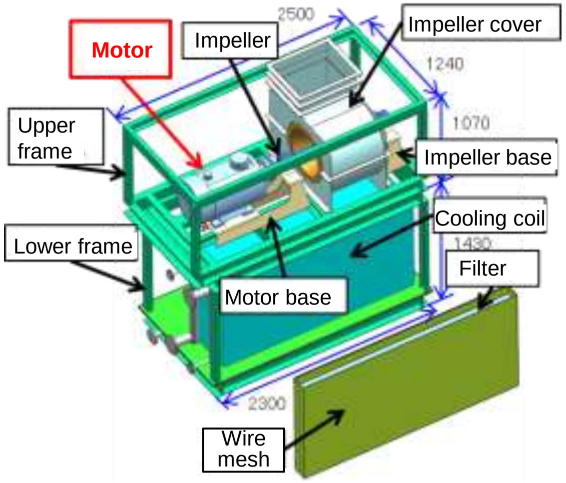
- At about 1.5m above the floor inside the HVH there is a motor which is a heavy object (several 100 kg). It is difficult to remove it while making sure it does not fall. Hence HVH disassembly technology that takes fall prevention into consideration needs to be developed.

[Implementation details]

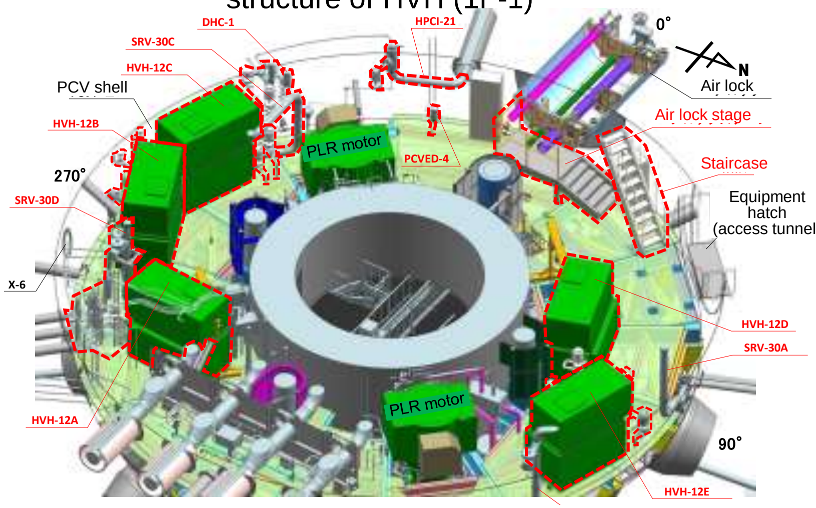
- Requirements for HVH disassembly and removal are studied and consolidated considering the impact of obstacles such as the grating installed outside the pedestal and other equipment, etc.
- Element tests are planned and conducted on the remotely operated equipment for disassembling the HVH and the equipment for cutting and collecting, and the feasibility of specific disassembly and removal methods is verified.
- The applicability of the equipment, etc. is studied by utilizing the knowledge obtained during the process of developing and test manufacturing the equipment for remote operation and other equipment developed so far.
- The viability of cutting and removing equipment that interfere when the equipment accesses the HVH and carries out disassembly work, is verified.

[Expected outcome]

- Presentation of the method of removing HVH



Overview of the internal structure of HVH (1F-1)



Status of the objects on the grating that are to be removed (1F-1)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Consolidation of pre-conditions

In order to select the HVH to be tested from the HVH in Units 1, 2 and 3, following (1) to (3) will be compared and the level of difficulty of disassembling HVH will be evaluated.

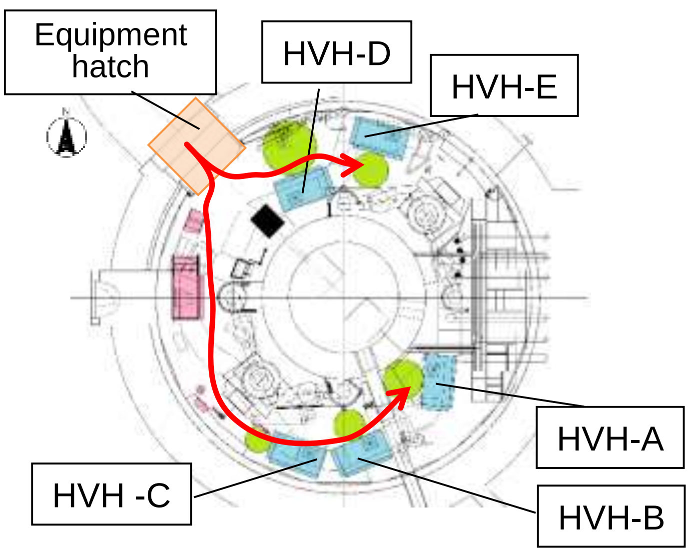
(1) Accessibility up to HVH

(2) Work space

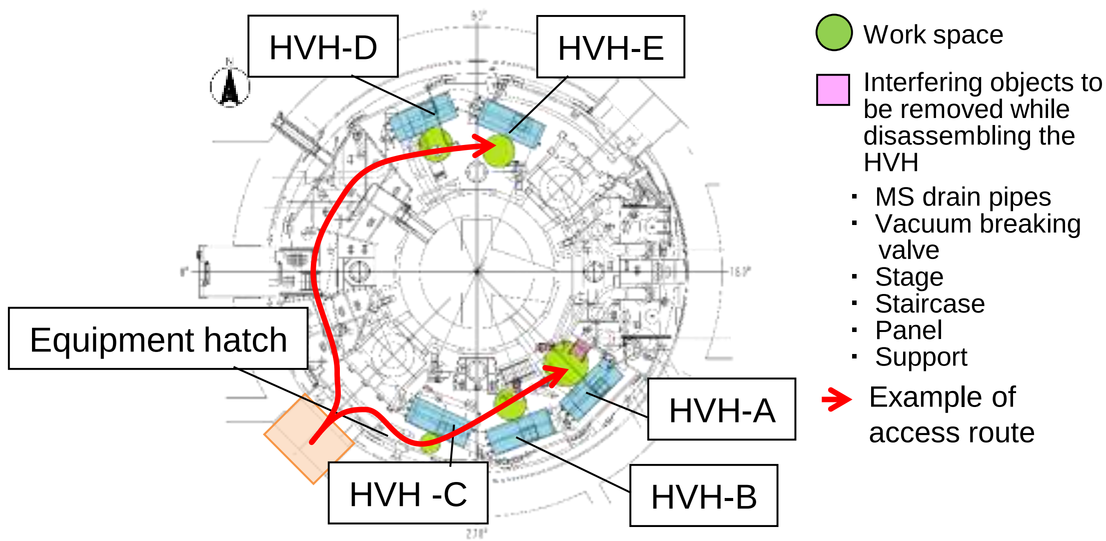
(3) Viability of transfer work

However, if the overall evaluation of all the HVHs is the same, the level of difficulty of disassembling pertaining to items related to work space will take precedence.

(This is because the results of tests conducted during the development carried out so far can be applied to issues related to accessibility.)



Layout drawing of the first floor of PCV (Unit 1)



Layout drawing of the first floor of PCV (Units 2, 3)

Note: The contents of this slide are cited from the results of the conceptual studies on HVH disassembly outsourced to TEPCO HD (Implemented in FY2020-21).

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

■Preconditions [Selecting the HVH to be disassembled]

➢ Results of evaluating HVH-A to E in Units 1, 2/3 are given below.

[Legend] Level of difficulty: Difficult (×), Easy (O)

No.	Unit	HVH No.	Accessibility up to HVH			Work space		Viability of transfer work		Comprehensive evaluation Difficulty level: High / Medium / Low (Number of instances evaluated as x) (*)
			Length of the route	Number of bends	Number of interfering objects that are difficult to remove	Work location of the robot (*)	Ratio to the Φ800 work space at the time of disassembling HVH	Ratio to the Φ800 work space at the time of removing HVH	Number of level differences or slopes that will have an adverse impact on transfer	
1	1	HVH-A	Approx. 21 m [x]	3 locations [x]	0 locations [O]	Long [O]	2.2 [O]	2.2 [O]	0 locations [O]	Level of difficulty: High (x: 2)
2	1	HVH-B	Approx. 18m [O]	2 locations [x]	0 locations [O]	Long [O]	1.8 [O]	1.8 [O]	0 locations [O]	Level of difficulty: Medium (x: 1)
3	1	HVH -C	Approx. 13 m [O]	1 locations [x]	0 locations [O]	Short [×]	1.5 [O]	1.5 [O]	0 locations [O]	Level of difficulty: High (×: 2)
4	1	HVH-D	Approx. 4m [O]	0 location [O]	0 locations [O]	Long [O]	3.0 [O]	3.0 [O]	0 locations [O]	Level of difficulty: Low (x: 0)
5	1	HVH-E	Approx. 7 m [O]	0 location [O]	0 locations [O]	Long [O]	2.0 [O]	2.0 [O]	0 locations [O]	Level of difficulty: Low (x: 0)
6	2/3	HVH-A	Approx. 12 m [O]	0 locations [O]	0 locations [O]	Long [O]	2.6 [O]	2.6 [O]	0 locations [O]	Level of difficulty: Low (x: 0)
7	2/3	HVH-B	Approx. 10 m [O]	0 locations [O]	0 locations [O]	Long [O]	1.9 [O]	1.9 [O]	0 locations [O]	Level of difficulty: Low (x: 0)
8	2/3	HVH -C	Approx. 5 m [O]	0 locations [O]	0 locations [O]	Long [O]	1.2 [×]	1.2 [×]	0 locations [O]	Level of difficulty: High (x: 2)
9	2/3	HVH-D	Approx. 15 m [O]	1 location [×]	0 locations [O]	Long [O]	2.0 [O]	2.0 [O]	0 locations [O]	Level of difficulty: Medium (x: 1)
10	2/3	HVH-E	Approx. 18m [O]	2 location [×]	0 locations [O]	Long [O]	1.9 [O]	1.9 [O]	0 locations [O]	Level of difficulty: Medium (x: 1)
Reference value or average value			Approx. 20 m	0.9 location	0 locations	—	1.5	1.5	0 locations	—

Level of difficulty: From the HVH that are difficult to disassemble, those for which the difficulty is related to work space are prioritized, and as the level of difficulty is evaluated as high for the work of disassembling and removing HVH-C in Units 1, 2/3, HVH-C in Units 1, 2/3 are selected for disassembling.

Note: The contents of this slide are cited from the results of the conceptual studies on HVH disassembly outsourced to TEPCO HD (Implemented in FY2020-21).

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

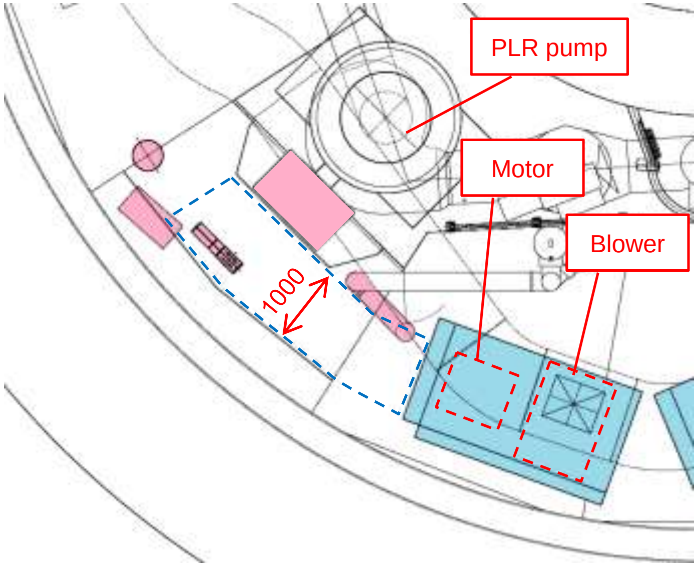
① HVH disassembly

➢ The target HVH and the element test policy

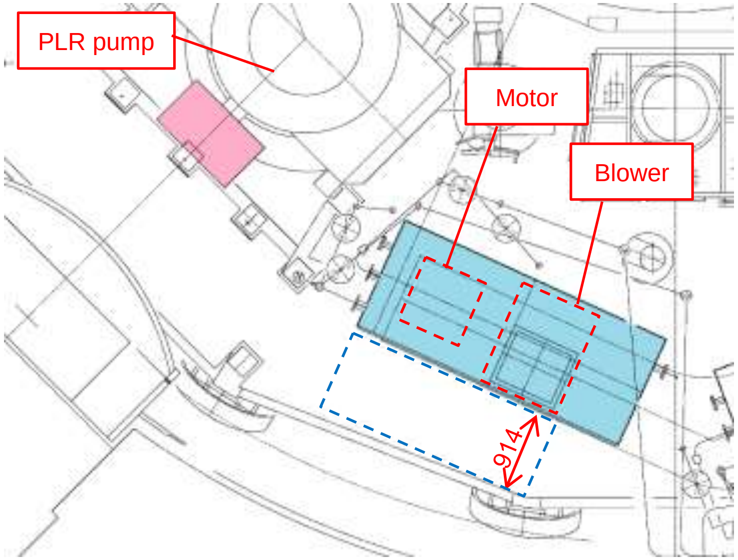
The placement of the Unit 1 HVH-C and Unit 3 HVH-C selected for testing is shown below.
As evaluated on the previous page, as the robot will work on the longer side of the Unit 3 HVH-C, the conditions are similar to almost all other HVHs and hence the Unit 3 HVH-C is used as the typical HVH.

Meanwhile, since the robot works on the shorter side only in Unit 1 HVH, if multiple robots and equipment are used in combination for carrying out work, the work contents differ from the other HVHs.

Hence, the element tests are conducted based on the placement of Unit 3 HVH-C. However, the step in which multiple robots and equipment are used in combination, the placement of Unit 1 HVH-C is replicated.



Placement of Unit 1 HVH-C



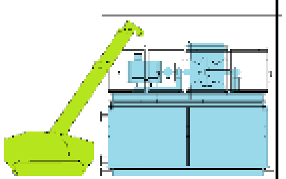
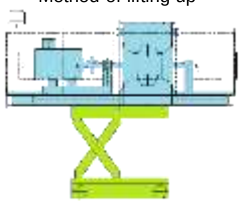
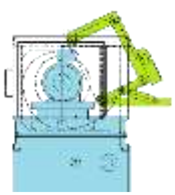
Placement of Unit 3 HVH-C

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Selection of the method of disassembling and removing the HVH

The methods studied and their characteristics are indicated below.

No.	Method	Outline	Merits	Demerits	Evaluation
①	Hoisting method 	The work of separating the heavy objects from the HVH at elevated locations is carried out, the heavy objects are hoisted using a roughter crane and removed.	• Since the boom of the roughter crane located at a little distance from the HVH is extended to lift the objects, workspace for the robots and equipment carrying out work in the vicinity of the HVH can be secured.	• In the case of lifting the blower, since the boom and the duct on top of the HVH interfere, the duct needs to be cut.	• It is determined that the hoisting method can be used as long as space for extending the outrigger of the roughter crane can be secured. → Based on the drawing, space can be secured. • Based on the drawing, it is determined that the duct can be cut.
②	Method of lifting up 	A pallet jack, etc. is set up under the upper blower unit, the position of the heavy object is lowered once, the work of separating the heavy objects from the HVH is carried out at a lower location, the heavy objects are hoisted using a roughter crane and removed.	• Amount of work to be carried out at elevated locations can be reduced. • Cutting the duct which is a demerit of No.① Hoisting method, is not required.	• Although it becomes necessary to remove the lower cooling coil unit while the upper blower unit still remains, since work needs to be carried out on both sides of the longer side of the HVH, this method may not be viable depending on the placement of the HVH. • After setting up the pallet jack, etc., the pallet jack, etc. is likely to interfere and thus it may not be possible to remove the lower cooling coil unit.	• Based on the drawings, since there are no solutions to the demerits due to work space, etc., it is determined that this method cannot be used.
③	Cutting (fine cutting) method 	Using dedicated cutting equipment, etc., the heavy objects are finely cut to a size and weight that can be handled by a robot, and the cut pieces are removed using the robot.	• Heavy objects do not need to be handled.	• It becomes necessary to develop a cutting method that can cut the motor. • Cutting work is expected to take time.	• It is difficult to cut objects that have a large diameter such as the motor, but it is determined that this method can be used for plate materials such as the blower.

The method of lifting was selected, and the course of removal work was determined based on the configuration of the roughter crane (crane) used for lifting and the robot used for the work of cutting, etc.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

- Primary concept of the HVH disassembly robot
  - Mounting electronic components (motor driver, etc.) is avoided to the extent possible in order to enhance radiation resistance.
  - Hydraulic operations cannot be used since oil is likely to leak or flammable gas is likely to be generated.
  - Objects located at a height such as the HVH counter top (H2500mm), damper (H3000-2500), etc. can be removed.
  - Objects located at a lower level such as the HVH frame, fasteners (on the grating), etc. can be removed.
  - The arm can access objects in confined spaces such as the HVH motor, blower, etc.
  - The heavy objects (motor, blower) are grabbed and hoisted with a crane (roughter crane).
  - The existing robots and equipment can be used for other works that follow a similar concept or for small scale modifications.

Based on these concepts the HVH disassembly robot is studied and test manufactured.

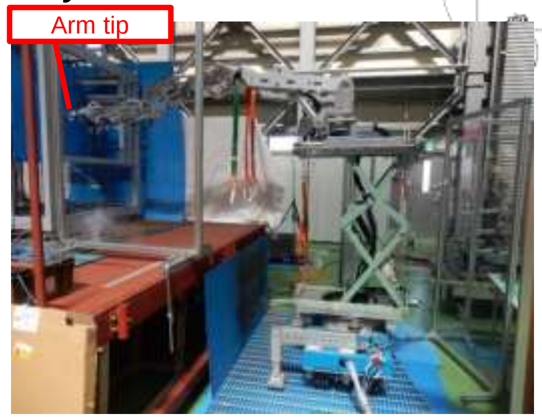
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

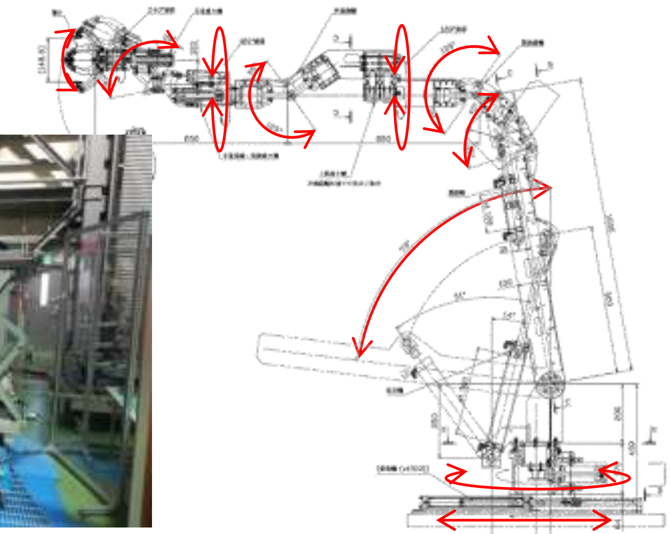
- Main specifications of the HVH disassembly robot

Overview of HVH disassembling robot

Position while traveling



Position while checking for a fall



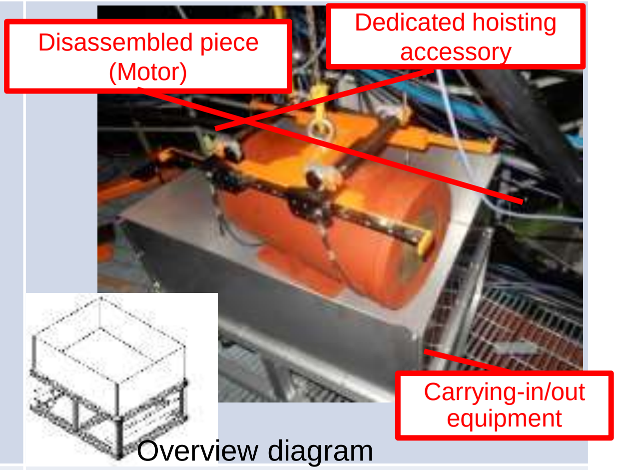
Parts of the arm that can move

	Specifications	Functions and remarks
Equipment dimensions	L1480 x W740 x H1350mm (while moving)	Dimensional constraints from the access tunnel to the equipment hatch: Dimensions such that the equipment can pass through D1000 x H1500 x L2400mm The scope of movement of the arm is such that it can cut and remove structures installed on top of the HVH (H2500mm).
Structure	Task arm with 10 shafts x 2	One arm grabs and operates the blades. The other arm grabs the disassembled pieces.
	Driving mechanism: tires	During the element test, the equipment is driven simply on tires, but on the actual site it is assumed that a crawler will be used.
Use	Work of disassembling and removing HVH Incidental work	The work of cutting the HVH, grabbing the disassembled pieces and delivering them will be carried out. Incidental work such as slinging the hoisting attachment, installing the bird's eye camera, etc. will be carried out.
Weight capacity of the work arm	Approx. 20kg/arm	Weight capacity for grabbing, moving and operating blades and disassembled pieces.
Weight of the equipment	Approx. 440kg	The equipment is equipped with the required functions, and is as light as possible. Its structure and mass is such that it will not turn over considering the momentum during work.
Power	Hydraulic pressure	Use of servo motor, etc. that has a low radiation resistance is avoided. The hydraulic mechanism that has a comparatively higher radiation resistance and draws power from a cylinder, is selected.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

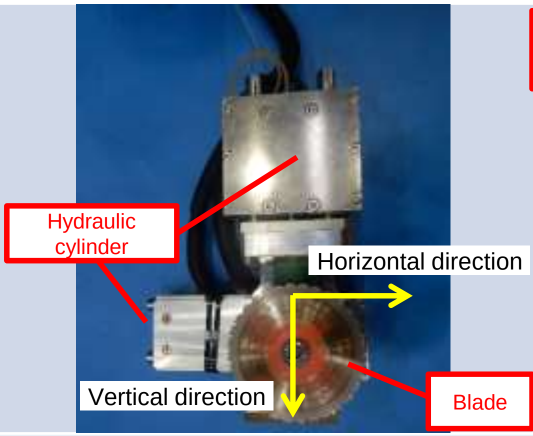
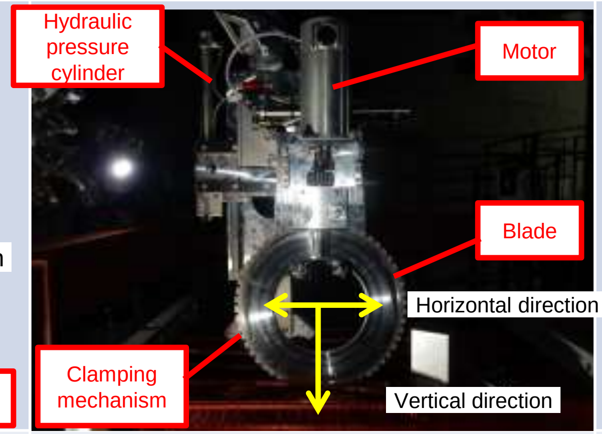
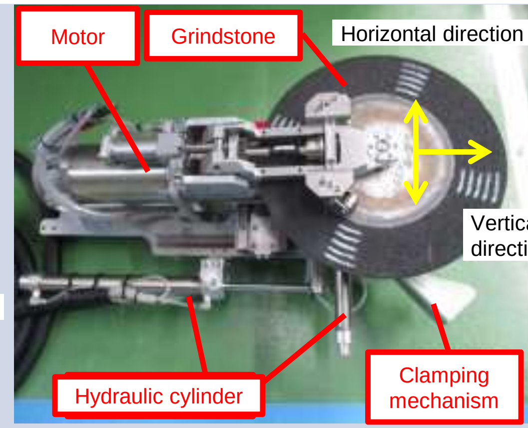
➢ Robots and equipment associated with the work of disassembling and removing the HVH

	Assist robot	Crane (for element tests)	Carrying-in/out equipment (For element tests)
Overview diagram			
Specifications	Power: Hydraulic pressure External dimensions: L1503 x W463 x H575mm Mass: approx. 100kg	Power: Electric power External dimensions: L3750 x W920 x 3148mm Mass: 490kg	Power: None Internal dimensions: L960 x W760 x H330mm External dimensions: L1000 x W800 x H732mm Mass: approx. 90kg Loaded: 400kg or more
Explanation	A multi-legged assist robot developed in the past is used. It assists in removing hoisting equipment, handling the cable hose, etc. with both task arms.	It is installed on the grating or the beam of the simulated PCV. During the element test, the scope of movement of the roughter crane that is planned to be used on the actual site, is simulated and the work of hoisting and delivering is verified.	The disassembled pieces of HVH are received and transported up to the equipment hatch. As the driving test is not to be conducted during the element test, the external form of the portion that will be collected and the portion that will be driven is simulated and the work up to collection is verified.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Blades associated with the work of disassembling and removing the HVH (1/ 2)

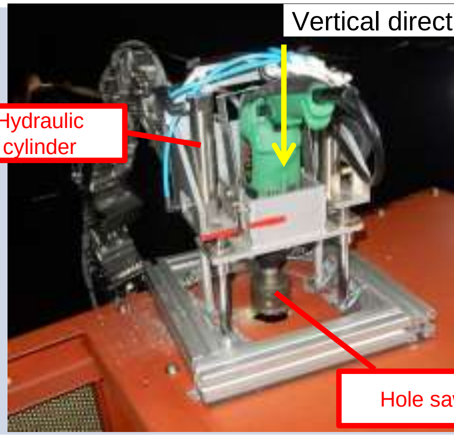
	Tip saw	Centerless tip saw	Grindstone grinder
Overview diagram			
Specifications	Power: Electric power / hydraulic pressure (stroke) External dimensions: 323 x 239 x 408mm Stroke[*1]: Vertical 75, Horizontal 200mm Mass: Approx. 15kg	Power: Electric power / hydraulic pressure (stroke) External dimensions: 305 x 244 x 767mm Stroke[*1]: Vertical 200mm, Horizontal 200mm Mass: Approx. 23kg	Power: Electric power / hydraulic pressure (stroke) External dimensions: 305 × 150 × 614mm Stroke[*1]: Vertical 175mm, Horizontal 100mm Mass: Approx. 20kg
Target	Damper, panel, casing (blower)	Frame, casing (Blower), cooling coil	Motor shaft, blower shaft, motor base, cooling coil
Explanation	The tip saw is operated with 2 strokes, and cutting is performed in a straight line.	The blade of the processed tip saw is used to cut [150 channels or block shaped cooling coils that require a long stroke. The clamping mechanism is changed in accordance with the object to be cut, and cutting is performed while the object is clamped.	It is used to cut shafts made of hardened carbon steel. And, it is used to cut motor shafts that are suspended using a crane. The clamping mechanism is changed in accordance with the object to be cut, and cutting is performed while the object is clamped.

1*: Direction of the stroke with respect to the object to be cut. The vertical direction is the direction in which the cut is made on the object to be cut.
The horizontal direction is the direction in which cutting progresses once the cut is made.

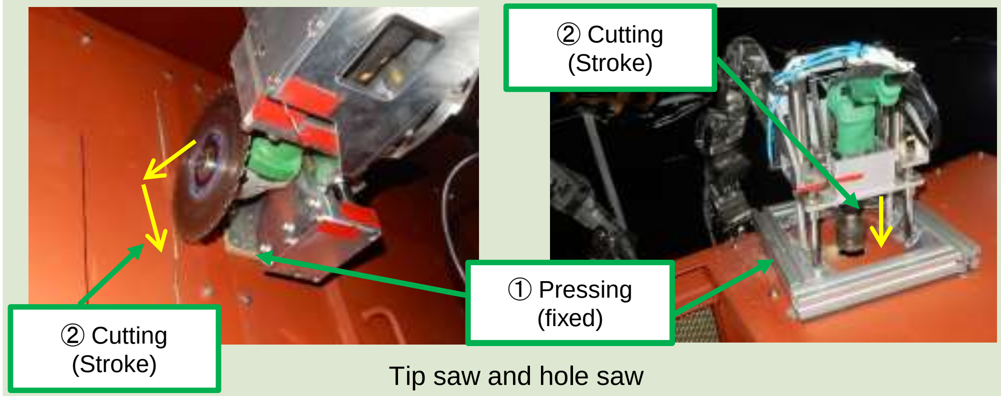
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

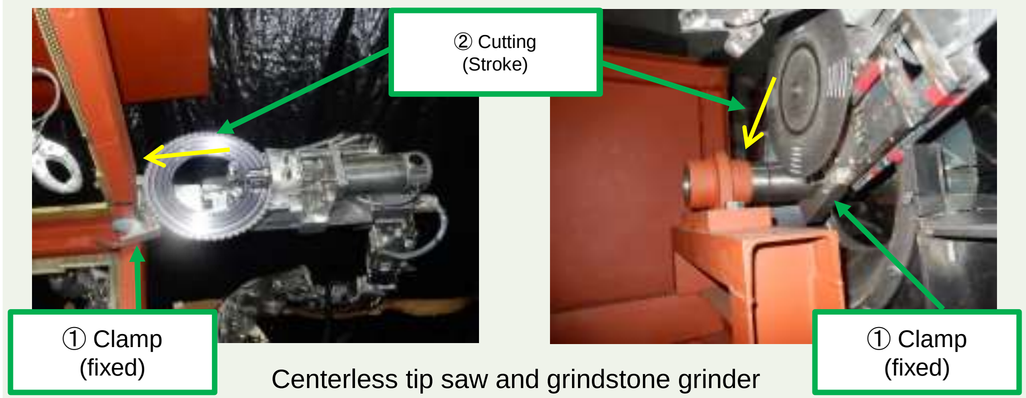
➢ Blades associated with the work of disassembling and removing the HVH (2/ 2)

	Hole saw
Overview diagram	
Specifications	Power: Electric power / hydraulic pressure (stroke) External dimensions: 400 × 300 × 300mm Stroke*1: 75 vertical mm Mass: Approx. 9kg
Target	Damper, panel, casing (blower)
Explanation	Holes are bored by stroking the hole saw with a hydraulic cylinder. A Φ60mm hole saw is used for the gripping section of the gripper.

(Additional information) Movement of the blades



Tip saw and hole saw



Centerless tip saw and grindstone grinder

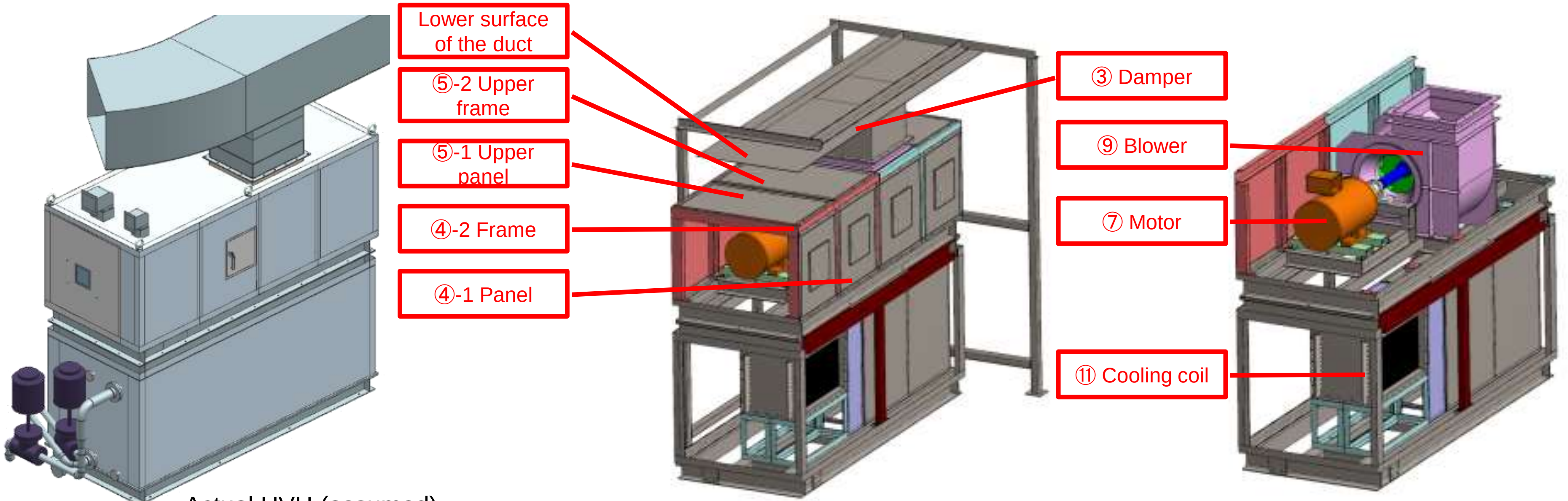
The blades have a "clamping mechanism" and a "cutting stroke mechanism" respectively.

1*: Direction of the stroke with respect to the object to be cut.
The vertical direction is the direction in which the cut is made on the object to be cut.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

- Scope of simulation in the element tests associated with the work of disassembling and removing the HVH (Simulated HVH)
  - Lower surface of the duct: The lower surface of the duct interferes with the work carried out on top of the HVH such as work related to the damper, upper panel, upper frame, etc. Hence the lower surface of the duct is simulated. Note that the dimensions of the area between the top of the HVH and the lower surface of the duct are simulated according to Unit 1 HVH where this area is a confined space.
  - Site to be cut: The simulated dimensions and material (including equivalent material) are the same as the actual equipment.
  - Motor impeller: It will not be cut, but its external form and mass are simulated as it will be lifted up.
  - Cooling coil: The simulated mass (including equivalent material) of the finned tube frame is the same as the actual site. In order to verify repetitive works, approx. 1/6th of the main body will be simulated for verifying typical work.

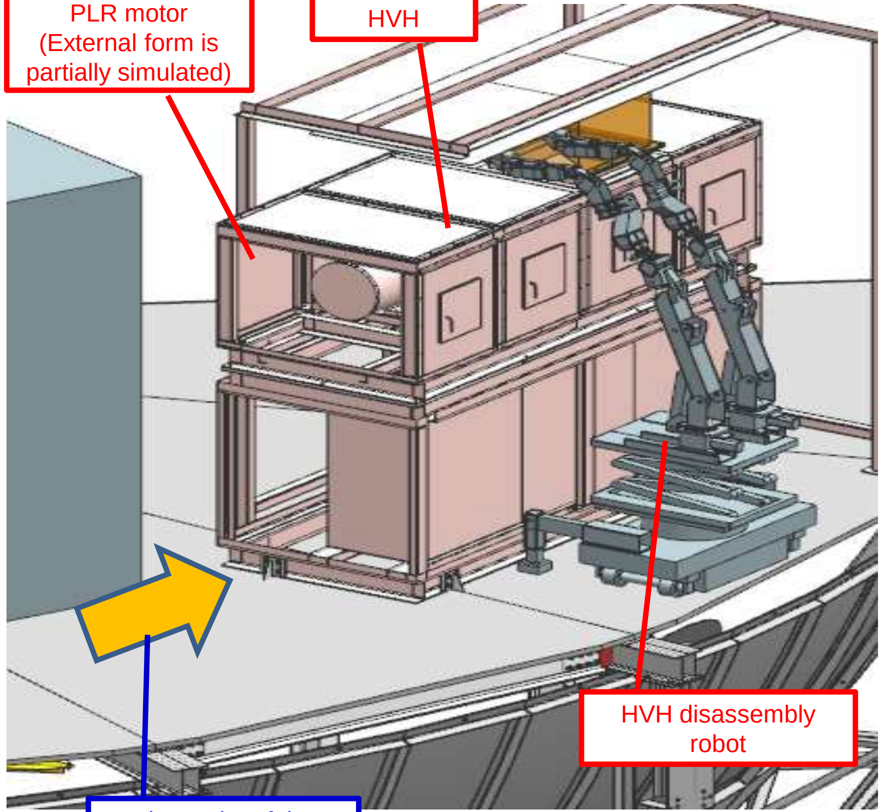


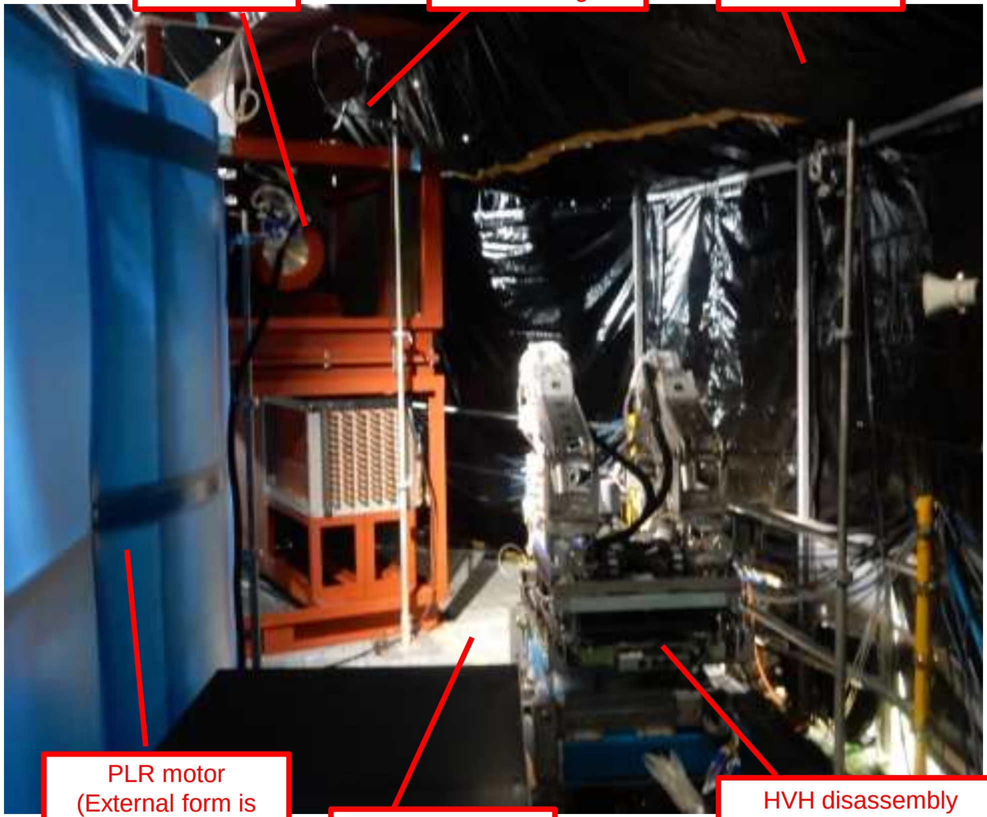
Actual HVH (assumed)　　Simulated HVH　　Simulated HVH (without the panels)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Scope of simulation in the element tests associated with the work of disassembling and removing the HVH (Surrounding environment)





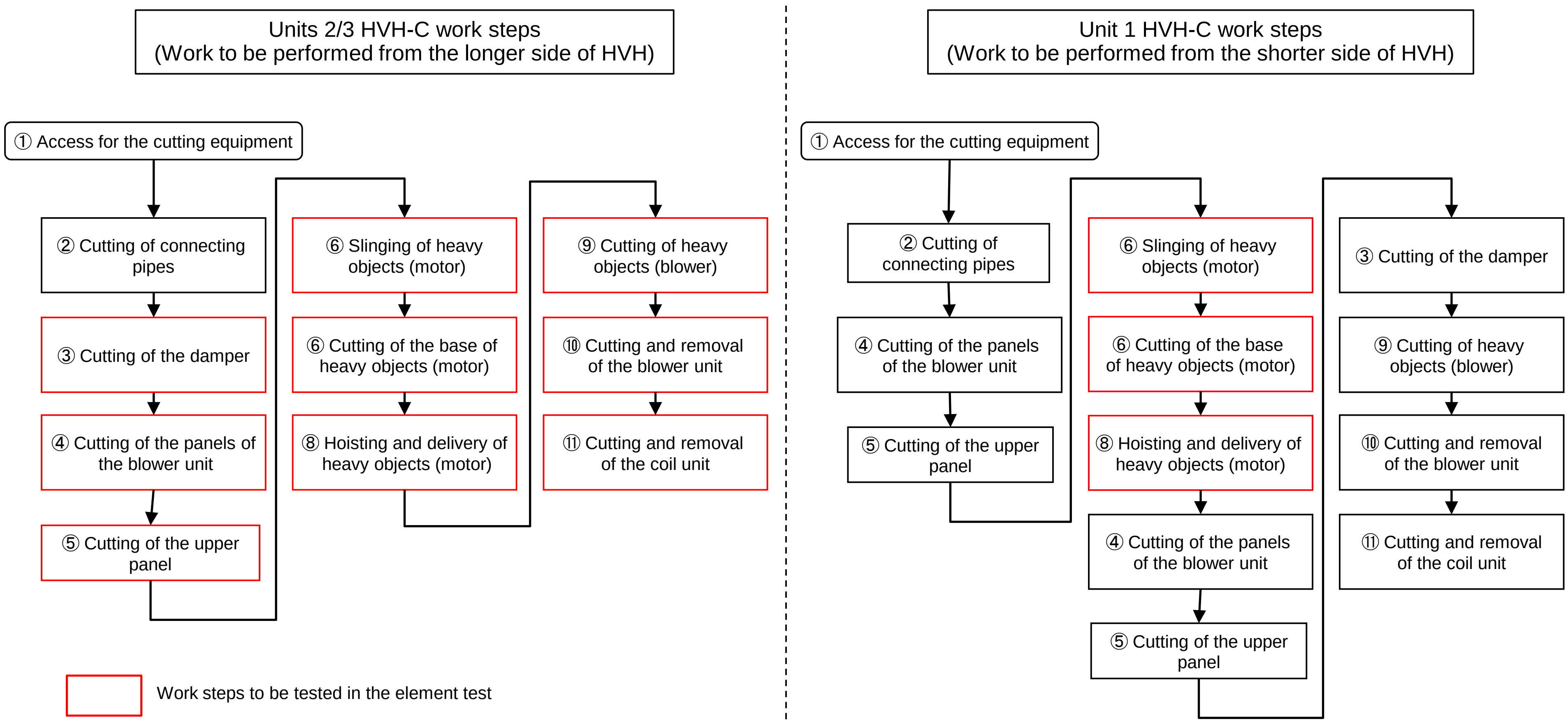
In the picture on the right, since manned work is underway, there is ambient light.
However, during the test work is carried out with only the light on the arm part of the HVH disassembly robot and the bird's eye camera + lights.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Work step

The main works from amongst the removal work steps are verified through element tests.



Note: The contents of this slide are cited from the results of the conceptual studies on HVH disassembly outsourced to TEPCO HD (Implemented in FY2020-21).

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Contents to be verified during the element tests

Work		Contents to be verified
Step	Contents	
(3) Damper removal	Cutting the damper	To verify the feasibility of the work of cutting at elevated locations and the work of collecting the disassembled pieces using the HVH disassembly robot, and the feasibility of access for the blades.
(4) Blower unit panel cutting	Cutting the panel on the outer periphery Cutting the frame	To verify the feasibility of the work of cutting at elevated locations and the work of collecting the disassembled pieces using the HVH disassembly robot, and the feasibility of access for the blades.
(5) Upper panel cutting	Cutting the upper panel Cutting the upper frame	To verify the feasibility of the work of cutting at elevated locations and the work of collecting the disassembled pieces using the HVH disassembly robot, and the feasibility of access for the blades.
(6) Heavy object (motor) slinging	Installing the motor hoisting accessory	To verify the feasibility of slinging work when the HVH disassembly robot and the lifting equipment are used in combination for the Units 2/3 HVH-C.
		To verify the feasibility of slinging work when the assist robot and the lifting equipment are used in combination for the Unit 1 HVH-C.
(7) Heavy object (motor) base cutting	Cutting the motor shaft / base	To verify the feasibility of cutting work when the HVH disassembly robot and the lifting equipment are used in combination for the Units 2/3 HVH-C. To verify the feasibility of access for the blades.
		To verify the feasibility of cutting work when the assist robot and the lifting equipment are used in combination for the Unit 1 HVH-C. To verify the feasibility of access for the blades. Also, to similarly verify whether the cutting equipment can access, although the structure of the Units 2/3 HVH-C and the motor base are different.
(8) Heavy object (motor) lifting and delivery	Hoisting / delivering the motor	To verify whether heavy objects can be lifted in confined spaces with the help of lifting equipment without interfering with the surrounding structures.
(9) Heavy object (blower) cutting	Cutting of casing	To verify the feasibility of the work of cutting at elevated locations and the work of collecting the disassembled pieces using the HVH disassembly robot, and the feasibility of access for the blades.
(10) Blower unit cutting and removal	Slinging the impeller Cutting the impeller Slinging / delivering the impeller	
(11) Coil unit cutting and removal	Cutting the cooling coil	To verify the feasibility of the work of cutting and the work of collecting the disassembled pieces using the HVH disassembly robot in confined spaces, and the feasibility of access for the blades.

Note: Each step corresponds to the work steps for Units 2/3 HVH-C on the previous page (Same is the case with the subsequent pages as well.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Overview of element test results

Work		Blades	Judgment	Results
Step	Contents			
(3) Damper removal	Cutting the damper	Tip saw Hole saw	○	It was verified that the damper can be cut and removed.
(4) Blower unit panel cutting	Cutting the panel on the outer periphery	Tip saw Hole saw	○	It was verified that the panel can be cut and removed.
	Cutting the frame	Centerless tip saw		It was verified that the frame can be cut and removed.
(5) Upper panel cutting	Cutting the upper panel	Tip saw Hole saw	○	It was verified that the upper panel can be cut and removed. It was verified that the upper frame can be cut and removed.
	Cutting the upper frame	Centerless tip saw		
(6) Heavy object (motor) slinging	Installing the motor hoisting accessory	-	○	It was verified that the motor hoisting accessory can be installed in the case of the placement in Units 2/3.
			○	It was verified that the motor hoisting accessory can be installed in the case of the placement in Unit 1.
(7) Heavy object (motor) base cutting	Cutting the motor shaft / base	Grindstone grinder	△	In the case of the placement in Units 2/3, since the motor hoisting accessory and the grindstone grinder interfered, the structure of the motor hoisting accessory needs to be modified. It was verified that the motor shaft / base can be cut.
		-	△	Based on the Units 2/3 results, it was found that similar issues would occur. It was decided that verification would be performed after modifying the structure of the motor hoisting accessory in the same manner as Units 2/3, and the test was resumed from the step after cutting.
(8) Heavy object (motor) hoisting and delivery	Lifting / delivering the motor	-	○	It was verified that the motor can be lifted and delivered in the case of the placement in Unit 1. It was verified that the motor can be lifted and delivered in the case of the placement in Units 2/3.
(9) Heavy object (blower) cutting	Cutting of casing	Centerless tip saw	○	It was verified that the casing can be cut and removed.
(10) Blower unit cutting and removal	Slinging the impeller Cutting the impeller Lifting / delivering the impeller	- Grindstone grinding -	○	It was verified that the slinging of the impeller is possible. It was verified that the impeller can be cut and removed. It was verified that the impeller can be lifted and delivered.
(11) Coil unit cutting and removal	Cutting the cooling coil	Centerless tip saw Grindstone grinder	○	It was verified that the cooling coil can be cut and removed.

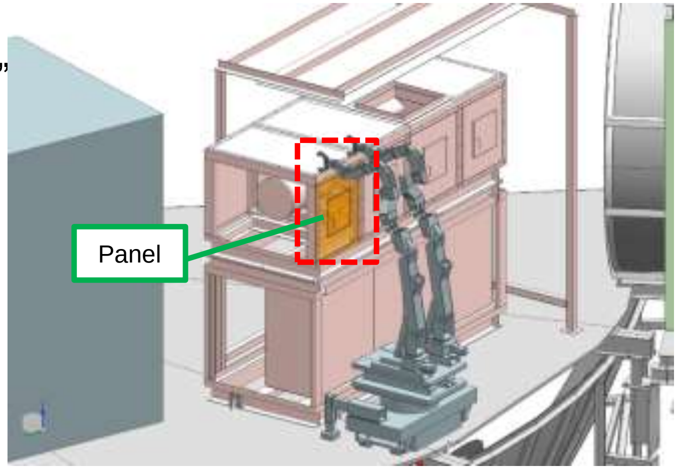
○ Good
△ Possible but there are issues

(Red box) Work steps that are explained on the following pages

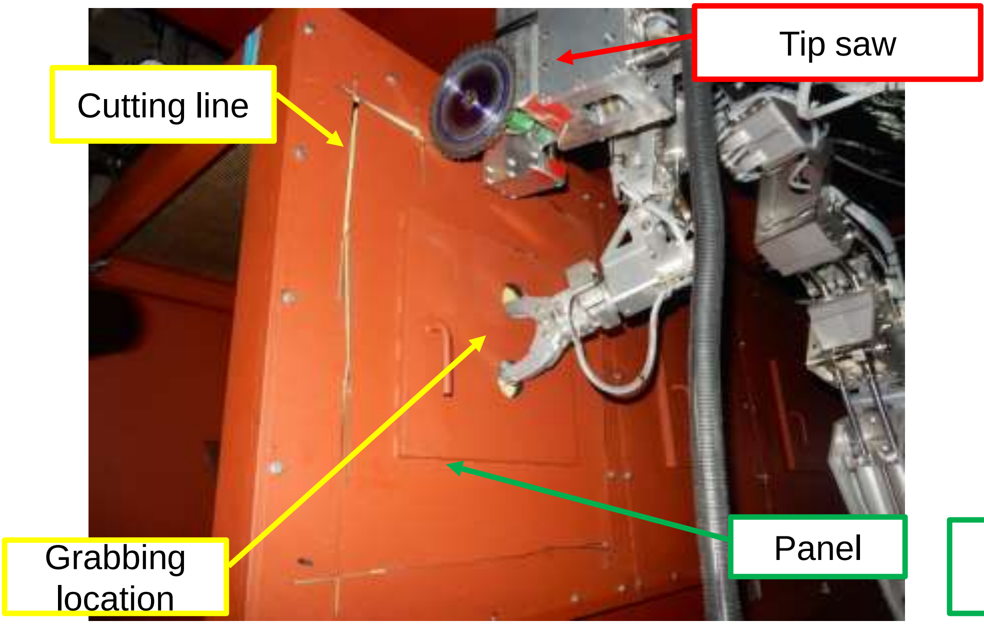
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

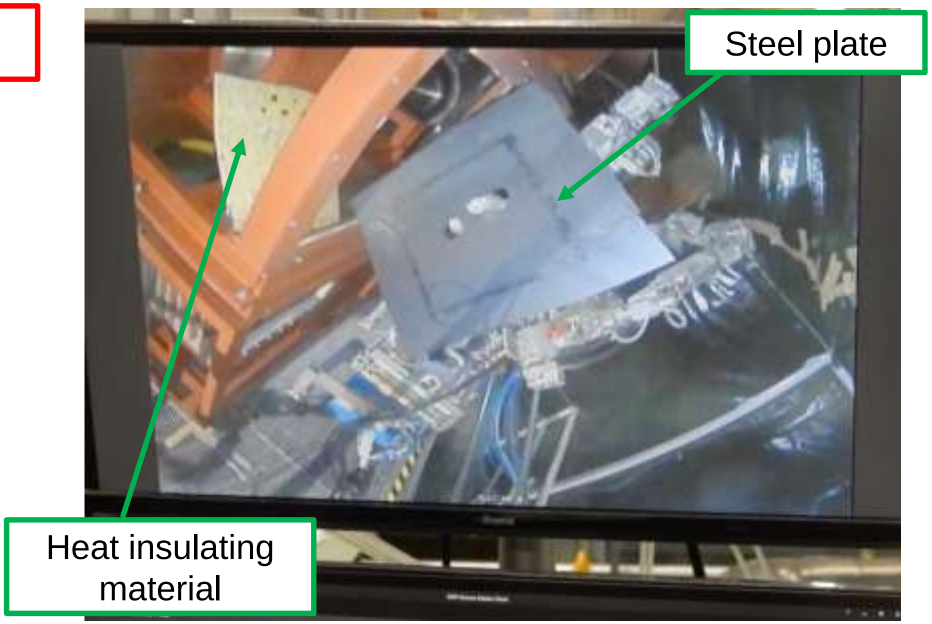
① HVH disassembly

➢ Element test results "④ Cutting of the panels of the blower unit"



It was verified that 3 layered panels installed at elevated location can be cut and removed.
The boring tracks of the hole saw were used for grabbing and the disassembled pieces were collected without letting them fall.
The tip saw is used to make multiple cuts, but it is difficult to align the position due to which the cutting lines did not connect. This issue was resolved by adding a slanted cutting-off assisting line.





6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Element test issues “④ Cutting of the panels of the blower unit”

While removing objects that have a broad surface such as damper, panels, etc., the cuttings lines did not connect. Modifications such as mounting a camera on the blade, etc. so that the operator can verify the area to be cut are required.
Also, since performing boring in advance using the hole saw so that the cutting lines connect, was an effective method as well, the cutting plan needs to be studied considering these factors.
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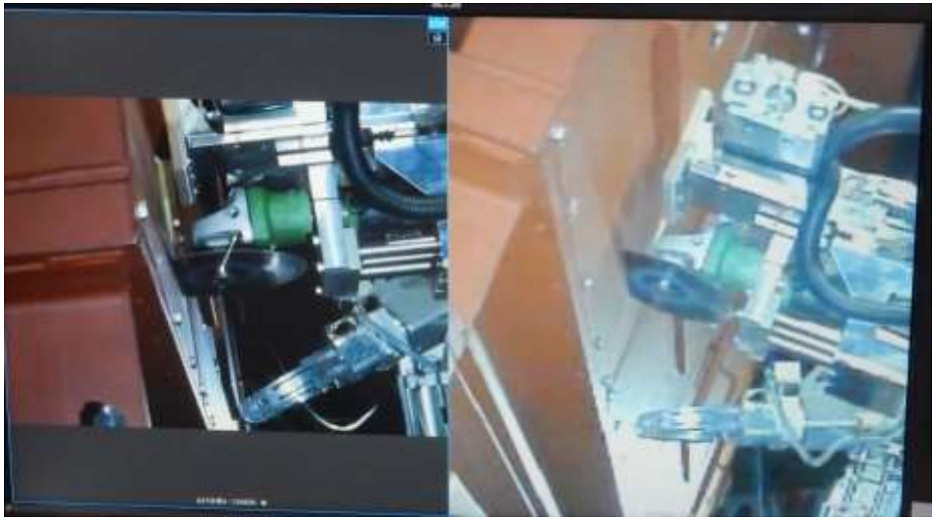
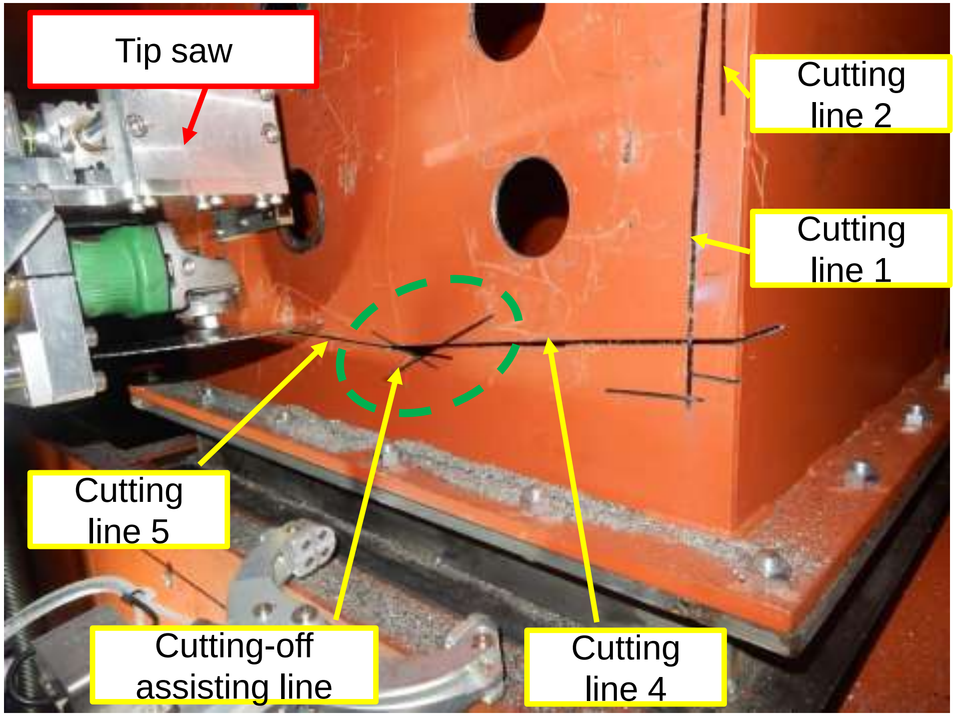


View point of the operator

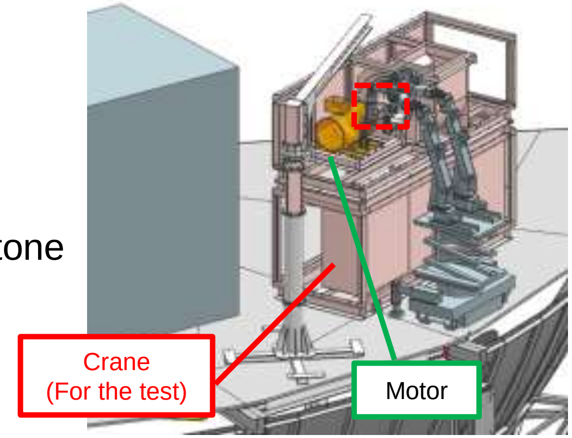


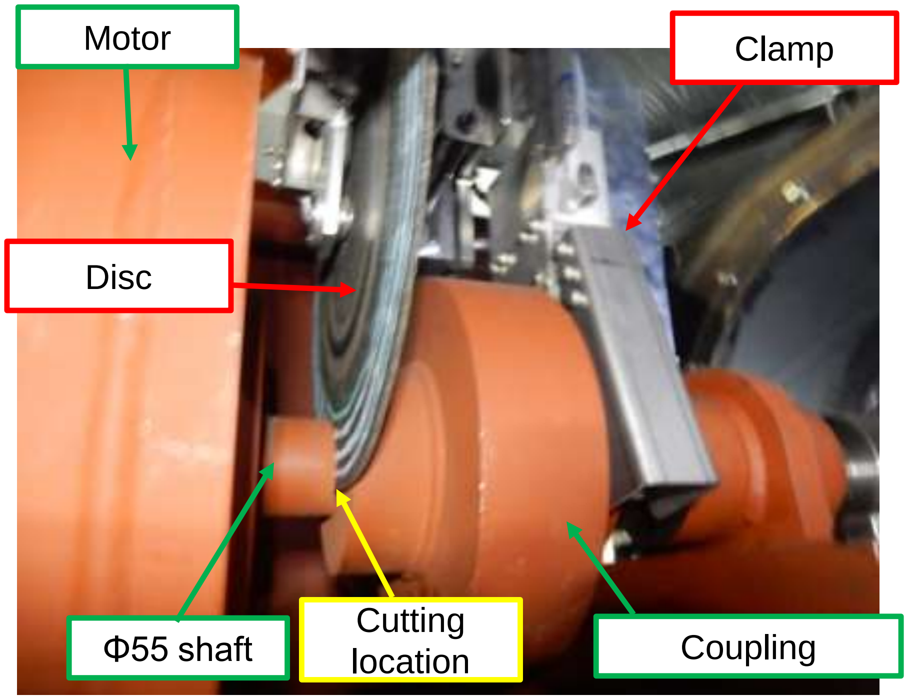
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

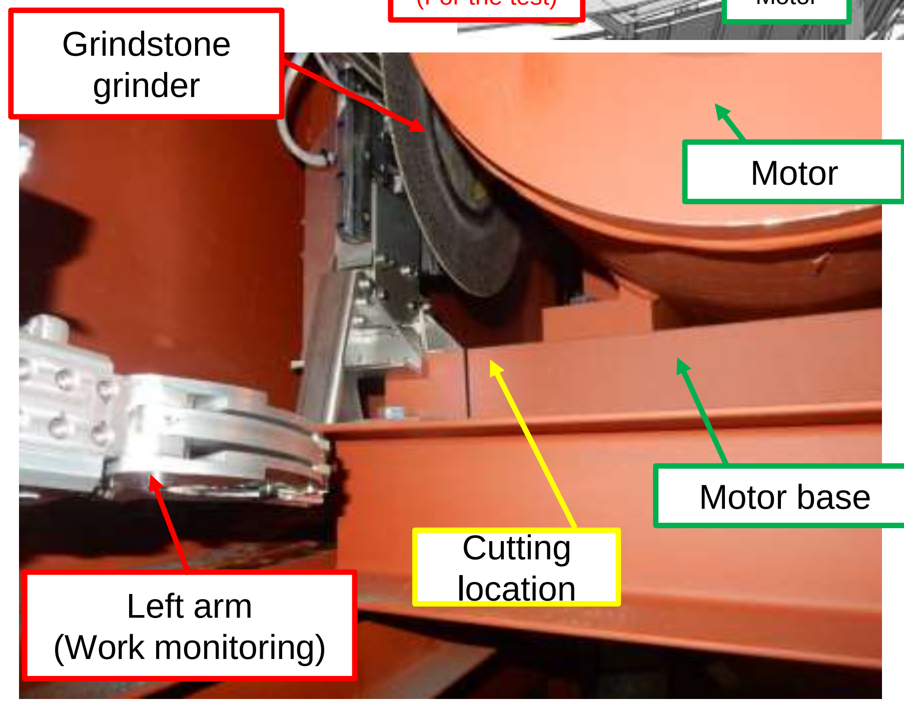
① HVH disassembly

- Element test results "⑦ Cutting of the base of heavy objects (motor)"

It was verified that the shaft and base of the motor installed at an elevated location can be cut and removed without allowing it to fall by working in combination with a crane.
While cutting the base of the motor, since there were locations that the grindstone grinder was unable to access, only for such locations temporary slinging was used to perform cutting work.





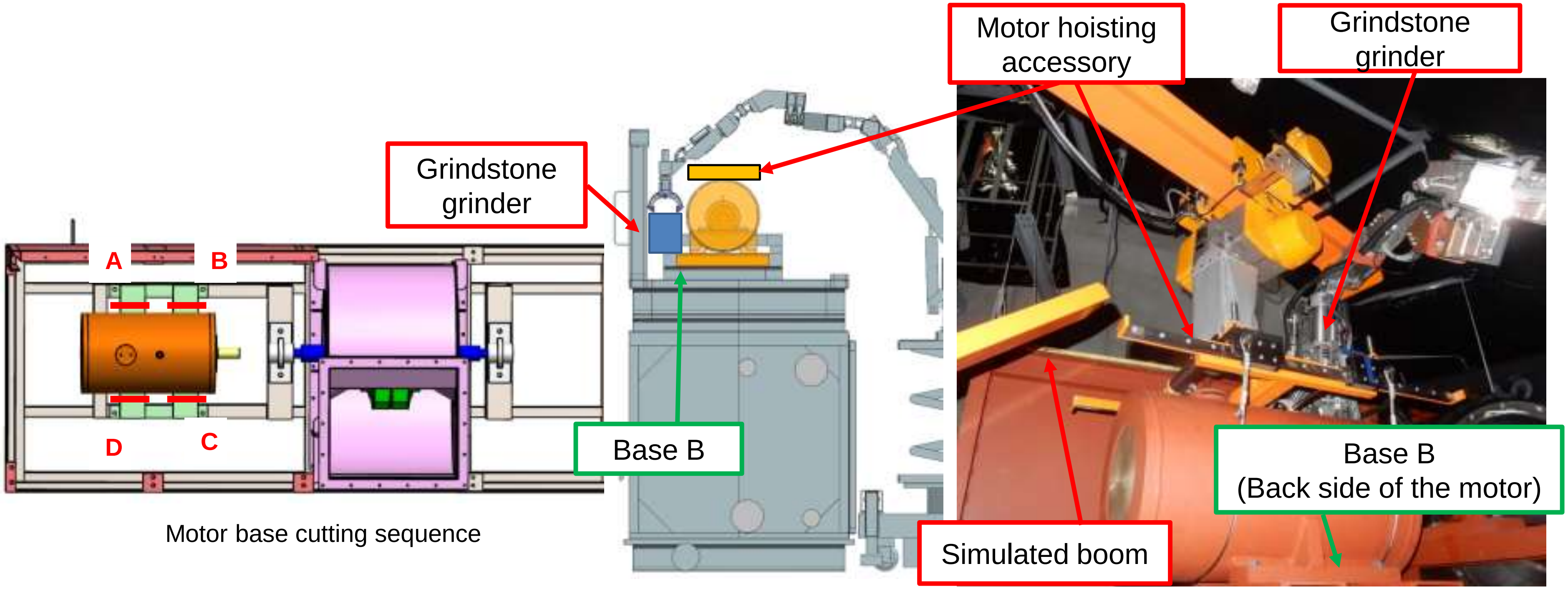


6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Element test issue "⑦ Cutting of the base of heavy objects (motor)"

Base B was unable to be cut due to the interference of the motor hoisting accessory and the grindstone grinder.
The plan was to install the motor hoisting accessory after cutting base A, and then to cut base B, but due to the confined space the grindstone grinder was unable to access it.
At the planning stage the grindstone grinder was expected to be able to access, but the access space reduced due to the limited field of vision of the operator.
As position alignment is expected to be possible by increasing the field of vision and expanding the access space, the structure of the motor hoisting accessory needs to be studied once again.



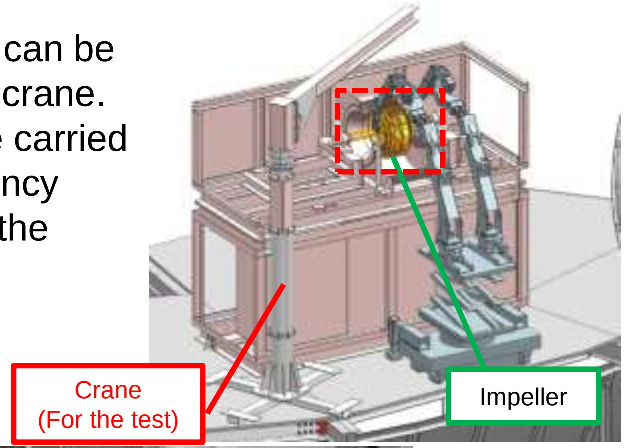
Motor base cutting sequence

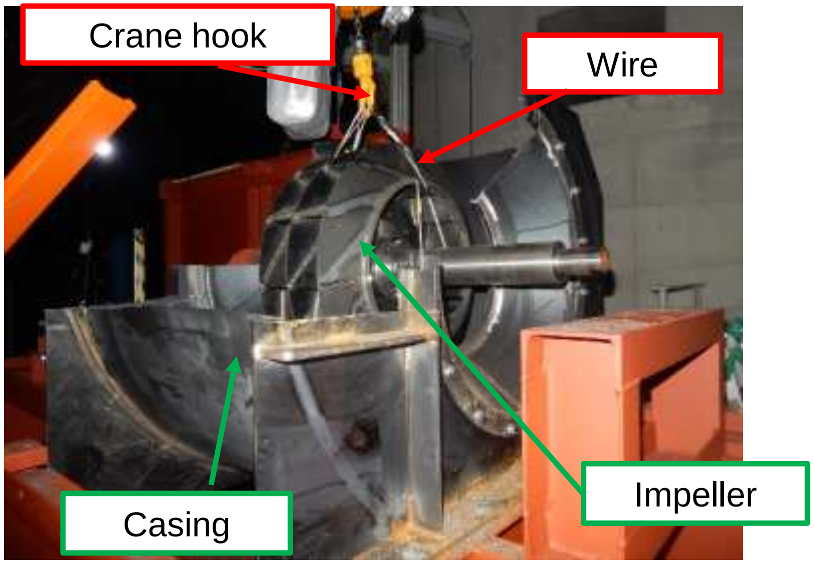
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

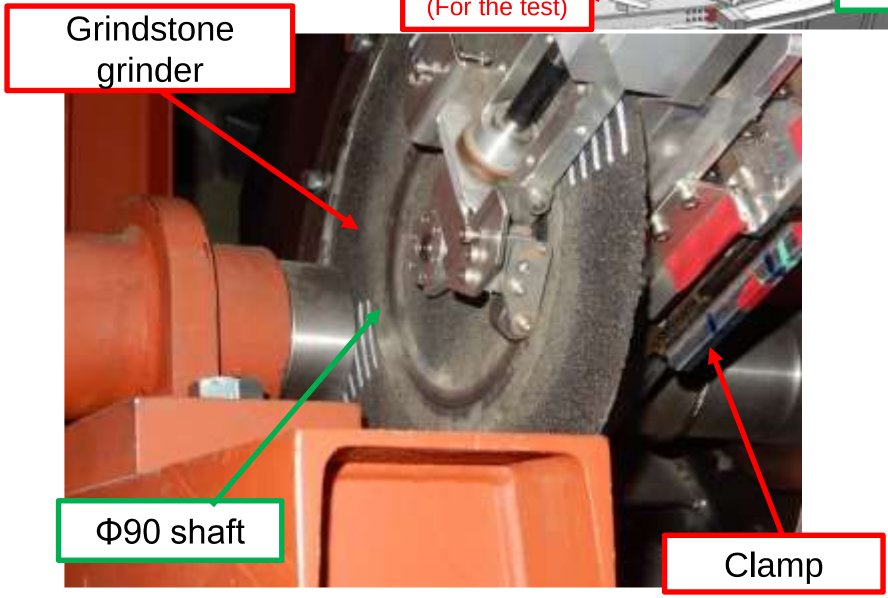
① HVH disassembly

➢ Element test results "⑩ Cutting and removal of the blower unit (Impeller)"

It was verified that the shaft of the impeller installed at an elevated location can be cut and removed without allowing it to fall by working in combination with a crane. Slinging of the impeller shaft and the work of cutting the impeller shaft were carried out in a confined space. While cutting the Φ90mm impeller shaft, the efficiency dropped during the latter half of the cutting process, but it was verified that the shaft can be cut.





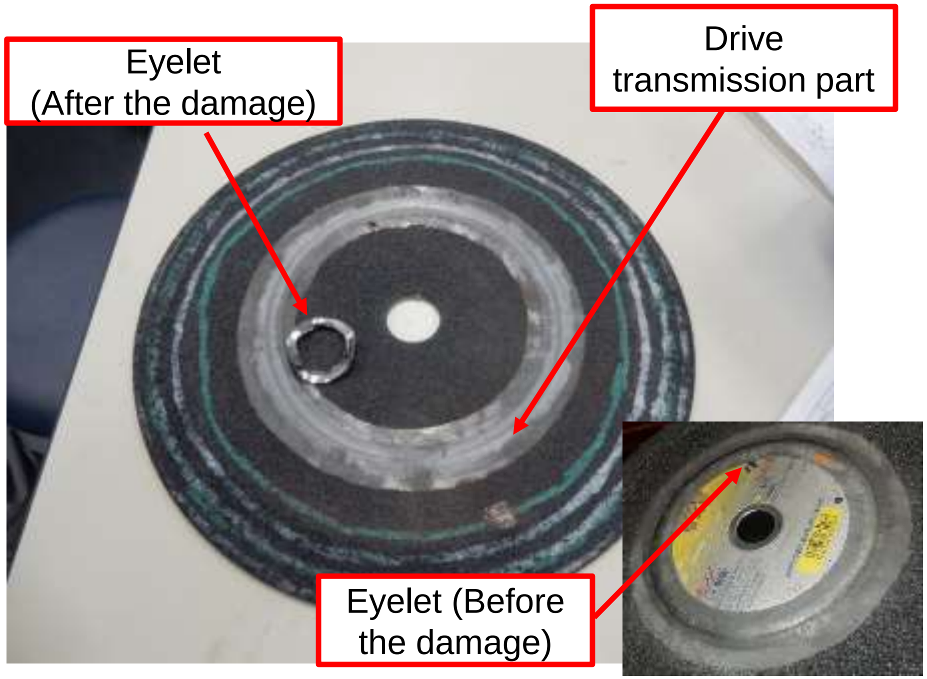


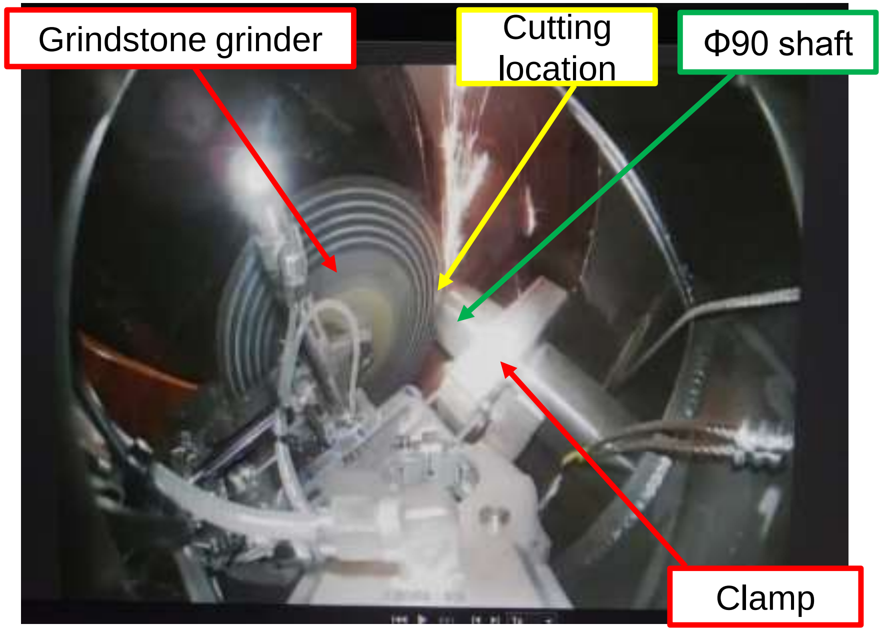
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Element test issue “⑩ Cutting and removal of the blower unit (Impeller)”

While cutting, the bearing of the disc of the grindstone grinder wore and needed to be replaced.
The structure of the grindstone grinder is such that the disc can be replaced through remote operation, and replacement is within expectation. However, although replacement of the disc had been expected, wearing of the bearing had not been expected.
As it is desirable to not have to replace the disc while cutting the shaft, reinforcement of the portion that wears off needs to be considered.

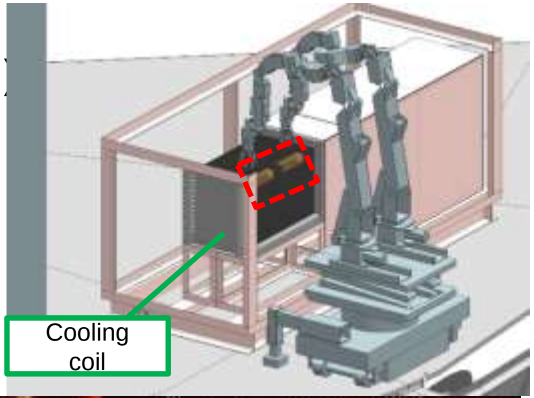




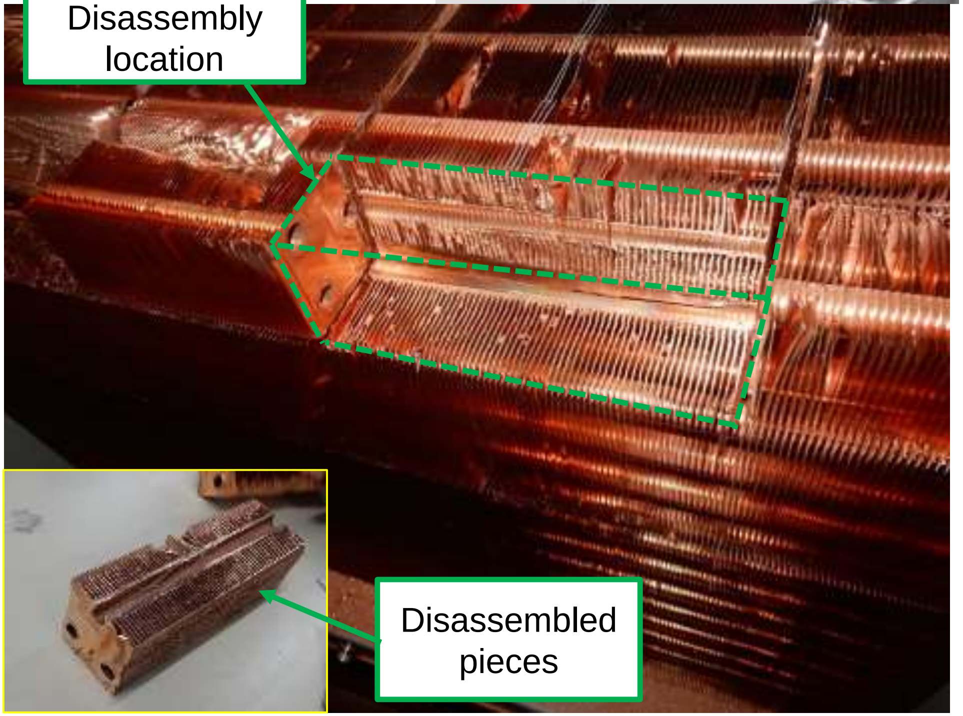
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Element test results “⑪ Cutting and removal of the coil unit (cooling coil)



It was verified that the cooling coil can be cut and removed using a centerless tip saw and a grindstone grinder.
However, in either case, cutting efficiency declined severely at a depth of 60mm or more. Also, in the case of centerless tip saw, the disassembled pieces sometimes got caught into the hole at the center and the saw got stuck.

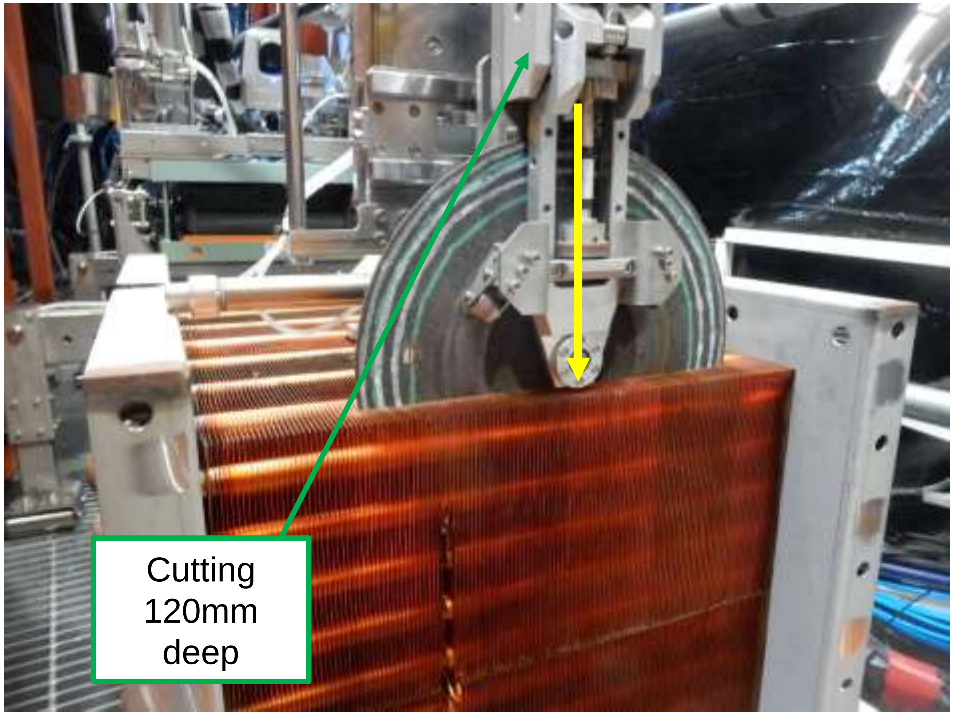


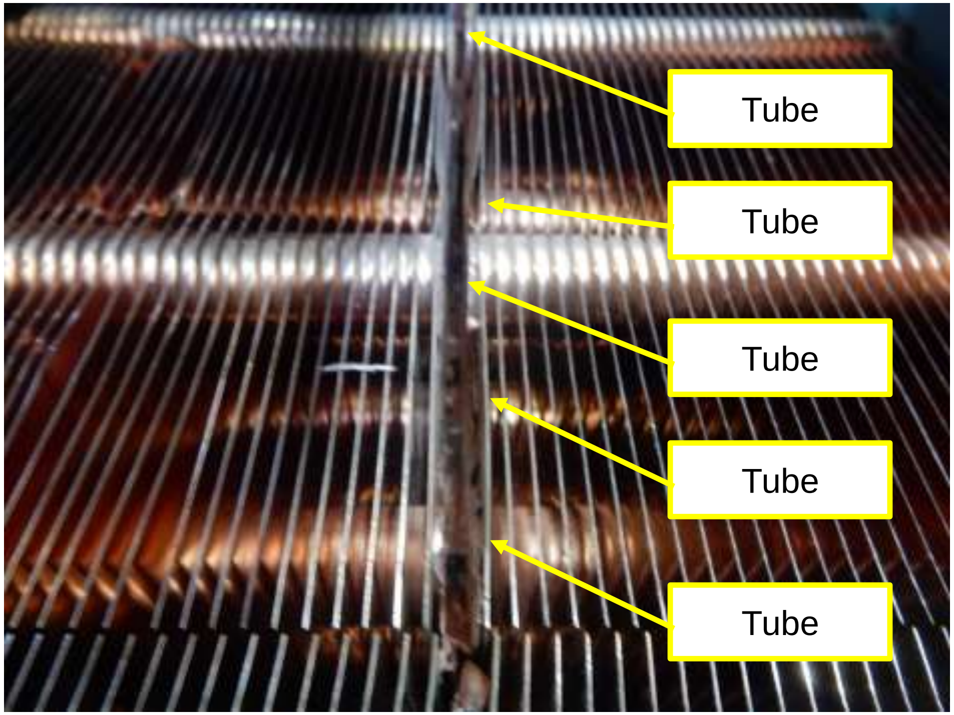
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

➢ Element test issues "⑪ Cutting and removal of the coil unit (cooling coil)"

In the case of the centerless tip saw as well as in the case of the grindstone grinder, when deeper cutting was performed, the area of contact increased due to which the rotational speed decreased leading to a decline in cutting efficiency. In the case of the grindstone grinder, it was verified that cutting can be performed up to the boundary, but it took an extremely long time.
Methods to reduce the time required including change in the cutting location needs to be studied.

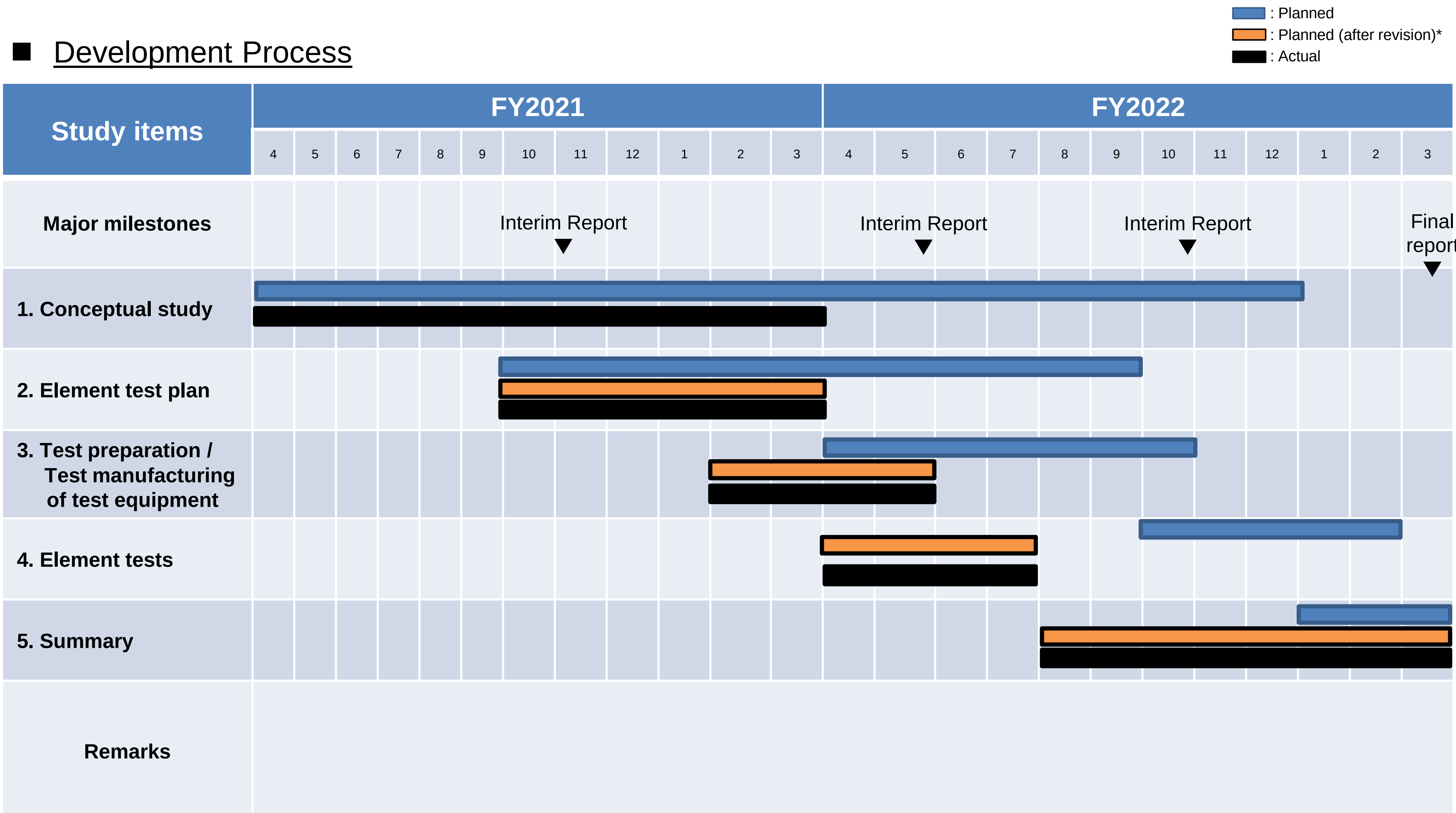




6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly

■ Development Process



* The plan was revised to reflect the study progress status and the results of element tests.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

① HVH disassembly: Summary

- **In FY2021, results of studies conducted on HVH disassembly concerning the selection of items to be tested based on the pre-conditions and level of difficulty of disassembly, selection of circular saw and grindstone grinder as the cutting technology, and identification of element test items based on the disassembly work steps were compiled. The work steps were examined in detail, issues in each of the steps were identified, an element test plan was formulated, and the test items, judgment criteria, etc. were studied.**

- **Unit tests (tests conducted using the stand-alone equipment outside the simulated environment) related to cutting were conducted, and the course of cutting was substantiated through element test.**

- **Element tests were conducted to verify the feasibility of the method of disassembling and removing the HVH, and the results were consolidated.**

- **Issues in application to the actual facility were identified, and the plan for reflecting them into the equipment design for the actual facility was consolidated.**

② Disassembly of CRD exchanger

Development is being carried out concerning disassembly, removal, etc. of interfering objects for further increasing the scale of retrieval of fuel debris and reactor internal structures. Technology for verifying the feasibility of the work of cutting and collecting pipes by accessing the inside of the pedestal within the PCV using remote controlled equipment, was developed so far.

It is absolutely necessary to remove the CRD exchanger, which is a large structure located at the center inside the pedestal, in order to ensure accessibility for carrying out the work of retrieval of fuel debris from the bottom part inside the pedestal. Also, as the pedestal opening from where the remote controlled disassembling equipment will enter inside the pedestal is small, the equipment needs to be able to operate in a small and uncertain on-site environment. Moreover, any interference with the CRD housing, etc. which is found to be damaged based on the results of PCV internal investigation, needs to be avoided, and the members of the CRD exchanger that will be disassembled need to be prevented from falling. During the development concerning this, upon studying and consolidating the requirements for disassembling and removing the CRD exchanger, elemental tests using simulated test pieces will be planned and implemented considering remote operation in limited space, and the feasibility of specific cutting/collection methods will be verified.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

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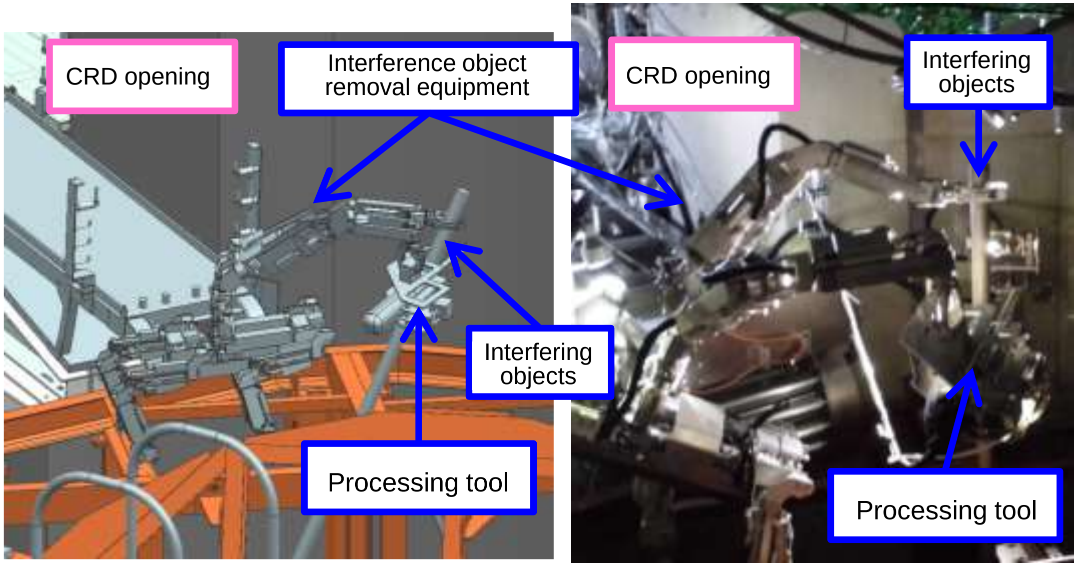
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Status of studies conducted up to FY2020

The method of accessing inside the pedestal and the method of removing small interfering objects such as the ICM housing, etc. were studied, and prospects of these methods being feasible were seen through elemental tests.
(Implemented as part of “Further increasing the scale of retrieval (Implemented in FY2019- 20): Method of removing interfering objects from inside the pedestal (Small equipment method)”)



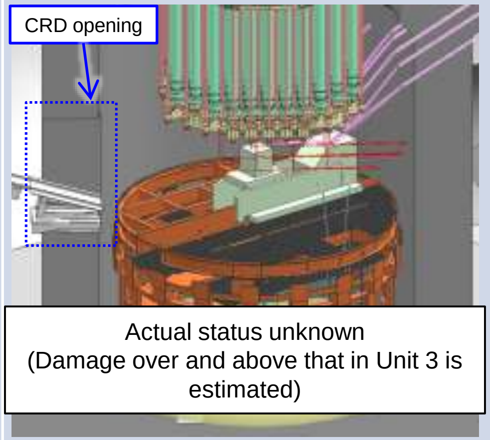
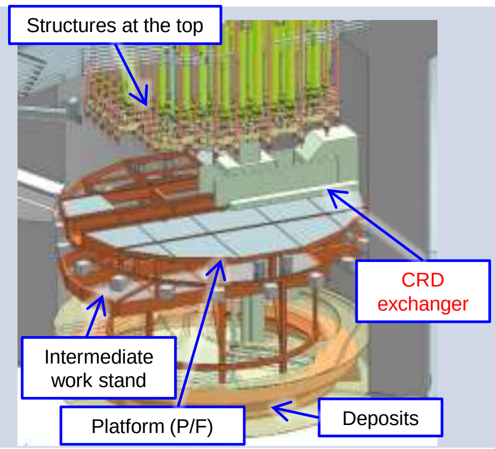
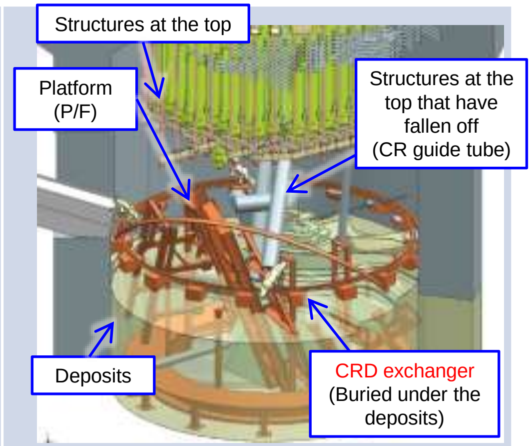
- The method of disassembling the CRD exchanger (large structure) that becomes an obstacle in the work of fuel debris retrieval, within the limited space inside the pedestal is studied.
- The disassembling equipment used in this method of disassembling the CRD exchanger is test manufactured and verified.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ On-site conditions (Estimation of the status inside the pedestal)

➢ The estimated status inside the pedestals in Units 1 - 3 is given below.

	Unit 1	Unit 2	Unit 3
Illustration showing the status inside the pedestal			
Results of estimation	The inside of the pedestal has not been investigated. (The above figure shows sound conditions)	The following was estimated based on the results of investigation • The platform (P/F) is remaining, and a part of the grating has fallen off. • The CRD exchanger is remaining on the P/F. • The intermediate work stand is remaining. • There are deposits at the bottom of the pedestal. (The status inside the deposits is unknown)	The following was estimated based on the results of investigation • The platform (P/F) and the CRD exchanger have fallen off. • The structures at the top (CR guide tube, etc.) have fallen off. • There are deposits at the bottom of the pedestal. (The status inside the deposits is unknown)

- In Unit 2, the CRD exchanger remains on the P/F, and its location and status have been ascertained. Also, the status of the P/F and the intermediate work stand (places where the grating has fallen off, etc.) has been ascertained.
- In Unit 3, the CRD exchanger has fallen off from the P/F, is buried under the deposits, and its location and status have not been identified.
- In Unit 1, as damage over and above that in Unit 3 is estimated, it is speculated that the status will be the same as Unit 3.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

Issues

- Ensuring that the disassembly and removal equipment is able to access the area around the CRD exchanger.
- Disassembling and removing the CRD exchanger, which is a large structure, using a small equipment that can be carried in through the CRD opening.
- Disassembling and removing the CRD exchanger, which is a large structure, into as large pieces as possible, in order to improve throughput.
- [Specific to Unit 2] Disassembling and removing the CRD exchanger, which is a large structure that hangs from the platform (P/F), without letting it fall to the bottom of the pedestal.
- [Specific to Units 1/3] Disassembling and removing the CRD exchanger (including other structures) that has fallen and gotten entangled without letting it collapse.

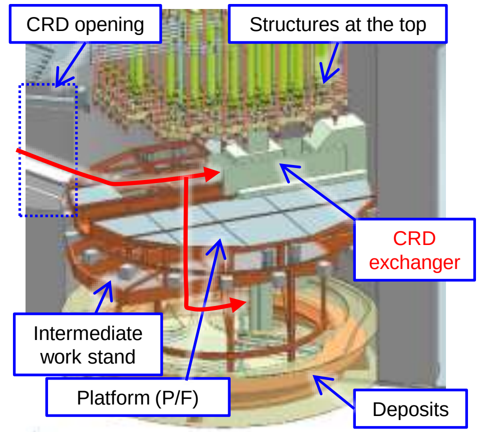


Figure illustrating the estimated conditions inside the pedestal (Unit 2)

Implementation details

- Various preconditions including the dimensions, etc. of the structures are consolidated.
- Requirements related to disassembling and removing the CRD exchanger are studied and compiled.
- The method of disassembling and removing the CRD exchanger is studied.
- The disassembly and removal equipment is designed and test manufactured.
- Element tests are planned considering remote operation in limited space.
- Simulated test pieces and full scale testing equipment are designed and test manufactured for conducting the tests.
- Feasibility of specific disassembly and removal is verified by element tests.

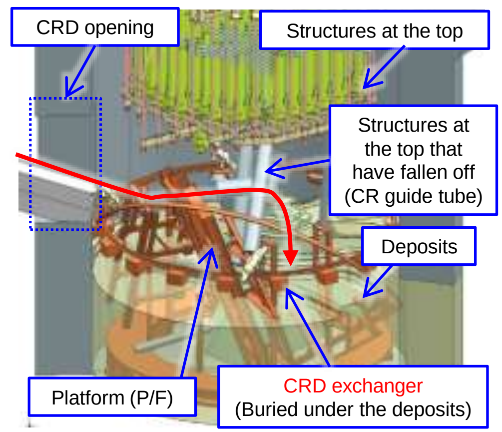


Figure illustrating the estimated conditions inside the pedestal (Units 1/3)

Expected outcome

- Presentation of the method of disassembling and removing the CRD exchanger.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [1/12]

The preconditions at the time of studying the method of disassembling have been compiled under the following 9 items based on the site status and information in the drawings.

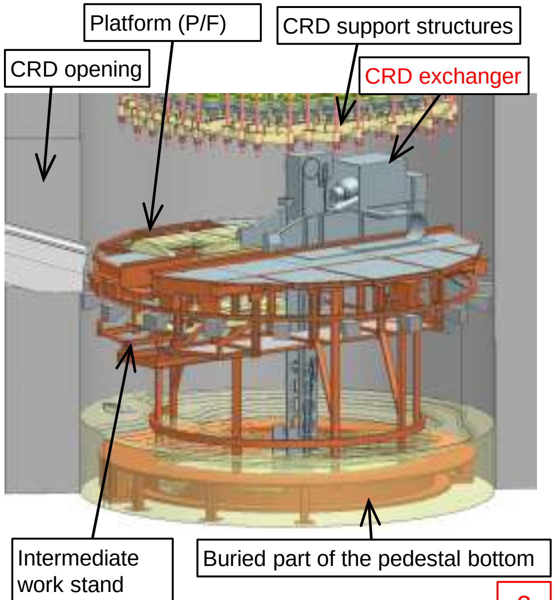
① Specifications of the CRD exchanger
② Specifications of the P/F
③ Specifications of the intermediate work stand
④ Specifications of the interfering objects (structures on top of the pedestal) around the CRD exchanger
⑤ Status of the deposits at the pedestal bottom, and scope of removal of the CRD exchanger
⑥ Access route to be used
⑦ Interfering objects on the access route
⑧ Transfer method
⑨ Range of access

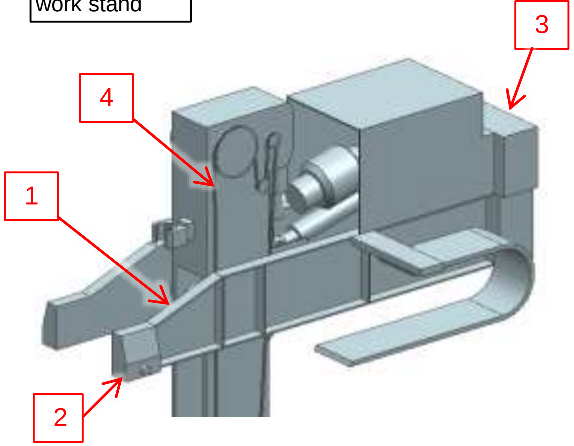
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

- Compilation of various pre-conditions [2/12] [① Specifications of the CRD exchanger [1/3]]

No.	Items	Specifications	Remarks
1	Trolley frame	[Dimensions] Height: 400 [mm], Width: 117 [mm], Length: 2,700 [mm] [Material]: SS400 [Thickness]: 20 [mm] [Mass]: Approx. about 100 [kg]	• The dimensions and plate thickness are estimates. • Mass of one side • Mass is a rough value
2	Wheels for traveling	[Dimensions] Diameter: Φ100 [mm], Thickness: 143 [mm] [Material]: S45C [Mass]: Approx. about 18 [kg]	• The dimensions and plate thickness are estimates • Mass is a rough value
3	Trolley drive unit	[Dimensions], [Material] [Thickness], [Mass] : Acquired at the stage of designing the actual facility	
4	Chain for the lifting carriage	[Dimensions], [Material], [Mass] : Acquired at the stage of designing the actual facility	





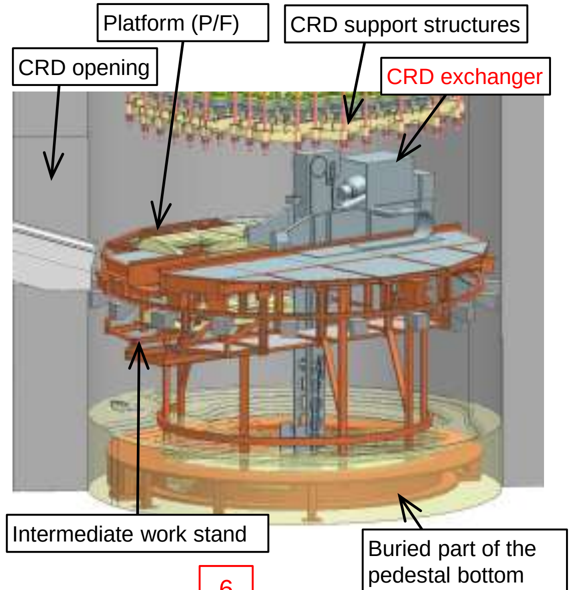
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

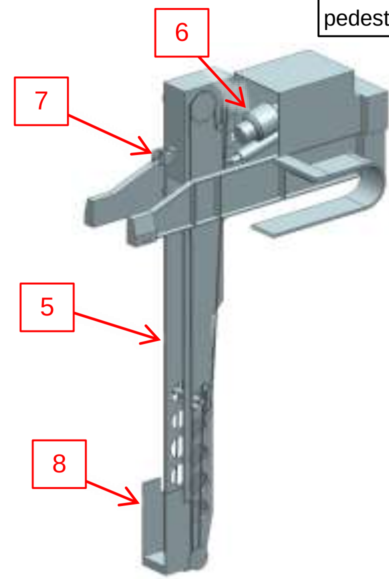
② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [3/12] [① Specifications of the CRD exchanger [2/3]]

No.	Items	Specifications	Remarks
5	Rotating frame	[Dimensions] Height: 4,351 [mm] Width: 370 [mm] (With shaft for rotating the hoisting axis: 450 [mm]) Length: 600 [mm] (estimated) Diameter of the shaft for rotating the hoisting axis: Φ100 [mm] (estimated) Frame rotating equipment shaft: φ75 [mm] (estimated) [Material]: Frame: SS400 Shaft: S45C (estimated) [Thickness]: 30 [mm]* [Mass]: Approx. about 800 [kg]	• The plate thickness is an estimate. • Mass is a rough value.
6	Frame rotating equipment	[Dimensions], [Material], [Thickness], [Mass]: Acquired at the stage of designing the actual facility	
7	Grabbing arm	[Dimensions], [Material], [Thickness], [Mass]: Acquired at the stage of designing the actual facility	
8	Hoisting carriage	[Dimensions] (estimated) Height: 775 [mm], Width: 370 [mm], Length: 270 [mm] [Material] SUS304 [Thickness]: Approx. 5 [mm] [Mass]: Approx. about 120 [kg]	• Dimension and plate thickness are estimates. • Mass is a rough value.

* Unit 1: Approx. 10 to 20mm.



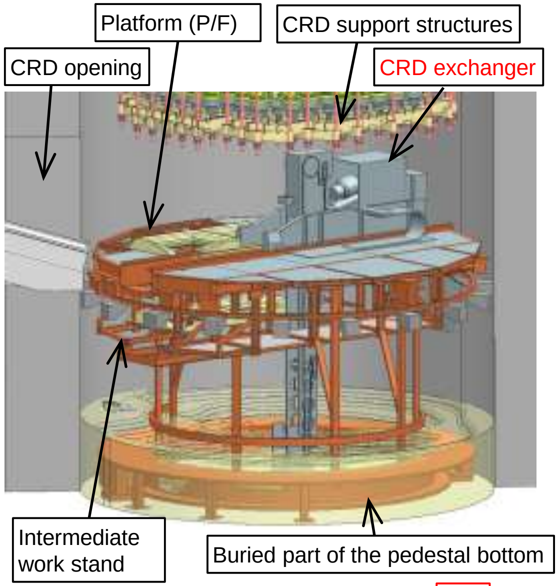


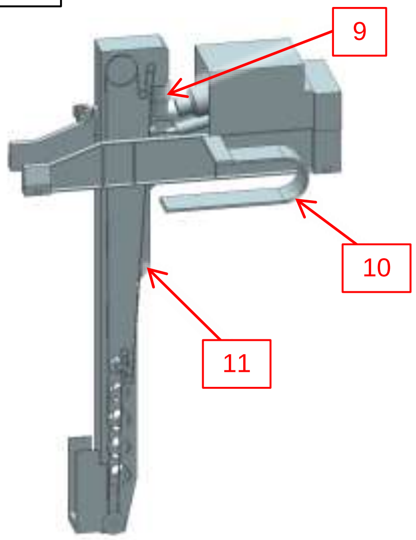
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [4/12] [① Specifications of the CRD exchanger [3/3]]

No.	Items	Specifications	Remarks
9	Hoisting drive unit	[Dimensions], [Material], [Thickness], [Mass]: Acquired at the stage of designing the actual facility	
10	Power supply unit (Cableveyor)	[Cable size]: Φ25 [mm] [Dimensions of connecting plate] 175 x 50 x 10t [mm] (U-shaped steel), Length: 540 [mm] [Material]: SUS304 (Connecting plate, cableveyor) Aluminum alloy (Cables) [Thickness]: 10 [mm] (Thickness of the connecting plate) [Mass]: Cableveyor (including the connecting plate): Approx. about 260 [kg] Cables (on the F/P): Approx. about 20 [kg] per cable	• Estimate • There are 10 cable (estimated)
11	Other drive units	[Dimensions], [Material], [Thickness], [Mass]: Acquired at the stage of designing the actual facility	• Embedded inside the rotating frame
12	Overall	[Dimensions] Height: 4,351 [mm] Width: 736 [mm] Length: 2,700 [mm] Mass: Approx. 2,000 [mm]	
13	Layout	[Height from the opening at the center] Up to the upper end of the exchanger: 1,170 [mm] (From the upper end of the exchanger to the hanger rod: 463.2 [mm]) Up to the upper end of the actuator: 979 [mm] (Upper end of the actuator to the hanger rod: 654.2 [mm])	



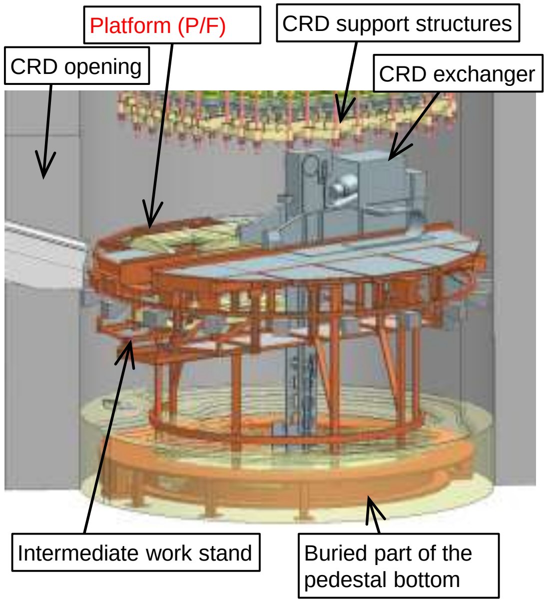


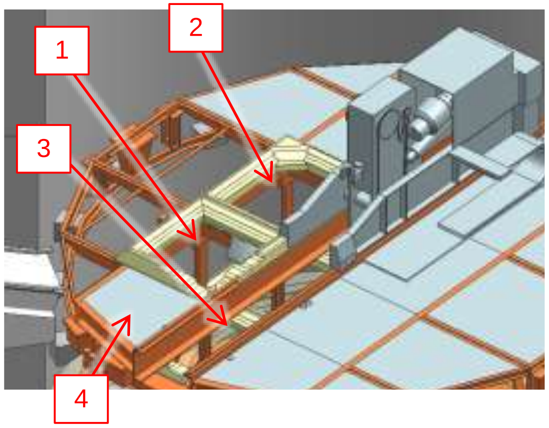
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [5/12] [② Specifications of the platform (P/F)]

No.	Items	Specifications	Remarks
1	Opening G	[Dimensions (as per the drawings)] Width: 755 [mm], Depth: 915 [mm] [Dimensions (when deposits are remaining)] Width: 682.25 [mm], Depth: 765 [mm]	• Estimate
2	Opening H	[Dimensions (as per the drawings)] Width: 598.1 [mm], Depth: 1,093 [mm] [Dimensions (when deposits are remaining)] Width: 657.25 [mm], Depth: 893 [mm]	• Estimate
3	Opening at the center	[Dimensions (as per the drawings)] Width: 596 [mm], Depth: Approx. 2,500 [mm]	• Estimate • It is assumed that the size of the opening has not reduced due to deposits.
4	Grating	[Height]: Maximum 38 [mm]	• Estimate • Acceptable maximum load of the grating is assumed to be 250 [kg/m^2] (This is 50 [%][Note] of the general strength indicator specified by the grating manufacturer.)
5	Layout	[Height] From the pedestal bottom to the top of the central rail: 3,281 [mm] From the pedestal bottom to the P/F grating: 3,200.8 [mm] From the top of the P/F to the hanger rod: 1,633.2 [mm]	• Estimated from Unit 4 It is assumed that the P/F cannot rotate due to damage. • The acceptable maximum load of the P/F is assumed to be the same as that of the grating. • The P/F and CRD exchanger are assumed to be fixed. However, the fixation of the P/F is assumed to be unstable (is likely to get detached due to impact, etc.).





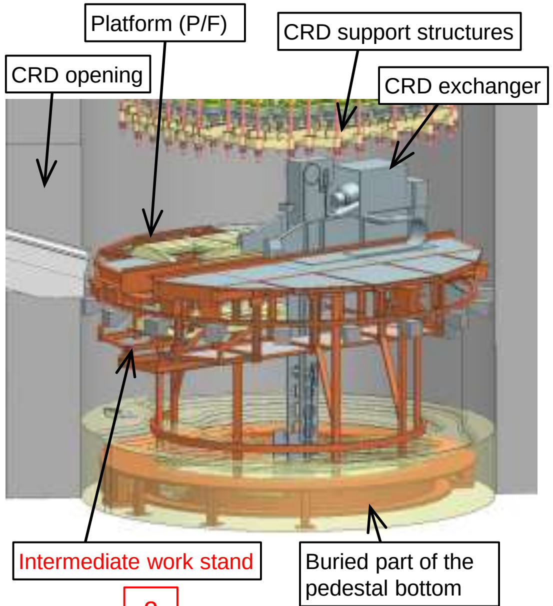
Note) There are no grounds for 50%. It will be revised if it is found to be difficult to work with.

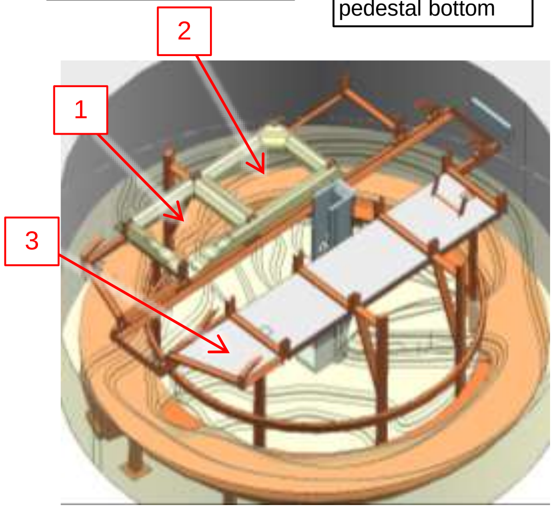
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [6/12] [③ Specifications of the intermediate work stand]

No.	Items	Specifications	Remarks
1	Opening G2	[Dimensions (as per the drawings)] Width: 800 [mm], Depth: 915 [mm]	• Estimate
2	Opening H2	[Dimensions (as per the drawings)] Width: 800 [mm], Depth: 1,090 [mm]	• Estimate
3	Grating	[Height]: Acquired at the stage of designing the actual equipment	
4	Layout	[Height] From the pedestal bottom to the intermediate work stand grating: 2,192 [mm]	• The intermediate work stand and CRD exchanger are assumed to be fixed. However, the fixation of the intermediate work stand is assumed to be unstable (is likely to get detached due to impact, etc.).





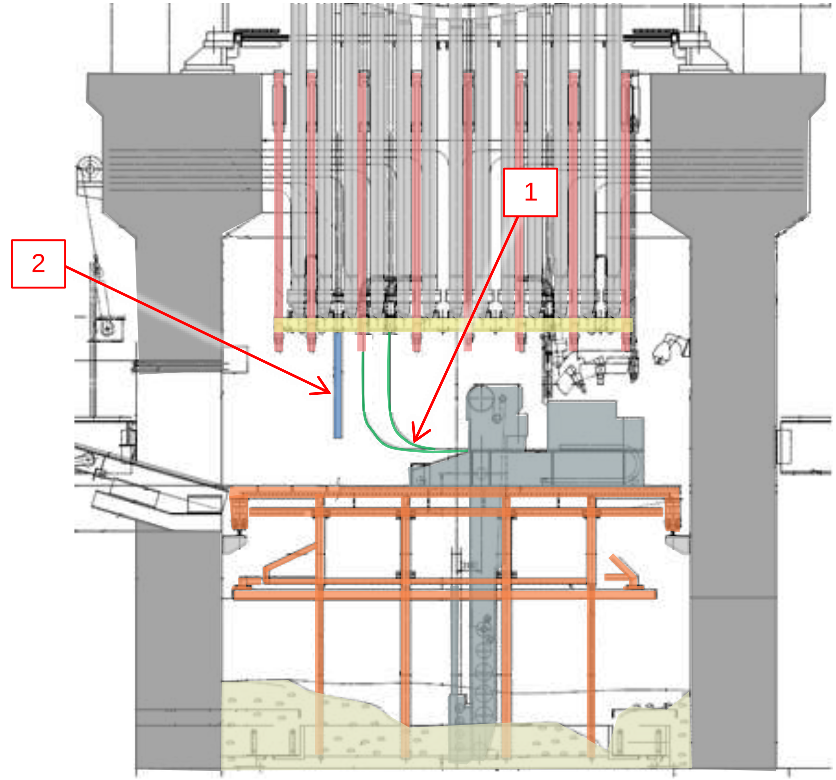
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

- Compilation of various pre-conditions [7/12] [④ Specifications of the interfering objects (structures on top of the pedestal) around the CRD exchanger]

Interfering objects that need to be removed before removing the CRD exchanger were identified. The identified items are listed below.

No.	Interfering objects	Specifications	Remarks
1	TIP guide tube	[Outer diameter]: Φ9.525 [mm] [No. of tubes]: 31 tubes [Material]: SUS304-TP	• (Unit 4)
2	TIP guide tube support	[Dimensions]: Height: 75 x 75 x t9 [mm] (U- shaped steel) Length: approx. 1,600 [mm] (From the top of P/F to the bottom end: 632.2 [mm]) [Mass]: Approx. about 25 [kg] [No. of supports]: 10 - 20 (assumed) [Material]: SUS304 (estimated)	• Used only in Unit 2

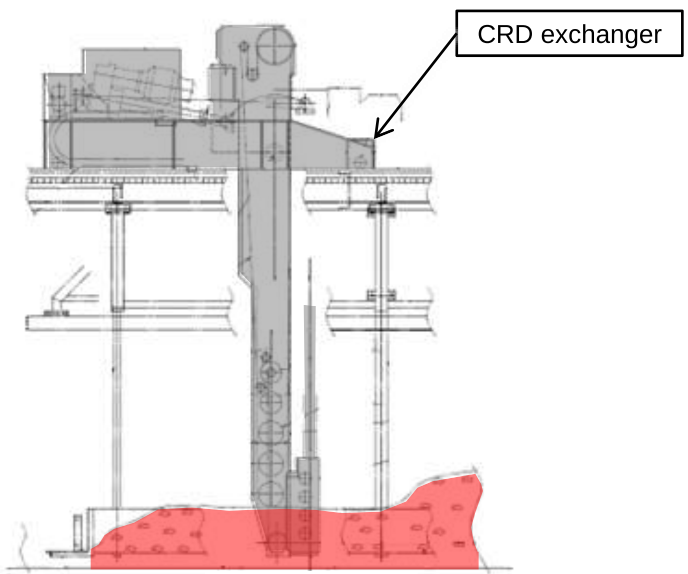


Vertical cross section of the CRD exchanger and other structures inside the pedestal

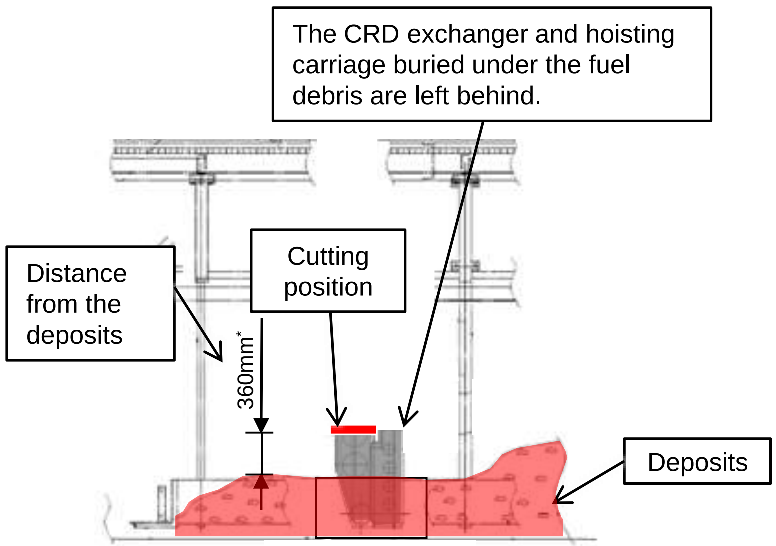
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

- Compilation of various pre-conditions [8/12] [⑤ Status of the deposits at the pedestal bottom, and scope of removal of the CRD exchanger]
  - The scope of removal of the CRD exchanger, which is common for Units 1 - 3, includes the structures other than the CRD exchanger and hoisting carriage that are buried under the deposits at the pedestal bottom. (The CRD exchanger and the hoisting carriage are assumed to be stuck in the deposits.)
  - For the CRD exchanger in Unit 2, the hole portion will be cut so that the cross sectional area at the time of cutting becomes small. Also, in order to secure distance between the cutting position and the deposits for availability of installation of blades, the CRD exchanger left behind is assumed to be at a height of 360mm# from the surface of the deposits.



Before removing the CRD exchanger (Example of Unit 2)



After removing the CRD exchanger (Example of Unit 2)

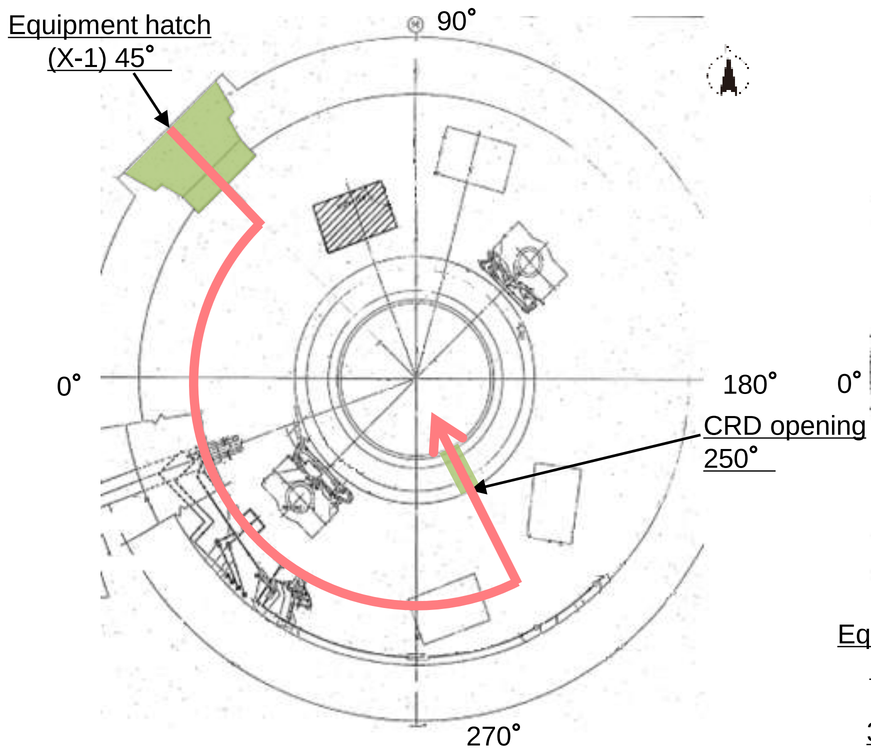
#Estimated.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

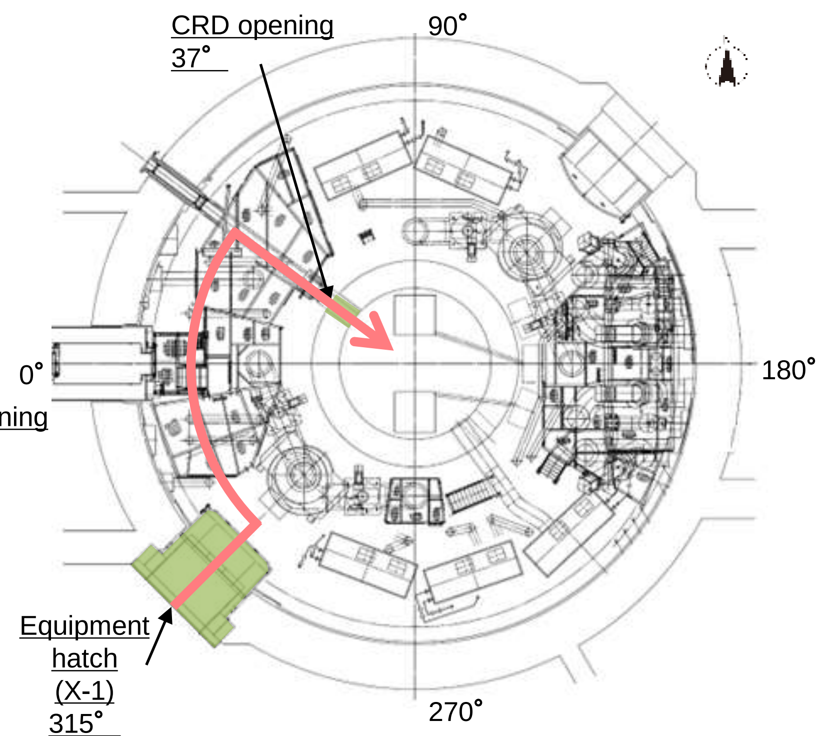
② Disassembly of CRD exchanger

■ Compilation of various pre-conditions [9/12] [⑥ Access route to be used]

- The shorter route outside the pedestal from X-1B to the CRD opening is considered as the access route.
- The same access route in the reverse order is the route for transporting disassembled pieces of the interfering objects inside the pedestal.
- The equipment for disassembling and removing interfering objects from inside the pedestal, tools, and disassembled pieces are transferred between the CRD opening and X-1B by loading them on a transportation cart.



Transportation route in Unit 1



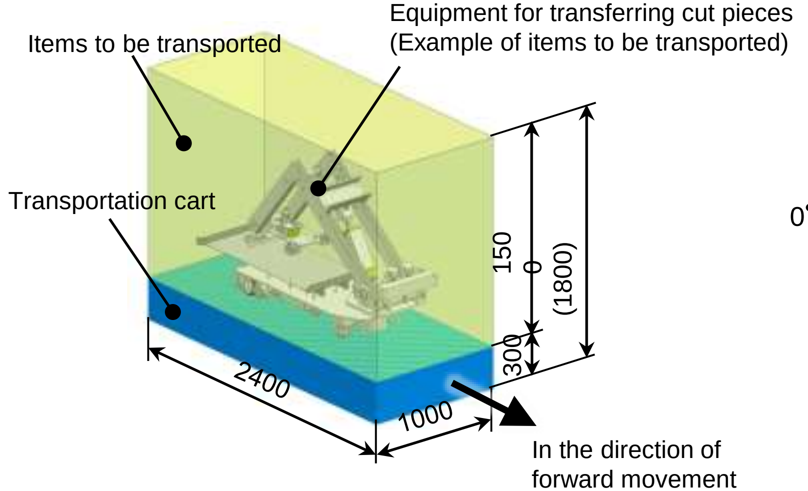
Transportation route in Units 2 and 3

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

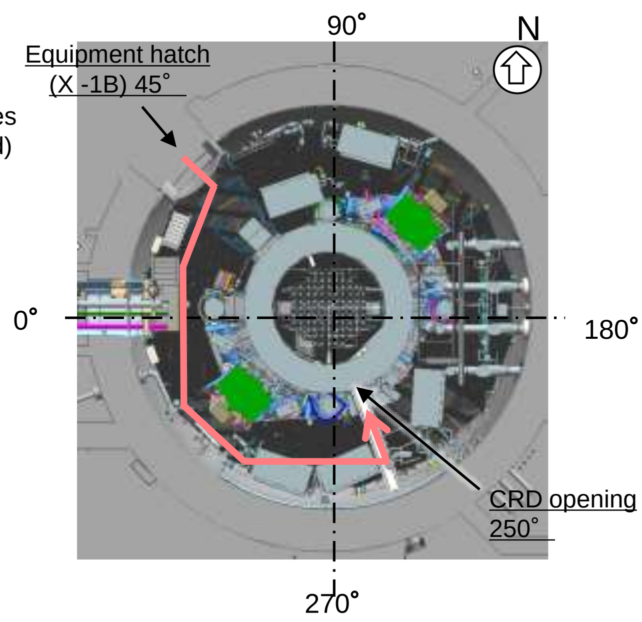
② Disassembly of CRD exchanger

■Compilation of various pre-conditions [10/12] [⑦ Interfering objects on the access route]

- The dimensions of the transportation cart and the travel route mentioned in the previous pages are given below.
- The interfering objects on the access route in Unit 1 and Units 2/3 have been listed up.
- Also, the ability to pass through confined spaces on the access route was studied using the 3D model.



Dimensions of the transportation cart
(with the items to be transported loaded)



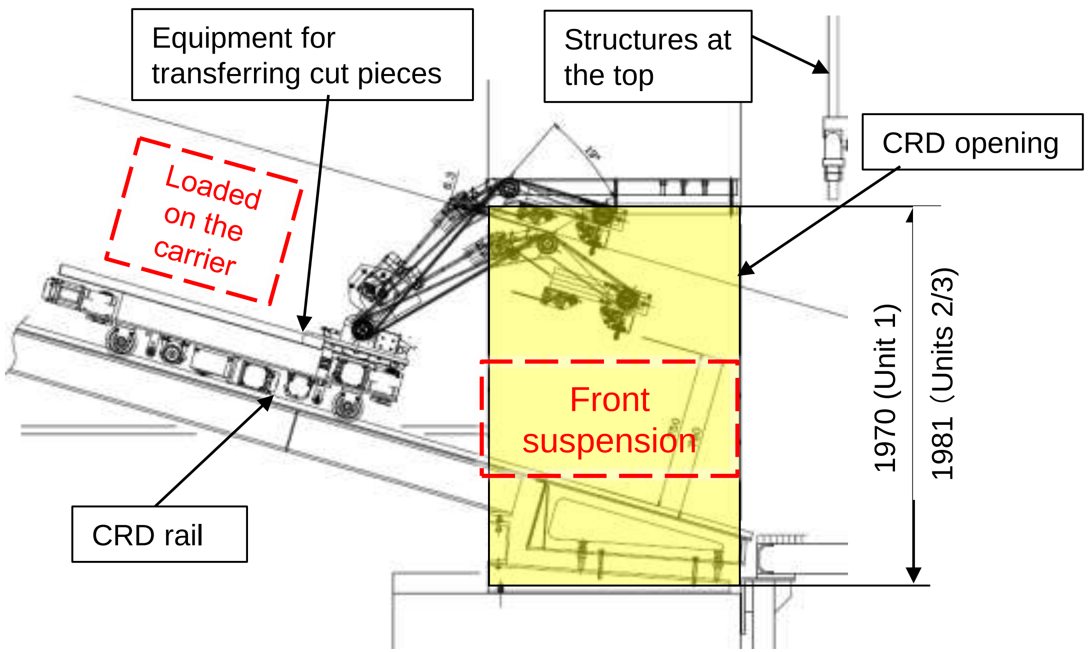
Transportation cart travel route (Example of Unit 1)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Compilation of various pre-conditions [11/12] [⑧ Transfer method]

- An image illustrating the transfer process is shown below.
- The equipment and tools to be carried inside the pedestal are transferred by loading them on the equipment carrier or by means of front suspension using a jig.
- The cut pieces to be carried outside the pedestal are transferred similarly by loading them on the equipment carrier or by means of front suspension using a jib.
- Dimensions of the items to be transferred (Same when loaded on the carrier or suspended in front): Height less than 750 mm, width less than 750 mm

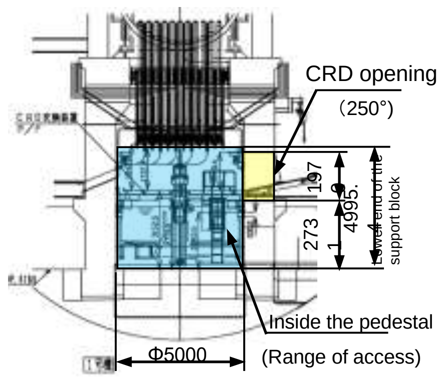
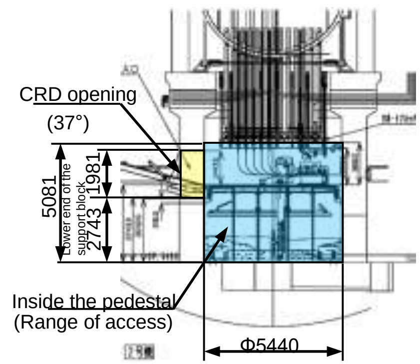
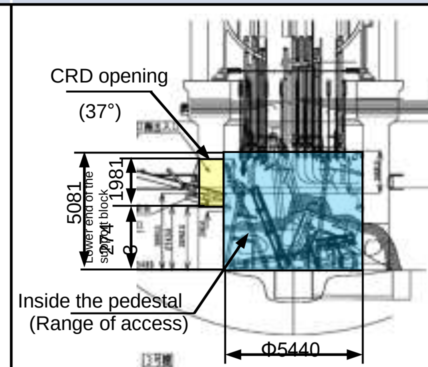


6. Implementation Items of This Project [1] (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Compilation of various pre-conditions [12/12] [⑨ Range of access]

- The entire region inside the pedestal (lower end of the CRD support block and lower) is considered to be the range of access.
- After entering the pedestal from the CRD opening, an arbitrary location inside the pedestal is accessed.
- The range of access inside of the pedestal in Units 1 - 3 at 1F is indicated below.

		Unit 1	Unit 2	Unit 3
Range of access	Inner diameter of the pedestal (r, θ direction)	5000mm	5440mm	5440mm
	Pedestal depth (Z direction)	4995.4 mm	5081 mm	5081 mm
Reference drawings				

6. Implementation Items of This Project [1] (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Requirements related to disassembling and removing the CRD exchanger

(1) Requirements with respect to the method

- [Specific to Unit 2] The CRD exchanger must be removed with the P/F still left behind.
  (As the CRD exchanger remains on the P/F, it would be difficult to remove the P/F and the intermediate work stand beforehand)
- [Specific to Units 1/3] Structures in the vicinity of the CRD opening must be removed sequentially.
- Large structures must be able to be transferred through the CRD opening, and the structures must be cut into pieces that are as large as possible and then transferred.
  (In order to enhance throughput by reducing the number of rounds of cutting.)
- Measures must be taken to ensure as much as possible that the cut pieces do not fall to the bottom of the pedestal.
- Measures must be taken to ensure as much as possible that equipment and tools do not fall to the bottom of the pedestal.
- The cut pieces, equipment and tools must not be stored temporarily at the bottom of the pedestal.
- As the integrity of the structures at the top (CRD support structures) inside the pedestal is unknown, equipment must not be installed on the structures at the top.
- As the integrity of the inner wall of the pedestal is unknown, work that requires anchors to be installed on the inner wall must not be performed.
  (The surface of the outer wall of the pedestal may be subjected to load and extended use of the wall surface on the left, right and upper side inside the CRD transfer outlet is possible.)

(2) Requirements with respect to the equipment and tools used

- The equipment and tools must be usable under the environmental conditions inside the pedestal (rainfall from the top of the pedestal, darkness, dose rate: 43Gy/h*1 or more).
- Special processes such as welding, etc. must not be required to be performed inside the pedestal.
- Cameras and lights must be installed for better visibility during work.

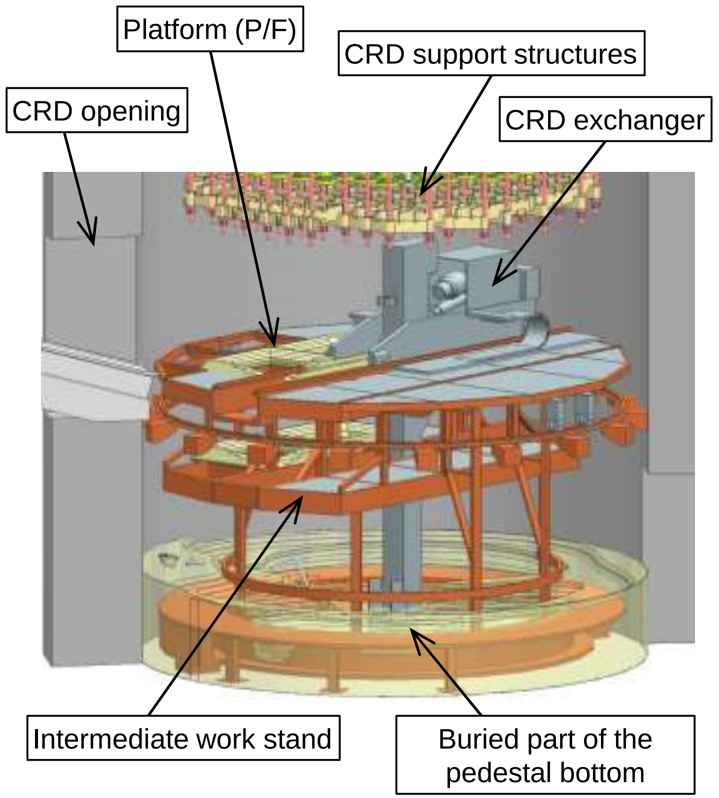


Illustration showing an overview of the inside of the pedestal (Example of Unit 2)

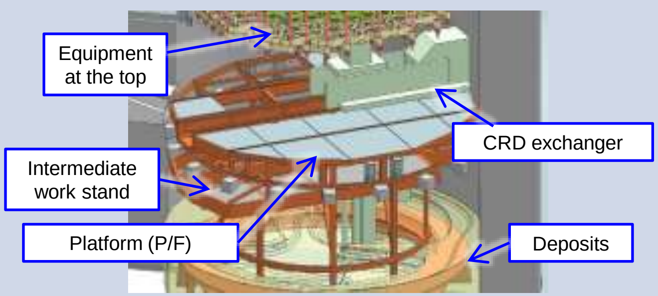
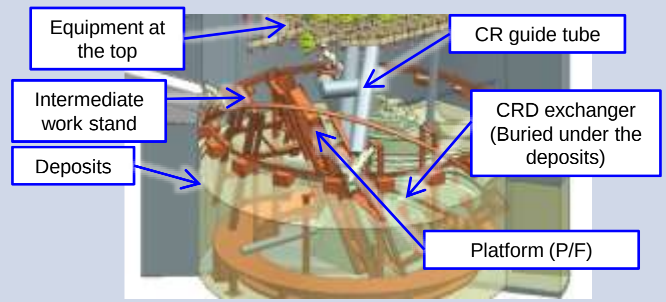
*1) Maximum dose rate outside the pedestal in Unit 2.
(Source: TEPCO website, Results of Internal Investigation of Unit 2 PCV [02/28/2019])

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Study of the method of disassembly and removal of the CRD exchanger

The method and policy for disassembly and removal of the CRD exchanger in Unit 2 and Units 1/3 are indicated below.

	Unit 2	Units 1/3
Illustration showing the status inside the pedestal		
Disassembly method	The CRD exchanger will be removed with the P/F still left behind. (As the CRD exchanger remains on the P/F, it would be difficult to remove the P/F and the intermediate work stand beforehand.)	The structures in the vicinity of the CRD opening (P/F, intermediate work stand, etc.) will be sequentially removed to secure work space, and then the CRD exchanger will be removed.
Disassembly policy	It should be possible to transfer cut pieces of large structures through the CRD opening, and the cut pieces should be as large as possible.	

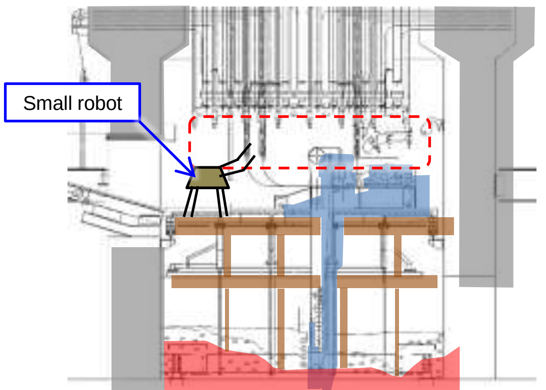
- The disassembly method for Unit 1 and that for Units 2/3 are different, but the disassembly policy is the same for all units, in that it should be possible to transfer cut pieces of large structures through the CRD opening, and the cut pieces should be as large as possible, in order to enhance the throughput by reducing the number of rounds of cutting.
- The work steps involved in the disassembly method for Unit 2 and that of Units 1/3 are described on the following pages.
- In the case of Units 1/3, there are many uncertainties (the position and condition of the CRD exchanger, condition of the deposits, etc.). In the future, the disassembly method will be reviewed at the stage when these uncertainties are eliminated.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

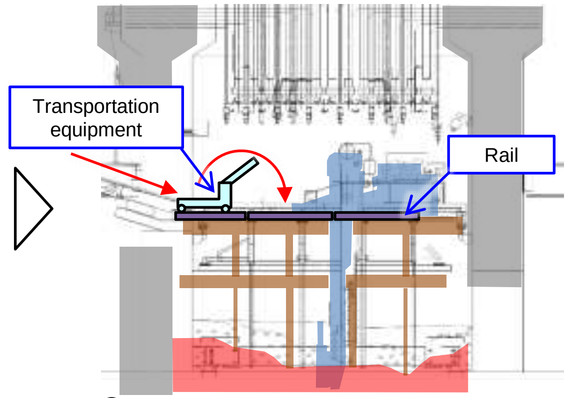
② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Unit 2)

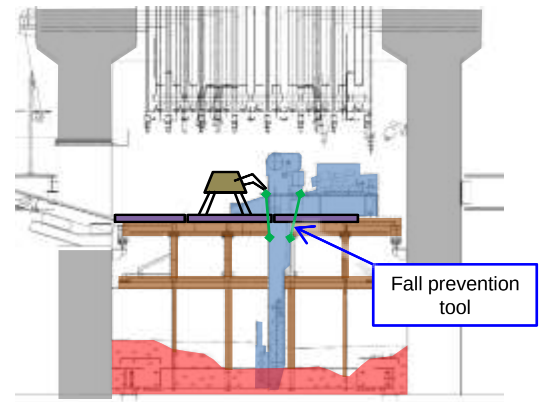
The work steps (overview) involved in the Unit 2 CRD exchanger disassembly and removal, which are to be performed inside the pedestal, are indicated below.
The study of the method of disassembly and removal targeting Unit 2, the element test plan and the results have been reported in FY2021.



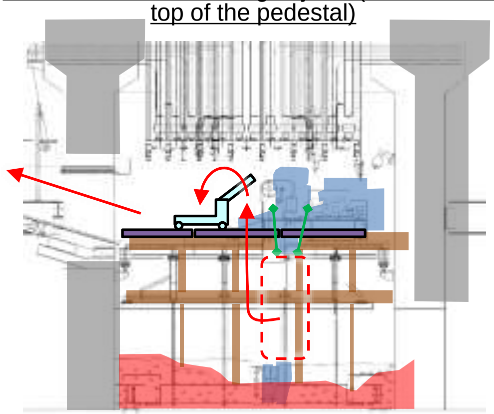
① Removal of interfering objects (structures on top of the pedestal)



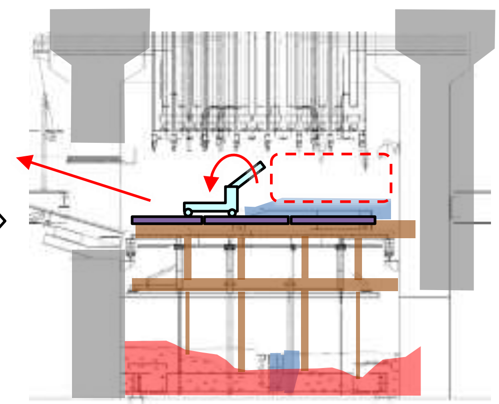
② Installation of rail for equipment access



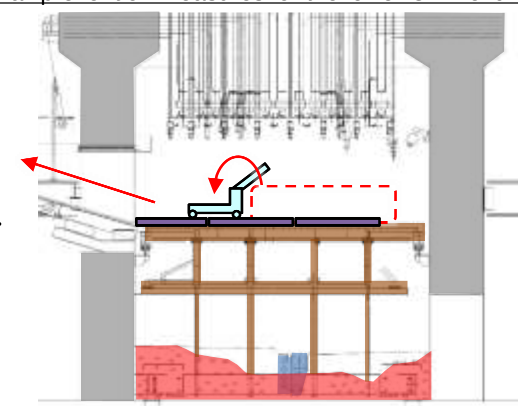
③ Fall prevention measures for the lower CRD exchanger



④ Removal of lower CRD exchanger (rotating frame, etc.)



⑤ Removal of upper CRD exchanger (trolley drive unit, etc.)



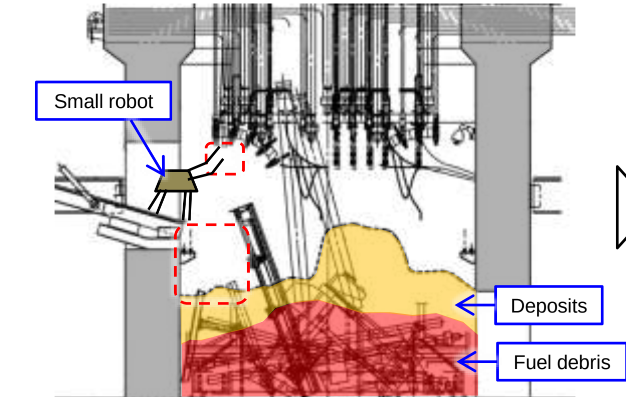
⑥ Removal of upper CRD exchanger (trolley frame, etc.)

A rail is installed on the P/F, and equipment and robots are moved to the specified locations over the rail.

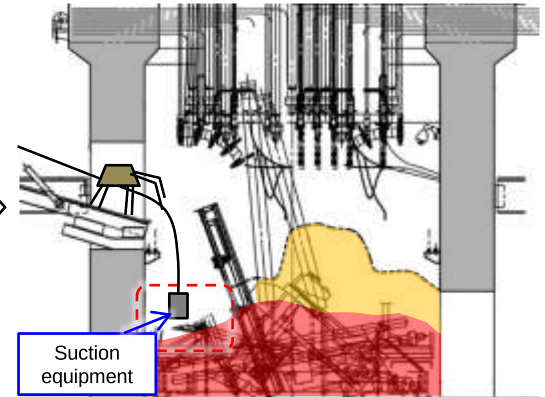
② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [1/ 8]

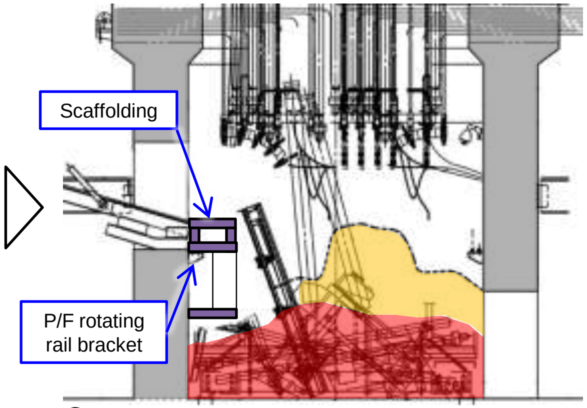
The work steps (overview) involved in Units 1/3 CRD exchanger disassembly and removal, which are to be performed inside the pedestal, are indicated below.



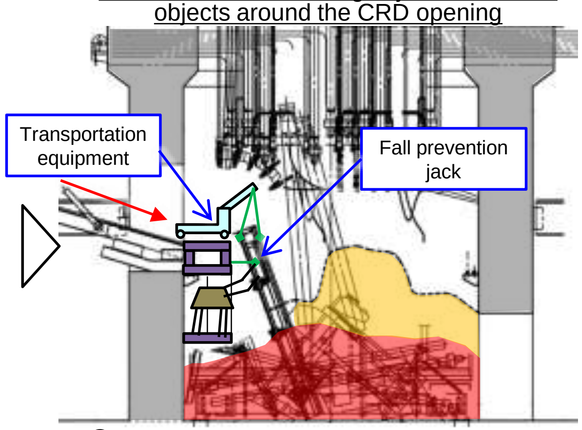
① Removal of interfering objects and fallen objects around the CRD opening



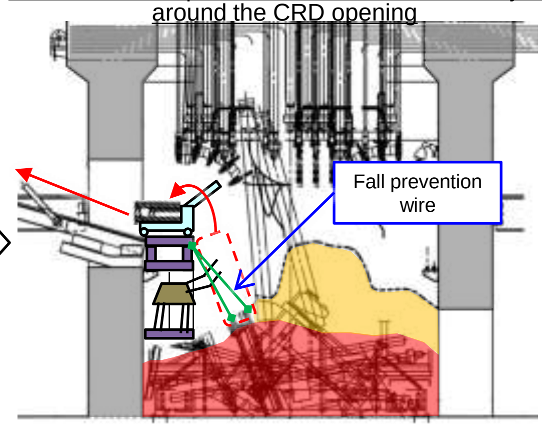
② Suction of deposits and removal of fallen objects around the CRD opening



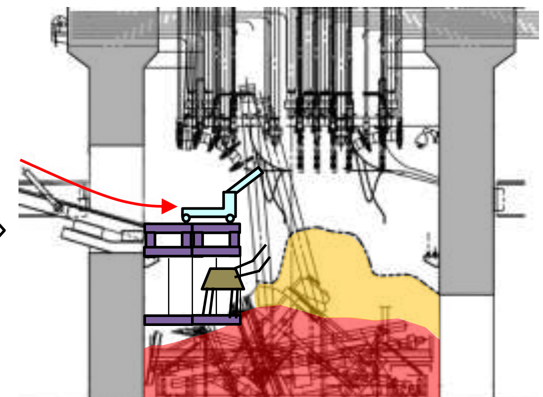
③ Installation of scaffolding for equipment access



④ Fall prevention measures for the objects to be removed (P/F, etc.)



⑤ Removal of objects to be removed (P/F, etc.)



⑥ Extension of the scaffolding for equipment access (repeated hereinafter)

The scaffolding is constructed using the P/F rotating rail bracket and the equipment and robots are moved to the specified location without any load being applied to the fuel debris at the bottom.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [2/8]

An image illustrating the construction of the scaffolding using the P/F rotating rail bracket is given below.

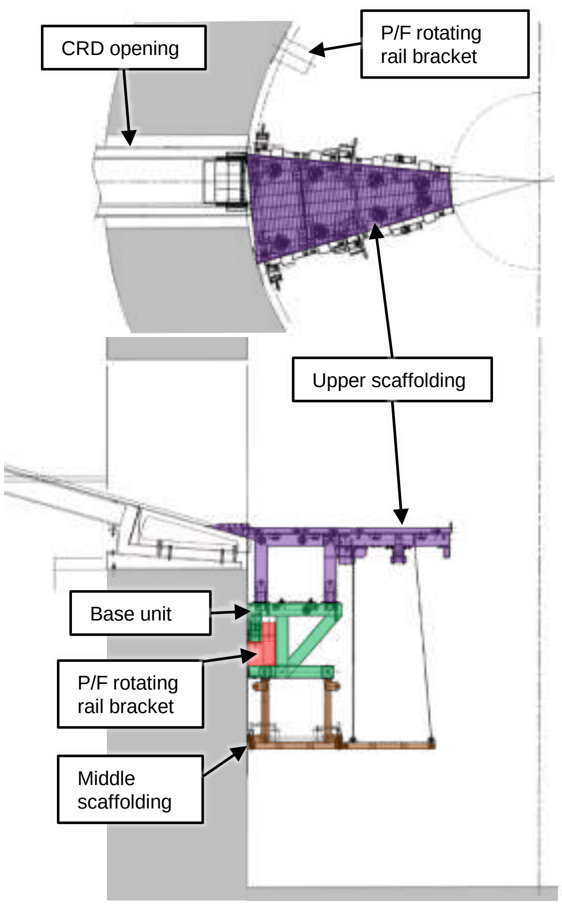
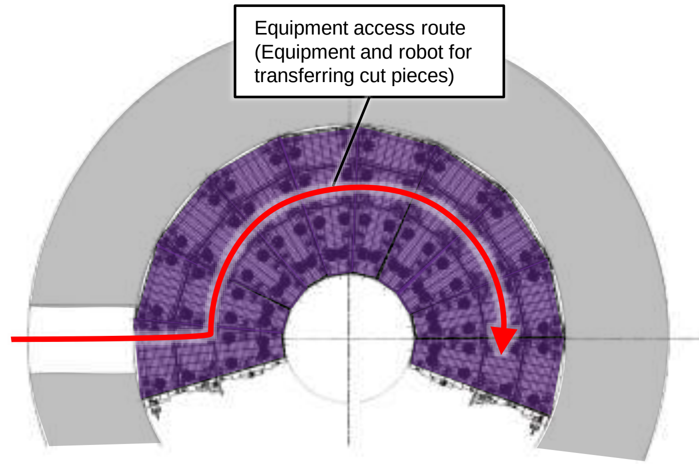


Illustration showing placement of scaffolding inside the pedestal



Example of placement of scaffolding during the element test

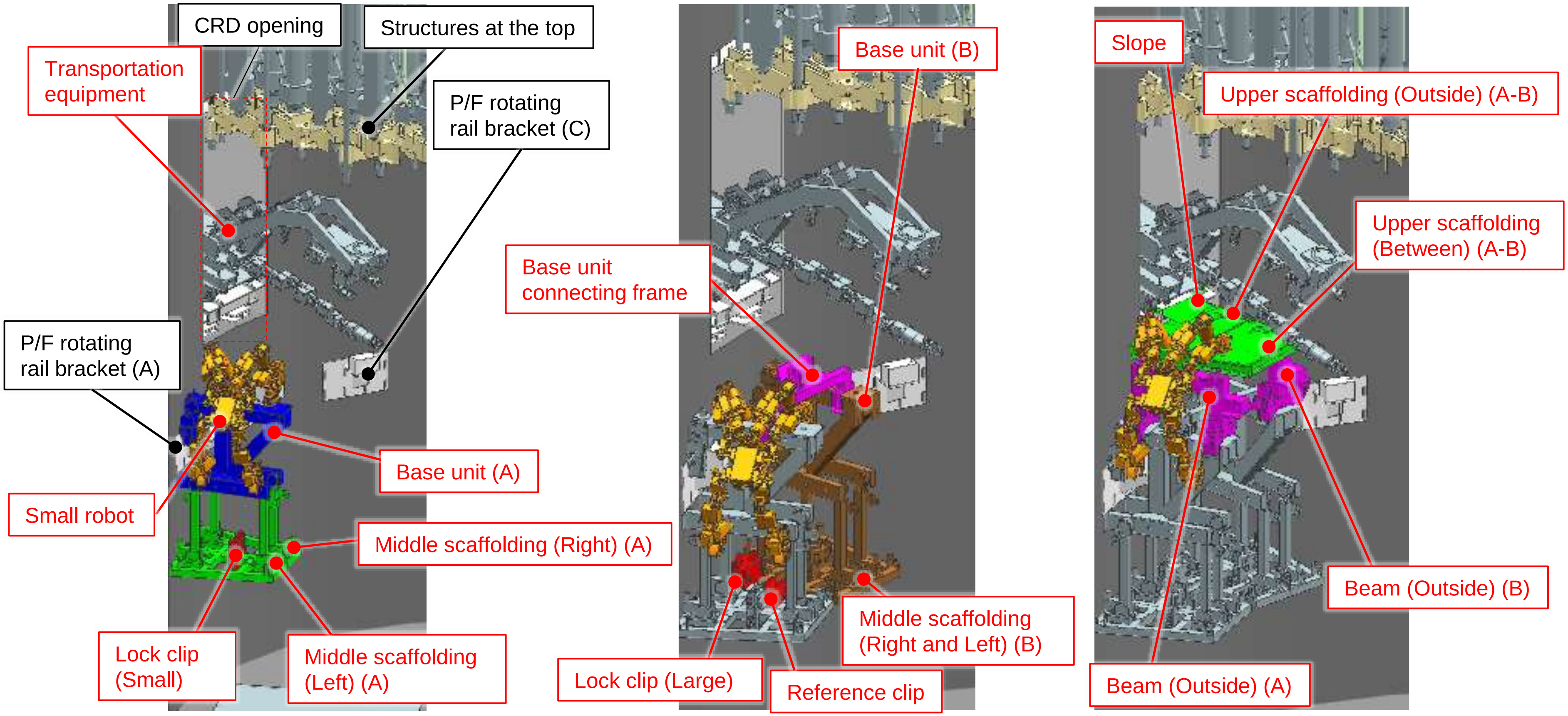
No.	Name	Details
1	Base unit	• Installed and temporarily clamped on the bracket by suspending and lowering while avoiding the rail on the bracket, and then a small robot clamps it on the top and bottom of the bracket using tools.
2	Upper scaffolding	• A scaffolding mainly for moving the equipment for transferring cut pieces to specified locations inside the pedestal. • Positioned on top of the base unit by inserting a pin and installed, and thereafter fixed by a small robot using tools.
3	Middle scaffolding	• A scaffolding mainly for moving small robots to specified locations inside the pedestal. • Fixed to the lower part of the base unit with the help of a wire sling or expandable foot. • The necessity to install the middle scaffolding is determined based on the height of the fuel debris and deposits at the bottom of the pedestal.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [3/8]

An image illustrating the procedure of installing ancillary facilities (construction of scaffolding) inside the pedestals of Units 1/3 in 1F is shown below.



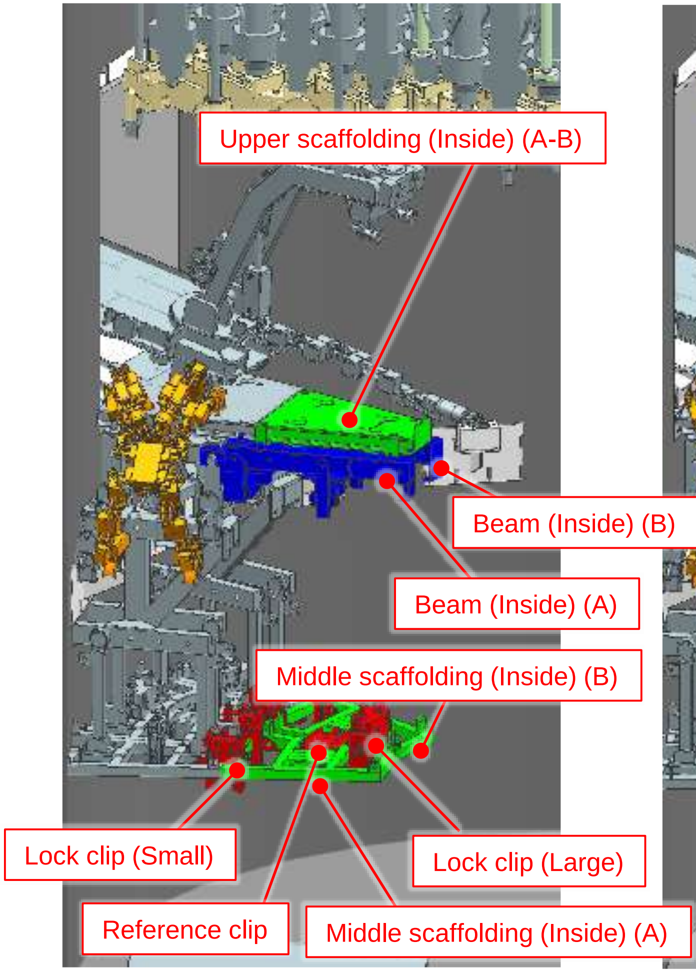
Components of a size that can be carried in from the CRD opening are carried inside the pedestal using transportation equipment, they are assembled inside the pedestal using small robots. The scaffolding is for moving the transportation equipment and small robots to specified locations inside the pedestal.

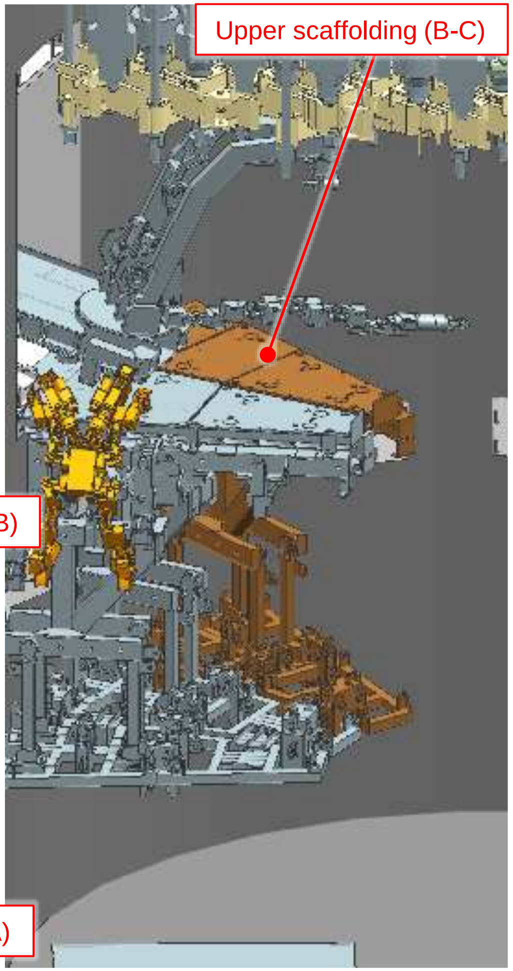
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

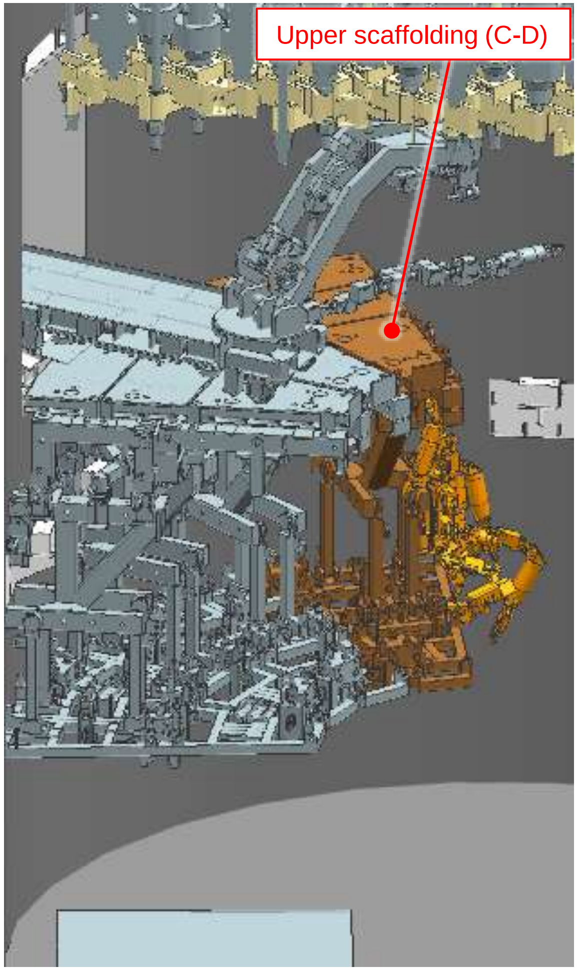
② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [4/8]

An image illustrating the procedure of installing ancillary facilities (construction of scaffolding) inside the pedestals of Units 1/3 in 1F is shown below.





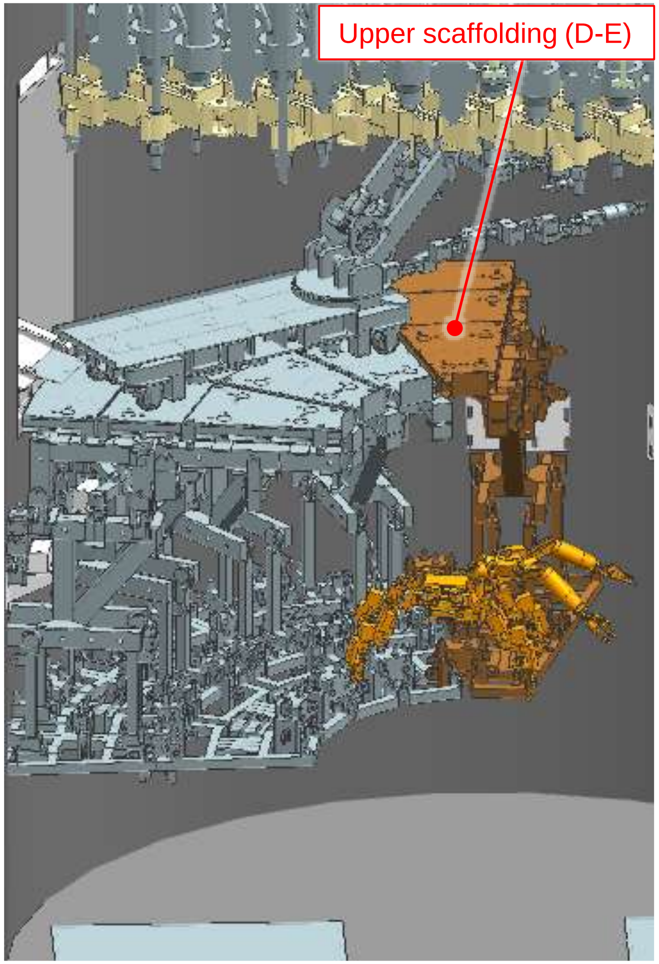


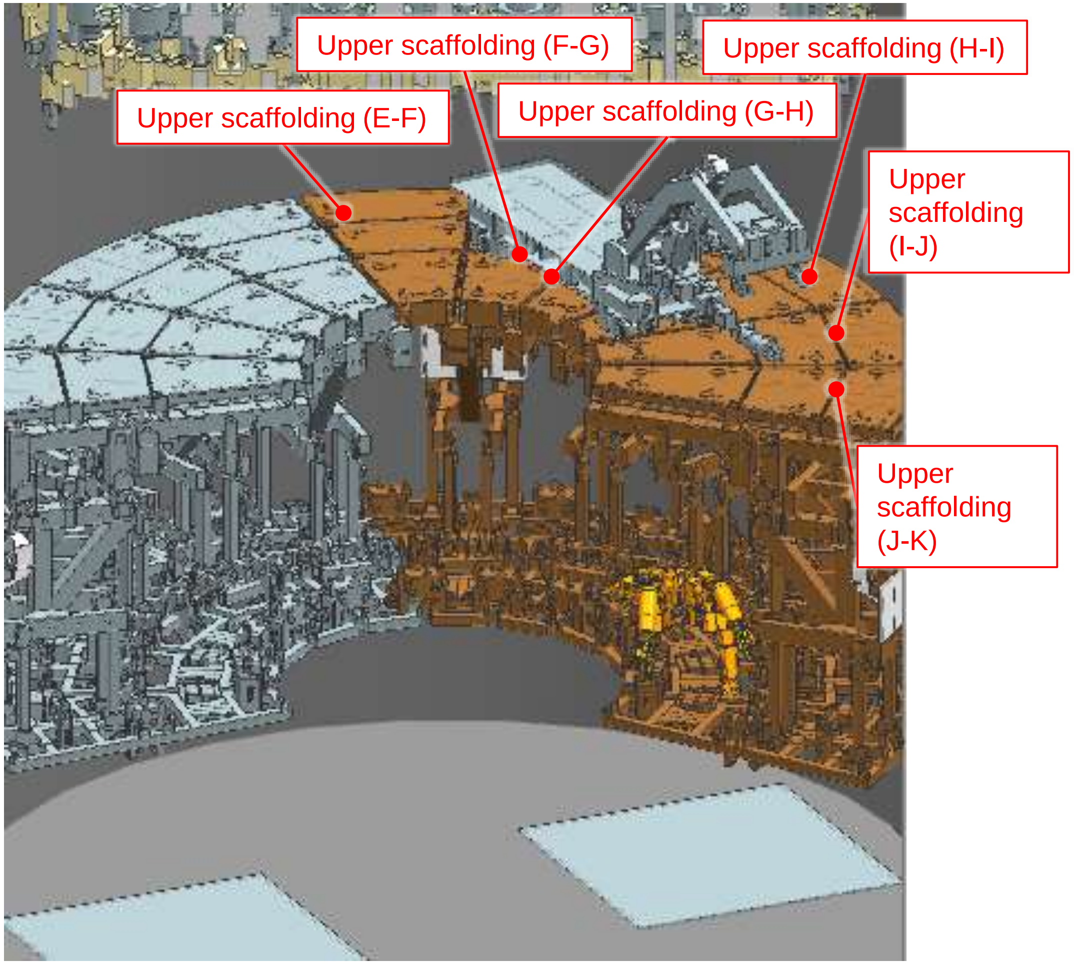
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [5/8]

An image illustrating the procedure of installing ancillary facilities (construction of scaffolding) inside the pedestals of Units 1/3 in 1F is shown below.



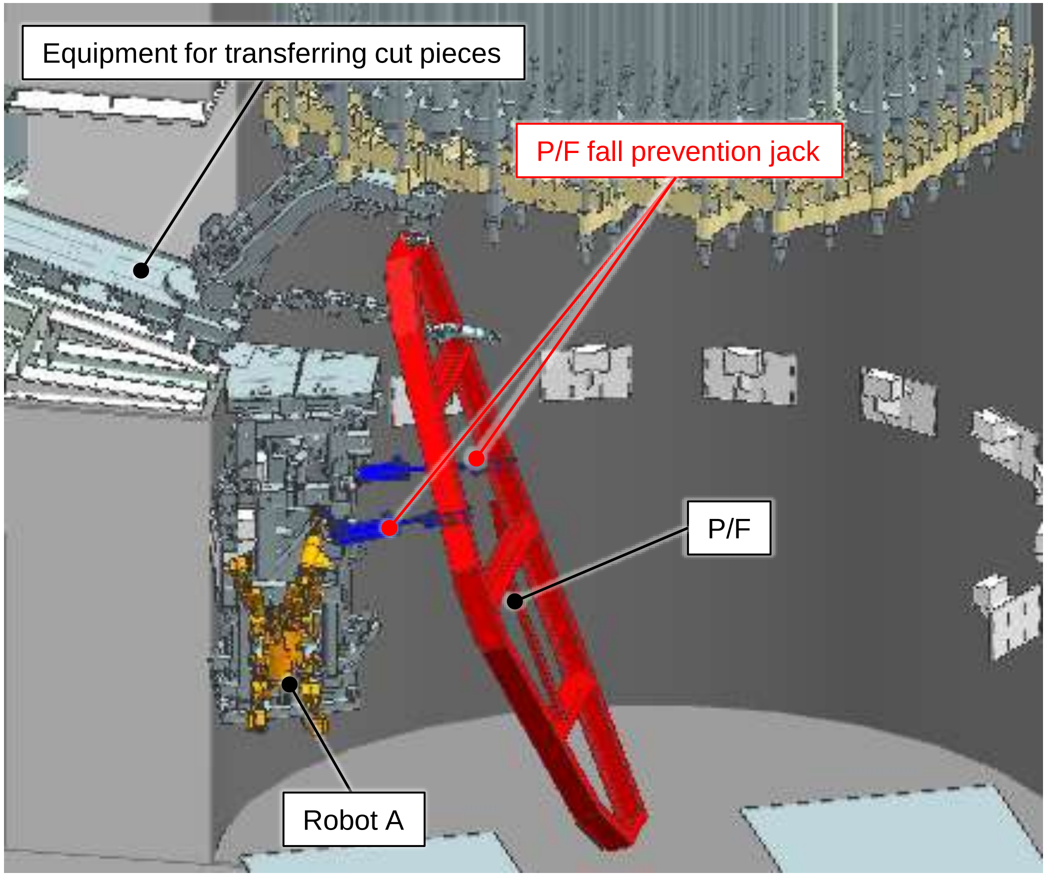


Hereinafter, similar steps are followed to construct scaffolding along the entire perimeter inside the pedestal.

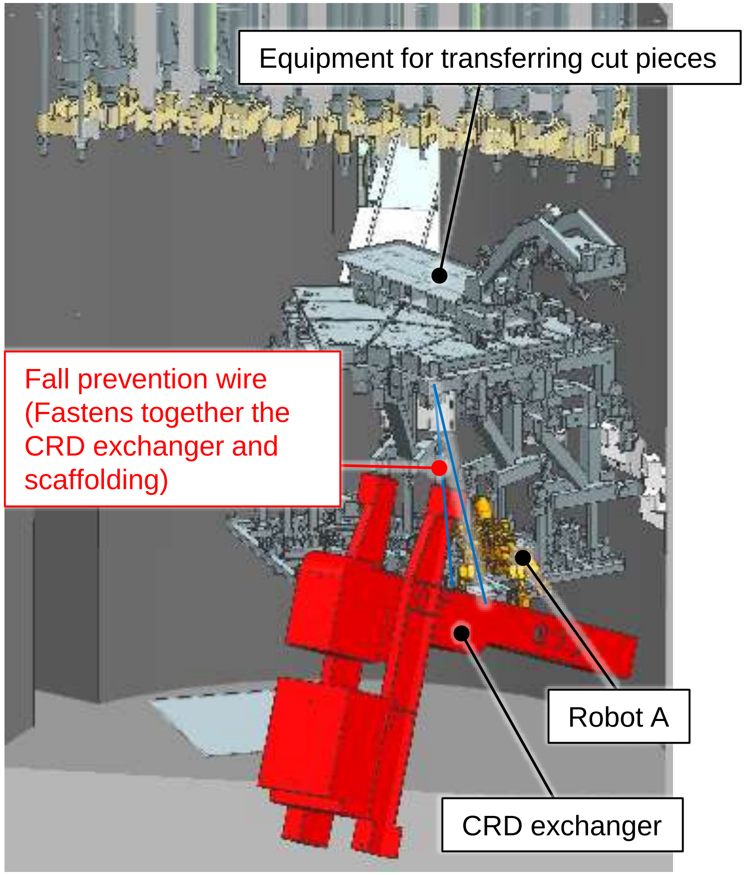
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]
② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Unit 1/ 3) [6/ 8]

An image illustrating the procedure for fall prevention of interfering objects inside the pedestals of Units 1/3 in 1F is shown below.



P/F fall prevention



CRD exchanger fall prevention

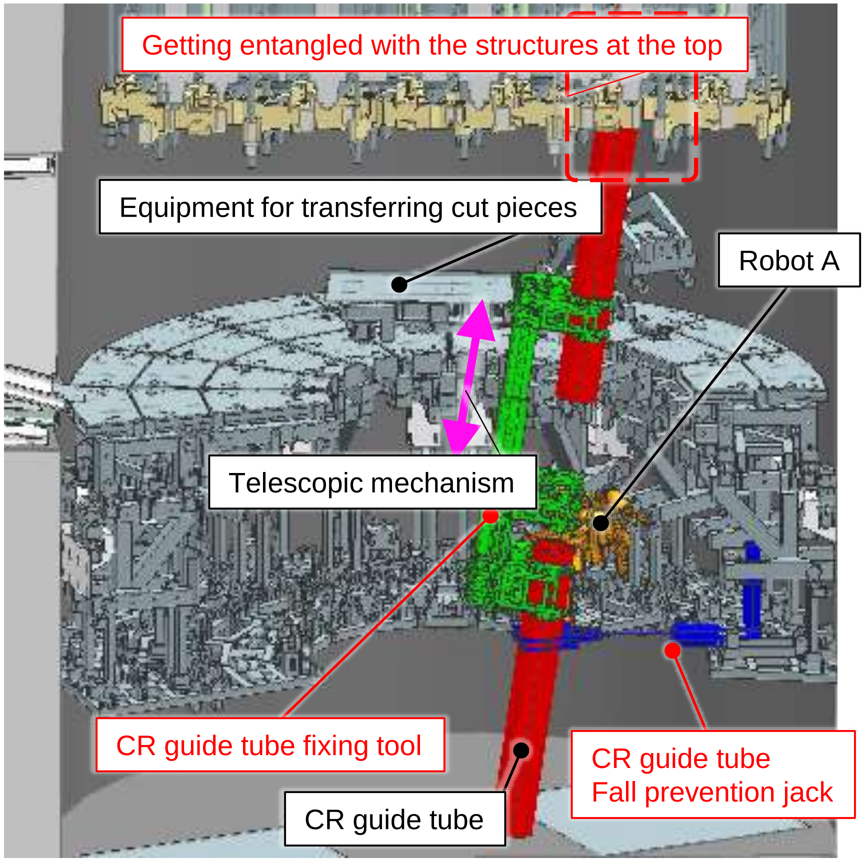
If there are interfering objects in the vicinity of the location where the scaffolding is constructed, the scaffolding and the interfering objects are fastened with a jig or a wire to prevent them from falling and then disassembly and removal are performed.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

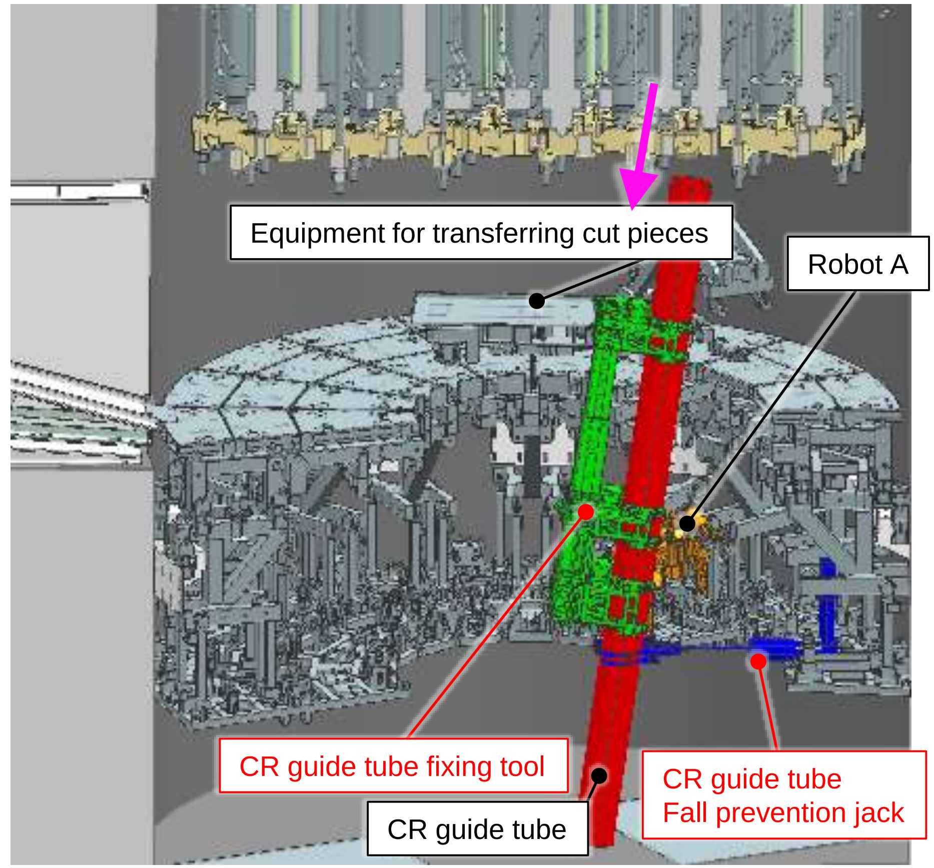
② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [7/8]

An image illustrating the procedure for fall prevention of interfering objects inside the pedestals of Units 1/3 in 1F is shown below.



CR guide tube fall prevention



Pulling out the CR guide tube

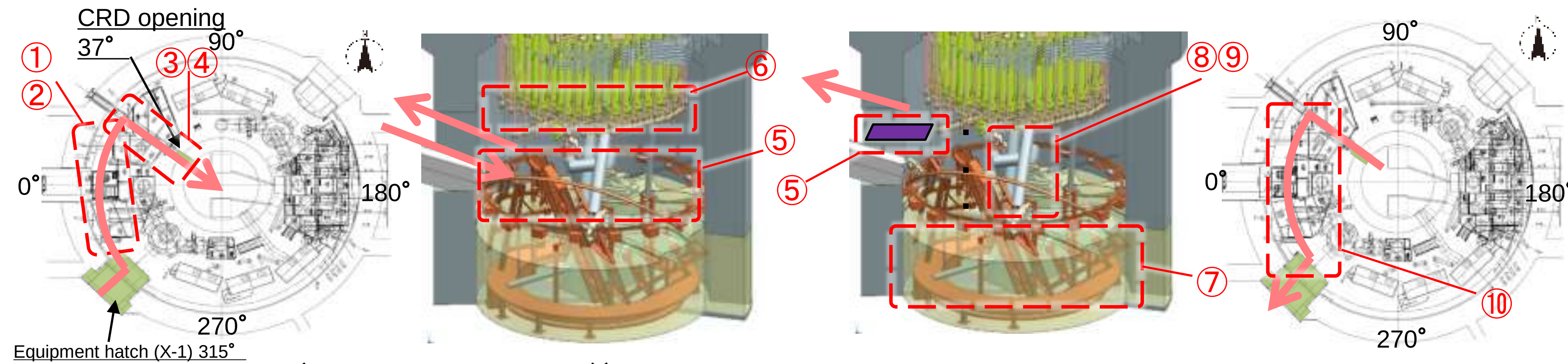
If there are interfering objects in the vicinity of the location where the scaffolding is constructed, the scaffolding and the interfering objects are fastened with a jig or a wire to prevent them from falling and then disassembly and removal are performed.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Study of the method of disassembly and removal of the CRD exchanger (Units 1/3) [8/8]

The overall work steps[*1] (outline) performed inside / outside the pedestal in 1F Units 1/3 are indicated below.



<Overview of work steps (□: Development target)>

① Investigation of access route up to the area around the CRD opening
→ ② Removal of interferences outside the pedestal
→ ③ Installation of ancillary facilities outside the pedestal (Construction of the utility line, installation of cameras & lights, etc.)
→ ④ Carrying-in of equipment and tools inside the pedestal through the CRD opening and investigation inside the pedestal
→ ⑤ Installation of ancillary equipment inside the pedestal (Construction of scaffolding, installation of cameras and lights, etc.)
→ ⑥ Removal and transfer of interfering objects in the upper part inside the pedestal (Cable, instruments)
→ ⑦ Removal and transfer of small interfering objects (pieces of broken structures, deposits, etc.) at the bottom of the pedestal
→ ⑧ Preparation for removal of large interfering objects (CRD exchanger, etc.) at the bottom inside the pedestal [*2]
→ ⑨ Removal and transfer of large interfering objects (CRD exchanger, etc.) inside the pedestal
→ ⑩ Moving of interfering objects outside the PCV through the CRD opening and transfer outside PCV
→ Hereinafter steps ④ to ⑩ are repeated (Sequence of steps is switched depending on circumstances)

*1) The schematic diagram shows Unit 3 as an example
*2) Fall prevention of interfering objects is included in the preparation for removal.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Element test items (Units 1/3) [1/2]

Test items for the unit tests and elemental tests were selected from the work steps that were studied.

Work			Unit test*1		Element test*2	
Unit	Step	Details	Necessity	Reason	Necessity	Reason
Common for Units 1 - 3	① Installation of ancillary facilities outside the pedestal (1/2)	Installation of bird's eye camera / lights (Outside the pedestal)	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).
		Utility line installation	Not required	Not required as this is being implemented as part of the FY2019 Subsidy Project (Construction of Water Circulation System).	Not required	Not required as this is being implemented as part of the FY2019 Subsidy Project (Construction of Water Circulation System).
	② Removal of interfering objects outside the pedestal	Cutting/grabbing/moving interfering objects outside the pedestal	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).
	③ Installation of ancillary equipment outside the pedestal (2/2)	Installation of utility unit	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).
		Installation of cable routing equipment	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).
		Installation of carrying-in/out rail	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).
		Installation of equipment for transferring the cut pieces	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).
	④ Investigation inside pedestal	Verification of the status of damage	Not required	Not required as this must be tested in a simulated environment.	Required	Required in order to verify whether or not it is possible to determine the status of damage when sufficient lights and bird's eye cameras are not installed.

*1) Unit test: Test conducted with a stand-alone equipment outside the simulated environment.
*2) Element test: Test conducted inside the simulated environment in which the surrounding environment is simulated.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Element test items (Units 1/3) [2/2]

Test items for the unit tests and element tests are selected from the work steps that were studied.

Work			Unit test*1		Element test*2	
Unit	Step	Details	Neces sity	Reason	Neces sity	Reason
1/3	⑤ Installation of ancillary facilities inside the pedestal	Installation of bird's eye camera / lights (Inside the pedestal)	Not required	Not required as this must be tested in a simulated environment.	Required	Required in order to verify whether or not the cameras and lights can be installed remotely at the designated locations inside the pedestal.
		Deployment and extension of the scaffolding inside the pedestal	Required	Required in order to verify that the conditions enable deployment and extension. (Scaffolding specific to Units 1/3)	Required	Required in order to verify that the rail can be deployed and extended without interfering with surrounding structures. (Scaffolding specific to Units 1/3)
	⑥ Removal and transfer of interfering objects inside the pedestal	Cutting/grabbing/moving pipes and support	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2020 Subsidy Project (Interference Removal Outside the Pedestal).
	⑦ Removal and transfer of small interfering objects at the bottom of the pedestal	Set up of deposit suction equipment	Not required	Not required as the properties of the deposits and whether or not the deposits can be sucked and collected have not been determined.	Not required	Not required as the properties of the deposits and whether or not the deposits can be sucked and collected have not been determined.
		Sucking of deposits	Not required	Not required as the properties of the deposits and whether or not the deposits can be sucked and collected have not been determined.	Not required	Not required as the properties of the deposits and whether or not the deposits can be sucked and collected have not been determined.
		Preparation for removal of fallen objects, and their removal	Not required	This is similar to the work carried out in ⑧' ⑨'. As it will be verified in ⑧' ⑨', this test is not required.	Not required	This is similar to the work carried out in ⑧⑨. As it will be verified in ⑧⑨, this test is not required.
	⑧ Preparation for removal of large interfering objects (CRD exchanger, etc.) at the bottom inside the pedestal	Carrying-in and installation of cutting equipment	Required	Required in order to verify that the conditions enable carrying-in and installation.	Required	Required in order to verify that the conditions enable carrying-in and installation.
		Carrying-in and installation of fall prevention tools	Required		Required	
		Moving of the tool for transferring cut pieces to the periphery of the objects to be cut	Required	Required in order to verify that the conditions enable moving.	Required	Required in order to verify that the tool can be moved without interfering with surrounding structures.
	⑨ Removal and transfer of large interfering objects (CRD exchanger, etc.) inside the pedestal	Cutting of objects to be removed	Not required	Not required as this is similar to Unit 2 Step ⑩.	Not required	Not required as this is similar to Unit 2 Step ⑩.
		Lifting up of the cut pieces of the objects to be cut by means of the equipment for transferring cut pieces.	Required	Required in order to verify that the conditions enable lifting of cut pieces from the pedestal bottom.	Required	Required in order to verify that the cut pieces can be lifted up without interfering with surrounding structures (fallen objects that have gotten entangled).
		Moving of the equipment for transferring cut pieces outside the pedestal	Not required	Not required as this is similar to Unit 2 Step ⑩.	Not required	Not required as this is similar to Unit 2 Steps ⑧⑩⑫.
		Transfer of cut pieces outside the pedestal (up to the equipment hatch)	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).	Not required	Not required as this is being implemented as part of the FY2018 Subsidy Project (Interference Removal Outside the Pedestal).

Unit tests and element tests that were determined to be required were conducted.

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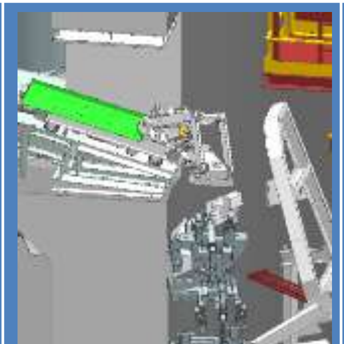
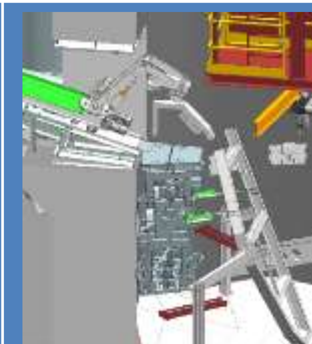
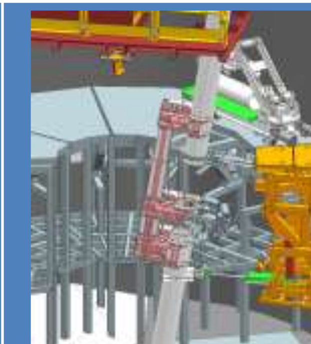
*1) Unit test: Test conducted with a stand-alone equipment outside the simulated environment.
*2) Element test: Test conducted inside the simulated environment in which the surrounding environment is simulated.

② Disassembly of CRD exchanger

■ Element test plan (Units 1/3) [1/3]

Images illustrating an overview of the element tests are shown below. Refer to the following pages for the Items to be verified.

✓: Items for verifying workability of remote operations during the element tests

No.	Test classification	 Investigation of the status of damage - construction of scaffolding	 P/F fall prevention - removal	 CRD exchanger fall prevention - removal	 CR guide tube fall prevention - removal
1	Investigation inside the pedestal (P/F rotating rail bracket)	✓			
2	Installation of ancillary facilities inside the pedestal (Installation of cameras and lights)	✓			
3	Installation of ancillary facilities inside the pedestal (Construction and extension of scaffolding)	✓	✓		
4	Equipment access to specified locations (Equipment and small robot for transferring cut pieces)	✓	✓	✓	✓
5	Fall prevention (P/F, CRD exchanger, CR guide tube)		✓	✓	✓
6	Cutting off the interfering objects (P/F, CRD exchanger, CR guide tube)		✓	✓	✓
7	Transfer of cut pieces of the interfering objects (P/F, CRD exchanger, CR guide tube)		✓	✓	✓

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]
② Disassembly of CRD exchanger

■ Element test plan (Units 1/3) [2/3]

The items to be verified in the element tests are indicated below.

No.	Test classification	Overview of tests	Items to be verified
1	Investigation inside the pedestal (P/F rotating rail bracket)	Equipment and small robot for transferring cut pieces, which are made to hold the camera for investigation, are operated remotely, access the target object and verify its visibility.	● Whether the camera can access the target object ● That the angle of view of the camera does not have a blind spot
2	Installation of ancillary facilities inside the pedestal (Installation of cameras and lights)	Equipment and small robot for transferring cut pieces, which are made to hold the cameras and lights, are operated remotely, access the target installation location and install the cameras and lights.	● Whether the cameras and lights can be installed by remote operation ● Whether the interfering objects inside the pedestal interfere (collide, etc.) with the equipment and tools that are installing the camera and lights
3	Installation of ancillary facilities inside the pedestal (Construction and extension of scaffolding)	The equipment and small robot for transferring cut pieces are operated remotely, and a series of procedures for constructing the scaffolding (assembly of components inside the pedestal) are performed.	● Whether the scaffolding can be constructed by remote operation ● Whether the interfering objects inside the pedestal interfere (collide, etc.) with the equipment and tools that are constructing the scaffolding ● Whether multiple sets of scaffolding can be connected and fixed (connection and fixing not being possible due to errors in assembly)
4	Equipment access to specified locations (Equipment and small robot for transferring cut pieces)	The equipment and small robot for transferring cut pieces are operated remotely and are moved on the scaffolding constructed inside the pedestal (from the CRD opening to the specified location inside the pedestal).	● Whether the equipment can be moved to the specified location on the constructed scaffolding ● Whether the stack or interfering objects inside the pedestal interfere (collide, etc.) with the equipment in motion
5	Fall prevention (P/F, CRD exchanger, CR guide tube)	The equipment and small robot for transferring cut pieces are operated remotely, and the hole drilling tool is positioned on the interfering object inside the pedestal. The hole drilling tool is operated remotely, and a hole is made in the interfering object inside the pedestal for slinging. The equipment and small robot for transferring cut pieces are operated remotely, and fall prevention tools (jack, wire) are installed on the part where the hole is drilled.	● Whether the tool for drilling the hole for slinging can be set up on the interfering object inside the pedestal and whether the hole can be drilled ● Whether the blade is broken or whether a stack is present ● Whether the fall prevention tools (jack, wire) can be installed on the interfering object inside the pedestal ● Feasibility of fall prevention using the tools (whether fall can be prevented)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Element test plan (Units 1/3) [3/3]

The items to be verified in the element tests are indicated below.

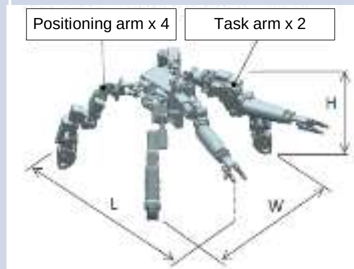
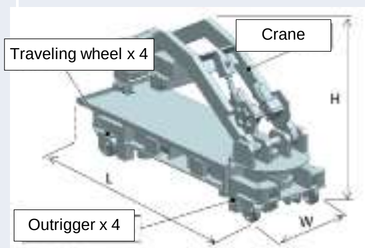
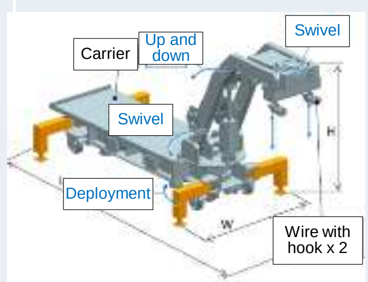
No.	Test classification	Overview of tests	Items to be verified
6	Cutting off the interfering objects (P/F, CRD exchanger, CR guide tube)	The equipment and small robot for transferring cut pieces are operated remotely, and the blade is positioned on the interfering object inside the pedestal. The blade is operated remotely, and the interfering object inside the pedestal is cut.	● Whether the blade can be set up on the interfering object inside the pedestal and whether the object can be cut. ● Whether the blade is broken or whether a stack is present ● Whether the interfering object being cut inside the pedestal falls
7	Transfer of cut pieces of the interfering objects (P/F, CRD exchanger, CR guide tube)	The equipment and small robot for transferring cut pieces are operated remotely, and a series of procedures for transferring cut pieces of the interfering object inside the pedestal (pulling out, lifting, loading the cut pieces and transferring them outside the pedestal) are performed.	● Whether cut pieces can be transferred by remote operation ● Whether the interfering objects inside the pedestal interfere (collide, etc.) with the cut pieces being transferred, and the equipment and tools that are transferring the cut pieces

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [1/13]

The equipment and tools used for the element tests are indicated below.

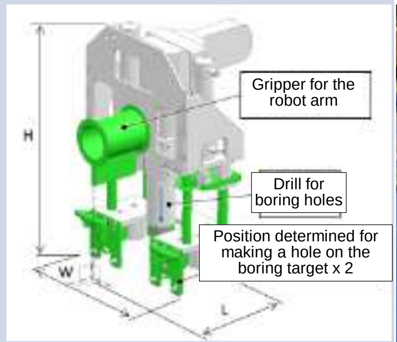
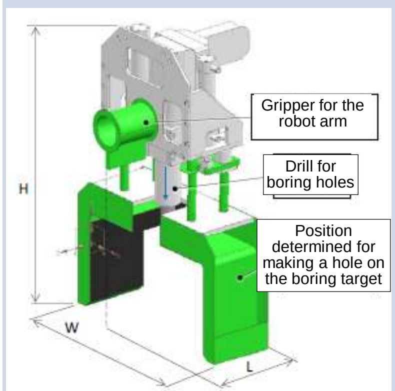
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
1	Small robot	L1,380 x W980 x H670 (Arm unfolded)	Approx. 100			• Is provided with 4 positioning arms and 2 task arms. • While moving on level ground, the robot can lower itself and move in a crawling position. • While moving on the middle scaffolding inside the pedestal, it clamps the scaffolding and moves. • It assists in positioning the equipment and tools for transferring cut pieces that are suspended and lowered with a crane, and performs the work of slinging and assembling the scaffolding.
2	Equipment for transferring cut pieces	L1,825 x W600 x H885 (When the jib is stowed) L2,640.5 x W1,060 x H1,361.5 (When the jib is deployed)	430			• After being installed on the CRD rail, the equipment enters inside the pedestal by remote operation, and travels on the upper scaffolding inside the pedestal. • Weight that can be lifted and transported using a crane: 250 [kg] • Lifting height: Approx. 5[m] • Performs works such as transportation, lifting and rough positioning of the equipment and tools (including scaffolding components) loaded on the carrier. • Performs works such as lifting the cut pieces, loading them on the carrier and transporting them outside the pedestal. • Provided with winding cable at 4 locations for lashing the equipment for transferring cut pieces to the floor surface, in addition to the outrigger.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [2/13]

The equipment and tools used for the element tests are indicated below.

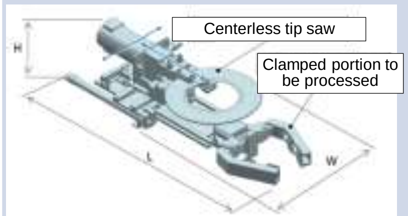
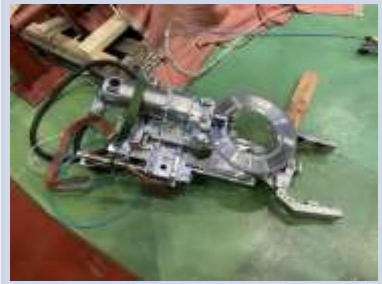
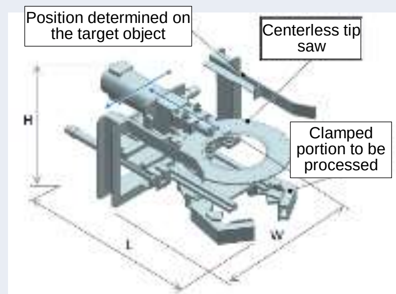
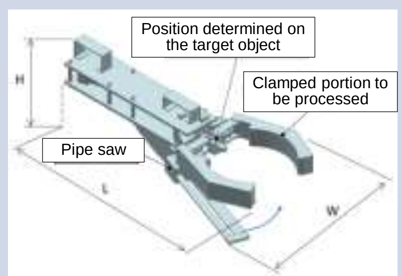
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
3	Tool for boring holes for slinging	L272 x W235 x H440.5 (For flat plate) L269.5 x W368 x H595.5 (For curved surfaces)	10	 	 	• A tool for boring holes for slinging to make it possible to lift various types of cut pieces. • Boring target: P/F, CRD exchanger (For flat plate) CR guide tube (For curved surfaces) • Dimensions of the hole to be bored: Φ25mm x Depth 35mm

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [3/13]

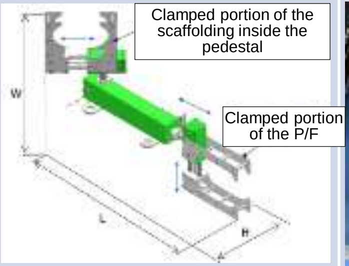
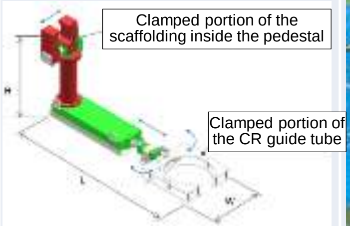
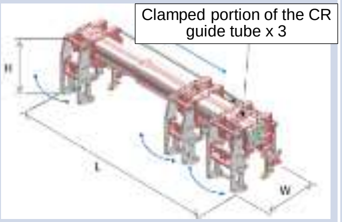
The equipment and tools used for the element tests are indicated below.

No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
4	P/F Cutting tool	L874 x W312.5 x H218	21			• Tool used in common with the HVH disassembly and removal element tests • The P/F is held and cut.
5	CRD exchanger cutting tool	L672 x W488 x H302	24			• Tool used in common with the HVH disassembly and removal element tests • The CRD exchanger (rotating frame) is held and cut.
6	CR guide tube cutting tool	L824 x W522 x H253	15			• Holes are made in the CR guide tube beforehand, and pins for the positions determined on the boring target are inserted. (To prevent misalignment of tools) • The CR guide tube is held and cut.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]
② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [4/13]

The equipment and tools used for the element tests are indicated below.

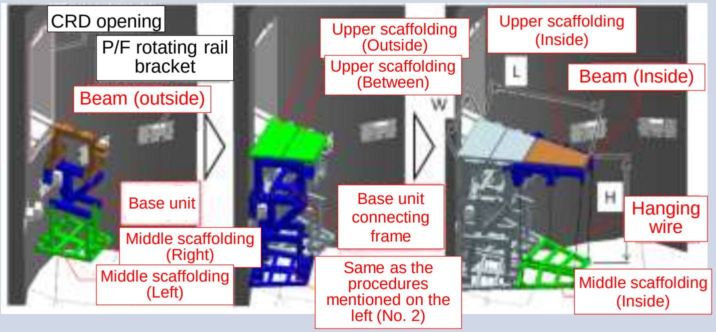
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
7	P/F Fall prevention jack	L788.1 x W457.5 x H224.2	10.8			• Weight that the jack can handle: 630kg/unit • Provided with a angle misalignment absorption mechanism consisting of rink + spring in front of each clamp. • It clamps the base unit on one side and the P/F on the other side thereby preventing any falling.
8	CR guide tube fall prevention jack	L1,180.5 x W350 x H633.5	36.4			• Weight that the jack can handle: 630kg/unit • Provided with a angle misalignment absorption mechanism consisting of rink + spring in front of each clamp. • It clamps the base unit on one side and the CR guide tube on the other side thereby preventing any falling.
9	CR guide tube fixing tool	L1,234 to 2234 x W600.7 x H704	207.5			• Lifting capacity of each clamped location: 150kg • A tool that is provided with 3 clamped locations and a telescopic mechanism, which fastens the CR guide tube (top and bottom) after pulling out the cut pieces.

6. Implementation Items of This Project [1] (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [5/13]

The equipment and tools used for the element tests are indicated below.

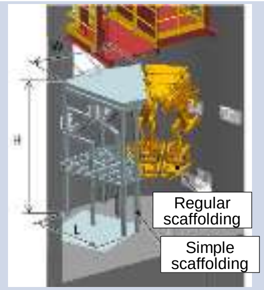
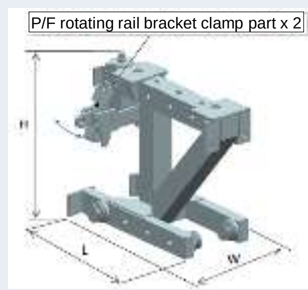
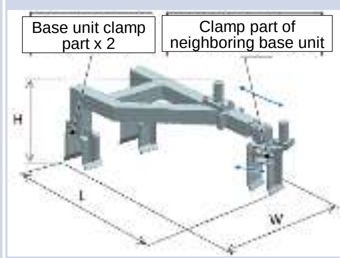
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)／Outer appearance (Photograph)	Overview
10	Scaffolding inside the pedestal (Regular scaffolding)	Approx. L1,700 x W885.2 x H1,804	570		• The scaffolding components indicated on the following pages are assembled inside the pedestal. • Scaffolding components are fastened together with a clamp. • 2 sets of components are arranged for.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [6/13]

The equipment and tools used for the element tests are indicated below.

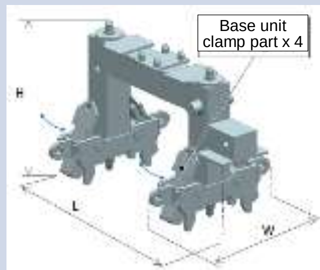
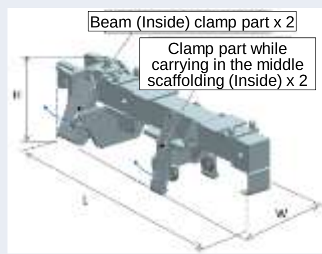
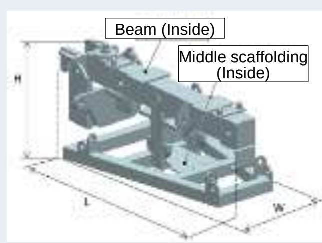
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
11	Simple scaffolding	L1,650 x W1,842 x H2,982	540			• From the viewpoint of deadline and the cost, it is not possible to provide regular scaffolding all around the inner circumference of the pedestal. Hence simple scaffolding equivalent to the size of 2 sets of regular scaffolding is provided. • Manually fastened at the base of the P/F rotating rail bracket, with feet resting at the bottom of the pedestal.
12	Base unit	L810 x W508 x H717	69.4			• Fits into the P/F rotating rail bracket from the top with its own body weight. • The top socket is operated with the rotating tool, and the base unit is clamped at the top and bottom. • The remaining scaffolding components are connected to the base unit.
13	Base unit connection frame	L963.2 x W427.3 x H366	27.3			• Neighboring base units are connected and fixed. • The top socket is operated with the rotating tool, it is extended and retracted (fine adjustment of the distance between the base units) and is clamped.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [7/13]

The equipment and tools used for the element tests are indicated below.

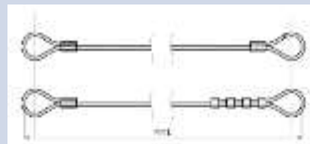
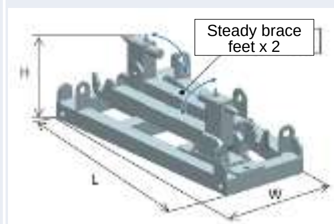
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
14	Beam (Outside)	L770 x W346 x H539	65.8			• Fits into the base unit from the top with its own body weight. • The top socket is operated with the rotating tool, and the base unit is clamped at the top and bottom. • The upper scaffolding is installed on top.
15	Beam (Inside)	L1,083 x W430 x H319 (Stand-alone beam) L1,083 x W588 x H319 (Beam + Middle scaffolding)	52.6 (Stand-alone beam) 65.5 (Beam + Middle scaffolding)	 		• Fits into the beam (Outside) from the top with its own body weight. • The top socket is operated with the rotating tool, and the base unit is clamped at the top and bottom. • The base is provided with a clamp part for fixing the middle scaffolding (Inside). # Form when it is carried inside the pedestal • The upper scaffolding is installed on top.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [8/13]

The equipment and tools used for the element tests are indicated below.

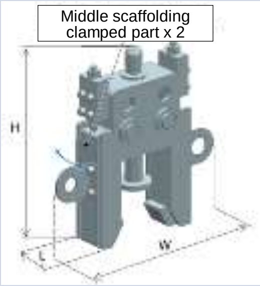
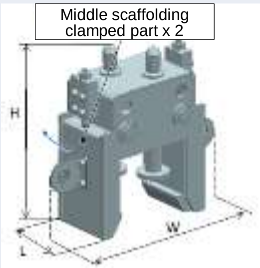
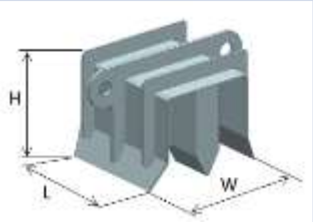
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
16	Hanging wire	L186 to 784	—			• Wire for connecting the scaffolding components with each other (in a suspended state). • Multiple wires of varied lengths in accordance with the use application are arranged for.
17	Middle scaffolding (Left / Right)	L800 x W448 x H243	37.7			• Connected to the underside of the base unit. • 2 types of middle scaffolding that are mirror images of each other are arranged for. • While carrying in, it is connected to the base unit with a hanging wire and suspended. • Thereafter, the steady brace feet are deployed and are actually connected to the base unit.
18	Middle scaffolding (Inside)	L800 x W588 x H135	12.9			• Connected to the beam (inside) with a hanging wire and suspended. • Fastened to the middle scaffolding (left/right) with a lock clip (small). • The load is borne by the hanging wire.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [9/13]

The equipment and tools used for the element tests are indicated below.

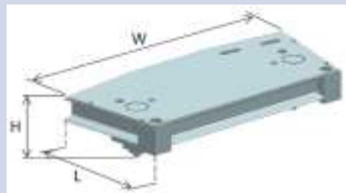
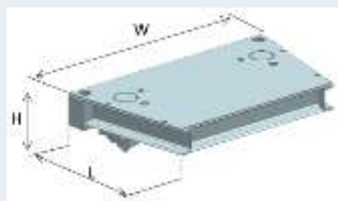
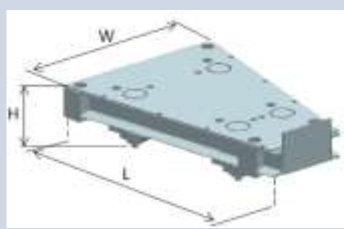
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
19	Middle scaffolding lock clip (Small)	L87 x W325 x H320	7.8			• A fixing jig for connecting and fixing the middle scaffolding (left/right) and the middle scaffolding (inside) to form a single set. • Used for fixing the middle scaffolding (left) and the middle scaffolding (right) as well. • Fits into the middle scaffolding from the top with its own body weight. • The top socket is operated with the rotating tool, and the clip is clamped at the top and bottom
20	Middle scaffolding lock clip (Large)	L147 x W375 x H325	15.8			• A fixing jig for connecting and fixing the middle scaffoldings that are connected to form a single set with the lock clip (small) for the middle scaffolding. • Fits into the middle scaffolding from the top with its own body weight. • The top socket is operated with the rotating tool, and the clip is clamped at the top and bottom.
21	Reference clip	L210 x W300 x H171.3	5.6			• A jig for correcting the position of the middle scaffoldings before installing the lock clip (large) for the middle scaffolding. • Fits into the middle scaffolding from the top with its own body weight and does not need a clamping mechanism.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [10/13]

The equipment and tools used for the element tests are indicated below.

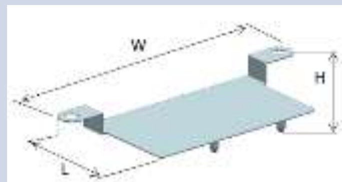
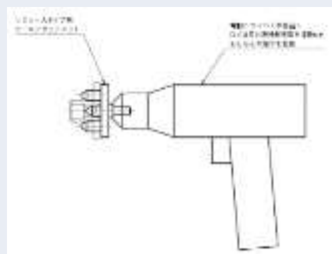
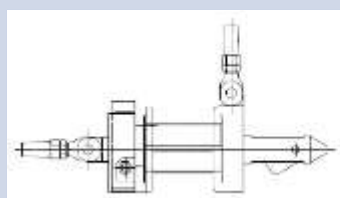
No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
22	Upper scaffolding (Outside)	L405 x W885.2 x H236	58.4			• Installed on the adjacent beam (outside). • The top socket is operated with the rotating tool, and the beam (outside) is clamped at the top and bottom. • The top surface has a punched structure so that the cooling water can pass through the holes to the bottom of the pedestal.
23	Upper scaffolding (Between)	L435.8 x W730 x H236	55.2			• Installed on the adjacent beam (outside). • The top socket is operated with the rotating tool, and the beam (outside) is clamped at the top and bottom. • The top surface has a punched structure so that the cooling water can pass through the holes to the bottom of the pedestal.
24	Upper scaffolding (Inside)	L556 x W804.4 x H236	85.4			• Installed on the adjacent beam (inside). • The top socket is operated with the rotating tool, and the beam (outside) is clamped at the top and bottom. • The top surface has a punched structure so that the cooling water can pass through the holes to the bottom of the pedestal.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [11/13]

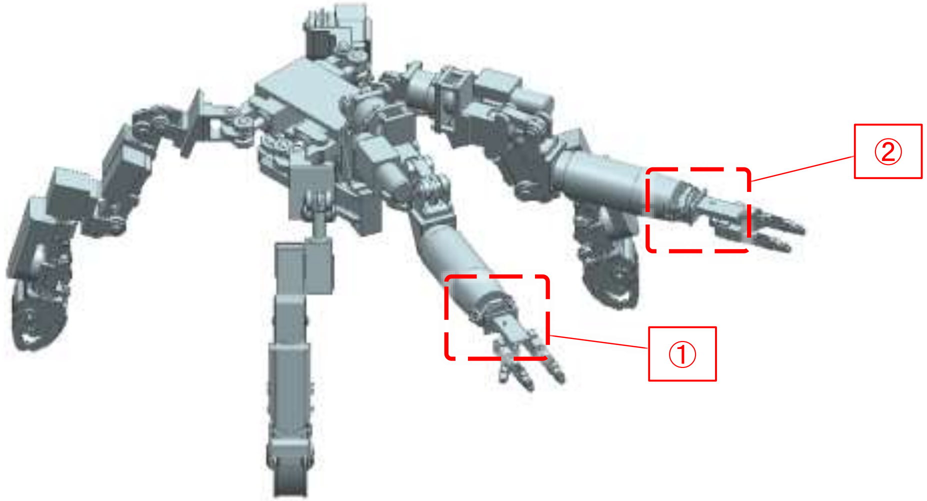
The equipment and tools used for the element tests are indicated below.

No.	Name	Approximate dimensions [mm]	Approximate mass [kg]	Outer appearance (schematic drawing)	Outer appearance (picture)	Overview
25	Slope	L200 x W516 x H79.7	1.1			• Provided for eliminating the gap between the distal end of the CRD rail and the upper scaffolding (outside). • Pins are inserted in the holes on the top surface of the upper scaffolding (outside), and the slope is fastened to the protruding parts on the top surface of the CRD rail.
26	Socket rotating tool	—	—			• A tool for operating the socket for various tools (scaffolding components, etc.) and fastening tools together. • Motor operated tools available on the market are used for the element tests.
27	Lifting hook	L177 x W77.3 x H91	1.9			• Hook for slinging when various equipment, tools and cut pieces are lifted up. • The method of slinging by inserting pins in the holes. • When held by the arm in the middle, the protrusion on the sides of the pin gets lowered, and it becomes possible to remove the pin. • As compared with the usual carbine hook, this hook is easier to operate with the robot arm and the risk of inadvertent slipping is lower.

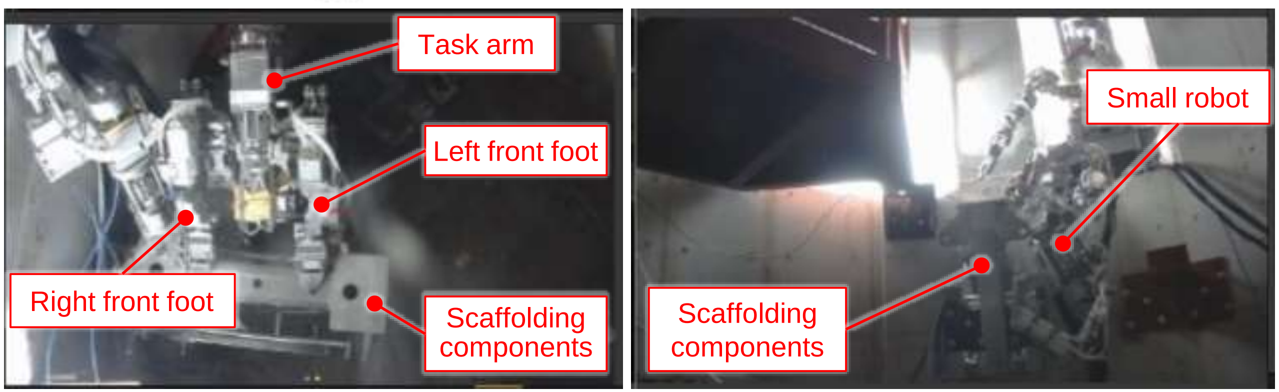
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

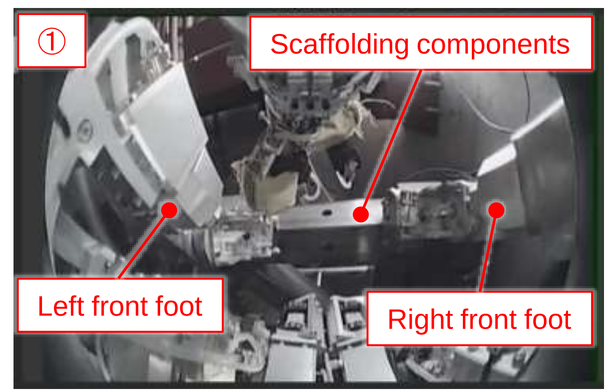
■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [12/13]



①： Camera at the tip of the right task arm
②： Camera at the tip of the left task arm
[Camera specifications: For vehicular installation]



Work during which the small robot is fastened on to the lateral surface of the scaffolding component



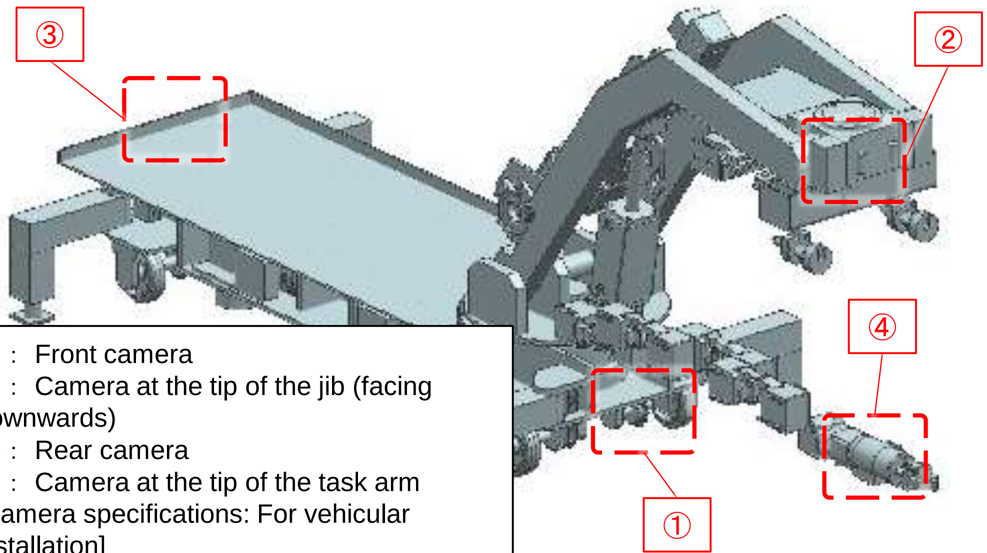
Verification of the grabbing location using the camera at the arm tip

Element tests were conducted by installing a camera on the small robot.

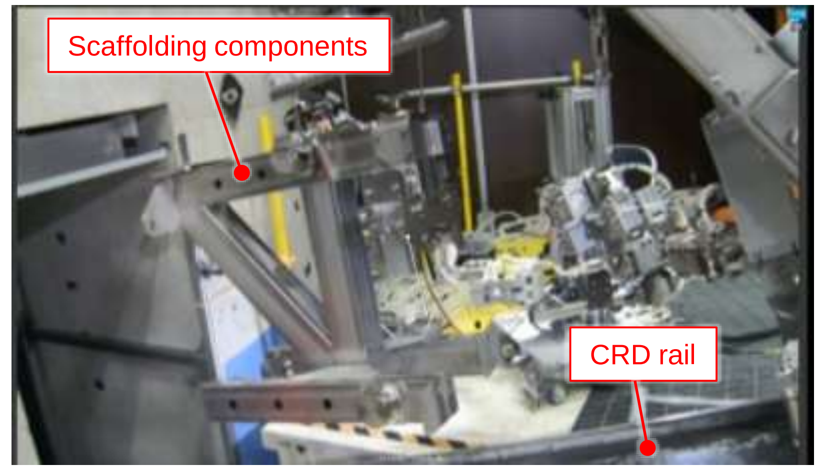
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

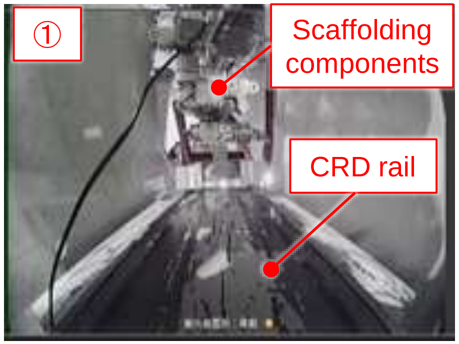
■ Designing and test manufacturing of the disassembly and removal equipment (Units 1/3) [13/13]

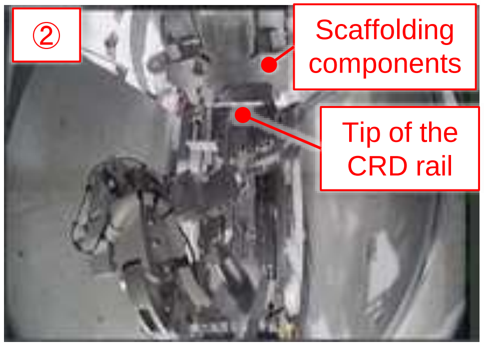


①： Front camera
②： Camera at the tip of the jib (facing downwards)
③： Rear camera
④： Camera at the tip of the task arm
[Camera specifications: For vehicular installation]



Work of carrying the scaffolding components inside the pedestal



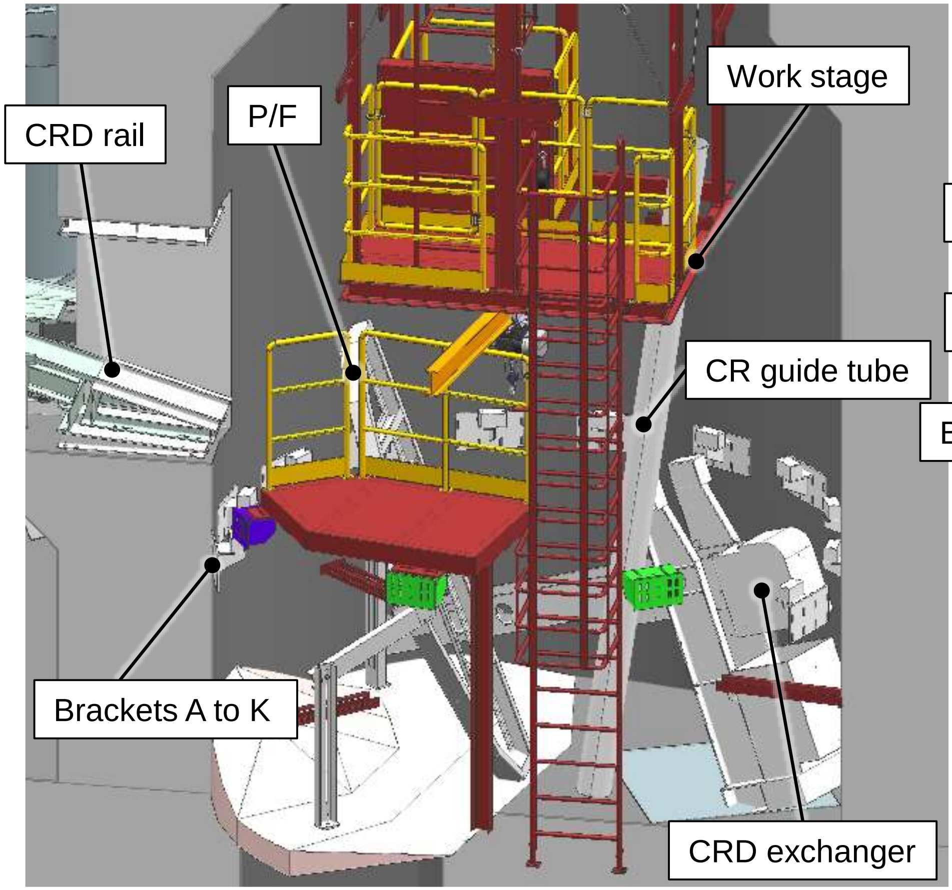


Element tests were conducted by installing a camera on the equipment for transferring cut pieces

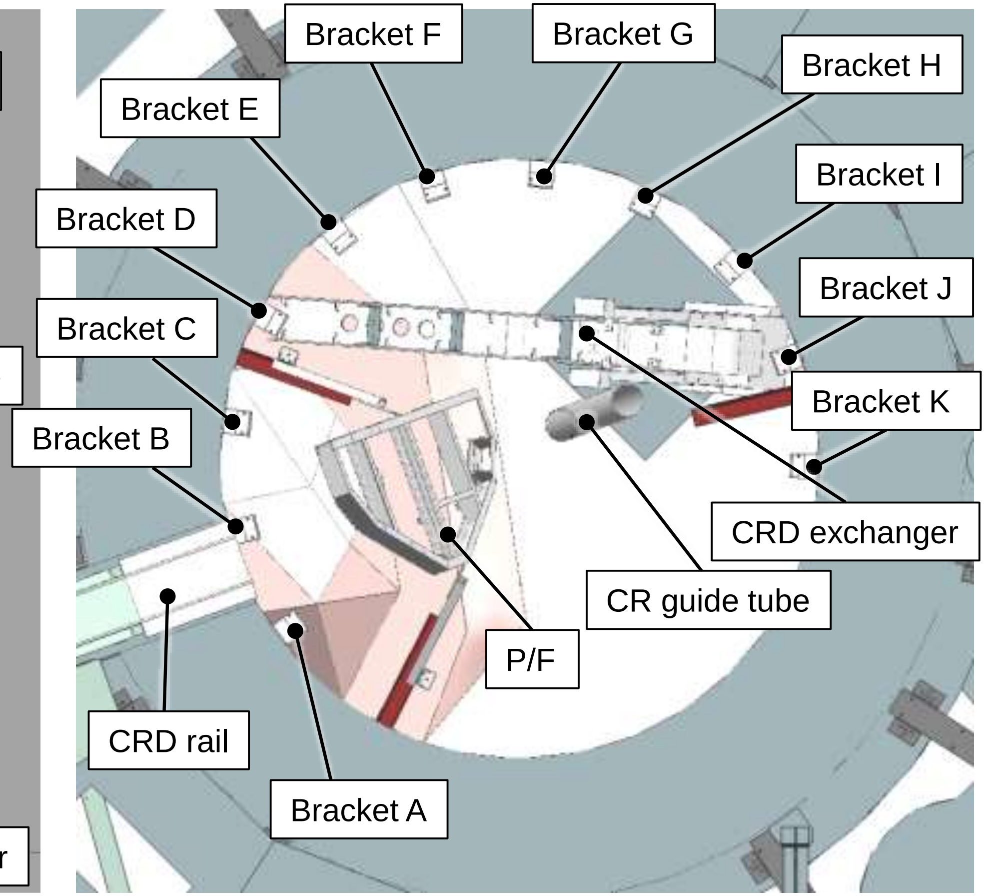
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Simulated test pieces and test equipment (Units 1/3) [1/4]



Test equipment simulating the inside of the pedestal in Units 1/3 (Bird's eye view)



Test equipment simulating the inside of the pedestal in Units 1/3 (Layout drawing)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

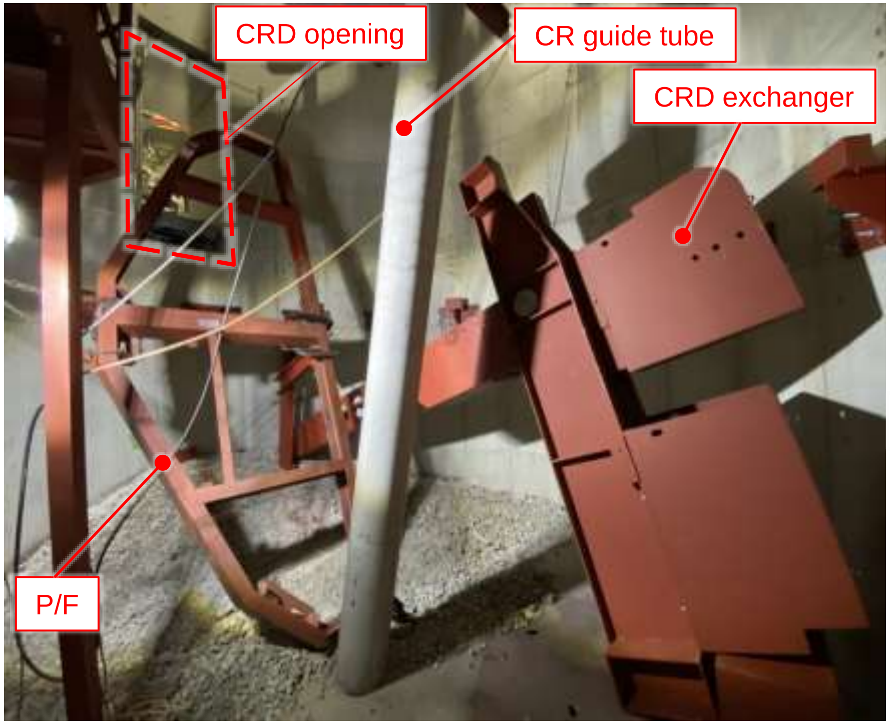
■ Simulated test pieces and test equipment (Units 1/3) [2/4]

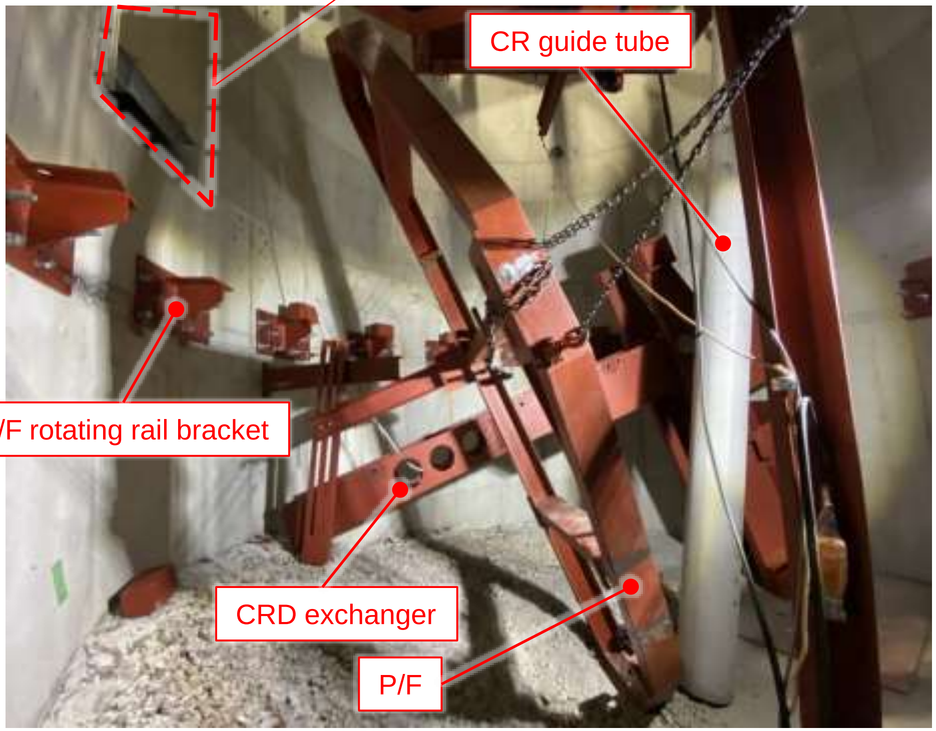
No.	Name of the structure in the simulated test equipment	Approach towards selection and placement	Approach towards fall prevention
1	P/F	Selected as the structure in the vicinity of the CRD opening while referring to the results of the internal investigation of 1F-3. Placed in an inclined manner so that it blocks the opening.	Prevented from falling by fastening it to a component (base unit) of the scaffolding constructed inside the pedestal using tools.
2	CRD exchanger	Selected as a structure that is large in size and has a large board thickness (rotating frame). Laid down at the bottom as it has not been seen during the internal investigation of 1F-3 (assumed to be buried under deposits).	Prevented from falling by fastening it with a wire from a scaffolding component (beam) as it is likely to have fallen to a location lower than the component (base unit) of the scaffolding constructed inside the pedestal.
3	CR guide tube	Selected as the structure that has fallen from above while referring to the results of the internal investigation of 1F-3. Placed so that it is held up in the wood of the CRD.H.	Prevented from falling by fastening it to a component (base unit) of the scaffolding constructed inside the pedestal using tools.
4	Work stage	The height of the lower end of the interfering object (CRD.H) in the upper part inside the pedestal is simulated.	—

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Simulated test pieces and test equipment (Units 1/3) [3/4]

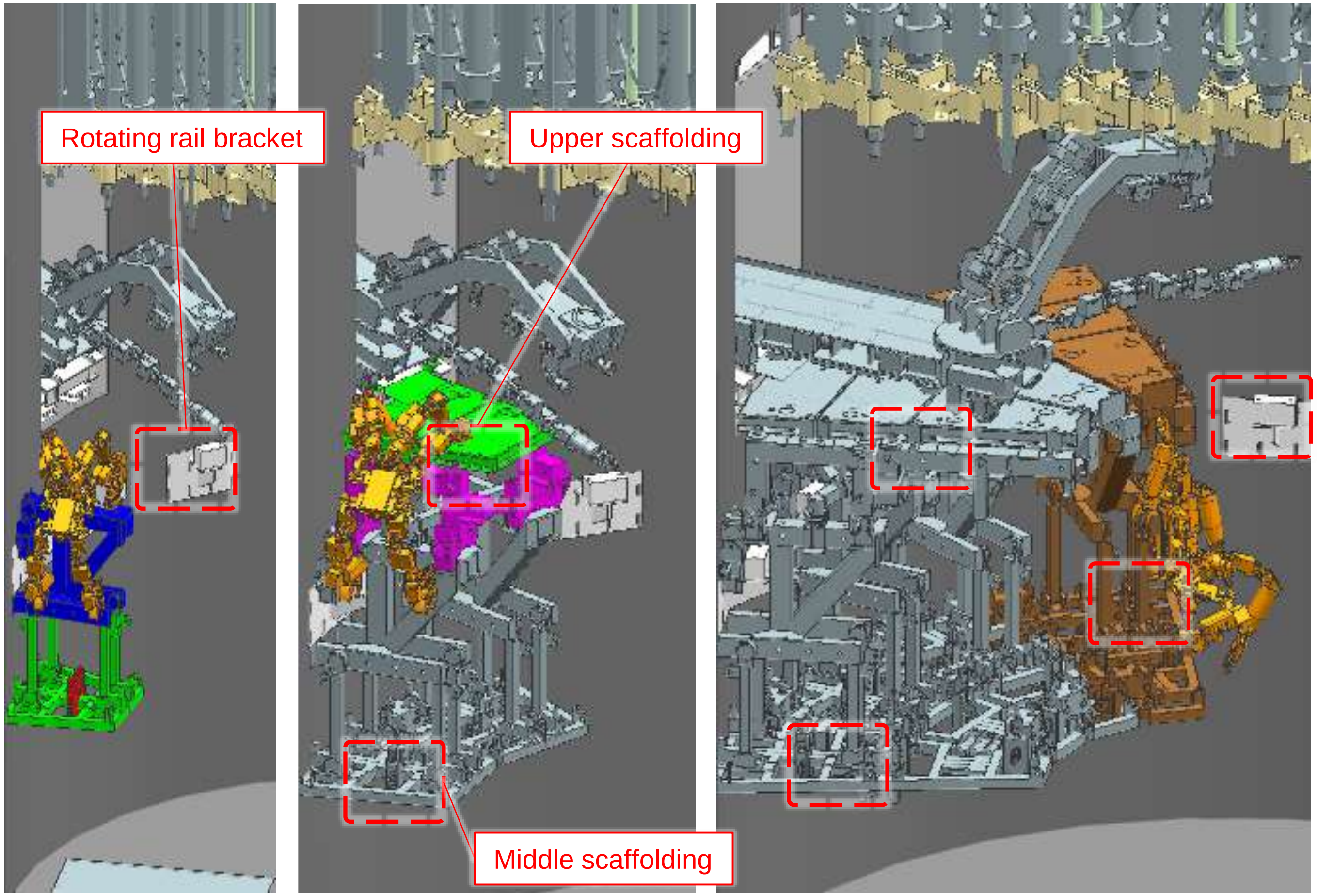




Element tests were conducted using the test equipment simulating the inside of Units 1/3 pedestal and the simulated fallen structures.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]
② Disassembly of CRD exchanger

■ Simulated test pieces and test equipment (Units 1/3) [4/4]



Camera ① (Also serves as the camera for investigation)
[Installation location: Rotating rail bracket]

Camera specifications: CID color camera (Pan tilt)

Camera ②
[Installation location: Upper scaffolding, middle scaffolding]

Camera specifications: CANON VB-M44

Element tests were conducted with cameras and lights installed on the upper scaffolding, middle scaffolding and rotating rail bracket in accordance with the progress in constructing the scaffolding inside the pedestal.

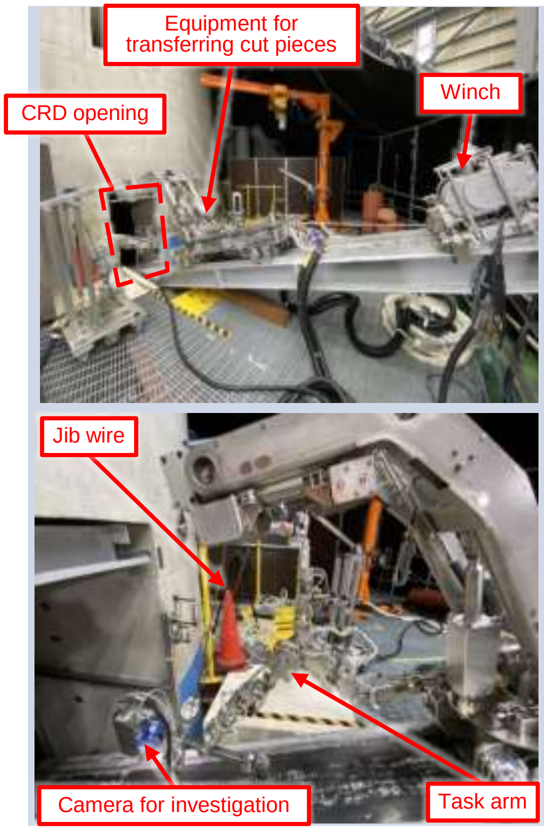
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

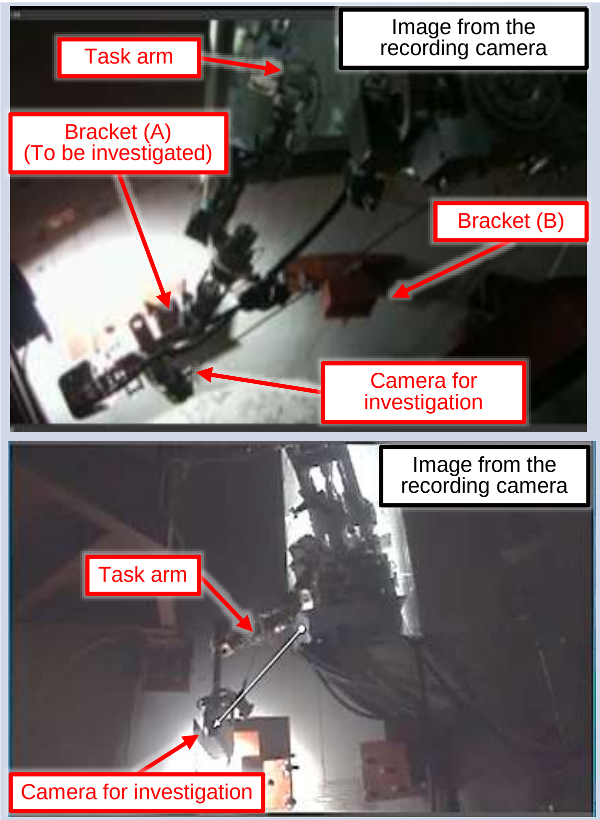
② Disassembly of CRD exchanger

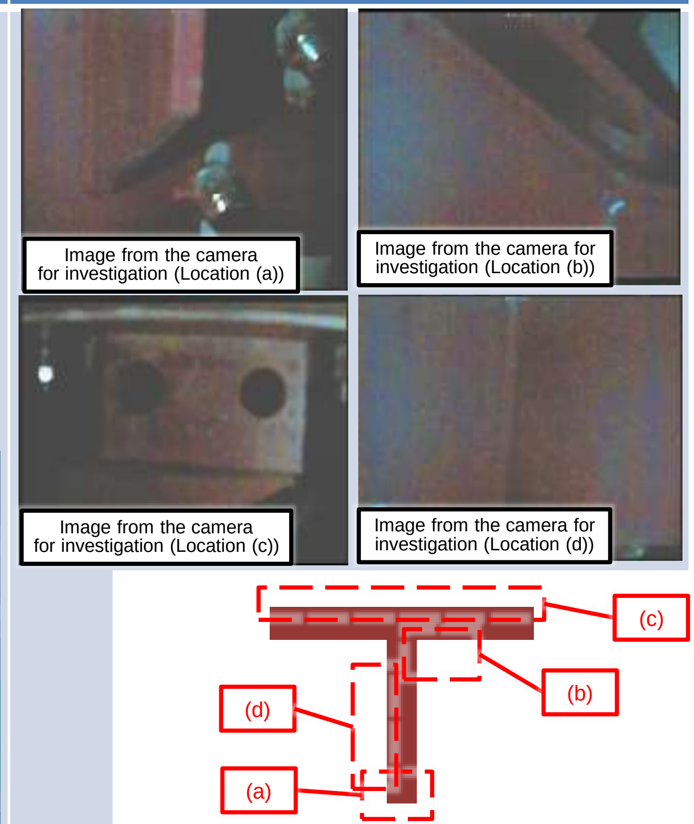
■ Element test results (Units 1/3) [1/7] [Investigation of the status of damage (P/F rotating rail bracket)]

An overview of the results of the element tests is given below.

(a) Carrying inside the pedestal	(b) Approaching the bracket camera	(c) Verifying the status of damage







It was verified that the task arm holding the camera for investigation can approach the P/F rotating rail bracket in the vicinity of the CRD opening, and the fillet welded part of the bracket can be captured in the angle of view of the camera (Prospects of being able to verify the status of damage of the bracket in the actual facility were seen.)

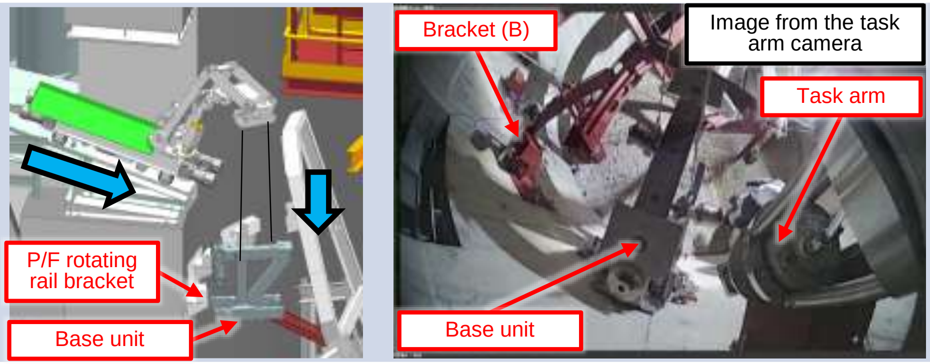
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

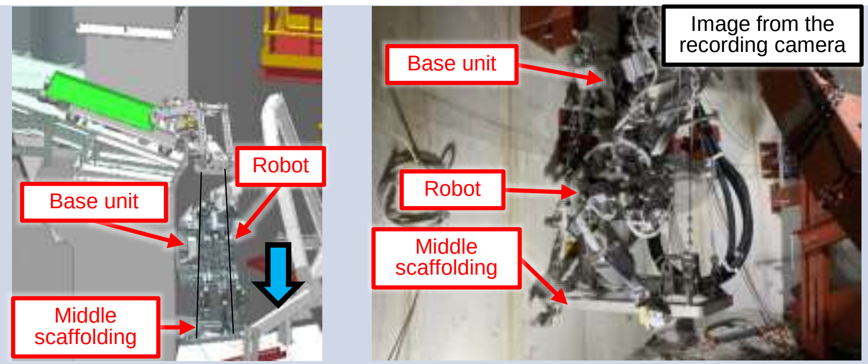
■ Element test results (Units 1/3) [2/7] [Construction of scaffolding inside the pedestal]

An overview of the results of the element tests is given below.

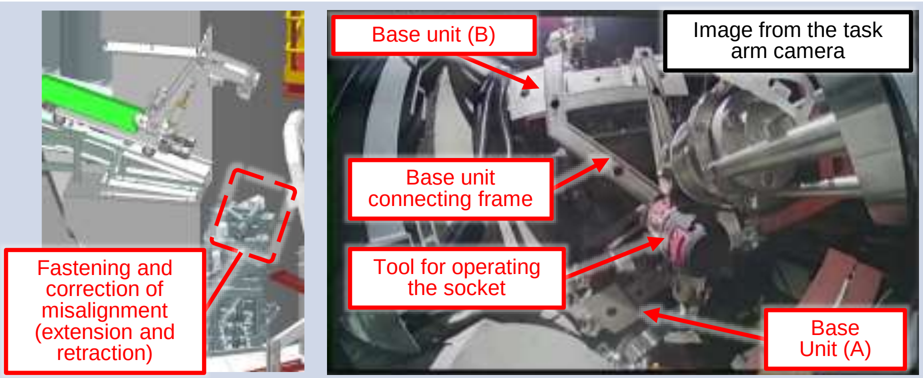
(a) Installing the base unit on the P/F rotating rail bracket



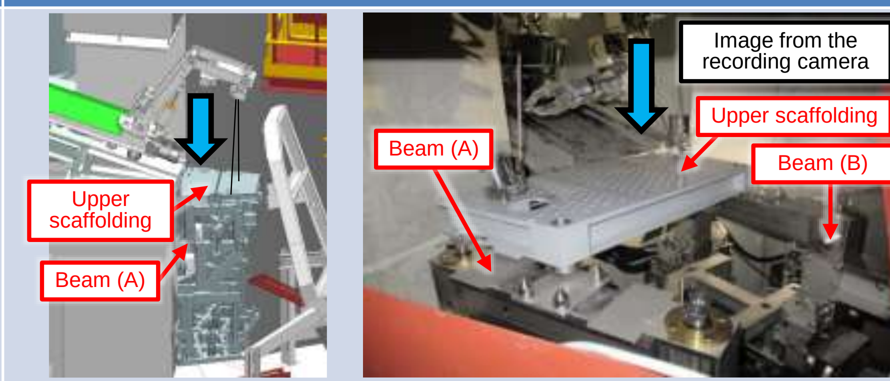
(b) Installing the middle scaffolding



(c) Fastening base units together and correcting misalignments



(d) Installing the upper scaffolding



The feasibility of the procedure for constructing the scaffolding for carrying in components through the CRD opening using equipment and small robots for transferring cut pieces, performing assembly work inside the pedestal, and moving the equipment and small robots to specified locations inside the pedestal, was verified.

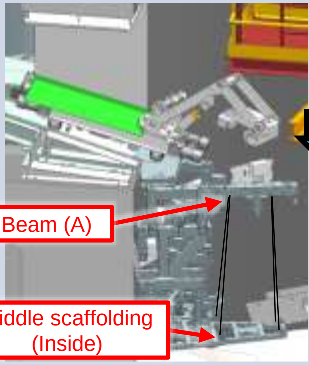
6. Implementation Items of This Project [1] (2) Development of Disassembly and Removal Technology

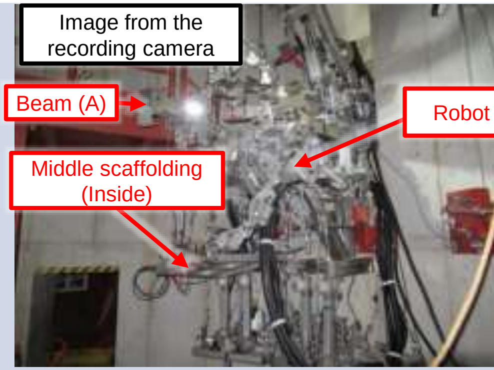
② Disassembly of CRD exchanger

■ Element test results (Units 1/3) [3/7] [Construction of scaffolding inside the pedestal]

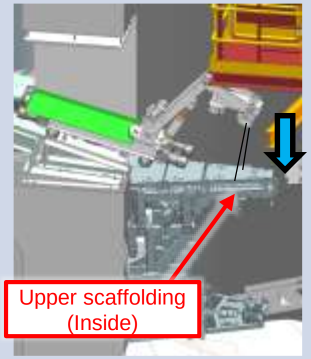
An overview of the results of the element tests is given below.

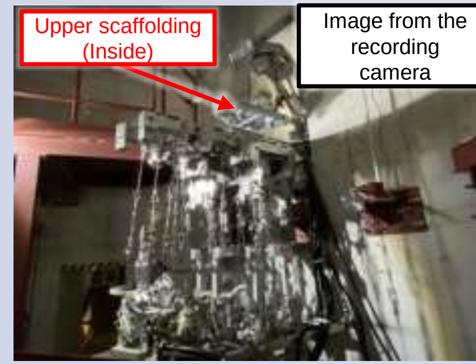
(e) Extending the beam and the middle scaffolding



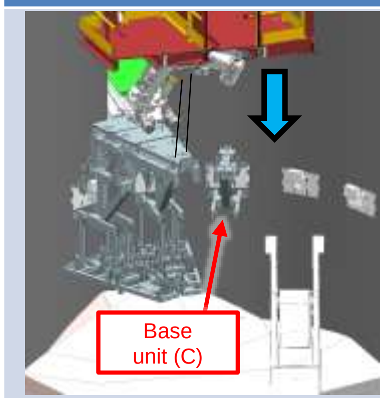


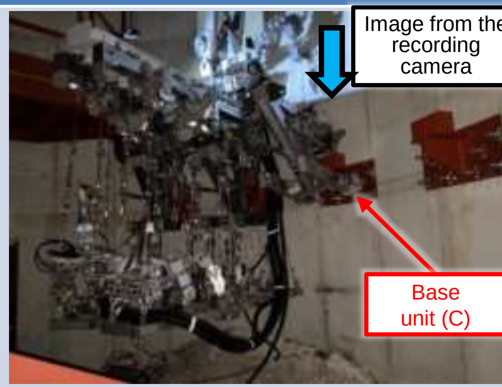
(f) Extending the upper scaffolding



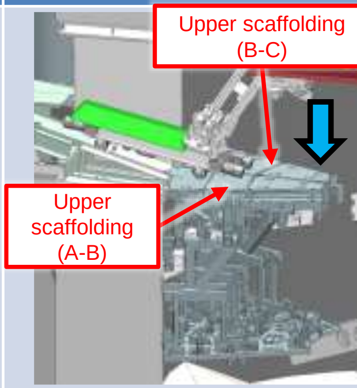


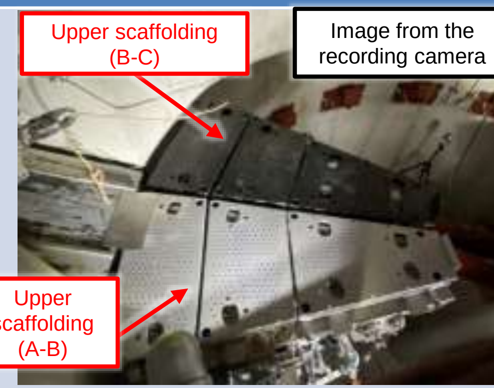
(g) Installing the base unit on the adjacent bracket





(h) Extending the scaffolding in the circumferential direction





The feasibility of the procedure for constructing the scaffolding for carrying in components through the CRD opening using equipment and small robots for transferring cut pieces, performing assembly work inside the pedestal, and moving the equipment and small robots to specified locations inside the pedestal, was verified.

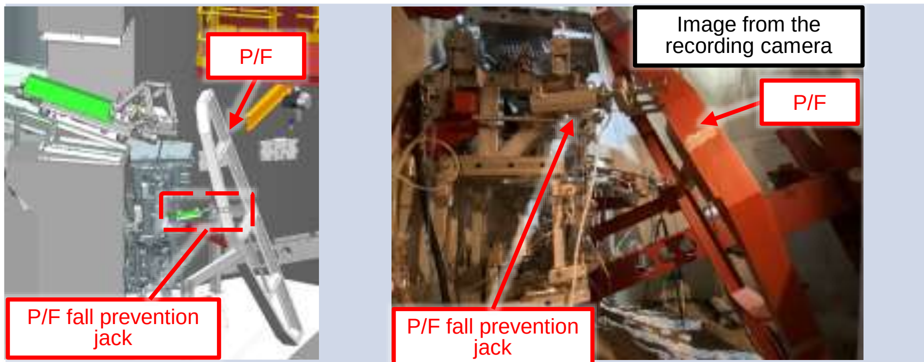
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

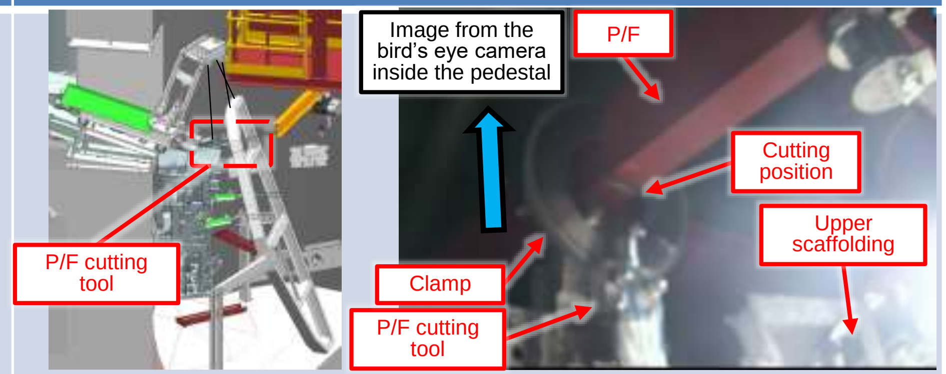
■ Element test results (Units 1/3) [4/7] [P/F fall prevention, cutting, transfer of cut pieces]

An overview of the results of the element tests is given below.

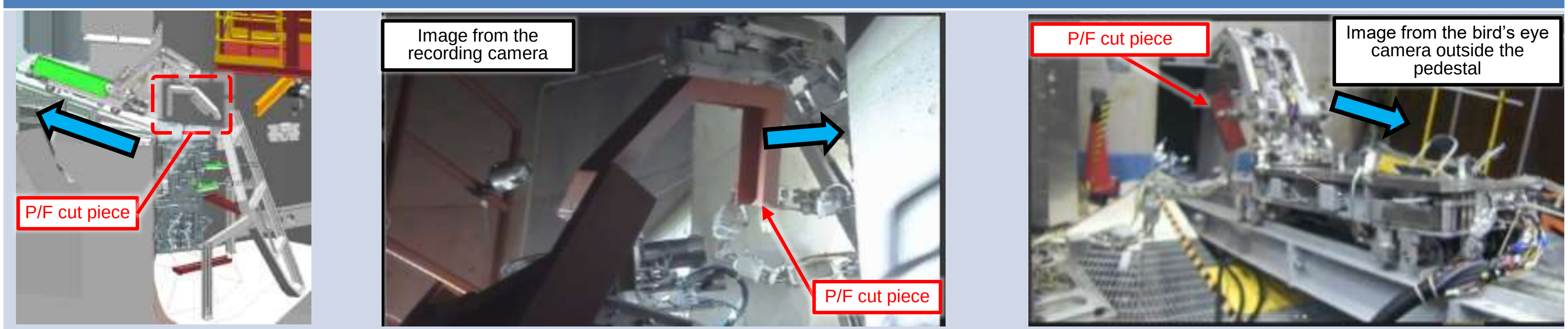
(a) P/F fall prevention



(b) P/F cutting



(c) Transferring P/F cut pieces



Prospects of being able to achieve fall prevention of the P/F by connecting it to the scaffolding inside the pedestal with a jack, being able to cut it using the blade that has been remotely positioned, and being able to transfer cut pieces outside the pedestal by suspending them in front with the jib of the equipment for transferring cut pieces, were seen.

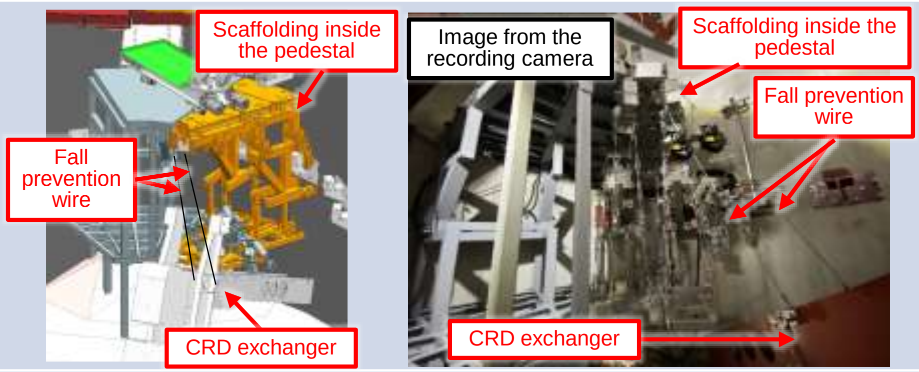
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

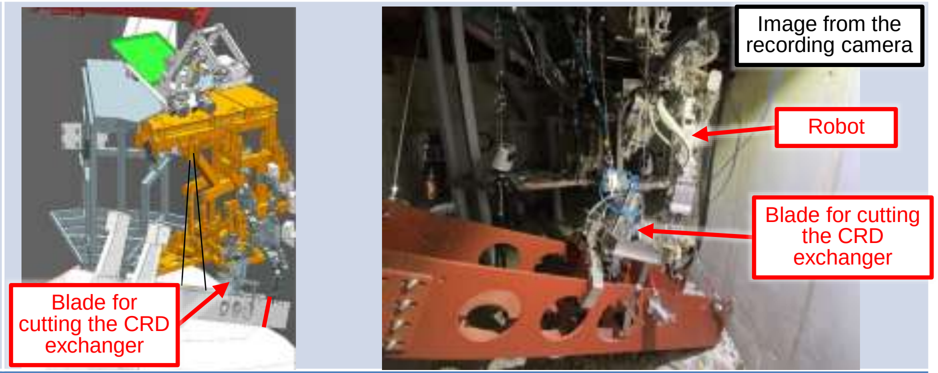
■ Element test results (Units 1/3) [5/7] [CRD exchanger fall prevention, cutting, transfer of cut pieces]

An overview of the results of the element tests is given below.

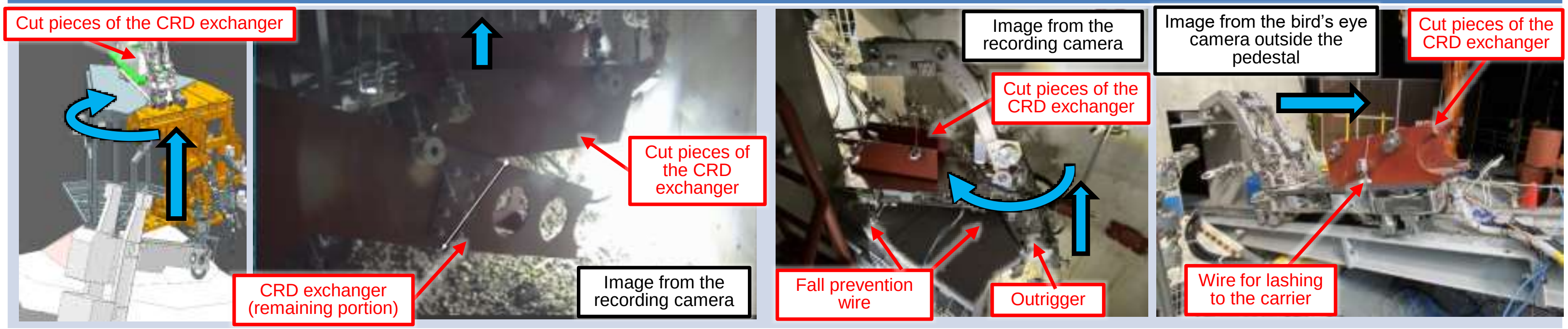
(a) CRD exchanger fall prevention



(b) Cutting of the CRD exchanger



(c) Transferring the cut pieces of the CRD exchanger



Prospects of being able to achieve fall prevention of the CRD exchanger by connecting it to the scaffolding inside the pedestal with a wire, being able to cut it using the blade that has been remotely positioned, and being able to lift and load the cut pieces on to the carrier of the equipment for transferring cut pieces and transfer the cut pieces outside the pedestal, were seen.

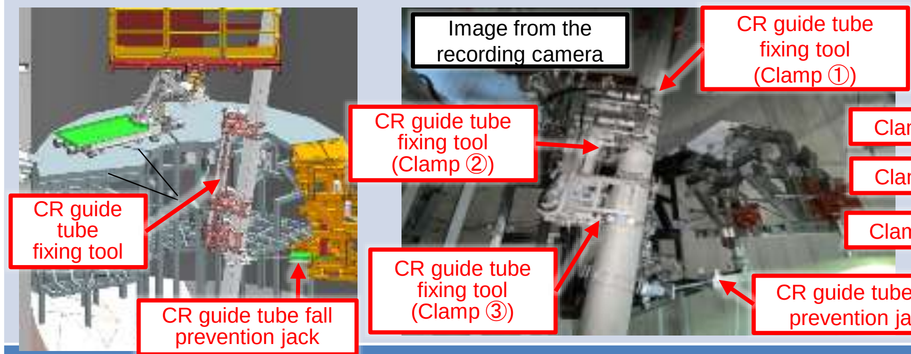
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

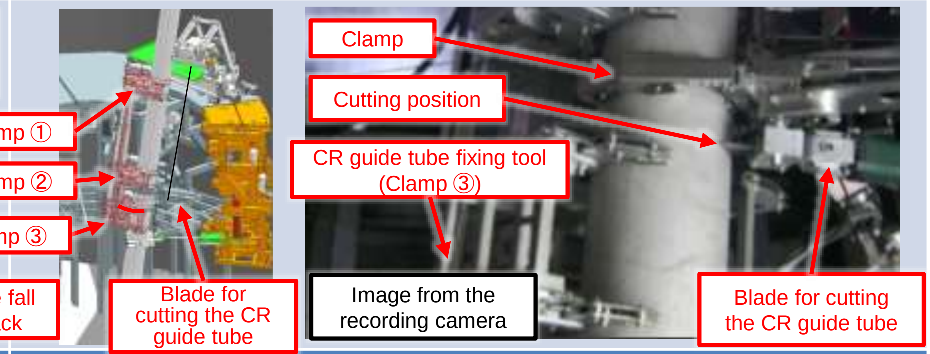
■ Element test results (Units 1/3) [6/7] [CR guide tube fall prevention, cutting, transfer of cut pieces, pulling out]

An overview of the results of the element tests is given below.

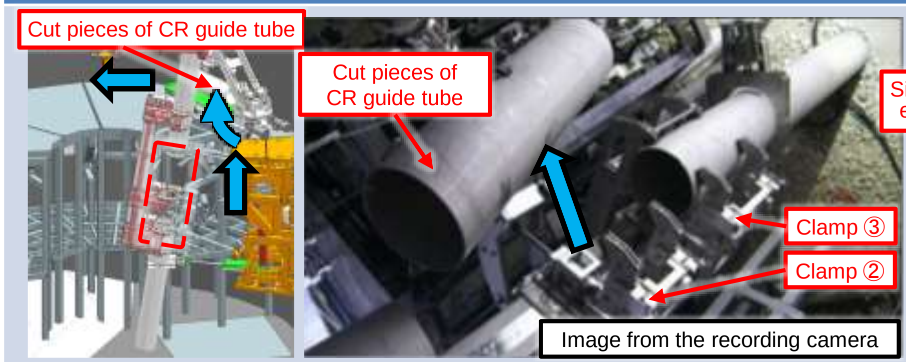
(a) CR guide tube fall prevention



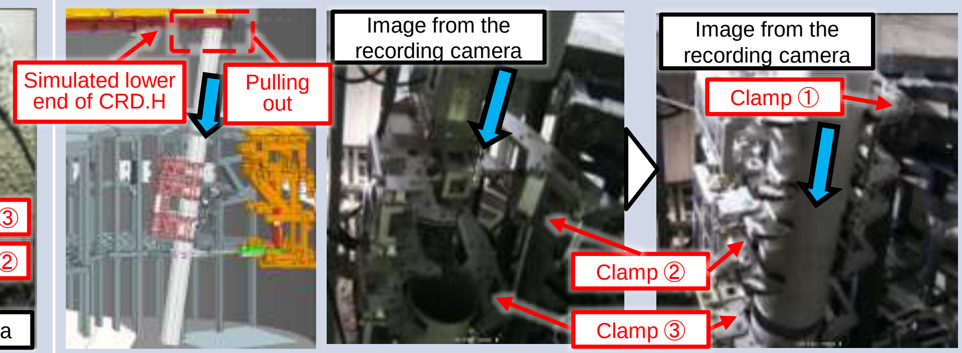
(b) Cutting of the CR guide tube



(c) Transferring the cut pieces of the CR guide tube



(d) Pulling out from the structures in the upper part of the pedestal



Prospects of being able to achieve fall prevention of the CR guide tube by connecting it to the scaffolding inside the pedestal with a jack, being able to cut it using the blade that has been remotely positioned, and being able to lift and load the cut pieces on to the carrier of the equipment for transferring cut pieces, and being able to transfer and pull out the cut pieces outside the pedestal, were seen.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Element test results (Units 1/3) [7/7] [Summary of element test results]

Results of the element tests are summarized below.

No.	Test classification	Test results
1	Investigation of the status of damage (P/F rotating rail bracket)	• It was verified that the task arm holding the camera for investigation can approach the P/F rotating rail bracket in the vicinity of the CRD opening, and the fillet welded part of the bracket can be captured in the angle of view of the camera (Prospects of being able to verify the status of damage of the bracket in the actual facility were seen.)
2	Construction of scaffolding inside the pedestal (Including installation of cameras and lights)	• A bird's eye camera was installed inside the pedestal using the equipment for transferring cut pieces and small robots and the feasibility of the procedure for constructing the scaffolding for carrying in components through the CRD opening using equipment and small robots for transferring cut pieces, performing assembly work inside the pedestal, and moving the equipment and small robots to specified locations inside the pedestal, was verified.
3	Equipment access to specified locations (Equipment and small robot for transferring cut pieces)	• Prospects that equipment can access specified locations, were seen since the equipment for transferring cut pieces moves over the upper scaffolding constructed inside the pedestal, and the small robots move over the middle scaffolding.
4	Fall prevention (P/F, CRD exchanger, CR guide tube)	• Prospects of being able to achieve fall prevention of P/F by connecting the P/F and the scaffolding inside the pedestal with a jack, were seen. • Prospects of being able to achieve fall prevention of the CRD exchanger by connecting the CRD exchanger and the scaffolding inside the pedestal with a wire, were seen. • Prospects of being able to achieve fall prevention of CR guide tube by connecting the CR guide tube and the scaffolding inside the pedestal with a jack, were seen.
5	Cutting off the interfering objects (P/F, CRD exchanger, CR guide tube)	• Prospects of being able to cut the P/F, CRD exchanger, CR guide tube using the blade that has been remotely positioned with the help of equipment for transferring cut pieces and small robots, were seen.
6	Transfer of cut pieces of the interfering objects (P/F, CRD exchanger, CR guide tube)	• Prospects of being able to transfer the cut pieces of P/F outside the pedestal through the CRD opening by suspending them in front using the jib of the equipment for transferring cut pieces, were seen. • Prospects of being able to transfer the cut pieces of the CRD exchanger and the cut pieces of the CR guide tube outside the pedestal through the CRD opening by loading the cut pieces on the carrier of the equipment for transferring cut pieces, were seen. • Prospects of being able to pull out the CR guide tube from the structures in the upper part of the pedestal using the CR guide tube fixing tool, were seen.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Issues identified based on the element tests

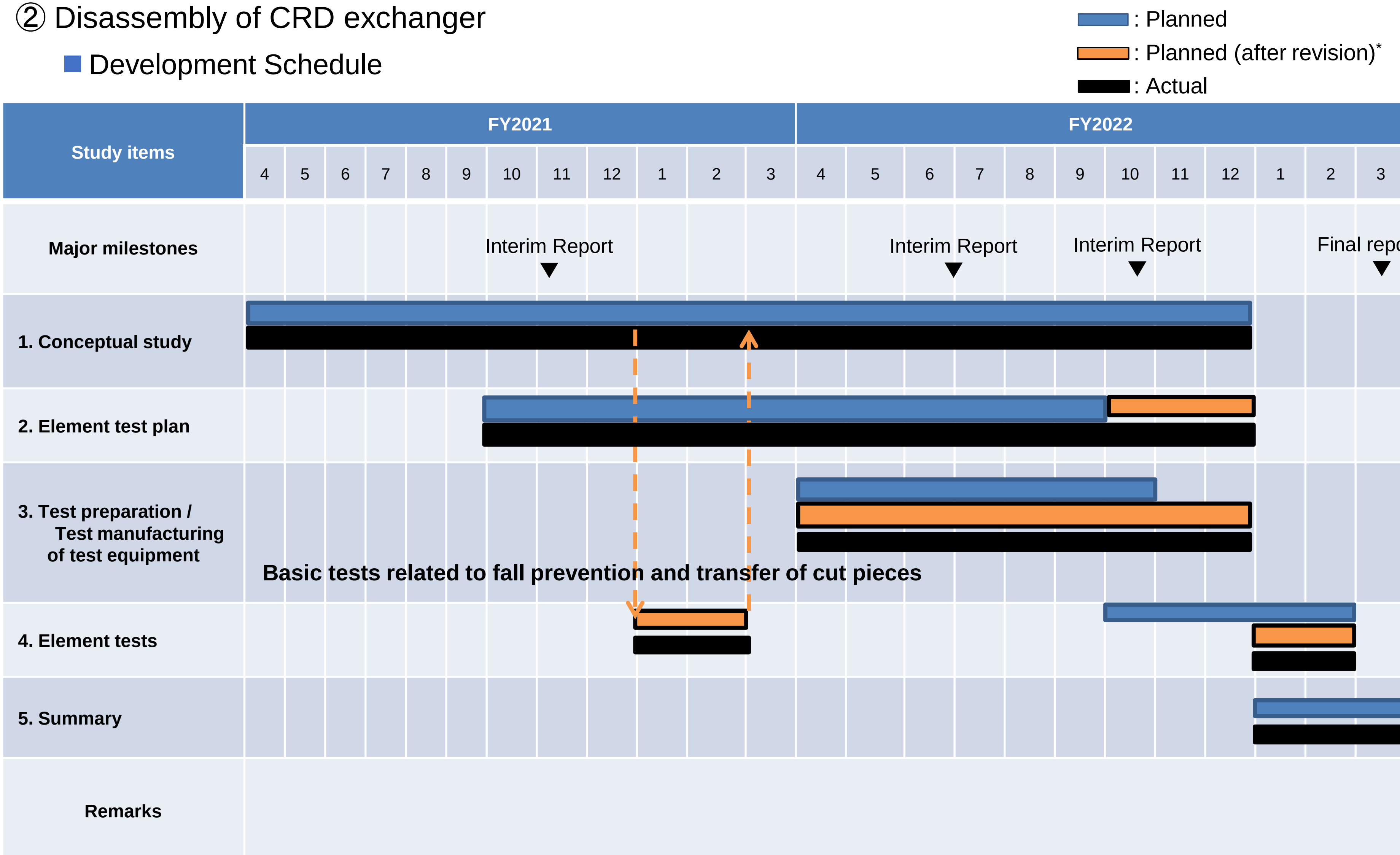
Issues identified based on the CRD exchanger disassembly element tests are described below.

No.	Test classification	Issues	Countermeasures (Considering the actual facility)
1	Investigation of the status of damage	There are very few camera images that can be used. There is no camera that can provide a bird's eye view to verify the overall position of the equipment in operation and the presence of interference with the structures inside the pedestal (There is a similar issue with the construction of scaffolding inside the pedestal mentioned in No. 2 below.)	A bird's eye camera to be used while investigating the status of damage should be installed in the vicinity of the CRD opening.
2	Construction of scaffolding inside the pedestal	Method for verifying completion of rotation of the socket.	Marking should be added. The structure should be modified so that the clamp pad is visible from the outside.
		Structure of the interface (tilted correction) between the base unit and the pedestal.	The structure of the interface should be modified such that it can be extended and retracted (actuator).
		Simplification of procedures for installing the middle scaffolding (method of suspending without using a robot).	The method should be modified so that the upper scaffolding and the middle scaffolding form an integrated structure and it gets deployed inside the pedestal.
		The swinging movement of the arm of the robot on the middle scaffolding is difficult due to interference with the hanging wire, etc. of the middle scaffolding.	Along with the measures mentioned above, the number of hanging wires should be reduced.
		Fall prevention measures for the equipment for transferring cut pieces while installing the base unit (C).	A structure that stretches along the inner wall of the CRD opening should be added to the equipment for transferring cut pieces.
		There is no camera for verifying the clamping status of the clamp part of base unit (C).	A camera with extendable tools should be used as required.
3	Fall prevention	The P/F fall prevention jack clamp part (wrist) follows the P/F.	The structure should be modified to that including an actuator rather than following by means of a spring.
		Controlling the tool rotation while suspending the tool for making holes.	The hanging ceiling should be adjusted. The cable feed should be adjusted.
4	Cutting off the interfering objects	The edge (entire tool) gets damaged at the time of making holes and holes cannot be made anymore.	A clamping mechanism corresponding to the shape of the location where the hole is to be made should be added to the hole making tools.
		Reduction in the frequency of rotational stops because of getting wedged between the blades while cutting the rotating frame	Changing the cutting method from tip saw to grindstone grinder should be considered.
		Enhancing the stability while making holes on and cutting the CR guide tube, reducing the required time, increasing the service life of the blade.	The mechanism for clamping the tool on to the CR guide tube (clamping force) should be modified.
		Whether it will be possible to perform cutting if there are any structures inside the CR guide tube and measures against falling of cut pieces.	Internal investigation should be carried out after making the holes. If there are any embedded objects, the objects should be finely cut and removed.
5	Transfer of cut pieces of the interfering objects	Measures against interference of the clamp part with the upper CR guide tube when the CR guide tube is being pulled out.	The structure of the clamp part that interferes should be changed from one that opens only on one side to one that opens on both sides.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger

■ Development Schedule



* The plan was revised to reflect the progress status of the studies and the results of basic tests.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

② Disassembly of CRD exchanger: Summary

- **The pre-conditions pertaining to the disassembly of the CRD were consolidated, the method of disassembly and removal of CRD exchangers in Units 1 to 3 and the work steps involved were studied, and the test items were selected.**
  - **Unit 2: The method of carrying out disassembly and removal by installing a rail on the P/F, and moving the equipment to the specified locations inside the pedestal by traveling over the rail.**
  - **Units 1/3: The method of carrying out disassembly and removal by constructing a scaffolding inside the pedestal using the P/F rotating rail bracket on the inner wall of the pedestal, and moving the equipment to the specified locations inside the pedestal by traveling over the scaffolding.**

- **The simulated facility, test pieces, equipment and tool used in the element tests were test manufactured separately for the Unit 2 base and for the Units 1/3 bases, the work steps were substantiated, and the element test plan was formulated.**

- **The feasibility of the method of disassembling and removing the CRD exchanger was verified through element tests. Issues in application to the actual facility were identified and reflected into the equipment design for the actual facility.**

③ Interfering objects removal from pump pit

A submersible pump needs to be installed in the pump pit inside the PCV as one of the methods for circulating water inside the PCV while increasing the scale of retrieval of fuel debris and reaction internal structures. Elemental tests have been conducted based on development carried out in the past and it has been projected that the pump can be suspended, lowered and installed (fixed) inside the pit, however, interfering objects such as existing pump, etc. present inside the pit need to be removed.

For removing interfering objects from inside the pump pit, removal equipment, etc. will need to be installed in the limited space inside PCV, and the interfering objects such as existing pump, etc. present inside the pump pit will need to be removed remotely from the basement floor. The gap between the inner surface of the pit and the pump is small, and it is not easy to access with tools, etc. Hence, the method of confirming the status of the target objects by means of images captured by the camera, and then cutting, etc. and transferring will be studied in detail, and feasibility will be verified by element tests.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

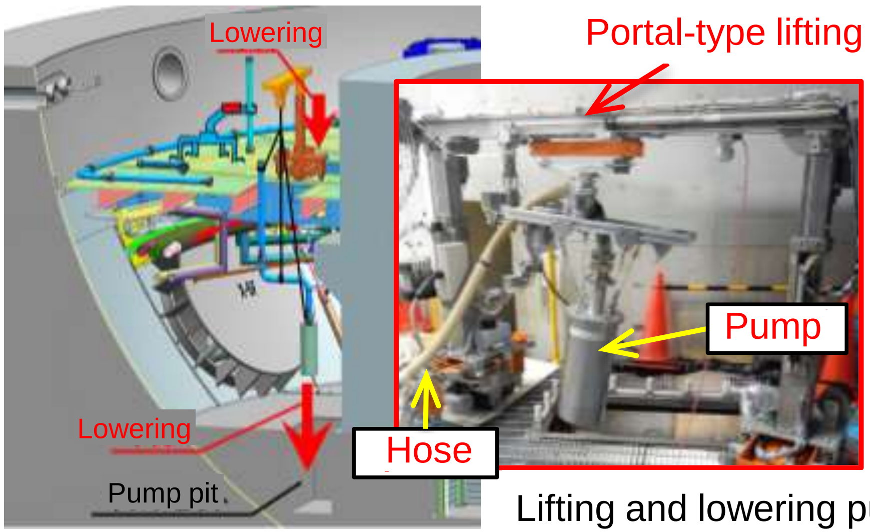
Table of Contents

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

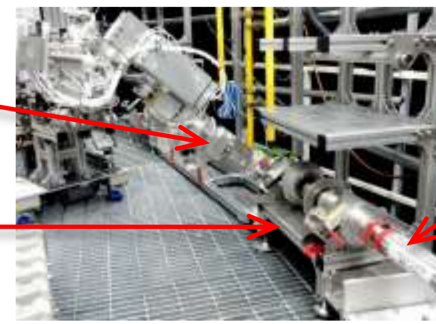
[Status of studies conducted up to FY2020]

- Prospects of feasibility of accessing the pump pit and of the method of installing the submersible pump were seen based on the element tests.
 (Implemented as part of the “Development of technology for the establishment of water circulation systems inside PCV”)



Lifting and lowering pumps

Submersible pump suspension test



Water intake piping installation (connection) test

⇒ The above-mentioned study was conducted on the pre-condition that interfering objects present inside the pump pit have already been removed.
 The method for removing interfering objects from inside the pump pit, which is a pre-condition, will be specified and feasibility will be verified by element tests.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

[Issues]

- The plan is to install a submersible pump inside the pump pit located at the lowest location inside PCV in order to control contaminated water at a still lower location by means of the water circulation system, however, there are interfering objects such as existing pump, etc. inside the pump pit, which makes it difficult to install the submersible pump. Hence technology needs to be developed for removing interfering objects from inside the pump pit.

[Implementation details]

- Actual equipment information, results of the analyses and investigations carried out so far on the status of interfering objects in the periphery of the pump pit for each unit are consolidated, and the preconditions at the time of interference removal are studied.
- The method of remotely removing interfering objects such as existing pump, etc. present inside the pump pit from the basement floor is studied.
- The remote controlled equipment, cutting equipment required for implementing the removal method considered, are studied.
- Element tests are planned and implemented to verify the feasibility of the considered technology for removing interfering objects from inside the pump pit.

[Expected outcome]

- Presentation of the method of removing interfering objects such as existing pump, etc. from inside the pump pit.

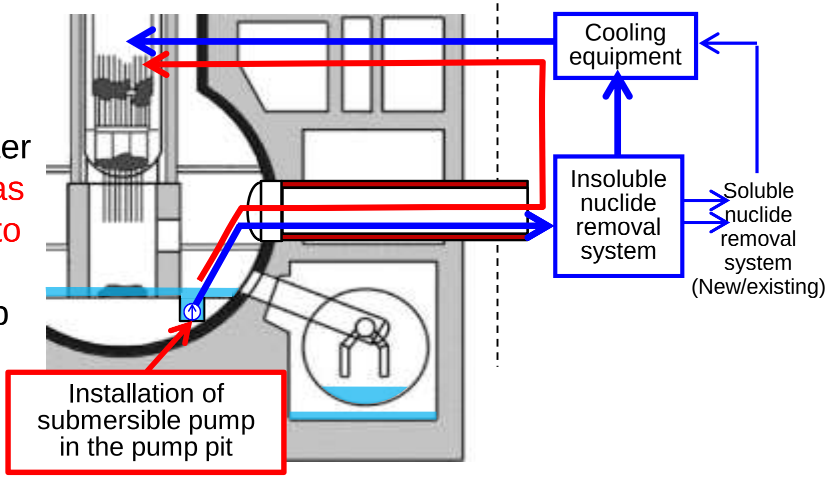
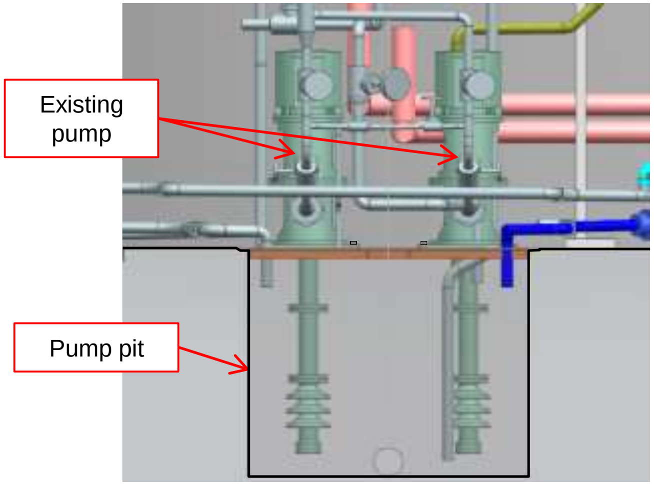


Illustration after making the D/W water intake lines



Cross section of pump pit (Unit 1)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

[FY2021 Implementation Details]

- **Compilation of information on the actual site**
- **Compilation of pre-conditions**
- **Study of work steps**
- **Selection of element test items**
- **Study of equipment used**

[FY2022 Implementation Details]

- **Scope of simulation in element tests (Test equipment)**
- **Unit test plan (Test items)**
- **Element test plan (Test items)**
- **Unit and element test items, and test contents and items to be verified**
- **Scope of simulation in element tests (Simulated pump)**
- **Scope of simulation in element tests (Simulated environment: Unit 1, Unit 2)**
- **Study of equipment for remote operation used in the element tests**
- **Study of cutting equipment used in the element tests**
- **Study of tools involved in the work of removing interfering objects from the pump pit**
- **Unit test results**
- **Element test results**
- **Issues identified based on the element tests on removal of interfering objects from the pump pit**

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]
③ Interfering objects removal from pump pit

■ Consolidation of pre-conditions Summary of pre-conditions

➢ The pre-conditions pertaining to the studies conducted during this subsidy project were consolidated. The consolidated results are given below.

No.	Items		Target unit, location	Reason	Remarks
1	Status of fuel debris present above the pump pits and inside them (Scope of removal of existing pump)		・Units 1 - 3 (Case 2: Removal in parts) ・Units 2 and 3 (Case 4: Complete removal [unitized removal])	As locations where fuel debris will not be retrieved are selected	2 patterns will be studied
2	Pump specifications	Height	Unit 2 (2,247[mm])	As it was determined that objects that are the tallest (longest) will be difficult to remove	
		Mass	Assuming Unit 2 (320[kg])	As it was determined that objects that are the heaviest will be difficult to remove	
		Diameter	All units (Φ305[mm])	As the dimensions are the same for all units	
3	Pump pit specifications		Units 2 and 3 (1,250(W) x 700(D) x 1,230(H)[mm])	As it was determined that work will be difficult in the most confined space	
4	Pump pit location		・ Pump pit (225°) inside PCV in Unit 1 ・ Pump pit (202.5°) inside PCV in Units 2 and 3	The one in which performing work would be difficult was selected.	2 patterns will be studied

<Selection of No. 4 pump pit location>
- The pump pit (225°) inside PCV in Unit 1 is likely to be buried under fuel debris. However, the status of fuel debris is just an estimation. Hence, the approach that by verifying the viability of work that has a higher level of difficulty, the viability of work with a lower level of difficulty stands verified, was adopted for selecting the location to be tested this time.
- While selecting the target pump pit, the kerf (level difference), etc. is believed to be a condition that must be considered, but as detailed information on the kerf, etc. has not been obtained, the level of difficulty was considered as the guideline for selecting the target pump pit.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Study of work steps a. Overview of work steps

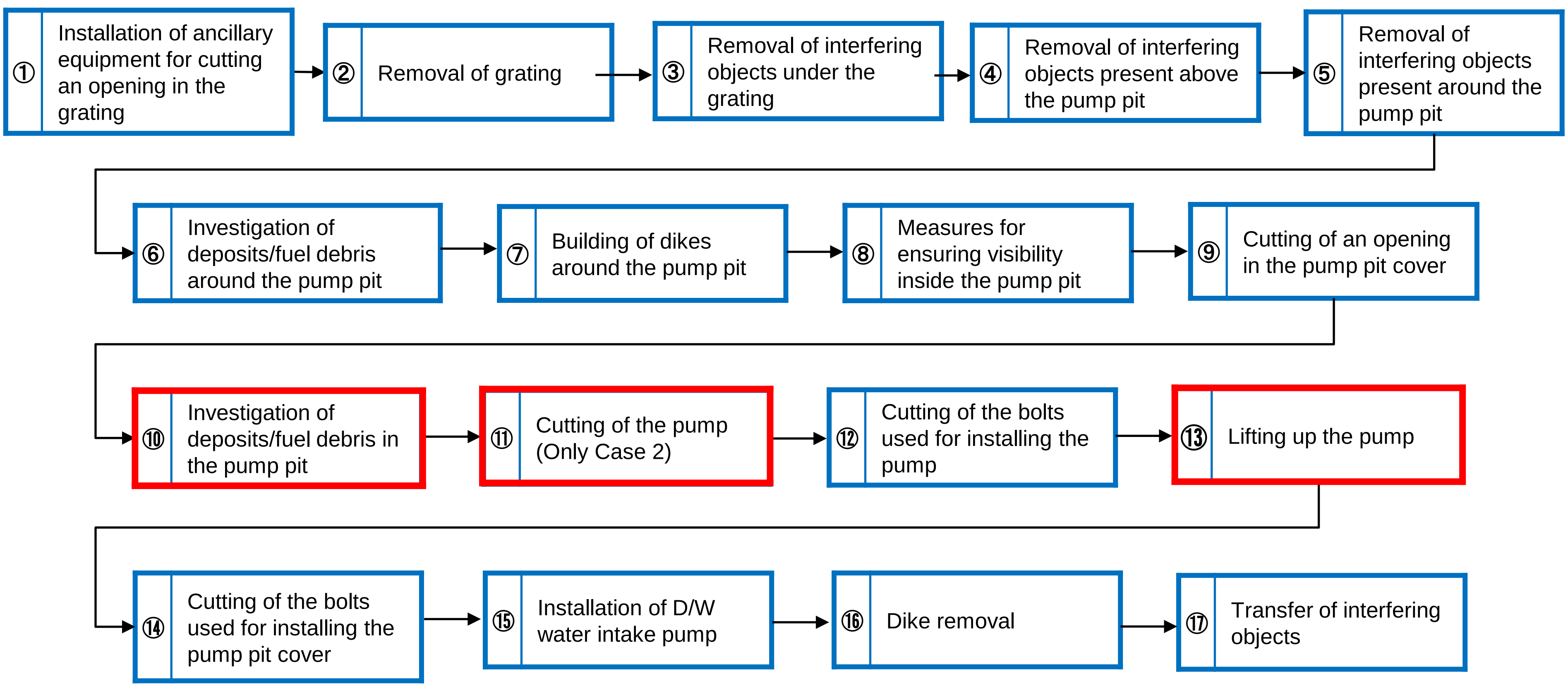
➢ An overview of the work steps involved in removing interfering objects from inside the pump pit was studied. The work steps studied are given below.

[Pre-conditions]

- The interfering objects on the access route from the equipment hatch up to the top of the pump pit on PCV first floor are assumed to have been removed.
- The equipment used for the work is assumed to have been moved to the top of the pump pit on PCV first floor.

<Overview of work steps> Same for Units 1, Unit 2, Unit 3

Work steps to be tested in the element tests



6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Unit and element test items, and test contents and items to be verified

Reports of element tests

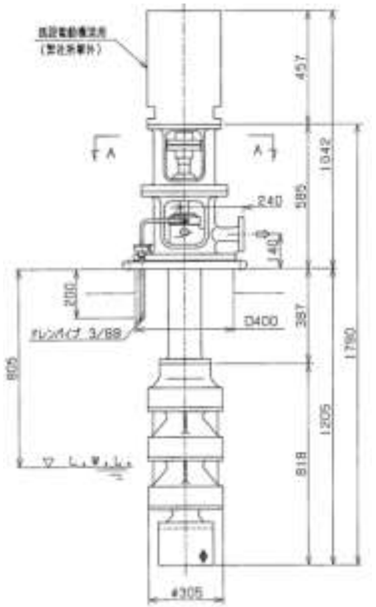
No.	Step / test item	Test contents	Items to be verified / records
1	⑩ Investigation of deposits/fuel debris in the pump pit ・Handling of cameras/lights for investigation inside the pump pit	The visibility of the submersible camera in a dark environment, under water and in a muddy water environment is verified.	● Setting of conditions so that the target object can be verified (distance, light intensity, etc.) ● Conditions are recorded
2	⑪ Cutting of the pump (Only Case 2) ・Cutting/grabbing the pump in the pump pit (Case 2)	Feasibility of remote operations is verified by suspending the cameras, lights and cutting equipment from the grating opening, and cutting the pump.	● Interference of structures while lifting up and suspending the cameras, lights and cutting equipment ● Placement of the cameras and lights ● Adjustment of the installation position of the cutting equipment ● Fastening and release of cutting equipment ● Cutting of the external pipes of the pump and the shaft using the cutting equipment (pressure, current value) ● Time required for work is recorded
3	⑬ Lifting up the pump ・Slinging the pump	Feasibility of remote operations is verified by slinging the pump with the help of a robot.	● Interference of structures while suspending the slinging tools ● Handling of slinging tools by the robot (grabbing, passing through and installing) ● Placement of the cameras and lights ● Time required for work is recorded
4	⑬ Lifting up the pump ・Lifting up the pump (Case 4)	Feasibility of remote operations is verified by lifting up the pump with the help of robots and cranes.	● Whether the tension of the wires can be adjusted using a crane ● Interference with structures while lifting up the pump (Unit 1, Unit 2) ● Placement of the cameras and lights ● Time required for work is recorded
5	⑬ Lifting up the pump ・Lifting up the upper part of the pump (Case 2)	Feasibility of remote operations is verified by lifting up the pump with the help of robots and cranes.	● Whether the tension of the wires can be adjusted using a crane ● Interference with structures while lifting up the pump (Unit 1, Unit 2) ● Placement of the cameras and lights ● Time required for work is recorded
6	⑬ Lifting up the pump ・Moving the pump (D/W first floor)	The suspension length adjustment tool is installed using small robots on the pump that has been lifted up by means of the crane, and the pump is mounted on the transportation equipment that is placed within the range of movement of the crane.	● Handling of the suspension length adjustment tool by the small robot ● Interference with structures while mounting the pump on the transportation equipment ● Placement of the cameras and lights ● Time required for work is recorded

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Scope of simulation in element tests (Simulated pump)

- Simulated pump: The dimensions and mass of the pump in Unit 2 are simulated. Since cutting will be performed multiple times, the shape of the lower part of the pump is not simulated.
- Simulated dummy: A dummy of the same dimensions as the simulated pump is simulated for verifying interference.
- Pit cover: Unit 1 and Unit 2 pit covers are simulated.
- Pit： Common for Unit 1 and Unit 2.



Unit 2 Drawing of the drain sump pump

Simulated pump for the element tests

Pit cover (Unit 1)

Pit cover (Unit 2)

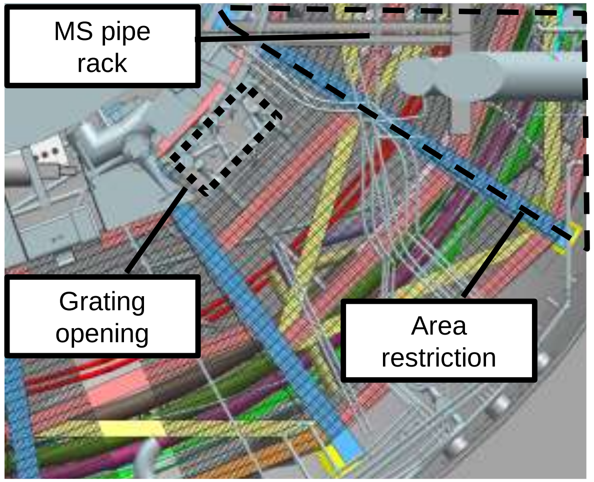
Pit for the element tests

Layout of the simulation (Unit 1)
Left: Dummy, Right: Simulated pump

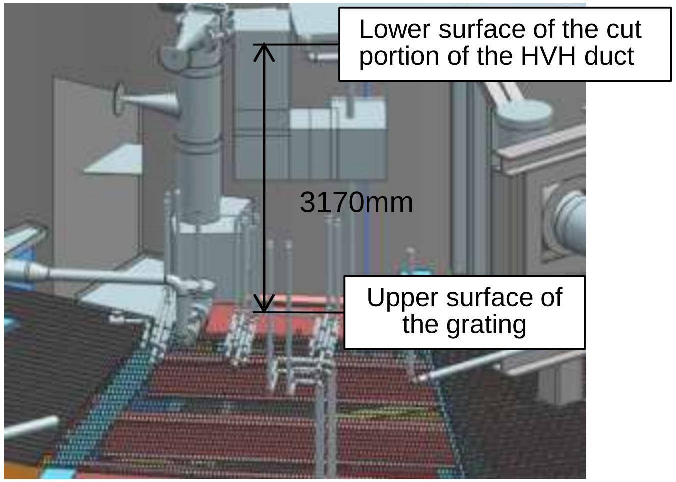
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

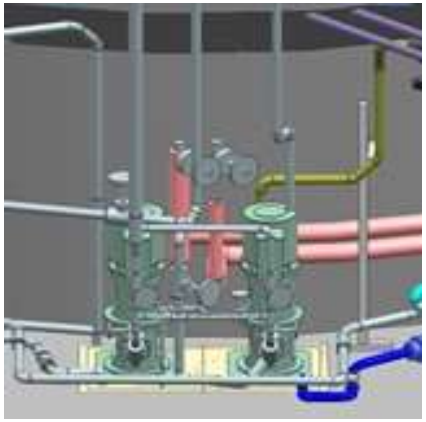
- Scope of simulation in element tests (Simulated environment: Unit 1)
  - The environment in Unit 1 was simulated by restricting the area to the MS pipe rack that interferes at the time of lifting up and moving the pump assuming this is being done in the actual facility, and element tests were conducted.



Layout drawing of the Unit 1 PCV first floor at 225˚



Bird's eye view of of Unit 1 PCV first floor at 225˚


Bird's eye view of of Unit 1 PCV basement floor at 225˚

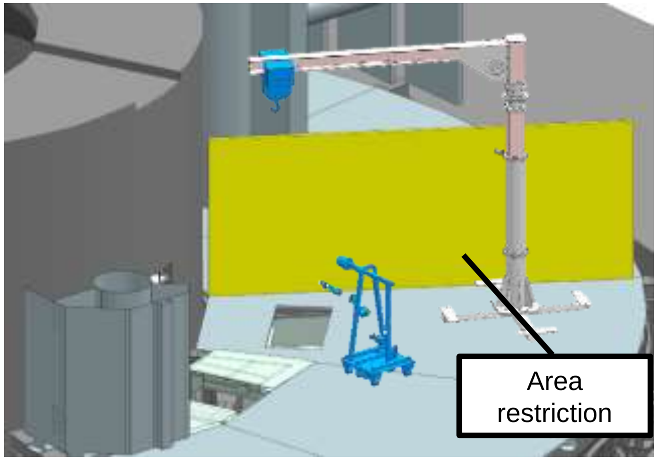
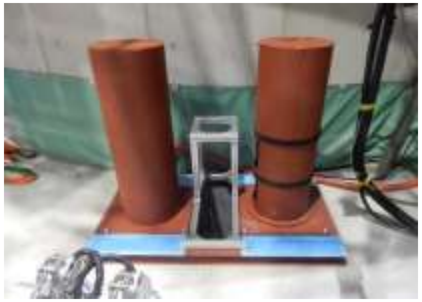


Image illustrating the simulation for the element test (Unit 1 PCV first floor)


Status of the element test (Unit 1 PCV first floor)


Status of the element test (Unit 1 PCV basement floor)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Scope of simulation in element tests (Simulated environment: Unit 2)

- The environment in Unit 2 was simulated by restricting the area to the MS pipes and MS pipe rack that interfere at the time of lifting up and moving the pump assuming this is being done in the actual facility, and setting up a simulation of the pipes, and then element tests were conducted.

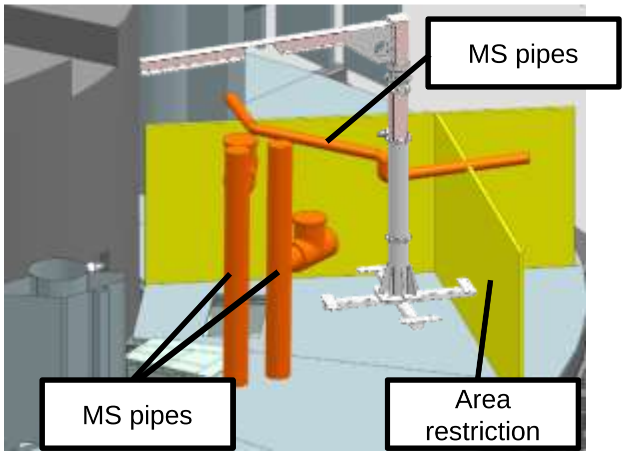


Image illustrating the simulation for the element test (Unit 2 PCV first floor)

Status of the element test (Unit 2 PCV first floor)

Status of the element test (Unit 2 PCV basement floor)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

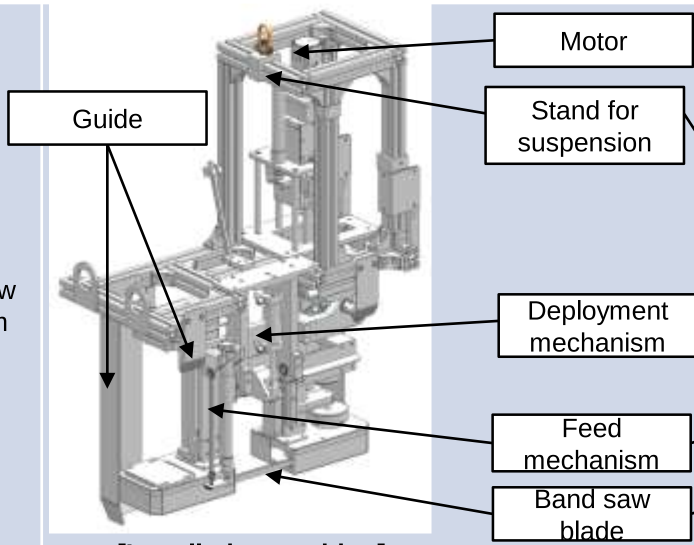
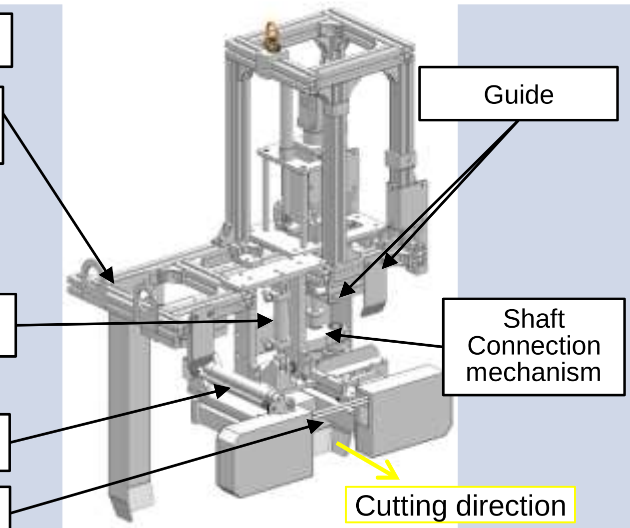
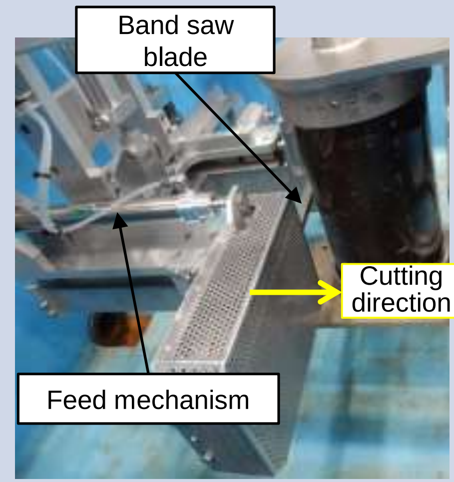
- Study of equipment for remote operation used in the element tests

	Small robot	Crane (for element tests)	Robot for suspension
Overview diagram			
Specifications	Power: Hydraulic pressure External dimensions: L1503 x W463 x H575mm Mass: Approx. 100kg Portable Weight: Approx. 7kg/arm	Power: Electric power External dimensions: L3750 x W920 x 3148mm Mass: 490kg Rated load: 490kg	Power: Hydraulic pressure External dimensions: L2513 x Φ330 x H732mm Mass：approx. 110kg Portable Weight：Approx. 20kg
Explanation	A multi-legged small robot developed in the past is used. It handles hoisting equipment and performs slinging operations with both task arms. It carries out work mainly on the PCV first floor and basement floor.	It is installed on the grating or the beam of the simulated PCV. During the element test, the scope of movement of the roughter crane that is planned to be used on the actual site, is simulated and the work of hoisting and delivering is verified. (Used in common with the HVH disassembly) It carries out work mainly on the PCV first floor.	A multi-legged robot developed in the past is used. It assists in handling the hoisting equipment and the cable hose with task arms. It carries out work mainly on the PCV basement floor.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

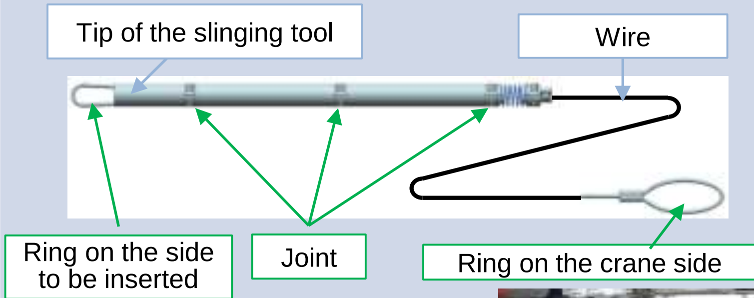
■ Study of cutting equipment used in the element tests

	Cutting equipment		
Overview diagram	 **[Installation position]**	 **[Cutting position]**	 **[Cutting equipment Band saw part]**
Specifications	Power: Electric power / hydraulic pressure (stroke) External dimensions: 732mm x 370mm x 1140mm (Inside the pit: 560mm x 295mm x 560mm) Cutting stroke: 190mm (15mm in front / 150mm to be cut / 25mm at the back) Mass: 80kg	[Specifications of the blade] Saw width: 13mm Saw thickness: 0.5mm Pitch: 10/14 Saw length: 1335mm Material: M42 high speed	[Cutting conditions] Motor rotation (rpm): 2700 Drive roller rotation (rpm): 150 Circumferential speed (m/s): 0.96 Current (A) rated 1.9A: 1.5A or less Blade delivery pressure (MPa): 0.3
Target	Pump: External pipe (FC25), shaft (SUS304)		
Explanation	The cutting equipment is suspended from the grating opening, and is installed inside the pit using the guide. The cutting equipment is deployed 90° with the help of the deployment mechanism, the blade is delivered with the delivery mechanism and the external pipe and shaft are cut. The stand for lifting up / suspending (including the motor) is positioned over the band saw part.		

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Study of tools involved in the work of removing interfering objects from the pump pit

	Pump slinging tool	Suspension length adjustment tool
Overview diagram	  	 
Specifications	Power: None External dimensions：Φ27.4 x 2626mm Mass：0.7kg Wire：Φ6 Joints：3 Angle：Total 80° with 3 joints	Power: None External dimensions：87.2mm x 88mm x 558.5mm Mass：3.4kg Lifting height：2500mm Rated load：0.25ton
Target	Pump	
Explanation	2 slinging tools are passed through the pump opening using a robot, and installed on the crane hooks.	The orientation of the pump is changed from vertical to horizontal with the suspension length adjustment tool and it is lifted up from over the grating.

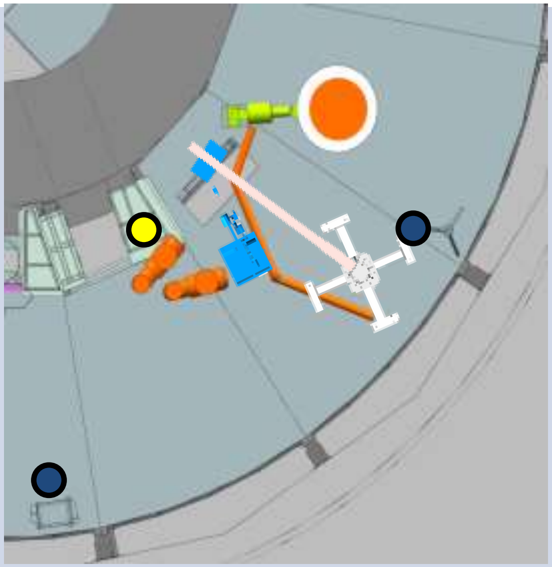
6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

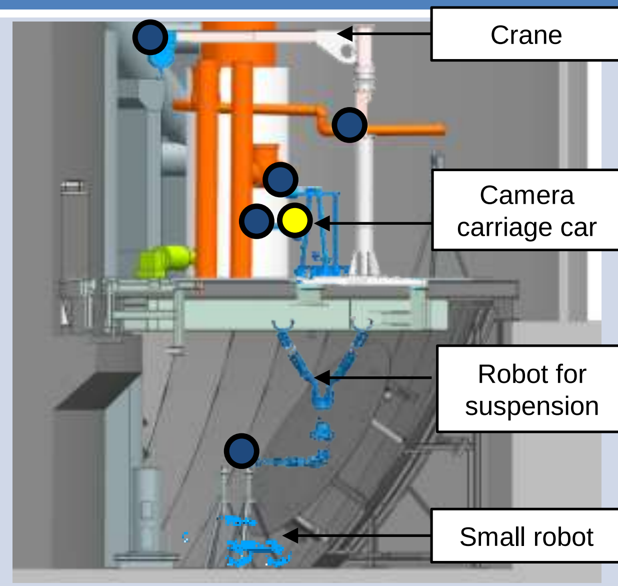
■ Study of the placement of cameras and lights used in the element tests

Placement of the cameras and lights

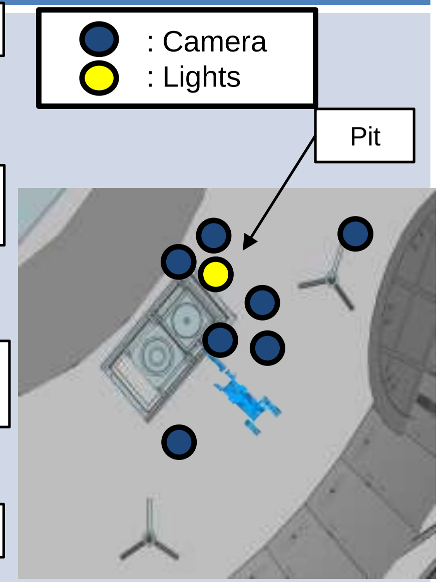
Layout drawing



[PCV first floor
Layout drawing of test equipment]
Common to Units 1 and 2



[PCV first floor to basement floor
Bird's eye view of the test equipment]
Common to Units 1 and 2



[Basement floor Layout drawing
of test equipment]
Common to Units 1 and 2

Details

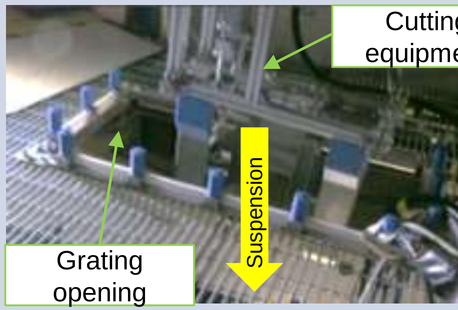
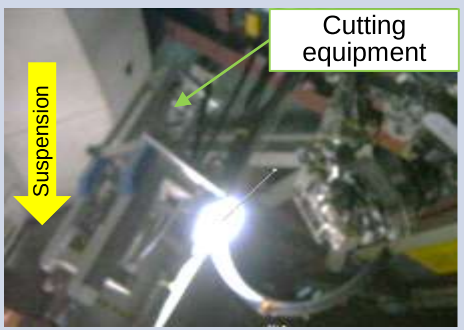
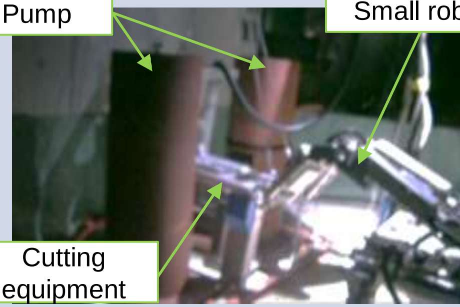
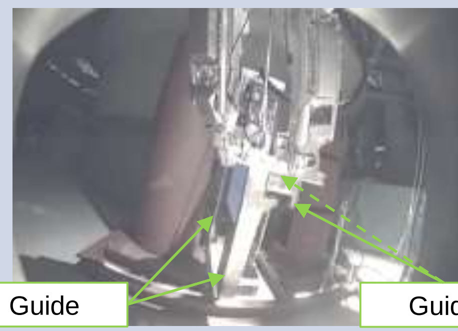
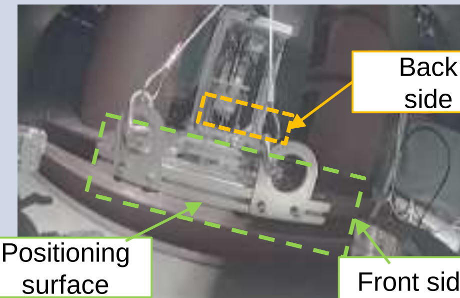
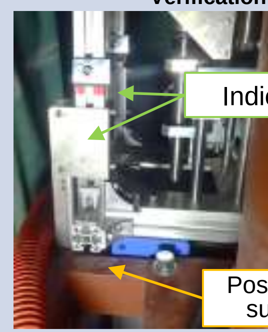
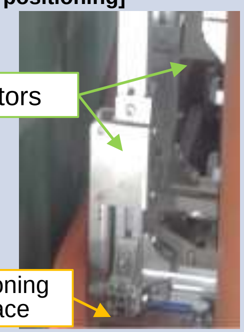
PCV first floor	PCV first floor to basement floor	Basement floor
Bird's eye cameras: 2 Lights: 1	Crane cameras: 2 Camera carriage car Cameras: 2 Lights: 1 Robot for suspension Cameras: 1	Bird's eye cameras: 2 Small robot Cameras: 3 Cameras inside the pit: 2 Lights: 1

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Element test results

No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

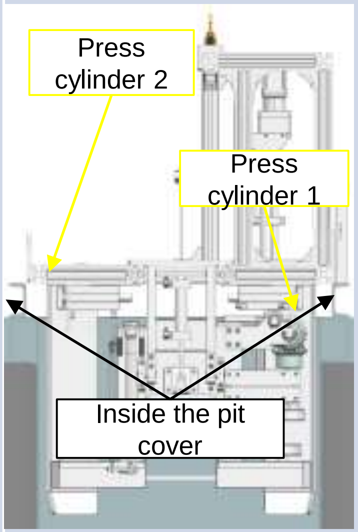
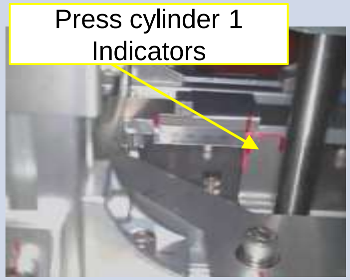
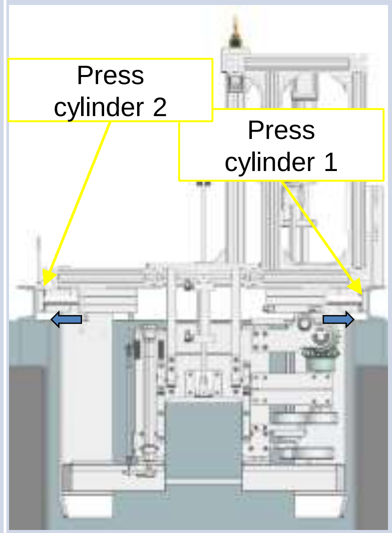
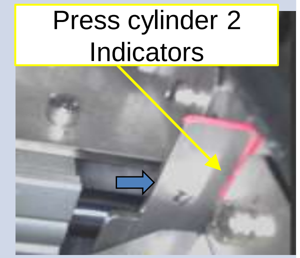
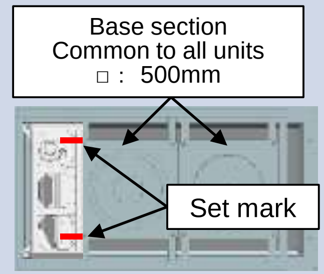
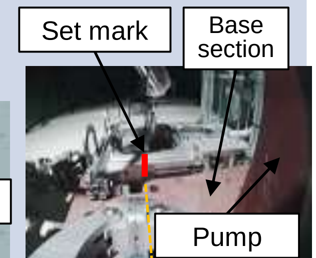
Work step	⑪-1 Suspending the cutting equipment	⑪-2 Installing the cutting equipment	⑪-3 Verifying the positioning of the cutting equipment
Test status	 **[Suspending the cutting equipment]**  **[Suspending the cutting equipment]**	 **[Position adjustment using small robots]**  **[Installing the cutting equipment]**	 **[Front side of cutting equipment Verification of positioning]**   **[Back side of cutting equipment Before positioning]** **[Verification after positioning]**
Test results	It was verified that the cutting equipment can be suspended from the grating opening by remote operation of the crane without any interference, etc. (Time required for work: 5 min)	It was verified that the cutting equipment can be installed using the guide without interfering with the pump by remote operation of small robots. (Time required for work: 25 min)	It was verified that the front side of the cutting equipment had been positioned using cameras. It was verified that the back side of the cutting equipment had been positioned by visually confirming the indicator with the cameras. (Time required for work: 15 min)

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Element test results

No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

Work step	⑪-4 Cutting equipment Before fixing	⑪-5 Cutting equipment After fixing
Test status	**[Front view of cutting equipment Before operation of press cylinder]** **[Press cylinder 1 Before operation]** **[Press cylinder 2 Before operation]**	**[Front view of cutting equipment After operation of press cylinder]** **[Press cylinder 1 After operation]** **[Press cylinder 2 After operation]** **[Top view of the Unit 2 pit cover cutting equipment]** **[Verification of the set mark by the camera at the tip of the robot]**
Test results	It was verified that the cutting equipment can be fixed and set up by operating press cylinder 1 at full stroke and press cylinder 2 up to the set mark by remote operation. (Time required for work: 25 min)	
Issues	・Measures to be taken if there are foreign material or existing structures inside the pit cover.	

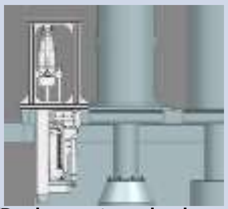
6. Implementation Items of This Project [1] (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

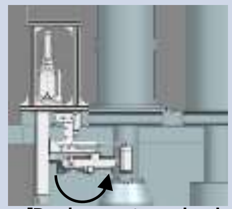
■ Element test results

No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

Work step		⑪-6 Making preparations for cutting the pump
Test status	Unit 2	
Test results		It was verified that as preparation for cutting, the deployment mechanism can be deployed at 90°, the shaft connection mechanism can be operated and the motor can be connected in between the gears. The indicators and mechanical stoppers were verified using a camera from above the pit by operating the mechanisms. By considering the blade delivery shaft as the scale indicator, the progress in cutting were ascertained from above the pit.



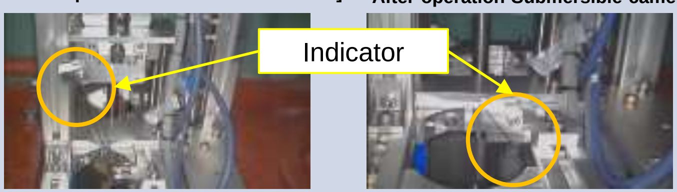
[Deployment mechanism Before operation Illustration]



[Deployment mechanism After operation Illustration]

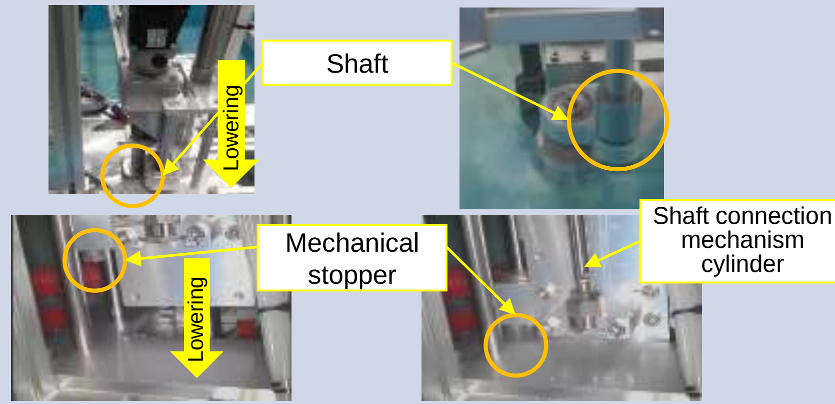
[Deployment mechanism Before operation Submersible camera]

[Deployment mechanism After operation Submersible camera]



[Deployment mechanism Before indicator operation]

[Deployment mechanism After indicator operation]



[Shaft connection mechanism Before operation]

[Shaft connection mechanism After operation]

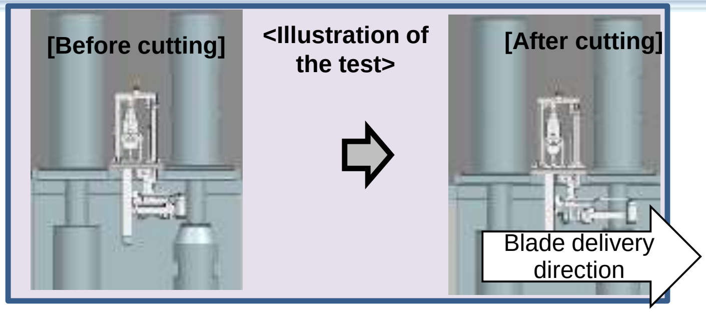
[Blade delivery shaft Indicator]

[Blade delivery shaft Indicator extension]

6. Implementation Items of This Project
[1) (2) Development of Disassembly and Removal Technology]

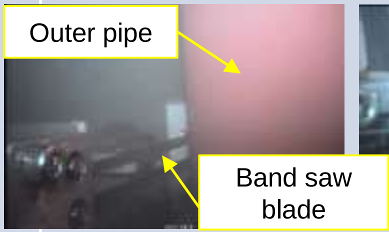
③ Interfering objects removal from pump pit

■ Element test results



No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

Work step	⑪-7 Cutting the pump
Test status	Unit 1



[Cutting location: 0mm]

[Cutting location: 40mm]

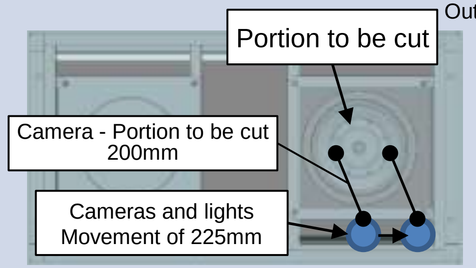
[Cutting location: 77mm]

[Cutting location: 130mm]
Adjustment of the position of the cameras and lights (manual)

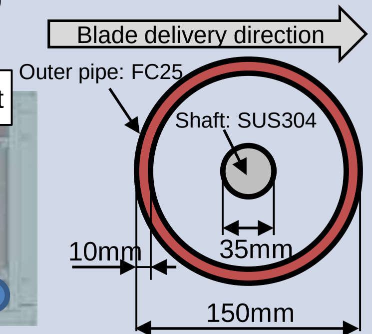
A pad was installed under the pump but it fell due to its own resulting in a gap

[Cutting location: 150mm]

Control items \ Cutting location	0mm	40mm (Outer pipe part)	77Mm (Outer pipe + Shaft)	130mm (Outer pipe part)	150mm (Outer pipe part)
Motor rotational speed (rpm)	2700	2700	2700	2700	2700
Current value (A)	0.44A (No load)	0.66	0.95	0.84	0.47
Blade delivery pressure (MPa)	0.3	0.3	0.3	0.3	0.3



[Top view of the installation of cameras and lights]



[Top view of the cutting scene]

Test results	It was verified that the pump can be cut while monitoring the current and blade delivery pressure by remote operation. The pump was possible to be cut while verifying the status of cutting with the help of the submersible Φ14 CCD camera and indicators. (Time required for work: 58 min) (without formation of turbidity, before cutting 0.58NTU, after cutting: 9.74NTU)
Issues	・Cameras and lights that can follow in accordance with the progress in cutting are required. ・Positioning of cameras so that the edge of the blade of the band saw and the object to be cut are visible.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

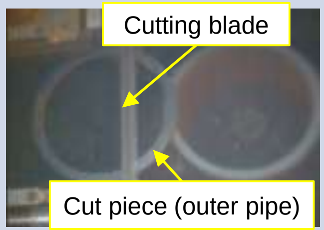
■ Element test results

No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

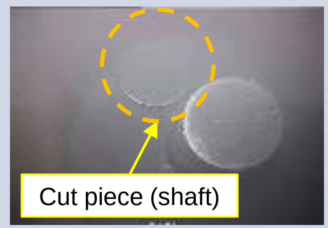
Work step	⑪-8 Status after cutting the pump

Test status — Unit 1

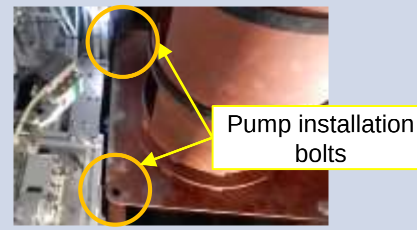
[After withdrawing the blades]



[After lifting up the upper part of the pump]



[Inside the outer pipe after lifting up the upper part of the pump]



[Removal of pump installation bolts (2 bolts on the cutting equipment side)]

⑪ Cutting of the pump (Only Case 2) → ⑫ Cutting of pump installation bolts → ⑬ Lifting up the pump

(Installing/uninstalling the cutting equipment)

Proposed revision in work steps

⑪ Cutting of pump installation bolts (2 bolts on the cutting equipment side) → ⑫ Cutting of the pump (Only Case 2) → ⑬ Cutting of pump installation bolts (Remaining 2) → ⑭ Lifting up the pump

(Installing the cutting equipment)

Uninstalling the cutting equipment

Test results	It was verified that the cut piece (outer pipe) comes out wedged between the cutting blades when the blades are withdrawn by remote operation. If the cut piece is wedged between the blades, the cutting equipment cannot be uninstalled. Hence the work steps need to be revised.
Considerations	The work steps should be revised, and it should be verified whether the pump in Unit 2 can be cut by removing the 2 pump installation bolts on cutting equipment side.
Issues	・Measures to be taken if the cutting equipment gets stuck.

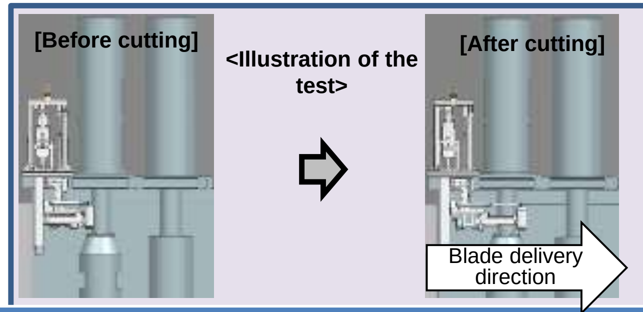
6. Implementation Items of This Project
[1] (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Element test results

No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

No.402

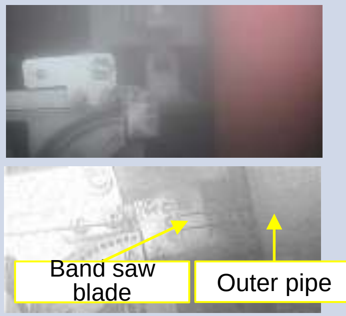


Work step	⑪-9 Cutting the pump

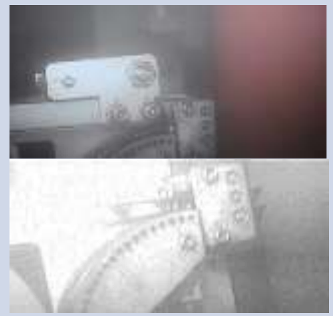
Test status — Unit 2

Upper level: Φ14CCD camera

Lower level: Φ55CMOS camera



[Cutting location: 0mm]

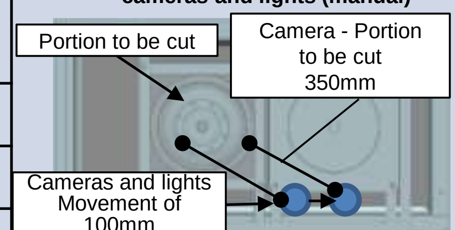


[Cutting location: 73mm]

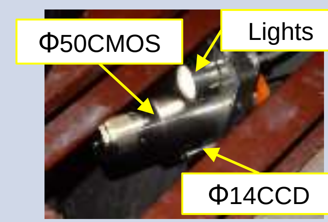
[Cutting location: 115mm]
Adjustment of the position of the cameras and lights (manual)

[Cutting location: 150mm]

Control items \ Cutting position	0mm	73Mm (Outer pipe + Shaft)	115mm (Outer pipe part)	150mm (Outer pipe part)
Motor rotational speed (rpm)	2700	2700	2700	2700
Current value (A)	0.44A (No load)	0.95	0.84	0.47
Blade delivery pressure (MPa)	0.3	0.3	0.3	0.3



[Top view of the installation of cameras and lights]



[Layout drawing of the cameras and lights]
(Installed manually)

Test results	It was verified that the Unit 1 pump can be cut under the same cutting conditions and by delivering the same blade that was used for cutting, while monitoring the current and blade delivery pressure. Also, cutting was performed without any impact such as vibrations, etc. caused by the removal of the 2 pump installation bolts. (Time required for work: 55 min) (without formation of turbidity, before cutting 15.57NTU, after cutting: 14.63NTU)
Issues	・As the external form of the Φ55CMOS camera is large, it is not suitable for installation inside the pit, hence the size of a highly radiation resistant camera needs to be reduced. ・Measures to be taken if foreign material, etc. adheres to the lens of the camera and the visibility deteriorates.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

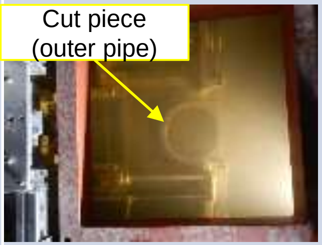
③ Interfering objects removal from pump pit

■ Element test results

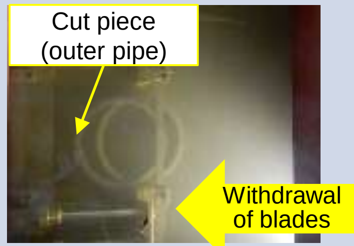
No. 2 [Step ⑪] Cutting of the pump (Only Case 2)
・ Cutting/grabbing the pump in the pump pit (Case 2)

Work step		⑪-10 Status after cutting the pump

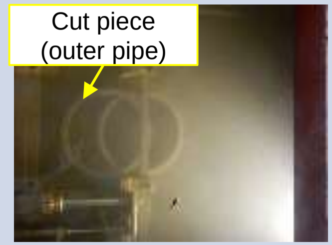
Test status — Unit 2



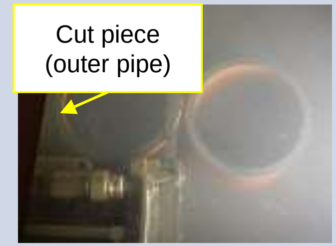
[After lifting up the upper part of the pump]



[25mm withdrawal of blades]



[75mm withdrawal of blades]



[Complete withdrawal of blades]

[Revised work steps]

⑪ Cutting of pump installation bolts (2 bolts on the cutting equipment side) → ⑫ Cutting of the pump First pump (Only Case 2) → ⑬ Cutting of pump installation bolts (Remaining 2) → ⑭ Lifting up the pump → ⑮ Uninstalling the cutting equipment →

(Installing the cutting equipment)

Steps ⑪ to ⑮ are repeated for the second pump

Test results

It was verified that the cut piece (outer pipe) can come out wedged between the cutting blades when the upper part of the pump is lifted up and the blades are withdrawn by remote operation.
It was verified whether it would be possible to manually recover the cut piece (outer pipe) wedged between the blades, and it was found that this was possible.
It was verified that a series of operations can be performed by revising the work steps.

Issues

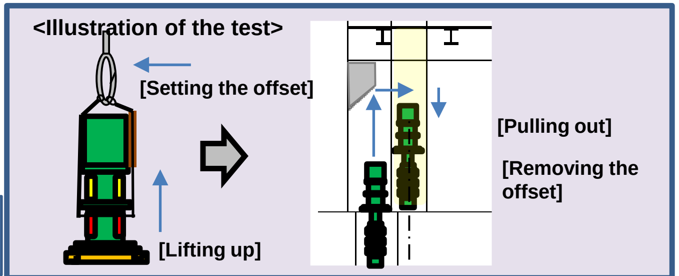
・Method of recovering the cut piece (outer pipe) using the robot arms under water.

6. Implementation Items of This Project
[1) (2) Development of Disassembly and Removal Technology]

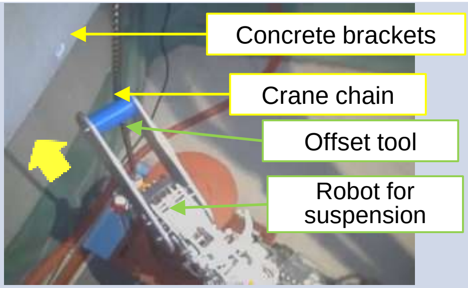
③ Interfering objects removal from pump pit

■ Element test results

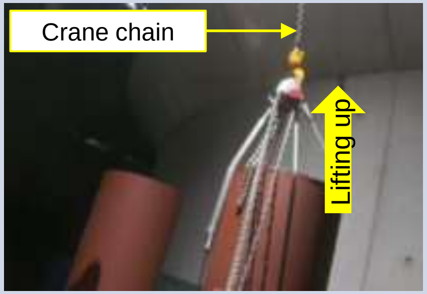
No. 4 [Step ⑬] Lifting up the pump
・ Lifting up the pump (Case 4)



Work Step ⑬-1 Setting the offset — Whether the tension of the wires can be adjusted

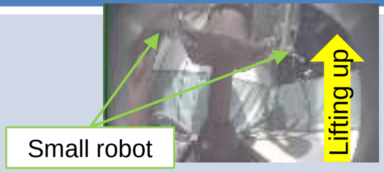


[Offset using the robot for suspension]

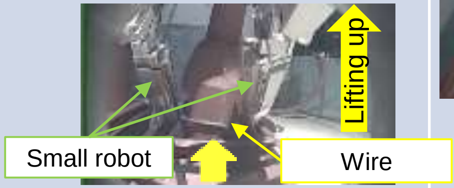


[Verifying the tension]

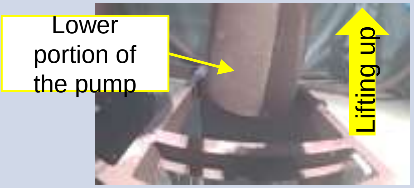
Work Step ⑬-2 Pulling out the pump from inside the pit



[Controlling the rotation of the pump]

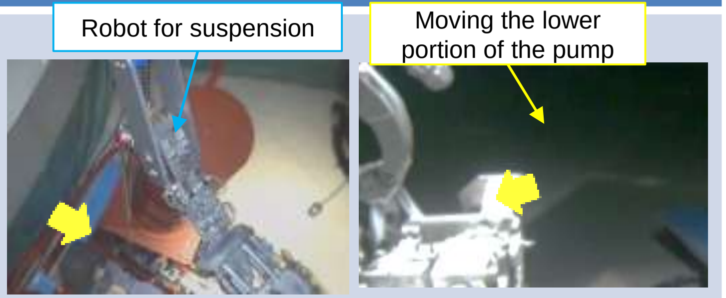


[Pushing in the pump]

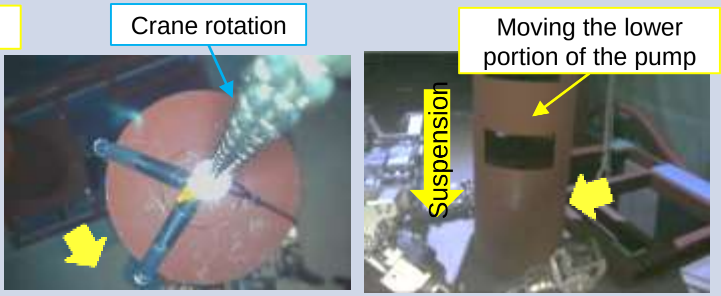


[After pulling out the pump]

Work Step ⑬-3 Removing the offset



[Removing the offset using the robot for suspension]



[Positioning on the basement floor surface]

Work Step		⑬-1 Setting the offset Whether the tension of the wires can be adjusted	⑬-2 Pulling out the pump from inside the pit	⑬-3 Removing the offset
Test status	Unit 1	[Offset using the robot for suspension] [Verifying the tension]	[Controlling the rotation of the pump] [Pushing in the pump] [After pulling out the pump]	[Removing the offset using the robot for suspension] [Positioning on the basement floor surface]
Test results		It was verified that the tension can be adjusted by aligning the hoisting center by means of the offset tools using the robot for suspension and lifting up using the crane. (Time required for work: 10 min)	It was verified that the pump can be lifted up with the crane and it can be pulled out with the help of small robots. (Time required for work: 10 min)	It was verified that the pump can be positioned on the basement floor surface by removing the offset with the help of the robot for suspension, rotating the crane and suspending the pump. (Time required for work: 10 min)
Issues		・Measures to be taken if the pump is fixed, etc. and cannot be lifted up.		

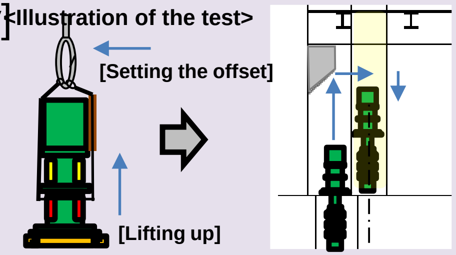
6. Implementation Items of This Project
[1] (2) Development of Disassembly and Removal Technology

③ Interfering objects removal from pump pit

■ Element test results

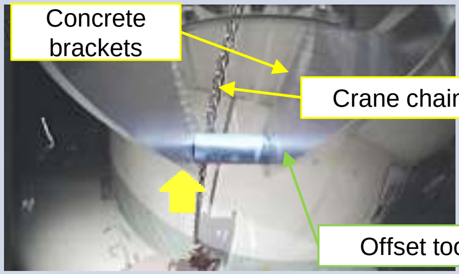
No. 4 [Step ⑬] Lifting up the pump
・ Lifting up the pump (Case 4)

<Illustration of the test>

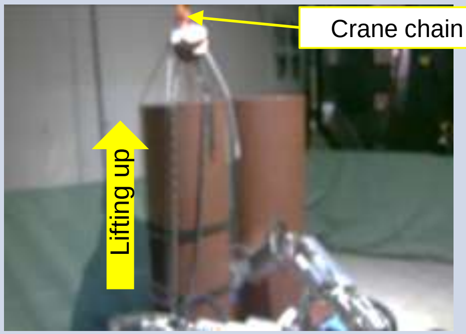


Work step	⑬-1 Setting the offset Whether the tension of the wires can be adjusted	⑬-2 Pulling out the pump from inside the pit	⑬-3 Removing the offset

Test status – Unit 2

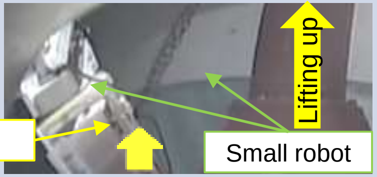


[Offset using the robot for suspension]



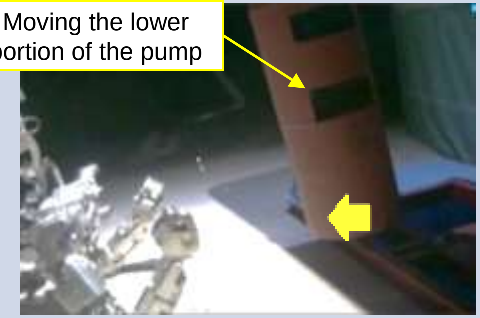
[Verifying the tension]

[Controlling the rotation of the pump]

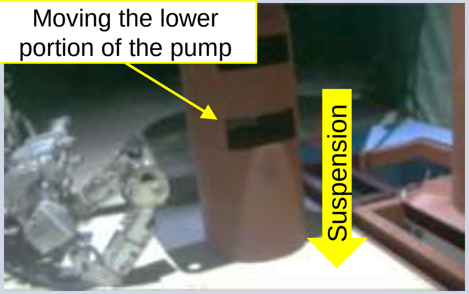


[Pushing in the pump]

[After pulling out the pump]



[Removing the offset using the robot for suspension]



[Positioning on the basement floor surface]

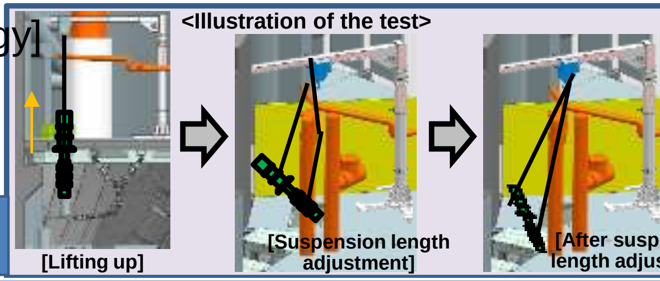
	⑬-1	⑬-2	⑬-3
Test results	It was verified that the tension can be adjusted by aligning the hoisting center by means of the offset tools using the robot for suspension and lifting up using the crane. (Time required for work: 10 min)	It was verified that the pump can be lifted up with the crane and it can be pulled out with the help of small robots. (Time required for work: 18 min)	It was verified that the pump can be positioned on the basement floor surface by removing the offset with the help of the robot for suspension, rotating the crane and suspending the pump. (Time required for work: 17 min)
Issues	・Measures to be taken if the pump is fixed, etc. and cannot be lifted up.		

6. Implementation Items of This Project
[1] (2) Development of Disassembly and Removal Technology

③ Interfering objects removal from pump pit

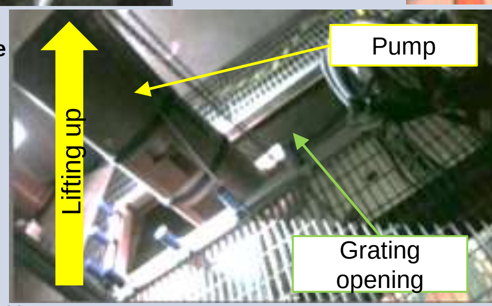
■ Element test results

No. 4 [Step ⑬] Lifting up the pump
・ Lifting up the pump (Case 4)

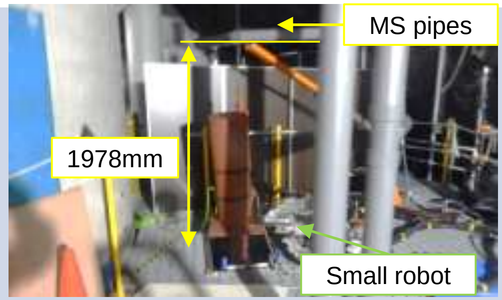


Work step		⑬-4 Lifting up the pump
Test status	Unit 2	(see photographs below)

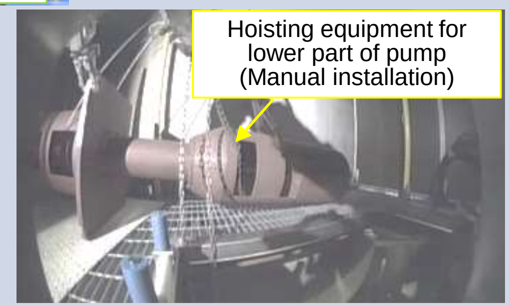
[Lifting up the pump] From the basement floor to the grating opening



[Lifting up the pump] Over the PCV first floor grating



[Suspension length adjustment with the help of small robots]



[Pump lifted up completely]

Test results	It was verified that the pump can be lifted up by remote operation of the crane without any interference. The pump rotates when it is being lifted up. It was verified that the rotation of the pump can be controlled by means of the robot for suspension. It was verified that in order to avoid the MS pipes in Unit 2, when the pump is halfway through the grating opening, it can be tilted using the suspension length adjustment tool and can then be lifted up through the grating opening. (Time required for work: 58 min)
Issues	・Studies are required for confirming that the hoisting equipment can be installed on the lower portion of the pump by remote operation, ・The chain of the suspension length adjustment tool is long and hence the work requires time.

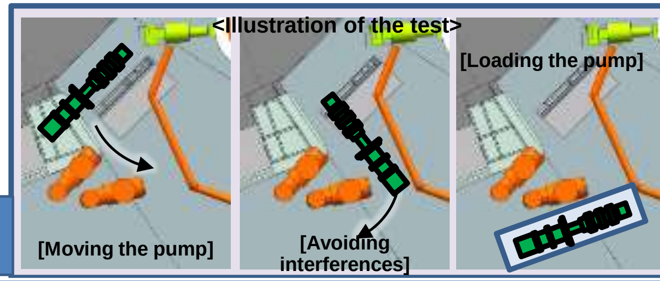
6. Implementation Items of This Project

[1] (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Element test results

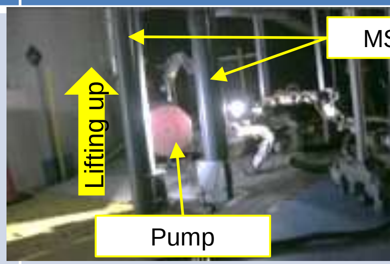
No. 6 [Step ⑬] Lifting up the pump
・ Moving the pump (D/W first floor)



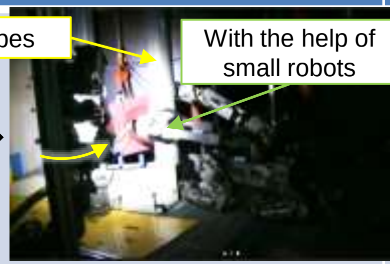
Work step	⑬-5 Moving the pump	⑬-6 Loading the pump
Test status (Unit 2)	see photos below	see photos below

Test status – Unit 2

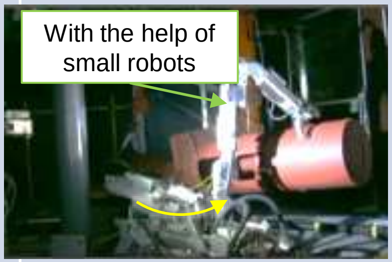
⑬-5 Moving the pump



[Lifting up the pump]



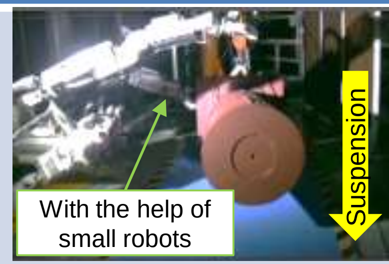
[Avoiding interfering objects]



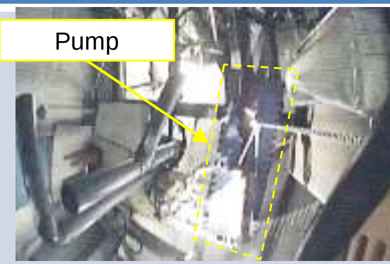
[Controlling the rotation of the pump]

[Rotating the crane]

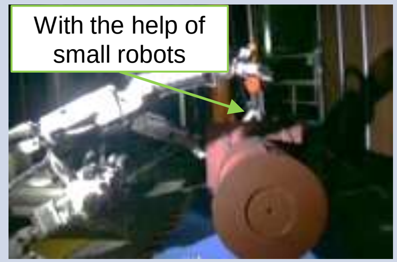
⑬-6 Loading the pump



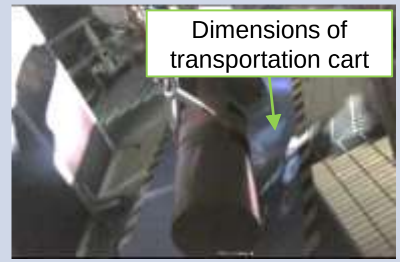
[Suspending the pump]



[Camera at the tip of the crane jib]



[Pump completely suspended]



[Pump completely suspended]

	⑬-5 Moving the pump	⑬-6 Loading the pump
Test results	It was verified that the pump can be moved by lifting it up with a crane that is remotely operated, by rotating the crane while the pump is in a horizontal position, or avoiding the interfering objects with the help of small robots, or controlling the rotation of the pump. (Time required for work: 30 min)	It was verified that the pump can be loaded within the dimensions of the transportation cart with the help of small robots by suspending the pump using a crane that is remotely operated. (Time required for work: 10 min)
Issues	・The small robots need to be frequently moved in restricted spaces and cable needs to be routed every time the robots are moved.	

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Issues identified based on the element tests on removal of interfering objects from the pump pit (1/2)

No.	Step / test item	Issues	Countermeasures (Considering the actual facility)
1	⑪ Cutting of the pump (Only Case 2) ・ Cutting/grabbing the pump in the pump pit (Case 2)	・ Measures to be taken if there are foreign material or existing structures inside the pit cover.	・ Verifying the status of field investigation. ・ Considering a design that enables pressing even inside the pit.
		・ Ensuring of visibility to the extent that the cameras and lights can follow in accordance with the progress in cutting inside the pit.	・ Considering a waterproof and small size pan tilt mechanism for the cameras and lights.
		・ Necessity to position the cameras so that the edge of the blade of the band saw and the object to be cut are visible.	・ Mounting the cameras and lights inside the cutting equipment.
		・ Measures to be taken if the cutting equipment gets stuck.	・ Mounting the cutting mechanism of the blade inside the cutting equipment. ・ Design so that the blade gets ripped apart due to the thrust of the withdrawal cylinder.
		・ The outer form of a highly radiation resistant camera is large and is thus difficult to handle inside the pit. (Φ55CMOS)	・ Selecting an appropriate radiation resistant camera after verifying the dose through field investigation. ・ To be accomplished through a combination of time management and replacement of cameras.
		・Measures to be taken if foreign material, etc. adheres to the lens of the camera and the visibility deteriorates.	・ Coating the lens. ・ Designing the equipment so that the foreign material can be removed by spraying water.
		・ Method of recovering the cut piece (outer pipe) using the robot arms under water.	・ Designing so that the robot arm can be operated under water. ・ Considering radiation resistance and water resistance of the arm camera.
2	⑬ Lifting up the pump ・ Slinging the pump	Measures to be taken if there is no space for the slinging tool to pass due to foreign material in the pump opening part.	・ Verifying the status of field investigation. ・ Considering alternative measures. (Proposal to use a lifting magnet, to slip on a flange, etc.)

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6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Issues identified based on the element tests on removal of interfering objects from the pump pit (2/2)

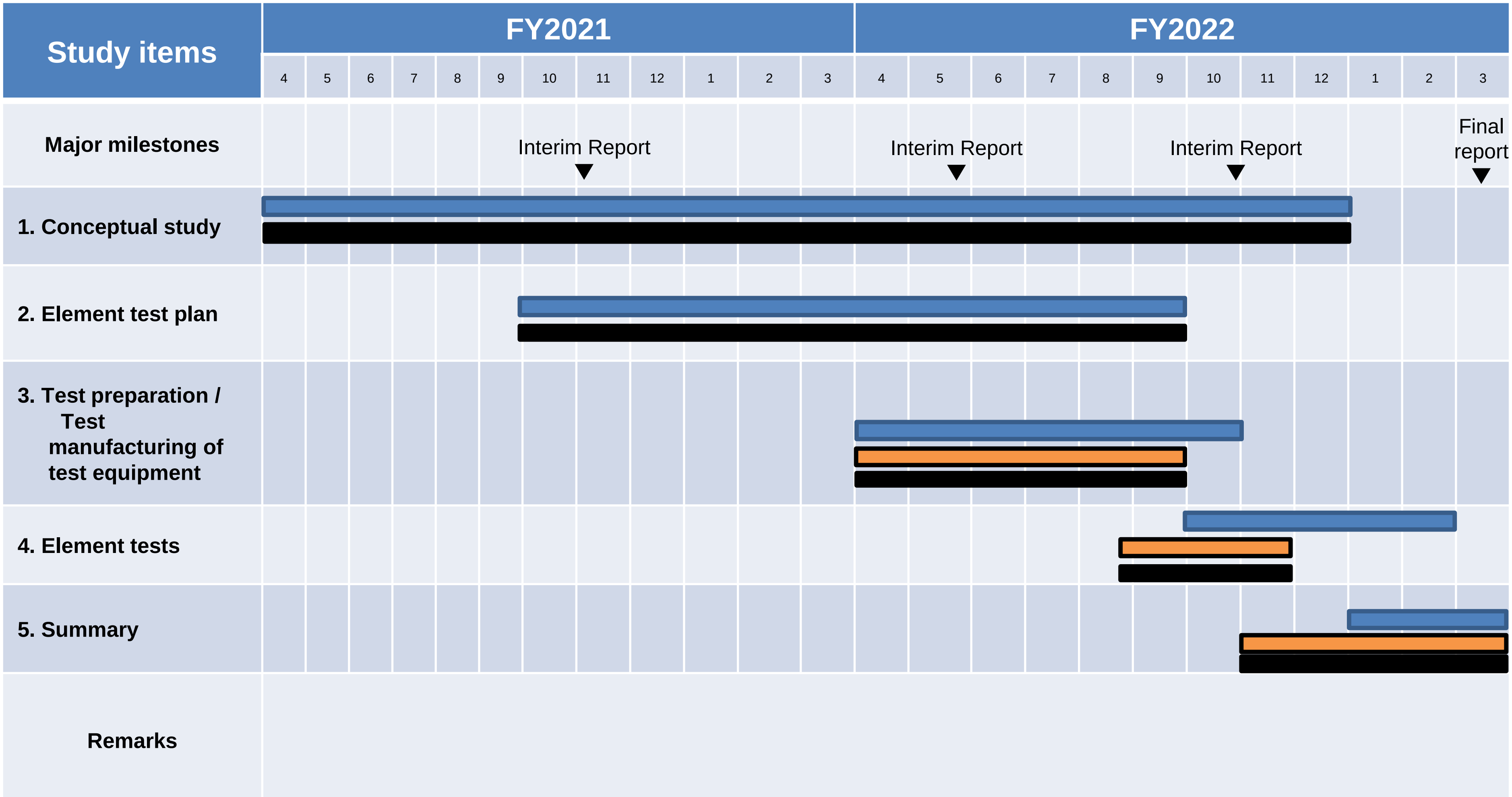
No.	Step / test item	Issues	Countermeasures (Considering the actual facility)
3	⑬ Lifting up the pump ・ Lifting up the pump (Case 4)	・ Measures to be taken if the pump is fixed, etc. and cannot be lifted up.	・ Verifying the status of field investigation. ・ Considering alternative measures. (Proposal to cutting the pump base, etc.)
		・Studies are required for confirming that the hoisting equipment can be installed on the lower portion of the pump by remote operation. (This time the shape of the lower portion of the pump has not been simulated)	・ The simulated hoisting equipment is designed according to the actual facility.
		・The chain of the suspension length adjustment tool is long and hence the work requires time.	・ Reducing the length of the chain. ・ Designing equipment that is motor operated. ・ Considering installation of a main winding hook and an auxiliary winding hook mechanism on to the roughter crane assuming the actual facility.
4	⑬ Lifting up the pump ・ Lifting up the upper part of the pump (Case 2)	・ Measures to be taken if the pump is fixed, etc. and cannot be lifted up.	・ Verifying the status of field investigation. ・ Considering alternative measures. (Proposal to cut the pump base, etc.)
5	⑬ Lifting up the pump ・ Moving the pump (D/W first floor)	・The small robots need to be frequently moved in restricted spaces and cable needs to be routed every time the robots are moved.	・ Designing equipment in which a task arm is installed on the transportation cart. ・ Considering reduction of size of the cable recovery equipment.
6	Other	・ Measures to be taken against dust dispersion if the pump falls.	・ Designing water sprinkling equipment. ・ Acquiring data on dust dispersion

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit

■ Development Schedule

: Planned
: Planned (after revision)*
: Actual



* The plan was revised to reflect the study progress status and the results of element tests.

6. Implementation Items of This Project [1) (2) Development of Disassembly and Removal Technology]

③ Interfering objects removal from pump pit: Summary

- **The status of fuel debris inside the pump pit, specifications of pump to be removed, specifications of pump pit, and its location were studied and consolidated in FY2021 as preconditions for removing interfering objects from inside the pump pit. The work steps involved in removing interfering objects from inside the pump pit were studied, and test items were selected.**

- **The simulated pump and pump pit, equipment and tools, etc. to be used in the element tests were studied, the work steps were substantiated and the element test plan (consolidation of items to be verified, test contents, etc.) was formulated.**

- **It was verified through element tests that the pump can be cut, lifted up, etc. by remote operation, and the feasibility of the method of removing interfering objects from the pump pit was verified as well. Issues in application to the actual facility were identified and reflected into the equipment design for the actual facility.**

6. Implementation Items of This Project

1) Development of side access method

(3) Advancement and development of retrieval methods

① Remote controlled tip tools for retrieval

In parallel with the study of prospective methods for further increasing the scale of retrieval of fuel debris and reactor internal structures, evaluation of the throughput is being carried out as well. For enhancing the throughput of the side access method, it has become necessary to consider optimization of the positioning of the tip tools, grabbing of the target object, replacement of the tip tools, etc. during fuel debris processing and collection work, and carry out related development.

Various techniques have been studied during the development carried out in the past related to the tip tools of the remote controlled equipment used for fuel debris retrieval and disassembly/removal of reactor internal structures, however, tip tools suitable for optimization including the technologies available on the market, will be investigated and consolidated.

In addition, typical techniques pertaining to the tip tools and operation systems (interference avoidance and control system, etc.) that can be used for works that need to be optimized and improved, will be selected based on the requirements for on-site application, and tip tools and operation systems will be test manufactured for on-site use by making improvements in technologies available on the market or by developing new technologies. With the help of these test manufactured tip tools and operation systems, the procedures for processing fuel debris and collecting it in unit cans, operability of the tip tools, efficiency, etc. will be verified through tests using mock-ups (appropriate partial models or scale models are permissible as well) considering the mechanical properties, etc. of the items to be processed such as fuel debris, etc., interfering objects such as structures, etc. inside PCV, and the viability of a series of operations will be verified. Also, the actual data on the work procedures will be acquired and organized, to create data for evaluating the throughput.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

Table of Contents

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(1) Development results achieved so far and correlation with this project

[Advancement of fundamental technology (Implemented in FY2017-18)]
- Development of access equipment
  - ➢ Combination test of access route and robot arm
    - ✓ Installation of access route
    - ✓ Guiding the robot arm inside the pedestal

Combination test of rail and arm

Combination test of rail and arm

[Further increasing the scale of retrieval (Implemented in FY2019-2020)]
- Review of side access method for on-site application
  - ➢ Study of fixed rail method

  (Downsizing of access equipment ⇒ Reduction in cell height)
- Development of suction and collection system for granular fuel debris

Study of fixed rail method

Suction and collection of granular fuel debris

[Implemented in this project]
- Study and element tests on tip tools, remote operation support systems
- Acquisition of data for throughput evaluation

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

Exce

① Remote controlled tip tools for retrieval

(1) Development results achieved so far and correlation with this project

[Status of development carried out so far]

- Processing methods suitable for items to be collected from inside the PCV were investigated.
- Processing element tests were implemented on the processing technology believed to have good prospects, from among the processing methods investigated.
- Procedures for collecting structures, fuel debris were studied.
- The fuel debris retrieval throughput was estimated based on the results of the processing element tests, results of the accessibility test, results of the desk study, etc.

Examples of the processing methods investigated in the past
(excerpts from FY2019-20 reports)

	Handling of a variety of fuel debris	Processing speed	Accessibility (small head)	Heat input	Fume emission (dispersion in air)	Quantity of scrap produced (dispersion in water)	Downsizing of utilities	Need for supply
Core boring	○	△	○	○	○	△	○	○
Circular saw	○	○	△	○	○	○	○	○
Wire saw	△	△	×	○	○	○	○	○
Band saw (reciprocating saw)	△	△	×	○	○	○	○	○
Ultrasonic core drill	△	△	○	○	○	△	○	○
Cutter (shears)	△	○	○	○	○	△	○	○
Chisel	△	○	○	○	○	○	○	○
AWJ	△	△	○	○	○	×	×	○
Laser	○	△	○	△	△*	△	×	○
Plasma arc	×	×	○	△	×	△	×	○
Plasma jet	○	△	○	△	×	△	×	×
Gas	×	△	○	△	×	△	△	○
Milling	×	○	×	○	○	○	×	○

Past processing element tests

FY2014:
- Core boring
- Laser gouging
- Plasma
- AWJ
- Laser (shaving)

FY2015-16
- Core boring
- Laser gouging

FY2017-18
- Chisel
- Ultrasonic core boring
- AWJ
- Laser
- Circular cutter
- Wire saw

FY2019-20
- Hydraulic cutter
- Grindstone
- Tip saw
- Wedge and shim
- Ultrasonic core boring

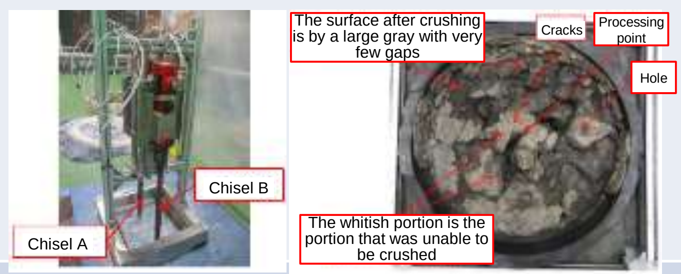
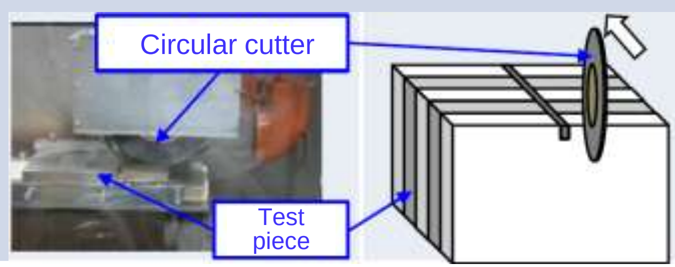
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(1) Development results achieved so far and correlation with this project

[Status of development carried out so far]

Past processing element tests (Example)

Year	Processing method	Simulation	Status of test (Installed in the machine tool, etc.)	Processing speed
2015-2016	Core boring	・SUS304 ・Alumina		2.86[mm/min] ・Outer diameter of cutter: Φ66mm ⇩ 2.5[kg/h] ・FY2017-18 Estimation results
2017-2018	Chisel	・Simulated MCCI		36.7[kg/h]
2017-2018	Circular cutter	・SUS304 ・Zirconia		750[mm^2/min] ・Depth: 1.5mm ・Length: 100mm ・Time: 0.2min

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(1) Development results achieved so far and correlation with this project

[Issues]

- With the current processing speed, the target retrieval period of 10 years is exceeded.
- The throughput is estimated based on the processing time obtained through the processing test using mainly machine tools, but the processing time is likely to extend when processing work is carried out using tip tools mounted on remote controlled equipment that lacks rigidity.
- The throughput for a lot of work (positioning the tip tools, etc.) other than processing work is estimated assuming the time required for work, and hence its accuracy needs to be improved.

[Implementation details]

- Study of throughput improvement measures
  - ➢ Study of procedures for collecting structures, fuel debris inside PCV
  - ➢ Study of processing methods
  - ➢ Enhancement of equipment operability
- Obtaining processing time considering the specifications of the access equipment
  - ➢ Manufacturing and processing tests of the tip tools that meet the specifications of the access equipment
  - ➢ Acquisition of data for throughput evaluation such as processing time, life of the blades, etc.
- Enhancement of safety and work efficiency by developing a remote operation support system for reducing the operator load while operating the manipulator
  - ➢ Development of a remote operation support system that creates the route for avoiding interfering objects.
  - ➢ Verification of the feasibility of work by means of simulation, scale model mock-ups
  - ➢ Acquisition of data for throughput evaluation (obtaining improvement effects resulting from accuracy improvement and optimization)

[Expected outcome]

- Verification of the methods for disassembly and removal of structures inside PCV, and the procedures for processing and collecting fuel debris.
- Acquisition of data for throughput evaluation.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(1) Development results achieved so far and correlation with this project

[Flow of studies]

Study of throughput improvement measures

Tip tools

- Technical research on tip tools
- Conceptual study of the method of retrieving structures and fuel debris from inside PCV
- Tip tools element tests planning
- Designing and maufacturing of tip tools and test equipment for the element tests
- Tip tools element tests (Processing tests for throughput evaluation)

Interfering objects and fuel debris processing time

Operation system (Interference avoidance control system)

- Conceptual study of the operation system
- Operation system software development
- Operation system simulation verification
- Operation system element tests planning
- Designing and manufacturing of operation system test equipment
- Operation system element tests (Series of operations for throughput evaluation using the scale model mock-up)

Time required for manipulator work (Time required for moving and positioning)

Acquisition of data for throughput evaluation

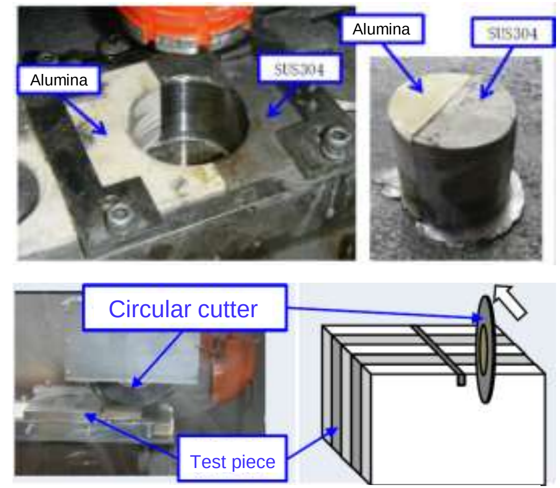
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

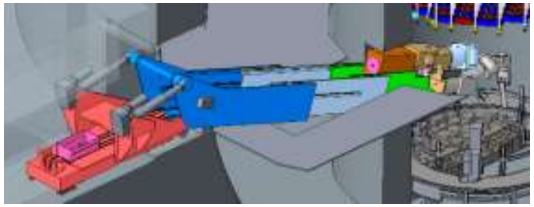
(2) Background and purpose of this research (Tip tools)

✓ **Reasons for this research**

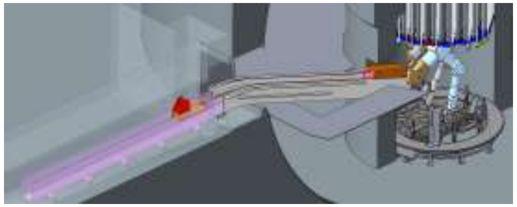
- So far, the processing methods suitable for the items to be collected from inside the PCV have been investigated, processing tests have been implemented, and the throughput has been estimated based on the results.
- The throughput is estimated based on the processing time obtained through the processing test using mainly machine tools, but the processing time is likely to extend when remote controlled equipment that lacks rigidity is used.
- Therefore, tip tools with specifications suitable for the current remote controlled equipment (access equipment) will be manufactured, and processing tests will be conducted to improve the accuracy of the processing time.



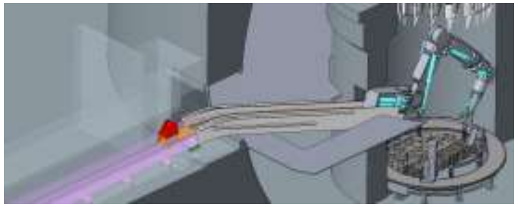
Status of past processing tests



Telescopic dual motor-operated arms



Fixed rail type dual motor-operated arms



Fixed rail type single hydraulic arm

Remote controlled equipment (access equipment) assumed at present

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(2) Background and purpose of this research (Tip tools)

✓ **Expected outcome of this research, reflection destination, and contribution of the outcome**

[Expected outcome]
- Applicability of the tip tools to the actual equipment, issues and response measures
- Data for throughput evaluation
  - Processibility
  - Processing time
  - Life of the blades
- Required specifications of the remote controlled equipment (Access equipment)
  - Processing reaction force (required tip tool pressing force), etc.

[Reflection destination]
- Designing of remote controlled equipment
- Evaluation of throughput

[Contribution]
- Enhancement of specificity of the fuel debris retrieval method
- Evaluation of the fuel debris retrieval period

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval
(2) Background and purpose of this research (Operation system)

✓ **Reasons for this research**

- The work of removing interfering objects and retrieving fuel debris will be carried out while avoiding obstacles in a confined space such as that of the PCV. A manipulator with a redundant degree of freedom (having multiple joints with 7 shafts or more) is effective for the work.
- However, remotely operating the manipulator with a redundant degree of freedom while avoiding obstacles under conditions with limited visibility puts too much load on the operator, and the manipulator is likely to collide with obstacles.
- Hence, the load on the operator is planned to be reduced by means of an “operating system that supports remote operation” thereby enhancing work efficiency.

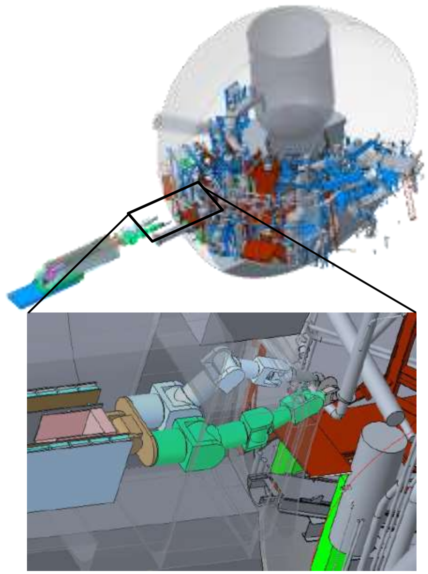


Illustration of the work of removing interfering objects in Unit 3

✓ **Expected outcome of this research, reflection destination, and contribution of the outcome**

[Expected outcome]: Automation of obstacle avoidance by the manipulator

[Reflection destination]: Development will be carried out assuming the outcome will be used in the remote controlled robot for fuel debris retrieval, but application to various other works and robots in the future will be aimed for. (The environment model and the robot model will be changeable)

[Contribution]: Enhancement of work safety and efficiency can be expected.*

- With the operational support resulting from the previous research “Development of remote operation support methods in environments with low visibility and narrow spaces” implemented in FY2019-20, there has been a reduction of approx. 90% in the time required for manual operation by veteran operators, and a reduction of approx. 80% in the time required for creating teaching data. With the current development, this will be implemented and enhanced further.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(3) Goals (Tip tools)

✓ **Requirements from the reflection destinations**

- Processing tests with the processing conditions extensively considered as parameters
  Processing tests will be conducted by extensively considering the processing conditions such as pressing force, etc. as parameters, so as to be able to apply the outcome to various equipment without limiting it to the specific access equipment.
- Throughput improvement
  Tests for throughput improvement will be conducted during the process tests as well.

✓ **Goals based on the above-mentioned requirements**

- Processing tests will be conducted not only for testing the pressing force (motor-operated arms 150kg, hydraulic arm 2ton) of the access equipment currently being assumed, but also for testing the low pressing force assuming smaller access equipment. The processibility will be verified and data for throughput evaluation will be acquired.
- Tests will be conducted by increasing the current core boring size of Φ66mm in order to reduce the processing time for block fuel debris (fuel debris accumulated at the pedestal bottom) which comprises a major portion of the throughput.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(3) Goals (Operation system)

✓ **Requirements from the reflection destinations**

- **Reducing the load on the operator**

  While determination of status, adjustment of the movement speed will be performed by the operator, complex selections, procedure studies, and wide range monitoring will be left to the system as far as possible so as to reduce the load on the operator.
- **Expandability**

  The application will not be limited to specific equipment. The tools will be deployed to various other works and equipment in the future. Also, they will be linked to the integrated management system that is responsible for planning, management and keeping records during decommissioning.

✓ **Goals based on the above-mentioned requirements**

- Tests will be conducted with mock-ups simulating the inside of the pedestal in Unit 3 using the test manufactured operation system, the procedures involved in grabbing, cutting and transferring interfering objects and collecting fuel debris in unit cans will be verified, and viability of a series of operations will be confirmed. Also, the actual data on the work procedures will be acquired and organized, to create data for evaluating the throughput.
- Case studies on the operation system application conditions, assumed issues, etc. will be consolidated as an input for planning the procedures for disassembly and removal.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(4) Implementation items, their mutual correlation, and correlation with other research (Tip tools)

✓ **Implementation items of this research**

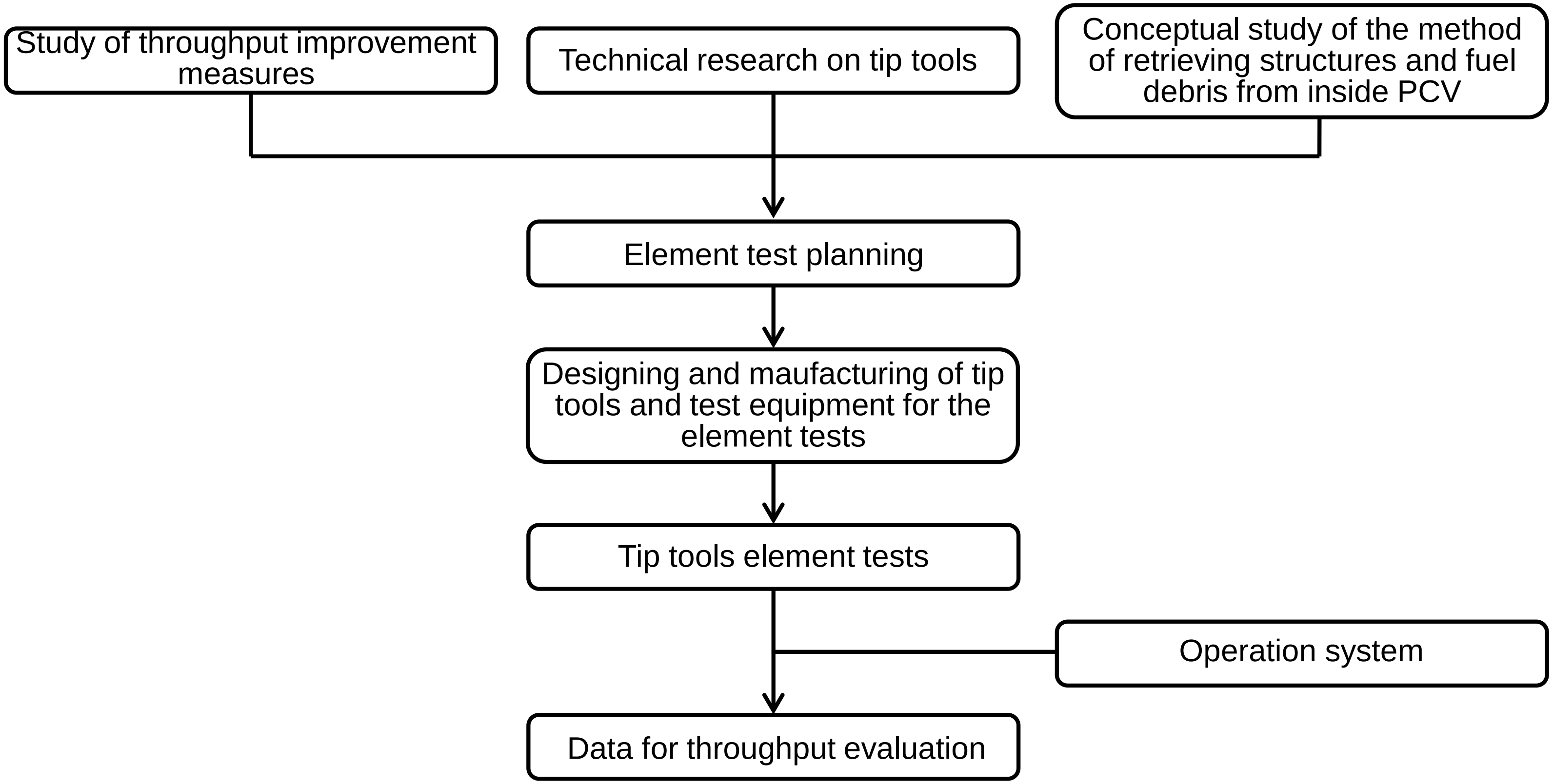
- Study of throughput improvement measures
  - ➢ Analysis of past throughput estimations
  - ➢ Study of the contents to be implemented in element tests
- Technical research on tip tools
  - ➢ Consolidation of results of past investigations on processing methods
  - ➢ Investigation of new processing methods
- Conceptual study of the method of retrieving structures and fuel debris from inside PCV
  - ➢ Study of procedures for collecting structures, fuel debris
  - ➢ Study of methods for processing structures and fuel debris
- Element test planning
  - ➢ Conceptual designing of tip tools for the actual equipment
  - ➢ Study of test items and test method
- Designing and manufacturing of tip tools and test equipment for the element tests
  - ➢ Designing and manufacturing of test equipment
- Tip tools element tests
  - ➢ Processing tests using the tip tools
  - ➢ Evaluation of processing test results (including evaluation of throughput improvement measures)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(4) Implementation items, their mutual correlation, and correlation with other research (Tip tools)

✓ **Correlation between implementation items**



✓ **Correlation with other research (Input and output information)**

- **The processing limit will be studied while controlling criticality and sharing information.**

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

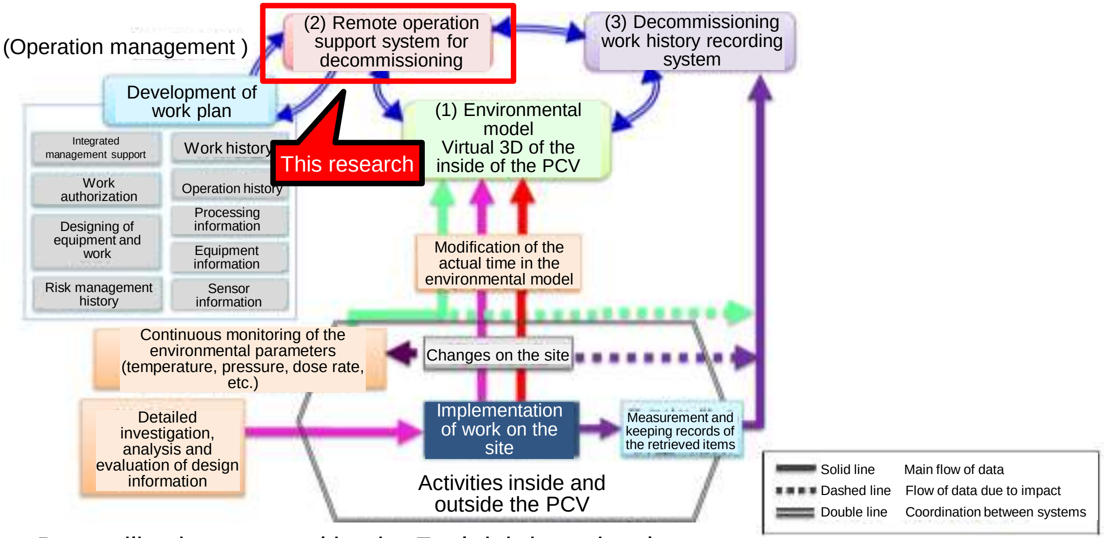
(4) Implementation items, their mutual correlation, and correlation with other research (Operation system)

✓ **Implementation items of this research**

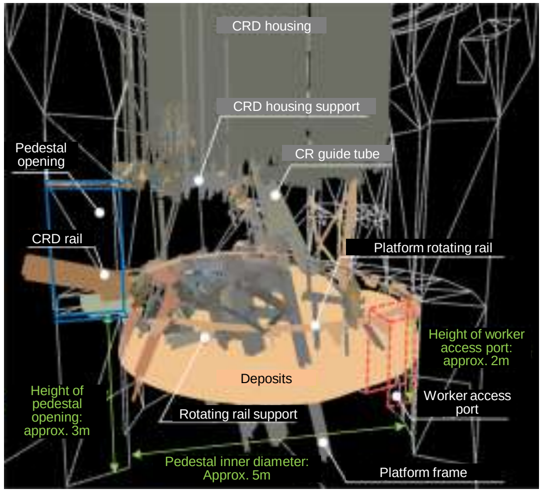
- Test manufacturing of the operation system, verification of viability of a series of works by means of mock-up tests
- Acquisition of actual data on the work procedures, creation of data for throughput evaluation

✓ **Correlation between implementation items, correlation with other research (Input and output information)**

- Conceptual study on utilization of data is underway together with the Fuel debris retrieval monitoring/support/integrated management WG.
- The model has been manufactured based on the 3D damage model of the inside of the Unit 3 pedestal.



Data utilization proposal by the Fuel debris retrieval monitoring/support/integrated management WG



3D damage model of the inside of the pedestal reproduced based on the images from the Unit 3 Internal Investigation conducted in July 2017

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

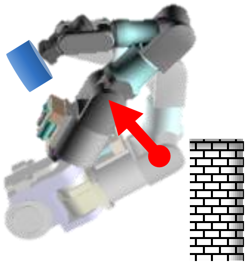
① Remote controlled tip tools for retrieval

(4) Implementation items, their mutual correlation, and correlation with other research (Operation system)

✓ Development results achieved so far and correlation with this project

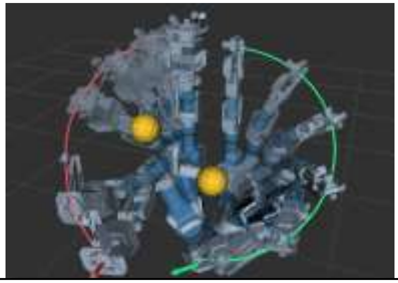
While carrying out research on obstacle avoidance by the multi-jointed (articulated) manipulator, its versatality and practicality are being enhanced as well.

Development project	Details
Development of technology for remote decontamination inside R/B (FY2013 - FY2014)	A technique for generating self motion was developed as a method for remote intuitive maneuvering of the manipulator with a redundant degree of freedom and its effect was verified.
Advancement of fundamental technology for retrieval of fuel debris and internal structures (FY2017-FY2018) “Development of a technique for planning the motion of a multi-degree of freedom robot considering avoidance of interference with the environment”	During the work of welding the cell adapter to the PCV wall surface in “one stroke”, a route following the welding line while avoiding interfering objects was created and the effectiveness was verified by mock-up welding tests.
Development of Technology for Further Increasing the Scale of Retrieval of Debris and Reactor Internal Structures (FY2019-FY2020) “Development of technique for remote operation support in environments with low visibility and confined spaces”	The trajectory for reaching the goal while avoiding obstacles was created automatically using a computer, the technology (trajectory planning) for setting the replay speed through joystick operation by the operator was developed, comparative verification with past operating techniques (manual operation, teaching) was carried out and the effectiveness was verified, for the purpose of interference removal work by means of a dual arm type manipulator. → The details of the research have been posted under Advanced Robotics in the Journal of the Robotics Society of Japan (Topic: A comparative study of manipulator teleoperation methods for debris retrieval phase in nuclear power plant decommissioning)
This Project (FY2021-FY2022) “Remote controlled tip tool for retrieval”	A technology will be developed for making it possible to carry out fuel debris retrieval work safely and in a short time, wherein when the dual arm type manipulator is being positioned for “grabbing”, “cutting”, etc., or if there is a gap between the 3D model and the actual condition, the gap will be corrected then and there and the route for avoiding obstacles will be regenerated.



Self motion (FY2013-FY2014)

Planning for movement over the welding route (FY2017-FY2018)



Dual arm type manipulator route planning (FY2019-FY2020)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(5) Implementation items (Tip tools)

✓ **Objective**

- Processing tests will be conducted using tip tools with specifications suitable for the current remote controlled equipment (access equipment), data for evaluating the throughput such as processing time, etc. will be acquired, and the accuracy of the data for throughput evaluation will be improved.

✓ **Project Goals**

- Processing tests will be conducted using tip tools with specifications suitable for the current remote controlled equipment (access equipment), whether or not processing is possible will be verified, processing time will be measured, and issues will be identified.
- Processing tests will be conducted not only for testing the pressing force (motor-operated arms 150kg, hydraulic arm 2ton) of the access equipment currently being assumed, but also for testing the low pressing force assuming smaller access equipment. The processibility will be verified and data for throughput evaluation will be acquired.
- Tests will be conducted by increasing the current core boring diameter of Φ66mm in order to reduce the processing time for block fuel debris (fuel debris accumulated at the pedestal bottom) which comprises a major portion of the throughput.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(1) Study of throughput improvement measures

- The throughput estimations from the "1F-3 Fuel Debris Retrieval Method Conceptual Study Contract (Part 3)" outsourced to TEPCO in FY2021, were analyzed.
  (This throughput is a result of revising the throughput estimated in the FY2017-18 Subsidy Project, during the project outsourced to TEPCO.
  - Removal of interferences outside the pedestal: 2,018 hours (84 days)
  - Removal of CRD rail: 63 hours (3 days)
  - Removal of CRD exchanger: 1,543 hours (65 days)
  - Removal of CRD housing: 4,717 hours (197 days)
  - Collection of granular fuel debris: 2,506 hours (105 days)
  - Collection of small pebble-shaped fuel debris:
  - 3,560 hours (149 days)
  - Collection of block fuel debris: 30,282 hours (1,262 days) ･･･Of which the processing time was 17,394Hr (725 days)
- In this development, studies and processing tests will be conducted aiming for reduction in processing time for block fuel debris (fuel debris accumulated at the pedestal bottom) which comprises a major portion of the above-mentioned throughput.
  - Technical study of new processing methods that have the potential of enhancing processing speed
  - Increasing the current core boring rotational speed to 150rpm
    (Since the payload of the robot arm is based on the pressing force of the current core boring, the pressing force is considered current).
  - Increasing the current core boring diameter of Φ66mm (The test will be conducted with a diameter of Φ65mm which is the same as that used in past tests, and a diameter of Φ130mm aiming for an increase in throughput by reducing the processing frequency).

(Example) Throughput of interference

Unit: Hours

Carrying in/out of equipment	Tool positioning	Processing	Cut pieces left behind	Cut pieces collected in containers	Replacement of blades within the cell	Transfer of collection containers	Total
2	669	54.5	335	66.8	836.3	53.9	2,017.5 (84 days)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(2) Technical research on tip tools

- So far, many processing methods suitable for the material and shape of items to be collected were investigated, and their applicability was studied.
- SUS304 and ceramic are assumed to be mixed in fuel debris.
- The processing method for fuel debris accumulated at the bottom of the pedestal, which comprises a major portion of the duration for fuel debris retrieval at present, was studied once again. Chisel and core boring were identified as applicable processing methods.

Processing method for fuel debris accumulated at the bottom of the pedestal

Processing method	Applicability	Evaluation
(1) Processing everything with a blade to form swarf	・ Can be processed. ・ Will require time.	△ : Processing requires time
(2) Processing everything with a chisel to form gravel	・ Whether or not processing is possible depends on the properties of the items to be processed. ・ If the item is brittle enough to be processed, processing is fast.	○ : Processing is fast
(3) Core boring	・ Can be processed. ・ A method of cutting out the core horizontally is required.	○ : Excellent processibility amongst the potential methods for processing hard layers ⑴, ⑶ to ⑹
(4) Cutting out by making intersecting cuts with a circular cutter	・ Can be processed. ・ As work progresses to the second and third layer, the shape of the surface becomes complex and hence processing becomes difficult.	△ : Processing is difficult from the second layer onwards
(5) AWJ (Abrasive Water Jet)	・ Can be processed from the viewpoint of material. ・ Processibility of shapes that cannot be penetrated, management of large quantity of abrasive are issues.	△ : Processing is difficult in the case of shapes that cannot be penetrated.
⑹ Laser	・ Can be processed from the viewpoint of material. ・ Processibility of shapes that cannot be penetrated, management of dross are issues.	△ : Processing is difficult in the case of shapes that cannot be penetrated.
(7) Plasma	・ Non-conducting ceramic cannot be processed.	x: Cannot be processed
(8) Gas	・ SUS304, ceramic cannot be processed as oxidation reaction is used.	x: Cannot be processed

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(3) Conceptual study of the method of retrieving structures and fuel debris from inside PCV

[Tip tools development procedure]

Procedures for collecting structures and fuel debris
・ Study of collection method

→ Study of collection procedures and collection method depending on the position, shape and properties of the structures and fuel debris

↓

Identification of the functions required of the tip tools
・ Conceptual designing

→ Identification of required functions, and conceptual designing of tip tools
・ Dimensions and mass that will enable the remote access equipment to guide
・ Function for recognizing the surrounding environment, visibility function for positioning the tool on the object to be processed
・ Operation system for reducing the load on the operator
・ Function for processing structures and fuel debris
・ Dust measures during processing

↓

Identification of items that need technical development from among the required functions

→ Identification of items that need technical development
・ Technology concerning the method (Cutting method, positioning, processing time, etc.)
・ Control technology (Automatic, semi-automatic, support, etc.)
・ Safety measures (Dust, fire, overall system, etc.)

↓

Technical development (Element tests)

→ Technical development through testing and analysis
・ Processing technology
・ Operation system for reducing the load on the operator
・ Dust measures during processing

□ : Scope of element tests

↓

Tip tools for the actual equipment
・ Verification using the access equipment

→ Verification of viability of a series of operations using equipment anticipating the actual equipment
・ Ability to access and be positioned on the object to be processed
・ Processing performance
・ Impact of the rigidity of the access equipment

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(3) Conceptual study of the method of retrieving structures and fuel debris from inside PCV

[Study of procedures for collecting structures and fuel debris]

- Overview of the current proposal

Interference removal using telescopic dual motor-operated arms (Outside the pedestal)

⬇

Interference removal using telescopic dual motor-operated arms (Inside the pedestal)

⬇

Changing to a fixed rail

⬇

Interference removal using dual motor operated arms

⬇

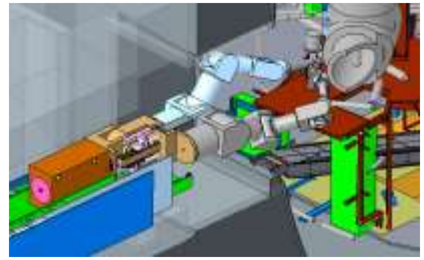
Suction of granular fuel debris using dual motor operated arms

⬇

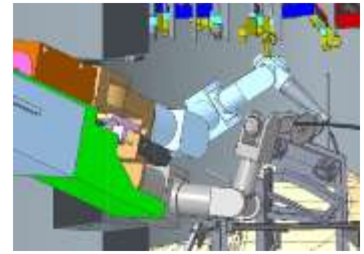
Block fuel debris processing using dual motor operated arms

⬇

Block fuel debris processing using single hydraulic arm

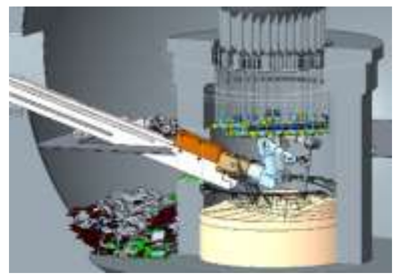


(Outside the pedestal)

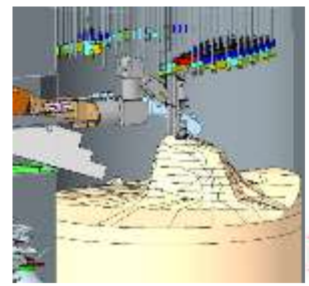


(Inside the pedestal)

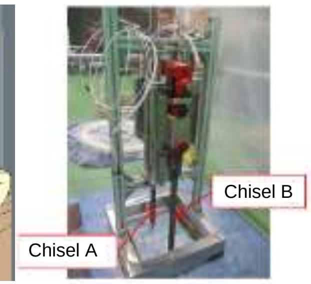
Interference removal using telescopic dual motor-operated arms



Interference removal using dual motor operated arms



Suction of granular fuel debris using dual motor operated arms



Block fuel debris processing using dual motor operated arms

Current core boring dimensions: Φ66mm x H100mm (342cm³)
Processing limit of 1 round: 16 cubic cm (4096cm³)

Making a hole at the center | **Core boring** | **Core cutting**

Block fuel debris processing using single hydraulic arm

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(3) Conceptual study of the method of retrieving structures and fuel debris from inside PCV

[Processing method depending on the items to be collected]

- Processing methods depending on the location and material of the items to be collected were studied and the following processing methods were selected.

Processing methods depending on the items to be collected

Items to be collected	Processing method	Reason for selection
Interfering objects (Structure)	Circular cutter	• As the interfering object needs to be held and cut while making sure it does not fall, it is assumed that one of the dual motor-operated arms will hold the piece and the other will cut. • The circular cutter that is compatible with various shapes was selected as the method for cutting the interfering objects, from among the processing methods studied in the element tests.
Granular fuel debris	Suction	• Granular fuel debris does not need to be processed, and as it is difficult to hold such small debris, suction was selected from the perspective of collection speed.
Block fuel debris (Brittle portion)	Chisel	• The chisel which has a faster processing speed was selected for the brittle portion of fuel debris accumulated at the pedestal bottom, from among the processing methods studied in the element tests. It is assumed that one of the dual motor-operated arms will process the debris with the chisel and the other will collect the processed pieces.
Block fuel debris (Hard portion)	Core boring (Including core cutting)	• Core boring was selected for the hard debris from the fuel debris accumulated at the pedestal bottom, which cannot be processed with a chisel, based on the results of the aforementioned studies on processing methods. As this debris is hard and is expected to require great force, it is assumed that the processing will be carried out with a single hydraulic arm.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(3) Conceptual study of the method of retrieving structures and fuel debris from inside PCV

[Study of methods for processing structures and fuel debris]

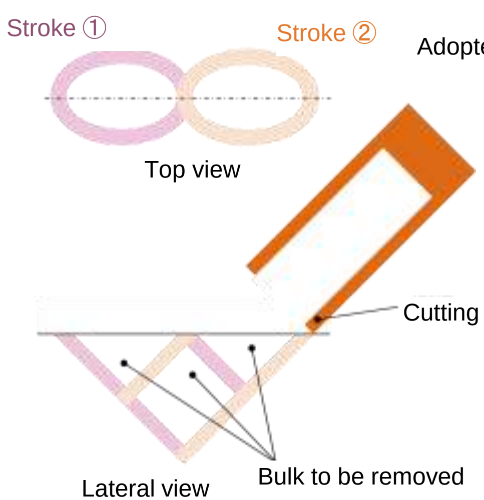
- Study of methods for collecting the core at the time of core boring

○: Merits x : Demerits

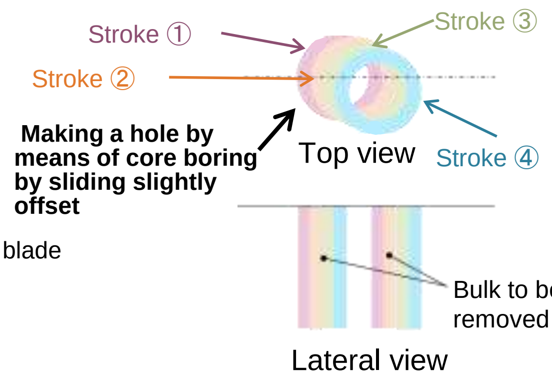
Core collection method	Characteristics
Core boring from 2 directions	○: The reactor core does not need to be cut (Only 1 type of tool is required). X : The reactor core remains inside the tool and is difficult to retrieve. X : As work progresses to the second and third layer, the shape of the surface becomes complex and hence processing becomes difficult.
Making a hole at the center by means of core boring for inserting the circular cutter, and then cutting the core with the circular cutter	○: Good processibility at the second and third layer. ○: Reactor core can be easily removed. X : Core cutting and core collection tools other than the core boring tools are required.

⇧

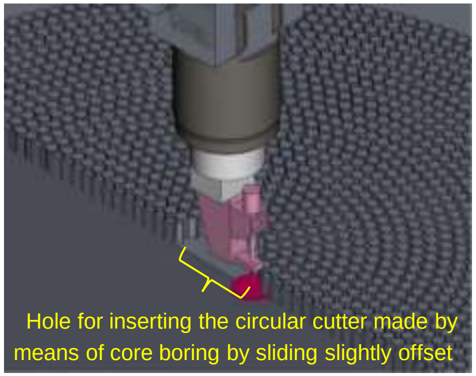
Adopted based on the processibility at the second and third layer



Core boring from 2 directions



(Making a hole for inserting the circular cutter by means of core boring)



(Core cutting using a circular cutter)

Making a hole at the center for inserting the circular cutter ⇒ cutting the core

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

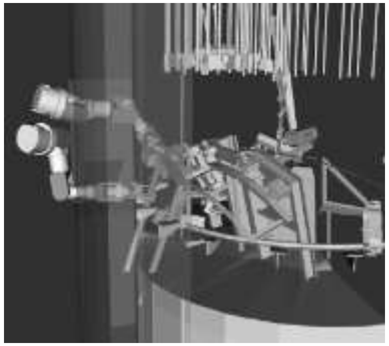
① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

Excer

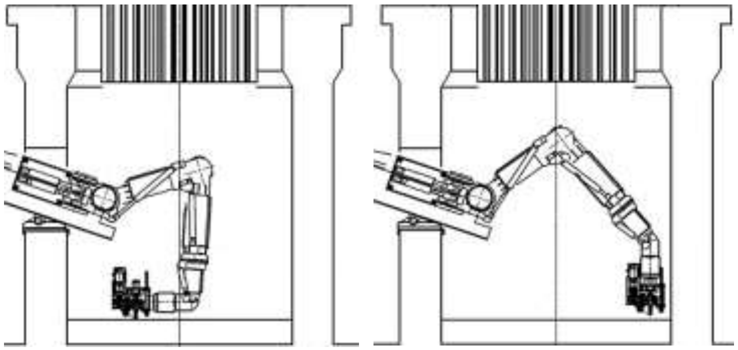
(4) Element test plan

[Purpose]

- Verification of processing capability as a tip tool
- Tip tools with specifications suitable for the current remote controlled equipment (access equipment) will be arranged and processing tests will be conducted using those tip tools for verifying whether or not processing is possible, measuring the processing time, and identifying issues.
  - ➢ Dual motor-operated arms
    - ✓ Payload: 150[kg]
    - ✓ Tip tool dimensions: W600×D500×H550[mm]
  - ➢ Single hydraulic arm
    - ✓ Payload : Facing down : 2[ton], Facing up: 1 [ton]
    - ✓ Tip tool dimensions: W600×D500×H750[mm]



Dual motor-operated arms



Single hydraulic arm

Study of tip tool accessibility

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Selection of items to be tested]

- The items to be tested in the element tests to be conducted in this project were selected, based on the results of the studies on methods for processing structures and fuel debris, and on the status of implementation of element tests so far.

Tip tools that will be tested during the element tests in this project

Items to be tested in this project	Processing method	Arm	Status of element tests conducted so far		Implementation of element tests during this project	
			Machine tools*1	Tools*2	Tools*2	Combination with the arm
Structures (Interfering objects)	Circular cutter	Dual motor-operated arms	✓	-	✓	-*3 **(Proven track record of using arms is available)**
Granular fuel debris	Suction	Dual motor-operated arms	-	✓	-	-
Block fuel debris (Brittle portion)	Chisel	Dual motor-operated arms	-	✓	-	-
Block fuel debris (Hard portion)	Core boring (Including core cutting)	Single hydraulic arm	✓	-	✓	○*4 **(Combination with hydraulic arm)**

*1: Processing test using machine tools that do not consider specifications such as payload, etc. of the access equipment being studied.
The processing time is likely to extend when processing work is carried out using tip tools mounted on remote controlled access equipment, which are inferior in terms of rigidity or rotational torque of the blade.

*2: Processing test using tip tools that consider specifications of the access equipment being studied.
*3: Test is not conducted as an arm suitable for the payload is not available. There is a track record of cutting of pipes in the past.
*4: Combination test with the test manufactured hydraulic arm and tip tools that consider specifications of the access equipment being studied.
The impact of the rigidity and vibration resistance of the arms will be verified.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

Excer

(4) Element test plan

[Conceptual designing of the tip tools for the actual equipment]

- The functions required of the tip tools will be identified based on the requirements of each work step, and the conceptual design will be developed.
- From among the functions required of the processing tools, those related to processibility will be verified during the elemental tests.

Functions required of the tip tools and verification items (1/2)

No.	Work step	Requirements	Required functions	Items to be verified during the element tests
1	Advanced preparations			
1-1	Verification of workability by means of a simulator	・A series of operations must be verified at the site by means of the simulator.	・Showing the work environment and robot in the form of a 3D model. ・Being able to operate the 3D model of the robot just like the actual robot.	—
2	On-site work			
2-1	Moving from cell → processing location	The cells must be transferred to the predetermined location while avoiding obstacles by remote operation. ・The dimensions and mass must be such that the robot arm can be guided. ・The surrounding environment must be visually observed or confirmed by means of 3D scanning when the robot arm is being guided.	・The dimensions and mass equal to or lower than that which enables the robot arm to be guided. ・ Visual inspection function ・3D scanning function ・Operation system (Function of assisting the operator)	— (Tip tools designed with dimensions and mass equal to or lower than that which enables the robot arm to be guided.)
2-2	Environment verification	・The condition of the work environment must be confirmed by remote operation.	・ Visual inspection function ・3D scanning function	—
Circular cutter				
2-3	Grabbing the items to be removed	・ Remote operation must be conducted to position the tip tool and grab the items to be removed.	・Grabbing function ・Function of following the same pattern for the items to be grabbed ・ Visual inspection function	—
2-4	Processing the items to be grabbed	・Remote operation must be conducted to position the tip tool and process the items to be removed. ・The blade must be cooled. ・Dispersion of machining dust must be reduced.	・Processing function ・Function of verifying the processing status (Speed of the motor, etc.) ・Visual inspection function (Verification of surrounding environment and processing status) ・Blade cooling function ・Dust reduction function ・Measures to prevent getting jammed in the cutter ・Operation assistance (Function of assisting the operator)	・Whether or not processing is possible (including cooling of blade) ・Processing conditions (speed, torque, pressing force) and processing time ・Life of blade ・Processing reaction force (required pressing force)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Conceptual designing of the tip tools for the actual equipment]

Functions required of the tip tools and verification items (2/2)

Content in red: The functions required of the processing tools.

No.	Work step	Requirements	Required functions	Items to be verified during the element tests
Suction				
2-5	Suction of granular fuel debris	・Remote operation must be conducted to position the tip tool and suck the granular fuel debris.	・Suction function ・Function of verifying suction status (Status of pump operation, etc.) ・Visual inspection function (Verification of surrounding environment and suction status) ・Operation system (Function of assisting the operator)	–
Chisel				
2-6	Processing the items to be grabbed	・Remote operation must be conducted to position the tip tool and process the items to be removed. ・Dispersion of dust must be reduced.	・Processing function ・Visual inspection function (Verification of surrounding environment and processing status) ・Dust reduction function (Water supply, etc.) ・Operation system (Function of assisting the operator)	–
Core boring (Including core cutting)				
2-7	Processing the items to be grabbed	・Remote operation must be conducted to position the tip tool and process the items to be removed. ・The blade must be cooled. ・Dispersion of machining dust must be reduced.	・Processing function ・Function of verifying the processing status (Speed of the motor, etc.) ・Visual inspection function (Verification of surrounding environment and processing status) ・Blade cooling function ・Dust reduction function ・Operation system (Function of assisting the operator)	・Whether or not processing is possible (including cooling of blade) ・Processing conditions (speed, torque, pressing force) and processing time ・Life of blade ・Processing reaction force (required pressing force) ・Work in combination with the arms (Stand-alone tool for core cutting)
2-8	Leaving behind the items to be removed / storing in container	・Remote operations must be conducted to transfer items to be removed up to the predetermined location ・Same as 2-1	・Same as 2-1	–

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Simulated bodies for the element tests]

- The simulated bodies used in element tests so far were not changed. The followings were selected based on the properties and availability of material derived from fuel debris.
  - ➢ Interfering objects: SUS304, SUS304 + Alumina 99
  - ➢ Fuel debris: SUS304 + Alumina 99
    - ・ SUS304 simulates the material of reactor internal structures.
    - ・ Alumina is selected as material which is highly hard and easily obtainable, from among the ceramic material that is considered to be similar to fuel components.
    - ・ In the case of SUS304 + Alumina 99, since both materials are processed under the same conditions, the shape of the blade will be improvised so that it can work on both the materials.

  [Reference] Vickers hardness of ceramic material Alumina 99: 15.2GPa, Zirconia: 12.3 GPa
- The following simulated bodies will be tested in some of the tests.
  - ➢ Interfering objects: SS400 + Alumina 99
  - ➢ Fuel debris: SS400 + Alumina 99, granite
    - ・ SS400 simulates the material of structures inside the pedestal.
    - ・ SS400 will be replaced with SUS304, and the processibility of SUS304 and SS400 will be compared.
    - ・ Granite is selected because its hardness is halfway of the metals (SUS304, SS400) and Alumina 99.
    - ・ Processibility of material that is brittle and less hard will be verified with granite.

Note) Hereinafter SUS304 will be referred to as SUS, SS400 as SS and Alumina 99 as Alumina.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Specifications of the blade]

- Ceramics (Alumina) need to be processed, but generally ceramics are hard due to which cutting (cutting into the material with sharp blades) is not possible, hence these will be processed using abrasive grains.
- Diamond, CBN (Cubic Boron Nitride) are abrasive grains that are harder than ceramics and have the following characteristics.
  - ➢ Diamond: The carbon in diamond reacts easily with steel material under high temperatures, and hence it is not suitable for processing steel material.
  - ➢ CBN: Has better heat resistance as compared to diamond, doesn't react easily with steel material, hence is widely used for processing steel material.
- This time, since ceramics and steel material need to be processed, a mixture of diamond and CBN will be used as abrasive grains.

Applicability of abrasive grains to ceramics and steel material (metal)

	Ceramics	Steel material (Metal)
Diamond	✓	△
CBN	x	✓

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

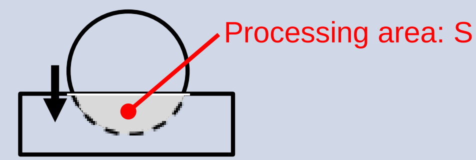
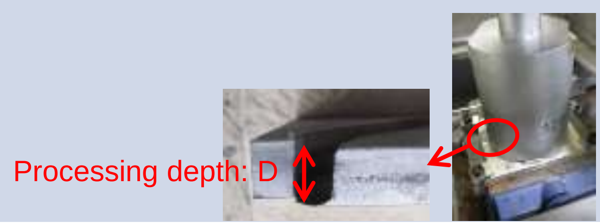
Excer

(4) Element test plan

[Acquired data]

- Processing tests (Refer to the next page onwards) will be conducted for each tip tool (circular cutter, core boring, core cutting) to obtain the following data.

Acquired data (1/2)

Items	Details
Applicability to actual equipment, issues and response measures	Based on the test results, issues in on-site applicability will be identified and response measures will be studied.
Processibility	The status of processing such as whether or not processing is possible, presence of chatter marks, etc. will be verified.
Processing time	The processing speed will be calculated from the amount of processing and the processing time. ・Circular cutter: **[mm^2/min] will be calculated from the processing area (S) and processing time (t). Processing speed = S/t  ・Core boring: **[mm/min] will be calculated from the processing depth (D) and processing time (t). Processing speed=D/t 

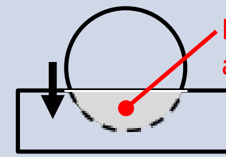
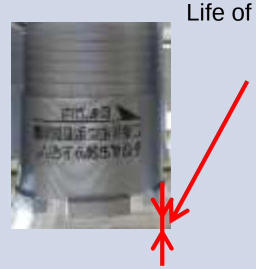
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

Excerp

[Acquired data] Acquired data (2/2)

Items	Details
Life of the blades	The amount of processing that can be performed with 1 blade will be calculated based on the height of the abrasive grains part before processing , the amount of processing and the abrasion loss. ・ Circular cutter: Area that can be processed (= defined as life of the blades) **[mm2] will be calculated from the height of the abrasive grains part before processing (R), processing area (S), height of the abrasive grain part after processing (r). Life of the blades = R・S/(R-r)   ・Core boring: The depth that can be processed (= defined as life of the blades) **[mm] will be calculated from the height of the abrasive grains part before processing (H), processing depth (D) and the height of the abrasive grain part after processing (h). Life of the blades = H・D/（H-h）    Whether the life of the blades can be determined from the current of the motor for rotating the blade, tool slide stroke, etc. will be verified.
Required specifications of remote controlled equipment (access equipment)	The reaction force involved in the processing (blade pressing force, blade rotating force) will be obtained for provided it as input for the remote controlled equipment (access equipment).
Workability in combination with the arms (Core boring)	The status of processing such as whether or not processing is possible in combination with the arm, presence of chatter marks, etc. will be verified.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Circular cutter (Only the stand-alone tool)

- The specifications required of the actual equipment will be identified for designing the equipment for the element test.
  - ➢ Aerial cutting while lowering the water level is assumed (However, the equipment will have a waterproof structure since cooling water will splash on it).
  - ➢ The mass is set at 100kg considering the mass of cables and hoses since the payload of the dual motor-operated arms is 150kg.
  - ➢ The size that can be cut is set at 150mm based on the dimensions of the structure to be cut.

Specifications required of the circular cutter for the dual motor-operated arms

It is assumed that the grating, beam, and CRD exchanger will be cut.

Required functions	Specifications, etc.
Dimensions	About W600 × D500 × H550mm: Determined based on the accessibility of the tool
Mass	Maximum 150kg (Target 100kg): Determined based on the payload of the arm
Processing	Circular cutter: Size that can be cut 150mm (Cutter size About Φ400 to 500mm)
	Rotational torque of cutter: The largest motor that can be mounted on the tool will be selected
	Cutter rotational speed: The largest motor that can be mounted on the tool will be selected
Cooling of blades	Cooling water supply for cutter
Dust control	Installation of cover for preventing dispersion of machining dust
	Supply of machining water to the portion to be cut
Visual inspection of part to be processed	Installation of cameras and lights for monitoring the status of processing

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Circular cutter (Only the stand-alone tool)

- Conceptual planning of the actual equipment based on the specifications required of the actual equipment
- Study of test equipment and test items for verifying the functions related to processing from among the functions of the actual equipment

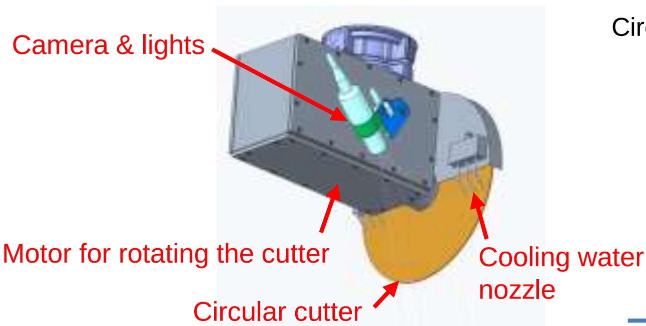


Illustration of actual equipment

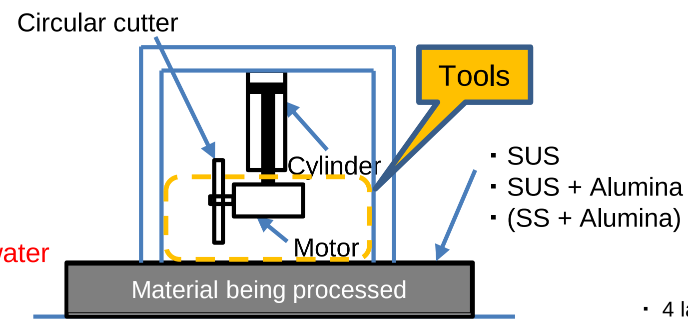
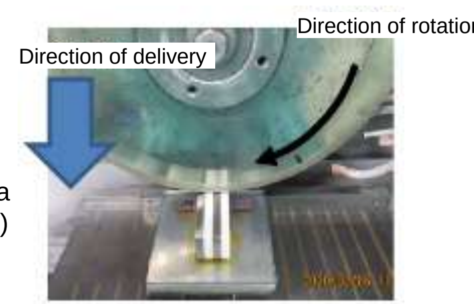
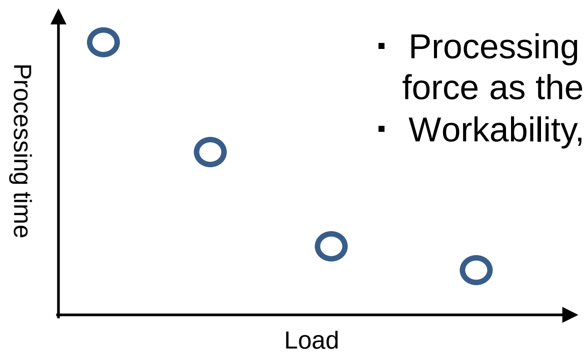


Illustration of test equipment



・ 4 layers SUS (t5mm) and Alumina (t5mm) stacked

Sample image of testing



- Processing test will be conducted with the type of blade, speed, pressing force as the parameters.
- Workability, processing time, load torque and life of the blade will be verified.

It is assumed that the grating, beam, and CRD exchanger will be cut.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Core boring (Stand-alone tool + combination with arm)

- The specifications required of the actual equipment (next page) will be identified for designing the equipment for the element test.
  - ➢ Aerial cutting while lowering the water level is assumed (However, the equipment will have a waterproof structure since cooling water will splash on it).
  - ➢ The payload of the single hydraulic arm is 1 ton, but the target mass will be set at 500kg.
  - ➢ If the cutter is pressed with the arm, the arm bends, but the bend changes depending on the processing reaction force that depends on the hardness of the object to be processed.
    Since the cutter cannot be sent straight ahead if the bend of the arm changes, the tool will be pressed in with the arm, its reaction force will be received by outriggers at 4 locations, the cutter will be sent in with the cylinder inside the tool under such conditions and processing (pressing force: Maximum 2ton) will be carried out.
  - ➢ Colling water will be supplied to the inner side of the blade, and the machining dust will be pushed up from the outer side of the blade.
- Conceptual planning of the actual equipment based on the specifications required of the actual equipment

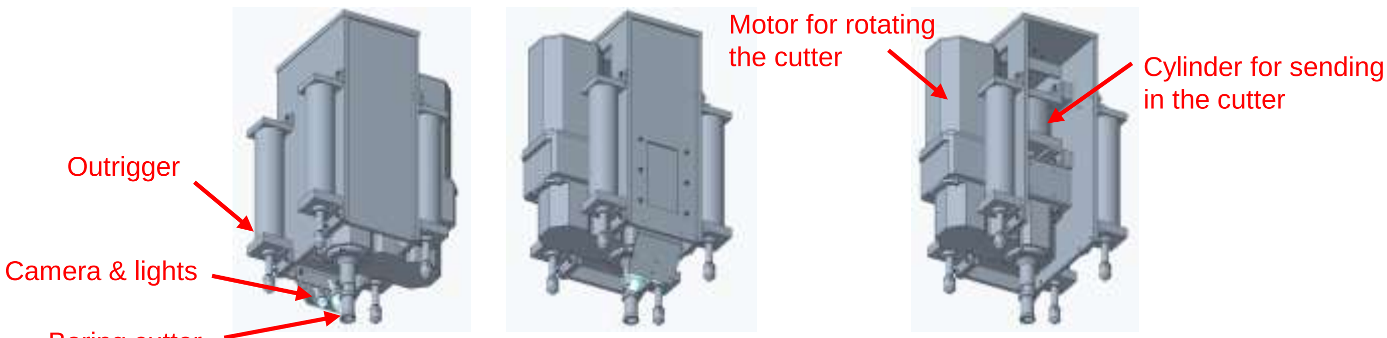


Illustration of actual equipment

(4) Element test plan

[Study of test items and testing methods]

Core boring (Stand-alone tool + combination with arm)

Specifications required of the core boring for single hydraulic arm

It is assumed that a hard layer of block fuel debris will be cut.

Required functions	Specifications, etc.
Dimensions	About W650×D900×H750mm: Determined based on the accessibility of the tool
Mass	Maximum 1000kg (Target 500kg): Determined based on the payload of the arm
Processing	Core boring cutter: A cutter of diameter Φ65mm which is similar to the Φ66mm cutter used in past element tests, and that of diameter Φ130mm aiming for an increase in throughput by reducing the processing frequency will be assumed.
	Rotational torque of cutter: The largest motor that can be mounted on the tool will be selected
	Cutter rotational speed: The largest motor that can be mounted on the tool will be selected
	Cutter pressing force: Maximum 2ton (Pressing force of the arm)
	Receiving of the cutter pressing force reaction force: Installation of outrigger
	Discharge of cutting swarf: Water will be supplied inside the cutter
Cooling of the blade	Cooling water supply for cutter
Dust control	Prevention of dispersion with the help of cooling water for cutter
Visual inspection	Installation of cameras and lights for monitoring the status of processing

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Core boring (Stand-alone tool + combination with arm)

- Study of test equipment and test items for verifying the functions related to processing from among the functions of the actual equipment

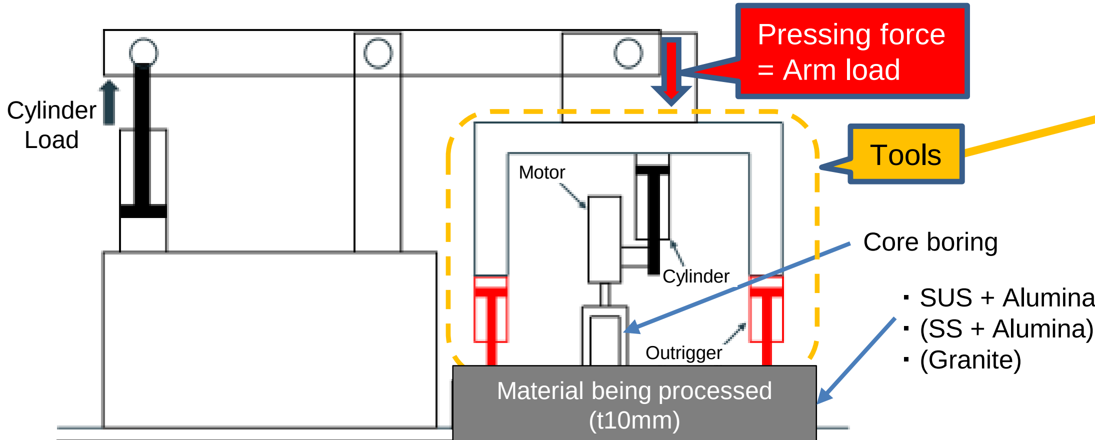
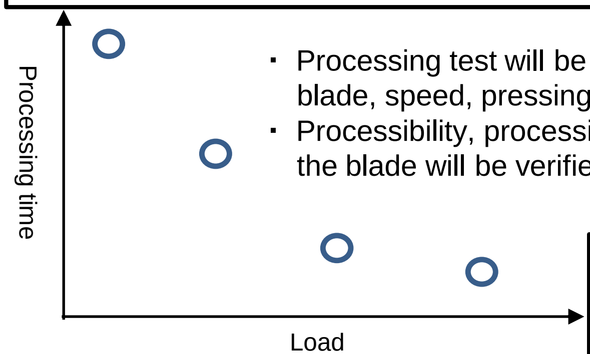


Illustration showing the tool unit test equipment

Illustration of arm combination test

・ Processibility using the arm will be verified under conditions determined during the unit test.
(The impact of the rigidity and vibration resistance of the arms will be verified）.



・ Processing test will be conducted with the type of blade, speed, pressing force as the parameters.
・ Processibility, processing time, load torque and life of the blade will be verified.

It is assumed that a hard layer of block fuel debris will be cut.

Sample image of testing

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Core cutting (Only stand-alone tool)

- The specifications required of the actual equipment will be identified for designing the equipment for the element test.
  - ➢ Aerial cutting while lowering the water level is assumed (However, the equipment will have a waterproof structure since cooling water will splash on it).
  - ➢ The target mass will be set at 100kg similar to the circular cutter so that it can be handled by both, the dual motor-operated arms and the single hydraulic arm.
  - ➢ Cutting will be performed while holding the core so as to make it easier to retrieve the core after cutting.

Specifications required of the circular cutter for core cutting

Required functions	Specifications, etc.
Dimensions	About W650×D500×H750mm: Determined based on the accessibility of the tool
Mass	Maximum 150kg (Target 100kg) : Determined based on the payload of the arm
Processing	Circular cutter: Determined based on the core boring size
	Rotational torque of cutter: The largest motor that can be mounted on the tool will be selected
	Cutter rotational speed: The largest motor that can be mounted on the tool will be selected
	Cutter pressing: Maximum 300kg
	Receiving of the cutter pressing force reaction force: Installation of core clamp
Cooling of the blade	Cooling water supply for cutter
Dust control	Prevention of dispersion with the help of cooling water for cutter
Visual inspection	Installation of cameras and lights for monitoring the status of processing

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(4) Element test plan

[Study of test items and testing methods]

Core cutting (Only stand-alone tool)

- Conceptual planning of the actual equipment based on the specifications required of the actual equipment
  - ➢ The reactor core will be held with the clamping mechanism, the blade will be sent in with the cylinder inside the tool and processing will be performed.
- Study of test equipment and test items for verifying the functions related to processing from among the functions of the actual equipment

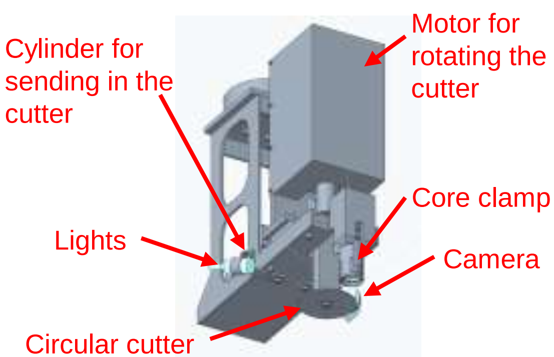


Illustration of actual equipment

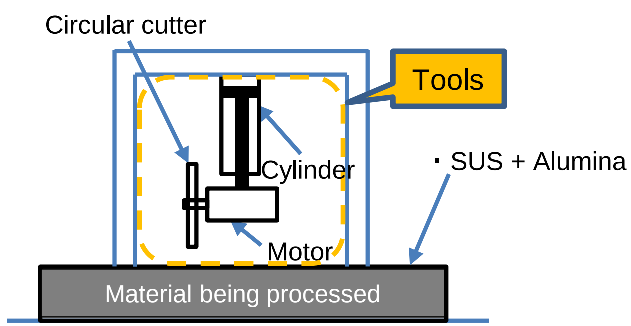
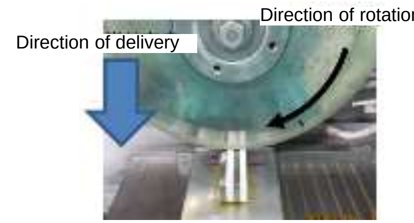


Illustration of test equipment

Step 1: For setting the processing conditions



Sample image of testing

・ Since preparation for halving the round bars (Alumina) of the size of the outer diameter of the reactor core is not an easy task, it will be replaced with square shaped blocks of the size of the outer diameter of the core.

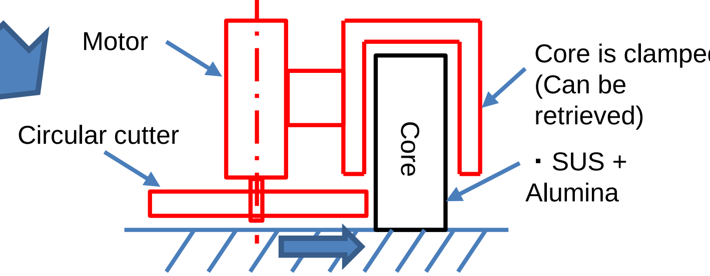
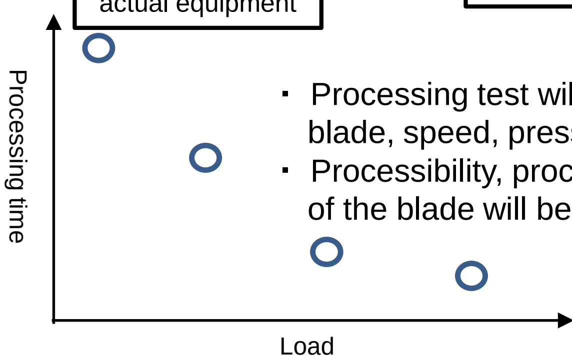


Image illustrating the actual equipment test

Step 2: For simulating the actual equipment



- Processing test will be conducted with the type of blade, speed, pressing force as the parameters.
- Processibility, processing time, load torque and life of the blade will be verified.

・ Whether or not processing will be possible with the tool will be verified. (Whether or not the processing reaction force can be endured when the core is clamped.)
・ Performance of the core clamp will be verified.

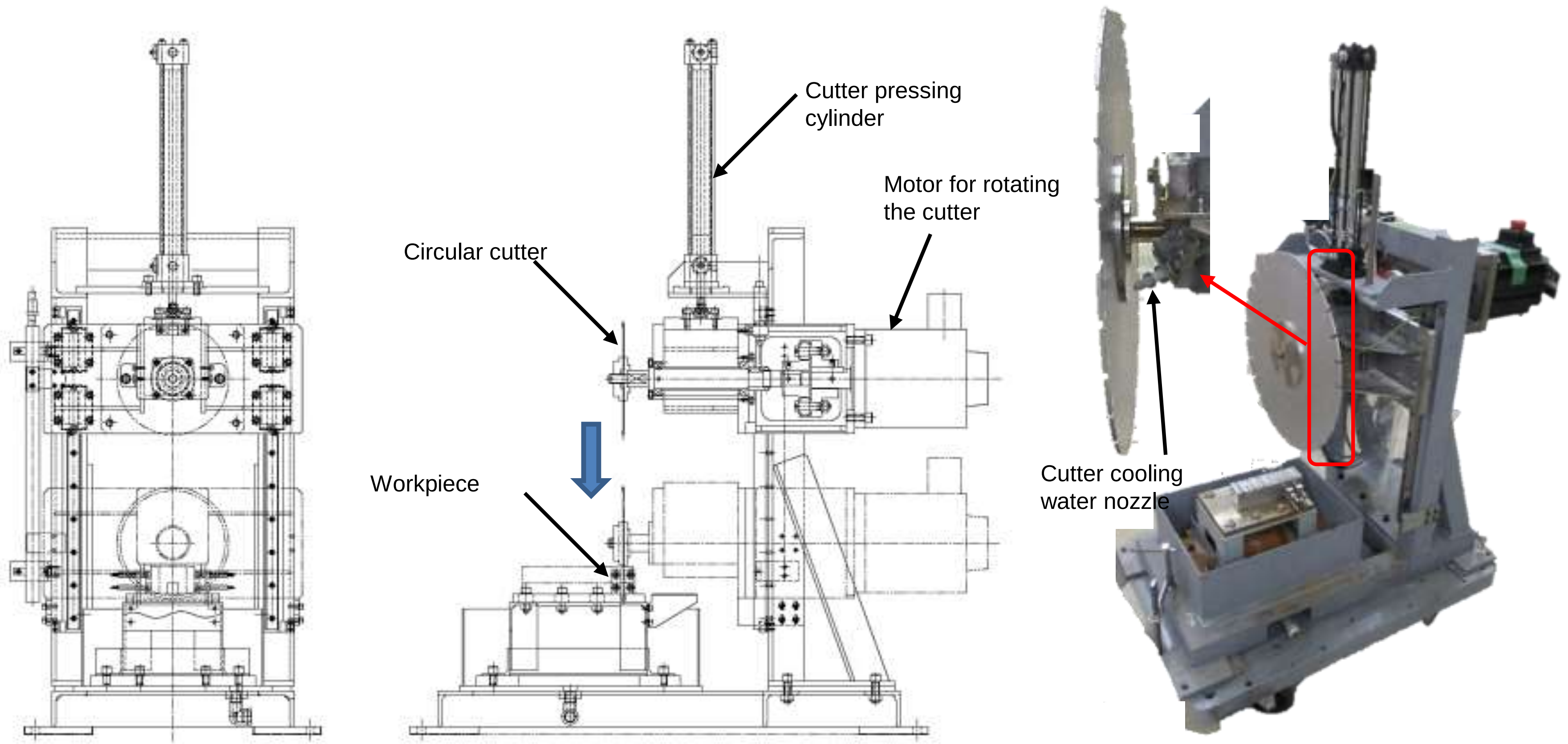
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]

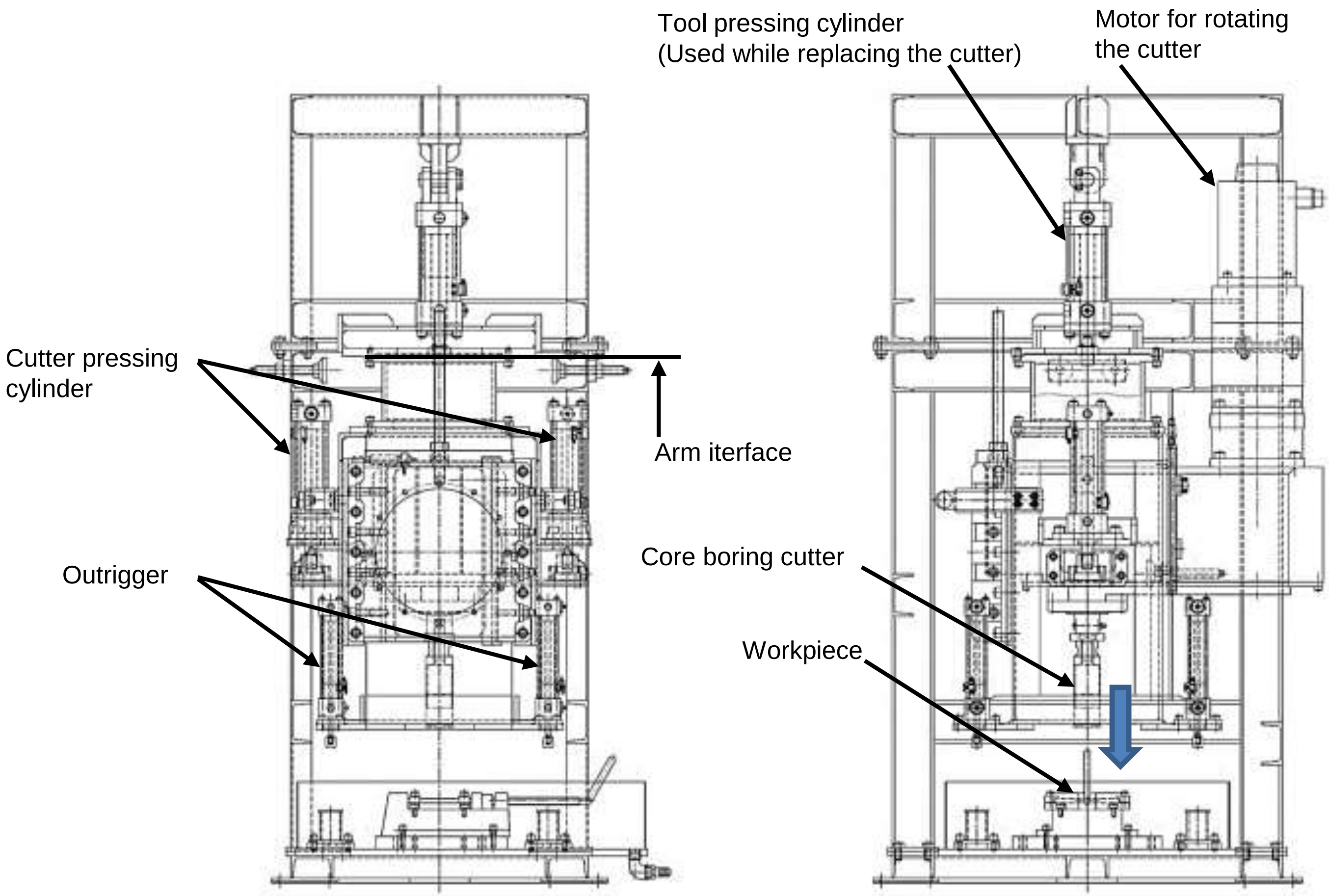
- Test equipment will be designed and manufactured based on results of conceptual studies on the equipment, and results of studies on test items and test methods.

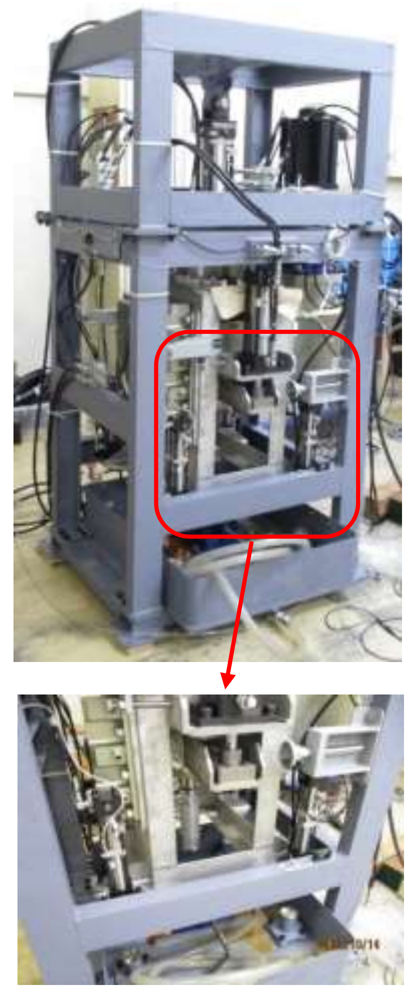


Test equipment (Circular cutter)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]





Test equipment (Core boring)

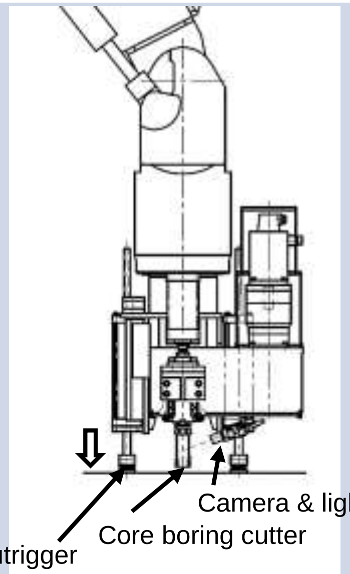
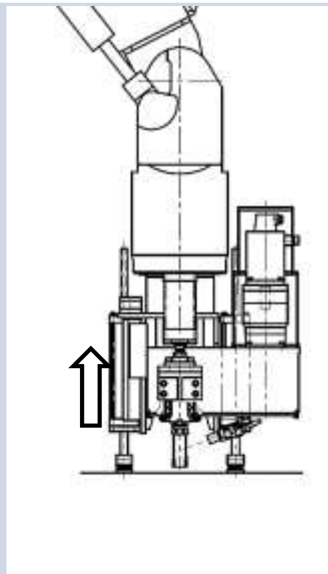
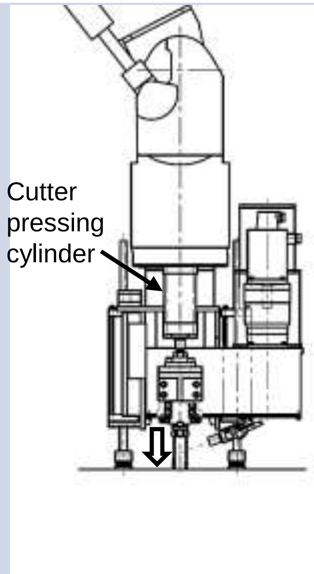
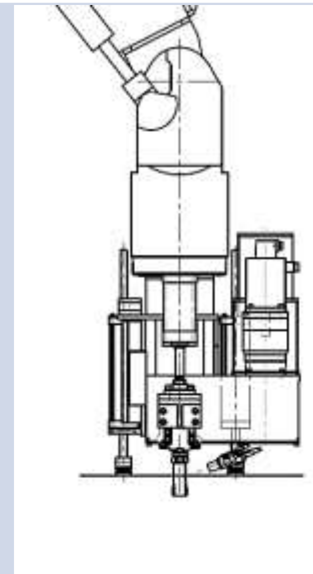
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]

Core boring work steps

Work step	1. Outrigger ground contact	2. Outrigger pressing	3. Core boring (Cutter pressing)	4. Core boring (Processing)
Illustration of work steps				
Details	・Positioning the arm. ⇒ The arm is fixed after it is positioned. Only withstands the outrigger pressing force and cutter pressing force. ・Extending the outriggers (4 units) to connect to the ground.	・Further pressurizing the outriggers. ⇒ The outriggers extend further, the tool is lifted up with only the extended portion and the arm bends upwards. ・Closing the valve of the outrigger cylinder. ⇒ Outrigger pressing force becomes the arm pressing force.	・Pressing the cutter with the cutter pressing cylinder present inside the tool while rotating the cutter (Cutter pressing foce < outrigger pressing force). ⇒ The load on the outrigger reduces.	・Processing with the cutter

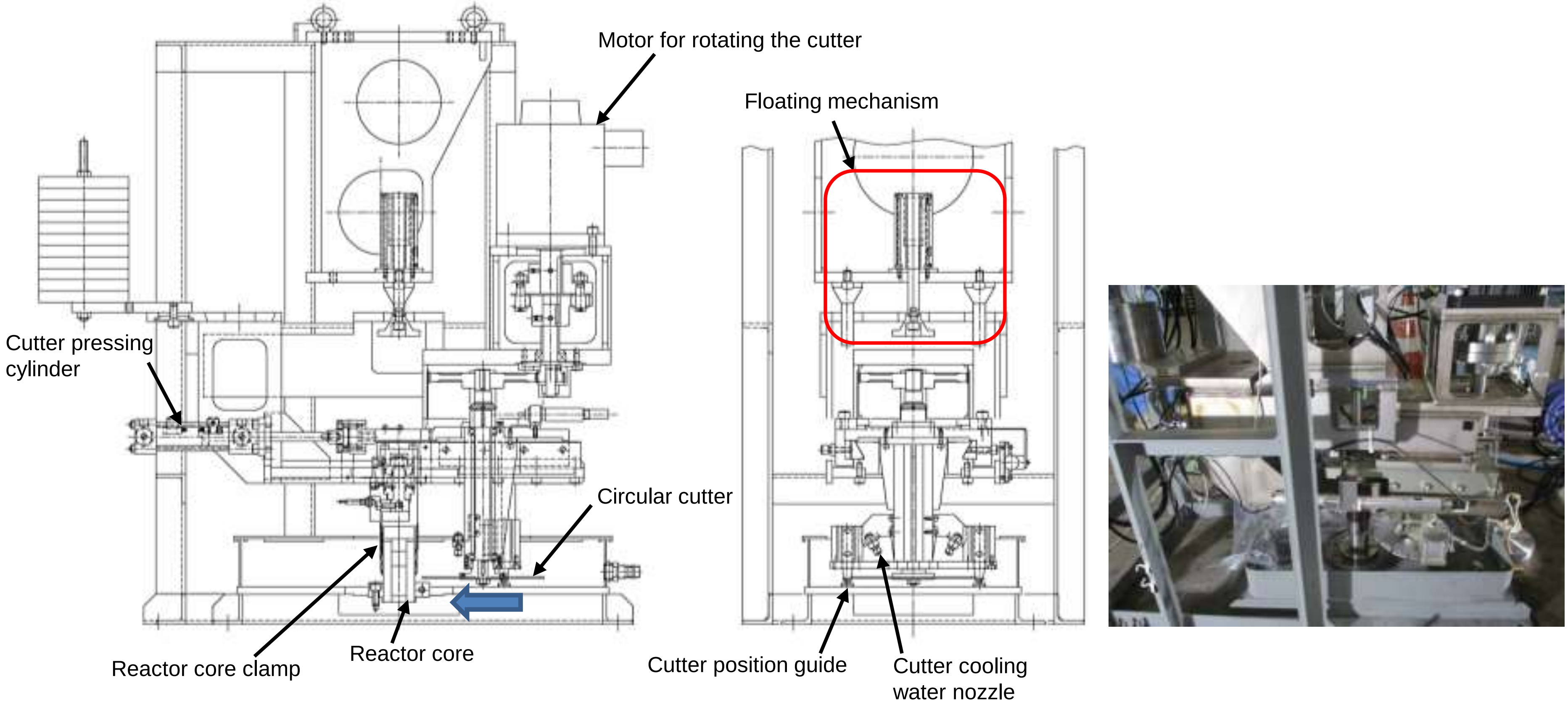
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]

- The equipment is fixed by clamping the reactor core in the radial direction with 3 claws, the reaction force resulting from pressing of the circular cutter and the force that rotates the equipment resulting from rotation of the circular cutter are received by the reactor core clamp.



Test equipment (Core cutting)

Excer

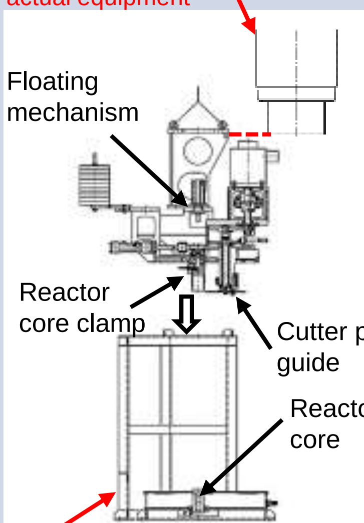
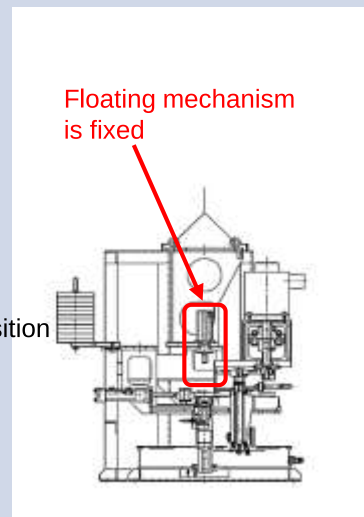
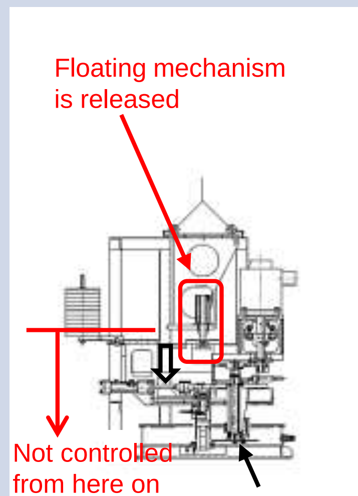
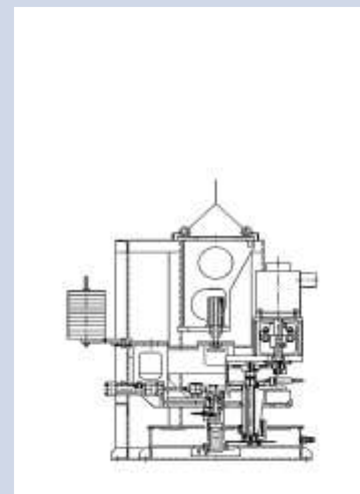
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]

Core cutting Work steps (1/2)

Work step	1. Suspending the equipment	2. Inserting the clamp into the reactor core	3. Fixing and releasing the floating mechanism	4. Clamping the reactor core
Illustration of work steps				
Details	・ Suspending the equipment while the floating mechanism is fixed. (Performed by the arm in the actual equipment)	・ Installing on the frame and inserting the tip of the clamping mechanism into the reactor core. (Performed by the arm in the actual equipment)	・ Releasing the floating mechanism. ・ Lowering the equipment along the reactor core.	・ Clamping the reactor core.

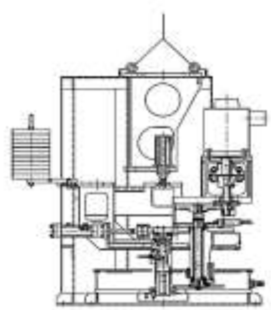
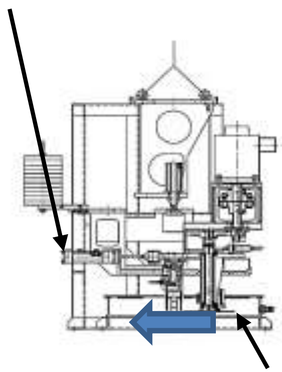
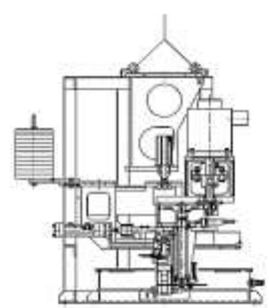
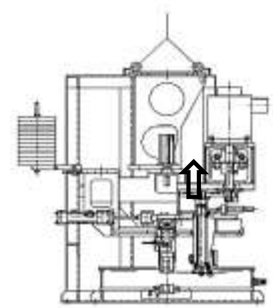
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(5) Designing and manufacturing of tip tools and test equipment for the element tests

[Designing and manufacturing of test equipment]

Core cutting Work steps (2/2)

Work step	5. Fixing the floating mechanism, and stowing the cutter position guide	6. Core cutting	7. Core cutting completion	8. Core collection
Illustration of work steps				
Details	・ Moving the floating mechanism in the fixing direction (to prevent the cutter from getting stuck after cutting is completed). ⇒ The equipment follows the reactor core.	・ The size of the cutter pressing cylinder is reduced and the core is cut.	・ Moving the circular cutter to its original position after completing core cutting.	・ Raising the equipment with the help of the floating mechanism.

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Specifications of the test equipment and acquired data]

- Processing tests will be conducted for verifying the processing speed and abrasion loss of core boring and circular cutter (including core cutting) in order to verify the processibility of the fuel debris and interfering objects.

Specifications of the test equipment

	Rotation of blades	Pressing of blades	Blades	Workpiece
Circular cutter (Removal of interfering objects)	・ Electric motor ・ Output: 2.4[kW] ・ Rated torque: 7.64[N･m] ・ Rated rotational speed: 3,000[rpm] ・ Reduction ratio: 2/3, 1/2, 1/4	・ Hydraulic cylinder ・ Maximum 150[kg]	・ Φ 457 × t3.8	・ SUS ・ SUS + Alumina ・ (SS + Alumina)
Core boring	・ Electric motor ・ Output: 5[kW] ・ Rated torque: 31.8[N･m] ・ Rated rotational speed: 1,500[rpm] ・ Reduction ratio: 1/5, 1/8, 1/16	・ Hydraulic cylinder ・ Maximum 2 [ton]	・ Φ 130 × Φ118 ・ Φ 65 × Φ53.4	・ SUS + Alumina ・ (SS + Alumina) ・ (Granite)
Circular cutter (Core cutting)	・ Electric motor ・ Output: 4.5[kW] ・ Rated torque: 14.3[N･m] ・ Rated rotational speed: 3,000[rpm] ・ Reduction ratio: 2/3, 1/2, 1/4	・ Hydraulic cylinder ・ Maximum 300[kg]	・ Φ203 × t3	・ SUS + Alumina

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Specifications of the test equipment and acquired data]

Common

- Test parameters
  - Blade pressing force
  - Rotational speed of the blade
- Measured data
  - Processing speed
  - Life of the blade (calculated based on the abrasion loss)
  - Load torque (calculated based on the motor current)

[Test preparation]

Common

- The relation between the pressure supplied to the hydraulic cylinder of the test equipment and the blade pressing force is measured.
  ⇒ The pressing force is controlled by the supplied force.
- The maximum pressing force by which the blade rotates (can process) in the case of each reduction ratio is measured.
- 3 to 5 cases of pressing forces to be tested (Example: 100%, 75%, 50% and 25% of the maximum pressing force) are determined from the maximum pressing force.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Test contents]

List of tests contents (1/2)

	Test Item	Test contents	Workpiece
Circular cutter (Removal of interfering objects)	(1) Processing speed verification test	The processing speed, life of the blade, and load torque are verified with blade pressing force and rotational speed as the parameters.	・ SUS + Alumina ・ SS + Alumina (some conditions)
	(2) Test on processing a larger workpiece	The processibility is verified by selecting good conditions based on the test results in (1), and increasing the blade contact area.	・ SUS + Alumina
	(3) SUS stand-alone processing test	The processibility of SUS alone is verified by selecting good conditions based on the test results in (1).	・ SUS
Core boring	(1) Processing speed verification test	The processing speed, life of the blade, and load torque are verified with blade pressing force and rotational speed as the parameters.	・ SUS + Alumina ・ SS + Alumina (some conditions) ・ Granite (some conditions)
	(2) Swarf dischargeability verification test	The processibility of the plank is verified (If the processing goes deeper, dischargeability of swarf worsens and is likely to have an impact on processing) by selecting good conditions based on the test results in (1).	・ SUS + Alumina
	(3) Test on making a hole for inserting the circular cutter for core cutting	The processibility if the processing groove is covered is verified (if the processing groove is covered, the blade is likely to run towards the preceding processing groove), by selecting good conditions based on the test results in (1).	・ SUS + Alumina
	(4) 30°incline processing test	The processibility when the part to be processed is inclined 30° is verified (The blade is likely to slide along the incline and have an impact on processing) by selecting good conditions based on the test results in (1).	・ SUS (Since a plank is required for simulating the 30°inclined Alumina workpiece, which is difficult to obtain, the test is conducted using SUS.)
	(5) Arm combination test	The processibility of above mentioned (1), (3) and (4) by means of the arm is verified by selecting good conditions based on the test results in (1).	・ SUS + Alumina

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Test contents]

List of tests contents (2/2)

	Test Item	Test contents	Workpiece
Circular cutter (Core cutting)	(1) Processing speed verification test	The processing speed, life of the blade, and load torque are verified with blade pressing force and rotational speed as the parameters.	・ SUS + Alumina ・ SS + Alumina (some conditions)
	(2) Test for verifying whether processing is possible using the tool	The processibility when the core is clamped with the tool is verified by selecting good conditions based on the test results in (1).	・ SUS + Alumina

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

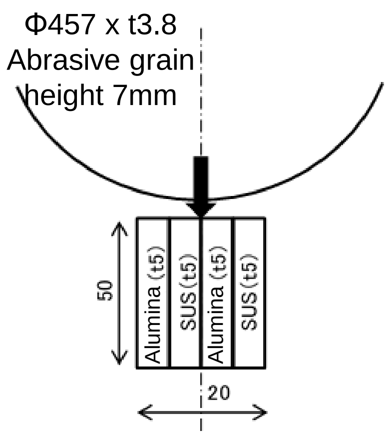
[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

① Processing speed verification test

- The workpiece shown in the drawing below is processed, and the processing speed, life of the blade (calculated based on the abrasion loss) and load torque (calculated based on the motor current) are calculated.
- In order to understand the trend, the pressing force and rotational speed over a broad set of 3 - 4 points are considered and verified.
- Processing is not possible with the arranged motor (2.4kW) and spur gear reduction (1/4) due to lack of torque.

⇒ In the actual equipment, since 1/7 decelerator can be installed within the permissible dimensions, the test is conducted simulating the torque of 2.4kW motor + 1/7 decelerator by combining the core cutting motor (4.5kW) and the spur gear reduction (1/4).



Circular cutter (Removal of interfering objects)
processing speed verification test

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

① Processing speed verification test

- Processing was possible without any issues and without any chatter marks.
  ⇒ However, in the future, processing capability using the arms needs to be verified.
- According to the results obtained, the processing speed and life of the blades exceeded the results of past processing tests.
- The life of the blades can be determined from the drop in the cutter rotating motor load (drop in current).
- It was verified that the data can be reproduced under typical numerical conditions.

Processing speed (Upper level: [mm/min], Lower level: [mm²/min])

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
300	14.3 286	23.8 476	#1
425	15.2 303	28.6 571	#1
575	20.8 417	36.2 725	37.6 752
800	27.8 556	45.5 909	#2

Life of the blades (Upper level: [mm], Lower level: [mm²])

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
300	6360 127000	7000 140000	#1
425	5830 116000	6360 127000	#1
575	4660 93300	6360 127000	7000 140000
800	3500 70000	4660 93300	#2

Load torque [N･m]

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
300	35.4	58.9	#1
425	28.7	47.5	#1
575	24.5	47.5	56.8
800	26.1	44.4	#2

- Past processing test results
  - Processing speed: 750 [mm²/min], Life of the blades: 1,500 [mm²]
  - Processing speed: 80 [mm²/min], Life of the blades: 19,000 [mm²]

#1: Unable to be processed due to large load torque.
#2: Data unable to be acquired as alumina cracks.
(red box): Good conditions with maximum processing speed and maximum life of blades

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

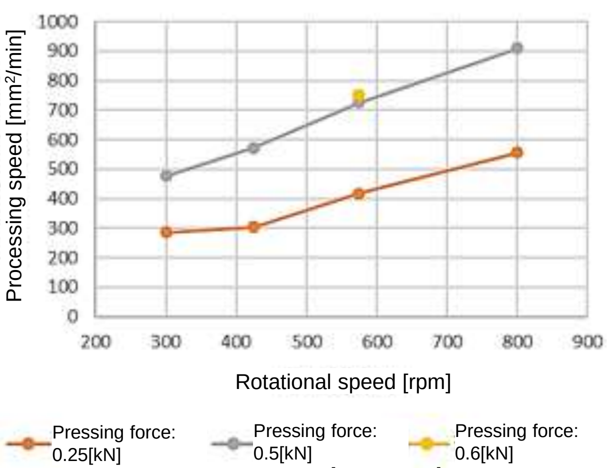
① Processing speed verification test

- Higher the pressing force and rotational speed, faster was the processing speed.
- Higher the pressing force, longer was the life of the blades.

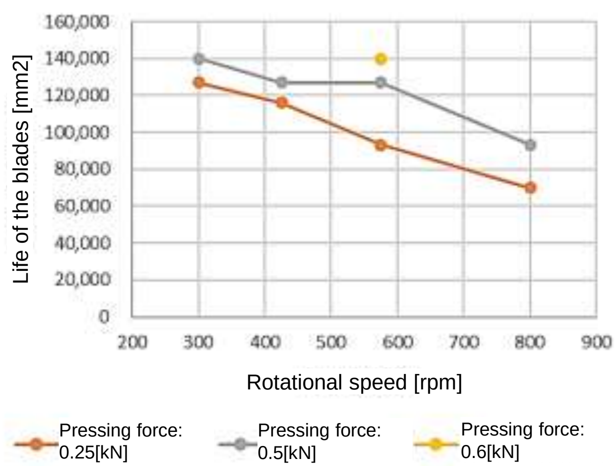
⇒ If the pressing force is low, it is presumed that processing does not progress at all and the blade only gets worn out.

- Higher the rotational speed, shorter was the life of the blades.
- Higher the pressing force, larger was the load torque.
- In spite of the variations, even if the rotational speed changed, the load torque remained almost constant.

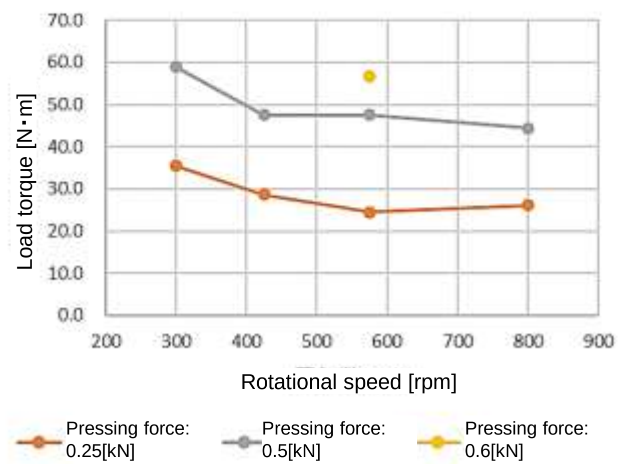
⇒ The processing load must have been determined by the pressing force, and must not have had any correlation with the rotational speed. It is believed that the load torque is determined by the contact resistance (this is determined by the pressing force) between the blade and the work piece, and the rotational speed is irrelevant.



Processing speed



Life of the blades



Load torque

(6) Tip tools element tests

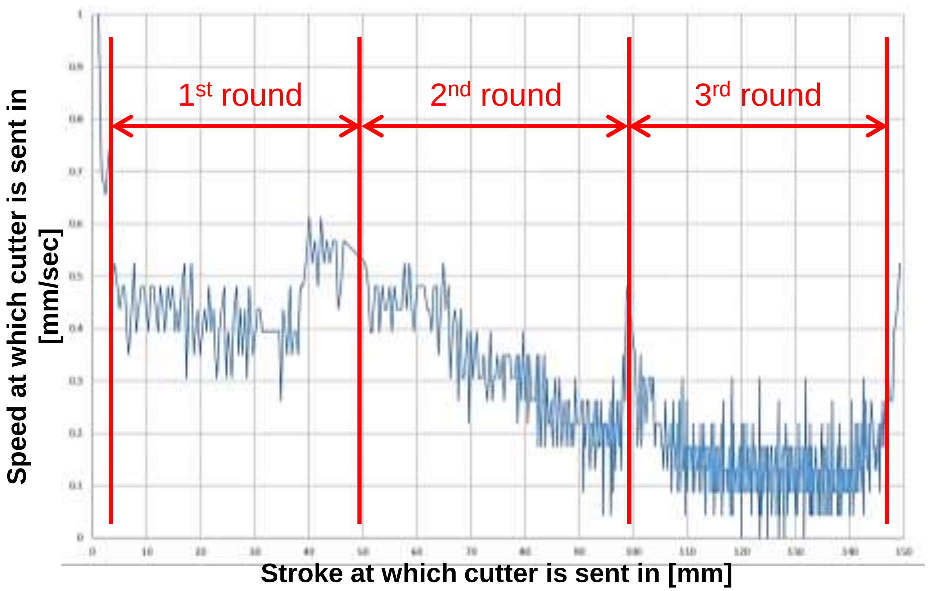
[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

① Processing speed verification test

- When processing was repeated, the processing speed dropped gradually.
  ⇒ It was verified that the processing speed is restored by means of dressing[#1].
  Dressing requires a few seconds.
  In the actual equipment, the grindstone for dressing needs to be mounted on the tip tool.

#1: The action of revealing fresh abrasive grains by scraping off just the layer of bonding material from the surface of the grindstone with a soft grindstone when there is clogging on the grindstone.



Decline in processing speed due to an increase in the number of processing rounds.

Dressing being conducted

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

① Processing speed verification test

- SUS + Alumina was replaced with SS + Alumina, and the processing capability of SUS and SS was compared (implemented under some of the conditions).

- Processing was possible without any issues and without any chatter marks.
- The processing speed was slightly faster in the case of SS, but the life of the blades was shorter and the load torque was larger.

⇒ Generally SS has better processing capability than SUS.

In the case of core boring mentioned later, the processing speed is faster, the life of the blades is longer and the load torque is smaller, in the case of SS.

In the case of processing using abrasive grains, since the grains, the specifications of the bond that hardens the abrasive grains, the material of the workpiece, processing conditions, etc. are deeply intertwined, according to the blade manufacturer, the processing speed and life of the blades will not necessarily show the same tendency.

Processing speed [mm²/min] (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	—	725 730	752 #1
800	556 645	909 926	#2

Life of the blades [mm²] (Upper level SUS, Lower level：SS)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	—	127000 63600	140,000 #1
800	70000 66600	93300 60800	#2

Load torque [N·m] (Upper level SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	—	47.5 58.2	56.8 #1
800	26.1 28.0	44.4 52.0	#2

#1: Unable to be processed due to large load torque. #2: Data unable to be acquired as alumina cracks.

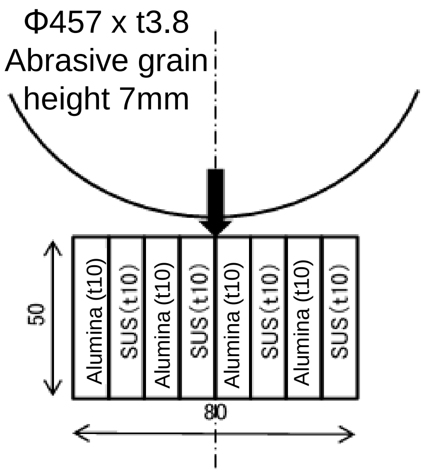
(6) Tip tools element tests

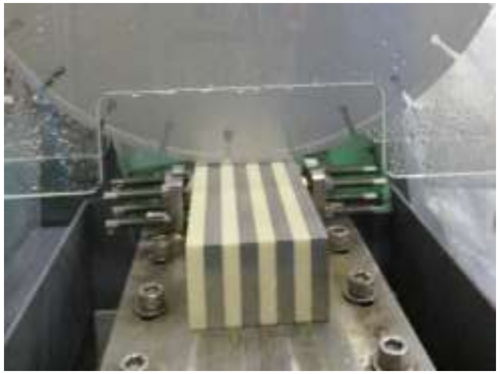
[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

② Test on processing a larger workpiece

- The processing capability was verified by selecting good conditions based on the test results in ①, and increasing the blade contact area by processing a wider (20 ⇒ 80) workpiece.





Test on processing a larger workpiece with a circular cutter
(Removal of interfering objects)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

② Test on processing a larger workpiece

- The processing capability was verified by selecting good conditions based on the test results in ①, and increasing the blade contact area by processing a wider (20 ⇒ 80) workpiece.

- Processing was possible without any issues and without any chatter marks.
- However, a thickness of 50 mm was unable to be processed.
  ⇒ Dressing is required halfway through.
- The processing speed and life of the blades were not much different than the 20 mm workpiece.
- The load torque increased due to the increase in blade contact area.

Processing speed [mm²/min] (Upper level: width 20, Lower level: width 80)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	417 371	725 #1	752 #1
800	556 714	909 845	#2

Life of the blades [mm²] (Upper level: width 20, Lower level: width 80)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	93300 87700	127000 #1	140,000 #1
800	70000 78000	93300 100000	#2

Load torque [N·m] (Upper level: width 20, Lower level: width 80)

Rotational speed [rpm]	Pressing force [kN]		
	0.25	0.5	0.6
575	24.5 41.1	47.5 #1	56.8 #1
800	26.1 38.5	44.4 57.0	#2

#1: Unable to be processed due to large load torque. #2: Data unable to be acquired as alumina cracks.

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

③ Stand-alone SUS processing test

- The processing capability of stand-alone SUS was verified by processing the workpiece shown in the following figure under processing conditions described in ②.

Stand-alone SUS processing test with circular cutter
(Removal of interfering objects)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (Removal of interfering objects)

③ Stand-alone SUS processing test

- The processing capability of stand-alone SUS was verified by processing a SUS workpiece of width 20 x height 50 under processing conditions described in ②.

- Processing was possible without any issues and without any chatter marks.
- A tendency to be easier to process as compared to SUS + Alumina was not seen.
- Stand-alone SUS showed almost the same tendencies as SUS + Alumina.

Processing speed [mm²/min]
(Upper level: SUS + Alumina, Lower level: SUS)

Rotational speed [rpm]	Pressing force [kN] 0.25	0.5	0.6
575	417 286	725 #1	752 #1
800	556 614	909 1920	#2

Life of the blades [mm²]
(Upper level: SUS + Alumina, Lower level: SUS)

Rotational speed [rpm]	Pressing force [kN] 0.25	0.5	0.6
575	93300 53800	127000 #1	140,000 #1
800	70000 60800	93300 82300	#2

Load torque [N·m]
(Upper level: SUS + Alumina, Lower level: SUS)

Rotational speed [rpm]	Pressing force [kN] 0.25	0.5	0.6
575	24.5 45.4	47.5 #1	56.8 #1
800	26.1 36.1	44.4 53.7	#2

#1: Unable to be processed due to large load torque.
#2: Data unable to be acquired as alumina cracks.

(Red box) The throughput is evaluated using this data that is likely to anticipate an improvement in throughput.

- Based on the test results ① to ③, SUS + Alumina, SS + Alumina, and stand-alone SUS can all be processed, the processing speed and life of the blades is the best in all three cases. The test results of SUS + Alumina when the pressing force is 0.5kN and the rotational speed is 800 rpm is used for throughput evaluation.

⇒ An average thickness of 10mm is assumed, processing speed is considered to be 91mm/min and the life of the blade is considered to be 9,330mm.

(6) Tip tools element tests

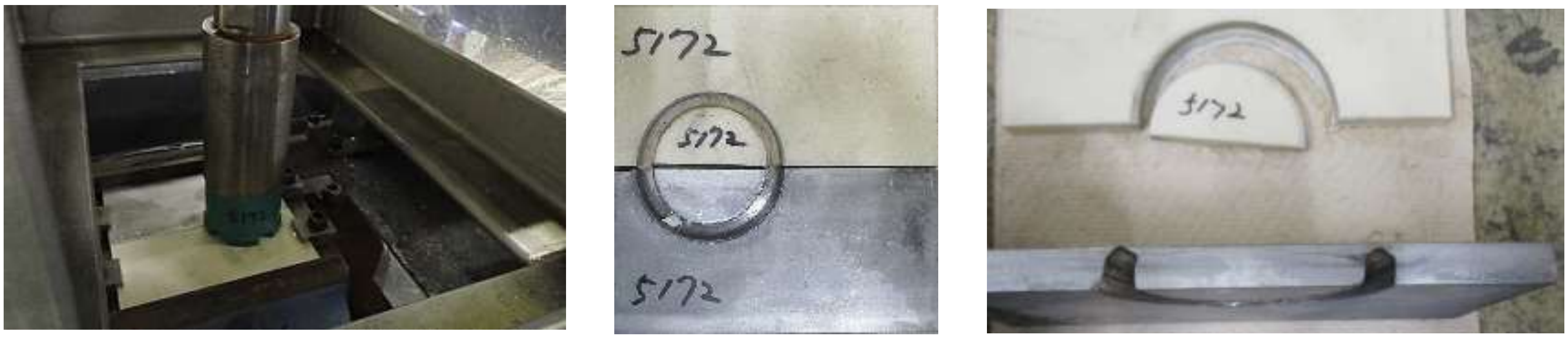
[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test

- The butt-welded portion of 10mm thick SUS and Alumina was processed, and the processing speed, life of the blades (calculated based on the abrasion loss) and load torque (calculated based on the motor current) were calculated.

Φ65



Φ130

Core boring　Processing speed verification test

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test

- The butt-welded portion of 10mm thick SUS and Alumina was processed, and the processing speed, life of the blades (calculated based on the abrasion loss) and load torque (calculated based on the motor current) were calculated.
- In order to understand the trend, the pressing force and rotational speed over a broad set of 3 - 4 points were considered and verified.

- Processing was possible in spite of the chatter marks (The higher the rotational speed, larger were the chatter marks once again in the case of Φ130).
- In particular, chatter marks were large until the blade latched on during the initial stage of processing.
  ⇒ It is believed that increasing the contact pressure by using a blade with a tapered edge would be effective.
- The resulting processing speed was lower than the past processing test results (2.86mm/minin the case of Φ66）.
  ⇒ This is believed to be due to the difference in blades (as blades identical to those used in the previous tests were unable to be obtained, the test was conducted using different blades) or due to the difference in equipment.
- The life of the blades can be determined from the drop in the cutter rotating motor load (drop in current).
- It was verified that the data can be reproduced under typical numerical conditions.

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test (Φ65)

- The test was conducted using blades with 3 types of hardness.
- The blades with “medium” and “high” hardness were intended for long life and hence the test was conducted using high pressing force.
- The processing test was conducted with blades that were 7mm high.
- The life of the blades was evaluated using blades that were 18mm high[#1]. The issues in processing with blades that were 18mm high are verified in “② Swarf dischargeability verification test”.

#1: Evaluated value from the results of tests conducted using the core bit of the 7mm high blades (the processable depth of every 1mm of the blade calculated from the abrasive loss of the blade and the processing depth, times 18.)

Processing speed [mm/min] (Blade hardness: Low)

Rotational speed [rpm]	Pressing force [kN] 3	6	10	15
63	0.27	0.53	0.60	Unable to be processed as the blade was absent.
94	0.24	0.54	0.90	
125	Was not conducted due to the number of tests.			
188	0.19	0.79	1.19	
250	Was not conducted due to the number of tests.			
300	0.31	1.14	#1	

Processing speed [mm/min] (Blade hardness: Medium, High)

Rotational speed [rpm]	Pressing force [kN] 3	6	10	15
63	Unable to be processed as the pressing force was too low.		0.44	
94		0.17	0.63	0.99
125				1.20
188		0.87	1.44	#2
250			1.53 / 1.09	#2
300		1.28	#2	#2

Life of the blades [mm] (Blade hardness: Low)

Rotational speed [rpm]	Pressing force [kN] 3	6	10	15
63	23.2	12.1	7.38	Unable to be processed as the blade was absent.
94	30.1	14.2	9.18	
125	Was not conducted due to the number of tests.			
188	65.9	33.7	16.6	
250	Was not conducted due to the number of tests.			
300	120	45.0	#2	

Life of the blades [mm] (Blade hardness: Medium, High)

Rotational speed [rpm]	Pressing force [kN] 3	6	10	15
63	Unable to be processed as the pressing force was too low.		113	
94		396	80.6	77.8
125				66.4
188		101	55.3	#2
250			50.2 / 99.0	#2
300		84.8	#2	#2

#2: Unable to be processed due to large load torque.

(Red box) The throughput was evaluated using this data that is likely to anticipate an improvement in throughput.
・ Conditions under which the processing speed is the fastest using blades having a life of 50mm or more, considering that a processing depth of 50mm or more is required for cutting the core.
・ Conditions under which the processing speed is the fastest using blades having a life of about 100mm when the processing depth is configured to 100mm which is double.

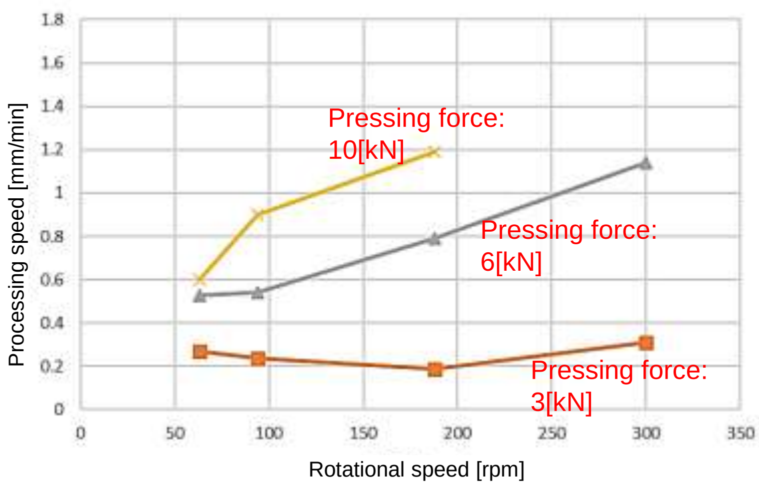
(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

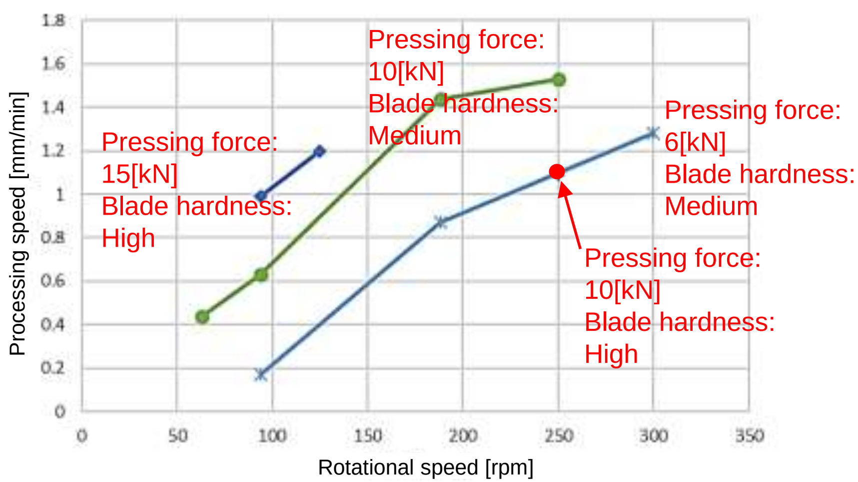
Core boring

① Processing speed verification test (Φ65)

- Higher the pressing force, faster was the processing speed. However, the life of the blades was shorter (Refer to the next page).
- Lower the hardness of the blades, faster was the processing speed. However, the life of the blades was shorter (Refer to the next page).
- Higher the rotational speed, faster was the processing speed.
- Higher the rotational speed, longer was the life of the blades when the blade hardness was “low”, and shorter was the life of the blades when the blade hardness was “medium” and “high” (Refer to the next page).



Processing speed [mm/min]
(Blade hardness: Low)



Processing speed [mm/min]
(Blade hardness: Medium, High)

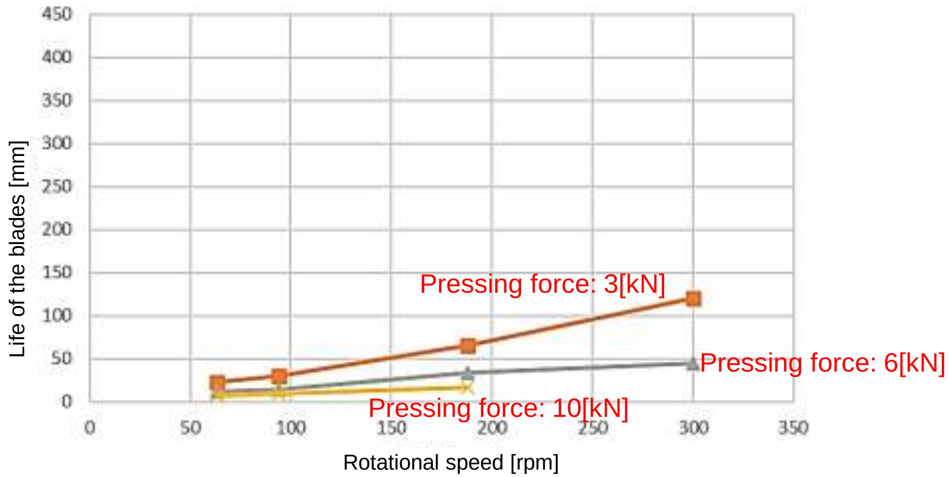
(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

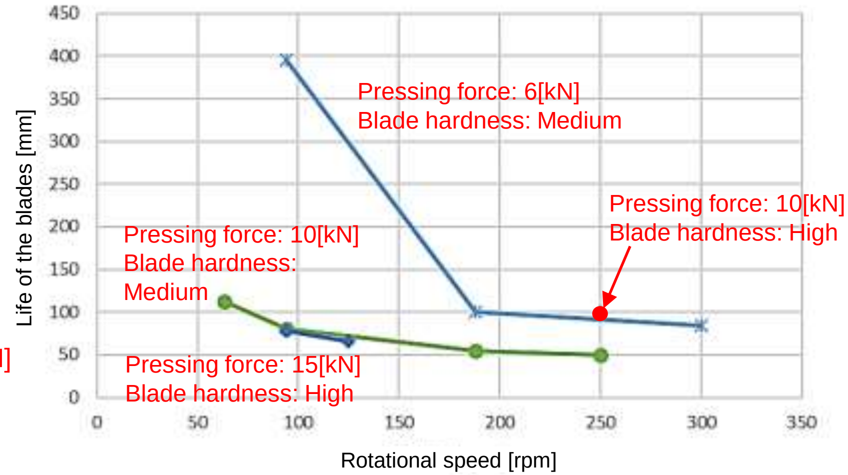
Core boring

① Processing speed verification test (Φ65)

- Higher the pressing force, faster was the processing speed (Refer to the previous page). However, the life of the blades was shorter.
- Lower the hardness of the blades, faster was the processing speed (Refer to the previous page). However, the life of the blades was shorter.
- Higher the rotational speed, faster was the processing speed (Refer to the previous page).
- Higher the rotational speed, longer was the life of the blades when the blade hardness was “low”, and shorter was the life of the blades when the blade hardness was “medium” and “high”.



Life of the blades [mm]
(Blade hardness: Low)



Life of the blades [mm]
(Blade hardness: Medium, High)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test (Φ65)

- Higher the pressing force, larger was the load torque.
- Even if the rotational speed changed, the load torque remained almost constant.

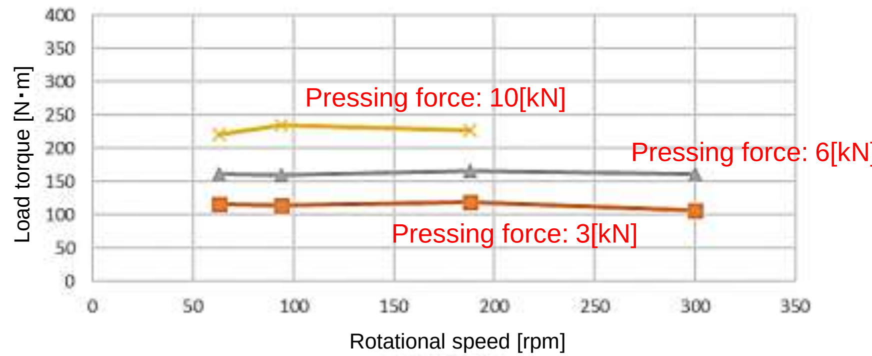
Load torque [N·m]
(Blade hardness: Low)

Rotational speed [rpm]	Pressing force [kN]			
	3	6	10	15
63	139	162	220	Unable to be processed as the blade was absent.
94	114	160	234	
125	Was not conducted due to the number of tests.			
188				
250	Was not conducted due to the number of tests.			
300				

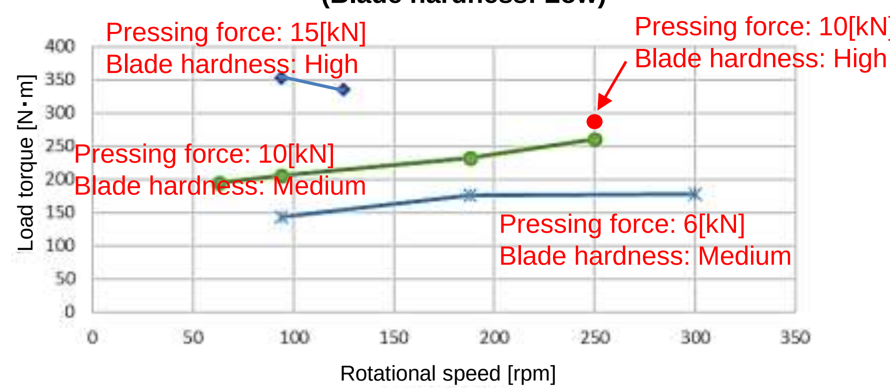
Load torque [N·m]
(Blade hardness: Medium, High)

Rotational speed [rpm]	Pressing force [kN]			
	3	6	10	15
63	Unable to be processed as the pressing force was too low.		195	
94		144	206	353
125				335
188		176	232	#1
250			261 286	#1
300		178	#1	#1

#1: Unable to be processed due to large load torque.



Load torque [N·m]
(Blade hardness: Low)



Load torque [N·m]
(Blade hardness: Medium, High)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test (Φ30)

- Test was conducted with blade hardness of "Φ65 (low)".
- The processing test was conducted with blades that were 7mm high.
- The life of the blades was evaluated using blades that were 18mm high[#1].

#1: Evaluated value from the results of tests conducted using the core bit of the 7mm high blades (the processable depth of every 1mm of the blade calculated from the abrasive loss of the blade and the processing depth, times 18)

Processing speed [mm/min]

Rotational speed [rpm]	Pressing force [kN]		
	3	6	10
31	0.07	0.33	0.47
94	0.23	0.42	1.00
150	0.13	0.39	#2
188	0.13	0.50	#2
250	#3	0.79	#2

Life of the blades [mm]

Rotational speed [rpm]	Pressing force [kN]		
	3	6	10
31	59.4	17.5	13.9
94	59.9	36.0	25.7
150	66.8	67.5	#2
188	46.8	90.0	#2
250	#3	71.1	#2

Load torque [N·m]

Rotational speed [rpm]	Pressing force [kN]		
	3	6	10
31	199	403	467
94	242	336	559
150	172	285	#2
188	177	280	#2
250	#3	299	#2

#2: Unable to be processed due to large load torque. #3: Unable to be processed due to large chatter marks.

The throughput was evaluated using this data that is likely to anticipate an improvement in throughput.
・ Conditions under which the processing speed is the fastest using blades having a life of 50mm or more, considering that a processing depth of 50mm or more is required for cutting the core.
・ Conditions under which the processing speed is the fastest using blades having a life of about 100mm when the processing depth is configured to 100mm which is double.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

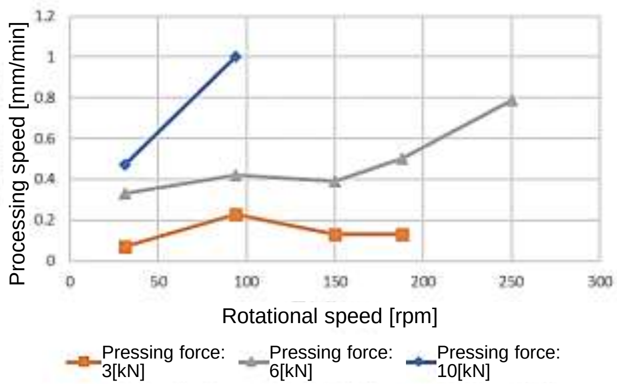
Core boring

① Processing speed verification test (Φ130)

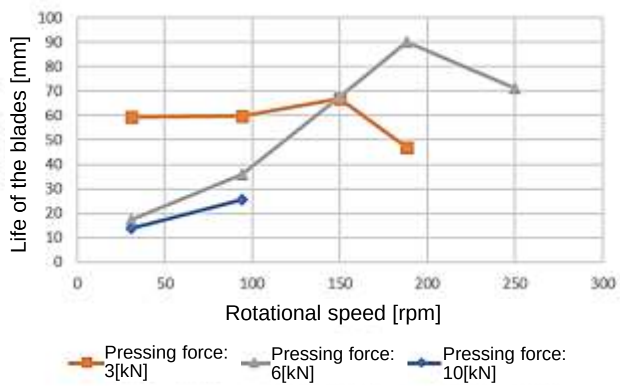
- Higher the pressing force and rotational speed, faster was the processing speed.
- Lower the pressing force, longer was the life of the blades.
- Higher the rotational speed, longer was the life of the blades, but it peaked.

⇒ Higher the rotational speed, faster was the processing speed. Hence it is important to assess the rotational speed at which the life of the blades is longer.

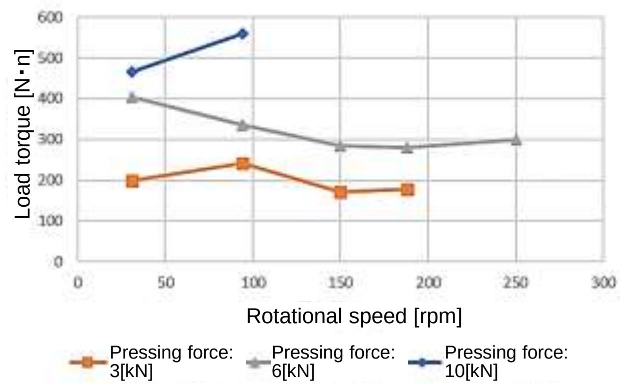
- Higher the pressing force, larger was the load torque.
- There was no correlation between rotational speed and load torque.



Processing speed



Life of the blades



Load torque

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test (Material change, Φ65, Φ130)

- SUS + Alumina was replaced with SS + Alumina, and the processing capability of SUS and SS was compared (implemented under some of the conditions).

- Processing was possible in spite of the chatter marks (The higher the rotational speed, larger were the chatter marks once again in the case of Φ130).
  ⇒ Tendency identical to SUS.
- In the case of SS, the processing speed was faster, the life of the blades was longer and the load torque was smaller.
  ⇒ SS has better processing capability than SUS.

Processing speed [mm/min]： Φ65 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	1.20 2.22
250	1.53 2.91	—

Life of the blades [mm]： Φ65 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	66.4 78.3
250	50.2 56.3	—

Load torque [N･m]： Φ65 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	335 309
250	261 219	—

Processing speed [mm/min]： Φ130 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]
	6
250	0.79 0.88

Life of the blades [mm]： Φ130 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]
	6
250	71.1 138

Load torque [N･m]： Φ130 (Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]
	6
250	299 270

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

① Processing speed verification test (Material change, Φ65, Φ130)

- SUS + Alumina was replaced with granite, and the processability of material that is brittle and less hard was verified (implemented under some of the conditions).
- Processing was possible without any issues and without any chatter marks.
- During the processing conducted this time with 10mm thickness, the blades did not get worn out and hence the life of the blades was unable to be obtained.

Processing speed [mm/min] : Φ65 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	1.20 17.9
250	1.53 25.0	—

Life of the blades [mm] : Φ65 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	66.4 Unable to be obtained
250	50.2 Unable to be obtained	—

Load torque [N･m] : Φ65 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]	
	10	15
125	—	335 260
250	261 184	—

Processing speed [mm/min] : Φ130 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]
	6
250	0.79 10.4

Life of the blades [mm] : Φ130 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]
	6
250	71.1 Unable to be obtained

Load torque [N･m] : Φ130 (Upper level: SUS + Alumina, Lower level: Granite)

Rotational speed [rpm]	Pressing force [kN]
	6
250	299 137

[Red box] The throughput was evaluated using this data that is likely to anticipate an improvement in throughput.
・ It was evaluated that the blades do not get worn out.
・ Of the 2 conditions, Φ65 was evaluated under conditions with faster rotational speed.

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

② Swarf dischargeability verification test (Pressing force 10kN, rotational speed 250rpm)

- The butt-welded portion of 50mm thick SUS and Alumina was processed to verify processability of thick plates.
  (If the processing goes deeper, dischargeability of swarf worsens and is likely to have an impact on processing)
- This test was conducted with blades that were 18mm high, and the strength of the 18mm high blades was verified as well.
- This test was conducted with Φ65 and blades with "medium" hardness.
  (In the case of Φ130, as there are several blades, and since the pressing force for each blade and the force resulting from cutter rotation are both small, the test did not need to be conducted.)

- With a pressing force of 10kN and rotational speed of 250rpm, the chatter marks were large and edge of the blades fell off from the base.

⇒ It is believed that the chatter marks became larger due to the large vibrations caused by rattling of the attaching portion and because the edge of the blades became longer.

In the future, chatter marks need to be reduced by changing the method of installing the blades and by reducing the length of the blades (The blades used this time were about 200mm long as they were intended for scraping out, but a length of 100mm should suffice).

Core boring swarf dischargeability verification test (10kN, 250rpm)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

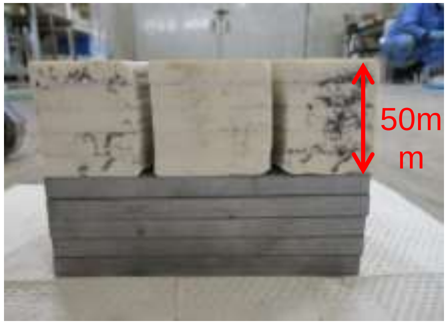
Core boring

② Swarf dischargeability verification test (Pressing force 10kN, rotational speed 125rpm)

- The butt-welded portion of 50mm thick SUS and Alumina was processed to verify processability of thick plates.
  (If the processing goes deeper, dischargeability of swarf worsens and is likely to have an impact on processing)
- This test was conducted with blades that were 18mm high, and the strength of the 18mm high blades was verified as well.
- This test was conducted with Φ65.
  (Since in the case of Φ130, there are several blades, and the pressing force for each blade and the force resulting from cutter rotation are both small).

- In order to reduce the chatter marks, the pressing force of 10kN was kept as is and the rotational speed was changed from 250rpm to 125rpm.
  (Even if the rotational speed is changed, since the load torque does not change, there is no impact on strength verification.)
- The chatter marks reduced and processing was possible with blades that were 18mm high.
- The processing speed at the initial stage of processing and that at the final stage remained the same.
  ⇒ Even if the depth of processing increases, there is no impact on processing.





Core boring swarf dischargeability verification test (10kN, 250rpm)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

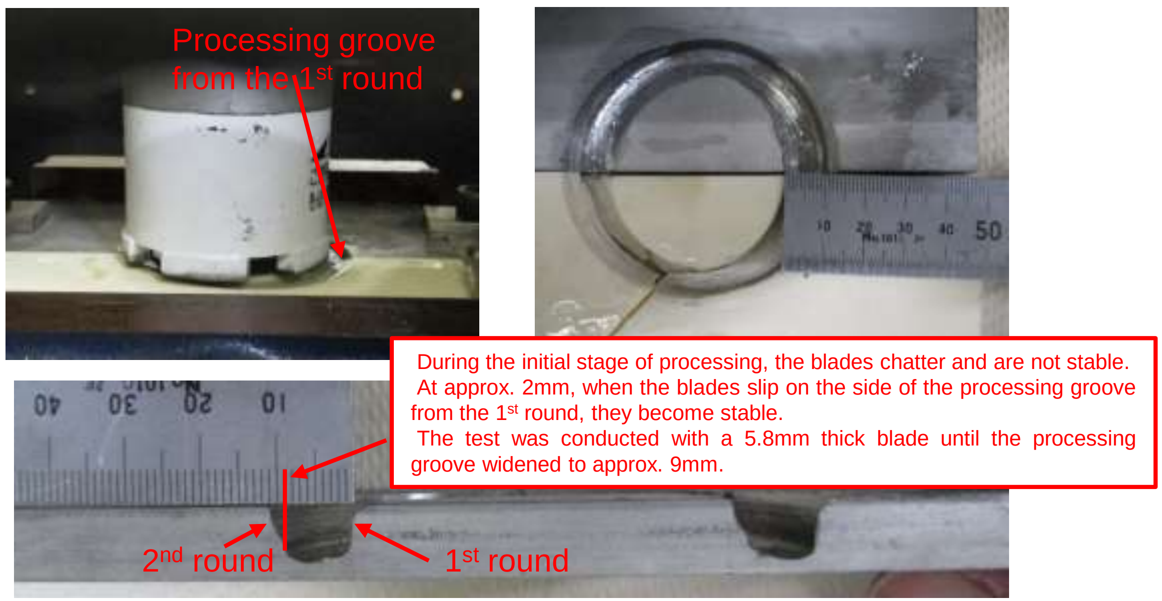
③ Test on making a hole for inserting the circular cutter for core cutting

- The processability when the butt-welded portion of 10mm thick SUS and Alumina is processed and the processing groove is covered was verified.

(If the processing groove is covered, the blade is likely to run towards the preceding processing groove).

- Although the blade runs somewhat on the side of the processing groove from the 1st round, processing is possible.

⇒ It is believed that processability will improve further upon implementing measures to reduce chatter marks (changing the method of installing the blades, and shortening the length of the blades).



Test on making a hole for inserting the circular cutter for core cutting (10kN, 250rpm)

(6) Tip tools element tests

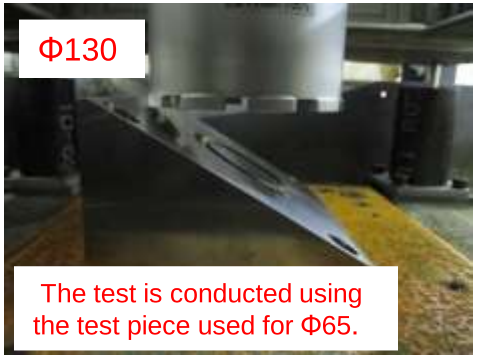
[Processing test using the tip tools and evaluation of processing test results]

Core boring

④ 30°inclined part processing test

- The processability when the part to be processed is inclined 30° was verified.
  (The blades are likely to slide along the inclined part thereby having an impact on processing)
- The test was conducted using an SUS workpiece (Since a thick plate is required for the 30°inclined Alumina workpiece, which is difficult to obtain)

- Processing was possible if the chattering was controlled by reducing rotations (94rpm).
  ⇒ It is believed that increasing the rotational speed when the blades have entered to a certain extent is effective in terms of processing speed.
- While starting the processing, since the blade contact area was small and the contact pressure was high, the pressing force needed to be gradually increased.
  - Φ65: Pressing force 2.5kN ⇒ 10kN
  - Φ130: Pressing force 2.5kN ⇒ 4.5kN
- In the case of Φ130, the blades got used up, and processing was unable to be carried out up to the area where the entire blade makes contact, but it is believed that if the blades are able to reach up to this area, they do not slide along the inclined surface.



Core boring 30°inclined part processing test

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

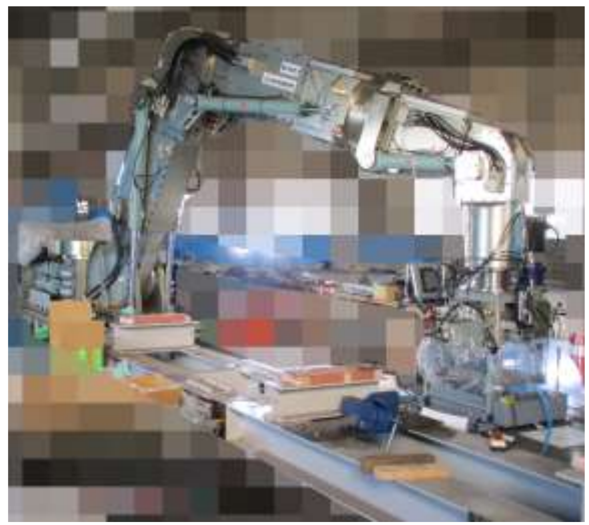
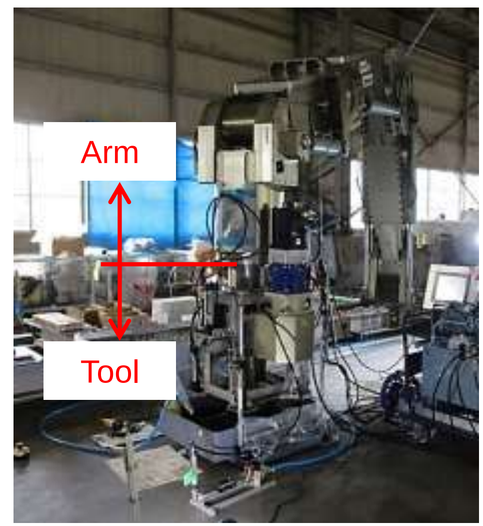
Core boring

⑤ Arm combination test (Core boring equipment installed on the robot arm)

- The processability when the arm is used was verified by selecting good conditions based on the test results in ①.
- The following tests were conducted from among the stand-alone tool tests.
  - ➢ Processing speed verification test
  - ➢ Test on making a hole for inserting the circular cutter for core cutting (Was supposed to be conducted, but has been canceled. The reasons are described later.)
  - ➢ 30° inclined part processing test (Was supposed to be conducted, but has been canceled. The reasons are described later.)

Arm combination test conditions and overview of test results

Blade size	Pressing force [kN]	Rotational speed [rpm]	Test results
Φ65	10	250	Can be processed
Φ65	15	125	Cannot be processed ⇩ Can be processed if the workpiece is changed from SUS + Alumina to SUS.
Φ130	6	250	Cannot be processed ⇩ Can be processed if the rotational speed is changed to 125rpm

Arm combination test

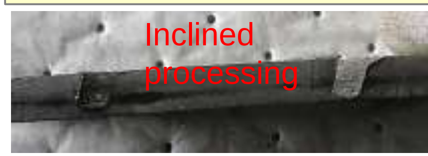
(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

⑤ Arm combination test (Φ65, pressing force 10kN, rotational speed 250rpm)

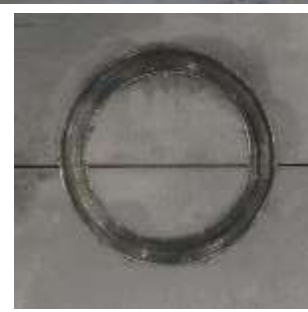
- Processing of SUS + Alumina was possible.
- However, the blades entered in an inclined manner and the processing groove became inclined as well.
  ⇒ The reason for this is that due to the difference in cutting resistance of SUS and Alumina, the rotating joint of the arm rotated slightly.
  A swing motor was used for the rotating joint, and since the swing motor had an internal leak, it slightly rotated due to external forces.
  It would be effective to add brakes in the future.
- The processing speed, life of the blades were almost identical to when the stand-alone tool was used.
  Improvement is likely if the rotating shaft of the arm is fixed.
- The reason why the processing groove became inclined is believed to be the difference in cutting resistance of SUS and Alumina. Hence if stand-alone SUS is processed, vertical processi
  is possible.



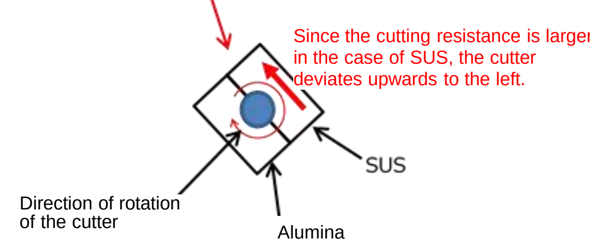
Processing groove of SUS + Alumina

Comparison between stand-alone tool + combination with arm

	Processing speed [mm/min]	Life of the blades [mm]
Stand-alone tool	1.53	50.2
Combination with arm	1.46	42.3



Processing groove of stand-alone SUS



Reasons for inclined processing

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

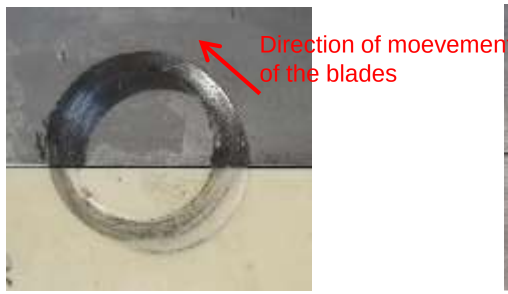
Core boring

⑤ Arm combination test (Φ65, pressing force 15kN, rotational speed 125rpm)

- Processing of SUS + Alumina was not possible. The equipment slowly shook due to which the blades were unable to enter.

⇒ Looking at the processing marks, it appears that the blades have moved in the same direction as when the processing groove became inclined (Refer to the previous page). It is believed that the reason would be the same. Processing may be possible if the rotating shaft of the arm is fixed.

- In this case as well, processing is possible if stand-alone SUS is processed.



Processing groove of SUS + Alumina

Processing groove of stand-alone SUS

- If the cutting resistance does not act uniformly around the entire circumference of the blade, the rotating joint of the arm moves slightly. In the case of the “Test on making a hole for inserting the circular cutter for core cutting” and the “30°inclined part processing test”, since the cutting resistance does not act uniformly and the arm moves which is dangerous, it was decided to postpone these tests.

⇒ Since results equivalent to when the stand-alone tool is used are obtained in terms of processing speed and life of the blades, and since it is believed based on the status of vibrations at the time of processing that the rigidity is equivalent to when the stand-alone tool is used, it is believed that processing is possible if the rotating shaft of the arm is fixed.

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Core boring

⑤ Arm combination test (Φ130, pressing force 6kN, rotational speed 250rpm ⇒ 125rpm)

- With a rotational speed of 250rpm, the chatter marks were large and the blades were unable to enter.
  ⇒ Processing may become possible upon implementing measures to reduce chatter marks (changing the method of installing the blades, and shortening the length of the blades).
- Processing was possible if the rotational speed was changed to 125rpm.
  ⇒ The processing marks were not as conspicuous as Φ65 but the blades moved in the same direction.
- The processing speed, life of the blades were equal to or greather than the results obtained when the stand-alone tool was used.

Arm combination test (Φ130)

Comparison between stand-alone tool + combination with arm

	Processing speed [mm/min]	Life of the blades [mm]
Stand-alone tool	0.40	52.0
Combination with arm	0.41	62.1

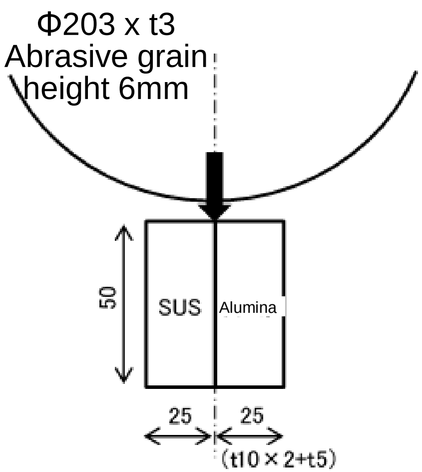
(6) Tip tools element tests

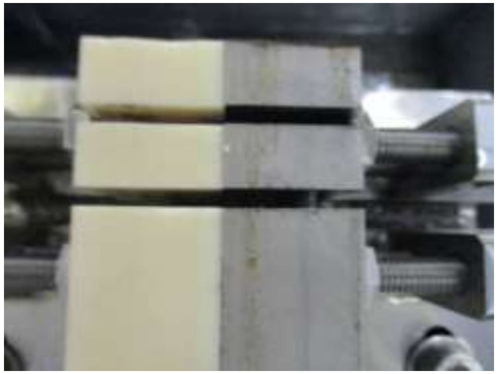
[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

① Processing speed verification test

- The workpiece shown in the drawing below was processed, and the processing speed, life of the blades (calculated based on the abrasion loss) and load torque (calculated based on the motor current) were calculated, assuming core cutting is carried out after core boring of Φ65×Φ53.4.
- In order to understand the trend, the pressing force and rotational speed over a broad set of 3 - 4 points were considered and verified.





Circular cutter (core cutting) processing speed verification test

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

① Processing speed verification test

- Processing was possible without any issues and without any chatter marks.
  ⇒ However, in the future, processability using the arms needs to be verified.
- According to the results obtained, the processing speed and life of the blades exceeded the results of past processing tests.
- The life of the blades can be determined from the drop in the cutter rotating motor load (drop in current).
- It was verified that the data can be reproduced under typical numerical conditions.

Processing speed (Upper level: [mm/min], Lower level: [mm²/min])

Rotational speed [rpm]	Pressing force [kN]		
	0.5	0.75	1
500	1.85 92.6	9.26 463	16.1 807
750	3.18 159	11.6 581	19.2 962
1000	3.91 195	10.0 500	#1
1200	4.20 210	9.62 481	#1

Life of the blades (Upper level: [mm], Lower level: [mm²])

Rotational speed [rpm]	Pressing force [kN]		
	0.5	0.75	1
500	2850 142000	2140 107000	1270 63800
750	3520 176000	2720 136000	1990 100000
1000	3750 187000	2500 124000	#1
1200	2720 136000	2850 142000	#1

Load torque [N·m]

Rotational speed [rpm]	Pressing force [kN]		
	0.5	0.75	1
500	36.6	50.4	58.4
750	32.3	44.0	51.3
1000	23.6	31.4	#1
1200	21.6	27.8	#1

- Past processing test results
  - Processing speed: 750[mm²/min], Life of the blades: 1,500 [mm²]
  - Processing speed: 80[mm²/min], Life of the blades: 19,000 [mm²]

#1: Unable to be processed due to large load torque.

(red box): Good conditions with maximum processing speed and a good balance of processing speed and life of blades

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

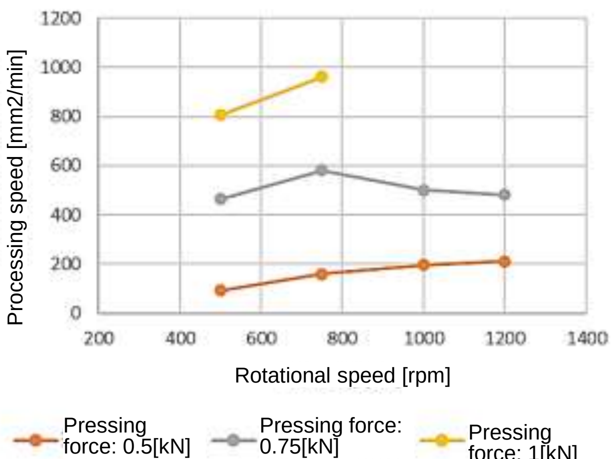
Circular cutter (core cutting)

① Processing speed verification test

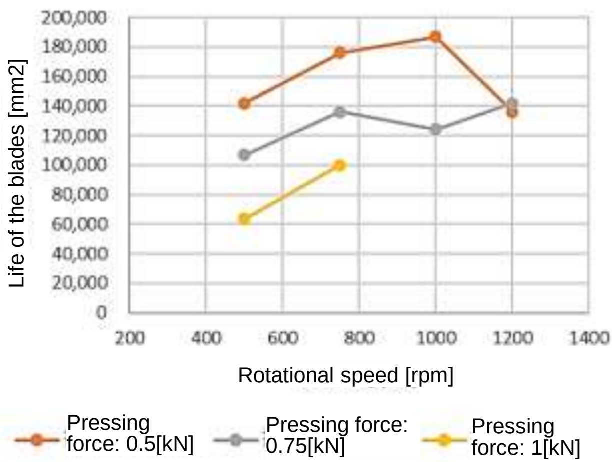
- Higher the pressing force and rotational speed, faster was the processing speed.
- Lower the pressing force, longer was the life of the blades.
- Higher the rotational speed, longer was the life of the blades.
- Higher the pressing force, larger was the load torque.
- Higher the rotational speed, smaller was the load torque.

⇒ The processing load must have been determined by the pressing force, and must not have had any correlation with the rotational speed. Even if the rotational speed increased, the processing speed did not increase as much.

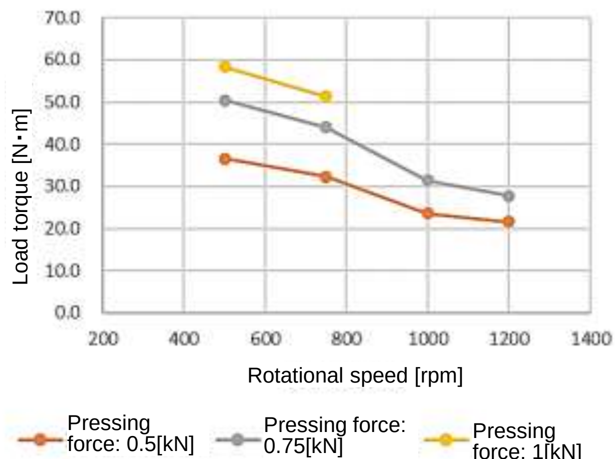
When the rotational speed is high, it is believed that the engagement between the abrasive grains and the workpiece becomes superficial, the processing speed does not increase as much, and the load torque reduces.



Processing speed



Life of the blades



Load torque

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

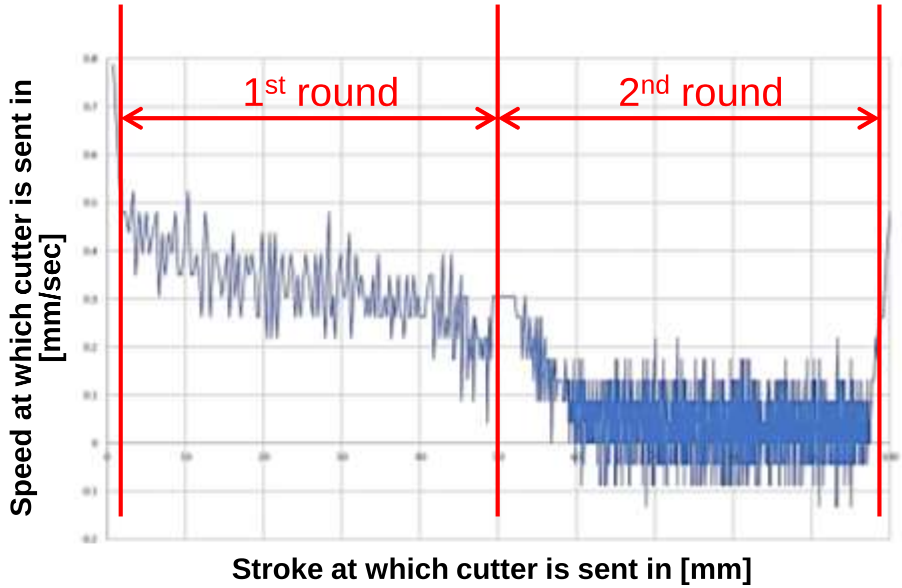
Circular cutter (core cutting)

① Processing speed verification test

- When processing was repeated, the processing speed dropped gradually.

⇒ It was verified that the processing speed is restored by means of dressing[#1].
Dressing requires a few seconds.
In the actual equipment, the grindstone for dressing needs to be mounted on the tip tool.

#1: The action of revealing fresh abrasive grains by scraping off just the layer of bonding material from the surface of the grindstone with a soft grindstone when there is clogging on the grindstone.



Decline in processing speed due to an increase in the number of processing rounds.

Dressing being conducted

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

① Processing speed verification test

- SUS + Alumina was replaced with SS + Alumina, and the processability of SUS and SS was compared (implemented under some of the conditions).

- Processing was possible without any issues and without any chatter marks.
- The processing speed was faster in the case of SS, but the life of the blades was shorter and the load torque was larger.

(Same tendency as the circular cutter for removing interfering objects)
⇒ Generally SS has better processability than SUS.

In the case of core boring mentioned earlier, the processing speed was faster, the life of the blades was longer and the load torque was smaller, in the case of SS.

In the case of processing using abrasive grains, since the grains, the specifications of the bond that hardens the abrasive grains, the material of the workpiece, processing conditions, etc. are deeply intertwined, according to the blade manufacturer, the processing speed and life of the blades will not necessarily show the same tendency.

Processing speed [mm^2/min]
(Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	0.75	1
750	581 926	962 1040

Life of the blades [mm^2]
(Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	0.75	1
750	136000 60000	100000 48300

Load torque [N･m]
(Upper level: SUS, Lower level: SS)

Rotational speed [rpm]	Pressing force [kN]	
	0.75	1
750	44.0 53.7	51.3 62.3

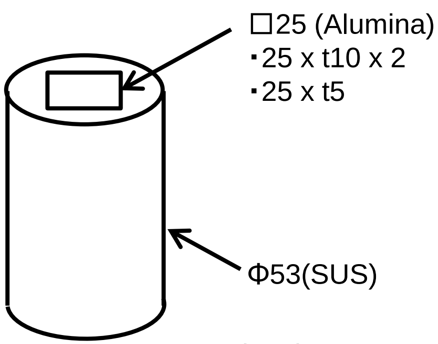
(6) Tip tools element tests

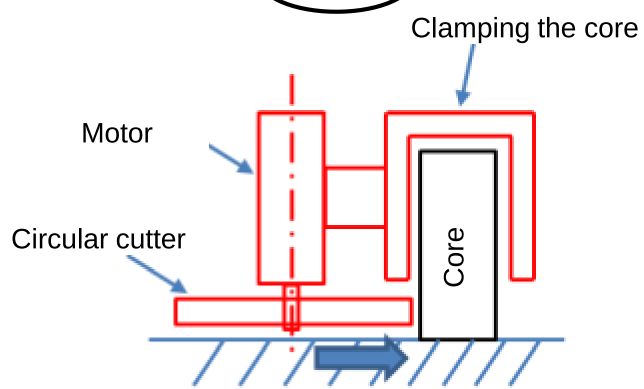
[Processing test using the tip tools and evaluation of processing test results]

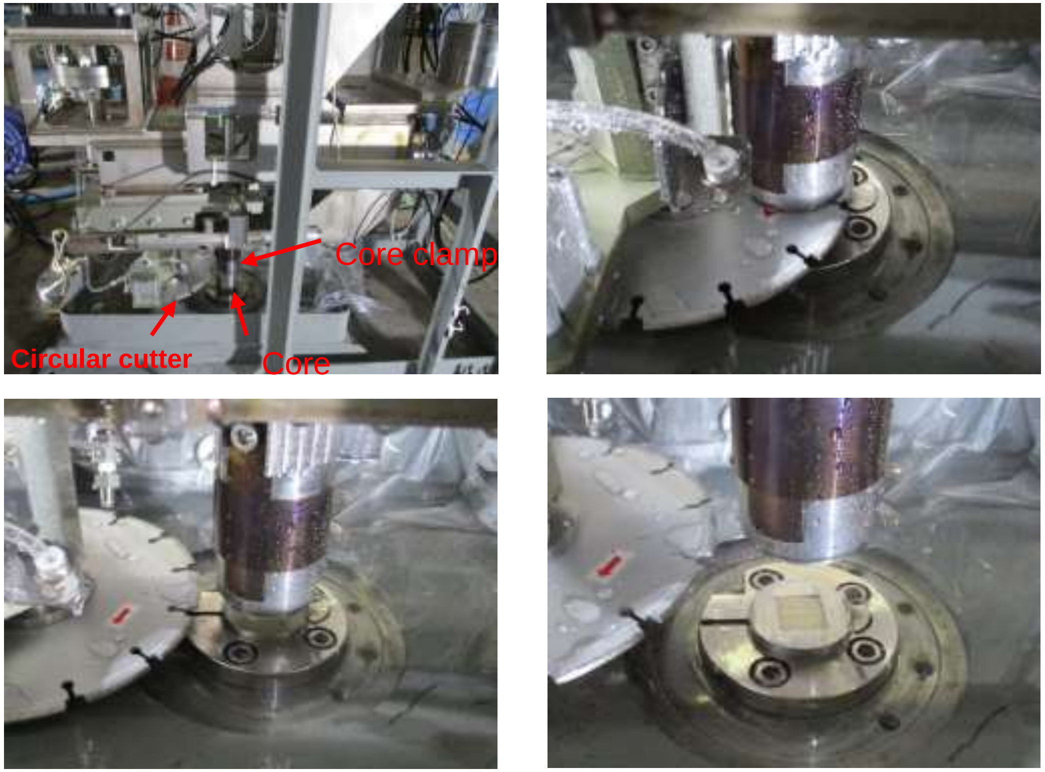
Circular cutter (core cutting)

② Test for verifying whether processing is possible using the tool

- The clamping performance and processability when the tool is used was verified by selecting good conditions (pressing force 1kN, rotational speed 750rpm) based on the test results in ①, and processing the workpiece shown in the figure below.







Test for verifying whether core cutting is possible

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

② Test for verifying whether processing is possible using the tool

- Processing was possible without any issues and without any chatter marks. ⇒ There was no issue in clamping performance.
- The processing speed and life of the blades were less than the element test without the clamp.
  ⇒ In the element test without the clamp, the ratio of SUS and Alumina was fifty-fifty, but in this test, since the ratio of SUS which is difficult to cut, was higher, the processing speed and life of the blades were lower.
- Core clamping (from completion of positioning on the core to start of cutting) required 1.5 minutes.
  ⇒ This was included in throughput evaluation.
- There were no issues in the workability of the series of tasks from core clamping to core retrieval.

Comparison of processing speed and life of blades

	Processing speed [mm^2/min]	Life of the blades [mm^2]
Element test with no clamp	962	100000
Tool with a clamp	826	52900

[red box]: **The throughput was evaluated using this data that is likely to anticipate an improvement in throughput.**

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

② Test for verifying whether processing is possible using the tool

Results of the test for verifying whether core cutting is possible (1/2)

№	Items	Test results		
1	Does the equipment go down along the reactor core?	Good	Can go down with its own weight.	 ⇨ 
2	Does the equipment follow the reactor core due to the reactor core clamp? (Does the incline get corrected?)	Good	The incline can be corrected by lifting up the floating mechanism after clamping.	 ⇨ 
3	Is core cutting possible?	Good	Cutting is possible. There was no issue in gripping force of the clamp.	

(6) Tip tools element tests

[Processing test using the tip tools and evaluation of processing test results]

Circular cutter (core cutting)

② Test for verifying whether processing is possible using the tool

Results of the test for verifying whether core cutting is possible (2/2)

№	Items	Test results		
4	Does the circular cutter get stuck after completing core cutting?	Good	Did not get stuck. There were no issues in the movement of the circular cutter back to its initial position. It was verified that after the cutter moves back, there is a gap between the cutter and the cut portion.	
5	Is retrieval of the reactor core possible?	Good	Can be retrieved. The reactor core did not fall even as the equipment was lifted up.	 ⇨ 
6	Does the reactor core fall when the core clamp is released?	Good	The reactor core falls when the core clamp is released.	

(6) Tip tools element tests

[Evaluation of processing test results]

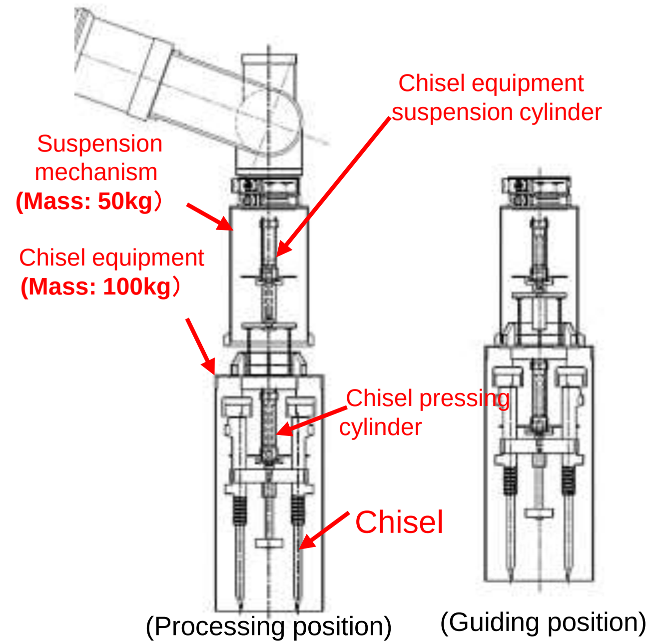
① Required specifications of remote controlled equipment (access equipment)

- The processing reaction forces (blade pressing, blade rotation) obtained from the test results were consolidated as requirements of the robot arm.

⇒ The maximum values were identified from the test conditions used for evaluating throughput.

The horizontal reaction force was calculated from the load torque and the blade size.

- The structure of the chisel was such that the chisel equipment is suspended with a chain just like it was done in past tests, and the chisel is pressed with the cylinder inside the chisel equipment. Thus, the vibrations of the chisel can be prevented from getting transmitted to the arm.
- The arm length and number of shafts were not included in the study this time since the access had to be studied while considering dodging of interfering objects.

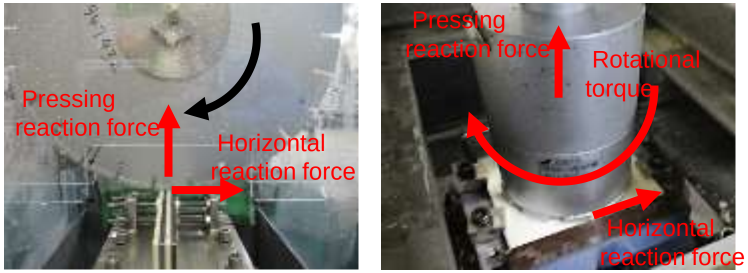


Chisel equipment guiding method

Payload and processing reaction force required of the robot arm

	Payload [kg]	Pressing reaction force [kN]	Horizontal reaction force [kN]	Rotational torque [N·m]
Circular cutter	150	0.5	0.1	— #1
Core boring	1000	15#3	4.6	299
Core cutting	150	—#1	—#1	— #1
Chisel	150	—#1	—#2	— #2

#1: Since the reaction force is received inside the tool, the reaction force does not act on the arm.
#2: Does not get generated while processing with a chisel.
#3: Outrigger pressing force 5kN is applied to the processing reaction force.



(Circular cutter) (Core boring)

Reaction force due to processing

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

(6) Tip tools element tests

[Evaluation of processing test results]

② Throughput evaluation

- The throughput evaluation carried out as part of the “1F-3 Fuel Debris Retrieval Method Conceptual Study Contract (Part 3)” outsourced to TEPCO in FY2021 was evaluated once again using the throughput evaluation data obtained this time (including the data obtained by the operating system mentioned later).
- Core boring of the block fuel debris which comprises a lot of time of the throughput was evaluated under multiple processing conditions.

⇩

- Although the time required for processing using the circular cutter did not change, the throughput was able to be reduced by reducing the frequency of blade replacement by increasing the time taken for positioning the tool and by extending the life of the blades.
- In the case of core boring, the processing speed as well as the life of the blades were lower than the previous throughput evaluation results, and the throughput increased.
- In particular, the life of the blades was configured based on an assumption the previous time and was thus significantly short. This was the main reason for the increase in throughput this time.
- The size of the blades was increased (Φ66mm⇒ Φ130mm) in order to improve throughput, but throughput improved due to a drop in processing frequency.

(6) Tip tools element tests

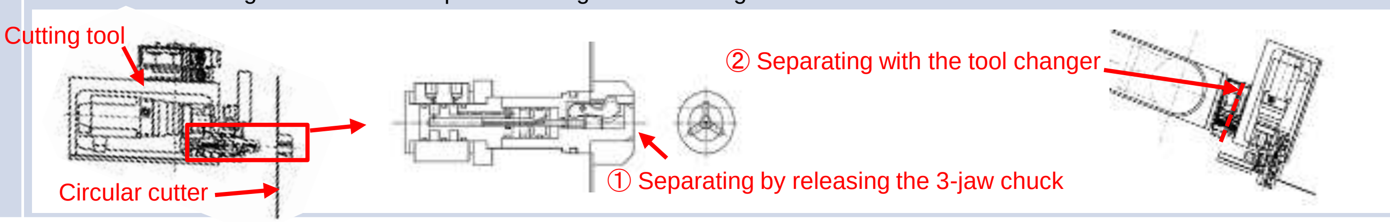
[Evaluation of processing test results]

③ Applicability to actual equipment, issues and response measures

- In the case of the circular cutter, processability using the robot arm needs to be verified. In the case of core boring, in spite of pending issues such the necessity to add a brake to the robot arm, etc., there are prospects of being able to apply it to the actual equipment.
- Measures in response to the issues that became evident as a result of the processing tests conducted this time were studied.

Issues and response measures (1/3)

№	Issues	Response measures
1	・Jamming of the circular cutter Although this didn't occur during the test conducted this time, since it is likely to occur during the actual work, measures need to be taken.	(1) The object to be cut expands due to the heat generated during processing and the cutter gets stuck. ⇒ Instead of using a rimmed disc-shaped cutter, a segmented cutter with slits all around the circumference, and which has good heat dissipation properties should be used, and cooling water should be used as well. ……Already used in the processing test conducted this time. (2) The object to be cut gets deformed right before cutting is completed, and the cutter gets stuck. ⇒ The plan is to use dual arms, such that one arm holds and the other arm cuts. Whether deformation can be controlled by means of the arms should be verified by conducting a processing test using the arms. (3) Retrieving the arms if the cutter gets jammed. ⇒ Even if the circular cutter gets jammed, the arms must be retrieved. Whether the arms can be retrieved by the following methods should be verified by conducting the test using the arms. ① Leaving only the circular cutter behind and retrieving the arms. The circular cutter should be installed using a 3-jaw chuck so that when the chuck is released only the circular cutter is left behind. ② Leaving the cutting tool behind and retrieving the arms. The cutting tool should be separated using the tool changer and left behind.



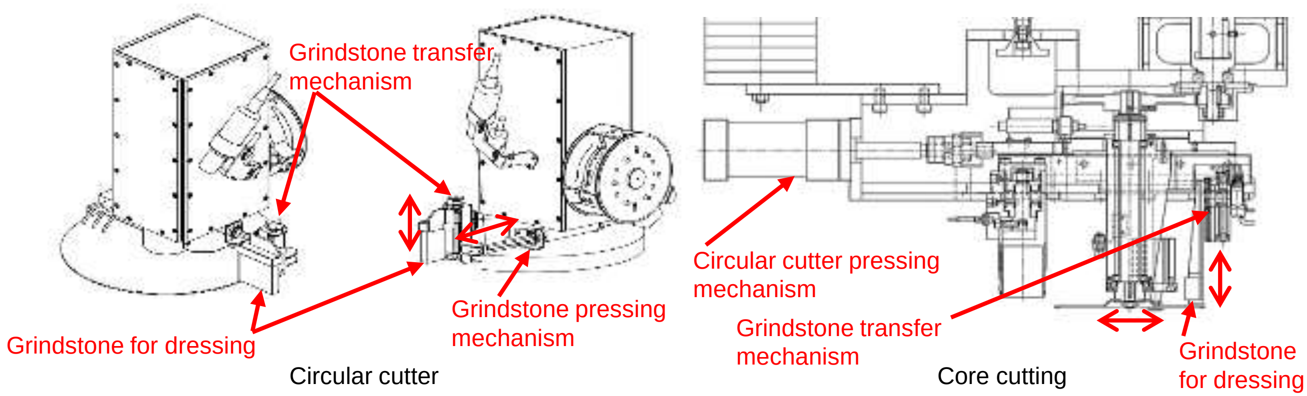
(Note) The contents listed under "Response measures" are planned to be studied during engineering, etc. in the future.

(6) Tip tools element tests

[Evaluation of processing test results]

③ Applicability to actual equipment, issues and response measures

Issues and response measures (2/3)

№	Issues	Response measures
2	・Processability of the circular cutter when the arms meant for the actual equipment are used There were prospects of being able to process with the stand-alone tool, but the processability when the arms meant for the actual equipment are used needs to be verified.	The impact of the rigidity and vibrations of the arms should be verified by conducting processing tests using the arms meant for the actual equipment.
3	・Dressing of the circular cutter The processing speed gradually drops due to clogging, etc. of the grindstone. Dressing is required halfway through the processing.	 e

(Note) The contents listed under "Response measures" are planned to be studied during engineering, etc. in the future.

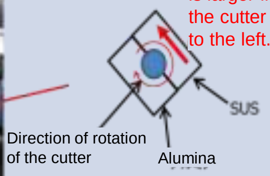
(6) Tip tools element tests

[Evaluation of processing test results]

③ Applicability to actual equipment, issues and response measures

Issues and response measures (3/3)

№	Issues	Response measures
4	・Chatter marks during the initial stage of core boring It takes time for the blades to latch on due to chatter marks.	(1) In order to increase the contact pressure during the initial stage of processing, blades should be changed to those with tapered edges. (2) The rattling of the cutter installation part should be controlled in order to control run-out of the blade edge. (3) The length of the cutter should be shortened in order to control run-out of the blade edge.
5	・Core boring blades replacement frequency The life of the blades is short and the time required for changing the blades has a major impact on the throughput.	Whether changing the specifications (size, shape and quantity of abrasive grains) of the abrasive grains would be effective should be verified. However, as the processing speed and life of the blades change depending on the composition of the target object, during actual work, measures should be taken according to the circumstances.
6	・ Rotation of the rotating joint of the arm during core boring The rotating joint of the arm slightly rotates due to the horizontal reaction force during core boring because of which the blade egde moves.	The swing motor used for the rotating joint has an internal leak due to which external forces act on the joint resulting in slight rotation. Brakes should be added in order to cotrol the rotation.



(Note) The contents listed under “Response measures” are planned to be studied during engineering, etc. in the future.

(6) Tip tools element tests

[Evaluation of processing test results]

④ Summary of test results

- In the case of the circular cutter, processability using the robot arm needs to be verified. In the case of core boring, in spite of pending issues such a the necessity to add a brake to the robot arm, etc., there are prospects of being able to apply it to the actual equipment.
- Issues were identified and response measures were studied.
- Throughput evaluation data was obtained and the throughput was re-evaluated.
- The processing reaction forces (blade pressing, blade rotation) obtained from the test results were consolidated as requirements of the robot arm.

Overview of test results (1/3)

	Test item	Overview of test results	Considerations and countermeasures
Circular cutter (Removal of interfering objects)	(1) Processing speed verification test	・ Processing was possible without any issues and without any chatter marks. ・ The processing speed, life of the blades, and load torque were obtained with blade pressing force and rotational speed as the parameters. ・ The processing speed as well as life of the blades exceeded the results of past processing tests. ・ When processing was repeated, the processing speed dropped gradually, but the processing speed was restored upon carrying out dressing for several seconds.	・ A conceptual diagram illustrating the mounting of a grindstone for dressing on to the tip tool has been created. ・ If the blade, guide and cylinder are not in a straight line, the pressing cylinder thrust is not equal to the blade pressing force due to loss caused by momentum. Hence the actual equipment needs to be designed carefully.
	(2) Test on processing a larger workpiece	・ Even if the blade contact area increased, the processing speed (mm^2/min) and the life of the blades (mm^2) did not change. ・ The load torque increased due to the increase in blade contact area.	—
	(3) Stand-alone SUS processing test	・ SUS that is difficult to cut can be processed without any issues.	—

(6) Tip tools element tests

[Evaluation of processing test results]

④ Summary of test results Overview of test results (2/3)

	Test item	Overview of test results	Considerations and countermeasures
Core boring	(1) Processing speed verification test	・ Processing was possible in spite of chatter marks. ・ The processing speed, life of the blades, and load torque were obtained with blade pressing force and rotational speed as the parameters. ・ The processing speed was lower than the results of past processing tests. However, by increasing the size of the core, equivalent or higher results were obtained.	・ It is believed that increasing the contact pressure by using a blade with a tapered edge would be effective to overcome the impact of chatter marks present during the initial stage of processing. ・ If the blade, guide and cylinder are not in a straight line, the pressing cylinder thrust is not equal to the blade pressing force due to loss caused by momentum. Hence the actual equipment needs to be designed carefully.
	(2) Swarf dischargeability verification test	・ In the 50mm depth processing test, as a result of the processing conditions, chatter marks were large and there was blade damage. ・ The processing speed at the initial stage of processing and that at the final stage remained the same (Even if the depth of processing increased, there was no impact on processing).	・ It is believed that the rattling of the blade installation part and increase in run-out of the blade tip caused by the increased length of the blade edge were the reasons for the chatter marks. ⇒ In the future, chatter marks need to be reduced by changing the method of installing the blades and by reducing the length of the blades (The blades used this time were about 200mm long as they were intended for scraping out, but a length of 100mm should suffice).
	(3) Test on making a hole for inserting the circular cutter for core cutting	・ Although the blade runs somewhat on the side of the processing groove from the 1st round when the processing groove is covered, processing is possible.	–
	(4) 30°inclined part processing test	・ Processing was possible if the chatter marks were controlled by reducing the rotational speed. ・ Processing was possible if the pressing force was kept low at the start of processing.	・ It is believed that keeping the rotational speed low at the initial stage of processing and then increasing the rotational speed when the blades have entered to a certain extent is effective in terms of processing speed. ・ While starting the processing, since the blade contact area is small and the contact pressure is high, the pressing force needs to be gradually increased.

(6) Tip tools element tests

[Evaluation of processing test results]

④ Summary of test results Overview of test results (3/3)

	Test Item	Overview of test results	Considerations and countermeasures
Core boring	(5) Arm combination test	・ Processing was possible by combining the tool with the arm. However, the blades entered in an inclined manner and the processing groove was inclined as well. ・ The processing speed, life of the blades were almost identical to when the stand-alone tool was used.	・ It is believed that the blades entered in an inclined manner as the rotating joint of the arm rotated slightly due to the difference in cutting resistance of SUS and Alumina. It would be effective to add brakes in the future. ・ The reason why the processing groove became inclined is believed to be the difference in cutting resistance of SUS and Alumina. Hence if stand-alone SUS is processed, vertical processing is possible.
Circular cutter (Core cutting)	(1) Processing speed verification test	・ Processing was possible without any issues and without any chatter marks. ・ The processing speed, life of the blades, and load torque were obtained with blade pressing force and rotational speed as the parameters. ・ The processing speed as well as life of the blades exceeded the results of past processing tests. ・ When processing was repeated, the processing speed dropped gradually, but the processing speed was restored upon carrying out dressing for several seconds.	・ A conceptual diagram illustrating the mounting of a grindstone for dressing on to the tip tool has been created. ・ If the blade, guide and cylinder are not in a straight line, the pressing cylinder thrust is not equal to the blade pressing force due to loss caused by momentum. Hence the actual equipment needs to be designed carefully.
	(2) Test for verifying whether processing is possible using the tool	・ Processing was possible without any issues and without any chatter marks. ・ There were no issues in the workability of the series of tasks from core clamping to core retrieval.	・ In the element test without the clamp, the ratio of SUS and Alumina was fifty-fifty, but in this test, since the ratio of SUS which is difficult to cut, was higher, the processing speed and life of the blades were lower. ・ The time required for core clamping has been reflected in the throughput evaluation.

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

✓ **Results**

- Applicability of the tip tools to actual equipment, issues and response measures.
- Data for throughput evaluation, and throughput evaluation.
- Required specifications of remote controlled equipment (access equipment).

✓ **Contribution of the results towards the reflection destination**

- The concreteness of the fuel debris retrieval equipment improved through studies on measures in response to the issues obtained as a result of processing tests.
- The throughput was refined.

✓ **Analysis from the viewpoint of applicability to the site**

- The accessibility of the tip tools inside the pedestal was studied, and the dimensions of the tip tools were determined.
- The properties of fuel debris were unknown, but SUS was selected for simulating reactor internal structures and Alumina was selected for simulating fuel components, and assuming that these were mixed at the site, processing of SUS and Alumina simultaneously was tested.

① Remote controlled tip tools for retrieval (5) Implementation items (Tip tools)

✓ **Level of achievement compared to the goals**

All goals were achieved.

- Processing tests with the processing conditions extensively considered as parameters were conducted, processability was verified and the data for throughput evaluation was obtained.
- The size of core boring had to be increased but it was effective in reducing the processing time.

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

✓ **Objective**

The load on the operator will be reduced and work efficiency will be enhanced by means of the operation system that supports remote operation.

✓ **Project goals**

- Tests will be conducted with mock-ups simulating the inside of the Unit 3 pedestal using the test manufactured operation system, to verify the procedures for grabbing/cutting/transferring interfering objects and collecting the fuel debris in unit cans, and the viability of the series of operations will be verified. Also, data will be created for throughput evaluation by acquiring and consolidating actual results of work procedures.
- Case studies on the operation system application conditions, assumed issues, etc. will be consolidated as an input for planning the procedures for disassembly and removal.

✓ **Implementation items**

- Test manufacturing of the operation system, verification of viability of the series of operations by means of mock-up tests.
- Acquisition of actual data on the work procedures, creation of data for throughput evaluation.

✓ **Outcome (FY2022)**

- Acquisition of actual data on the work procedures, creation of data for throughput evaluation.

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

An operating system that supports remote operation by the operator

- Background of development
  The work of removing interfering objects and retrieving fuel debris will be carried out while avoiding obstacles in a confined space such as that of the PCV. (Figure 1)
  ⇒ A manipulator with a redundant degree of freedom will be effective: As it has 7 or more joints, and its elbows can be evasively maneuvered while retaining the posture and position of the arm tip. (Figure 2)

- Issues that must be resolved
  Remotely operating the manipulator with a redundant degree of freedom while avoiding obstacles under conditions with limited visibility puts too much load on the operator, and the manipulator could collide with obstacles.

- Purpose of development
  The load on the operator will be reduced and work efficiency will be enhanced by means of the operation system that supports remote operation (Supports the manipulator in avoiding obstacles).

- Course of development
  - Study of operation system
  - Development of operation system
  - Verification of effectiveness

  by means of element tests ⇒ Verification of operating time of the manipulator through mock-up tests and reflection into the throughput

- Expected outcome
  Automation of operation of the manipulator to avoid obstacles, enhancement of safety and efficiency of work
  (Application to various other work and robots in the future will be aimed for.).

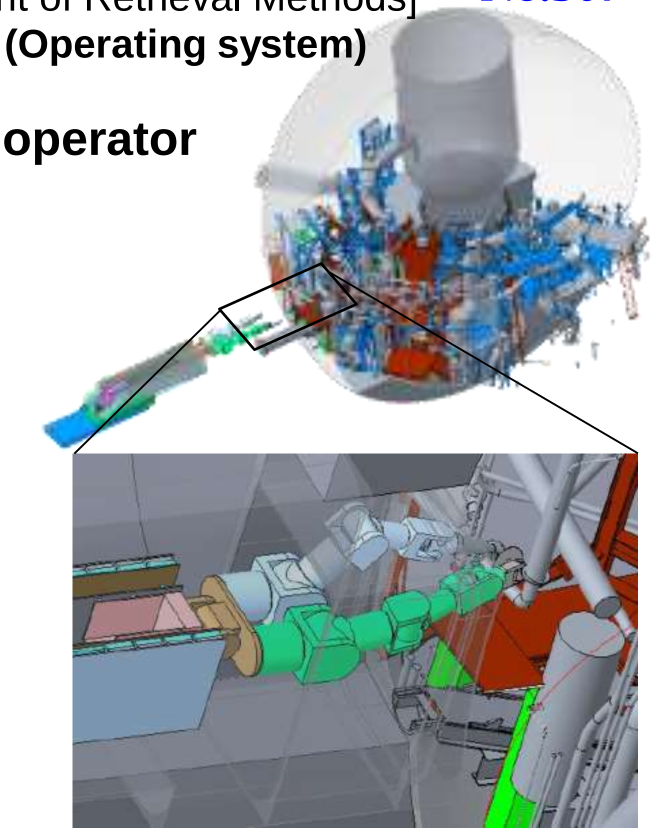


Figure 1 Illustration of interference removal work in Unit 3

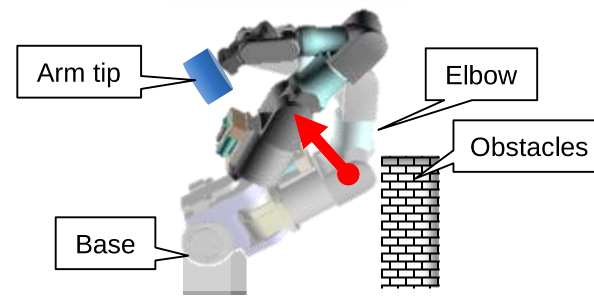


Figure 2 Evasive maneuvering of the manipulator with redundant degree of freedom

An operating system that supports remote operation by the operator

- Fuel debris retrieval work flow (Example)

Work plan

⓪ Prior verification of work (Using the simulator)

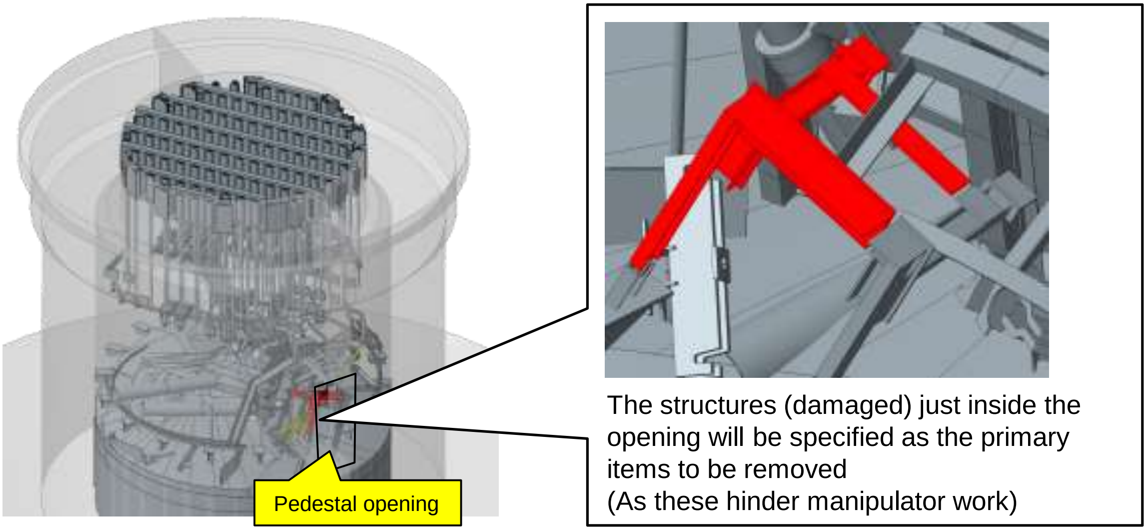
On-site work

① Moving inside the pedestal

② Grabbing and cutting the items to be removed

③ Transferring of items to be removed outside the pedestal

④ Leaving behind the transferred items to be removed / storing in container



The structures (damaged) just inside the opening will be specified as the primary items to be removed
(As these hinder manipulator work)

⓪ The items to be removed will be determined using the simulator, and the viability of manipulator work will be verified.

- It is assumed that the interfering objects outside the pedestal have been removed.
- A 3D model of the inside of the pedestal has been developed up to a certain extent with a certain accuracy based on the internal investigation.
- Viability of the series of removal work will be verified by means of a simulator.

- The procedures for removing collapsed structures will need to be studied separately.
- There are two kinds of removal procedures, namely, “Removing sequentially from the front” and “Removing the items from the back while avoiding obstacles”. The level of difficulty of the latter is higher.
  (Tests that have a higher level of difficulty will be set up.)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

An operating system that supports remote operation by the operator

- Fuel debris retrieval work flow (Example)

Work plan

⓪ Prior verification of work (Using the simulator)

On-site work

① Moving inside the pedestal

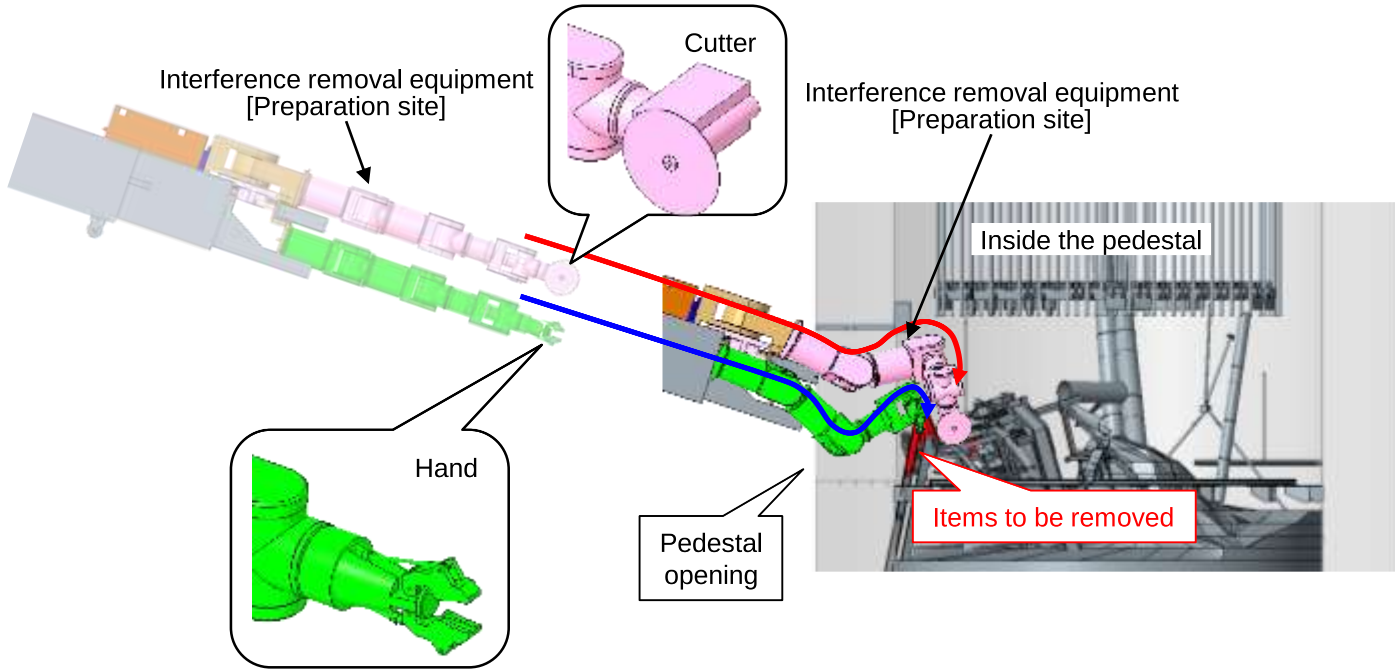
② Grabbing and cutting the items to be removed

③ Transferring of items to be removed outside the pedestal

④ Leaving behind the transferred items to be removed / storing in container

① Moving the hand cutter to the area around the items to be removed (10 to 20 cm in front) while avoiding obstacles

・ 2 manipulators and their bases (access rail) are interlinked and together avoid obstacles and move objects
・ The trajectory plan has been developed during the "Development of techniques for remote operation support in environments with low visibility and narrow spaces" in FY2020.



① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

An operating system that supports remote operation by the operator

- Fuel debris retrieval work flow

Work plan
- ⓪ Prior verification of work (Using the simulator)

On-site work
- ① Moving inside the pedestal
- ② Grabbing and cutting the items to be removed
- ③ Transferring of items to be removed outside the pedestal
- ④ Leaving behind the transferred items to be removed / storing in container

② Grabbing the items to be removed with the hand and cutting the items to be removed with a cutter

[Grabbing] The operator slightly moves the hand manually while confirming the camera images, etc.
(Bottom left figure: Movement from A → B)
[Cutting] The operator slightly moves the cutter manually while confirming the camera images, etc.
(Bottom right figure: Movement from C → D)

After cutting, the arm tips (hand and cutter) are moved back to spots A and C respectively.
- Work space (space) in which the manipulator can move slightly will be secured in advance (⓪)
- Verification of gripping force, method of determining the cutting location, method of adjusting the cutting speed, etc. will be studied separately.

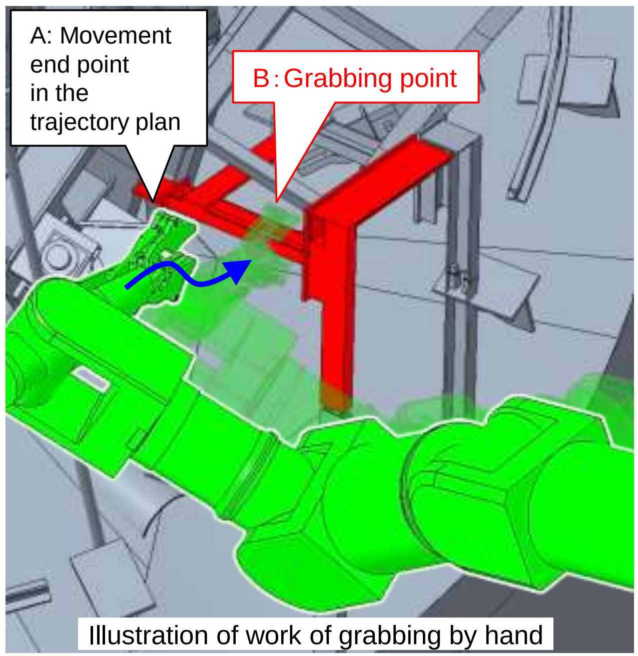


Illustration of work of grabbing by hand

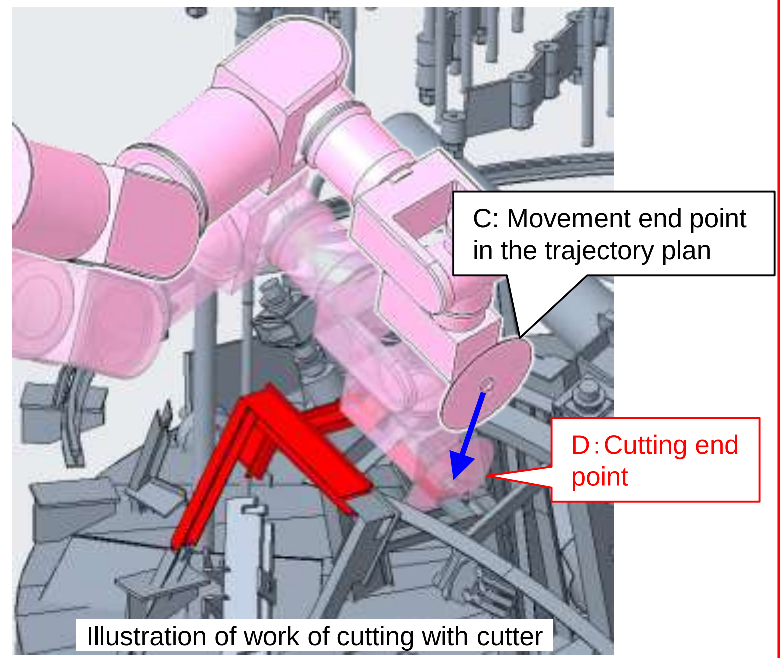


Illustration of work of cutting with cutter

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

An operating system that supports remote operation by the operator

- Fuel debris retrieval work flow

Work plan

⓪ Prior verification of work (Using the simulator)

↓

On-site work

① Moving inside the pedestal

↓

② Grabbing and cutting the items to be removed

↓

③ Transferring of items to be removed outside the pedestal

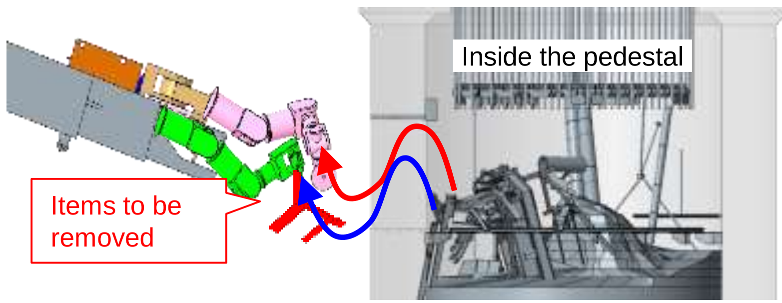
↓

④ Leaving behind the transferred items to be removed / storing in container

③ Grabbing the item to be removed and moving it outside the pedestal while avoiding obstacles [Same procedure as aforementioned ①]

・The route for avoiding obstacles is automatically generated using the trajectory plan, including the items to be removed that are grabbed by the hand.

Measures for preventing the grabbed object from falling will be studied separately



Separate trajectory plans will be made for the onward route and the return route.

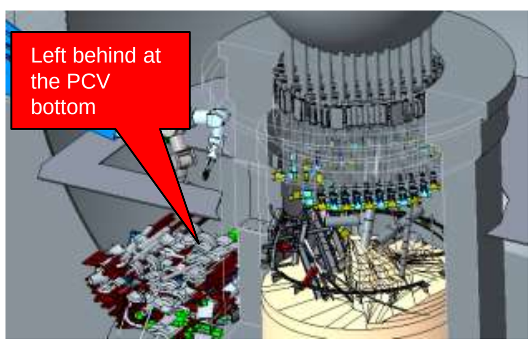
- Part of the environment changes
- The robot model changes

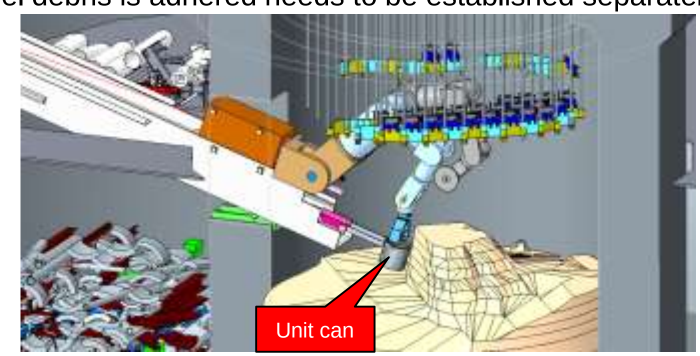
④ Leaving behind the items to be removed (structures/fuel debris) at the PCV bottom / storing in unit cans

・“Structures to which fuel debris is not adhered” are left behind in the PCV (Bottom left figure)

・The “fuel debris” is placed in the unit can, the unit can trolley travels over the rail and is transferred outside the PCV (Bottom right figure)

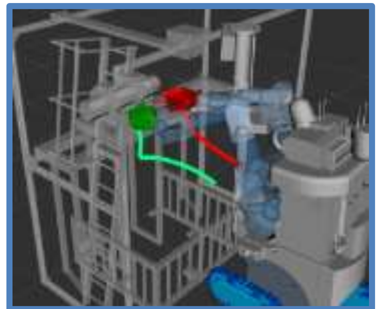
The method of determining whether or not fuel debris is adhered needs to be established separately.

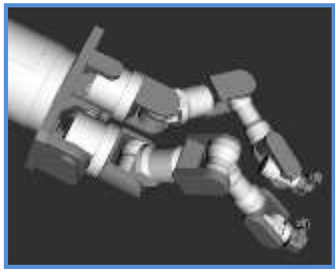




6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods] ① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Overview of the trajectory plan developed until last year





Information on the robot and environment

- 3D model of the robot
- 3D model of the environment
- Camera image

Trajectory plan algorithm

- **Route computation up to the destination**
- **Determination of collision with the robot model and the environment model → Computation of position so that both do not interfere with each other**

Goal is determined

Target angle of each joint is output

Robot

- Motor for each joint
- Servo controller
- Order to each joint
- Integrated controller

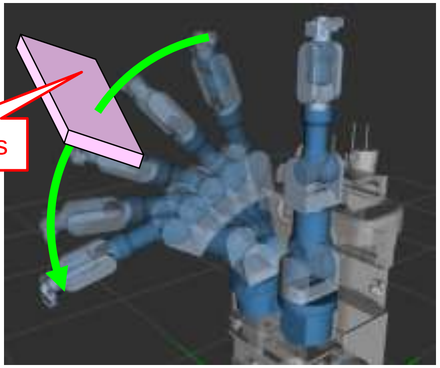
Operator

Operator manipulates the replay speed

Issues with the trajectory plan

- There is a risk of missing obstacles

  The route from the start to the goal is divided into smaller segments, and the obstacles are determined for each moment in the divided segments.
  ⇒ If the number of segments is less (roughly), the obstacles in between them get missed.
  If the number of segments is increased, the computation time increases as a trade off.



- As the work of high accuracy positioning such as for grabbing, cutting, etc. is switched over to manual operation, the risk of collision increases.

  When the hand or cutter is slightly moved towards the target object, minor adjustments in millimeters are made based on the camera images. As such minute movements are not included in the trajectory plan, the operation needs to be switched to manual operation.
  ⇒ As manual operation heavily relies on the skills of the operator, the risk of collision is high particularly in the case of beginners.
  As the focus remains completely on the arm tip, the risk of collision by the elbow, etc. is high.

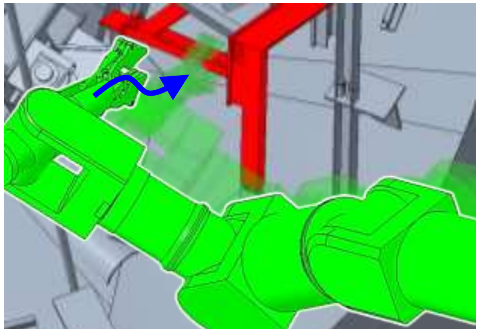


Image illustrating work of grabbing by hand

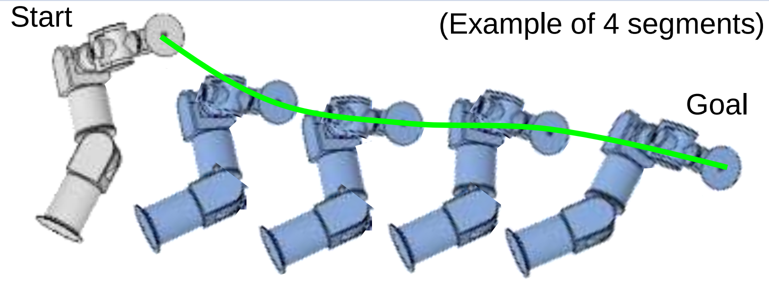
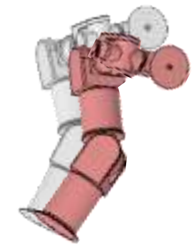
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Development details

A "Trajectory plan" will be incorporated into the operating system as a measure for resolving issues.
The trajectory plan consists of the following 2 types.

Joint research with Kobe University

	Wide range trajectory plan	Local trajectory plan
Conceptual diagram		
Route computation	A series of movements from start to the goal (separate)	Only the position after 0.1 seconds
Determination of collision	Computation of position so that both do not interfere with each other by determining collision with the robot model and the environment model.	
Computation time	Long (Number of segments: 20 to 30 segments of 1 to 2 minutes)	Short (Target: 0.1 seconds or less)
Timing of computation	Computed in advance and verified by operator using the simulator	
	- (Not real time)	Real time (Sequential computation as the robot moves)
Main operation method	Foot pedal (Adjustment of speed based on the extent to which the pedal is stepped on) 	Game pad (Operating with the position of the arm tip and the posture) 

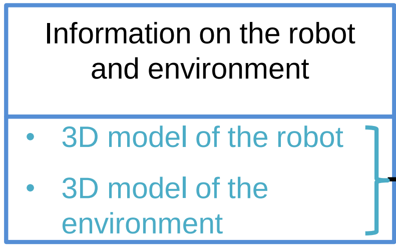
[Additional Notes]

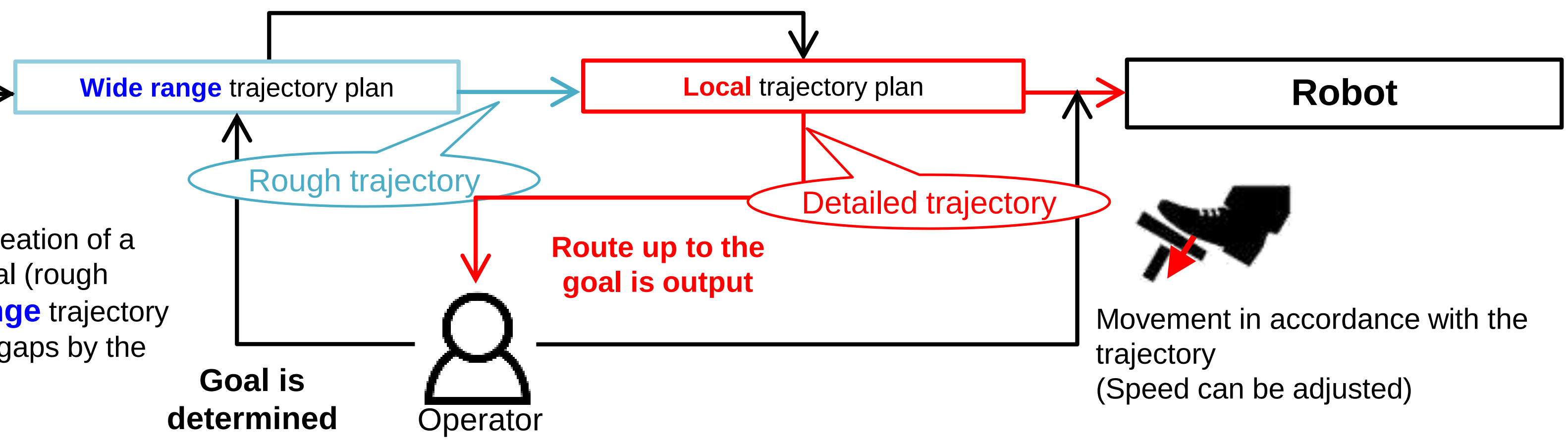
The margin value (gap between the robot and the environmental model) was set at 40mm in the mock-up test conducted this time.
(The mock-up manufacturing accuracy, laser sensor measurement accuracy and position adjustment tool repetition accuracy total to approx. 20mm. The margin was set by doubling this number.
However, the accuracy of repetitive positioning by means of crawler movement has not been considered.)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

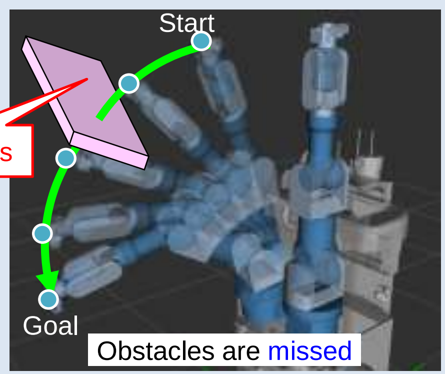
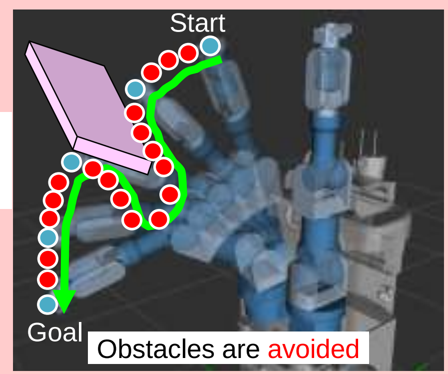
Measures to resolve the issues with the trajectory plan

There is a risk of missing obstacles ⇒ Obstacles will not be missed by means of the "Local trajectory plan"





Consists of 2 stages comprising creation of a series of tasks from start to the goal (rough trajectory) based on the **Wide range** trajectory plan, and then interpolation of the gaps by the **Local** trajectory plan.

	Only Wide range trajectory plan	Wide range + Local trajectory plan
Simulated movement		● Rough trajectory based on the Wide range trajectory plan ● Detailed trajectory based on the Local trajectory plan 

Measures to resolve the issues with the trajectory plan

The risk of collision increases with manual operation ⇒ Collision is avoided by means of the "Local trajectory plan"

Information on the robot and environment
- 3D model of the robot
- 3D model of the environment

→ **Local** trajectory plan → **Robot**

Position in which the robot and the environment do not interfere with each other (Each axis value is arranged)

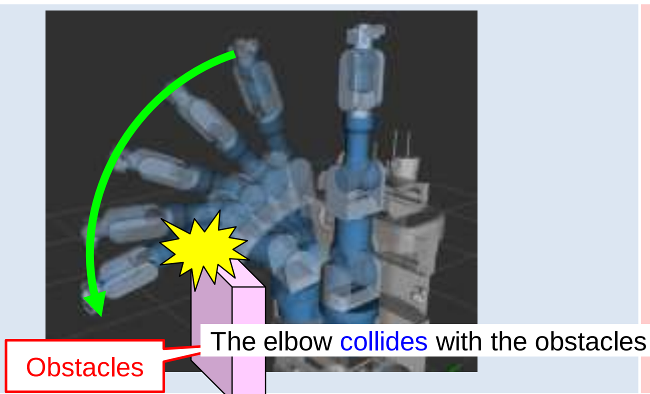
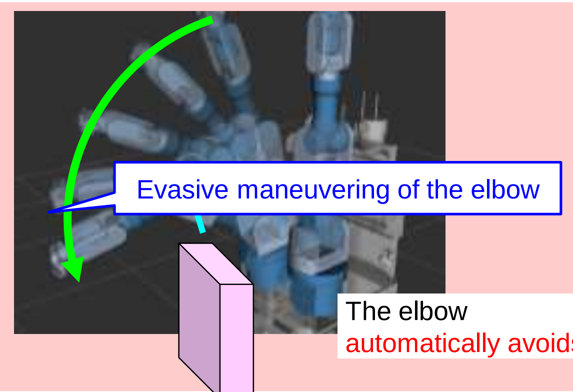
Arbitrary movement
(Issuing instructions for the position of the arm tip)
[Control of breakup rate]

Operator

Past operating method

[Past operating method]
There are times when the manipulator elbow moved in a direction not intended by the operator.

[Local trajectory plan]
As positions can constantly be changed in real time for avoiding interference, the operator can focus on operating the arm tip.

	Past operating method	Local trajectory plan
Simulated movement		

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Pre-conditions for the mock-up tests

- It is assumed that the 3-D model has been built up to a certain extent based on internal investigation. However, it is assumed that there are errors and unknown territories (Areas that have not been investigated) (The current condition of Unit 3 is assumed).
- The objective of this development is to develop a remote operation system equipped with a function to avoid obstacles with a multi-joint manipulator. "The work of removing interfering objects from the vicinity of the pedestal opening by means of a dual-arm manipulator" will be taken up as the subject for verifying this technology. Please note that this technology is intended for application to various other environments and robots in the future. Therefore, the purpose of the mock-up tests is to verify and evaluate versatile (general) remote operation procedures (workflows) rather than digging deeper into the method.
- As an example of remote operation procedures, "cutting" and "grabbing" will be incorporated into the flow, but they will not be investigated further. (They will be consolidated as issues and will be studied in details separately.)

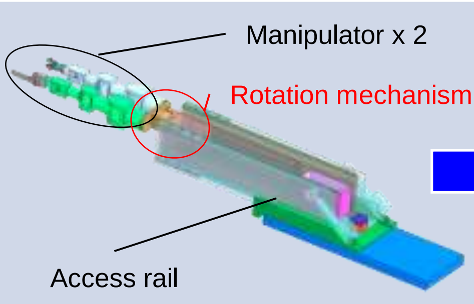
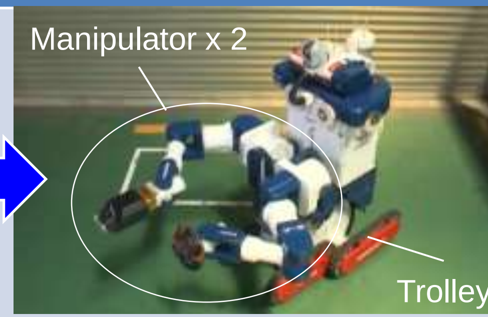
  [Items of this development that will not be investigated any further]
  - Planning of removal procedures using physical simulation, etc. so that the damaged structures inside the pedestal are retained. (Not included in the scope this time).
  - The structure of the gripper for grabbing the target object and the method of grabbing (This time a simple hand will be used for the test).
  - Controlling the delivery of the cutter for cutting the target object (This time only the procedure until the cutter makes contact with the target object is included in the scope).
  - Selection of radiation resistant sensors and equipment (This time cameras and sensors available on the market will be mounted).
  - Applicability to single arm hydraulic manipulator (This time only the dual-arm motor operated manipulator will be used).

- The focus will remain on developing an operation system for performing the work safely and efficiently without letting the manipulator collide.

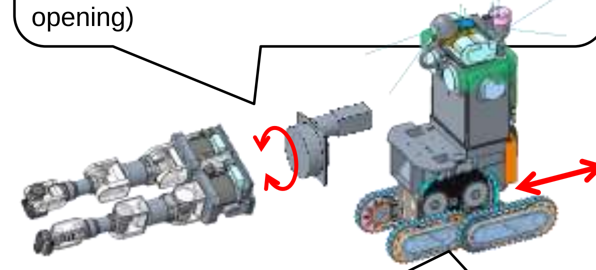
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Mock-up test plan

- Test equipment with an axial configuration close to that of the interference removal equipment will be used. (The linear motion of the access rail is substituted by the forward movement of the trolley)
- A scaled down mock-up (1/1.8) will be prepared in accordance with the ratio of the test equipment, as the workability of the interference removal equipment will be simulated.

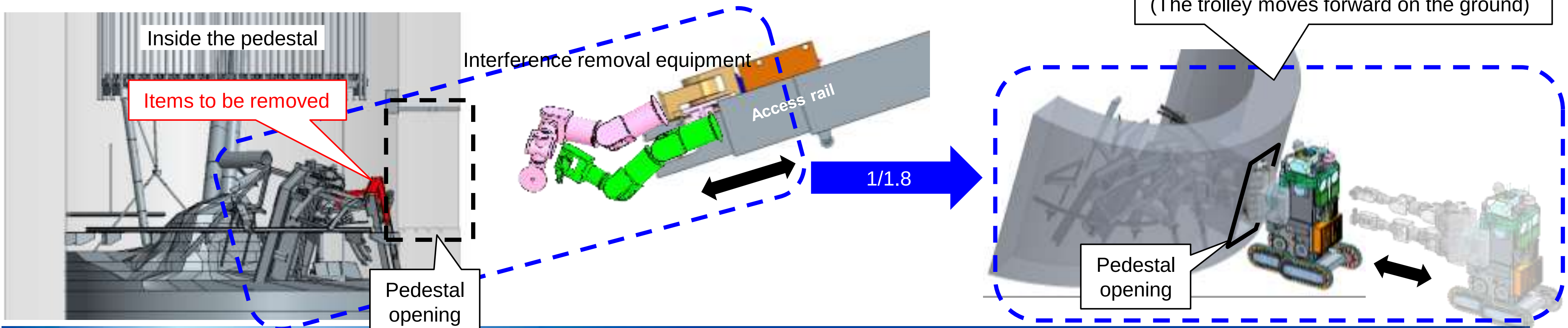
	Interference removal equipment [Under examination]	Mock-up test equipment (Upper floor decontamination equipment)
External appearance of the equipment		1/1.8 → 
Main specifications	Manipulator: 8 axes x 2 types Rotation mechanism: 1 Access rail: 1 (Extension)	Manipulator: 8 axes x 2 types Rotation mechanism: 1 (Additionally installed) Trolley: 1 (Forward motion /Backward motion)

[Remodeling of the mock-up test equipment ①]
In accordance with the actual equipment, a pivot will be added (In order to position the manipulator vertically while passing through the opening)



[Remodeling of the mock-up test equipment ②]
In accordance with the actual equipment, the crawler movement of the trolley will be handled as the linear motion axis
(In order to simulate the linear motion of the access rail)

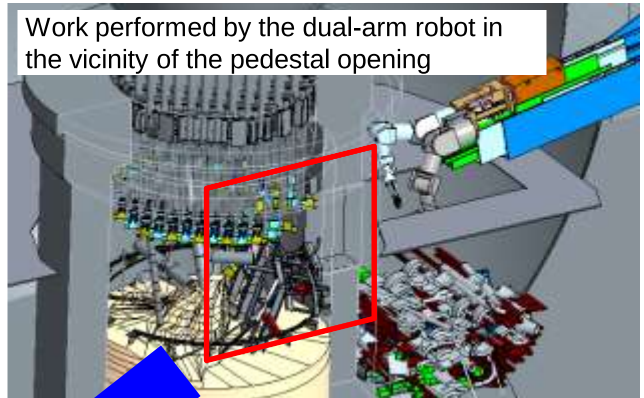
As the movement of the access rail that approaches from diagonally above will be simulated, the mock-up **will be installed tilted 15°**
(The trolley moves forward on the ground)



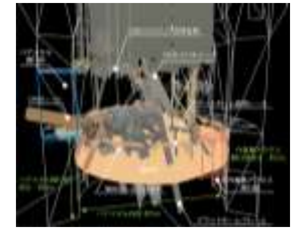
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Status of manufacturing the mock-up

In order to conduct the test under conditions that are close to the actual environment, a 1/1.8 mock-up was created based on the 3D damage model of the inside of the pedestal obtained as a result of the Unit 3 PCV internal investigation (2017).
(During the test lights will be turned off to simulate darkness.)



Work performed by the dual-arm robot in the vicinity of the pedestal opening


3D damage model of the inside of the pedestal reproduced based on the images from the Unit 3 Internal Investigation conducted in July 2017


External appearance of the mock-up (Pedestal opening)


Mock-up of the damaged structures inside the pedestal
(A tilted platform frame is present in the vicinity of the opening)

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Mock-up test equipment

In order to simulate the interference removal equipment (Under examination), cameras were installed on the mock-up test equipment.

- Tip tool: Installed at 2 locations as the claws of the hand and the blade of the cutter will be positioned from the horizontal and vertical direction.
- Main body of the robot: A pan-tilt zoom camera was installed on top and 4 fixed corner cameras were installed facing the 4 corners of the opening.

Although installing bird's eye view cameras inside the environment would make it easier to perceive the conditions, the cameras were installed in this manner in order to simulate the difficult conditions without bird's eye view cameras during the initial stages.

Image from the pan-tilt zoom camera used by the operator for monitoring

Placement of cameras on the main body of the robot

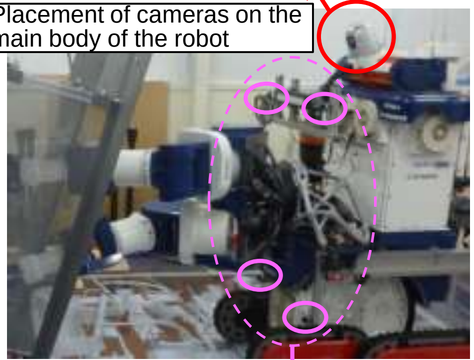
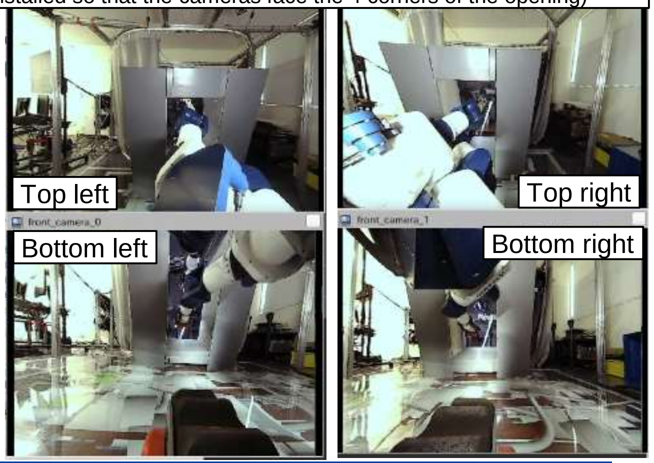


Image from the 4 fixed corner cameras used by the operator for monitoring (Installed so that the cameras face the 4 corners of the opening)



Hand tool

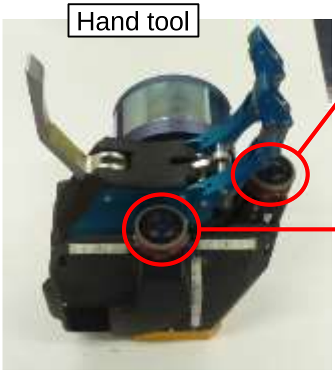
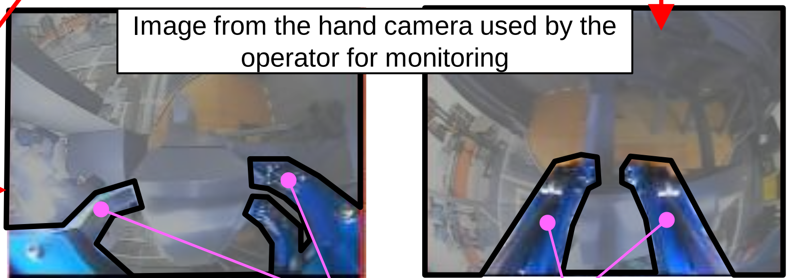


Image from the hand camera used by the operator for monitoring



Cutter tool (Saber saw)

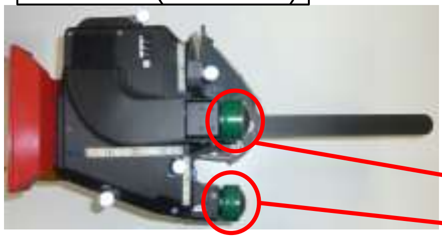
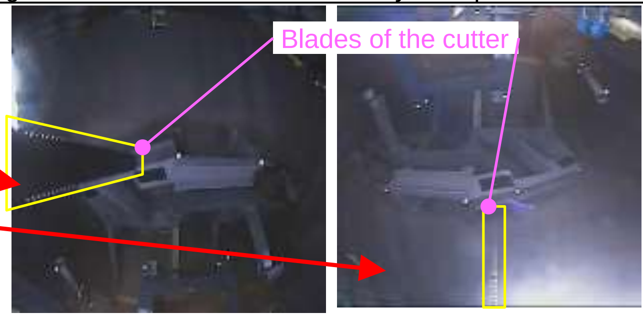


Image from the cutter camera used by the operator for monitoring



① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Mock-up test conditions

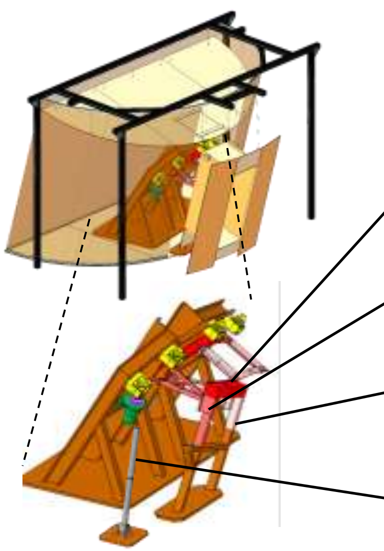
- 4 operators participated in the interfering objects removal tests 1 - 4 (Table below).
  (A series of movements including entering the pedestal opening, approaching the item to be removed, grabbing, cutting, transferring and storing in collection container)

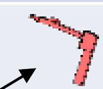
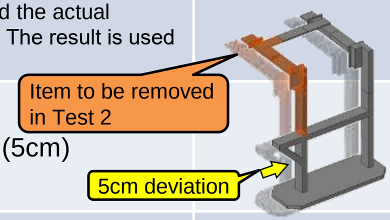
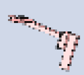
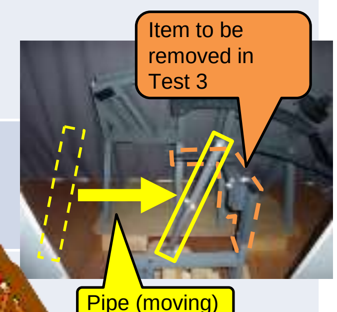
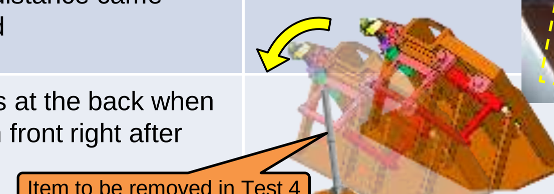
- The extent to which the operators can handle "errors" and "unforeseen incidents" set up in the mock-up while operating the actual equipment (site) was verified without informing the operators beforehand about the "worst case scenarios" in tests 2 - 4 (Comments such as "Various steps involving judgment should be incorporated assuming actual work", "Case studies should be conducted on structural changes and issues caused by the work itself" were reflected.)

- The viability of work was verified and the trajectory data was created as "Advance planning" (simulation) respectively for each test, and then "Actual operation" was performed at the site (illustrations on the right).
  (However, if there are worst case scenarios, those cannot be handled with the trajectory data created during advance planning. It becomes necessary to correct the environmental model on site and calculate the trajectory data once again.)

Advance planning (simulation)
Each of the 4 operators were provided with laptops and advance planning was carried out all at once in the conference room.

Operation of the actual equipment (site)
Each operator operating the actual equipment on site using the trajectory data created during advance planning



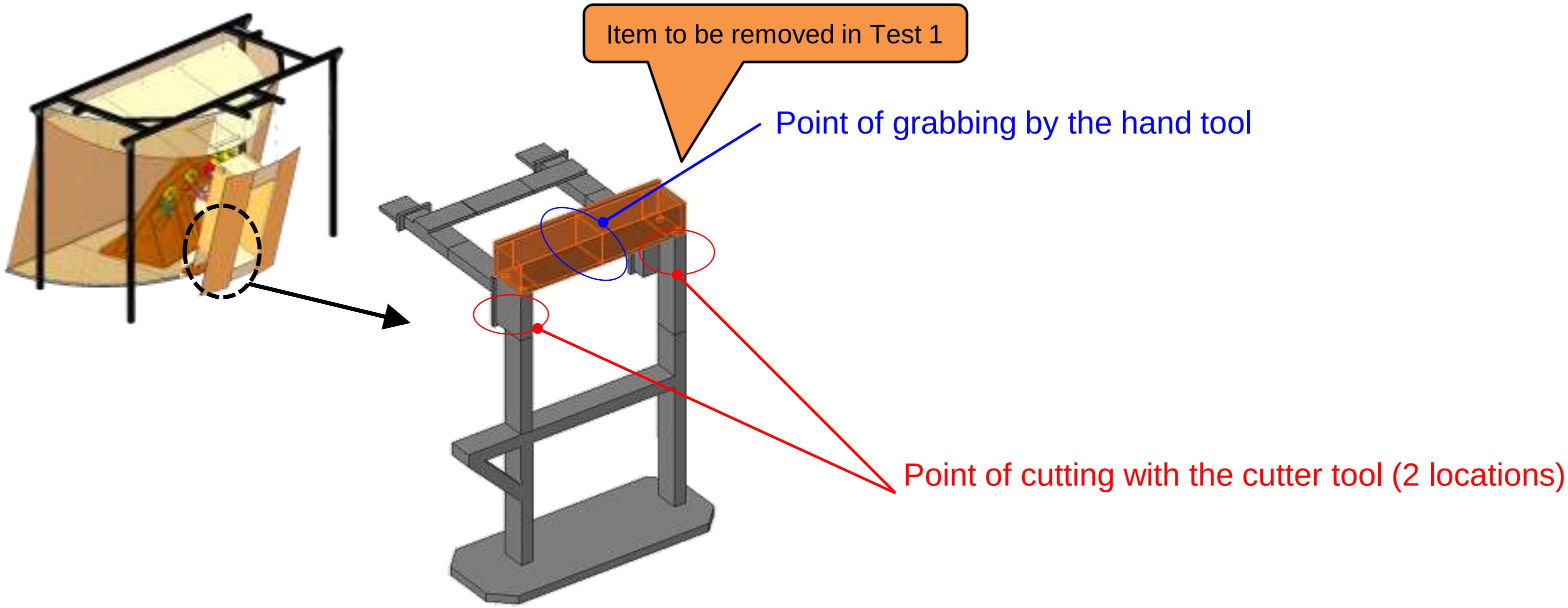
Item to be removed	Name of the test	Worst case scenarios (Operators not informed about these beforehand)	Overview
	Test 1	None (Standard test in which the simulator and the actual equipment in the mock-up are matched → The result is used for calculating throughput)	—
	Test 2	Shift in the position of item to be removed (5cm)	
	Test 3	Assumption that a pipe that was at a distance came falling towards the item to be removed	
	Test 4	Assumption that the structure that was at the back when the test began, collapsed and came in front right after grabbing and cutting	

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Characteristics of Test 1

- Standard test
- Without worst case scenarios: The simulator (environmental model) and the mock-up (actual equipment) are matched to the extent possible. However, since there is deviation in the position due to movement of the crawler, position is adjusted as required.#

In the beginning, the start position had to be adjusted, and thereafter the position was adjusted at the discretion of the operator (Same for Tests 1 - 4)

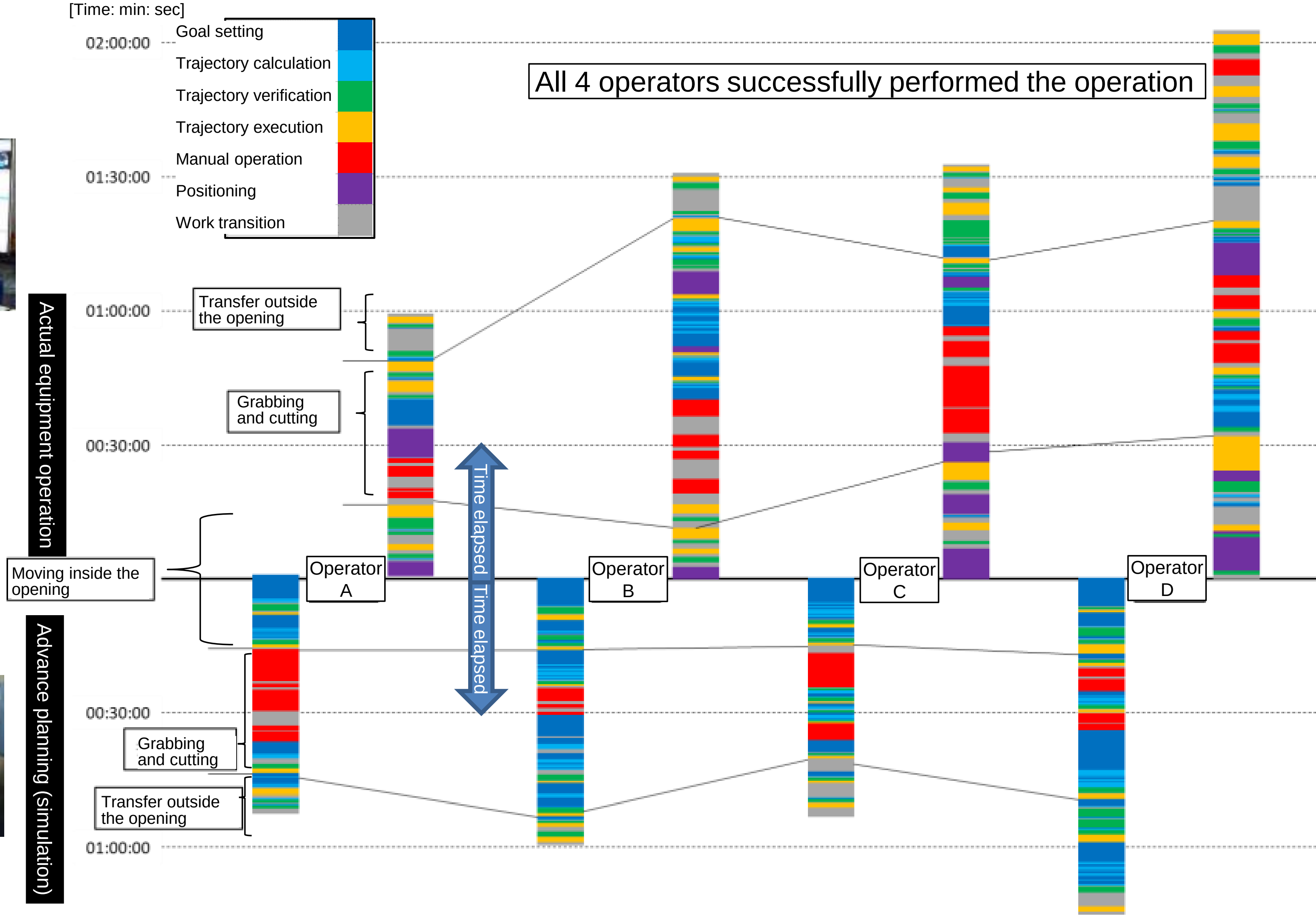


Results of Test 1

- All 4 operators successfully performed the operation.
- All 4 operators spent around 1 hour on advance planning and 1 - 2 hours on actual equipment operation.
- The throughput (positioning, retrieval work) was calculated based on the actual equipment operation by the 4 operators.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results of Test 1



6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

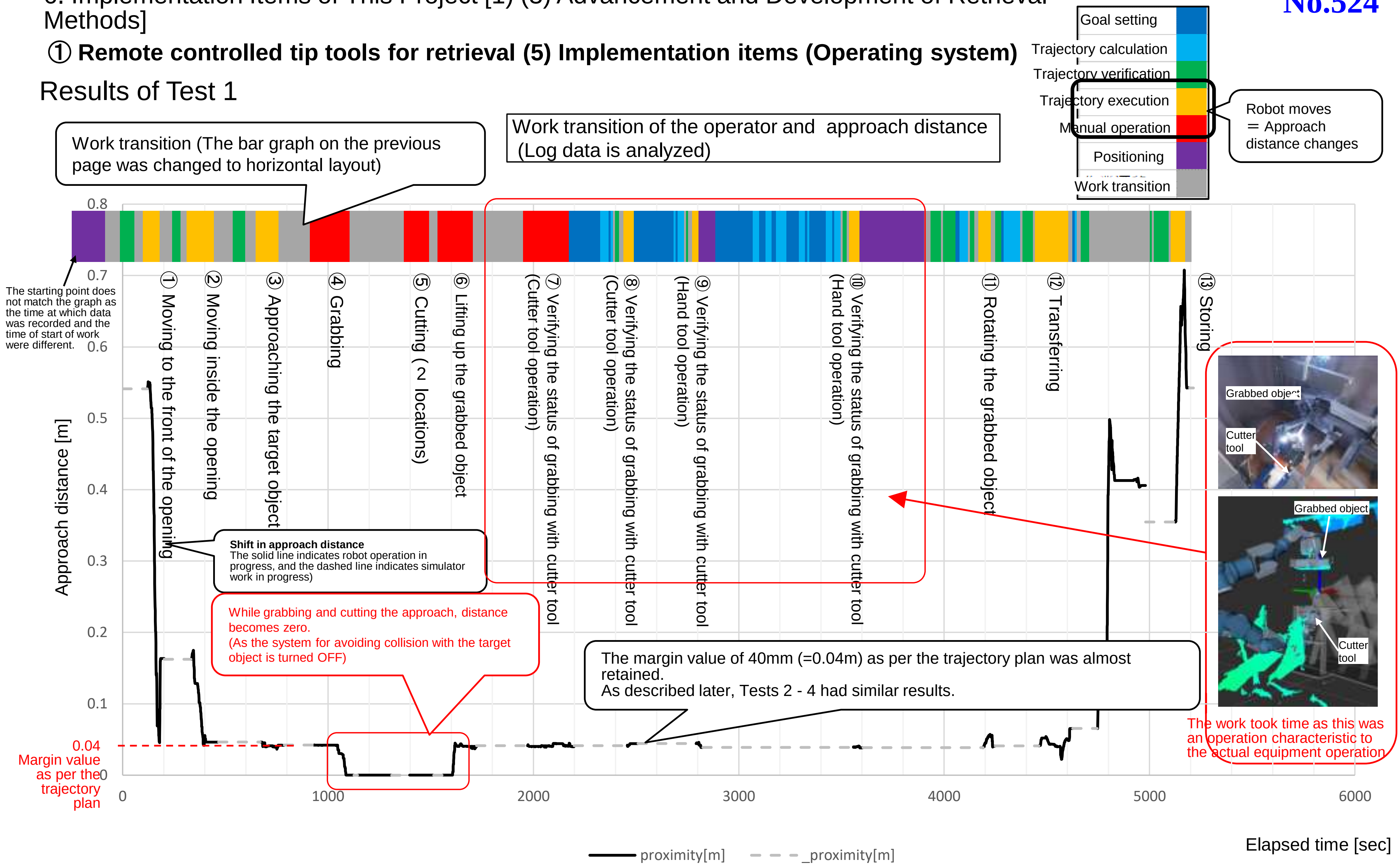
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results of Test 1

Work transition (The bar graph on the previous page was changed to horizontal layout)

Work transition of the operator and approach distance (Log data is analyzed)

Robot moves ＝ Approach distance changes

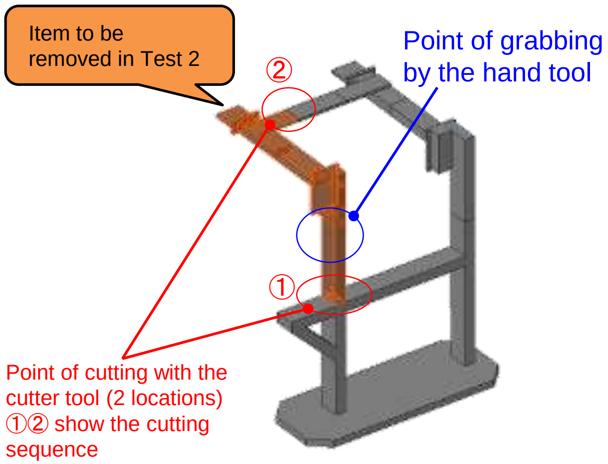


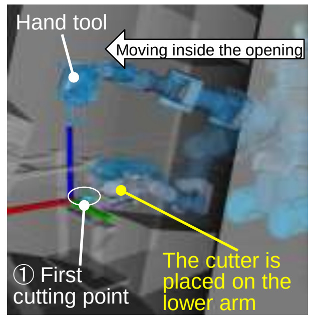
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

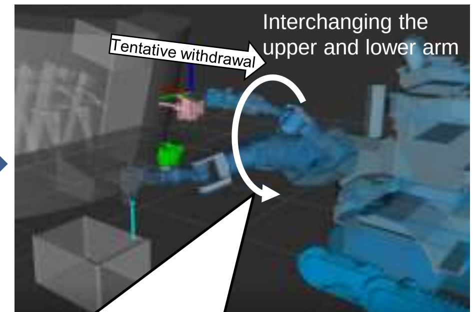
Characteristics of Test 2

- Test that requires lot of efforts
  - Since the grabbing point is located between 2 cutting points, “cutting at 2 locations while grabbing” cannot be accomplished.
    → Cutting is performed at the first location first, and then after withdrawing outside the opening, the upper and lower arms are interchanged and grabbing + cutting of the second location is performed.

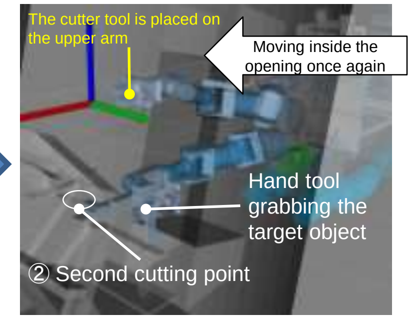




Cutting at the first location



Since the opening is small, the arms need to be withdrawn tentatively and the upper and lower arms are interchanged.



Grabbing and cutting at the second

- With worst case scenarios: The item to be removed is set up in the mock-up (actual equipment) at a position that is 5 cm away from its locatio in the simulator (environmental model). The operators were made to participate in actual operation without being informed about this.

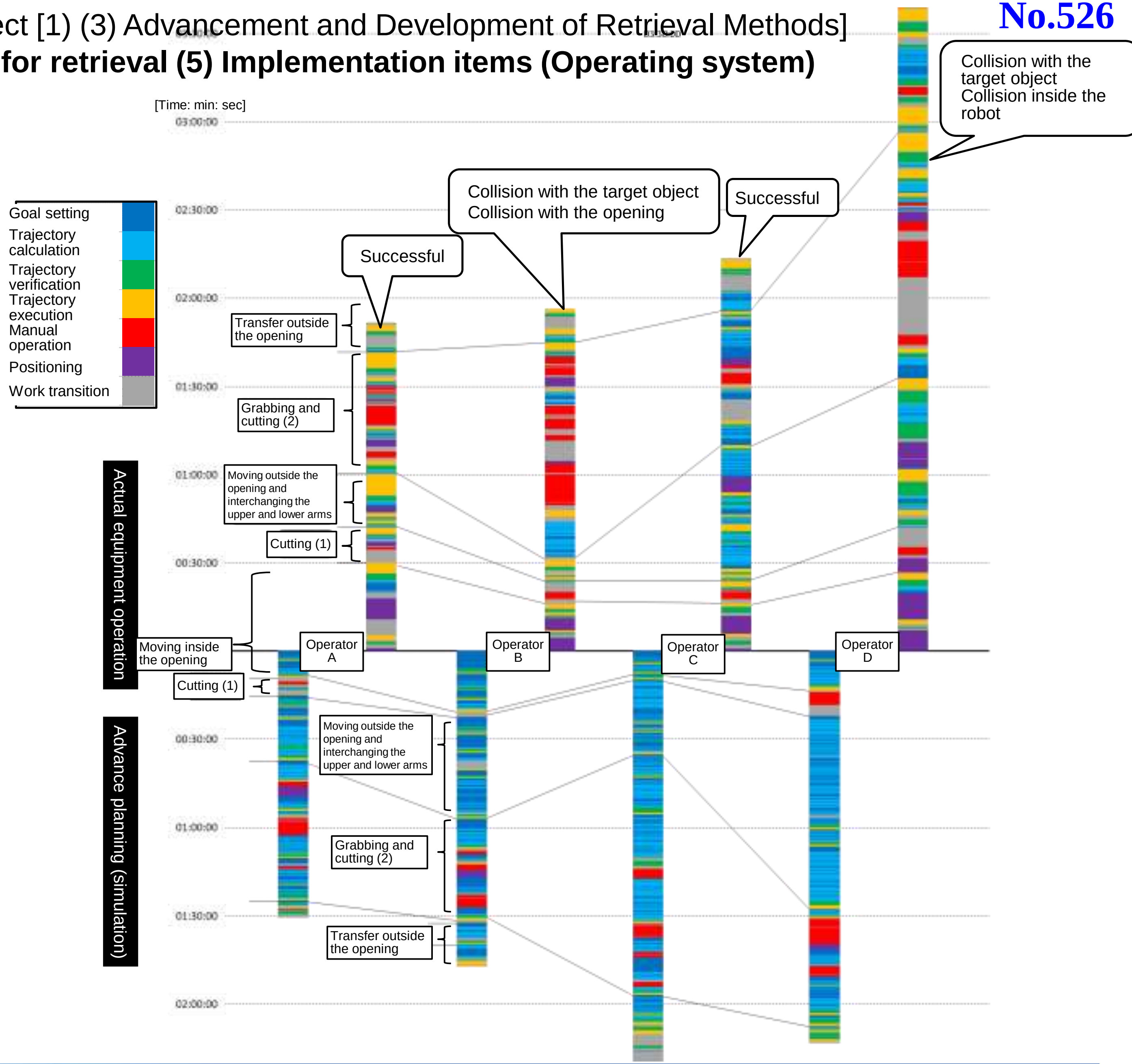
The item to be removed is placed at a position that is 5 cm away (white marking) from its location in the simulator.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results of Test 2

- Operators A and C performed the operation successfully.
- The worst case scenarios did not have any impact. (The deviation of about 5cm is corrected by adjusting the position)
- Operators B and D moved the hand too close to the target object while performing the grabbing action and pushed down the target object. (During the grabbing movement, the collision avoidance system of the hand is turned OFF) → The administrator restored the target object and the test was resumed.
- Operator B let the elbow of the manipulator collide with opening even though the collision avoidance system was ON. → Details are described later. The administrator informed the operator about the collision and the test was resumed.
- In the case of Operator D, a collision occurred inside the robot (tip tool and the carrier). Restoration took time. (This was caused by an error in the setup by the administrator).

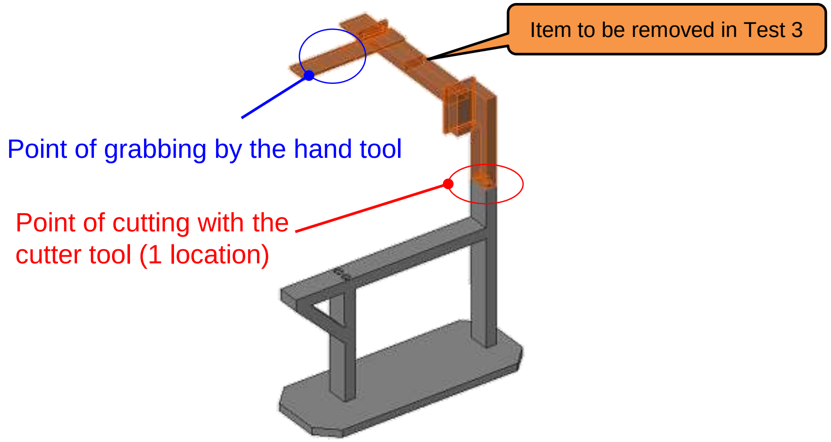


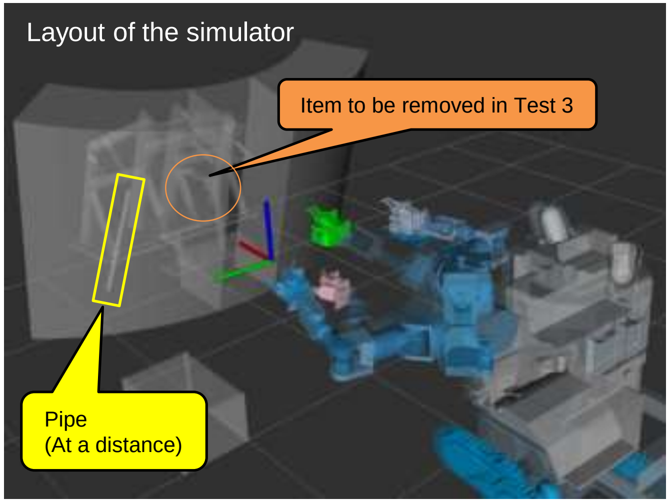
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

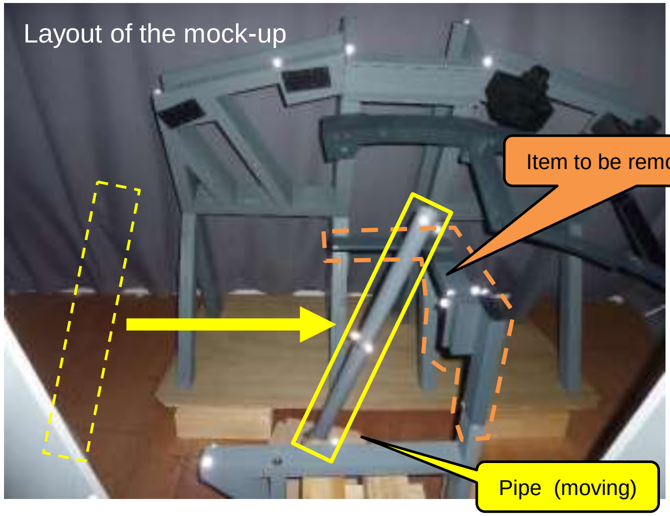
Characteristics of Test 3

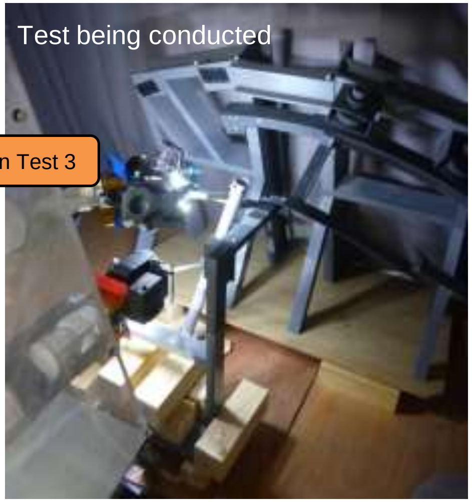
- Simple test using the simulator

- With worst case scenarios: The pipe that was at a distance in the simulator (environmental model) was moved in the mock-up (actual equipment) to a position such that it gets in the way of the grabbing point. (Assuming that the pipe came falling), → Whether the operator is aware of the environment, and what he decides to do thereafter is verified.







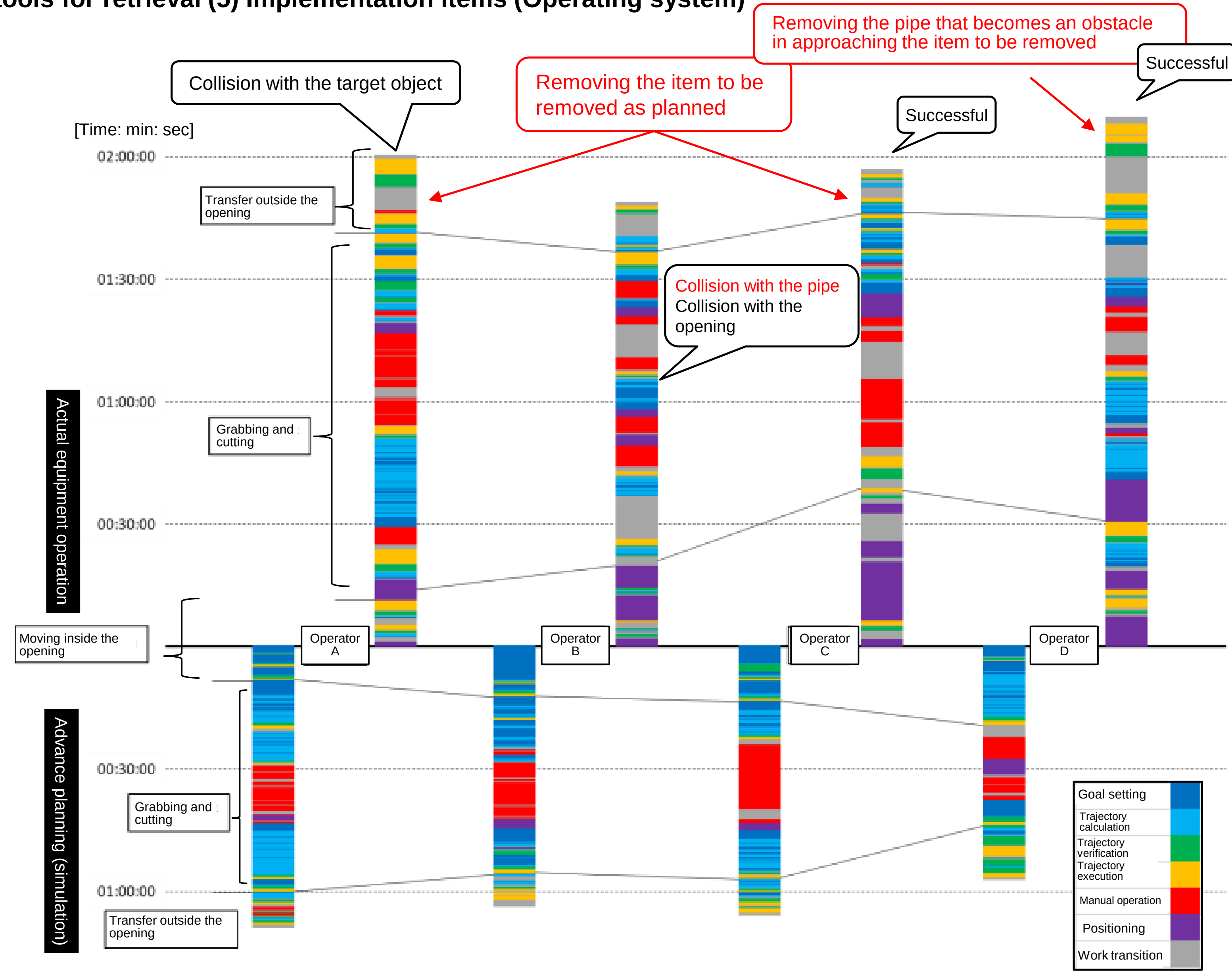


6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results of Test 3

- Operators C and D performed the operation successfully. However, Operator C removed the item to be removed and Operator D removed the pipe that became an obstacle (Each operator decided to act differently).
- Operator A pushed down the target object with the hand while performing the grabbing action (the collision avoidance system of the hand is turned OFF during the grabbing action). → The administrator restored the target object and the test was resumed.
- The Operator B did not notice the pipe and let the hand collide with the pipe. → The administrator informed the operator about the collision and the test was resumed.
- Operator B let the elbow of the manipulator collide with the opening even though the collision avoidance system was ON. → Details are provided later.



6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

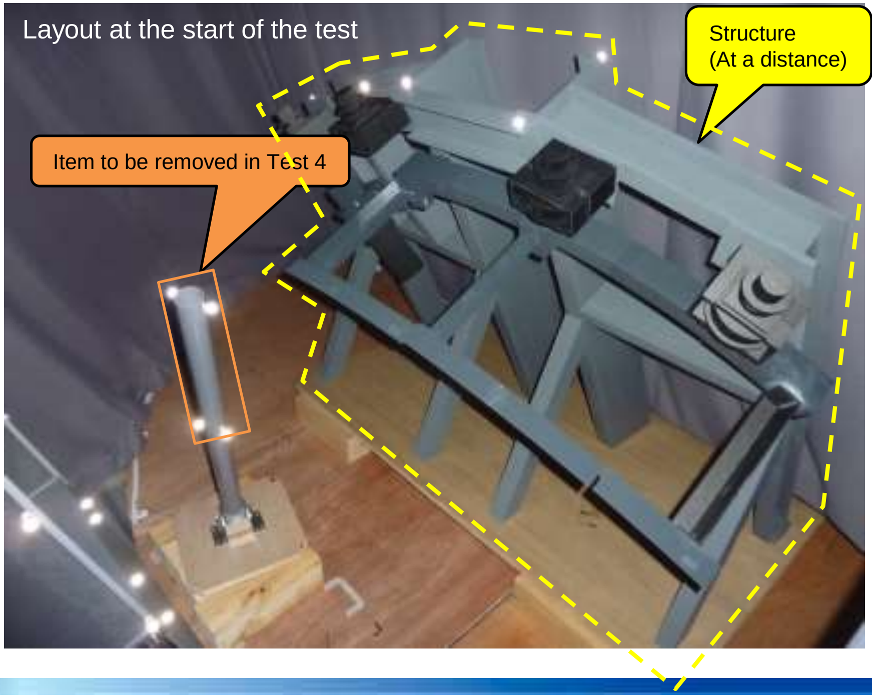
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

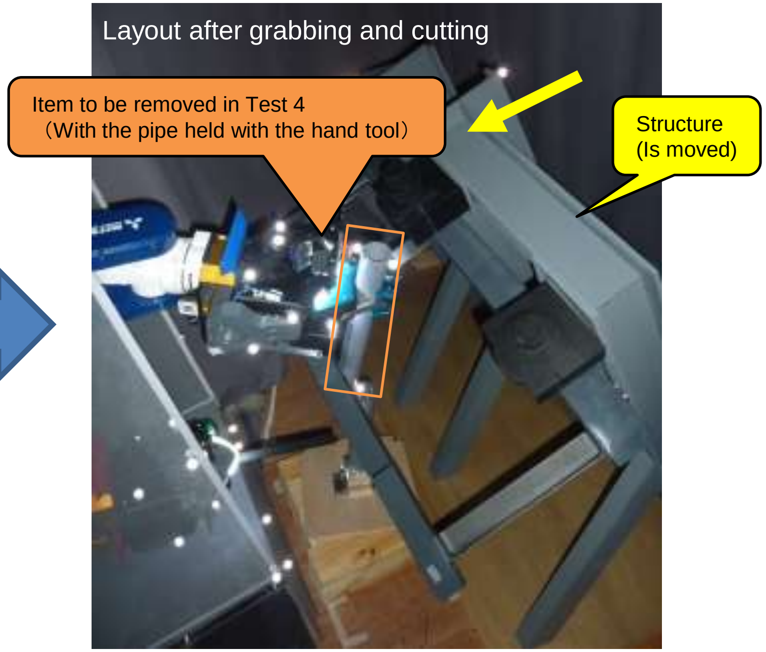
Characteristics of Test 4

- Simple test using the simulator (Simplest amongst Test 1 - 4)

- With worst case scenarios: It is assumed that the structures that were at a distance (at the back) when the test started collapsed and came in front right after grabbing and cutting the target object (pipe) (The test is stopped temporarily, the administrator changes the position of the structures so that the operator cannot view them.) → Whether the operator is aware of the environment, and what he decides to do thereafter is verified.

As compared to Test 3 in which the complete picture was possible to be verified before grabbing and cutting, in Test 4, since the environment changes while the operator is still holding the pipe, the operator cannot move the robot freely and has to perceive the environment with the information obtained from a narrow range of view.

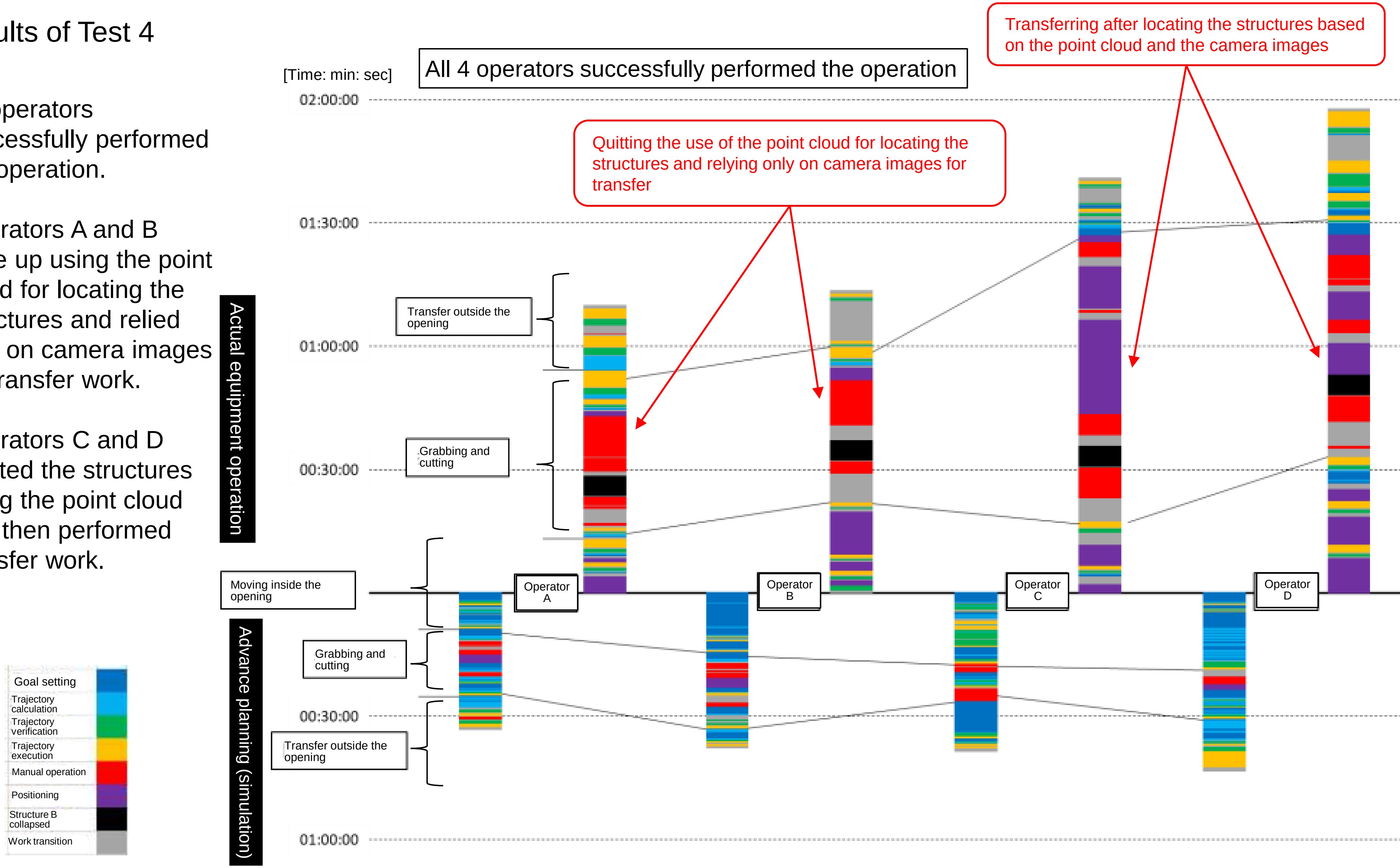




6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results of Test 4

- All operators successfully performed the operation.
- Operators A and B gave up using the point cloud for locating the structures and relied only on camera images for transfer work.
- Operators C and D located the structures using the point cloud and then performed transfer work.



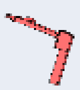
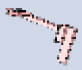
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Summary of test results

- 4 operators participated in the interfering objects removal mock-up test using the operation system (trajectory planning) that has been developed. It was verified that a series of tasks was feasible in a confined environment such as the pedestal opening due to the collision avoidance function of the operation system. Also, it was verified that gaps (errors) between the simulator and the actual site or unforeseen incidents can be handled by using the position adjustment function.

- The importance of position adjustment and the necessity of collision avoidance while performing the grabbing action were clarified through the mock-up tests. Also, the work items that the operators took time to perform were verified as well.

Tests 2 - 4 were worst case scenario tests. The purpose of these tests was to find out the limit up to which the operation system can be used.

Items to be removed	Name of the test	Worst case scenarios (Operators not informed about these beforehand)	Test results	Remarks
	Test 1	None (Standard test in which the simulator and the actual equipment in the mock-up are matched → The result is used for calculating throughput)	All 4 operators successfully performed the operation	The work was completed in 1 - 2 hours which was satisfactory.
	Test 2	Shift in the position of item to be removed (5cm)	2 operators successfully performed the operation There was collision in the case of 2 operators	・The shift in location did not have any impact ・There is a risk of collision as the collision avoidance function is turned OFF in order to let the hand approach the target object while performing the grabbing action.
	Test 3	Assumption that a pipe that was at a distance came falling towards the item to be removed	2 operators successfully performed the operation There was collision in the case of 2 operators	・One of the operators did not notice the movement of the pipe which led to a collision. ・There was individual difference in judgment.
	Test 4	Assumption that the structure that was at the back when the test began, collapsed and came in front right after grabbing and cutting	All 4 operators successfully performed the operation	All 4 operators appropriately ascertained the change in environment based on partial information.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

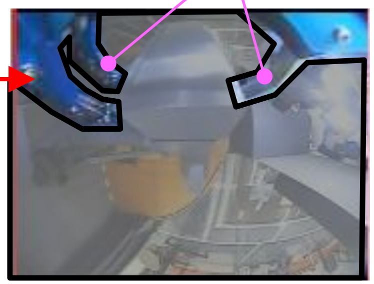
Results and considerations ①

- Collision accidents occurred 6 times during the 16 rounds of mock-up tests (4 operators x Tests 1 - 4)
  - Pushing down of the target object with the hand tool … 4 times (The remaining 2 times were caused due to lateral slip caused by the crawler movement: Described on the next page)

The camera screen that the operator was focusing on while performing the grabbing action with the hand tool

Hand tool

Claws of the hand



Test 2　Operator D

Collision with the hand

[Cause] The operator did not get a sense of the distance and went too close to the target object

Test 3　Operator A

Collision with the claws of the hand

[Cause] If you focus on one place, the surroundings are not visible

There is a risk of collision as the collision avoidance fuunction is turned OFF in order to let the hand approach the target object while performing the grabbing action.

[Countermeasures]
① A mechanism that can accurately and precisely measure the approach distance should be used or grabbing mechanism for following the other person by roughly adjusting the position should be used.
② A support technology for complementing the visual perception characteristics of human beings should be developed.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

Results and considerations ②

- The manipulator (elbow) coming in contact with the opening … 2 times (Both instances occurred in the case of Operator B)

→ Although the interference avoidance function was ON, the lateral slip caused by the crawler movement led to these incidents.

Characteristics of the operator B: ① High acceleration and deceleration speed → The crawler was likely to deviate easily (There was a lot of forward and backward movement during tests 2 and 3 in which the incident of contact occurred)
② Position was not adjusted appropriately after the crawler moved → The gap was unable to be corrected

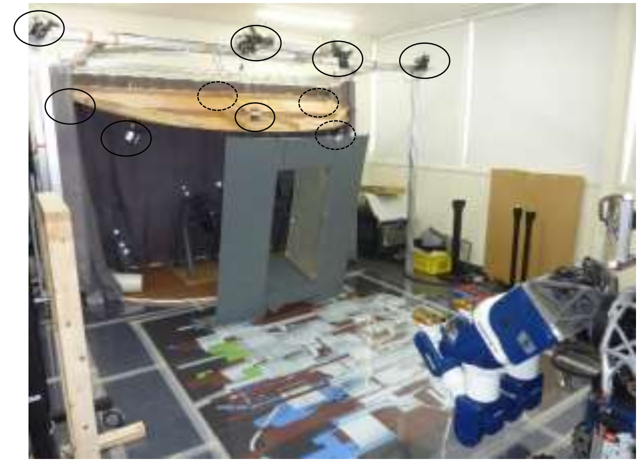
It is believed that this issue can be resolved if the position is adjusted appropriately. (In the actual equipment, since the movement is over the rail, lateral slip does not occur)

⇒ [Conclusion] Manipulator interference can be avoided by appropriately adjusting the position.

The result of measuring the extent of lateral slip at the time of completion as against the position in the beginning with the help of motion capture cameras during Test 3, and comparison with the pedal operation

Operator	Lateral slip [cm]	Vertical axis: Extent of stepping on the pedal (0 - 1) (Horizontal axis: Time elapsed during the test)
B	3.2	
C	1.5	
D	1.8	

○: Motion capture cameras



Operator B stepped much harder on the pedal as compared to Operators C and D.
= Higher speed of operation
And high frequency of pedal operation
⇒ It is believed that this led to a larger crawler deviation

Operator A did not obtain any data.

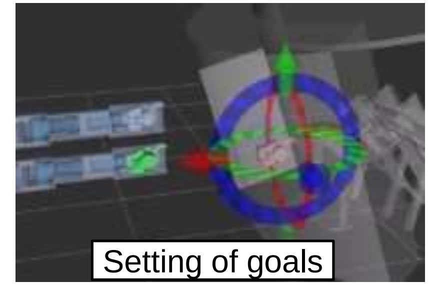
6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]
① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

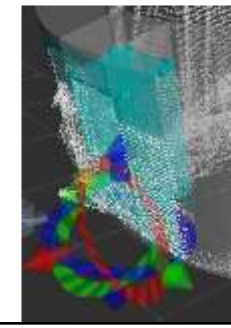
Results and considerations ③

- Based on the analysis of the mock-up test results, it may be possible to further shorten the time required.
  - In the advance planning (simulation), a lot of time (30%) was required for “Goal setting”.
    → If there is an automatic position adjustment function to adjust the position with respect to the target object, the time required can be shortened.
    (There was a comment from the operators that “It is difficult to make fine adjustments using the mouse”.)

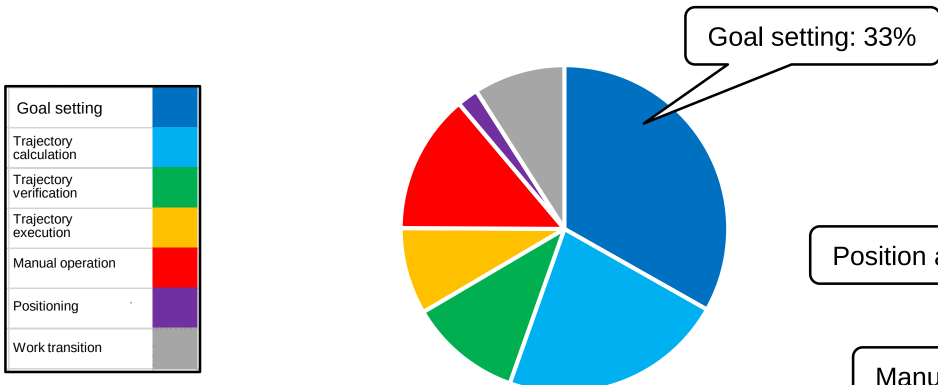
  - While operating the actual equipment, “trajectory execution”, “manual operation” and “position adjustment” using the robot comprised a higher proportion of the time.
    → If “manual operation” and “position adjustment” are made semi-automatic, it may be possible to shorten the time required.

⇒ [Conclusion] It may be possible to further shorten the time required by means of automation.

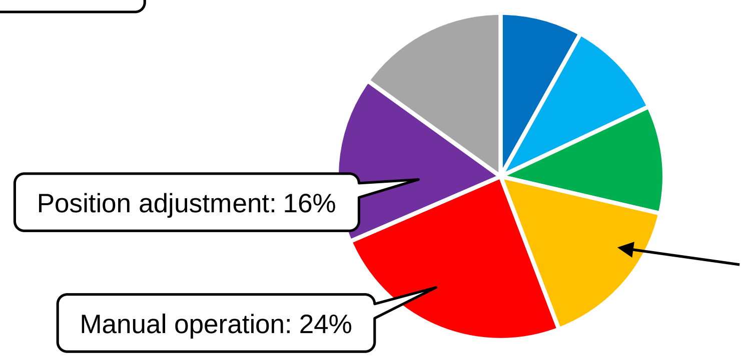




Position adjustment



Ratio of time required for work in the advance planning (simulation)
(Average value for 4 operators participating in Tests 1 - 4)



Ratio of time required for work while operating the actual equipment (site)
(Average value for 4 operators participating in Tests 1 - 4)

The proportion of time that “trajectory execution” comprises is quite large as well, but as the time required has already been shortened by using the method of regenerating trajectory data during pedal operation, it is believed that further improvement would be difficult.

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

✓ **Contribution of the results towards the reflection destinations**

[Outcome]: Automation of interference avoidance by the manipulator.
[Reflection destination]: Development will be carried out assuming the outcome will be used in the remote controlled robot for fuel debris retrieval, but application to various other works and robots in the future will be aimed for. (The environment model and the robot model will be modifiable).
[Contribution]: Enhancement of safety and efficiency of work can be expected.#

With the operational support resulting from the previous research "Development of techniques for supporting remote operation in environments with low visibility and narrow spaces" implemented in FY2019-20, there has been a reduction of approx. 90% in the time required for manual operation by veteran operators, and a reduction of approx. 80% in the time required for creating teaching data. The previous project will be implemented and advanced further in the current project.

✓ **Analysis from the viewpoint of applicability to the site**

- Site applicability is verified by confirming the viability of the series of operations using the remote controlled system including the mock-up simulating the actual site and the element test equipment, and points of improvement are identified.
- A system which is highly applicable to the site is developed in cooperation with the Fuel debris retrieval monitoring/support/integrated management WG, while incorporating the comments from site operators participating in the mock-up tests and experts in manipulator technology.

① Remote controlled tip tools for retrieval (5) Implementation items (Operating system)

✓ **Level of achievement compared to the goals**

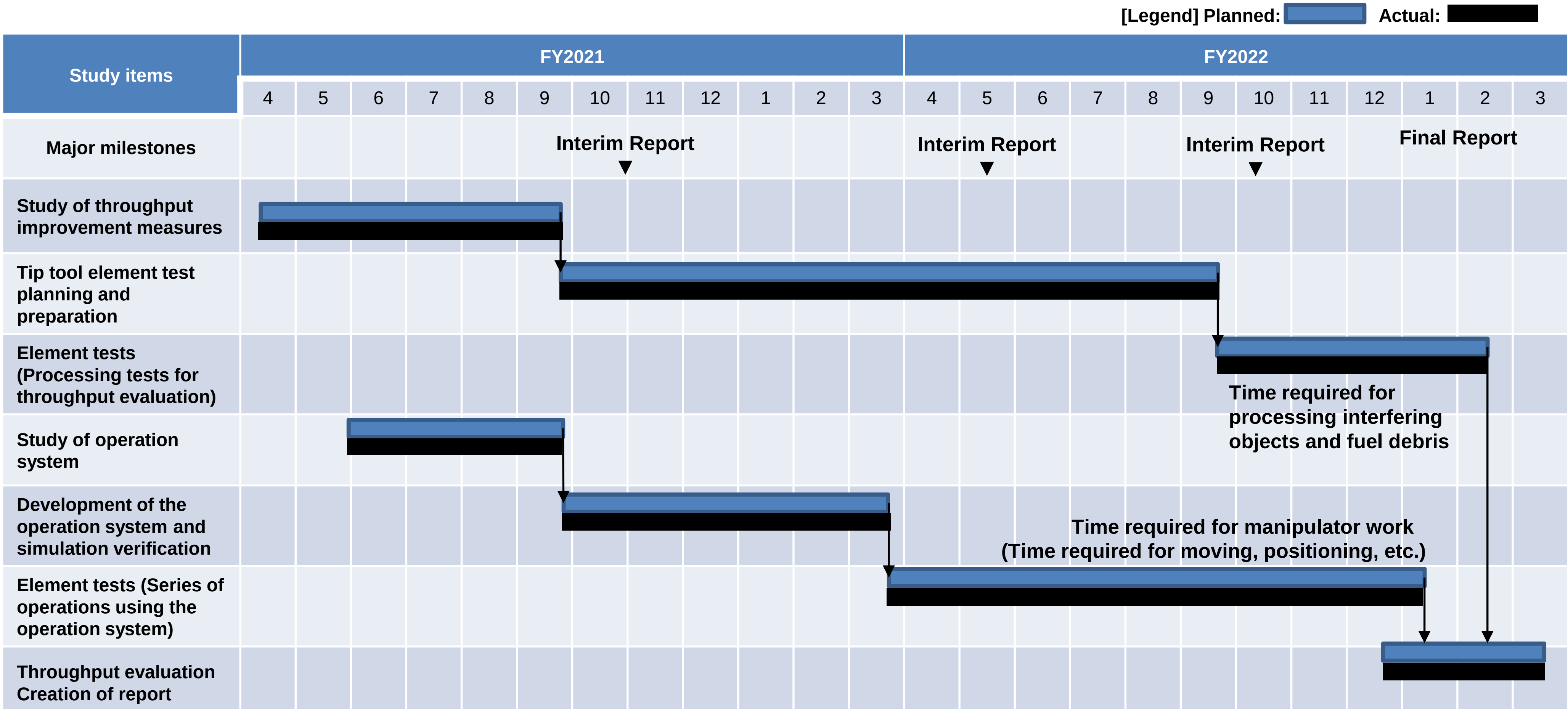
Accomplishment of all the following items (Implemented through the mock-up tests)

- Test manufacturing of the operation system
- Study of grabbing/cutting/transfer of interfering objects
- Verification of the viability of a series of operations
- Acquisition and consolidation of actual data on work procedures
- Creation of data for throughput evaluation
- Consolidation of case studies on the operation system application conditions, assumed issues, etc.

6. Implementation Items of This Project [1) (3) Advancement and Development of Retrieval Methods]

① Remote controlled tip tools for retrieval

(6) Development schedule



Remarks

A panel of experts met on July 13, 2021 in connection with the operation system.
A panel of experts met on February 8, 2022 in connection with the operation system.
A panel of experts met on August 26, 2022 in connection with the operation system.
A panel of experts met on February 8, 2023 in connection with the operation system.

① Remote controlled tip tools for retrieval

(7) Summary

Tip tool

- Processing tests were conducted using tip tools that consider the specifications of access equipment, and prospects of application of those that had issues to actual equipment were obtained. Also data for throughput evaluation such as processing time, life of blades, etc. was refined.
- Throughput was evaluated using the above-mentioned data for throughput evaluation, and was further refined.
- Requirements of the robot arm in terms of the processing reaction forces (blade pressing, blade rotation) were obtained through processing tests.
- Measures were planned in response to the issues that became evident as a result of the processing tests.

Operation system

- 4 operators participated in the interfering objects removal mock-up test using the operation system (trajectory planning) that has been developed. It was verified that a series of tasks was feasible in a confined environment such as the pedestal opening due to the collision avoidance function of the operation system.
- The importance of position adjustment and the necessity of collision avoidance while performing the grabbing action were clarified through the mock-up tests. Also, the work items that the operators took time to perform were verified as well.
- Items for further improving safety and efficiency of work in the future were selected from the issues identified through the mock-up tests conducted this time.

2) Development of top access method

(1) Development of technology for realizing the concept of retrieving large structures

① Method of cutting large structures

With respect to retrieving fuel debris and reactor internal structures, in order to enhance the throughput using the top access method, the method of transferring unitized large structures is being studied as part of the development being undertaken since FY2019. For establishing that method, structures need to be cut out and transferred. However, during the work of cutting out, reactor internal structures that comprise a variety of equipment from steam dryer to sparger, shroud, jet pump, etc. need to be cut in a high-dose radiation environment and in a confined space inside the reactor, and transferred. Also, the method of cutting and transferring large structures other than the reactor internal structures such as PCV head, RPV head, etc. under a high-dose radiation environment, in order to access the inside of the reactor, needs to be studied.

As it is presumed that the fuel has melted and is present inside the RPV, a method of cutting and separating while taking into consideration metallic reactor internal structures and ceramic fuel debris, will be studied, and element tests will be conducted using simulated test pieces. Also, the method of transferring structures after they have been cut, including PCV head, etc. until the structures are loaded on to the large transfer equipment, will be studied, and its site applicability will be evaluated.

① Method of cutting large structures

Table of Contents

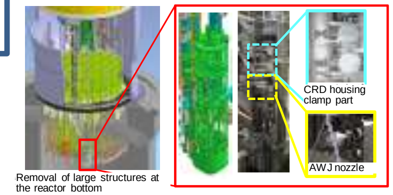
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures

Development results related to the top access method achieved so far and correlation with this project are indicated below.

Project of Development of Upgrading of Fundamental technology (Implemented in FY2017-18)

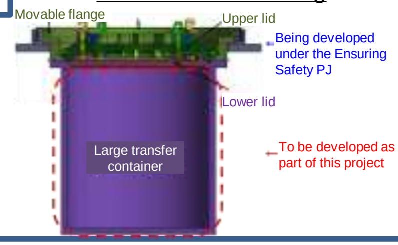
[Study of the method for finely cutting inside PCV]
- Implementation of element tests using simulated reactor bottom structures
- Estimation of throughput, identification of issues

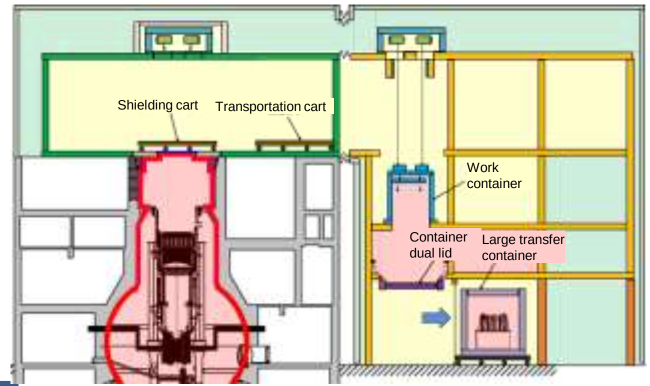


Method of fine cutting

Project of Further Increasing the Retrieval Scale of Fuel Debris (Implemented in FY2019- 20)

[Study of the method of transferring the unitized structures]
- Implementation of element tests related to disassembling the reactor bottom
- Conceptual study related to the large transfer containers
- Study of the method of criticality control until storage in containers





Method of transferring unitized large structures

Ensuring Safety Project (Implemented in FY2020-21)

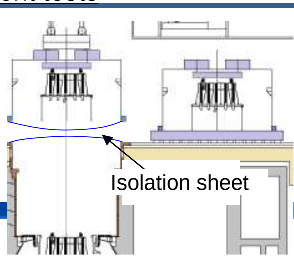
[Feasibility verification of the large transfer container lid]
- Development of the air tight mechanism for the container lid and element tests
- Study of the method of criticality control after storage in containers (during transfer)

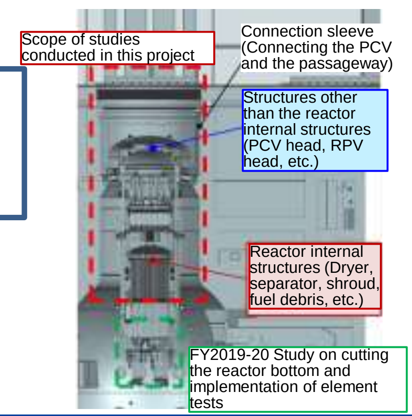
This project

[Development of technology for realizing the concept of retrieval]
- Study of the method of cutting large structures
- Study of large transfer containers (Main body)
- Study of large transportation equipment

Isolation Technology Project (Implemented in FY2021-22)

[Development of isolation technology to prevent the spread of contamination]
- Development of isolation technology and element tests





Items to be studied in future
- Study of developmental issues identified during engineering and technical development, etc.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

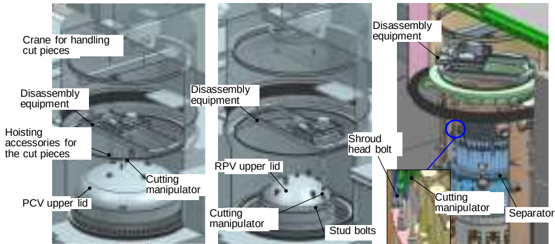
① Method of cutting large structures

No.542

Development of technology pertaining to items in red will be carried out in this project

Development results related to the top access method achieved so far and items to be developed in this project are indicated below.

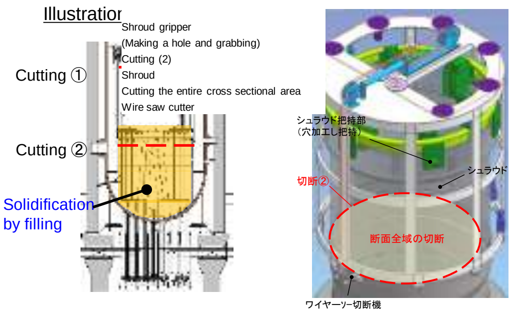
Method of cutting large pieces

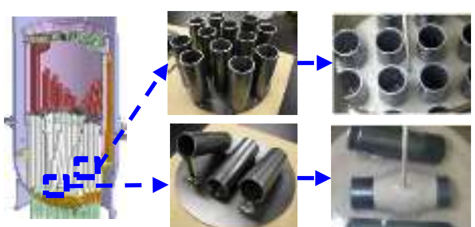


Implementation of conceptual study of the Further Increasing The Scale of Retrieval PJ (FY2019- 20)

Method of cutting structures other than reactor internal structures

Method of cutting the reactor internal structures



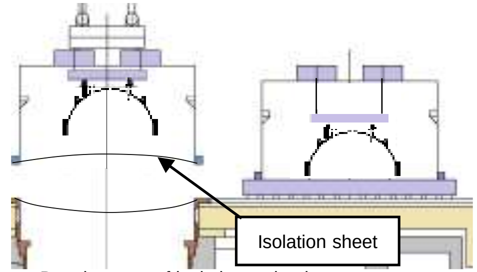


Simulation of collapsed CRGT

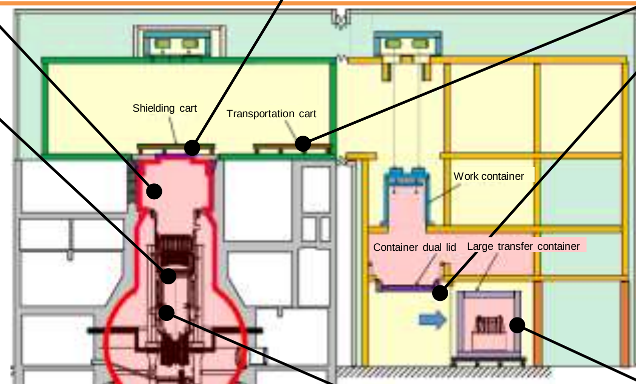
Filled with geopolymer (Inner diameter of container 300mm)

Implementation of element tests pertaining to the Further Increasing The Scale of Retrieval PJ (FY2019- 20)

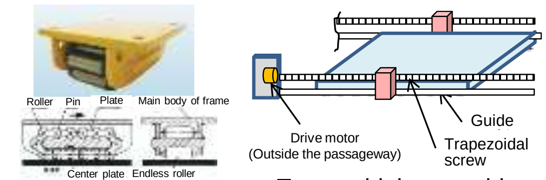
Isolation sheet



Development of isolation technology to prevent the spread of contamination (FY2021-22)

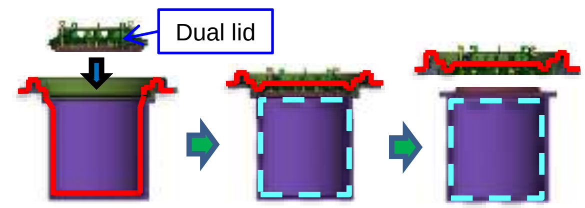


Large transportation equipment



Implementation of conceptual study of the Further Increasing The Scale of Retrieval PJ (FY2019- 20)

Air tight mechanism with dual lid



Element tests for the Ensuring Safety PJ (FY2020-21) are being planned

Cutting structures at the reactor bottom

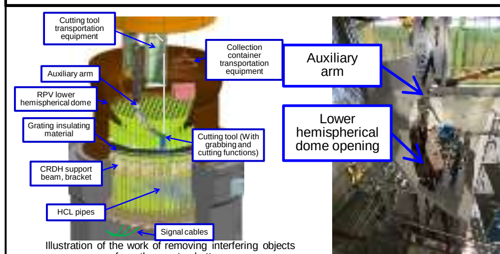
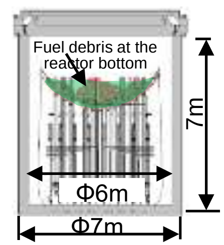


Illustration of the work of removing interfering objects from the reactor bottom

Implementation of element tests pertaining to the Further Increasing The Scale of Retrieval PJ (FY2019- 20)

Large transfer container



Implementation of conceptual study of the Further Increasing The Scale of Retrieval PJ (FY2019- 20)

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures

[Issues]

- Structures need to be cut and transferred in a high-dose radiation environment and in a confined space.
- The methods for cutting and removing structures other than the structures at the reactor bottom (reactor internal structures in the reactor core, PCV/RPV head, etc.) need to be studied and their feasibility needs to be verified.
- The feasibility of the methods for lifting up the cut structures up to the passageway needs to be verified.

[Implementation details]

・Preconditions for the studies will be consolidated.

・Method and procedures for cutting and transferring reactor internal structures and structures other than the reactor internal structures will be studied.

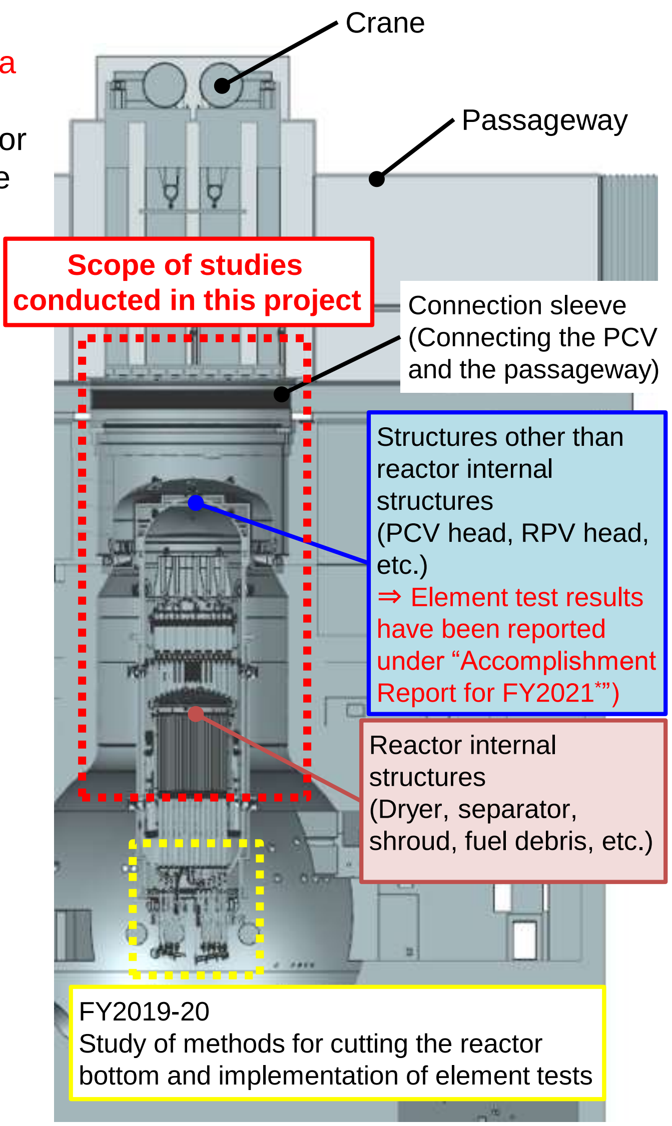
・With the method of filling, solidification and then transfer of fuel debris in mind, the methods for cutting and separating structures that are a mixture of metallic and ceramic material including the filler material will be studied for retrieving reactor internal structures, element tests will be planned and implemented, and feasibility will be verified.

・ The methods of cutting large structures such as the PCV head, etc. will be studied based on the studies on the connection sleeve to which structures other than the reactor internal structures are joined inside the reactor well, element tests will be planned and implemented, and feasibility will be verified. (Reported under "Accomplishment Report for FY2021*")

・ The methods for transferring structures after they have been cut, including the PCV head, etc. until the structures are loaded on to the large transportation equipment, will be studied, and their site applicability will be evaluated.

[Expected outcome]

- Presentation of methods for cutting reactor internal structures.
- Presentation of the methods for loading structures after they have been cut on to the large transportation equipment.



*Accomplishment Report for FY2021: https://irid.or.jp/wp-content/uploads/2022/08/2022007_deburitoridashi.pdf

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures

The development for the method of cutting large structures has been carried out by dividing it into the items, (a) - (c). The status of studies (results) and the contents of the report this time are as indicated below.

Item no.	Implementation items			Status of studies (Results)	Contents of the report	
①	Method of cutting large structures	(a)	Method of transferring large structures in their entirety	The results of the studies conducted on methods for transferring unitized large structures, including the method of application of the isolation sheet that is being implemented in another subsidy project (Isolation Technology PJ*) were consolidated.	Results of the conceptual study and overall steps	Reported in this section (Section ①)
		(b)	Structures other than reactor internal structures	The methods for cutting the stud bolts of the RPV head from among the structures inside the reactor well were studied, and element tests were implemented.	Reported under "Accomplishment Report for FY2021*"	
		(c)	Reactor internal structures	Conceptual study pertaining to the methods for cutting reactor internal structures, and element tests were conducted.	Test results report	Reported in this section (Section ①)
②	Large transfer container			Large transfer containers were test manufactured, element tests were conducted for verifying air-tightness when combined with the dual lid test manufactured during the Ensuring Safety PJ.	Conceptual study results and test results report	Reported in Section ②
③	Large transportation equipment			A comparative evaluation of the drive systems for the large transportation equipment was carried out, the motor-operated connnector system was selected, and element tests were conducted.	Conceptual study results and test results report	Reported in Section ③

*Isolation Technology PJ: "Development of fuel debris retrieval method (Development of isolation technology to prevent the spread of contamination during retrieval and transportation of large structures)" PJ

*Accomplishment Report for FY2021: https://irid.or.jp/wp-content/uploads/2022/08/2022007_dehuritoridashi.pdf

① Method of cutting large structures

[Preconditions for the methods for transferring large structures in their entirety]

✓ Preconditions for the study on methods for transferring unitized large structures are indicated in the table below.

ID.	Pre-conditions	Evidence	Remarks
1	An additional building for the top access method should be installed in addition to the additional building for the side access method.	In the case of the top access fuel debris retrieval method, transferring the unitized structures is being considered. Hence it would be difficult to use the delivery equipment in common with the side access fuel debris retrieval method.	Whether or not 1 additional building can be used in common for the top and side access equipment needs to be studied through separate engineering.
2	A frame structure should be installed so that the load of the passageway in which retrieval equipment, etc. will be installed is supported by the ground surface.	Considering the acceptable maximum load of the operation floor, it will be difficult to support the load of the passageway.	
3	After transferring the unitized RPV head, the load of the retrieval equipment can be placed on the surface of the RPV head flange.	At the current stage, since the RPV head is being supported, it is assumed that load can be placed after the RPV head is retrieved.	
4	The load of the retrieval equipment can be placed on the support for the load of existing structures inside the RPV (including on top of the structures).	As the collapse of the existing structures has not been verified at the current point in time, it is assumed that the load support can be used.	
5	The method for transferring as largest a size as possible should be considered.	As the status of damage has not been verified, the study should be conducted with a large size which is the most difficult to handle.	The transfer dimensions will be revised depending on the status inside the reactor.
6	Existing hanging metal fittings can be used while transferring structures.	Since the structures that are taller than the separator have not reached their melting point according to the results of existing analysis, it is assumed that hanging metal fittings can be used.	
7	Cutting policy of connecting parts such as bolts, etc. should be considered.	The cutting policy should be studied considering the possibility that connecting parts such as bolts, etc. may not turn due to deformation, galling, etc.	Whether the bolts should be cut or loosened needs to be evaluated depending on the actual conditions.
8	Large transfer containers should be used for transferring structures.	The policy of preventing spread of contamination should be maintained by using large transfer containers.	

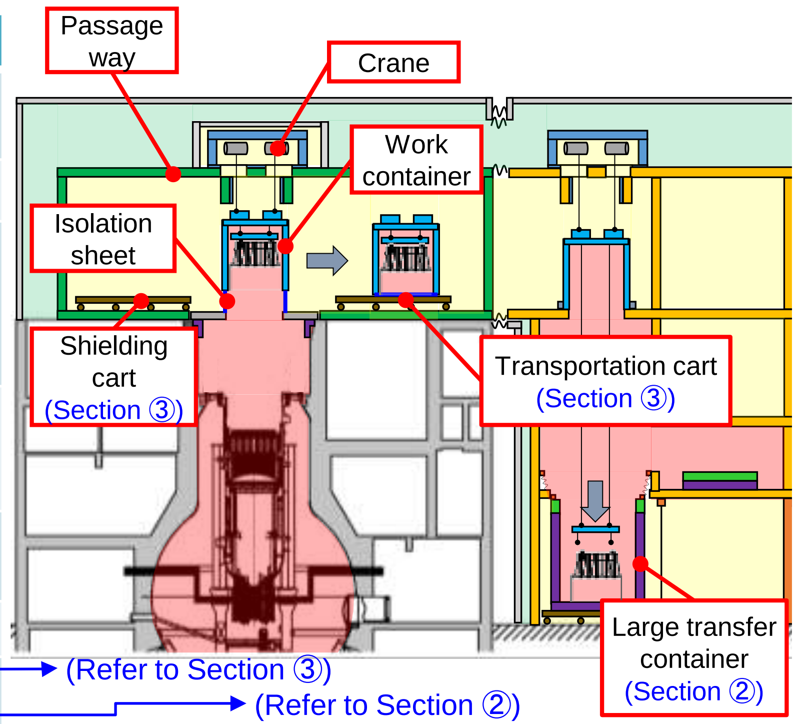
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures: (a) Method of transferring unitized large structures

[Concept of the method, and the main equipment]

- ✓ The work of cutting and transferring fuel debris and structures is implemented inside the PCV using disassembly equipment installed in the work container (access equipment inside the PCV) or a crane. The fuel debris and structures are retrieved in the form of large unitized structures without cutting them finely as far as possible.
- ✓ The retrieved large unitized fuel debris (structures) is stored in large transfer containers inside the additional building, and transferred within the premises. Further, structures (shield plug, RPV head, etc.) that are larger than the large transfer containers are cut and divided inside the additional building.
- ✓ The isolation sheet* is installed at the bottom of the work container and on top of the well for controlling spread of contamination while disengaging the work container.

No.	Equipment name	Specifications and functions
1	Passageway	• Connects to the PCV and forms the primary boundary • Confinement and shielding of radioactive materials
2	Crane	Lifting of work equipment (Does not have a transportation function)
3	Work container	• Installed on the floor surface of the passageways and on the RPV flange surface, etc., and ensures shielding thickness required while lifting the internal disassembly equipment, and during the work of storing and transferring fuel debris and waste.
4	Isolation sheet	Spread when the work container is hoisted, cut out to form a sheet on the boundary surface between the passageway and the PCV to control the spread of contamination to the passageway when the work container is disengaged.
5	Transportation cart	Transportation of equipment, fuel debris and structures (radioactive waste) between the additional building and the passageways.
6	Shielding cart	Shields the top of the reactor well when the work container is disengaged.
7	Large transfer container	Stores and transfers the structures (fuel debris) transported from inside the PCV.



*Detailed studies and element tests related to the isolation sheet were carried out as part of the Isolation Technology PJ ("Development of fuel debris retrieval method (Development of isolation technology to prevent the spread of contamination during retrieval and transportation of large structures)" PJ).

① Method of cutting large structures：(a) Method of transferring unitized large structures

[Results of studies related to the passageway]

- ✓ The mass of the passageway is several thousand tons and thus there is enormous load on the existing R/B. Hence studies were conducted assuming that a gantry would be installed in the area surrounding the R/B and the passageway would be installed on top of said gantry.
- ✓ The height of the passageway was reduced except for the well by making use of cranes. The height over the DSP was further reduced (approx. 5m) by ensuring that only the shielding cart is carried over it.
- ✓ The site boundary dose was assumed to be 10μSv/year, and the shielding thickness was re-calculated. The required shielding thickness was 58mm for the passageway and 250mm for the work container. The passageway together with the ancillary equipment were expected to be approx. 5600ton.

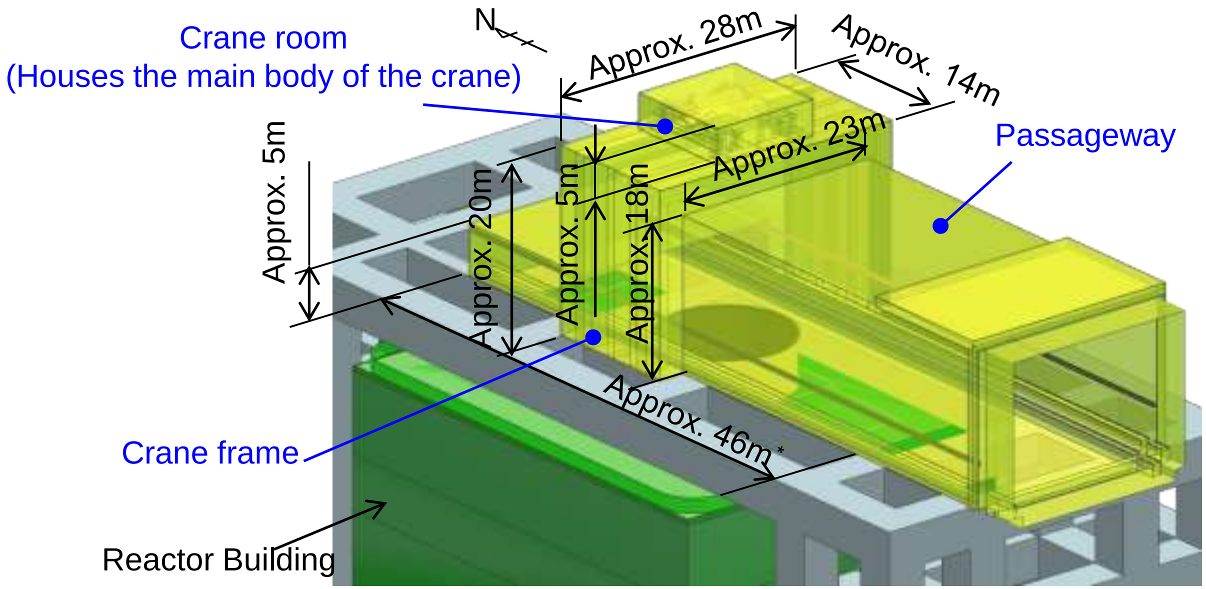


Illustration of the external appearance of the passageway

[Passageway specifications]

Items		Specifications
Function		• Confinement of radioactive materials • Shielding of radiation
Size		EW23 x NS46 x H18m
Mass		Approx. 5600 ton (Including equipment)
Shielding thickness	Passageway	58mm
	Work container	250mm

Note) The length of the passageway in the NS direction includes only the upper part of the R/B and does not include the length of the gantry. Hence, the mass of the retrieval cell will increase depending on the size of the gantry.

① Method of cutting large structures: (a) Method of transferring unitized large structures

[Method of connecting the passageway and the PCV]

- ✓ The displacement between the old operation floor and the passageway is absorbed by inserting the outer peripheral cover (installed between the old operation floor and the passageway) into the drain pipe (water seal / installed on the old operation floor side).
- ✓ The PCV, well, passageway and the outer peripheral cover form the primary boundary.

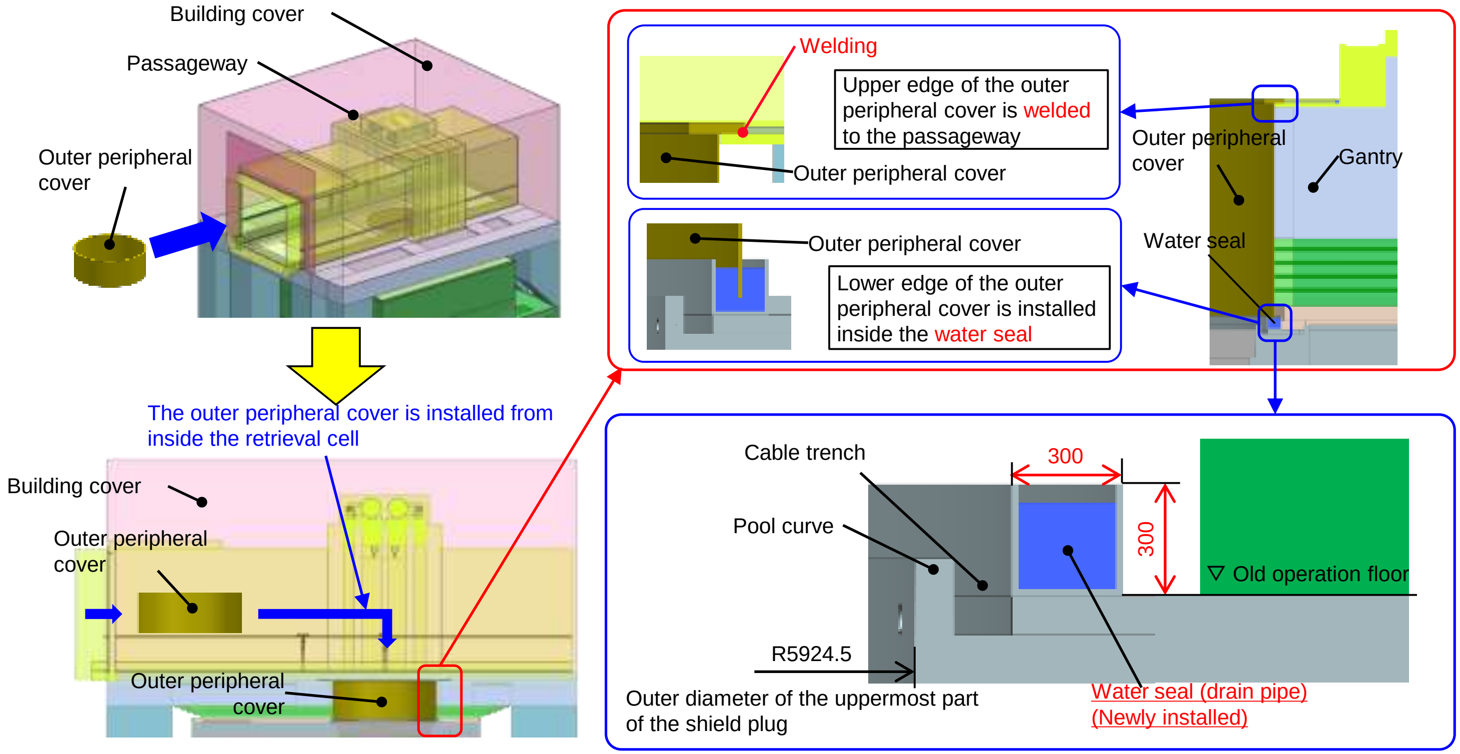
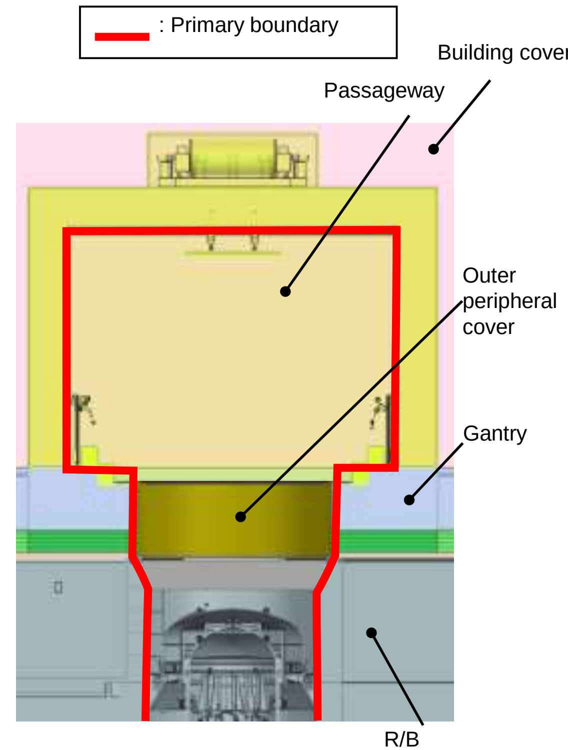


Illustration showing the carrying in and installation of the outer peripheral cover
(A pattern for carrying-in while installing the passageway is indicated as well)



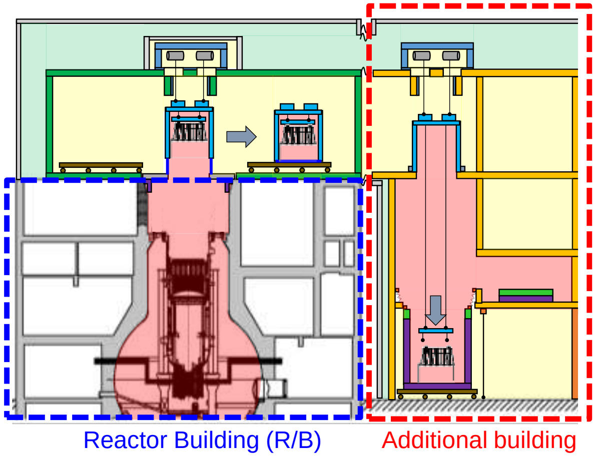
Schematic view of the structure of the primary boundary

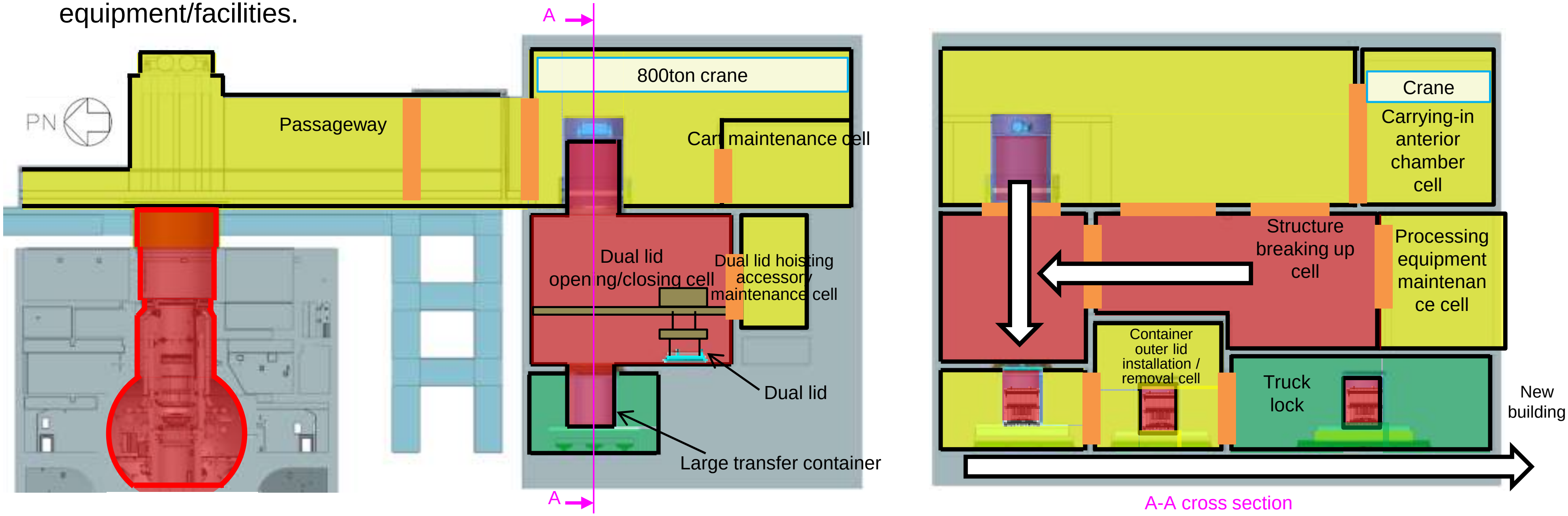
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures: (a) Method of transferring unitized large structures

[Results of studying the layout of the additional building (1/3)]

- ✓ The retrieved large unitized structures and fuel debris from inside the PCV will be stored in large transfer containers and transferred.
- ✓ For transfer using large transfer containers, work of closing the lid and the work of breaking up some of the structures (structures that are larger than the inner diameter of the large transfer container) are required. In addition to these works, in order to perform maintenance work on the transportation cart or the work equipment used inside the PCV, an additional building is required adjacent to the R/B.
- ✓ The layout of the additional building was studied considering the required work processes and the size of the equipment/facilities.

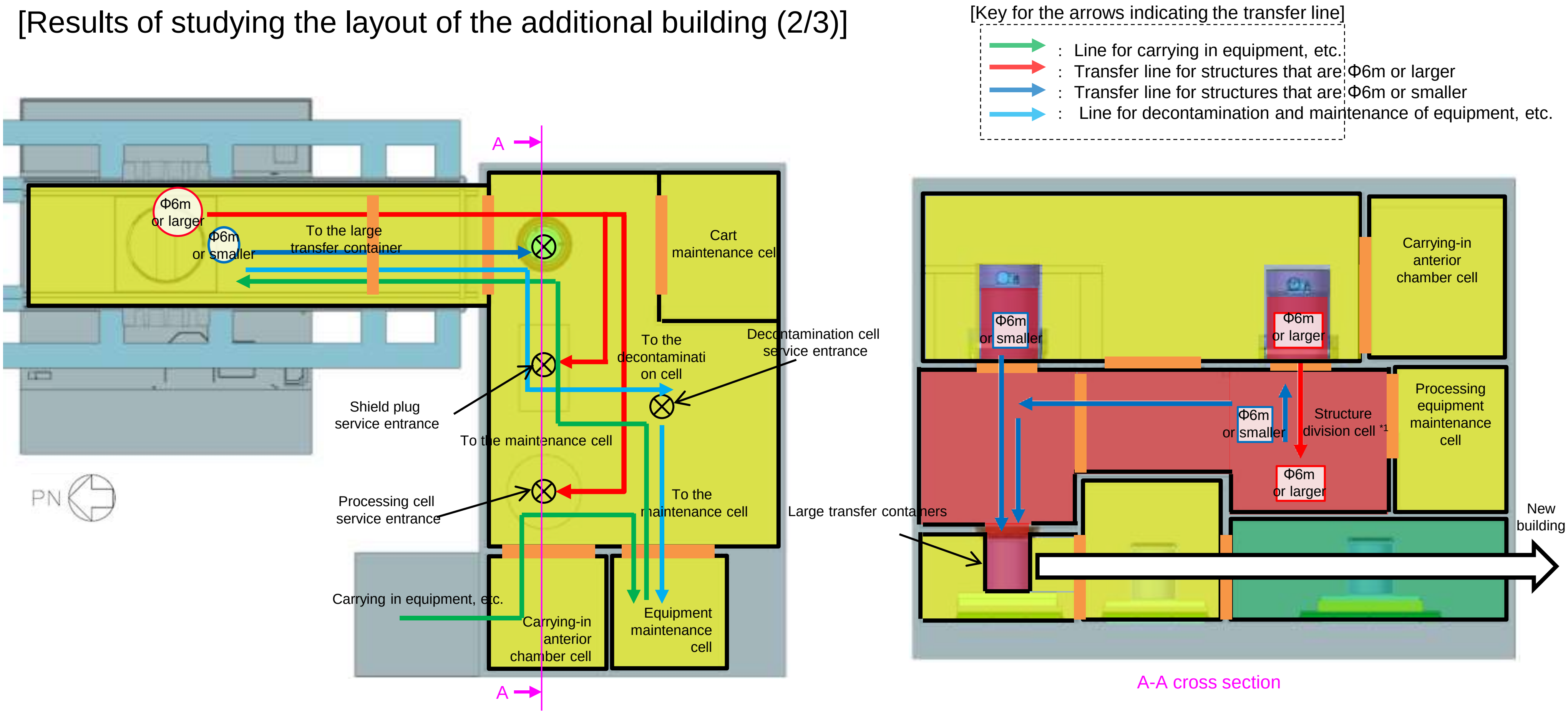




Results of studying the layout of the additional building: Transfer line for large unitized structures

① Method of cutting large structures : (a) Method of transferring unitized large structures

[Results of studying the layout of the additional building (2/3)]



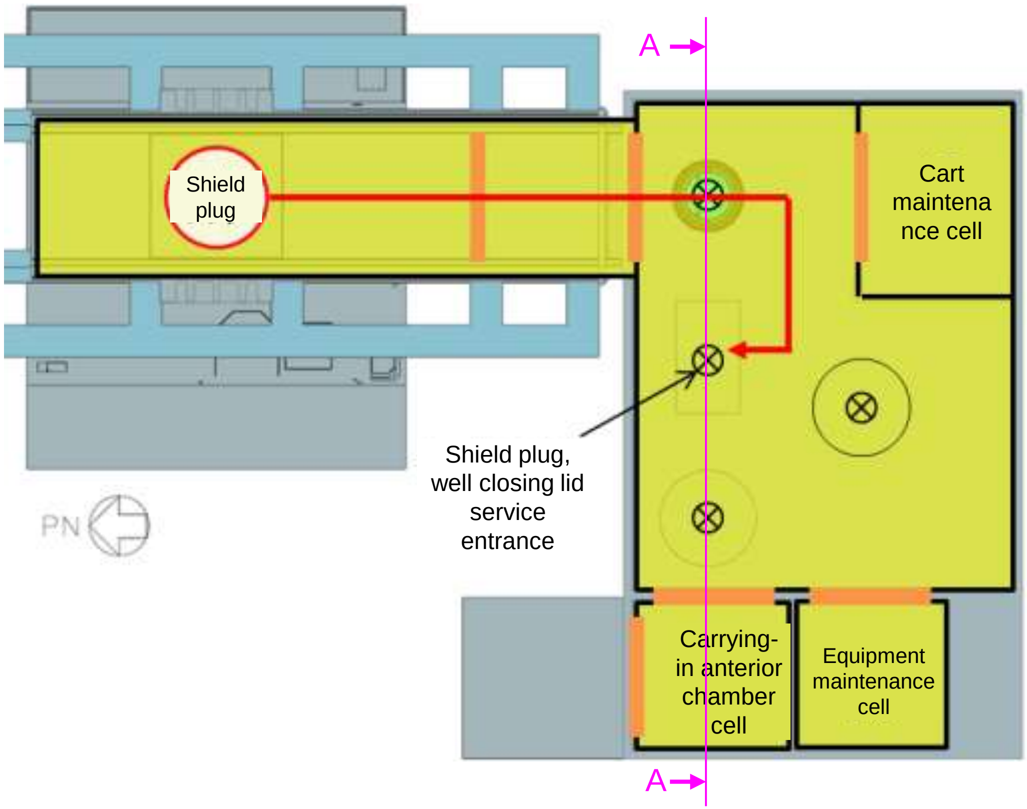
A-A cross section

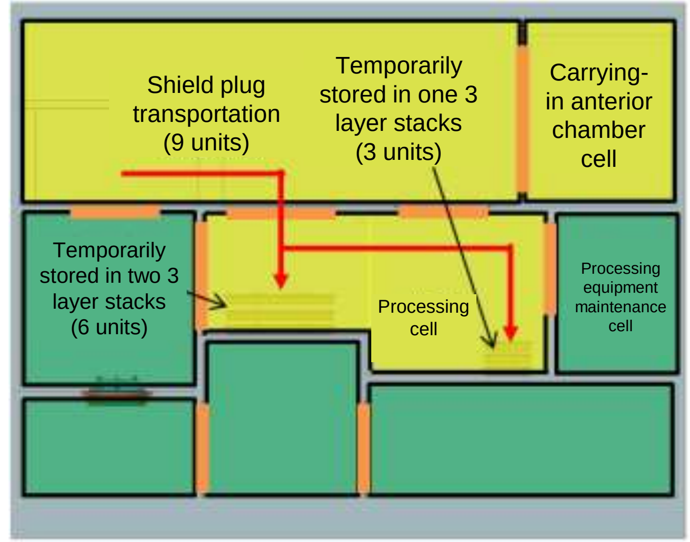
*1 Details of work carried out in the structure division cell:
- Cutting of structures (Φ6m or larger) (Saw, laser, AWJ, etc.)
- Transportation of structures that are cut to pieces that are Φ6m or smaller and their storage in large transportation containers.
(Assuming that an overhead crane is used.)

<u>Results of studying the layout of the additional building: Transfer line for large unitized structures (other than shield plug)</u>

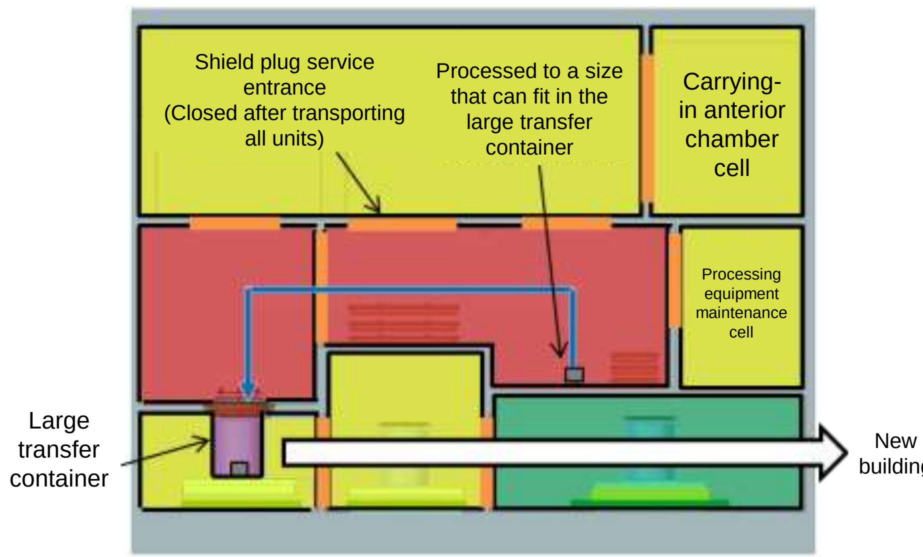
① Method of cutting large structures:
(a) Method of transferring unitized large structures

[Results of studying the layout of the additional building (3/3)]





A-A cross section (Transfer to the processing cell)



A-A cross section (Transfer after processing)

Results of studying the layout of the additional building: Transfer line for shield plug

① Method of cutting large structures: (a) Method of transferring unitized large structures

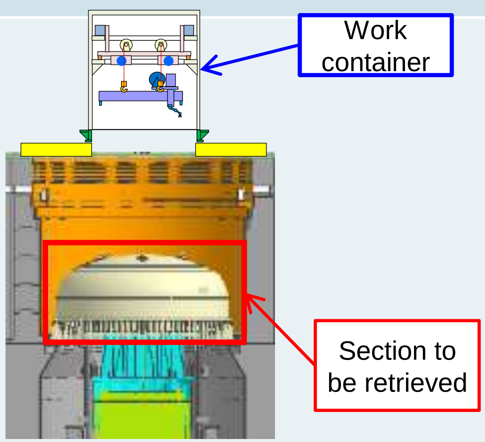
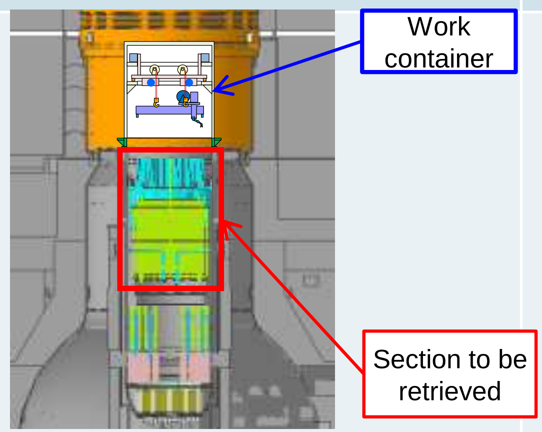
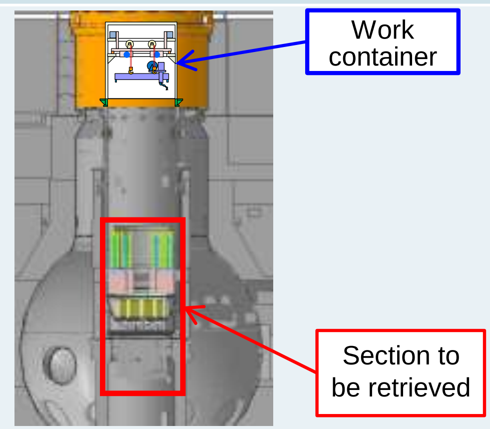
[Results of the conceptual study related to work containers]

- ✓ The work containers should be of the same height and diameter as far as possible. The inside of the containers for processing and the containers for transfer needs to be configured differently. The containers should be dedicated to the respective functions. Since the reactor core and the reactor bottom are heavier as compared to the reactor internal structures, large cranes need to be used.

  ⇒ Arrangements are made for 3 types of work containers in all.

- ✓ The location where the work container is installed changes depending on the target object to be retrieved (From the perspective of reducing the lifting height of the crane).

<u>List of locations where the work container is installed with respect to the items to be transferred and the work containers used.</u>

Items to be transferred	PCV head, RPV head insulating material, RPV head	Dryer, separator, **FDW/CS**, etc.	Reactor core and reactor bottom
Height at which work container is installed	On the operation floor (floor surface of the cell)	RPV flange surface	
Work container (At the time of cutting)	Work container ①		
Work container (At the time of transferring)	Work container ①’		Work container ② (For transferring heavy weight objects)
Image illustrating installation of work container			

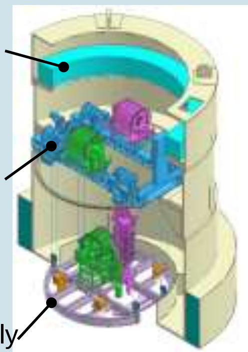
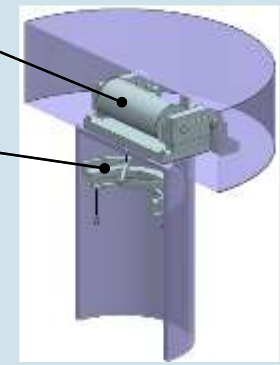
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures：(a) Method of transferring unitized large structures

[Results of the conceptual study related to work containers]

✓ Configuration of the 3 types of work containers used for the unitized transfer method is given below.

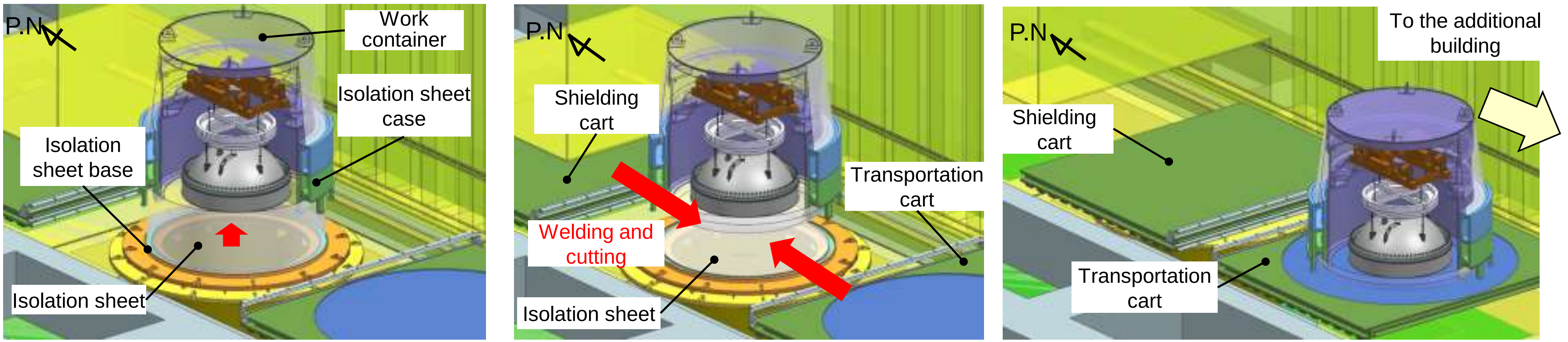
*The crane room has been excluded

	Work container ①	Work container ①’	Work container ②
Illustration			
Application	Cutting of structures and fuel debris	Transfer of structures and fuel debris	Transfer of reactor core and reactor bottom
Built-in equipment	Crane, cableveyor, disassembly equipment	Crane (150ton), hoisting accessories	Crane (400ton), hoisting accessories
Dimensions [mm]	Φ8900 x H9500	Φ8900 x H13270	Φ12600 x H11840 (Φ6000 x H7770: excluding the crane room)
Mass[ton] (Container only)	Approx. 680	Approx. 680	Approx. 410
Shielding thickness [mm]	250	250*	250*

① Method of cutting large structures: (a) Method of transferring unitized large structures

[Method of using the isolation sheet* in combination with the work container]

- ✓ An isolation sheet case is installed alongside the work container. The isolation sheet is enclosed in this case.
- ✓ The isolation sheet is installed for the purpose of controlling the spread of contaminated substances from inside the PCV and from inside the work container to the retrieval cell at the time of disengaging the work container.
- ✓ Following are the methods for using the isolation sheet:
  - ◆ The end of the isolation sheet is attached to the isolation sheet base at the time of placing the work container. The sheet is spread when the work container is raised.
  - ◆ The welding and cutting of the isolation sheet is carried out using the lateral part of the shielding cart and the transportation cart.
  - ◆ The work container that is sealed air-tight with the isolation sheet is transferred to the additional building using the transportation cart.



Step 1: Lifting up the work container (raising)
Step 2: Welding and cutting the isolation sheet
Step 3: Transferring the work container to the additional building

Image illustrating the transfer of a work container using the isolation sheet

*Detailed studies and element tests related to the isolation sheet were carried out as part of the Isolation Technology PJ ("Development of fuel debris retrieval method (Development of isolation technology to prevent the spread of contamination during retrieval and transportation of large structures)" PJ).

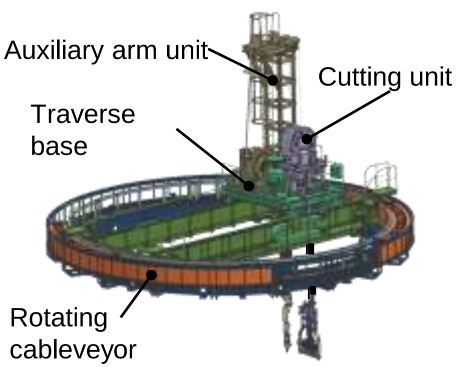
① Method of cutting large structures： (a) Method of transferring unitized large structures

[Basic approach towards transferring structures]

- ✓ The effectiveness of using the polar crane method as disassembly equipment was verified during the PRV head stud bolt cutting test conducted in FY2021.
- ✓ The method of supporting and installing the polar crane was the issue in cutting structures using this method.

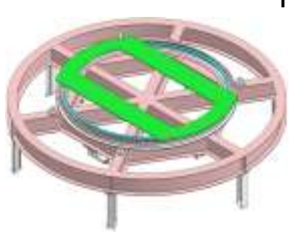
⇒ An "installation base" on which load can be actively placed inside the RPV will be used in combination. The main proposal is to install an installation base on existing structures or on the supporting elements inside the RPV, and thereafter to install the dismantling equipment used for the polar crane method on the installation base.

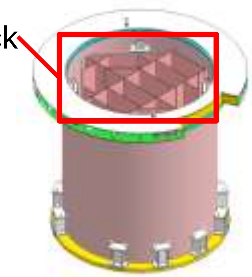
- ◆ The installation base is provided with functions other than supporting the dismantling equipment in accordance with the characteristics of the object to be cut. The method will also have additional functions such as using it also as a rack for storing the cut pieces, a fall prevention mechanism for the cut pieces, etc.
- ◆ Since the installation base and the dismantling equipment cannot be installed simultaneously (due to size limitations of the work container), the work container needs to be replaced once after carrying in the installation base.



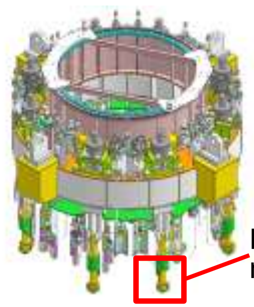
RPV head disassembly equipment (Polar crane)

[An example of installation base]

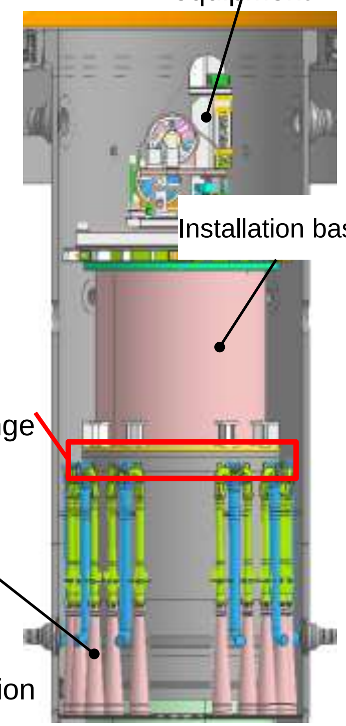

For PCV head



For jet pump (Mounting the rack)



For the reactor bottom (With a fall prevention mechanism)



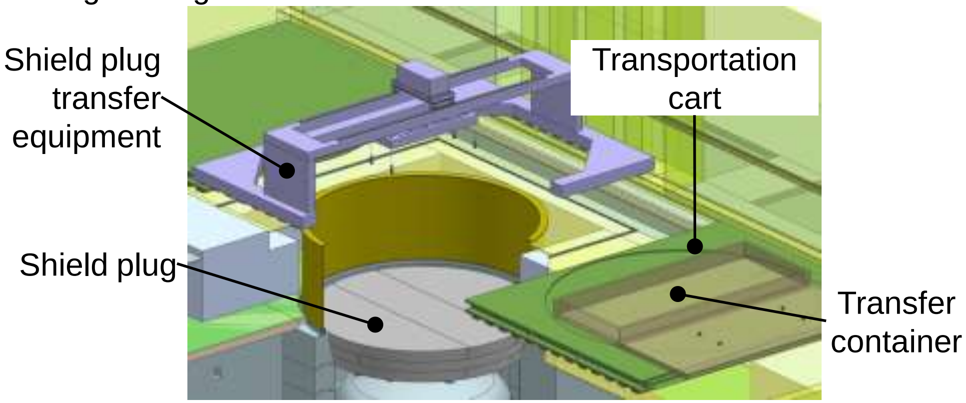
Configuration of the equipment while transferring with jet pump

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

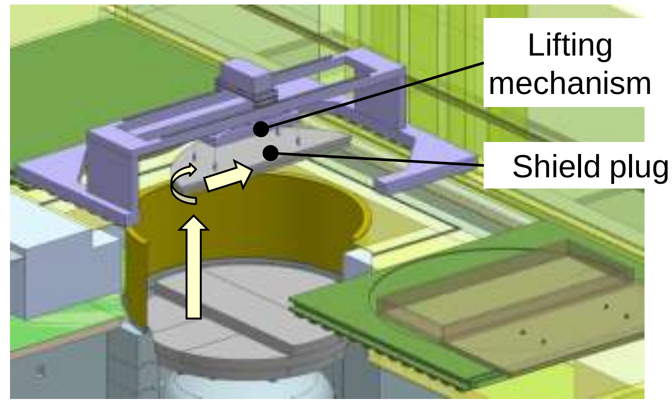
① Method of cutting large structures：(a) Method of transferring unitized large structures

[Basic approach towards transferring structures]

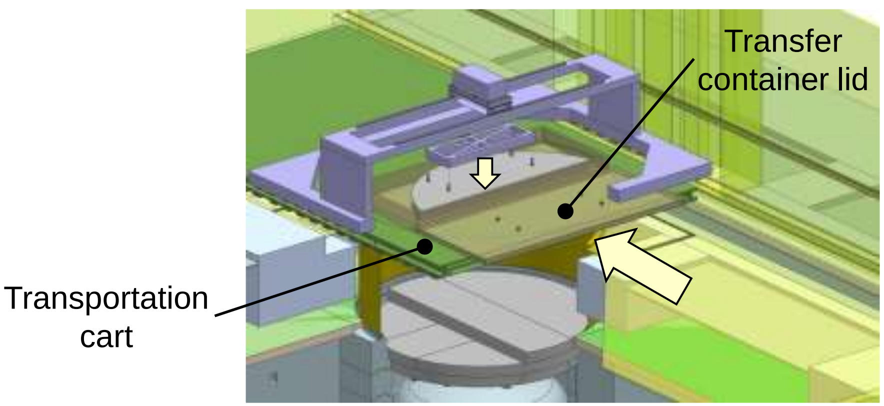
- ✓ It was determined that it would not be reasonable to transfer the shield plug using a work container from the perspective of the installation location and size.
- ✓ It will be removed by using a transportation cart in combination with a dedicated transfer equipment (shield plug transfer equipment) having a lifting mechanism that can rotate and traverse.



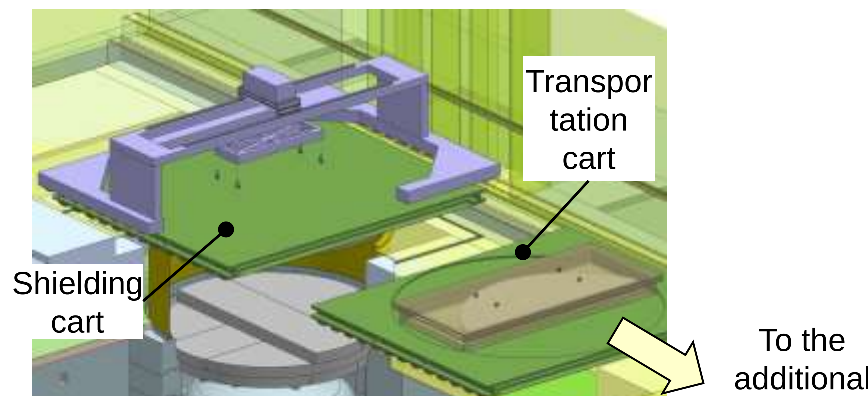
1. Carrying in the shield plug transfer equipment



2. Lifting up the shield plug



3. Moving the transportation cart under the shield plug and placing the shield plug into the container

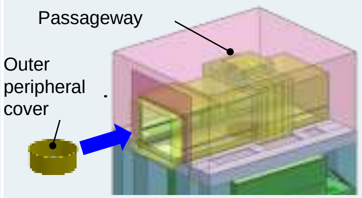
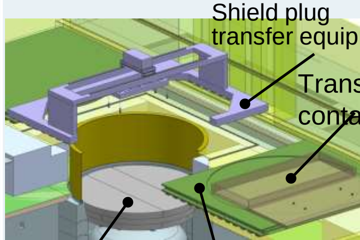
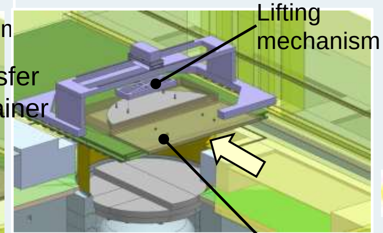
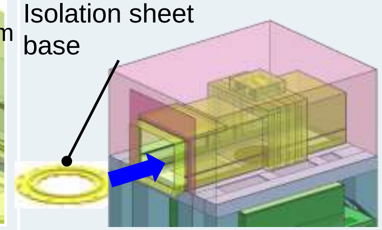
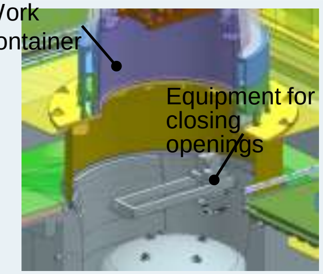


4. Closing the lid of the transfer container and transferring with the transportation cart

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures : (a) Method of transferring unitized large structures

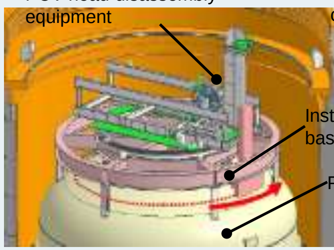
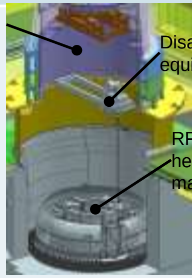
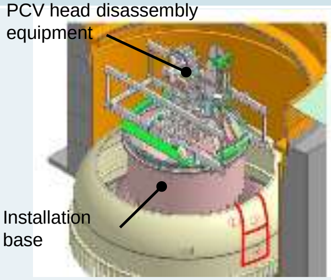
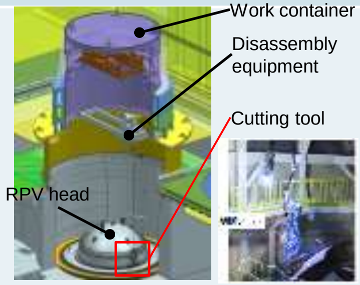
[Work steps (1/4)]

Step	1. Preparatory work	2. Shield plug transfer		3. Closing of the well opening	
Contents	Passageway installation and R/B connection	Carrying in of dedicated equipment	Shield plug removal and transfer	Isolation sheet base installation	Closing of the well opening
Work illustration					
Remote operation / manual	Remote operation / manual	Remote operation		Remote operation	Remote operation
Details of work contents	The passageway is installed on the gantry. In parallel, after installing the water seal drain pipe on the surface of the old operation floor, the outer peripheral cover is installed on the cell floor surface and is secured by welding.	The dedicated equipment (shield plug transfer equipment) is carried in from the additional building, and is positioned on the well. Simultaneously, the transfer container is mounted on the transportation cart, and is positioned near the transfer equipment.	The shield plug is lifted up using the shield plug transfer equipment, the transportation cart is moved under the shield plug, and the shield plug is placed in the container. After closing the lid, it is transferred with the transportation cart (moved to the additional building).	The isolation sheet base for installing the work container on the well is carried in, and installed on the passageway floor surface. The transportation cart is used for carrying it in from the additional building.	The work container is installed on the well, the equipment for closing the opening inside the work container is lowered, and the existing opening inside the well is closed using the arm at the extremity.
Issues	• Study of temporary shield during manual work • Optimization of the number of partitions in the cell by reducing the shielding thickness for installation	• Study of the hoisting accessories for transferring the deformed shield plug • Method of controlling dust dispersion while removing the shield plug		• Method of installation by remote operation	• Method of closing the openings • Substantiation of equipment for closing the openings
Remarks					

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures：(a) Method of transferring unitized large structures

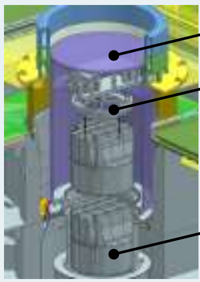
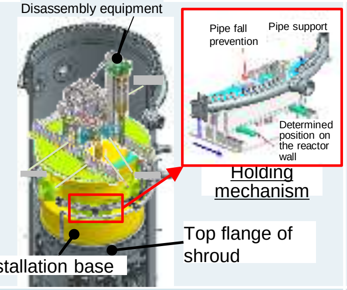
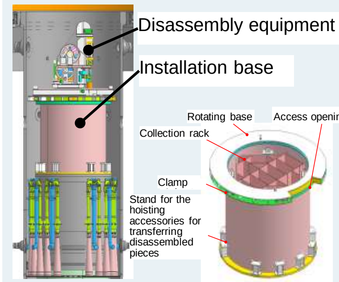
[Work steps (2/4)]

Step	4. Transfer of PCV head and heat insulating material			5. RPV head transfer	
Contents	Disassembly of top portion of PCV head	Transfer of RPV head and heat insulating material	Disassembly of bottom portion of PCV head	Cutting of stud bolts	Transfer of RPV head
Work illustration					
Remote operation / manual	Remote operation			Remote operation	
Details of work contents	After installing the installation base on the PCV head, the PCV head disassembly equipment is set up on the installation base. After cutting the PCV head top portion with the PCV head disassembly equipment, the cut pieces of the PCV head top portion as well as the installation base are placed in the work container and transferred.	The cutting tool is suspended from the disassembly equipment installed inside the work container, and the bolts fastening the heat insulating material are cut. The work container is replaced, and the heat insulating material is placed inside the work container and transferred.	After installing the installation base on the RPV head, the PCV head disassembly equipment is set up on the installation base. After cutting the PCV head bottom portion with the PCV head disassembly equipment, the cut pieces are placed in the installation base. The cut pieces of the PCV head bottom portion as well as the installation base are placed in the work container and transferred.	The cutting tool is suspended from the disassembly equipment installed inside the work container, and the stud bolts are cut.	The hoisting accessory inside the work container is suspended, and slung on to the RPV head. The RPV head is lifted up, placed inside the work container, and transferred to the additional building.
Issues	• Disassembly and removal method when the PCV head hanging metal fitting is not in a sound condition • Remote slinging method			• Remote slinging method	
Remarks				Element tests have been implemented (End of FY2021)	

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures：(a) Method of transferring unitized large structures

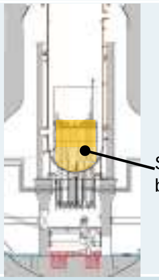
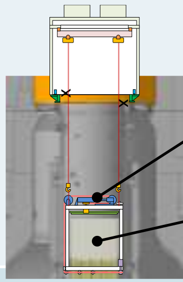
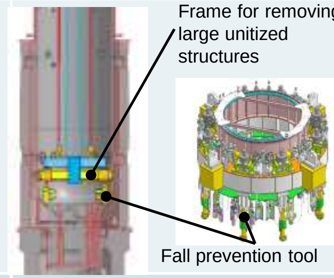
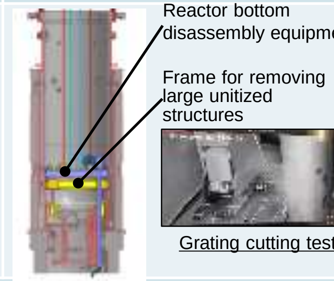
[Work steps (3/4)]

Step	6. Dryer transfer	7. Separator transfer	8. FWS/CS pipe removal	9. Jet pump transfer	10. Upper grid plate transfer
Contents	Dryer transfer	Separator transfer	FWS/CS pipe removal	Jet pump transfer	Upper grid plate transfer
Work illustration					
Remote operation / manual	Remote operation	Remote operation	Remote operation	Remote operation	
Details of work contents	The hoisting accessory inside the work container is suspended, and slung on to the dryer. The dryer is lifted up, placed inside the work container, and transferred to the additional building.	After installing the installation base on the separator, the disassembly equipment is set up on the installation base. The cutting tool is suspended from the disassembly equipment, the bolts are rotated (or cut) and the fastening is released. After replacing the work container, the separator is lifted up, placed inside the work container and transferred.	After installing the installation base on the top flange of the shroud, the disassembly equipment is set up on it. The pipe is cut with the cutting tool suspended from the disassembly equipment while holding the pipe with the holding mechanism inside the installation base. The cut pipe as well as the installation base are placed in the work container and transferred.	After installing the installation base on the top flange of the shroud, the disassembly equipment is set up on it. The cutting tool is suspended from the disassembly equipment, and the jet pump is cut. The cut pieces are placed on the rack inside the installation base. The cut pieces are placed in the work container along with the installation base and transferred.	After installing the installation base on the top flange of the shroud, the disassembly equipment is set up on it. The cutting tool is suspended from the disassembly equipment, and the portion under the middle flange of the shroud is cut. The top portion of the shroud is placed inside the work cotainer along with the upper grid plate and transferred.
Issues	• Remote slinging method • Sound condition of the hanging metal fitting	• Remote slinging method • Sound condition of the hanging metal fitting	• Fall prevention of pipe • Sound condition of the top flange of the shroud	• Remote slinging method • Sound condition of the top flange of the shroud	• Remote slinging method • Sound condition of the top flange of the shroud
Remarks				It is assumed that the structures below the jet pump will be handled as fuel debris.	

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures: (a) Method of transferring unitized large structures

[Work steps (4/4)]

Step	11. Reactor core transfer		12. Reactor bottom transfer		
Details	Filling and solidification	Reactor core cutting and transfer	Fall prevention tool installation	Reactor bottom disassembly	Reactor bottom transfer
Work illustration				 Grating cutting test	
Remote operation / manual	Remote operation		Remote operation		
Details of work contents	The equipment for injecting geopolymer is suspended from the work container, and the reactor core and reactor bottom are filled from the upper surface of the shroud and solidified.	• After suspending the disassembly equipment and setting it up on the shroud support, the portion of the shroud under the lower flange of the shroud is cut using the cutting tool at the tip. • After changing the disassembly equipment (cutting tool), the reactor core (filled) is cut. After cutting the shroud and reactor core, shroud as well as the reactor core are placed inside the work container and transferred.	After making an opening in the lower hemispherical dome of the RPV, the installation base is installed on the shroud support, and is fastened to the lower hemispherical dome using the fall prevention tool at the tip.	After setting up the reactor bottom disassembly equipment on the frame for removing large unitized structures, interfering objects and connecting parts such as grating, heat insulating material, beams, etc. are cut using the disassembly equipment. After completing the work of cutting the fastening and connecting parts, the portion of the lower hemispherical dome that is left is cut, and the lower hemispherical dome is separated from the RPV.	The hoisting accessory inside the work container is suspended, and slung on to the frame for removing large unitized structures. Along the frame for removing large unitized structures, the reactor bottom is placed in the work container and transferred to the additional building.
Issues	• Filling method in accordance with the status of damage	• Sound condition of the shroud support	• Sound condition of the shroud support • Sound condition of the lower hemispherical dome	• Sound condition of the shroud support • Method of effectively cutting the interfering objects and the connecting parts	• Remote slinging method • Sound condition of the lower hemispherical dome
Remarks				Element tests have been implemented (FY2020)	

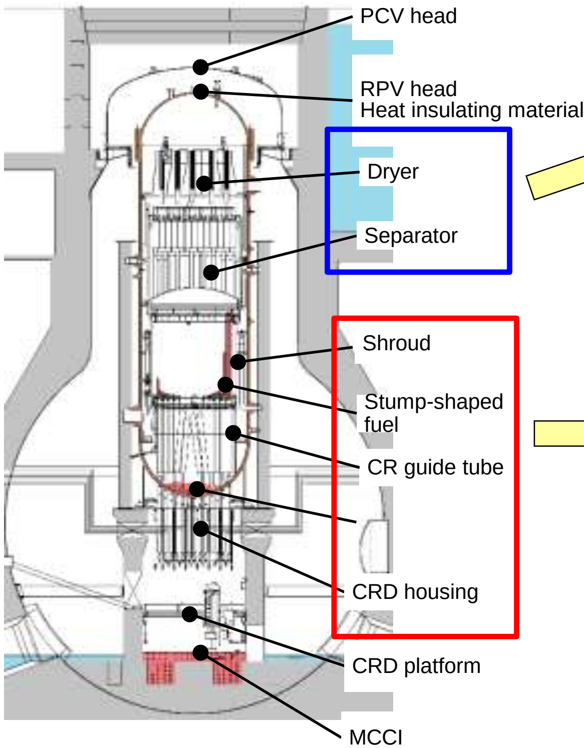
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

No.561

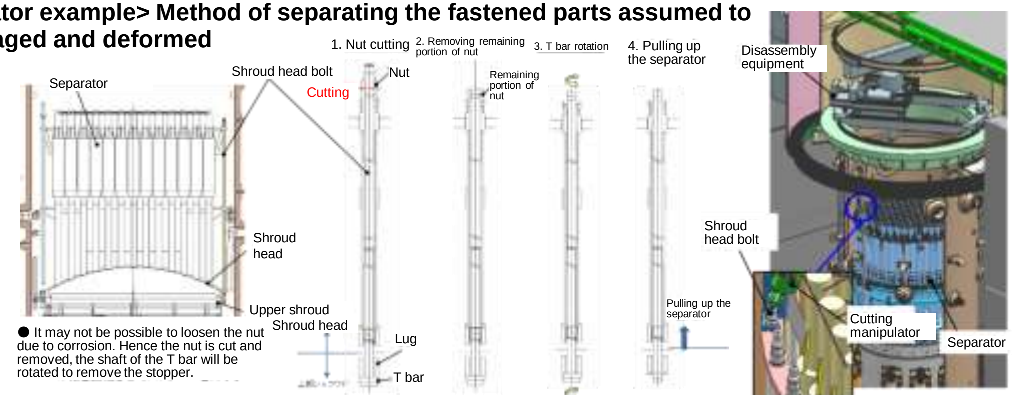
① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Development policy]

Element tests on the reactor core filling and solidification material for the reactor internal structures below the shroud were implemented focusing on the study on the method for cutting structures into large pieces and the concept of the equipment.



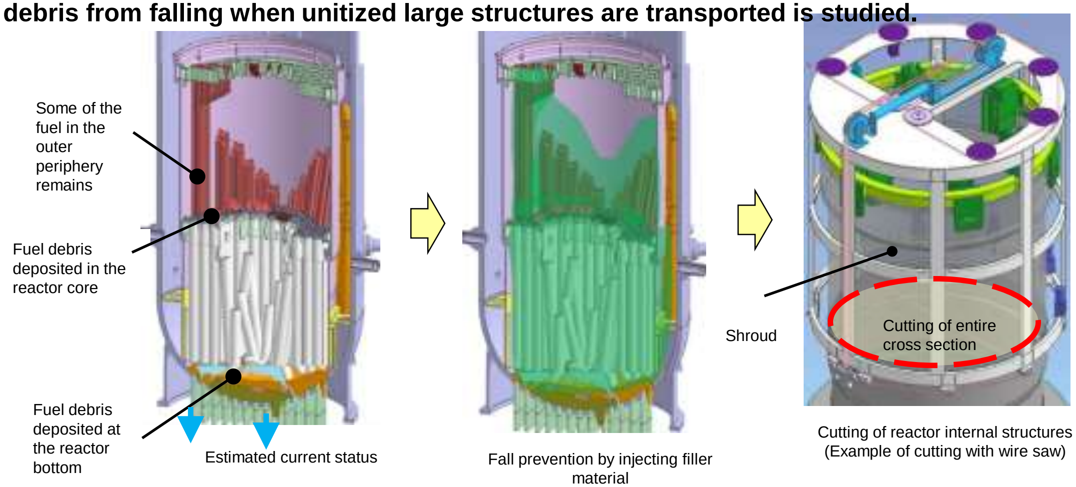
<Separator example> Method of separating the fastened parts assumed to be damaged and deformed



Example of the concept of disassembly equipment

Studies are conducted on the method of cutting structures and the concept of the equipment.

<Example of shroud> Fuel debris retrieval by means of filling and solidification for preventing fuel debris from falling when unitized large structures are transported is studied.



Cutting of reactor internal structures (Example of cutting with wire saw)

Studies were conducted on the method of cutting structures and the concept of the equipment, and element tests were conducted related to the rector core filling and solidification material.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Study conditions]

- The study conditions pertaining to cutting reactor internal structures are indicated below.

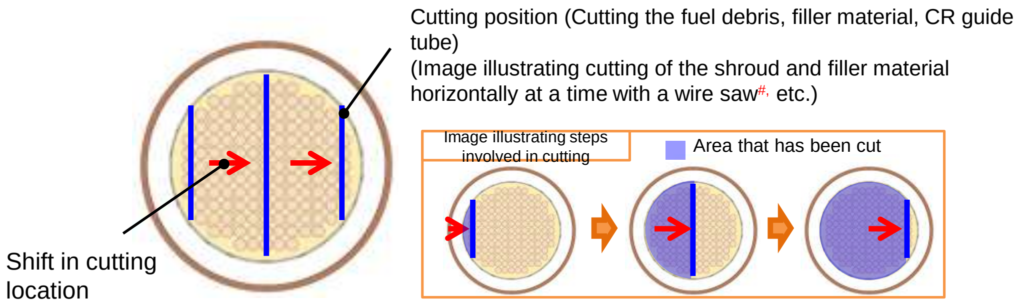
ID.	Study conditions	Supplementary explanation	Remarks
1	The method of filling and solidification, and cutting will be studied under the conditions wherein the interfering objects from the reactor well to the separator are removed.	Work will be performed under the condition wherein the structures other than reactor internal structures such as dryer and separator are already removed.	
2	The outflow when geopolymer is filled inside the shroud is comparatively less. A condition wherein the geopolymer continues to pile up is assumed.	First, as the viability, etc. of large scale filling will be verified, study will be conducted under the conditions wherein the filler material can be filled. If the reactor bottom is significantly damaged and filling is difficult, the method of localized filling around the fuel debris will be selected.	
3	The cutting method will be studied under the conditions wherein filler material is filled inside the shroud without any gaps.	As cutting including the shroud as well as the filler material is assumed to be most difficult.	
4	The jet pump must be removed at the time of cutting the shroud.	As it is assumed that at the time of cutting the shroud the jet pump will have already been removed and the tool will have been set in the gap between the shroud and the RPV inner surface	Since the prospects of viability of cutting the jet pump (SUS304, maximum sheet thickness 11mm) is comparatively high, the level of priority of development is evaluated to be low.
5	The shroud, etc. must not be significantly tilted.	The condition of the shroud is uncertain, but it was tentatively installed for the study. A configuration that would make it possible to modify the method of fixing the tools depending on the actual site conditions will be studied.	Results of the estimation of shroud condition carried out during the Understanding the Status Inside the Core PJ Unit 1: Likely to have been damaged Unit 2: It is assumed that there is no large scale damage Unit 3: Likelihood of being sound and likelihood of being damaged, both are conceivable. Source: IRID "Subsidy Project of Decommissioning and Contaminated Water Management (Upgrading of the Comprehensive Identification of Conditions inside Reactor) Accomplishment Report for FY2017"

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Study on the course of cutting]

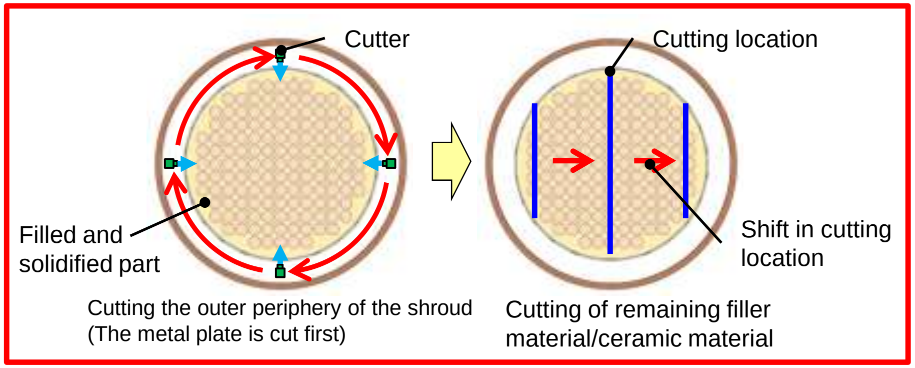
- In order to cut the reactor core after filling and solidification, methods of cutting the shroud structures and the filled and solidified parts were studied.
- Several structures (materials) need to be cut for removing the shroud as a unitized structure.
- If bulk cutting indicated in Cutting Example 1 is considered as a pre-condition, adopting a technology that enables cutting of both the outer circumference of the shroud and the filled and solidified part becomes a pre-condition. However, under the current circumstances, there are no prospects of a technology for cutting both at a time.
- First, Cutting Example 2: Cutting in parts is considered as a pre-condition, and a technology that can be applied to cutting the outer periphery of shroud and the filled and solidified part is studied.
- During Cutting Example 2: Cutting in parts, first the shroud is cut, thereafter, the filled and solidified part is cut with the wire saw which has prospects of being able to cut the filled and solidified part.

① Configuration: ・Outer periphery: Sheet thickness approx. 38mm, Material SUS
・Interior: Inner diameter approx. 4.4m, Material　Filler material + CR guide tube (SUS) + Fuel debris (ceramic material)
② Prospective filler material: Geopolymer



#: The wire saw is a technology that is extensively used in cutting concrete, however, it is difficult to cut thick stainless steel plates with it.

[Cutting Example 1: Bulk cutting]



[Cutting Example 2: Cutting in parts]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Selection of cutting method]

A remote operation cutting technology is desirable for the shroud considering the reaction force while cutting and emergency collectability.
The remote operation cutting technology, its applicability to cutting the shroud, merits and demerits are consolidated in the table below. Since stainless steel cannot be cut by means of gas cutting, and in the case of plasma arc, since there is a risk of not being able to cut depending on the properties of the object to be cut, these two methods were excluded from the potential cutting methods.

[Merits and demerits of the various types of remote operation cutting technologies]

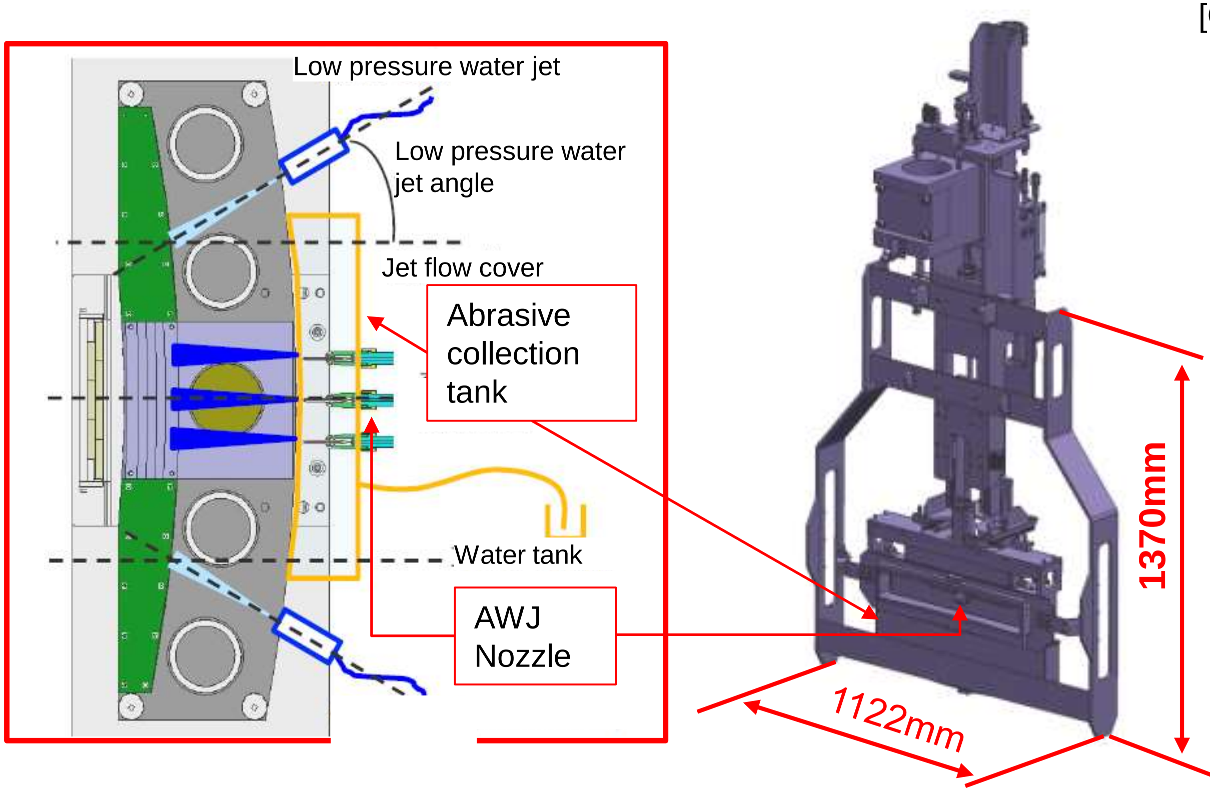
(Red frame: Prospective cutting technologies)

Cutting technology	Applicability to shroud cutting	Merits	Demerits
Gas cutting	• Cannot cut stainless steel	-	-
Laser	• Can cut stainless steel • Can cut thick plates depending on the power	• Can reduce the size of the cutting head • Relatively small amount of secondary waste (Tools for collecting secondary waste are not required)	• Dross gets generated and hinders cutting • Spread of contamination due to formation of fumes • The fuel debris inside the reactor is likely to get damaged (Risk of criticality due to change in shape)
Plasma arc	• Can cut stainless steel (However, may not be able to cut parts that are adhered to fuel debris) • Can cut thick plates depending on the power	• Can reduce the size of the cutting head • Relatively small amount of secondary waste	• Dross gets generated and hinders cutting • Spread of contamination due to formation of fumes • Needs adjustment of torch position • Cannot cut areas that do not conduct power
AWJ	• Can cut stainless steel • Can cut thick plates	• Can reduce the size of the cutting head • Comparatively less heat input into the structure	• Relatively large amount of secondary waste as abrasive is sprayed • The fuel debris inside the reactor is likely to get damaged (Risk of criticality due to change in shape)

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Selection of cutting method]

The major demerit of AWJ is the generation of secondary waste as a result of spraying abrasive.
The quantity of abrasive used per bolt in the RPV head bolt cutting element test conducted in FY2021, and the rate of collection of abrasive in the actual equipment (assumed value) are indicated in the figure on the right.
The configuration of the equipment for collecting the secondary waste when the shroud is cut using AWJ needs to be studied.



[RPV head bolt cutting equipment]

[Quantity of abrasive used/collected per stud bolt (dry state)]

Item	Mass[kg]
Quantity of abrasive used (per bolt)	15.6
Rate of collection	80% (assumed)
Quantity of abrasive used (per bolt) based on the studies on reducing the quantity of abrasive#	4.8

#: Subsidy Project of Decommissioning and Contaminated Water Management

Calculated while referring to results of the WJ flow rate and abrasive supply effectiveness verification test conducted while developing the technology for internal investigation of RPV

① Method of cutting into large structures :(c) Reactor internal structures

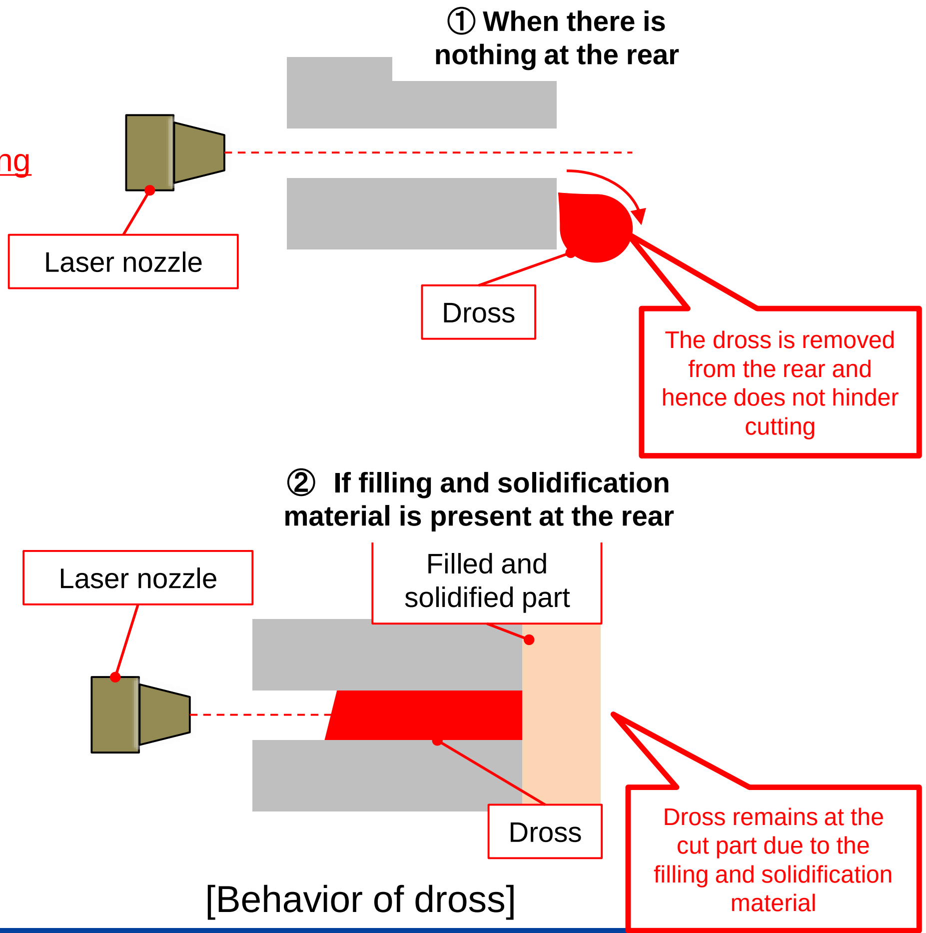
[Method of cutting reactor internal structures into large pieces Selection of cutting method]

The laser cutting technology which has relatively minor demerits based on the study described till the previous page is being considered for cutting the outer periphery of the shroud.
The issues in the laser cutting technology are consolidated in the bottom left table.

The processing tool needs to be equipped with functions for being able to remove dross, and being able to control the generation of fumes and cutting of surrounding structures.

[Issues in laser cutting technology]

No.	Issues	Details
1	Dross removal	Residual dross at the location of cutting hinders laser heat input.
2	Spread of contamination due to fumes	There is a risk of spread of contamination due to vaporization of activated material.
3	Damage of surrounding structures (including filler material and fuel debris)	The structures located behind the objects to be cut may get cut due to the laser.



[Behavior of dross]

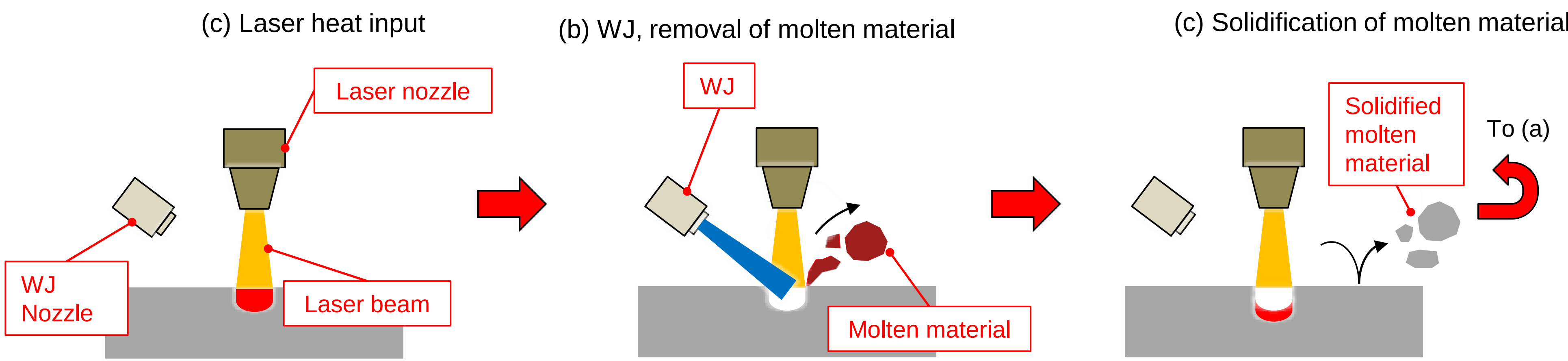
① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Selection of cutting method]

Laser + WJ cutting technology for cutting the outer periphery of the shroud is being studied.
The procedure while using this technology is indicated in the figure below. The following 3 effects are expected from WJ.

- Removal of dross by means of the WJ force
- Control of generation of fumes by means of the cooling effect
- Preventing cutting of surrounding structures by means of the cooling effect

If WJ is carried out continuously, it is likely to hinder laser heat input. Hence intermittent jet spray is considered as a pre-condition.



- The target object to be cut is melted by means of laser irradiation
- The molten target object to be cut is removed by means of WJ
- The removed molten material solidifies due to the cooling effect of WJ (Preventing it from adhering to the cutting location)

[Laser + WJ cutting process]

① Method of cutting into large structures :(c) Reactor internal structures

[Reactor internal structures (Laser + WJ Cutting)]

The issues in the laser + WJ cutting technology and the response policy are consolidated in the table below.

Element tests were conducted on Laser + WJ cutting for ① Verification of the optimum laser + WJ conditions, ② Quantitative evaluation of fume control effect, and ③ Verification of applicability to structures other than the shroud.

[Issues in laser + WJ cutting technology]

No.	Issues	Details	Response policy
1	Optimal laser + WJ conditions	If the WJ flow rate and the jet spray duration are increased excessively, the melting of the target object to be cut is hindered due to the cooling effect, and as a result the processing quantity (processing depth) reduces. Meanwhile, if the WJ flow rate and the jet spray duration are not sufficient, molten material remains on the location of cutting and solidifies due to which processing quantity reduces. Whether or not the WJ flow rate and the jet spray duration are sufficient depends on the quantity of molten material. Hence it is influenced by laser conditions such as laser power, distance up to the object to be cut, etc. as well.	The Optimal laser + WJ conditions will be verified through tests.
2	Evaluation of fume control effect	It is assumed that the generation of fumes can be reduced by means of the cooling effect of WJ, but quantitative evaluation has not yet been carried out.	The changes in the quantity of fumes generated due to the presence or absence of WJ will be verified through tests.
3	Applicability to structures other than the shroud	It is assumed that various materials and shapes will need to be cut for applying this technology to structures other than the shroud as well. Since the melting point or thermal conductivity changes depending on the material, and the manner in which the WJ hits the target object changes depending on the shape of the object, it is assumed that the optimal laser + WJ conditions will differ for every object to be cut.	The characteristics of cutting conditions will be consolidated for the test pieces of various materials and shapes assuming the structures in the actual equipment.

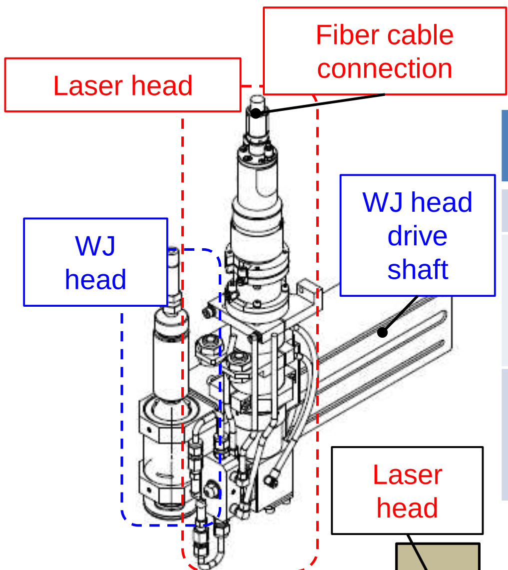
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Element tests (Test equipment)]

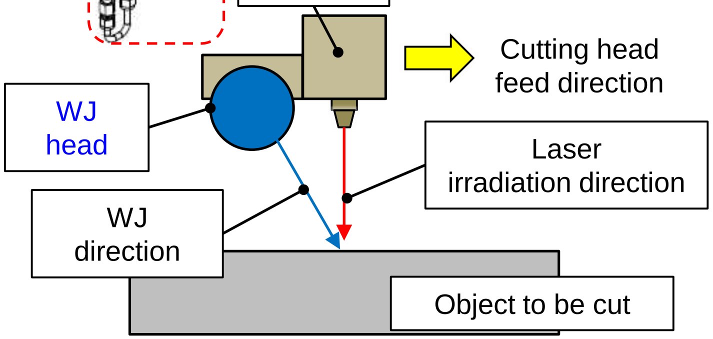
2 types of cutting heads namely, horizontal cutting type and vertical cutting type, were used in the laser + WJ cutting element tests.
The cutting head consists of a laser head that irradiates laser and blows gas and a WJ head that shoots a WJ.

Horizontal cutting type cutting head



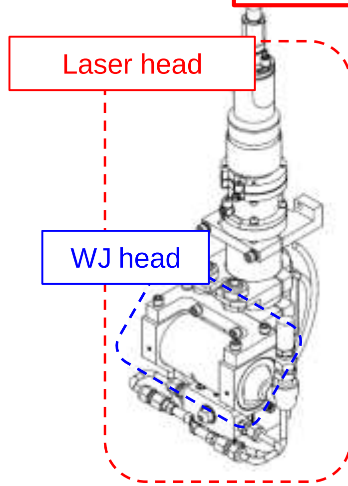
[Rough dimensions (horizontal cutting)]

Location	Dimensions [mm]
Width	136
Depth (Excluding the WJ head drive shaft)	145
Height (Fiber cable connection and below)	535



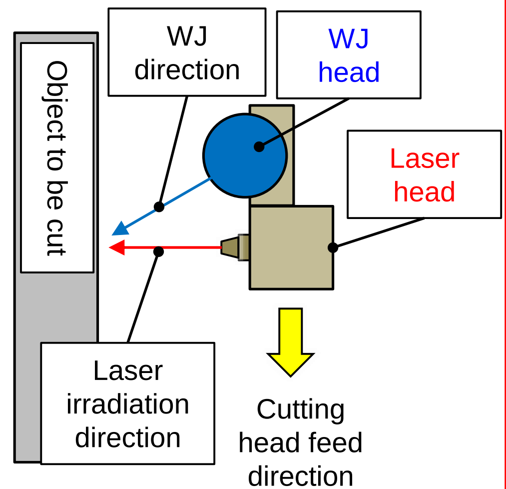
[Illustration of horizontal cutting (Side view)]

Vertical cutting type cutting head



[Rough dimensions (vertical cutting)]

Location	Dimensions [mm]
Width	208
Depth	150
Height (Fiber cable connection and below)	475



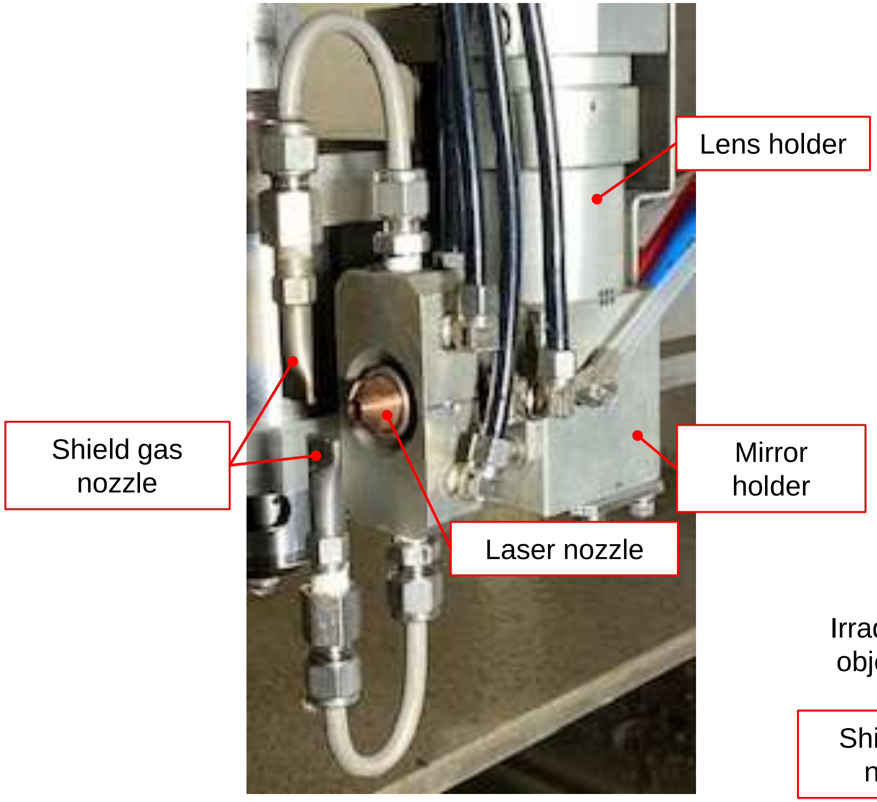
[Illustration of vertical cutting (Side view)]

① Method of cutting into large structures :(c) Reactor internal structures

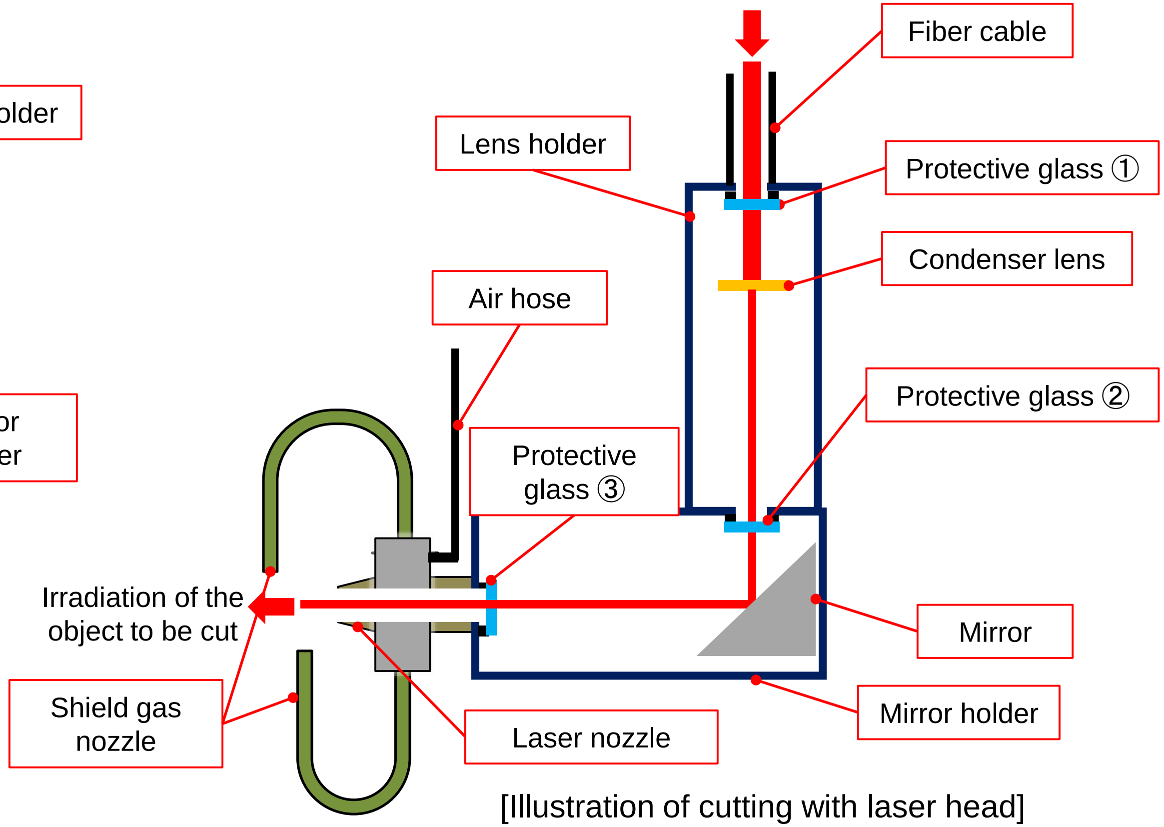
[Method of cutting reactor internal structures into large pieces　　Element tests (Test equipment)]

The laser head consists of ① An optical system such as a fiber cable, condenser lens, mirror, etc. and ② A gas system (explained on the next page) for protecting the laser head from the spatter that is generated while cutting.

The laser beam formed by the laser transmitter is transmitted through the fiber cable, after it is focused through the condenser lens the irradiation direction is determined by means of the mirror, and the target object to be cut gets irradiated through the laser nozzle.



[External appearance of laser head]



[Illustration of cutting with laser head]

① Method of cutting into large structures : (c) Reactor internal structures

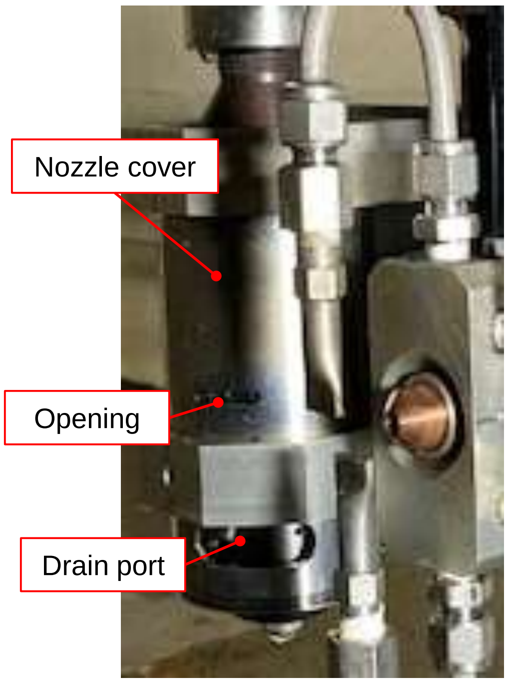
[Method of cutting reactor internal structures into large pieces Element tests (Test equipment)]

The WJ head is made up of the WJ nozzle unit at the center and the nozzle cover surrounding the WJ nozzle unit.

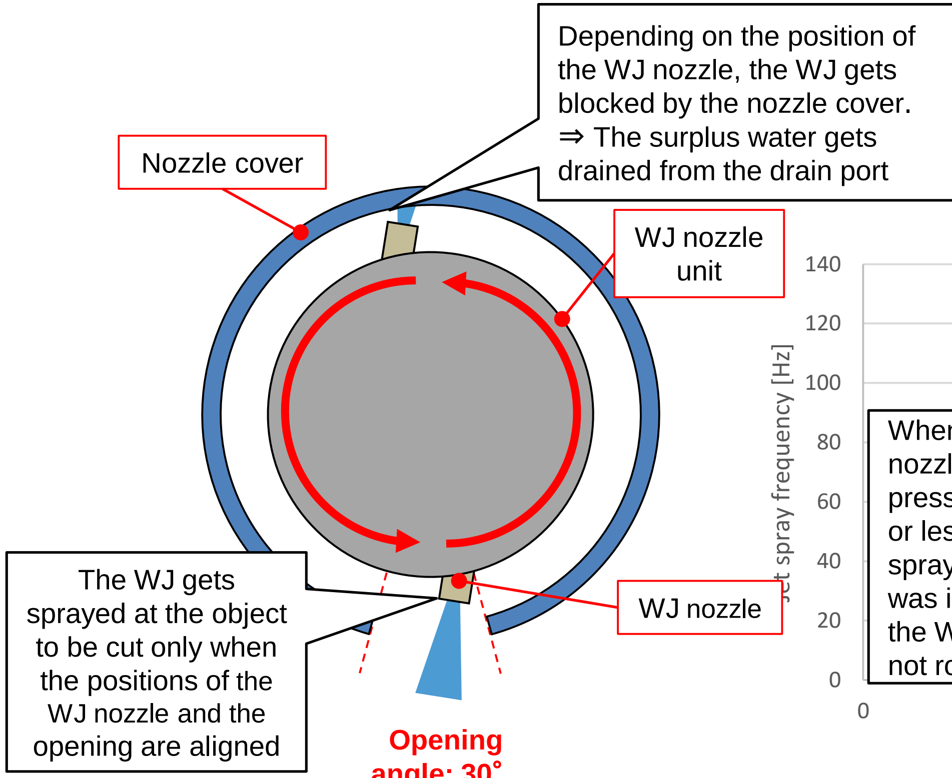
The WJ nozzle is connected to the WJ nozzle unit, and the WJ nozzle unit rotates as a result of the WJ jet spray reaction force.

The nozzle cover has an opening, and since the WJ gets sprayed at the object to be cut only when the positions of the WJ nozzle and the opening are aligned, there is intermittent WJ spraying.

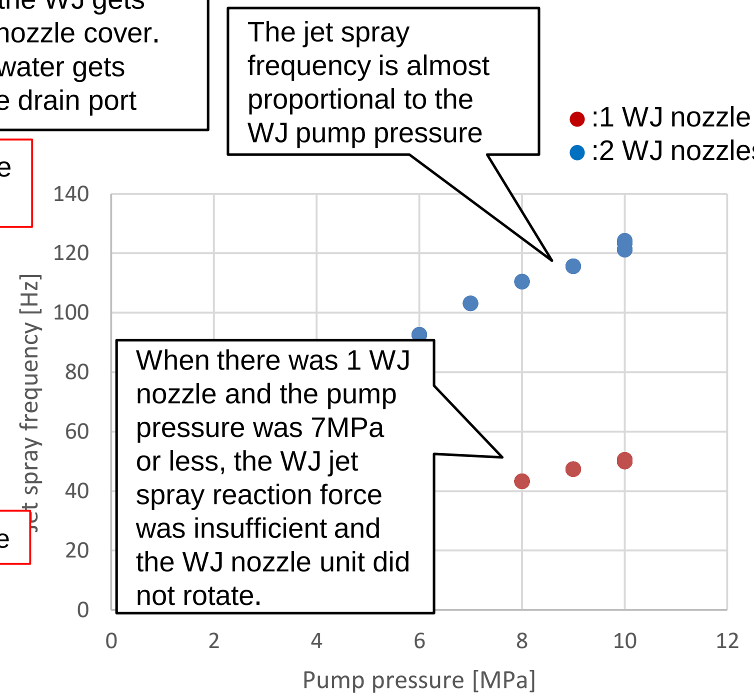
The frequency of intermittent spraying is determined by the WJ pump pressure and the number of WJ nozzles. (Refer to the graph on the bottom right)



[External appearance of WJ head]



[Illustration of the WJ head (Traverse section)]



[Correlation between WJ pump pressure and jet spray frequency]

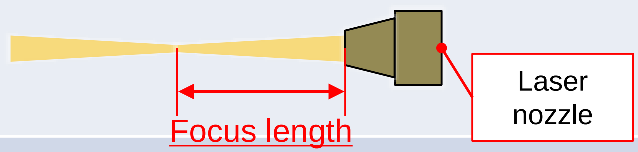
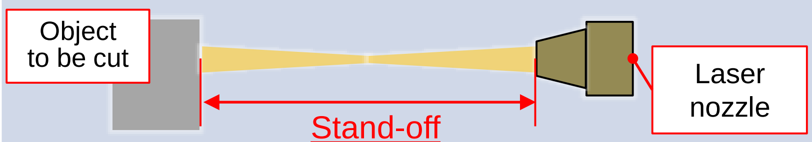
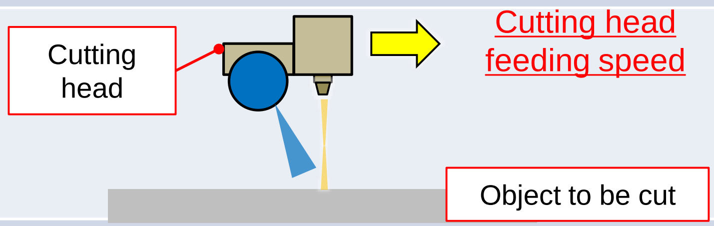
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Control parameters)]

The control parameters for the Laser + WJ cutting element tests are indicated in the table below.

[Control parameters for the Laser + WJ cutting element tests]

No.	Parameters	Illustration	Details
①	Power [kW]	-	• Fixed at 7.8kW based on the equipment specification
②	Focus length [mm]		• Fixed at 98mm based on the equipment specification • The size of the laser spot (diameter of the laser beam cross-section projected on the plane perpendicular to the laser beam) at the focus length is 3mm
③	Stand-off [mm]		• Distance between the laser nozzle tip and the surface of the object to be cut • The nearer the standoff to the focus distance, smaller is the laser spot, greater is the quantity of heat input per unit area and greater is the amount of melting of the object to be cut.
④	Cutting head feeding speed [mm/s]		• The feeding speed of the cutting head while cutting • The smaller the cutting head feeding speed, greater is the heat input per unit area, greater is the amount of melting of the object to be cut, but greater is the processing time.
⑤	WJ Pump pressure [MPa]	-	• The maximum pressure is 10MPa based on the specifications of the pump used. • The larger the WJ pump pressure greater is the jet spray frequency and WJ flow rate.
⑥	Number of WJ nozzles [-]	-	• 1 - 2 WJ nozzles can be installed in the WJ nozzle unit. • Larger the number of WJ nozzles greater is the jet spray frequency.
⑦	Jet spray frequency [Hz]	-	• WJ jet spray frequency per second • Fluctuates depending on the WJ pump pressure and number of WJ nozzles

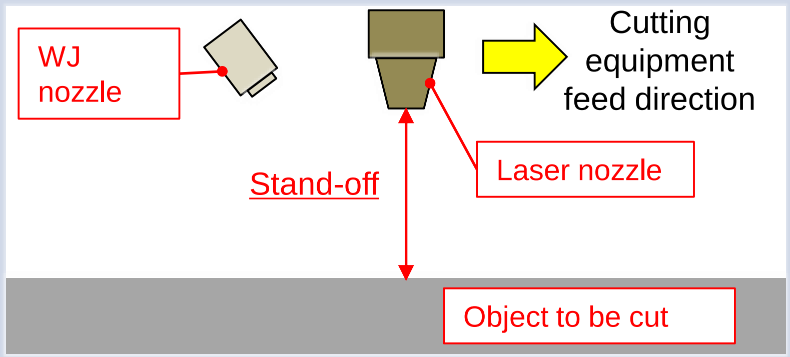
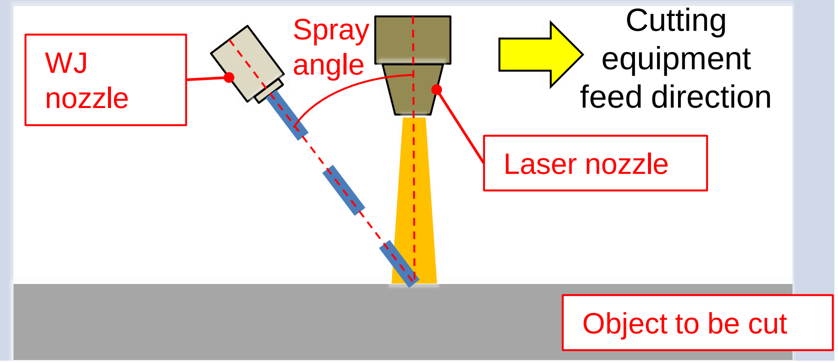
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　　Element tests (Test items)]

The test items of the element tests, their overview, objectives are consolidated in the table below.

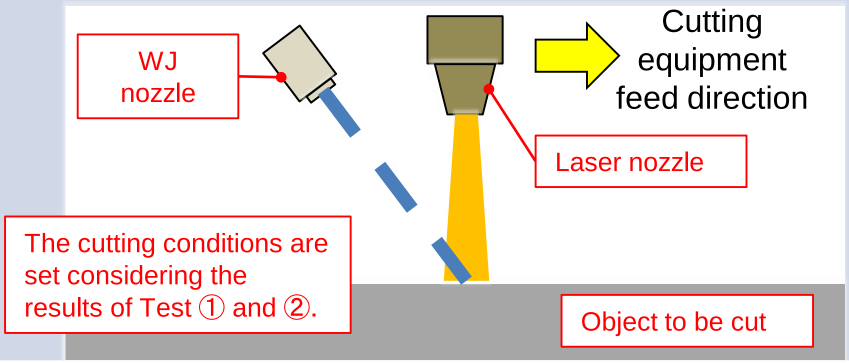
[Laser + Pulse WJ cutting element test items (1/3)]

	① Stand-off conditions comparison test	② WJ conditions comparison test
Conceptual diagram	 	
Overview	• The cutting test is performed while changing the stand-off and feeding speed of the cutting head, and the impact on the processing quantity is verified. • Assuming that the shroud will be cut, the test piece is made of SUS304 plate material (about t30mm).	• The cutting test is performed while changing the various conditions concerning pulse WJ (pump pressure, jet spray frequency), and the impact on the processing quantity is verified. • Assuming that the shroud will be cut, the test piece is made of SUS304 plate material (about t30mm).
Objective (Feedback for the actual equipment)	• To verify the optimum stand-off conditions for cutting SUS304 plate material, and to reflect it in the shroud cutting conditions in the actual equipment. • To verify the maximum stand-off with which cutting is possible, and to reflect it in the access plan for the cutting head in the actual equipment.	• To verify the optimum WJ conditions for cutting SUS304 plate material, and to reflect it in the shroud cutting conditions in the actual equipment. • To perform the cutting test in the presence and absence of WJ jet spray, and to verify the effect of WJ on controlling generation of fumes.
Measurement items	• Whether or not cutting is possible (processing depth) • Processing time	• Whether or not cutting is possible (processing depth) • Processing time • Amount of fumes generated • Density of fumes

① Method of cutting into large structures : (c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test items)]

[Laser + Pulse WJ cutting element test items (2/3)]

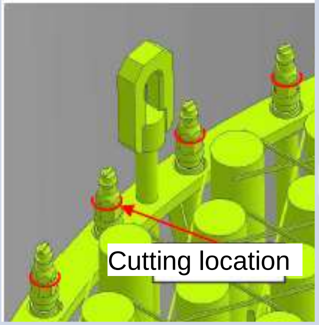
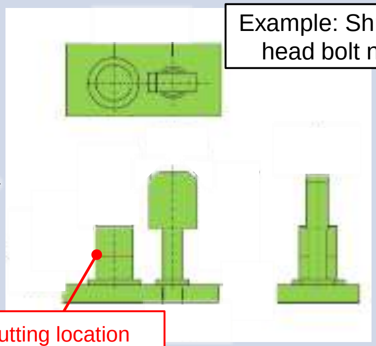
	③ Materials comparison test	④ Shape comparison test
Conceptual diagram		
Overview	• Cutting test is performed on plate material of materials other than SUS304 that are used as reactor internal structures (carbon steel, inconel, low alloy steel, etc.), under optimal cutting conditions for SUS plate material that were verified through tests ① and ②.	• Cutting test is performed on test pieces simulating various shapes of the reactor internal structures (plate, solid cylinder, hollow cylinder, etc.) under optimal cutting conditions for SUS plate material that were verified through tests ① and ② (The test piece is used in common with the simple simulated test piece cutting test at a later stage).
Objective (Feedback for the actual equipment)	• To verify whether or not SUS304 plate material can be cut under optimal cutting conditions. If cutting is not possible, to identify issues (plan for changing the conditions) and to reflect them in the cutting conditions for various structures in the actual equipment. • To perform the cutting test in the presence and absence of WJ jet spray, and to verify the effect of WJ on controlling generation of fumes.	• To verify whether or not SUS304 plate material can be cut under optimal cutting conditions. If cutting is not possible, to identify issues (plan for changing the conditions) and to reflect them in the cutting conditions for various structures in the actual equipment.
Measurement items	• Whether or not cutting is possible (processing depth) • Processing time • Amount of fumes generated (SM400B) • Density of fumes (SM400B)	• Whether or not cutting is possible (processing depth) • Processing time

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

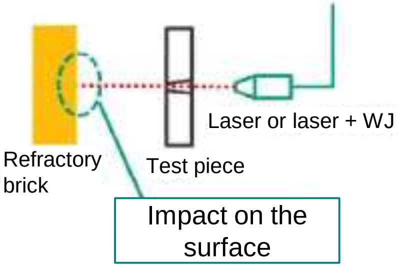
① Method of cutting into large structures：
(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces
Element tests (Test items)]

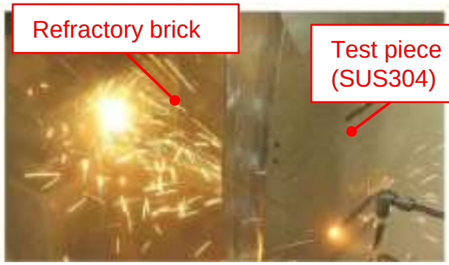
[Laser + Pulse WJ cutting element test items (3/3)]

	⑤ Simple simulated test piece cutting test
Conceptual diagram	 
Overview	• Cutting test is performed on simple simulated test pieces simulating the structures that are planned to be cut in the actual equipment as well as the surrounding structures under optimal cutting conditions for SUS plate material that were verified through tests ① and ②.
Objective (Feedback for the actual equipment)	• To verify whether or not SUS304 plate material can be cut under optimal cutting conditions. If cutting is not possible, to identify issues (plan for changing the conditions) and to reflect them in the cutting conditions for various structures in the actual equipment. • To check for presence of traces of surrounding structures being cut, and if there are traces, to modify the conditions (increasing stand-off, etc,) to reduce the impact and reflect these changes in the cutting conditions in the actual equipment.
Measurement items	• Whether or not cutting is possible • Processing time • Presence of traces of surrounding structures being cut

[Test for assessing the impact on the surrounding structures]



[Image illustrating the test]



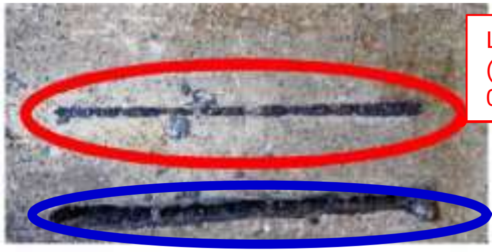
[Cutting being performed]

[Test details]
- A refractory brick is placed in front of the test piece
- Cutting test is conducted using stand-alone laser irradiation or laser + WJ

[Test conditions (Common for stand-alone laser irradiation / Laser + WJ)]
- Laser power: 8kW
- Cutting head feeding speed: 5mm/s
- Stand-off: 60mm
- WJ pump pressure: 10MPa

[Test results]
- Cutting depth of the brick using stand-alone laser irradiation: 10mm
- Cutting depth of the brick using laser + WJ: 0.5mm

⇒It is assumed that the impact of the cooling effect of WJ on surrounding structures at the time of laser cutting can be mitigated.

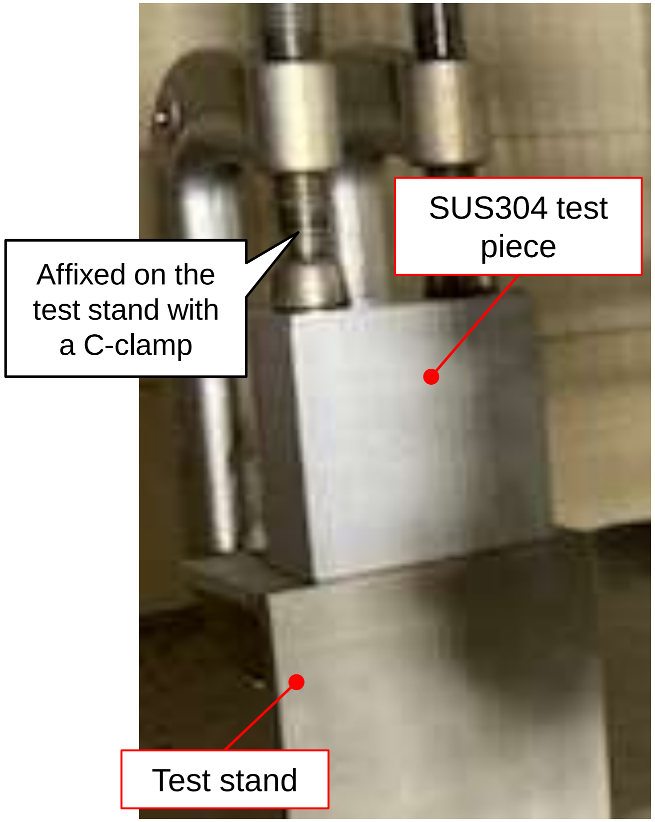


[Traces of the refractory brick being cut]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Element tests (Test results: Method of evaluating the processing depth in the stand-off and WJ conditions comparison test)]

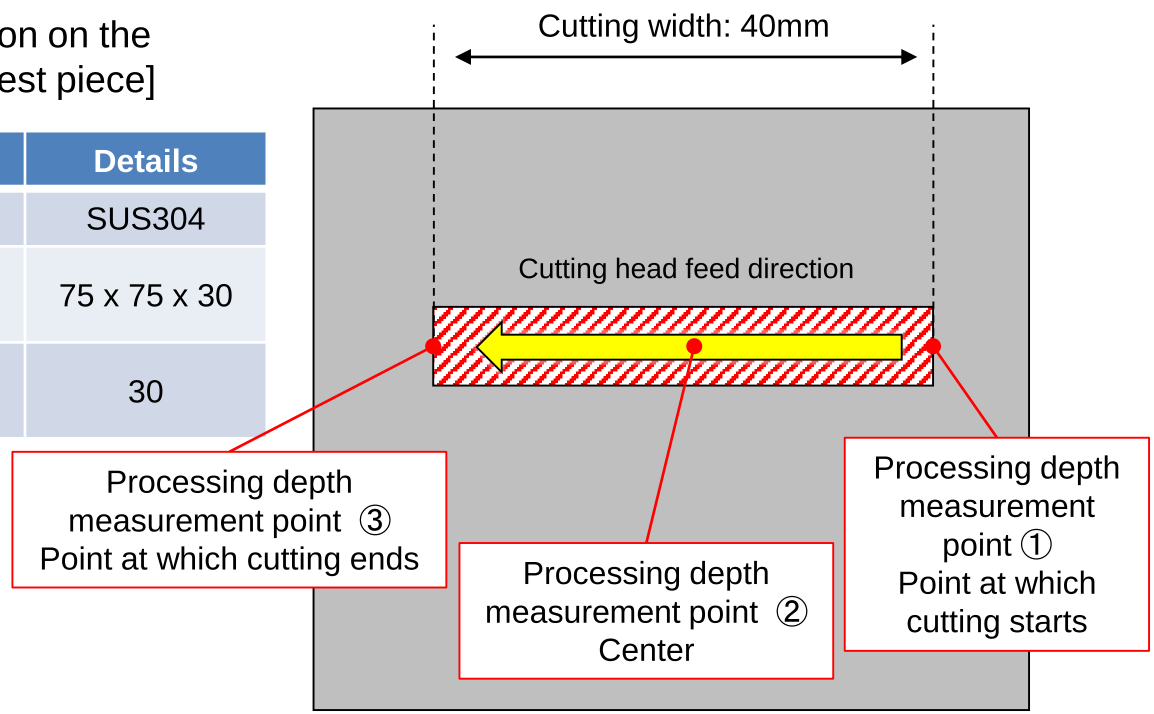
The test pieces used in the stand-off and WJ conditions comparison test, and the policy for measuring the processing depth are as described below.
A 40mm wide cut was made on the SUS304 test piece from right → left and the processing depth was measured at the following 3 locations.
The average of the measurement values at the 3 locations (hereinafter, "average processing depth") will be used for assessing the processing depth.



[Outer appearance of SUS304 test piece]

[Information on the SUS304 test piece]

Items	Details
Material	SUS304
Dimensions [mm]	75 x 75 x 30
Cutting thickness [mm]	30



[Cutting width]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Stand-off and WJ conditions comparison test)]

Results of the stand-off and WJ conditions comparison test, and the optimal cutting conditions for the said cutting head are as described below.

[Results of the stand-off and WJ conditions comparison test]

No.	Laser power [kW]	Assist gas flow rate [L/min]	Stand-off [mm]	Cutting head feeding speed[mm/s]	Number of WJ nozzles [-]	WJ pump pressure [MPa]	WJ jet spray angle [°]	Jet spray frequency [Hz]	Cutting frequency [-]	Average processing depth [mm]
1	7.8	350	98	1	1	10	30	50.5	1	18.5
2	7.8	350	184	1	1	10	16	50.5	1	11.3
3	7.8	350	254	1	1	10	11	50.5	1	4.5
4	7.8	350	316	1	1	10	9	50.5	1	2.1
5	7.8	350	98	[illegible]	1	8	30	43.3	1	14.9
6	7.8	350	98	[illegible]	2	[illegible]	30	110.5	1	9.33
7	7.8	350	98	[illegible]	1	[illegible]	30	[illegible]	[illegible]	15.1
8	7.8	350	98	1	2	9	30	[illegible]	[illegible]	9.33
9	7.8	350	98	1	1	10	30	50.5	[illegible]	15.3
[illegible]	7.8	350	98	1	2	10	30	123.5	1	9.11
[illegible]	7.8	350	98	5	1	10	30	50.5	5	22.2
12	7.8	350	98	10	1	10	30	50.5	10	24.0
13	7.8	350	98	10	1	8	30	50.5	10	21.3
14	7.8	350	98	10	[illegible]	[illegible]	[illegible]	50.5	10	22.0

Optimal cutting conditions

The processing depth increases when the cutting head feeding speed is increased and cutting is performed repeatedly.

The ability to remove molten material is greater when the WJ pressure is higher.

Average processing depth is maximum

The WJ flow rate is lower when there is 1 nozzle as compared to when there are 2 nozzles, and thus the test piece does not get cooled excessively.

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Materials comparison test)]

The test pieces used in the materials comparison test are as described in the table below.

Similar to the stand-off and WJ conditions comparison test, a 40mm wide cut was made in the test pieces mentioned in the table below, and the average processing depth was compared with that of the SUS304 test piece that was cut under similar conditions.

[Test pieces used in the materials comparison test]

Material	SM400B	SQV2A	NCF600	Geopolymer
External appearance				
Dimensions [mm]	75 x 75 x 30	227 x 700 x 30	Φ430 x 70	Φ55 (There are individual differences in the length)

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

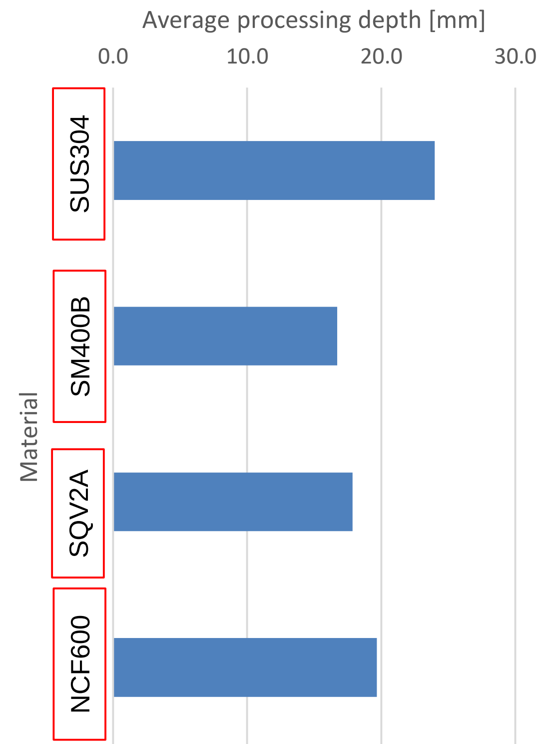
① Method of cutting into large structures：(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Element tests (Test results: Materials comparison test)]

The results of cutting SM400B, SQV2A, and NCF600 test pieces using stand-alone laser irradiation / laser + WJ are indicated below.

[Difference in the status of cutting depending on the presence/absence of WJ]

Conditions	SM400B	SQV2A	NCF600
WJ Absent	 • The molten material flowed upwards on the right • The molten material was very viscous	 • The molten material flowed downwards on the right • The molten material was very viscous	 • The molten material adhered to the cut part
WJ Present	 • The molten material did not adhere to the surface • Lot of molten material adhered to the right side of the cut part	 • The molten material did not adhere to the surface	 • The molten material adhered to the surface on the right side



[Result]

• **It was found that the processing depth of the material that became very viscous upon melting**, namely SM400B and SQV2A, **reduced.**

[Considerations]

• There is strong adhesive power (surface tension) between molten materials of SM400B and SQV2A, and hence it is believed that the molten material was not be removed with WJ.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

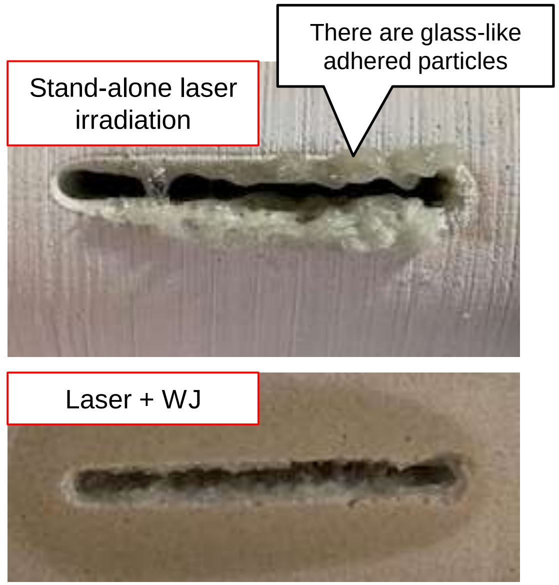
① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Element tests (Test results: Materials comparison test)]

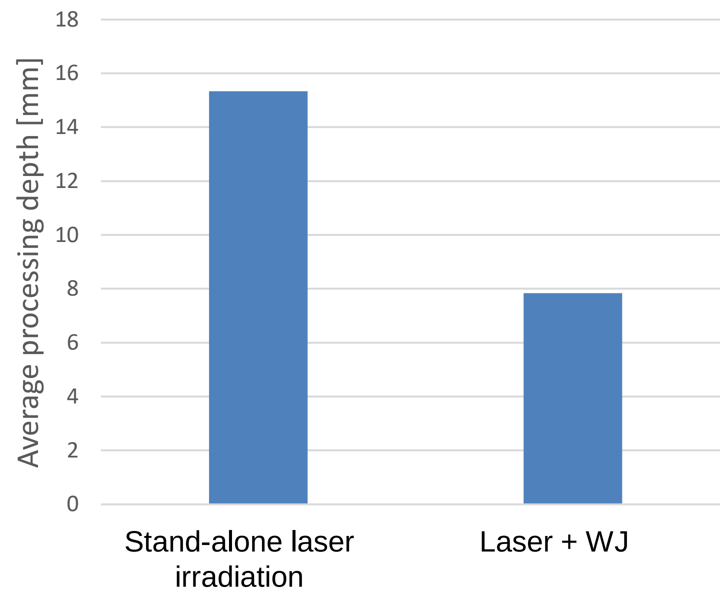
The results of cutting geopolymer test pieces using stand-alone laser irradiation / laser + WJ are indicated below.

[Cutting conditions (Geopolymer)]

Conditions	①	②
Stand-off [mm]	98	
Cutting head feeding speed [mm/s]	5	
WJ pump pressure [MPa]	-	10
Cutting frequency [-]	1	
Remarks	WJ Absent	WJ Present



[Cutting status (Geopolymer)]



[Average processing depth of geopolymer]

[Result]

- **It was found that the average processing depth was larger when stand-alone laser irradiation was used** as compared to when laser + WJ was used for cutting.
- When stand-alone laser irradiation was used, it was found that geopolymer melted and the molten material got dispersed due to the assist gas (There were no sparks).
- In the case of stand-alone laser irradiation, glass-like adhering particles were seen around the cut part.

[Considerations]

- In the case of laser + WJ, the cooling effect of WJ prevented the geopolymer from melting and the processing depth decreased.

→ **If it is preferred that filled and solidified part are not cut as far as possible, in the case of laser + WJ cutting, the cutting depth can be controlled to several mm.**

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

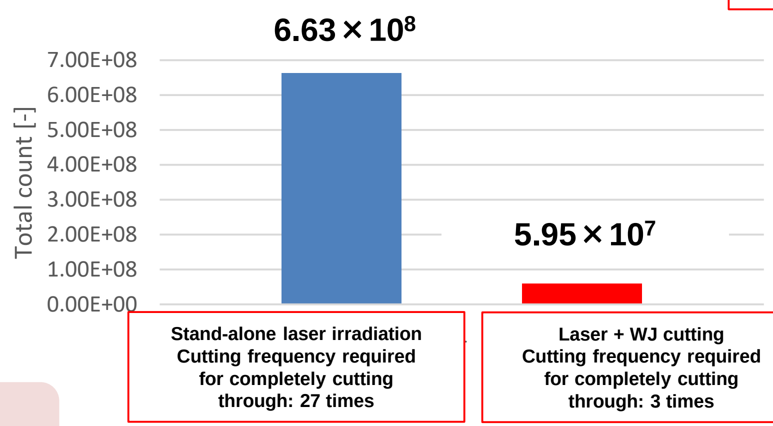
① Method of cutting into large structures ：(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces　Element tests (Test results：Measurement of fumes)]

The SUS304 test piece (t10mm) was cut through completely by means of stand-alone laser irradiation / laser + WJ cutting.
The total count of the fumes generated, and the particle size distribution are indicated below.

[Cutting conditions (SUS304 fume measurement)]

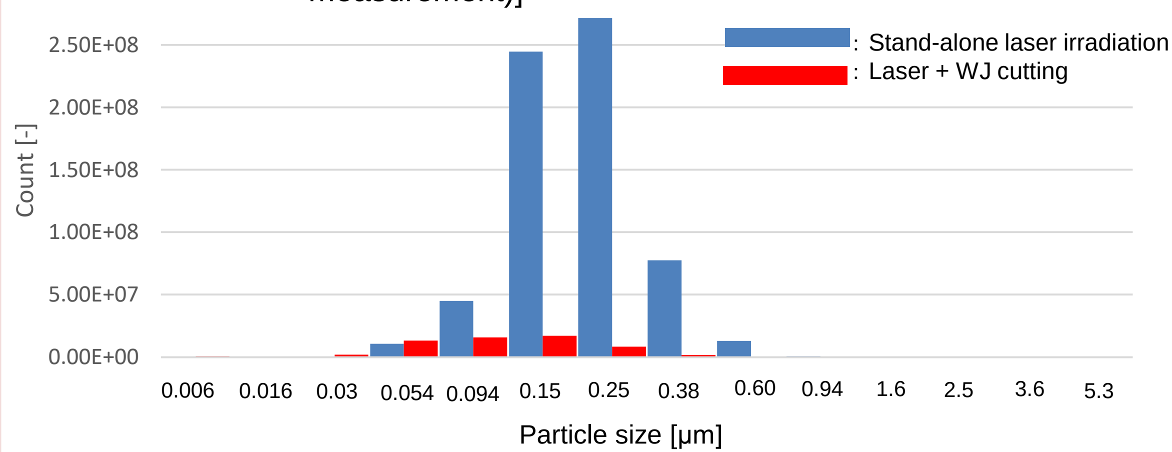
Conditions	①	②
Laser power [kW]	7.8	
Stand-off [mm]	98	
Cutting head feeding speed [mm/s]	10	
WJ pump pressure [MPa]	-	10
Remarks	WJ Absent	WJ Present



[Total count (SUS304 fume measurement)]

Fume measurement equipment (Electronic low pressure impactor)

Items	Details
Range within which particle size can be measured [µm]	0.006 to 10
Number of channels [-]	14
Sampling frequency [Hz]	10



[Particle size distribution (SUS304 fume measurement)]

[Results]
- The total count of fumes when WJ was present declined up to about 9% of when WJ was absent.
- The count of particles that were 0.094µm or larger in size declined largely (about 1/10th), while the count of particles that were smaller than 0.094µm increased slightly.

[Considerations]
- The amount of fumes generated for cutting 10mm deep declined largely if WJ was provided.
- If the amount of fumes generated is evaluated for every round of cutting, 2.45×10^{7} units of fumes were generated in the absence of WJ and 1.98×10^{7} units of fumes were generated in the presence of WJ, and thus there was not much difference. However, since the number of rounds of cutting declined largely, consequently the amount of fumes generated declined as well.

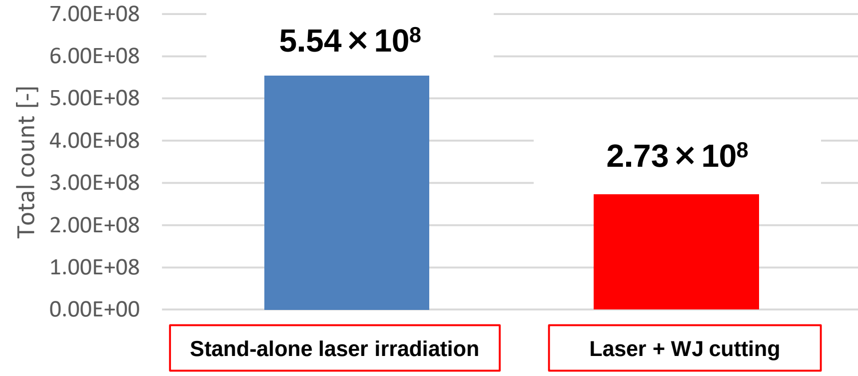
① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Measurement of fumes)]

Cutting was performed for a period of 40 seconds on SM400B test pieces (Same as the test pieces used in the materials comparison test) using stand-alone laser irradiation / laser + WJ cutting, and the total count of the fumes generated, and the particle size distribution are indicated below.

[Cutting conditions (SM400B fume measurement)]

Conditions	①	②
Laser power [kW]	7.8	
Stand-off [mm]	98	
Cutting head feeding speed[mm/s]	10	
WJ pump pressure [MPa]	-	10
Remarks	WJ Absent	WJ Present



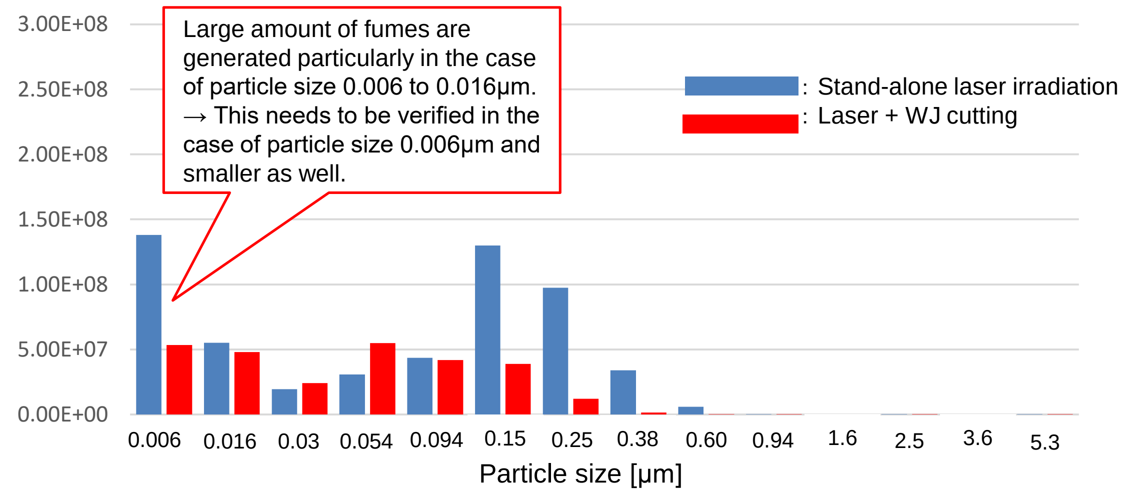
[Total count (SM400B fume measurement)]

[Result]

- The total count of fumes when WJ was present declined up to about 50% of when WJ was absent.
- The fume count for particle size 0.054 to 0.094μm increased when WJ was present (decreased otherwise)

[Considerations]

- Even if the cutting duration (frequency) was the same, the total count of fumes declined when WJ was provided.
  → This is presumed to be the fume reduction effect of WJ.
- In the case of SM400B, it is believed that fumes need to be measured for particle size 0.006μm and smaller as well.



[Particle size distribution (SM400B fume measurement)]

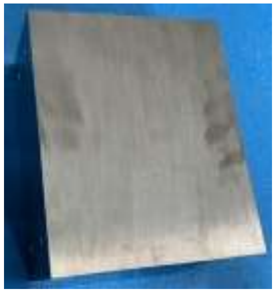
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Simple simulated test piece cutting test)]

The target objects that the simulated test pieces used in the shape comparison test and the simple simulated test piece cutting test, are as described below.

Guide rod bracket



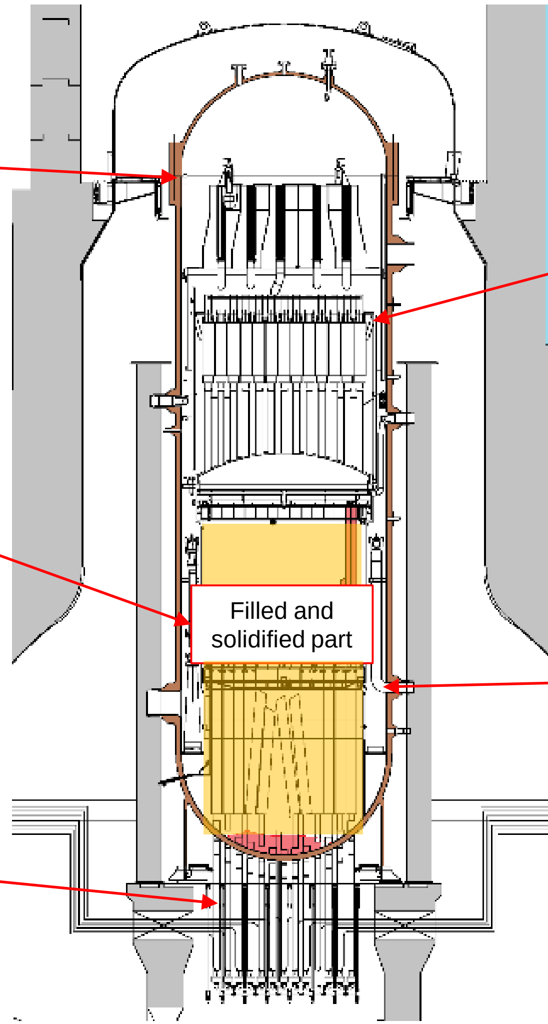
Material: SUS304
Dimensions: 200mm x 165mm x t90mm

Shroud + filled and solidified part

Shroud
Material: SUS304
Dimensions: t38mm
Filled and solidified part
Material: Geopolymer
Dimensions: Half of Φ55mm

CRD housing support Beam

Material: SM400B
Dimensions: 300mm x 480mm x t75 to 115mm



Shroud head bolt Nut

Material: SUS304
Dimensions: Φ88mm x 281mm

Jet pump Riser pipe

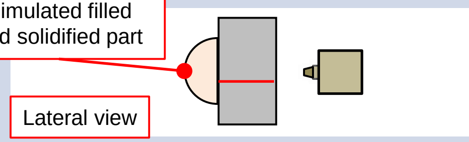
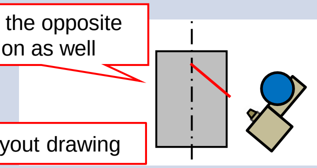
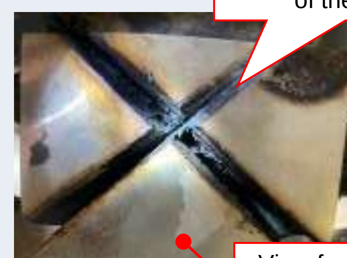
Material: SUS304
Dimensions: Φ273mm x 200mm x t11mm

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Simple simulated test piece cutting test)]

The results of cutting various simulated test pieces are described below.

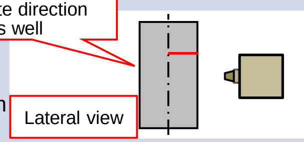
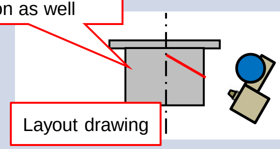
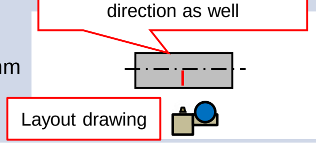
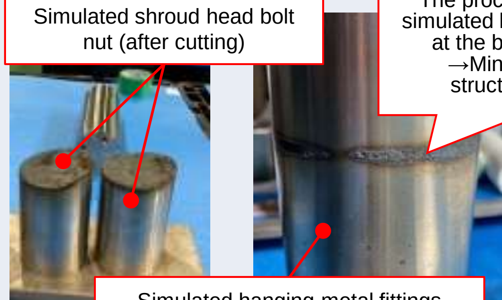
Items	Shroud + filled and solidified part	Guide rod bracket
Material	SUS304 + geopolymer	SUS304
Cutting conditions	Laser power: 7.8kW Stand-off: 98mm Head feeding speed: 1, 5mm/s (changes depending on the progress in cutting) Number of WJ nozzles: 2 WJ pump pressure: 10MPa Spray frequency: 123.5Hz	Laser power: 7.8kW Stand-off: 98mm Head feeding speed: 10mm/s Number of WJ nozzles: 1 WJ pump pressure: 10MPa Spray frequency: 38.2Hz
Cutting policy	Cutting direction: 1 direction Target processing depth: 38mm 	Cutting direction: 2 directions (V shaped) Target processing depth: 60mm 
Status of cutting	Cutting (through) completed The cutting location was shifted while maintaining a space of 3mm each vertically in order to make it easier to remove the molten material (6 cutting lines). ・The cutting depth of the filled and solidified part is 5mm on an average ・Adhesion of the molten SUS304 is seen  	Cutting completed  The molten material collects in the cutting groove at the intersection of the V shape 
Duration of cutting	1392[s]≒23[min] (In the case of the shroud in the actual equipment: 137[h])	8630[s]≒144[min]

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Test results: Simple simulated test piece cutting test)]

The results of cutting various simulated test pieces are described below.

Items	Shroud head bolt nut	Riser pipe	Beam
Material	SUS304	SUS304	SM400B
Cutting conditions	Laser power: 7.8kW Stand-off: 98mm Head feeding speed: 5mm/s Number of WJ nozzles: 2 WJ pump pressure: 10MPa Spray frequency: 123.5Hz	Laser power: 7.8kW Stand-off: 98mm Head feeding speed: 5, 10mm/s (changed as necessary) Number of WJ nozzles: 1 WJ pump pressure: 10MPa Spray frequency: 38.2Hz	Laser power: 7.8kW Stand-off: 98, 48mm (changed as necessary) Head feeding speed: 1, 5mm/s (changed as necessary) Number of WJ nozzles: 2 WJ pump pressure: 10MPa Spray frequency: 194.2Hz
Cutting policy	Cutting direction: 2 direction Target processing depth: 44mm  	Cutting direction: 2 directions (V shaped) Target processing depth: 160mm  	Cutting direction: 2 direction Target processing depth: 75mm 
Status of cutting	Cutting (through) completed  	Cutting completed  	Cutting not completed 
Duration of cutting	2434[s]≒41[min]	2856[s]≒97[min]	16128[s]≒269[min] (Up to processing depth of 39.9mm on an average)

① Method of cutting into large structures :(c) Reactor internal structures

[Method of cutting reactor internal structures into large pieces Element tests (Summary)]

Element tests on laser + WJ cutting were conducted. The results obtained are listed below.

- **The optimal cutting conditions for plate-shaped structures made of SUS304 material** using the current cutting head were verified.
- The difference in cutting performance in the case of various materials used in reactor internal structures such as **SM400B, SQV2A, NCF600** and **in the case of SUS304** was verified.
- **The effect of reduction in generation of fumes when WJ was used** in the case of SUS304 and SM400B was verified.
- Cutting was performed on simple simulated test pieces simulating the material/shape of reactor internal structures, in particular, those that are believed to be difficult to cut, and **the reactor internal structures that could by and large be cut using the laser + WJ cutting technology were verified**, and in addition, improvement strategies for reducing the duration of cutting were identified.
- The impact on the filled and solidified part during shroud cutting was verified, and it was found that the filled and solidified part practically does not get cut when laser + WJ cutting is used.

Also, following are the issues in further enhancing the ability to cut using the laser + WJ cutting technology and in improving the work efficiency on the actual equipment.

- It is necessary to verify the ability to cut with respect to the domain of parameters that did not materialize during these element tests.

  (There are prospects of being able to enhance the ability to remove molten material by controlling the WJ flow rate and increasing WJ pressure)
- Although there were cases when cutting was performed by tilting the cutting head due to the correlation with the size of the cutting head, as the target processing depth increases when cutting is performed in an oblique direction, it is necessary to reduce the size of the cutting head as much as possible and reduce the time required for cutting.
- Since there were cases when the molten material adhered once again, it is necessary to get creative in terms of the operation of the cutting head such as securing a wider area for cutting, beginning to cut from the edge of the object to be cut, etc.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: FY2020 results]

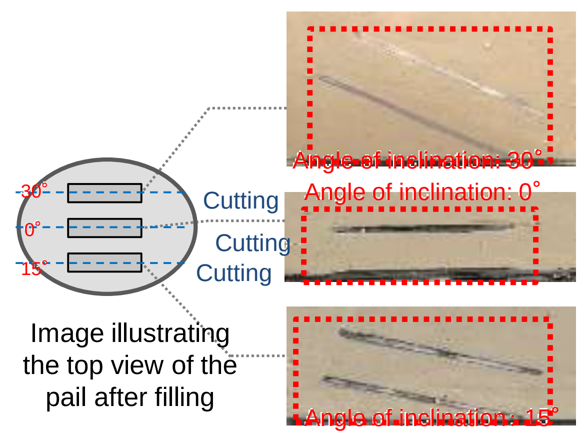
- In FY2020, a conceptual study was conducted on the functions required of the filler material aiming for fall prevention/re-criticality prevention.
- From amongst those functions, functions No. 1 - 4 that influence the feasibility of the filling method were verified through basic tests.

No.	Required function	Details	Desk study	Basic test
1	Good fluidity at the time of filling and filling without any gaps	Shape maintenance and fall prevention of the stump-shaped fuel and fuel debris should be possible by means of the filler material	–	✓
2	Sub-criticality guarantee of the filling method	Sub-criticality maintenance should be guaranteed at the time of solidification / transfer	✓ Criticality evaluation	✓ Addition of absorption material
3	Physical strength of the filler material	Filler material should be strong enough to endure processing / transfer	–	✓
4	Heat resistance of filler material	Cracks should not be formed in the filler material even if it is affected by decay heat from the fuel debris	–	✓
5	Control of hydrogen generation by the filler material	The filler material should be able to control generation of hydrogen transfer/transportation work	✓	–

<Results of Basic Test No. 1>

CRTG was installed at the bottom of the pail and it was verified whether filling can be accomplished without any gaps

[Test conditions of the basic tests on filling]



[Results of the basic test on filling (Verifying the inside by cutting)]

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Identification of study items]

- The following studies were conducted in response to the issues identified in FY2020.
- The characteristics of geopolymer, which is a prospective filler material, need to be ascertained in order to study the method of controlling outflow from the through hole and for studying the method of filling taking the actual equipment into consideration.
- In FY2021, the characterization test mentioned in ID.4 was conducted to evaluate the cross-sectional observation of the solidified unit.

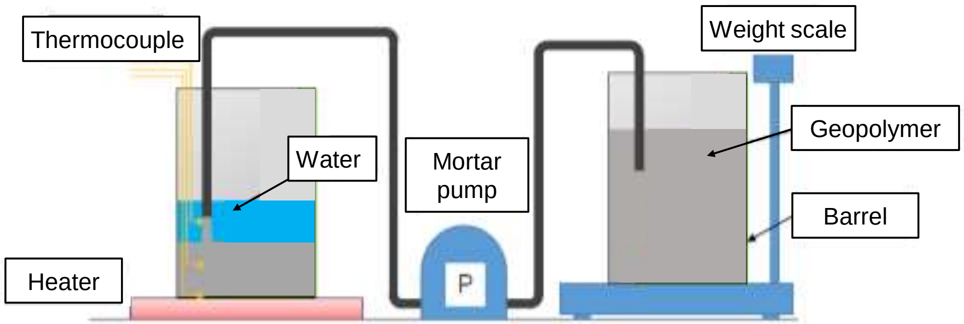
Issues (FY2020)	ID.	Study items	Details	Implemented in (year)	Status
Study related to maintaining the function of the filled and solidified units	1	Evaluation of the impact on solidification function assuming environmental condition (temperature) inside RPV (Implemented along with ID.4)	Upon evaluating the temperature assumed inside RPV, its impact on the solidification function was evaluated (time required for solidification, change in strength, etc. under high temperatures were verified).	FY2021	Explained on the following page
	2	Study related to maintaining the function under harsh environment	The status of maintaining the required functions (impact on the change in strength when α rays are irradiated) offered by geopolymer under harsh environment was verified.	FY2021-2022	Explained later
Study of filling filler material inside the RPV anticipating the actual equipment	3	Study of the method of filling filler material inside the reactor	The method by which filler material ought to be injected into RPV (how it ought to be filled at the point of injection and thereafter) was studied.	FY2022	Explained later
	4	Characterization through injection test conducted using a barrel (Implemented along with ID.1)	Characterization of geopolymer (verifying whether or not it can be filled, its strength, etc.) was carried out through an injection test conducted on a scale larger than the previous basic test, by using a barrel.	FY2021	Explained on the following page
	5	Study of the method of controlling outflow from the through hole	The size of the opening that will enable control of outflow with an appropriate combination of temperature and additives was studied.	FY2022	Explained later
	6	Study of the filling procedures and methods anticipating filling at the actual site	The type of equipment required was studied considering the results of the studies in ID.3 and ID.4.	FY2022	Explained later
Evaluation of impact of filling	7	Impact on treatment and disposal	The impact on treatment and disposal of the filled and solidified units will be studied.	To be studied in the future	To be studied in the future
	8	Impact when heat generating elements are solidified	The impact on the solidified units and the method of heat dissipation (cooling), etc. when fuel debris (heat generating element) is inside the solidified unit will be studied.	To be studied in the future	To be studied in the future

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Barrel injection test]

- The test conditions and the image illustrating the verification tests (barrel injection test) for characterization are given below.
- The condition of geopolymer with different combinations when solidified under RPV internal environmental conditions (environment in which water is present and heat is released) was verified. In that case, silica sand was mixed with geopolymer as simulated neutron absorbing material, etc.

ID.	Item	Conditions	Remarks
1	Types of geopolymer	3 types	The properties of geopolymer with different combinations were verified.
2	Quantity of silica sand filling	About 30%	Combined assuming neutron absorption material. The greater the quantity of filling, harder it was to break.
3	Barrel heating temperature	No heating, 60℃, 80℃	Assuming that heat will be released by fuel debris (the bottom part was heated).
4	Water level	100mm	・ Although details were not yet verified, it was assumed that the water level inside RPV is not as high. ・ Current sub-criticality was taken into consideration (Assumed based on the water level of sub-criticality in an infinite plane.)
5	Temperature measurement position	Measured at the bottom, 175mm, 350mm, 525mm + water surface	・ About 80% (700mm) geopolymer was injected in a 200L barrel of height 900mm. ・ The internal temperature at the time of geopolymer solidification was monitored at the bottom, and at 1/4, 2/4, 3/4 the height of the barrel. ・ The temperature of water was measured by floating a thermocouple on the surface of water using a floating tube.
6	Temperature of the basic ingredient of geopolymer	Cooled to 10℃ or less	Each basic ingredient was cooled to 10℃ or less, and was mixed at room temperature, in order to control the solidification reaction during injection.
7	Geopolymer injection speed	Natural course (about 30 min)	The reduction in weight of the barrel on the supply side was measured with a weighing scale and the injection speed was calculated from the time required and the change in weight.



[Evaluation items]
・Verification of the condition after filling and solidification
(The solidified unit was cut into half with a wire saw and the cross section was observed)

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Barrel injection test results]

- Test results (Typical example)

・The test piece in Test No. 1 (without heating) was cut, and the cross-section was observed. It was found that several horizontal cracks had been formed.

→ Since the intervals between the cracks matched the intervals of holes for the metal fittings used for supporting the thermocouple, it is assumed that the development of cracks originated from these holes.

It is speculated that the amount of change in volume of the outer side (vertical) and the middle of the solidified unit varied depending on

- Study on effectiveness of the measures (Verified by Test No. 6 and No. 7)

[Test No. 6] The difference in temperature in the middle of the solidified unit and on the outer side is reduced by lowering the injection speed and improving heat release.

Note) The method of fixing the thermocouple is changed (metal fitting is excluded) in order to eliminate the anchor effect of the thermocouple support fitting.

→ It was verified that no cracks are formed. However, excluding the thermocouple support fitting could have an impact.

Overall

Enlarged view

Test No. 1 (Without heating) cross-section Comparison of the cracks and the thermocouple support fittings

Test No. 6 (1 round of injection) cross-section

① Method of cutting into large structures：(c) Reactor internal structures

[Study on filler material: Barrel injection test results]

- [Test No. 7] Heat release is improved further by splitting injection into 3 rounds at the same injection speed as No. 6.

Test No. 7 (3 rounds of injection) cut surface

Test No. 7 (3 rounds of injection) results of core boring

・It was verified that a boundary line is formed for every injection. The cut pieces were bound when the cross-section was observed but got separated at the boundary line due to the impact at the time of core boring. → The possibility of lack of adhesion was verified.

- The FY2022 implementation details were studied based on the cause of formation of cracks and the response measures.

Cause

- The difference in temperature in the middle of the solidified unit and on the outside was large
- Major shrinkage on curing
- Large thermal expansion

Countermeasures

- **Improving heat release** → It was verified in FY2021 that the measures were effective. → Implemented even in FY2022 since lack of adhesion was an issue (Study item ID. 4-3)#
- Reducing GP ratio (= Increasing the fine aggregates such as silica sand, etc.) → Implemented in FY2022 as fundamental measures for controlling generation of defects (Study item ID. 4-2)#
- Using low heat release GP → The necessity of implementation will be determined based on the FY2022 results

Described on the next page

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: FY2021 results and FY2022 implementation items]

: Added in response to the results of ID. 4

Issues (FY2020)	ID.	Study items	Details	Implemented in (year)	Status
Study related to maintaining the function of the filled and solidified units	1	Evaluation of the impact on solidification function assuming environmental condition (temperature) inside RPV	Upon evaluating the temperature assumed inside RPV, its impact on the solidification function was evaluated (time required for solidification, change in strength, etc. under high temperatures was verified).	FY2021	Implemented
	2	**Study related to maintaining the function under harsh environment**	**The status of maintaining the required functions (impact on the change in strength when α rays are irradiated) offered by geopolymer under harsh environment was verified.**	**FY2021-2022**	**Explained on the following pages.**
Study of filling filler material inside the RPV anticipating the actual equipment	3	**Study of the method of filling filler material inside the reactor**	**The method by which filler material ought to be injected into RPV (how it ought to be filled at the point of injection and thereafter) was studied.**	**FY2022**	**Explained on the following pages.**
	4	Characterization through injection test conducted using a barrel (Implemented along with ID.1)	Characterization of geopolymer (verifying whether or not it can be filled, its strength, etc.) was carried out through an injection test conducted on a scale larger than the previous basic test, by using a barrel.	FY2021	Implemented
	4-2	**Measures by increasing the amount of filling of silica sand** (Implemented along with ID.1)	**A test was conducted using a barrel wherein the amount of shrinkage of the entire solidified unit was reduced by increasing fine aggregates, as a crack countermeasure.**	**FY2022**	**Explained on the following pages.**
	4-3	**Extension work**	**The impact of extension work on the strength of the geopolymer was verified as a countermeasure for lack of adhesion. Whether there is an extension interval that does not reduce the strength was verified.**	**FY2022**	**Explained on the following pages.**
	5	**Study of the method of controlling outflow from the through hole**	**The size of the opening that will enable control of outflow with an appropriate combination of temperature and additives was studied.**	**FY2022**	**Explained on the following pages.**
	6	**Study of the filling procedures and methods anticipating filling at the actual site**	**The type of equipment required was studied considering the results of the studies in ID.3 and ID.4.**	**FY2022**	**Explained on the following pages.**
Evaluation of impact of filling	7	Impact on treatment and disposal	The impact on treatment and disposal of the filled and solidified units will be studied.	To be studied in the future	To be studied in the future
	8	Impact when heat generating elements are solidified	The impact on the solidified units and the method of heat dissipation (cooling), etc. when fuel debris (heat generating element) is inside the solidified unit will be studied.	To be studied in the future	To be studied in the future

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

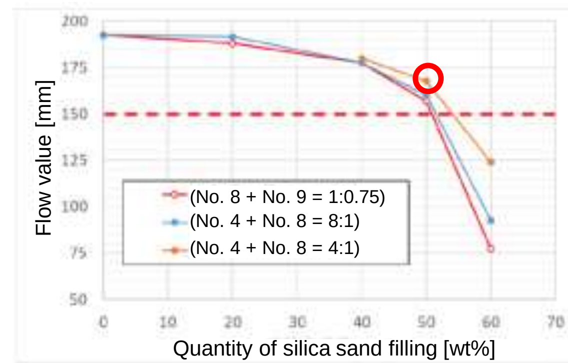
① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Measures by increasing the amount of filling of silica sand]

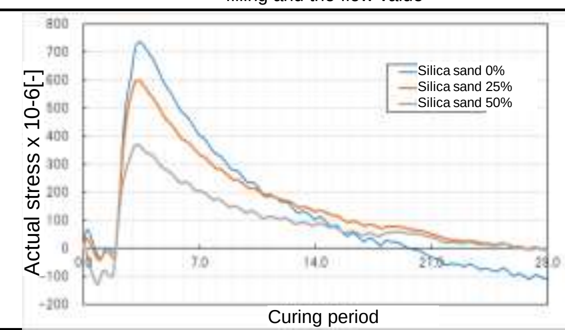
ID.	Study items	Details
4-2	Measures by increasing the amount of filling of silica sand	A test was conducted using a barrel wherein the amount of shrinkage of the entire solidified unit was reduced by increasing fine aggregates, as a crack countermeasure.

- Table flow test(#) and strain measurement test were conducted to verify the combination with silica sand used in the test using a barrel and its effectiveness. (#) Test that shows the indicator of softness of mortar

Test item	Objective	Test results
Table flow test	To study the combination with silicon sand such that the table flow that can be pumped up using the existing mortar pump is 15cm or more.	・Amongst the combinations that were studied, the table flow exceeded 15 cm when the addition was 50wt% and was under 15cm with 60wt%. Hence 50wt% silica sand filling was selected. ・And amongst those combinations, silica sand combination of No. 4 : No. 8 = 4 : 1 was selected as the test condition. (Particle size No. 4: 0.21 to 1.18mm, No. 8: 0.05 to 0.15mm)
Stress measurement test	In order to verify whether increasing the amount of silica sand filling is effective as a crack countermeasure, the impact of thermal expansion was verified with the combination selected in the table flow test.	・It was verified that the change in volume decreases when the amount of silica sand filling is increased, and it was verified that adding fine aggregates is effective as a crack countermeasure. → It was verified that 50% silica sand filling was an effective combination this time.



Correlation between the quantity of silica sand filling and the flow value



Change in stress against the number of days elapsed.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Test using a 200L barrel]

● Conditions for the test using a 200L barrel:

	FY2021			FY2022	
Test No.	1, 2, 3	6	7 (3 rounds of injection)	Preliminary test using 200L barrel	This test using a 200L barrel
Types of geopolymer	SIAL® (Combination assuming that it is used under water and that it solidifies in a short time)	Metakaolin + Na series		SIAL® (Combination assuming that there is almost no water but that the humidity in the environment is close to 100%)	
Silica sand combination	Only No. 8	Only No. 9		No. 4 : No. 8＝ 4:1	
Quantity of silica sand filling(wt%)	16	30	20/40/40	50	
Flow value (cm)#1	21	20	Not measured	17	
Thermocouple	Present (in the middle of the barrel, with support)	Present (in the middle of the barrel, without support)#2	Absent	Absent	Present (in the middle of the barrel, without support)#2
Water level (mm)	100	Absent		Absent	
Heating with a heater	No heating/ 60℃/ 80℃	No heating		No heating	40℃ (lateral side + bottom)#3 approx. 2 weeks
Injection method	Pump injection			Absent	Repairs
Injection speed (kg/min)	29.7/11.8/15.2	8.5	9.9 (Reference value)	―	5
Weight (kg)	282/276/259 (Before solidification)	331 (Before solidification)	326.4 (Before solidification)	314.6 (After solidification)	244.4 (Before solidification)

(#1) Value measured during the test conducted in the laboratory
(#2) Since cracks were formed in the long plate-shaped support, it was changed to a thin elongated metal shaped support
(#3) Configured while referring to the current RPV bottom temperature (33.9℃/Unit 2), and heater added to the lateral side in order to heat evenly.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Test using a 200L barrel]

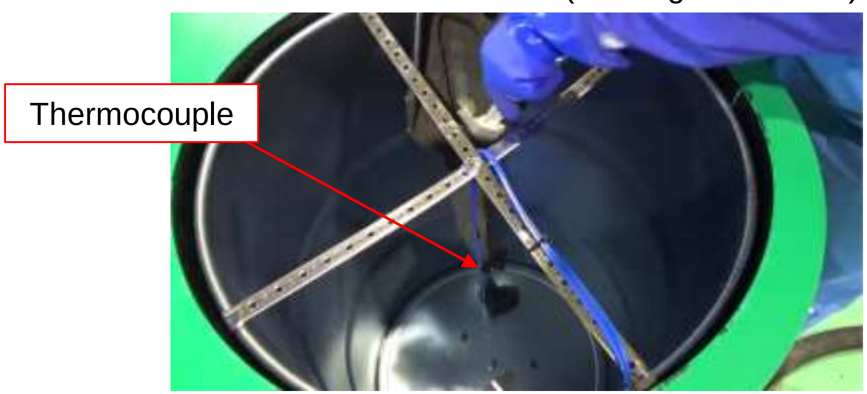
- Test equipment, etc.:

Blending equipment

Blending equipment (Pouring Metakaolin)

Blended geopolymer

Cutting equipment (Wire saw)



Injection started

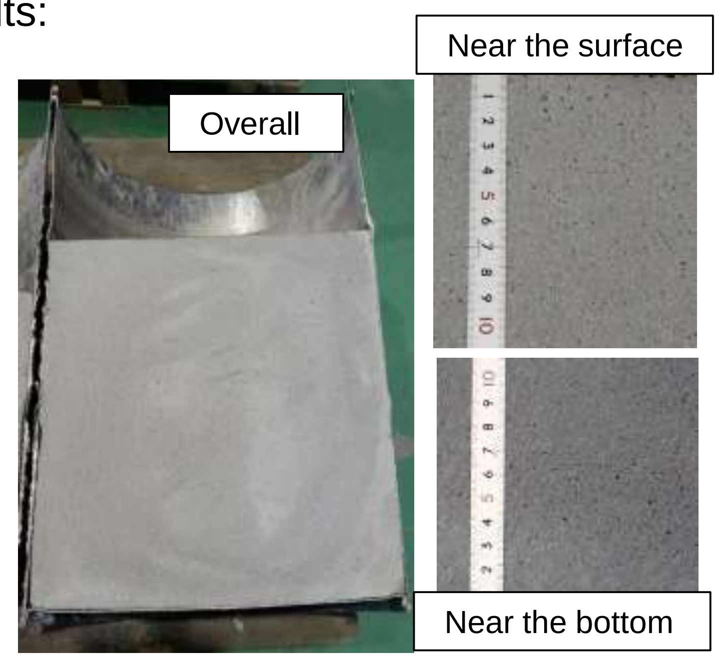
Injection completed (50 minutes after start of injection)

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

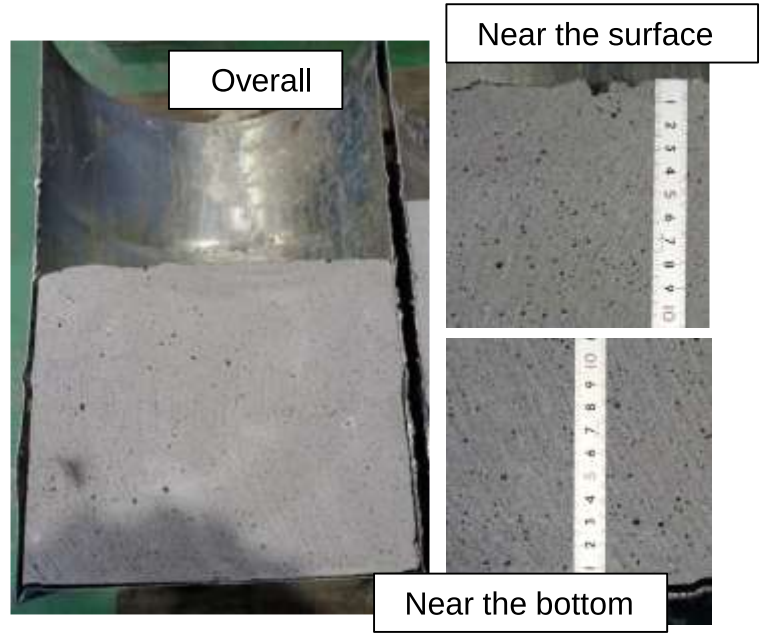
① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Results of test using a 200L barrel]

- Test results:



Preliminary test using 200L barrel (Without injection)



This test using a 200L barrel (Repairs)

･As a result of observing the cross-section, it was found that there are no cracks on the inside, and silica sand is evenly distributed.
→ It was verified that the response measure of increasing the amount of filling of silica sand is effective.

･ On comparing the preliminary test using 200L barrel and this test using 200L barrel, it was found that there was a difference in the size (number) of holes.
→ It is assumed that since air got trapped while performing the filling due to the repairs, the air remained as is in this test.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Extension work]

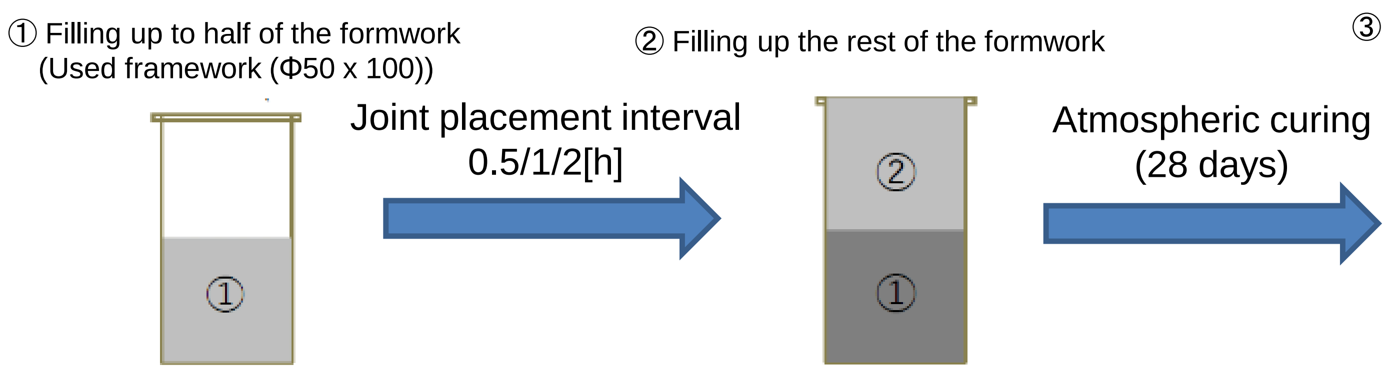
ID.	Study items	Details
4-3	Extension work	The impact of extension work on the strength of the geopolymer was verified as a countermeasure for lack of adhesion. Whether there is an extension interval that does not reduce the strength was verified.

- Joint placement test

<Test details> Compression test and tensile test of the test piece with joint placement were conducted, and its cross-section was observed. The results were compared with those of a test piece without any joint placement.

<Test conditions> The intervals between the joints were changed. The geopolymer used was from Company A (Same blend as the test using a 200L barrel)

<Test procedures>



Picture of the direct tensile test

- Direct tensile test method

Both end surfaces of the test piece were polished and smoothened, and the tool was fixed with epoxy resin adhesive. After letting it stand for 24 hours, the tensile test was conducted.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Joint placement test results]

- Results of the compression test / direct tensile test

		Joint placement intervals [h]	0 (No joint placement, for comparison)			0.5			1			2		
Compression test	Compressive strength [MPa]	Individual	1	2	3	1	2	3	1	2	3	1	2	3
			72.3	76.1	92.1	84.2	69.7	98.9	77.2	96.7	66.6	107.2	109.2	98.2
		Average	80.2			84.3			80.2			104.9		
Tensile test	Tensile strength [MPa]	Individual	1	2	3	1	2	3	1	2	3	1	2	3
			6.4	5.2	5.8	6.3	5.1	5.1	5.8	6.3	6.6	6.7	6.7	4.9
		Average	5.8			5.5			6.2			6.1		

External appearance of test piece after the test

(Typical examples)

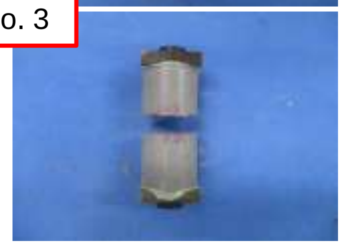
No. 1


No. 2


No. 1


No. 2


No. 3


No. 3


No. 3


No. 3


□ : Breaks at the joint

・It was verified that there is some variation in the compressive strength and tensile strength up to a joint placement interval of 2 hours, but the strength does not decrease.

・As a result of observing the external appearance of the tensile test, it was found that the test piece breaks not just at the interface of the joint (center) but at other parts as well, and was thus verified that the joint interface was not different than other sites in terms of its strength.

→ It was verified that joints can be placed up to 2 hours which is within the timeframe of the test.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Joint placement test results]

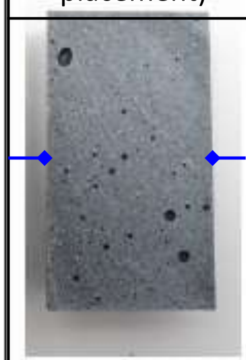
- Results of cross-sectional observation

・The area near the cut part and the joint interface of the test pieces that did not undergo the compression and tensile test were observed.

→ In the case of all test pieces, there were no interfaces and no uneven distribution of silica sand.

→ It is believed that the first and second geopolymer bodies blended until the 2 hour joint placement interval which is within th scope of the implemented test.

・In the future, it is necessary to acquire data when the extension interval is 2 hours or more assuming the actual equipment is being used.

Joint placement interval [h]			
0 (No joint placement)	0.5	1	2
			

Joint interface

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study related to maintaining functions under harsh environment (When α rays are irradiated)]

ID.	Study items	Details
2	Study related to maintaining the function under harsh environment	The status of maintaining the required functions (impact on the change in strength when α rays are irradiated) offered by geopolymer under harsh environment are verified.

- Observation of external appearance and SEM observation, measurement of Vickers hardness (geopolymer from Company C)

<Test details> Fuel pellets (radiation flux approx. 4.5 x 10^9 α/m^2·s) to which broken cladding is adhered, which are collected from fuel elements with an average burn-up of approx. 57 GWd/t are embedded in geopolymer, and are observed and measured after a predetermined time has passed.

<Test condition> Measured 4 times, retrieved from the hot lab at the start of the test and after 30 days, 64 days and 427 days have passed since the start of the test.

Vickers hardness measurement location: Region of contact of the test piece for hardness measurement to the fuel, middle region, top region, weight: 10g (98mN)

<Test piece> Age 21 days, solid state, without additives (blank conditions)

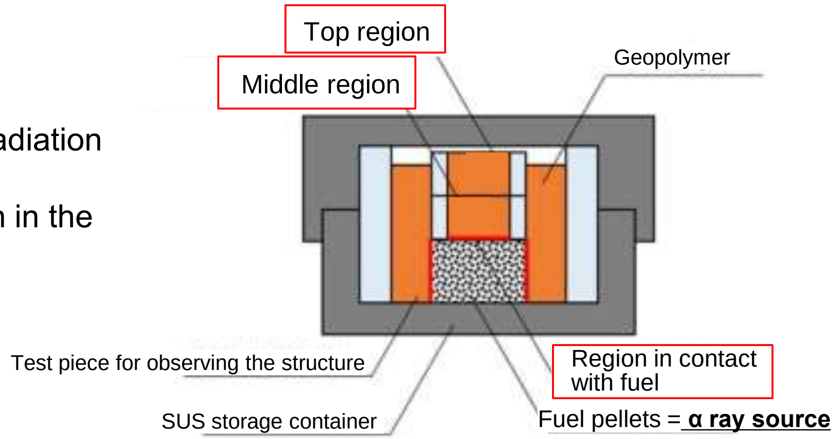
<Test results: External appearance observation and SEM observation>

It was verified in the composition observation performed during external appearance observation and SEM observation that there are no major changes.

<Test results: Vickers hardness measurement>

・The hardness was greater in the case of locations that were exposed to α radiation as compared to locations that were not exposed.

・Since hardness tends to increase due to α radiation, measuring the strength in the future is considered.



6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures：(c) Reactor internal structures

[Study on filler material: Study of the method of controlling outflow from the through hole]

ID.	Study items	Details
5	Study of the method of controlling outflow from the through hole	The size of the opening that will enable control of outflow with an appropriate combination of temperature and additives is studied.

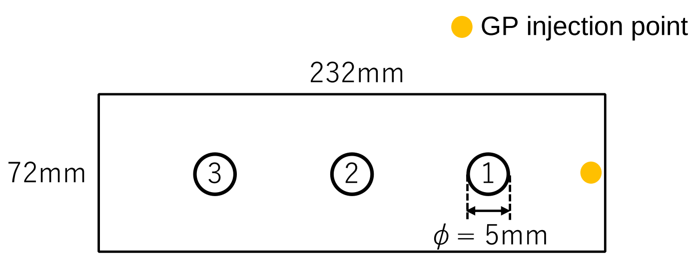
- Opening sealability verification test (Geopolymer from Company C)

<Test details> The prepared geopolymer is poured into the transparent polypropylene 40 x 76 x 236mm container that is 2mm thick and at the bottom surface of which 3 holes of size 5mm have been made, and the vertical sealability at the point in the hole where it has reached is verified.

<Test conditions> The following 3 types of geopolymer are used.

No.	State of GP	Density [g/ml]	Viscosity [Pa･s]	Flow value [cm]	Remarks
1	Blank	1.79	2.58	21.3	---
2	50% silica sand added	1.98	5.75	15.9	Silica sand is added to prevent shrinkage that increases viscosity
3	Cured for 6 hours after preparation	1.79	5.48	Not measured#	Cured for increasing viscosity

Reference value after 7 hours of curing: 13.7 [cm]



Overview diagram of the openings at the bottom of the container
(Length of the side excludes the thickness of the container)

Distance from the point of injection of geopolymer to the opening

Hole	Distance from the point of injection [cm]
①	5.7
②	11.6
③	17.5

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Opening sealability test results]

・It was verified that all 3 types of geopolymers dripped continuously right after reaching the opening, the quantity that was falling decreased gradually and the opening got sealed.

	No.1 (Blank)	No.2 (50% silica sand added)	No.3 (Cured for 6 hours)
Density [g/ml]	1.79	1.98	1.79
Viscosity [Pa･s]	2.58	5.75	5.48
Flow value[cm]	21.3	15.9	Not measured
Right after reaching opening ③			
After 5 minutes			
Quantity of geopolymer falling	Medium	Largest	Smallest
Speed of falling	Fastest	Slowest	Medium
Time until the opening was sealed	6 minutes	11 minutes or more	5.5 minutes

・As a result of comparing No. 1 and No. 3, it was found that under similar density conditions as viscosity increased the sealability increased.
・As a result of comparing No. 2 and No. 3, it was found that under close viscosity conditions greater the density lower was the sealability.
→ It is believed that using a geopolymer that is characterized by greater viscosity and lower density would be effective for vertical sealing of the opening.
・In the case of the combination with 50% silica sand as well, which is used in ID.4-2, 3, there were prospects of being able to seal Φ5mm openings.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Consolidation of requirements]

○: Issues are present
△: Countermeasures are being implemented
×: No issues

No.	Requirements	Evaluation items	Numerical target (Tentative)	Remarks and countermeasure policy	Whether there are problems
1	It should be possible to secure sufficient time from completion of blending to completion of pouring under the prescribed temperature	Time, temperature	6 hours at 10℃ or lower	Pouring equipment that can maintain the prescribed temperature will be studied.	○
2	Feeding with a pump should be possible	Flow values	15cm or more	Temporarily set using the existing pump. In the future, feeding will be set depending on the pumping capability when using the actual equipment.	○
3	The filler material should be able to penetrate the gaps in the fuel debris and structures	Viscosity	10Pa･S	It has been verified in FY2020 that the feeding material can penetrate CRD.GT gaps when the viscosity is 10Pa･S and the temperature is 60℃. Since there is the risk of cracks if there are inclusions, verification test needs to be conducted on the geopolymer combination prepared this time.	△
4	It should be possible to maintain sub-criticality	Quantity of neutron absorption material, homogeneity	Will be set in the future	It has been verified that the neutron absorption material (B or Gd) can be mixed with geopolymer.	△
5	Strength should not decline after extension work	Tensile strength	Will be set in the future	It has been verified that the strength does not decline up to a 2 hour extension work interval. In the future, the extension work interval that would be effective in the actual equipment needs to be verified.	△
6	It should be able to seal the openings	Viscosity, density	Will be set in the future	It has been verified that openings with a 5mm diameter can be sealed.	△
7	It should solidify and be able to withstand its own weight	Compressive strength, tensile strength	Will be set in the future	Requirements in terms of strength will be studied based on the filling method (complete filling, partial filling) depending on the status inside the reactor.	○
8	Its strength should not be lower than the prescribed strength under radiation environment	Compressive strength and tensile strength after exposure to radiation	Will be set in the future		
9	Its strength should not be lower than the prescribed strength under water injection environment	Compressive strength and tensile strength under water	Will be set in the future		
10	It should be able to withstand the decay heat from fuel debris (Cracks, etc. should not form)	Upper temperature limit	300° C	It has been verified in a laboratory that it can withstand temperature up to an upper temperature limit of 300℃.	△
11	It should be possible to control the generation of hydrogen as a result of radiolysis of water	Amount of hydrogen generated (G value)	Will be set in the future	It has been verified that the amount of hydrogen generated in the case of the test piece in which the geopolymer is mixed with Pd powder is below the lower limit of detection.	△
12	It should be possible to cut it.	Hardness	Will be set in the future	There are proven track records of being able to cut using concrete cutter, wire saw and laser cutting.	△

Note: Consolidation of requirements related to long-term storage (radioactive nuclide confinement function), waste treatment and disposal are issues that will be studied in the future and hence are not included in this table.

① Method of cutting into large structures：(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

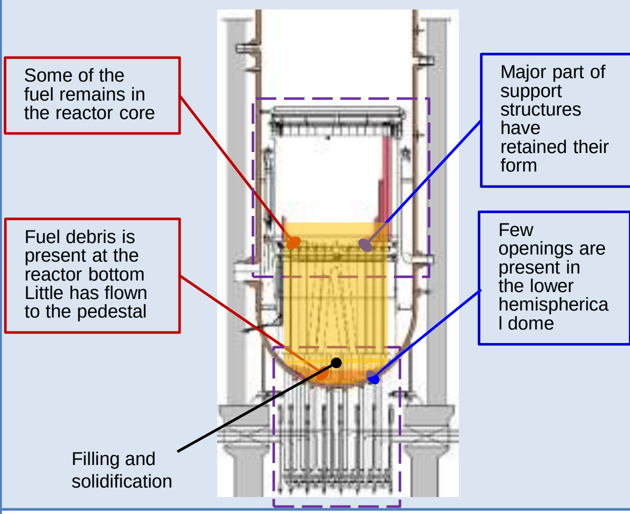
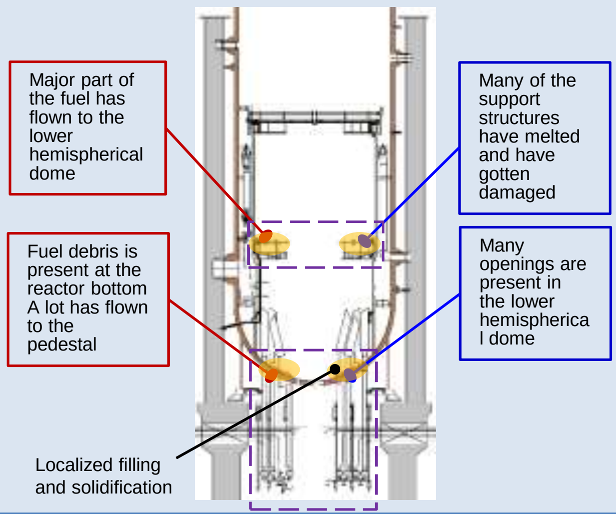
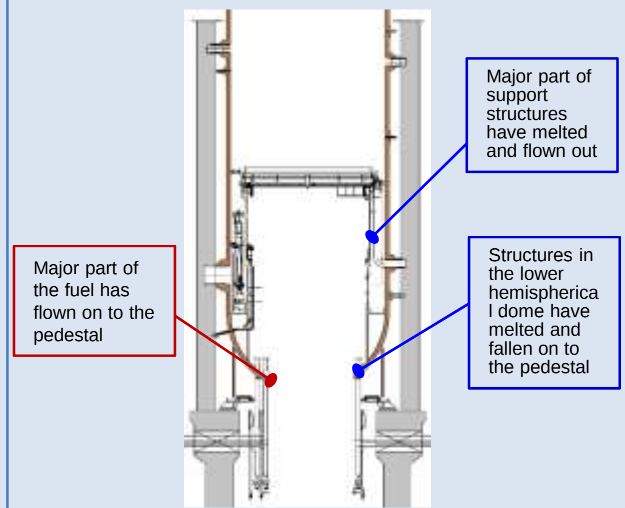
ID.	Study items	Details
3	Study of the method of filling filler material inside the reactor	The method by which filler material ought to be injected into RPV (how it ought to be filled at the point of injection and thereafter) is studied.
6	Study of the filling procedures and methods anticipating filling in the actual equipment	The type of equipment required is studied considering the results of the studies in ID.3 and ID.4.

- The methods of filling filler material into the reactor are largely classified into complete filling and partial filling.
- The filling methods are consolidated in accordance with the status of damage.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

	A. Damage progression Small scale	B. Damage progression Medium scale	C. Damage progression Large scale
Conceptual diagram			
Response	• Filling and solidification of fuel debris inside the reactor core and at the reactor bottom • Cutting and transferring as large structures	・Localized filling and solidification of the remaining fuel debris ・Reducing the scope to the part where fuel debris remains, cutting into large pieces and transferring	・Filling and solidification not required ・Cutting into portions as large as can be transferred
Merits	・ Detailed positioning of the scope of filling is not required	・ Small quantity of geopolymer required	—
Demerits	・ Large quantity of geopolymer required	・Dikes need to be set up so that the geopolymer does not flow out from where it has been filled	—

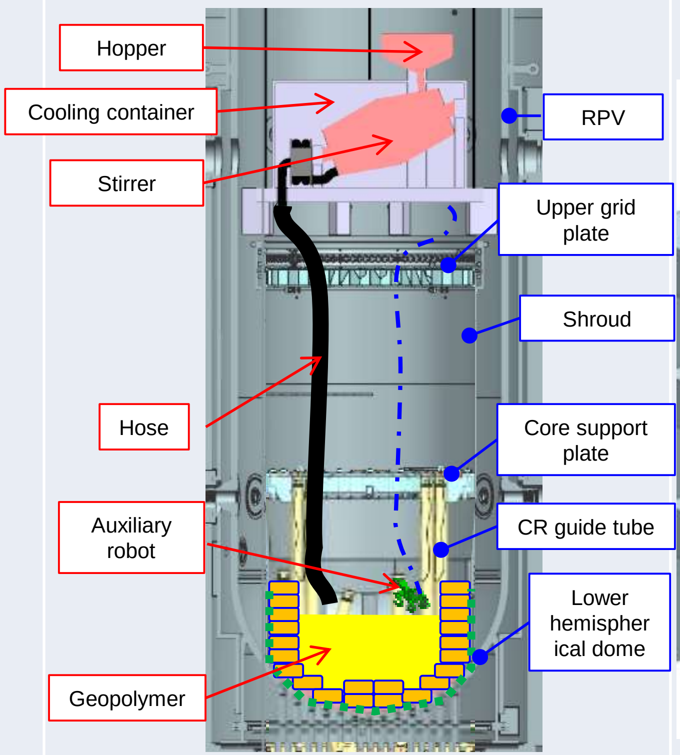
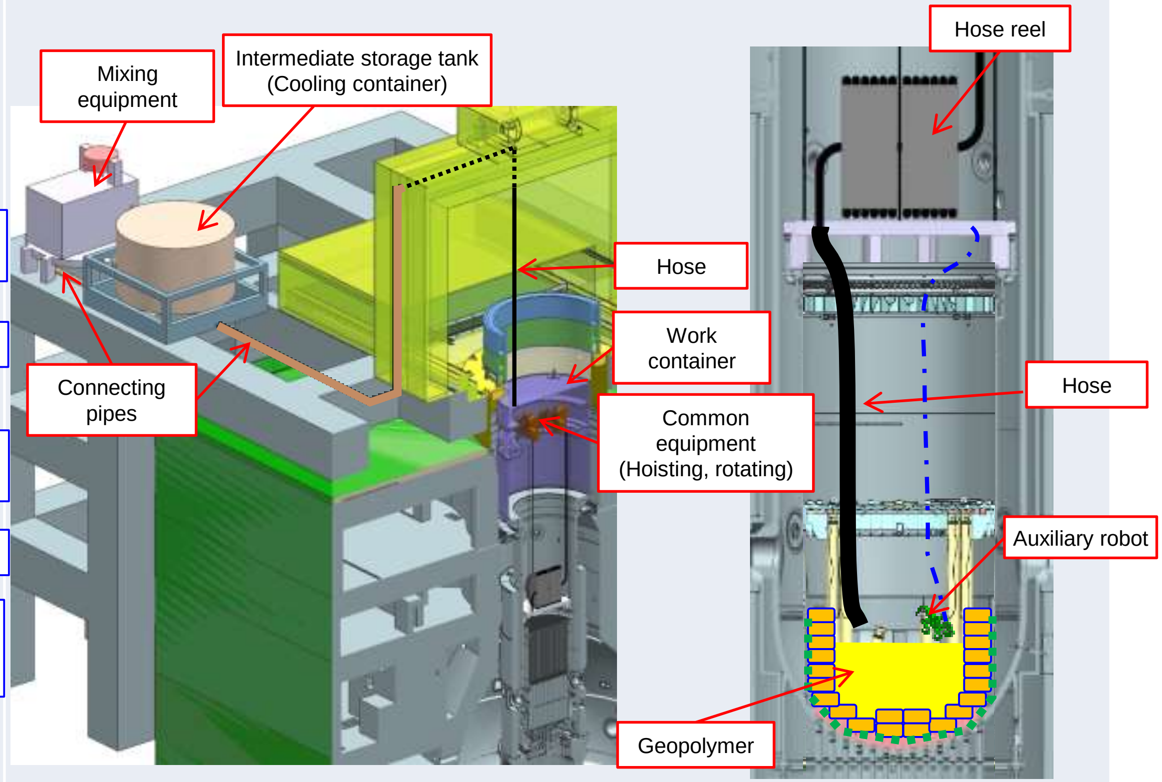
- The filling methods for the above-mentioned status of damage are studied in this document.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

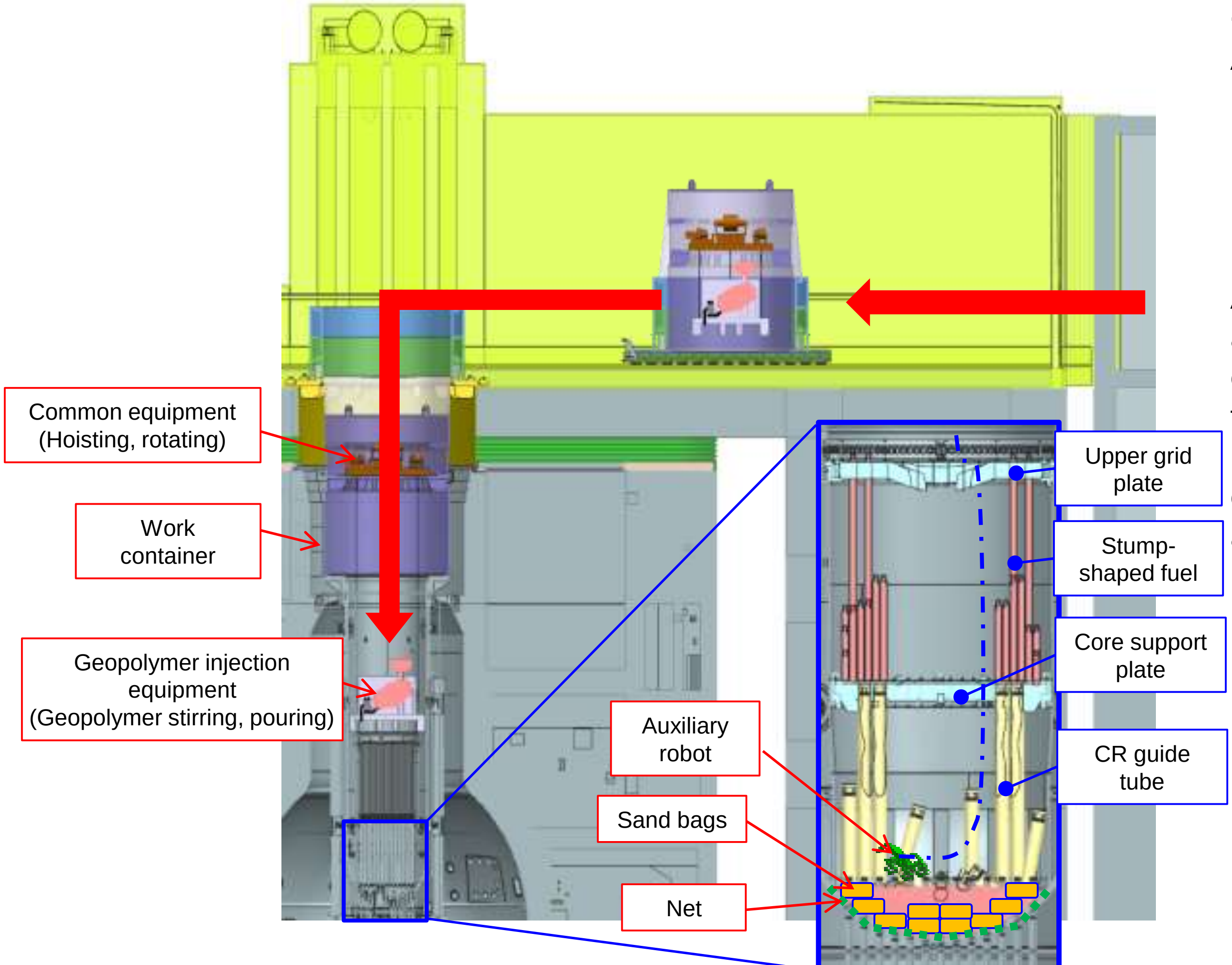
- The following 2 methods for filling geopolymer were studied.

	Batch processing	Continuous pouring
Concept	The material is mixed inside the reactor, and by reducing the distance up to the filling location, filling is carried out while retaining fluidity	The material is mixed on the gantry and is fed into the reactor with a hose thus carrying out continuous pouring
Illustration		

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

- Overview of the batch processing method (1/2)



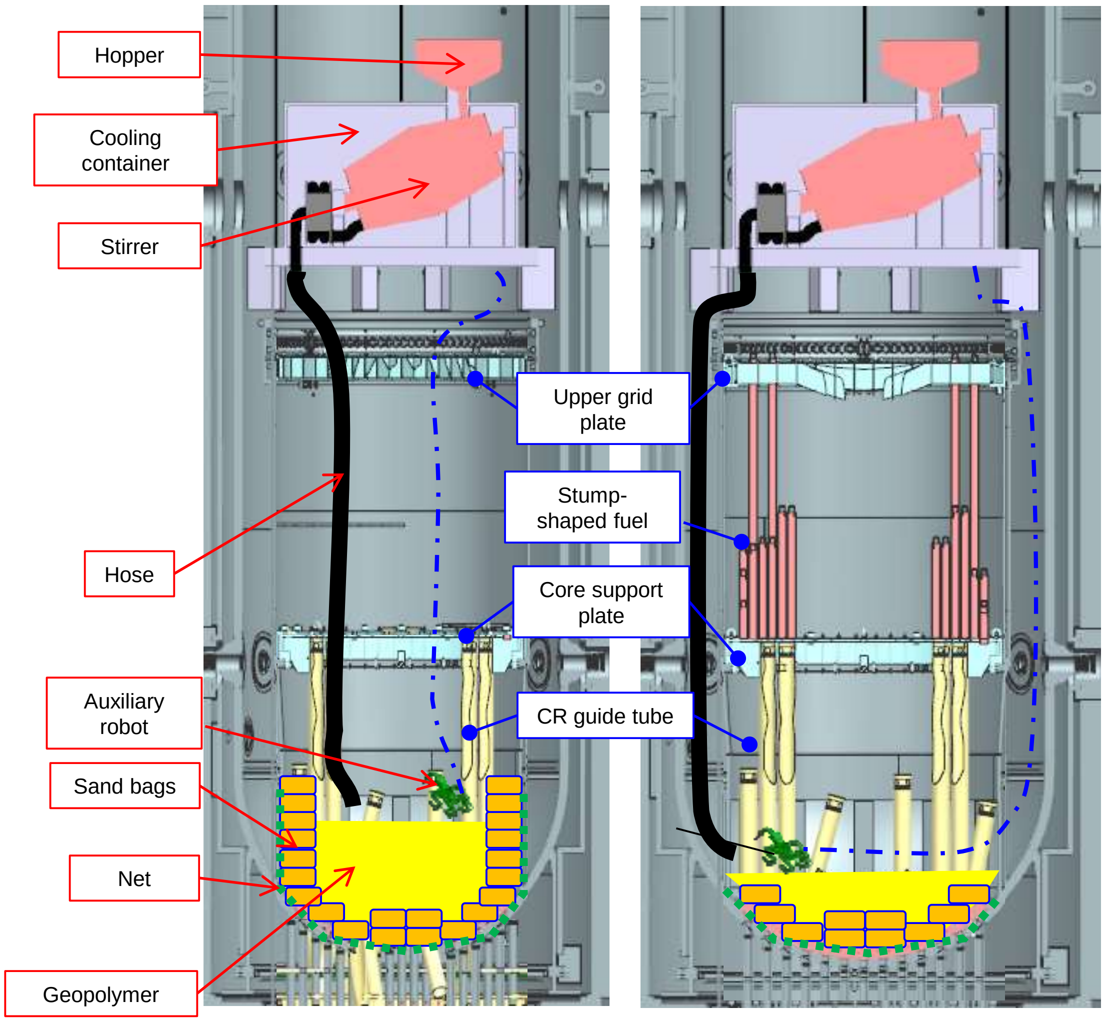
<Pre-conditions>
After removing the interfering objects with the help of disassembly equipment and auxiliary robot, the size of the opening in the reactor bottom lower hemispherical dome is reduced by installing a net and sand bags, thus making it possible to seal the opening with geopolymer.
At the time of reactor core meltdown, sand bags are piled up to prevent geopolymer from flowing out from gaps in the shroud leg (explained on the following page).
If it is difficult to install a net due to the condition of the lower hemispherical dome, fallen objects are collected using a fall prevention sheet installed from the reactor bottom.

- The geopolymer injection equipment is loaded in the work container inside the additional building, and is transferred inside the RPV.
- The equipment for injecting geopolymer is suspended from the work container, and is installed on the upper surface of the shroud.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

- Overview of the batch processing method (2/2)



During reactor core meltdown

When there are remains at the reactor core

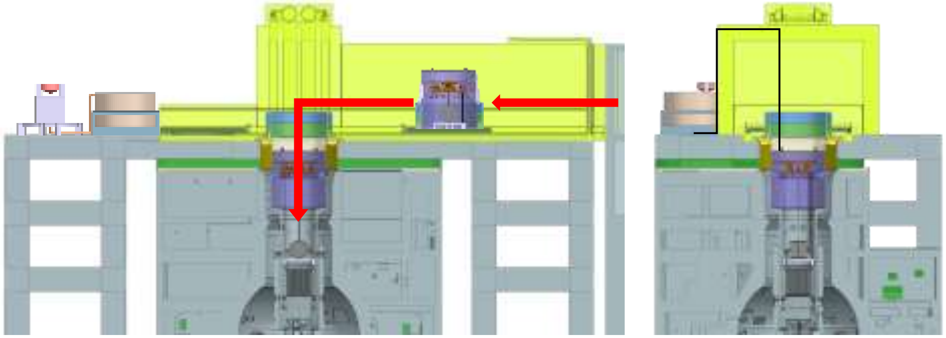
- The material inside the hopper is poured into the stirrer and geopolymer is prepared.
- The prepared geopolymer is injected into the reactor bottom by means of a hose. In doing so, the point of injection is adjusted with the auxiliary robot.
- If the reactor bottom cannot be accessed because of remnant structures in the reactor core, the bottom is accessed from the outer periphery of the shroud leg, the reactor bottom is solidified and then the reactor core is filled.
- After completing the work of injecting geopolymer from inside the stirrer, the hose is transferred to the additional building for refilling the next batch of material.
- Hereafter the process is repeated.

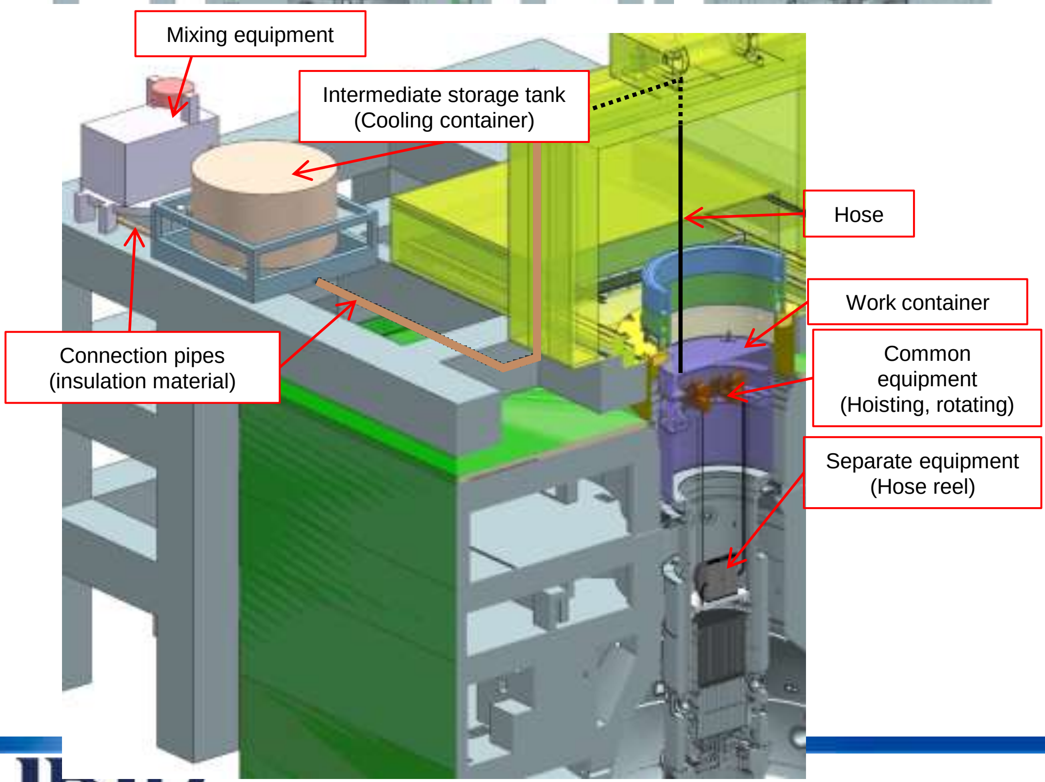
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

- Overview of continuous pouring method





<Pre-conditions>
Similar to the batch processing method

- A work container on which a hose reel is mounted is installed on the top surface of the shroud.
- The hose from the hose reel is connected to the connecting pipes from the intermediate storage tank installed on the gantry.

- The geopolymer is prepared using the mixing equipment and is pumped to the intermediate storage tank.
- The hose from the hose reel is connected to the connecting pipes from the intermediate storage tank installed on the gantry.
- Once the tip of the hose is positioned on the injection point at the reactor bottom, the geopolymer is pumped from the intermediate storage tank.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Study of the method of filling filler material inside the reactor]

- Comparison of the filling methods

	Batch processing	Continuous pouring
Merits	・Fluidity is retained easily as the injection point is near the mixing location. ・Maintenance is easy as the equipment is changed every time	・Supply of material is easy as the material is mixed on the gantry. ・The amount of work can be reduced as the equipment does not have to be changed.
Demerits	・Since only a small quantity can be injected at a time, many extensions are required. ・Since the work of changing the equipment (including refilling material) takes time, the work until completion of filling takes time.	・A longer hose is required due to which it is difficult to pump or cool (heat insulation) the geopolymer. ・As the hose is long, the geopolymer is likely to get solidified inside the hose while it is being pumped. Also, in that case, it is difficult to handle the hose and emergency retrieval of the hose becomes challenging. ・Since mixing and intermediate storage is carried out on the gantry, the size of the gantry may have to be increased.

- Conclusion

Since hose treatment is required and a temperature of 10℃ or lower (to ensure fluidity) must be retained, the batch processing method that is easy to manage will be studied as the potential method.

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Summary]

- The characterization of geopolymer that is being considered as a filler material was carried out through injection tests using a barrel.
- Solidified units without cracks can be prepared using a barrel at the assumed temperature inside the RPV (40℃).
  The effectiveness of increasing the quantity of silica sand filling (50% addition) as a crack countermeasure was verified.
  In the future, the effectiveness of crack countermeasures when there are inclusions remaining, needs to be verified.
- As a result of the extension work test, it was verified that joints can be placed up to 2 hours.
  Blending of the first and second geopolymer body was verified. Even in terms of strength, there was no difference with other sites.
  In the future, the extent to which the joint placement time can be extended needs to be verified.
- It was verified through impact verification tests that hardness tends to increase as a result of radiation exposure.
  In the future, strength needs to be verified as well.
- The specifications required of the filler material were consolidated, and issues in actual equipment application and in scaling up were identified.
- The method of filling filler material in the actual equipment was studied, and considering the batch processing method as a potential method from the perspective of retaining fluidity of the geopolymer, conceptual studies were conducted including on the method of controlling outflow from the through holes.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting into large structures :(c) Reactor internal structures

[Study on filler material: Summary]

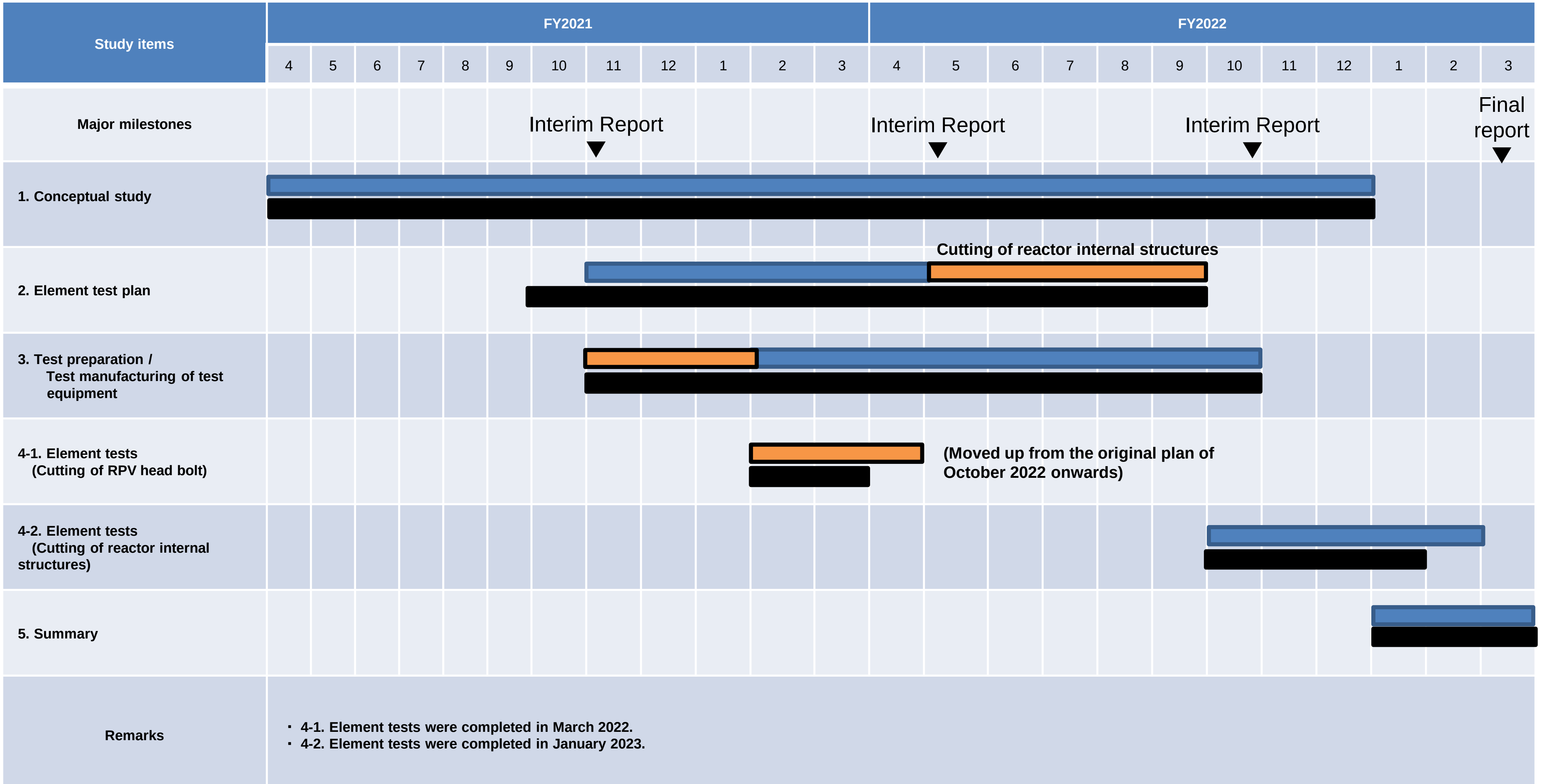
Issues	ID.	Study items	Study results	Issues
Study related to maintaining the function of the filled and solidified units	1	Evaluation of the impact on solidification function assuming environmental condition (temperature) inside RPV	It was verified that solidified units without cracks can be prepared using a barrel at 40℃ which was the assumed temperature inside the RPV.	It is necessary to improve data on the strength and temperature at the extension interval (2 hours or more) assuming the actual equipment is being used.
	2	Study related to maintaining the function under harsh environment	It was verified that there is no major change in the external appearance and the composition when exposed to α radiation, and that hardness tends to increase.	The impact of α radiation during the period from completion of mixing to completion of solidification of the geopolymer needs to be verified.
Study of filling filler material inside the RPV anticipating the actual equipment	3	Study of the method of filling filler material inside the reactor	The batch processing method and continuous pouring method were studied as methods of filling filler material in the RPV. The batch processing method will be studied as a potential method from the perspective of retaining fluidity of the geopolymer.	The filling equipment needs to be substantiated for its use in the actual equipment and issues in the filling method need to be identified by conducting element tests. Also, studies need to be conducted on methods for improving throughput.
	4	Characterization through injection test conducted using a barrel (Implemented along with ID.1)	It was verified by conducting the injection test using a barrel that the geopolymer can be filled and that it meets the requirements as filler material.	The thermal expansion effect measurement data needs to be improved assuming the use of actual equipment. Also, the effect of crack countermeasures while the geopolymer is inside the structures assuming its use in the actual equipment needs to be verified.
	4-2	Measures by increasing the amount of filling of silica sand (Implemented along with ID.1)	It was verified that solidified units without cracks can be prepared using a barrel by increasing fine aggregates as a crack countermeasure. Also, it was verified by conducting a stress measurement test that increasing fine aggregates is effective in controlling thermal expansion.	
	4-3	Extension work	It was verified that joints can be placed up to 2 hours which is within the time frame of the test. At that time, blending of the first and second geopolymer bodies was verified based on cross-sectional observation, and it was verified that the joint interface was not different than other sites in terms of its strength.	Refer to ID.1
	5	Study of the method of controlling outflow from the through hole	It was verified that an opening of Φ5mm can be sealed by injecting a geopolymer composition consisting of 50% silica sand filling.	Issues in the methods (combined with net, sand bags, etc.) of controlling outflow from the through holes assumed to be present in the actual equipment need to be identified by conducting element tests.
	6	Study of the filling procedures and methods anticipating filling in the actual equipment	Conceptual studies were conducted on equipment required for the batch processing method.	Refer to ID.3
Evaluation of impact of filling	7	Impact on treatment and disposal	The impact on treatment and disposal of the filled and solidified units will be studied. (To be studied in the future)	In addition to the track record of application to high-level radioactive waste (stored in barrels), it is being said that the cesium leaching control effect is being verified as part of the JAEA wisdom projects. Treatment and disposal methods need to be studied based on these data on geopolymer properties.
	8	Impact when heat generating elements are solidified	The impact on the solidified units and the method of heat dissipation (cooling), etc. when fuel debris (heat generating element) is inside the solidified unit will be studied. (To be studied in the future)	Along with acquiring fundamental data from when the fuel debris is embedded in the heat generating elements, filling methods to be used in the actual equipment (heat dissipation, cooling) need to be studied.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

① Method of cutting large structures

■ Development Process

: Planned
: Planned (after revision)*
: Actual



* The plan was revised to reflect the study progress status and the results of element tests.

① Method of cutting into large pieces: Summary

- **Pre-conditions pertaining to the method of transferring unitized large structures were consolidated, and overall steps were created.**
- **The methods for cutting the stud bolts of the RPV head from among the structures inside the reactor well were studied in FY2021, as a part of cutting "structures other than reactor internal structures", test pieces (RPV head, bolts) simulated to the actual equipment scale were manufactured, and element tests on cutting the bolts with AWJ were conducted. The feasibility of the method of cutting the RPV head bolts was verified, and issues were consolidated.** (Reported under "Accomplishment Report for FY2021*")
- **In order to cut the reactor core after filling and solidification, methods of cutting the shroud structures and the filler material were studied, as a part of cutting "reactor internal structures". The method of cutting the outer periphery of the shroud was developed on a priority basis in order to proceed with cutting the inside (filled and solidified part) in parts after cutting the outer periphery of the shroud.**
- **The laser + pulse WJ cutting was selected as the method for cutting the outer periphery of the shroud, element test plan was drafted and the tests were conducted. Based on the results of the element tests, the feasibility of application of the method to cutting the outer periphery of the shroud was verified, and issues were identified and consolidated in preparation for designing the actual equipment.**
- **In addition to the characterization of geopolymer that is being considered as a filler material, carried out through injection tests using a barrel, tests were conducted to verify the impact of exposure to radiation and issues were identified and consolidated in anticipation of application in actual equipment and scaling up. Also, work steps involved in filling and solidification were organized.**

*Accomplishment Report for FY2021: https://irid.or.jp/wp-content/uploads/2022/08/2022007_deburitoridashi.pdf

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

With respect to retrieving fuel debris and reactor internal structures, in order to enhance the throughput using the top access method, the method of transferring unitized large structures is being studied as part of the development being undertaken since FY2019. To make this possible, the structures need to be separated from the reactor and these large structures need to be transferred. Large transfer containers used for transferring the large structures, which will have a contamination spread prevention function and a shielding function for the high radiation items stored in them, need to be developed.

From FY2020, the preconditions and the required development items for the large transfer containers are being studied and consolidated, the site applicability of the large transfer containers is being evaluated through development of the air-tight and shielding structure for the lid portion of the large transfer containers, conceptual studies on the transfer systems and element tests related to the viability of the air-tight structure of the lid portion, and the issues are being consolidated.

The diameter of the large transfer containers will be about the same as the RPV with a height of nearly 10m as the structures separated from the reactor core will be unitized and stored in the containers. Hence further substantiation of the large transfer containers is required based on the issues consolidated. Therefore detailed studies will be conducted related to the establishment of the concept of the transfer system including the storage method, the air-tight and shielding structure of the overall large transfer container including the lid part, the manufacturing procedures, etc. Also, the structure of the large transfer container will be such that the inside can be decontaminated so that the container can be reused. Thereafter, a full scale transfer container will be test manufactured, its performance will be verified through element tests, its viability will be verified and issues in site applicability will be identified.

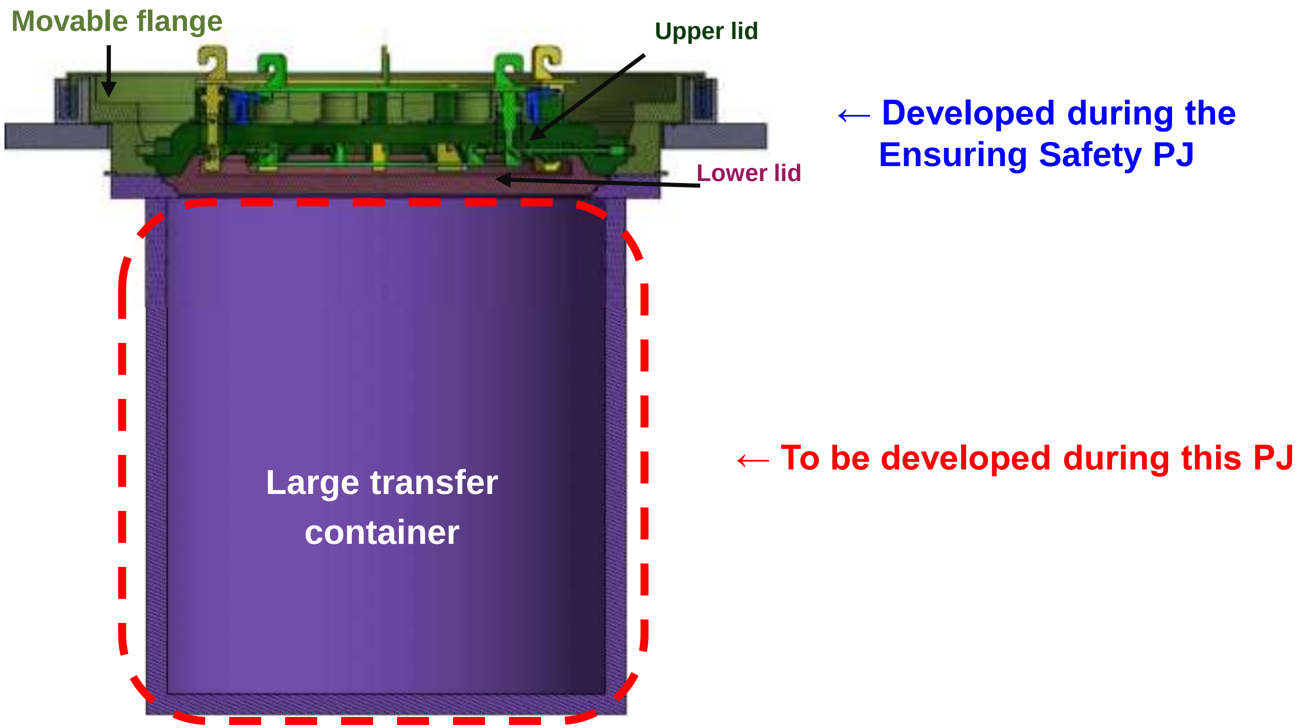
② Large transfer containers

Table of Contents

② Large transfer containers

[Status of studies conducted up to FY2020]

- Conceptual study on the large transfer containers was conducted.
- The element tests related to air-tightness of the lid part of the large transfer container were conducted during the Ensuring Safety PJ.



⇒ The structure of the main body of the large transfer container will be substantiated and the viability of the structure including the manufacturing capability will be studied. Air-tightness of the container body will be verified by test manufacturing the container.

*Ensuring Safety PJ: "Development of Technology for Further Increasing the Scale of Retrieval of Fuel Debris and Reactor Internal Structures (Development of technology related to ensuring safety during fuel debris retrieval)"

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R: Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

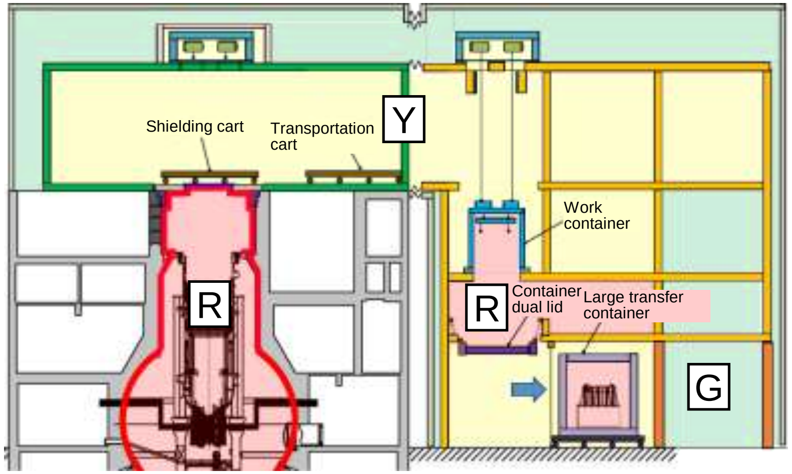
[Issues]

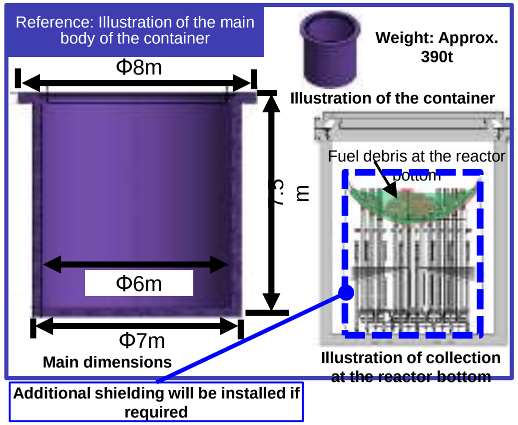
- In order to transfer unitized large structures, large transfer containers with a function for preventing the spread of contamination need to be developed.
- Study on the confinement performance including when the large transfer container is opened and closed, and verification of feasibility.
- Study on manufacturing capability including processing and assembly, and verification of feasibility.
- Method of remotely connecting the large transfer container and the lid, etc., handling capability.

[Implementation details]

- The pre-conditions related to the study will be consolidated.
- Studies will be conducted on establishment of the concept of the transfer system including the method of storing into the large transfer container and the detailed procedures for transferring the entire large transfer container, based also on issues studied during the Ensuring Safety PJ.
- Structural designing of the large transfer container will be carried out. Studies will be conducted considering decontamination of the inside of the container assuming that the transfer container will be reused.
- Element tests will be planned, the large transfer container will be test manufactured, feasibility will be verified and issues will be consolidated.

Note) This figure explains how the large transfer container is used.
For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.





[Expected outcome]

- Presentation of a detailed process diagram of the transfer system using large transfer containers
- Presentation of a structural drawing considering manufacturing capability.
- Presentation of results of verification of air-tightness by means of element tests, feasibility evaluation and issues.

② Large transfer containers

[Pre-conditions]

- Pre-conditions for the method of transferring unitized large structures are given below.

ID.	Pre-conditions	Basis
1	The structure of the container must enable storage of the structures cut into large pieces. (The container must be able to store structures that are about Φ5.5m, H5.5m.)	The structure of the container must enable storage of units that have been cut and transferred for every structure using the method of transferring unitized large structures.
2	The large transfer container must serve as an on-site transportation container for moving objects from the additional building to another building such as the storage building, etc.	First, it will be verified if the container is viable as an on-site transportation container, and its applicability to storage will be evaluated in future subsidy projects.
3	The structure of the large transfer container must be such that it can be repeatedly used as an on-site transportation container.	As repeated use of the large transfer container would be economical.
4	The results of studies conducted during the Ensuring Safety PJ must be reflected as appropriate for other basic specifications of the large transfer container.	Will be continued in coordination with the Ensuring Safety PJ.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

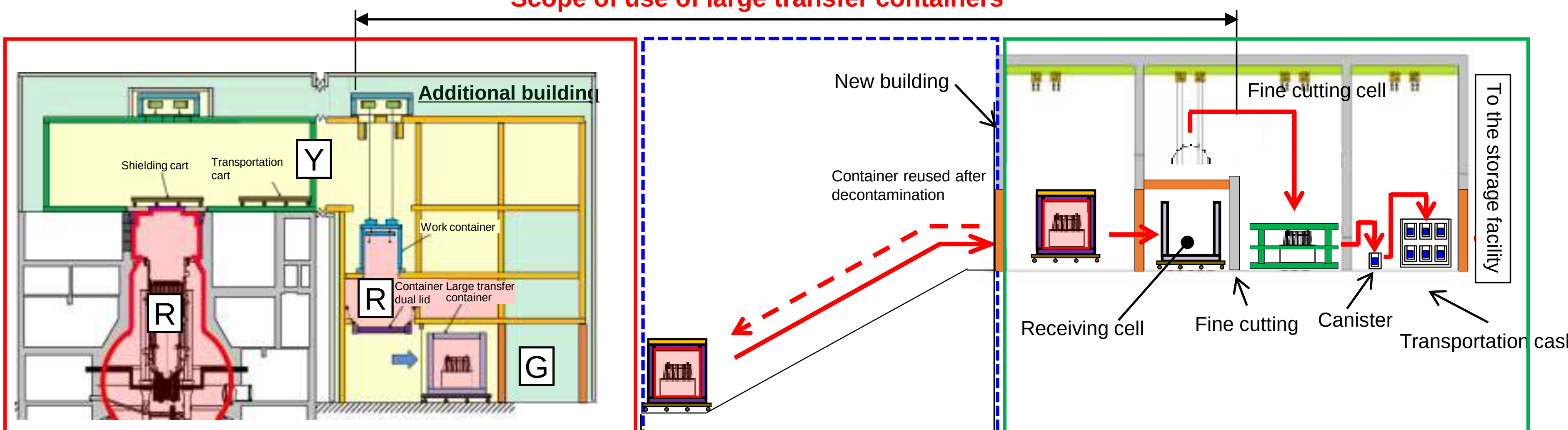
[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

[Pre-conditions]

A rough outline of the steps involved in using the large transfer container are given below.

(A) Unitized structures transferred from the PCV will be transported to the additional building and stored in large transfer containers.
(B) The structures stored in the large transfer containers will be transported on site to the New building.
(C) The structures will be removed from the large transfer containers inside the New building, they will be finely cut and stored in canisters and transportation casks.

Scope of use of large transfer containers



(A) Operations in the additional building

[Details of the operations]
- The connecting parts of the structures will be cut, the structures will be lifted up using a crane and unitized large structures will be transferred from the PCV.
- After the structures are moved over the operation floor using the transportation cart, they will be lowered with the help of the crane in the additional building, stored in large transfer containers and delivered.
- Empty large containers will be received, they will be connected to the additional building, and preparations will be made for storing the transferred structures.

(B) On-site transportation

[Details of the operations]
- The structures stored in the large transfer containers will be transported on site to the New building.
- After being decontaminated in the New building, the empty containers will be transported on-site.

(C) Operations in the New building

[Details of the operations]
- The structures will be removed from the large transfer containers.
- The structures will be finely cut and stored in canisters and transportation casks.
- The transportation casks will be delivered and stored at the storage facility.
- The empty containers will be decontaminated and inspected, and delivered to the additional building for reuse.

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in using the large transfer containers.
For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

[Functions required of the large transfer containers]

・A comparison of the structural outline of the large transfer container and the spent fuel transportation container used in Fukushima Unit 3 is shown in the table below.

According to the table, the structures in the large transfer container are planned to be similar to the structures required of existing transportation containers, and it is believed that it will be feasible to use the large transfer container as a container for on-site transportation.

ID.	Item	Fukushima Unit 3 Spent fuel transportation container#	Large transfer container
1	Shielding structure (γ radiation source, neutron radiation source)	①The carbon steel in the body, bottom plate and outer casing, and the stainless steel in the lid are γ rays shielding materials ② Water in the body and the resin between the body and outer casing are the neutron shielding material	① **γ rays shielding material** is made up of **carbon steel** in the main body, the lid and the additional shielding. ② **Neutron shielding material** is made up of the **resin** in the main body and lid.
2	Criticality prevention structure	The basket (borated stainless steel) containing the fuel has a grid-shaped structure that keeps the fuel in the prescribed geometric form.	The container is already filled with the required quantity of **insoluble neutron absorption material (Glass material containing B and Gd)** for preventing criticality. (Filter, filling structure, etc. need to be studied from the perspective of preventing obstruction of drainage during decontamination)
3	Heat removal structure	The heat that gets transferred to the main body of the container is mainly dissipated by the heat transfer fin provided in the resin of the neutron shielding part.	The necessity of the residual heat structure (heat transfer fin, etc.) depends on the quantity of heat generated by the inclusions (According to the results of the rough evaluations at this point in time the heat transfer fin is not required). If required, a ceramic **heat transfer fin can be added** to the side and at the bottom of the main body of the container.
4	Air leakage inspection	The leakage rate from the primary lid, secondary lid and the port cover respectively should not exceed 9 x 10-1 ref cm^3/s when a pressure of 0.9MPaG or more is applied to the sealed part of the transportation container.	Since a transportation lid + a metal O ring are used during on-site transportation, it is believed to be **equivalent to a metal cask**.
5	Structural strength	The possibility of occurrence of events are studied considering measures to prevent such occurrences, focusing on initiating events that are assumed to occur during transportation, as also on handling the containers for on-site transportation, based on the handling flow. The containers are not meant for transportation outside the plant. They are used exclusively for on-site transportation. Within the premises of 1F, the vehicles are slowed down so as not to come in the way of other vehicles. Hence falls that could occur assuming an accident during transportation are not taken into account as a design requirement. Also, it is verified that the structural strength is sufficient to withstand load generated while the container is being handled within the 1F premises. Further, since measures have been taken to prevent the fall of the transportation container, the event of falling during handling is not taken into consideration as a design requirement.	The possibility of occurrence of events is studied considering measures to prevent such occurrences, focusing on initiating events that are assumed to occur during transportation, as also on handling the containers for on-site transportation, based on the handling flow. **Since the large transfer containers are also meant exclusively for on-site transportation, just as it has been described in the left column, falls resulting from accidents are not taken into account as a design requirement.** Also, since the container is not lifted up during transportation, and **fall prevention measures are planned to be taken** by using a gantry for transportation, **falls during handling are not taken into account as a design requirement.**

#Source: Nuclear Regulation Authority website "Application for approval of changes in the equipment for removing fuel from the spent fuel pool".

② Large transfer containers

[Functions required of the large transfer containers]

・The functions required of the large transfer containers and their current specifications are given below.

ID	Required functions	Items	Current container specifications	Remarks
1	It must be possible to store and transport on site the structures retrieved by transferring unitized large structures.	Items to be transported	Dryer, separator, upper grid plate, reactor core, reactor bottom, etc.	It is assumed that reactor internal structures are stored as unitized structures. Items besides those mentioned on the left will be studied as well considering the impact such as the weight, dose, etc. of isolation sheet, etc.
2		Approximate dimensions of the container	Inner diameter Φ6000 x H7500[mm]	Shape of the container is such that typical structures can be stored.
3	It must be possible to store structures inside the cell in the additional building while preventing spread of contamination.	Function of maintaining boundaries	The structure must have a dual lid for maintaining the boundaries through a series of procedures	The sealed part will be studied considering the use of a double door.
4		Pressure within the cell	-400 [PaG]	The lid will be closed while connected with the -400Pa in the container (red zone).
5		Target leakage rate (During the operation inside the cell in the additional building)	0.1[vol%/h]	Set based on the design basis for the nuclear facility air management considering that the leakage rate is around the same as the acceptable leakage rate for the cell inside the boundary.
6	Shielding must be possible during transportation of the structures.	Maximum dose rate of contents	300[Sv/h]	Evaluated based on the radiation dose from the stored structures
7		Shielding thickness (γ rays)	280 [mm]	A 130mm separate additional shield will be installed beforehand for structures with a high radiation dose.
8		Shielding thickness (neutron rays)	100 [mm]	Will be evaluated based on the radiation source of fuel debris.
9		Approximate weight	520 [ton]	Only the main body of the container, lower lid, and transportation lid (not including the structures) Structures, transportation conditions will be studied based on the total weight including additional shielding. (Approx. 1300 ton)
10	Repeated use of the container must be possible.	Number of times it will be used	Planned to be used multiple times	The main material of the container and the material of the sealed part have been studied during the Ensuring Safety PJ assuming the container will be used multiple times.
11		Main material of the container	Carbon steel	The sealed part and the inner surface must be SUS clad.
12		Material of the sealed part	Rubber O ring (CR)	Considering that the dual lid will be opened and closed multiple times and considering that it could fall, it was installed in a dovetail groove.
13		Decontaminability	Must have a drain and must be lined with SUS	SUS lining and drain will be installed taking into account that the inner surface will be washed with water.
14	The design must consider generation of heat by the fuel debris.	Container surface design temperature	130 [° C]	The amount of heat generated by fuel debris is set tentatively based on estimation. Further, with the current sealed part, the calculated temperature is approx. 60℃. Hence it is believed that there are no issues with this specification.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

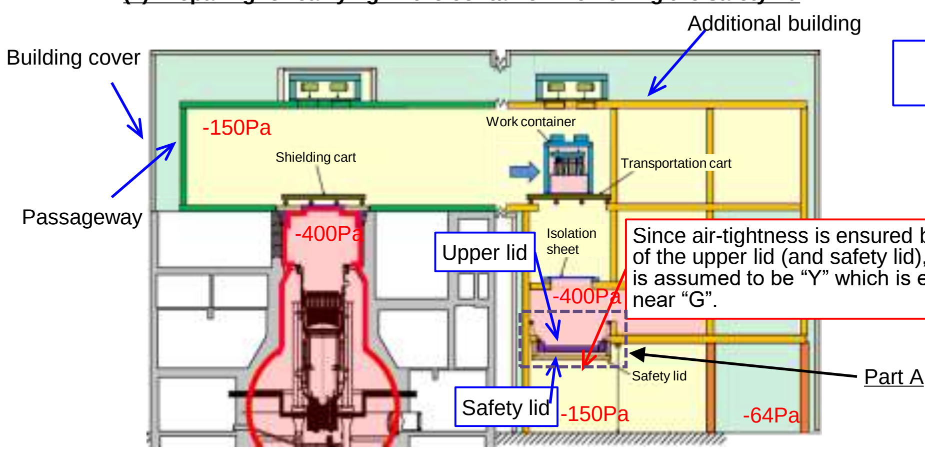
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

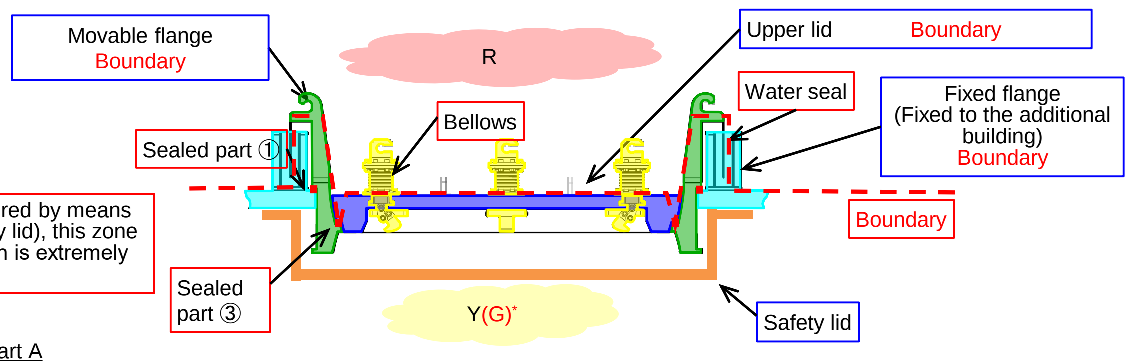
[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (1/7)]

The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(1) Preparing for carrying-in the container: Removing the safety lid

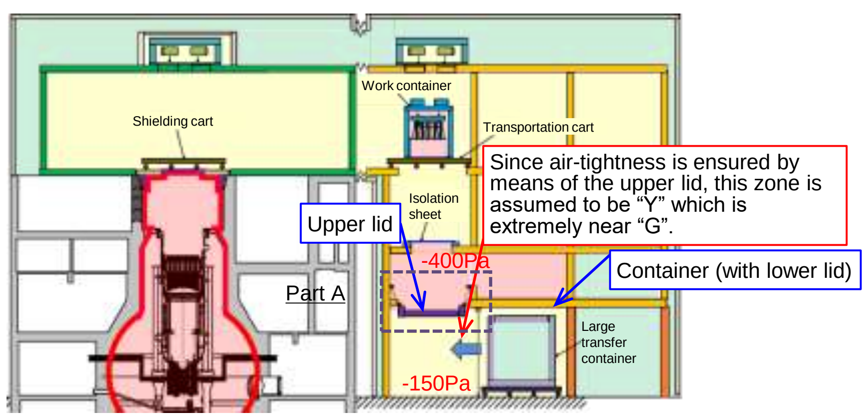


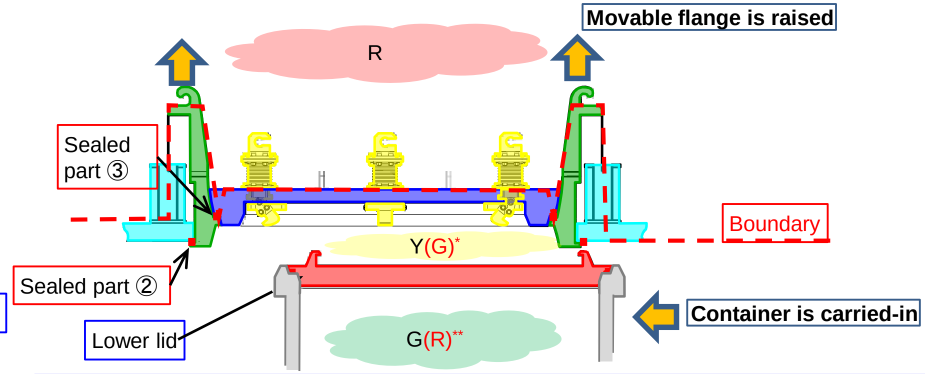
Enlarged view of Part A



(1) Preparing for carrying-in the container: Removing the safety lid

(2) Carrying-in the container: Carrying-in the large transfer container





(2)-1: Raising the movable flange
(2)-2: Carrying-in the large transfer container (The container moves only in the horizontal direction)

* Assumed to be "Y" which is extremely near "G"
** When the large transfer container is reused, the inside of the container may not be "G".

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

Since the classification of contaminated areas is under examination, it could change in the future.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

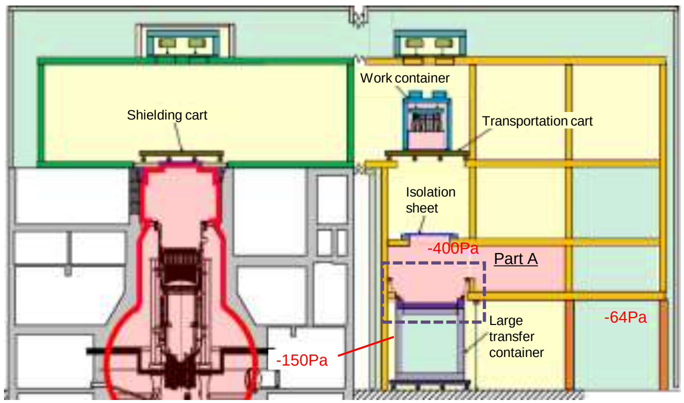
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

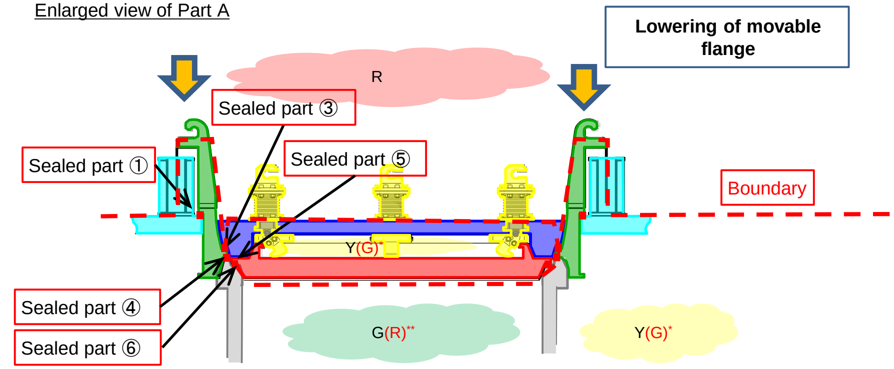
[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (2/7)]

The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(3) Connecting the container: Connecting the upper lid and lower lid (container)

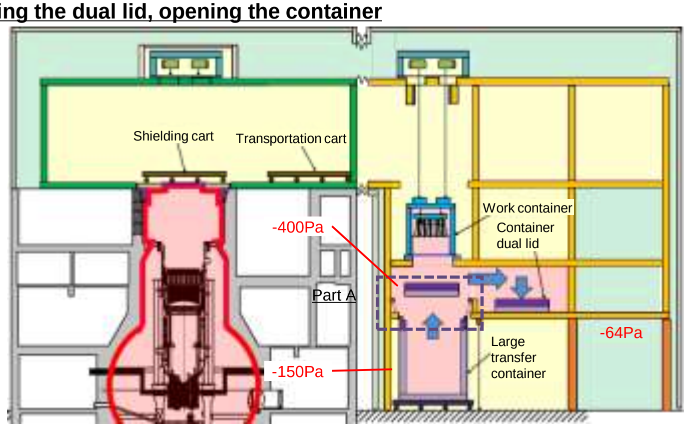


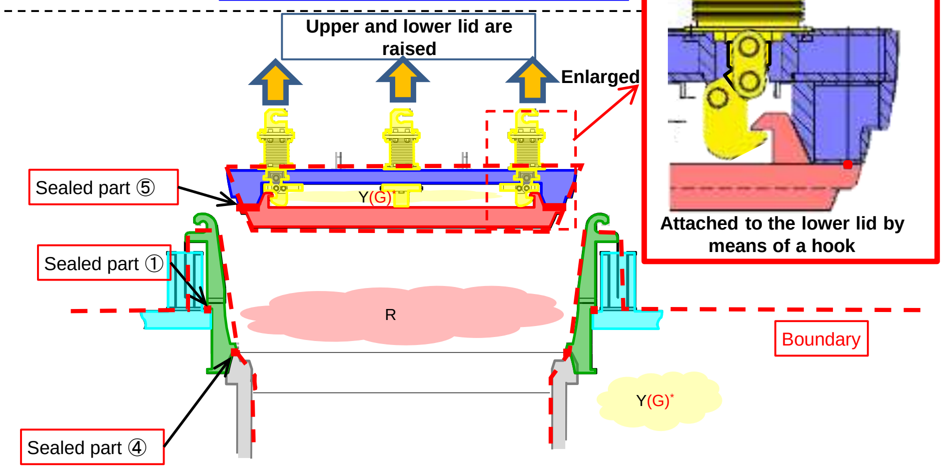
Enlarged view of Part A



(3)-1: Lowering the movable flange
(3)-2: Connecting the upper lid and lower lid (container)

(4) Lifting the dual lid, opening the container





(4)-1: Lifting the dual lid and opening the container

* Assumed to be "Y" which is extremely near "G"
** When the large transfer container is reused, the inside of the container may not be "G".

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

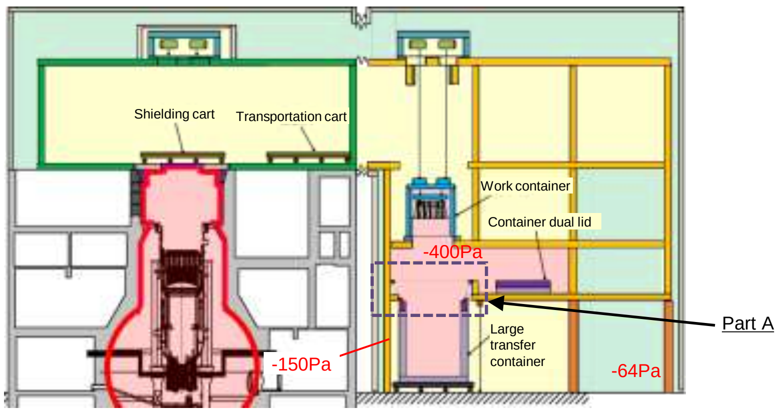
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

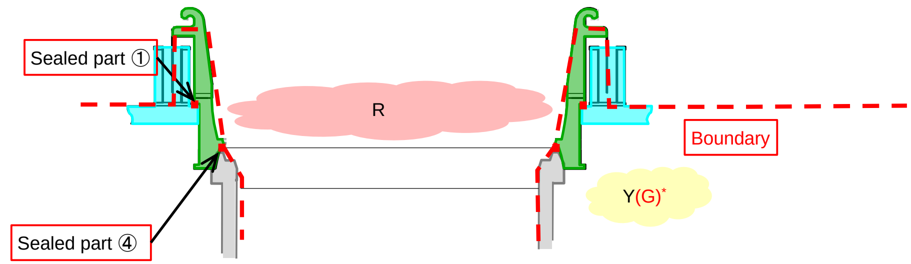
[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (3/7)]

The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(5) Completely opening the container

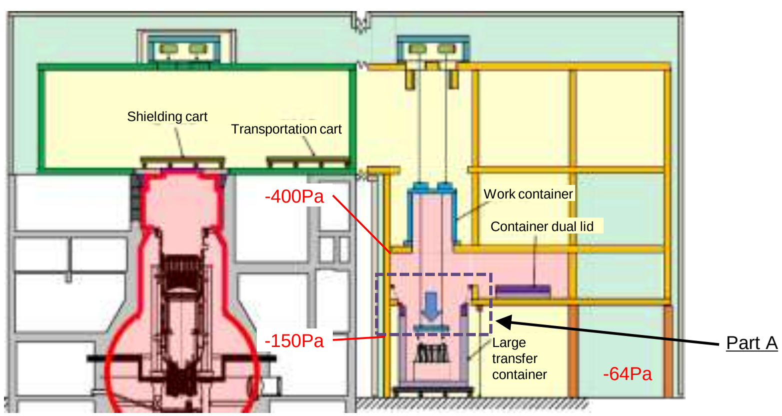


Enlarged view of Part A

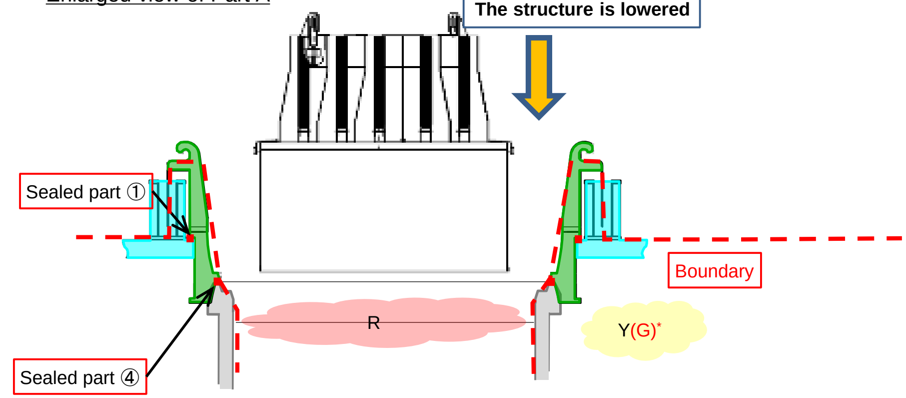


(5): Opening the container

(6) Placing the structures in the container



Enlarged view of Part A



(6): Lowering and placing the structures in the container

* Assumed to be "Y" which is extremely near "G"

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

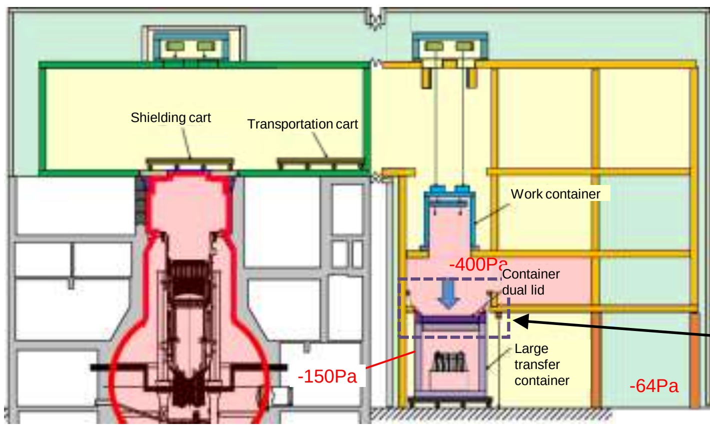
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

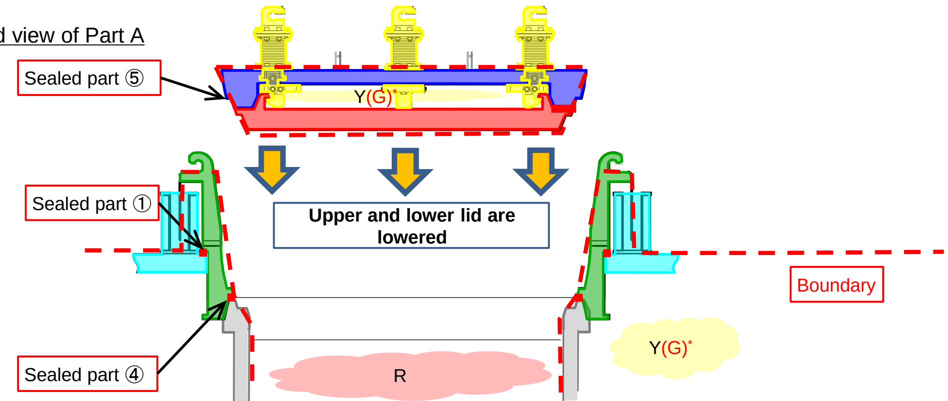
[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (4/7)]

The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(7) Lowering the dual lid

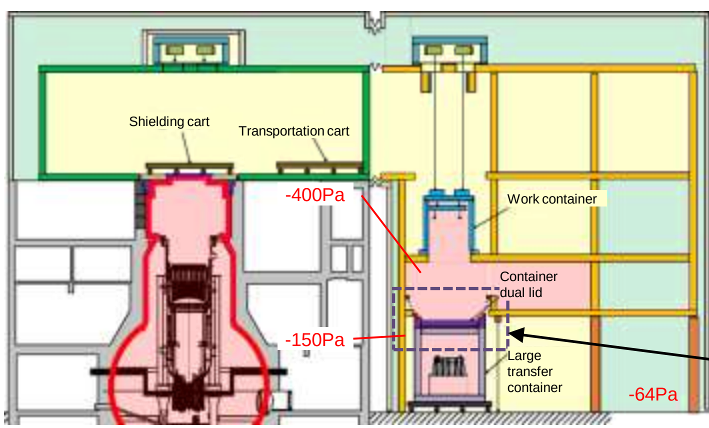


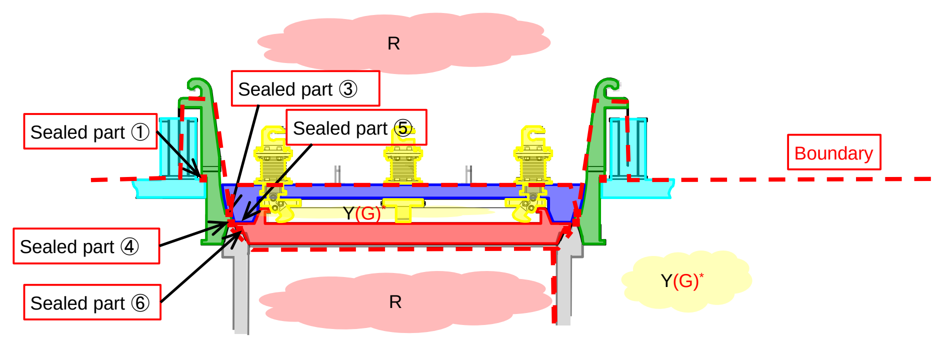
Enlarged view of Part A



(7)-1: Inspecting and cleaning the sealed surface (removing trash, etc.)
(7)-2：Lowering the dual lid

(8) Closing the dual lid of the container





(8): Closing the lid of the large container

*"Y" is assumed to be infinitely near "G"

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1) ①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

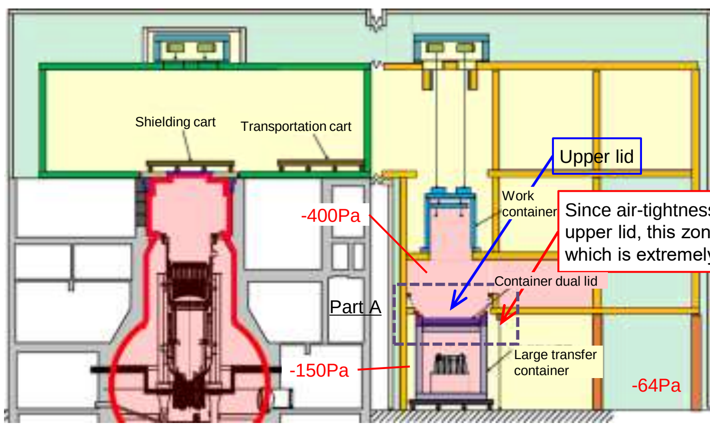
[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

② Large transfer containers

[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (5/7)]

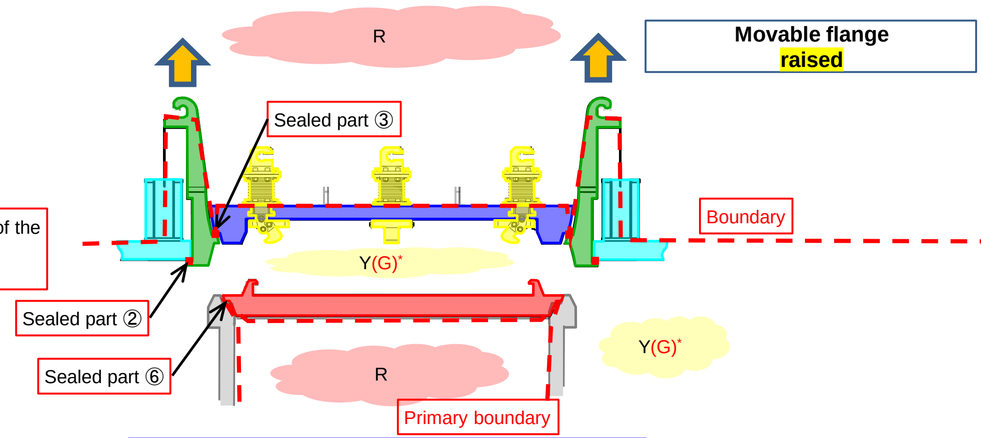
The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(9) Separating the container: Decoupling the upper lid and lower lid



*"Y" is assumed to be infinitely near "G"

Enlarged view of Part A



(9)-1: Raising the movable flange
(9)-2: Decoupling the upper lid and lower lid

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

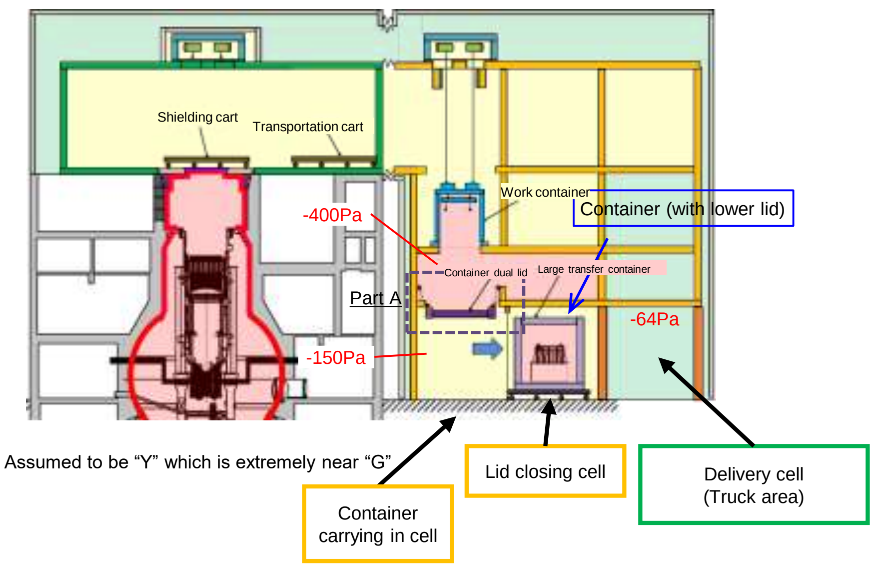
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (6/7)]

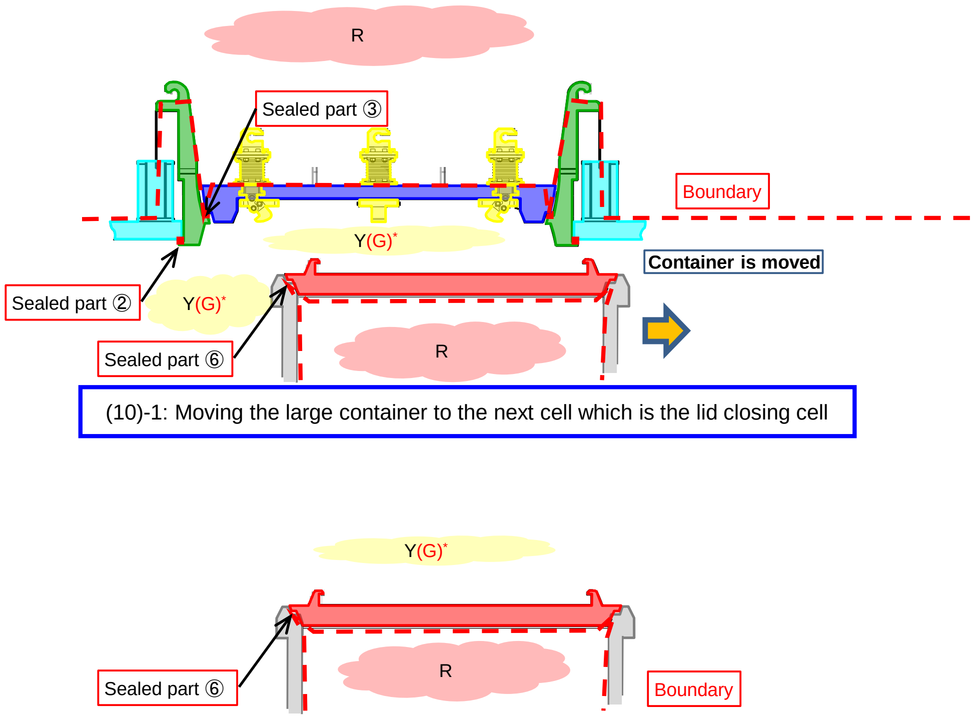
The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(10) Transferring the container: Transferring the large transfer container



* Assumed to be "Y" which is extremely near "G"

Enlarged view of Part A



(10)-1: Moving the large container to the next cell which is the lid closing cell

(10)-2: Moving the large container to the lid closing cell

Since the classification of contaminated areas is under examination, it could change in the future.

Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

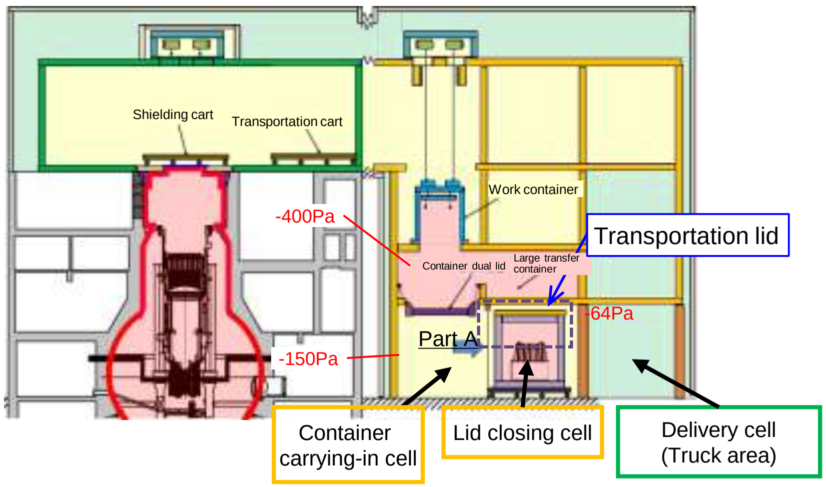
② Large transfer containers

[Notes]
Colors indicate the following contamination levels*
R (Red): Red (high contamination) zone
Y: Yellow (moderate contamination) zone
G: Green (low contamination) zone
*Besides color, the main zones are marked as R, Y and G.

[Steps involved in operating the dual lid in connection with transferring structures by the method of transferring unitized large structures (7/7)]

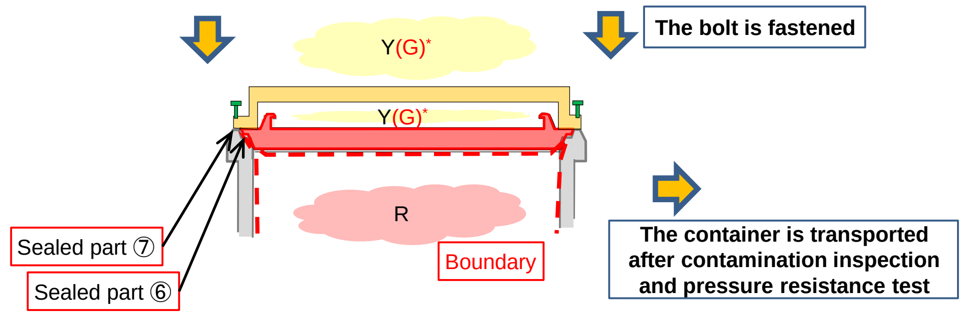
The steps involved in operating the dual lid while transferring structures and the boundaries are given below.

(11) Installing the secondary lid: Installing the transportation lid for on-site transportation



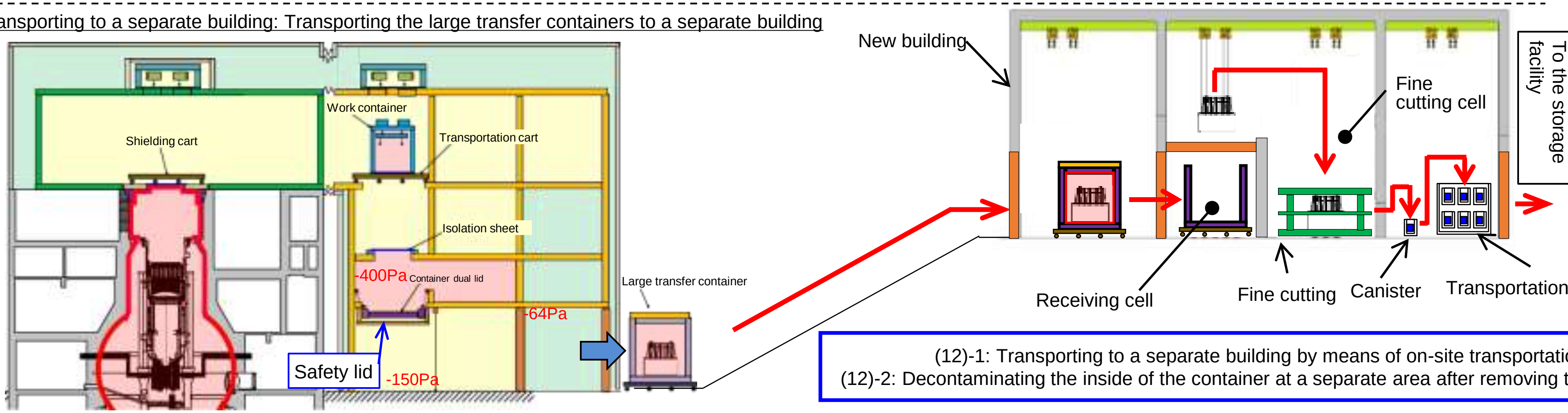
Enlarged view of Part A

*"Y" is assumed to be infinitely near "G"



(11)-1: Installing a lid for on-site transportation on the large container
(11)-2: Moving to the delivery cell after contamination inspection and air-tightness verification

(12) Transporting to a separate building: Transporting the large transfer containers to a separate building



(12)-1: Transporting to a separate building by means of on-site transportation
(12)-2: Decontaminating the inside of the container at a separate area after removing the structures

Since the classification of contaminated areas is under examination, it could change in the future.

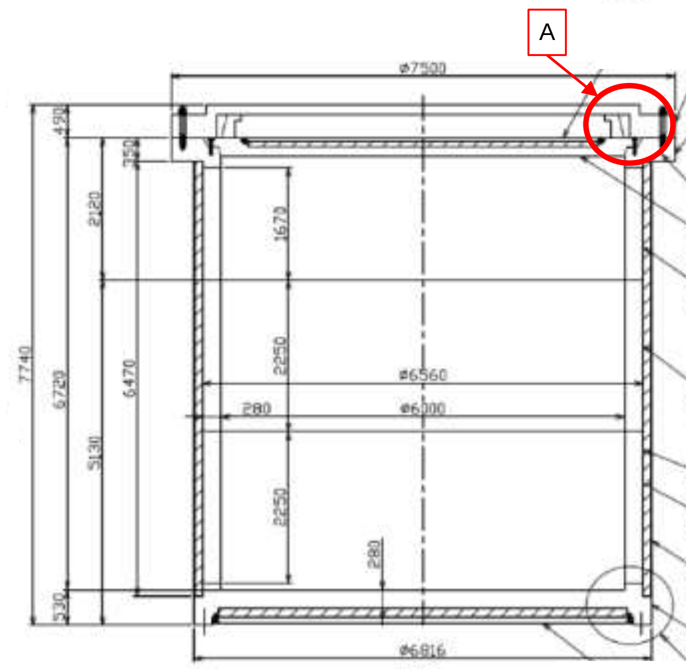
Note) This figure explains the steps involved in closing the lid of the large transfer container. (The pressure mentioned in the diagram is an assumed value) For the seating position of the work container, please refer to the conceptual diagram shown in 6.2)(1)①(a) Method of transferring unitized large structures and the results of studying the layout of the additional building.

② Large transfer containers

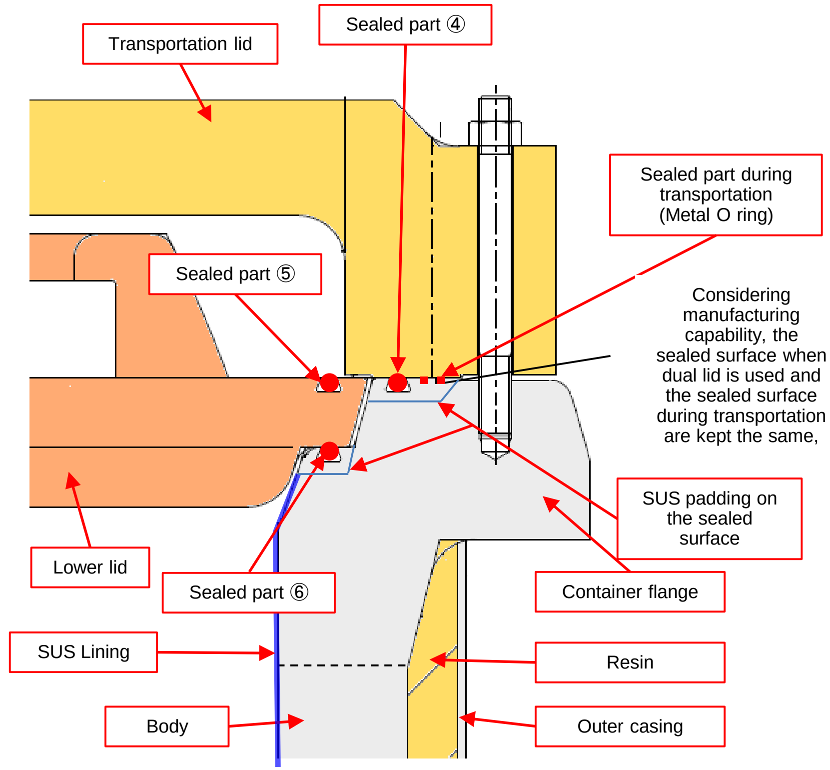
[Structural design of the large transfer containers]

Structural design of the actual large transfer containers was studied.

Upon studying the manufacturing procedures based on this structure in the element tests, a container will be manufactured for the test with a structure such that its manufacturing capability can be verified.



Proposed structure of the actual large transfer container



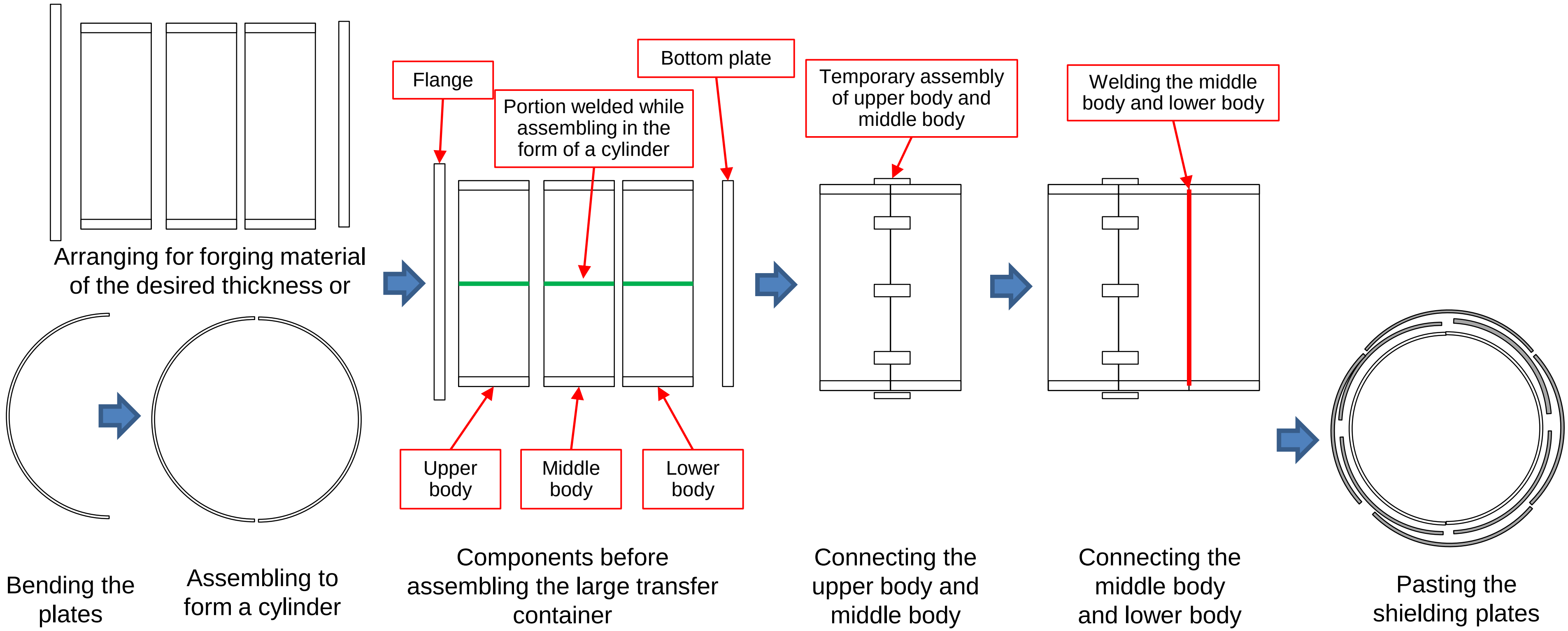
Details of Part A

② Large transfer containers

[Structural design of the large transfer containers]

The manufacturing procedures were studied based on the structural design of the actual large transfer container.

- Also, for the thickness of the container, plates with a thickness that enables cold bending will be bent, they will be assembled to form a cylinder, and the parts of bent plates will be pasted until the desired plate thickness is achieved, or forging material of the desired thickness is manufactured.
- The container body is planned to be manufactured by dividing the material vertically into 3 parts and welding those parts together to form the body.



Proposed procedures for manufacturing large transfer containers

② Large transfer containers

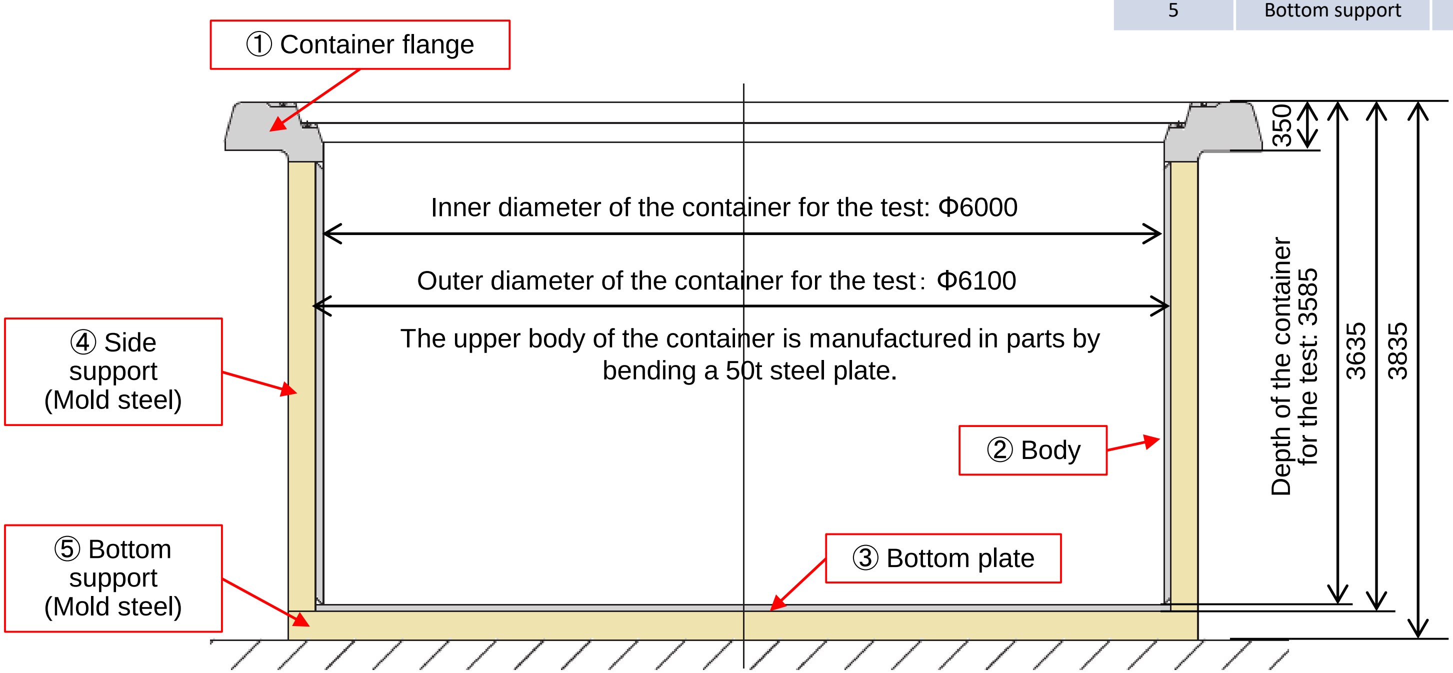
[Element test plan (Large transfer container for the element test Rough specifications)]

It was decided to manufacture the container flange with a structure equivalent to the actual equipment based on the results of the studies on the structure of the actual large transfer container and manufacturing procedures.

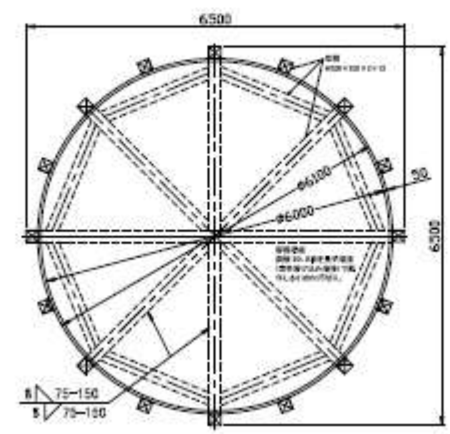
The height of the main body of the container for the element test was kept at approx. 4m (height of one part of the divided plate) which was about half of 7.5m which is the height of the container for the actual equipment considering that the height was sufficient as long as the plate can be bent and welded.

Large transfer container for the element test Component table

Product Number	Product Name	Number of units	Material	Remarks
1	Container flange	1	SF440A	Carbon steel forged component
2	Body	1 set	SS400	Bent plate in parts
3	Bottom plate	1 set	SS400	Steel plate in parts
4	Side support	1 set	SS400	
5	Bottom support	1 set	SS400	



Large transfer container for the element test Cross section



Bottom structure

② Large transfer containers

For development and test manufacturing

[Element test plan (Scope of simulation of actual equipment)]

ID.	Equipment	Actual equipment specifications (approximate dimensions)	Mock-up specifications (approximate dimensions)	Simulation method for the test
1)	Movable flange	➢ Diameter 9300, height 1600, weight 150ton	➢ Diameter 8000, height 1100, weight 46ton	➢ The shape of the connection part is simulated.
2)	Fixed flange	➢ Diameter 11100, thickness 375, weight 170ton	—	➢ Not simulated this time.
3)	Upper lid	➢ Diameter 6800, height 800, weight 50 ton	➢ Same as the actual equipment (Unit manufactured during the Ensuring Safety PJ is used.)	➢ Actual equipment shape is simulated.
4)	Lower lid	➢ Diameter 6800, thickness 280, weight 80 ton	➢ Same as the actual equipment (Unit manufactured during the Ensuring Safety PJ is used.)	➢ Actual equipment shape is simulated.
5)	Container	➢ Inner diameter 6000, thickness 280, height 7500, weight 390 ton	➢ Inner diameter 6000, thickness 50, height 3635, weight 85 ton	—
6)	Lifting hook	➢ Diameter 500, height 1500	➢ Diameter 500, height 1500	➢ Shape of the hook is simulated.

Differences with the mock-up structure for the dual lid test that was studied and tested as part of the Ensuring Safety PJ are given below.
- The height of the container body was determined considering the procedures for manufacturing the actual equipment. (Bare minimum structure with which manufacturing capability, etc. of the container can be verified)
- A structure with which the flange part of the movable flange can be raised and lowered. (Adjustment of position can be verified with a shape that is similar to the actual equipment)

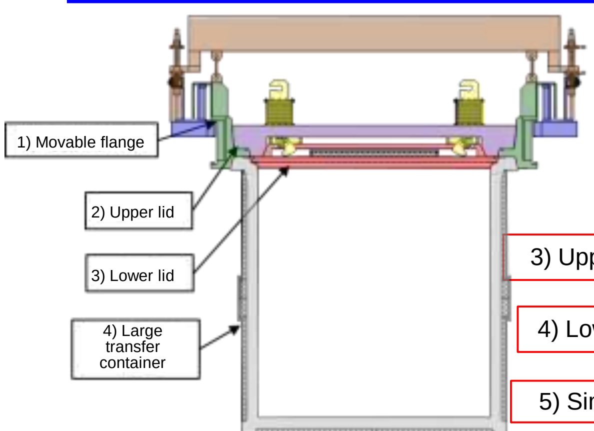


Illustration of actual equipment

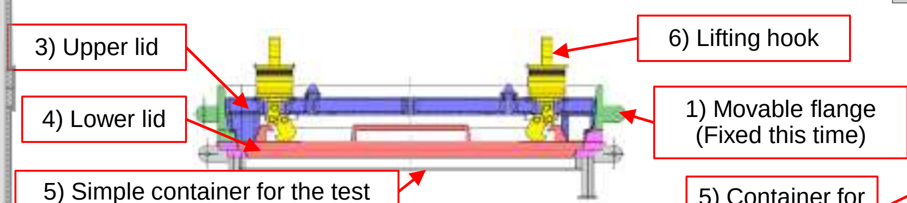


Illustration of the mock-up structure for the Ensuring Safety PJ

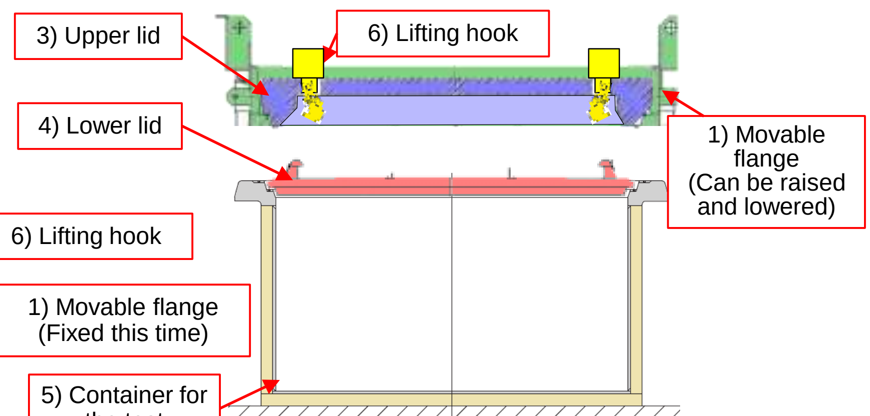


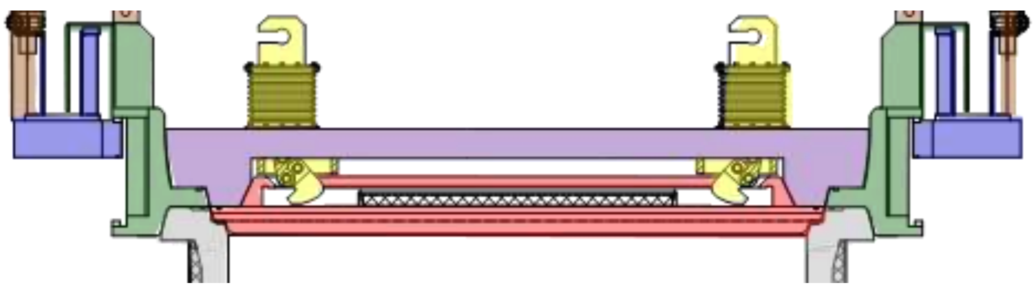
Illustration of the mock-up structure for this project

② Large transfer containers

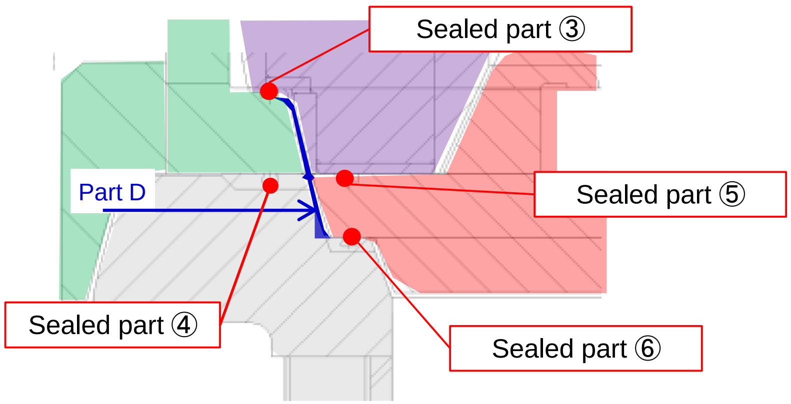
[Element test plan (Sealed parts to be verified through the test)]

Considering the operational steps at the actual site, the air-tightness of the following 4 sealed parts will be verified during the element tests.

ID.	Sealed part	Air tight joint	Method of ensuring air-tightness	Operational steps that require air-tightness	Remarks
1	Sealed part ③	● Between the upper lid and the movable flange	➢ The upper lid presses down the O ring with its own weight to secure the prescribed flattening of the O ring.	➢ (3) Before being connected to the container ➢ (9) After being separated from the container	➢ Studied and tested during the Ensuring Safety PJ ➢ The impact of raising and lowering the movable flange will be verified in this project.
2	Sealed part ④	● Between the movable flange and the container flange	➢ The movable flange presses down the O ring with its own weight to secure the prescribed flattening of the O ring.	➢ (3) Connecting the upper and lower lids (container) ➢ (8) Closing the lid of the large container	➢ Will be tested in this project.
3	Sealed part ⑤	● Between the upper and lower lids	➢ The upper lid presses down the O ring with its own weight to secure the prescribed flattening of the O ring.	➢ (4) Lifting up the dual lid, opening the container ➢ (7) Lowering the dual lid	➢ Studied and tested during the Ensuring Safety PJ ➢ The impact of raising and lowering the movable flange will be verified in this project.
4	Sealed part ⑥	● Between the lower lid and container	➢ The lower lid presses down the O ring with its own weight to secure the prescribed flattening of the O ring.	➢ (2) Carrying-in the container ➢ (10) Transferring the container	➢ Studied and tested during the Ensuring Safety PJ ➢ Will be verified using the container flange manufactured in this project.



Schematic view of the actual equipment



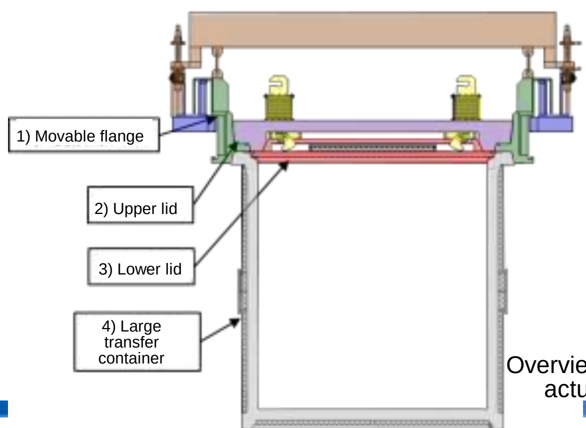
Enlarged view of Part D

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

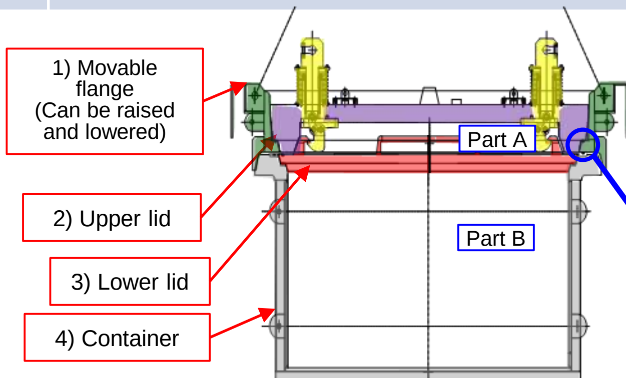
② Large transfer containers

[Element test items and test details]

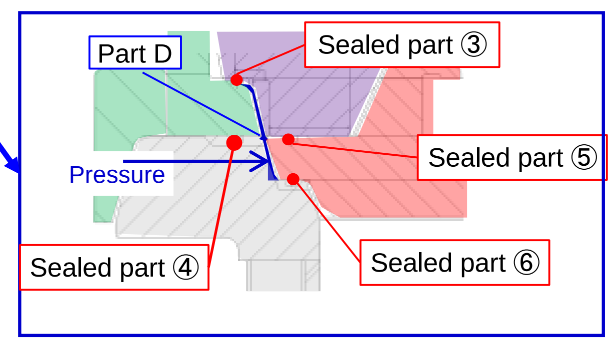
Test No.	Name of the test			Test details	Remarks
1-1	Prior verification test	Upper lid + lower lid		Conducted to make sure that there is no defect in the equipment itself. (Conducted as prior verification) The sealing function and integrity are verified with the assembly of each stand-alone equipment. (The fitting of the stand-alone equipment with other equipment, air-tightness and foaming are tested.)	Unit test of Part A Verified for the case when the dual lid is lifted up as well.
1-2		Upper lid + movable flange			Used for the container＋ movable flange as well
1-3		Lower lid + container			Unit test of Part B
1-4		Movable flange + container			Verified in No.1-2
2-1	Comprehensive functionality test	Fitting test	Without misalignment	● Verification of whether there is abnormal sound or rattling when the lifting hook is installed and removed ● Verification of the connection and gaps, etc. when the upper lid and lower lid are lifted up together (dual lid) with the help of a hook ● Verification of the connection and gaps, etc. when the upper lid and movable flange are lifted up together	The steps involved in the operation using the actual equipment are simulated and the fitting and air-tightness function are verified.
2-2			With misalignment	The above fitting is carried out with some misalignment (within 50mm from the center), and it is verified whether the assembly can be carried out without any issues following the shape of the guide.	
3		Air-tightness test		It is verified that air-tightness is achieved at every stage after each fitting test. (In the actual equipment, opening of the dual lid, attachment and detachment of the container are the conditions for determining whether air-tightness is achieved.	



Overview diagram of the actual equipment



Overview diagram of the test apparatus assemblage



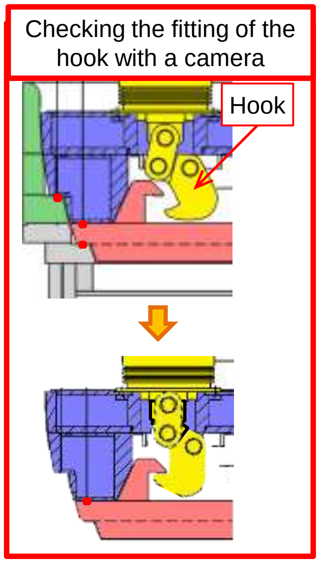
Enlarged view of sealed portion in the air-tightness test

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

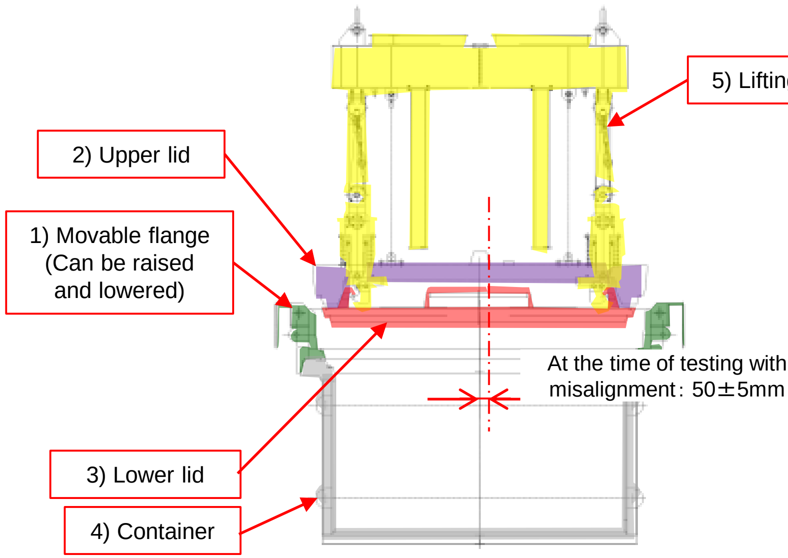
② Large transfer containers

[Element test items and test details]

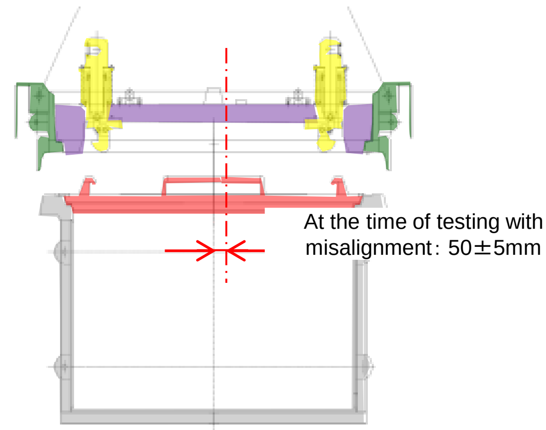
Test No.	Name of the test			Test details	Criteria
2-1	Comprehensive functionality test	Fitting test	Without misalignment	● Verification of whether there is abnormal sound or rattling when the lifting hook is installed and removed ● Verification of the connection and gaps, etc. when the upper lid and lower lid are lifted up together (dual lid) with the help of a hook ● Verification of the connection and gaps, etc. when the upper lid and movable flange are lifted up together	All equipment should fit and be smoothly positioned without any abnormal noise.
2-2			With misalignment	The above fitting is carried out with some misalignment (within 50mm from the center), and it is verified whether the assemblage is possible without any issues following the shape of the guide.	



Verification at the time of lifting the upper lid + lower lid
⇒ Verification of whether there is abnormal noise or rattling when the lifting hook is installed and removed



At the time of lifting up the dual lid
⇒ Verification of the connection and gaps, etc. when the upper lid and lower lid are lifted up together (dual lid) with the help of a hook



At the time of lifting up the movable flange
⇒ Verification of the connection and gaps, etc. when the upper lid and movable flange are lifted up together

② Large transfer containers

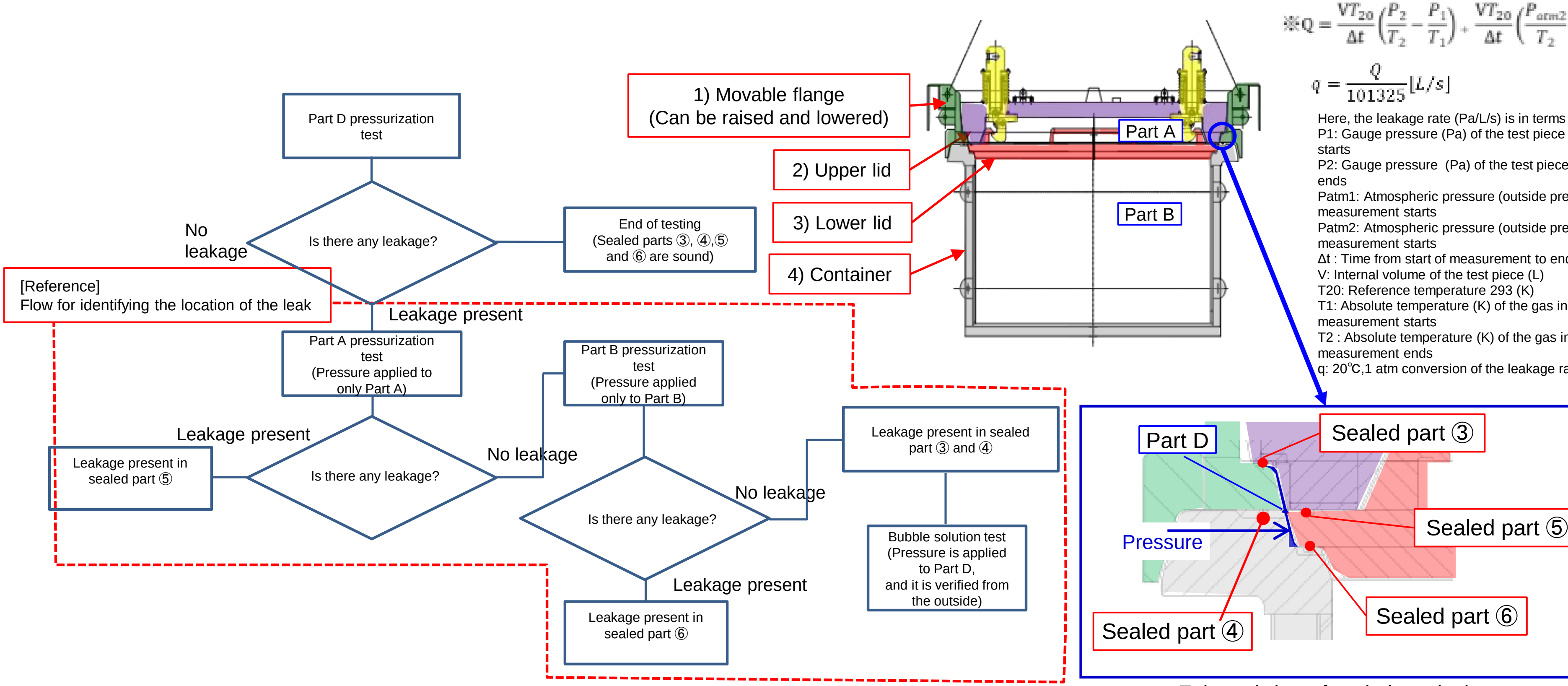
[Element test items and test details]

Test No.	Name of the test		Test details	Criteria
3	Comprehensive functionality test	Air-tightness test	It is verified that air-tightness is achieved at every stage after each fitting test. (In the actual equipment, opening of the dual lid, attachment and detachment of the container are the conditions for determining whether air-tightness is achieved.)	Quantity of leakage q ≦ 12L/h #

※ $$Q = \frac{VT_{20}}{\Delta t}\left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right) + \frac{VT_{20}}{\Delta t}\left(\frac{P_{atm2}}{T_2} - \frac{P_{atm1}}{T_1}\right) [Pa\cdot L/s]$$

$$q = \frac{Q}{101325} [L/s]$$

Here, the leakage rate (Pa/L/s) is in terms of Q: 20° C
P1: Gauge pressure (Pa) of the test piece when the measurement starts
P2: Gauge pressure (Pa) of the test piece when the measurement ends
Patm1: Atmospheric pressure (outside pressure) (Pa) when measurement starts
Patm2: Atmospheric pressure (outside pressure) (Pa) after measurement starts
Δt : Time from start of measurement to end of measurement (s)
V: Internal volume of the test piece (L)
T20: Reference temperature 293 (K)
T1: Absolute temperature (K) of the gas inside the test piece when measurement starts
T2 : Absolute temperature (K) of the gas inside the test piece when measurement ends
q: 20℃,1 atm conversion of the leakage rate (L/s)



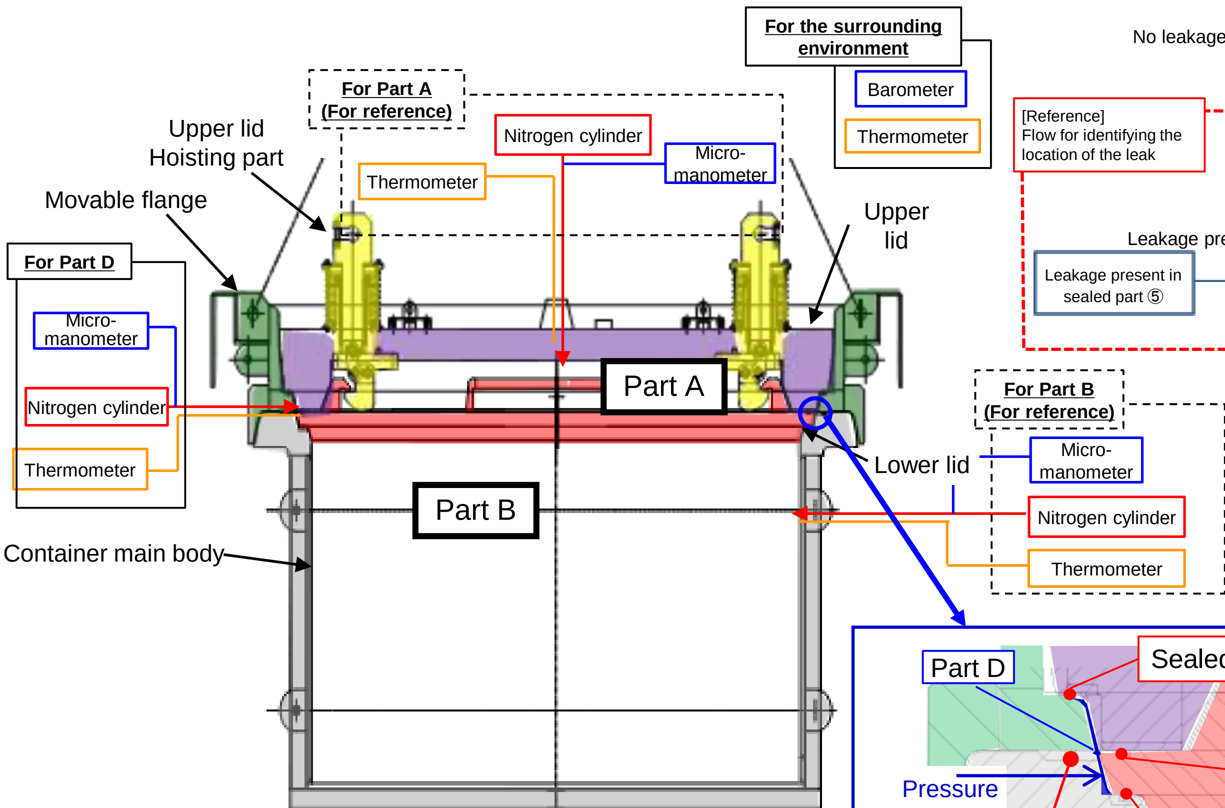
Enlarged view of sealed part in the air-tightness test

Outline diagram of the air-tightness test

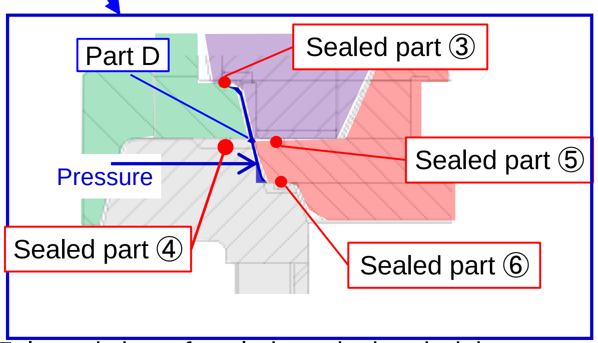
② Large transfer containers

[Element test items and test details]

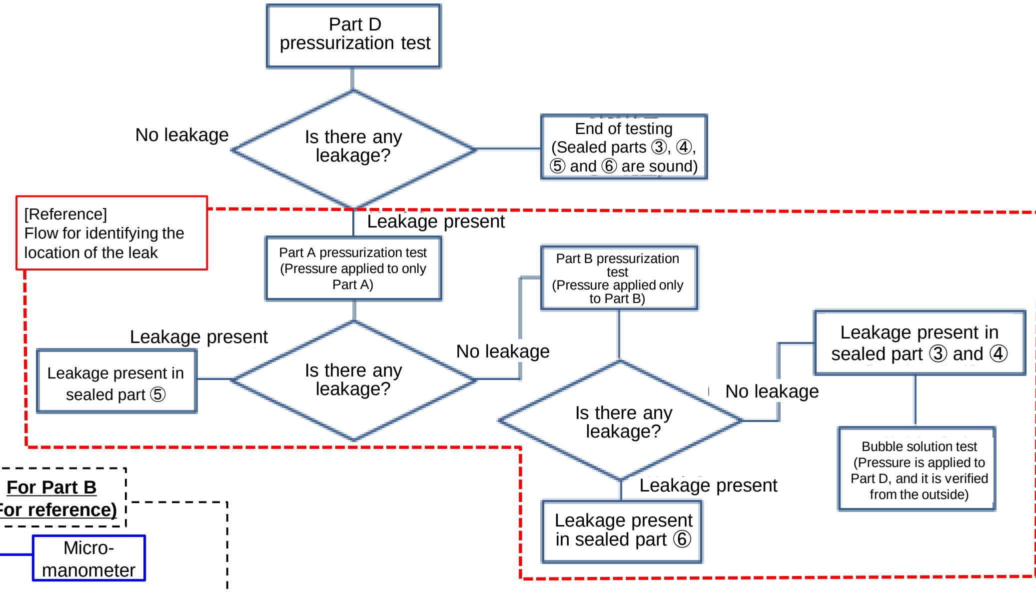
The air-tightness of the sealed parts is verified by applying pressure on Part D and verifying the fluctuations in pressure. If there is a leak, pressure is applied separately to each area (Part A, Part B) that is kept air-tight by the sealed part, and the fluctuations in the pressure are verified.



Air-tightness verification test
(Image illustrating pressure resistance test)



Enlarged view of sealed part in the air-tightness test



Flow for verification of air-tightness

② Large transfer containers

[Element test results]

・Test status

Pictures illustrating the main movement steps are shown in the figure.

Movement step procedure of the element test (This procedure is repeated 6 times including 3 times with misalignment and 3 times without misalignment.)

Movement of movable flange

→ Air-tightness test →

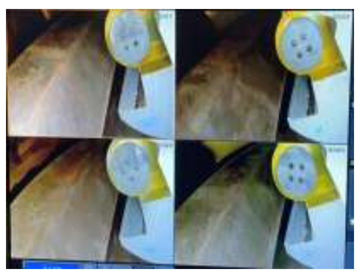
Opening and closing movement of dual lid

→ Air-tightness test →

Moving of movable flange

Movable flange after movement + upper lid

Status of the guide when the movable flange moves



Before arresting the dual lid hook

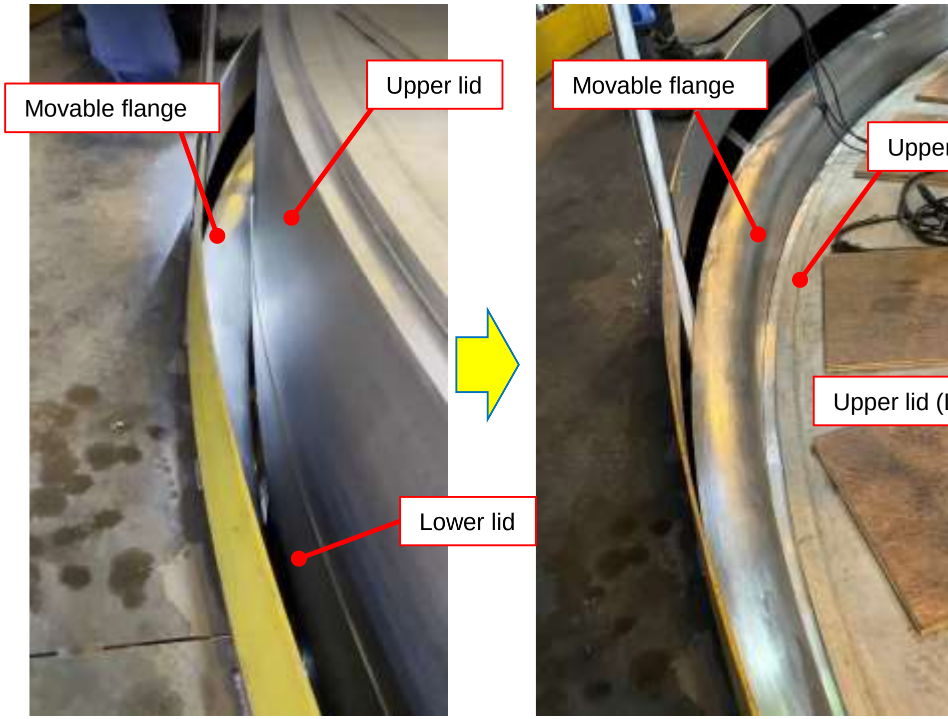
After arresting the dual lid hook

Container + lower lid after moving of movable flange

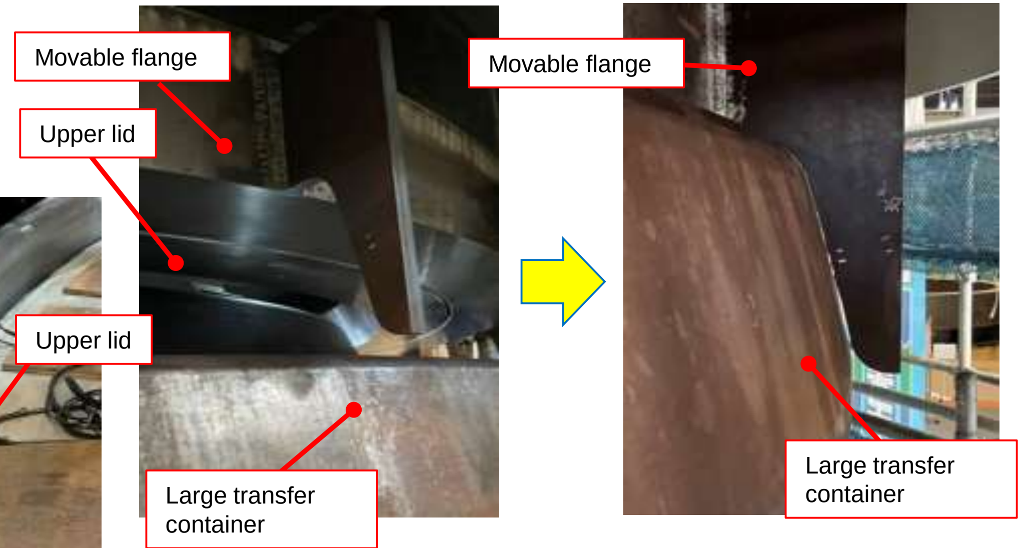
② Large transfer containers

[Element test results]

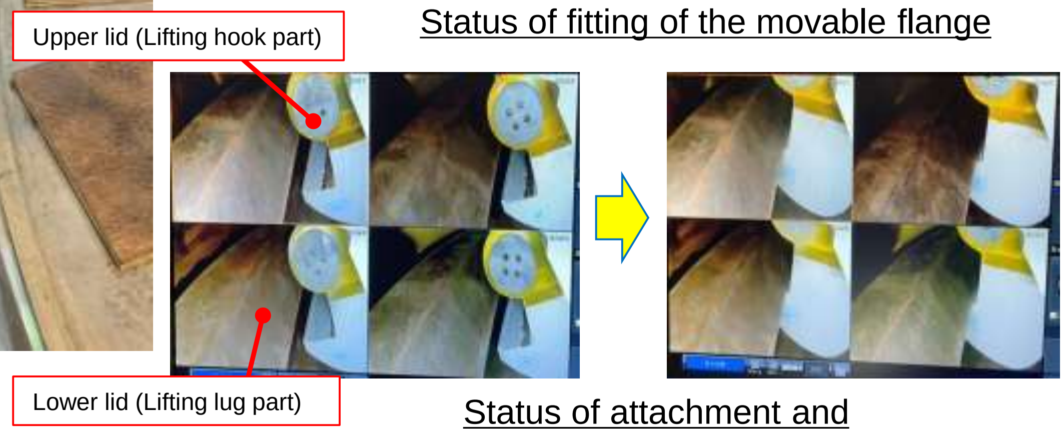
・Fitting test



Status of fitting of the dual lid



Status of fitting of the movable flange



Status of attachment and detachment of dual lid

It was verified that the movable flange as well as the dual lid fit at the prescribed position without any abnormal noise, etc. following the guide even when there is some misalignment. Also, it was verified that the dual lid hook is attached and detached without any abnormal noise, etc.

② Large transfer containers

[Element test results]

・Air-tightness test

The leakage rate when the pressurization method is used, is calculated using the following formula (#1).

$$Q = \frac{VT_{20}}{\Delta t}\left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right) + \frac{VT_{20}}{\Delta t}\left(\frac{P_{atm2}}{T_2} - \frac{P_{atm1}}{T_1}\right) [Pa\cdot L/s]$$

$$q = \frac{Q}{101325} [L/s]$$

Criteria: $q < 0.003L/s = 12L/h$

Here, leakage rate (Pa/L/s) is in terms of Q: 20° C

P_1: Gauge pressure (Pa) of the test piece when measurement starts

P_2: Gauge pressure (Pa) of the test piece when measurement ends

Patm1: Atmospheric pressure (outside pressure) (Pa) when measurement starts

Patm2: Atmospheric pressure (outside pressure) (Pa) after measurement starts

Δt : Time from start of measurement to end of measurement (s)

V: Internal volume of the test piece (sealed part) 101(L)

T_{20}: Reference temperature 293 (K)

T_1: Absolute temperature (K) of the gas inside the test piece when measurement starts

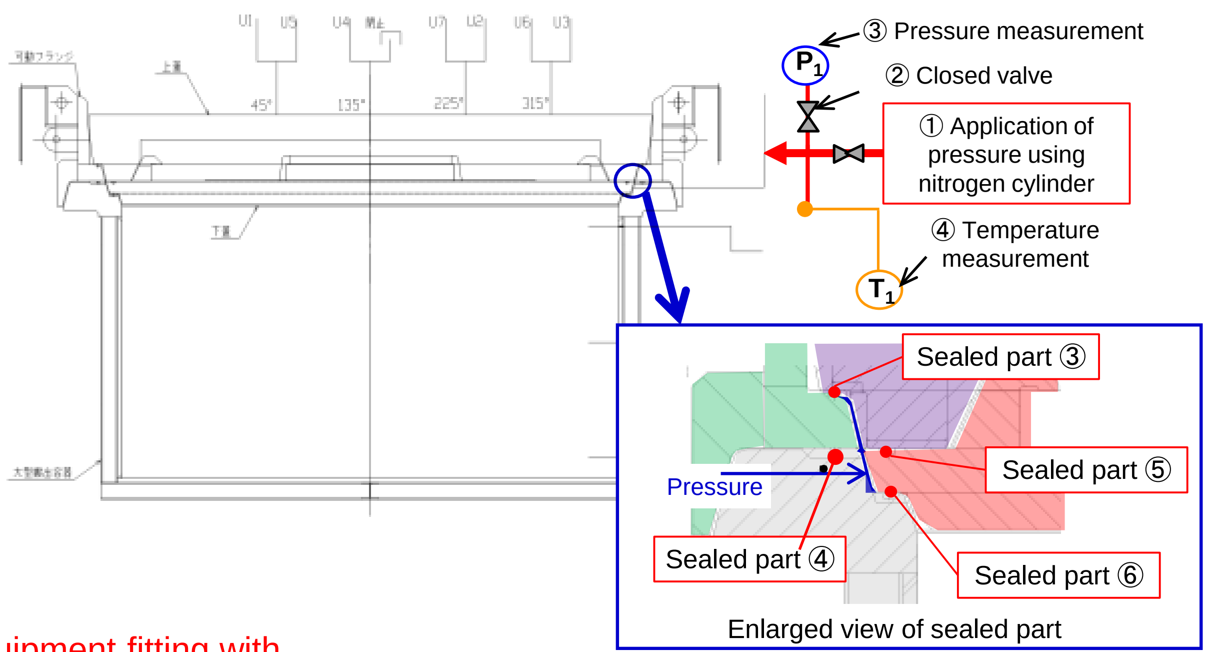
T_2: Absolute temperature (K) of the gas inside the test piece when measurement ends

q: Leakage rate (L/s) in terms of 20℃ and 1 atmospheric pressure

(*1): Based on the pressure change and pressurization method stipulated in JIS Z 2332 Leak testing method using pressure change.

Legend: ● Pass, ✕ Fail

Without misalignment			With misalignment		
Round1	Container connection	● +0.02 L/h	Round1	Container connection	● +0.01 L/h
	Opening and closing of dual lid	● +0.02 L/h		Opening and closing of dual lid	● +0.02 L/h
Round2	Container connection	● −0.01 L/h	Round2	Container connection	● +0.02 L/h
	Opening and closing of dual lid	● +0.02 L/h		Opening and closing of dual lid	● +0.03 L/h
Round3	Container connection	● −0.02 L/h	Round3	Container connection	● −0.02 L/h
	Opening and closing of dual lid	● +0.01 L/h		Opening and closing of dual lid	● 0.00 L/h



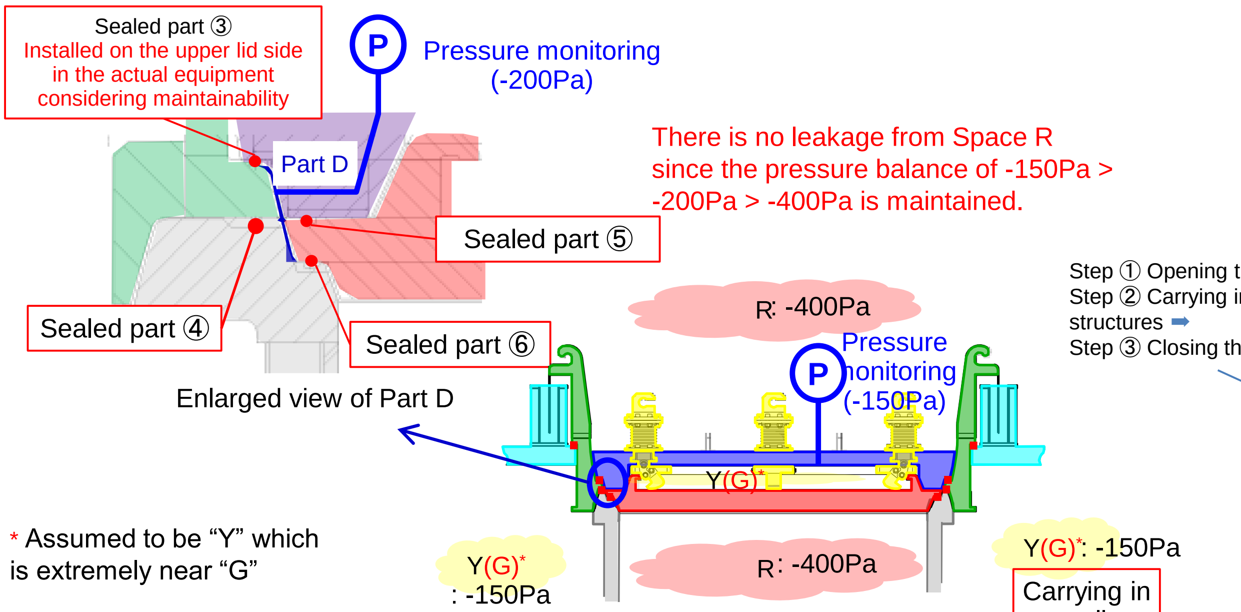
Enlarged view of sealed part

<u>Air-tightness test was conducted after each equipment fitting with misalignment as well as without misalignment. There was no leakage in any of the tests, the judgment criteria was met and all tests were passed.</u>

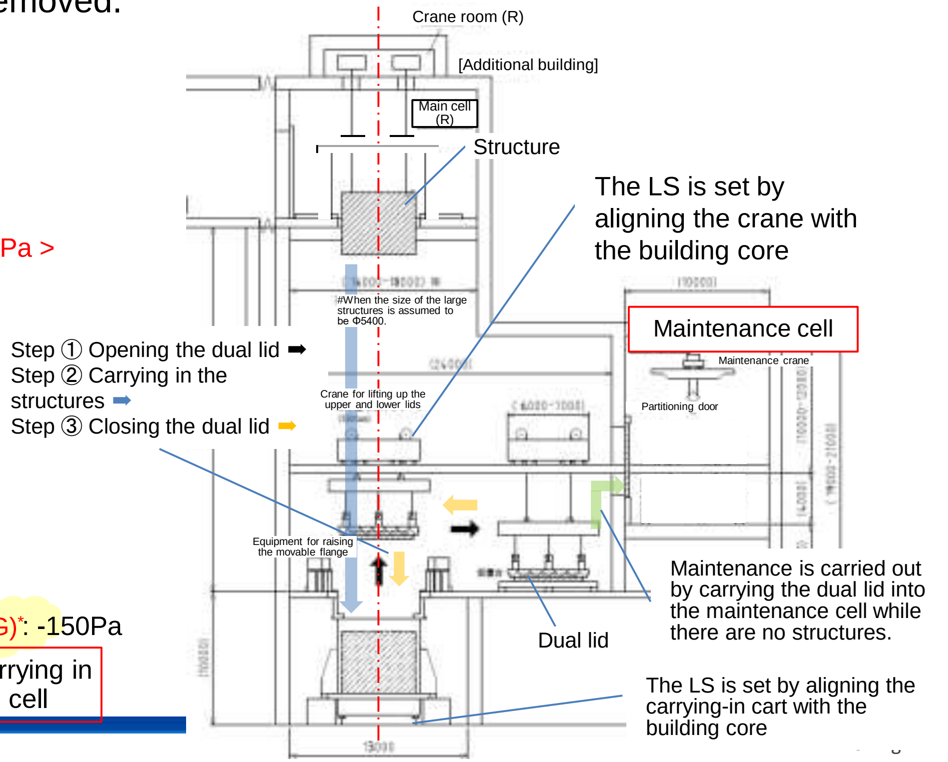
② Large transfer containers

[Policy for reflection into actual equipment]

- The position adjustment of the container will be set so that it aligns with the core of the building because of the LS (limit switch) on the rail of the carrying-in cart.
- The position adjustment of the dual lid will also be set so that the lifting beam + crane stop at the core of the building because of the LS, etc.
- The air-tightness when the dual lid is used will be verified by monitoring the space (Part D) that is enclosed inside the sealed part, the dual lid (between the upper lid and lower lid), and the pressure balance inside the container.
- In addition to this, a dosimeter will be installed in the carrying in cell to check for leakage.
- The maintenance of the dual lid crane, etc. will be carried out in the maintenance cell. The O ring of the sealed part ③ will be replaced in the maintenance cell as it is installed on the upper lid side. Sealed parts ④, ⑤, ⑥ will be replaced together when the container is decontaminated after the structures are removed.



* Assumed to be "Y" which is extremely near "G"



② Large transfer containers

[Policy for reflection into actual equipment]

The results of studies conducted on the structure of large transfer containers based on the results of element tests are indicated in the figure below.

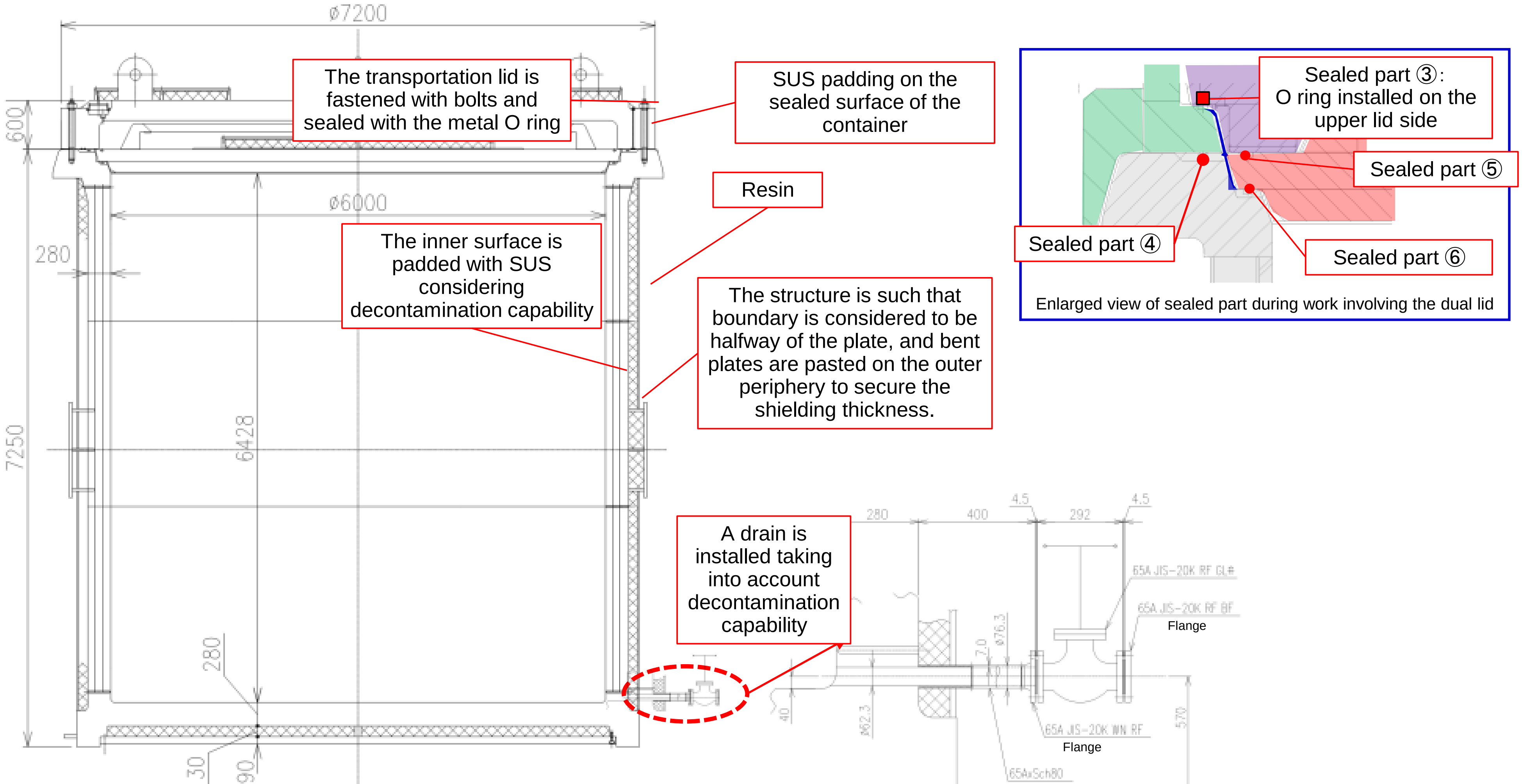


Figure illustrating the structure of the actual large transfer container

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

[Policy for reflection into actual equipment]

The following main issues were identified and the response policy was studied.

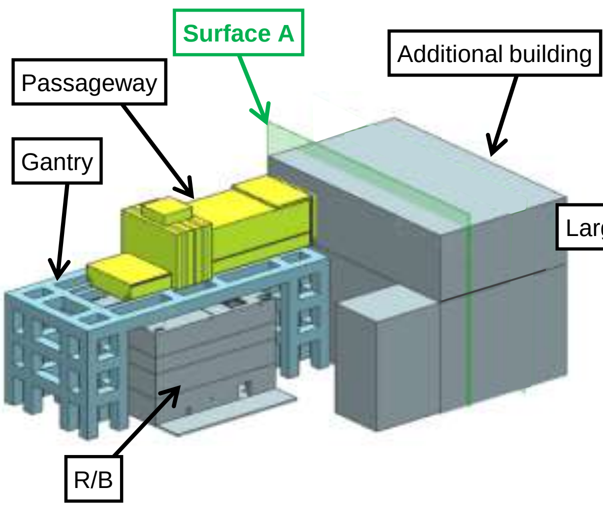
List of issues identified with respect to the large transfer container

No.	Issues	Response policy
1	Replacement and maintenance of the O ring of the sealed parts, method of condition monitoring and cleaning of the groove	The O ring of the upper lid sealed part ③ will be replaced and the groove will be cleaned after enclosing the dual lid in the maintenance cell. Further, the cleaning equipment will be carried from the maintenance cell for cleaning the sheet surface of the movable flange. The other lower lid and container sealed parts ④⑤⑥ will be handled along with the decontamination to be carried out in the New building after the container is transported on-site and the structures are transferred. Also, cameras will be installed in the additional building (dual lid work cell) for monitoring the sealed surface (including the groove), to make sure that trash, etc. has not come inside.
2	Method of decontaminating the container	After transferring the structures from the container, the container will be decontaminated in the New building by inserting a decontamination equipment. Before decontamination, the neutron absorbing material is planned to be removed by means of cleaning equipment and drained through the drain after decontamination. (Studies will be conducted for making sure that the neutron absorbing material does not obstruct the drain.)
3	Since the structure will be changed so that the O ring of the sealed part ③ is installed in the direction from the movable flange surface to the upper lid sealed portion, the impact of this change needs to be verified.	It is believed that if the groove is a dovetail groove, the O ring is not likely to fall and thus there is no impact. It will be verified once again that there is no impact on air-tightness when the actual equipment will be manufactured.
4	Method of monitoring the pressure inside Part D and the dual lid (between the upper and lower lids) when the actual equipment is used.	A Part D pressure monitoring line will be installed on the upper lid side and a another one will be installed for monitoring the pressure inside the dual lid. The pressure gauge will be connected and the pressure will be monitored using a camera, etc.

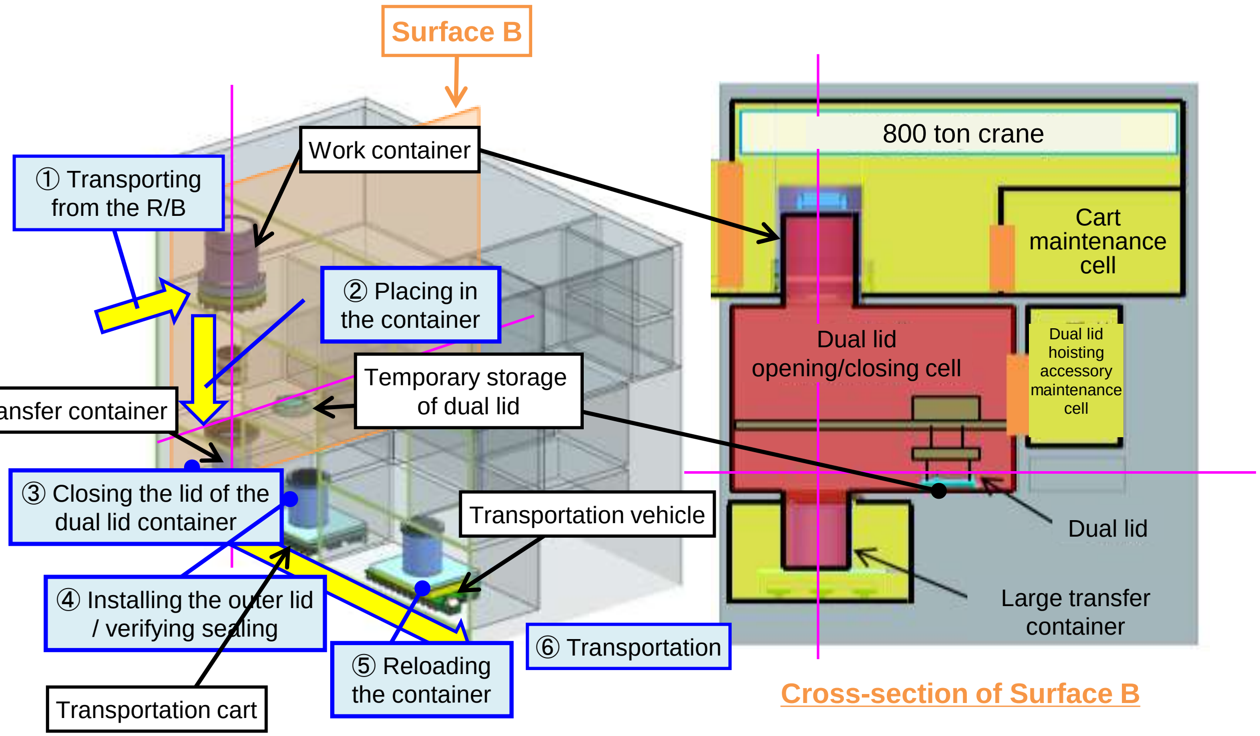
② Large transfer containers

[Policy for reflection into actual equipment]

- The flow from placing the structures inside the large transfer container, fastening the transportation lid (secondary lid) with bolts, to on-site transportation is indicated below.
- A large opening was made in the floor surface of the additional building. (Issue while studying the additional building)



Conceptual diagram of the layout of the additional building



Transfer of large unitized structures (Cross-section of Surface A)

Cross-section of Surface B

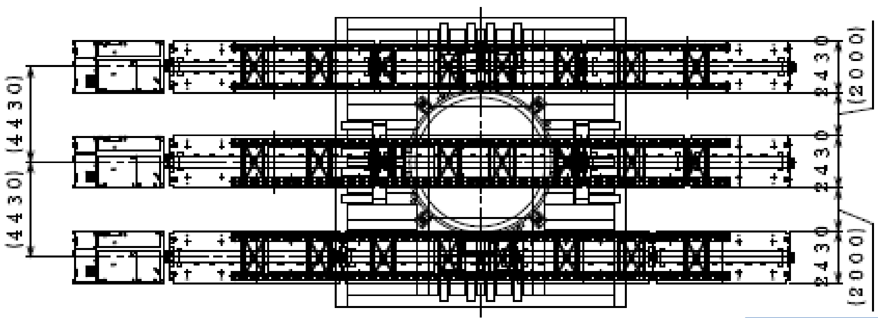
* The pink line in the figure above corresponds to the cross-section of Surface A.
However, since the illustration of the crane and layout of the maintenance cell are included in the figure above, it does not completely correspond to the cross-section of Surface A.

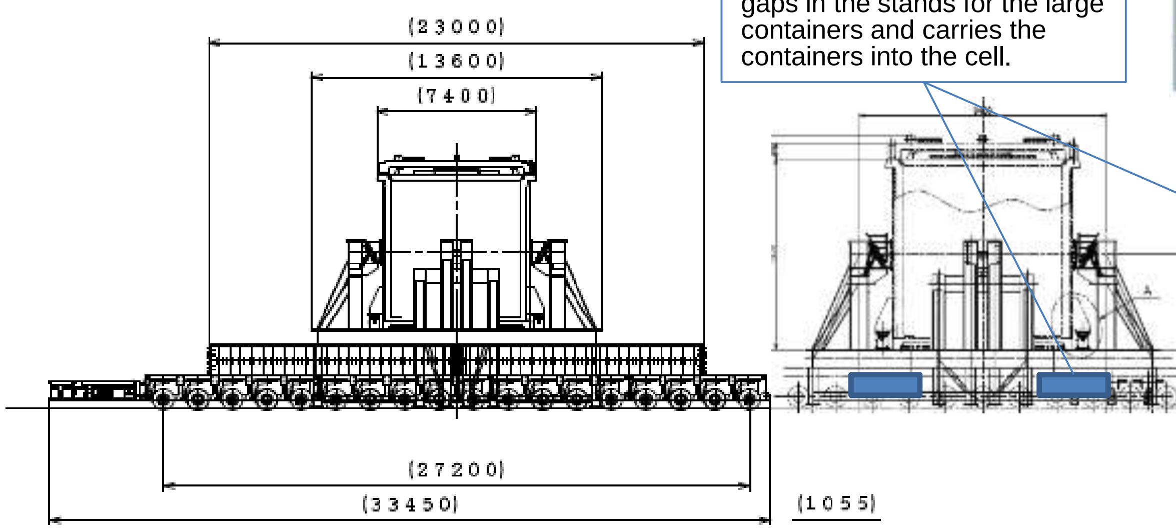
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

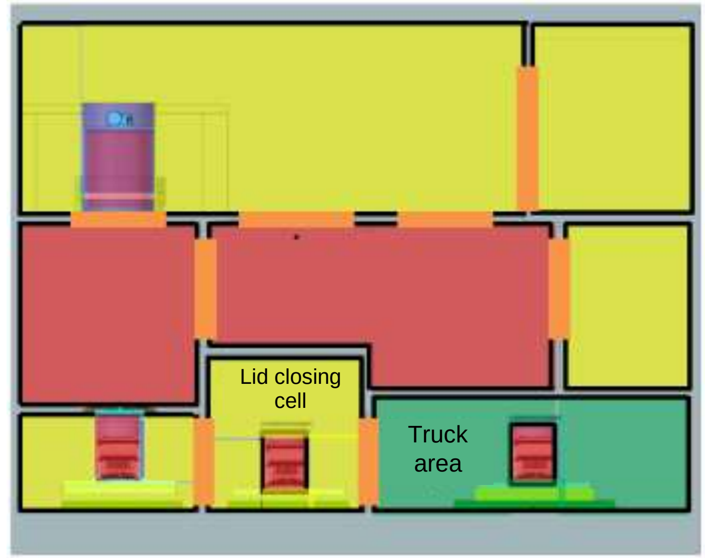
[Policy for reflection into actual equipment]

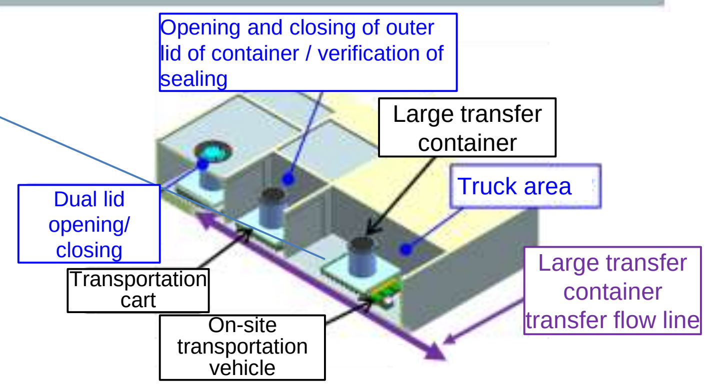
- The structure of the transportation dolly is indicated.
- The containers are reloaded on transportation dollies in the vicinity of the building for transportation. (Or an area is secured so that the containers can be directly driven into the area using dollies.)





The cart passes through the gaps in the stands for the large containers and carries the containers into the cell.



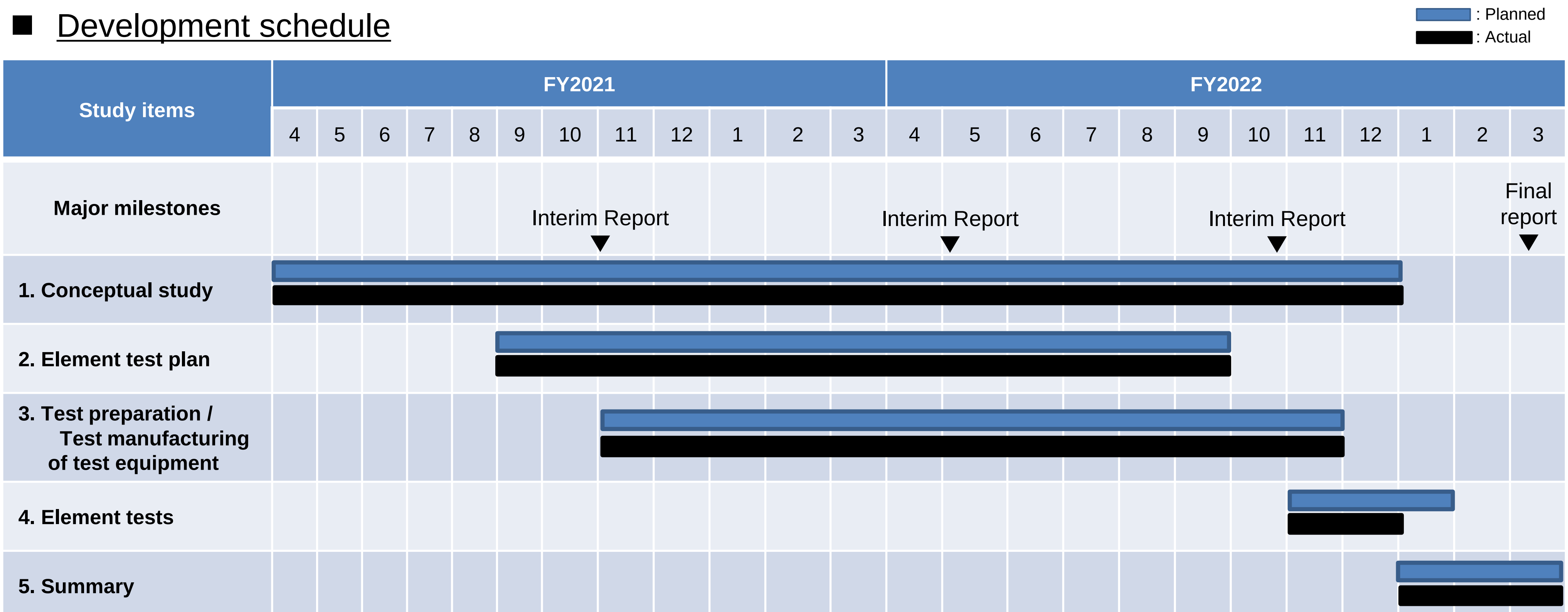


Layout of first floor of additional building

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

② Large transfer containers

■ Development schedule



Remarks	・ Element tests were completed in December 2022.

② Large transfer container: Summary

- **Pre-conditions pertaining to large transfer containers were consolidated in FY2021 and the development policy and method of using them were studied. Also, the aspects to be covered by the simulation during the test were studied considering the structure of the large transfer containers, their manufacturing procedure and the method of using them. Since the step of opening and closing the container by moving the dual lid is important in terms of air-tightness while using the large transfer containers, it was planned to verify air-tightness during the step of opening and closing the container by moving the dual lid, by conducting element tests using a container manufactured for the element tests.**

- **The structural designing of the actual large transfer container was carried out considering the manufacturing capability and the method of using it.**

- **The feasibility of the large transfer container was verified by conducting element tests.**

● As a result of the fitting test, it was verified that the equipment can fit as expected when the equipment is operated simulating the steps involved while operating the actual equipment, and that the container can connect to the prescribed location following the equipment guide even if there is some misalignment.

● As a result of the air-tightness test, it was verified that the rate of leakage at Part D (the sites sealed by sealed parts ③, ④, ⑤, ⑥) at the above-mentioned fitting position can meet the reference value.

- **Issues in application to actual equipment were identified, and the items to be reflected into the container specifications and equipment design of the actual equipment were consolidated.**

③ Large transportation equipment

With respect to retrieving fuel debris and reactor internal structures, in order to enhance the throughput using the top access method, the method of transferring unitized large structures is being studied as part of the development being undertaken since FY2019. To make this method possible, large structures need to be separated from the reactor and transferred, however, the large transportation equipment inside the R/B that will be used for transferring those structures needs to be developed so that the structures separated from the reactor can be loaded on it as unitized structures, and it can distinguish the transportation route that requires containment and shielding at the air-tight gate.

The large transportation equipment needs to be small and light in order to reduce the load on the operating floor of the R/B, and its traveling function should not be affected by deformation, etc. caused when heavy structures are mounted on it. Also, if the transportation equipment will be like a cart, generally one that is towed with a wire can have a lower floor as compared to the automated one, and is suitable for reducing the size as well. However, if an air-tight gate will be installed for compartmentalizing contaminated areas, such transportation equipment will be difficult to use. Such preconditions for the large transportation equipment and items that need to be developed for its use will be studied and consolidated, the methods for properly transporting large and heavy contaminated structures including their applicability when there is an air-tight gate will be investigated and studied, the structure of the transportation equipment including the drive mechanism will be studied and element tests will be conducted for evaluating the on-site applicability of the large transportation equipment, and for consolidating related issues.

③ Large transportation equipment

Table of Contents

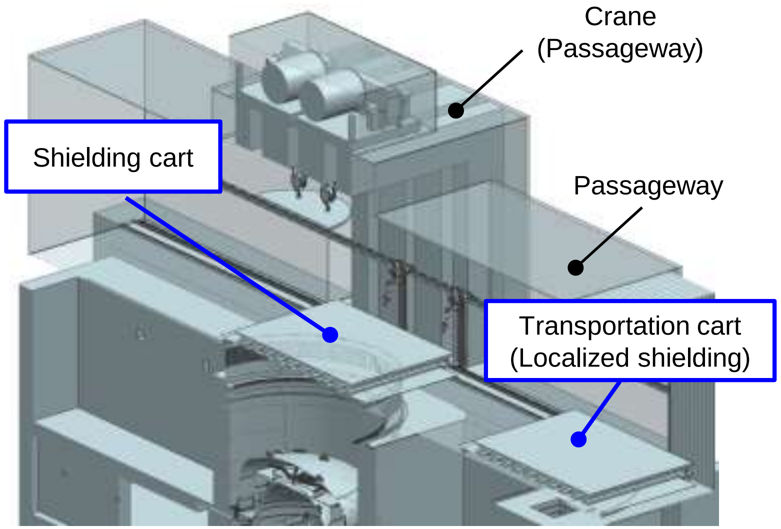
③ Large transportation equipment

[Issues]

- Since the items to be transported are heavy, the impact of loading heavy items on the large transportation equipment needs to be considered.
- Maintaining air-tightness by means of the air-tight gate in the passageway and transporting heavy items by means of the large transportation equipment, both need to be accomplished together.
- The floor of the large transportation equipment needs to be made as low as possible considering the height of the ceiling of the passageway and the hoisting clearance of the work container.

[Implementation details]

- The pre-conditions and required functions of the large transportation equipment that do not hinder the function of the air-tight gate (compartmentalizing the contaminated areas by maintaining air-tightness) inside the passageway will be consolidated.
- Existing technology and track record, etc. related to the method of transporting large and heavy structures will be investigated and studied.
- The configuration of the large transportation equipment including the drive mechanism will be studied.
- The method for reducing the size and weight of the large transportation equipment will be studied for reducing the load on the R/B operation floor.
- The impact of loading heavy items on traveling will be studied.
- The feasibility of placing the large transportation equipment and its drive mechanism inside the passageways will be studied.
- The elements that need to be developed in particular will be identified from among the large transportation equipment, element tests will be planned and implemented for verifying the application to the actual equipment at said location, on-site applicability of the large transportation equipment will be evaluated and issues will be consolidated.



(Note) “Large transportation equipment” refers to “Shielding cart” and “Transportation cart”.

[Expected outcome]

- Results of evaluating the on-site applicability of large transportation equipment, and related issues

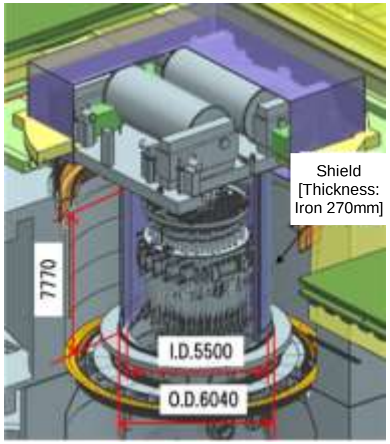
③ Large transportation equipment

[Pre-conditions]

- Pre-conditions pertaining to the design of the large transportation equipment (shielding/transportation cart) are indicated below.

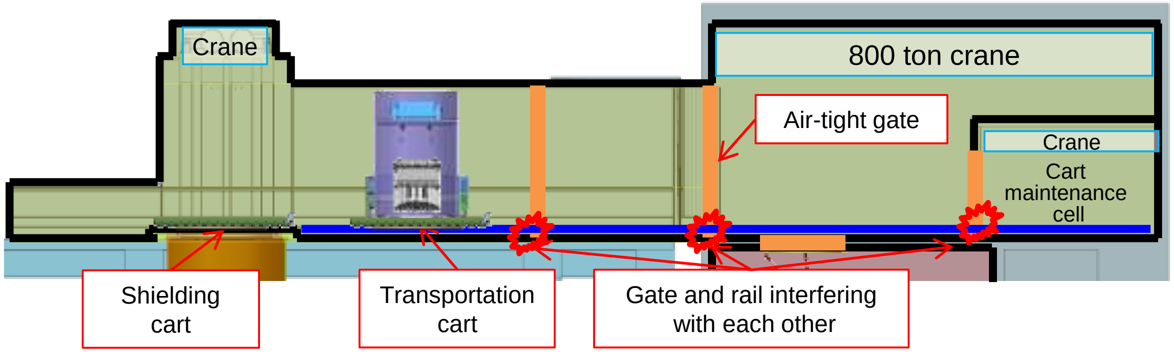
ID.	Pre-conditions	Remarks
1	An additional building for the top access method should be set up in addition to the additional building for the side access method.	In the case of the top access method, transferring unitized structures is being considered. Hence it would be difficult to use the delivery equipment in common with the side access method.
2	A frame should be installed so that the load of the passageway in which retrieval equipment, etc. will be installed is supported by the ground surface. The transportation cart travels on the frame.	Considering the acceptable maximum load of the operation floor, it will be difficult to support the load of the passageway.
3	The transportable weight should be studied considering that large heavy structures and work containers will be transported.	The design should consider the maximum size and maximum temperature so that large heavy structures and work containers can be transported.
4	An air-tight gate[#2] should be installed in the passageway for compartmentalizing contaminated areas.	The configuration of the large transportation equipment that does not hinder the function of the air-tight gate should be studied.

#2: This year, the shielding/transportation cart were studied assuming that the air-tight gate is a simple shutter. The detailed configuration of the air-tight gate will be studied next year onwards, and the results of the studies will be reflected appropriately in the structure of the shielding/transportation cart.



#1: The maximum size and maximum weight that is loaded on the large transportation equipment (Assuming the bottom is being removed)
Maximum size: Φ6040mm x H7770mm
Maximum weight: 800 ton

[Maximum size and weight loaded]



[Illustration of large transportation equipment]

③ Large transportation equipment

[Functions required of the shielding/transportation cart]

- The function required of the shielding/transportation cart and the corresponding items of comparative evaluation of the drive systems for the shielding/transportation cart described later are mentioned in the table below.

[List of functions required of the shielding/transportation cart]

No.	Required functions	Details	Items of comparative evaluation of the drive systems
1	Remotely operated traveling function	① Must be able to travel by remote operation with internal / external power	① Extent of difficulty in traveling by remote operation
2	Moving between cells and controlling spread of contamination (Inside/outside the cell)	① Must be able to move across cells ② Must be able to travel even if the passageway is sloping (assuming about 1/1000) ③ The shielding/transportation cart must be able to be controlled independently ④ Must avoid interference with the air-tight gate that compartmentalizes the cell ⑤ Must be able to control expansion of the contaminated area if it interferes with the air-tight gate ⑥ Must be able to control the spread of radioactive materials to the outside if there is a through hole in the cell	① Extent of difficulty in transportation between cells ② Extent of difficulty in stopping on slopes ③Extent of difficulty in independently controlling the shielding/transportation cart ④ Interference with the air-tight gate ⑤ Risk of expansion of the contaminated area (inside the cell) ⑥ Risk of expansion of the contaminated area (outside the cell)
3	Positioning on the well	① The shielding/transportation cart must be able to stop within a stipulated range on the well.	① Positioning accuracy
4	Transportation of large heavy structures (tentative value: 800 ton)	① Must be able to move upon being loaded with large heavy structures and the work container ② It must be possible to control deflection of the transportation cart resulting from loading of large heavy structures, or the cart must be able to travel even if it gets deflected.	① Extent of difficulty in transporting large heavy structures ② Omitted (Will be dealt with by means of the structure of the shielding/transportation cart)
5	Shielding the well	① It must be possible to control the radiation dose from inside to reactor to the passageway by stopping the shielding/transportation cart on the well.	① Omitted (Will be dealt with by means of the structure of the shielding/transportation cart)
6	Maintenance by remote operation / emergency retrieval	① It must be possible to carry out maintenance of the equipment contributing to the operation of the shielding/transportation cart by remote operation. ②It must be possible to retrieve the shielding/transportation cart back to the additional building if equipment contributing to the operation of the shielding/transportation cart breaks down.	① Extent of difficulty in maintaining and replacing the drive unit by remote operation ② Extent of difficulty in retrieving the shielding/transportation cart
7	Manufacturing capability of the drive unit and feasibility of placement	① It must be technologically possible to manufacture the drive unit. ② The scale of the equipment must be such that it can be placed between the passageway and the additional building.	① Extent of difficulty in manufacturing (including the air-tight gate) ② Extent of difficulty in placement feasibility

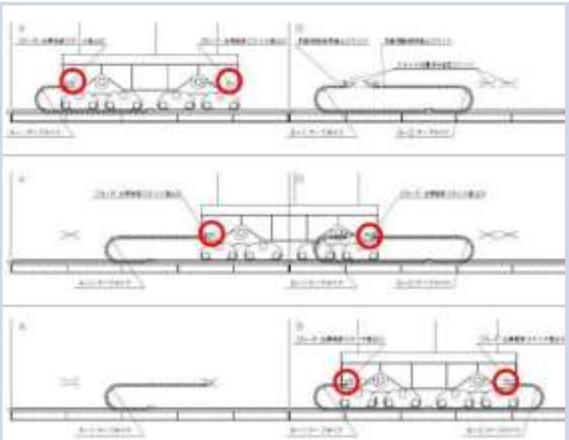
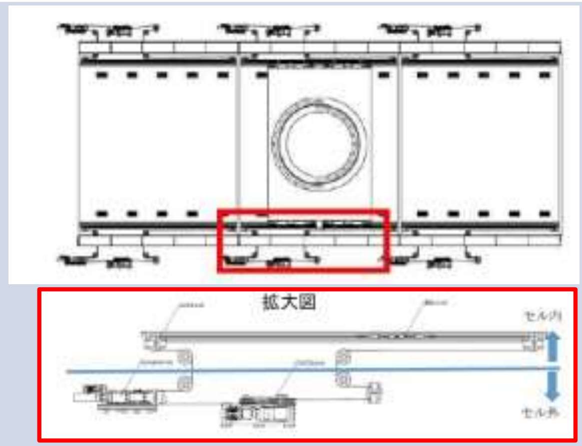
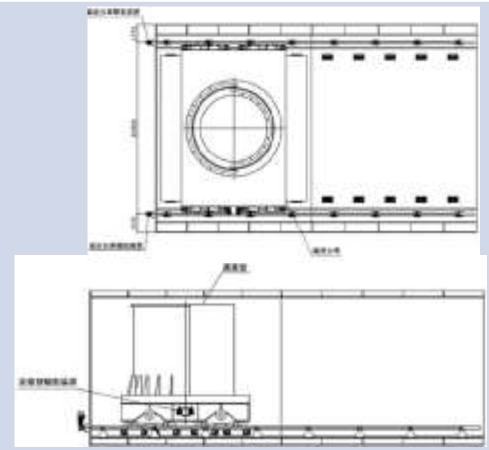
6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Drive system for the shielding/transportation cart]

- The drive systems (a) to (g) mentioned below were studied as the drive systems having the required function (in particular, functions that need to be fulfilled by the drive system) of the shielding/transportation cart mentioned above, while referring to existing technology and track record.

[Proposed drive systems for the shielding/transportation cart (1/2)]

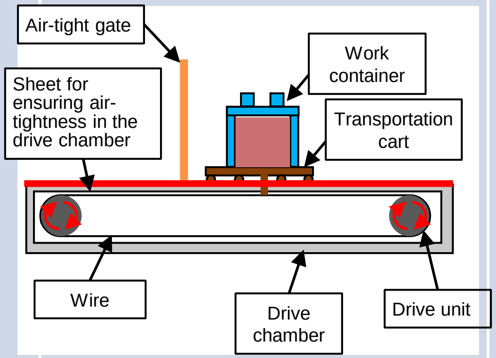
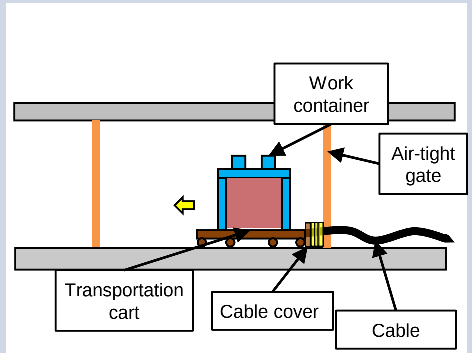
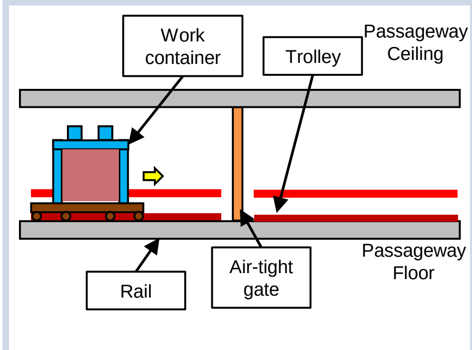
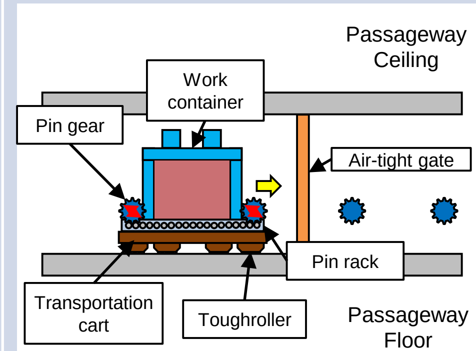
Drive system	(a) Remote connector system	(B) Wire transportation system	(c) Screw shaft type transportation system
Conceptual diagram			
Power	Electric motor (power supply through the connector)	Towed by a wire	Rotation of screw shaft
Overview	• The cart is moved by repeatedly connecting/disconnecting the power supply connector installed above the cell and the connector insertion port in the front and back of the shielding/transportation cart by remote operation.	• The shielding/transportation cart is moved by operating the wire that passes through the cell wall.	• The screw shaft is rotated, and the driving force is transmitted to the shielding/transportation cart via the half nut installed on the shielding/transportation cart.
Issues	• The feasibility of remotely connecting/disconnecting the connector on an actual equipment scale is uncertain. • Maintenance of the power supply connector / cableveyor is difficult inside the cell.	• Wire replacement by remote operation is difficult. • Securing space for placing the wire and drive unit for the shielding/transportation cart is difficult.	• Manufacturing large and horizontal screw shaft is difficult. • Securing space for placing the wire shaft for the shielding/transportation cart is difficult.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Drive system for the shielding/transportation cart]

[Proposed drive systems for the shielding/transportation cart (2/2)]

Drive system	(d) Wire drive system	(e) Cable power supply system	(f) Trolley system	(g) Pin gear system
Conceptual diagram				
Power	Towed by a wire	Electric motor (power supply through the cable)	Electric motor (power supply through the trolley)	Rotation of pin gear
Overview	• The shielding/transportation cart is moved by connecting the shielding/transportation cart to the wire under the cell floor (or in the side wall of the cell) and operating the wire.	• Power is supplied through the cable to the electric motor mounted on the shielding/transportation cart.	• Power is supplied through the trolley mounted on the shielding/transportation cart.	• The pin gear installed on the side wall of the cell is rotated while it is biting into the pin rack on the shielding/transportation cart.
Issues	• The risk of expansion of the contaminated area passing through the drive chamber is high. • If the drive chamber is installed under the floor, the risk of interference of the drive unit and the well opening is high.	• Replacement of the cable by remote operation is difficult. • Independent control of the shielding/transportation cart is difficult.	• As the trolley is large for remote handling, its replacement by remote operation is difficult.	• Handling the penetration shaft while maintaining air-tightness during maintenance/replacement of the drive unit outside the cell is difficult.

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Comparative evaluation of the drive systems for the shielding/transportation cart]

- Evaluation results in line with the evaluation items pertaining to the drive systems mentioned earlier are indicated below (Only those items in which there is major difference are listed).
- In particular, (a) Remote connector system and (f) Trolley system which have minor issues, were considered as promising drive systems.
- Of the 2 systems mentioned above, since (a) Remote connector system is believed to be more promising as a drive system with greater versatility in terms of supplying water and air to the transportation cart, etc., the structure of the shielding/transportation cart was studied and element tests were conducted considering this drive system.

Content in red: Items that have major issues in particular

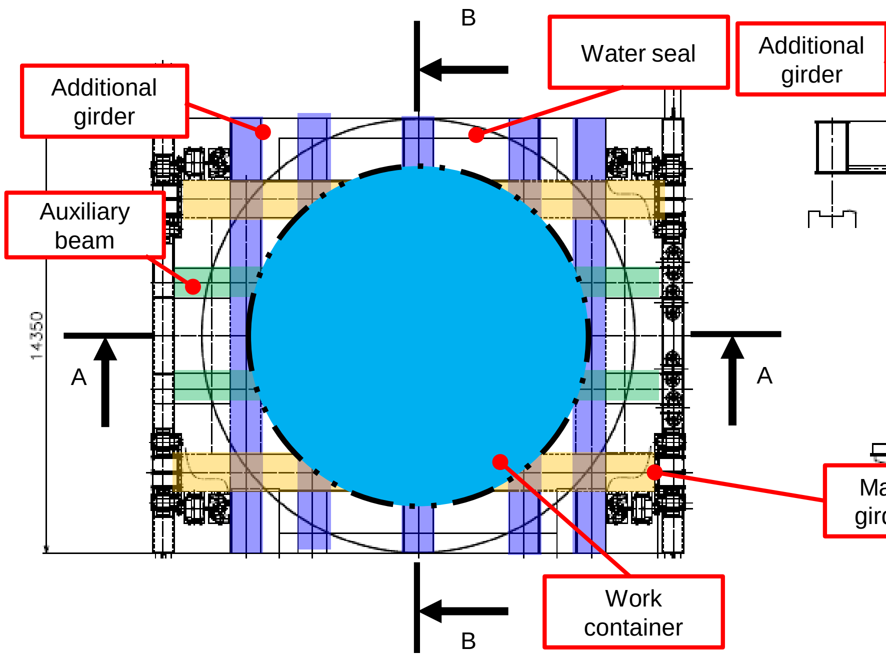
[Results of comparative evaluation of the drive systems]

Drive system	(a) Remote connector system	(b) Wire transportation system	(c) Screw shaft type transportation system	(d) Wire drive system	(e) Cable power supply system	(f) Trolley system	(g) Pin gear system
Extent of difficulty in manufacturing (including the air-tight gate)	○: Comparatively easy (Minor issues in manufacturing)	△: Comparatively difficult (Issues in maintaining air-tightness where the wire passes through the cell)	▲: Difficult (Manufacturing the long and horizontal screw shaft is difficult.)	○: Comparatively easy (Minor issues in manufacturing)	△: Comparatively difficult (Issues in the opening for the cable in the air-tight gate)	○: Comparatively easy (Minor issues in manufacturing)	○: Comparatively easy (Minor issues in manufacturing)
Extent of difficulty in placement feasibility	△: Comparatively difficult (The risk of placement not being feasible increases if the number of cables increases.)	▲: Difficult (Issues in securing space for placement of the drive system within and outside the cell)	▲: Difficult (Issues in securing space for the screw shaft, screw shaft penetration part, and the bearing)	▲: Difficult (There is a risk of interference with the well opening when multiple drive units are required)	△: Comparatively difficult (Space for laying the cables for the shielding/transportation cart needs to be secured.)	△: Comparatively difficult (The risk of placement not being feasible increases if the number of trolleys increases.)	△: Comparatively difficult (Space for installing the drive units needs to be secured)
Extent of difficulty in maintaining and replacing the drive unit by remote operation	△: Comparatively difficult (Improvements can be made by modifying the structure so that replacement is not necessary and so that attachment and detachment as a single unit is possible.)	▲: Difficult (Changing the wire by remote operation is difficult (Method of changing the wire considering control of spread of contamination outside the cell, and attachment and detachment of the transportation unit by remote operation.))	△: Comparatively difficult (A structure for straight connection of the screw shaft is necessary)	▲: Difficult (Changing the wire by remote operation is difficult (detachment from the drive unit by remote operation, access to the drive chamber))	▲: Difficult (Changing the cable by remote operation is difficult (Retrieving the cable when it is disconnected))	△: Comparatively difficult (Studying a structure that does not need replacement and that enables attachment and detachment as a single unit)	▲: Difficult (Handling the penetration shaft during drive unit maintenance is difficult (Work of replacement while maintaining air-tightness)

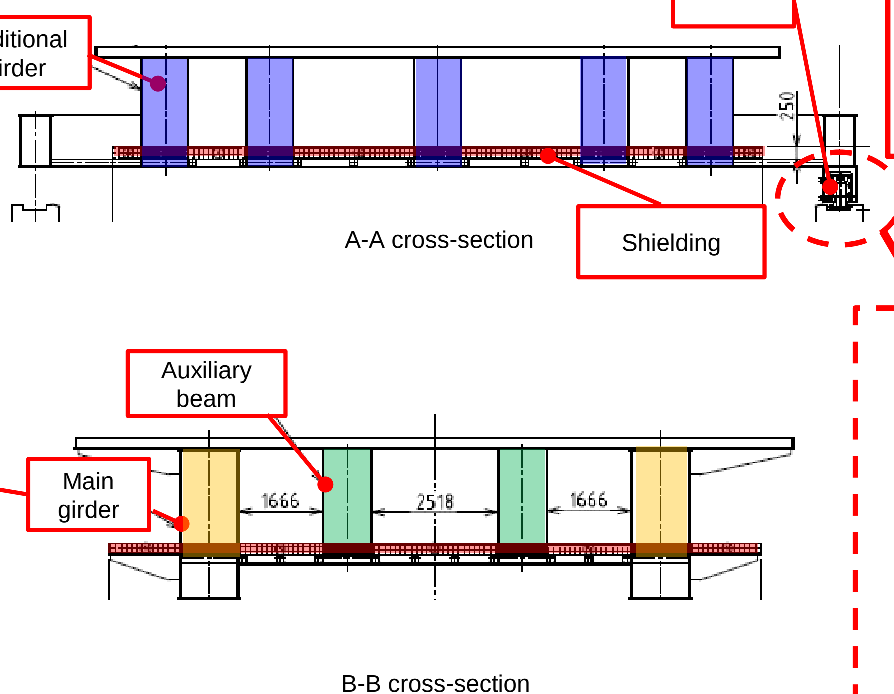
③ Large transportation equipment

[Study of the structure of the shielding/transportation cart ①]

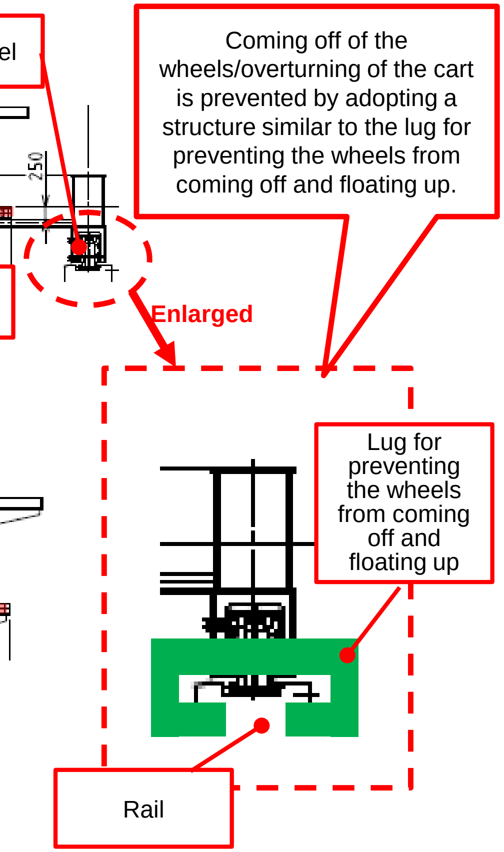
- The shielding/transportation cart# was made as light in weight as possible with a structure as shown in the figure below (Cart weight: approx. 547ton).
- If the shielding/transportation cart is made even more lighter, as almost the entire shielding/transportation cart is made up of strength members, the strength members themselves need to be worked on. As a result, deflection, etc. that is important for the design is likely to lead to deviation from the acceptable values.
- As a measure to prevent the shielding/transportation cart from overturning, a structure similar to the lug for preventing the wheels from coming off and floating up needs to be adopted.



[Planar view of the transportation cart]



[Cross-sectional view of the transportation cart (Top: AA cross section, Bottom]

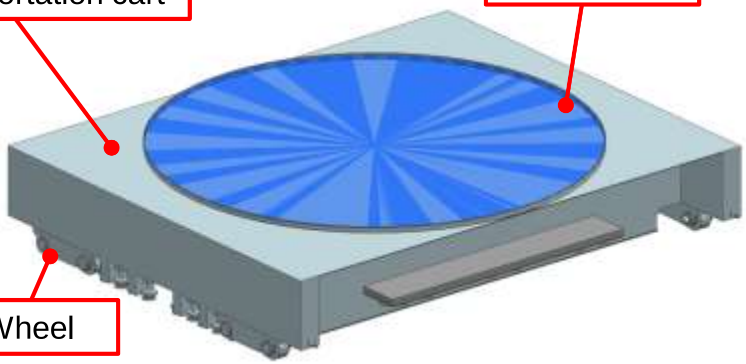


#: The shielding cart has a structure in which the water seal is eliminated from the structure of the transportation cart mentioned above

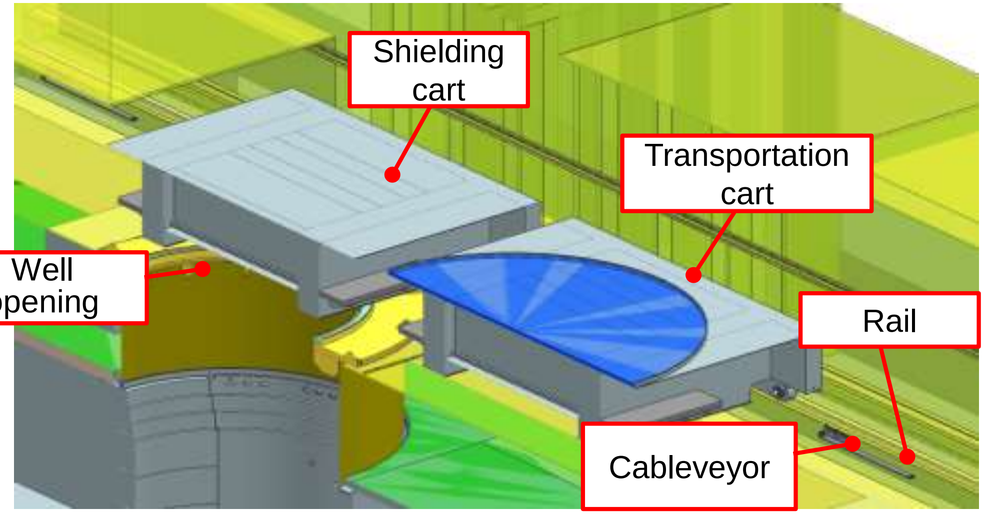
③ Large transportation equipment

[Study of the structure of the shielding/transportation cart ②]

- Structural drawing of the transportation cart, and layout drawing of the passageway are indicated.

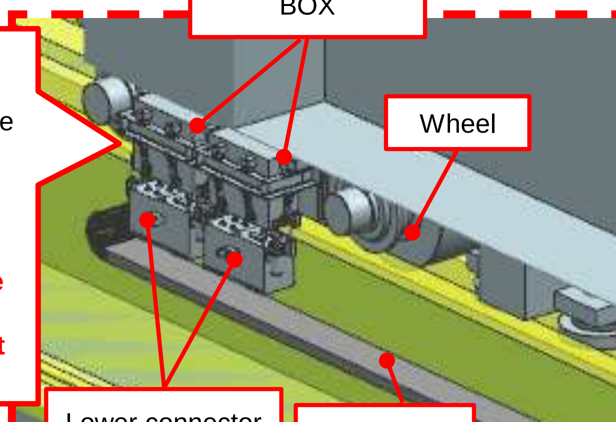


[Structure drawing of the transportation cart]

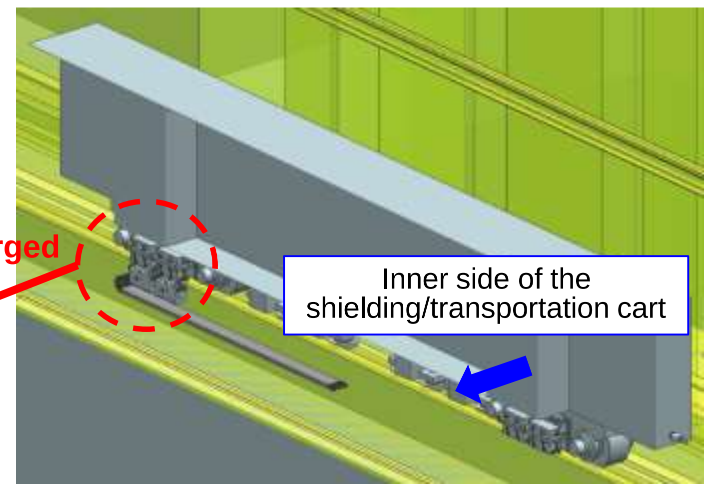


[Layout drawing of the shielding/transportation cart]

[Impact on traveling when large heavy structures are mounted]
Due to the deflection of the transportation cart, the upper connector BOX tilts and is likely to hinder attachment and detachment of the upper/lower connector BOX by remote operation.
→ **Whether or not the upper/lower connector BOX can be attached and detached by remote operation when the transportation cart is deflected, was verified by conducting element tests.**



Enlarged



[Cross-section of the shielding/transportation cart]

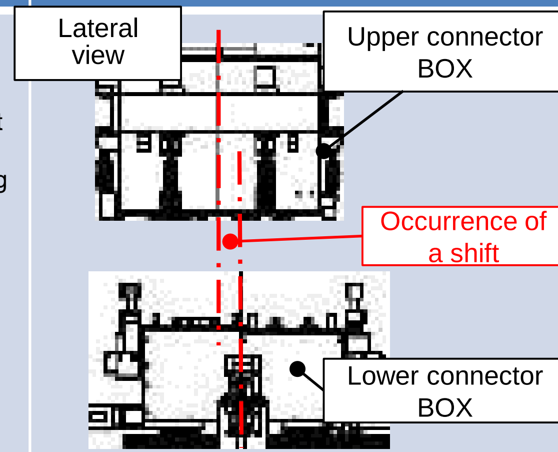
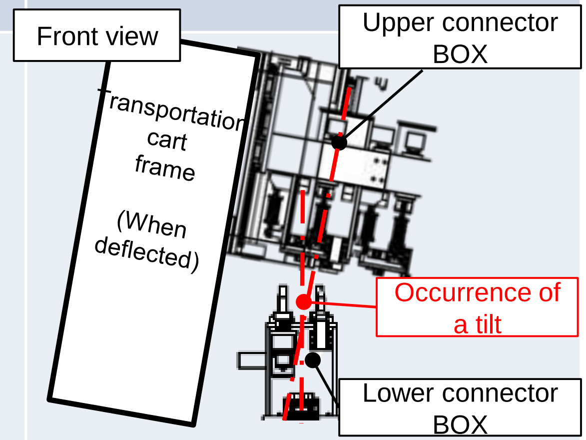
#: Mounted as equipment for preventing spread of contaminants present at the bottom of the work container

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Study of the structure of the shielding/transportation cart ③]

- The items to be verified in the element tests were consolidated based on the results of the studies on the shielding/transportation cart.

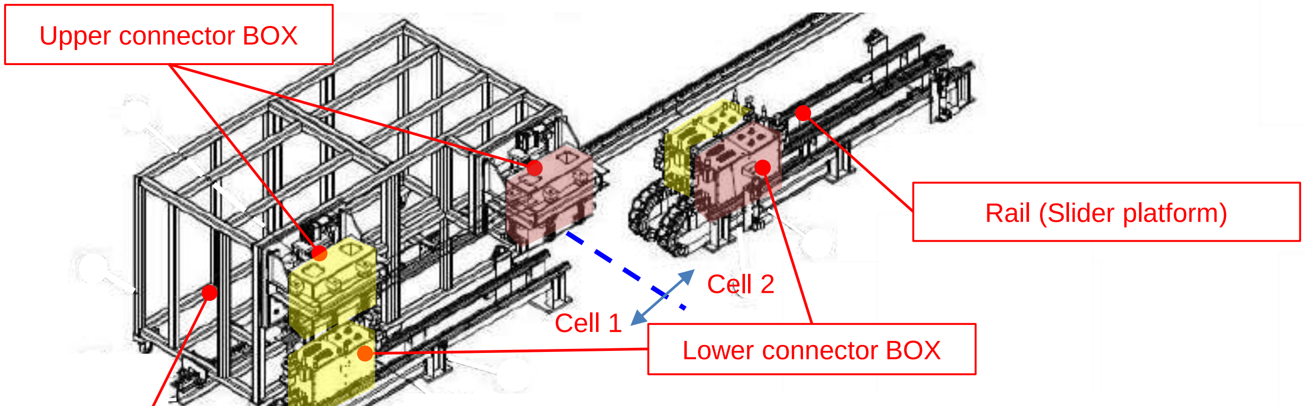
Items to be verified	Reason	Illustration Note) The shift and tilt are overstated
Whether or not the connector can be connected when the stopping position shifts (Test item No. 4)	The stopping precision (shift in the stopping position as against the target stopping position) of the shielding/transportation cart, the structure of which was studied, is assumed to be approx. ± 6 mm based on results of calculations. → When the shielding/transportation cart stops at the target stopping position (when shift is 0mm), it has stopped at a position where the lower connector BOX is right below the upper connector BOX. → When the shielding/transportation cart stops at a position that has shifted from the target stopping position, as the upper connector BOX and lower connector BOX becomes misaligned in a similar manner, <u>the shift needs to be absorbed while making the connection.</u>	
Whether or not the connector can be connected when there is deflection (Test item No. 5)	The transportation cart, the structure of which was studied, gets deflected when large heavy structures are mounted on it. →The extent of deflection (angle of inclination) is assumed to be approx. 0.14° in the direction of travel and at right angles, referring to the "Limit of deflection of the overhead crane" mentioned in the industry standards for cranes. → Due to the said deflection, since the upper connector BOX that is mounted on the transportation cart is tilted with respect to the lower connector BOX, <u>the tilt needs to be absorbed while making the connection.</u>	

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

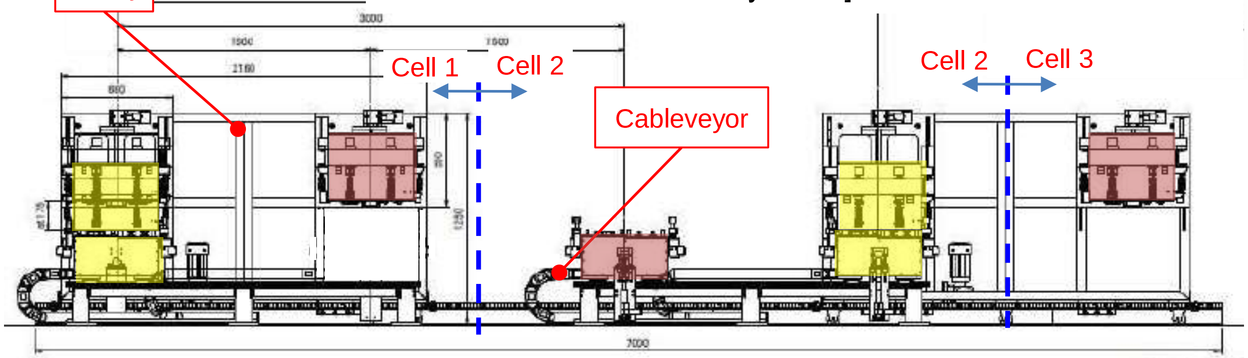
③ Large transportation equipment

[Remote connector system element test plan ①]

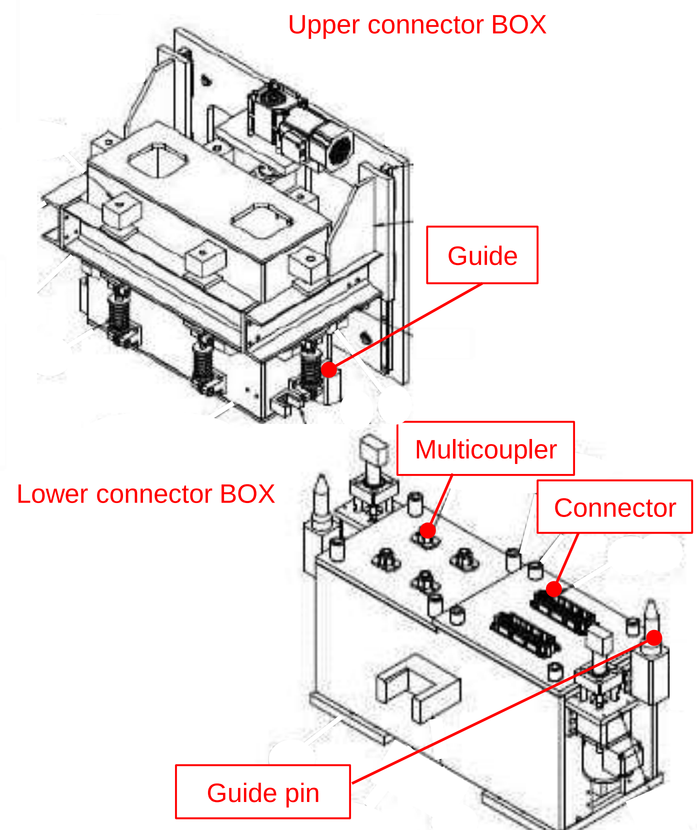
- The purpose of the element tests is to verify the feasibility of connection and disconnection of the connector by remote operation and movement of the cart between cells on an actual equipment scale.
- Structural outline of the element test equipment is indicated in the figure below.
  (Equivalent to actual equipment: Upper and lower connector BOX, rail (sliding platform)
  (1/4 scale: Span of the connector box, length of the sliding platform)



[Remote connector system element test equipment bird's eye view]



[Remote connector system element test equipment schematic diagram]

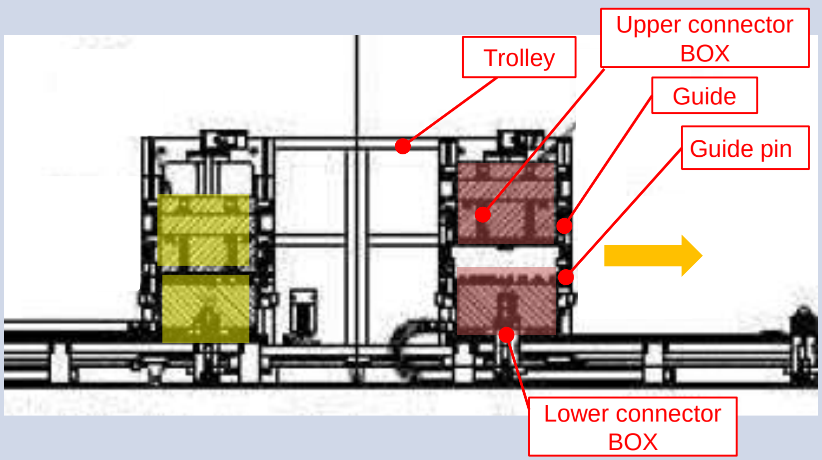
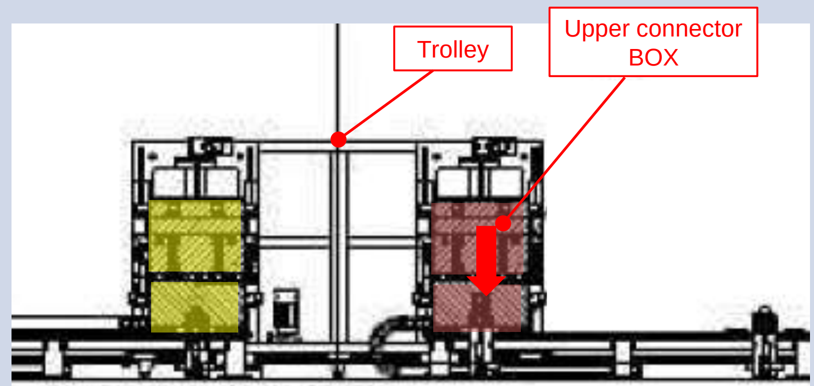


[Upper/Lower connector BOX schematic diagram]

[Remote connector system element test plan ②]

- The procedures for connecting the remote connector during the element tests are indicated below.
- The following procedures are performed for the upper connector BOX when its placement is appropriate/when there is a shift in position/when there is a tilt respectively.
- The shift in position is assumed to be the shift in position while stopping the shielding/transportation cart the structure of which was studied.
- The tilt is assumed to be the deflection of the transportation cart when large heavy structures are mounted on it.

[Procedures for connecting the connector BOX by remote operation]

<table>
<tr><th>STEP</th><th>① Positioning</th><th>② Lowering the upper connector BOX</th></tr>
<tr><td>Illustration</td><td>
</td><td>
</td></tr>
<tr><td>Details</td><td>The upper connector BOX is positioned by horizontally moving the cart.
After completing the positioning, the upper connector BOX is lowered, and it is confirmed that the guide pin of the lower connector BOX passes through the guide part of the upper connector BOX.</td><td>The connector is connected by only lowering the upper connector BOX.
Power is supplied and signals are transmitted to the cart and it is verified that the cart can move according to the instructions (that the connector connection has been completed).</td></tr>
</table>

③ Large transportation equipment

[Remote connector system element test plan ③]

- The test items and judgment criteria mentioned in the table below were set.

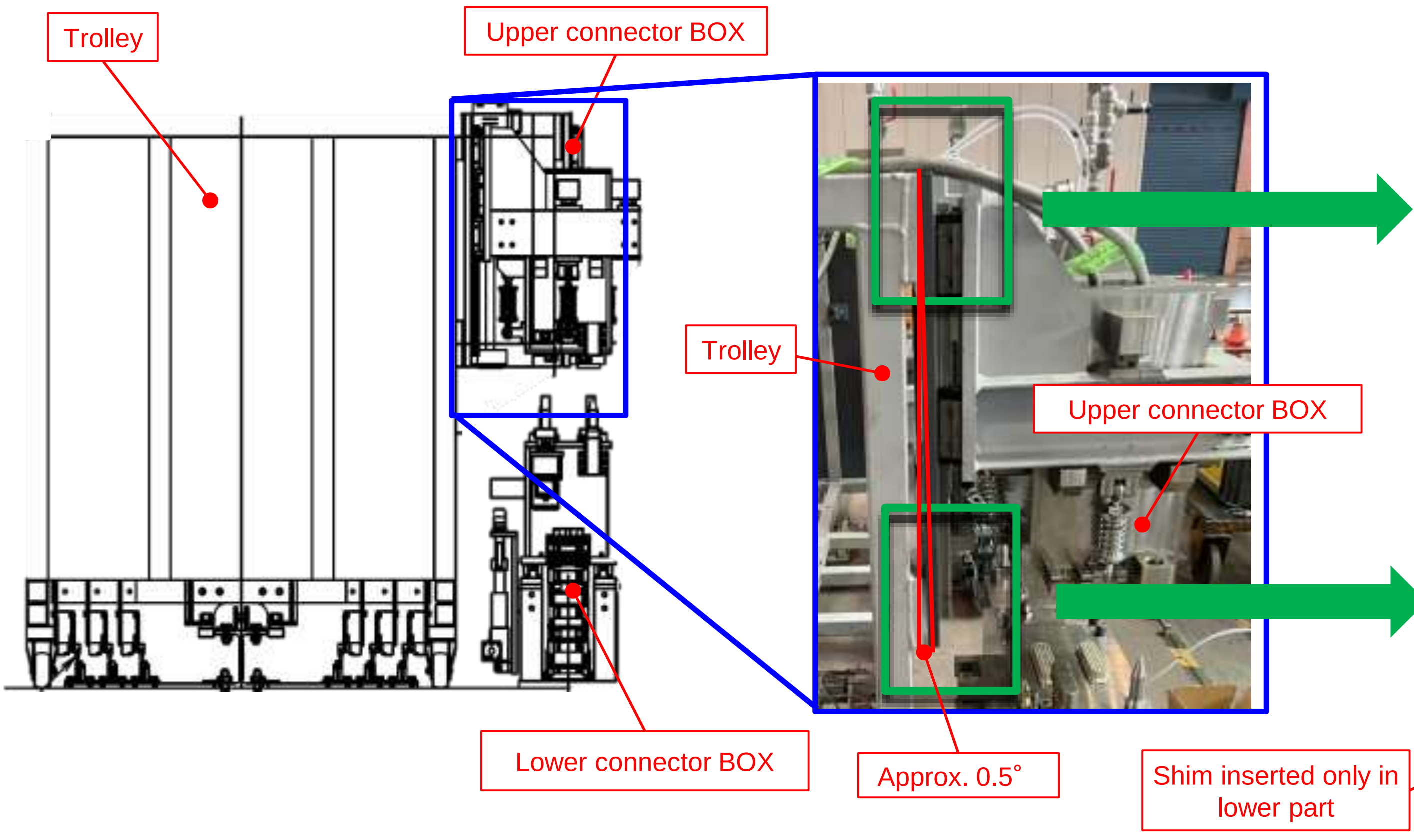
[Element test List of test items]

No.	Test Item	Details	Criteria
1	Whether or not the connector can be connected by remote operation	It is verified that the power supply connector can be connected by remote operation.	①: There should be no interference while lowering the upper connector BOX ②: The position of the upper connector BOX should be according to the design after it has been lowered. ③: The power lamp on the control panel should be lit up after the connector is connected. ④: The cart should move forward without any issues in response to instructions for moving forward.
2	Whether or not the connector can be disconnected by remote operation	It is verified that the power supply connector can be disconnected by remote operation.	①: The position of the upper connector BOX should be according to the design after it has been lifted up. ②: There should be no interference while lifting up the upper connector BOX ③: The cart should move forward without any issues in response to instructions for moving forward. ④: The connectors and couplers should not be damaged and deformed. ⑤: There should be no harmful scratches on the surface of the connectors and couplers.
3	Whether or not the cart can move between cells	It is verified that transportation cart can move to adjacent cells by repeating the procedures for connecting/disconnecting the connector by remote operation.	①: The cart should be able to move from Cell 1 → Cell 2 → Cell 3 → Cell 2 → Cell 1 by remote operation only. ②: The horizontal shift in the stopping position of the cart from the stipulated stopping position to the actual stopping position at each cell should be ±10mm (fitting precision of the guide) or less. ③: The cart should completely cross over the gaps in the rail (The rear wheels of the cart when the cart is moving forward should be on the rail inside the cell into which the cart is moving)
4	Whether or not the connector can be connected when there is a shift in the stopping position	It is verified that the connector can be connected even when the stopping position of the cart is intensionally shifted in the range of ±10mm (range of the shift in position anticipated in the actual equipment).	①: The power lamp on the control panel should be lit up. ②: The cart should move forward without any issues in response to instructions for moving forward. ③: There should be no interferences besides the guide pin and the part in which it fits.
5	Whether or not the connector can be connected when there is deflection	It is verified that the connector can be connected even when the upper connector BOX is tilted with respect to the lower connector BOX anticipating deflection of the cart in the actual equipment. (The BOX is tilted 0.5° considering the deflection in the actual equipment and is perpendicular to the rail.)	①: There should be no interference while lowering the upper connector BOX ②: The position of the upper connector BOX should be according to the design after it has been lowered. ③: The power lamp on the control panel should be lit up after the connector is connected. ④: The cart should move forward without any issues in response to instructions for moving forward. ⑤: The connectors and couplers should not be damaged and deformed. ⑥: There should be no harmful scratches on the surface of the connectors and couplers.

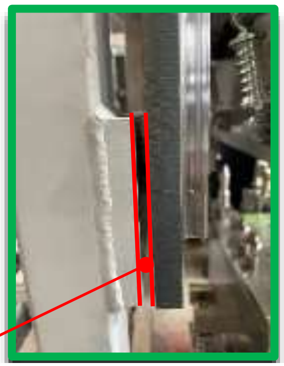
6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]
③ Large transportation equipment

[Remote connector system element test plan ④]

- The shift in the stopping position of the shielding/transportation cart is replicated by manually shifting the cart (considering the safety factor) ±10 mm.
- The deflection of the cart is replicated by tilting the lifting equipment for the upper connector BOX (considering the safety factor) approx. 0.5° .
- A shim is inserted in the holding part for the lifting equipment and the cart for tilting the lifting equipment.



Upper connector BOX
Holding part of the lifting equipment (top)



Lower connector BOX
Holding part of the lifting equipment (bottom)

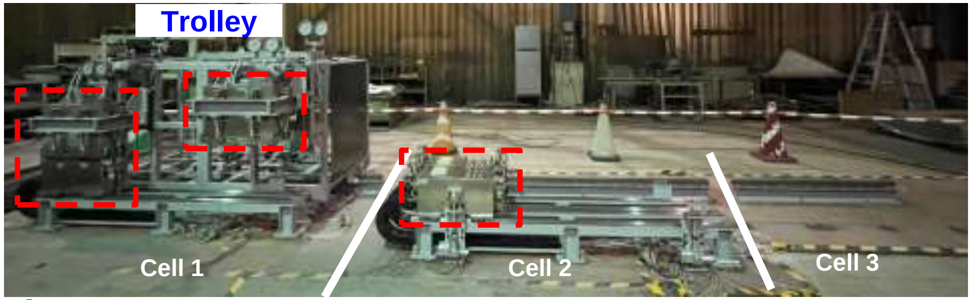
[Method of replicating the deflection (tilting of connector) Schematic diagram]

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

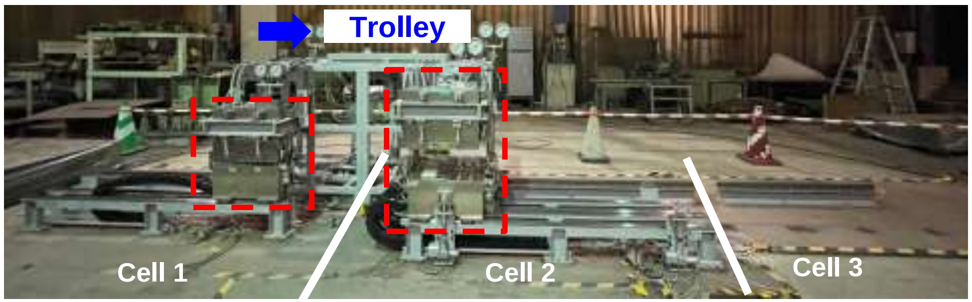
③ Large transportation equipment

[Status of element tests (While verifying whether or not the cart can move between cells)]

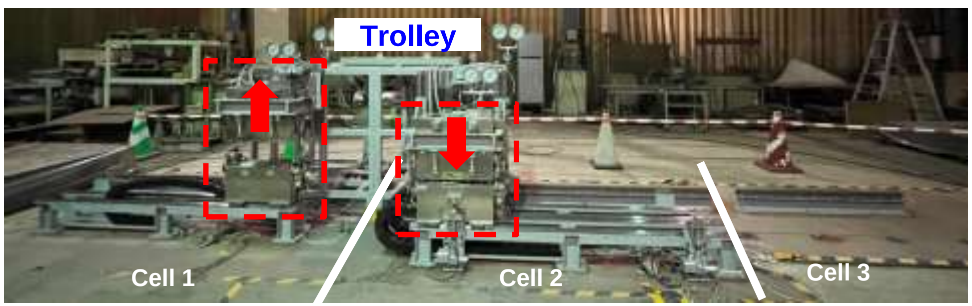
: Connector BOX



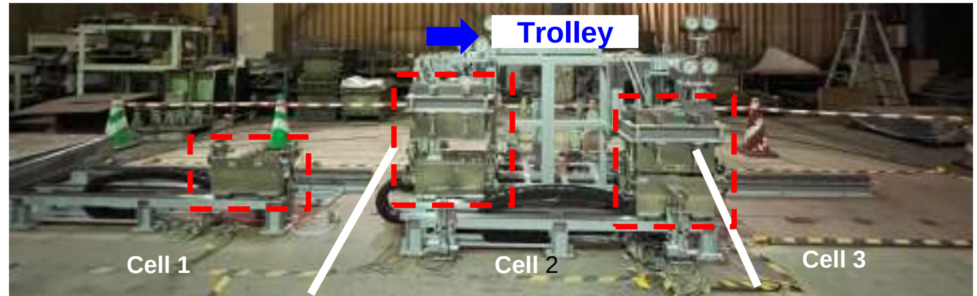
① Initial condition



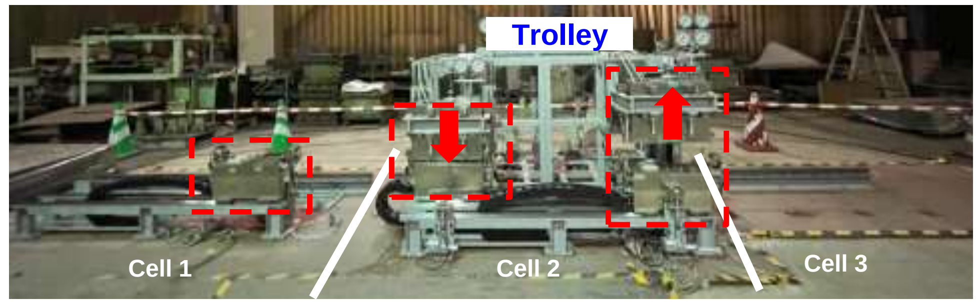
② Movement of the cart (In between Cells 1 and 2)



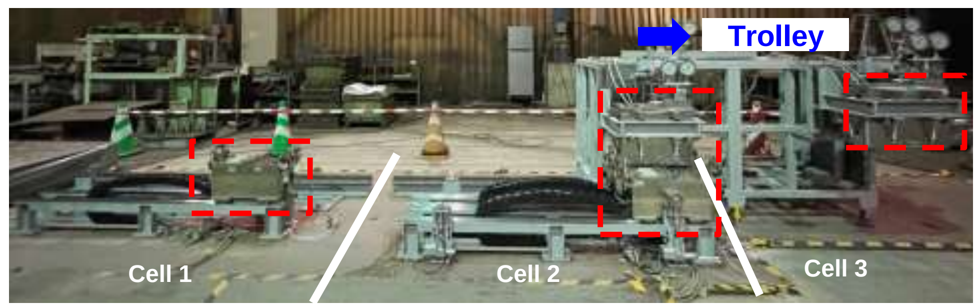
③ Changing of the connection of the connector BOX (In between Cells 1 and 2)



④ Movement of the cart (To Cell 2)



⑤ Changing of the connection of the connector BOX (Cell 2)



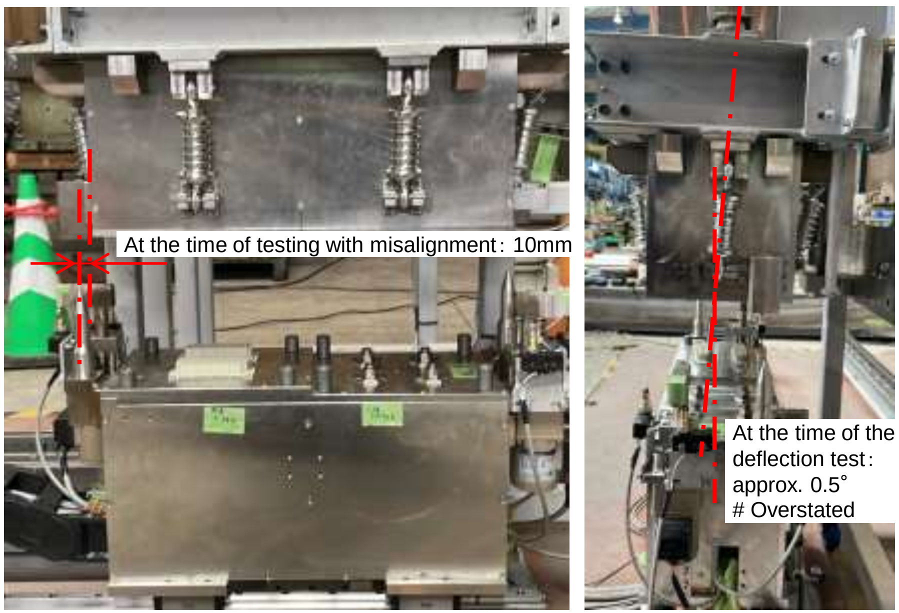
Movement of the transportation cart (In between Cells 2 and 3)

6. Implementation Items of This Project [2] (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Element test results ①]

- After connecting the connector, power was supplied and signals were transmitted to the transportation cart through the connector, and it was verified that the transportation cart can be operated according to the instructions.
- While 2 connectors were connected to the transportation cart, one of the connectors was disconnected by remote operations. Power was supplied and signals were transmitted through the other connector, and it was verified that the transportation cart can move independently of the connector that was disconnected.
- It was verified that the connector can be connected even when the stopping position of the cart is intensionally shifted in the range of ±10mm (range of the shift in position anticipated in the actual equipment), and even when the upper connector BOX is tilted approx. 0.5° .



a. Before connecting

b. After connecting

[Status of connecting the remote connector]

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures]

③ Large transportation equipment

[Element test results ②]

- Element tests were conducted on connecting and disconnecting the remote connector.
- The results of all the element tests for all test items met the judgment criteria.
- The feasibility of connecting and disconnecting the connector and movement of the cart between cells on an actual equipment scale was verified based on the judgment results.

No.	Test Item	Criteria	Test results
1	Whether or not the connector can be connected by remote operation	①: There should be no interference while lowering the upper connector BOX ②: The position of the upper connector BOX should be according to the design after it has been lowered. ③: The power lamp on the control panel should be lit up after the connector is connected. ④: The cart should move forward without any issues in response to instructions for moving forward.	The judgment criteria were met. After connecting the connector, power was supplied and signals were transmitted to the transportation cart through the connector, and it was verified that the transportation cart can be operated according to the instructions.
2	Whether or not the connector can be disconnected by remote operation	①: The position of the upper connector BOX should be according to the design after it has been lifted up. ②: There should be no interference while lifting up the upper connector BOX ③: The cart should move forward without any issues in response to instructions for moving forward. ④: The connectors and couplers should not be damaged and deformed. ⑤: There should be no harmful scratches on the surface of the connectors and couplers.	The judgment criteria were met. It was verified that while 2 connectors were connected to the transportation cart, one of the connectors can be disconnected by remote operation. Also, it was verified that after changing over the connector, the transportation cart can be operated by supplying power and transmitting signals through the other connector.
3	Whether or not the cart can move between cells	①: The cart should be able to move from Cell 1 → Cell 2 → Cell 3 → Cell 2 → Cell 1 by remote operation only. ②: The horizontal shift in the stopping position of the cart from the stipulated stopping position to the actual stopping position at each cell should be ±10mm or less. ③: The cart should completely cross over the gaps in the rail (The rear wheels of the cart when the cart is moving forward should be on the rail inside the cell into which the cart is moving)	The judgment criteria were met. It was verified that movement is possible by remote operation alone from the cell at one end to the cell at the other end by repeating the procedures for connecting/disconnecting the power supply connector.
4	Whether or not the connector can be connected when there is a shift in position	①: The power lamp on the control panel should be lit up. ②: The cart should move forward without any issues in response to instructions for moving forward. ③: There should be no interferences besides the guide pin and the part in which it fits.	The judgment criteria were met. It was verified that the connector can be connected even when the stopping position of the cart is intensionally shifted in the range of ±10mm (range of the shift in position anticipated in the actual equipment).
5	Whether or not the connector can be connected when there is deflection	①: There should be no interferences besides the guide pin and the part in which it fits. ②: The position of the upper connector BOX should be according to the design after it has been lifted up. ③: The power lamp on the control panel should be lit up. ④: The cart should move forward without any issues in response to instructions for moving forward. ⑤: The connectors and couplers should not be damaged and deformed. ⑥: There should be no harmful scratches on the surface of the connectors and couplers.	The judgment criteria were met. It was verified that the transportation cart can be operated according to the instructions by supplying power and transmitting signals to the transportation cart through the connector after connecting the connector, even when the upper connector BOX is tilted approx. 0.5° with respect to the forward motion of the cart.

③ Large transportation equipment

[Issues (Items to be studied in the future）]

- Evaluation results related to on-site applicability -

- Prospects of being able to move the transportation cart (deflection and stopping precision simulated in the element tests) on which 800 tons of large heavy structures were mounted between cells by remote operation by means of the remote connector system, were obtained.

- Issues -

- Equipment (robot) for replacing the lower connector BOX and cableveyor by remote operation needs to be studied.

(As a concept of replacement by remote operation, it is anticipated that the lower connector BOX and cableveyor will be removed together from the connector BOX on the passageway side with the help of a robot, and thereafter, these will be mounted on the emergency retrieval cart and transported to the additional building.)

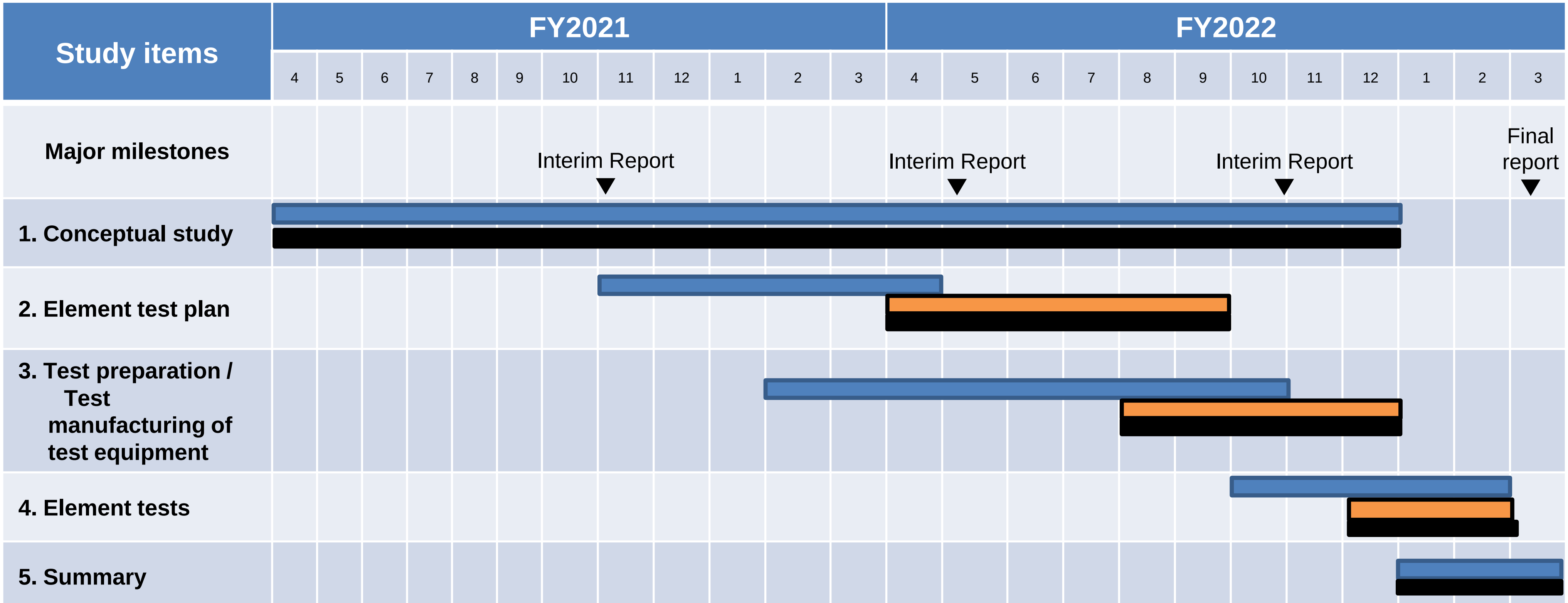
- The feasibility of connecting the upper/lower connector BOX by remote operation to cables that will be present in the actual equipment needs to be verified.
- The functionality achieved by combining the air-tight gate and the drive unit of the shielding/transportation cart needs to be verified.

6. Implementation Items of This Project [2) (1) Development of Technology for Realizing the Concept of Retrieving Large Structures] **No.668**

③ Large transportation equipment

: Planned
: Planned (after revision)*
: Actual

■ Development schedule



Remarks

・ **Since the study of the steps involved in carrying-in/out and consolidation of issues required time, the design of the test plan was started from FY2022.**

IRID * The plan was revised to reflect the progress status of the studies.

③ Large transportation equipment

- **Pre-conditions pertaining to the structure of the large transfer equipment were put together in FY2021 and the development policy was studied.**
- **The required functions of the large transportation equipment were studied and consolidated. Also, potential drive systems for the shielding/transportation cart that can be used in large transportation equipment were identified by investigating existing technology/track records, further comparative evaluation was carried out based on the required functions that have been consolidated, and the drive system that was found to be promising in particular was studied.**
- It was decided that **element tests will be conducted focusing on the remote connector system** in which power is supplied through the remote connector, and **a test plan was designed (test items, verification details, judgment criteria were consolidated).**
- **Element tests were conducted to verify feasibility. Issues in application to the actual equipment were identified and reflected into the equipment design for the actual facility.**

7. Summary

1) Development of side access method

(1) Development of the method of installing access equipment

① Installation of large heavy structures

- **The structure was detailed focusing on the boundary (connected parts, assembled parts and installed parts) of the cell adapter, shielding door and fuel debris retrieval cell that form the access equipment.**

- **The access equipment and other fuel debris retrieval equipment cells need to be installed accurately in a straight line between the pedestal opening and the X-6 penetration opening, in order to establish the shortest access route.**

Hence, the installation procedures and structure were studied, and proposals on the structure and installation feasible on the whole were developed considering the fitting accuracy.

- **As a part of the study for enhancing throughput, the work carried out inside the cells was detailed for improving the accuracy of the results of calculating throughput.**

- **The work steps involved in installing large heavy structures were detailed and revised, issues in each step were identified, and element tests (establishment of the installation reference location, verification of the 3D processing technique for the cell adapter flange, verification of whether or not insertion is possible, and overall structure) for determining the policy for responding to the issues and for verifying it were designed and conducted.**

- **Since the work of installation will be carried out under high radiation dose environment, the cell adapter will need to be installed by remote operations. Hence the detailed steps involved in the installation procedure were organized and related issues were consolidated. Also, a test plan for clarifying the required conditions for the remotely controlled equipment was created based on a structure that was substantiated and the tests were conducted.**

1) Development of side access method

(1) Development of the method of installing access equipment (Continued)

② PCV connection sleeve remote installation and welding

Remote installation of sleeve

- **In FY2021, the requirements (pre-conditions) for remote installation of the sleeve, results of studying the concerned delivery method and equipment were consolidated. "The method of delivering the whole unit" which is the same as the method used for delivering the main access tunnel was selected, and the issues and items that need to be verified by tests, etc. were consolidated.**
- **Based on the results consolidated as mentioned above, the specifications pertaining to the remote sleeve installation equipment, sleeve structure, opening part, installation procedures, etc. were studied using mock-ups. The actual equipment (assumed) and the mock-up equipment were compared and the results were compiled. Test plans including sensing were created, and a gap of 20mm or less (target 7.5mm or less) was established as the judgment criteria.**
- **Preparations were made for a full-scale test equipment and facility for remote installation of the sleeve, and tests for verifying the feasibility related to the procedures for remote installation of the sleeve and the equipment were conducted.**
- **As a result of the tests, it was verified that the target of 7.5mm or less is met. Also, issues in application to the actual equipment were identified and consolidated.**

7. Summary

1）Development of side access method

(1) Development of the method of installing access equipment (Continued)

② PCV connection sleeve remote installation and welding (continued)

Remote welding of the sleeve

- **The methods of responding to the issues pertaining to remote welding of the sleeve consolidated during the FY2019-20 subsidy project were studied in FY2021, and issues as well as items that need to be verified through tests, etc. were consolidated.**
- **Items to be verified, monitored, measured and recorded were substantiated through the welding, polishing and fluorescent PT (inspection) tests, and judgment criteria were established.**
- **Preparations were made for element test equipment and facility for remote welding of the sleeve, and element tests were conducted for verifying the feasibility related to the procedures and equipment for remote welding of the sleeve.**
- **Feasibility of remote welding for a welding gap of 7.5mm or less was verified by conducting full-scale tests. However, there is a possibility that the welding conditions for a welding gap of 7.5mm to 20mm will need to be revised. Also, maintenance was studied to verify applicability to the actual equipment.**
- **Issues in application to the actual equipment were identified from the test results and consolidated.**

1）Development of side access method

(1) Development of the method of installing access equipment (Continued)

③ Installation of shield

- **In FY2021, the study plan and the preconditions were consolidated and thereafter shielding was evaluated, for studying the method for additional installation of shield. It was found that as the radiation dose from neutron beams is high, neutron shielding needs to be installed to reduce the shielding thickness.**
- **Interference with the work of constructing the additional building is expected to be avoided (the access tunnel unit is expected to be pulled over with a crawler crane) by revising the required shielding thickness from 300mm wall (iron) to 200mm (iron) (part of it added to the cart inside the access tunnel). The method for additional installation of shield continued to be studied as additional shielding will be installed as required after ascertaining the status inside the PCV.**
- **It was determined that feasibility of the proposal to additionally install spherical shields needs to be verified through element tests. The items to be verified, and items to be monitored, measured and recorded during the filling test were studied, a filling rate of 60% was planned as the criteria and the test was conducted.**
- **As a result of the element test, it was verified that the spherical shielding material can be filled up to 20m ahead by using the blast equipment and the straight nozzle. Also, it was found that filling was possible up to a cell width of 500m, and that the structures inside the cell (reinforcement material) did not have an impact on filling.**
- **Since spherical shielding material can be filled up to 20m ahead, it was verified that the operation can be performed from outside the R/B and thus worker exposure can be reduced.**

7. Summary

1）Development of side access method

(1) Development of the method of installing access equipment (Continued)

④ Disassembly of shield plug

- **The course of study and preconditions pertaining to the method of disassembling the shield plug in Unit 1 and concrete blocks in Units 2, 3 were consolidated in FY2021, and the disassembly and removal procedures were studied briefly. The disassembly procedures were consolidated. Issues in the methods were identified and a rough exposure dose evaluation was carried out.**
- **The cranes and tools to be used were substantiated, and whether or not the items to be processed such as concrete blocks, etc. can be processed was studied. The necessity of the test including the study of smoothening methods was evaluated, and the test plan was created (test items, verification contents and judgment criteria were consolidated).**
- **Element tests were conducted based on the above-mentioned test plan, and it was thus anticipated that it will be possible to remove concrete blocks in Unit 3 by combining the methods tested this time (3 ton class crane + breaker). Also, issues in application to the actual equipment were identified from the test results and consolidated.**

1）Development of side access method (Continued)

(2) Development of disassembly and removal technology

① HVH disassembly

- In FY2021, results of studies conducted on HVH disassembly concerning the selection of items to be tested based on the pre-conditions and level of difficulty of disassembly, selection of circular saw and grindstone grinder as the cutting technology, and identification of element test items based on the disassembly work steps were compiled. The work steps were examined in detail, issues in each of the steps were identified, an element test plan was created, and the test items, judgment criteria, etc. were studied.
- Unit tests (tests conducted using the stand-alone equipment outside the simulated environment) related to cutting were conducted, and the course of cutting was substantiated through element tests.
- Element tests were conducted to verify the feasibility of the method of disassembling and removing the HVH, and the results were consolidated.
- Issues in application to actual equipment were identified, and the plan for reflecting them into the equipment design for the actual equipment was consolidated.

7. Summary

1）Development of side access method (Continued)

(2) Development of disassembly and removal technology (continued)

② Disassembly of CRD exchanger

- **The pre-conditions pertaining to the disassembly of the CRD exchanger were consolidated, the method of disassembly and removal of CRD exchangers in Units 1/3 and the work steps involved were studied, and the test items were selected.**
  - **Unit 2: The method of carrying out disassembly and removal by installing a rail on the P/F, and moving the equipment to the specified locations inside the pedestal by traveling over the rail.**
  - **Units 1/3: The method of carrying out disassembly and removal by constructing a scaffolding inside the pedestal using the P/F rotating rail bracket on the inner wall of the pedestal, and moving the equipment to the specified locations inside the pedestal by traveling over the scaffolding.**
- **The simulated facility, test pieces, equipment and tools used in the element tests were test manufactured separately for the Unit 2 base and for the Units 1/3 bases, the work steps were substantiated, and the element test plan was created.**
- **The feasibility of the method of disassembling and removing the CRD exchanger was verified through element tests. Issues in application to the actual equipment were identified and reflected into the equipment design for the actual equipment.**

7. Summary

1）Development of side access method (Continued)

(2) Development of disassembly and removal technology (continued)

③ Interfering objects removal from pump pit

- The status of fuel debris inside the pump pit, specifications of pump to be removed, specifications of pump pit, and its location were studied and consolidated in FY2021 as preconditions for removing interfering objects from inside the pump pit. The work steps involved in removing interfering objects from inside the pump pit were studied, and test items were selected.
- The simulated pump and pump pit, equipment and tools, etc. to be used in the element tests were studied, the work steps were substantiated and the element test plan (consolidation of items to be verified, test details, etc.) was created.
- It was verified through element tests that the pump can be cut, lifted up, etc. by remote operation, and the feasibility of the method of removing interfering objects from the pump pit was verified as well. Issues in application to the actual equipment were identified and reflected into the equipment design for the actual equipment.

7. Summary

1）Development of side access method (Continued)

(3) Advancement and development of retrieval methods

① Remote controlled tip tools for retrieval

Tip tools

- **Processing tests were conducted using tip tools that consider the specifications of access equipment, and the importance of the prospects of application of the tip tools that had issues to actual equipment and the necessity to avoid collision during the grabbing action become evident. Also, operators who had participated in the tests were made available. Also data for throughput evaluation such as processing time, life of blades, etc. was refined.**
- **Throughput was evaluated using the above-mentioned data for throughput evaluation, and was further refined.**
- **Requirements of the robot arm in terms of the processing reaction forces (blade pressing, blade rotation) were obtained through processing tests.**
- **Measures were planned in response to the issues that became evident as a result of the processing tests.**

Operation system

- **4 operators, who had participated in tests, participated in the interfering objects removal mock-up test using the operation system (trajectory planning) that has been developed. It was verified that a series of tasks were feasible in a confined environment such as the pedestal opening due to the collision avoidance function of the operation system.**
- **The importance of position adjustment and the necessity of collision avoidance while performing the grabbing action were clarified through the mock-up tests. And, the work items that the operators took time to perform were verified as well.**
- **Items for further improving safety and efficiency of work in the future were selected from the issues identified through the mock-up tests conducted this time.**

7. Summary

2) Development of top access method

(1) Development of technology for realizing the concept of retrieving large structures

① Method of cutting large structures

- **Pre-conditions pertaining to the method of transferring unitized large structures were consolidated, and overall steps were created.**
- **The methods for cutting the stud bolts of the RPV head from among the structures inside the reactor well were studied in FY2021, as a part of cutting "structures other than reactor internal structures", test pieces (RPV head, bolts) simulated to the actual equipment scale were manufactured, and element tests on cutting the bolts with AWJ were conducted. The feasibility of the method of cutting the RPV head bolts was verified, and issues were consolidated. (Reported under "Accomplishment Report for FY2021*")**
- **In order to cut the reactor core after filling and solidification, methods of cutting the shroud structures and the filler material were studied, as a part of cutting "reactor internal structures". The method of cutting the outer periphery of the shroud was developed on a priority basis in order to proceed with cutting the inside (filled and solidified part) in parts after cutting the outer periphery of the shroud.**
- **The laser + pulse WJ cutting was selected as the method for cutting the outer periphery of the shroud, element test plan was designed and the tests were conducted. Based on the results of the element tests, the feasibility of application of the method to cutting the outer periphery of the shroud was verified, and issues were identified and consolidated in preparation for designing the actual equipment.**
- **In addition to the characterization of geopolymer that is being considered as a filler material carried out through injection tests using a barrel, tests were conducted to verify the impact of exposure to radiation and issues were identified and consolidated in anticipation of application in actual equipment and scaling up. Also, work steps involved in filling and solidification were organized.**

*Accomplishment Report for FY2021: https://irid.or.jp/wp-content/uploads/2022/08/2022007_deburitoridashi.pdf

7. Summary

2）Development of top access method (Continued)

(1) Development of technology for realizing the concept of retrieving large structures（Continued）

② Large transfer containers

- **Pre-conditions pertaining to large transfer containers were consolidated in FY2021 and the development policy and method of using them were studied. Also, the aspects to be covered by the simulation during the test were studied considering the structure of the large transfer containers, their manufacturing procedure and the method of using them. Since the step of opening and closing the container by moving the dual lid is important in terms of air-tightness while using the large transfer containers, it was planned to verify air-tightness during the step of opening and closing the container by moving the dual lid, by conducting element tests using a container manufactured for the element tests.**
- **The structural designing of the actual large transfer container was carried out considering the manufacturing capability and the method of using it.**
- **The feasibility of the large transfer container was verified by conducting element tests.**

● As a result of the fitting test, it was verified that the equipment can fit as expected when the equipment is operated simulating the steps involved while operating the actual equipment, and that the container can connect to the prescribed location following the equipment guide even if there is some misalignment.

● As a result of the air-tightness test, it was verified that the rate of leakage at Part D (the sites sealed by sealed parts ③, ④, ⑤, ⑥) at the above-mentioned fitting position can meet the reference value.

- **Issues in application to actual equipment were identified, and the items to be reflected into the container specifications and equipment design of the actual equipment were consolidated.**

2）Development of top access method (Continued)

(1) Development of technology for realizing the concept of retrieving large structures（Continued）

③ Large transportation equipment

- Pre-conditions pertaining to the structure of the large transfer equipment were put together in FY2021 and the development policy was studied.
- The required functions of the large transportation equipment were studied and consolidated. Also, potential drive systems for the shielding/transportation cart that can be used in large transportation equipment were identified by investigating existing technology/track records, further comparative evaluation was carried out based on the required functions that have been consolidated, and the drive system that was found to be promising in particular was studied.
- It was decided that element tests will be conducted focusing on the remote connector system in which power is supplied through the remote connector, and a test plan was created (test items, verification details, judgment criteria were consolidated).
- Element tests were conducted to verify feasibility. Issues in application to the actual equipment were identified and reflected into the equipment design for the actual equipment.

1) Development of side access method (1) Development of the method of installing access equipment	① Installation of large heavy structures [Objective] The structure and installation method for installing the cell adapter, shielding door and cell that build the access route that is connected to the PCV should be detailed, and its feasibility should be shown through element tests. (Target TRL at completion: Level 4) [Evaluation of level of achievement] The structure and installation method for installing the cell adapter, shielding door and cell that build the access route that is connected to the PCV were detailed, and its feasibility verified through element tests. (TRL: Level 4)
	② PCV connection sleeve remote installation and welding [Objective] The method of remotely installing the access tunnel sleeve connected to the PCV should be studied, the requirements should be consolidated, and feasibility should be shown through element tests. Also, feasibility of the method of welding by remote operation should be shown through element tests. (Target TRL at completion: Level 4) [Evaluation of level of achievement] The method of remotely installing the access tunnel sleeve connected to the PCV was studied, the requirements were consolidated, and feasibility was verified through element tests. Also, feasibility of the method of welding by remote operation was verified through element tests. (TRL: Level 4)

1) Development of side access method (Continued) (1) Development of the method of installing access equipment (Continued)	③ Installation of shield [Objective] Feasibility such as manufacturing capability, etc. of the access tunnel shield should be shown through element tests. (Target TRL at completion: Level 3) [Evaluation of level of achievement] The feasibility of the method of installation of additional access tunnel shielding was verified element tests. (TRL: Level 3)
	④ Disassembly of shield plug [Objective] Feasibility of the cutting/disassembly methods with regards to the method of removing the shield plug, etc. (shield plug, blockout) located in front of the equipment hatch when the side access method is used, should be shown through element tests. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Feasibility of the cutting/disassembly methods with regards to the method of removing the shield plug, etc. (concrete block) located in front of the equipment hatch was verified through element tests. (TRL: Level 3)
(2) Development of disassembly and removal technology	① HVH disassembly [Objective] Feasibility of specific cutting/collection methods with regards to the method of removing HVH, which are large systems among the equipment installed outside the pedestal, should be shown through element tests. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Feasibility of specific cutting/collection methods with regards to the method of removing the HVH exchanger was verified through element tests. (TRL: Level 3)

1) Development of side access method (Continued) (2) Development of disassembly and removal technology (continued)	② Disassembly of CRD exchanger [Objective] Feasibility of specific cutting/collection methods with regards to the method of removing the CRD exchanger, which is a large structure located at the center of the pedestal, should be shown through element tests. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Feasibility of specific cutting/collection methods with regards to the method of removing the CRD exchanger was verified through element tests. (TRL: Level 3)
	③ Interfering objects removal from pump pit [Objective] Feasibility of the method of cutting, etc. and transferring with regards to the method of removing interfering objects from inside the pump pit, which is required for installing the submersible pump into the pump pit inside the PCV, should be shown through element tests. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Feasibility of the method of cutting, etc. and transferring with regards to the method of removing interfering objects from inside the pump pit was verified through element tests. (TRL: Level 3)
(3) Advancement and development of retrieval methods	① Remote controlled tip tools for retrieval [Objective] The viability of a series of operations from processing interfering objects and fuel debris from inside the PCV to collecting the cut pieces in unit cans should be shown through element tests, etc., and data for evaluating the throughout should be acquired. (Target TRL at completion: Level 3) [Evaluation of level of achievement] The viability of a series of operations from processing interfering objects and fuel debris from inside the PCV to collecting the cut pieces in unit cans was verified through element tests, etc., and data for evaluating the throughout was acquired. (TRL: Level 3)

2) Development of top access method (1) Development of technology for realizing the concept of retrieving large structures	① Method of cutting large structures [Objective] Feasibility of the cutting and separating with regards to the method of cutting structures when the top access method is used, should be shown through element tests. Also, the method of transferring structures after they have been cut until the structures are loaded on to the large transportation equipment, should be studied, and its site applicability should be evaluated. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Element tests related to cutting the RPV head bolt and cutting the outer periphery of the shroud with regards to the method of cutting structures when the top access method is used, were conducted, and the feasibility was verified. Also, the overall steps including the steps from removing the structures to transferring them were created, and issues were identified. (TRL: Level 3)
	② Large transfer containers [Objective] The performance of the container in which unitized structures are stored and transferred when the top access method is used, should be verified through element tests, and the issues in site applicability should be indicated. (Target TRL at completion: Level 3) [Evaluation of level of achievement] Element tests were conducted related to air-tightness of the container for storing the unitized structures and transferring them (large transfer container) when the top access method is used, the feasibility including the manufacturing capability was verified, and issues in application to the actual equipment were identified. (TRL: Level 3)

2) Development of top access method (Continued) (1) Development of technology for realizing the concept of retrieving large structures (Continued)	③ Large transportation equipment [Objective] The site applicability of the large transfer equipment including its drive mechanism, which is used for transferring structures retrieved by means of the top access method within the R/B should be verified through element tests, and the issues should be consolidated. (Target TRL at completion: Level 3) [Evaluation of level of achievement] The feasibility of large transfer equipment including its drive mechanism as transportation equipment was verified, and issues were identified. (TRL: Level 3)

TRL level	Explanation	Phase
TRL7	Stage at which implementation is complete.	For practical use
TRL6	Stage at which field verification is conducted.	Field verification
TRL5	Stage at which a prototype is manufactured based on the actual equipment and verified in a simulated environment at the factory, etc.	Simulated verification
TRL4	Stage at which functional tests are implemented at the test manufacturing level as a development and engineering process.	Research for practical use
TRL3	Stage at which development and engineering are being carried out by applying or combining past experiences. Or, stage at which development and engineering are being carried out based on fundamental data in domains in which there is no prior experience.	Applied research
TRL2	Stage at which development and engineering are being carried out in domains in which there is almost no applicable prior experience, and the required specifications are being defined.	Applied research
TRL1	Stage at which specific details pertaining to the development and engineering targets are clarified.	Basic research

Explanation of terminology (1/2)

No.	Term	Explanation
1	1F	Fukushima Daiichi Nuclear Power Plant
2	R/B	Reactor Building
3	Rw/B	Radioactive waste treatment building
4	T/B	Turbine Building
5	PCV	Primary Containment Vessel
6	RPV	Reactor Pressure Vessel
7	CRD	Control rod drive mechanism
8	Refueling floor	Refueling floor
9	X-6 penetration	One of the PCV penetration parts
10	S/C	Suppression chamber
11	Cell adapter	The piece that connects the PCV and the cell
12	BSW	Biological shielding wall
13	MCCI	Molten Core - Concrete Interaction
14	UC	Unit can (Container in which fuel debris is placed)
15	AWJ	Abrasive Water Jet
16	HVH	Heating Ventilating Handling Unit
17	CRGT	Control Rod Guide Tube
18	G/H	Greenhouse
19	LLW	Low level radioactive waste
20	MSM	Master - Slave Manipulator Note: Since the term master-slave contains discriminatory words, its use is generally avoided, but as the term has been established as an academic term in robotics since a long time, it is being used as is as a term. While using the term in the future, we will refer to the trend of related societies such as The Robotics Society of Japan, etc.

Explanation of terminology (2/2)

No.	Term	Explanation
21	CW	Counter weight
22	AVC	Arc voltage adjustment function (Function of correcting the arc length by controlling the voltage fluctuations between the welding torch and the base material to keep them within a certain range)
23	OSC	Function of controlling the shaking of the welding torch
24	P/F	Platform
25	TIP	Traversing In Core Probe System
26	CID	Charge Injection Device
27	MS	Main steam
28	DSP	Dryer Separator Pit
29	FWS/CS	Feed Water System / Core Spray System
30	ICM	In-core nuclear instrumentation