Subsidy Project of Decommissioning, Contaminated Water, and Treated Water Management

Development of Investigation Technology for inside the Reactor Pressure Vessel (RPV) (Upgrading of Processing Technology for the Top-Access Investigation Method and Development of the Bottom Access Investigation Method)

FY2022 Final Report

June 2023

International Research Institute for Nuclear Decommissioning (IRID)

Contents

1. Research background and objectives

[Purpose of investigating inside the reactor pressure vessel (RPV)]

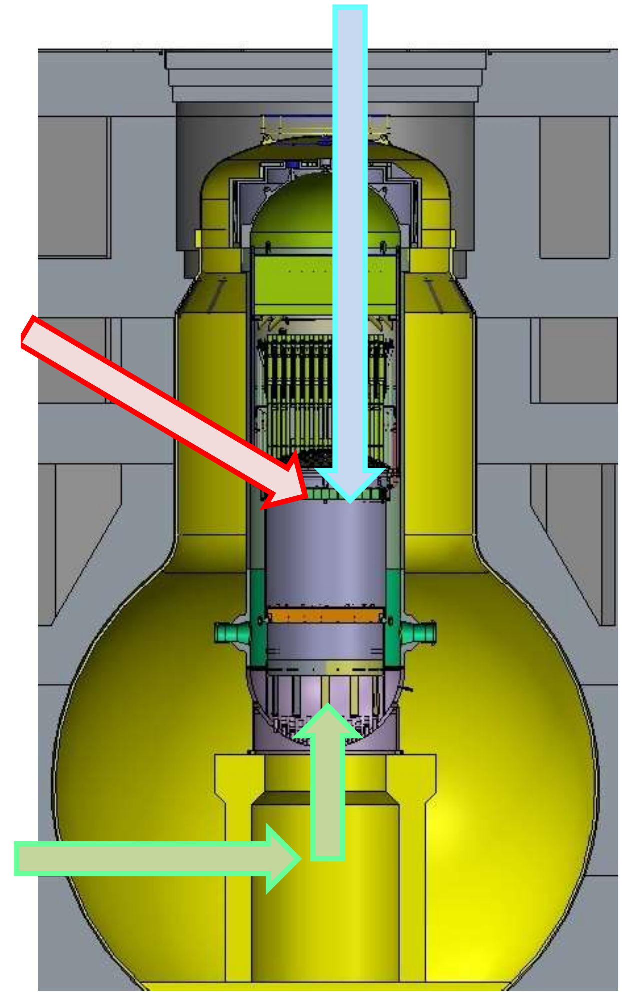
Acquisition of basic information about the RPV interior (distribution of fuel debris, radiation dose, structure condition, etc.) in order to retrieve fuel debris.

[Implementation details up to FY2021]

By FY2019, the applicability of top and side access investigation methods had been studied with actual equipment.

Since FY2020, to address the remaining issues in the top-access investigation method, alternative methods for opening reactor internals to establish an access route to the shroud have been developed as processing technologies that would generate less secondary waste inside the RPV than the conventional abrasive water jet (AWJ) method.

It is also important to continue developing methods that enable investigation inside the RPV at earlier stages, since it is assumed that the top and side access investigation methods will require some time before they can be applied on site. Therefore, starting in FY2020, investigation plans for the bottom access investigation method have been formulated, and conceptual studies of bottom access and investigation equipment have been conducted. In this method, investigation equipment is introduced into the primary containment vessel (PCV) using the access route already constructed for investigation inside the PCV, and the equipment is introduced into the RPV through an opening that is assumed to exist at the bottom of the RPV.



[Future applications of this project]

Development of Investigation Technology for inside the RPV → Actual equipment investigation → Study of fuel debris retrieval method / equipment design

Information on the RPV interior (visual information, dose rate, etc.)

1. Research background and objectives

[Implementation details of this project]

Testing will be used to verify the functionality required of processing technologies developed as of FY2021 for on-site use as a processing technology for the top access investigation method.

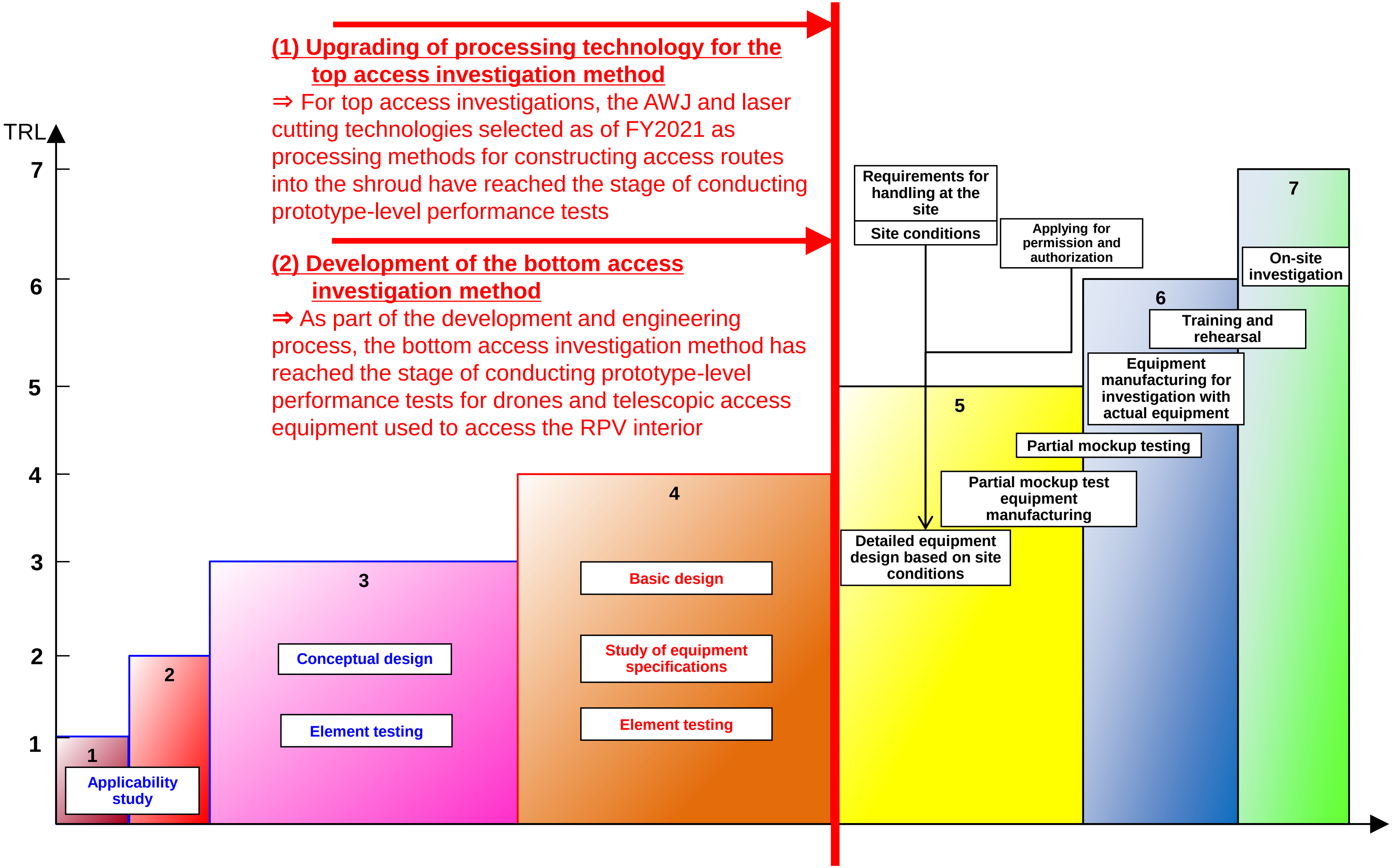
In addition, a prototype of bottom access and investigation equipment to investigate the RPV interior will be manufactured based on the results of conceptual studies obtained by FY2021, and tests will confirm the functions necessary for on-site application.

Specifically, the following items will be studied and undergo technical development.

(1) Upgrading of processing technology for the top-access investigation method
- ① Study of the functions necessary for the on-site application of processing technologies
- ② Verification of the performance of the functions of element prototypes

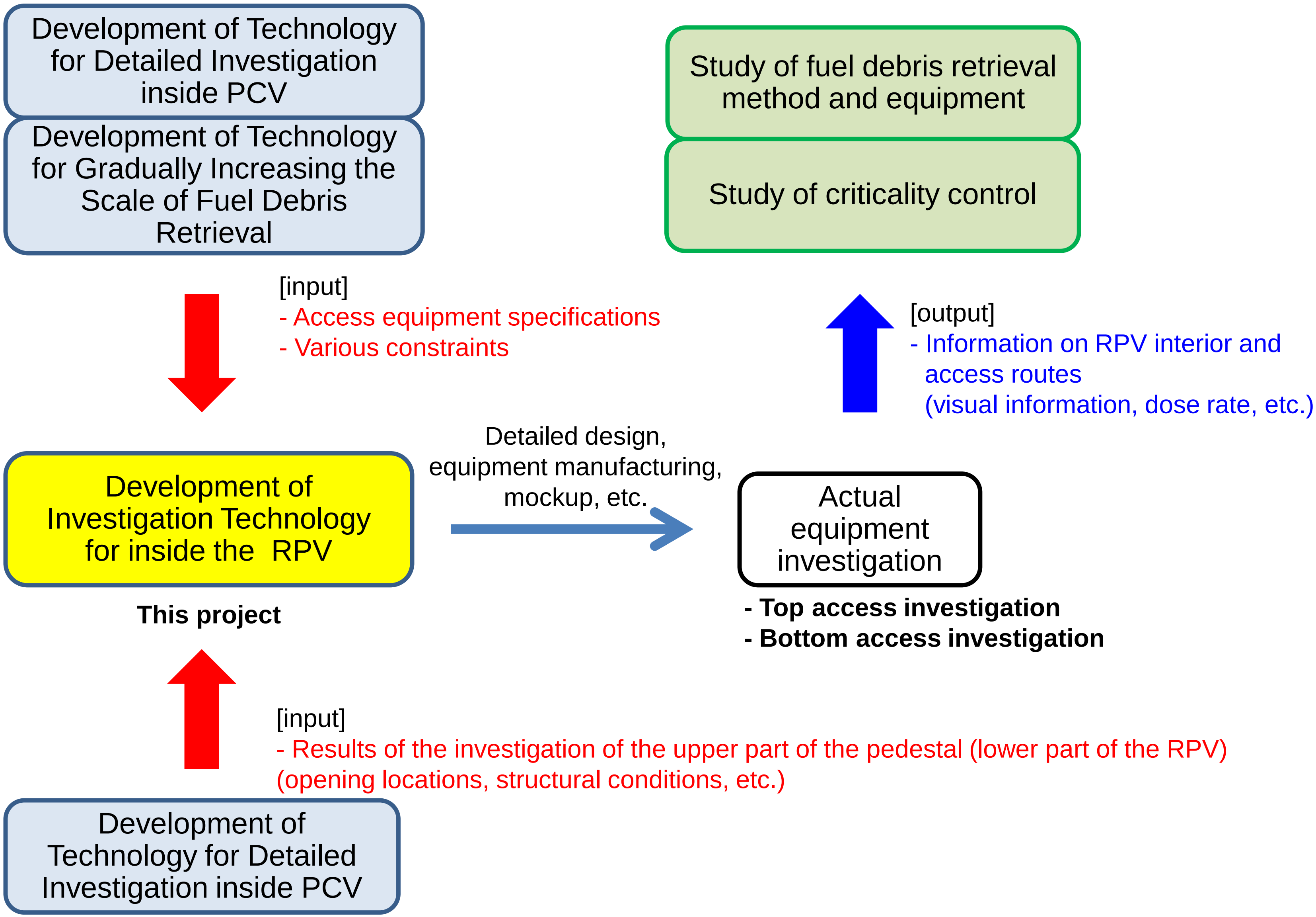
(2) Development of the bottom access investigation method
- ① Formulation of a bottom access investigation plan and development plan for investigation equipment
- ② Test manufacturing of bottom access and investigation equipment, functional verification testing

2. Goals

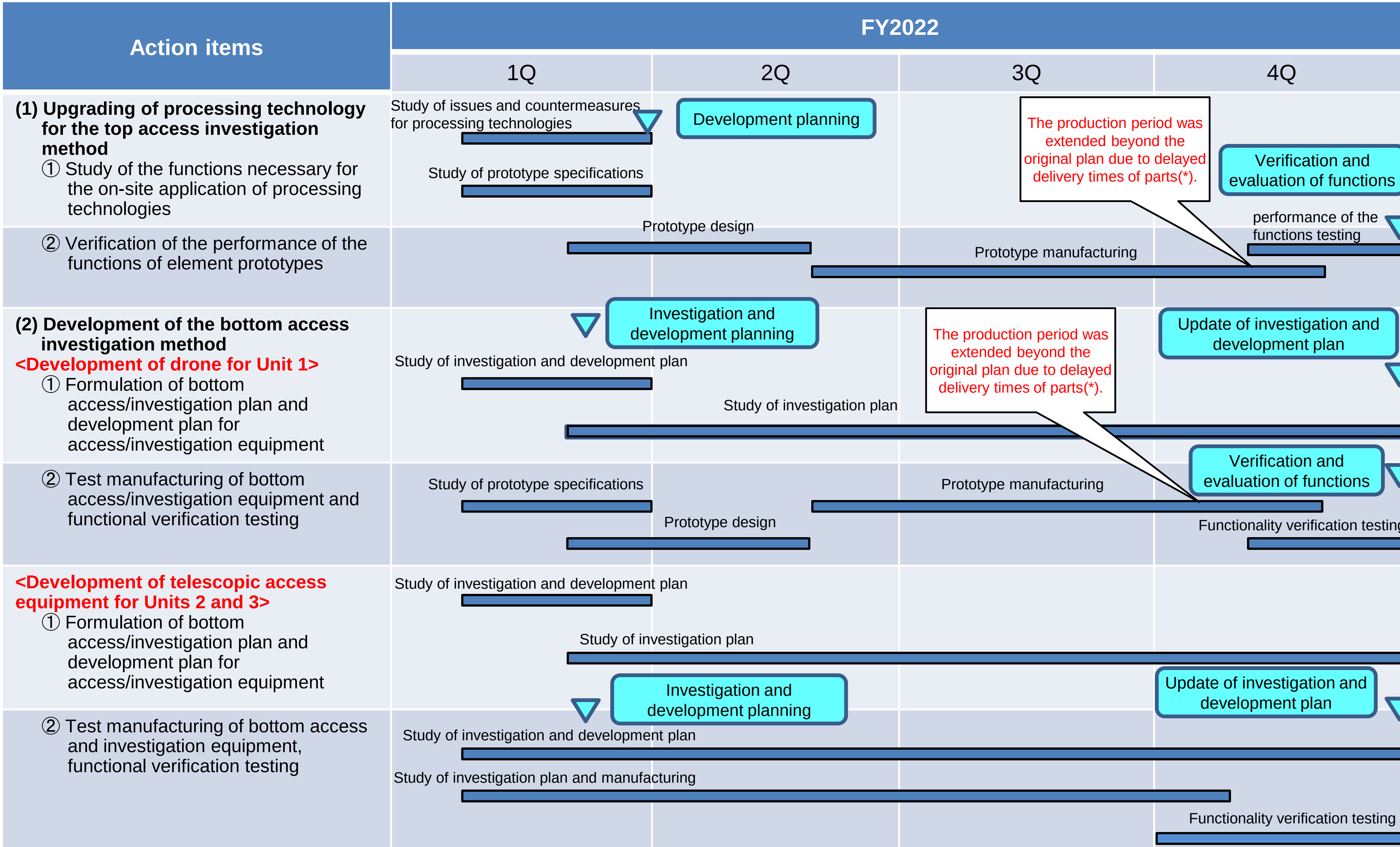


(1) Upgrading of processing technology for the top access investigation method
⇒ For top access investigations, the AWJ and laser cutting technologies selected as of FY2021 as processing methods for constructing access routes into the shroud have reached the stage of conducting prototype-level performance tests
(2) Development of the bottom access investigation method
⇒ As part of the development and engineering process, the bottom access investigation method has reached the stage of conducting prototype-level performance tests for drones and telescopic access equipment used to access the RPV interior
TRL
7
6
5
4
3
2
1
Applicability study
2
3
Conceptual design
Element testing
4
Basic design
Study of equipment specifications
Element testing
Requirements for handling at the site
Site conditions
Applying for permission and authorization
5
Detailed equipment design based on site conditions
Partial mockup test equipment manufacturing
Partial mockup testing
6
Equipment manufacturing for investigation with actual equipment
Training and rehearsal
7
On-site investigation

3. Action items, their inter-relation and relation to other studies No.5



4. Implementation schedule



(*) Some countries producing materials and parts underwent lockdown due to COVID-19, resulting in longer delivery times for parts.

5. Project organization chart

This project aims to develop technology for investigation inside the RPV. The interface with each development project team is of the utmost importance. Therefore, IRID Head Office, Toshiba ESS, and Hitachi GE will work together to develop a safe, reliable, logical, rapid, and site-oriented fuel debris retrieval technology for 1F, through mutual technological cooperation among IRID Japanese plant component manufacturers, in order to analyze the on-site situation and to develop a series of measures that are consistent with the fuel debris retrieval plan, etc.

International Research Institute for Nuclear Decommissioning (Head Office)
- ○ Formulation of overall plan and technological supervision
- ○ Technological management of technology development progress, etc.

Tokyo Electric Power Company Holdings, Inc.
- ○ Adjustments for on-site applicability

Toshiba Energy Systems & Solutions Corporation

(2) Development of the bottom access investigation method
- ① Formulation of bottom access/investigation plan and development plan for access/investigation equipment
- ② Conceptual study of bottom access and investigation equipment

Hitachi-GE Nuclear Energy, Ltd.

(1) Upgrading of processing technology for the top-access investigation method

(2) Development of the bottom access investigation method
- ① Formulation of bottom access/investigation plan and development plan for access/investigation equipment
- ② Test manufacturing of bottom access and investigation equipment, functional verification testing

Partner development project teams
- Development of Technology for Gradually Increasing the Scale of Fuel Debris Retrieval
- Development of Technology for Detailed Investigation inside PCV

Sugino Machine Ltd.
- (1) Structural design for upgrading the processing technology for the top-access investigation method
- (2) Structural design for the development of the bottom access investigation method

Hitachi Plant Construction, Ltd.
- (1) Technological study for upgrading the processing technology for the top-access investigation method
- (2) Technological study for the development of the bottom access investigation method

Toko Corporation / Chugai Technos Corporation
- (2) Structural design for the development of the bottom access investigation method

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

<Implementation details up to FY2021>

The focus was narrowed down to improved abrasive waterjet (AWJ) cutting and laser cutting, as both methods produce less secondary waste than conventional AWJ cutting, and efforts were made to further refine the selected methods.

<Summary of implementation in FY2022>

① Study of the functions necessary for the on-site application of processing technologies

The application of AWJ cutting and laser cutting on actual equipment was studied, issues regarding remote processing and the functions required for the equipment were reviewed, and the details of element prototyping were examined to verify these issues.

② Verification of the performance of the functions of element prototypes

A prototype was designed and manufactured, and its performance of the functions was confirmed to be satisfactory.

<Implementation details for FY2022>

Processing technology	Implementation details	
Laser	①	Study of issues and countermeasures for processing technologies
	②	Study of development plan
	③	Specification study, design, and test manufacturing of remote equipment considering actual equipment
	④	Functional verification testing and combined operations verification testing for the laser cutting device (prototype)

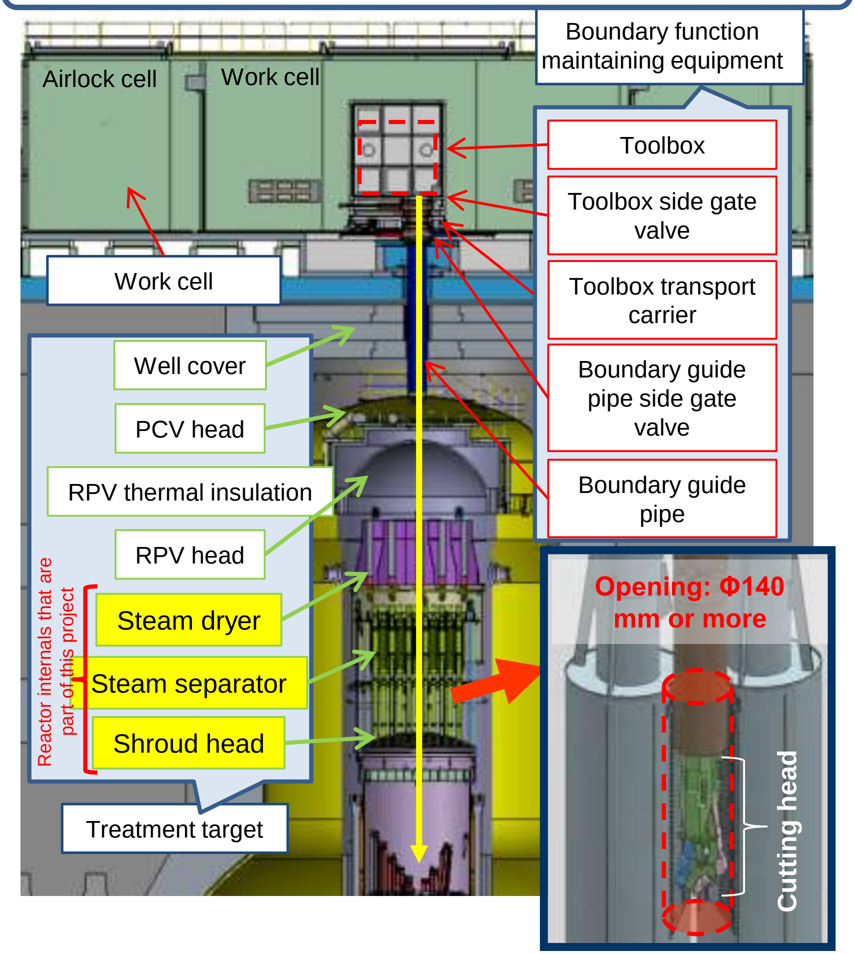
Processing technology	Implementation details	
AWJ	①	Study of issues and countermeasures for processing technologies
	②	Study of development plan
	③	Specification study, design, and partial element prototyping of abrasive feed rate stabilization mechanism
	④	Study, design, and partial element prototyping of nozzle maintenance method
	⑤	Functional verification testing of each element prototype
Common	①	Study of patterns of uncollectible connecting guide pipes

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

1) Results as of FY2021 (Overall summary)

With investigation of the RPV interior via the top access investigation method, processing technology was developed to create a minimum Φ140 mm opening in the reactor inner structure in order to establish an access route.



Drawing of steam separator opening

Outline of in-core structure opening

Major results as of FY2021 and implementation details for FY2022

As of FY2019

- Verified that AWJ cutting can be used to cut reactor internals
- Verified via prototype that operation can be conducted with remote equipment
- An issue of approximately 8.8 tons of secondary waste (abrasive use)

FY2020

- Studied improvements to AWJ cutting and the applicability of other processing technologies to reduce secondary waste (Target: Less than 500 kg of secondary waste)
- The cutting capacity of AWJ cutting has improved by implementing smaller nozzles that enable insertion into narrow areas and placement closer to the workpiece (secondary waste volume reduced to approximately 1.3 tons)
- Testing verified laser cutting as another processing technology for vertical cutting (WJ, hole saws, and disc saws are not applicable)
  Laser cutting is not applicable for horizontal cutting due to difficulties with inserting the nozzle into narrow areas

FY2021

- AWJ cutting was studied to reduce secondary waste, and laser cutting was studied to be applied to all cutting points of the in-core structure
- AWJ cutting was tested under low abrasive feed conditions, and secondary waste was reduced to approximately 0.3 tons (target of 500 kg was achieved)
- Laser cutting is expected to be applicable to all parts within the core structure due to the reduced nozzle size

- The low abrasive feed in AWJ cutting caused a feed instability event

- The feasibility of remote equipment with laser cutting requires verification

FY2022

- AWJ cutting: Abrasive feed stabilization study and element testing
  Nozzle and camera remote replacement method study

- Laser cutting: Remote equipment study, prototype production, and
  Functional verification testing

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

1) Results through FY2021 (Summary of FY2020 and FY2021 results)

Results of studies through FY2019 confirmed that AWJ cutting is capable of cutting reactor internals, but the large amount of secondary waste was an issue.
Therefore, in FY2020 and FY2021, studies focused on processing technologies with low volumes of secondary waste. (Target: Less than 500 kg of secondary waste)

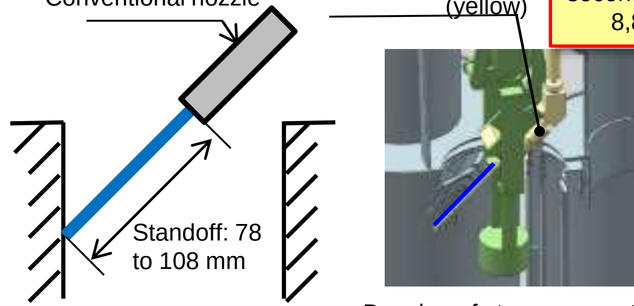
FY2020

1) **The following five methods** were selected based on a desk study to narrow down the applicable processing technologies.
① AWJ cutting (small nozzle) ② Water jet cutting ③ Laser cutting ④ Hole saw ⑤ Disk saw

2) Tests were conducted to evaluate the applicability of the five selected methods, and ① AWJ cutting and ③ laser cutting were evaluated as applicable methods.
① **AWJ cutting** is designed to use a small nozzle surrounded by three steam separator cylinders, enabling improved operational conditions and reducing the amount of secondary waste.

<Operational conditions until 2019>

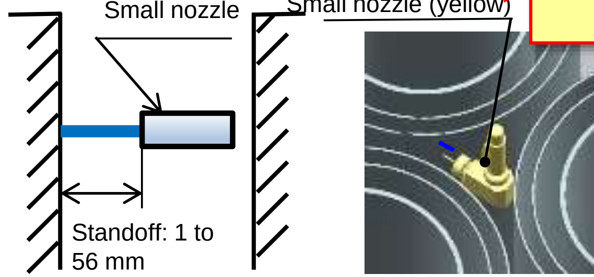
Estimated secondary waste 8,810 kg



Drawing of steam separator cutting

<Operational conditions with a small nozzle>

Estimated secondary waste 1,293 kg



Drawing of steam separator cutting

② **Laser cutting** was confirmed to be applicable for vertical cutting. Design and manufacturing of a nozzle capable of horizontal cutting is required for FY2021.

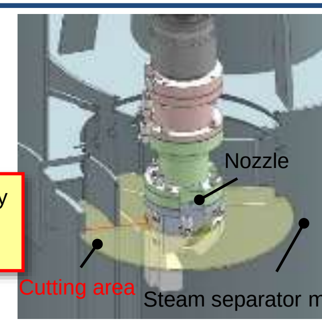
FY2021

1) Further reductions of secondary waste in AWJ cutting and the application of laser cutting to all cutting lines of the in-core structure were studied and confirmed through testing.
① Verified an abrasive feed rate with good cutting efficiency and confirmed that **AWJ cutting** was possible under those operational conditions, providing the prospect of achieving a secondary waste volume target of 500 kg.

Improved abrasive feed rate

Conventional abrasive feed conditions 500 g/min	→	Conventional abrasive feed conditions 100 g/min	Estimated secondary waste 328 kg

② A nozzle to make horizontal **laser cutting** possible was designed and fabricated, providing the prospect of cutting all in-core structure cutting lines. (The image on the left shows a horizontal cut.)



Laser cutting Image of cutting the steam separator

IRID

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

2) Review of issues and development plans for upgrading processing technologies (1/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items
1	Laser cutting	Processing equipment	Feasibility of the remote equipment considering actual equipment - Remote insertion of a cutting nozzle into narrow spaces - Verification method for the status of the treatment target before and after cutting (Concerns about camera visibility and lens damage) - Fiber transmission lines for actual equipment length (Concerns about attenuation of laser output) - Incorporation into the fiber drum (Concerns about bending resistance of fiber) - Application of slip rings to high power lasers (8 kW)	Design and manufacture a prototype of remote equipment that incorporates countermeasures to the issues listed on the left, and confirm the feasibility of remote equipment by simulating the assumed height of the actual equipment (max. 18 m).	Conducted	- Design and prototyping of remote equipment considering actual equipment - Functional verification testing and combined testing of remote equipment (Verification of remote insertability, camera view range, laser power, etc.) ⇒ See slides No.16 to 27
2			Nozzle maintenance (Nozzle durability was verified without issue in FY2021, but this is a countermeasure against nozzle failure)	Study nozzle maintenance methods.	– (None)	– (Nozzle maintenance methods for AWJ cutting will be studied, and laser cutting will use those results. Expected to be implemented in FY2024 or later.)
3		Processing technology	Effect of dross on cutting (Seek cutting parameters that facilitate dross dispersion and reduce the risk of re-welding)	Optimize parameters such as assist gas flow rate and direction, laser power and nozzle speed, and verify conditions that facilitate dross dispersal.	– (None)	– (Conditions that permit operation without re-welding were confirmed in FY2021 testing. After confirming the feasibility of the remote equipment, further risk reduction and the necessity of such is expected to be considered in FY2024 or later.)
4		Environment simulation	Influence of the actual operating environment (Temperature, humidity, and atmospheric conditions)	Examine the impact of the actual operating environment and, if necessary, verify its impact through testing.	– (None)	– (Will be evaluated after verifying the feasibility of the remote equipment and is expected to be conducted in FY2024 or later.)
5		Verification of the impact on other systems	Assist gas restrictions (Type, flow rate)	Verify the limitations of the actual equipment and test as necessary.	Conducted	- Verification of limitations of actual equipment (desk study) ⇒ See slide No.17

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

2) Review of issues and development plans for upgrading processing technologies (2/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items
6	AWJ cutting	Processing equipment	Feasibility of the remote equipment considering actual equipment	The feasibility of the remote equipment considering actual equipment was confirmed through FY2019, so the impact of changes since FY2019 will be verified.	― (None)	― (The main change from FY2019 is nozzle shape and the impact of which is assumed to be minor. The results of the No.1 laser cutting prototype will be deployed to AWJ cutting in FY2024 and beyond, if necessary.)
7			Abrasive feed rate stabilization (The abrasive feed rate was set at 100 g/min in FY2021, but verification is required as to whether a stable supply is attainable with remote equipment considering actual equipment.)	Confirm whether a stable supply of abrasive is possible with remote equipment considering actual equipment. Variable abrasive feed rates will also be studied.	Conducted	- Study of abrasive feed rate stabilization - Design and manufacture of partial element prototypes - Functional verification testing of partial element prototypes ⇒ See slides No.28 to 32
8			Nozzle maintenance (FY2021 test results set nozzle life at approximately 8 hours, while the expected operation time on actual equipment is approximately 42 hours (for angled nozzles), so maintenance is required.)	Study nozzle maintenance methods. (A change to the material of the severely damaged mixer part (SUS630 → Carbide) could be considered, but it is not assumed to be able to last for the actual operation time)	Conducted	- Study of nozzle maintenance method - Design and prototyping of partial element prototypes - Functional verification testing of partial element prototypes ⇒ See slides No.33 to 36
9		Abrasive reduction	Further reduction in the amount of abrasive used - Further exploration into the appropriate abrasive feed rate value - Selection of optimum nozzle shape - Reduction in the number of cuts for locations that require numerous cuts	Because the target abrasive amount of 500 kg or less has been achieved, the response has been set to HOLD and the need for a response will be reconfirmed based on the results of responses to other issues.	― (None)	― (HOLD)

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

2) Review of issues and development plans for upgrading processing technologies (3/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items
10	Common	Processing equipment	Treatment of cut pieces (transfer) (In FY2021 tests, cut pieces interfered with cutting at other locations)	Study the cut piece transfer method.	– (None)	— (Development issues for the equipment body will be prioritized and measures for ancillary equipment will be implemented; expected to be conducted in FY2024 or later)
11			Radiation resistance of components	Conduct irradiation tests on components at risk of damage, and select appropriate components.	– (None)	— (It was deemed reasonable to verify such after determining the configuration of equipment for remote equipment; expected to be conducted in FY2024 or later)
12			Durability of components	Identify hoses and other components at risk of deterioration and verify their durability. (The durability of each nozzle was confirmed in FY2021)	– (None)	— (Since nozzles with a high risk of deterioration were confirmed in FY2021, it was determined reasonable to verify other components using products equivalent to actual equipment; expected to be conducted in FY2024 or later.)
13		Risk response	Installation method in case of damaged and deformed reactor internals	Since the process of inserting the nozzle between the three steam separator cylinders is considered to pose a high risk of failed installation due to deformation, methods for expanding the space between the three cylinders will be examined.	– (None)	— (The next phase includes a detailed design of equipment reflecting site conditions; expected to be implemented in FY2024 or later.)
14			Responses to uncollectible connecting guide pipes	Examine patterns where collection was not possible and consider countermeasures as necessary.	Conducted	- Examination of uncollectable patterns (Desk study) ⇒ See slide No.37

IRID

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

3) Upgrading of processing technology Development flow (draft)

Category	As of FY2021	FY2022	FY2023 (*)	FY2024 and later (*)
TRL attainment level	**TRL: 3 to 4** - Lasers achieved TRL 3 in FY2020 and FY2021. - The feasibility of AWJ remote equipment achieved TRL 4 by FY2019.	**TRL: 4** The objective is to reach a stage where prototype-level performance tests can be conducted.	Laser and AWJ will be tested on prototypes to confirm the feasibility of remote equipment.	**TRL: 5** / **TRL: 6** / **TRL: 7** / **Using actual equipment** Manufacturing and design of actual equipment / mockup testing / training phase
—	**Major achievements:**	**Desk study** / **Design/ Prototyping** / **Functional verification testing**	**Element testing** / **Evaluation**	**Design and manufacturing of actual equipment** **Mockup testing** **Training**
Laser	**Verification of processing technology** - Prospect that everything to be processed can be cut.	**Prototype production and functional verification testing of remote equipment considering actual equipment (Issue No.1)** Desk study: - Examine the function and contents of element prototypes. Design/ Prototyping: - Reflect the content of examinations in the design and create a prototype. Functional verification testing: - Conduct functional verification testing of the prototype. **Assist gas restrictions (Issue No.5)** - Verify limitations with actual equipment. If required, test in FY2024 or later	**Simulation of actual equipment via a prototype Cutting test (Issue No.1)** Element testing: - Conduct cutting tests using a mock-up of the actual equipment to be processed. Evaluation: - Use test results to evaluate applicability to actual equipment.	**- Laser nozzle maintenance (Issue No.2)** **- Influence of the actual operating environment (Issue No.4)** **Reduction of the influence of dross during cutting (Issue No.3) (Laser only)**
AWJ	**Verify feasibility of remote equipment** - Feasibility of remote equipment was confirmed with a prototype as of FY2019. **Abrasive use reduced (target achieved)** - Prospect of achieving the target of using less than 500 kg of abrasive.	**Prototype and functional verification verification of abrasive feed rate stabilization mechanism (Issue No.7)** **Element prototyping and maintainability verification of nozzle maintenance mechanism (Issue No.8)** Desk study: - Examine methods of stabilizing and adjusting the abrasive feed rate. - Examine nozzle maintenance methods. Design/ Prototyping: - Reflect the content of examinations in the element prototype design and create prototypes. Functional verification testing: - Conduct functional verification testing of element prototypes.	**Cutting test using prototype (Issue No.7)** Element testing: - Element testing will be conducted as needed based on FY2022 results. Evaluation: - Use test results to evaluate applicability to actual equipment.	**Design, manufacturing, and mockup testing of remote maintenance equipment (Issue No.8)** **Design, manufacturing, and mockup testing of cutting piece treatment tools (Issue No.10)** **Examination of installation method in case of deformed reactor internals (Issue No.13)**
Common	—	**Study of patterns of uncollectible connecting guide pipes (Issue No.14)** If necessary, measures will be considered and reflected in the design in FY2024 or later	**Radiation resistance of components (Issue No.11)**	**Equipment durability (Issue No.12)**

(*) Plans for FY2023 and beyond are proposals from the project implementer and have not been decided.

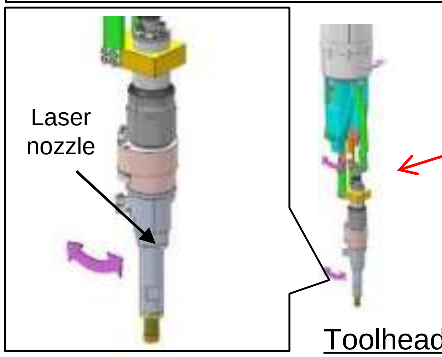
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

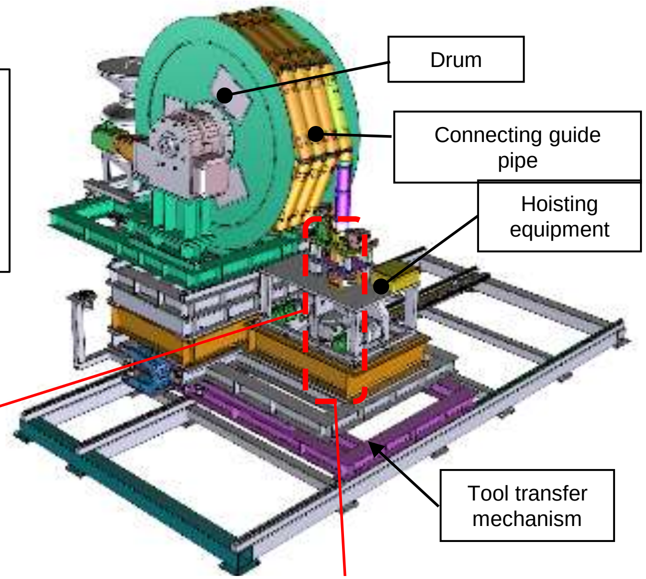
4) Upgrading of processing technology Implementation details

Laser cutting

[Implementation details in FY2022]
- Examination of prototype specifications
- Design and prototyping of remote equipment considering actual equipment
- Functional verification testing and combined operations testing of remote equipment



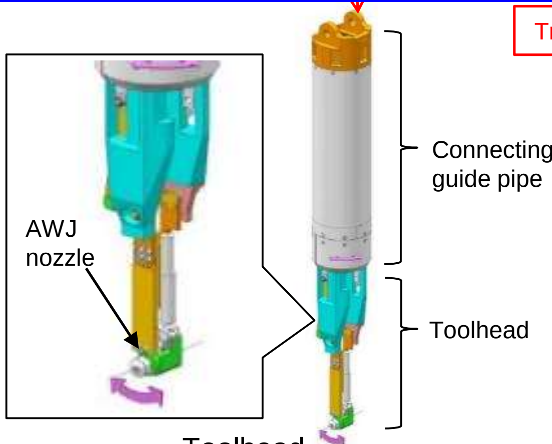
Toolhead



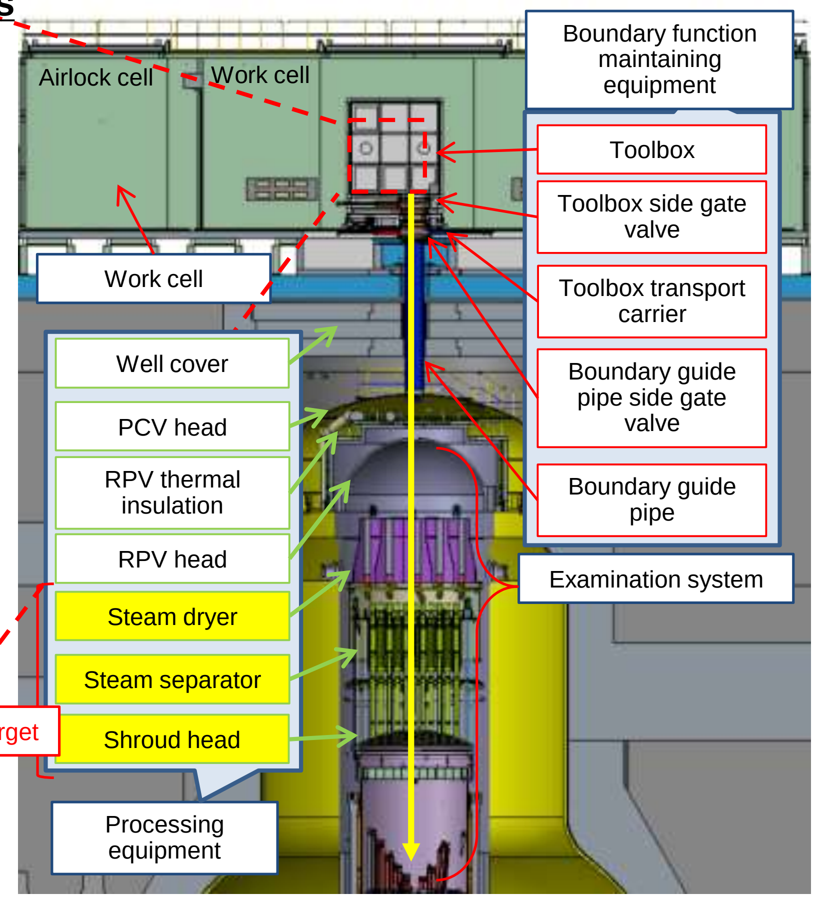
Reactor internals processing equipment

AWJ cutting

[Implementation details in FY2022]
- Study of abrasive feed rate stabilization
- Study of nozzle maintenance method
- Specification study of each element prototype
- Design and manufacture of element prototypes
- Functional verification testing of element prototypes



Toolhead



Conceptual drawing of the top access investigation method

Common

[Implementation details in FY2022]
- Study of patterns of uncollectible connecting guide pipe

6. Implementation details

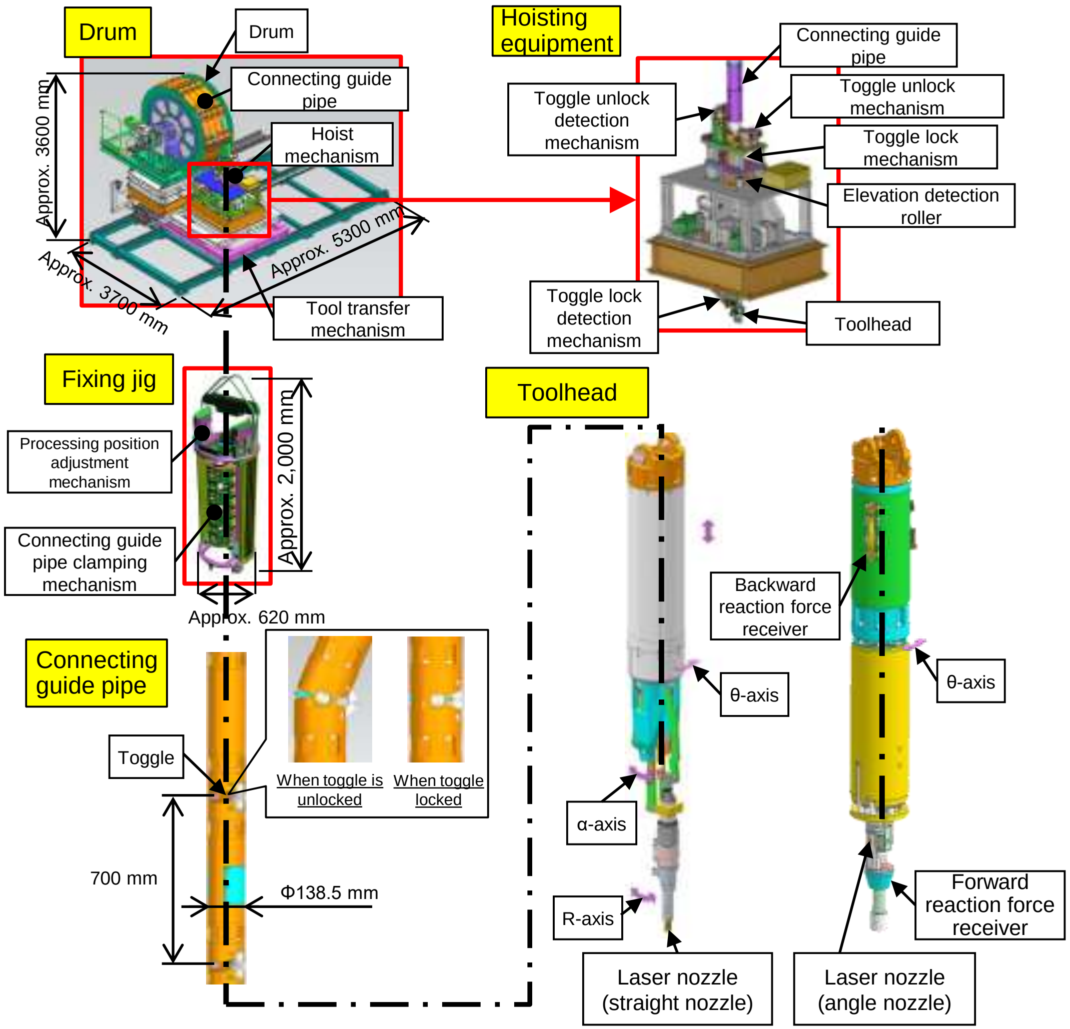
(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

① Specification study and design of laser cutting device (prototype)

<Equipment overview>

Equipment to open the steam dryer, steam separator, and shroud head at the planned opening position in the work cell (directly above the RPV reserve nozzle)



<Specification study and design of prototypes>

① Specifications

[Composition]
- The laser cutting device consists of a toolhead with laser nozzle, connecting guide pipes, hoisting equipment, a drum, and a tool transfer mechanism.
- A laser oscillator is installed separately.

[Toolhead]
- The toolhead (for angle nozzles) consists of a laser nozzle, a forward/backward reaction force receiver, and a θ-axis motor that swivels the toolhead.
- The toolhead (for straight nozzles) consists of a laser nozzle, α-axis and R-axis motors that adjust the position and angle of the laser nozzle, and a θ-axis motor that swivels the toolhead.

[Connecting guide pipe]
- The guide pipe consists of a series of 700 mm long pipes with the toolhead connected at the end.
  The other end is attached to the drum.
- The drum rotates to feed or wind the connecting guide pipe with attached toolhead.
- Each joint locks together so that the axes of the upper and lower pipes are aligned when passing through the hoisting mechanism, and the toolhead is supported.

[Hoisting equipment]
- This component consists of a hoisting roller and a toggle lock mechanism to assist in the lifting and lowering of the connecting guide pipe.

[Drum]
- Its function is to feed and wind the connecting guide pipe.
- The horizontal position of the drum can be adjusted (drum horizontal axis and drum forward-backward axis).

[Tool transfer mechanism]
- Its function is to adjust the horizontal position of the in-core structure processing equipment (X and Y tool travel axes).

② Main design points for laser cutting

[Hoisting apparatus (drum + hoisting equipment)]
① Fiber integrated into equipment
② Design with high-power laser transmission
(slip ring and rotary coupler inclusion study, etc.)
③ Design featuring cooling water and various gas systems for the laser nozzle

⇒ See slide No.18

[Toolhead]
- Newly designed for lasers.

⇒ See slide No.17

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

② Toolhead design

[Main design details]

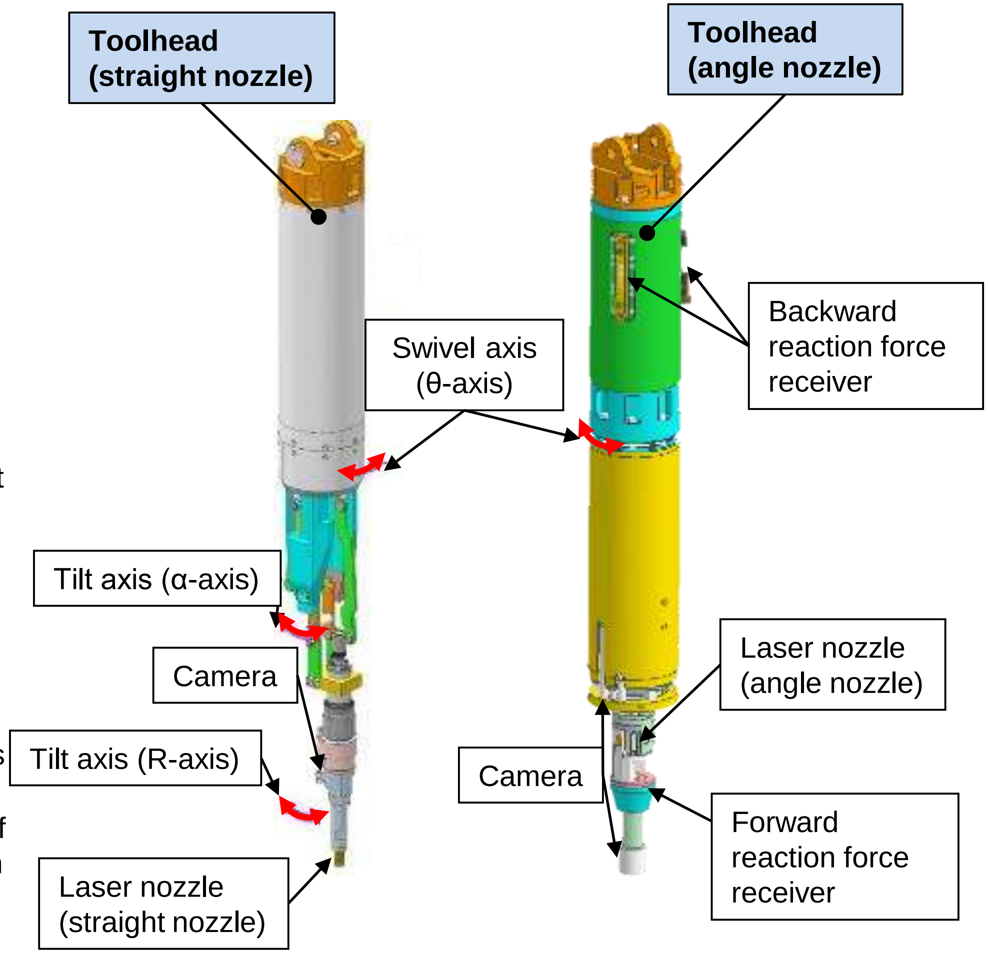
- Design for each drive axis (movement range/speed)
  : Drive shaft designed for operations under the operational conditions established from the results of FY2021 tests.

- Reaction force receiver design
  : Designed with a mechanism to reduce toolhead vibration (for angle nozzles) from the reaction force of assist gas injection.
  Reaction force vibration is small with the straight nozzle toolhead, so it was determined that a reaction force receiver was unnecessary for straight nozzles.

- Laser transmission system design
  : Designed to connect the fiber cable within the toolhead to the laser nozzle at the tip of the toolhead.

- Equipped with a camera
  : A camera is installed to check toolhead position for easier access and to check the treatment target.

- Assist gas restrictions
  : Nitrogen, which is currently sealed in the RPV, will be used as the assist gas and the design allows for connection of a nitrogen cylinder.
  The assist gas flow rate is expected to be higher than the current flow rate of the nitrogen inside the RPV, but possible operational countermeasures such as intermittent disconnection are being considered, and it has been determined that such countermeasures do not need to be reflected in the equipment design.
  Operational countermeasures are expected to be thoroughly considered in the TRL 5 phase, when the actual equipment information is input.



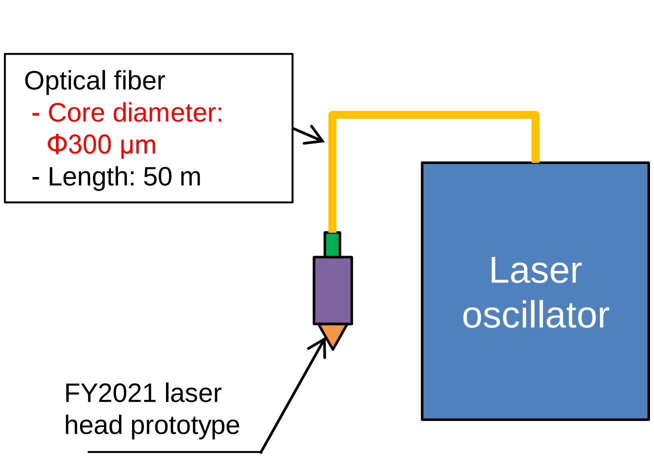
Toolhead (laser cutting)

6. Implementation details

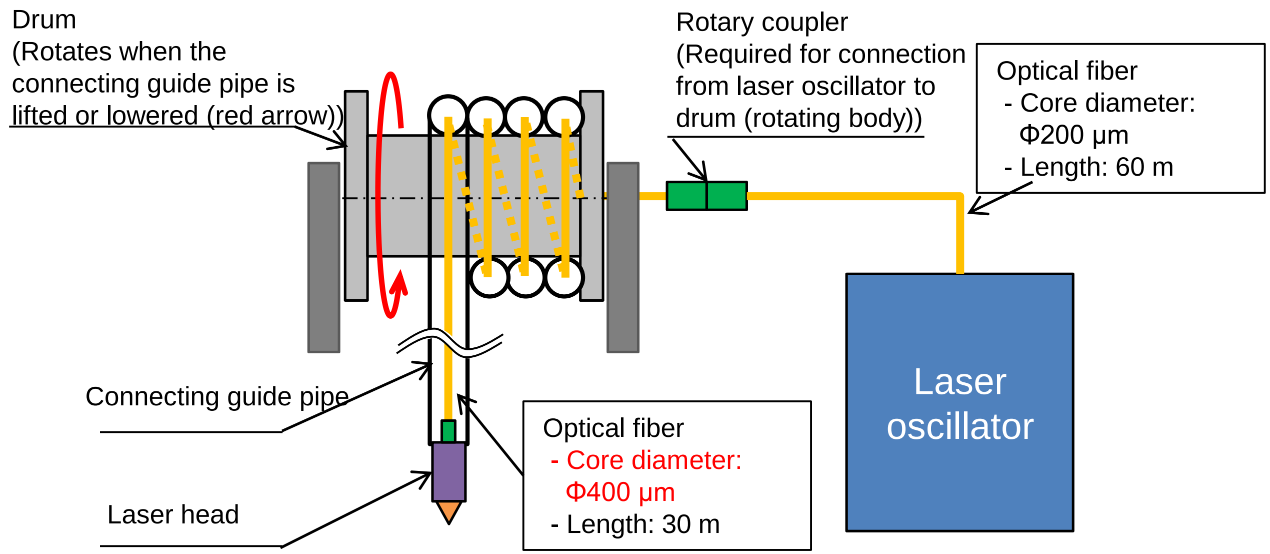
(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

③ High-power laser transmission design



Configuration at the time of FY2021 element testing



Configuration of laser cutting device for actual equipment

- The FY2021 laser head prototype uses optical fiber (core diameter: Φ300 μm, length: 50 m) attached to the laser oscillator, and cutting tests verified its potential for application.
- Consider the following when designing for actual equipment:
  ① For the optical fiber connecting the oscillator to the drum, select fiber with a core diameter of Φ200 μm and assume a transmission distance of approximately 50 m.
  ② Use a rotating coupler to connect the optical fiber from the laser oscillator to the drum, as the drum is a rotating body.
  The core diameter on the drum side must be 200 μm larger than that on the oscillator side to allow for fiber misalignment in the rotating coupler section.
- Compared to the FY2021 prototype, the diameter of the optical fiber core connected to the laser head has increased (laser beam diameter has increased and power density has decreased), and there is concern that cutting performance will decrease.
- Operational countermeasures to the reduction in power density can be considered, such as lowering the nozzle speed (cutting speed) during operation, and cutting performance tests must be conducted to verify whether cutting is possible and the conditions under which cutting is possible.

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

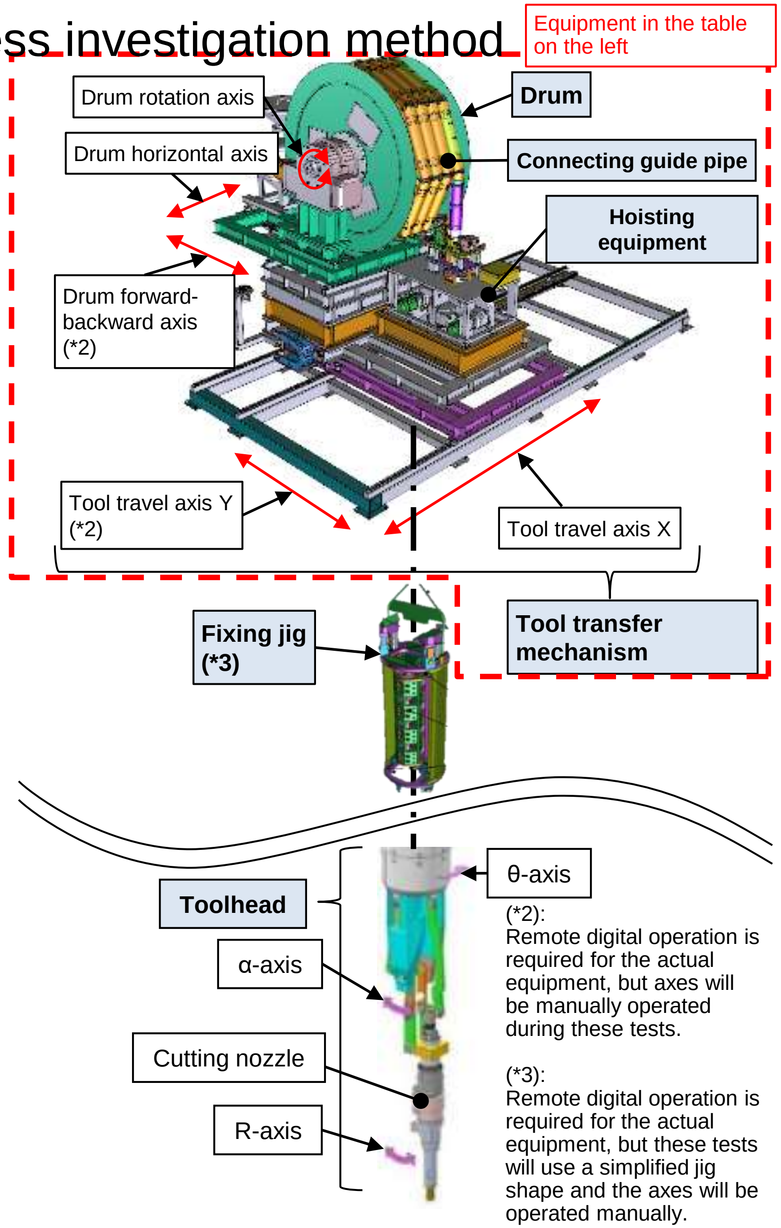
5) Results of laser cutting technology

④ Functional verification testing plan for the laser cutting device (1/2)

Test items are extracted for each target area, focusing on parameters that affect cutting performance.

No.	Target area	Related elements	Test item	Remarks
1	**Drum, hoisting equipment (*1)**	- Drum rotation axis - Drum horizontal axis - Hoisting equipment	Checking the accuracy of the speed of lifting and lowering the connecting guide pipe	A parameter that affects nozzle speed during steam separator cutting (vertical cutting) and is related to cutting performance.
			Checking the lifting and lowering range of the connecting guide pipe	The connecting guide pipe must be able to be lifted and lowered to the cutting position for processing.
			Checking the accuracy of the lifting and lowering position of the connecting guide pipe	A parameter related to cutting performance, as it affects standoff.
			Checking the distance of one inching operation	A parameter that affects the accuracy of adjustments to vertical positioning and is related to standoff setting and other cutting performance factors. Actual performance is measured. (No criteria)
2	**Connecting guide pipe**	- Toggle	Checking the amount of connecting guide pipe sway at no reaction force [Reference measurement]	This item does not affect cutting performance, but it is related to opening passability and actual performance is measured for reference.
			Checking the amount of connecting guide pipe deflection to reaction forces from the assist gas	A parameter related to cutting performance, as deflection in a toolhead without a reaction force receiver (straight nozzle) may affect standoff, etc. However, this can be compensated for by using the α/R-axis of the toolhead, so the actual value shall be measured in this functional test.
3	**Tool transfer mechanism**	- Tool travel axis X - Tool travel axis Y	Operating range/accuracy [Reference measurement]	No changes have been made from the FY2019 design that was verified as feasible, and so verification is deemed unnecessary. Only the operating range of tool travel axis Y is measured for reference because the axis is operated manually and a simplified model is used. Tool travel axis X is operated digitally for workability considerations and the operating range and accuracy are measured as a reference.

(*1) When lowering the connecting guide pipe, the drum and hoisting mechanism shall be interlocked and checked at that time.



(*2): Remote digital operation is required for the actual equipment, but axes will be manually operated during these tests.

(*3): Remote digital operation is required for the actual equipment, but these tests will use a simplified jig shape and the axes will be operated manually.

Reactor internals processing equipment

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

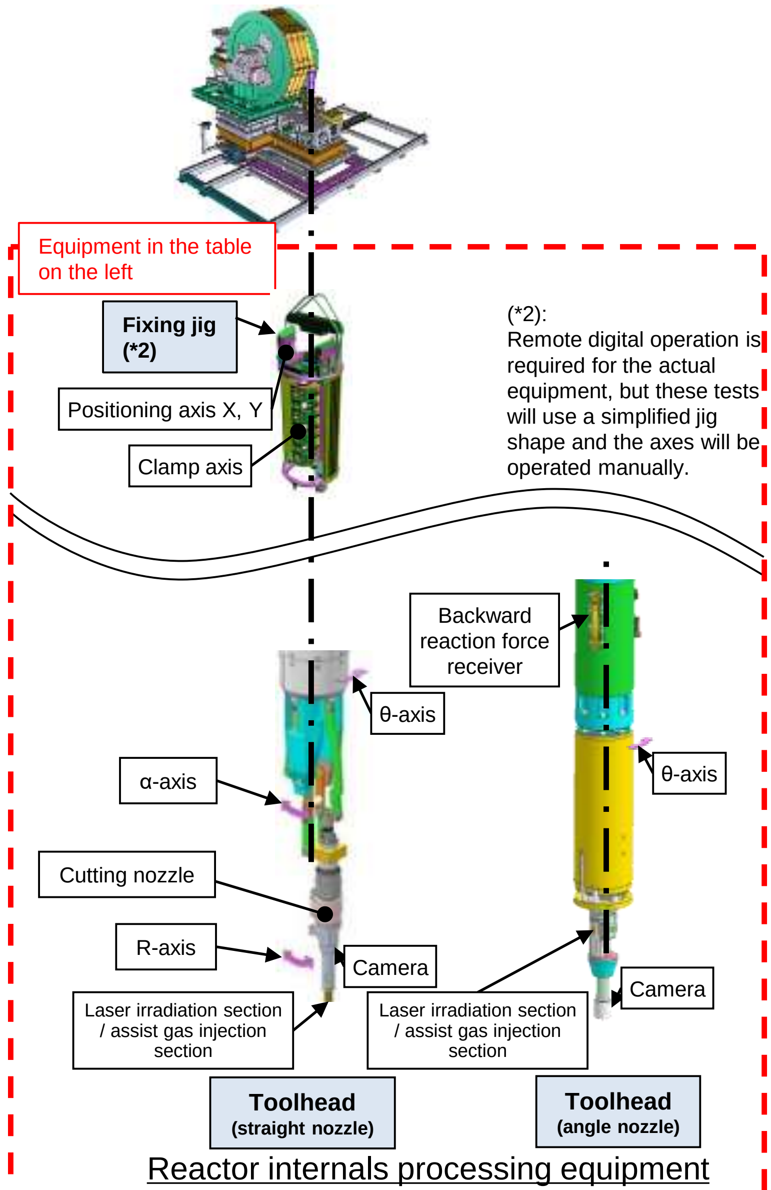
5) Results of laser cutting technology

④ Functional verification testing plan for the laser cutting device (2/2)

Test items are extracted for each target area, focusing on parameters that affect cutting performance.

No.	Target area	Related elements	Test item	Remarks
4	**Fixing jig**	- Positioning axis X, Y - Clamping axis	Measurement operating range [Reference measurement]	No changes have been made from the FY2019 design that was verified as feasible, and so verification is deemed unnecessary. Only the operating range is measured for reference because each axis is operated manually and a simplified model is used.
5	**Toolhead** **(Common *1)**	- Laser irradiation section	Measuring laser output	A parameter related to cutting performance, and actual performance is measured. (No criteria)
		- Assist gas injection section	Measuring assist gas pressure / flow rate	A parameter related to cutting performance, and actual performance is measured. (No criteria)
		- Camera	Checking camera image	No direct impact on cutting performance, but verify that there are no issues with the image.
		- θ-axis	Drive speed accuracy	A parameter that affects nozzle speed in all cutting except steam separator cutting (vertical cutting) and is related to cutting performance.
			Measuring position setting accuracy	A parameter related to cutting performance factors, such as standoff and laser incidence angle during steam separator cutting (vertical cutting).
6	**Toolhead** **(Straight nozzle only)**	- α/R axes	Measuring position setting accuracy	The positioning accuracy for a given nozzle posture (angle and position) considered for each cutting target is a parameter that affects cutting performance, such as standoff and laser incidence angle.
7	**Toolhead** **(Angle nozzle only)**	- Backward reaction force receiver	Measurement operating range	A parameter related to cutting performance because if the operating range is less than the design value, it will not remain near the surrounding structure and deflection will increase.

(*1) Testing items that require verification for both straight and angled nozzle toolheads.



6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

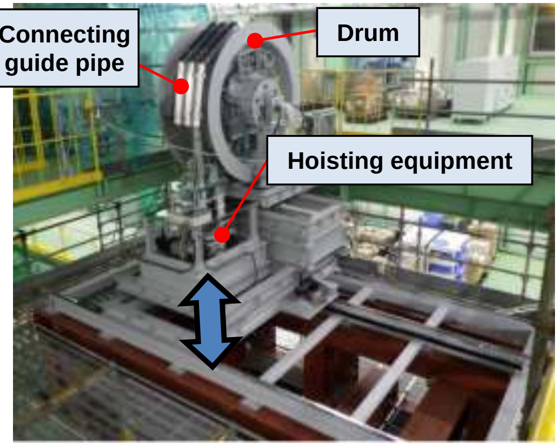
⑤ Results of functional verification tests of the laser cutting device (1/4)

[Drums and hoisting equipment]

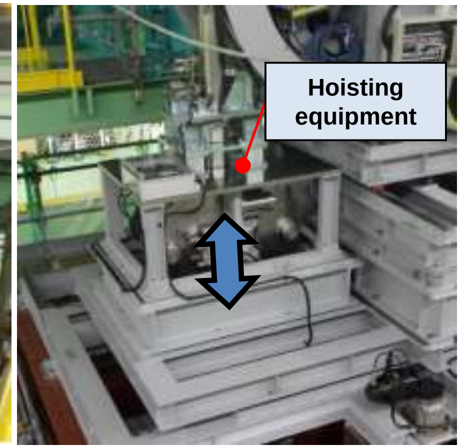
<Test outline>

The following items were checked by using the drum and hoisting equipment to lift and lower the connecting guide pipe.

① The accuracy of the speed of lifting and lowering the connecting guide pipe
② The connecting guide pipe hoisting range
③ The accuracy of the lifting and lowering position of connecting guide pipe
④ The distance of one inching operating



Drum and hoisting equipment



Hoisting equipment

<Test results>

Test item	Assessment criteria	Test method	Results (○: satisfies the assessment criteria)
① The accuracy of the speed of lifting and lowering the connecting guide pipe	The measured value must be within ±10% of the set value (60, 120, 300 mm/min).	Operate the device for a predetermined distance and measure the time with a stopwatch.	- Accuracy of hoisting speed: -1.7% to +2.3% - Accuracy of lowering speed: +2.0% to +4.8% ○
② The connecting guide pipe hoisting range	16192 mm or greater	Use a tape measure to measure operating distance at full stroke.	Measured stroke: 16570 mm ○
③ The accuracy of the lifting and lowering position of the connecting guide pipe	The measured value must be within ±5 mm of the target position.	Use a tape measure to measure the deviation from the target position.	Difference between measured and target values Target position 13544.2 mm (height of steam dryer): -2.2 mm Target position 15001 mm (height of top of steam separator): -2.5 mm Target position 16618 mm (height of bottom of steam separator): -3.0 mm ○
④ The distance of one inching operating	No assessment criteria as this is a reference measurement.	Use a tape measure or metal ruler to measure the operating distance.	Operating distance of one inching: 0.2 mm

<Conclusion>

⇒ The drum and hoisting equipment are determined to satisfy the prescribed functions.

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

⑤ Results of functional verification tests of the laser cutting device (2/4)

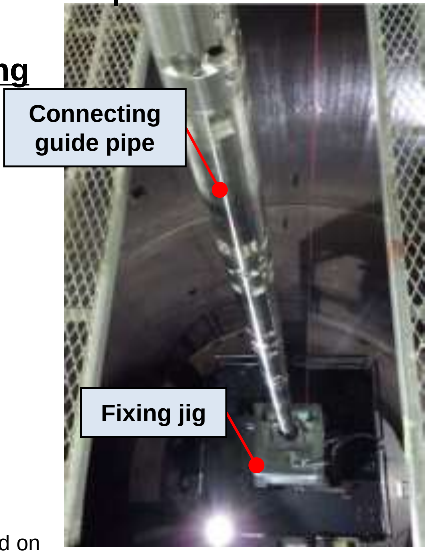
[Connecting guide pipe]

<Test outline>

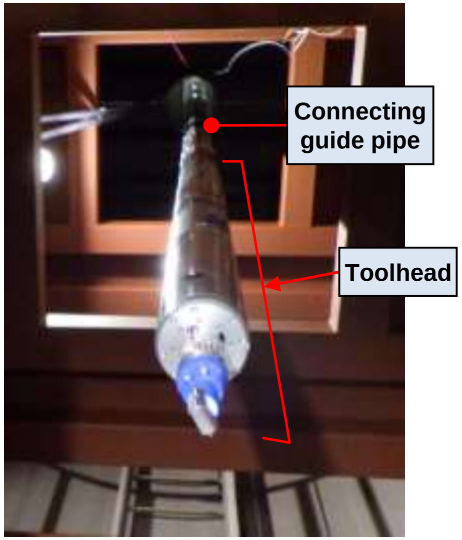
Lower the connecting guide pipe to the specified height and check the following items:

① Checking the amount of connecting guide pipe sway at no reaction force

② Check the amount of deflection in the connecting guide pipe from assist gas reaction force



Connecting guide pipe



Connecting guide pipe and toolhead

<Test results>

(*): The amount of deflection indicates the amount of movement of the connecting guide pipe when subjected to the assist gas reaction force, based on the position of the connecting guide pipe when not subject to assist gas reaction force.

Test item	Assessment criteria	Test method	Results (○: satisfies the assessment criteria)
① Checking the amount of connecting guide pipe sway at no reaction force	No assessment criteria as this is a reference measurement.	Use a laser level and metal ruler to measure the amount of sway in the guide pipe.	① (Steam dryer bottom plate) position: 18.0 mm ② (Top of steam separator) position: 27.3 mm ③ (Bottom of steam separator) position: 36.5 mm ④ Lower edge position: 40.5 mm
② Amount of deflection of the connecting guide pipe due to assist gas reaction force (*)	No assessment criteria as this is a reference measurement.	Use a laser level and metal ruler to measure the deflection of the guide pipe.	① (Steam dryer bottom plate) position: 1.0 mm ② (Top of steam separator) position: 2.1 to 4.0 mm ③ (Bottom of steam separator) position: 3.0 to 4.5 mm ④ Lower edge position: 3.5 to 4.5 mm

<Conclusion>

⇒ Verified the actual values of runout and deflection of the connecting guide pipe.
These values must be reflected in future designs and operation of the actual equipment.

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

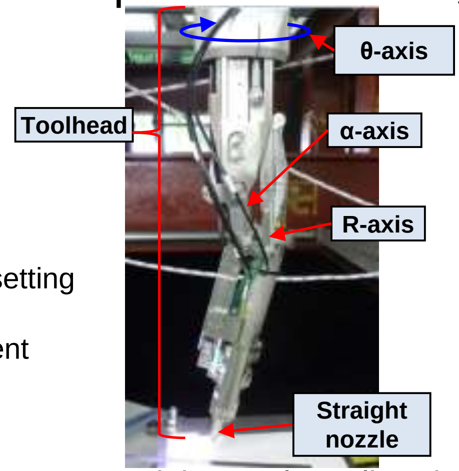
5) Results of laser cutting technology

⑤ Results of functional verification tests of the laser cutting device (3/4)

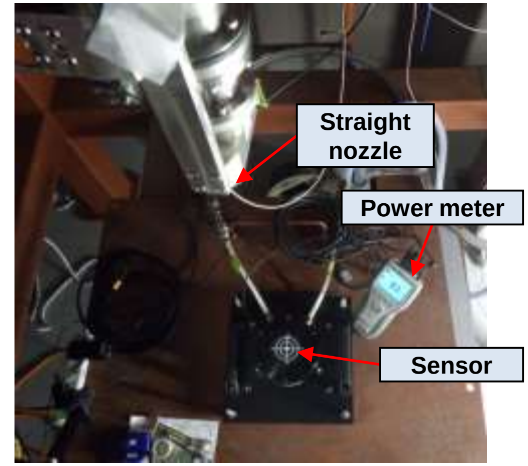
[Straight nozzle toolhead]

<Test outline>

Operate the toolhead (straight) and check the following items:
① Accuracy of θ-axis rotation speed, ② Accuracy of α/R-axis position setting
③ Accuracy of θ-axis position setting, ④ α/R-axis travel range
⑤ θ-axis travel range, ⑥ Assist gas pressure and flow rate measurement
⑦ Laser output measurement



Straight nozzle toolhead



Laser output measurement setup

<Test results> (*): θ-axis rotation speed setting values: 20, 40, 90, 110, 190, 280, 350, 510 (° /min)

Test item	Assessment criteria	Test method	Results (○: satisfies the assessment criteria)
① Accuracy of θ-axis rotation speed	The measured value must be within ±10% of the set value (*).	Operate the device for a predetermined distance and measure the time with a stopwatch.	Measured value relative to setting value: -1.1% to 1.5% ○
② Accuracy of α/R-axis position setting	The measured value must be within the following values to the target position. Nozzle tip position within ±1 mm Nozzle tip angle within ±1°	Use a caliper and angle gauge to measure position during operation.	- Misalignment: ±0.0 mm - Angular misalignment: -0.6° to +0.6° ○
③ Positioning accuracy of θ-axis	The measured value must be within ±1° of the target position.	Use a tape measure to measure the deviation from the target position.	Amount of deviation from the target position: +180° position: ±0°, -180° position: ±0° ○
④ α/R-axis travel range	The stroke must be within the following values: - α-axis: -6 mm to +13 mm - R-axis: -17 mm to +16 mm	Check that equipment operates up to the soft limit set for the stroke.	Verified that equipment operates up to the soft limit set for the design stroke. ○
⑤ θ-axis travel range	Must operate at 370° or more.	Use a tape measure to measure operating distance.	Actual measured value: 376.37° ○
⑥ Assist gas pressure & flow rate measurement	No assessment criteria as this is a reference measurement.	Use the pressure indicator and flow meter installed on the system to measure.	- Pressure: 0.63 MPa - Flow rate: 810 L/min
⑦ Laser output measurement	No assessment criteria as this is a reference measurement. (FY2021 cutting tests were conducted with an output of 7.2 kW)	Use a power meter to measure output. (Thermal measurement method)	Actual measured value: 7.75 kW

<Conclusion>

⇒ The toolhead for straight nozzles is deemed to satisfy the prescribed functions.
(Laser output loss is comparable to FY2021 estimated levels, so no issue exists.)

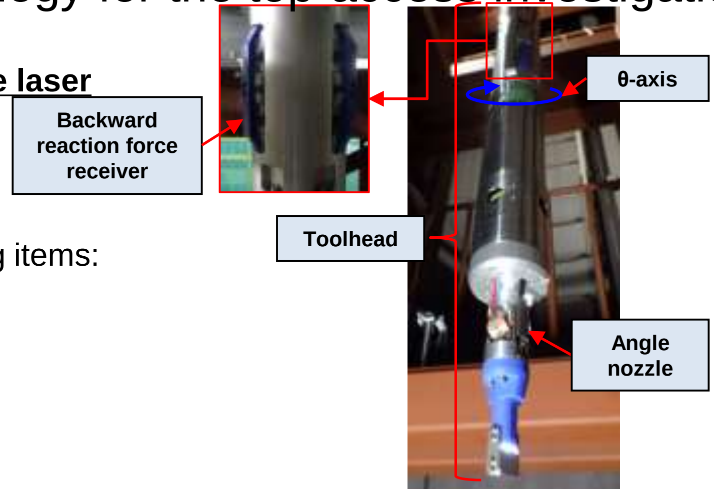
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

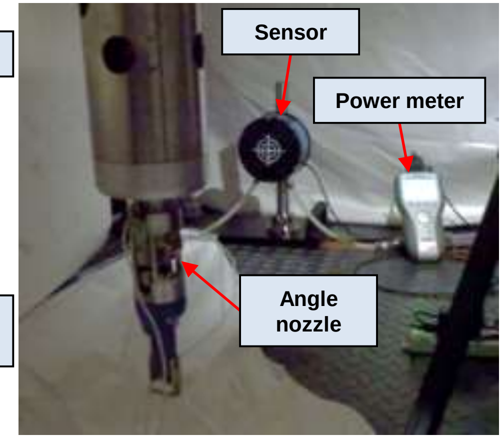
5) Results of laser cutting technology

⑤ Results of functional verification tests of the laser cutting device (4/4)

[Angle nozzle toolhead]



Angle nozzle toolhead



Laser output measurement setup

<Test outline>

Operate the toolhead (angle) and check the following items:

① Accuracy of θ-axis rotation speed
② Accuracy of θ-axis position setting
③ Backward reaction force receiver travel range
④ Assist gas pressure and flow rate measurement
⑤ Laser output measurement

<Test results>

Test item	Assessment criteria	Test method	Results (○: satisfies the assessment criteria)
① Accuracy of θ-axis rotation speed	The measured value must be within ±10% of the set value (190° /min).	Operate the device for a predetermined distance and measure the time with a stopwatch.	Accuracy of measured value relative to set value: -0.1% to -0.2% ○
② Accuracy of θ-axis position setting	The measured value must be within ±1° of the target position.	Use a tape measure to measure the deviation from the target position.	Amount of deviation from the target position: +180° position: +0.43°, -180° position: +0.02° ○
③ Backward reaction force receiver travel range	Actual measurement shall be 13±0.4 mm.	Use calipers to measure operating distance.	Actual measurement: 12.61 to 12.63 mm ○
④ Assist gas pressure & flow rate measurement	No assessment criteria as this is a reference measurement.	Use the pressure indicator and flow meter installed on the system to measure.	- Pressure: 0.68 MPa - Flow rate: 890 L/min
⑤ Laser output measurement	No assessment criteria as this is a reference measurement. (FY2021 cutting tests were conducted with an output of 7.2 kW)	Use a power meter to measure output. (Thermal measurement method)	Actual measured value: 7.24 kW

<Conclusion>

⇒ The toolhead for angle nozzles is deemed to satisfy the prescribed functions.
(Laser output loss is comparable to FY2021 estimated levels, so no issue exists.)

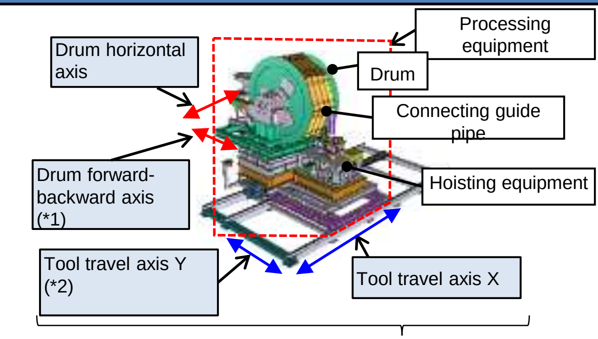
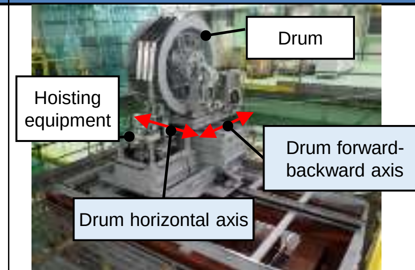
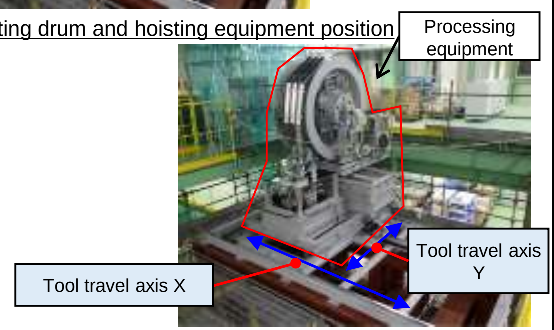
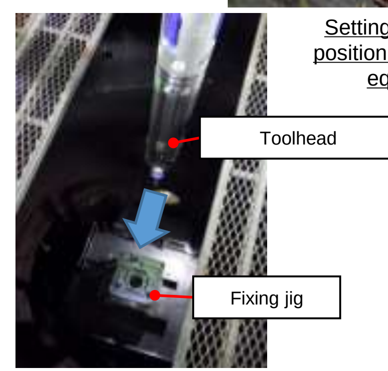
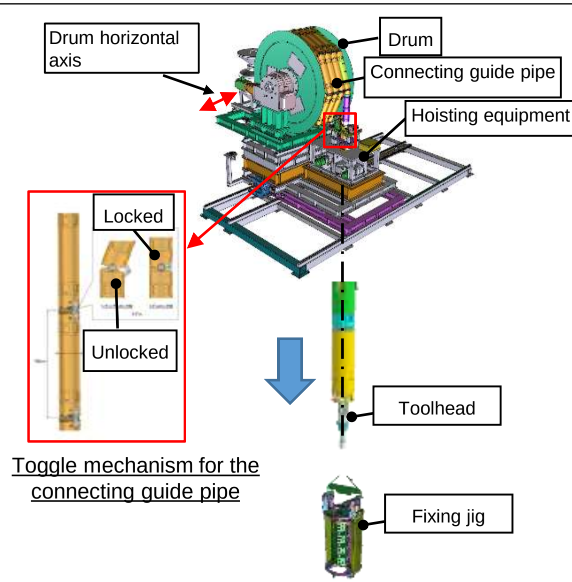
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

⑥ Laser cutting device combined operations testing results (1/3)

⇒ Tests are conducted in combination with each equipment to verify a series of operations with the assumed actual operating equipment.

No.	Actual workflow (Test content)	Operations image	Test results (○: satisfies the prescribed functions)	Details
1	1.1 Adjust drum and hoisting equipment position ↓ 1.2 Set the X and Y position of processing equipment (in the toolbox) (*1)	 (*1, *2) Manual axes for testing Tool transfer mechanism	- The position of the drum and hoisting equipment align with the drum forward-backward axis and the drum horizontal axis. - Verified that X and Y positions of the processing equipment can be set.	 Adjusting drum and hoisting equipment position  Setting the X and Y position of processing equipment  Lowering the toolhead to fixing jig
2	2. Lower the toolhead to fixing jig	 Toggle mechanism for the connecting guide pipe	- Verified that the toolhead can be lowered to the fixing jig by synchronizing it with the drum horizontal axis. - Verified that lifting and lowering with the hoisting equipment is possible while the toggle lock is engaged.	

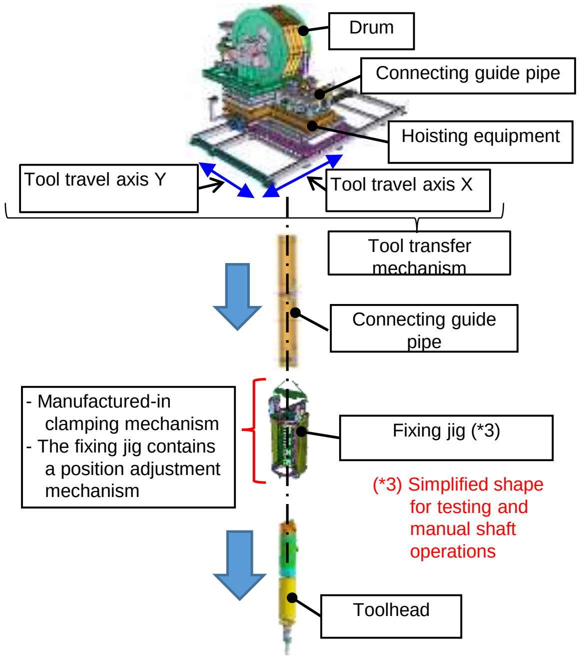
(*1): The toolbox was not used in the test.
(The basic design of the toolbox has been completed as of FY2019 and is not subject to development in the FY2022 subsidy project)

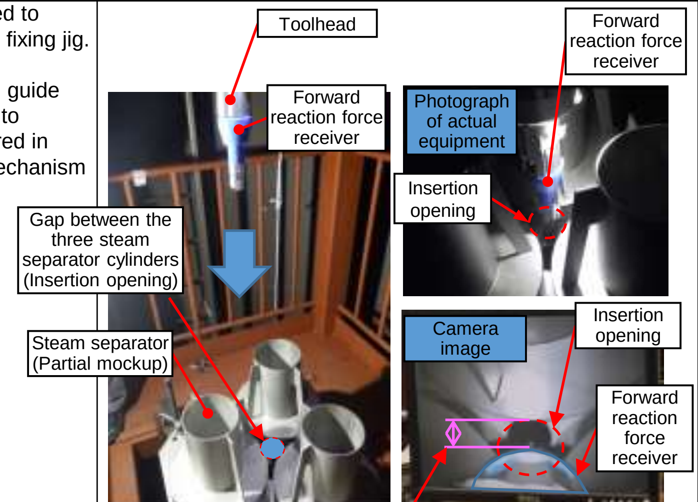
6. Implementation details

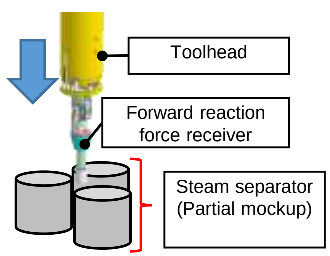
(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

⑥ Laser cutting device combined operations testing results (2/3)

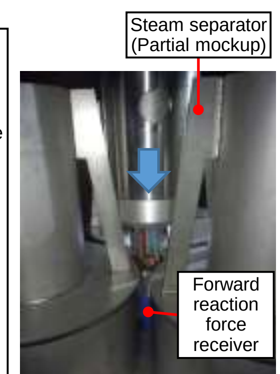
<table>
<tr><th>No.</th><th>Actual workflow
(Test content)</th><th>Operations image</th><th>Test results
(○: satisfies the prescribed functions)</th><th>Details</th></tr>
<tr><td>3</td><td>3.1 Adjust the position of the fixing jig and toolhead
↓
3.2 Insert the toolhead into the fixing jig
↓
3.3 Lower toolhead near operation height</td><td>
</td><td>- Camera images can be used to insert the toolhead into the fixing jig.

- Verified that the connecting guide pipe can be lowered close to operation height and secured in place with the clamping mechanism on the fixing jig.</td><td>

① Toolhead reaches near operation height
② Toolhead X and Y position adjustment</td></tr>
<tr><td>4</td><td>4.1 Adjust the X/Y position of the toolhead
↓
4.2 Lower to operation height</td><td>

Insertion of forward reaction force receiver</td><td>- Confirmed that camera images can be used to adjust position relative to a partial mockup of the steam separator.

- Verified that the toolhead can be lowered to operation height.</td><td>[Position adjustment method]
- While rotating the toolhead, measure the distance from the forward reaction force receiver to the insertion opening at three locations and at a pitch of 120° (measured using camera images).

- The fixing jig and tool transfer mechanism adjust the X/Y to minimize the difference in distance measured (i.e., to minimize any misalignment between the insertion opening and toolhead).


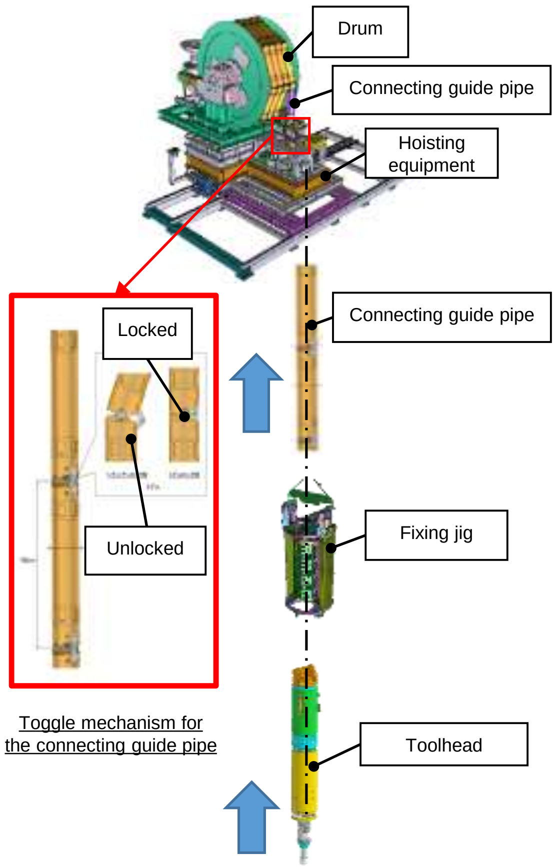
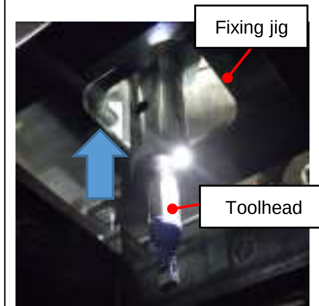
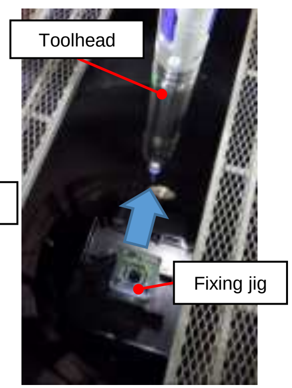
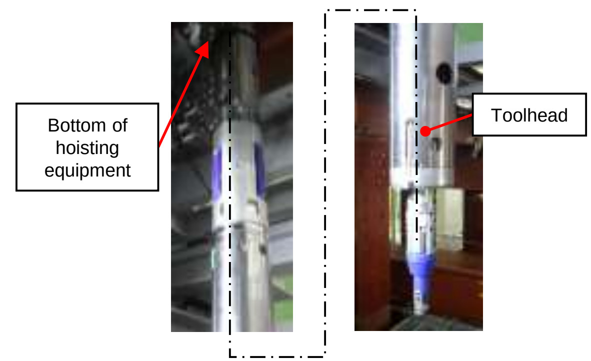
③ Insertion of the toolhead forward reaction force receiver</td></tr>
</table>

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

5) Results of laser cutting technology

⑥ Laser cutting device combined operations testing results (3/3)

No.	Actual workflow (Test content)	Operation details	Test results (○: satisfies the prescribed functions)	Details
-	Target of cutting treatment	Not applicable to this study		
5	5.1 Raise toolhead ↓ 5.2 Release from fixing jig ↓ 5.3 Raise toolhead (recovery)	 Toggle mechanism for the connecting guide pipe	- Verified that camera images can be used to return the toolhead to the specified height. - Verified that the hoisting equipment can lift the toolhead while the toggle is unlocked.	 ① Toolhead reaches the vicinity of the fixing jig  ② Released from fixing jig (Toolhead rises)  ③ Toolhead reaches the end of drum winding

<Conclusion>

⇒ Confirmed the feasibility of operations in combination with each equipment.

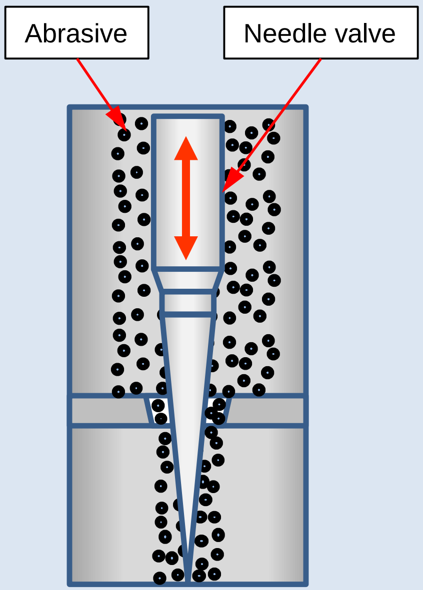
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

6) AWJ cutting technology results

①-1 Abrasive feed rate stabilization study (structure review study)

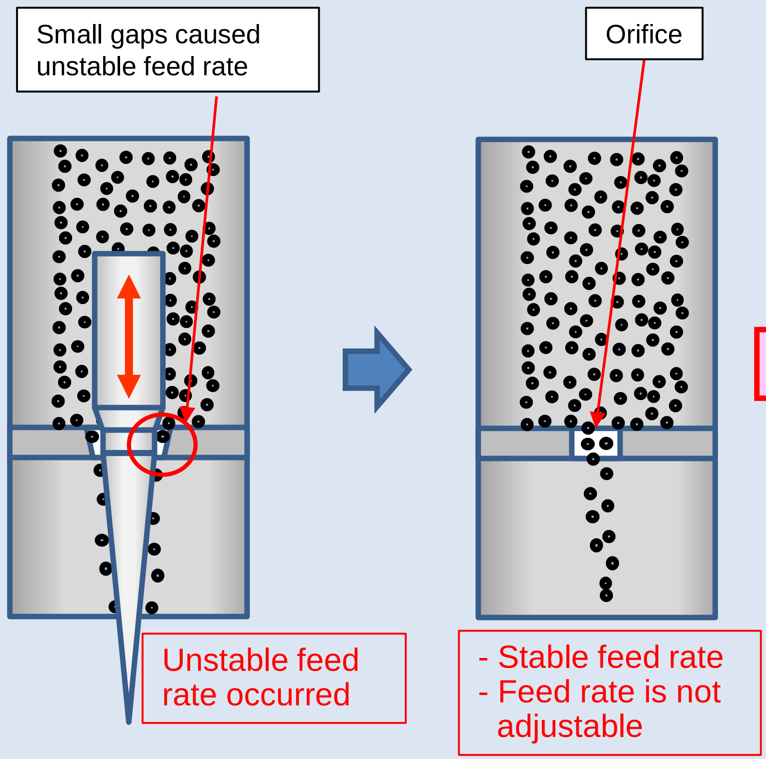
Conventional abrasive adjustment mechanism



Abrasive feed rate: 500 g/min

- Needle valve opening adjusts abrasive feed rate (free fall from gap)

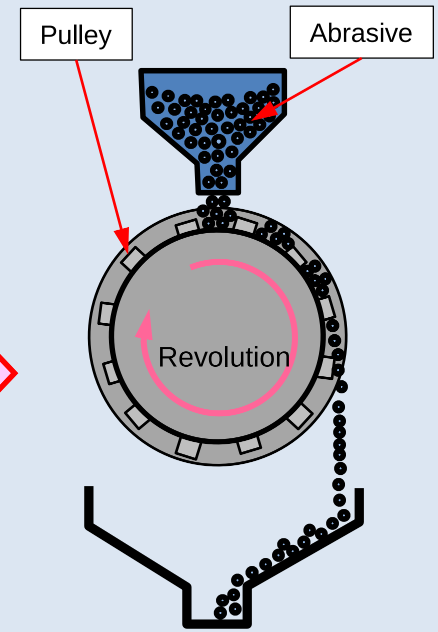
Issues from FY2021 testing



Abrasive feed rate: 100 g/min

- Feed rate was unstable in low abrasive feed
- The opening of the needle valve was small and it is believed that the small gap destabilized passage of the abrasive
- The design changed to an orifice and the feed rate stabilized
  ⇒ Feed rate is determined by the hole diameter, so the feed rate cannot be adjusted.

Implementation details in FY2022



Abrasive feed rate: 100 g/min or more

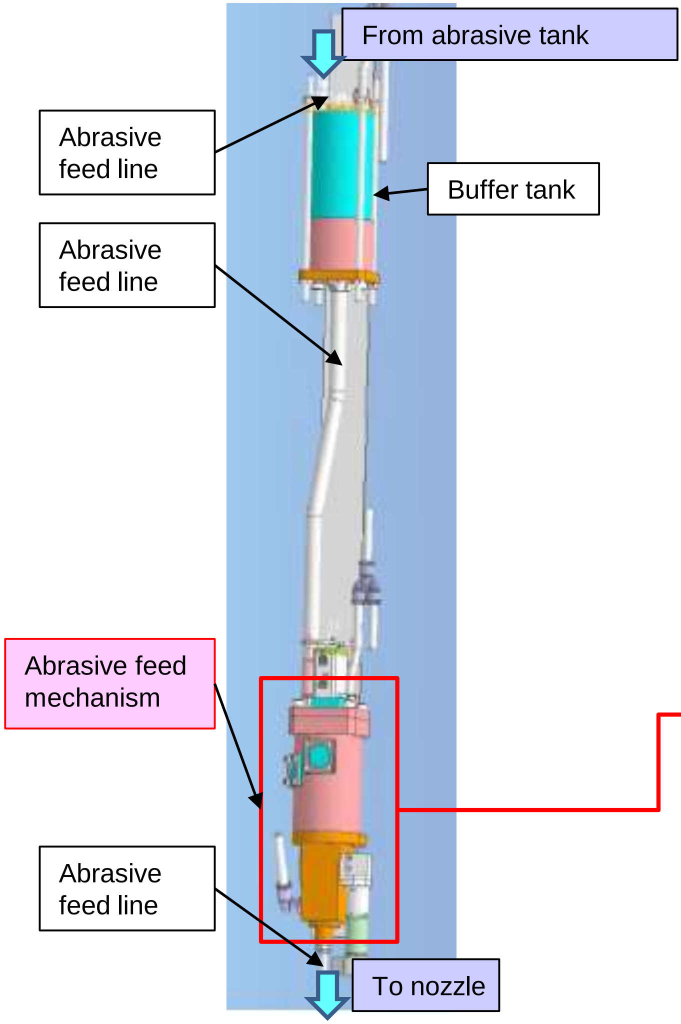
- Adopts a method of transporting abrasives via the rotation of a pulley
- Feed rate can be adjusted by changing rotation speed

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

6) AWJ cutting technology results

①-2 Abrasive feed rate stabilization study (feed mechanism design)



Abrasive feed mechanism external view

[Main design details]

Design of the abrasive feed mechanism

- Adopts a pulley type feed mechanism
- Structure designed in response to low abrasive feed rate
- Size and layout designed to allow the feed mechanism and buffer tank to fit inside the connecting guide pipe

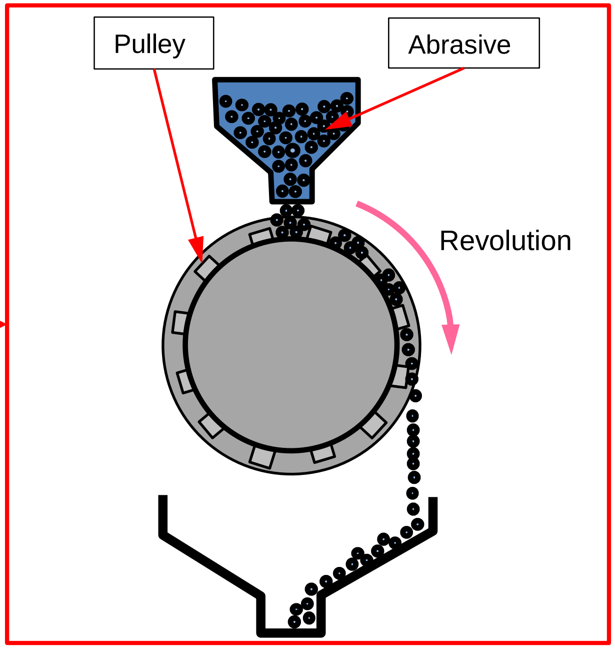


Illustration of pulley type feed mechanism

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

6) AWJ cutting technology results

①-3 Abrasive feed rate stabilization study (Element prototype testing plan)

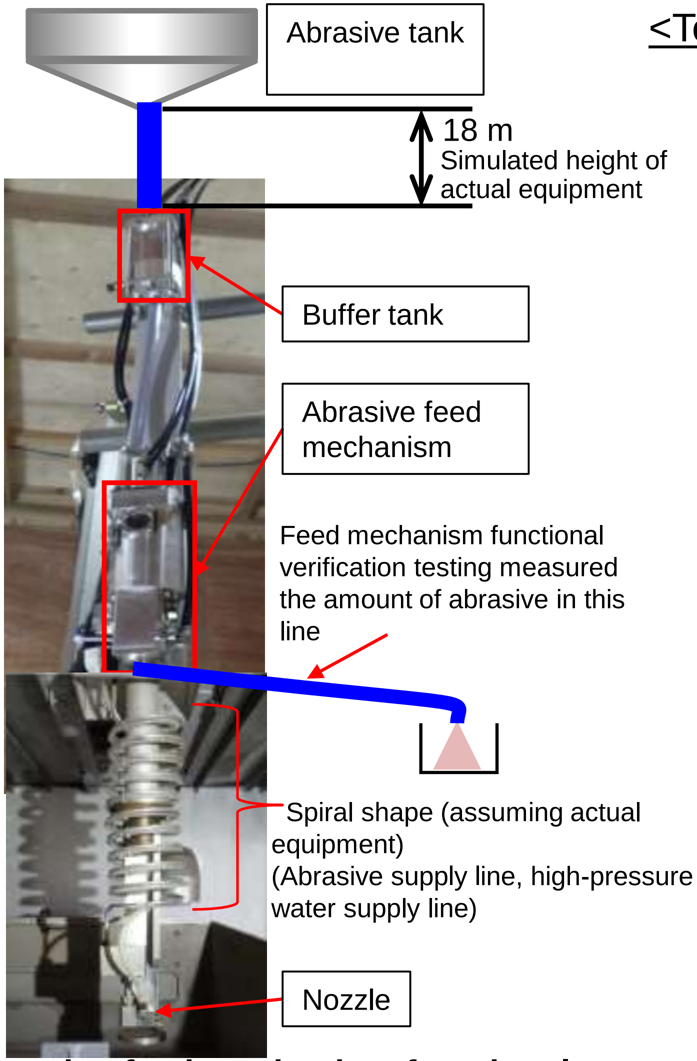
Test item	Details and conditions to confirm	Measurement and confirmation items
1. Abrasive feed mechanism performance verification	1.1 Feed mechanism functional verification - Confirm that the abrasive feed rate can be adjusted by adjusting pulley rotation speed and that a stable feed rate can be achieved with only the feed mechanism (without water jet injection). [Test conditions] Set feed rate: 100 g/min 110 g/min 120 g/min 200 g/min, 500 g/min (reference)	① Check the pulley rotation speed for the set feed rate. ② Verify that a stable feed is possible.
	1.2 Performance check during water jetting - Based on the test results of 1.1 above, conduct a feed rate verification test with a water jet to confirm that the set feed rate can be adjusted and that a stable feed rate is possible. [Test conditions] Set feed rate: 100 g/min 110 g/min 120 g/min 200 g/min, 500 g/min (reference)	① Check the pulley rotation speed for the set feed rate. ② Verify that a stable feed is possible. ③ The difference with and without water jet
2. Simple evaluation of cutting performance	2.1 Flat plate cutting test - Make cuts down the thick edge of a metal plate and evaluate performance by comparing whether cut depth is equivalent to FY2021 cutting performance. [Test conditions] - Flow rate: approx. 3 L/min - Pressure: 343 MPa - Cutting speed: 60 mm/min - Feed rate: 100 g/min - Standoff: 20/50 mm	① The performance should be equivalent to the FY2021 flat cutting performance.

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

6) AWJ cutting technology results

①-4 Abrasive feed rate stabilization study (abrasive feed mechanism performance testing)



Abrasive feed mechanism functional verification testing system

<Test results> *1: Listed feed rate is the average of three tests.

Feed mechanism functional verification test results (without water jet)

No.	Set feed rate (g/min)	Pulley rpm (min-1)	Feed rate *1 (g/min)	Remarks
1	100	16	98.0	Set value for actual equipment
2	110	18.6	110.5	Set value for actual equipment × 1.1
3	120	20.6	120.2	Set value for actual equipment × 1.2
4	200	36.4	203.2	<Reference> Set value for actual equipment × 2
5	500	115.5	494.0	<Reference> Set value for conventional use

⇒ ① Verified that feed rate can be controlled at 10 g/min pitch between 100 and 120 g/min by adjusting pulley rpm

Performance test results during water jet injection

No.	Set feed rate (g/min)	Pulley rpm (min-1)	Feed rate *1 (g/min)	Remarks
1	100	16.4	100.0	Set value for actual equipment
2	110	18.9	112.8	Set value for actual equipment × 1.1
3	120	20.7	122.6	Set value for actual equipment × 1.2
4	200	36.6	211.1	<Reference> Set value for actual equipment × 2
5	500	115.5	499.4	<Reference> Set value for conventional use

⇒ ① Verified that feed rate can be controlled at 10 g/min pitch between 100 and 120 g/min by adjusting pulley rpm, even with water jet injection

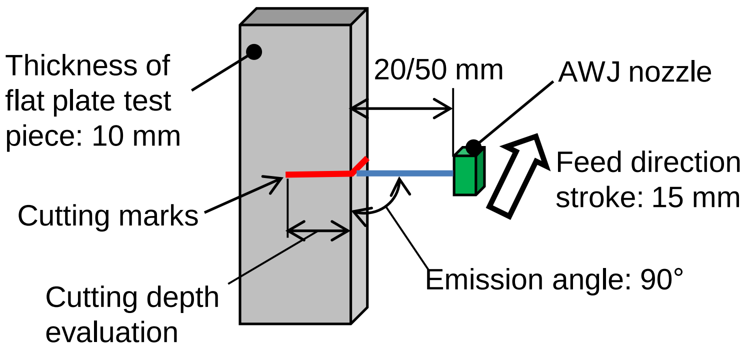
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

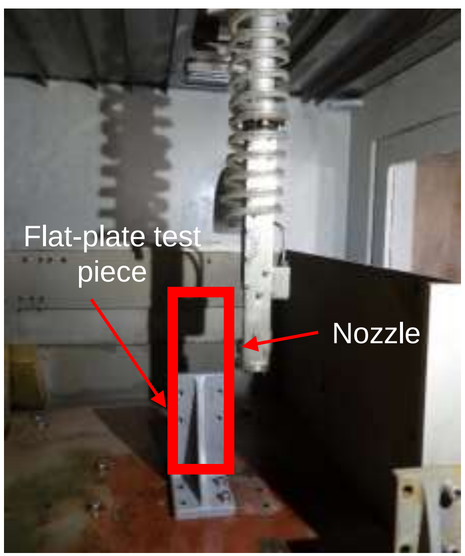
6) AWJ cutting technology results

①-5 Abrasive feed rate stabilization study (simple evaluation of cutting performance)

<Test conditions>



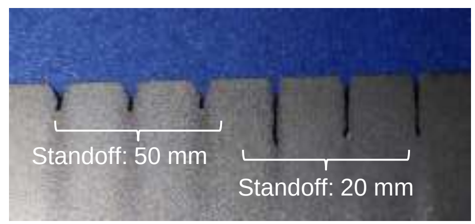
Abrasive feed rate: 100 g/min



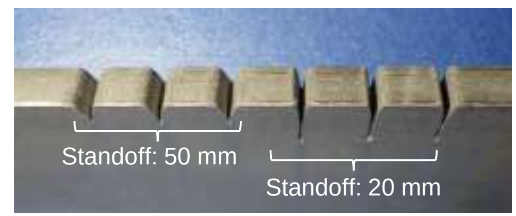
Setup for simple evaluation test of cutting performance

<Test results>

No.	Standoff (mm)	Cutting depth (mm)	
		FY2022 Results	FY2021 Results
1	20	6	
2	20	6	7
3	20	6	
4	50	4	
5	50	4	4
6	50	5	



Cutting plate after cutting test
(Standoff: 20, 50 mm) (front view)



Cutting plate after cutting test
(Standoff: 20, 50 mm) (top view)

⇒ ① A simple evaluation test after a change to the abrasive feed mechanism confirmed that cutting performance was equivalent to conventional performance (FY2021 test results).

② This simple evaluation test contained only a few test parameters, so future tests must be conducted on flat plates and structure mockups to verify that performance is equivalent to that of the conventional feed mechanism.

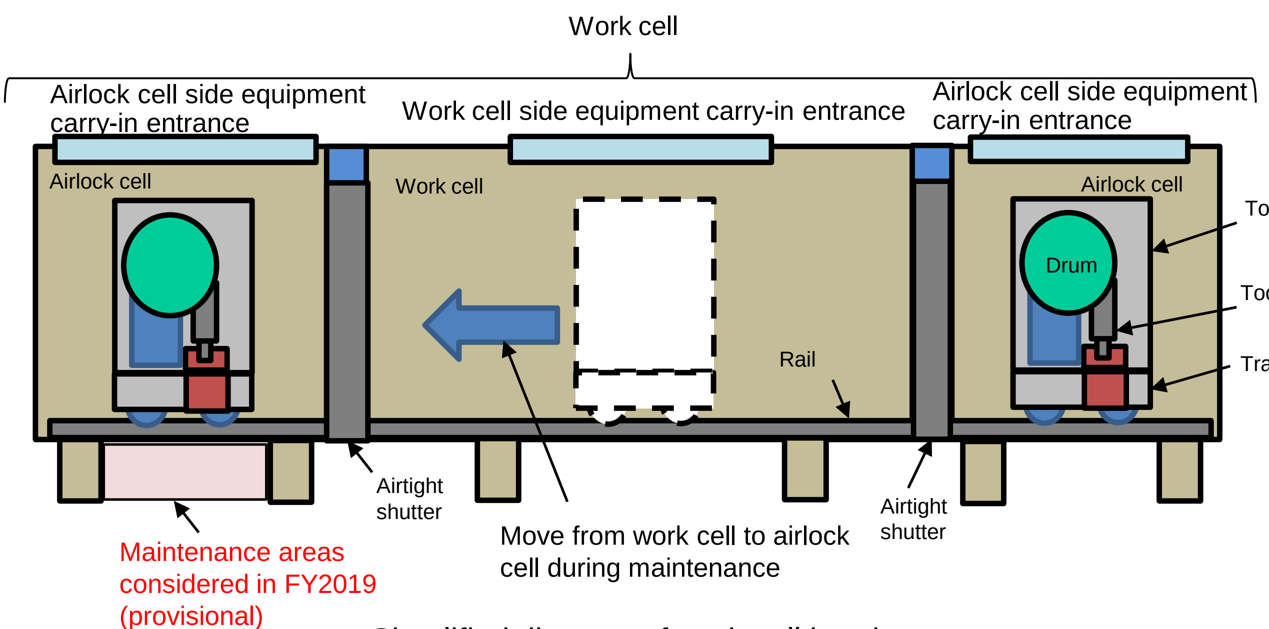
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

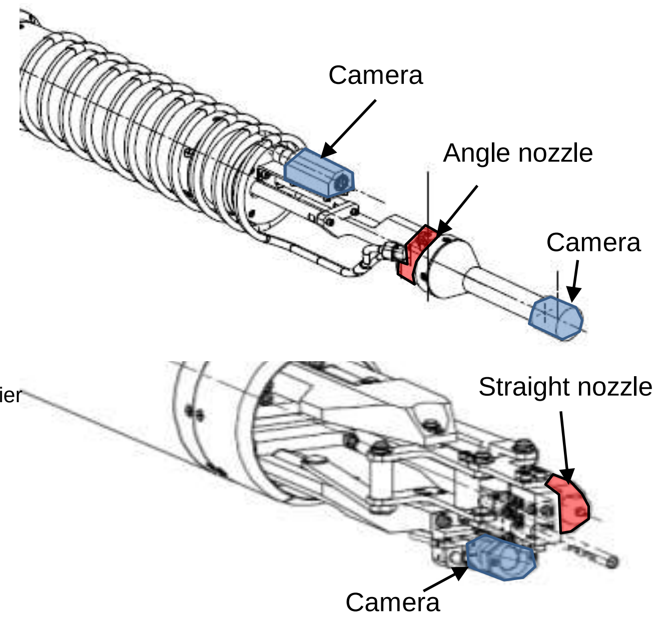
6) AWJ cutting technology results

②-1 AWJ nozzle maintenance (organization of preconditions)

No.	Items	FY2019	FY2022
1	Maintenance area	Area below the airlock cell (see figure below)	Examination of areas provisionally assumed in FY2019, including changes.
2	Replacement method	Unexamined	Examine either remote replacement or manned replacement with exposure and contamination countermeasures.
3	Exchange target	- Camera	- Camera - Nozzle (FY2021 test results set nozzle life at about 8 hours. Operation time is about 42 hours, however, so replacement is required.)



Simplified diagram of work cell interior



Exchange target

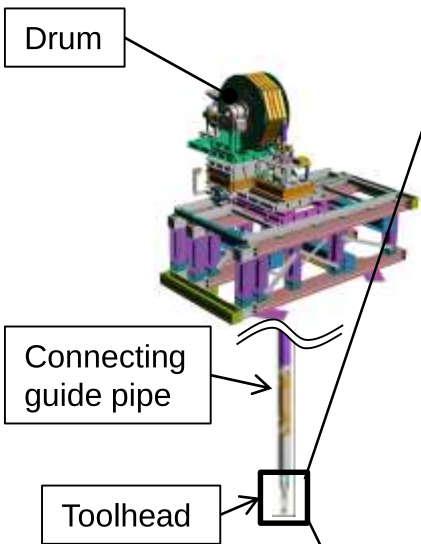
6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

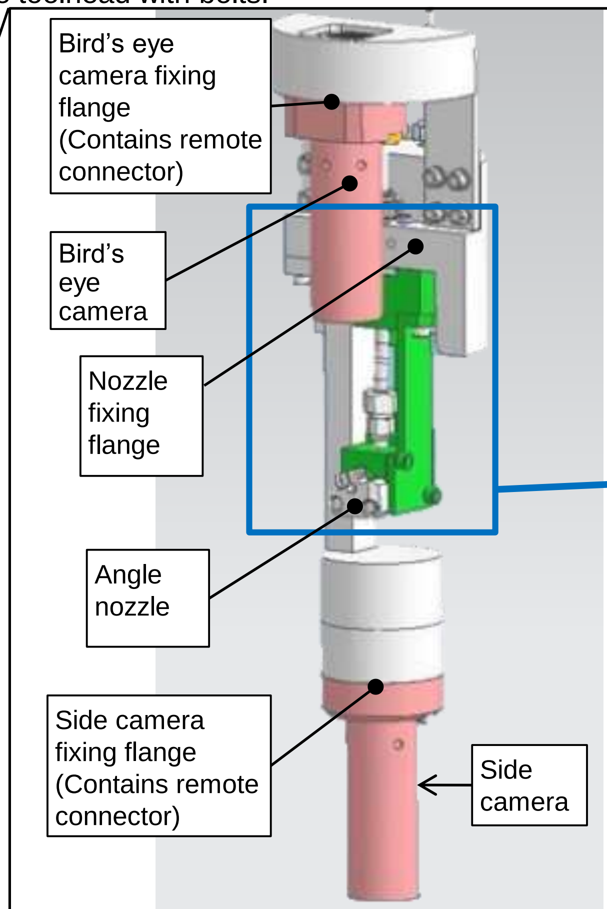
6) AWJ cutting technology results

②-2 AWJ nozzle maintenance (toolhead tip structure review)

- A flange part was added to allow for detachment and replacement of the nozzle part, which wears out due to AWJ injection, and the structure affixes to the toolhead with bolts.
  (See the figure below)
- A connector and flange that can be remotely attached/detached were added to the base of the overhead/side-view camera, and the structure affixes to the toolhead with bolts.



Full equipment view



Toolhead tip (angle nozzle example)

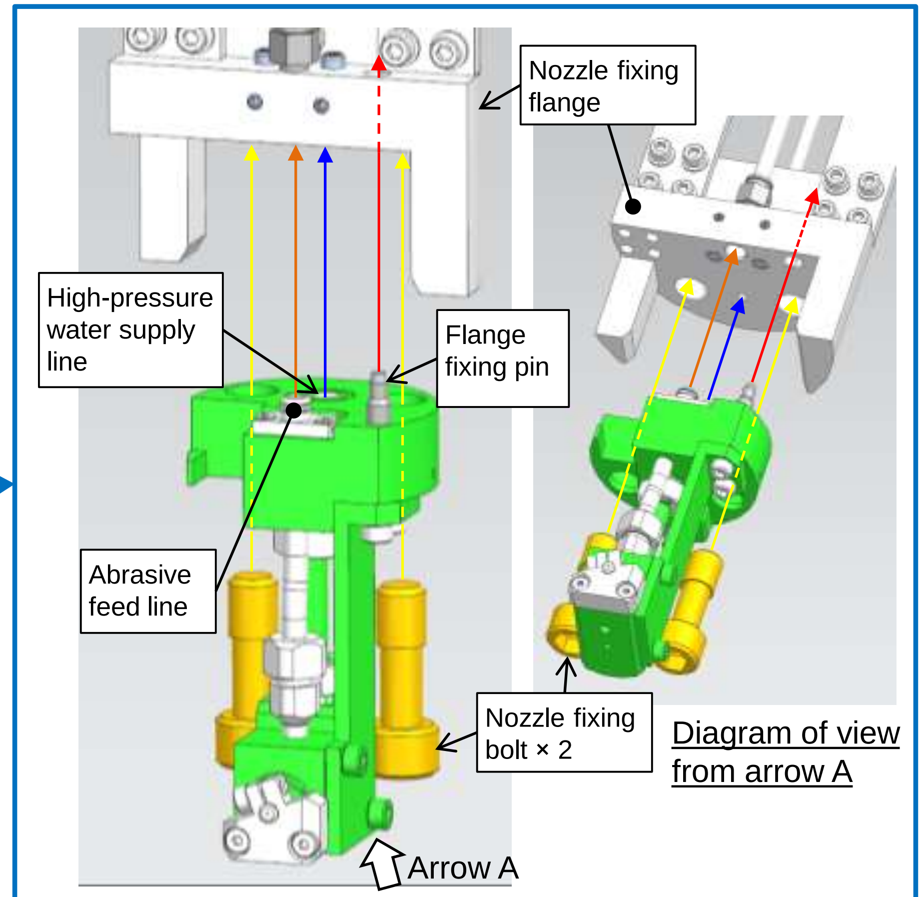


Diagram of view from arrow A

Separated state (angle nozzle example)

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

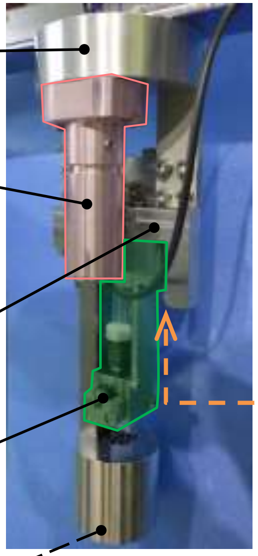
6) AWJ cutting technology results

②-3 AWJ nozzle maintenance (functional verification testing plan for partial element prototypes)

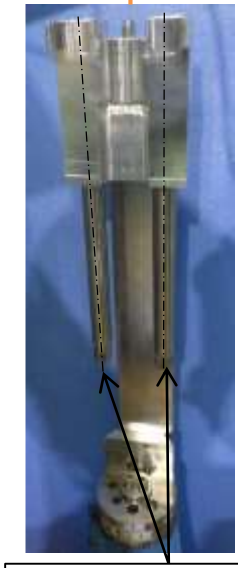
Use a prototype of a partial element at the toolhead tip that can simulate the nozzle and bird's eye camera flange structure and a prototype of a partial replacement jig to confirm the feasibility of the replacement operation and to check the integrity of each part before and after replacement.
Items to be checked in the test are as follows.

Nozzle replacement jig (Enlarged tip)

Items and conditions to confirm	Assessment criteria
Verify replacement operation	The nozzle and camera must be able to attach and detach.
Verify nozzle and camera integrity before and after replacement ① Check high-pressure water jet - Check the pressure of high-pressure water (pump pressure) Set pressure: 343 MPa ② Check abrasive injection - Check abrasive feed rate Set feed rate: 100 g/min ③ Check camera image	① Reaches set pressure. ② Capable of feeding within ±10% of set feed rate. ③ No issues with images.



Toolhead tip (Partial element prototype)



Nozzle replacement jig part prototype

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

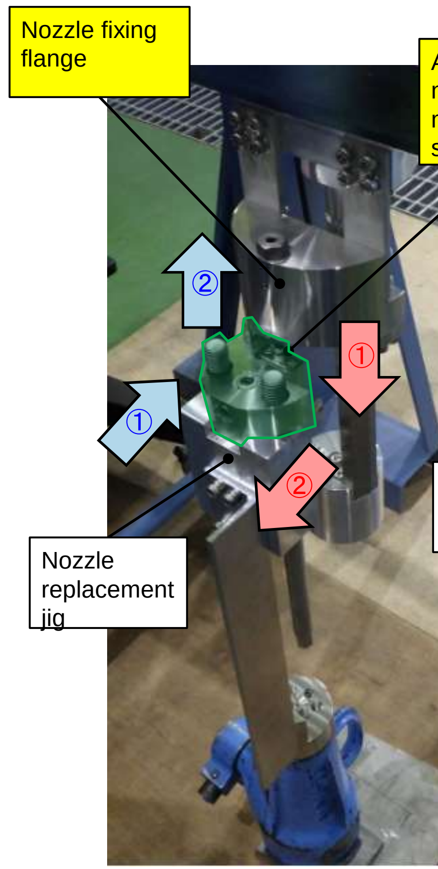
6) AWJ cutting technology results

②-4 AWJ nozzle maintenance (results of functional verification tests of partial element prototypes)

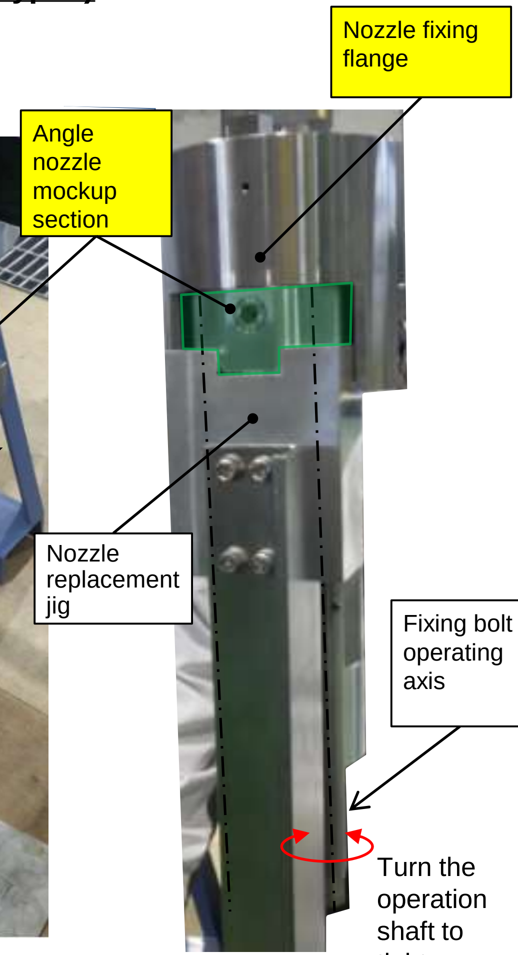
<Test results>

Items and conditions to confirm	Assessment criteria	Results
Verify replacement operation	The nozzle and camera must be able to attach and detach.	Satisfactory
Verify nozzle and camera integrity before and after replacement ① Check high-pressure water jet - Check the pressure of high-pressure water (pump pressure) Set pressure: 343 MPa ② Check abrasive injection - Check abrasive feed rate Set feed rate: 100 g/min ③ Check camera image	① Reaches set pressure. ② Capable of feeding within ±10% of set feed rate. ③ No issues with images.	Satisfactory Satisfactory (+1%) Satisfactory

⇒ The feasibility of the nozzle and camera with the flange structure was verified, and so they will be reflected in future designs of actual equipment. Replacement jigs must be designed for remote operation. (When information on the actual equipment is input and maintenance area constraints are well-understood, expected to be TRL 5 or later.)



Replacement procedure (Installation procedure: blue, Removal procedure: red)



When the replacement jig is attached

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

7) Results of common issues for laser & AWJ cutting technologies

① Study of patterns of uncollectible connecting guide pipes

Cause of event		Risk reduction measures	Response (including examination items)
(1) Interference from an obstacle (Snagging)	① Poor visibility or failure of surveillance cameras and/or lights due to vapor, etc.	- Consider installing surveillance cameras that can monitor the area from the boundary guide pipe to the steam dryer in addition to the cameras mounted on the toolhead. - Use the installed surveillance cameras and lights to check visibility conditions on the access route.	1) Attempt to remove the interference by moving the connecting guide pipe vertically. 2) If the issue remains unresolved, use an external crane to forcibly collect the connecting guide pipe, drum, and other equipment. (When doing so, it is necessary to consider covering the area with an elastic sheet to prevent contamination, high pressure water decontamination, and other hazards.)
(2) Drum failure	① Drive motor operation failure (Drum rotation / forward-backward / horizontal axis)	- Verify operation prior to processing.	[If the drive motor is a heavy weight object] 1) Consider using two drive motors, so that the drum can operate even if one of the motors fails. 2) If the issue remains unresolved, use an external crane to forcibly collect the connecting guide pipe, drum, and other equipment. (When doing so, it is necessary to consider covering the area with an elastic sheet to prevent contamination, high pressure water decontamination, and other hazards.) [If the drive motor is a light weight object (can be carried by hands)] 1) Manually replace with the spare drive motor and collect the connecting guide pipe using regular operations.
(3) Hoisting equipment failure	① Defective hoisting operation (hoisting drive roller)	- Verify operation prior to processing.	1) Collect the connecting guide pipe by simply rotating the drum while monitoring the winding condition.
	② Toggle unlock mechanism / detection mechanism operation failure	- Use the surveillance camera to check the unlock operation and unlock detection prior to processing.	1) Use surveillance cameras to confirm whether toggle unlocking is enabled or disabled and whether it is detected. 2) If the unlocking mechanism is inoperative, restart the drive source to confirm that it is back in operation. 3) If the unlock detection mechanism is inoperative, collect the connecting guide pipe while using a surveillance camera to check whether unlocking is possible. 4) If the toggle unlock mechanism is inoperative, have someone enter the toolbox to collect the connecting guide pipe while manually operating the toggle unlock.
(4) Fixing jig failure	① Guide pipe clamp operation failure	- Verify operation prior to processing.	1) Release the pressure on the guide pipe by releasing the water pressure in the clamp cylinder to free the cylinder, and collect the connecting guide pipe. 2) Collect the connecting guide pipe and then collect the fixing jig.
	② An object catches on the fixing jig (except for defective clamp operation)		1) Release the jig clamp and remove the connecting guide pipe. Leave the fixing jig as is.
(5) Toolhead operation failure	① Malfunction at maximum operation of α-axis or R-axis	- Check shaft operation before collecting the connecting guide pipe.	1) It is necessary to consider an axis that allows joints to become free and collectible when the α- and R-axes interfere with the fixing jig during connecting guide pipe collection.
	② Backward reaction force receiver operation failure	- Taper the shape of the backward reaction force receiver. Consider this design so that even if the reaction receiver push operation fails, the guide pipe can be lifted and lowered to allow the reaction receiver to slide and be collected without snagging, even if it interferes with other equipment.	–

Note: The necessary spare parts for all matters should be prepared ahead of time.

6. Implementation details

(1) Upgrading of processing technology for the top-access investigation method

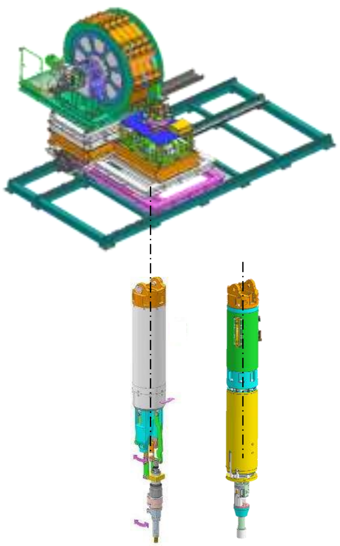
8) Summary

① Results obtained in FY2022

[Common (Laser & AWJ cutting)]
- Issues and countermeasures for each processing technology were examined based on results obtained through FY2021, and a development plan was formulated.

[Laser cutting]
- The specifications of the laser cutting device (prototype) were studied, and a prototype was designed and manufactured.
- The functional verification of the laser cutting device (prototype) was tested, and its functional verification was deemed to be satisfactory.

[AWJ cutting]
- The composition was reviewed to stabilize the abrasive feed rate and a prototype of this sub-element was designed and manufactured.
- A partial element prototype of a toolhead tip that allows for remote replacement of the nozzle and camera was designed and manufactured.
- Functional verification tests were conducted for each component prototype and their functional verification was deemed to be satisfactory.



Laser cutting equipment (prototype)

② Issues to be addressed (FY2023 and beyond)

Processing technology	No.(*)	Issues to be addressed
Laser	1	Feasibility of the remote equipment considering actual equipment (Prototype machine cutting performance)
	2	Nozzle maintenance
	3	Effect of dross on cutting
	4	Influence of the actual operating environment (Temperature, humidity, and atmospheric conditions)
	5	Assist gas restrictions (type and flow rate)

Processing technology	No.(*)	Issues to be addressed
AWJ	7	Abrasive feed rate stabilization (partial element prototype cutting performance)
	8	Nozzle maintenance (design and manufacture of actual equipment, etc.)
Common	10	Treatment of cut pieces (transfer)
	11	Radiation resistance of components
	12	Durability of components
	13	Installation method in case of damaged and deformed reactor internals
	14	Responses to uncollectible connecting guide pipes

(*): The Issue No. corresponds to the list of development issues on slides 11 to 13.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

<Implementation details up to FY2021>

For investigations into the reactor pressure vessel (RPV) interior, the necessity of investigation via bottom access was verified, existing technologies that have been developed or are currently in development in other subsidy projects were reviewed, and the applicability of access technologies for each unit was evaluated. Investigations for Unit 1 were narrowed down to a use of a drone (wired/wireless). Simplified testing and element testing were conducted to evaluate the feasibility of the selected technologies.

<Summary of implementation in FY2022>

① Formulation of a bottom access investigation plan and development plan for investigation equipment
Develop an investigation plan that incorporates access equipment under development in other projects and formulate a development plan for investigation equipment.

② Test manufacturing of bottom access and investigation equipment, functional verification testing
Design and manufacture prototypes and confirm that unit functions are satisfactory.

<Implementation details for FY2022>

Implementation details	
①	Study countermeasures to investigation issues
②	Examine and draft an investigation plan and development plan
③	Specification study/design and manufacturing of investigation equipment considering actual equipment
④	Confirmation of performance of the functions by functional verification tests

<Results>

- Based on results up to FY2021, issues were identified and countermeasures were examined.
- The investigation plan and development plan were reviewed with consideration to customizing access equipment under development in other projects and incorporating them into plans.
- The specifications of each device were studied, and devices were designed and manufactured. Functional verification tests were also conducted on these devices to evaluate their performance of the functions.

(2) Development of the bottom access investigation method (drone)

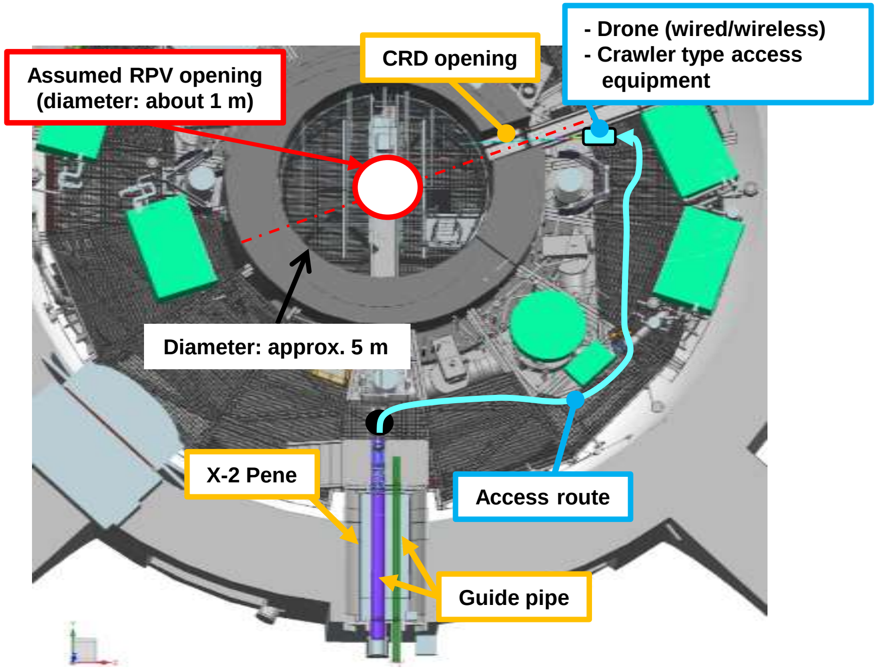
1). Results as of FY2021 (1/2)

For investigations into the reactor pressure vessel (RPV) interior, the necessity of investigation via bottom access was verified, existing technologies that have been developed or are currently in development in other subsidy projects were reviewed, and the applicability of access technologies for each unit was evaluated. Investigations for Unit 1 were narrowed down to a use of a drone (wired/wireless). Simplified testing and element testing were conducted to evaluate the feasibility of the selected technologies.

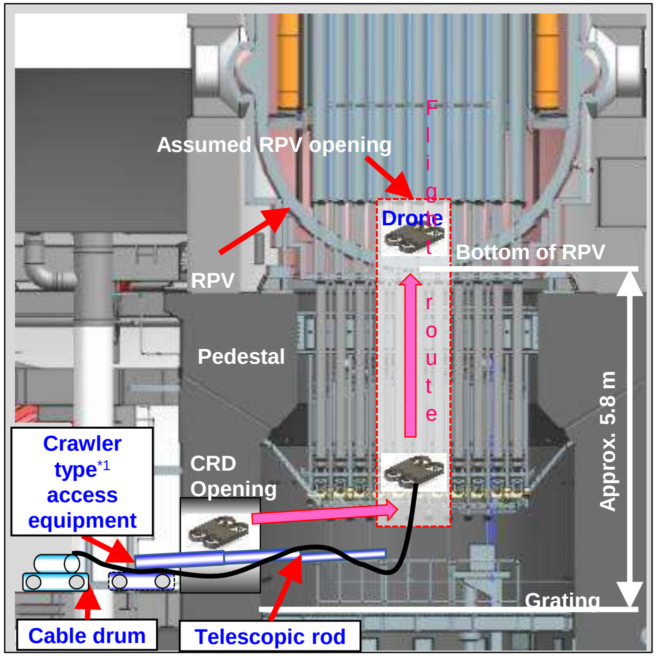
Implementation details and results

1. Narrowing down access technologies based on investigation demands

Investigation demands	Obtain image data and dose rate	Access technology	The access technology for Unit 1 was narrowed down to the use of a drone (wired/wireless).



Access route overview (X-2 Penetration (Pene) to CRD opening)



*1: Assumed applications include cable feed for wired drones and radio relay for wireless drones.

Access route overview (CRD opening to RPV interior bottom)

6. Implementation details

Unit 1 **No.41**

(2) Development of the bottom access investigation method (drone)

1). Results as of FY2021 (2/2)

For investigations into the reactor pressure vessel (RPV) interior, the necessity of investigation via bottom access was verified, existing technologies that have been developed or are currently in development in other subsidy projects were reviewed, and the applicability of access technologies for each unit was evaluated. Investigations for Unit 1 were narrowed down to a use of a drone (wired/wireless). Simplified testing and element testing were conducted to evaluate the feasibility of the selected technologies.

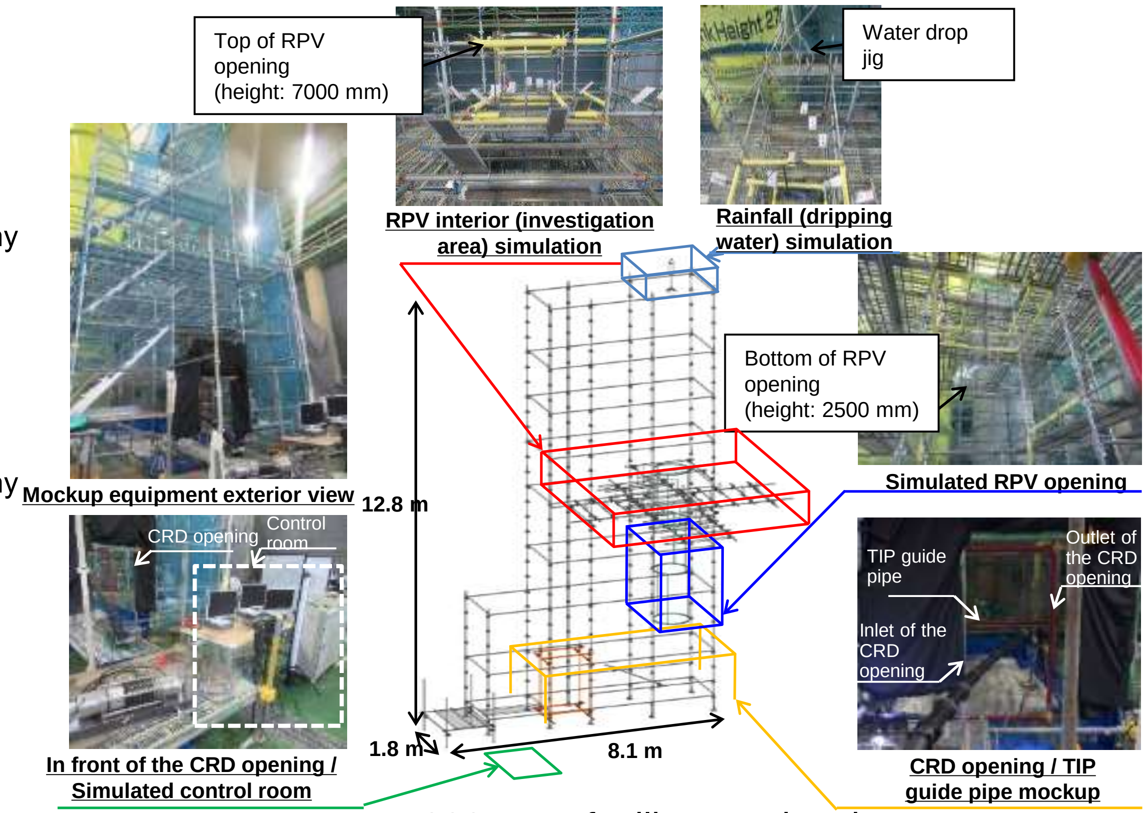
Implementation details and results

2. Conduct simplified tests and element tests

Wired drone:
- Improved flight performance
  → Achieved target flight height of 7 m.
- Improved investigation performance
  → Verified that investigation is possible in dark/rainy environments by panning and tilting the camera.

Wireless drone:
- Improved flight performance
  → Continuous flight time of about 6 minutes is possible.
- Improved investigation performance
  → Verified that investigation is possible in dark/rainy environments by panning and tilting the camera.
- Communications check
  → Based on tests and analyses, prospects of communication with the actual equipment are favorable.

Ancillary system:
- Cable drum
  → Verified electrified cable drum performance.
- Bird's eye camera
  → Bird's eye camera monitored drones in flight to improve maneuverability.



FY2021 test facility exterior view

6. Implementation details

(2) Development of the bottom access investigation method (drone)

2). Development flow

Target	FY2021 results (issues) Example content/result	FY2022 Desk study / Prototype design and manufacturing		FY2022 Test	FY2023 (*) Examination of applicability to actual equipment / combined test	FY2024 and later (*) Preparation for application to actual equipment
Overall method	**Element testing** ① Identify advantages, disadvantages, and issues for both wired and wireless drones	**Review of investigation plan** ① Review investigation procedures for wired and wireless drones ② Case studies for the investigation plan ③ Reconfirm issues	**Formulation of proposed development plan** ① Establish evaluation items and target goals for the method ② Examine the outline and test items of FY2022 functionality verification tests ③ Formulate a draft development plan for FY2022 and beyond	– (FY2022 is scheduled to focus on verifying performance of the functions)	**Formulation of development plan for actual equipment** ① Review the development plan as necessary, reflecting equipment design and test results ② Examine risk response scenarios such as recovering from a crash, the collection method if an object becomes stuck, and measures to take in the event of contamination ③ Formulate an investigation plan for actual equipment	**Manufacturing equipment for investigations of actual equipment** Work verification / Feedback **Mockup testing**
Wired and wireless drones / access equipment	**Element testing** ① Heat generated by interior parts [wired] ② Insufficient reserve flight time [wireless] ③ Cable drum feeding failure	**Re-examination of existing products and technologies** ① Research electronic components that generate little heat ② Reevaluate mounted cameras ③ Examine the applicability of equipment developed in other PJ (access equipment and cable assistance devices)	**Equipment design and prototyping** ① Re-organize assumptions, design conditions, and required specifications ② Design equipment for actual equipment (initial design) ③ Research lightweight high-capacity batteries ④ Evaluate and review improvements of equipment developed in other PJs	**Functionality verification testing** ① Confirm the possibility of achieving required specifications (projected) ② Identify points for improvement for FY2023 and beyond		**Detailing of work procedures and investigation process** **Work training** Review
Individual issues (Example)	**Element testing** ① Insufficient radiation resistance of some onboard electronic components	**Re-examination of existing products and technologies** ① Research flight controllers without products that cause radiation resistance degradation	**Study of electronic components** ① Newly design and prototype electronic components when commercial products do not exist	**Functionality verification testing** ① Conduct irradiation tests to verify radiation resistance	**Equipment improvements & combined testing** ① Reflect the results of each functionality verification test in designs of devices for the actual equipment ② Conduct combined tests	Using actual equipment
	② Drones can pass through an opening of □800 while contacting the frame [wired/wireless]	**Review of operation and control methods** ① Examine control methods that can improve in-flight stability ② Investigate the need to improve operability	**Study of control methods** ① Consider whether to implement the drone being developed ② Study improvements to increase operability	**Functionality verification testing** ① Confirm the degree of improvement in in-flight stability	**Preparation of mockups** ① Create a mockup verification plan ② Draft a basic design of mockup equipment	Evaluation of items assumed in actual equipment and reflection in procedures - Route for investigation - Investigation performance (camera visibility) - Flight time, flight performance (including operational performance) - Prospect of obtaining information - Performance assessment of peripheral equipment such as telescopic rods, cable drums, cable supports, etc.
	③ Lack of extra payload makes it difficult to use small dosimeters developed in other PJs in wireless drones [wireless]	**Re-examination of existing products and technologies** ① Research lightweight dosimeters that can be mounted on wireless drones	**Development of dosimeters** ① Newly design and manufacture dosimeters when commercial products do not exist	**Functionality verification testing** ① Check whether the required functions can be achieved		

Plans for FY2023 and beyond are proposals from the project implementer and have not been decided.

6. Implementation details

Unit 1

(2) Development of the bottom access investigation method (drone)

3). Development issues and action policies (1/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items	Corresponding slide No.
1	Overall investigation method	—	Feasibility of the investigation method series (including access from X-2 Pene to CRD opening)	Based on FY2021 test results, the investigation method series will be studied when using wired/wireless drones and ancillary equipment (including products developed in other projects).	Conducted	- Gather information from other projects - Desk study	No.46 to 48
2	Equipment for accessing the inside of the pedestal	Telescopic rod	Cable pinching during rod retraction	Encase the cable inside the telescopic rod. (Lateral development from other projects)	Conducted	Reflect in prototype design and conduct functional verification tests	No.54
3			Radiation resistance of electronic components	Order the applicable conditions (air dose rate and investigation time) and conduct irradiation testing to confirm the radiation resistance of electronic components.	— (None)	— (To be conducted in FY2023 or later because it can refer to development results of surveys of pedestal interior and the payload constraints of the equipment are small, so shielding measures, etc. are easy to adopt)	—
4			Equipment durability	Conduct continuous operation tests in an environment simulating actual operating conditions to confirm durability.	— (None)	— (To be conducted in FY2023 or later, as it was deemed reasonable to check with equivalent equipment after the design of the actual equipment is decided)	—
5		Cable drum (wired drone)	Improved cable feed - Event of cable feeding to the back of the drum - Cable feed roller idling - Unable to verify feed rate	- Review of cable drum structure and function - Study of the feed rate verification method (additional cameras, etc.)	Conducted	Reflect in prototype design and conduct functional verification tests	No.55
6			Treatment of cable drum drive cable	Examine devices that can assist the driving cable. (Including consideration of the applicability of the cable assistance device being developed in the investigation inside the pedestal)	Conducted	- Desk study - Gather information from other projects - Reflect findings in prototype design and conduct functional verification testing	No.56
7			Radiation resistance of electronic components	Order the applicable conditions (air dose rate and investigation time) and conduct irradiation testing to confirm the radiation resistance of electronic components.	— (None)	— (To be conducted in FY2023 or later because it will travel outside the pedestal, where the dose rate is relatively low (approximately 10 Sv/h), and the payload constraints of the equipment are small, so shielding measures, etc. are easy to adopt)	—
8			Equipment durability	Conduct continuous operation tests in an environment simulating actual operating conditions to confirm durability.	— (None)	— (To be conducted in FY2023 or later, as it was deemed reasonable to check with equivalent equipment after the design of the actual equipment is decided)	—

6. Implementation details

(2) Development of the bottom access investigation method (drone)

3). Development issues and action policies (2/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items	Corresponding slide No.
9	Access equipment from inside the pedestal to inside the RPV	Common to wired/wireless drones	Drone miniaturization	Conduct case studies on miniaturization. (Also examine miniaturization by reducing the number of on-board components)	**Conducted**	- Desk study - Reflect findings in prototype design and conduct functional verification testing	**No.49**
10			Flight control	Review of control methods	**Conducted**	Desk study	**No.70**
11			Water droplets on camera lens	Examine measures such as applying lens coatings.	**Conducted**	Reflect in prototype design and conduct functional verification tests	**No.50 and 52**
12			Landing position confirmation (FY2021 once-through tests in dark environments experienced visibility issues with landing position)	Examine measures such as adding lighting to ancillary equipment.	**Conducted**	Reflect in prototype design and conduct functional verification tests	**No.54 and 55**
13			Radiation resistance of electronic components	- Research new flight controllers (because FY2021 irradiation tests determined that the compass sensor was unusable) - Organize the applicable conditions (air dose rate and survey time) and conduct irradiation testing in an energized state to verify the radiation resistance of electronic components and the impact on operation. (including confirmation of the impact on camera images)	**Conducted**	- Review of flight controller - Irradiation testing	**No.51 and 53** **No.80 and 81** **No.86 to 88**
14			Equipment durability	Conduct continuous operation tests in an environment simulating actual operating conditions to confirm durability.	— (None)	— (To be conducted in FY2023 or later, as it was deemed reasonable to check with equivalent equipment after the design of the actual equipment is decided)	—
15			Increasing flight altitude limit	Testing will verify whether the drones can fly above 11 m (core support plate height). (FY2021 tests confirmed the feasibility of the 7 m target flight height required for investigations, so the response is set to HOLD. The need for a response will be reconfirmed based on the results of responses to other projects and other issues)	— (None)	— (HOLD)	—

6. Implementation details

(2) Development of the bottom access investigation method (drone)

3). Development issues and action policies (3/3)

No.	Major items	Intermediate items	Development issues	Action policy (plan)	Conducted or not in FY2022	FY2022 test/action items	Corresponding slide No.
16	Access equipment from inside the pedestal to inside the RPV	Wired drone	Heat generation of electronic components	Examine measures such as reviewing the internal structure and adding heat sinks, air-cooling fans, or other components.	**Conducted**	Reflect in prototype design and conduct functional verification tests	**No.50**
17			Inclusion of the drone in the investigation images	Consider reviewing the structure.	**Conducted**	Reflect in prototype design and conduct functional verification tests	**No.50**
18		Wireless drone	Research or consideration of lightweight radiation sensors that can be mounted	Consider small and lightweight radiation sensors.	**Conducted**	- Desk study - Prototyping of element technologies	**No.52**
19			Extending flight time	- Consider reviewing the battery. - Study measures to reduce power consumption (Although FY2021 tests showed that the flight time required for the survey was achievable, studies will be continued in consideration of combination with ancillary equipment and providing reserve flight time.)	**Conducted**	- Desk study - Prototyping of element technologies	**No.52**
20	Others	Installation equipment for the PCV	Feasibility of X-2 Pene passage via installation equipment used in other projects	Determine if installation equipment for investigations inside the pedestal can be diverted. If it cannot, organize changes to make.	**Conducted**	- Desk study - Prototyping of element technologies	**No.57 to 60**
21		Risk response	Drone crash impact assessment	Extract risks and study countermeasures, then reflect them in the design.	**Conducted**	Desk study	**No.69**
22			Contamination of components	Extract risks and study countermeasures, then reflect them in the design.	— (None)	— (To be conducted in FY2023 or later, as it was deemed reasonable to prioritize studies of equipment designs for which a survey can be conducted)	—

6. Implementation details

Unit 1 No.46

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ① Revision of investigation plan

- From the results of the case studies below, the following operations were determined to be highly feasible for investigations using wired and wireless drones.
  1. A wired drone with ample flight time will verify damage and the flight path for the following wireless drone. If possible, it will also investigate the bottom of the RPV interior (approximately 7 m above the platform inside the pedestal) and then return.
  2. A wireless drone will investigate the area near the top of the core support plate (approximately 11 m above the platform inside the pedestal), as wired drones cannot investigate this area.
- FY2022 prototypes will have on-board equipment and body configurations according to the respective roles of wired and wireless drones.

No.	Investigation case	Investigation equipment configuration		Investigation procedure	Drone-mounted investigation equipment (*1)		Advantages	Disadvantages	Feasibility for investigation	Feasibility for investigation (*2) (Image acquisition only)
		Wired drone	Wireless drone		Investigation equipment	Components				
1	Single wired drone	1 unit	-	Investigation of the bottom of the RPV interior (altitude approx. 7 m) with a single wired drone	Wired drone	- Steering/ investigation camera - Dosimeter	- Long flight (investigation) times are possible - Stable communication (steering/video)	- Limited flight freedom/altitude (FY2021 test results: maximum flight height of 8 m). - If the bottom of the RPV interior cannot be accessed vertically, there is a risk that increasing the tow cable length would prevent the drone from reaching the investigation location.	△	○
2	Single wireless drone	-	1 unit	Investigation of the bottom of the RPV interior (altitude approx. 7 m) with a single wireless drone	Wireless drone	- Steering/ investigation camera - Dosimeter	Ample flight freedom and altitude	- Short flight duration (FY2021 test results: approx. 6 minutes) - Video noise (from multipath) - Risk of wireless communication failure	×	×
3	Multiple wireless drones	-	2 units (*1)	1. The wireless drone A checks for damage, verifies the flight path for the following drone B, and then returns 2. Wireless drone B investigates the bottom of the RPV interior (altitude approx. 7 m)	Wireless drone A (preliminary investigation) Wireless drone B (investigation)	- Steering camera - Steering/ investigation camera - Dosimeter	- Wireless drones A/B have the same advantages listed in No.2 - Wireless drone A can have extended flight time (due to reduced aircraft weight) - Wireless drone A will check the flight route, so the flight time of wireless drone B can be shortened	- Wireless drones A/B have the same disadvantages listed in No.2 - Short flight time may prevent adequate investigation	△	△
4	Combination of wired drone/wireless drone	1 unit	1 unit (*1)	1. The wired drone will check for damage and verify the flight path for the following wireless drone. If possible, it will investigative the bottom of the RPV interior (height approx. 7 m) and then return 2. The wireless drone will investigate from the bottom of the RPV interior (altitude: approx. 7 m) to the top of the interior (top of the core support plate) (height approx. 11 m)	Wired drone (preliminary investigation) Wireless drone (investigation)	- Steering/ investigation camera - Dosimeter - Steering/ investigation camera - Dosimeter	- The wired drone has the same advantages listed in No.1 and the wireless drone has the same as those listed in No.2 - The wired drone can scout the flight route of the wireless drone, reducing flight time for the wireless drone - There are prospects for obtaining additional information on the upper section of the RPV interior	The wired drone has the same disadvantages listed in No.1 and the wireless drone has the same as those listed in No.2	○	◎

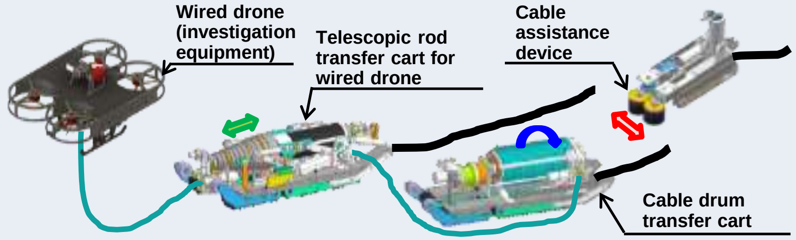
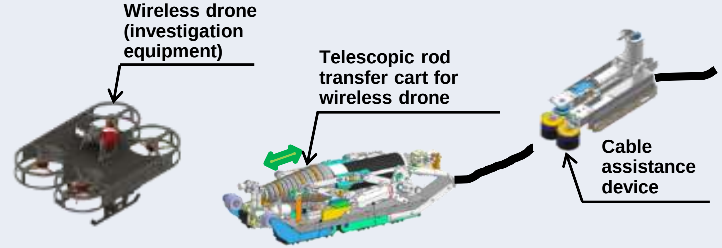
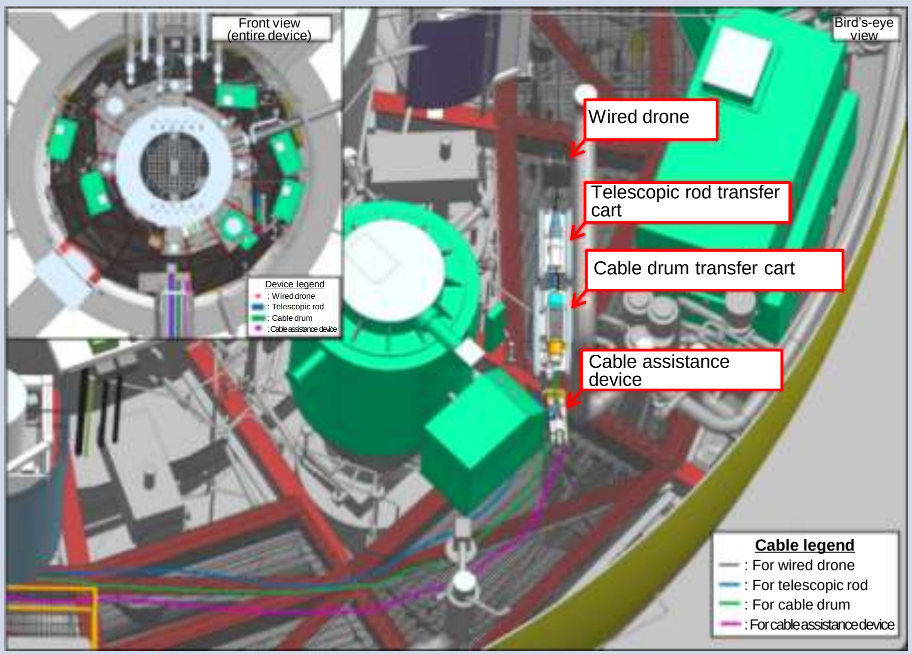
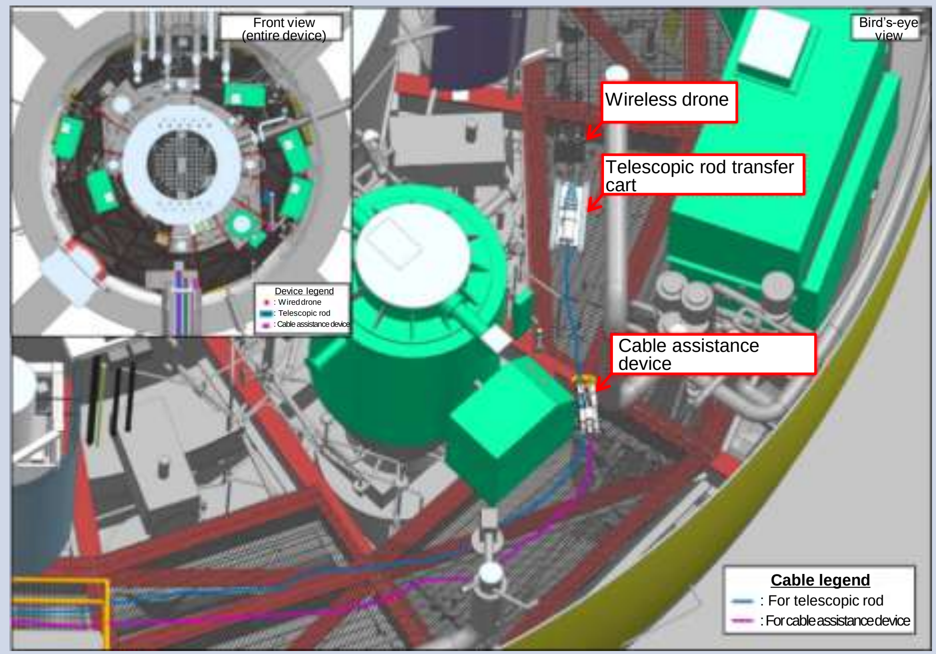
(*1) The number of units, investigation procedures, and the configuration of drone-mounted investigation equipment will be reviewed as necessary depending on the progress of the study.
(*2) Feasibility of investigation when the drone is not equipped with a dosimeter and used solely to obtain images. A wired drone will not require a dosimeter cable, reducing the weight of the composite cable and increasing flight altitude. The mass of the wireless drone can be reduced by the mass of the dosimeter, thereby extending flight time.

Investigation feasibility legend:
◎: Highly feasible, may be able to obtain additional information
○: Highly feasible
△: Some parts may not be feasible
×: Low feasibility

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ② Overall investigation system configuration (1/2)

Category	Wired drone investigation system	Wireless drone investigation system
Equipment configuration	Wired drone / Telescopic rod transfer cart / Cable drum transfer cart / Cable assistance device / Installation equipment / Other devices (surveillance cameras, etc.)	Wireless drone / Telescopic rod transfer cart / Cable assistance device / Installation equipment / Other devices (surveillance cameras, etc.)
Outline (after installation)		
Bird's-eye view (after installation)		

6. Implementation details

Unit 1

No.48

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ② Overall investigation system configuration (2/2)

Category		Equipment overview	Test-manufactured or not in FY2022		Slide No. describing prototype
Wired	Wired drone	• Installs through the 350A opening of the X-2 Pene, flies over the platform outside the pedestal, enters the pedestal through the CRD opening, and accesses the RPV interior through the anticipated opening at the bottom of the RPV. • Investigates (obtains video and measures dose rate) the bottom of the RPV (about 7 m from the CRD replacement platform) while towing the composite cable that is fed from the tip of the telescopic rod.	Manufactured	Improvements from the FY2021 prototype	No.49 to 51
	Telescopic rod transfer cart for wired drone	• Once the wired drone is installed, installs in the PCV through the 350A opening of the X-2 Pene and travels over the remaining B1 investigation equipment to the front of the CRD opening. • Extends the telescopic rod from the CRD opening to near the bottom of the anticipated opening on the bottom of the RPV inside the pedestal. • The rod tip contains a mechanism that can feed and wind the composite cable from the wired drone.	Manufactured	Partial improvements from other project equipment*	No.54
	Cable drum transfer cart	• After the telescopic rod transfer cart is installed, installs through the 350A opening of the X-2 Pene and travels over the remaining B1 investigation equipment to the front of the telescopic rod transfer cart. • The cable drum winds the composite cable on the wired drone and contains a mechanism that can feed and wind the cable. The composite cable on the wired drone runs along the telescopic rod on the telescopic rod transfer cart and connects to the wired drone via the cable feed/wind mechanism at the tip of the rod.	Manufactured	• Improvements to the cable drum from the FY2021 prototype • Partial improvements to the drive function from other project equipment*	No.55
Wireless	Wireless drone	• Installs through the 350A opening of the X-2 Pene, flies over the platform outside the pedestal, enters the pedestal through the CRD opening, and accesses the RPV interior through the anticipated opening at the bottom of the RPV. • Investigates (obtains video and measures dose rate) the upper surface of the core support plate (about 11 m from the CRD replacement platform) while communicating wirelessly with the wireless equipment at the tip of the telescopic rod.	Manufactured	Improvements from the FY2021 prototype	No.40, 52 and 53
	Telescopic rod transfer cart for wireless drone	• Once the wireless drone is installed, installs in the PCV through the 350A opening of the X-2 Pene and travels over the remaining B1 investigation equipment to the front of the CRD opening. • Extends the telescopic rod from the CRD opening to near the bottom of the anticipated opening on the bottom of the RPV inside the pedestal. • The rod tip contains a transceiver for wireless communication with the wireless drone.	Manufactured	Partial improvements from other project equipment*	No.54
Common to wired & wireless	Cable assistance device	Installs from the 250A opening of the X-2 Pene, and uses the cable assistance mechanism to assist and move the composite cable from either the telescopic rod transfer cart or the cable drum transfer cart installed on the platform outside the pedestal within the area up to the front of the remaining B1 investigation equipment in order to prevent snagging and other issues.	Manufactured	Partial improvements from other project equipment*	No.56
	Installation equipment	This device installs equipment inside the PCV from existing X-2 Pene guide pipes.	Manufactured (Partial prototype)	Partial improvements from other projects devices*, element prototype for 350A only	No.57 to 60
	Other auxiliary machines	Installs in the X-2 Pene opening to assist during installation and uninstallation. (Assumes surveillance cameras for installation and uninstallation, equipment dose rate measurement and cleaning devices for uninstallation, and equipment for cutting the composite cable in the event of an emergency (auxiliary machines shall be reviewed accordingly based on the results of future studies)).	–	No FY2022 prototype	–

*Development of Technology for Detailed Investigation inside PCV

6. Implementation details

(2) Development of the bottom access investigation method (drone)

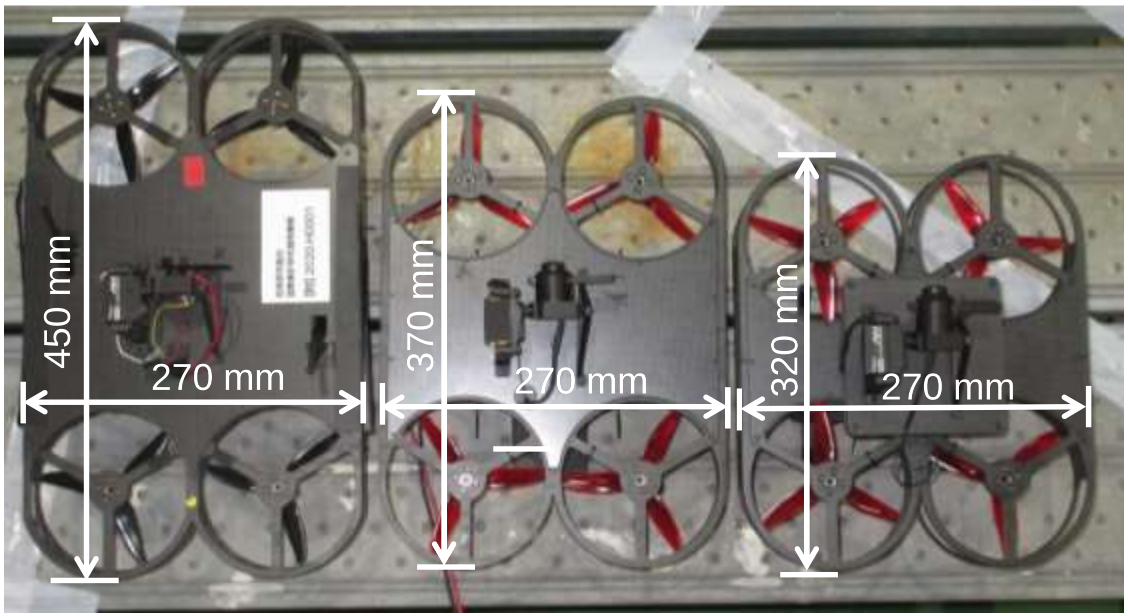
4). FY2022 implementation details ③ FY2022 prototypes (wired/wireless drone miniaturization)

- **Reduction in the size of both wired and wireless FY2021 prototype drones by reviewing parts and their configuration on the devices**
- **The wireless drone was designed to investigate areas that the wired drone cannot reach (assumed to be the upper inside area of the RPV and wall surfaces), so its size was reduced by eliminating the pan/tilt function of the camera on the bottom of the drone and placing the battery and dosimeter in the vacant space.**

Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
9	Drone miniaturization	Reviewed component layout and configuration, miniaturized

*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.



FY2021 wireless drone (wired drone has the same shape)
FY2022 wired drone
FY2022 wireless drone

Drone miniaturization (compared to FY2021 drone prototype)

Appearance of the lower part of the FY2022 wired drone

Appearance of the lower part of the FY2022 wireless drone

6. Implementation details

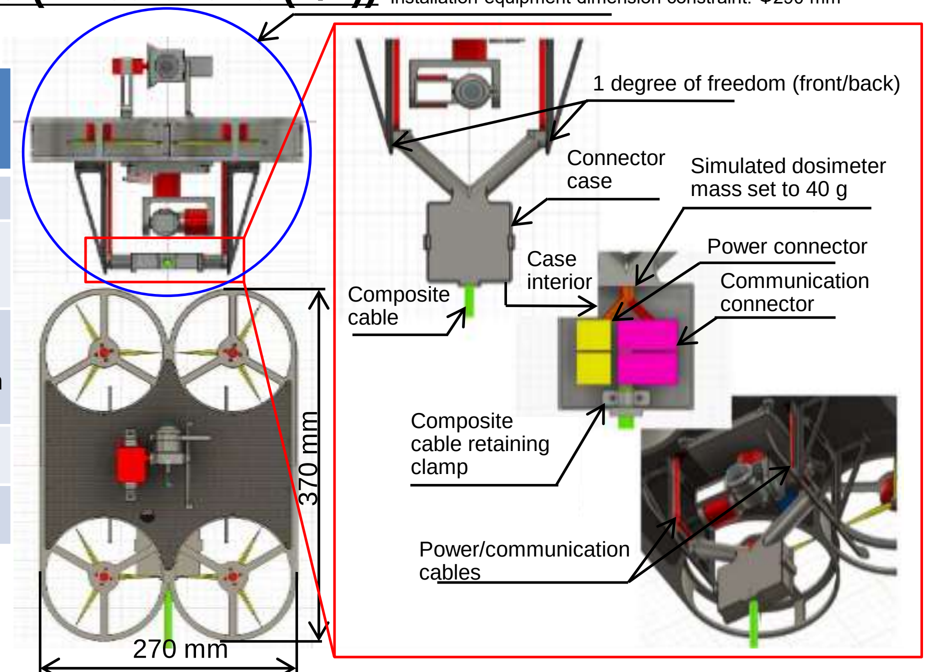
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (wired drone (1/2))

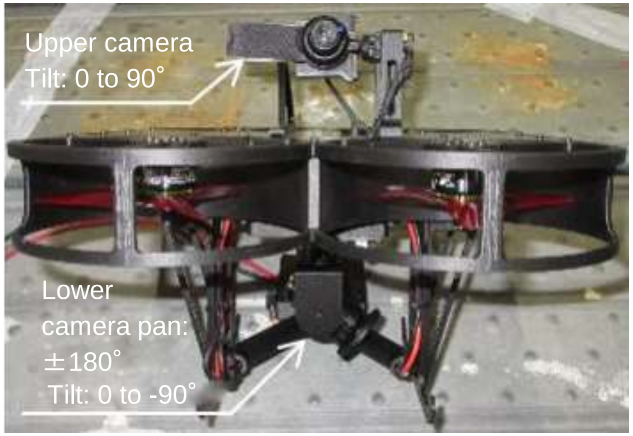
Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
11	Water droplets on camera lens	Hydrophilic coating on camera lens
12	Landing position confirmation	Addition of LED lights to mark the landing position on the telescopic rod transfer cart and cable drum transfer cart (see No.54 and 55)
13	Radiation resistance of electronic components	• Installation of a flight controller that does not have a compass sensor • Cameras were selected and mounted based on irradiation tests (see slides No.80 and 81)
16	Heat generation of electronic components	Added air cooling fan
17	Inclusion of the drone in the investigation images	Reviewed the design of cable connections

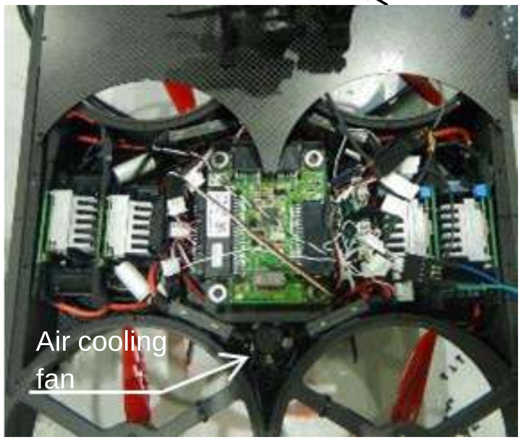
*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.



FY2022 prototype drawing



External view of FY2022 prototype



Inside the FY2022 prototype

*2 Dosimeter optical fiber (0.04 g/m) is not installed. PEEK tube for protection is installed.

During horizontal flight

6. Implementation details

(2) Development of the bottom access investigation method (drone)

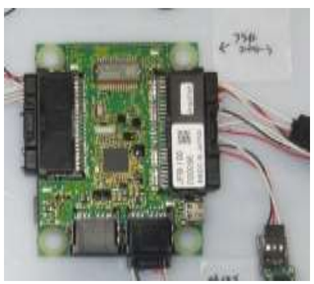
4). FY2022 implementation details ③ FY2022 prototype (wired drone (2/2))

Configuration of drone body interior

DC-DC converter

View of the added DC-DC converter

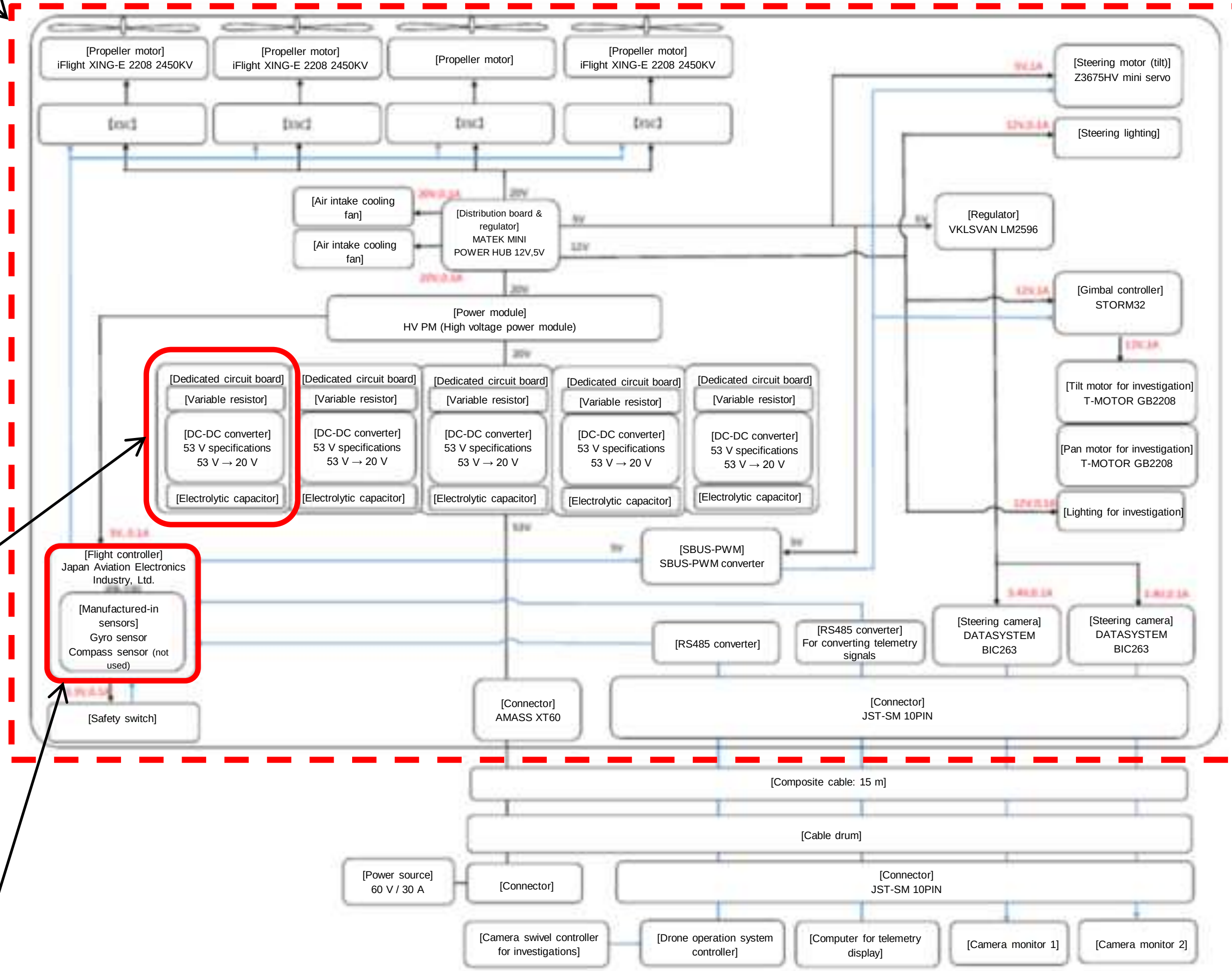
Insufficient power output prevented the drone from flying at the target height (7 m) during preliminary confirmation testing, so one DC-DC converter was added to increase output capacity from 1200 W to 1500 W as a countermeasure.



Flight controller appearance

FY2021 irradiation testing revealed that the compass sensor in the flight controller was defective, so a flight controller without compass sensor was installed.

FY2022 wired drone



Overview of configuration of FY2022 wired drone prototype

6. Implementation details

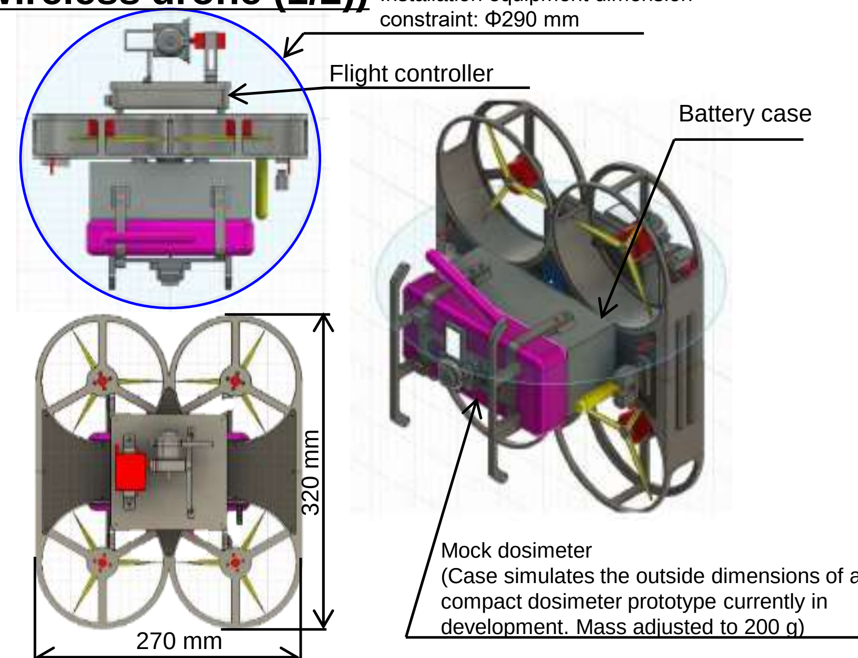
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (wireless drone (1/2))

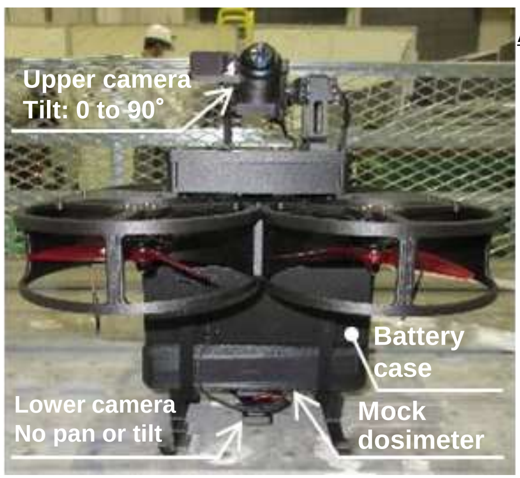
Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
11	Water droplets on camera lens	Hydrophilic coating on camera lens
12	Landing position confirmation	Addition of LED lights to mark the landing position on the telescopic rod transfer cart and cable drum transfer cart (see No.54 and 55)
13	Radiation resistance of electronic components	• Installation of a flight controller that does not have a compass sensor • Cameras were selected and mounted based on irradiation tests (see slides No.80 and 81)
18	Research or consideration of lightweight radiation sensors that can be mounted	Compact and lightweight radiation sensor in development
19	Extending flight time	• Elemental prototyping of in-house batteries • Equipped on wireless drones for energy efficient imaging (revised from 1 W to 0.01 W)

*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.



FY2022 prototype drawing



External view of FY2022 prototype

Appearance of compact dosimeter (pulse measurement type) *2

Items	FY2022 prototype
Appearance	
Size	165 × 80 × 35 mm (excluding antenna)
Weight	367 g (body: 280 g, batteries (4 pcs.): 96 g)

*2 The feasibility of a COMS type dosimeter employing a different method is being studied alongside development of the pulse measurement type. The target development weight for the next and subsequent years is 200 g or less.

Appearance of in-house battery element prototype

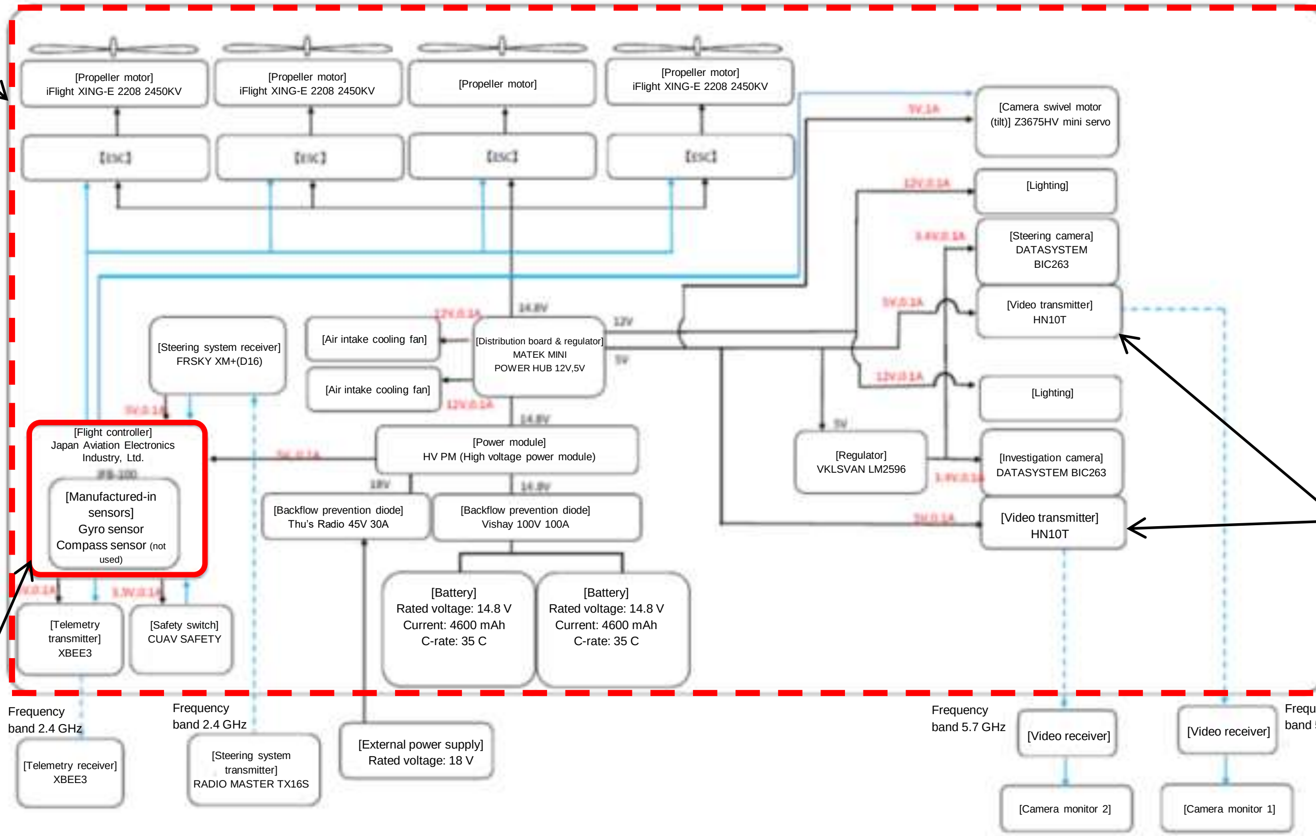
Items	In-house battery (in development)	Regular battery
Appearance		
Size	46 × 60 × 53 mm	44 × 135 × 30 mm
Capacity	6000 mAh (design value)	4600 mAh
Weight	298 g (measured value)	385 g

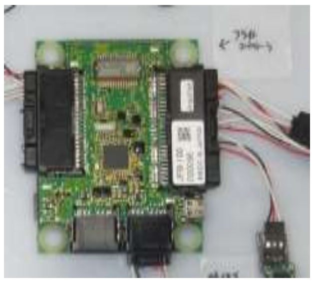
6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (wireless drone (2/2))

Configuration of drone body interior





Flight controller appearance

FY2021 irradiation testing revealed that the compass sensor in the flight controller was defective, so a flight controller without compass sensor was installed.

Output of the video system transmitter was revised from 1 W (installed in FY2021) to 0.01 W. (To reduce standby power, size, and weight.)

Overview of FY2022 wireless drone prototype configuration

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (Telescopic rod transfer cart for wired/wireless drone)

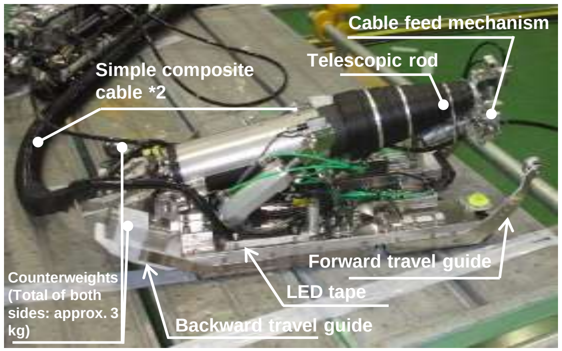
Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
2	Cable pinching during rod retraction	Encase the cable inside the telescopic rod. (Horizontal development from other projects (Development of Technology for Detailed Investigation inside PCV))

*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.

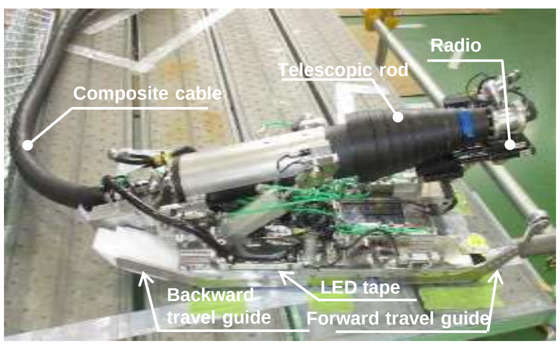
Main differences from equipment developed in other projects

Category	Main differences from equipment developed in other projects
Wired	• Addition of a cable feed mechanism at the tip of the rod • Addition of a cable guide ring • Addition of LED lighting to mark drone landing location • Pan tilt range of the camera at the tip of the rod
Wireless	• Addition of a radio at the tip of the rod • Addition of LED lighting to mark drone landing location

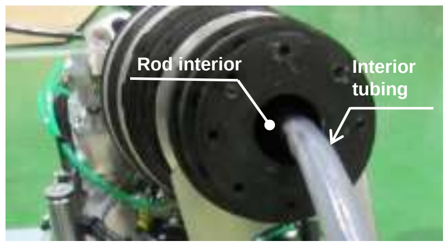


*2 Alternative because long lead times for some products prevented cable unification

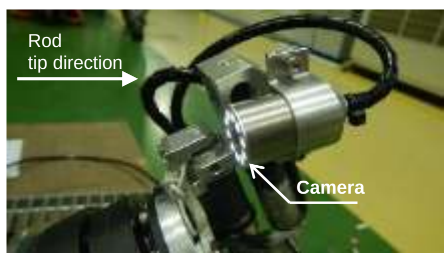
External view of FY2022 prototype (wired)



External view of FY2022 prototype (wireless)



Interior tubing for power and signal cables (both wired and wireless drones)



Revision of the pan tilt range for the camera on the tip of the wired drone rod *3

*3 To monitor the condition of the drone's composite cable at the rear of the equipment.

Appearance of the cable feed mechanism at the tip of the rod on the wired drone

Addition of guiding rings for pre-operation verification

*4 Cable guide rings and locations where the wired drone composite cable contacts the equipment were wrapped in PTFE tape to reduce chafing with the composite cable.

Overview of composite cable routing for wired drone

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (cable drum transfer cart for wired drone)

Items improved from FY2021

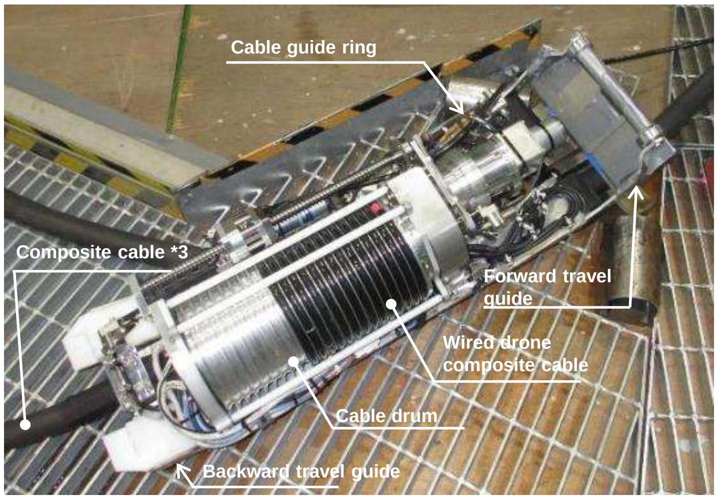
No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
5	Improved cable feed - Event of cable feeding to the back of the drum - Cable feed roller idling - Unable to verify feed rate	- Review of cable drum structure and function - Review of the direction of the cable feed - Improving roller clamping force - Adding camera to verify feed rate

*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.

Main differences from equipment developed in other projects *2

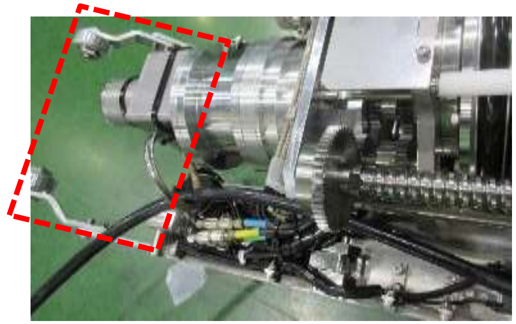
Main differences from equipment developed in other projects
• Addition of a cable guide ring • Revision of the forward travel guide structure • Addition of LED lighting to mark drone landing location

*2 Installed the crawler currently in-development from among the investigation equipment used in the Development of Technology for Detailed Investigation inside PCV PJ.



External view of FY2022 prototype

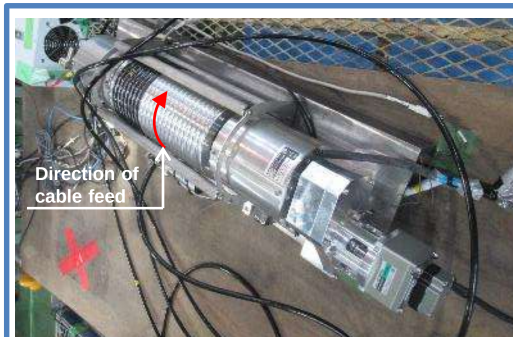
*3 Preliminary confirmation testing confirmed insufficient output power in the wired drone due to voltage drop. The power supply cable inside the composite cable on the cable drum transfer cart was thin and caused a large voltage drop, so the cable was revised from AWG14 to AWG6. The diameter of the composite cable on the cable drum transfer cart is expected to be between Φ30 mm to Φ40 mm.



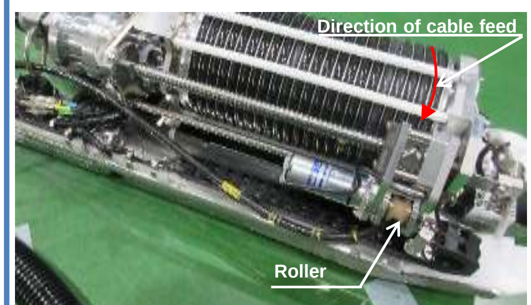
Before travel guide improvement

After travel guide improvement

Revision of the forward travel guide structure



Event of cable feeding to the back of the drum (FY2021)



Improved cable feed mechanism (FY2022)

Improved cable feed

6. Implementation details

Unit 1 No.56

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (cable assistance device)

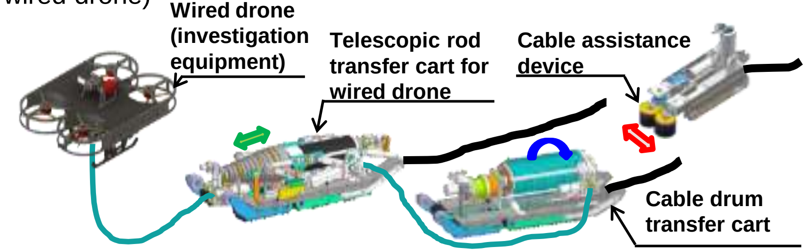
Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
6	Treatment of cable drum drive cable	Prototype cable assistance device (Horizontal development from other projects (Development of Technology for Detailed Investigation inside PCV))

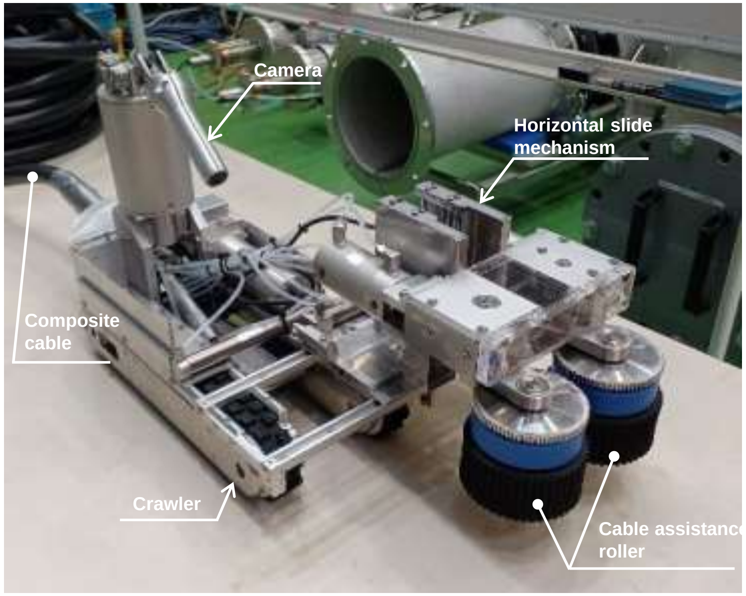
*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.

Main differences from equipment developed in other projects

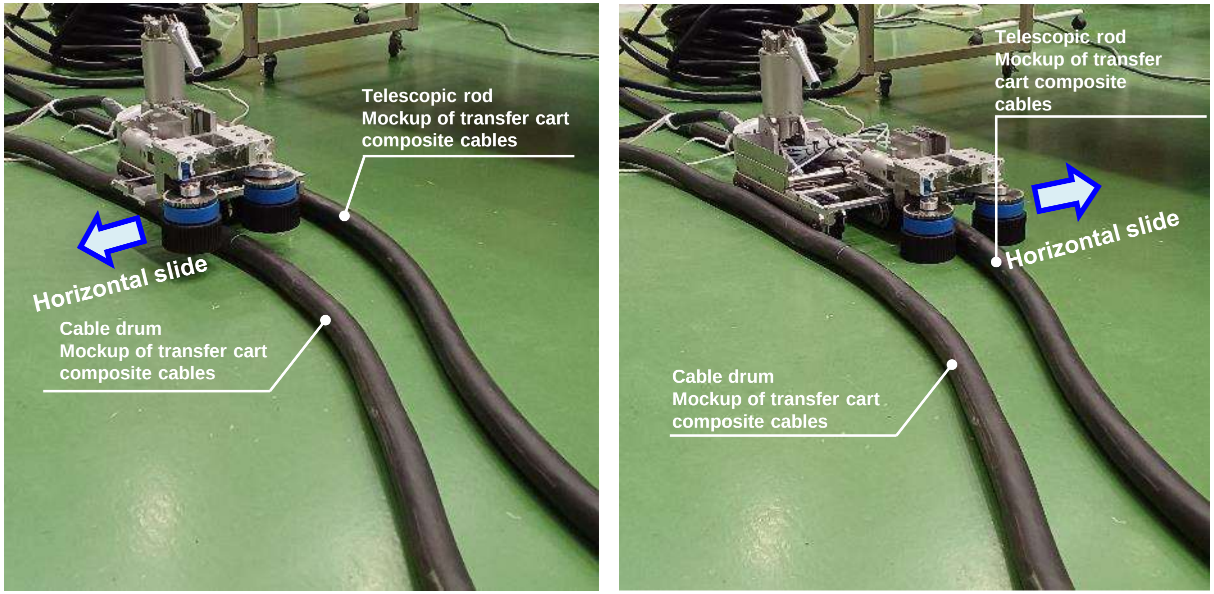
Main differences from equipment developed in other projects
Added a horizontal sliding mechanism to the cable assistance mechanism (to address the need to assist two composite cables for investigations with a wired drone)



Wired drone investigation system



External view of FY2022 prototype



When assisting two composite cables

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (installation equipment for 350A (1/4))

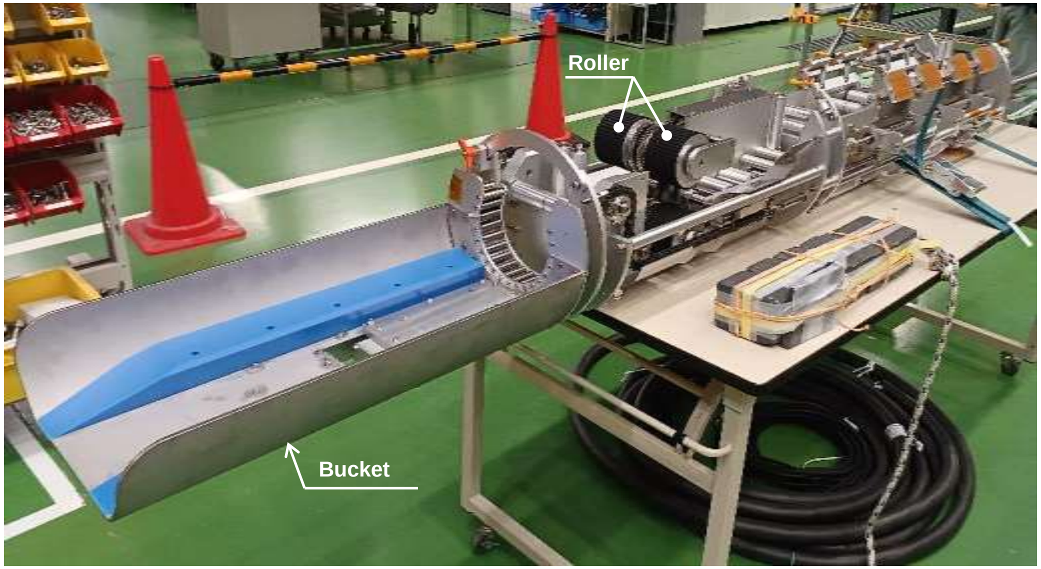
Items improved from FY2021

No. *1	Development issues extracted from FY2021 results	Details of FY2022 countermeasures
20	Feasibility of X-2 Pene passage via installation equipment used in other projects	Prototype of installation equipment for 350A (Horizontal development from other projects (Development of Technology for Detailed Investigation inside PCV))

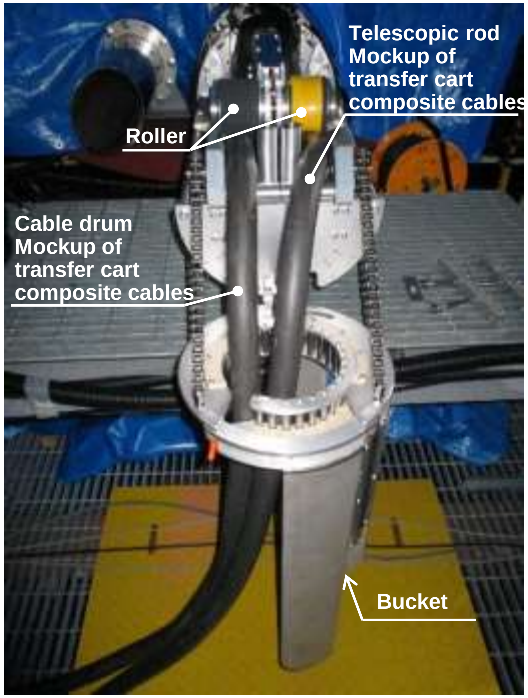
*1 Corresponding to development issues No.43 to 45 and the action policy (plan) development issue No.

Main differences from equipment developed in other projects

Main differences from equipment developed in other projects
Added cable extrusion rollers (to address the need to handle two cables for investigations with a wired drone)



External view of FY2022 prototype



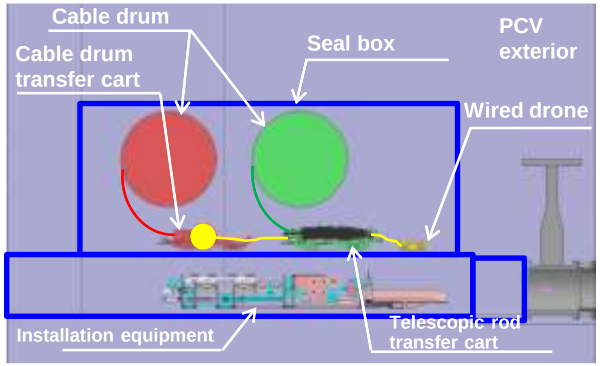
Handling of two composite cables

6. Implementation details

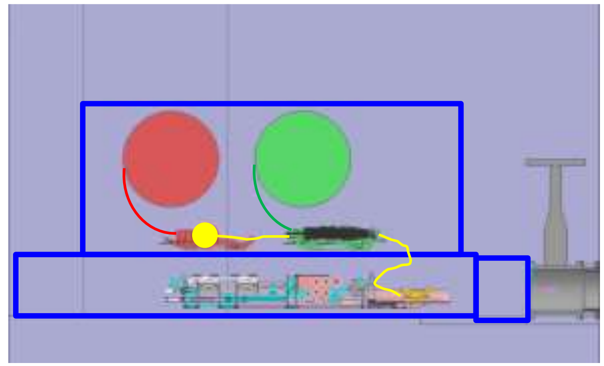
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (installation equipment for 350A (2/4))

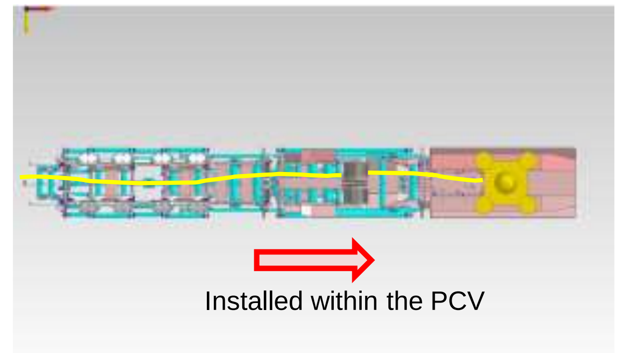
The image below shows installation of the equipment, using the 350 A Penetration during investigation with a wired drone.



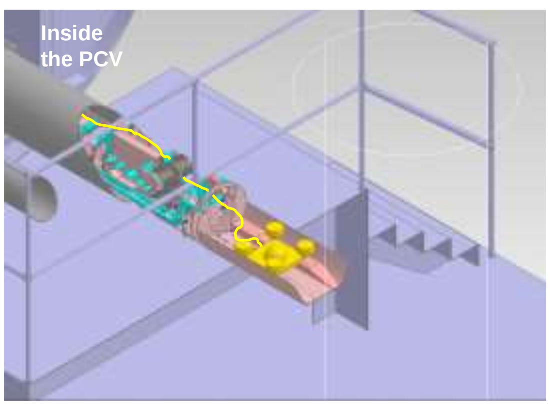
① Initial condition



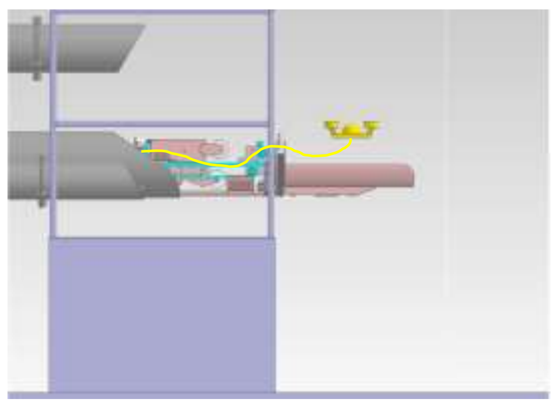
② Drone placement in the bucket



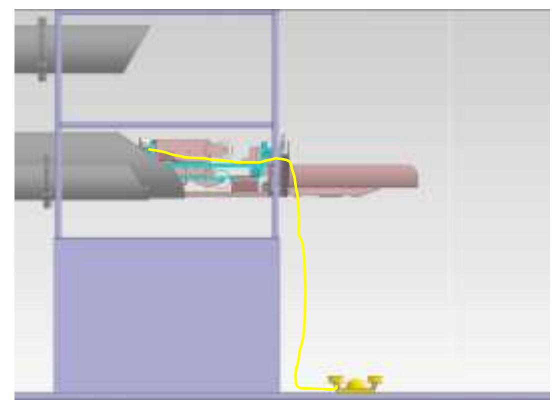
③ Drone installation



④ Arrival of drone in PCV



⑤ Drone rising



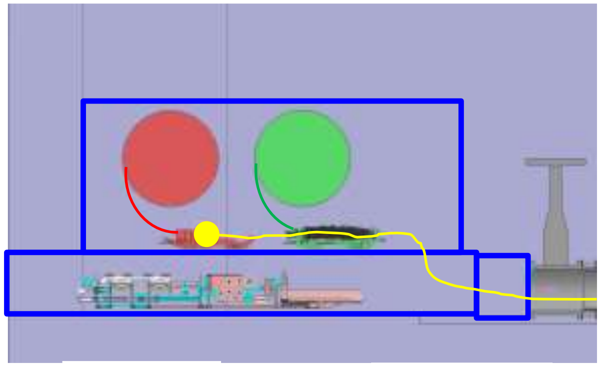
⑥ Drone landing on platform

6. Implementation details

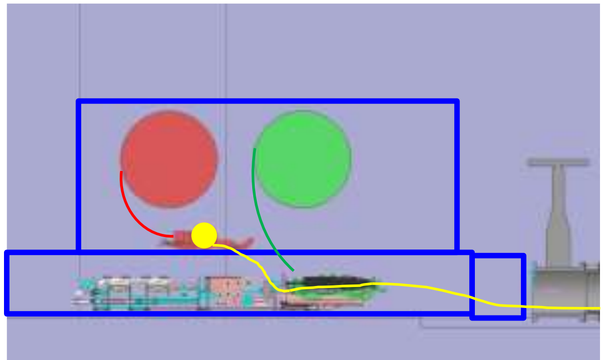
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (installation equipment for 350A (3/4))

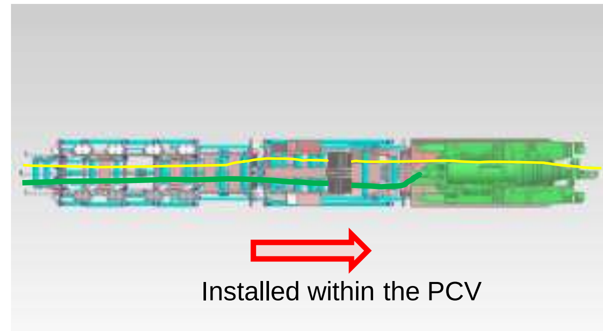
The image below shows installation of the equipment, using the 350 A Penetration during investigation with a wired drone.



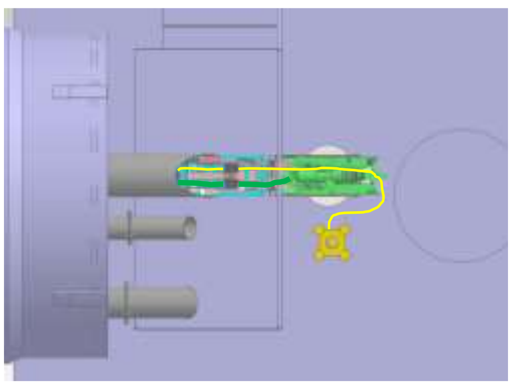
⑦ Collection of installation equipment



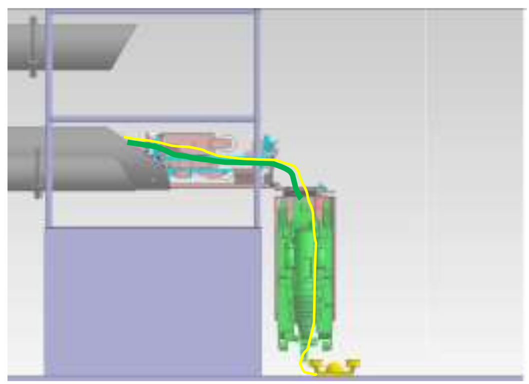
⑧ Installation of telescopic rod transfer cart in the bucket



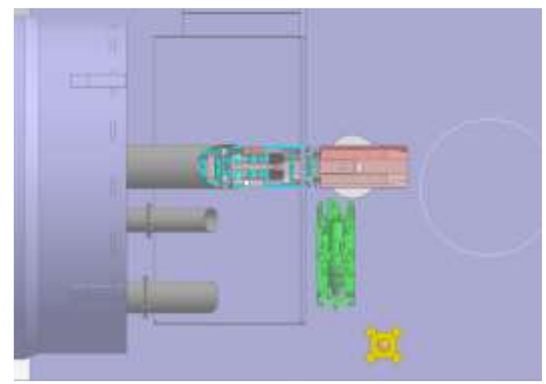
⑨ Installation of telescopic rod transfer cart



⑩ Arrival of telescopic rod transfer cart in the PCV



⑪ Bending of the bucket and lowering of the telescopic rod transfer cart



⑫ Touchdown of the telescopic rod transfer cart on the platform

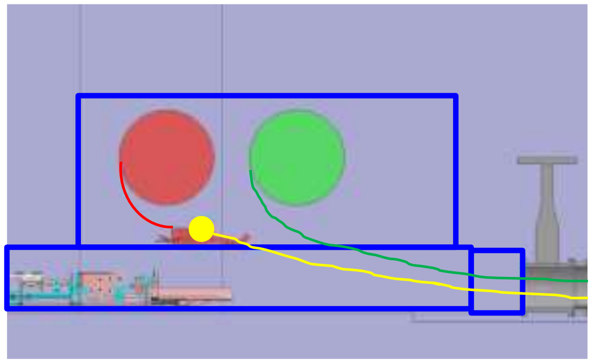
6. Implementation details

Unit 1 No.60

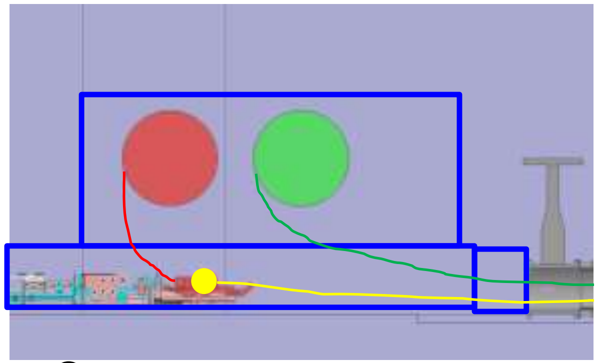
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ③ FY2022 prototype (installation equipment for 350A (4/4))

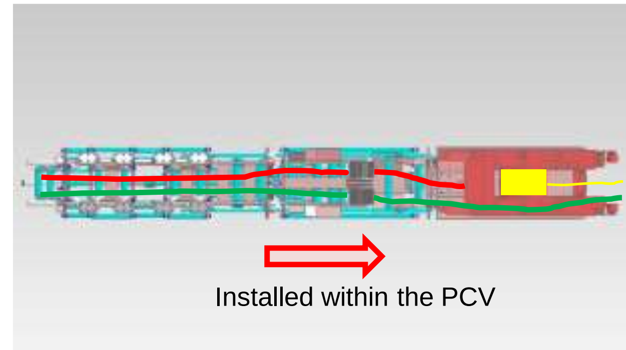
The image below shows installation of the equipment, using the 350 A Penetration during investigation with a wired drone.



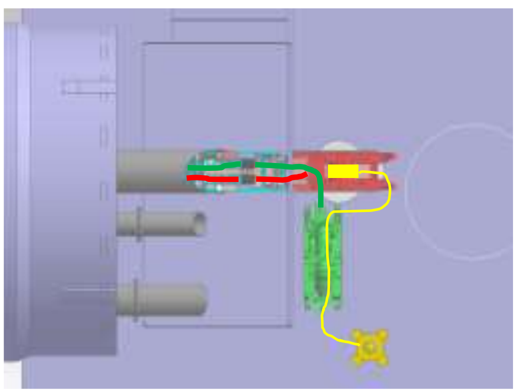
⑬ **Collection of installation equipment**



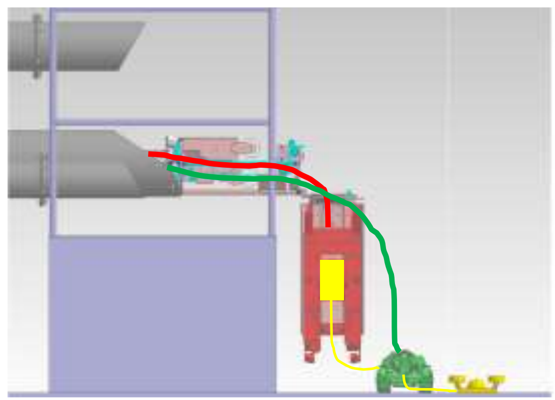
⑭ **Installation of the cable drum transfer cart in the bucket**



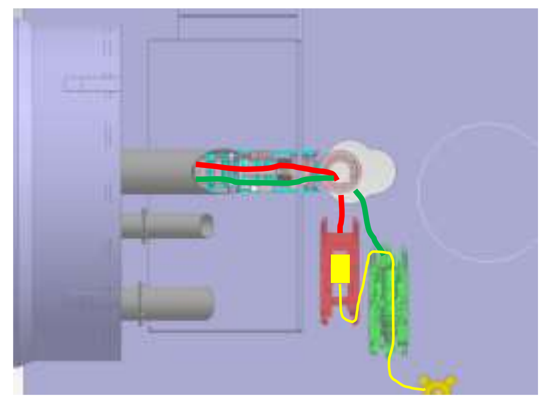
⑮ **Installation of the cable drum transfer cart**



⑯ **Arrival of the cable drum transfer cart in the PCV**



⑰ **Bending of the bucket and lowering of the cable drum transfer cart**



⑱ **Touchdown of the cable drum transfer cart on the platform**

6. Implementation details

Unit 1

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ④ Items for functional verification tests (1/3)

Target	Category: Wired	Category: Wireless	Items	Test No.	Functional verification tests	Output/Assessment criteria	Relevant section
(a) Drone							
	Conducted	Conducted	Flight performance (lift)	①	Flight height verification test	Ability to reach target height (wired: 7 m, wireless: 11 m)	No.73
	Conducted	Conducted		②	Payload verification test	Maximum payload	No.74
	Conducted	Conducted	Flight performance (sway)	③	Verification test for passing through performance in narrow part	- Minimum passable space - Amount of sway during flight (vertical orientation)	No.75 and 76
	—	Conducted	Flight performance (flight time)	④	Flight time verification test	Maximum flight time	No.77
	Conducted	Conducted	Visibility/lighting functions	⑤	Camera performance verification test (Dark and vaporous environments)	Ability to see objects in dark and vaporous environments	No.78 and 79
	Conducted	Conducted		⑥	Camera irradiation test	- Changes in images over time - Radiation resistance (target: 1000 Gy)	No.80 and 81
	Conducted	Conducted		⑦	In-flight visibility verification test	Image sway during flight	No.82
	—	Conducted	Dose rate measurement performance (wireless only)	⑧	Dosimeter irradiation test	Measurable range (FY2022 development target: 0 to 100 Sv/h)	No.83 and 84
	—	Conducted		⑨	Dosimeter noise influence verification test	Effects of noise on dosimeter	No.85
	Conducted	Conducted	Radiation resistance	⑩	Drone irradiation test	Radiation resistance of drones (target: 1000 Gy)	No.86 to 88
	Conducted	Conducted	Electronic component performance	⑪	Temperature / current value verification test	Change in temperature and current values of electronic components (ESC) due to increases in output	No.89
	Conducted	Conducted	Waterproof performance	⑫	Waterproof performance verification test	Waterproof performance (reference measurement)	No.90

6. Implementation details

Unit 1

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ④ Items for functional verification tests (2/3)

Target	Category		Items	Test No.	Functional verification tests	Output/Assessment criteria	Relevant section
	Wired	Wireless					
(b) Telescopic rod transfer cart							
	Conducted	Conducted	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (Dry or wet conditions)	No.91 and 92
	Conducted	Conducted	Driving performance	②	Driving performance verification test *Wired: Tests (b)-② and (c)-② are conducted simultaneously	Driving performance on grating (Dry or wet conditions)	No.93
	Conducted	Conducted		③	Verification test of travelling ability	Ability to traverse remaining B1 investigation equipment (Dry or wet conditions)	No.94
	Conducted	Conducted	Rod extension/retraction performance	④	Rod extension/retraction test (Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously / Wireless: Tests (b)-④ and b-⑤ are conducted simultaneously)	- Extension/retraction time - Amount of deflection	No.95 to 98
	Conducted	Conducted		⑤	Passage performance verification test (Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously / Wireless: Tests (b)-④ and b-⑤ are conducted simultaneously)	Ability to pass structures in the CRD opening	
	Conducted	—	Composite cable feed/wind performance	⑥	Composite cable feeding/winding test (linkage with rod extension/retraction) (Wired: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ are conducted simultaneously)	Connection with rod extension/retraction during composite cable feeding/winding	
	Conducted	—		⑦	Composite cable feeding/winding test (linkage with cable drum) (*Wired: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ are conducted simultaneously)	Connection with cable drum during composite cable feeding/winding	

6. Implementation details

Unit 1

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ④ Items for functional verification tests (3/3)

Target	Category: Wired	Category: Wireless	Items	Test No.	Functional verification tests	Output/Assessment criteria	Relevant section
(c) Cable drum transfer cart							
	Conducted	—	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (Dry or wet conditions)	No.99
	Conducted	—	Driving performance	②	Driving performance verification test *Wired: Tests (b)-② and (c)-② are conducted simultaneously	Driving performance on grating (Dry or wet conditions)	No.100
	Conducted	—		③	Verification test of travelling ability	Ability to traverse remaining B1 investigation equipment (Dry or wet conditions)	No.101
	Conducted	—	Composite cable feed/wind performance	④	Composite cable feeding/winding test (linkage with telescopic rod) *Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously	Connection with cable drum during composite cable feeding/winding	No.95 to 98
(d) Cable assistance device							
	Conducted	Conducted	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (Dry or wet conditions)	No.102
	Conducted	Conducted	Driving performance	②	Driving performance verification test	Driving performance on grating (Dry or wet conditions)	No.103 and 104
	Conducted	Conducted	Cable assistance performance	③	Cable grabbing performance verification test	Cable grabbing performance	No.105
	Conducted	Conducted		④	Cable feed force verification test	Cable feed force / speed / clamping force	No.106 and 107
	Conducted	Conducted		⑤	Rollover verification test	Possibility of roling over when assisting cables	No.108
(e) Installation equipment (for 350A)							
	Conducted	Conducted	Install/uninstall performance	①	Bending load verification test	Bending performance under load at the bucket	No.109 and 110
	Conducted	Conducted		②	Cable feed force verification test	Cable feed force/clamping force	No.111 and 112
	Conducted	Conducted		③	Cable feeding operations verification test	Two cables can be fed simultaneously or not	No.113

6. Implementation details

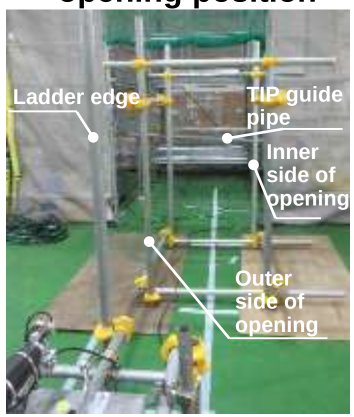
(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑤ Equipment for functional verification tests (1/2)

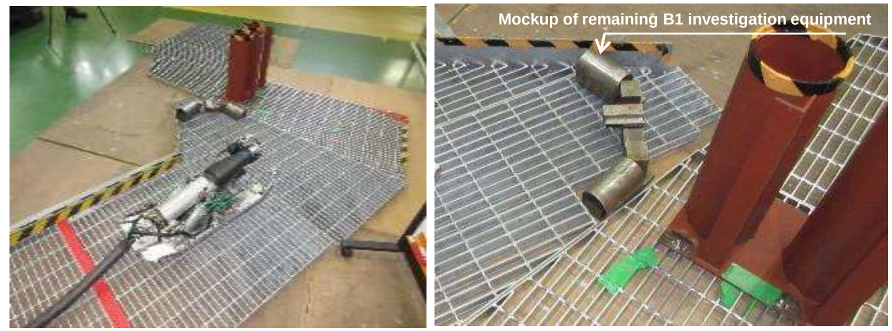
The following shows an overview of the test equipment for wired and wireless drones, the telescopic rod transfer cart, and the cable drum transfer cart.

Test frame

Assumed RPV opening position



Simulated CRD opening



Mockup of remaining B1 investigation equipment

Simulated control room

Appearance of FY2022 test equipment

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑤ Equipment for functional verification tests (2/2)

The following shows an overview of the test equipment for the cable assistance device and 350A installation equipment.

Simulated platform inside the PCV

Simulated 350A Penetration

Mockup of remaining B1 investigation equipment

Appearance of FY2022 test equipment

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑥ Summary of results of functional verification tests (1/3)

Unit 1 No.66

Target	Items	Test No.	Functional verification tests	Output/Assessment criteria	Test results		Applicability to actual equipment	
					Wired specification	Wireless specification	Wired specification	Wireless specification
(a) Drone								
	Flight performance (lift)	①	Flight height verification test	Ability to reach target height (wired: 7 m, wireless: 11 m)	Can hover for 10 seconds at target height (7 m)	Can hover for 10 seconds at target height (11 m)	Prospect is to be able to reach the bottom of the RPV interior, which is the survey location.	Prospect is to be able to reach the top of the core support plate.
		②	Payload verification test	Maximum payload	933 g	600 g	No payload margin when flying at target flight height.	Additional components can be installed. However, the trade-off with flight time must be considered.
	Flight performance (sway)	③	Verification test for passing through performance in narrow part	① Minimum passable space ② Amount of sway during flight (vertical orientation)	①: □700 mm / □500 mm (vertical/horizontal) ②: 211 mm / 275 mm (length/width)	①: □600 mm / □500 mm (vertical/horizontal) ②: 253 mm / 258 mm (length/width)	Passable diameter for the assumed opening projected to be Φ1 m (however, dependent on pilot skill)	Passable diameter for the assumed opening projected to be Φ1 m (however, dependent on pilot skill)
	Flight performance (flight time)	④	Flight time verification test	Maximum flight time	—	Without dosimeter: 10 min. 4 sec. With dosimeter: 8 min. 40 sec. With dosimeter + weight (300 g): 6 min. 47 sec.	—	Limiting additional equipment can extend flight time.
	Visibility/lighting functions	⑤	Camera performance verification test (in dark and vaporous environments)	Ability to see objects in dark and vaporous environments	Water vapor (none): 2.5 m visibility confirmed Water vapor (low): 2.5 m visibility confirmed Water vapor (high): 2.5 m visibility not confirmed	Water vapor (none): 2.5 m visibility confirmed Water vapor (low): 2.5 m visibility confirmed Water vapor (high): 2.5 m visibility not confirmed	Projected to be able to see RPV interior walls with low water vapor levels.	Projected to be able to see RPV interior walls with low water vapor levels.
		⑥	Camera irradiation test	- Changes in images over time - Radiation resistance (target: 1000 Gy)	Of cameras A through D, cameras B and C achieved the target cumulative dose (1000 Gy) Camera B weighs less and was selected as the camera for the drone		Radiation resistance is expected to be applicable for use with actual equipment. However, radiation noise reduction methods for 1000 Gy/h environments must be considered.	
		⑦	In-flight visibility verification test	Image sway during flight	Flight caused no noticeable deterioration in visibility	Flight caused no noticeable deterioration in visibility	Projected to be able to see the survey target.	Projected to be able to see the survey target.
	Dose rate measurement performance (wireless only)	⑧	Dosimeter irradiation test	Measurable range (FY2022 development target: 0 to 100 Sv/h)	—	Pulse measurement type: 0.09 to 1077 Sv/h CMOS type: 0.08 to 90 Sv/h	—	Pulse measurement type achieved final target of 1000 Sh/h. Consider for implementation in FY2023.
		⑨	Dosimeter noise influence verification test	Effects of noise on dosimeter	—	Pulse measurement type: Noise level during drone operation was verified to have no effect on dose rate measurement accuracy.	—	Reverify after manufacturing products for actual equipment.
	Radiation resistance	⑩	Drone irradiation test	Radiation resistance of drones (target: 1000 Gy)	Electronic components failed at a cumulative dose of 122 Gy	Electronic components failed at a cumulative dose under 175 Gy	Operating methods and the configuration of electronic components on the drone must be reviewed.	Operating methods and the configuration of electronic components on the drone must be reviewed.
	Electronic component performance	⑪	Temperature / current value verification test	Change in temperature and current values of electronic components (ESC) due to increases in output	The addition of an air cooling fan had no effect	The addition of an air cooling fan had no effect	The cooling function in the drone must be reviewed.	The cooling function in the drone must be reviewed.
	Waterproof performance	⑫	Waterproof performance verification test	Waterproof performance (reference measurement)	Operable after sprayed with water	Operable after sprayed with water	Must be considered along with dust resistance	Must be considered along with dust resistance

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑥ Summary of results of functional verification tests (2/3)

Target	Items	Test No.	Functional verification tests	Output/Assessment criteria	Test results		Applicability to actual equipment	
					Wired specification	Wireless specification	Wired specification	Wireless specification
(b) Telescopic rod transfer cart								
	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (Dry or wet conditions)	Dry: approx. 274 to 392 N Wet: approx. 98 to 196 N	Dry: approx. 245 to 343 N Wet: approx. 98 to 215 N	A certain amount of tractive force is confirmed. Planning to verify applicability in future combined tests.	A certain amount of tractive force is confirmed. Planning to verify applicability in future combined tests.
	Driving performance	②	Driving performance verification test	Driving performance on grating (Dry or wet conditions)	Can drive back and forth over grating in dry or wet conditions without issue	Can drive back and forth over grating in dry or wet conditions without issue	A certain level of drivability was confirmed. Planning to evaluate cable handling, etc. in future combined tests.	A certain level of drivability was confirmed. Planning to verify applicability in future combined tests.
		③	Verification test of travelling ability	Ability to traverse remaining B1 investigation equipment (Dry or wet conditions)	Dry: Can travel forward and backward Wet: Can travel forward and backward	Dry: Can travel forward and backward Wet: Can travel forward and backward	Projected to be able to travel over the remaining B1 investigation equipment. Planning to verify applicability in future combined tests.	Projected to be able to travel over the remaining B1 investigation equipment. Planning to verify applicability in future combined tests.
	Rod extension/retraction performance	④	Rod extension/retraction test (Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously / Wireless: Tests (b)-④ and b-⑤ are conducted simultaneously)	① Extension/retraction time ② Deflection	Initial rod angle: 14.3° ①: 5 min. 15 sec. / 7 min. 36 sec. (Extension/retraction) ②: Approx. 150 mm	Initial rod angle: 12.1° ①: 6 min. 6 sec. / 7 min. 37 sec. (Extension/retraction) ②: Approx. 185 mm	Check rod passability and linkage between rod and cable drum. However, the assumed procedure for actual equipment will be optimized in future combined tests in order to evaluate applicability.	Rod passability was confirmed. The assumed procedure for actual equipment will be optimized in future combined tests in order to evaluate applicability.
		⑤	Passage performance verification test (Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously / Wireless: Tests (b)-④ and b-⑤ are conducted simultaneously)	Ability to pass structures in the CRD opening	Passable at initial rod angle (14.3°)	Passable at initial rod angle (12.1°)		
	Composite cable feed/wind performance	⑥	Composite cable feeding/winding test (linkage with rod extension/retraction) (Wired: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ are conducted simultaneously)	Connection with rod extension/retraction during composite cable feeding/winding	Interlocking is projected to be possible by using the cable ring guides to align the composite cable. However, there is room for optimization in the assumed procedure for actual equipment.	–		–
		⑦	Composite cable feeding/winding test (linkage with cable drum) (Wired: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ are conducted simultaneously)	Connection with cable drum during composite cable feeding/winding	Interlocking is projected to be possible by using the cable ring guides to align the composite cable. However, there is room for optimization in the assumed procedure for actual equipment.	–		–

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑥ Summary of results of functional verification tests (3/3)

Target	Items	Test No.	Functional verification tests	Output/Assessment criteria	Test results		Applicability to actual equipment	
					Wired specification	Wireless specification	Wired specification	Wireless specification
(c) Cable drum transfer cart								
	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (dry or wet conditions)	Dry: approx. 245 to 392 N Wet: approx. 215 to 294 N	—	A certain amount of tractive force is confirmed. Planning to verify applicability in future combined tests.	—
	Driving performance	②	Driving performance verification test	Driving performance on grating (dry or wet conditions)	Can drive back and forth over grating in dry or wet conditions without issue	—	A certain level of drivability was confirmed. Planning to evaluate cable handling, etc. in future combined tests.	—
		③	Verification test of travelling ability	Ability to traverse remaining B1 investigation equipment (dry or wet conditions)	Dry: Can travel forward and backward Wet: Can travel forward and backward	—	Projected to be able to travel over the remaining B1 investigation equipment. Planning to verify applicability in future combined tests.	—
	Composite cable feed/wind performance	④	Composite cable feeding/winding test (linkage with telescopic rod) *Wired: Tests (b)-④, ⑤, ⑥, ⑦ and (c)-④ are conducted simultaneously	Connection with cable drum during composite cable feeding/winding	Interlocking is projected to be possible by using the cable ring guides to align the composite cable. However, there is room for optimization in the assumed procedure for actual equipment.	—	Verify the linkage between the rod and cable drum. However, the assumed procedure for actual equipment will be optimized in future combined tests in order to evaluate applicability.	—
(d) Cable assistance device								
	Traction performance	①	Tractive force verification test	Actual performance of cable traction force (dry or wet conditions)	Target tractive force (100 N) achieved under all conditions. Traction in wet conditions was about 10% less than in dry conditions		A certain amount of tractive force is confirmed. Planning to verify applicability in future combined tests.	
	Driving performance	②	Driving performance verification test	Driving performance on grating (dry or wet conditions)	Can drive back and forth over grating in dry or wet conditions without issue		A certain level of drivability was confirmed. Planning to verify applicability in future combined tests.	
	Cable assistance performance	③	Cable grabbing performance verification test	Cable grabbing performance	Capable of grabbing composite cables on both sides of equipment		Projected to be able to grab cables.	
		④	Cable feed force verification test	Cable feed force / speed / clamping force	Target feed force (100 N) achieved under all conditions.		A certain amount of feed force was confirmed. Planning to verify applicability in future combined tests.	
		⑤	Rollover verification test	Possibility of roling over cables	Each operation poses a low risk of roling over *Recovery is possible if the angle of fall is less than 90°.		Projected low likelihood of roling over from each operation.	
(e) Installation equipment (for 350A)								
	Install/ uninstall performance	①	Bending load verification test	Bending performance under load at the bucket	Capable of conducting bending operations with 65 kg load		A certain level of installation feasibility was confirmed. Planning to verify applicability in future combined tests.	
		②	Cable feed force verification test	Cable feed force/clamping force	Target feed force (100 N) achieved with both Φ40 mm and Φ10 mm cables			
		③	Cable feeding operations verification test	Two cables can be fed simultaneously or not	Can feed two cables simultaneously without difficulty			

6. Implementation details

Unit 1 **No.69**

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑦ Other items for consideration (impact of drone crashes)

[Wireless]: Wireless drone
[Wired]: Wired drone

Assumed risk	Cause of event		Countermeasures and responses: Risk reduction measures	Countermeasures and responses: Response during occurrence	
Drone crash					
	Collision with an obstacle	Camera blind spots and poor visibility	- Mount two cameras with a pan tilt mechanism or wide-angle lens. - Consider the installation of sensors to detect obstacles.	[Wired / wireless] - Reattempt the flight. - In worst case scenarios, leave the drone where it is.	[Wired] - If flight is not possible, wind the cable to reel in and collect the drone.
		Insufficient flight stability	- Improve flight stability by enhancing control performance.		
	Failure	Insufficient durability and radiation resistance	- Conduct resistance tests on circuits and machinery. - Only install components with sufficient radiation resistance.		
		Ingress of water and/or dust	Apply dustproof and waterproof measures and conduct testing to verify.		
	[Wireless] Communication failure due to insufficient signal strength		- Use the extension rod to place a radio transceiver inside the pedestal. - Conduct mockup testing to verify transmission stability.		
	[Wireless] Dead battery		- Install a high-capacity battery. - Check remaining battery power during flight.	- When the remaining battery charge approaches the amount required for the return trip, suspend the investigation and have the drone return. - In worst case scenarios, leave the drone where it is.	
Impact on plant during drone flight or crash					
	(Flight) Damage to X-100B thermometer/water level gauge	Drone crashes into the section not protected by steel pipe	- Conduct the investigation using a route that is not extremely close to the X-100B thermometer/water level gauge.	- Continue measuring data using the undamaged portion of the X-100B thermometer/water level gauge.	
	(Flight) Increased dust levels in the PCV interior	Winding from drone flight scatters dust	- If the effect of dust is a concern, consider countermeasures by reviewing operations and components.	- If dust levels exceed permissible values, temporarily land the drone and enter standby or retrieve the drone.	
	(Flight) Fluctuation in PCV thermometer readings	Winding from drone flight impacts the thermometer	- If there is concern about fluctuations in thermometer readings, consider countermeasures by reviewing operations and components.	- If measurements must be made using a thermometer within the PCV interior, either land the drone or fly it at a distance from the thermometer.	
	(Failure) Fire	[Wireless] Battery fire	- Properly protect the drone so that it is not damaged by external forces. - Select batteries with excellent durability and verify that they do not catch fire even under severe conditions.	- Monitor the situation with other devices.	
	(Crash) Hydrogen generation	[Wireless] Battery reacts with accumulated water	- Apply waterproof treatments to prevent a reaction between water and the cells inside the drone. - Examine the amount of hydrogen generated from the battery.	- Monitor the hydrogen concentration value in the PCV interior.	

6. Implementation details

(2) Development of the bottom access investigation method (drone)

4). FY2022 implementation details ⑦ Other items for consideration (sensing technologies and flight control)

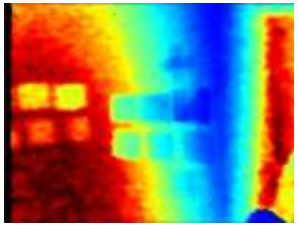
Risks associated with drone flight

Potential risk	Impact of risk
Unstable drone attitude during flight	① Collisions with obstacles and crashes ② Inability to fly in narrow areas ③ Blurry investigation images
Obstacles may be difficult to verify with existing cameras	① Collisions with obstacles and crashes
Operator is constantly overburdened and cannot rest during flight	④ Possibility of operational errors occurring
Only highly skilled and experienced operators can pilot the drones	⑤ Difficulty in securing human resources during investigations at the site
Drones are unable to determine their position and attitude	⑥ Unable to identify the location for investigation

Development items for risk elimination (proposal)

Development item	Target result	Method utilized (proposed)
Development of drone sensing technology	Estimation of position and attitude	- Input to flight control - Identification of the target investigation location (⑥)
	Assessing the state of obstacles in the surrounding area	- Collision and crash avoidance (①)
Development of drone flight control technologies	Improved stability during flight	- Collision and crash avoidance (①) - Investigation in narrow areas (②) - Reduction of blur in investigation images (③) - Reduction of burden on operator (④) - Improved operability for non-skilled workers (⑤)

RGB image



Point cloud depth image

(Reference) Image from a point cloud data sensor mounted on investigation equipment in another project (Detailed Investigation inside PCV)

(① to ⑥ correspond to the number in the risk table)

6. Implementation details

Unit 1 No.71

(2) Development of the bottom access investigation method (drone)

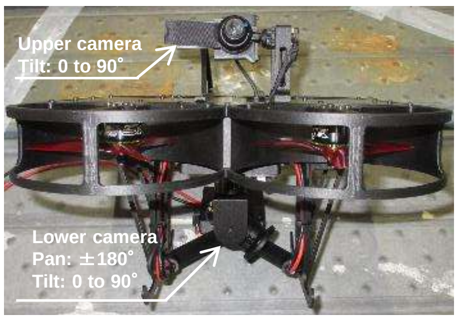
5). Summary

① FY2022 results

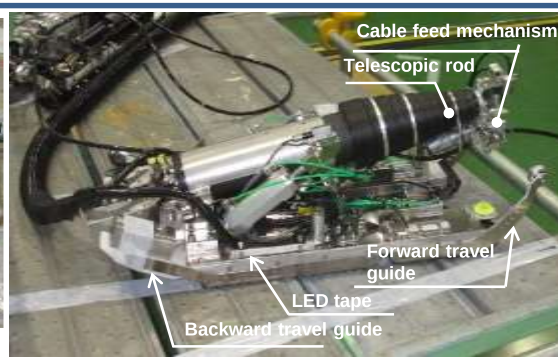
- Based on results up to FY2021, issues were identified and countermeasures were examined.
- Access equipment under development in other projects were customized and the investigation plan and development plan were studied in consideration of integrating that equipment into the plans.
- The specifications of each device were studied, and devices were designed and manufactured. Functional verification tests were also conducted on these devices to evaluate their performance of the functions.

② Issues for FY2023 onward

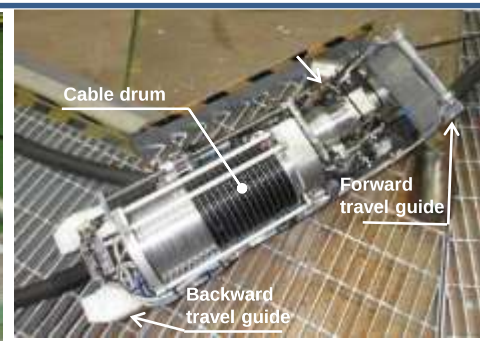
- Review the development plan and reflect the results of functional verification tests. Also improve equipment.
- Use combined tests to confirm the feasibility of the investigation method and proceed with the development of equipment for actual equipment.
- Identify risks for actual equipment and incorporate them into the design as necessary. Complete operational scenarios.



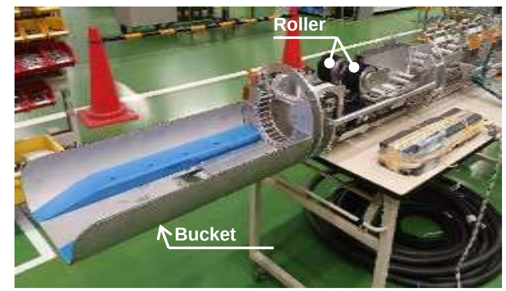
Wired drone



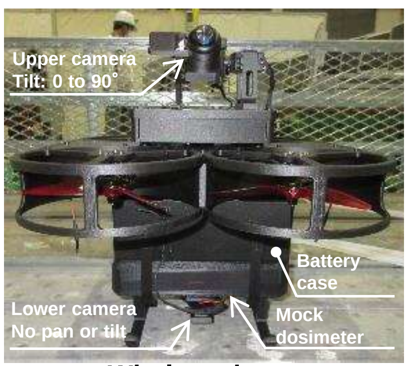
Telescopic rod transfer cart for wired drone



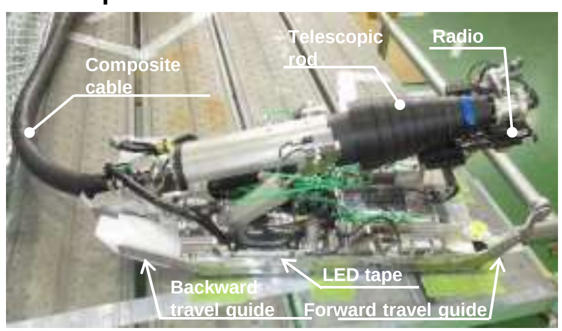
Cable drum transfer cart



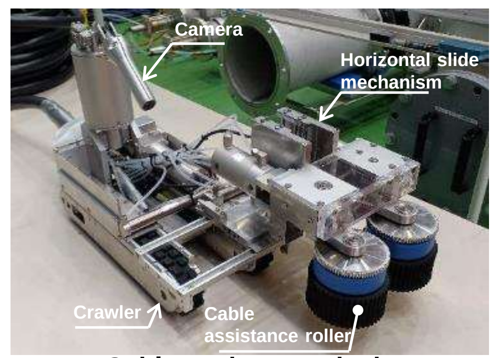
Installation equipment for 350A



Wireless drone



Telescopic rod transfer cart for wireless drone



Cable assistance device

External view of FY2022 prototype

Supplementary materials for results of drone functional verification tests are described in No.73 – 113.

(Supplementary material) Results of functional verification tests for FY2022 (drone)

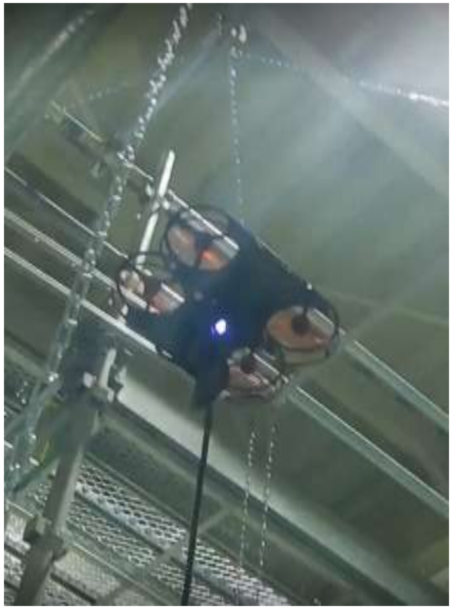
Test (a)-①: [Flight height verification test]

Target	Drone (wired / wireless)
Test method	① Device placed at the position expected for the actual equipment. ② Flew drone to the mark on the test frame (wired: 7 m, wireless: 11 m) and hovered it there for 10 seconds. ③ For wired only, measured maximum flight height. (Reference measurement)
Output/ Assessment criteria	Ability to hover for 10 seconds at target height (wired: 7 m, wireless: 11 m)
Test results	

Flight height verification test

No.	Drone	Capability of reaching target height	Capability of hovering for 10 seconds at target height	[Reference measurement] Maximum flight height
1	Wired	7 m reachable	Able to hover for 10 seconds	8 m reachable
2	Wireless	11 m reachable	Able to hover for 10 seconds	-

- Both wired and wireless drones were capable of hovering for 10 seconds at the target height (wired: 7 m, wireless: 11 m).



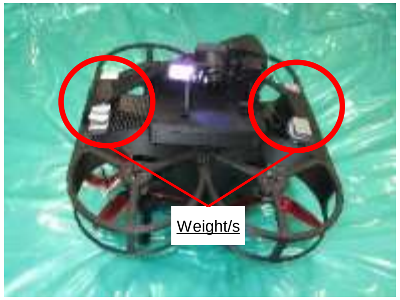
Drone in flight (wired)

Flight height test performance (wireless)

(Supplementary material) Results of functional verification tests for FY2022 (drone)

Test (a)-②: [Payload verification test]

Target	Drone (wired / wireless)
Test method	① Loaded weight, then hovered drone at a height of 1 m above the floor. ② If able to hover for 10 seconds, added more weight and hovered drone again at a height of 1 m above the floor. ③ Repeated ② until the drone could no longer hover for 10 seconds, and verified maximum payload.
Output/ Assessment criteria	Maximum payload that can be hovered for 10 seconds at a flight height of 1 m



Drones loaded with weights (left: wired, right: wireless)

Test results

Payload verification test results

No.	Drone	Maximum payload [g]	Remarks
1	Wired	933 (*1)	Airframe mass: 1650 g Cable mass: 133 g/m
2	Wireless	600 (*2)	Airframe mass: 1989 g Dosimeter: 200 g

(*1) Weight (800 g) + 1 m of cable (133 g)
(*2) Dosimeter (200 g) + 1 m of cable (133 g)


Flight performance at height of 1 m (left: wired, right: wireless)

- The maximum payload that could be hovered for 10 seconds at a flight height of 1 m was 933 g for wired drones and 600 g for wireless drones.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

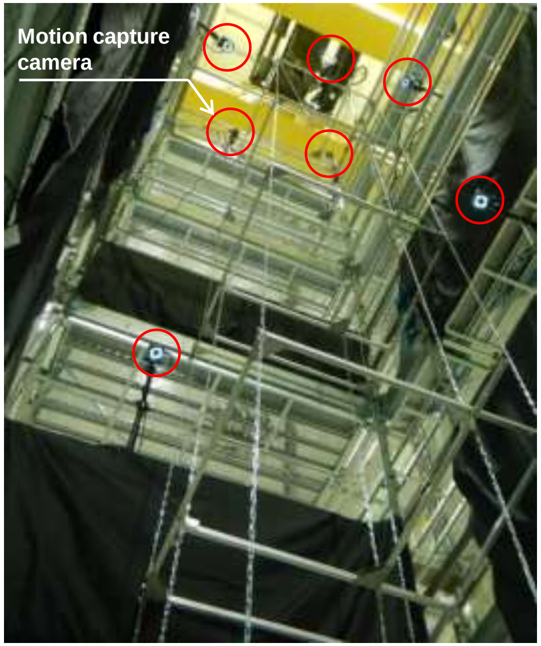
(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-③: [Verification test for passing through performance in narrow part (1/2)]

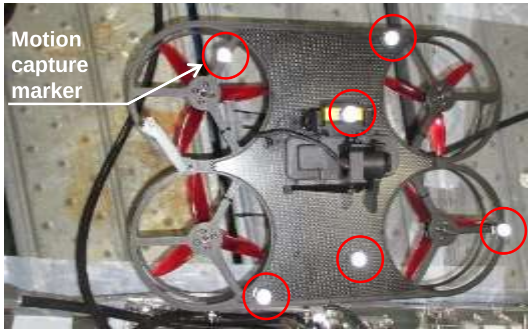
Target	Drone (wired / wireless)
Test method	① Flew drone back and forth within a □1000 mm x 5000 mm rectangular prism flight path. Checked horizontal and vertical flight path patterns. ② If the drone passed, reduced the flight path dimensions and flew drone through again. [Note] For the vertical orientation, motion capture was used to measure the amount of fluctuation during flight.
Output/ Assessment criteria	- Dimensions of smallest possible flight path - Amount of fluctuation during flight (vertical orientation)

Frame set-up during flight in vertical orientation

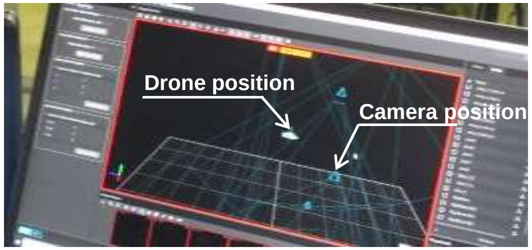
Frame set-up during flight in horizontal orientation



Arrangement of motion capture cameras



Placement of motion capture markers



View of PC screen during motion capture

Overview of motion capture system

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-③: [Verification test for passing through performance in narrow part (2/2)]

Test results (Vertical orientation)

Results of verification test for passing through performance in narrow part (vertical orientation)

Category	Passage dimensions [mm]	Passage capability	Amount of fluctuation during flight [mm]		Remarks
			Long direction (including the dimensions of the drone)	Short direction (including the dimensions of the drone)	
FY2022 wired drone	□700	Round trip passage possible	211 (581)	275 (545)	Measurement error is ±0.64 mm
FY2022 wireless drone	□600	Round trip passage possible (*1)	253 (573)	258 (528)	Measurement error ±0.587 mm
FY2021 wireless drone	□700	Round trip passage possible	200 (650)	347 (617)	Measurement error is ±0.64 mm

*1 During descent there were cases in which a camera noise caused the aircraft to lose its position for a moment and fly out of the frame.


Wireless drone camera footage (☐700 mm condition)


Wired drone camera footage (☐600 mm condition)

- Based on measurements of fluctuation, FY2022 wired / wireless drones are expected to be able to pass through the ☐600 mm frame.
- For the FY2021 wireless drone, ☐800 mm was the smallest flyable passage in the FY2021 element test, but in FY2022 a ☐700 mm passage was used for the first time as a reference, and the drone was able to pass through. Based on the measurements of fluctuation, ☐700 mm is considered the minimum passable dimension.
- Results for FY2021 and FY2022 wireless drone prototypes were compared and no significant difference in the amount of fluctuation was observed.

Test results (Horizontal orientation)

Results of verification test for passing through performance in narrow part(horizontal orientation)

Category	Passage dimensions [mm]	Passage capability
FY2022 wired drone	□500	Round trip passage possible
	□400	Round trip passage not possible
FY2022 wireless drone	□500	Round trip passage possible
	□400	Round trip passage not possible


Wired drone camera footage (☐400 mm condition)


Wireless drone camera footage (☐400 mm condition)

- FY2022 wired / wireless drones were able to pass through the ☐500 mm frame. (☐600 mm was the smallest flyable passage for FY2021 element test results)

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-④: [Flight time verification test]

Target	Drone (wireless)
Test method	① Equipped drone with two commercial batteries (4600 mAh). ② Flew drone until it became unable to fly, and measured the time until landing. ③ The flight method was repeated ascent and decent between 1 and 7 m. ④ Kept flight speed low, avoided sudden rises and falls. ⑤ The mass of the drone had one of the following three patterns. (1) Without mock dosimeter (200 g) (2) With mock dosimeter (200 g) (3) Mock dosimeter (200 g) + weight (300 g) [Note] For reference, the test was also conducted with a mock dosimeter (200 g) + the wireless drone's maximum payload (600 g).
Output/ Assessment criteria	Amount of time drone can remain in flight [Note] In the FY2021 element test (two 3500 mAh batteries) the drone could remain in flight for about 6 minutes.

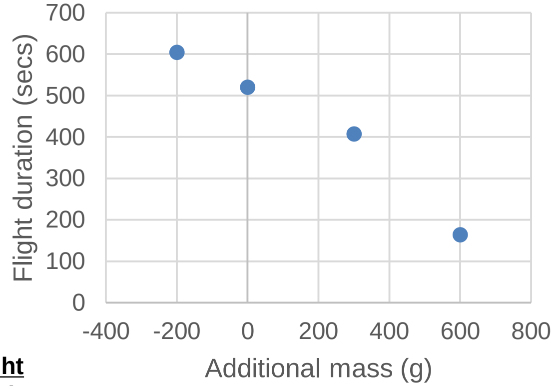
Test results

Results of flight time verification test

No.	Combination of mock dosimeter and weight (additional mass)	Maximum flight time	Battery 1 charge [%]		Battery 2 charge [%]	
			Before flight	[After flight]	Before flight	[After flight]
1	Without mock dosimeter (200 g)	10 min. 4 sec.	100	0	100	0
2	With mock dosimeter (200 g)	8 min. 40 sec.	100	0	99	0
3	Mock dosimeter (200 g) + weight (300 g)	6 min. 47 sec.	99	0	100	1
(Reference)	Mock dosimeter (200 g) + weight (600 g)	2 min. 44 sec.	99	38	100	41

Wireless drone in flight

Adjustment of additional weight (Mock dosimeter (200 g) + weight (600 g))



Additional mass - characteristics of flight time

- The flight time with the mock dosimeter (200 g) was approximately 8 min. 40 sec.
- It was also confirmed that flight time decreases in proportion to the increase in additional mass.

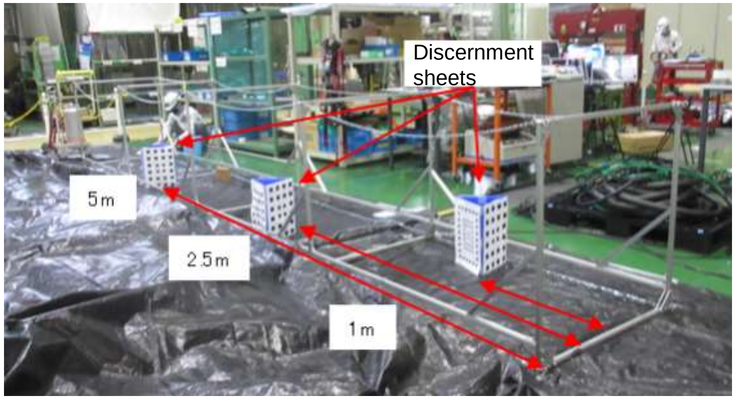
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑤: [Camera performance verification test (in dark and vaporous environments) (1/2)]

Target	Drone (wired / wireless)
Test method	1. Darkness condition ①Horizontally installed a □1000 mm × 7000 mm square pillar (aluminum frame). ②Installed discernment sheets at a distance of 1 m, 2.5 m, and 5 m from the edge of the aluminum frame. ③Covered the aluminum frame with a blackout curtain to create the dark condition, and placed drone at the edge of the aluminum frame. ④Turned on drone-mounted LED lights, took footage of the discernment sheets, and reviewed footage. 2. Darkness + water vapor condition ①Checked the footage from investigation inside the PCV, and filled the dark room with water vapor to approximate actual equipment conditions. (*1) ②Turned on drone-mounted LED lights, took footage of the discernment sheets, and reviewed footage. (*2) (*1) An illuminometer was set up at 5 m from the edge of the aluminum frame to measure illuminance when the LED lighting was turned on without water vapor. The room was filled with water vapor until the illuminance was about 1/3 to 1/2 or 1/10 of said illuminance. (*2) Recording was conducted without drone propeller rotation for the darkness condition, and with drone propeller rotation for the darkness + water vapor condition.
Output/Assessment criteria	Ability to see objects 2.5 m away in a dark, water vapor-filled environment.



Installation of discernment sheets


Installation of blackout curtain (dark condition)


Darkness + water vapor

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑤: [Camera performance verification test (in dark and vaporous environments) (2/2)]

Test results

Camera performance verification test results (in dark and vaporous environments)

No.	Water vapor	Drone specification	Illuminance at 5 m away [lux]	Distance from camera [m]	Visibility: Assessment	Visibility: Resolution	Visibility: Details
1	No	Wired	3.7	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				5	Partially discernable	300 × 420 mm	The A3 sheet (300 × 420 mm) is discernable but the dots (□30 mm) are not.
2		Wireless	1.8	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				5	Partially discernable	300 × 420 mm	The A3 sheet (300 × 420 mm) is discernable but the dots (□30 mm) are not.
3	Yes (low)	Wired	1.9	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				5	Not discernable	N/A	The A3 sheet (300 × 420 mm) is not discernable.
4		Wireless	0.5	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Partially discernable	□30 mm or larger	Depending on how much water vapor is on the A3 sheet, the dots (□30 mm) may or may not be discernable.
				5	Not discernable	N/A	The A3 sheet (300 × 600 mm) is not discernable.
5	Yes (high)	Wired	0.2	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Not discernable	N/A	The A3 sheet (300 × 420 mm) is not discernable.
				5	Not discernable	N/A	The A3 sheet (300 × 420 mm) is not discernable.
6		Wireless	0.1	1	Discernable	□30 mm	Dots (□30 mm) can be discerned.
				2.5	Not discernable	N/A	The A3 sheet (300 × 420 mm) is not discernable.
				5	Not discernable	N/A	The A3 sheet (300 × 420 mm) is not discernable.

Drone camera footage

Environmental conditions	Wired drone	Wireless drone
Darkness (Water vapor: none)		
Darkness + water vapor (Water vapor: small amount)		
Darkness + water vapor (Water vapor: large amount)		

- In darkness, the camera could discern an object 2.5 m away.
- For the darkness + water vapor condition, discernment was possible only up to 1 m away when water vapor was relatively high, but 2.5 m away when water vapor was low.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

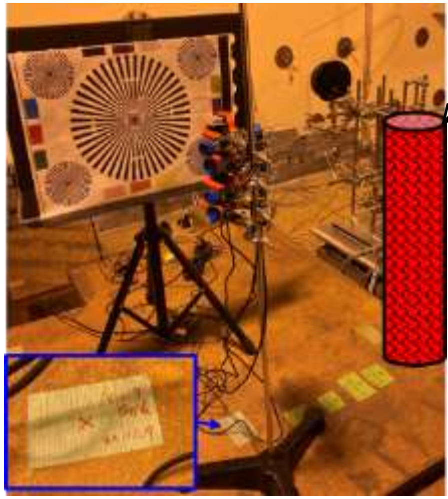
Test (a)-⑥: [Camera irradiation test (1/2)]

Target	Drone (wired / wireless)
Test method	① In order to determine camera installation position, measured and confirmed in advance the location where radiation was 1000 Gy/h. ② Installed cameras A to D one by one from top to bottom at the location where radiation was 1000 Gy/h. Also installed other equipment in designated locations. ③ Initiated irradiation. During irradiation, constantly filmed the discernment sheets on camera, and stored the footage.
Output/ Assessment criteria	- Changes in images over time - Radiation resistance (target: 1000 Gy)

Four irradiated cameras*1

No.	A	B	C	D
Appearance				
Model no.	RVC801	BIC263	CMOS-320	MS-183HTTR23
Camera sensors	CMOS (1/4 inch)	CMOS (1/4 inch)	CMOS (1/3.6 inch)	CMOS (1/3 inch)
Resolution	Approx. 320000 pixels	Approx. 400000 pixels	Approx. 330000 pixels	Approx. 470000 pixels
Dimensions	23 mm × 21 mm × 34 mm	Exposure: Φ28 × 12 mm Embedding: Φ23 × 15 mm	23.4 mm × 23.4 mm × 26.1 mm	26 mm × 23 mm × 25 mm
Mass	25 g (camera body)	17 g (camera body)	23 g (camera body)	80 g (camera body)
Angle of view	140° horizontal / 105° vertical	180° horizontal	195° horizontal	110° horizontal
Operating temperature	-20 to +65°C	-20 to +65°C	—	-20 to +50°C
Dustproof / waterproof	IP67	IP67	IP67	IP67
Video transmission method	NTSC	NTSC	NTSC	NTSC

*1 Taking into consideration the required specifications, inventory, delivery dates, etc., from among 20 small cameras, 4 were selected.



Camera placement*2

*2 Based on repeated pre-measurements, it was decided to conduct the irradiation test by placing the camera at the point where radiation is 1009 Gy/h (because it is difficult to find the exact point where 1000 Gy/h is reached).

View of the camera monitor *3

*3 CAMERA 01/02/03/04 footage is from cameras A/B/C/D respectively.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

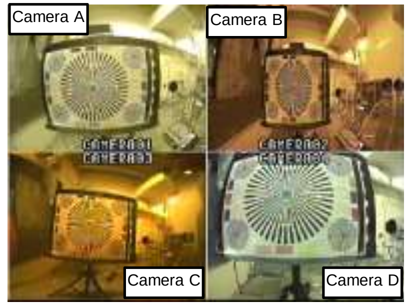
(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑥: [Camera irradiation test (2/2)]

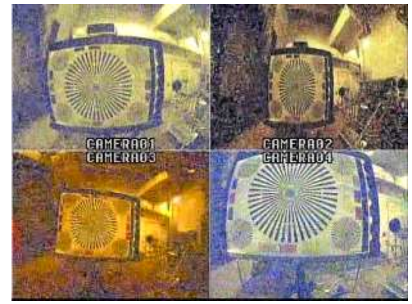
Test results

Camera irradiation test results

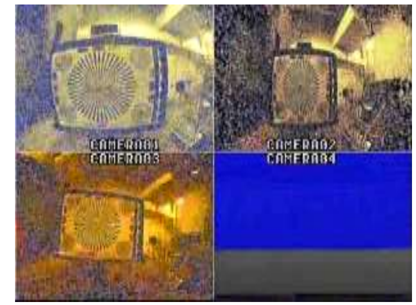
Category	Radiation resistance	Video status
Camera A	420 Gy	Radiation noise was observed from the start of irradiation, and the video was interrupted at 420 Gy.
Camera B	Over 1000 Gy	Radiation noise was observed from the start of irradiation, but there was no interruption to video recording during the irradiation test.
Camera C	Over 1000 Gy	Radiation noise was observed from the start of irradiation, but there was no interruption to video recording during the irradiation test.
Camera D	957 Gy	Radiation noise was observed from the start of irradiation, and video recording failed at 957 Gy.



① Before irradiation test (without radiation source)



② Radiation source installed (Start of irradiation: 0 min.)



③ After about 25 minutes of irradiation: 420 Gy accumulated dose

④ After about 57 minutes of irradiation: 957 Gy accumulated dose

⑤ After 60 minutes of irradiation: 1009 Gy accumulated dose

⑥ After irradiation test (without radiation source)

Changes in camera footage over time

- About 25 minutes after the start of irradiation, video recording from Camera D failed, (420 Gy accumulated dose), followed by recording from Camera A about 57 minutes later (957 Gy accumulated dose).
- Video recording from both cameras B and C was uninterrupted, even when the accumulated radiation dose exceeded the 1000 Gy target value for radiation resistance.
- Camera B is lighter than Camera C (Camera B: 17 g, Camera C: 23 g), so Camera B was chosen for the drone camera on account of compatibility with drone mounting.

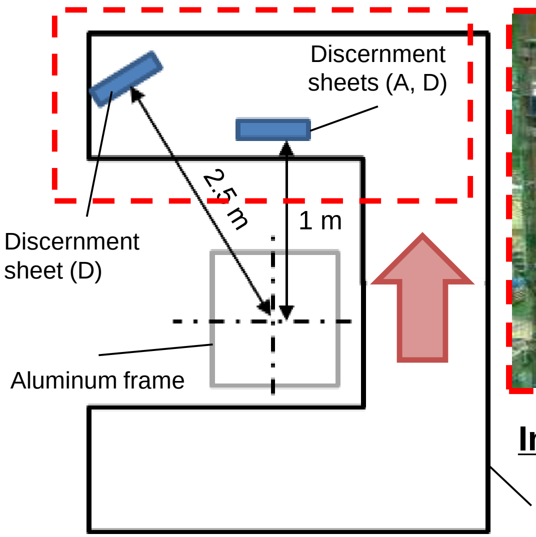
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑦: [In-flight visibility verification test]

Target	Drone (wired / wireless)
Test method	① Placed a discernment sheet at a height of 7 m from the floor and filmed it with the camera for 10 seconds. ② Installed discernment sheets 1 m and 2.5 m from the center of the aluminum frame. (See figure below.) ③ Filmed the discernment sheets 1 m and 2.5 m away while grounded, and compared to video recorded during flight.
Output/ Assessment criteria	Severity of disturbance to camera footage during flight



Test frame (ground plan)

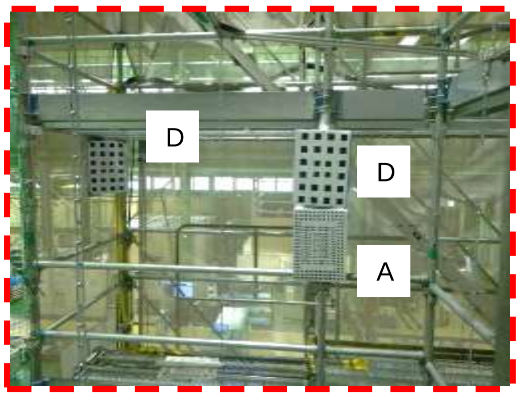


Image of view in (⇧) direction

Test results

Wired drone (left: in flight, right: grounded)

Wireless drone (left: in flight, right: grounded)

- For both wired and wireless systems there was no significant difference in video footage (visibility) recorded during fight versus while grounded. (*)
  (*) The dot pattern of the discernment sheet was discernable in the footage during flight.
- Flight control technology, including quantitative evaluation of the amount of fluctuation, is scheduled for study from FY2023 onward.

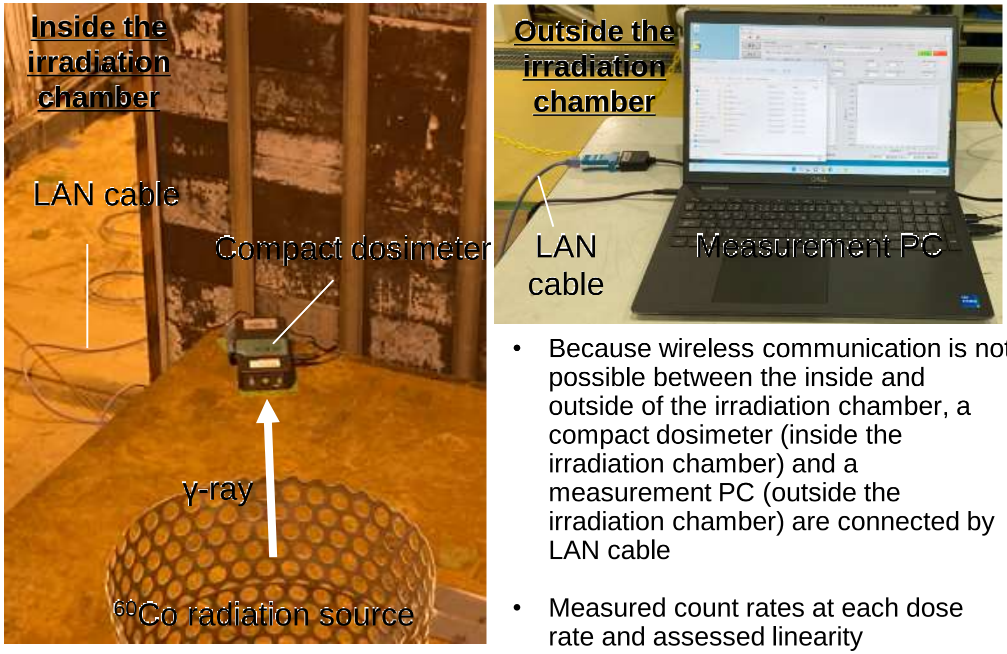
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑧: [Dosimeter irradiation test (1/2)]

Target	Compact dosimeter (pulse measurement type) (for wireless drones)
Test method	Irradiated the prototype with γ-rays in the ^{60}Co irradiation chamber and evaluated the dose rate linearity
Verification items / assessment criteria	Verification of measurable range of dose rate (Target development value for FY2022 (1 to 100 Sv/h))



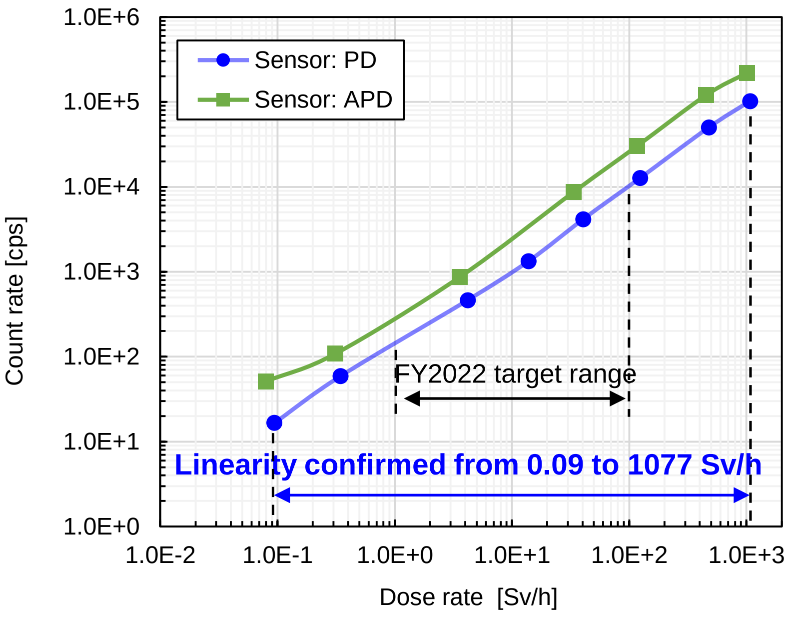
- Because wireless communication is not possible between the inside and outside of the irradiation chamber, a compact dosimeter (inside the irradiation chamber) and a measurement PC (outside the irradiation chamber) are connected by LAN cable
- Measured count rates at each dose rate and assessed linearity

Test system

Test results

- Photodiodes (PD) and avalanche photodiodes (APD) were confirmed to have dose rate linearity from 0.09 to 1077 Sv/h, meeting the FY2022 development target value (1 to 100 Sv/h)

The actual value of radiation resistance is scheduled to be evaluated from FY2023 onward



Results of dose rate linearity assessment

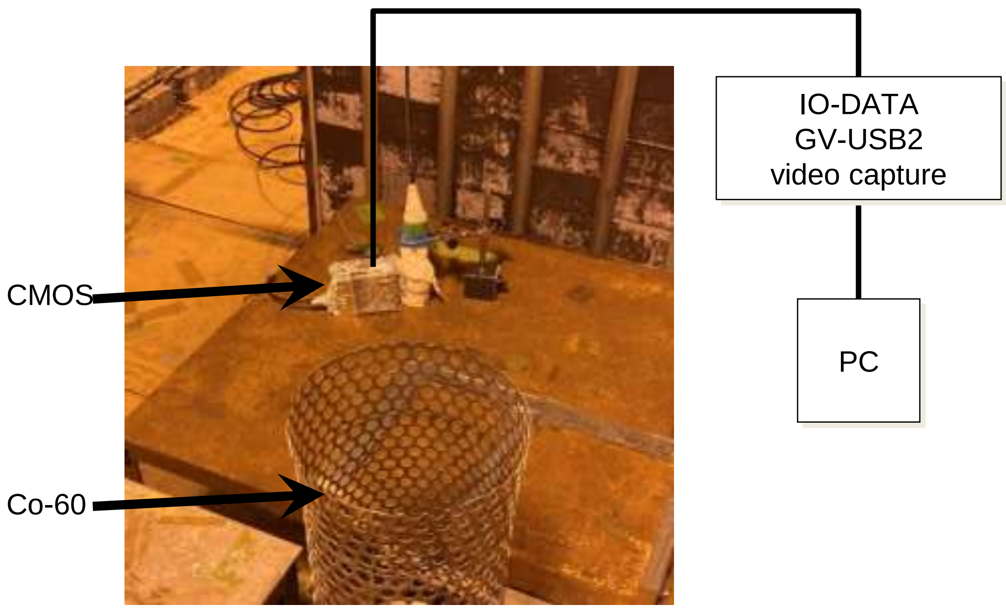
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑧: [Dosimeter irradiation test (2/2)]

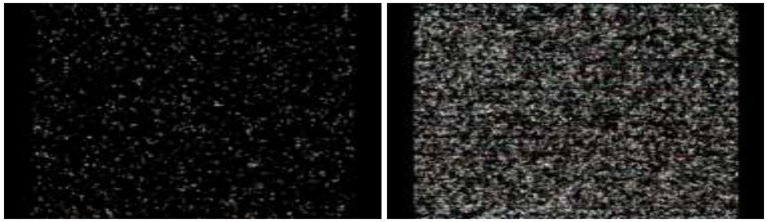
Target	Compact dosimeter (CMOS type) (for wireless drone)
Test method	Irradiated the prototype with γ-rays in the ^{60}Co irradiation chamber, assessed dose rate linearity
Verification items	Verification of measurable range of dose rate (Target development value for FY2022 (1 to 100 Sv/h))



Test system

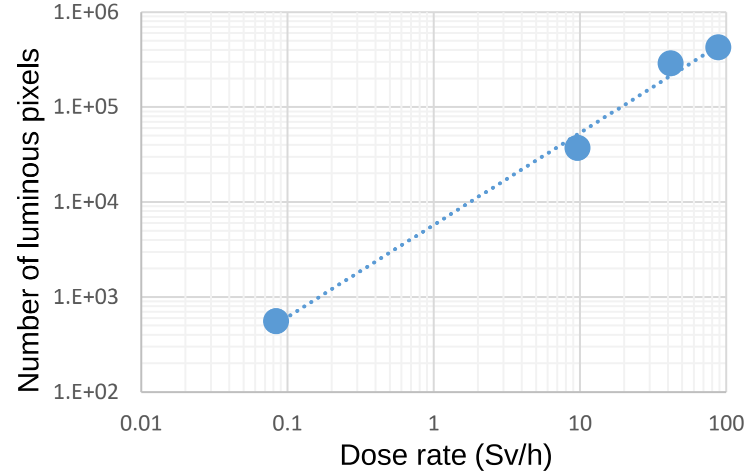
Test results

• Count of number of luminous pixels in the image at each dose rate



9.6 Sv/h

42 Sv/h



Results of dose rate linearity assessment

- Confirmed that there is a correlation between the number of luminous pixels and the dose rate at 0.08 to 90 Sv/h, and it was possible to measure the dose rate

The actual value of radiation resistance is scheduled to be evaluated from FY2023 onward

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑨: [Dosimeter noise influence verification test]

Target	Compact dosimeter (pulse measurement type) (for wireless)
Test method	• Mounted a compact dosimeter on the drone, measured count rate from the time the drone started until the time it stopped • Compared two methods of supplying power to dosimeters: dry cell batteries / drone batteries
Verification items / assessment criteria	• Threshold set below the value at the time of dose rate measurement and count rate of 0 cps • Threshold at the time of dose rate measurement: 100 channels (PD), 0.2 V (APD)

Configuration	Power source	Properties
①	Dry cell battery	Electrical separation of drone and dosimeter
②	Drone	Supply of 6 V/2 A from drone battery (15 V) to dosimeter

Test system

Test results

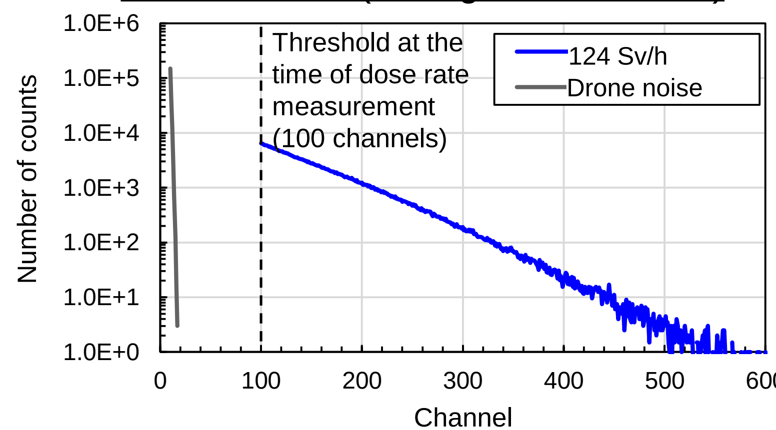
- In configurations ① and ②, the count rate of the photodiode (PD) and avalanche photodiode (APD) was 0 cps.
- Based on the peak value spectrum measurement results, it was confirmed that the noise level during drone operation was below the threshold at the time of dose rate measurement and had no effect on the accuracy of dose rate measurement

Results of count rate measurement

Unit: cps

Configuration	PD	APD
① (Dry cell battery)	0 (Threshold: 50 ch.)	0 (Threshold: 0.2 V)
② (Drone battery)	0 (Threshold: 50 ch.)	0 (Threshold: 0.2 V)

Results of peak value spectrum measurement (Configuration ②, PD)



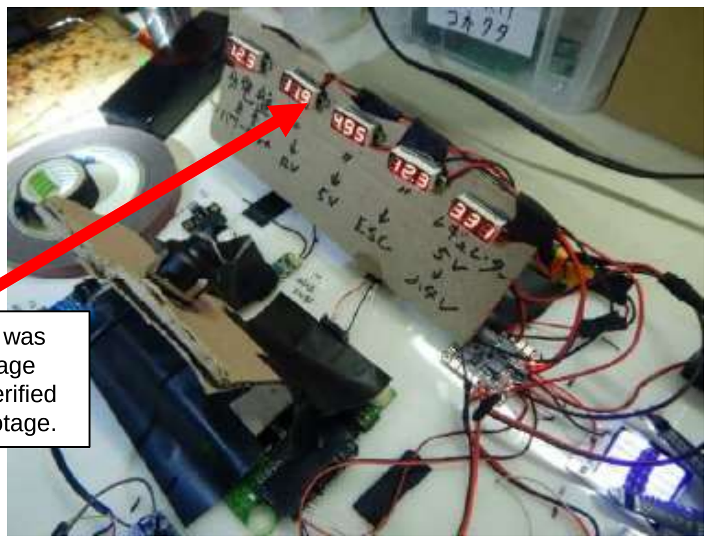
6. Implementation details

(2) Development of the bottom access investigation method (drone)

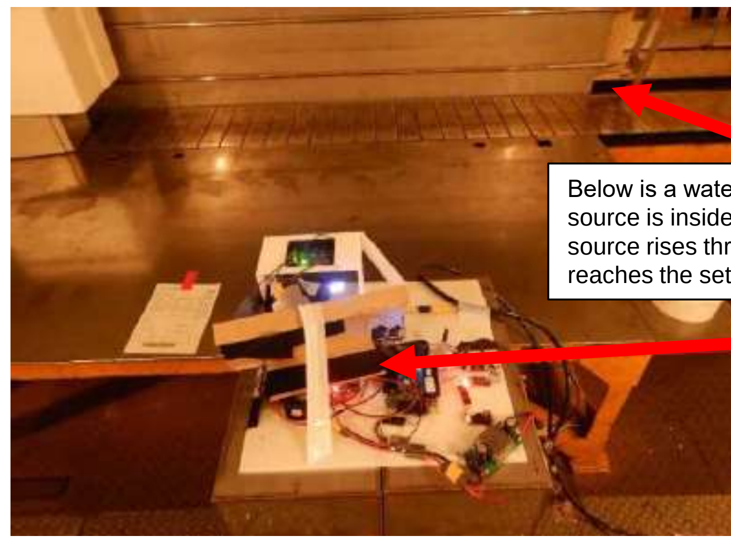
(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑩: [Drone irradiation test (1/3)]

Target	Drone (wired / wireless)
Test method	① Used wired and wireless drones, excluding the airframe, for irradiation with 1000 Gy/h. ② During irradiation, activated the drone, monitored camera footage and voltage values, and terminated irradiation if any abnormalities were found in the camera footage or voltage values. ③ After irradiation, checked the operation of each on-board device to identify which on-board device malfunctioned. [Note] A digital voltmeter was added so that voltage values could be verified via the camera footage.
Output/Assessment criteria	Components resistant to radiation of 1000 Gy/h (target)



Digital voltmeter



Dose rate measurement

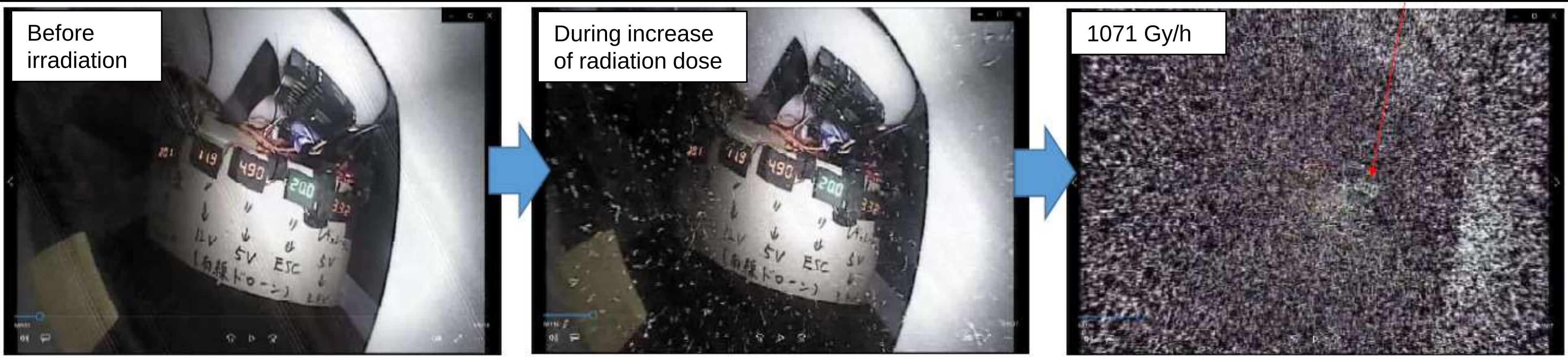
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑩: [Drone irradiation test (2/3)]

Test results (wired drone)



Changes in camera footage over time

Changes in drone over time

Time irradiated	Cumulative dose	Drone status
0 to 6 min.	107 Gy	The camera footage became noisy and only the digital voltmeter display was discernable. Pan-tilt (panning and tilting) of the camera was possible.
6 min. 53 sec.	122 Gy	Pan-tilt became uncontrollable.
7 min. 1 sec.	125 Gy	The pan-tilt angle was pulled downward under the camera's own weight.
7 min. 31 sec.	134 Gy	Test completed.

- The camera's pan-tilt camera became uncontrollable at a cumulative dose of 122 Gy.
- No significant change was observed in the voltage values before and after irradiation.
- After irradiation, since the propeller motor could not be operated by the controller, a PC was connected to the flight controller to check operation. Since the response could be confirmed on the PC, it was concluded that the motor would not operate because the flight controller or electronic components (ESC) were not outputting a signal.
- The FY2021 irradiation test was conducted without a supply of electric current, so the FY2022 irradiation test was conducted with a supply of electric current, but as in FY2021, malfunctions were observed at a cumulative dose of about 100 Gy, so the procedures for drone operations and the configuration of electric parts in the airframe need to be reviewed.

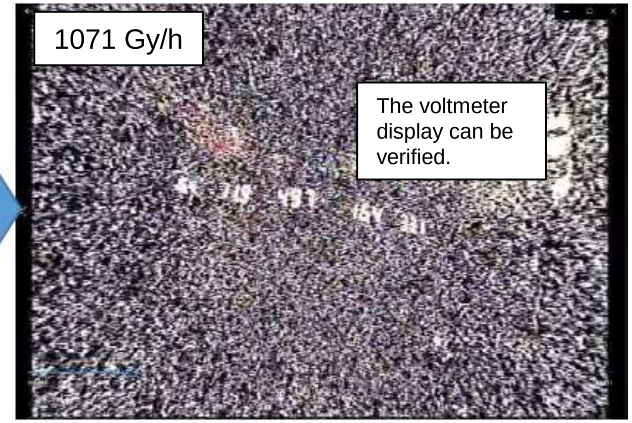
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑩: [Drone irradiation test (3/3)]

Test results (wireless drone)



Changes in drone over time

Time irradiated	Cumulative dose	Drone status
0 to 10 min.	175 Gy	The camera footage became noisy and only the digital voltmeter display was discernable.

Changes in camera footage over time

- The noise in the camera footage made it impossible to check the operation of the motors and servo motors, and since it was impossible to verify abnormalities, the test was completed in 10 minutes based on the wired drone results.
- No significant change was observed in the voltage values before and after irradiation.
- After irradiation, the propeller motor could not be operated using the controller.
- The LED display on the receiver antenna for the control system was off, indicating that the receiver was damaged and inoperable. Additionally, since camera footage could be checked even after irradiation, it was concluded that there was no abnormality in the video transmitter.
- The FY2021 irradiation test was conducted without a supply of electric current, so the FY2022 irradiation test was conducted with a supply of electric current, but malfunctions were observed at less than the target 1000 Gy, so the procedures for drone operations and the configuration of electric parts in the airframe need to be reviewed.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑪: [Temperature / current value verification test]

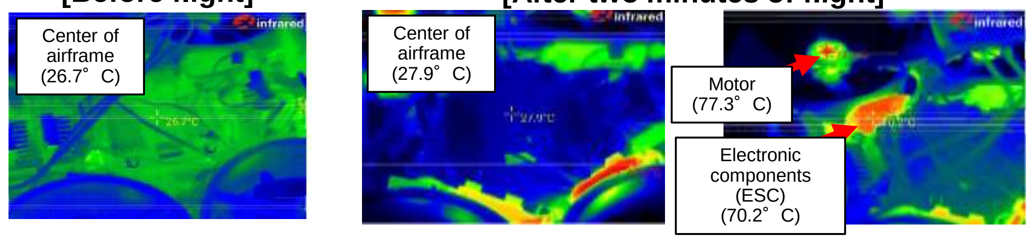
Target	Drone (wired / wireless)
Test method	① Drone hovered at a height of 1 m above the floor for 1 or 2 minutes. ② Measured the temperature of the center of the airframe and the electronic components (ESC) both before and after flight. Also measured the maximum electric current value during flight. [Note] For reference, temperatures were measured using a thermal camera.
Output/Assessment criteria	Change in temperature / electric current value of electronic components as output rises

Test results

Temperature / current value verification test (wired drone)

No.	Flight time [min.]	Temperature [°C]				Maximum current value [A]
		Center of airframe		Electronic components (ESC)		
		Before flight	[After flight]	Before flight	[After flight]	
1	1	19.8	23.4	21.6	48.0	17
2	2	21.8	28.0	20.2	56.0	17

[Before flight] **[After two minutes of flight]**

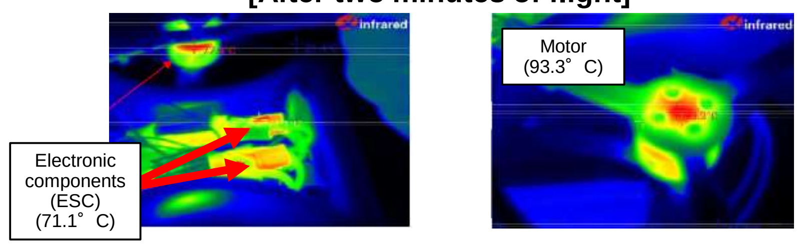


Measurement by thermal camera* (wired drone)

Temperature / current value verification test (wireless drone)

No.	Battery capacity	Flight time [min.]	Temperature [°C]				Maximum current value [A]
			Center of airframe		Electronic components (ESC)		
			Before flight	[After flight]	Before flight	[After flight]	
1	Two 4600 mAh batteries	1	20.6	32.0	20.0	40.0	65
2		2	21.0	36.0	20.0	46.0	70

[After two minutes of flight]



*Thermal camera measurements are for reference.

Measurement by thermal camera* (wireless drone)

- The thermal camera measurements revealed that the components with the highest rate of temperature rise with increasing output were the motor and the electronic components (ESCs).
- In FY2022, cooling fans were installed to make cooling of the airframe interior more efficient, but there is room to consider more efficient methods for cooling electronic components (ESCs), which have a high rate of temperature increase.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (drone)

Test (a)-⑫: [Waterproof performance verification test]

Target	Drone (wired / wireless)
Test method	① Flew drone at a height of 1 meter. ② Sprinkled water from above the drone for 5 minutes at a rate of approximately 5 L/min using a water sprinkler. ③ After sprinkling, checked drone for operational abnormalities.
Output/Assessment criteria	No abnormality in drone operation after sprinkling of water from above for 5 minutes [reference measurement]

Test results

Waterproof performance verification test (wired specification)

Waterproof performance verification test (wireless specification)

- No abnormalities in operation were observed after sprinkling of water.
- Water pressure and dust may also have an impact, so waterproofing and dustproofing measures must be considered in the future.

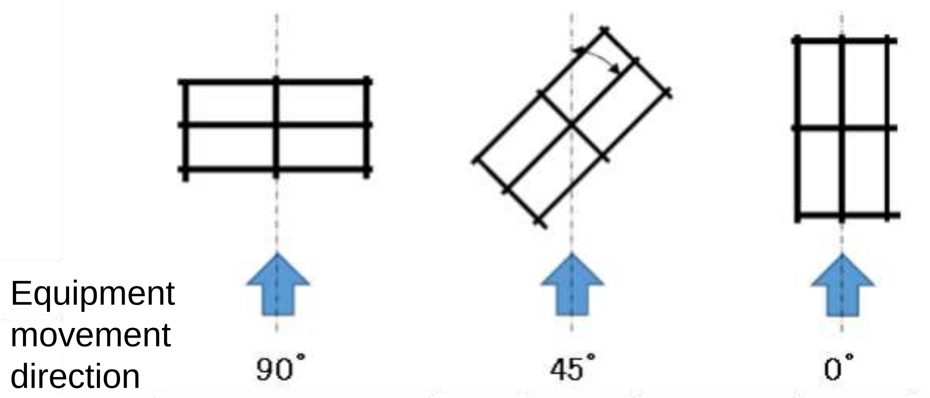
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

Test (b)-①: [Tractive force verification test (1/2)]

Target	Telescopic rod transfer cart (wired specification / wireless specification)
Test method	① Installed the equipment on the grating. ② Operated the crawler forward and measured the tractive force using a spring scale fixed opposite to the direction of movement. ③ The grating was dry or wet, and oriented in three patterns: vertical, diagonal, or horizontal (0°, 45°, or 90° to the direction of movement).
Output/Assessment criteria	Actual value of crawler cable tractive force in dry or wet conditions



Orientation of grating

Crawler

6. Implementation details

(2) Development of the bottom access investigation method (drone)

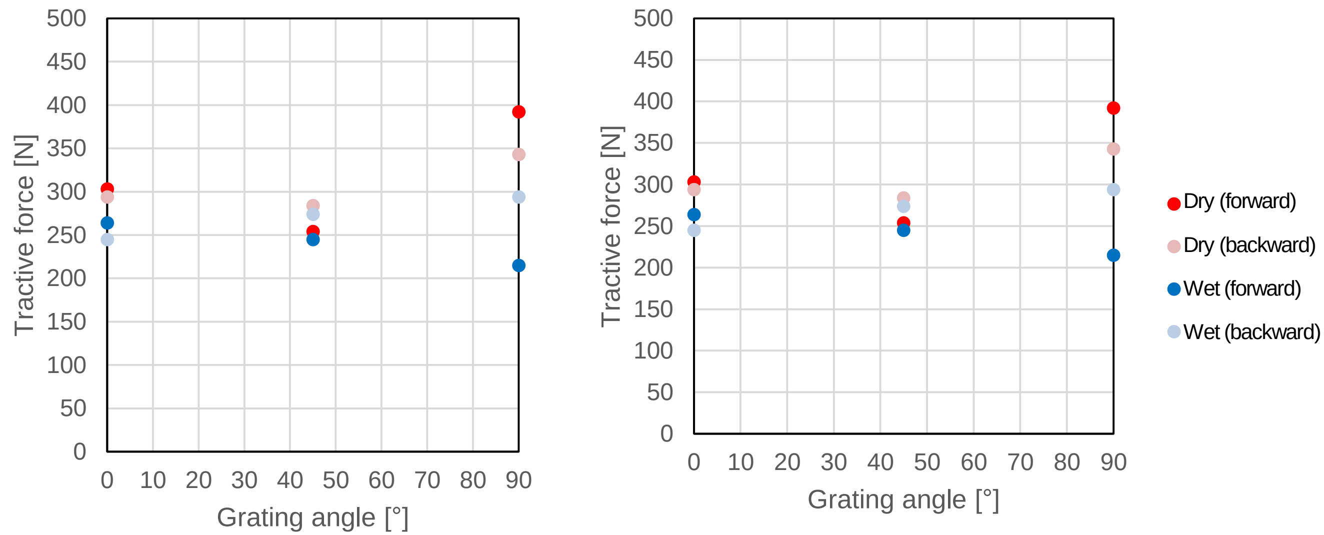
(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

Test (b)-①: [Tractive force verification test (2/2)]

Test results

Tractive force verification test

No.	Grating		Direction of movement	Tractive force [N]	
	Condition	Angle [°]		Wired specification	Wireless specification
1	Dry	0	Forward	274	254
2			Backward	323	254
3		45	Forward	303	225
4			Backward	274	196
5		90	Forward	303	343
6			Backward	392	294
7	Wet	0	Forward	107	147
8			Backward	107	147
9		45	Forward	176	196
10			Backward	147	98
11		90	Forward	176	215
12			Backward	196	441



Tractive force verification test (left: wired specification, right: wireless specification)

- The tractive force of the telescopic rod transfer cart was found to be greater in dry conditions than in wet conditions for both wired and wireless specifications.
- The minimum tractive force in these measurements was about 98 N (conditions: wireless specification / wet / 45° / backward).

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

Test (b)-②: [Driving performance verification test]*

*Wired specifications: Test (b)-② and test (c)-② were conducted simultaneously.

Target	Telescopic rod transfer cart (wired specification / wireless specification)
Test method	① The equipment made round trips on top of the grating. (The outward journey is forward and the return journey is backward.) ② When maneuvering, controlled the device by camera footage only. ③ Checked maneuverability in dry and wet conditions. [Note] Conducted as another project (mockup equipment for Detailed Investigation inside PCV)
Output/Assessment criteria	Ability to drive the telescopic rod transfer cart on grating in dry or wet conditions without problems
Test results	

Driving performance verification test

No.	Grating condition	Direction of movement	Maneuverability	
			Wired specification	Wireless specification
1	Dry	Forward	Pass	Pass
2		Backward	Pass	Pass
3	Wet	Forward	Pass	Pass
4		Backward	Pass	Pass

Driving performance verification test (wired specification)

Driving performance verification test (wireless specification)

- Round trips were made without any problems.
- However, for the wired drones there were cases of cables getting caught, so the amount of cable feeding and rewinding for the wired drones needs to be optimized.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

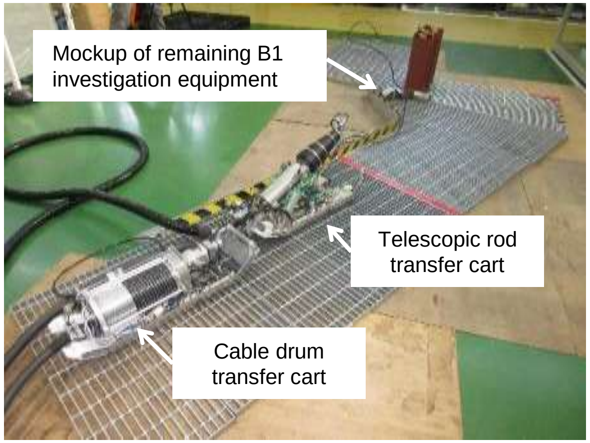
Test (b)-③: [Verification test of travelling ability]*

*Wired specifications: Test (b)-③ and test (c)-③ were conducted simultaneously.

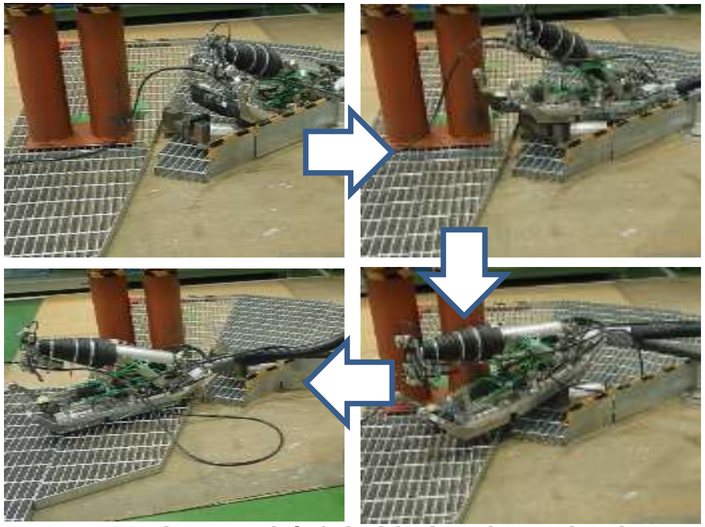
Target	Telescopic rod transfer cart (wired specification / wireless specification)
Test method	Placed the mock left-behind B1 investigation equipment on the grating and verified that it could be traversed both forward and backward. [Note] Taking into account actual device considerations for the wired specification, the test was conducted with wired drone cables set-up, and linked to a cable drum transfer cart.
Output/Assessment criteria	Ability of the telescopic rod transfer cart to traverse the mock left-behind B1 investigation equipment in dry or wet conditions
Test results	

Verification test of travelling ability

No.	Grating condition	Direction of movement	Travelling ability	
			Wired specification	Wireless specification
1	Dry	Forward	Pass	Pass
2		Backward	Pass	Pass
3	Wet	Forward	Pass	Pass
4		Backward	Pass	Pass



Travelling ability verification test (wired specification)



Traversing mock left-behind B1 investigation equipment (wired specification)

- The telescopic rod transfer cart was able to traverse the mock left-behind B1 investigation equipment in both dry and wet conditions.
- To simplify the procedure assuming actual equipment, the mock left-behind B1 investigation equipment was traversed while the cable for the wired drone was fed/wound only at the telescopic rod tip. (The cable at the rear of the equipment was assisted by hand, since it’s expected that there will be a cable assistance device.)

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

Test (b)-④: [Rod extension/retraction test]
Test (b)-⑤: [Passage performance verification test]
Test (b)-⑥: [Composite cable feeding/winding test (linkage with rod extension/retraction operation)]
Test (b)-⑦: [Composite cable feeding/winding test (linkage with cable drum)]

Test (c)-④: [Composite cable feeding/winding test (linkage with telescopic rod)]

Combined →

Wired specification: Test (b)-④, ⑤, ⑥, ⑦ and Test (c)-④
Wireless specification: Test (b)-④ and ⑤

- **The above five tests were conducted for each of the above combinations of wired and wireless specifications using the following provisional procedures for actual equipment, which were determined based on preliminary verification tests.**

Rod extension/retraction: Provisional procedures for actual equipment (wired specification)

No.	During extension	During retraction
1	Extend rod by 1 m	Retract rod by 1 m
2	Feed 1 m of cable from drum transfer cart	Wind 1 m of cable with drum transfer cart
3	Extend rod by 1 m	Retract rod by 1 m
4	Feed 1 m of cable from drum transfer cart	Wind 1 m of cable with drum transfer cart
5	Extend rod by 1 m	Retract rod by 1 m
6	Bring the cable back 0.5 m at the rod tip	Wind 1 m of cable with drum transfer cart
7	Extend rod by 1 m	Retract rod by 1 m
8	Bring the cable back 0.5 m at the rod tip	Wind 1 m of cable with drum transfer cart
9	Extend rod by 1 m	Retract rod by 1 m
10	Feed 3 m of cable at the tip	Wind 1 m of cable with drum transfer cart

For the wireless system, there is no interaction with cables and only a simple extension/retraction operation, so the procedures are not explicitly stated.


Expected arrangement of actual equipment

6. Implementation details

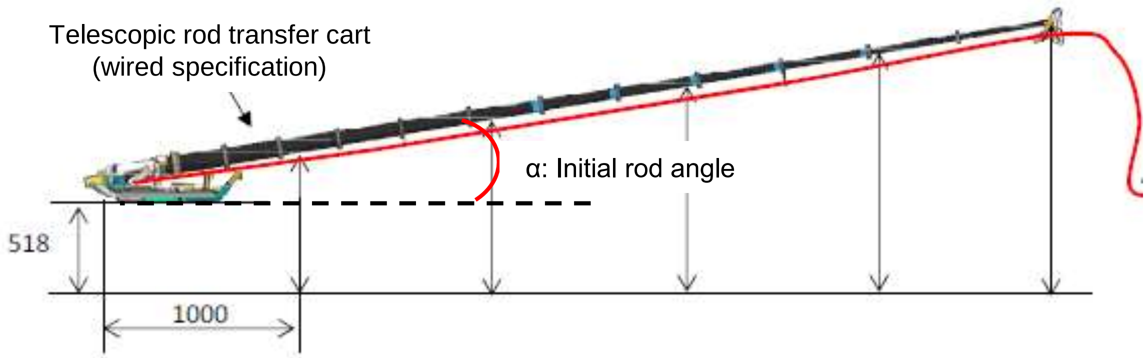
(2) Development of the bottom access investigation method (drone)

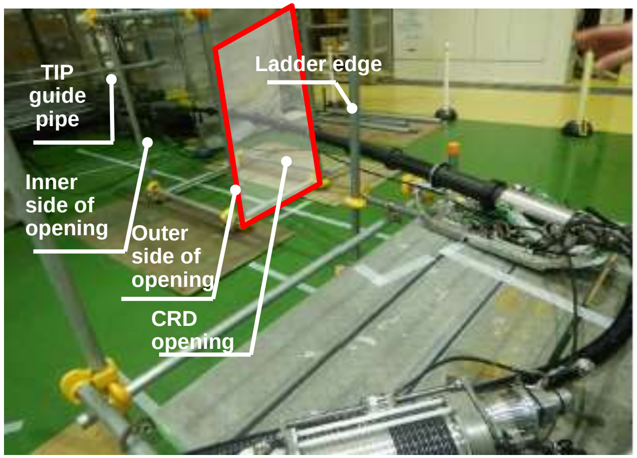
(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

[Rod extension/retraction test (1/3)]*

*Wired specification: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ were conducted simultaneously.
Wireless specification: Tests (b)-④ and ⑤ were conducted simultaneously.

Target	Telescopic rod transfer cart (wired specification / wireless specification), cable drum transfer cart (wired specification)
Test method	① Extended and retracted the telescopic rod according to the provisional procedures for actual equipment, and measured the amount of time needed for extension and retraction operations. ② During extension, measured the amount of bending of the telescopic rod (the distance from the floor to the center of the rod pipe) at every 1 m from the rear end of the equipment to the tip. [Note] • In consideration of the actual equipment for the wired specification, the test was conducted with the cable for the wired drone connected to the rod tip. • The initial feed rate was set at 5 m.
Output/ Assessment criteria	• Time needed for extension and retraction operations • The amount of bending of the telescopic rod for every meter from the rear end of the equipment to the tip (the distance from the floor to the center of the rod pipe) • Ability to pass through the TIP guide pipe (mock-up), which is a structure inside the pedestal • Optimal initial rod angle during rod extension (see figure below) • Telescopic rod extension/retraction and linkage with cable drum during composite cable feeding/winding





Rod extension/retraction combined test (wired specification)

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

[Rod extension/retraction test (2/3)]*

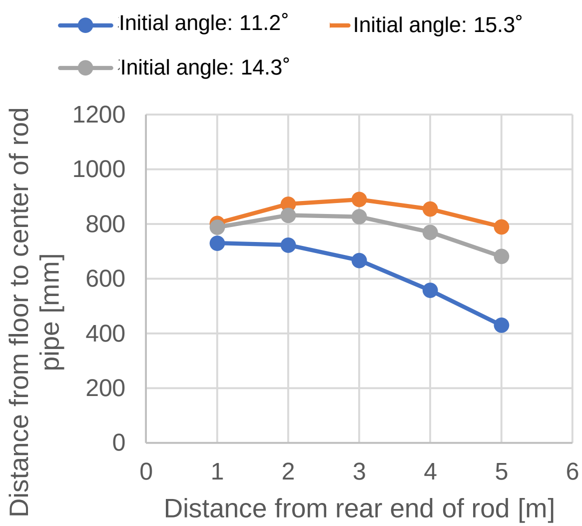
*Wired specification: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ were conducted simultaneously.
Wireless specification: Tests (b)-④ and ⑤ were conducted simultaneously.

Test results (wired specification)

Rod extension/retraction combined test (wired specification)

No.	Initial rod angle [°]	Passability (Test (b)-⑤)	Rod extension/retraction (Test (b)-④)							Linkage (Test (b)-⑥ and ⑦, Test (c)-④)	
					Distance from floor to center of rod pipe [mm]						
		Passage capability	Amount of time needed for extension	Amount of time needed for retraction	1 m from the rear end of the rod	2 m from the rear end of the rod	3 m from the rear end of the rod	4 m from the rear end of the rod	5 m from the rear end of the rod	Linkage with rod extension/retraction	Linkage with cable drum
1	11.2	Pass	4 min. 26 sec.	7 min. 53 sec.	730	723	667	558	430	No problems	No problems
2	15.3	Unsatisfactory	4 min. 32 sec.	7 min. 2 sec.	803	873	890	855	790	No problems	No problems
3	14.3	Satisfactory*	5 min. 15 sec.	7 min. 36 sec.	788	832	827	770	682	No problems	No problems

*Although passable, the cable of the pan-tilt camera at the end of the rod came in contact with the TIP guide tube.



Bending during rod extension/retraction

- The optimal initial angle at which the rod can pass through the TIP guide tube (mock-up), which is a structure inside the pedestal, is considered to be the angle at which the rod tip is highest after extension, making it easier to check conditions in the upper part of the pedestal, and this angle was confirmed to be 14.3° .
- In addition, the time needed for extension/retraction at said initial angle was; extension: 5 min. 15 sec. / retraction: 7 min. 36 sec.
- The difference in the amount of bending between the highest and lowest points was approximately 150 mm.
- There were no problems with rod extension/retraction and linkage with the cable drum during composite cable feeding/winding, and 7 m of cable could be fed/rewound by feeding the cable at the rod tip. However, the wired drone composite cable that had become loose during rod extension got caught on the structure, so the provisional procedures for actual equipment need to be revised.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplemental explanatory material) Results of functional verification tests for FY2022 (telescopic rod transfer cart)

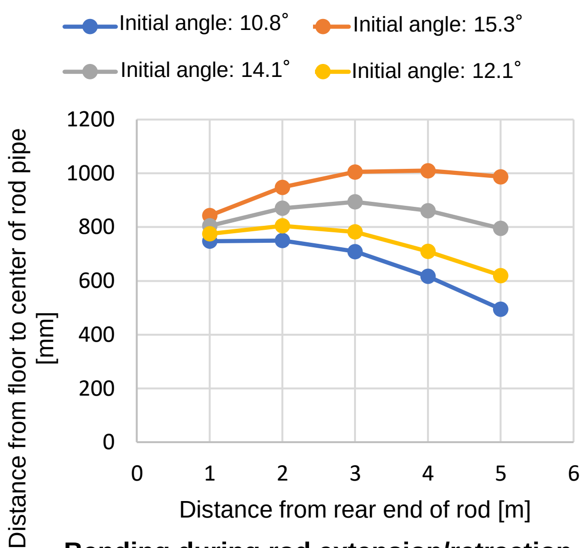
[Rod extension/retraction test (3/3)]*

*Wired specification: Tests (b)-④, ⑤, ⑥, ⑦, and (c)-④ were conducted simultaneously.
Wireless specification: Tests (b)-④ and ⑤ were conducted simultaneously.

Test results (wireless specifications)

Rod extension/retraction combined test (wireless specification)

No.	Initial rod angle [°]	Passing performance (Test (b)-⑤)	Rod extension/retraction (Test (b)-④)						
					Distance from floor to center of rod pipe [mm]				
		Passage capability	Amount of time needed for extension	Amount of time needed for retraction	1 m from the rear end of the rod	2 m from the rear end of the rod	3 m from the rear end of the rod	4 m from the rear end of the rod	5 m from the rear end of the rod
1	10.8	Pass	3 min. 58 sec.	6 min. 54 sec.	748	750	709	617	495
2	15.3	Unsatisfactory	19 min. 28 sec.	11 min. 23 sec.	843	948	1005	1010	987
3	14.1	Unsatisfactory	7 min. 45 sec.	8 min. 21 sec.	805	870	894	861	795
4	12.1	Pass	6 min. 6 sec.	7 min. 37 sec.	775	805	782	710	620



Bending during rod extension/retraction

- The optimal initial angle at which the rod can pass through the TIP guide tube (mock-up), which is a structure inside the pedestal, is considered to be the angle at which the rod tip is highest after extension, making it easier to check conditions in the upper part of the pedestal, and this angle was confirmed to be 12.1° .
- The initial angle is smaller than for the wired specification because there are no cables.
- In addition, the time needed for extension/retraction at said initial angle was; extension: 6 min. 6 sec. / retraction: 7 min. 37 sec.
- The difference in the amount of bending between the highest and lowest points was approximately 185 mm.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

Unit 1

No.99

(Supplementary material). Results of functional verification tests for FY2022 (cable drum transfer cart)

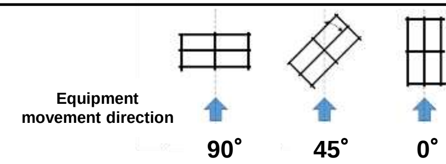
Test (c)-①: [Tractive force verification test]

Target

Cable drum transfer cart (wired specification)

Test method

① Installed the equipment on the grating.
② Operated the crawler forward and measured the tractive force using a spring scale fixed opposite to the direction of movement.
③ The grating was dry or wet, and oriented in three patterns: vertical, diagonal, or horizontal (0°, 45°, or 90° to the direction of movement) (see figure on the right).



Output/Assessment criteria

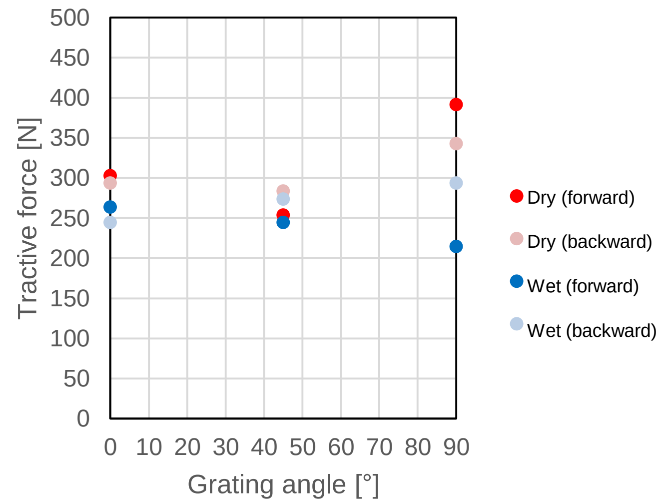
Actual value of crawler cable tractive force in dry or wet conditions

Test results

- For grating angles of 0° and 90°, the tractive force of the cable drum transfer cart was greater in the dry condition than in the wet condition, regardless of the direction of movement.
- There was no significant difference in tractive force between wet and dry when the grating angle was 45°.
- The minimum tractive force in these measurements was about 215 N (conditions: wet / 90° / forward).

Tractive force verification test

No.	Grating		Direction of movement	Tractive force [N]
	Condition	Angle [°]		
1	Dry	0	Forward	303
2			Backward	294
3		45	Forward	254
4			Backward	284
5		90	Forward	392
6			Backward	343
7	Wet	0	Forward	264
8			Backward	245
9		45	Forward	245
10			Backward	274
11		90	Forward	215
12			Backward	294



Tractive force verification test

6. Implementation details

Unit 1

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable drum transfer cart)

Test (c)-②: [Driving performance verification test]*

***Wired specifications: Test (b)-② and test (c)-② were conducted simultaneously.**

Target	Cable drum transfer cart (wired specification)
Test method	① The equipment made round trips on top of the grating. (The outward journey is forward and the return journey is backward.) ② When maneuvering, controlled the device by camera footage only. ③ Checked maneuverability in dry and wet conditions. [Note] Conducted as another project (mockup equipment for Detailed Investigation inside PCV)
Output/Assessment criteria	Ability of the cable drum transfer cart to move on top of grating in dry or wet conditions without any problems
Test results	

Driving performance verification test

No.	Grating condition	Direction of movement	Maneuverability	
1	Dry	Forward	Pass	Pass
2		Backward	Pass	Pass
3	Wet	Forward	Pass	Pass
4		Backward	Pass	Pass

Driving performance verification test

- Round trips were made without any problems.
- However, there were cases of wired drone cables getting tread upon, so the amount of cable feeding and rewinding for the wired drones needs to be optimized.

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable drum transfer cart)

Test (c)-③: [Verification test of travelling ability]*

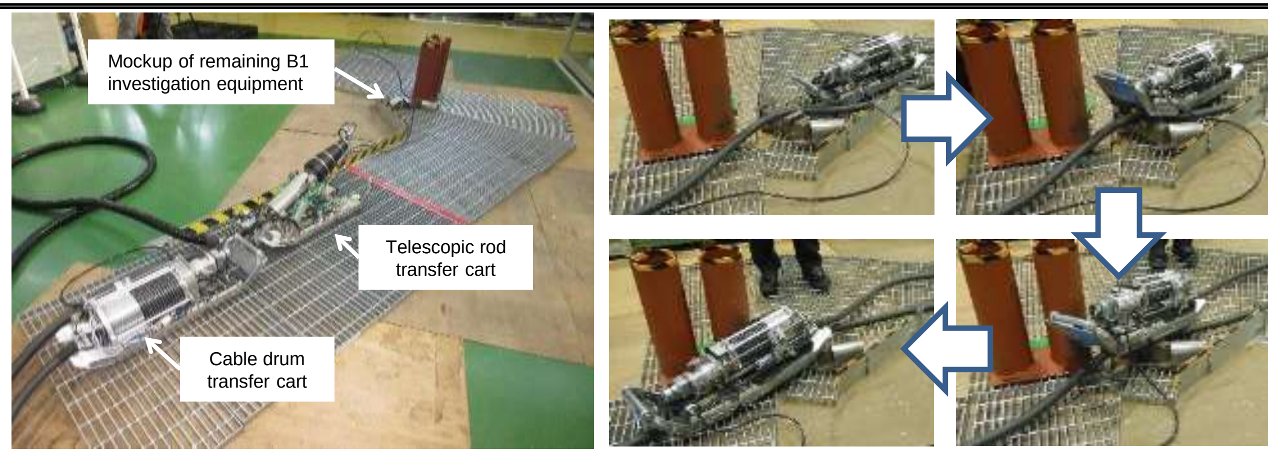
*Test (b)-③ and Test (c)-③ were conducted simultaneously.

Target	Cable drum transfer cart (wired specification)
Test method	Placed the mock left-behind B1 investigation equipment on the grating and verified that it could be traversed both forward and backward.
Output/Assessment criteria	Ability of the telescopic rod transfer cart to traverse the mock left-behind B1 investigation equipment in dry or wet conditions
Test results	

Verification test of travelling ability

No.	Grating condition	Direction of movement	Travelling ability	
			Wired specification	Wireless specification
1	Dry	Forward	Pass	Pass
2		Backward	Pass	Pass
3	Wet	Forward	Pass	Pass
4		Backward	Satisfactory (*)	Pass

(*) When the cable drum transfer cart was moved backward to traverse the B1 investigation equipment, the part that clamped the cable at the rear of the equipment and protruded beyond the diagonal guide parts sometimes interfered with the mock left-behind B1 investigation equipment and prevented the cart from traversing the equipment.



Verification test of travelling ability (wired specification)

- The cable drum transfer cart was able to traverse the mock left-behind B1 investigation equipment in both dry and wet conditions. However, the ease of traversing varied depending on the condition of the cable and the condition of the mock left-behind B1 investigation equipment. This must be reviewed in more detail in future combined tests in order to respond to various situations in application of actual equipment.
- All cameras mounted on the cable drum transfer cart were fixed cameras. Since it is difficult to check the cables during movement, a pan-tilt camera should be used in the actual equipment, and the design should be improved to allow checking of cables.
- To simplify the procedure assuming actual equipment, the mock left-behind B1 investigation equipment was traversed while the cable for the wired drone was fed/wound only at the telescopic rod tip.

(The cable at the rear of the equipment was assisted by hand, since it’s expected that there will be a cable assistance device.)

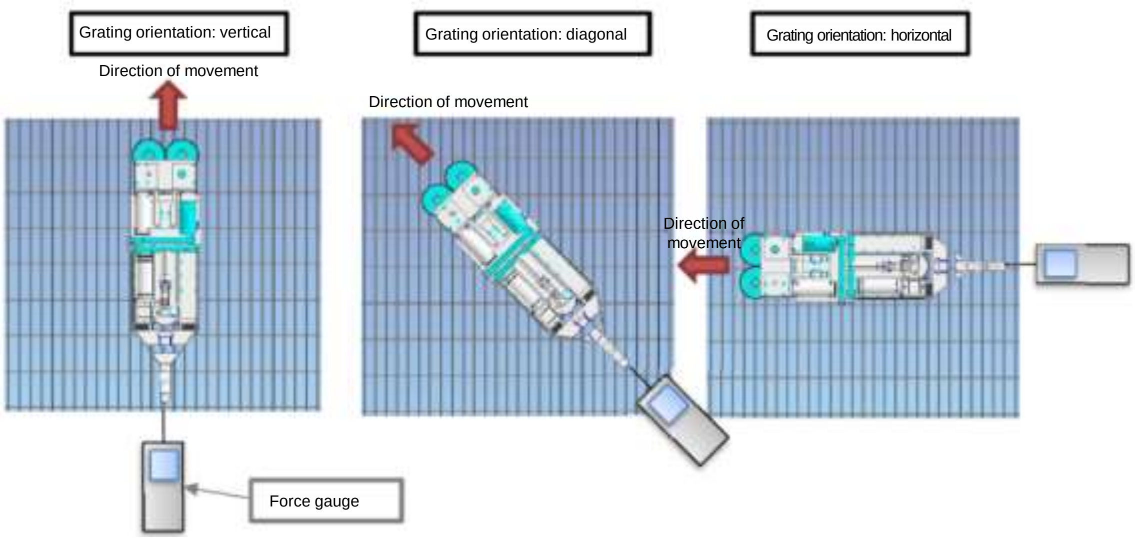
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-①: [Tractive force verification test]

Target	Cable assistance device (wired specification / wireless specification)
Test method	① Installed the equipment on the grating. ② Operated the crawler forward and measured the tractive force with a force gauge fixed opposite to the direction of movement. ③ Repeated the process with vertical, horizontal, or diagonal grating orientations and under wet or not wet conditions.
Output/ Assessment criteria	Actual value of crawler cable tractive force (Target: 100 N)



Conceptual drawing of the test

Test results

Tractive force verification test

No.	Grating		Tractive force [N]
	Grate	Wetting	
1	Vertical	No	210
2	Horizontal	No	250
3	Diagonal	No	190
4	Vertical	Yes	190
5	Horizontal	Yes	230
6	Diagonal	Yes	180

- In all conditions, the target tractive force of 100 N was exceeded.
- Tractive force was strongest when the grating orientation was horizontal, and about 20 to 30% weaker when vertical or diagonal.
- Tractive force was about 10% weaker when the grating was wetted versus when not wetted.

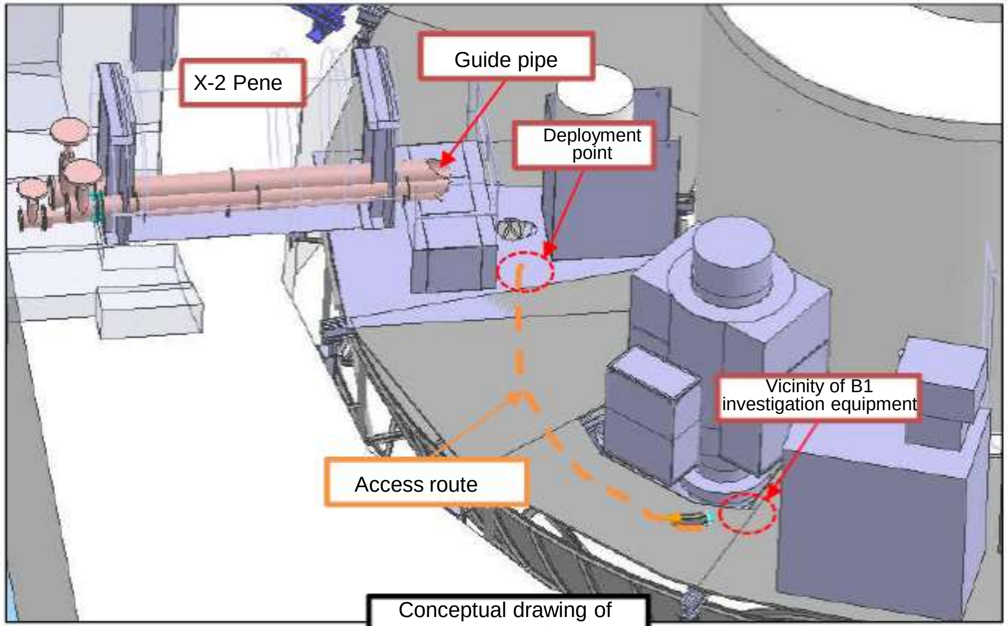
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-②: [Driving performance verification test (1/2)]

Target	Cable assistance device (wired specification / wireless specification)
Test method	① Performed crawler operations along the access route on the grating, made round trips on the access route. ② The grating was either dry or wet. Guide pipe
Output/ Assessment criteria	Ability to make round trips between the deployment point on the grating and the vicinity of the B1 investigation equipment without problems in dry or wet conditions.



Conceptual drawing of access route

Conceptual drawing of the test

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-②: [Driving performance verification test (2/2)]

Test results

- Round trips were made without any problems.
- It was confirmed that a 2-cable pushing maneuver is possible.
- When two cables were vertically aligned on one side of the B1 investigation equipment, the device by itself could not free the cables in a lateral direction.
- However, it may be possible to free cables if there is linkage to other equipment (drum transfer cart).

Maneuvering toward the B1 remnant

Cable pushing maneuver

Freeing a cable overlap

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-③: [Cable grabbing performance verification test]

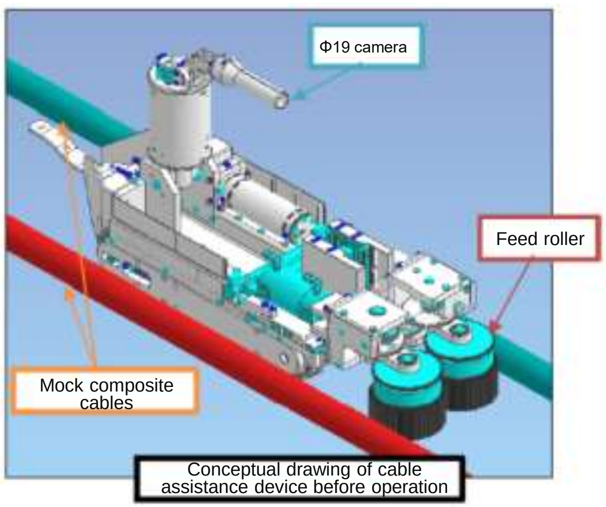
Target	Cable assistance device (wired specification / wireless specification)
Test method	① Laid Φ40 mm mock composite cables on both sides (left and right) of the cable assistance device. ② Checked whether the feed rollers can grip the cables for operations in each axis. ③ Checked to see if the camera footage can be used to assess gripping of cables.
Output/ Assessment criteria	Ability to grip the composite cables that are spread across the grating on the left and right sides of the equipment, and ability to assess gripping of cables via camera footage

Test results

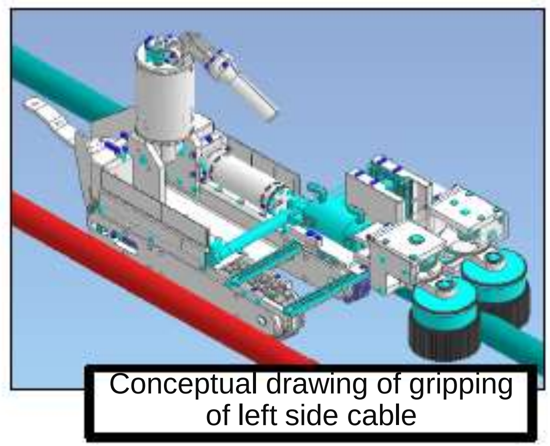
Cable grabbing performance verification test

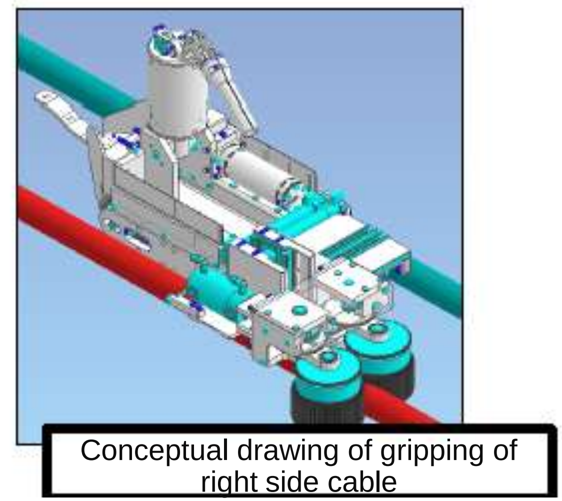
Cable placement	Grab ability	Video verifiability
Left side	Pass	Pass
Right side	Pass	Pass

- The ability to grip the composite cables on the left and right sides of the equipment was confirmed.
- Although difficult, by raising and lowering the camera, it was possible to assess gripping of cables via camera footage.



Conceptual drawing of cable assistance device before operation


Conceptual drawing of gripping of left side cable


Conceptual drawing of gripping of right side cable

Conceptual drawing of the test

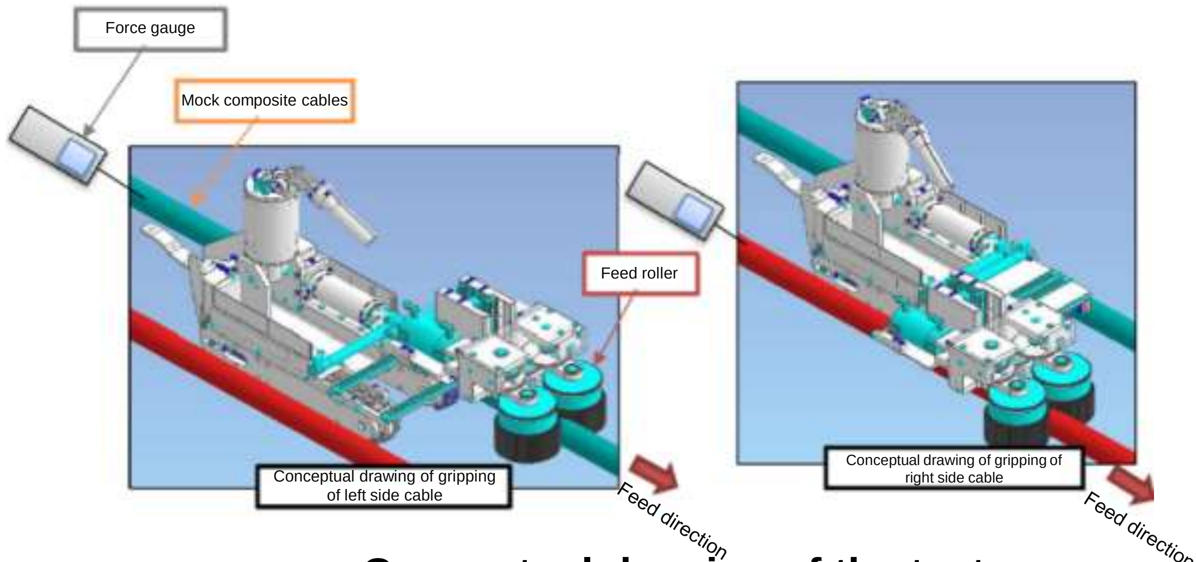
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-④: [Cable feed force verification test (1/2)]

Target	Cable assistance device (wired specification / wireless specification)
Test method	① Laid Φ40 mm mock composite cables on both sides (left and right) of the cable assistance device. ② Gripped one of the cables with the feed roller. ③ Fed cable and measured the feed force using a force gauge fixed in the direction opposite to cable feeding. ④ Repeated ② and ③ under both wet and dry conditions for each cable gripping position. ⑤ Measured the cable clamping pressure and cable feed rate under each condition.
Output/ Assessment criteria	Cable feed performance (cable feed force*/ speed / clamping force) *Target feed force: 100 N



Conceptual drawing of the test

6. Implementation details

Unit 1 No.107

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-④: [Cable feed force verification test (2/2)]

Test results

Cable feed force verification test

Cable		Feed force [N]	Clamping pressure [MPa]	Feed speed [mm/s]
Gripping position	Wetting			
Left side	No	112	0.4	12.5
Right side		118		
Left side	Yes	123	0.4	
Right side		114		
Right side		132	0.3	
Right side		180	0.2	
Right side		150	0.1	

Cable feed force verification test (sand adhesion condition)

Cable		Feed force [N]	Clamping pressure [MPa]	Feed speed [mm/s]
Gripping position	Sand adhesion			
Right side	Yes	168	0.2	12.5

Measurement of feed force

Zeolite Z-13

Cable after application of sand

- In all conditions, the target feed force of 100 N was exceeded.
- Table 1 shows that neither cable gripping position nor wetness had a significant effect on feed force. Furthermore, the clamping pressure with maximum feed force was 0.2 MPa.
- An additional feed test with sand(*) adhered to the cable was conducted and cable feeding was possible without any problems.
  (*)Sand specifications: Powdered zeolite Z-13.
- The equipment exhibited backward movement behavior during cable feeding, but it was possible to compensate by (on the spot gripping) maneuvering the crawler.

Unit 1 No.108

(2) Development of the bottom access investigation method (drone)

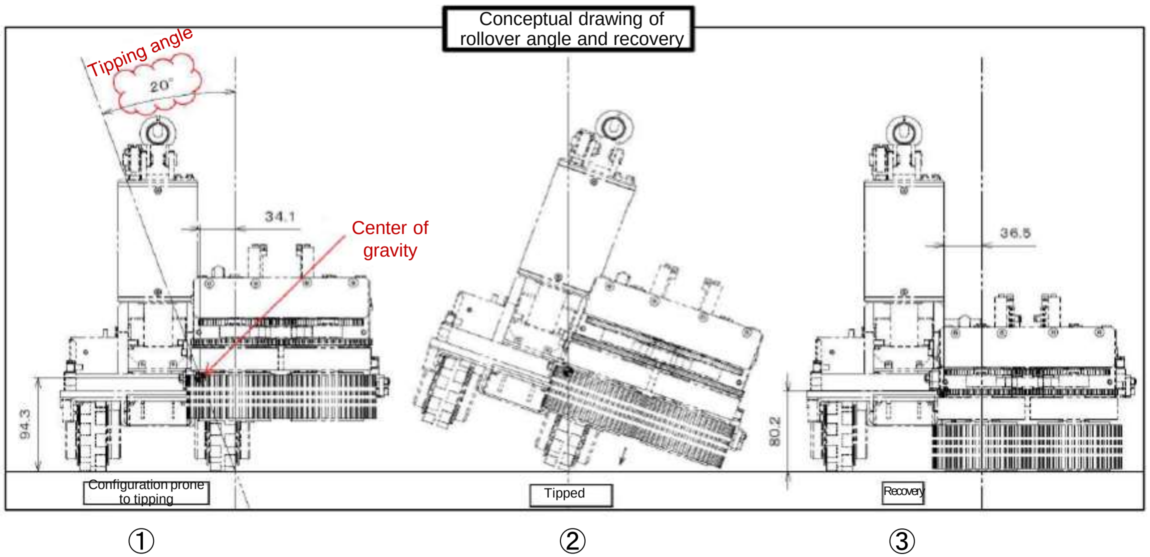
(Supplementary material). Results of functional verification tests for FY2022 (cable assistance device)

Test (d)-⑤: [Rollover verification test]

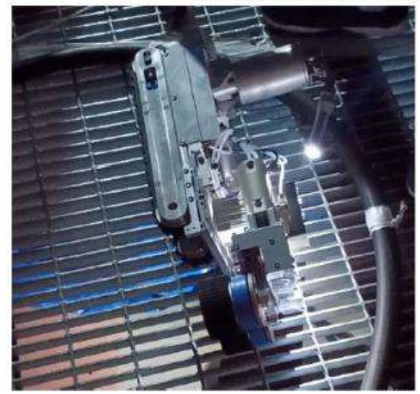
Target	Cable assistance device (wired specification / wireless specification)
Test method	① Installed cable assistance device on the grating. ② Performed operations in each axis and checked whether there was a risk of rolling over. ③ Checked whether the device can recover after rolling over.
Output/ Assessment criteria	• No risk of cable assistance device rolling over in each operation • Ability to recover after rolling over

Test results

- The device traversed the Φ40 cable in a configuration prone to rolling (conceptual drawing of test ①), but did not tip over.
- Even if the device tipped over, if it tipped over at 90° or less, it could recover using the sliding mechanism.



Conceptual drawing of the test



Tipped (approx. 90°)

Activation of slide mechanism

After recovery

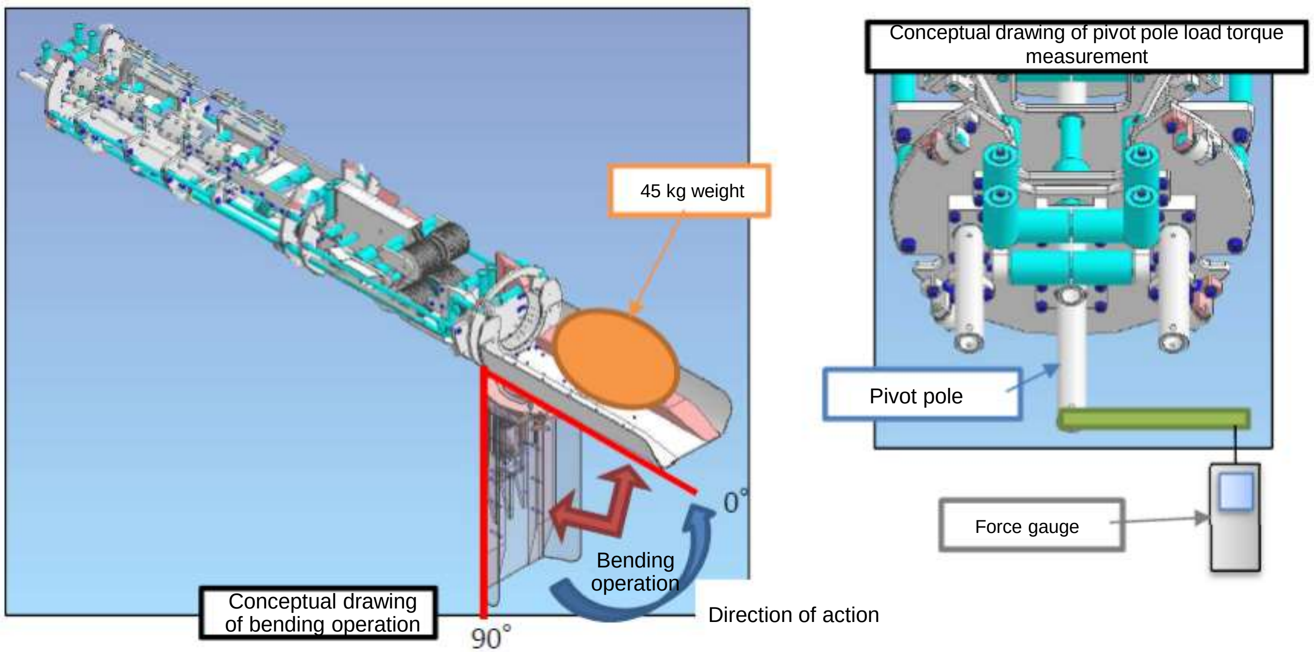
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (350A installation equipment)

Test (e)-①: [Bending load verification test (1/2)]

Target	Installation equipment (wired specification / wireless specification)
Test method	① Placed equipment (40 kg) on the scoop section. ② Turned the bending pole and verified that bending operations were possible. ③ Measured the maximum load torque of the bending pole.
Output/ Assessment criteria	Bending ability with the weight of the investigation equipment (45 kg) on the scoop section.



Conceptual drawing of the test

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (350A installation equipment)

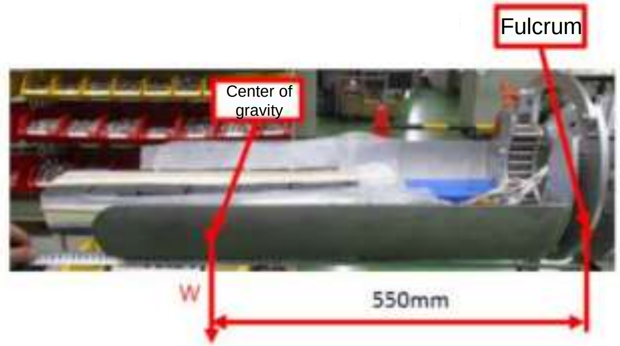
Test (e)-①: [Bending load verification test (2/2)]

Test results

- Bending movement with a 45kg load was possible.
- An additional test with 65 kg was conducted and there were no problems with bending operations.
- The force on the pole was greatest when the bending angle was 10° .

Bending load verification test

No.	Weight/s [kg]	Bending angle [°]	Maximum load torque [N·m]
1	45	0	5.4
2		10	6.6
3		20	5.8
4		30	5.0
5		40	4.6
6		50	4.2
7		60	3.6
8		70	2.6
9		80	2.4
10		90	1.4
11	65	0	7.4
12		10	8.4
13		20	6.8




During testing

With 45 kg load


With 65 kg load

6. Implementation details

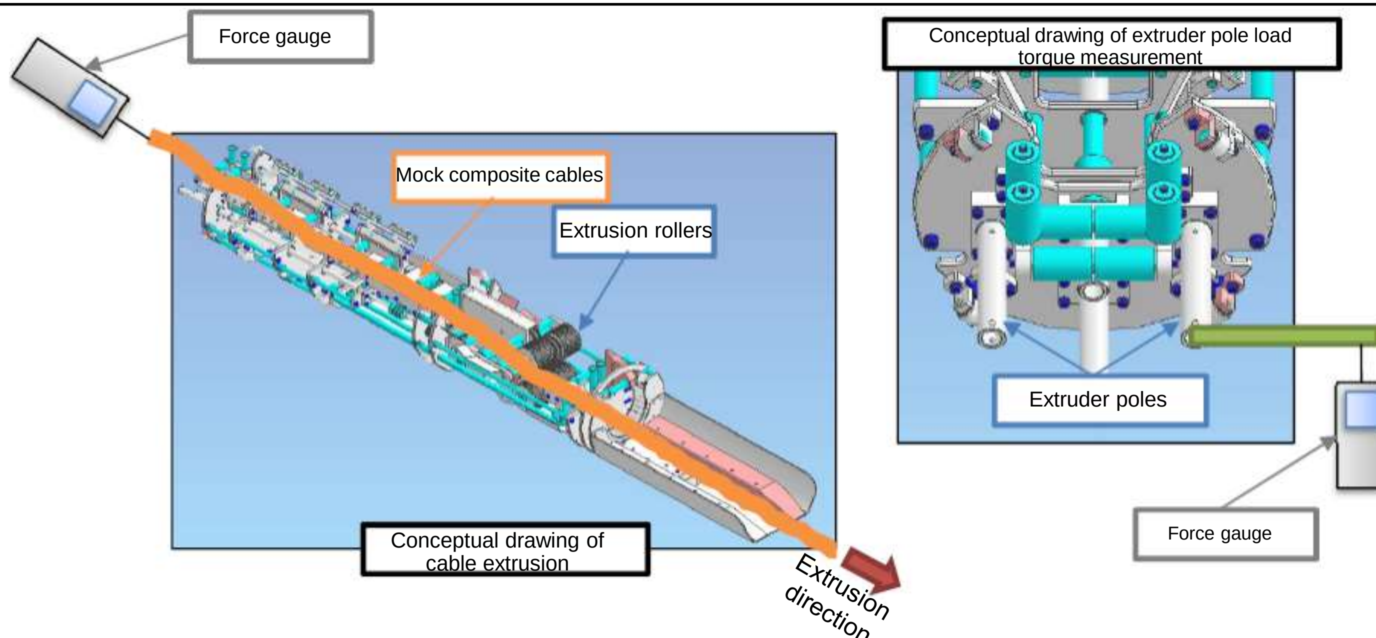
Unit 1 No.111

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (350A installation equipment)

Test (e)-②: [Cable feed force verification test (1/2)]

Target	Installation equipment (wired specification / wireless specification)
Test method	① Clamped the mock composite cables with the extrusion rollers of the installation equipment. ② Turned the extruder pole and measured the extrusion force using a force gauge fixed opposite to the direction of extrusion. ③ Measured the maximum load torque of the extruder pole. ④ Measured cable clamping pressure. ⑤ Repeated the process for the conditions of left vs. right extrusion roller, composite cable diameter, and wetness.
Output/ Assessment criteria	Cable feed performance (cable feed force / speed / clamping force)



Conceptual drawing of the test

6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (350A installation equipment)

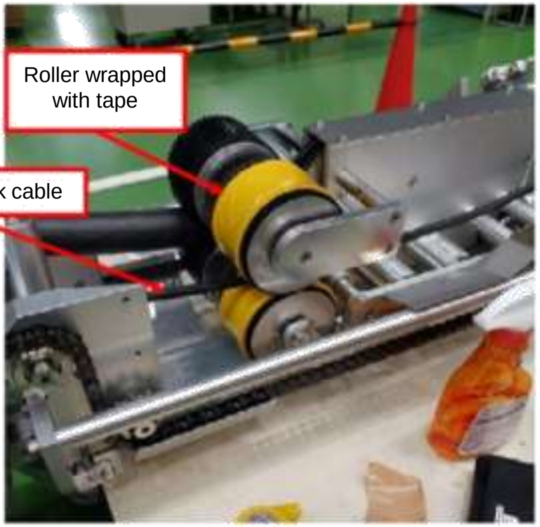
Test (e)-②: [Cable feed force verification test (2/2)]

Test results

- The test results show that the optimum clamping pressure is 0.3 MPa.
- The target feed force of 100 N was exceeded for both Φ40 mm and Φ10 mm cables.
- There was no difference in feed force between the left and right extrusion rollers, and there were no changes caused by conditions of wetness.
- The extrusion rollers need to be modified in order to firmly clamp Φ10 mm cables.
- Improvements are needed as the cables are not easy to install and remove.

Cable feed force verification test

No.	Cable used	Cable		Feed force [N]	Clamping pressure [MPa]	Maximum load torque [N·m]	Remarks
		Gripping position	Wetting				
1	Φ40 mm	Right side	No	75	0.1	7.0	Investigate optimal clamping pressure
2		Right side		73	0.2		
3		Right side		84	0.3		
4		Right side		50	0.4		
5	Φ9.5 mm	Left side	No	8	0.1	0.4	The cable was smaller in diameter than expected and could not be clamped firmly, so there was no change in feeding force.
6		Left side		10	0.2	1.0	
7		Left side		10	0.3	1.0	
8		Left side		10	0.4	1.0	
9	Φ40 mm	Left side	No	87	0.3	7.0	
10		Right side	Yes	80		7.0	
11		Left side		89		7.0	
12		Right side		100		9.0	
13		Right side		170		14.0	
14	Φ9.5 mm	Right side	Yes	10		0.6	
15		Left side		9		0.8	
16	Φ9.5 mm (Wrapped with tire tape)	Left side	No	100		6.8	Conducted by clamping with tape wrapped around the rollers
17		Left side		168		8.8	



Roller wrapped with tape

Installing Φ40 cable

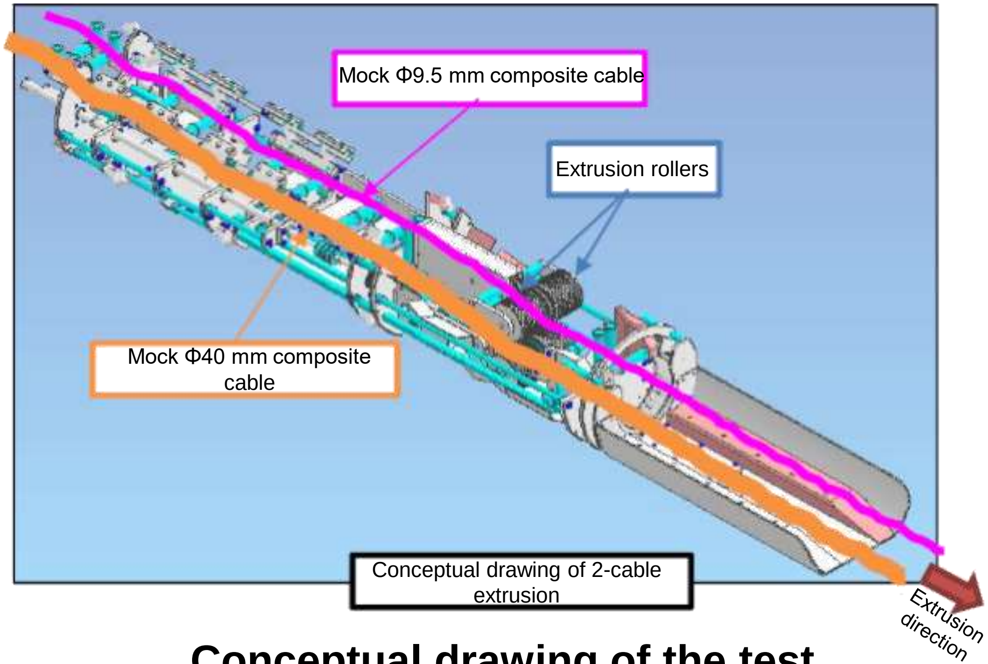
6. Implementation details

(2) Development of the bottom access investigation method (drone)

(Supplementary material). Results of functional verification tests for FY2022 (350A installation equipment)

Test (e)-③: [Cable feeding operations verification test]

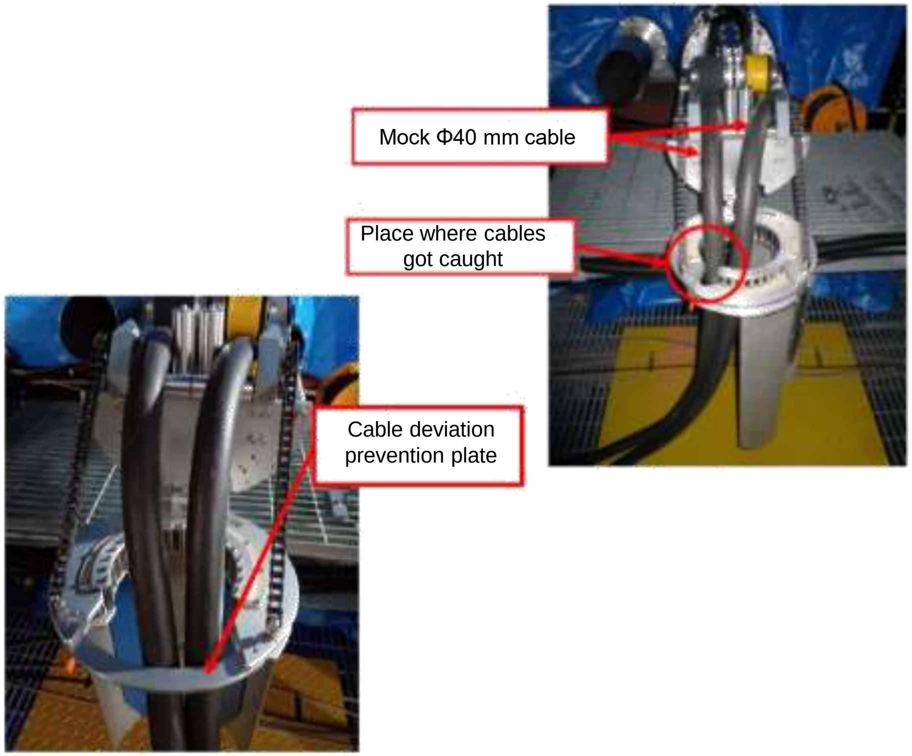
Target	Installation equipment (wired specification / wireless specification)
Test method	① Clamped the mock composite cables on the left and right sides of the installation equipment with the extrusion rollers on the left and right sides, respectively. ② Turned the extruder poles and checked the ease of feeding two cables (Φ40 mm, Φ10 mm).
Output/ Assessment criteria	Ability to feed two cables at the same time without difficulty



Conceptual drawing of the test

Test results

- The ability to extrude two cables was confirmed.
- When bending the scoop, there were incidents where the cables got caught at the base of the scoop.
- The cable deviation prevention plate needs to be modified to prevent the cables from getting caught.



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

<Implementation details up to FY2021>

Prototype telescopic access equipment with a total of 14 stages was manufactured as the bottom access investigation method for Units 2 and 3, and elemental tests were conducted. The function of telescopic access equipment was evaluated as feasible.

<Summary of implementation in FY2022>

Review the development plan based on the results of elemental tests conducted in FY2021, and proceed with study of each of the issues identified.

<Implementation details for FY2022>

- Review the development plan and identify issues based on the results of elemental tests conducted in FY2021
- Examination of proposed countermeasures to address issues
- Study of test plans to confirm proposed countermeasures and their effects
- Test to verify the effects of countermeasures

Note: Terms used in this document are defined as follows.

- Telescopic access equipment: A complete set of equipment consisting of telescopic pipes, winders, investigation equipment, etc.
- Telescopic pipe: A telescopic pipe forming a component of the above equipment

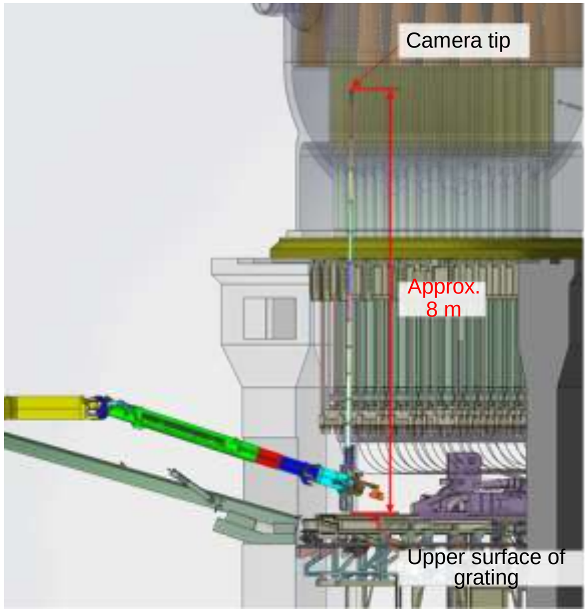
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

1) Summary of FY2021 results (1/2)

- Conceptual design and elemental tests were conducted to address development issues, including studies on interfacing with arm-type access equipment.

- A study was conducted on countermeasures to the issues of high leakage and sliding resistance at the sealing section identified in a simplified test conducted in FY2020 using a 3-stage telescopic pipe. Improvements to the roughness of the pipe's inner surface were reflected in the device specifications. A simplified test using a 3-stage telescopic pipe was conducted and verified the effects of the proposed countermeasures.



Drawing of access using telescopic pipe

Full retraction

Full extension

Simplified test using a 3-stage telescopic pipe

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

1) Summary of FY2021 results (2/2)

- Elemental tests were conducted to evaluate the feasibility of the full 14-stage access equipment.
  The function of telescopic access equipment was evaluated as feasible.

During retraction

2nd stage extension

Full extension

6. Implementation details

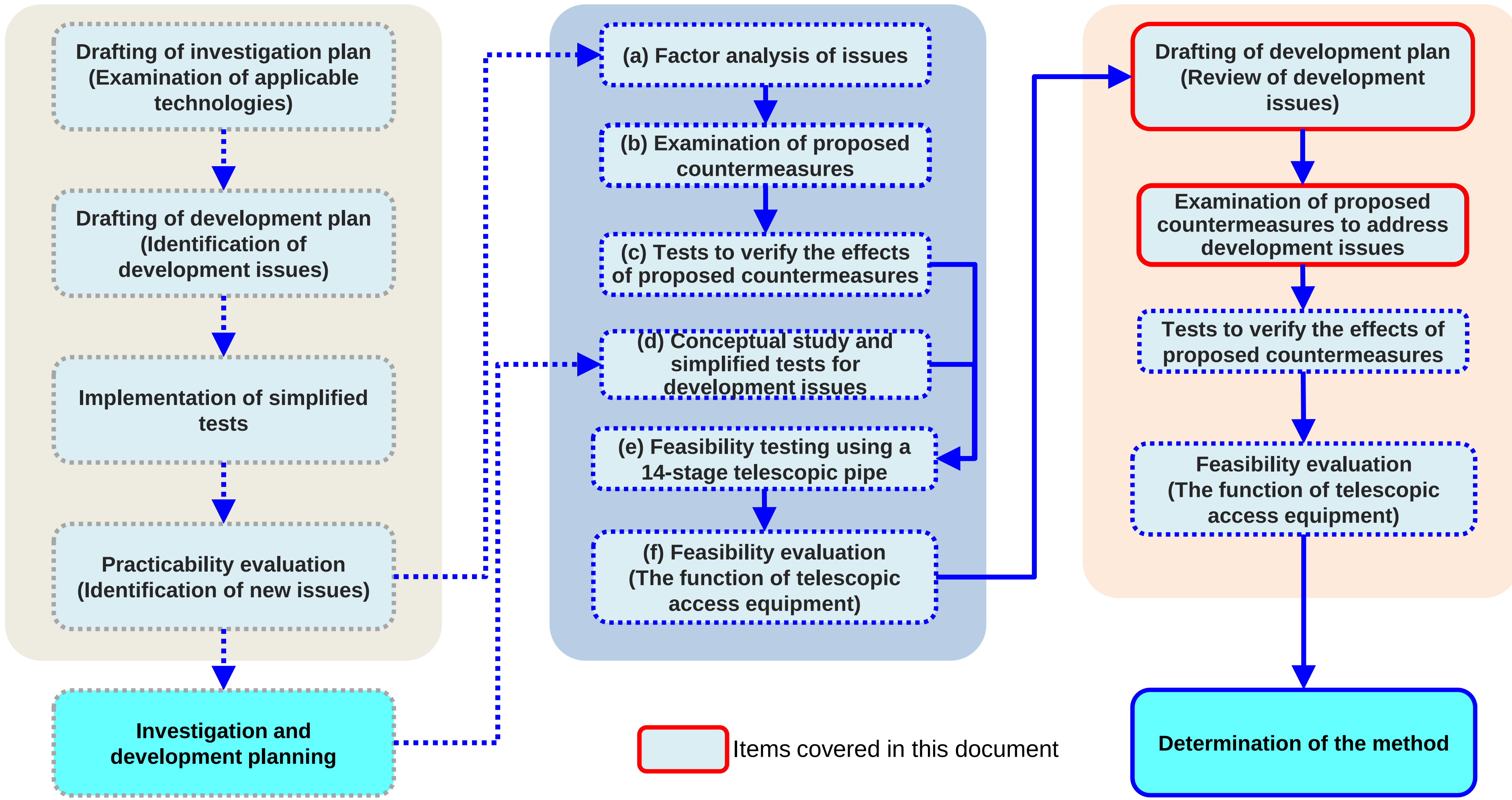
(2) Development of the bottom access investigation method (telescopic pipe)

2) Steps of “conceptual study of bottom access and investigation equipment”

FY2020
① Formulation of bottom access/investigation plan and development plan for access/investigation equipment

FY2021
② Conceptual study of bottom access and investigation equipment
<Conceptual design / Elemental testing>

FY2022
③ Conceptual study of bottom access and investigation equipment



6. Implementation details

Units 2 and 3

(2) Development of the bottom access investigation method (telescopic pipe)

3) Review of development plans (development issues and action policies)

No.	Major items	Intermediate items	Minor items	Development issues	FY2022 action policy	FY2022 test/action items
1	Equipment for accessing the inside of the pedestal	Verification of connection with the arm-type retrieval access equipment	Verification of detailed specifications of arm-type retrieval access equipment	- Tip positioning accuracy - Arm deflection/oscillation - Range of motion in each axis - Transportable weight - Arm external cable specifications - Emergency action policy	- Check the "Gradually Increasing the Scale of Retrieval" project for information conducive to the study of equipment specifications	Gather information from other projects
2			Verification of attachment and detachment method, specifications	- Verification of feasibility of procedures/transport casks for transfer in and out of the enclosure - Methods of attachment and removal using Dexter	- Check the "Gradually Increasing the Scale of Retrieval" project for information conducive to the study of equipment specifications	Gather information from other projects
3	Access equipment from inside the pedestal to inside the RPV	Telescopic access equipment design	Examination of basic structure	- Structural feasibility under the dimensional constraints imposed by use of arm-type retrieval access equipment	- Verification of bonding strength assuming a cylindrical pipe shape - Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe	**<u>Bonded section strength verification test</u>** **<u>Partial fabrication of aluminum pipes</u>**
4			Understanding extension/retraction behavior	- Joint connection accuracy (pipe tilt) - Swaying during extension (investigation equipment section) - Amount of tip deviation (looseness/deflection) during vertical extension - Verification of extension/retraction behavior when telescopic pipe is tilted - Verification of extension/retraction motion when snagging occurs (check extension possible when telescopic pipe snagged and retraction possible when investigation equipment snagged) - Effects of adhered matter on extension/retraction behavior	- Control of tilt behavior in the direction of the anti-rotation rails during telescopic pipe extension - Control of looseness due to gaps between pipes, prevention of tilting caused by gaps during emergency retraction (in emergencies) - Evaluation of telescopic pipe behavior when the arm-type retrieval access equipment sways	Desk study **<u>14-stage operation verification test</u>**
5			Understanding unique characteristics of extension/retraction operations	- Required air pressure during extension - Positioning control - Sliding resistance between air gasket and telescopic pipe - Sliding resistance of telescopic pipe rotation control guide	- Design study	Desk study **<u>14-stage operation verification test</u>**

IRID

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

3) Review of development plans (development issues and action policies)

No.	Major items	Intermediate items	Minor items	Development issues	FY2022 action policy	FY2022 test/action items
6	Access equipment from inside the pedestal to inside the RPV	Telescopic access equipment design	Design of cable winding mechanism	- Accuracy of wire tensile force measurement (whether slack can be detected) - Coordinated control of cable winding force and air pressure during extension/retraction of telescopic pipe - Limit detection - Mechanical arrangement (X6 Penetration passage, arm interference) - Pressure-resistant box design (approx. 0.1 MPa)	- Ensuring uniform drive torque for cable winding drums (reduction of cable tensile force loss)	Desk study
7			Design of posture adjustment mechanism	- Mechanical arrangement (X6 Penetration passage, arm interference)	- Test manufacturing and evaluation of posture control mechanism	**Posture control mechanism operation verification test** **14-stage operation verification test**
8	Investigation equipment	Investigation equipment design	Exterior design of investigation equipment	- X6 Pene, interference with reactor internals	- Design study	Desk study
9			Cable design	- Diameter reduction (target: Φ6 or less) - Tensile strength	- Design study	Desk study
10			Noise reduction method	- Noise during rotation when using slip rings (dosimeter)	- Design study - Evaluation of noise caused by investigation equipment to dosimeter	**Evaluation of noise caused by investigation equipment**
11			Measures to prevent matter adhering to cameras and lights	- Effects of water droplets and adhered matter, etc. on camera and lights	- Design study	Desk study
12			Visibility	- Verification of long-distance visibility when there is machinery/structures near the camera (halation problem) - Understanding characteristics of vision quality loss due to noise caused by radiation dose	- Impact assessment of cumulative dose on video image due to CMOS camera irradiation	**CMOS camera irradiation test**
13	Others	Operability	Operability with camera	- Whether the camera on the investigation equipment and the camera on the wrist section can determine the operational situation, such as contact with a structure, and operation can be performed	- Evaluation of whether or not telescopic pipe passage clearance and extension length can be determined using the fixed-point camera at the tip of the arm-type retrieval access equipment - Evaluation of investigation equipment camera's ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture	**Study of equipment operation procedures using simulations**
14		Emergency response	Examination of items to be expected in case of emergency	- Response to power cutoff (disconnection, etc.), control failure (software excursion), control line disconnection, etc. - What kind of events, such as seismic activities and blackouts, should be expected?	- Evaluation of behavior during earthquakes	**14-stage operation verification test**

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

4) Details of implementation for FY2022 (1/3): Items related to element verification

① Verification of bonding strength assuming cylindrical pipe shape

- In FY2021, a bonding strength verification test was conducted on flat plates, and it was evaluated that there would be no shear failure stress degradation in the bonded section within 72 hours under the expected environment.
- In FY2022, tests will be conducted to confirm adhesive strength in cylindrical shapes (test methods, etc., to be determined upon consultation with partner manufacturers).

⇒ Evaluated as having the necessary strength for equipment operation. (No.123 to 128)

② Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe

- In FY2021, a test manufacturing and evaluation of the top three stages (stages 12 to 14) of aluminum pipe showed that the 13th stage warped by about 0.3 mm and could not be retracted inside the 12th stage pipe, which presented a challenge in terms of fabricability.
- In FY2022, a further test manufacture of an aluminum pipe with 3 stages at the tip / 3 breaks at the base was conducted to address the above issue, and the fabricability of the aluminum pipe will be re-evaluated. If there are prospects for fabricability, alternatives will be reexamined.

⇒ Determined that manufacture of aluminum pipes is possible (No.129 to 132)

③ Evaluation of noise caused by investigation equipment to dosimeter

- In FY2021, as a noise evaluation of the slip rings, an evaluation of the noise caused to the dosimeter due to cable drum drive motor operation was conducted, and found to be negligible.
- In FY2022, an evaluation of the noise caused to the dosimeter when combined with the investigation equipment will be conducted.

⇒ Determined that noise is present but can be counteracted. (No.133 and 134)

④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

- In FY2021, the vision quality of the CMOS camera was checked as part of the camera vision quality evaluation, and it was confirmed that there was no difference in vision quality between the CMOS camera and the CCD camera.
  However, it was confirmed that after irradiation, the video image was disturbed in low light intensity.
- In FY2022, another irradiation test of the CMOS camera will be conducted to confirm the accumulated dose at which the video image disturbing event occurs.

⇒ Confirmed that video image disturbance occurs at 1440 Gy and video stops at 1584 Gy to 2060 Gy. (No.135 to 139)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

4) Details of implementation for FY2022 (2/3): Items related to operations

⑤ Evaluation of whether or not telescopic pipe passage clearance and extension length can be determined using the fixed-point camera at the tip of the arm-type retrieval access equipment

⑥ Evaluation of investigation equipment camera's ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture
(No.140 to 149)

- In FY2021, a simulator was used to simultaneously acquire two simulated video images (object display and overhead view from a fixed point) from a camera mounted on the arm-type access equipment for retrieval (fixed-point camera) and a camera mounted on the investigation equipment (moving camera).
- In FY2022, a simulator will be used to check the field of view of the fixed-point camera and investigation equipment camera when the telescopic pipe is retracted/extended and when it is tilted, and to study the operation method of the entire system.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

4) Details of implementation for FY2022 (3/3): Items related to combined testing of the telescopic access equipment

⑦ Control of tilt behavior in the direction of the anti-rotation rails during telescopic pipe extension (No.150 to 156)

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies) (No.157 to 170)

- In FY2021, on the basis of elemental testing using a 14-stage telescopic pipe, the function of telescopic access equipment was evaluated as feasible.
  However, it was confirmed that the telescopic pipe tends to tilt in the direction of the anti-rotation rails located to the sides as it is extended, that if looseness between the pipe sections is unbalanced in one direction, the tip deviation of the telescopic pipe is +144.7 to -218.3 mm (the direction where the anti-rotation rail of the telescopic pipe is fixed is negative), and that during emergency retraction, when the pipe internal pressure is reduced from the fully extended state, the telescopic pipe gradually tilts, and the 14th stage at the tip titles at least 5.5 degrees.
- In FY2022, after implementing countermeasures (e.g., changing the arrangement of the anti-rotation rails, reviewing components, etc.) to address the above issues, elemental tests of the 14-stage telescopic pipe will be conducted again to evaluate the effectiveness of the countermeasures.

⑨ Test manufacturing and evaluation of posture control mechanism (No.171 to 173)

- In FY2021, an outline design of the posture control mechanism was conducted.
- In FY2022, a prototype posture control mechanism will be manufactured and elemental tests will be conducted in combination with the 14-stage telescopic pipe to evaluate feasibility.

⑩ Ensuring uniform drive torque for cable winding drums (reduction of cable tensile force loss)

- In FY2021, in an elemental test of the 14-stage telescopic pipe, it was confirmed that the cable tensile force (motor drive torque) fluctuated significantly in a short period of time and that the drive load may not be uniform due to imprecise assembly of the gears and drive shaft.
- In FY2022, after implementing measures to address the above issues, elemental tests of the 14-stage telescopic pipe will be conducted again to evaluate the effectiveness of the countermeasures.

⇒ Improvements were made and the countermeasures were evaluated as effective. (No.174 and 175)

⑪ Evaluation of telescopic pipe behavior when the arm-type retrieval access equipment sways

- In FY2021, the rigidity of the telescopic pipe against horizontal loads was confirmed, but no evaluation of the telescopic pipe's behavior when the arm-type access equipment sways was conducted.
- In FY2022, the natural frequency of the 14-stage telescopic pipe will be measured to confirm that it does not resonate when combined with the arm-type access equipment. In addition, the behavior of the 14-stage telescopic pipe when it sways will be confirmed by using the posture control mechanism scheduled to undergo test manufacturing.

⇒ Measure sway period. (No.187 and 188)

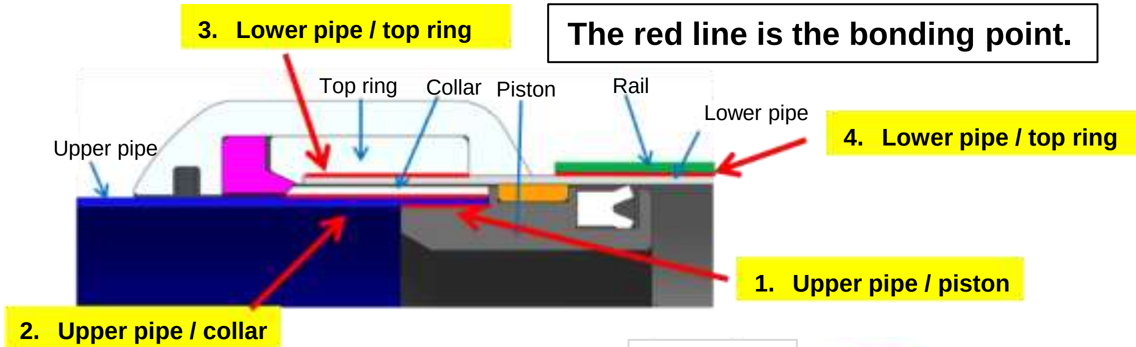
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

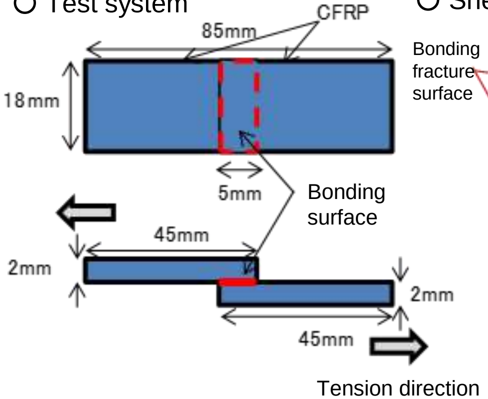
5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

〇 Background

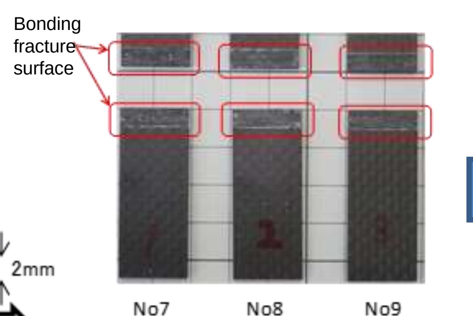
- For the bonding strength evaluation in FY2021, a bonded section fracture test was conducted on flat plates with reference to ISO.
- However, the bonding of the telescopic sections is at the cylindrically-shaped part, so tests will be conducted to check bonding strength on the cylindrical components.



〇 Test system

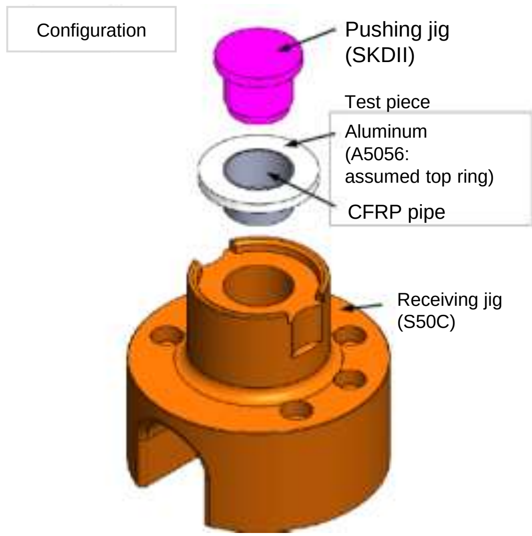


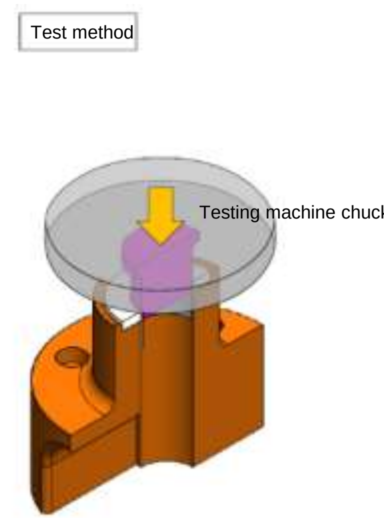
〇 Shear failure state



Shear failure test results after 24 hours of exposure at 7200 Gy of cumulative irradiation, 50˚ C, and 95% humidity

Testing system for FY2021





Testing system for FY2022

6. Implementation details

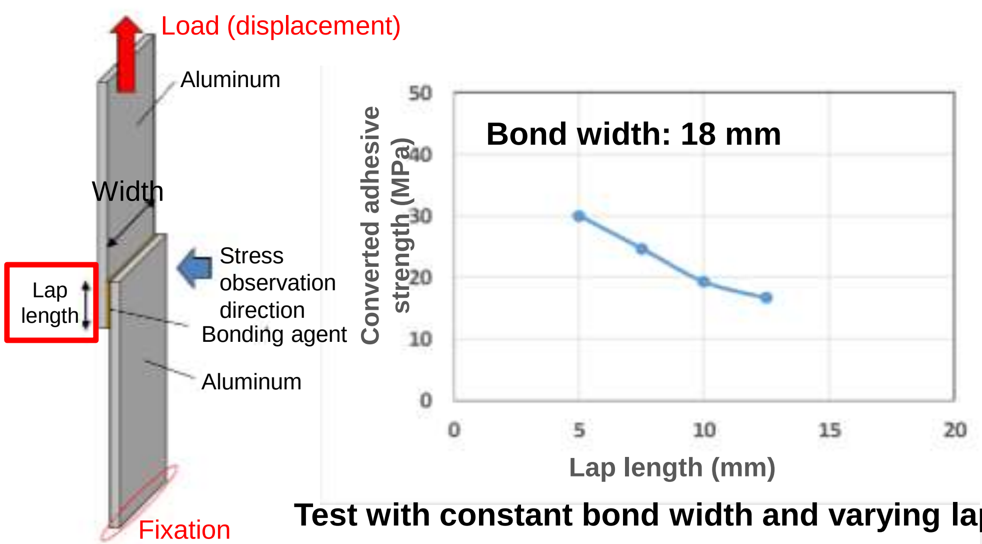
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

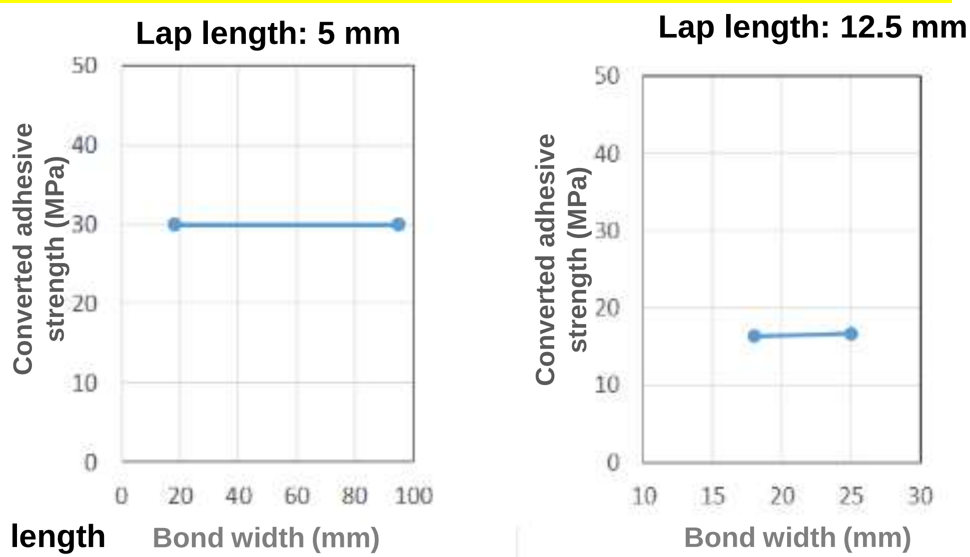
〇 Test plan study: Influence of pipe shape (diameter: bond width)

- For the 14-stage telescopic pipe, the bonding area differs for each stage where bonding is used, from a maximum inner diameter of Φ90 (2nd stage) to a minimum inner diameter of Φ30 (14th stage). Since the bonding strength depends on the bonding area, the bond length (lap length) and the bond width (pipe diameter) were examined.
- The results from the **aluminum plate test piece** confirmed that the bond strength **depends on the bond length (lap length) and is not affected by the bond width (pipe diameter)** (based on reference data from a partner company).

Bonding strength evaluation is performed under two conditions: maximum inner diameter Φ90 (2nd stage) and minimum inner diameter Φ30 (14th stage).



Test with constant bond width and varying lap length



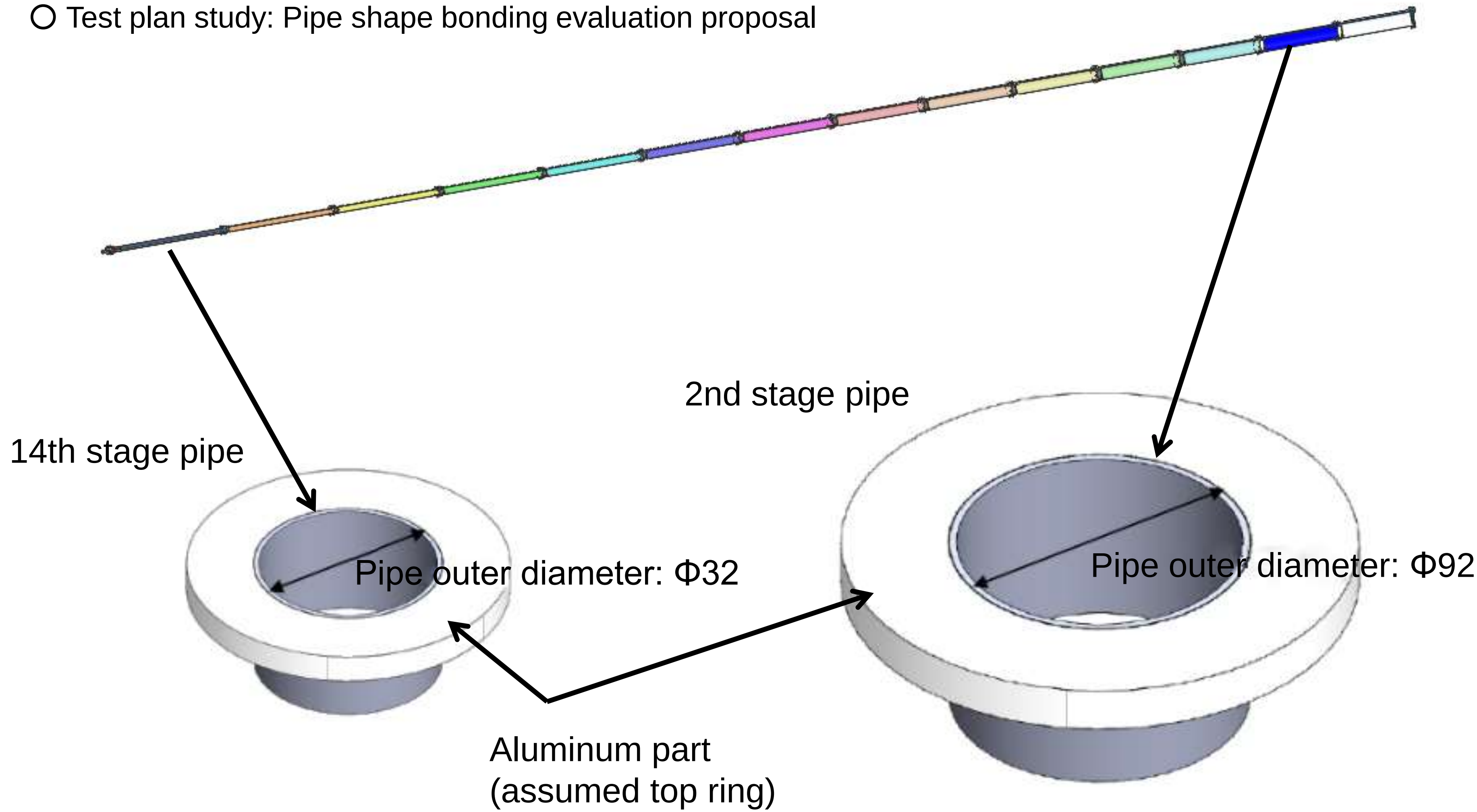
Test with constant lap length and varying bond width

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

○ Test plan study: Pipe shape bonding evaluation proposal



Note: 1st stage is aluminum pipe with no bonded section

6. Implementation details

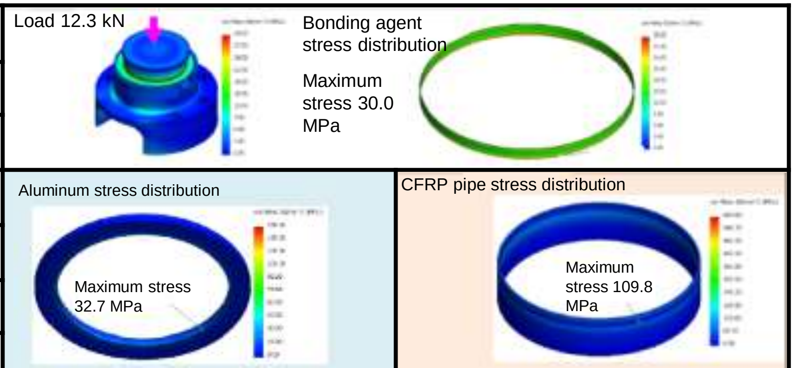
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

〇 Test plan study: Stress analysis of bonded parts

- Stress analysis was conducted of bonded parts in the 2nd and 14th stages.
- The strength of the CFRP pipe/aluminum parts is stronger than the maximum stress of the adhesive material of 30.2 MPa (result of previous fiscal years), so it was evaluated that the adhesive strength can be evaluated.

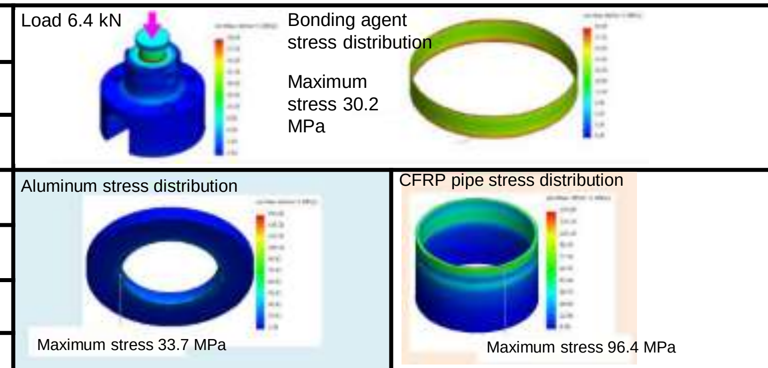
Pushing jig	Protruding section diameter	Φ29.9
	Outer diameter	Φ31.4
Pipe	Inner diameter	Φ30
	Outer diameter	Φ32
	Wall thickness	1
Bonding layer	Thickness	0.15
Receiving jig	Hole diameter	Φ32.8



Aluminum	CFRP pipe
The maximum stress generated is 32.7 MPa compared to the A5056 proof stress of 150 MPa, so bonding strength can be measured without any problem with this test piece shape	The maximum stress generated is 109.8 MPa compared to the CFRP strength of 603 MPa, so bonding strength can be measured without any problem with this test piece shape

Stress analysis results for the 2nd stage

Pushing jig	Protruding section diameter	Φ29.9
	Outer diameter	Φ31.4
Pipe	Inner diameter	Φ30
	Outer diameter	Φ32
	Wall thickness	1
Bonding layer	Thickness	0.15
Receiving jig	Hole diameter	Φ32.8



Aluminum	CFRP pipe
The maximum stress generated is 33.7 MPa compared to the A5056 proof stress of 150 MPa, so bonding strength can be measured without any problem with this test piece shape	The maximum stress generated is 96.4 MPa compared to the CFRP strength of 129 MPa, so bonding strength can be measured without any problem with this test piece shape

Stress analysis results for the 14th stage

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

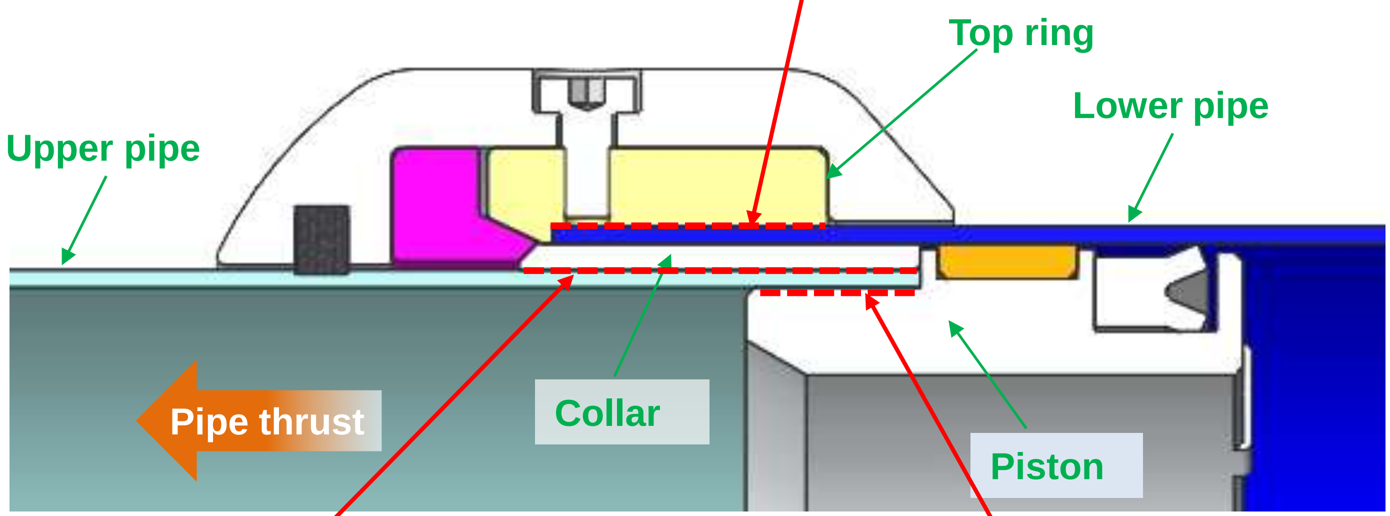
○ Required bonding strength of pipe

① Top ring/pipe bonding section

Maximum pneumatic thrust: 636 N (0.1 MPa)

Bonding area: 4318 mm^2

Required breaking strength: 2.4 MPa = (636 N/4318 mm2) × 18 (safety factor)



② Collar/pipe bonding section

Bonding area is larger than top ring, so lower load than ①

③ Piston/pipe bonding section

Not subjected to loads greater than the sliding resistance

6. Implementation details

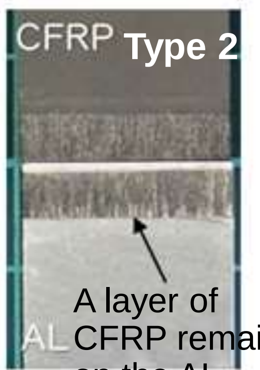
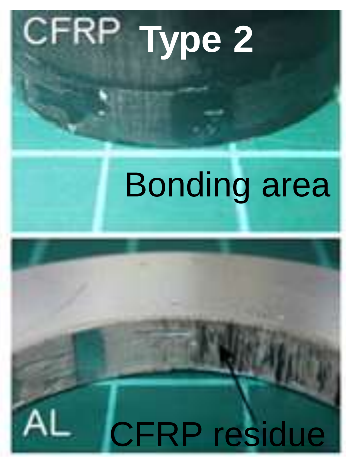
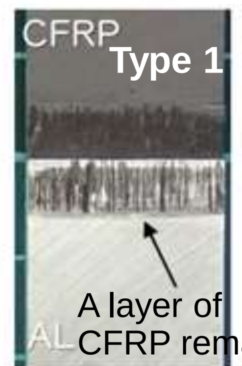
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ① Verification of adhesive strength assuming cylindrical pipe shape

○ Results of bonding strength confirmation test for pipe bonding sections

- Fracture strength was about 1/2 to 1/3 of that evaluated using flat plates.
- Although the Φ90 piece showed a larger drop, the bonding strength was 5.9 MPa, which was confirmed to exceed the required bonding strength of 2.4 MPa.

As such, it was determined that there was sufficient bonding strength required for equipment operation, even when using a cylindrical shape.

	Φ30		Φ90	
	Plate	Pipe	Plate	Pipe
Breaking stress [MPa]	24.4	14.0	18.6	5.9
Fracture mode	CFRP material fracture	CFRP material fracture	CFRP material fracture	CFRP material fracture
Fracture interface				

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ② Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe

Report for FY2021

Consideration of adopting aluminum as an alternative pipe material

Main target specifications			CFRP (inner and outer UD surface)	Aluminum (A7075)	Remarks
Fabricability	Pipe outer diameter	Φ100 (1st stage) to Φ35 (14th stage)	Manufacturable	Manufacturable	Since manufacturing issues were expected with the CFRP pipe, test manufacturing using aluminum for the 3 stages at the tip was conducted as an alternative Aluminum is difficult to manufacture with 1 mm wall thickness, and only one company accepted the order under the target precision conditions (test machining), so the evaluation was performed on a test manufacture of a thin pipe (12th, 13th, and 14th stages: inner diameter Φ40 to Φ30), which would difficult to make rigid using CFRP. This resulted in approx. 0.3 mm warping in the 13th stage, which prevented full retraction into the 12th stage. The aluminum telescopic pipe (1F2_investigation inside the PCV (A2)) manufactured previously has a wall thickness of 2.5 mm. With this thickness, if the maximum outer diameter is less than Φ100, only a 7-stage pipe can be formed and it will not be able to achieve the required length when extended (access to the furnace bottom will not be possible)
	Pipe length	431.5 mm (1st stage) to 658.2 mm (14th stage)	Manufacturable	Manufacturable	
	Number of pipe stages	14	Manufacturable	Manufacturable	
	Pipe wall thickness	1 mm or less	Manufacturable	Difficult to guarantee shape tolerance	
	Outer diameter tolerance	+0.2/0mm	Manufacturable	Manufacturable	
	Inner diameter tolerance	H9 1st stage: Φ95 +0.087 to 0 13th stage: Φ35 +0.062 to 0	Difficult to guarantee precision After manufacturing at +0.4/0 mm, match up the components that join together (pistons, etc.) in order to adjust dimensions	Manufacturable	
	Straightness	0.1 mm or less	Manufacturable	Difficult to machine 13th stage actual result: 0.3 mm	
	Roundness	0.2 mm or less	Manufacturable	Manufacturable	
	Inner surface roughness	Ra 3.2 or less	1.6 (actual result)	0.3 (actual result)	
Strength	Tensile strength (axial direction)	100 MPa or more	Pipe stages 2 to 9: 796 Pipe stages 10 to 14: 618	570	
	Tensile strength (circumferential direction)	100 MPa or more	Pipe stages 2 to 9: 603 Pipe stages 10 to 14: 129	570	CFRP: High-strength pre-preg cannot be used for stages 10 to 14 because of the small pipe diameter, so circumferential tensile strength is low
	Safety factor (0.3 MPa pressure resistance)	15 or higher	Pipe stages 2 to 9: 45 Pipe stages 10 to 14: 20	38	CFRP: High-strength pre-preg cannot be used for stages 10 to 14 because of the small pipe diameter, so the safety factor is low, but not low enough to be a problem
	Deflection	10 mm or less Looseness between stages not included	2.0	3.4	Structural analysis assuming zero looseness (bonding condition) for each stage of the telescopic pipe
Weight	14-stage weight	9 kg or less	8.0	9.4	Investigation equipment not included Includes scrapers, pistons, stopper rings, etc. in addition to pipes
Robustness	Cumulative dose resistance	7200 Gy or higher	7200 Gy or higher	7200 Gy or higher	3 days or more at 100 Gy/h
	Wear/repeatability	1 or more surveys possible	Evaluation required	Evaluation required	

Using aluminum is an issue in terms of fabricability (ease of machining)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

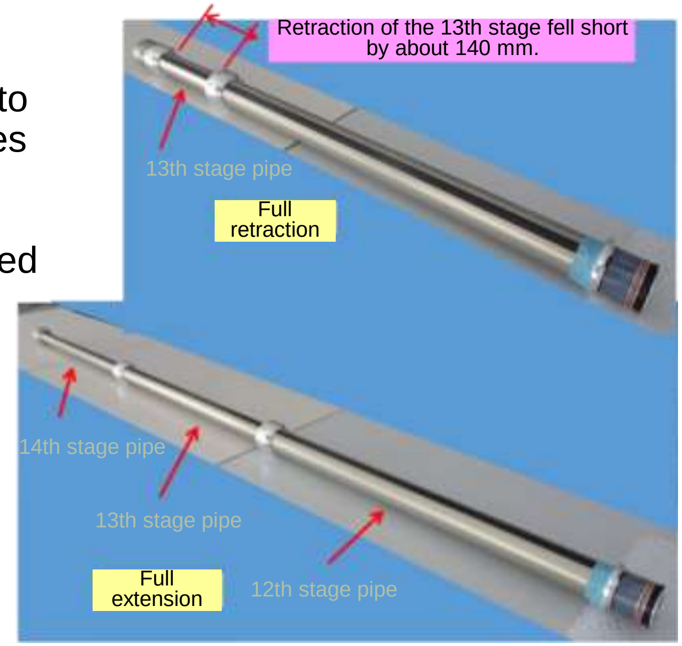
5) Investigation details ② Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe

○ Background

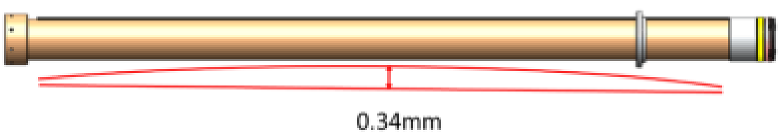
- In FY2021, a test manufacturing of the top three stages (stages 12 to 14) showed warping of about 0.3 mm at the 13th stage. When stages 12 to 14 were assembled, retraction of the 13th stage fell short by about 140 mm.
- Since there was no warpage in the machining process, it was inferred that the hard anodizing process performed after machining was the problem.

○ Countermeasures

Change hard anodizing method to improve stability.



Warping occurs in the 13th stage

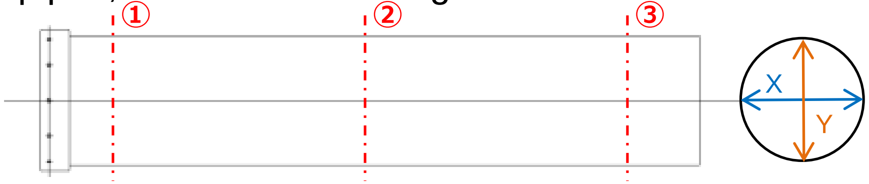


	Inner diameter target (mm)	Inner diameter result (mm)		Outer diameter target (mm)	Outer diameter result (mm)		Straightness target (mm)	Straightness result (mm)	
12th stage pipe	Φ40 +0.062/0	Pass	Φ40.05	Φ42±0.1	Pass	Φ41.98	0.1 or less	Pass	0.1 or less
13th stage pipe	Φ35 +0.062/0	Pass	Φ35.03	Φ37±0.1	Pass	Φ37.02	0.1 or less	**Fail**	**Around 0.3**
14th stage pipe	Φ30 +0.052/0	Pass	Φ30.03	Φ32 ±0.1	Pass	Φ32.04	0.1 or less	Pass	0.1 or less

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ② Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe

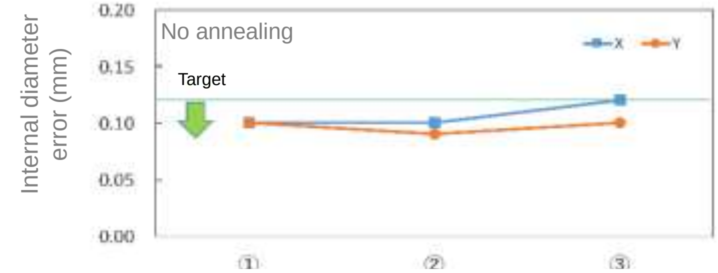


○ Background

- For the small-diameter stages 12 to 14, countermeasures involving changing the hard anodizing method appear promising.
- However, the 2nd and 3rd stages are thin-walled and large in diameter, making machining difficult.

○ Countermeasures

- For this reason, the 2nd and 3rd steps were prioritized for test manufacturing.
- The same processing method used for the small diameter pipe resulted in a 0.02 mm expansion of the pipe ends and a variation in the difference in inner diameter between the two ends and the center of the pipe. To eliminate residual stress in the aluminum material, **machining was performed after the annealing process**, which allowed the inner diameter error between the two ends and the center to be kept constant.
- After this, hard anodizing is performed.



Machining results after annealing treatment
Before hard anodizing (anodizing thickness: 15 μm assumed)

	Inner diameter target (mm)	Inner diameter result (mm)		Outer diameter target (mm)	Outer diameter result (mm)		Straightness target (mm)	Straightness result (mm)	
2nd stage pipe	Φ90 +0.12/-0.03	Pass	Φ90.12	Φ92±0.1	Pass	Φ91.95	0.1 or less	Pass	0.1 or less
3rd stage pipe	Φ85 +0.12/-0.03	Pass	Φ85.07	Φ87±0.1	Pass	Φ86.95	0.1 or less	Pass	0.1 or less

6. Implementation details

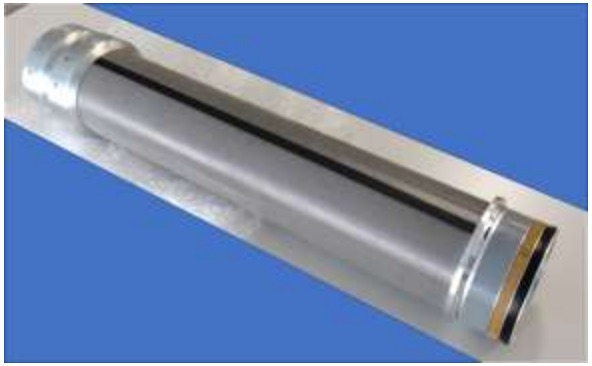
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ② Verification of fabricability of aluminum pipes, an alternative design for the telescopic pipe

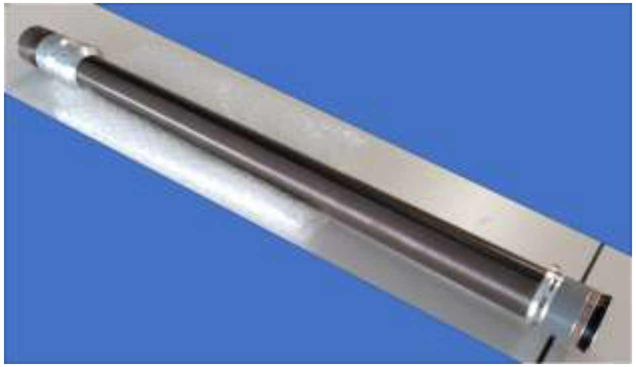
○ Confirmation of aluminum pipe assembly

- Operation was checked manually by assembling the manufactured aluminum pipes and it was verified that they extend and retract without any snagging.

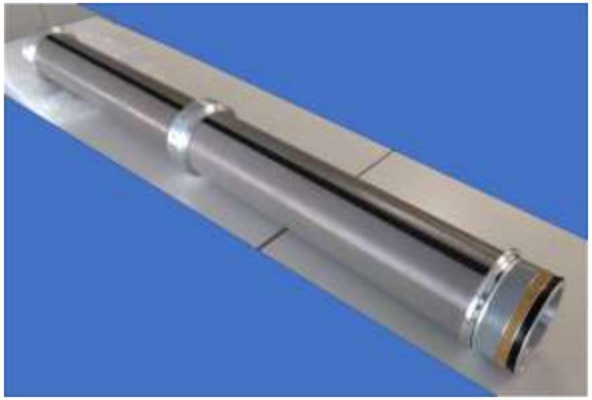
It was determined that manufacture is also possible using aluminum pipes.



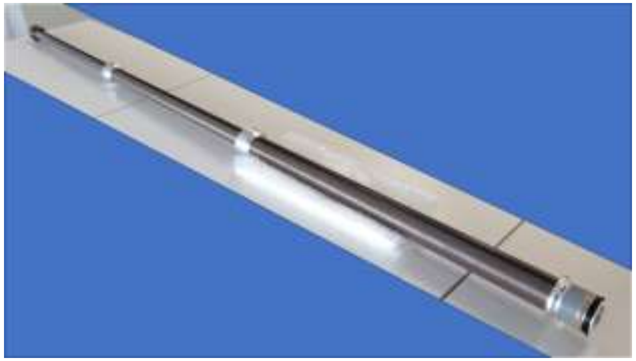
2nd and 3rd stages (retracted state)



12th to 14th stages (retracted state)



2nd and 3rd stages (extended state)



12th to 14th stages (extended state)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

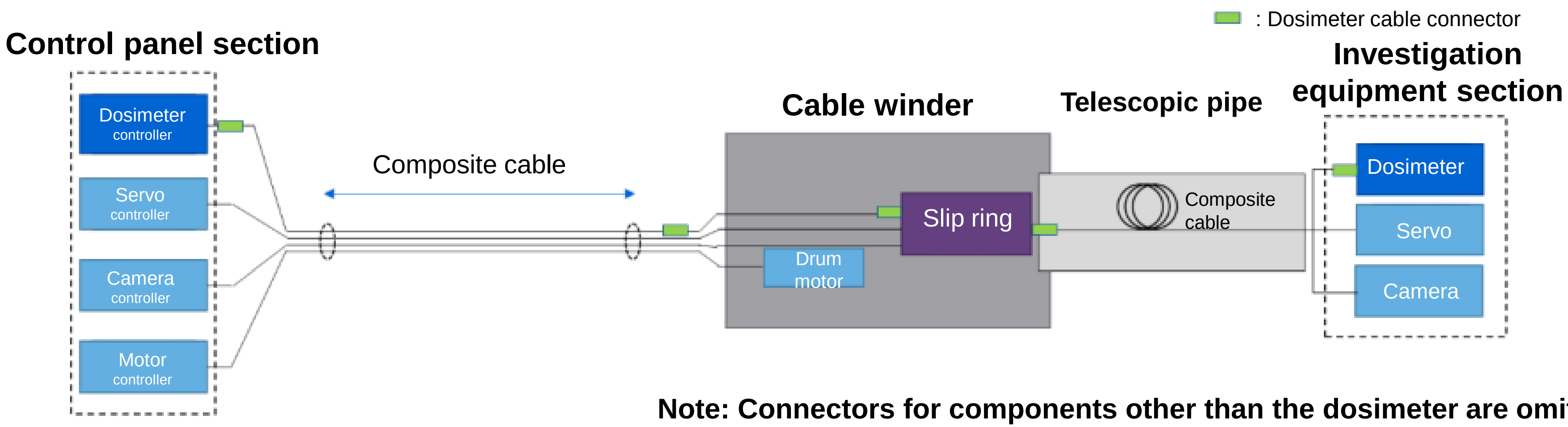
5) Investigation details ③ Evaluation of noise caused by investigation equipment to dosimeter

〇 Purpose

- Since the dosimeters used need to transmit minute currents of several pA, they are considered relatively vulnerable to leakage currents generated at mechanical contact points such as connectors and slip rings, and noise due to crosstalk from motor cables included in the composite cable. For this reason, tests to confirm the effects of noise will be conducted and noise reduction methods will be studied.
- In FY2022, the noise when combined with the investigation equipment will be evaluated. (Noise from slip rings during motor operation evaluated in FY2021)

〇 Test plan

- Connect the dosimeter elements to be used via composite cables and connectors equivalent to those used in the actual equipment.
- Check the effect of noise on the dosimeter with the motor and camera connected to the composite cable.



Note: Connectors for components other than the dosimeter are omitted

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ③ Evaluation of noise caused by investigation equipment to dosimeter

○ Test results

① Effect of leakage current

Leakage current value when the cable (including slip rings, etc.) is connected from the dosimeter controller to the investigation equipment section

- The current value acquired at the controller side was evaluated with a simulated measurement signal (10 nA; equivalent to 20 [Gy/h]) output from the dosimeter
  - ➢ Loss due to leakage current was confirmed to be 0.44 nA (equivalent to 0.9 Gy/h)
  - ➢ Although an error of about 5% was observed, it was confirmed that the leakage current values did not vary significantly over time

➡ It was determined that measures could be taken by preparing a calibration table in advance and anticipating the amount of loss

② Effects of noise

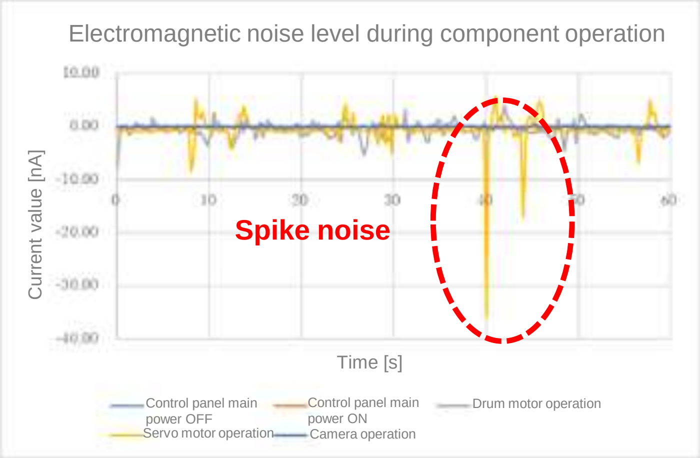
Impact from components with signal lines placed on the cable assembly where the dosimeter cable is located was evaluated

- Drives cable drum motors, servo motors, and investigation equipment camera during data acquisition under conditions where the dosimeter does not output a measurement signal
  - ➢ Noise of 35.7 nA (equivalent to 7.1 Gy/h) at peak value when driving cable drum motors and servo motors
  - ➢ Due to spike noise, measurement is not affected after motor operation is stopped

➡ It was determined that going forward, it will be possible to reduce the impact using a smoothing process, etc.

Unit: nA	Amount of noise (standard deviation)		Noise level (peak value)	
	No smoothing	Moving average*	No smoothing	Moving average*
Control panel main power OFF	0.20	0.05	0.20	0.05
Control panel main power ON	0.65	0.05	0.65	0.15
Drum motor operation	4.09	0.66	7.77	1.69
Servo motor operation	5.71	0.89	35.66	3.15
Camera operation	0.44	0.10	0.44	0.44

*Moving average time is 5 seconds



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

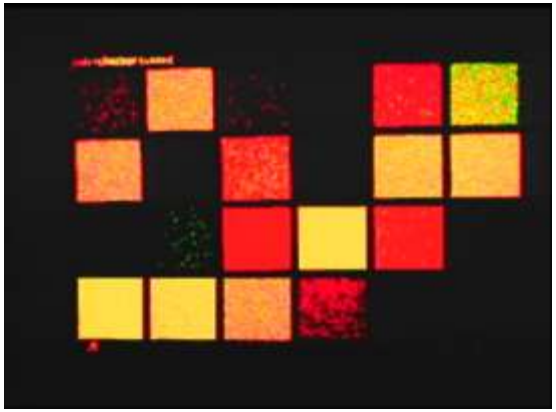
5) Investigation details ④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

〇 Background

- Radiation resistance evaluation conducted in FY2021 confirmed that video images could be output even after irradiation of 1600 Gy.
  However, it was confirmed that after irradiation, the video image was disturbed in low light intensity.
  Depending on the filming conditions, such as viewing a distant target, this phenomenon may occur, and there is a possibility that the target will not be seen.

Lighting conditions: Laboratory lighting (36 lx)

Before irradiation



Lighting conditions: Laboratory lighting (36 lx)

Lighting conditions: Camera lighting (570 lx)

After irradiation (total cumulative dose of 1600 Gy or more)

〇 Purpose

- Identify the accumulated dose at which the video image is disturbed.
- The accumulated dose (survey time) at which the image is disturbed will be reflected in the survey plan.

6. Implementation details

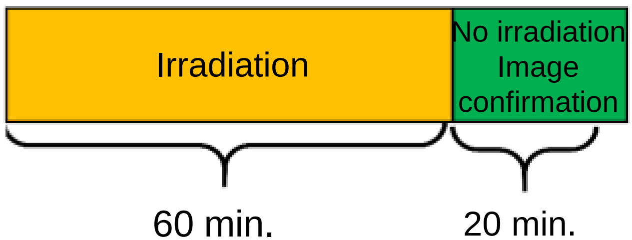
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

○ Test outline

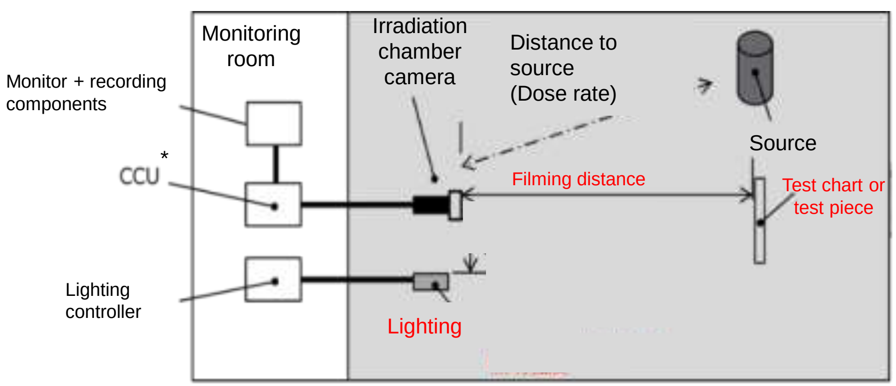
- Irradiation is performed at a constant dose rate, and the irradiation is stopped at regular intervals to check the images by changing the lighting intensity, object distance*, and other filming conditions, and the accumulated dose when the images are disturbed is recorded.

*The gain (brightness amplification rate) is changed by changing the area of the object in the image.



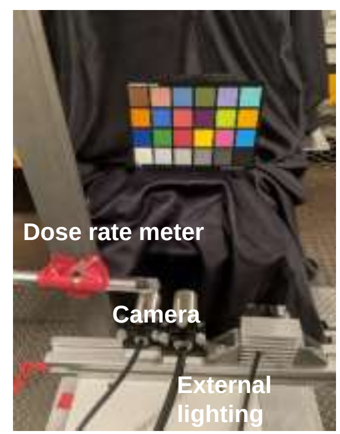
--- Conducted repeatedly

Proposed test schedule



*Camera Control Unit

Proposed system for radiation resistance testing



Conceptual image of test system

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

〇 Test result: New CMOS camera

Total dose at which image disturbance (color change) was observed: 1440 Gy

Cumulative dose at which the image stopped: 1584 Gy

Image

	Before irradiation	Cumulative 1152 Gy after 4th irradiation	Cumulative 1440 Gy after 5th irradiation	Cumulative 1584 Gy partway through 6th irradiation	Cumulative 1728 Gy after 6th irradiation
External lighting Approx. 650 lx					
External lighting Approx. 20 lx					

Change in contrast
Increased noise
(Identified from 576 Gy)

Color change in addition to an intensification in the change noted after the 4th irradiation

The image stopped during the 6th irradiation, so the irradiation was stopped and the image was checked
After that, the image was not stable (repeatedly restored and stopped)

Note: LEDs are normal, no abnormal heat generation in camera

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

〇 Test results: CMOS camera irradiated to 1600 Gy (used in the test conducted in the previous fiscal year)
Cumulative dose at which the image stopped: 2060 Gy

Image stopped during 2nd irradiation (after 1 h 40 m)
After that it reappeared and stopped several times, but eventually the output remained frozen

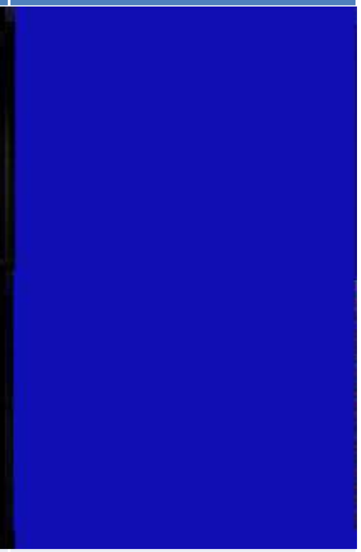
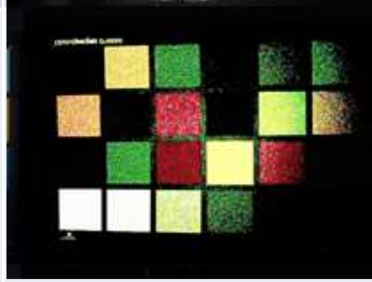
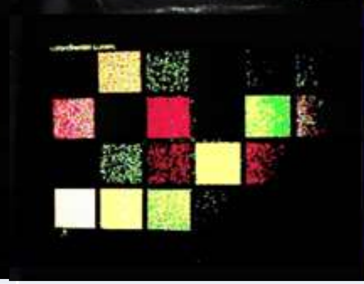
	Before irradiation Cumulative dose: 1600 Gy	After 1st irradiation Cumulative dose: 1888 Gy	After 2nd irradiation Cumulative dose: 2176 Gy
External lighting Approx. 650 lx			
External lighting Approx. 20 lx			

*Image cut-off status
After 2nd irradiation (cumulative 2176 Gy): Image stopped
After 3rd irradiation (cumulative 2464 Gy): Image not restored even after turning the power back on.
After 5th irradiation (cumulative 3040 Gy): Image restored after turning the power back on. However, stopped after about 10 seconds.
7th irradiation (cumulative 3616 Gy): Image not restored even after turning the power back on.

*Turning the power on and off tried.

6. Implementation details

Units 2 and 3

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ④ Impact assessment of cumulative dose on video image due to CMOS camera irradiation

○ Summary

The cumulative dose at which the video stopped was 1584 Gy for the new product and 2060 Gy for the old product, showing differences depending on the individual unit.

Disturbances (color changes) in the image were confirmed at around a cumulative dose of 1440 Gy.

	Image disturbance (color changes)	Image stopped
Unirradiated camera	1440 Gy	1584 Gy
Camera irradiated with 1600 Gy in the previous fiscal year	- (Confirmed after completing the test in previous fiscal year)	2060 Gy

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

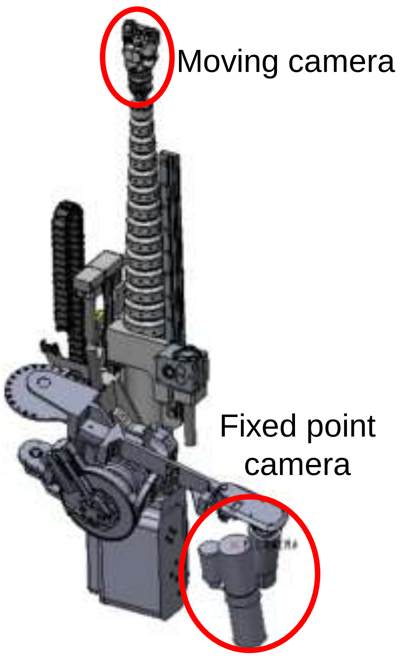
5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

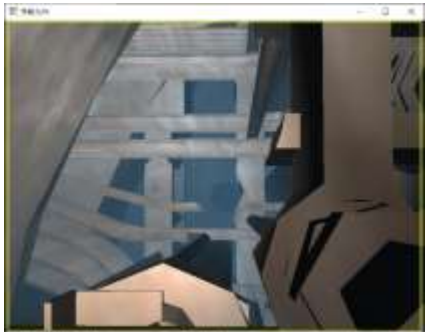
⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture

〇 Background

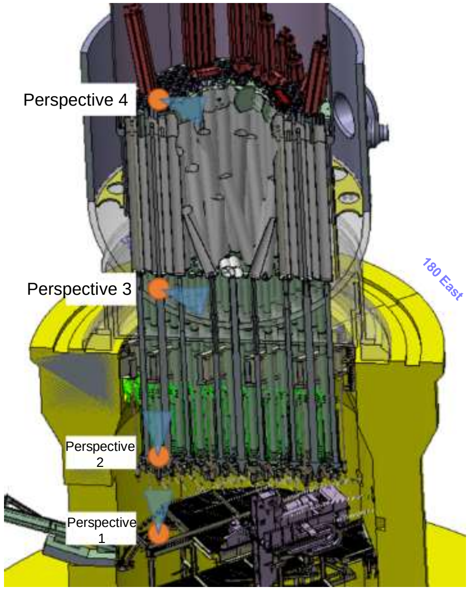
- In FY2021, a simulator was used to simultaneously acquire two simulated video images (object display and overhead view from a fixed point) from a camera mounted on the arm-type access equipment for retrieval (fixed-point camera) and a camera mounted on the investigation equipment (moving camera).
- In FY2022, a simulator will be used to check the field of view of the fixed-point camera and investigation equipment camera when the telescopic pipe is retracted/extended and when it is tilted, and to study the operation method of the entire system.



Fixed point camera image



Moving camera image



3D model of the structure used

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture

〇 Study policies

- Examine the operational procedures of the equipment in using the telescopic access equipment to access the anticipated hole location.
- The simulator is used to acquire simulated video images that anticipated to be obtained by the arm fixed-point camera/investigation equipment camera when positioning relative to the hole. In addition, a simulated video image obtained in the case of misalignment is acquired.
- The equipment operation procedures are reviewed based on the simulated video images obtained.

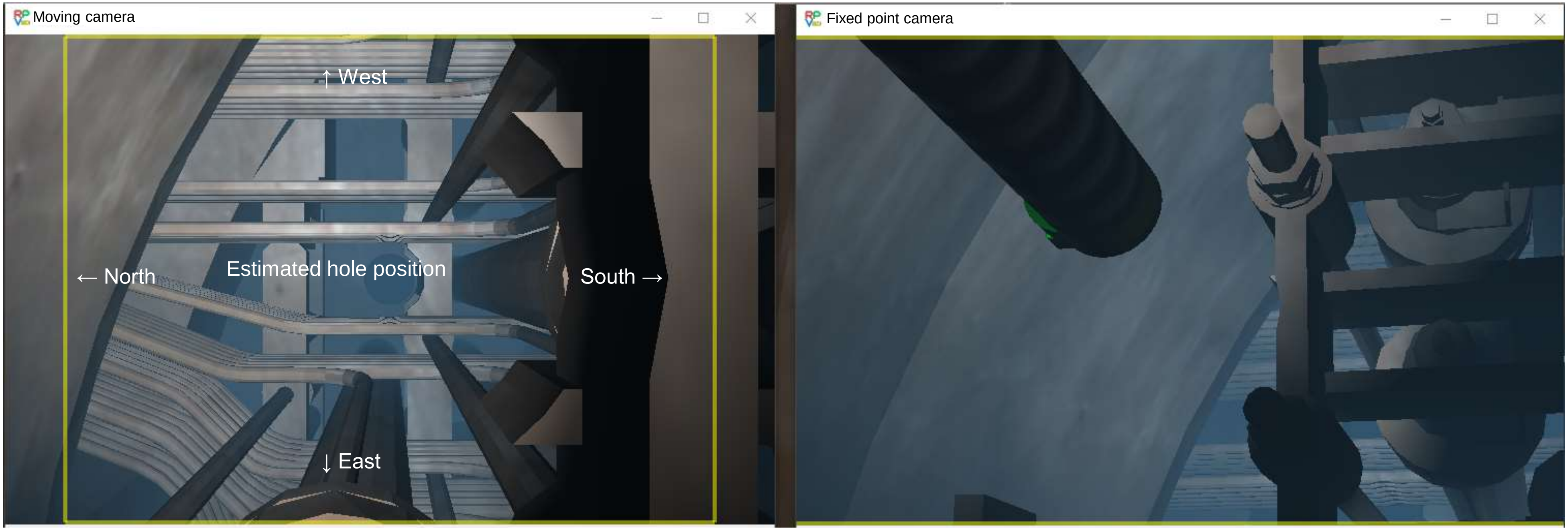
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe retracted

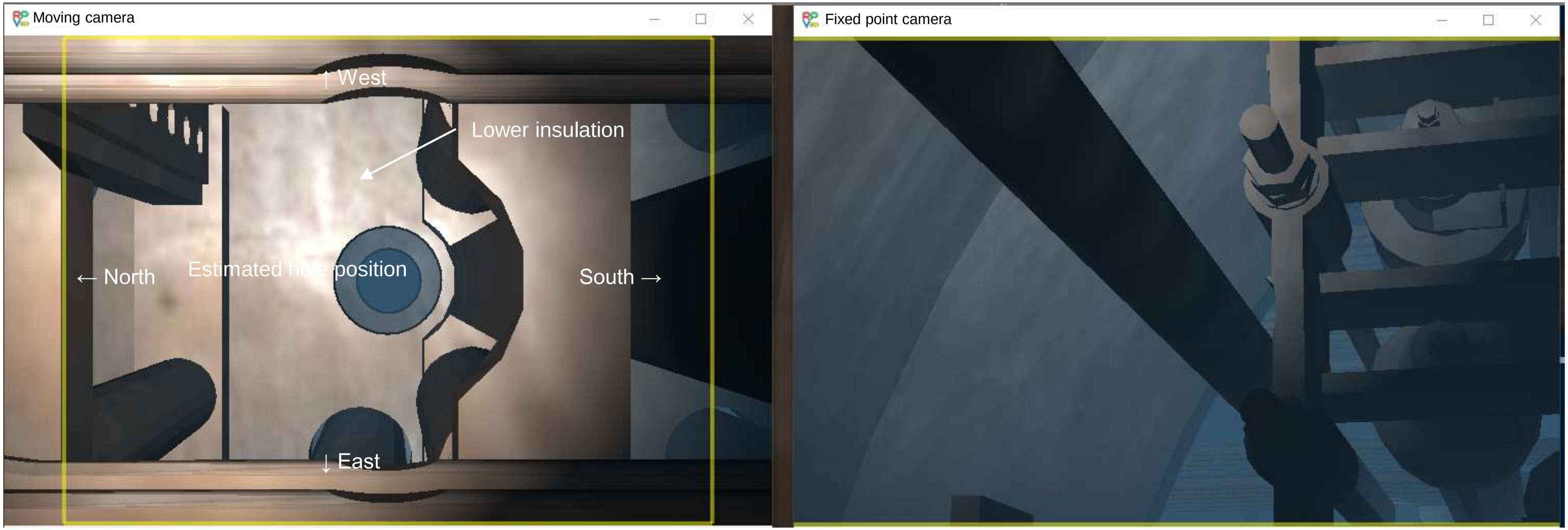
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe extended 2000 mm from retracted state

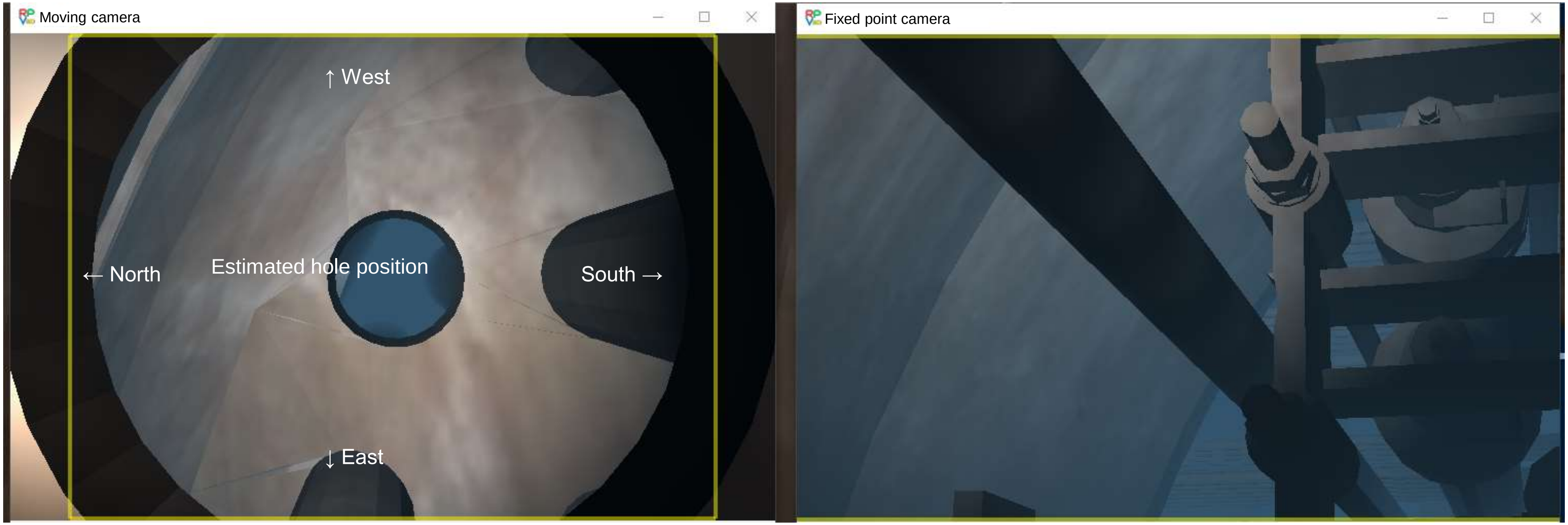
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe extended 3500 mm from retracted state

⇒ The fixed point camera on the arm can only check approximate behavior of the telescopic pipe

⇒ The presence of the investigation equipment at the center position of the opening is determined by whether the center of the opening is at the center position of the camera image.

⇒ The capability to determine the dimensions of the opening is necessary because the dimensions of the opening on the actual unit are unknown.

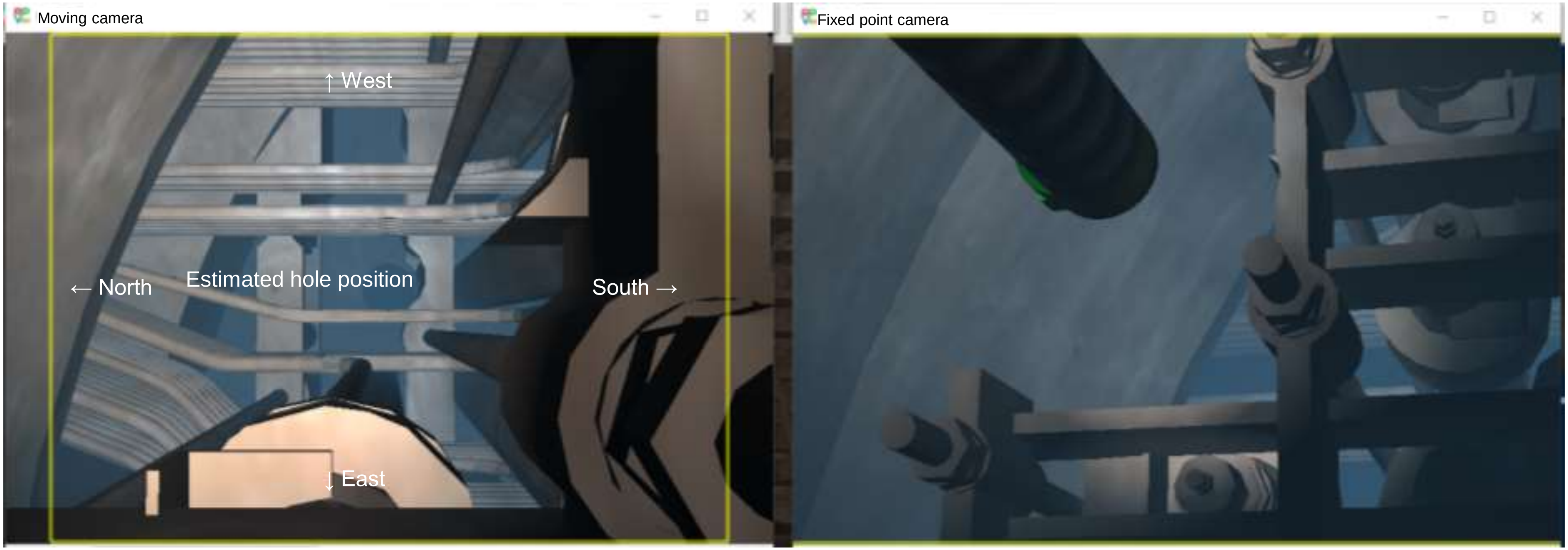
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera's ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe retracted (tilted 2° to the west)

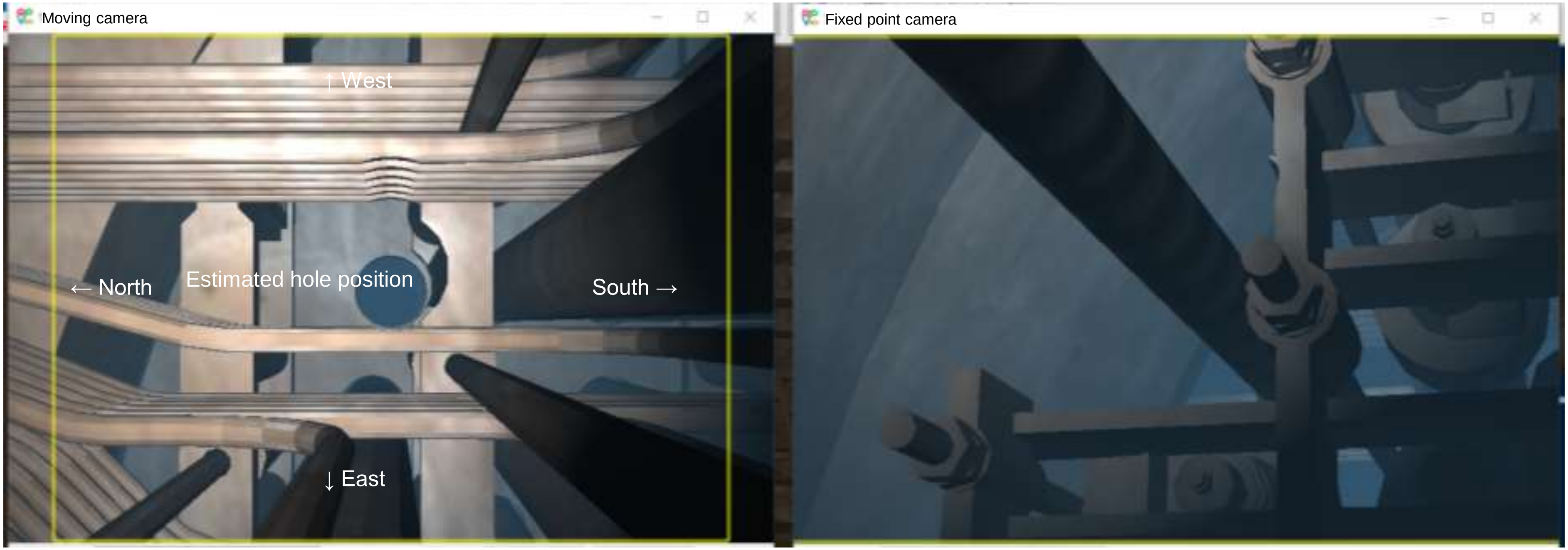
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera's ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe extended 1000 mm from retracted state (tilted 2° to the west)

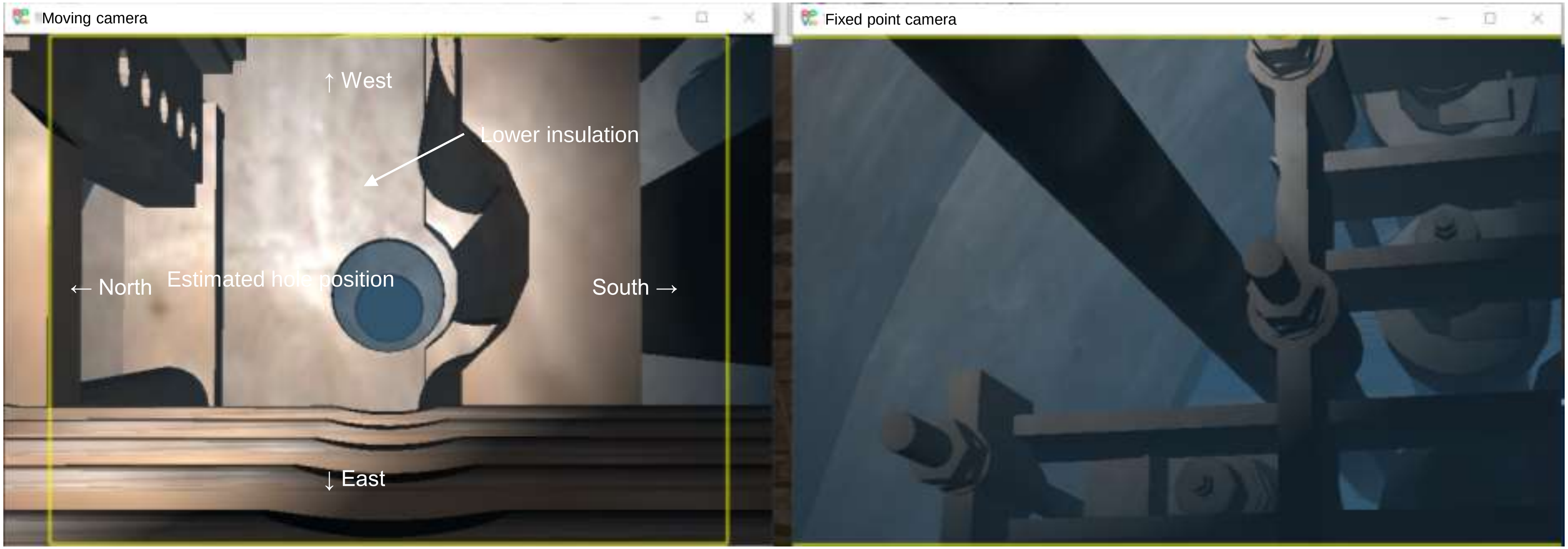
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe extended 2000 mm from retracted state (tilted 2° to the west)

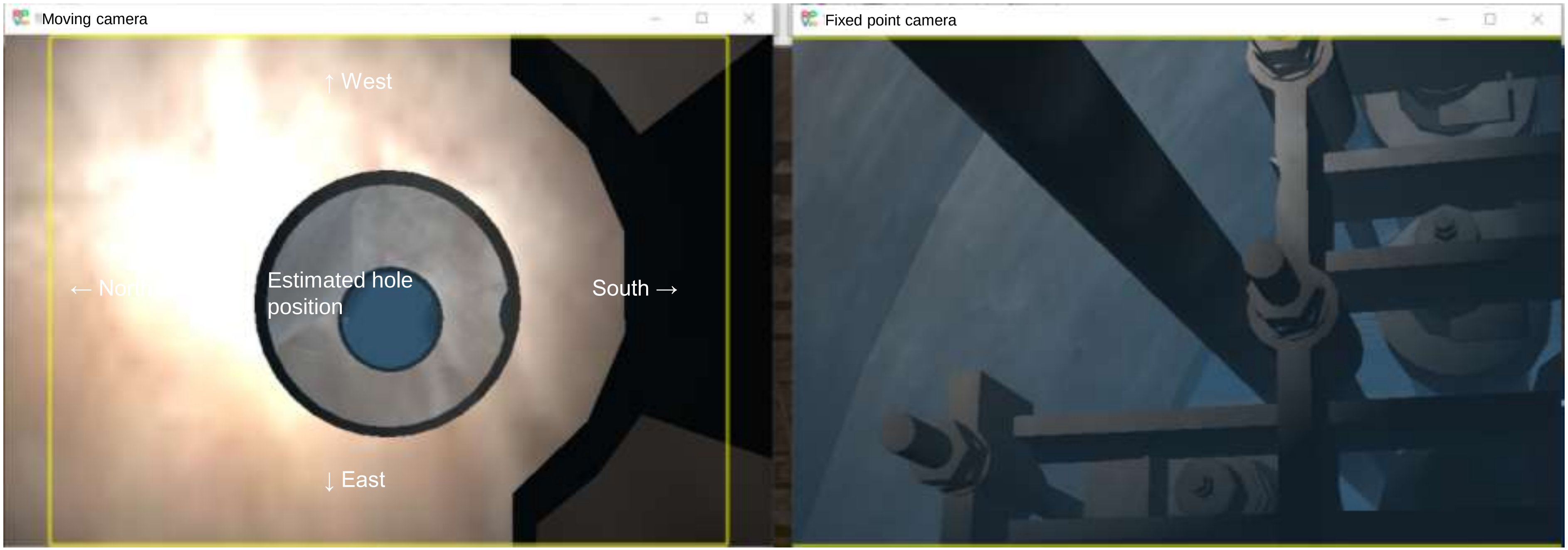
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera’s ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



Unit 2: Camera image with telescopic pipe extended 3000 mm from retracted state (tilted 2° to the west)

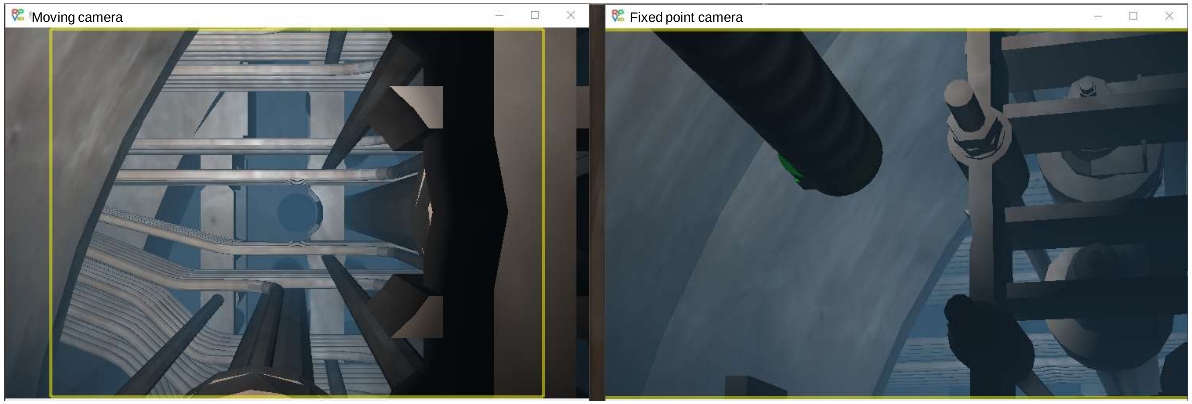
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

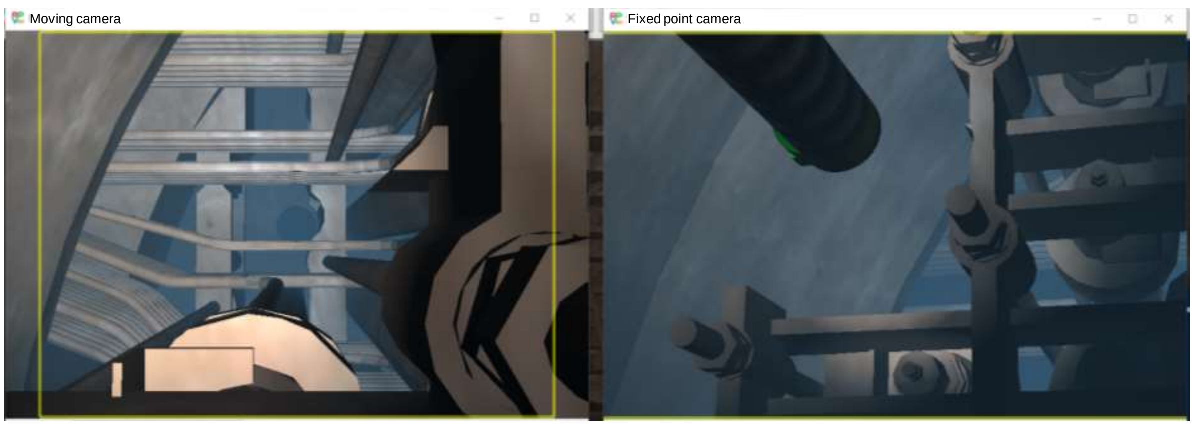
5) Investigation details

⑤ Evaluation of recognition by arm fixed-point camera of telescopic pipe passage clearance and extension amount

⑥ Evaluation of investigation equipment camera's ability to determine whether an opening can be passed through, and whether it can determine the direction of correction of telescopic pipe posture



If the telescopic pipe is vertical



If the telescopic pipe is tilted 2°.

⇒ Except in the case of a large tilt, it is difficult to determine the tilt from the image alone.

⇒ A function is required to determine the inclination of the telescopic pipe itself.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

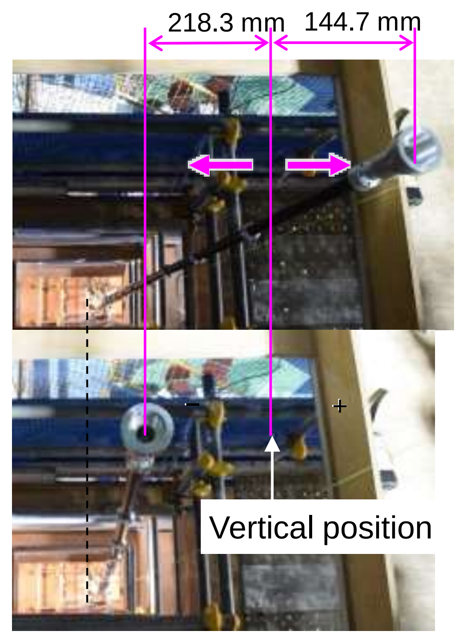
⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

〇 Background

- In the FY2021 test, it was confirmed that the 14-stage telescopic pipe tends to tilt in the direction of the anti-rotation rails located to the sides during extension, that if looseness between the pipe sections is unbalanced in one direction, the tip deviation of the telescopic pipe is +144.7 to -218.3 mm (the direction where the anti-rotation rail of the telescopic pipe is fixed is negative), and that during emergency retraction, when the pipe internal pressure is reduced from the fully extended state, the telescopic pipe gradually tilts, and the 14th stage at the tip titles at least 5.5 degrees.

Full extension



Amount of tip deviation caused by tilting due to looseness

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

○ Purpose

The feasibility evaluation test of the 14-stage telescopic pipe in FY2021 confirmed that the telescopic pipe tends to tilt in the direction of the anti-rotation rails. During the test, the telescopic pipe was found to be mounted with a 0.1° tilt in the direction of the rails. However, when converted to the amount of deviation at the end of the telescopic pipe when fully extended, the tilt was about 10 mm, so it was determined that the tilt would have no effect on the extension behavior, and the test was conducted with the telescopic pipe mounted in this condition.

It is estimated that the factors that cause the telescopic pipe to tilt toward the anti-rotation rails include the mounting angle of the telescopic pipe and the presence or absence of the anti-rotation rails. Therefore, in order to examine measures to deter tilting, verification was first performed on the FY2021 equipment and test system regarding the reproducibility of the tilting behavior identified in the previous year, as well as its dependence on the layout of the rotation control rails and the mounting angle of the telescopic pipe.

14-stage telescopic pipe, fully extended

○ Test plan

No.	Test name	Goal	Test conditions
1	Verify reproducibility of the FY2021 test	Checking to see if tilting toward the anti-rotation rails is reproduced.	- Anti-rotation rails direction: ① Same orientation as during the FY2021 test ② 180° from the orientation of ① - Mounting angle: vertical
2	Verification of tilt direction when telescopic pipe is slightly inclined	Check to see if slight inclination is a factor in determining the direction of tilt in one direction.	- Anti-rotation rails direction: Same orientation as the FY2021 test - Mounting angle: 0.1° inclination on the opposite side of the anti-rotation rails
3	Verification of tilt suppression effect when the layout of the anti-rotation rails is changed	Evaluate whether the tilt of the telescopic pipe can be suppressed by evenly arranging the anti-rotation rails, which were previously laid out in a single direction, and confirm the arrangement pattern that can best suppress the tilt.	- Anti-rotation rails direction: Laid out in a spiral pattern at 90° increments - Mounting angle: vertical

6. Implementation details

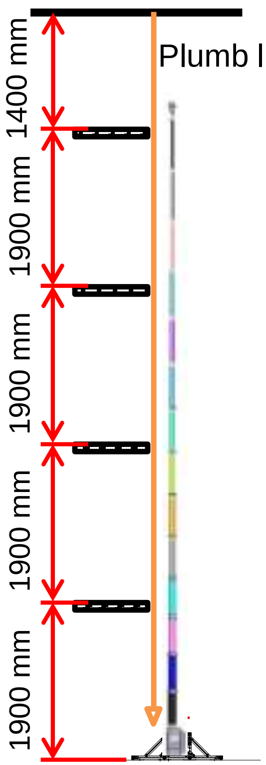
(2) Development of the bottom access investigation method (telescopic pipe)

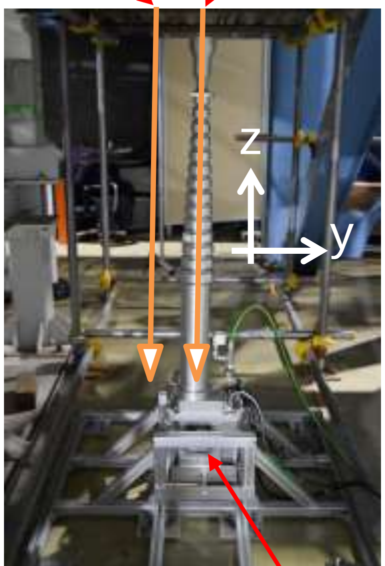
5) Investigation details

⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

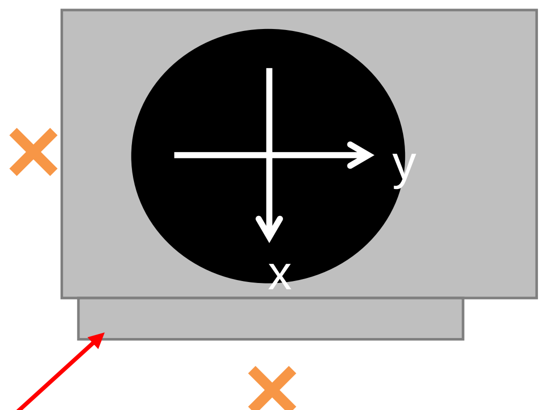
〇 Test system

- As in the FY2021 test, scaffolding was set up around the telescopic pipe and the telescopic pipe was made to extend and retract. The telescopic pipe's direction of tilt and the amount of tip deviation were determined by measuring the distance between the pipe and plumb lines (strings) placed at two locations in the +x and -y directions relative to the pipe.
- The telescopic pipe was mounted so that the 1st stage pipe was vertical (tilt measured at 90.0° in the x and y directions).
- The amount of tip deviation was measured three times when the telescopic pipe was extended up to the 7th stage pipe, where the direction of inclination of the telescopic pipe could be determined, and once when the pipe was extended all the way to the 14th stage.





Full diagram of the test system



Definition of orientations (top-down view of test apparatus)

Deviation measurement position

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

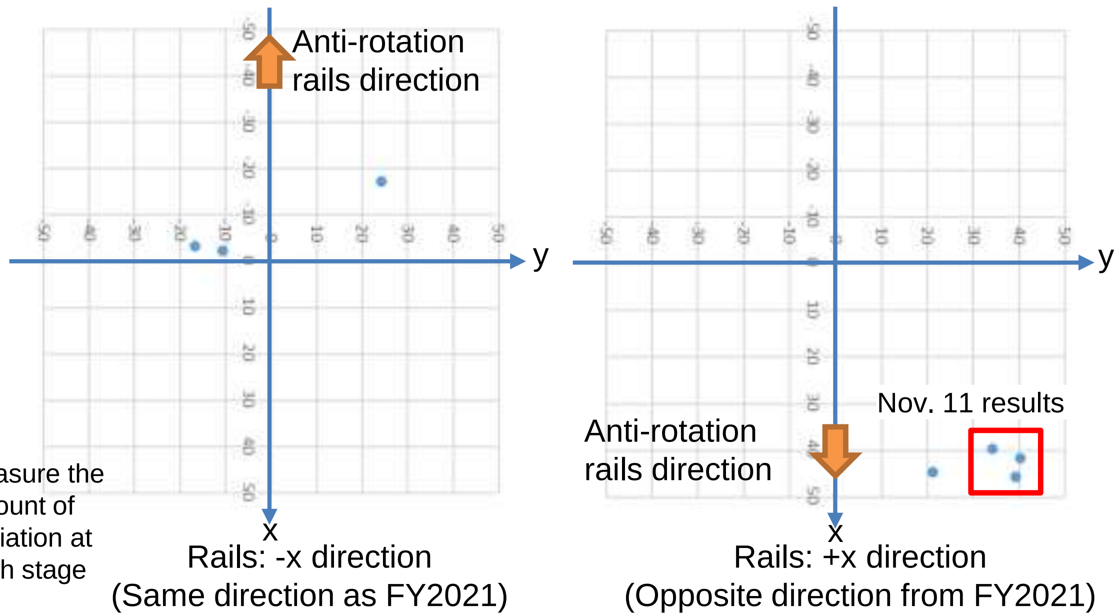
⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

○ Test No.1: Verify reproducibility of the FY2021 test

To confirm that the telescopic pipe always leans toward the anti-rotation rails as it is extended, as in the FY2021 test, the telescopic pipe was mounted vertically with high accuracy and tested under two conditions, one with the rails positioned in the -x direction and the other in the +x direction, as in FY2021.

Anti-rotation rails direction	Measurement (date performed)	Amount of tip deviation [mm] 7th stage pipe extension δx	7th stage pipe extension δy	Full extension of 14 stages δx	Full extension of 14 stages δy	Tilt direction
-x direction (Same orientation as the FY2021 test)	1st (Sep. 21, 2022)	-17	24	–	–	-x, +y
	2nd (Oct. 21, 2022)	-2	-11	–	–	-y
	3rd (Oct. 28, 2022)	-3	-17	-1	-128	-y
+x direction (opposite direction from the FY2021 test)	1st (Nov. 8, 2022)	45	21	126	124	+x, +y
	2nd (Nov. 11, 2022)	40	34	–	–	+x, +y
	3rd (Nov. 11, 2022)	46	39	–	–	+x, +y
	4th (Nov. 11, 2022)	42	40	–	–	+x, +y

Measure the amount of deviation at each stage



Amount of tip deviation at 7th stage extension

Test results

- Along with pipe extension, there was a tendency for it to tilt in the x-direction toward the anti-rotation rails, and it never tilted in the opposite direction to the rails. However, there was both plus and minus tilt in the y-direction, and the direction of tilting when the pipe was extended was indeterminate and did not reproduce the direction of tilting in the FY2021 test.
- Even under the same conditions, the direction of tilt and the amount of tip deviation varied depending on the test date, but as shown by the Nov. 11 results, with the rails positioned in the +x direction, the results were reproduced within the same test date.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

○ Test No.2: Verification of tilt direction when telescopic pipe is slightly inclined

The results of test No.1 showed that the direction of inclination of the FY2021 test was not reproduced and was indeterminate.
It is possible that the pipe had a tendency to tilt toward the rail because the 1st stage pipe was inclined 0.1° toward the rail in the FY2021 test.
Since in test No.1, the pipe never tilted to the side opposite the rails, in test No.2 the direction of tilt was evaluated by inclining the pipe 0.1° in the direction opposite the rails.

Rotation control rails direction	Measurement (date performed)	Amount of tip deviation [mm]				Tilt direction
		7th stage pipe extension		Full extension of 14 stages		
		δx	δy	δx	δy	
-x direction (orientation in the FY2021 test)	1st (Dec. 2, 2022)	18	-19	—	—	+x, -y
	2nd (Dec. 5, 2022)	18	-17	—	—	+x, -y
	3rd (Dec. 5, 2022)	17	-20	—	—	+x, -y

In all three measurements, a tendency to tilt in the +x direction, to which the pipe was inclined by 0.1° relative to the -x direction in which the rails were located, was identified.

Test results

- When the telescopic pipe was mounted vertically with high precision, the pipe did not tilt in the opposite direction of the anti-rotation rails, but when it was mounted inclined 0.1° to the opposite direction of the rails, it tilted in that direction when extended. This indicates that the direction of tilt of the telescopic pipe when extended is affected by the accuracy of the mounting posture. The reason that the pipe tilted only in the direction of the rails in the FY2021 test may also be due to the inclination at the time of mounting.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

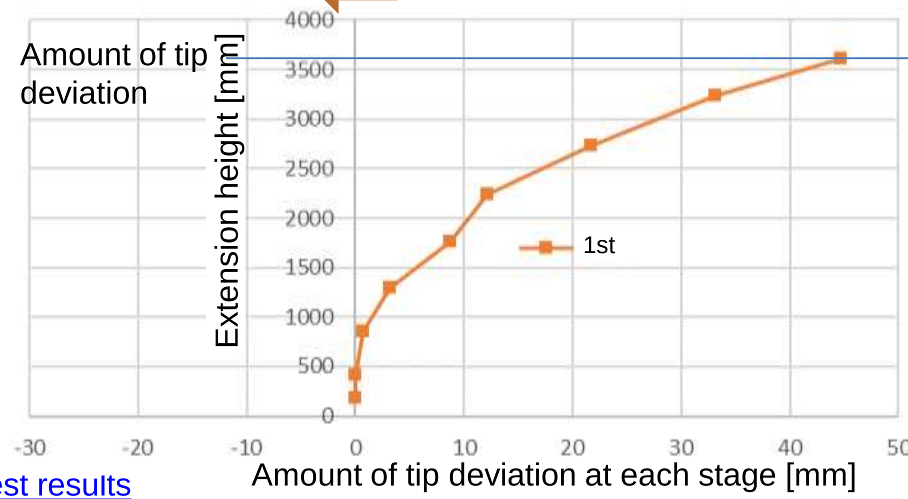
○ Test No.3: Verification of tilt suppression effect when the layout direction of the anti-rotation rails is changed

- The results of test No.1 show that as it is extended, the telescopic pipe tilts not only in the x-direction but also in the y-direction. The evaluation was performed by placing the anti-rotation rails in a spiral arrangement with the orientation of the rails changing by 90° at each stage, with the objective of suppressing tilting in both the x and y directions.

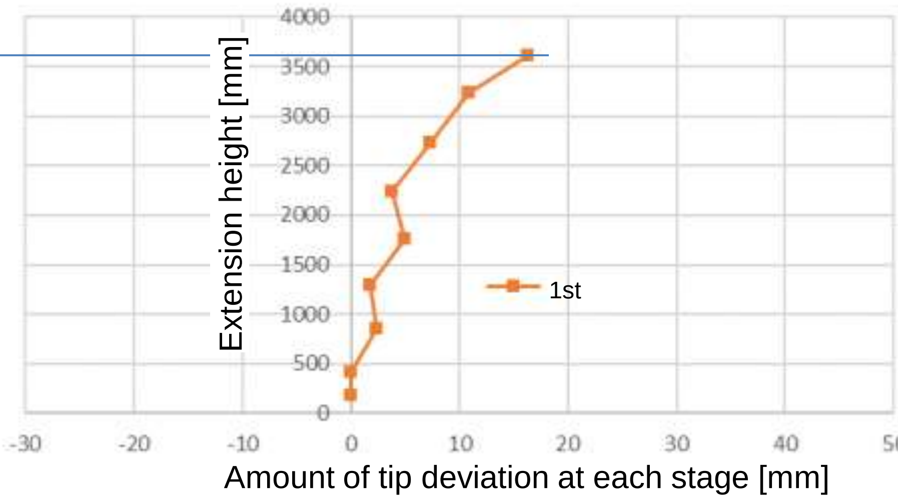
Anti-rotation rails direction	Measurement	Amount of tip deviation [mm]				Tilt direction
		7th stage pipe extension		Full extension of 14 stages		
		δx	δy	δx	δy	
Laid out in a spiral pattern at 90° increments	1st	45	16	185	124	+x, +y
-x direction (result of test No.1)	3rd	-3	-17	-1	-128	-y
+x direction (result of test No.1)	1st	45	21	126	124	+x, +y

Direction of anti-rotation rail for 2nd stage pipe

x-direction



y-direction



Test results

- Since the amount of tip deviation when the pipe was extended to the 14th stage was larger than when the rails were in one direction, changing the layout of the anti-rotation rails had no effect in suppressing tilt. This may be due to the significant effect of the tilt of the pipe on the base side.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension

○ Summary of the tests to verify the factors behind tilting of the telescopic pipe

- When the telescopic pipe was mounted vertically with high accuracy, it reproduced the same tendency to tilt toward the anti-rotation rails when extended as in the FY2021 test, but it also tilted perpendicular to the rails and its direction was indeterminate. Moreover, although the direction of tilt and amount of tip deviation were reproducible under the same conditions and on the same test date, they changed when the test date changed.

⇨ **It was determined that the direction of tilt is variable and difficult to predict prior to extension.**

- When the telescopic pipe was mounted at a slight incline, 0.1° to the vertical, it tilted in that direction during extension.

⇨ **It was determined that the direction of telescopic pipe extension is affected by the direction of inclination before extension, however small.**
In addition, the phenomenon observed in the FY2021 test, in which the telescopic pipe tilted toward the anti-rotation rails as it was extended, was determined to be due to the inclination at the time of mounting.

- When the orientation of the anti-rotation rails was changed for each stage of the pipe, the telescopic pipe showed greater tip deviation than when the rails were oriented in one direction.

⇨ **Changing the orientation of the anti-rotation rails was determined to have no effect.**
In this fiscal year’s test, as in the previous fiscal year, the rotation restraining rails were laid out in one direction.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

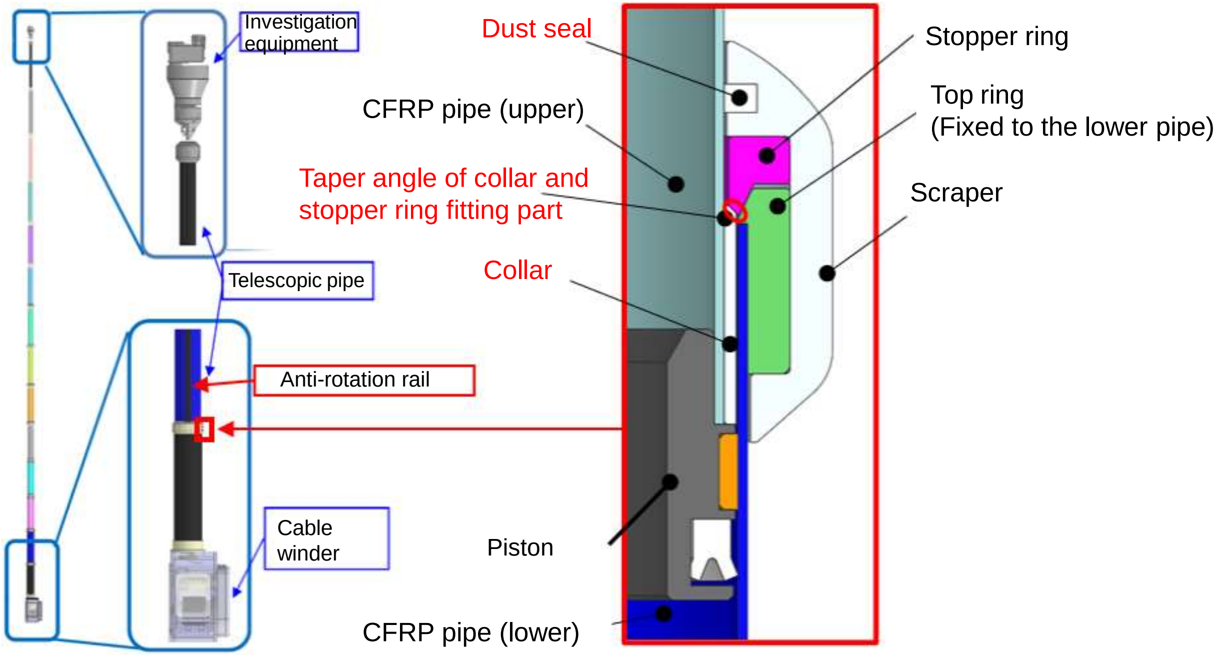
5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

○ Purpose

- The factors that cause tilting and rattling during telescopic pipe extension are considered to be the pipe-to-pipe fit and the gaps between the pipes.
  This year, the following measures were considered to prevent tilting of the telescopic pipe.
  ① Change of taper angle of collar/stopper ring (for easier fitting)
  ② Larger collar diameter (to narrow the gap between pipes)
  ③ Change to a harder dust seal (to prevent wobble)

- An evaluation was conducted to determine whether these measures produced an improvement and the effect on the extension/retraction motion of the telescopic pipe.



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

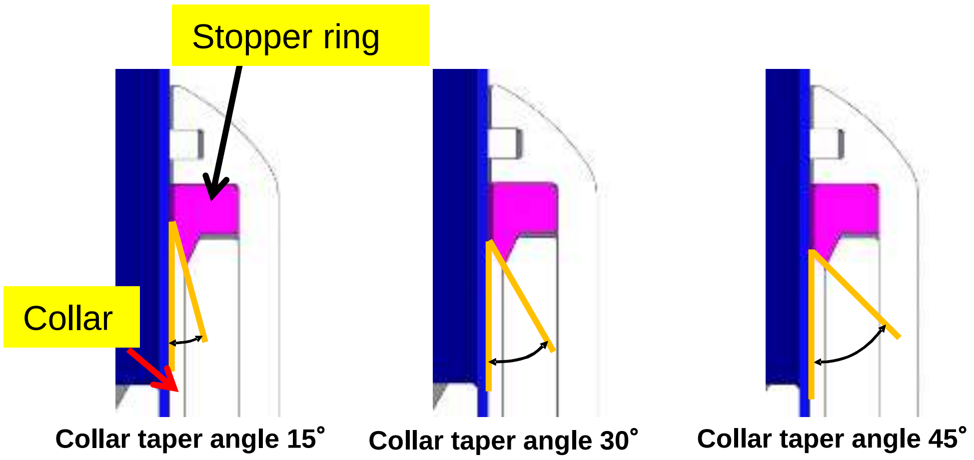
⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

① Change in taper angle of collar/stopper ring / ② Larger collar diameter

- In FY2021, the taper angle of the collar was 45° , but it is anticipated that a more acute angle will make it easier for the fitting parts to fit and increase rigidity. On the other hand, since jamming may occur, making it difficult for the telescopic pipe to pull out during retraction, three taper angles of 15° , 30° , and 45° were selected for comparison and evaluation in the test.
- When the gap between the collar and pipe is reduced (0.2 to 0.4 mm ⇒ 0.1 to 0.2 mm), sliding resistance may increase from FY2021. Also, consideration is being given to increasing the hardness of the sliding part material, but it is possible that the sliding resistance will also differ.

⇒ It was decided to evaluate by testing whether the sliding resistance increases to the extent that it affects the extension/retraction motion of the telescopic pipe, and whether the sliding resistance differs depending on the taper angle.

Items	FY2021	Proposed countermeasures for FY2022
Collar taper angle	45°	Select from 15°, 30°, 45
Gap between collar and pipe	0.2 to 0.4 mm	0.1 to 0.2 mm
Hardening of collar sliding part material	0.1 mm thick ultra-high molecular weight polyethylene tape	0.03 mm thick fluoroplastic coating



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

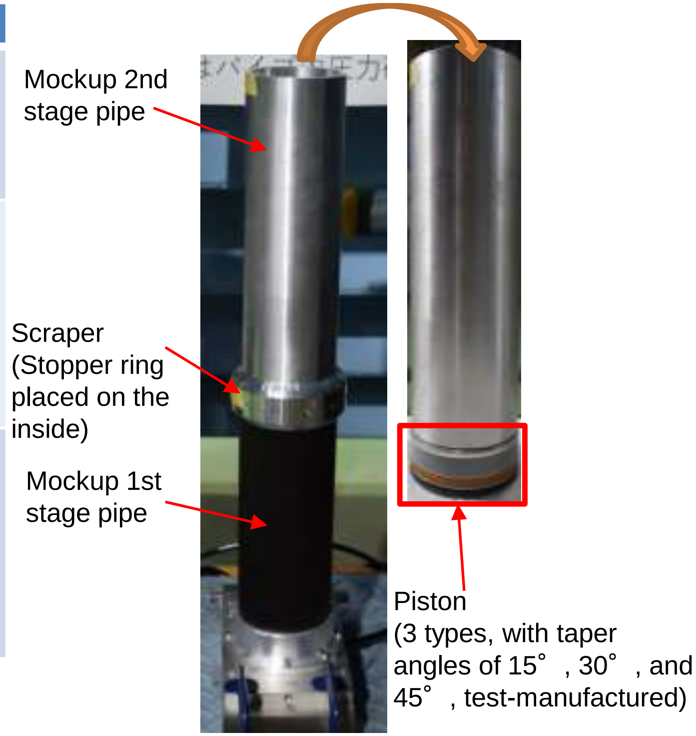
① Change in taper angle of collar/stopper ring / ② Larger collar diameter

〇 Test plan and test object

- If the collar taper angle is made acute, it will fit more easily into the stopper ring, which may have the effect of suppressing the telescopic pipe tilt, but it may also be more difficult to pull out during retraction due to jamming, etc. Therefore, the taper angle is selected by measuring the tilt suppression effect and the force required to remove the fitting parts (Test No.1/No.2)
- Increasing the diameter of the collar may increase sliding resistance, so sliding resistance will be measured to see if it affects telescopic pipe extension (Test No.1)

Test item	Goal	Test outline	Test conditions
Test No.1 Measurement of sliding resistance when collar diameter and sliding part material are changed	Check the effect on sliding resistance by increasing the collar diameter to narrow the gap between the collar and pipe and by changing the sliding part material.	A piston with a collar is placed in a pipe that simulates the 1st stage pipe. Sliding resistance is measured by pulling a wire attached to the piston with a load cell.	- Collar taper angle: 15°, 30°, 45°
Test No.2 Comparison of force required to remove the collar for different taper angles	Identify and evaluate the force required to remove at each taper angle, as an acute collar taper angle may make it fit more easily into the stopper ring and increase the force when the telescopic pipe retracts.	A piston with a collar is used in a pipe simulating the 1st stage pipe, and pneumatic pressure is applied to make the collar of the piston fit into the stopper ring of the 1st stage pipe. The pressure is then released and a load cell is used to apply a vertical load and measure the force required to remove.	- Collar taper angle: 15°, 30°, 45° - Pressure supplied: 0.1 MPa, 0.2 MPa
Test No.3 Verification of tilt suppression effect of different collar taper angles	When the collar taper angle is made acute, it will fit more easily into the stopper ring, which is expected to have a tilt suppression effect. Evaluate the effect of collar taper angle on tilt suppression	Using pipes simulating the thickness of the 1st and 2nd stages, pneumatic pressure is applied to make the collar of the 2nd stage pipe fit into the stopper ring of the 1st stage pipe. A horizontal load is applied to the end of the 2nd stage pipe until the looseness is collapsed, and the displacement of the end of the 2nd stage pipe is measured.	- Collar taper angle: 15°, 30°, 45° - Pressure supplied: 0.03 MPa, 0.1 MPa - Horizontal load: Until any looseness is collapsed

Note: Regarding the pressure supplied for the test, 0.03 MPa is the pressure supplied when extending the 2nd stage of the telescopic pipe, and 0.10 MPa is the maximum pressure supplied to the telescopic pipe until last year. This year, in order to suppress tilting, consideration was given to increasing the pressure supplied to the telescopic pipe, with 0.20 MPa being the maximum value.



Test piece

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

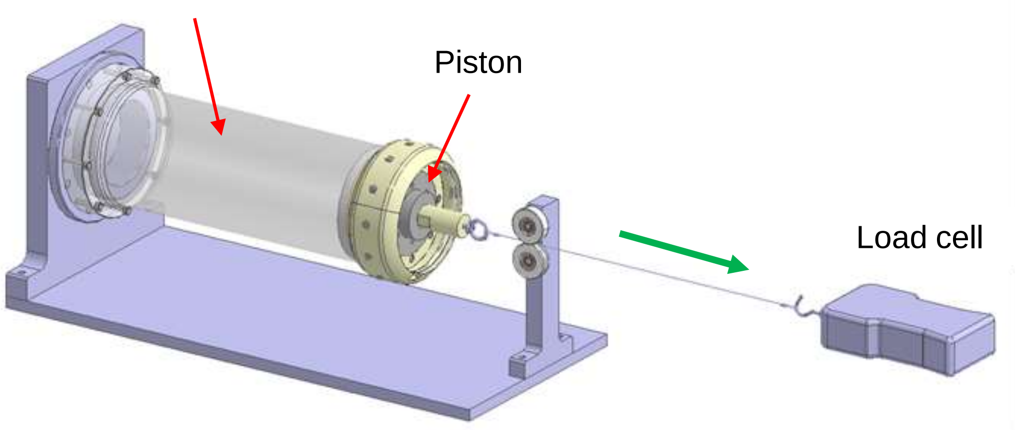
○ Test No.1: Measurement of sliding resistance when collar diameter and sliding part material are changed

Test purpose

Check the effect on sliding resistance by increasing the collar diameter and narrowing the gap between the collar and pipe and by changing the sliding part material.

Test outline

The 2nd stage piston is placed in the 1st stage pipe, and the sliding resistance of the moving piston is measured by a load cell to compare the effect of the collar taper angle.



Test system

Measurement results

Collar taper angle	15°	30°	45°
Sliding resistance	Approx. 10 N		

Test results

- The sliding resistance was about 10 N at any taper angle.

⇒ Verified that collar taper angle makes no significant difference.

⇒ Because a thrust force of approximately 130 N is generated in the 2nd stage pipe during telescopic pipe extension, and the rated tensile force of the cable winder used during telescopic pipe retraction is 170 N, the sliding resistance is sufficiently small compared to the force during extension/retraction, so it is determined that there will not be any problems with operation of the telescopic pipe.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

○ Test No.2: Comparative test of force required to remove the collar for different taper angles

Test purpose

A sharp collar taper angle may increase the tensile force required to retract the telescopic pipe because of the increased likelihood of jamming in the stopper ring. Evaluate the force required to remove the collar and stopper ring at each taper angle.

Test outline

Tests were conducted using a short mockup of a 1st stage pipe and a mockup of a piston with a collar attached. The piston is placed in a position such that the collar fits into the stopper ring, the pipe is opened to the atmosphere after a predetermined pressure (0.1 MPa/0.2 MPa) is applied, and a load cell is used to push the piston from above measure the force when it begins to descend.

Measurements of force* required to remove (average of 5 measurements each)

Pressure supplied	Taper angle		
	15°	30°	45°
0.1 MPa	27 N	30 N	28 N
0.2 MPa	47 N	27 N	27 N

*Value obtained by adding the weight of the piston to the load cell reading

- Test results

At 30° and 45°, there was no significant difference in the force required to lower the piston when the pressure supplied was increased, indicating that the required tensile force was unaffected.

On the other hand, at 15°, the measured values also increased when the supply pressure was increased to 0.2 MPa, indicating that increasing the pressure affects the required tensile force.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

○ Test No.3: Verification of tilt suppression effect of different collar taper angles

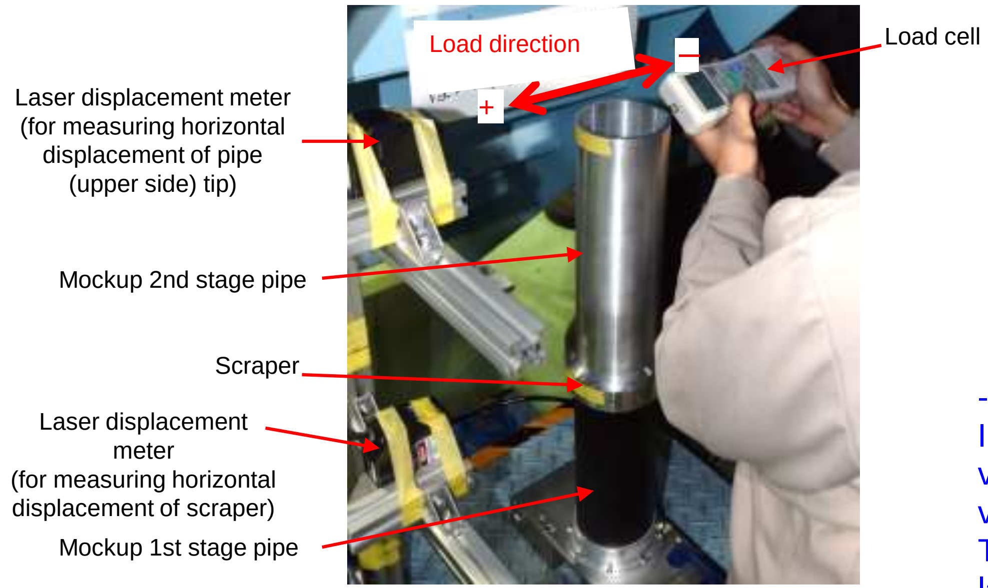
Test purpose

It is possible that if the collar taper angle is made acute, the collar will fit into the stopper ring more easily, which can be expected to suppress tilting.

Perform a comparative evaluation of the extent to which tilt can be suppressed by the collar taper angle

Test outline

The looseness width is evaluated by applying a pressure of 0.03 MPa/0.10 MPa to a short mockup of the 1st and 2nd stage pipes, applying a horizontal load to the tip of the 2nd stage pipe in the + and - directions, and measuring the displacement of the tip with a laser displacement meter. The horizontal load required to collapse the looseness is measured using the tip of the 2nd stage pipe as the load point.



Test system

Comparison of looseness width
(sum of looseness in + direction and - direction)

Pressure supplied	15°	30°	45°
0.03 MPa (Pressure used for telescopic extension)	5.7 mm	3.2 mm	2.1 mm
0.10 MPa	4.3 mm	3.2 mm	1.7 mm

- Test results

In terms of looseness, the relationship between the large and small values did not change when the pressure supplied was changed, and the values were 45° < 30° < 15°.

The horizontal load required to collapse the looseness was also the largest at the 45° taper angle, as was rigidity. As such, the trend was the same despite the change in pressure.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

Summary of test results: ① Change in taper angle of collar/stopper ring / ② Larger collar diameter

- To select the angle of the collar taper (15°/30°/45°) and to verify the effect of a larger collar diameter, the taper angle was changed and its effect on the sliding resistance, the force required to remove the pipe, and the tilt suppression effect was verified.

- When the collar diameter was enlarged, the sliding resistance was about 10 N with no significant difference when the taper angle was changed. As such, it was confirmed that to be sufficiently small compared to the force during telescopic pipe extension and retraction (during extension: the thrust generated during 2nd stage pipe extension, approx. 130 N; during retraction: the rated tensile force of the cable winder during telescopic pipe retraction, approx. 170 N).

⇒ **It was determined that there are no problems with telescopic pipe operation with a larger collar diameter.**

- The force required to remove the pipe was not significantly different between the 30° and 45° taper angles, with the force required for the 15° angle being greater.
- Regarding the tilt suppression effect, the taper angle of 45° was confirmed to have the smallest range of looseness and the greatest rigidity.

⇒ **The taper angle of the collar used for the telescopic pipe was set to 45°, the same as last year.**

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

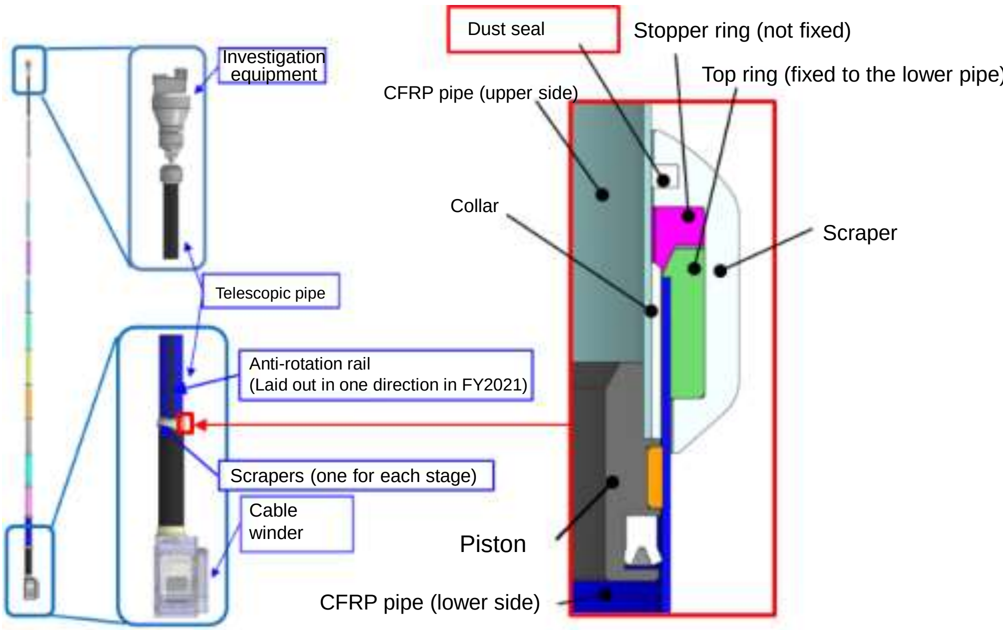
⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Change to a harder dust seal

〇 Background

- Each pipe is designed with a dust seal to prevent matter adhered to the pipe surface from entering the equipment during telescopic pipe retraction (see figure below).
- Extension/retraction motion while foreign matter (soil, alumina) was adhered to the device was verified in FY2021. The results showed no significant difference in the internal pressure during telescopic extension or the cable tensile force during retraction even when powdery foreign matter was adhered to the pipe, and as such, it was determined that there was no problem with extension/retraction motion even with foreign matter adhered to the pipe.
- On the other hand, the dust seal used was soft and there were concerns about its durability (susceptibility to wear and tear). Therefore, a survey of similar materials was conducted, and a relatively hard material was selected as an alternative candidate.
- The following items were evaluated to assess the impact of changing the dust seal.

(a) Effect on foreign matter removal performance
(b) Effect on telescopic pipe extension/retraction motion
(c) Effect on tilting behavior



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Change to a harder dust seal

○ Test plan

- Comparative tests were conducted on the following three items regarding the effects of changing dust seals.

Test name	Goal	Test conditions
Test No.1 Verification of effect on foreign material removal performance	Powder (soil/alumina) was applied to the surface of the 2nd stage pipe of the 14-stage telescopic pipe test-manufactured in FY2021, and verification was performed to ascertain foreign substance removal performance and determine whether retraction/extension operations were possible. (Changing the dust seal at the tip of the 1st stage)	- Dust seals: FY2022 dust seals (those from FY2021 have already been evaluated) - Foreign matter: ① soil, ② alumina - Attachment point: 2nd stage of 14-stage telescopic pipe test-manufactured in FY2021
Test No.2 Effect on telescopic pipe extension/retraction motion	Confirm that extension/retraction motion is possible, since the changed dust seal may have greater sliding resistance. Since the pipe driving force is smaller for emergency retraction (retraction using only depressurization in the pipe) than for normal extension/retraction motion, the operation was verified for the 14th stage pipe, where the retraction force due to the action of its own weight and negative pressure is especially small. (Changing the dust seal at the tip of the 13th stage)	- Dust seal: FY2022 dust seal
Test No.3 Confirmation of impact on tilt control effect	Using the short pipe used to select the taper angle, compare the tip displacement of the FY2022 dust seal with the FY2021 dust seal when a horizontal load is applied.	- Dust seal: FY2021 dust seal / FY2022 dust seal - Taper angle: 45° - Pressure supplied: 0.03 MPa (short pipe: pressure at 2nd stage extension)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Change to a harder dust seal

○ Test No.1: Effect on foreign matter removal performance

Test outline

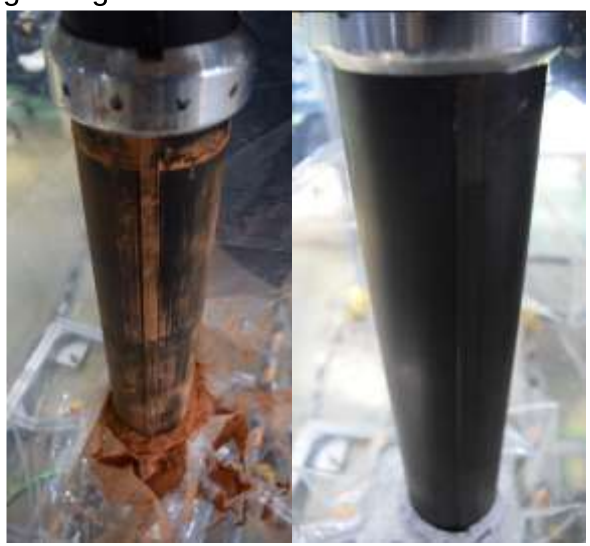
- The dust seal on the first stage of the telescopic pipe was changed and soil (15 μm particle size)/alumina (75 to 100 μm particle size) was applied to the surface of the 2nd stage pipe to check its performance in removing foreign particles by extending it after retraction.

Test results

- In the case of soil, the pipe surface after extension was wiped unevenly, but the alumina was wiped off uniformly. Although both soil and alumina appeared to have passed through the dust seal, adhesion to the gasket was minimal.
- Since the FY2021 test results showed uneven wiping of both soil and alumina, the dust seal selected this year was evaluated to have better performance in removing foreign matter.

(a) Soil (b) Alumina

Condition of pipe with powder adhered



(a) Soil (b) Alumina

Condition of pipe outer surface after retraction and re-extension

(a) Soil

(b) Alumina

Condition of dust seal after removal of foreign matter

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Change to a harder dust seal

○ Test No.2: Effect on telescopic pipe extension/retraction motion

Test outline

- The alternative product selected this year is stiffer than that selected in FY2021 and may have greater sliding resistance during telescopic pipe extension/retraction, so verification will be performed to determine if there is any effect on extension/retraction motion.
- Since the force to drive the telescopic pipe is smaller for emergency retraction (retraction using only depressurization in the pipe) than for normal extension/retraction motion, and the weight of the telescopic pipe itself is smaller on the tip end, the dust seal at the tip of the 13th stage will be changed and verification performed regarding whether retraction of the 14th stage pipe is possible.

Test results

- After pulling out the 14th pipe about 100 mm by hand, verification was performed to determine whether it could be retracted in case of emergency (performed once). Although the telescopic pipe did not retract under its own weight, it was confirmed that it did so when the internal pressure of the pipe was reduced to -22 kPa.
- In last year’s test of emergency retraction using dust seals, the 14th stage pipe began to retract under its own weight when the telescopic pipe internal pressure was 9 kPa. In terms of the difference in sliding resistance, the alternative product selected this year resulted in an increase in sliding resistance of 22 N.

⇒ Although sliding resistance increased, the 14th stage pipe, which is the hardest to retract, was confirmed to do so, and thus it was determined that there would be no problems with telescopic pipe operation.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Change to a harder dust seal

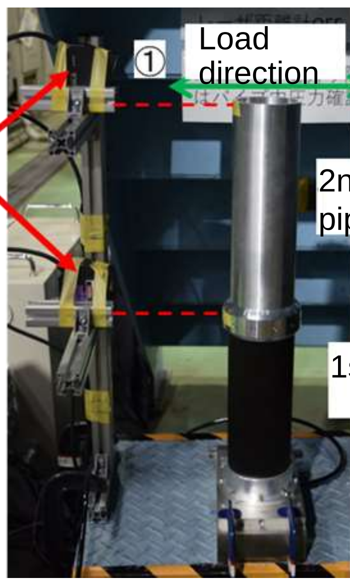
○ Test No.3: Evaluation of the effect on tilting behavior

Test outline

- Since the dust seal is a component that supports the telescopic pipe, verification is performed to determine if there is any effect on tilting behavior.
- The test system is shown below. The displacement was measured with a laser displacement meter when a horizontal load was temporarily applied to the end of the 2nd stage pipe in the direction of ① and ② and then no load was applied, and a comparison was made between the FY2021 dust seal and the current year's replacement in terms of the difference in looseness width.

Test results

- The results showed that the alternative product used this year was more resilient, and that when no load was applied, the pipe was pushed back vertically and the looseness width was reduced.



Comparison of looseness width

Pressure supplied	Dust seal	
	Selected in FY2021	Selected in FY2022
0.03 MPa (Pressure used at 2nd stage pipe extension)	2.1 mm	1.8 mm

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

③ Summary of changing to a harder dust seal

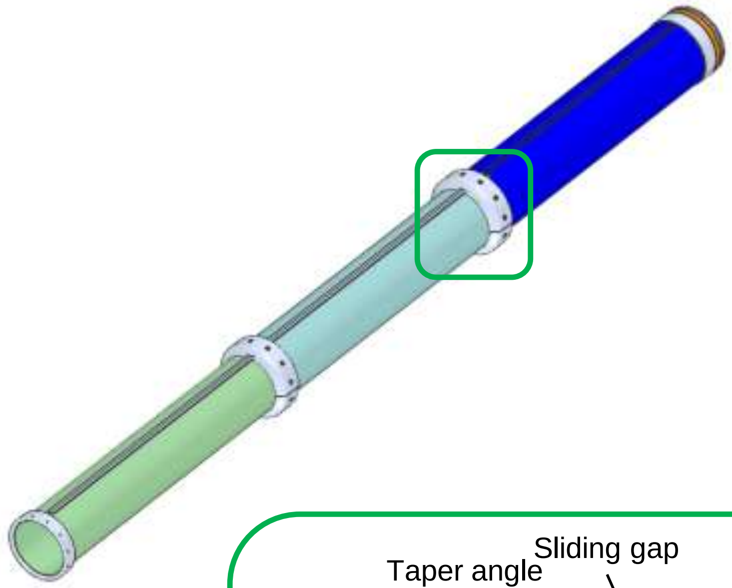
○ Summary of the tests to verify the factors behind tilting of the telescopic pipe

- A comparative evaluation between the dust seal from FY2021 and the alternative product selected this year was conducted.
- Better results in terms of foreign material removal performance were obtained for this year's alternative.
- With respect to the telescopic pipe's extension/retraction motion, verification was performed to ascertain weather emergency retraction was possible. The results showed that although sliding resistance increased, the 14th stage pipe, which is the hardest to retract, was confirmed to do so, and thus it was determined that there would be no problems with telescopic pipe operation.
- Regarding the suppression of tilting, the current year's alternative product was found to have a smaller looseness width and force that acts to push the pipe back in a vertical direction.

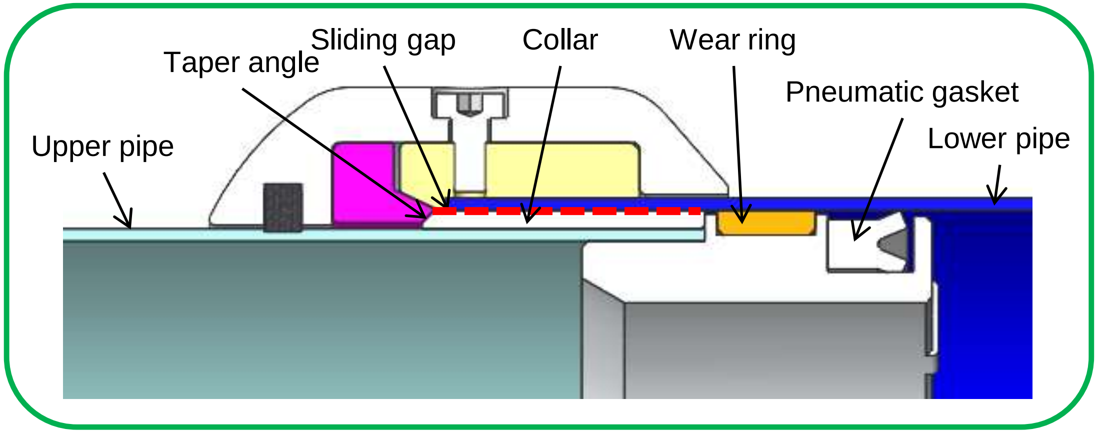
➡ **The 14-stage telescopic pipe test-manufactured this year will be fitted with the dust seals selected this year, and tests will be conducted to verify operation.**

6. Implementation details
(2) Development of the bottom access investigation method (telescopic pipe)
5) Investigation details
⑦ Control of tilt in the direction of the anti-rotation rails during telescopic pipe extension
⑧ Control of looseness due to gaps between stage pipes, and prevention of tilting caused by gaps during emergency retraction (in emergencies)

○ Based on the test results to date, the following improvements were made to the telescopic pipe to be test-manufactured this year.



Items evaluated in the test	Test-manufactured equipment in FY2021	Test-manufactured equipment in FY2022
Collar taper angle	45°	45°
Gap between sliding parts due to larger collar diameter	0.2 mm	0.1 mm
Hardening of collar sliding material	0.1 mm thick ultra-high molecular weight polyethylene tape	0.03 mm thick fluoroplastic coating
Dust seal	FY2020 alternative product	FY2022 selected product



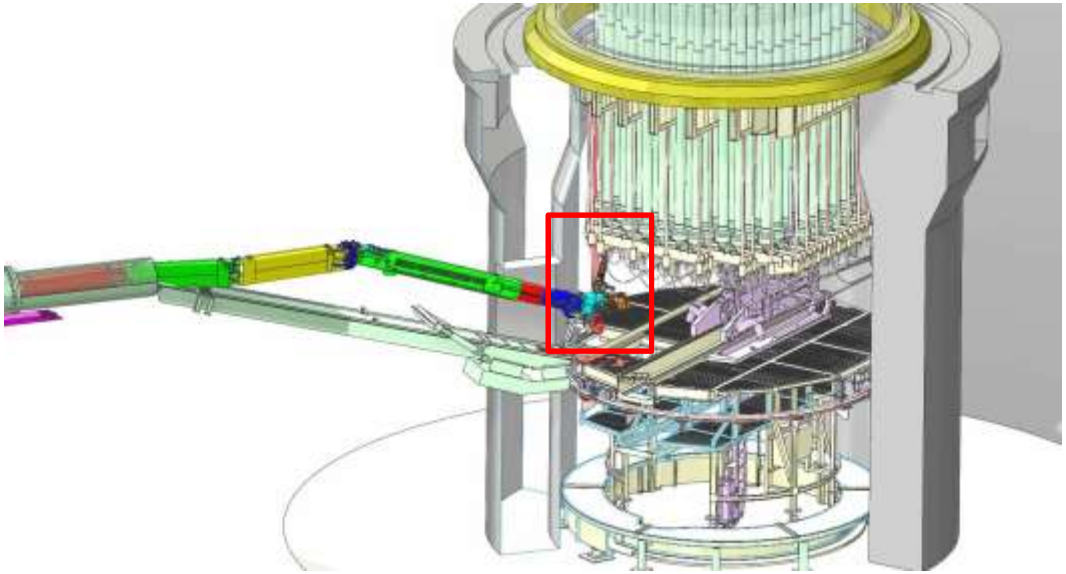
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

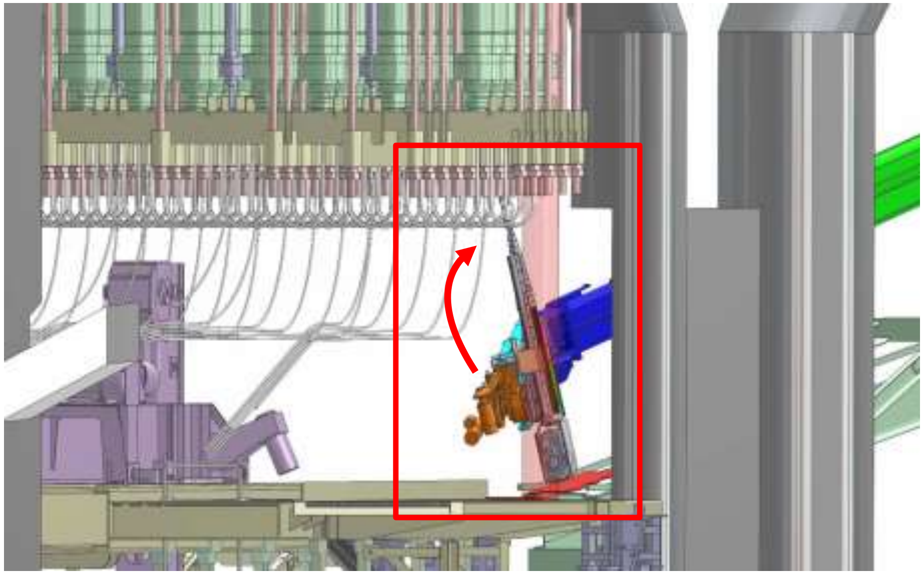
5) Investigation details ⑨Test manufacturing and evaluation of posture control mechanism

○ Background

- Due to the possibility that the degree of freedom of the arm for the "Gradually Increasing the Scale of Retrieval" project may not allow the telescopic pipe to be placed in a vertical position at the anticipated survey position, a two-axis posture control mechanism is being considered.



Bird's-eye view



Enlarged view of the posture control mechanism

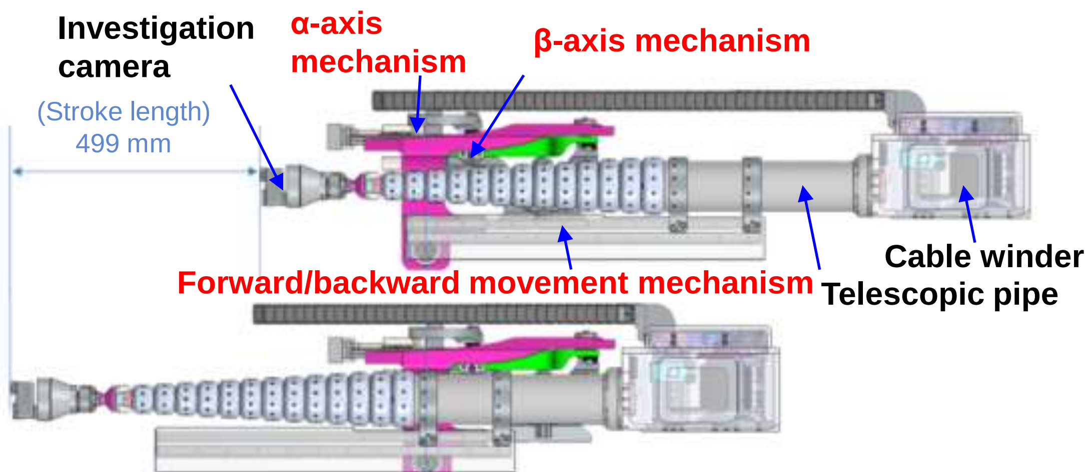
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

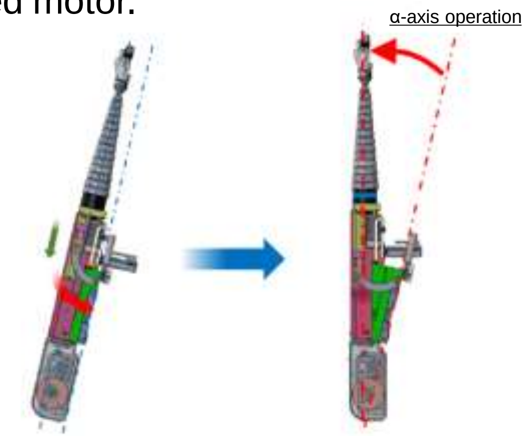
5) Investigation details ⑨Test manufacturing and evaluation of posture control mechanism

○ Equipment design

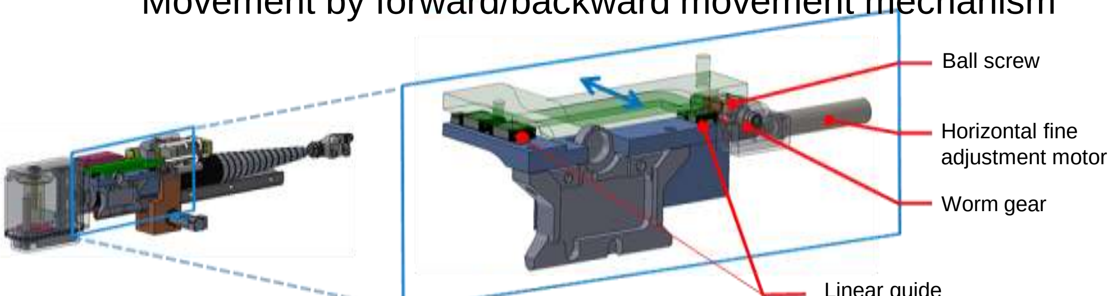
- A review of required specifications and conceptual design was conducted in FY2021. This year, detailed design work was conducted, and it was confirmed that the specifications for the range of motion and total weight were met.
- Due to the long delivery time for the motor selected for the posture control mechanism, it was not available in time for the test, so this year it was decided to use a motor that had been incorporated into the test equipment of a past project. Although the output torque is different, the plan for this test is to measure the torque (motor current value) during the operation test to confirm that there is no problem with the selected motor.



Movement by forward/backward movement mechanism



Movement by α-axis mechanism



Movement by β-axis mechanism

Design results of the posture control mechanism

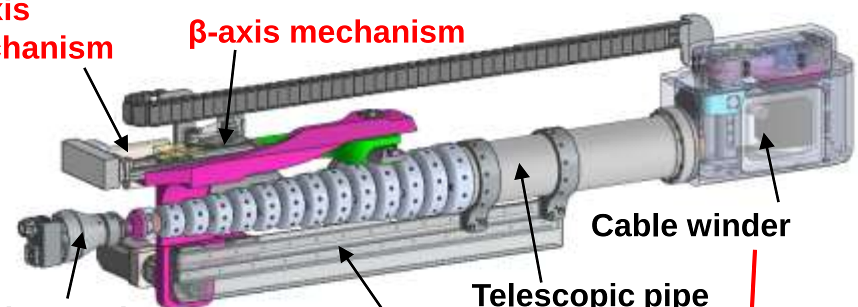
Items		Required specifications	Design results
Amount of movement	Forward/backward movement mechanism	499 mm or more	513 mm
	α-axis mechanism	13° or more	15°
	β-axis mechanism	20 mm or more	22 mm
Total weight		22 kg or less	21.0 kg

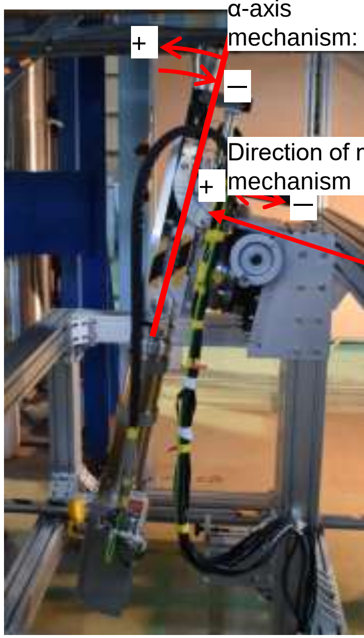
6. Implementation details

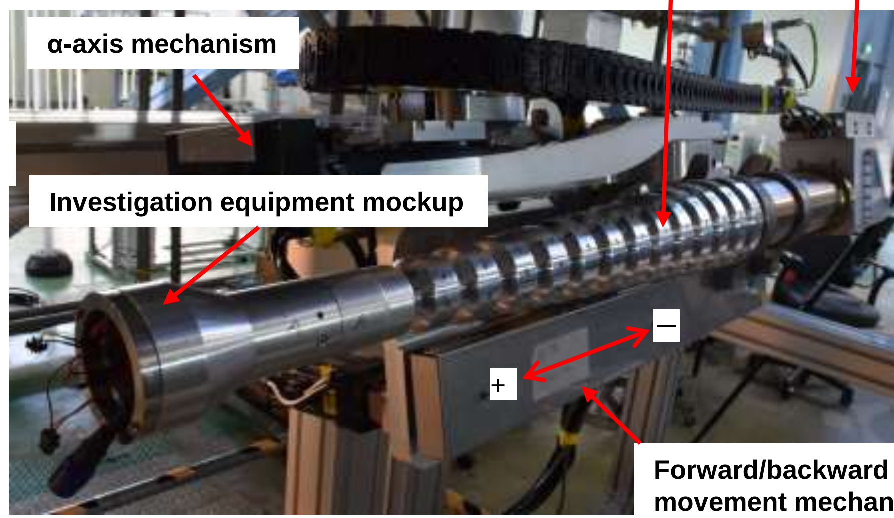
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ⑨Test manufacturing and evaluation of posture control mechanism

The test-manufactured posture control mechanism is shown below.







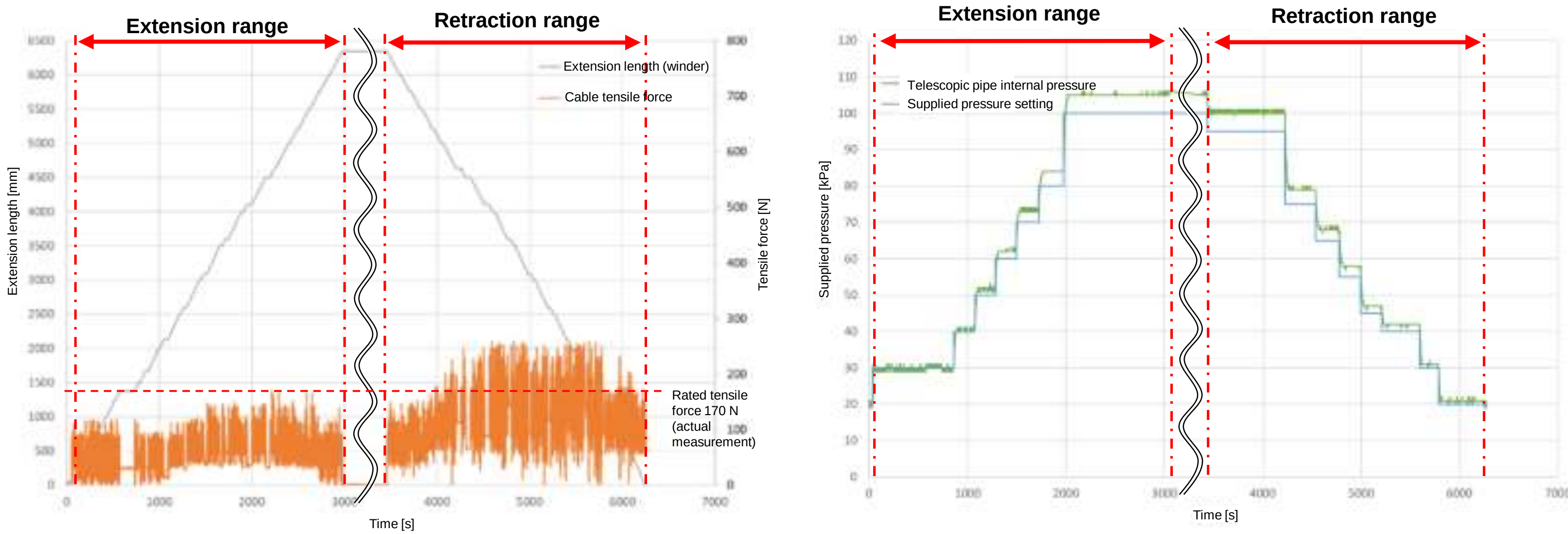
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ⑩ Ensuring uniform drive torque for cable winding drums (reduction of cable tensile force loss)

〇 Background

- In FY2021, in an elemental test of the 14-stage telescopic pipe, it was confirmed that the cable tensile force (motor drive torque) fluctuated significantly in a short period of time and that the drive load may not be uniform due to imprecise assembly of the gears and drive shaft.
- In FY2022, after implementing measures to address the above issues, elemental tests of the 14-stage telescopic pipe will be conducted again to evaluate the effectiveness of the countermeasures.



Changes in the extension length, cable tensile force, and internal pressure during telescopic pipe extension/retraction motion

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details ⑩ Ensuring uniform drive torque for cable winding drums (reduction of cable tensile force loss)

〇 Consideration of countermeasures

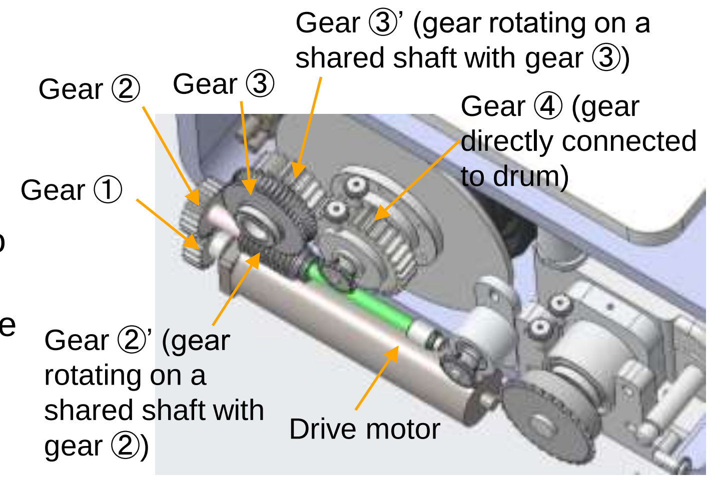
- The following factors were determined to be responsible for the torque fluctuation. After considering each improvement plan, it was decided to check the torque of the cable winder alone under no-load conditions.

① There was a slight interference between the side of the drum and the bolts on the cable winder housing. Therefore, design changes will be made this year to avoid interference.

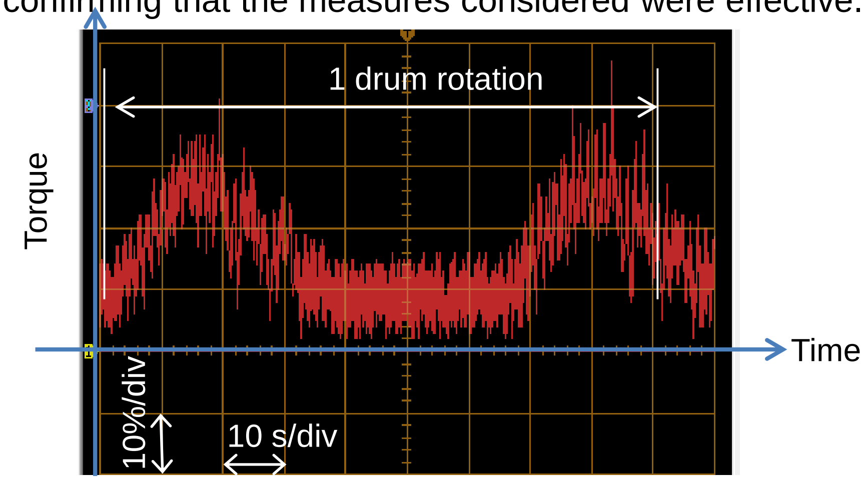
② Because of the use of multiple gears, in FY2021, in order to prevent a decrease in responsiveness due to gear backlash, the distance between gears was designed to be narrower than the standard value. Improvements will be made this year to change the distance between standard gears

〇 Results

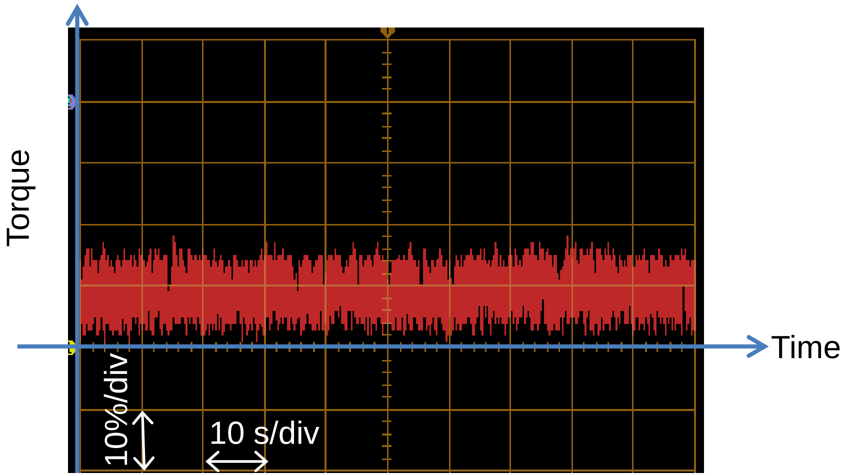
It was confirmed that the torque did not fluctuate under no-load conditions, confirming that the measures considered were effective.



Mechanism for transmission of torque from motor to cable winding drum



Variation in drum drive torque under no load conditions (Before improvement)



Variation in drum drive torque under no load conditions (After improvement)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Background

- An evaluation is conducted to confirm the function of the posture control mechanism newly test-manufactured this year and to evaluate its operation in combination with the telescopic pipe.
- To evaluate the effect of the improvements to the 14-stage telescopic pipe, which were made to suppress tilting during extension, the amount of tilt and looseness during extension, which were evaluation items for FY2021, will be evaluated, and the possibility of emergency retraction operation using depressurization will be verified.

○ Test plan

No.	Test items/outline	Verification items	Target (Criteria)	Applicable item
1	[Verification of extension/retraction motion of telescopic pipe in vertical position] - Check whether the telescopic pipe can be extended or retracted. (Check the effect of changing sliding parts (collars, dust seals))	- Whether or not extension is possible at the supplied pressure (0.1 MPa)	- Whether or not extension is possible at the supplied pressure (0.1 MPa)	⑩
2	[Verification of amount of tilt during telescopic pipe extension] - Check the amount of tilt during telescopic pipe extension. (Compare with the telescopic pipe test-manufactured in FY2021)	- Amount of tilt during telescopic pipe extension	- Is the amount of tilt improved compared to the telescopic pipe test-manufactured in FY2021?	⑦
3	[Verification of looseness during telescopic pipe extension] - Check the amount of looseness during telescopic pipe extension. (Compare with the telescopic pipe test-manufactured in FY2021)	- Amount of looseness at each stage of the telescopic pipe	- Is the amount of looseness improved compared to the telescopic pipe test-manufactured in FY2021?	⑧
4	[Verification of operation of the posture control mechanism when the telescopic pipe is extended] - Check if the position can be adjusted by the posture control mechanism while the telescopic pipe is extended.	- Whether or not tilt adjustment is possible using the posture control mechanism	- Whether or not operation within the rated torque of each axis motor is possible	⑨
5	[Understanding the behavioral characteristics of the telescopic access equipment when it sways] - To understand the swaying behavior of the telescopic access equipment when the telescopic pipe is in its extended state	- Swaying behavior of the tip of the telescopic pipe	— (Identify behavior only)	⑪
6	[Verification of emergency retraction operation] - Check if emergency retraction by depressurization is possible with the telescopic pipe extended.	- Whether or not retraction is possible at reduced pressure (max -0.092 MPa)	- Whether or not emergency retraction by telescopic pipe/posture control mechanism only is possible	⑧

6. Implementation details

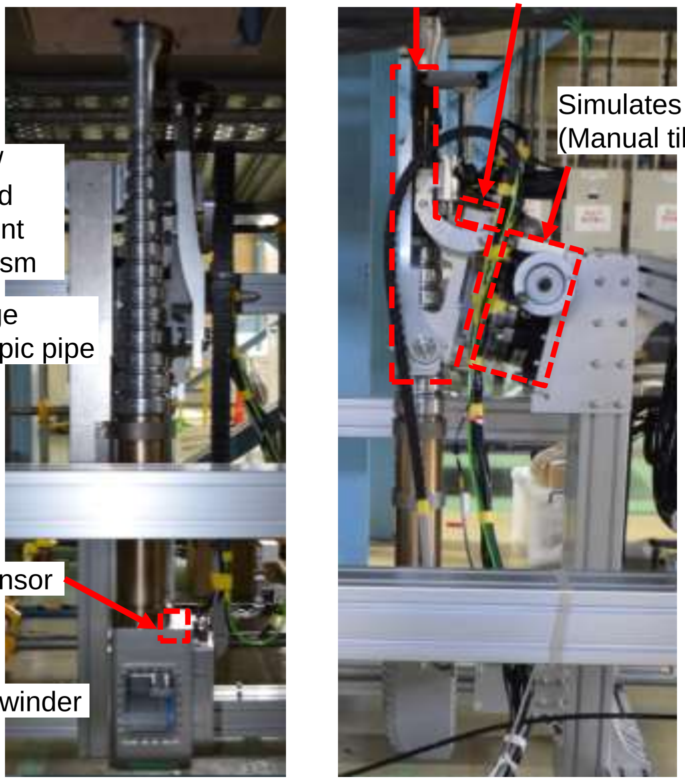
(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

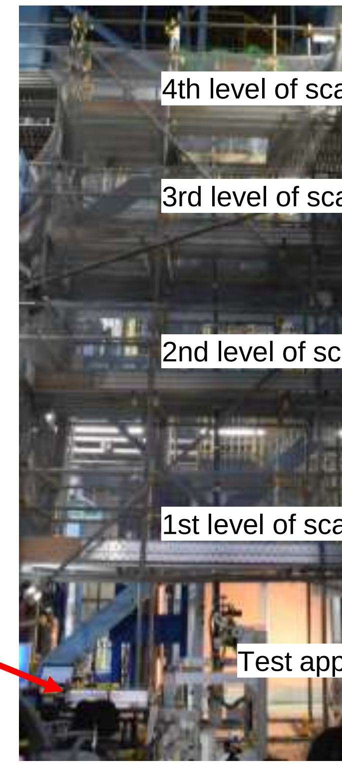
○ Test piece/test system

The test was conducted by combining a newly test-manufactured posture control mechanism (forward/backward mechanism, α-axis mechanism, β-axis mechanism) with the 14-stage telescopic pipe and cable winder to which improvements were made this year. As in the previous year, scaffolding was set up around the apparatus so that the behavior of the extended telescopic pipe could be observed.



Test apparatus

Operation table



Test system

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

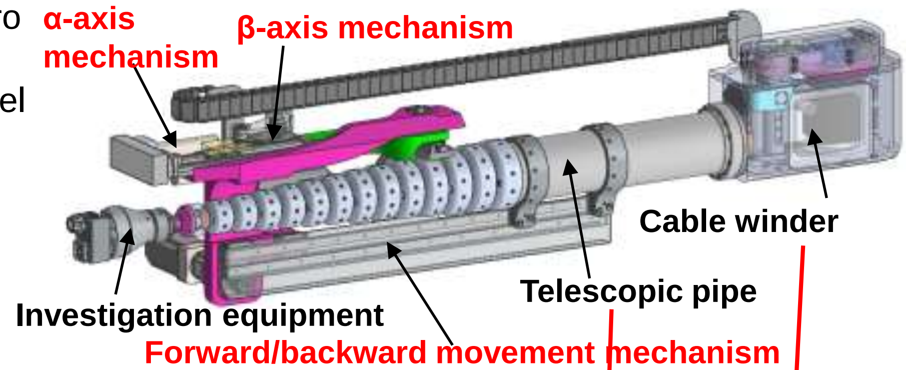
Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

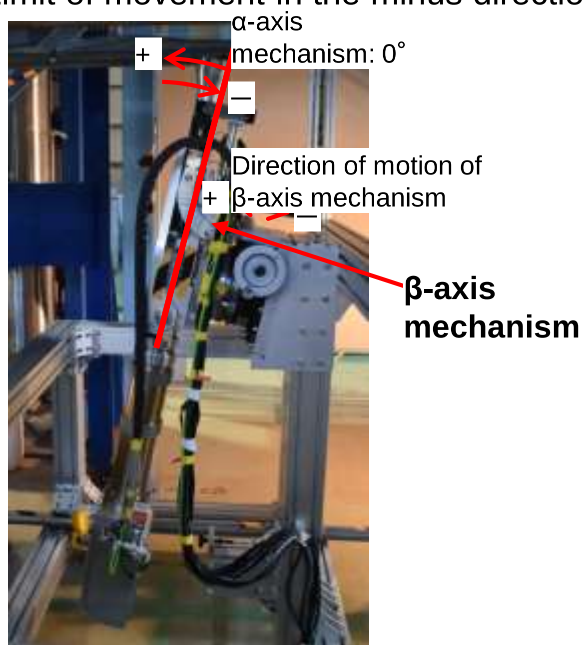
○ Test piece/test system

About the test-manufactured posture control mechanism

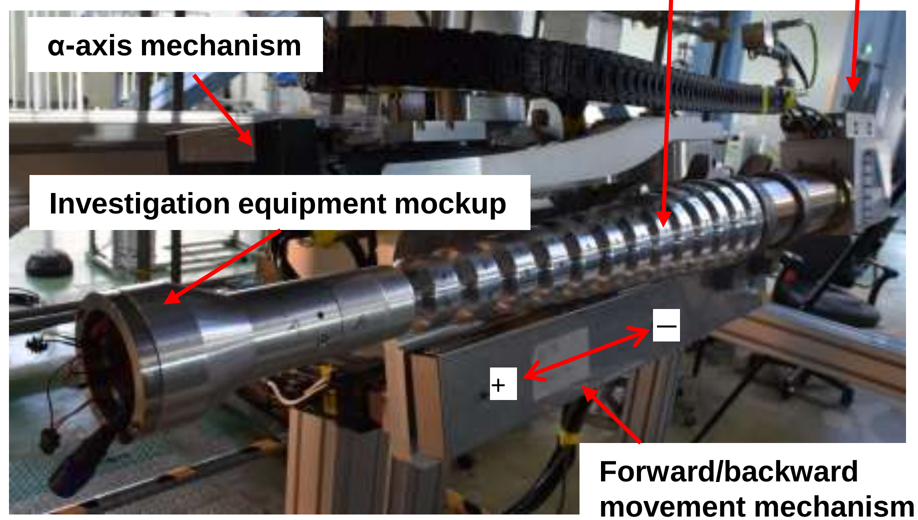
The + direction and - direction of each axis of the posture control mechanism are defined as shown in the figure, and the origin (zero point) position of each axis is shown below.

- Forward/backward movement mechanism: minus direction travel limit
- α-axis mechanism: Mounting surface of telescopic access equipment
- β-axis mechanism: Limit of movement in the minus direction





Direction of motion of α-axis and β-axis



Horizontal posture

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Test No.0: Verification of operation of posture control mechanism

Test results

It was confirmed that, with the telescopic pipe retracted, the posture control mechanism can be operated without the torque of each axis motor exceeding 100%, whether the telescopic access equipment is in either a vertical or horizontal posture. Although the operating range of the α-axis mechanism slightly failed to meet the required specifications, it is expected that the required specifications will be met by reviewing the shape of the components in the next fiscal year and thereafter. These results indicate that posture adjustment operations can be performed without problems in the assumed operational sequence with the telescopic pipe in the retracted state.

Motor torque measurement results (vertical axis: torque, horizontal axis: time)

	Vertical posture	Horizontal posture
Forward/ backward movement mechanism		
α-axis mechanism		
β-axis mechanism		

Measurement results of operating range

	Required specifications	Measurement results
Forward/ backward movement mechanism	499 mm or more	499 mm
α-axis mechanism*	0° to 13° or more	0.4° to 13.6°
β-axis mechanism	20 mm or more	22 mm

*Mounting surface of telescopic access equipment is defined as 0°

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

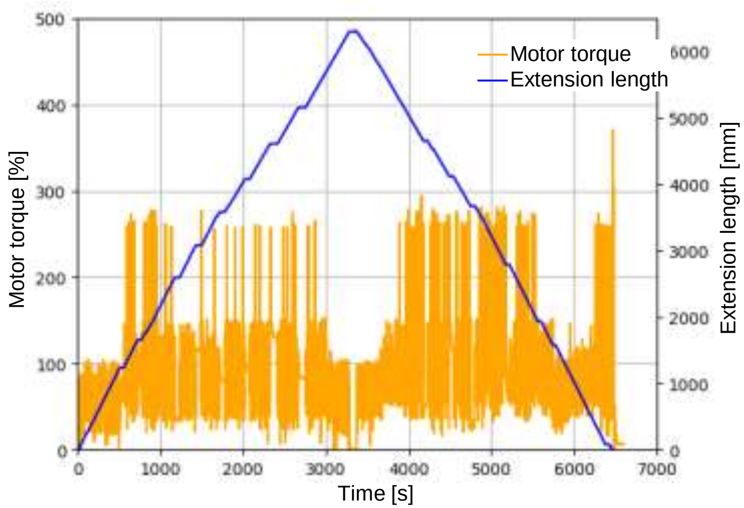
○ Test No.1: Verification of extension/retraction motion of telescopic pipe in vertical position

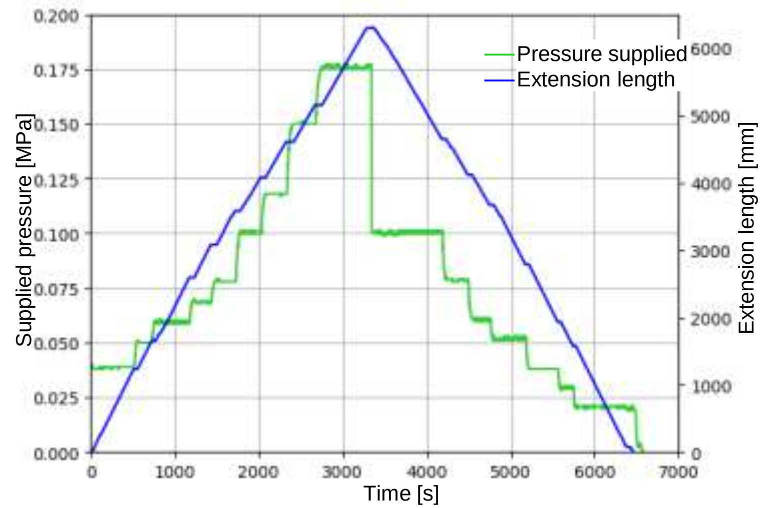
Test purpose

The telescopic pipe test-manufactured this year has a harder dust seal than last year's in order to suppress tilting during extension and emergency retraction. Since this change has increased sliding resistance, conduct verification to determine if extension/retraction motion can be performed without problems.

Test outline

Last year, the maximum supplied pressure was set at 0.1 MPa. This year, however, the pressure was increased to suppress tilting during extension. During retraction, the motor torque of the cable winder was evaluated at the same supplied pressure as last year.





Test results

Using the telescopic pipe to which improvements were made this year, it was confirmed that extension/retraction motion could be performed without any problems even when the supplied pressure was increased from the previous year. Although the motor torque exceeded 100%, no overload error occurred, and so it was determined that there was no problem.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

〇 Test No.2: Verification of amount of tilt during telescopic pipe extension

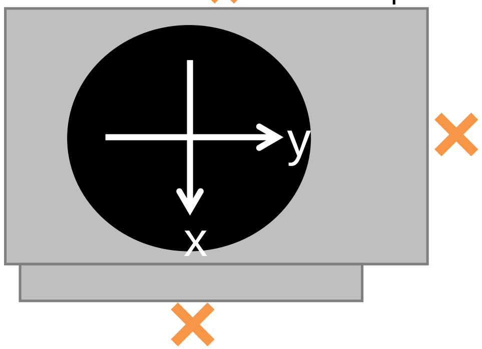
Test purpose

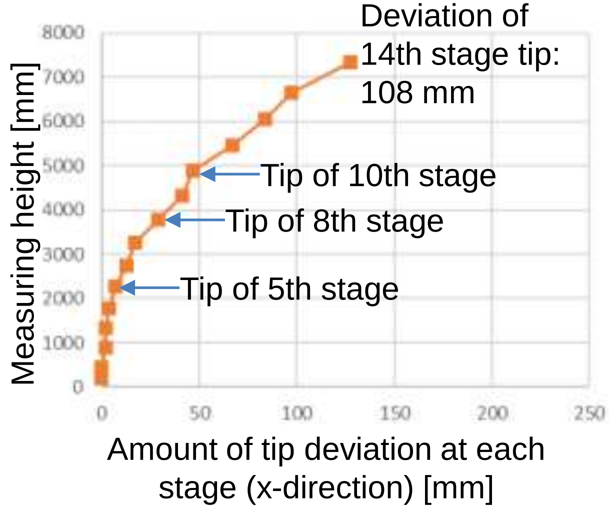
Verify whether the telescopic pipe to which tilt suppression measures were applied this year shows any improvements in the amount of tilt compared to the telescopic pipe of the previous year.

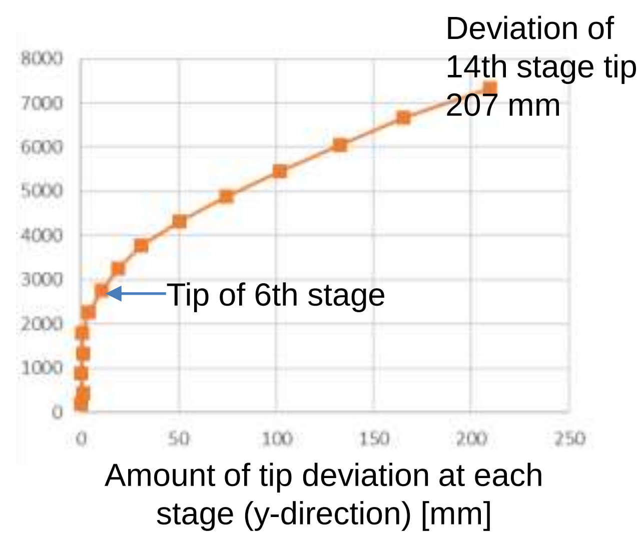
Test outline

The 14-stage telescopic pipe was fully extended, and as in the reproducibility verification test using the telescopic pipe from the previous year, plumb lines were hung at two points, and the distance between the tip of each stage of the telescopic pipe and the plumb lines was measured to evaluate the amount of tilt.

Black circle: Telescopic pipe
Gray: Cable winder
✕ : Positions plumb lines hung







Test results

In the fully extended state, the tip deviation was (x, y) = (108 mm, 207 mm). In the reproducibility verification test using last year's telescopic pipe, (x, y) = (1 mm, 128 mm), indicating that the telescopic pipe test-manufactured this year tilted more. This suggests that this year's telescopic pipe is more likely to fall over and to and retract less easily during depressurization for emergency retraction.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Test No.3: Verification of looseness during telescopic pipe extension

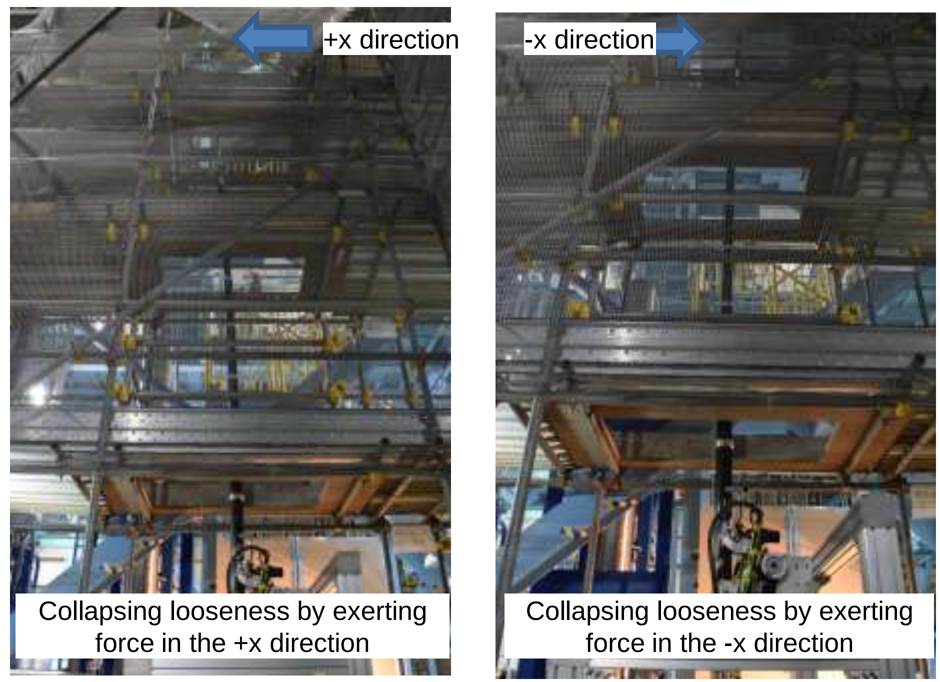
Test purpose

Verify whether the telescopic pipe to which tilt suppression measures were applied this year shows any improvements in the amount of looseness compared to the telescopic pipe of the previous year.

Test outline

Fully extend the 14-stage telescopic pipe and apply a force in the +x/-x direction to each stage to collapse the looseness. Evaluation is performed by measuring the distance between the tip of each stage of the telescopic pipe and a plumb line, in the same way as the amount of tilt was measured.

A bending force is applied to the pipe in order to tilt the 3rd stage



Telescopic pipe after the looseness is collapsed by applying a bending force

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

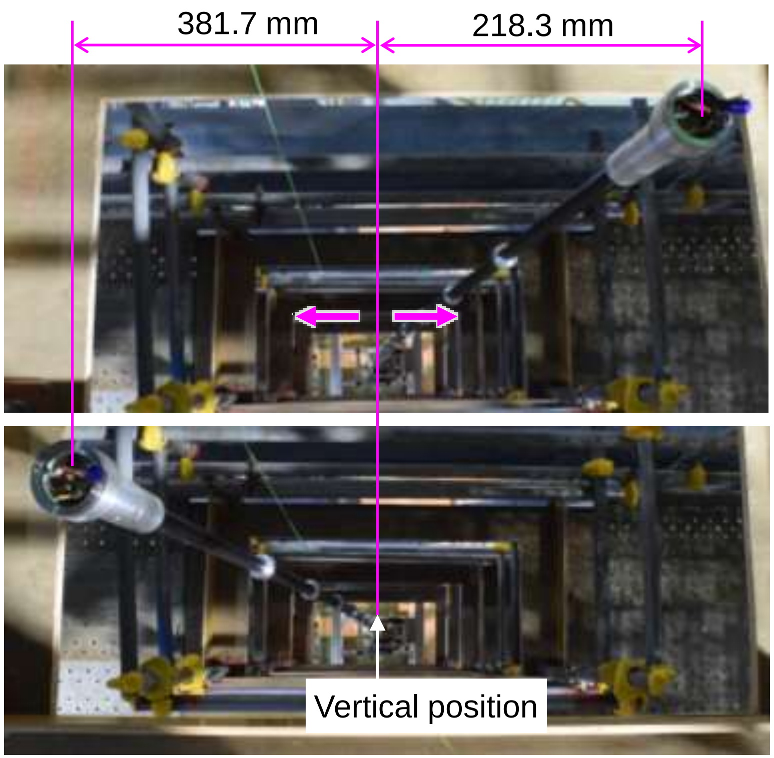
5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

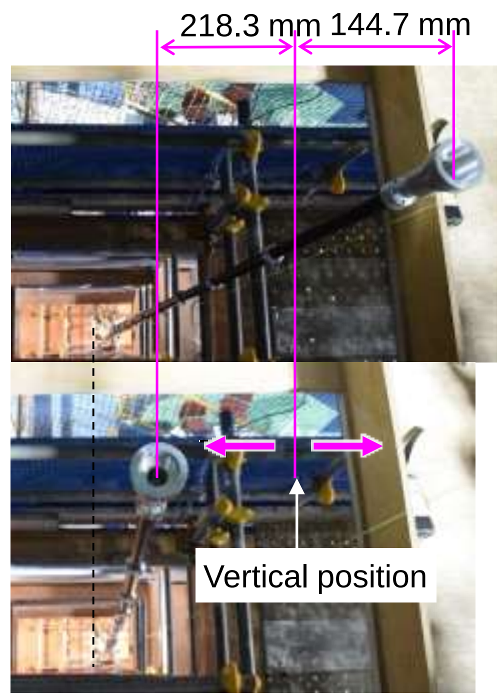
○ Test No.3: Verification of looseness during telescopic pipe extension

Test results

The telescopic pipe developed in this fiscal year was test-manufactured with a design featuring narrower gaps between the stage joints, but the results showed more looseness than with the pipe developed in last fiscal year.



Results of this year's telescopic pipe looseness verification



Results of last year's looseness verification

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Test No.4: Verification of operation of the posture control mechanism when the telescopic pipe is extended

Test purpose

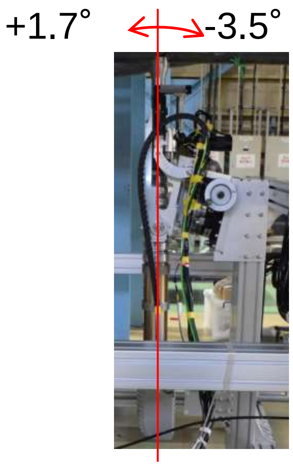
As consideration is being given to using α-axis and β-axis mechanisms for fine adjustment of the extension direction when passing through the opening at the bottom of the reactor, verification will be performed to ascertain if the telescopic pipe can be operated without problems even when extended.

Test outline

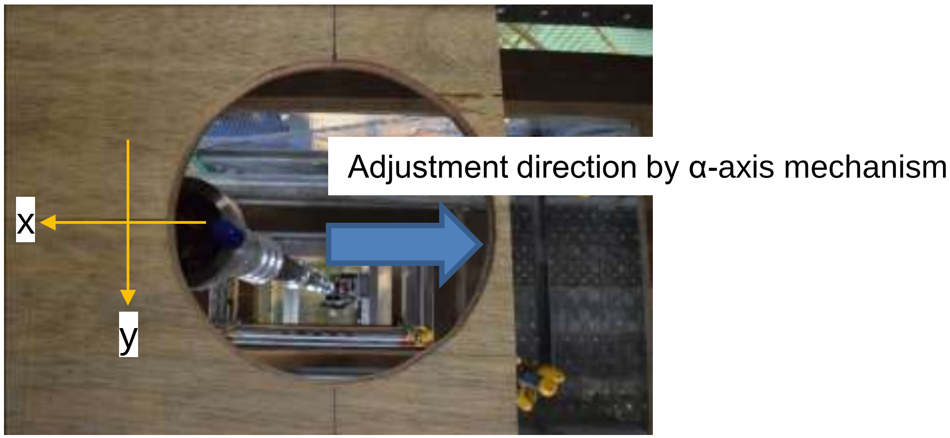
Two patterns of operation were evaluated: with the telescopic pipe fully extended and with the telescopic pipe extended to just before the opening.

α-axis mechanism
- Fully extended: Can the telescopic pipe be operated within the allowable tilt angle (-3.5 degrees) and α-axis motion limit when extended?
- Extended to just before the opening: Can the telescopic pipe be put in a position where it can pass through the opening while extended and tilted (For the y-direction, which cannot be adjusted by the α-axis, the test was conducted while manually ensuring no tilt)

β-axis mechanism
- Full extension: Is reciprocal movement within the operating range possible?
- Extended to just before the opening: Is operation within the operating range possible? (check only movement in the + direction)



Operating range of α-axis mechanism when fully extended



When extended just before the opening

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

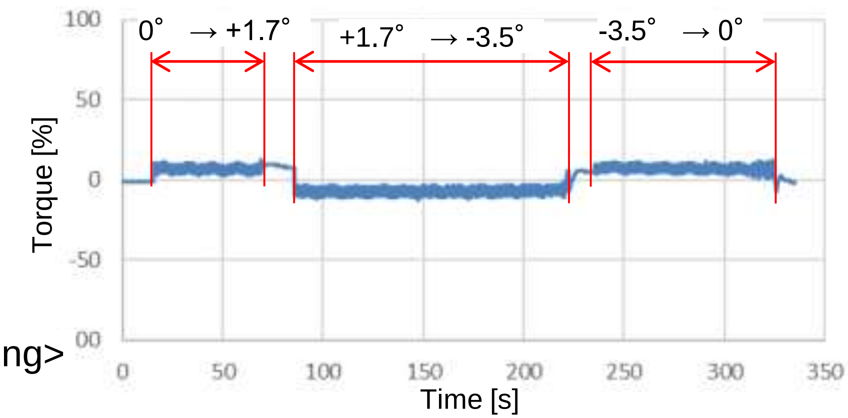
○ Test No.4: Verification of operation of the posture control mechanism when the telescopic pipe is extended

Test results (α-axis mechanism)

It was confirmed that there was no problem when the α-axis mechanism was operated while the telescopic pipe was extended, with torque remaining within 100%. It was found that the α-axis mechanism can be used to fine-tune the position for passing through the opening at the bottom of the reactor and for fine-tuning the position after full extension.

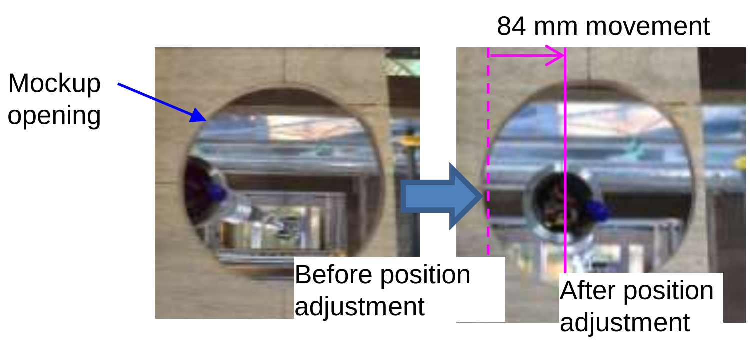
<Results of operation verification at full extension height>

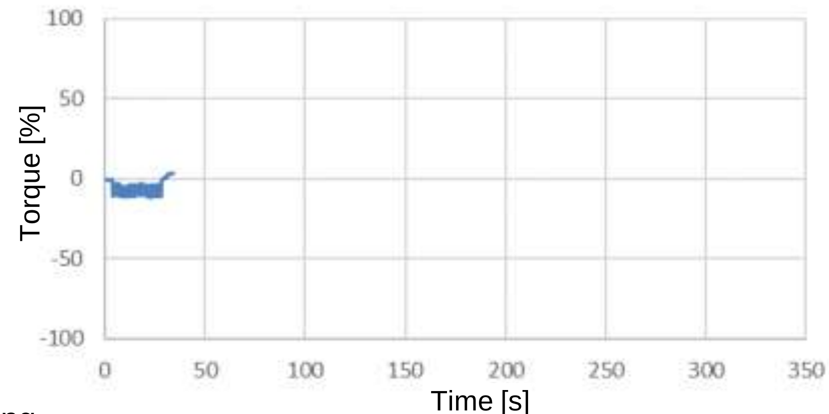
The α-axis was manipulated so that the cable winder angle changed as follows:
vertical posture (0°) → + side movement limit (+1.7°) → -3.5° → vertical posture (0°)



<Results of operation verification at height of just before the opening>

The α-axis mechanism was operated until the mockup investigation equipment was approximately at the center of the mockup opening. (Operation completion position was determined visually)





Position adjustment by α-axis mechanism at the position just before the opening

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Test No.4: Verification of operation of the posture control mechanism when the telescopic pipe is extended

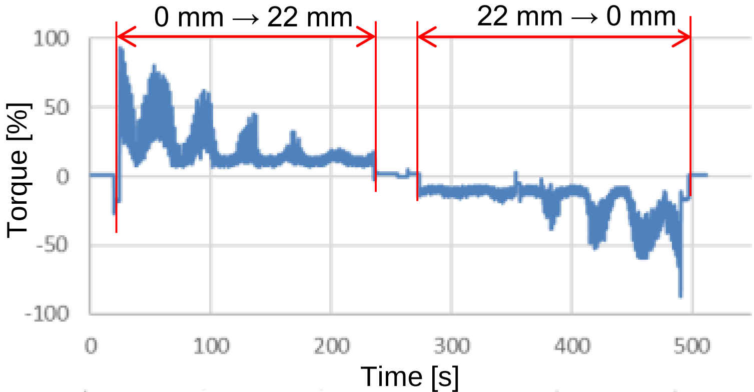
Test results (β-axis mechanism)

When the β-axis mechanism was operated with the telescopic pipe extended, the starting torque sometimes exceeded 100%, but it was confirmed that there was no problem because remained within 100% at all other times.

It was found that the β-axis mechanism can be used to fine-tune the position for passing through the opening at the bottom of the reactor and for fine-tuning the position after full extension.

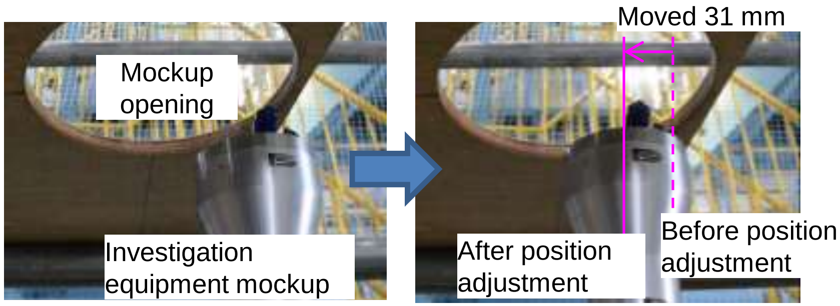
<Results of operation verification at full extension height>

The β-axis mechanism was moved from the origin (0 mm) to the operating limit of 22 mm, and then returned to the origin.

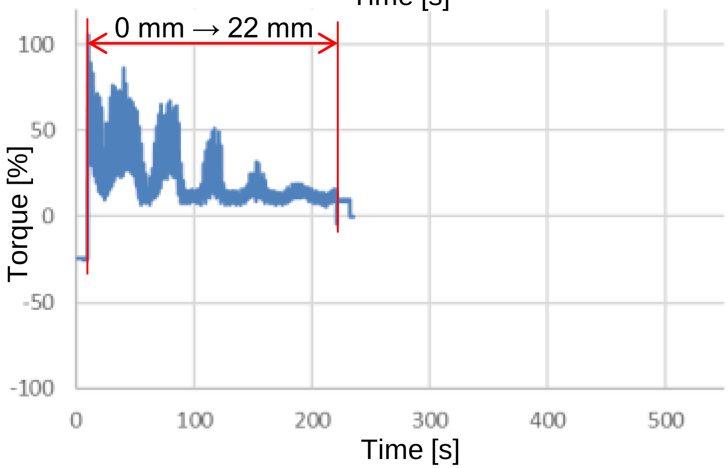


<Results of operation verification at height of just before the opening>

The mockup investigation equipment was moved manually to a position where it could pass through the mockup opening by operating the β-axis mechanism, and this was the starting position for operation. The operating range of the β-axis mechanism is 22 mm, but the tip moved about 31 mm. This is thought to be a result of looseness or other factors causing tilting at the base when the β-axis is moved.



Position adjustment by β-axis mechanism



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Test No.5: Understanding the behavior of the telescopic access equipment during swaying

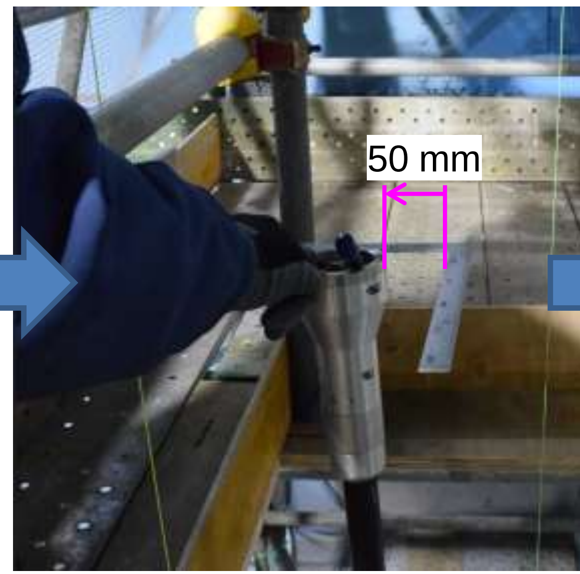
Test purpose

Determine the behavior of the telescopic pipe when it sways during extension.

Test outline

The end of the telescopic pipe was pulled a fixed distance (50 mm) and let go to allow it to sway freely, and the swaying behavior was captured and evaluated with a video camera. This was performed with the telescopic pipe extended to the 7th stage and when fully extended. Note that the pipe was made to sway by pulling in the +x and +y directions, respectively.

Tip position after extension



The pipe being pulled by hand

Hand removed

Making the telescopic pipe sway

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

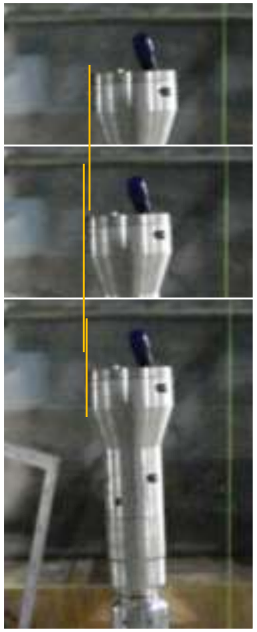
Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

〇 Test No.5: Understanding the behavior of the telescopic access equipment during swaying

Test results

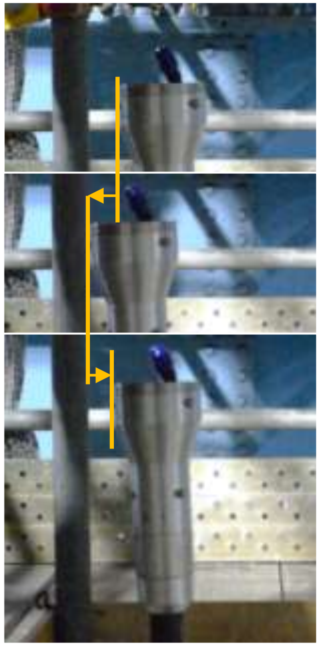
When extended to the 7th stage (extension height: approx. 3500 mm), the telescopic pipe swayed at a frequency of slightly over 1 Hz for only about 2 seconds, and when fully extended (extension height: approx. 7300 mm), it swayed at a frequency of slightly less than 1 Hz and continued to sway for about 90 seconds. Meanwhile, it was found that the swaying behavior did not change when the swaying direction changed.

<Extended to 7th stage>
The time taken to sway back and forth once was slightly less than one second.
The swaying lasted only about two seconds.



Swaying when extended to the 7th stage

<Fully extended>
The time taken to sway back and forth once was a little over one second.
The swaying lasted about 90 seconds.



Swaying when fully extended

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

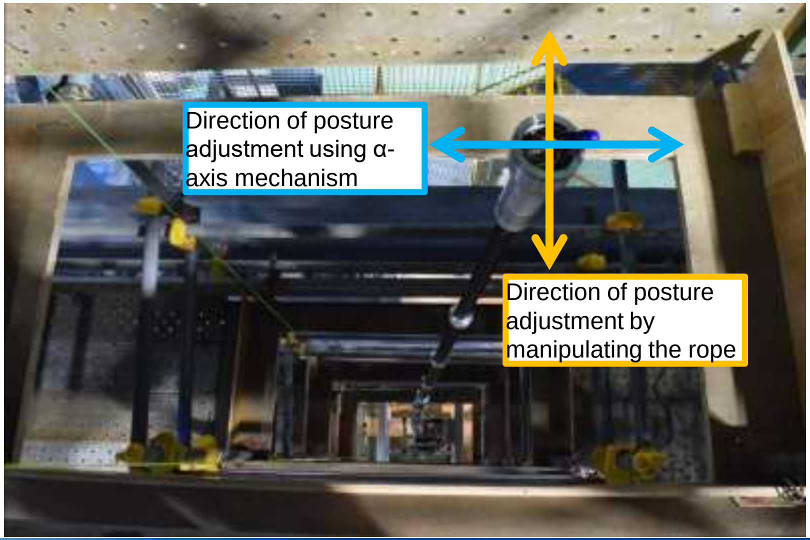
○ Test No.6: Verification of emergency retraction operation

Test purpose

As an method of emergency retraction in the event that the cable winder stops working, consideration is being given to creating a vacuum inside the telescopic pipe to retract it without winding the cable. Last year's telescopic pipe tilted during depressurization and failed to retract. This year's telescopic pipe, with narrower gaps between pipe sections, will be used to confirm whether emergency retraction is possible. It will also be verified whether adjusting the posture of the pipe using the posture control mechanism can make emergency retraction easier.

Test outline

Two patterns were evaluated: without and with posture adjustment using the posture control mechanism. For the evaluation with posture adjustment, because adjustment with the posture control mechanism is only possible in the x-direction using the α-axis mechanism, posture adjustment in the y-direction was performed by the tester manipulating a rope attached to the end of the telescopic pipe from above (y-direction posture adjustment for the actual equipment is to be performed using the tilt axis of the arm-type retrieval access equipment).



6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

〇 Test No.6: Verification of emergency retraction operation

<u>Test results</u>

In the case of no position adjustment, as in the previous year, the telescopic pipe tilted when depressurized and emergency retraction could not be performed.

For the evaluation with posture adjustment, the α-axis mechanism was able to adjust the position of the telescopic pipe, but it was found that because the adjustment was made with the pipe depressurized and thus unable to maintain its posture, near vertical position there was a risk of rapid collapse to the opposite side. Since it is assumed that in a survey using actual equipment, adjustment cannot be performed as in this test due to the presence of reactor internals around the telescopic pipe, the influence of such structures needs to be examined in the future. When emergency retraction was performed as in the previous year, the telescopic pipe did not retract completely and did not retract when pushed by hand (it protrude about 170 mm compared to when fully retracted). It is thought that the cable was pushed down and jammed in the telescopic pipe.

In the next fiscal year and beyond, studies will continue on tilt control measures to prevent the telescopic pipe from collapsing when depressurized. The impact on recovery operations of factors such as the pipe's failure to fully retract will be looked into going forward.

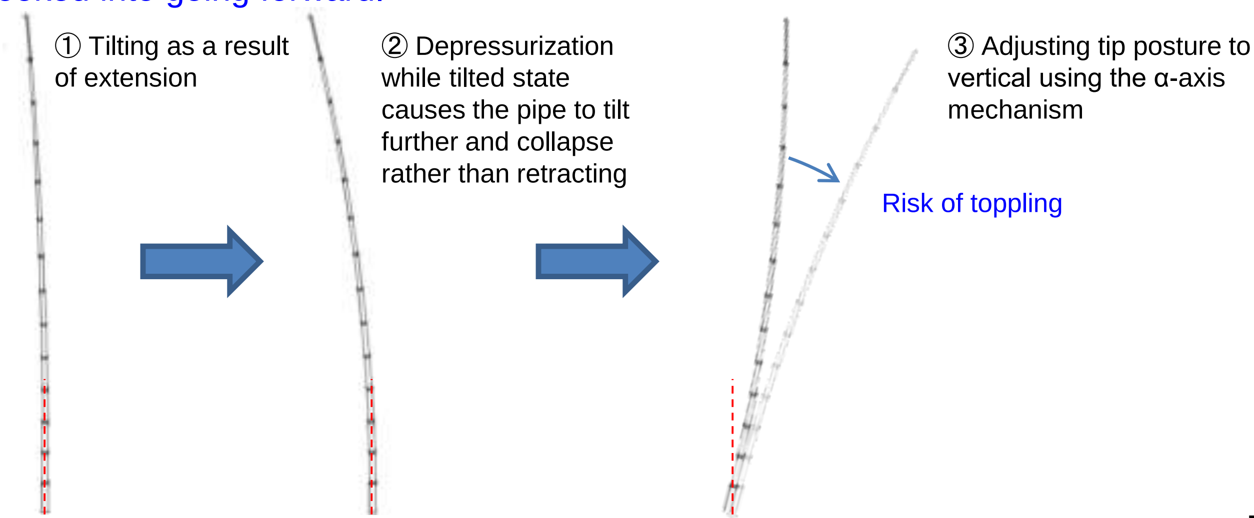


Diagram of telescopic pipe collapsing after depressurization

The pipe having failed to fully retract

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Summary of test results (1/2)

No.	Test items/outline	Verification items	Objective (evaluation criteria)	Results
0	[Verification of operation of posture control mechanism] - As a preliminary evaluation prior to the test, a check was performed to confirm that each axis of the posture control mechanism was able to operate with the telescopic pipe retracted.	Operating range of forward/backward movement mechanism	499 mm or more	Pass (Actual measurement: 499 mm)
		Operability of forward/backward movement mechanism	Ability to operate within the rated torque over the operating range	Pass (Operable within the rated torque)
		Operating range of α-axis	0° or below to 13° or above (closed state is 0°)	To be reviewed (Actual measurement: 0.4° to 13.6°. The shape of the part will be reviewed in the future because it makes contact, preventing full closure)
		Operability of α-axis	Ability to operate within the rated torque over the operating range	Pass (Operable within the rated torque)
		Operating range of β-axis	20 mm or more	Pass (Actual measurement: 22 mm)
		Operability of β-axis	Ability to operate within the rated torque over the operating range	Pass (Operable within the rated torque)
1	[Verification of extension/retraction motion of telescopic pipe in vertical position] - Check whether the telescopic pipe can be extended or retracted. (Check the effect of changing sliding parts (collars, dust seals))	Cable winder motor load	Ability to extend and retract without motor overload errors	Pass (No motor overload error)
2	[Verification of amount of tilt during telescopic pipe extension] - Check the amount of tilt during telescopic pipe extension. (Compare with the telescopic pipe test-manufactured in FY2021)	Amount of tilt at the tip of the telescopic pipe at full extension (horizontal distance from the center of the 1st stage pipe to the center of the 14th stage pipe)	Is the amount of tilt at the tip of the telescopic pipe less than or equal to the amount of tilt (128 mm) of the telescopic pipe test-manufactured in FY2021?	Fail (The amount of tilt was larger than that of the telescopic pipe test-manufactured the previous year)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

〇 Summary of test results (2/2)

No.	Test items/outline	Verification items	Objective (evaluation criteria)	Results
3	[Verification of looseness during telescopic pipe extension] - Check the amount of looseness during telescopic pipe extension. (Compare with the telescopic pipe test-manufactured in FY2021)	Amount of looseness at the tip of the telescopic pipe at full extension	Is the looseness at the end of the telescopic pipe in the direction of the anti-rotation rails less than or equal to the looseness (218 mm) of the telescopic pipe test-manufactured in FY2021?	Fail (The amount of looseness was larger than that of the telescopic pipe test-manufactured the previous year)
			Is the looseness at the end of the telescopic pipe in the opposite direction from the anti-rotation rails less than or equal to the looseness (144 mm) of the telescopic pipe test- manufactured in FY2021?	Fail (The amount of looseness was larger than that of the telescopic pipe test-manufactured the previous year)
4	[Verification of operation of the posture control mechanism when the telescopic pipe is extended] - Check if the position can be adjusted by the posture control mechanism while the telescopic pipe is extended.	Operability of α-axis when telescopic pipe is fully extended	Ability to operate within the rated torque by moving the α-axis within the range of 6.5° to 13.0° (angle when the telescopic pipe is in vertical position: 12.0°).	Pass (Operable within 100% of torque. It was confirmed that the α-axis is effective in fine-tuning the tip position when passing through the opening at the bottom of the RPV)
		Operability of β-axis when telescopic pipe is fully extended	Ability to operate within the rated torque over the operating range	Pass (Drive torque may exceed 100%, but no overload error occurs, and operation is possible within 100% torque except during startup)
5	[Verification of emergency retraction operation] - Check if emergency retraction by depressurization is possible with the telescopic pipe extended.	Can tilting during depressurization be controlled, allowing emergency retraction without posture adjustment?	Can be fully retracted using only depressurization, without human assistance or adjustment using the posture adjustment mechanism	Fail (When depressurized, the pipe collapsed without retracting, the same result as last year)
		Ability to retract the telescopic pipe through depressurization	Can be fully retracted in the range of -92 kPa to 0 Pa	To be reviewed (Depressurization to -85 kPa resulted in retraction of every pipe stage, but the retraction was incomplete. The impact of the inability to fully retract will be discussed in the future.)
		For the x-direction, ability to adjust the posture vertically using only the α-axis, without human assistance	Presence of human assistance	To be reviewed (Although the tip can be adjusted vertically using the α-axis, there is a risk that because the telescopic pipe is adjusted without being able to maintain its posture, near vertical position there is a risk of collapse to the opposite side)
6	[Evaluation of telescopic pipe behavior when the arm-type retrieval access equipment sways] - The tip of the telescopic pipe is swayed to evaluate its behavior. This is performed with the telescopic pipe extended to the 7th stage and when fully extended.	Behavior of telescopic pipe after being swayed while extended	Understanding sway behavior	— (The "—" was given because the purpose of this test is to understand the behavior, not to evaluate whether it is good or bad.)

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

○ Summary

- The operation of the newly test-manufactured posture control mechanism was checked and it was confirmed that there were no problems with its operation. The issue emerged that the operating range was narrower than the design value in some areas.

- It was confirmed that the α- and β-axis mechanisms of the posture control mechanism can fine-tune the tip position when the telescopic pipe is extended. Since it can be used to correct tip tilt and fine-tune the tip position when passing through the opening at the bottom of the reactor, this will be reflected in future operational studies.

- In order to suppress tilting during telescopic pipe extension, the gap between the pipe sliding parts was reduced, the dust seals were changed to harder ones, and tests were conducted to ascertain any improvements. The results confirmed that there was no problem in extension/retraction motion of the telescopic pipe. No improvements to tilting were achieved, with more tilt observed than last year.

- With respect to emergency retraction, the telescopic pipe was tilted and failed to retract when the inside was depressurized, as was the case the previous year.

- Hardware measures to reduce tilting and prevent tilting during emergency retraction might include making some of the telescopic pipes from aluminum or reviewing their design. In terms of operational measures, retraction could be performed by adjusting position using the posture control mechanism or by making use of the surrounding structures. We will consider countermeasures in the next fiscal year and beyond.

6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

5) Investigation details

Operation evaluation of telescopic access equipment (verification of ⑦ to ⑪)

Equipment put into horizontal position using the tilt axis

Tip tilt

Telescopic pipe tilted during extension

Tip is adjusted to a vertical position using the α-axis and the pipe is swayed

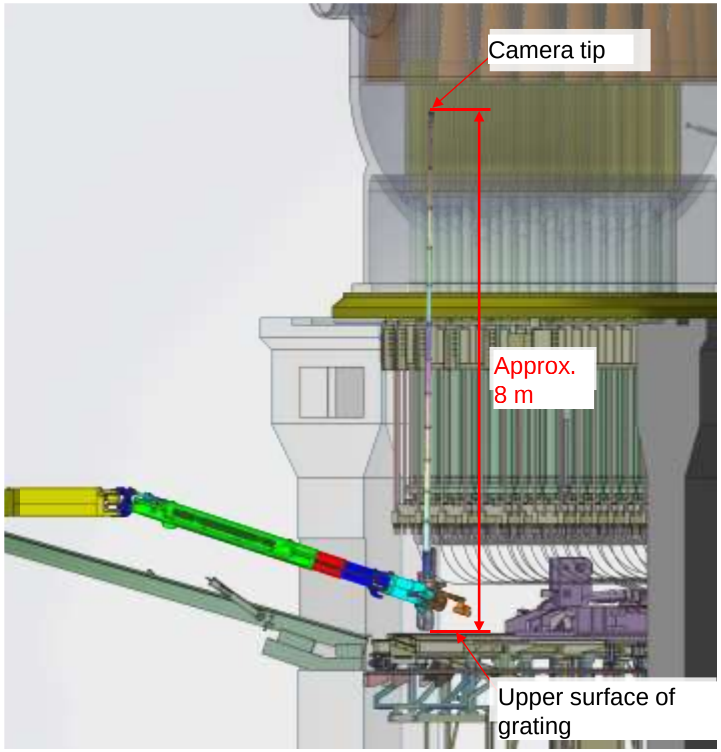
6. Implementation details

(2) Development of the bottom access investigation method (telescopic pipe)

6) Summary of results

① Results obtained in FY2022

- Based on the results through FY2021, the development plan was reviewed and issues were identified.
- Elemental tests were conducted to confirm the effectiveness of the proposed countermeasures against the identified issues, and the countermeasures were selected.
- Telescopic access equipment reflecting the proposed countermeasures was test-manufactured and tested to confirm its functionality.
- The results confirmed the basic operability of the telescopic access equipment and its feasibility as a piece of equipment.
  It was also confirmed that emergency retraction measures, etc., will continue to be an issue.
- Operation using the equipment camera was discussed, and it was confirmed that a method for measuring the dimensions of the RPV opening and a method for detecting posture are needed.



Picture of access using telescopic pipe

② Issues for the future (FY2023 and beyond)

- The FY2022 results will be taken into account when reviewing the development plan and re-identifying issues. Anticipated issues are given below.
  ① Study of countermeasures for emergency retraction
  ② Improvements to the posture control mechanism
  ③ Study of a method for determining the dimensions of the RPV opening
  ④ Study of a posture detection method for equipment
  ⑤ Consideration of interfacing with the arm-type access equipment currently under development in other projects