IRID

Subsidy Project of Decommissioning and Contaminated Water Management

Development of Technology for Investigation inside Reactor Pressure Vessel (RPV)

Interim Report for FY2020

August 2021

International Research Institute for Nuclear Decommissioning (IRID)

Contents

1. Research Background and Purpose

[Purpose of the investigation inside the Reactor Pressure Vessel (RPV)]

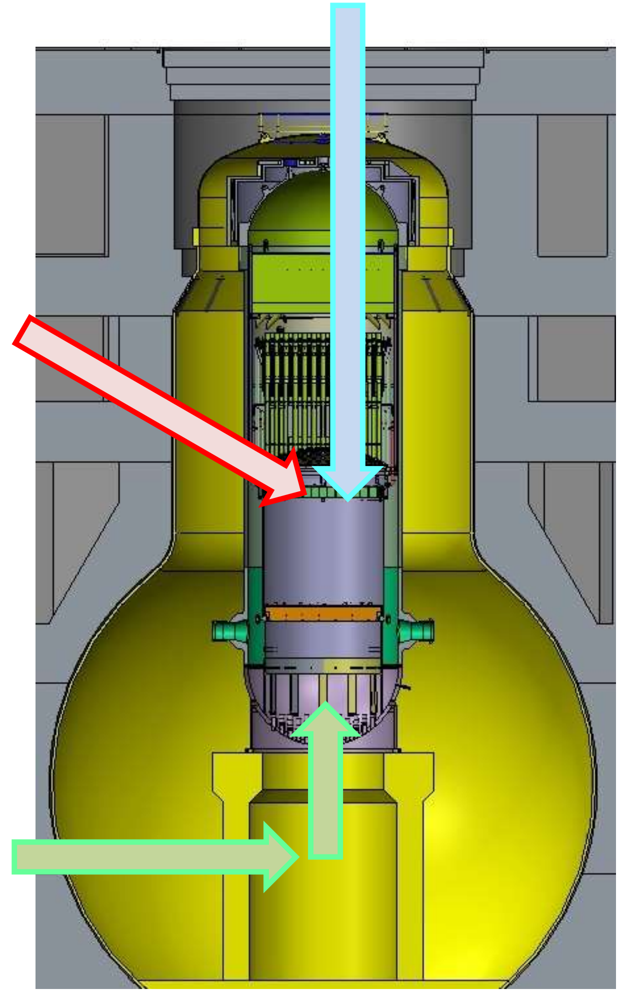
To obtain basic information regarding the inside of the RPV (fuel debris distribution, dose, condition of structures, etc.) for fuel debris retrieval.

[Implementation details until FY2019]

The method of accessing the reactor core from the top by opening a hole (hereinafter “top access investigation method”) and the method of accessing the reactor core from the side (hereinafter “side access investigation method”) were studied. In the previous project “Development of Technology for Investigation inside RPV” (FY2018-19), functional verification of both the methods was carried out through elemental tests of the equipment directed towards actual application, the concept of the method of investigation was examined and the equipment specifications were developed.

Top access investigation method

Side access investigation method



Bottom access investigation method

[Reflections of this project]

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

Information regarding the inside of RPV (Visual information, dose rate, etc.)

1. Research Background and Purpose

[Implementation details in this project]

A cutting method using abrasive water jet (AWJ) was developed, as a top access investigation method wherein an opening is created in the reactor internal structures (steam dryer, steam separator, shroud head, etc.) for establishing the access route to the inside of the shroud, while giving priority to reliably cutting the reactor internal structures regardless of their highly uncertain status. However, developing a method for further reducing the secondary waste (abrasive, etc.) resulting from the access route establishment, and a method for controlling the dispersion of radioactive dust during work, has become a challenge. Moreover, with the change in the method of removing spent fuel from Unit 2, engineering work to check how the side access investigation method is actually applicable on site has become a challenge.

Hence, in order to enhance the actual applicability of the top access investigation method, machining technology wherein the secondary waste (abrasive, etc.) generated or the radioactive dust dispersion resulting from cutting, etc. performed inside the RPV is less than that resulting from the conventional abrasive water jet (AWJ), will be developed in this project as a method for creating openings in the reactor internal structures (steam dryer, steam separator, shroud head, etc.) in order to establish the access route to the inside of the shroud.

⇒(1) Advancement of machining technology for the top access investigation method

Moreover, since it is anticipated that it would take a certain amount of time until the top access investigation method and the side access investigation method are applied on site, it is important to develop a method that could be used for investigating inside RPV early on, and hence the work of establishing the access route to the inside of PCV is being carried out for the detailed investigation inside PCV.

Therefore, a conceptual study will be conducted in this project, on the bottom access and investigation equipment for investigating inside RPV by inserting the investigation equipment into the RPV from the opening assumed to be present at the RPV bottom by introducing the investigation equipment inside the pedestal using the access route to the inside of the pedestal that has already been established for detailed investigation inside PCV or for increasing the scale of retrieval in stages.

⇒(2) Development of the bottom access investigation method

2. Project Goals

Aiming for the TRL of the hole drilling investigation method developed until FY2019

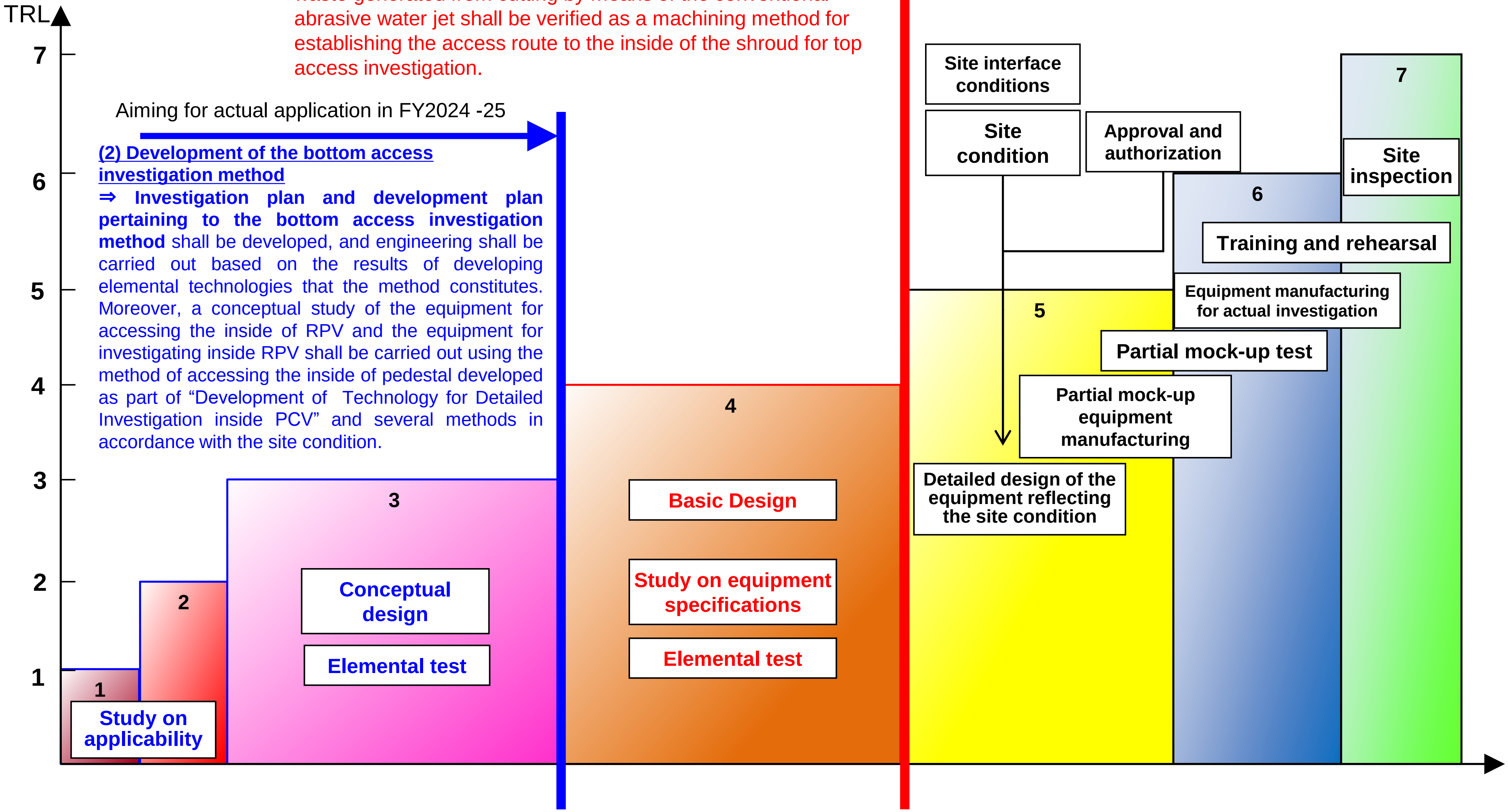
(1) Advancement of machining technology for the top access investigation method

⇒ Feasibility of machining technology involving less secondary waste generated from cutting by means of the conventional abrasive water jet shall be verified as a machining method for establishing the access route to the inside of the shroud for top access investigation.

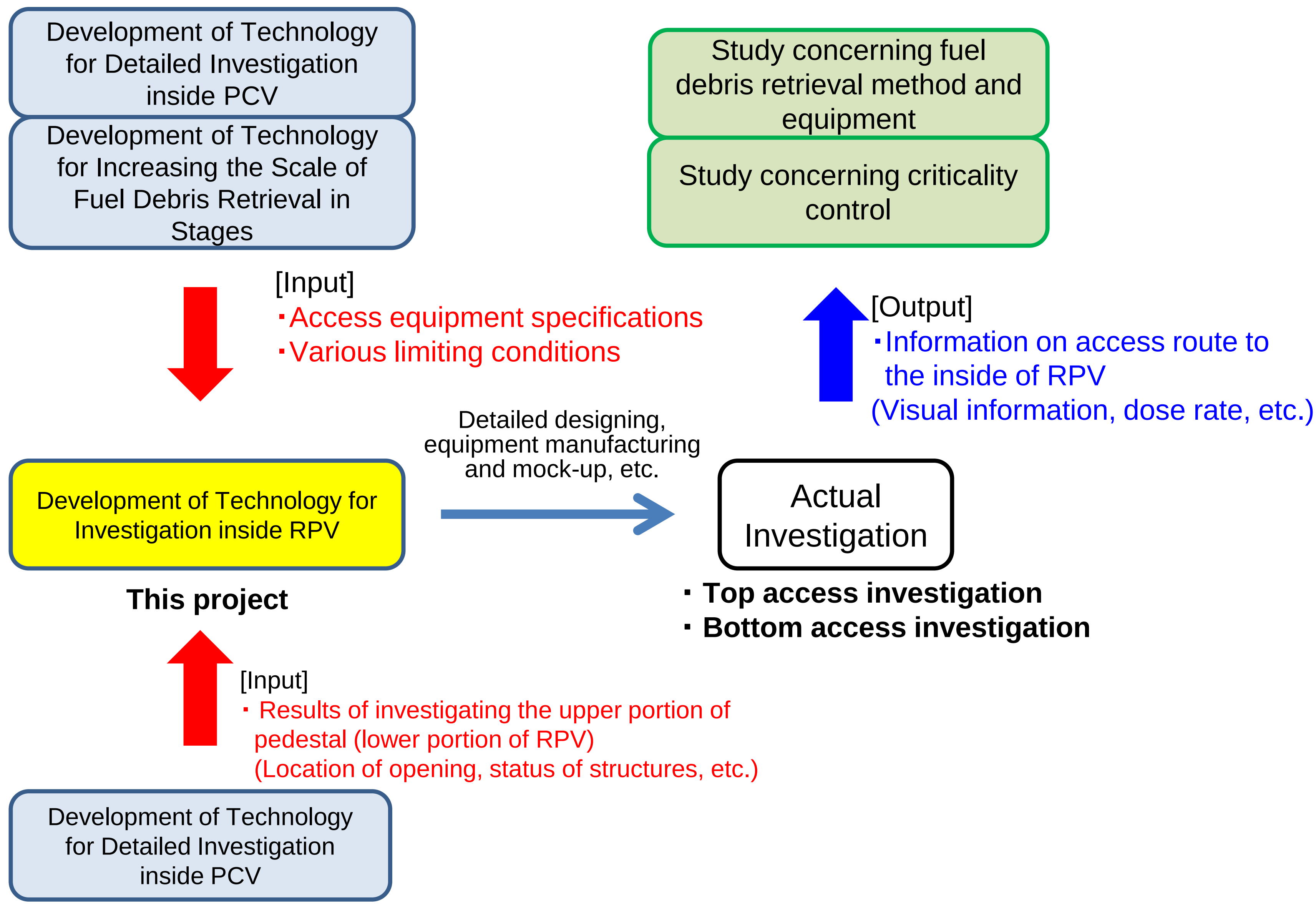
Aiming for actual application in FY2024 -25

(2) Development of the bottom access investigation method

⇒ **Investigation plan and development plan pertaining to the bottom access investigation method** shall be developed, and engineering shall be carried out based on the results of developing elemental technologies that the method constitutes. Moreover, a conceptual study of the equipment for accessing the inside of RPV and the equipment for investigating inside RPV shall be carried out using the method of accessing the inside of pedestal developed as part of “Development of Technology for Detailed Investigation inside PCV” and several methods in accordance with the site condition.



3. Implementation Items, their Correlations, and Relations with Other Research **No. 5**



4. Schedule

Implementation items	FY2020	FY2021
(1) Advancement of machining technology for the top access investigation method ① Investigation and evaluation of alternative machining technologies	Investigation items / parameter organization Simple test Comparative evaluation	**Selection of potential alternative machining technologies**
② Development planning for alternative machining technologies	Study of development plan	**Development of outline specifications of the alternative machining technologies**
③ Elemental test and feasibility verification of alternative machining technologies		Basic Design Elemental test Evaluation
(2) Development of the bottom access investigation method ① Planning of the bottom access / investigation and the development for the access / investigation equipment	Drafting of the investigation plan **Result of studying the potential technologies** Feasibility study (test) Feasibility evaluation	**Panning of investigation and development**
② Conceptual study of the bottom access / investigation equipment		Conceptual design **Method development** Elemental test Evaluation

5. Project Organizational Chart

The technology for investigation inside RPV has been developed under this project, but for that the interface between each development team becomes important. Hence, by getting involved in development through mutual technological cooperation, domestic plant equipment manufacturers who are organization members of IRID have undertaken a series of tasks including analyzing site conditions, conforming with the fuel debris retrieval plan, etc. to develop technology for safe, proper, reasonable, speedy and site oriented fuel debris retrieval at the Fukushima Nuclear Power Station (1F) and thus IRID Headquarters, Toshiba ESS and Hitachi GE are jointly carrying out development.

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

- Development of overall plan and technology management
- Technology management such as progress of technology development

Tokyo Electric Power Company Holdings, Inc.

- Various coordination for the site applicability

Toshiba Energy Systems & Solutions Corporation

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

Hitachi-GE Nuclear Energy, Ltd.

(1) Advancement of machining technology for the top access investigation method
 ① Investigation and evaluation of alternative machining technologies
 ② Development planning for alternative machining technologies
 ③ Elemental test and feasibility verification of alternative machining technologies

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

Project teams to cooperate for technological development

- Development of Technology for Increasing the Scale of Fuel Debris Retrieval in Stages
- Development of Technology for Detailed Investigation inside PCV

Sugino Machine Limited

・(1) Structural design concerning the advancement of machining technology for the top access investigation method

Hitachi Plant Construction, Ltd.

・(1) Investigation of technology concerning the advancement of machining technology for the top access investigation method

IRID

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

<Purpose>

To develop machining technology wherein the secondary waste (abrasive, etc.) generated or the radioactive dust dispersion is less than that resulting from the conventional abrasive water jet (AWJ) cutting technology, as a method for creating openings in the reactor internal structures (steam dryer, steam separator, shroud head, etc.) to establish the access route to the inside of the shroud.

<Implementation details>

・The following items were implemented this year targeting the steam separator.

① Investigation / evaluation and selection of machining technologies as an alternative to the conventional AWJ technology (implemented for equipment besides the steam separator as well)
② Optimization of the machining parameters with respect to AWJ cutting (reducing the volume of abrasive), and study on AWJ nozzle
③ Study on equipment and tools required when the selected machining technologies are applied
④ Implementation of simple tests and evaluation of the selected machining technologies, and narrowing down the machining technologies
⑤ Study on the implementation policy for FY2021

<Results>

① Alternative machining technologies were investigated and evaluated, and machining technology in which hole saw cutting, circular saw cutting and laser cutting are added to the AWJ cutting technology was selected.

② Equipment required for the above-mentioned 4 methods were studied and it was found that equipment that can be inserted through narrow spaces would be feasible.
③ A study was conducted on downsizing the nozzle used in AWJ cutting, the machining parameters were optimized and as a result of conducting simple tests, it was found that it would be possible to substantially reduce the volume of abrasive compared to what was used in the past (8 ton → 0.33 ton).

④ With regards to other machining technologies besides AWJ, laser cutting could be applicable for cutting in the vertical direction.

<Remaining issues>

① The applicability of the results of simple tests conducted this year to equipment other than the steam separator, and further reduction in the volume of abrasive.
② Using laser for horizontal cutting

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

① Investigation and evaluation of alternative machining technologies

The machining technologies were evaluated for each target (steam dryer bottom plate, steam separator, shroud head) as per the following table.
The technologies were narrowed down and **the AWJ (including WJ) with hole saw, circular saw and laser** was selected for the steam separator.

No.	Processing target	Processing technology classification	Cutting / grinding										Melting							
			A	B	C	D	E	F	G	H	I	J	K	K'	L	M	N	O	P	Q
		Evaluation item \ Processing technology	AWJ cutting (including WJ cutting)	Drill cutting	Cutting by hole saw / core boring / ultrasonic core drill / trepanning	Cutting by circular saw / circular cutter / circular grinder	Cutting by wire saw	Cutting by band saw	Cutting by saber saw (reciprocating saw)	Cutting by hydraulic cutter	Cutting by chisel	Cutting by milling cutter / end mill	Laser cutti	Laser gougi	Plasma arc cutting	Arc saw cutting	Contact type arc discharge	Consumable WJ cutting	Gas cutting	Electrical Discharge Machining (EDM)
1	Steam separator	Material to be cut	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	x	○
2		Thickness of plate to be cut	○	○	○	○	○	○	○	○	□	○	○	□	○	□	□	□	-	□
3		Surface to be cut (cylindrical)	○	x	△	○	○	○	○	○	△	x	□	□	□	□	□	□	-	□
4		Two fold pipe cutting (batch cutting / multi-stage cutting)	○	x	○	○	○	○	○	○	□	x	□	□	□	□	□	□	-	□
5		Cutting speed	○	○	○	○	○	○	○	○	○	○	○	□	△	□	□	□	-	□
6		Re-processing risk	○	○	○	○	○	○	○	○	△	○	△	△	△	□	□	□	-	□
7		Positioning standoff	○	○	○	○	○	○	○	○	○	○	△	□	x	x	x	x	-	□
8		Angle of the tool with the surface being processed	○	△	△	△	△	△	△	△	△	△	□	□	□	□	□	□	-	□
9		Work before processing	○	○	○	○	○	○	○	○	○	○	□	□	□	□	□	□	-	□
10		Discharge into the reactor core	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	-	△
11		Dust dispersion	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	-	□
12		Processing reaction force	△	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	-	□
13		Tool size (incidental equipment)		□	□	□	x	x	x	x	x	□	□	□	□	□	□	□	-	□
14		Device service life (maintainability)	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	-	□
15		Environmental conditions inside the reactor	○	△	△	△	△	△	△		△	△	□	□	□	□	□	□	-	x
Comprehensive evaluation (Applicability to the steam separator opening)			○	x	□	□	x	x	x	x	x	x	□	- *1	x	x	x	x	-	x
[Remarks]			[Legend]○: Expected to be applicable △: Measures required □: Cannot be evaluated (trial manufacturing and taste test are required for evaluation) X: Application expected to be difficult -: Application not possible (not evaluated) *1: Since laser gouging is a chipping technology, it was not evaluated. (Laser cutting is a cutting technology that follows the same principle.)																	

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

② Selection of machining technology (multiple options may be selected)

Machining technology was selected as per the study flow indicated in the table below.

Machining technology	AWJ cutting	Hole saw and circular saw cutting (Cutting and grinding technology)	Laser cutting (Melting cutting technology)
Current identified issues	• Lot of discharge into the reactor • Life of equipment is unknown (Need for maintenance unknown) • Propriety of AWJ jet spray in the horizontal direction is unknown	• Processing reaction force and its impact are unknown • Propriety of downsizing the equipment is unknown • Life of the equipment is unknown	• Compatibility with the steam separator with a changed stand-off tool angle is unknown • Processing reaction force and its impact are unknown • Propriety of downsizing the equipment is unknown • Life of the equipment is unknown

Study flow

First half of FY2020

- ②-1 (AWJ cutting)
  - Optimization of machining parameters (*)
  - Study on abrasive collection method

  (*) Volume of abrasive supplied, cutting speed, cutting procedures, etc.
- ②-2 (AWJ cutting): Study on a tool with a cross section of φ70mm or less and which enables AWJ jet spray in the horizontal direction
- ②-3 (Hole saw and circular saw cutting; Laser cutting): Study on equipment and tools required when each machining technology is applied → Primary screening from the perspective of feasibility prospects of the equipment and systems
- ②-4: Evaluation of the propriety and the strong points/weak points of each machining technology that is expected to be feasible in each cutting direction (vertical / horizontal) and study on the propriety of applying a stand-alone cutting technology or a combination of technologies
- ②-5: Analytical evaluation of the impact on other systems and review of the options
- ②-6: Planning for simple tests with revised parameters and abrasive collection method
- ②-7: Planning for simple tests on the feasibility of the studied machining technologies (Assumed test items: Verification of the impact of the machining reaction force, verification of the life of the equipment, verification of applicability to steam separator machining, dust dispersion verification test, etc.)

Second half of FY 2020

- ②-8: Manufacturing of prototype and test piece for the simple tests, implementation and evaluation of the simple tests (secondary screening)
- ②-9: Selection of machining technology and combinations that will continue to be verified in FY2021, and designing of the prototype

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

(*1) Legend for the “Level of priority of the studies”

Item / evaluation		Effect		
		Major	Medium	Minor
Feasibility	High	High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Low

② Study on optimization of machining parameters / abrasive collection method with respect to AWJ cutting

Factor analysis was conducted for reducing the volume of abrasive discharge, abrasive reduction effect resulting from improving the parameters and the feasibility were studied, and the future response policy was set.

No.	Study items: Major	Study items: Medium	Study items: Minor	Primary evaluation	Effect	Feasibility	Priority of the studies (*1)	Future implementation details
1	Reducing the abrasive discharge volume Discharge volume = Volume of abrasive used per unit of time x jet spray duration (for stage 1) x No. of cutting stages	Not using abrasive (Cutting by means of WJ)	—	Cutting by means of WJ is possible. Cutting performance needs to be verified.	Major	Low	Medium	Simple test
2		Reducing the volume of abrasive used per unit of time	—	Evaluation needs to be conducted by performing cutting tests with the volume of abrasive used per unit of time and the cutting speed as the parameters.	Medium	High	High	Simple test
3				If an abrasive material (carbide, ceramic, etc.) that has a high cutting performance is used, the nozzle gets worn out faster.	Minor	Medium	Low	—
4				Equipment specifications (nozzle size, nozzle length, etc.) for achieving high cutting performance need to be studied and evaluated.	Medium	Low	Low	Desk study
5		Reducing the duration of jet spray Jet spray duration = Length to be cut / cutting speed	Increasing the cutting speed	Since there are prospects that the tool can be downsized (refer to slide 12, 13), it is likely that the cutting speed can be increased by shortening the stand-off and improving cutting performance.	Major	High	High	Desk study Simple test
6			Shortening the length to be cut (Revision of cutting procedures)	Since there are prospects that the tool can be downsized (refer to slide 12, 13), it is likely that the length to be cut can be shortened by revising the cutting procedures.	Major	High	High	Desk study Simple test
7		Reducing the no. of cutting stages No. of cutting stages＝Height of steam separator opening / Cutting depth	Increasing the cutting depth (Revision of cutting procedures)	Since there are prospects that the tool can be downsized (refer to slide 12, 13), it is likely that the cutting depth can be increased by revising the cutting procedures.	Major	High	High	Desk study Simple test
8			Reducing the height of steam separator opening	Cannot be changed.	—	None	—	—
9	Abrasive collection	Collecting while cutting	—	Even through abrasive can be collected using a catcher, etc. after cutting through the cutting target, the range of applicability is small and abrasive reduction effect is limited.	Minor	Low	Low	Desk study
10		Collecting after cutting	—	The volume of abrasive accumulated on top of the shroud head is small due to the high pressure water sprayed during cutting and the abrasive reduction effect is limited.	Minor	Low	Low	Desk study

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-2. Study of the AWJ/WJ nozzle (1/2)

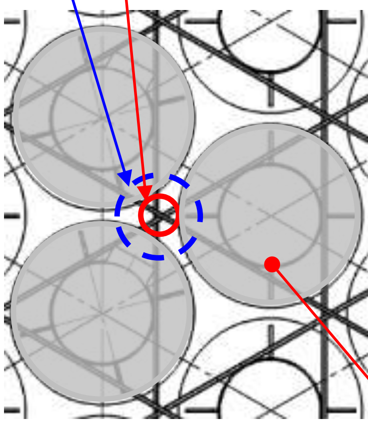
Downsizing of the AWJ/WJ nozzle was studied with the steam separators as the cutting target, which accounted for most of the volume of abrasive used in the FY2019 plan.

The dimensional conditions are as follows:

<Conceptual image of steam separator opening>

Size of opening：φ 160 mm or more

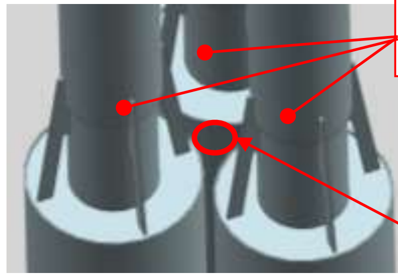
Gap in the outer casings of the steam separators (φ 70 mm)



Steam separator top surface opening location map

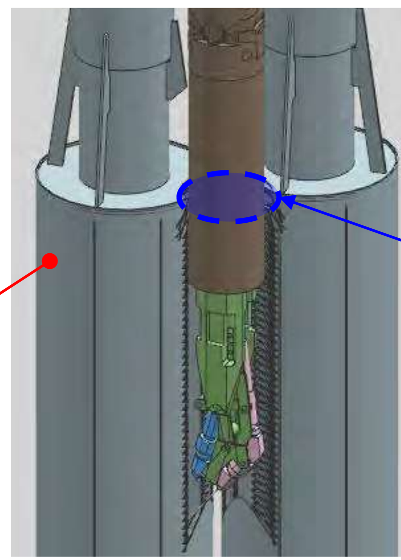
Steam Separator (SUS304, Board thickness: 3 mm, Outer diameter: 324 mm)

Steam Separator



Gap in the outer casings of the steam separators (φ 70 mm)

Conceptual image of the top portion of the steam separator (Before creating the opening)



Opening size: φ 160 mm or more

Conceptual image of cutting the steam separator (Tool used is the AWJ nozzle studied last year)

<Conditions of nozzle downsizing>

[Dimensional condition ①]
The cross-sectional configuration of the distal end of the tool that gets inserted into the gap in the outer casings of the steam separators shall be φ 70 mm or less.

[Dimensional condition ②]
The main body of the tool that does not get inserted into the gap in the outer casings of the steam separators shall be φ 140 mm or less so that it does not interfere with the opening.
(For the opening size of φ 160 mm a gap of 10 mm on one side shall be set)

6. Implementation Details

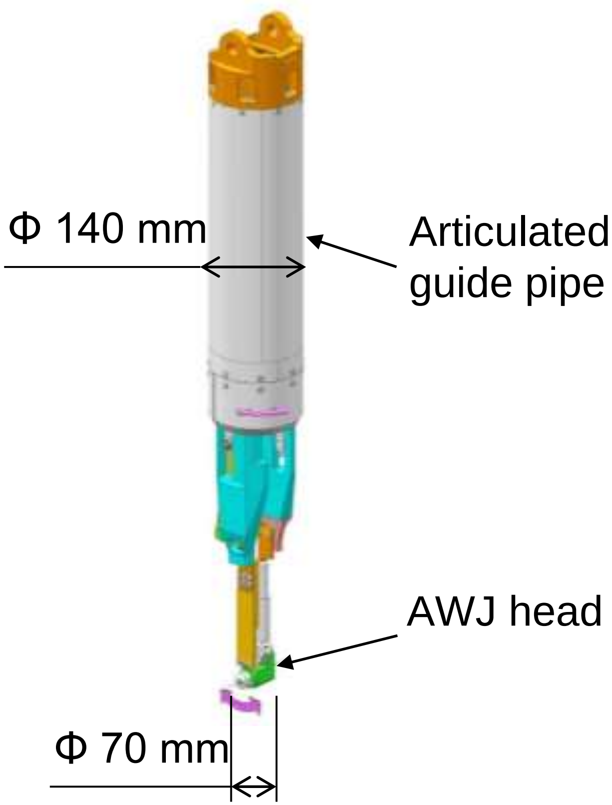
(1) Advancement of machining technology for the top access investigation method

②-2. Study of the AWJ/WJ nozzle (2/2)

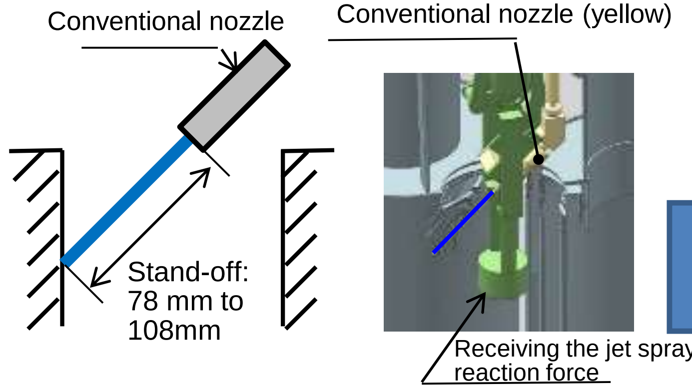
AWJ/WJ head were studied, and it was found that AWJ/WJ jet spray would be possible at φ 70 mm or less and in the horizontal direction.

⇒ It is expected that the volume of abrasive used can be reduced from the following perspectives, by using a small nozzle that can be inserted into the narrow space in the middle of the 3 casings of the steam separators.

- Shortening the length to be cut by revising the cutting procedures. ⇒ Shortening the cutting duration (reduction in volume of abrasive used)
- Enhancing the cutting efficiency by closing in on the stand-off. ⇒ Increasing the cutting speed and shortening the cutting duration (reduction in volume of abrasive used)

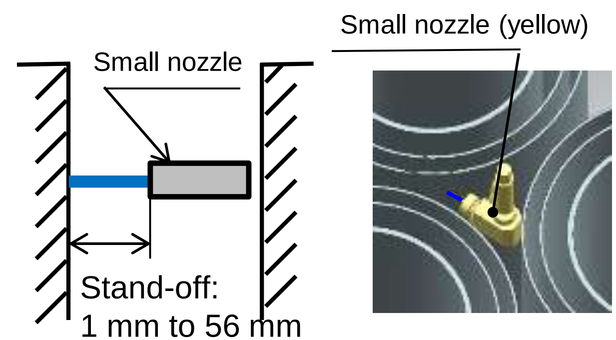


<Execution conditions until FY2019>



[Only the main body of steam separator]
- Length to be cut: Approx. 75m
- Cutting duration: Approx. 203 hours
- Volume of abrasive used: Approx. 8 ton

<Execution conditions with a small nozzle>



[Only the main body of steam separator]
- Length to be cut: Approx. 31m(*1)
- Cutting duration: Approx. 11 hours
- Volume of abrasive used: Approx. 0.33 ton

(Refer to Slide No. 29)

(*1) Result of preliminary calculations assuming that depth of 50 mm is cut at a time.

6. Implementation Details

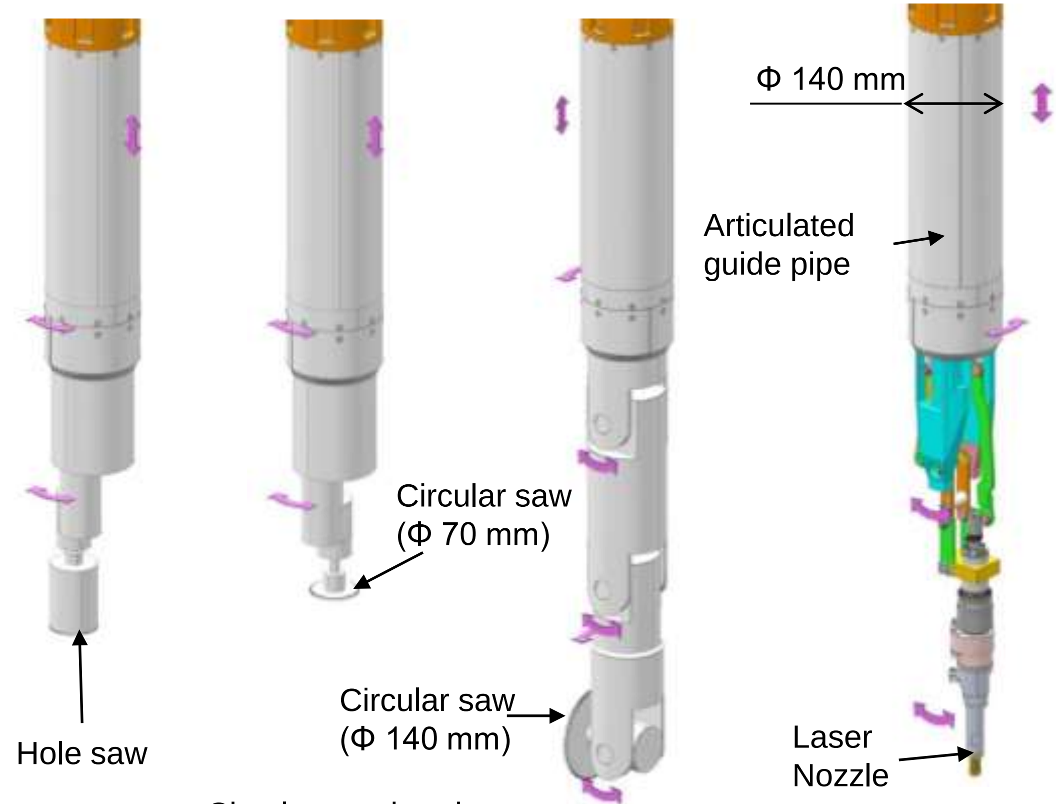
(1) Advancement of machining technology for the top access investigation method

②-3. Study on equipment and tools required when each machining technology is applied

Of the various machining technologies, tool heads for hole saw cutting, circular saw cutting and laser cutting were studied from the perspective of whether or not the cutting tool head fits in the cutting equipment (outer diameter φ 140 mm or less) developed until FY2019.

Simple tests or desk study were conducted for each technology as there were prospects that the outer diameter of each cutting tool head would be φ 140 mm or less.

No.	Cutting technology	Whether or not tool head expected to be Φ 140 mm or less
1	Hole saw cutting	Expected
2	Circular saw cutting	Expected
3	Laser cutting	Expected



Hole saw head
Circular saw head (For horizontal cutting)
Circular saw head (For vertical cutting)
Laser head

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-4. Study on propriety of cutting with a stand-alone technology and on combining cutting technologies (1/5)

The propriety and the strong points/weak points of each machining technology that is expected to be feasible in each cutting direction (vertical / horizontal) was evaluated and the propriety of applying a stand-alone cutting technology or a combination of technologies was studied.

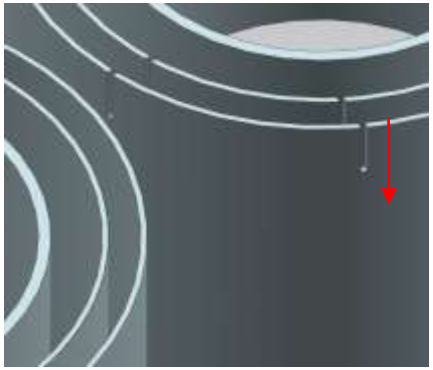
(1) Technology expected to be feasible as a stand-alone technology ⇒ AWJ/WJ and circular saw (*1)
(2) Technologies expected to be feasible in combination ⇒ AWJ/WJ, circular saw, laser, hole saw

(*1) As a result of conceptual study of the tool, it was determined that it would be difficult to apply laser for cutting in the horizontal direction.
It was determined that it would be difficult to apply hole saw for cutting in the horizontal direction due to its technical features.

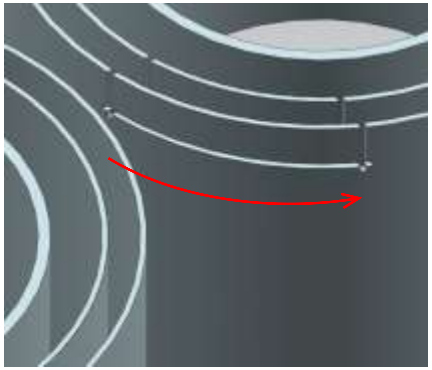
[Combination of machining technologies]

No.		1	2	3	4	5	6	7	8
Combination of technologies	Vertical direction	AWJ/WJ	Laser	Circular saw	Hole saw	AWJ/WJ	Laser	Circular saw	Hole saw
	Horizontal direction	AWJ/WJ	AWJ/WJ	AWJ/WJ	AWJ/WJ	Circular saw	Circular saw	Circular saw	Circular saw

[Conceptual image of cutting the steam separator (middle section)]



Cutting in the vertical direction



Cutting in the horizontal direction

Removing the cut piece

Stage 1 cutting completed

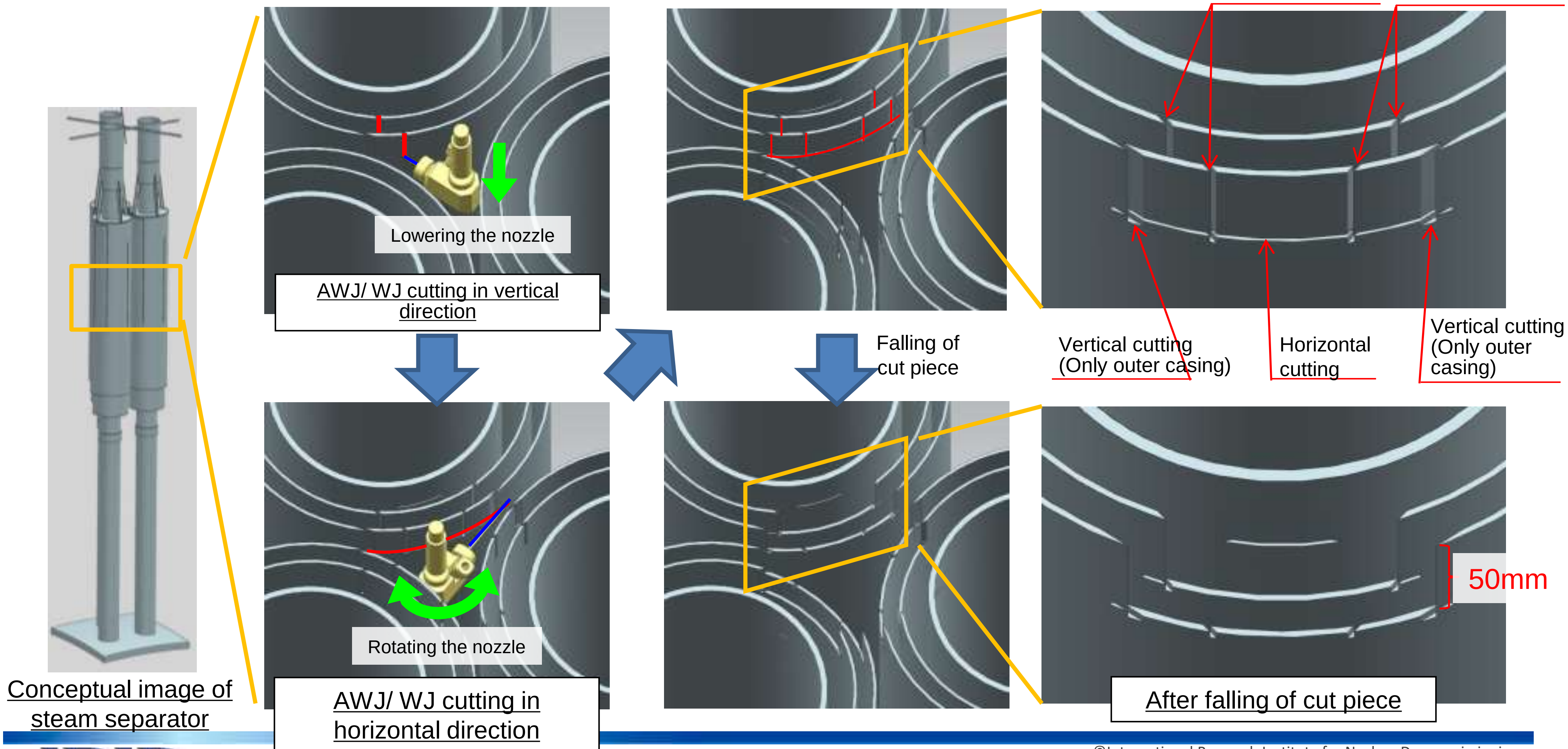
6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-4. Study on propriety of cutting with a stand-alone technology and on combining cutting technologies (2/5)

Cutting procedure for the steam separators, which accounted for most of the volume of abrasive used in the FY2019 plan, was studied.

[AWJ/WJ] An example of Combination No. 1 of machining technologies is shown in the figure below (refer to Slide 15 for the Combination No.)

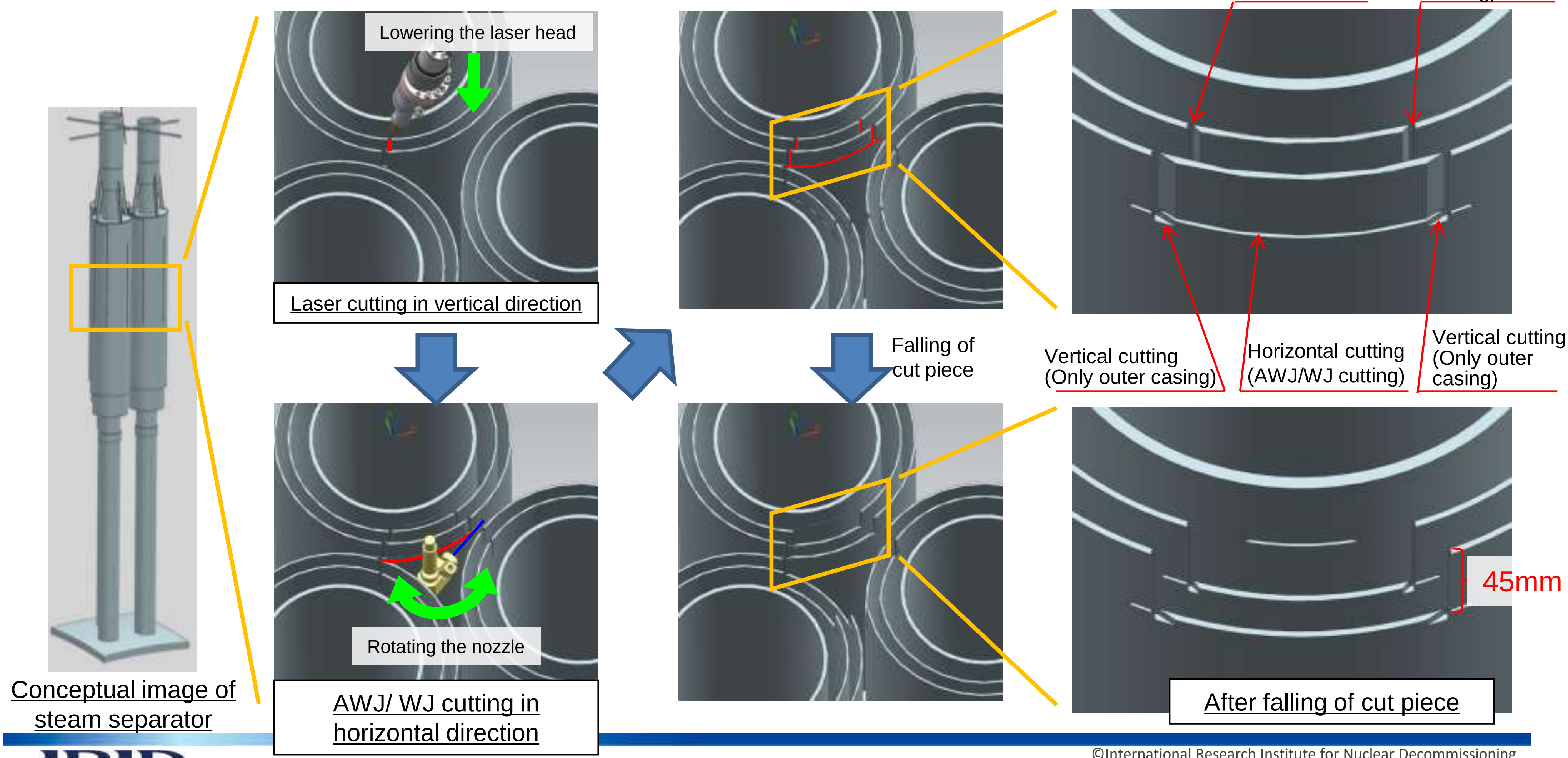


(1) Advancement of machining technology for the top access investigation method

②-4. Study on propriety of cutting with a stand-alone technology and on combining cutting technologies (3/5)

Cutting procedure for the steam separators, which accounted for most of the volume of abrasive used in the FY2019 plan, was studied.

[Laser] An example of Combination No. 2 of machining technologies is shown in the figure below (refer to Slide 15 for the Combination No.)



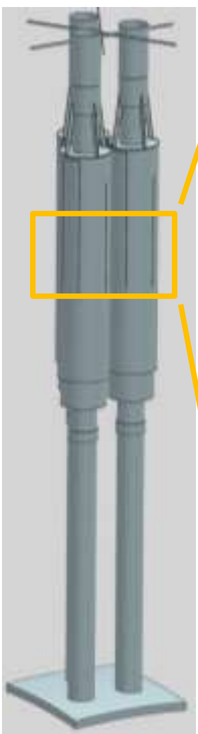
6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

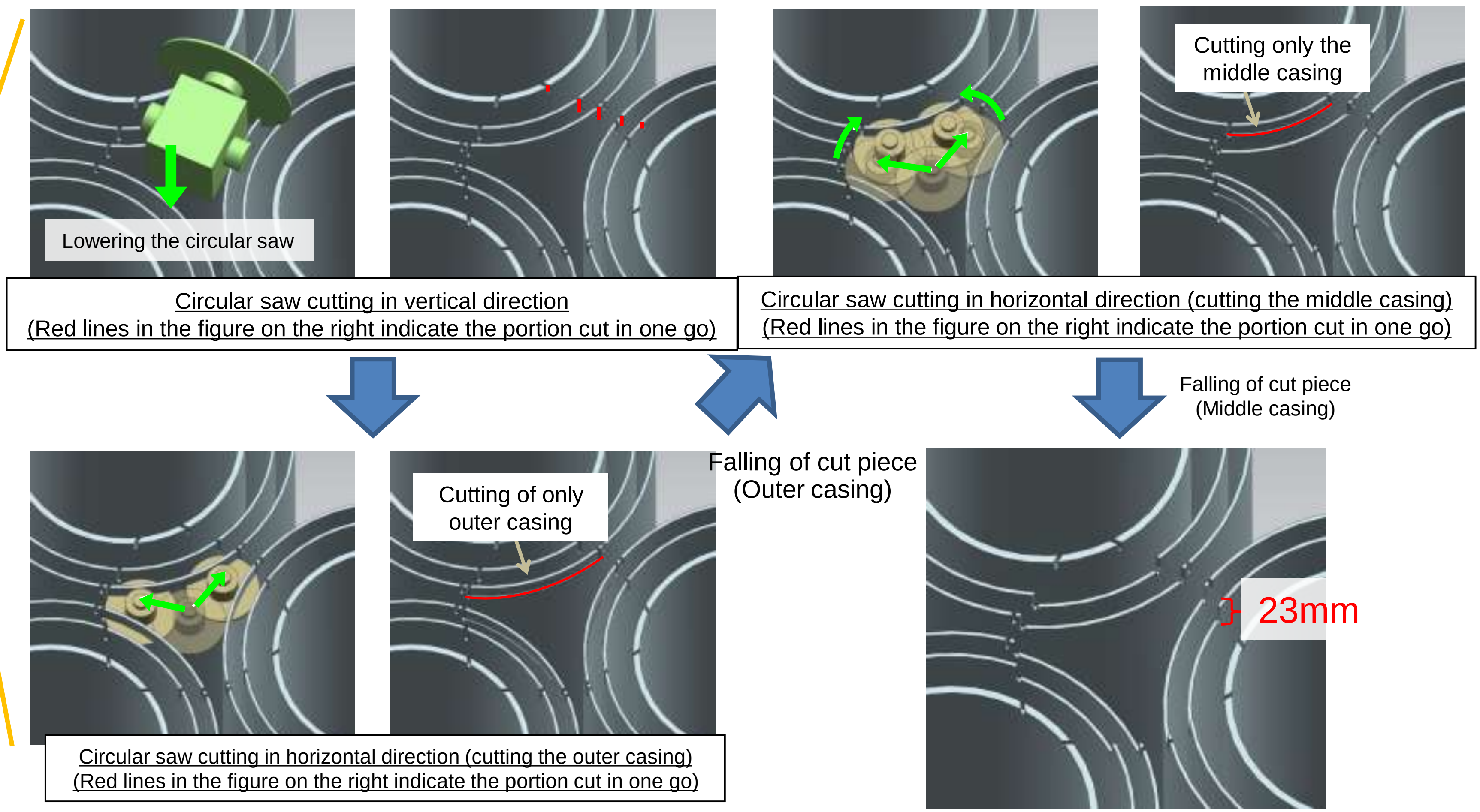
②-4. Study on propriety of cutting with a stand-alone technology and on combining cutting technologies (4/5)

Cutting procedure for the steam separators, which accounted for most of the volume of abrasive used in the FY2019 plan, was studied.

[Circular saw] An example of Combination No. 7 of machining technologies is shown in the figure below (refer to Slide 15 for the Combination No.)



Conceptual image of steam separator



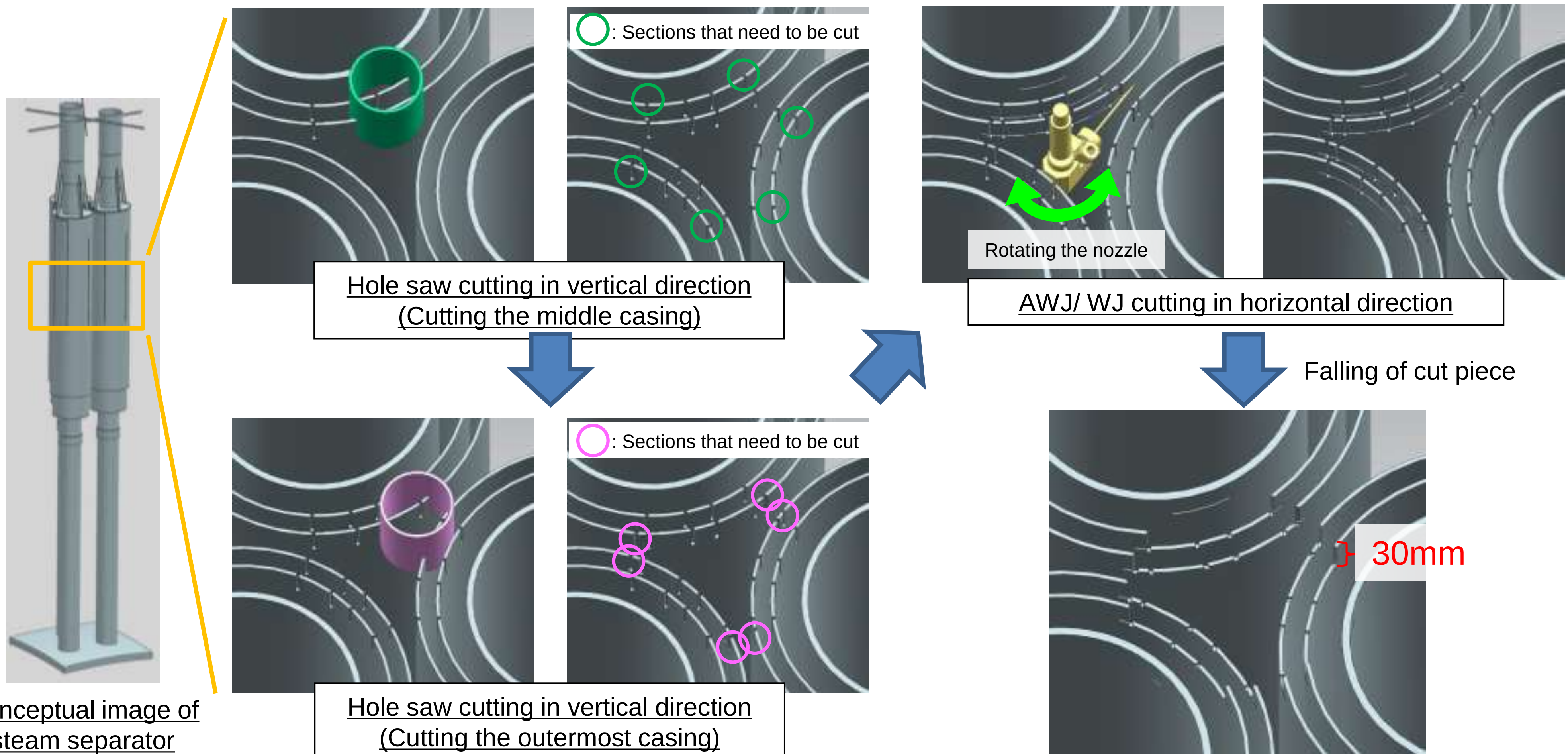
6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-4. Study on propriety of cutting with a stand-alone technology and on combining cutting technologies (5/5)

Cutting procedure for the steam separators, which accounted for most of the volume of abrasive used in the FY2019 plan, was studied.

[Hole saw] An example of Combination No. 4 of machining technologies is shown in the figure below (refer to Slide 15 for the Combination No.)



Conceptual image of steam separator

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-5. Evaluation of the impact on other systems

Factors having an impact on other systems were studied and evaluated for each cutting technology.

Items			AWJ	Circular saw	Hole saw	Laser
Influencing factor	Machining dust		Minor	Major	Major	Minor
	Processing water		Present	Present	Present	Absent
	Abrasive / air		Present	Absent	Absent	Present
	System heat input		Minor	Minor	Minor	Minor
Impact on other systems	Dust emission control	Impact	Units 1 / 3: Medium to major and Unit 2: Medium	Minor		Units 1 / 3: Medium to major and Unit 2: Medium
		Volume of dust dispersion ・Rise in PCV pressure	Major	Minor		Major
		Evaluation	• The objects to be cut should be sampled for contamination density, and the extent of water shooting out from the jet should be investigated as required, and a qualitative study of the preliminary estimations and actual measurements of the volume of dust dispersion should be conducted. • Cutting should be performed in stages based on the work achievements during investigation inside PCV, dust monitoring at the site of leakage (penetration part, etc.) from the RPV into PCV should be carried out in parallel with dust monitoring during PCV gas monitoring and the results should be sequentially reflected in the cutting plan.			
	Criticality control	Impact	• Unit 1: Medium, Unit 2: Minor to major, Unit 3: Minor to medium • Study bearing in mind the criticality risk due to falling of fuel debris from inside RPV. Relative comparison between the volume (estimated) of fuel debris remaining inside RPV in each Unit			
		Evaluation	• Fuel debris that did not fall even after the application of external forces such as aftershocks after the earthquake disaster, cooling water injection, etc., is unlikely to fall due to comparatively small external pressure such as that of machining water being used while machining the reactor internal structures, falling of cut pieces, etc. (However, concrete evaluation is difficult) • It is desirable to conduct prior investigation of places where machining equipment or machining byproducts are likely to fall and check for criticality risks.			
	Waste disposal	Impact	Medium	Minor		
		Evaluation	• Objects being cut and machining dust (garnet is added in case of AWJ) increase the volume of waste. • Hence work of adding collection and storage equipment as well as the cost increases. However, the impact is limited since the waste generated is a certain percentage or less (needs to be verified in the future) of the quantity assumed during retrieval. • As for equipment specifications, technology for collecting waste that is inside PCV and for waste that flows into the system is being developed respectively. • It has been confirmed during the investigation inside PCV that elution of garnet does not have any impact on the operation of the water treatment facility.			
	Fuel debris retrieval		• The secondary waste released at the time of fuel debris retrieval is being evaluated, but it is estimated that the amount will be larger than the amount generated from machining of reactor internal structures obtained as a result of investigation inside RPV.			
Evaluation of cutting technology (Propriety of application)			• Currently, although there are some unknowns with regards to the impact of the 4 machining methods mentioned in this table on other systems, the impact is expected to be minor or limited. • Currently none of the methods seem to have any crucial impact, but elemental tests will be conducted and the methods will continue to be studied.			

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-6. Planning for simple tests with revised parameters and abrasive collection method

The following tests are planned to be conducted with the purpose of studying how the volume of abrasive used for the AWJ cutting (including WJ cutting) can be reduced and the method of collecting the abrasive.

Implementation items	Simple test items	Target machining technology	Items to be verified	
[Evaluation of AWJ/WJ technology] Study on reducing the volume of abrasive used when the AWJ technology is used, and abrasive collection method.	Cutting conditions verification test	AWJ/WJ	･Cutting performance in the vertical direction ･Cutting performance in the horizontal direction	→ Implemented in test No. 23 and 24
	Dust dispersion verification test	AWJ/WJ	･Discharge into the reactor	→ (*1)
	Nozzle life verification test	AWJ/WJ	･Nozzle life	→ (*2)
	Abrasive collection test	AWJ	･Volume of abrasive collected	→ (*3)

(*1) Availability of implementing the dust dispersion verification test with the narrowed down machining technologies as the subject, and the test plan are planned to be studied based on the simple tests conducted this year.

(*2) The nozzle life verification test is planned to be conduced with the narrowed down machining technologies as the subject based on the simple tests conducted this year.

(*3) Simple tests will not be conducted since the volume of abrasive used is expected to substantially reduce based on the result of the cutting conditions verification test indicated in Slide 23 and 24, and since the volume of abrasive collected is expected to be limited based on the results of the desk study on abrasive collection.

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

② -7. Planning for simple tests on the feasibility of the studied machining technologies

The following tests will be conducted for AWJ cutting (including WJ cutting), hole saw cutting, circular saw cutting and laser cutting, for which simple tests are necessary, to verify cutting performance.

Implementation items	Simple test items	Target machining technology	Items to be verified	
[Simple tests on the machining technologies] Comparison of AWJ with other machining technologies	Multi-fold pipe cutting verification test	AWJ / WJ / Hole saw / circular saw / laser	・Cutting performance in the vertical direction	Test results are indicated in Slide No. 24 to 28.
		AWJ / WJ / Circular saw	・Cutting performance in the horizontal direction	
	Required positioning accuracy verification test	AWJ / WJ / Hole saw / circular saw / laser	・Position accuracy during cutting (Range of fluctuation)	Propriety of implementing the tests with the narrowed down machining technologies as the subject, and the test plan are planned to be studied based on the simple tests.
	Reaction force verification test	AWJ / WJ / Hole saw / circular saw / laser	・Reaction force during cutting	Test results are indicated in Slide No. 24 to 28.
	Secondary waste volume (*1) verification test	AWJ / WJ / Hole saw / circular saw / laser	・Risk of re-machining the discharge into the reactor ・Re-machining risk	Preliminary calculations are indicated in Slide No. 29.
	Dust dispersion verification test	Hole saw / circular saw / laser	・Discharge into the reactor	Propriety of implementing the tests with the narrowed down machining technologies as the subject, and the test plan are planned to be studied based on the simple tests.
	Pre-machining (incidental) work (*2) verification test	AWJ / WJ / Hole saw / circular saw / laser	・Cutting performance on machined surface	Verification of the requirement of pre-machining (incidental) work during the “Multi-fold pipe cutting verification test”
	Equipment life (maintainability) verification	AWJ / WJ / Hole saw / circular saw / laser	・Life of the tool	Propriety of implementing the tests with the narrowed down machining technologies as the subject, and the test plan are planned to be studied based on the simple tests.

(*1) Material generated as a result of machining, which is likely to fall inside the reactor, on top or on the side of the shroud head.

(However, this shall not include cut pieces. For example, abrasive from the AWJ or dross from laser cutting, etc.)

(*2) For example, the necessity to remove the dross from the machining performed the previous time.

[Scope (red frame) of verification by means of the multi-fold pipe cutting verification test]

No.		1	2	3	4	5	6	7	8
Combining technologies	Vertical direction	AWJ/WJ	Laser	Circular saw	Hole saw	AWJ/WJ	Laser	Circular saw	Hole saw
	Horizontal direction	AWJ/WJ	AWJ/WJ	AWJ/WJ	AWJ/WJ	Circular saw	Circular saw	Circular saw	Circular saw

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (AWJ/WJ: Cutting conditions verification test)

[Overview]

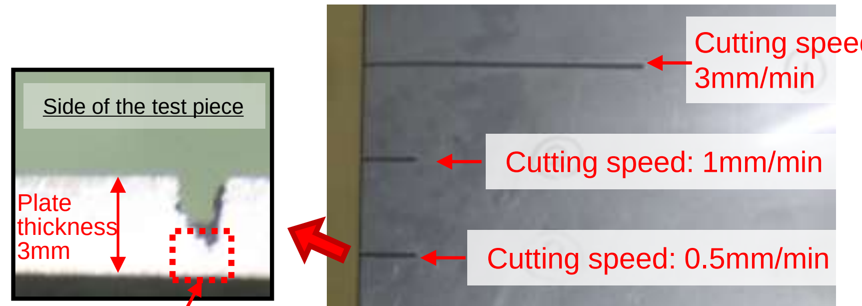
(1) A flat plate test piece (plate thickness 3 mm (*1)) was cut to confirm availability of cutting and appropriate cutting speed.

(*1) The plate thickness (3.2 mm) of the outer casing part of the steam separator was simulated.

(2) A simulated double pipe was cut according to the cutting procedures indicated in Slide No. 16, to confirm the availability of cutting in the vertical and horizontal directions as well as appropriate cutting speed.

[Results (flat plate cutting / WJ)]

① The flat plate test piece could not be cut by WJ in the shortest stand-off condition (stand-off: 1 mm) of the cutting procedures, therefore a cutting test for the simulated double pipe was not conducted.

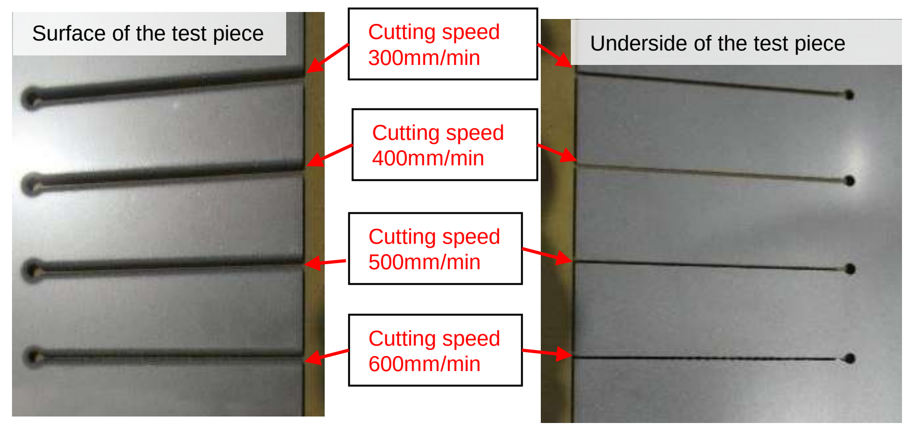


Results of flat plate test piece cutting test (WJ / Stand-off: 1mm)

[Results (flat plate cutting / AWJ)]

① The flat plate test piece could be cut by AWJ at 600mm/min, the highest speed of the test equipment.

- Stand-off: 20mm
- Volume of abrasive supplied: 500g/min



Results of flat plate test piece cutting test (AWJ / Stand-off: 20mm)

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (AWJ/WJ: Cutting conditions verification test)

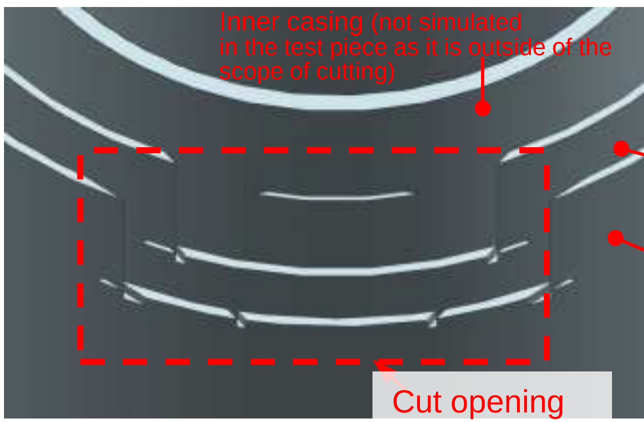
[Results (Double pipe cutting / AWJ)]

① The double pipe test piece could be cut by AWJ following the planned cutting procedures.

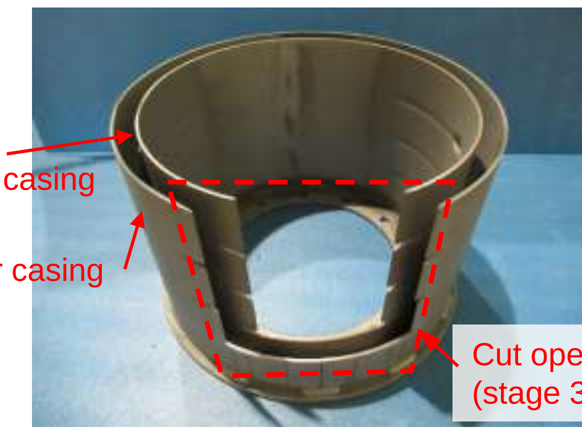
[Cutting speed] Vertical cutting (only outer casing): 30mm/min
Vertical cutting (outer casing + middle casing): 110mm/min
Horizontal cutting: 40° /min

② In case of cutting at the above-mentioned speed, the total amount of abrasive used for cutting the main body of the steam separator is tentatively calculated to be approx. 0.33 ton (approx. 8 ton last year).

③ AWJ cutting reaction force was applied approximately 40N in the direction opposite to the AWJ jet spray, therefore measures need to be taken in the future.



Conceptual image of cutting the steam separator



A result of partially simulated steam separator cutting test (AWJ)

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (Laser: Multi-fold pipe cutting verification test)

[Overview]

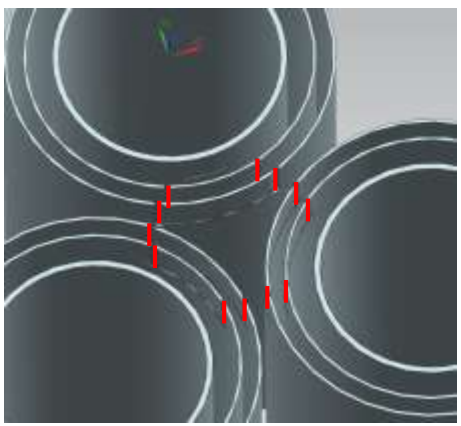
(1) Laser cutting specifications ⇒ Laser type: Fiber laser / Assist gas: Air

(2) A simulated double pipe was cut in the vertical direction according to the cutting procedures indicated in Slide No. 17, to confirm the availability of cutting and appropriate cutting speed.

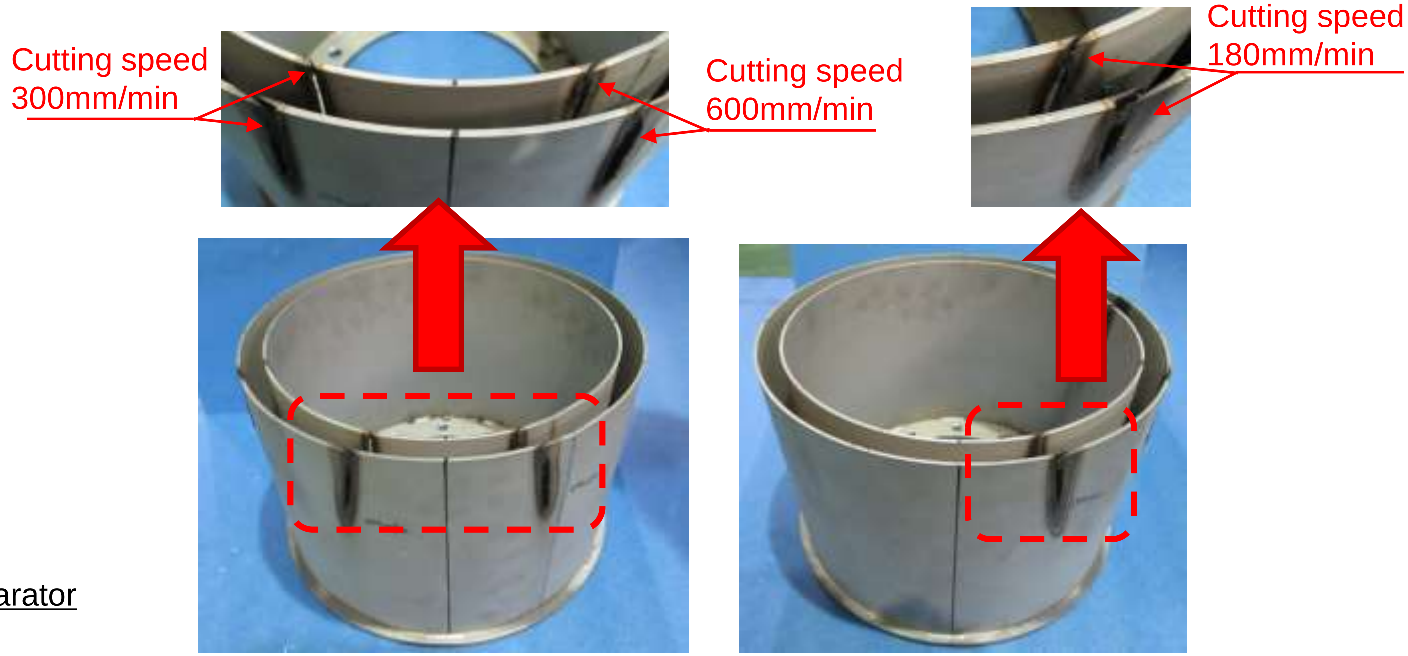
[Results]

① Although dross was found at the distal end where laser cutting is terminated, since it does not get re-deposited, the simulated double pipe could be cut.

② Cutting in the vertical direction is expected to be possible (speed at which cutting can be performed: up to 600 mm/min).
A reaction force of 8N was formed in the direction opposite to the assist gas jet, but as the laser head was inclined vertically downwards at approx. 12.5° , the reaction force applied in the horizontal direction is expected to be approx. 1.7N which is smaller than that in the case of AWJ.



Conceptual image of cutting the steam separator
(Red line: Laser cutting location)



Results of partially simulated steam separator cutting test (Laser)

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (circular saw: Multi-fold pipe cutting verification test) (1/2)

[Overview]

(1) A simulated double pipe and a simulated three fold pipe were simultaneously cut as per the cutting procedures indicated in Slide No. 18, and the cutting propriety in the vertical direction as well as the speed at which cutting can be performed were verified.

[Results (cutting in the vertical direction)]

① The double pipe and three fold pipe could be cut simultaneously, however the cutting was unstable as there arose fluctuations in the rotational speed during cutting.

② In addition, since the cutting speed was extremely low at 0.5 mm/min, the result showed that application of vertical cutting direction for the steam separator may not be realistic.

③ Inadequate rotating torque due to the design for downsizing the tool, or increase in cut resistance as the blade simultaneously comes in contact with 5 locations can be considered to be the causes for unstable cutting. (*1)

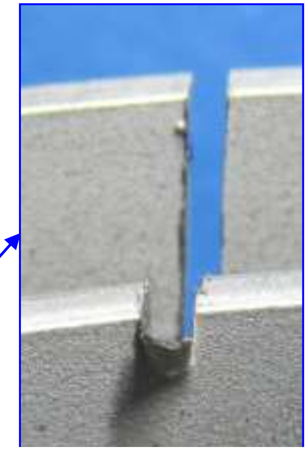
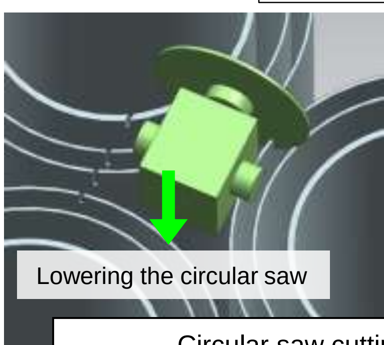
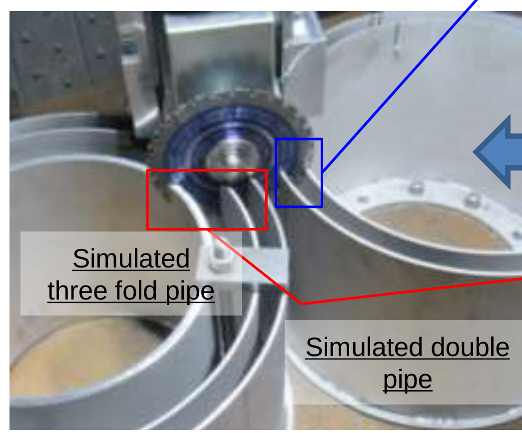


Photo of cut portion of a simulated double pipe

(*1) Cut resistance increases as cutting is simultaneously performed at maximum 5 locations.



Circular saw cutting in vertical direction
(Red lines in the figure on the right indicate the portion cut in one go)



Direction from which the cut part is photographed

Partially simulated steam separator cutting test results (Circular saw / vertical)

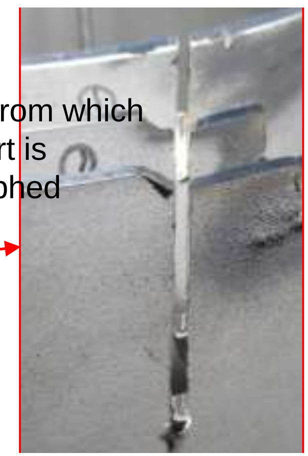


Photo of cut portion of a simulated three fold pipe

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (circular saw: multi-fold pipe cutting verification test) (2/2)

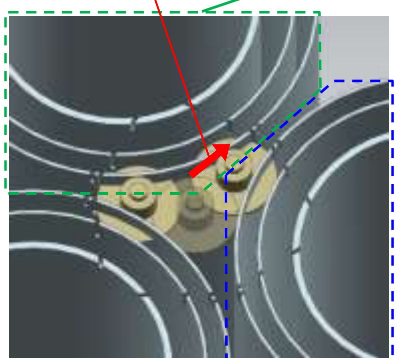
[Overview]

(1) A simulated double pipe was cut in the horizontal direction to verify availability of simultaneously cutting two double pipes in the horizontal direction in accordance with the cutting procedures indicated in slide No. 18.

[Results (cutting in the horizontal direction)]

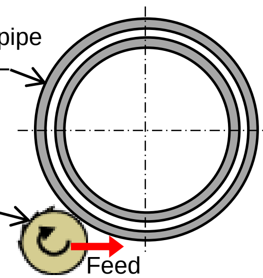
When cutting two steam separators simultaneously, the circular saw feed needs to accomplish up/down cut simultaneously in one cutting.

First of all, the down cut and up cut were cut individually at a time in this test. The result of the test showed that the down cut was not successful and so simultaneous cutting of two steam separators was not possible.

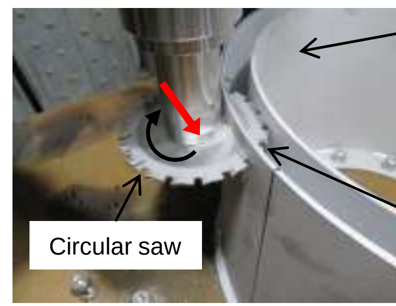


Conceptual image of cutting the steam separator
(Circular saw / horizontal)

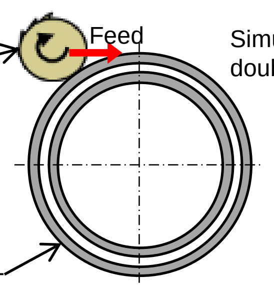
Feed direction:
Up cut



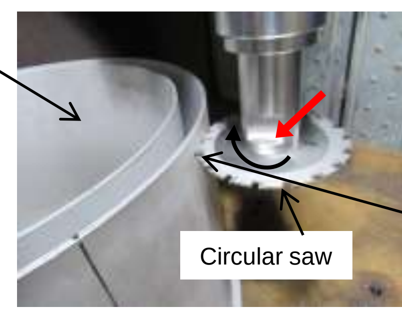
<Test Conceptual image>



Feed direction:
Down cut



<Test Conceptual image>



6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8. Implementation and evaluation of simple tests (hole saw: Multi-fold pipe cutting verification test)

[Overview]

(1) Two simulated double pipes were simultaneously cut in accordance with the cutting procedures indicated in slide No. 19, and availability of cutting in the vertical direction as well as the speed at which cutting can be performed were verified.

[Result]

① The amount of hole saw feeding in the vertical direction was approximately 1 mm and it suspended due to overload (cutting speed: 0.5mm/min).

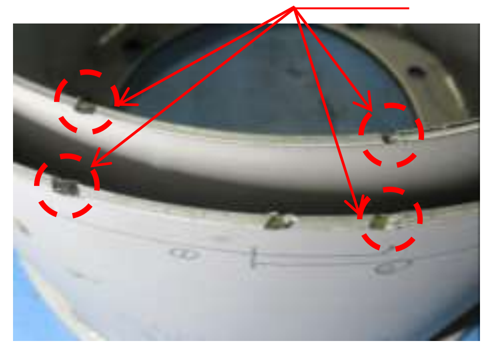
② Increasing the rotational torque of the hole saw can be considered for improving cutting performance, but with the current tool configuration and restrictions on dimensions, major increase in torque seems unlikely and hence hole saw is not applicable.

Hole saw Cutting in the vertical direction (Cutting of outer casing + middle casing)

Conceptual image of cutting the steam separator (Hole saw)

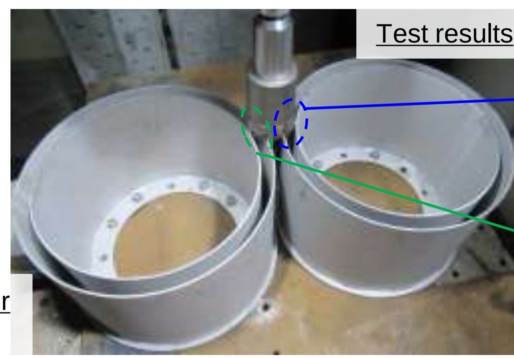
Test results

Cutting mark

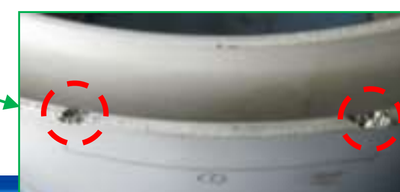


Hole saw Cutting in the vertical direction (Cutting of outer casing)

Conceptual image of cutting the steam separator (Hole saw)



Test results



6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-8 Implementation and evaluation of simple tests (final evaluation)

[Overview]

The preliminary calculations pertaining to the volume of secondary waste and the working time were added to the simple test results (slide No. 23 to 28) and the prospects of actually applying each machining technology were evaluated. Further, since the result of the flat plate cutting test showed that WJ cutting is not possible, it was not included in the evaluation.

[Result]

The circular saw and hole saw are not applicable in the actual site whereas AWJ and laser have prospects of actual application.

Items \ Machining technology		AWJ		Laser	Circular saw		Hole saw
		Vertical	Horizontal	Vertical	Vertical	Horizontal	Vertical
Cutting availability		Good	Good	Good	Acceptable (*2)	Unacceptable	Unacceptable
Volume of secondary waste	Evaluation	Good	Good	Good	Good	—	—
	Abrasive (kg)	182.7	141.1(*1)	0.0	0.0	—	—
	Machining dust	7.0	1.2(*1)	2.4	2.7	—	—
	Total (kg)	189.7	142.3(*1)	2.4	2.7	—	—
Working Time	Evaluation	Good	Good	Good	Unacceptable	—	—
	Working time (min)	365.4	282.1(*1)	29.7	18900 (315h)	—	—
Evaluation		**Good**	**Good**	**Good**	**Unacceptable**	**unacceptable**	**Unacceptable**

(*1) Volume of secondary waste resulting from AWJ cutting in the horizontal direction and corresponding working time when cutting of the main body of the steam separator is repeated in the vertical direction at a 50 mm pitch.

(*2) Even though cutting was possible, it was unstable due to lack of rotational torque (refer to Slide No. 26).

6. Implementation Details

(1) Advancement of machining technology for the top access investigation method

②-9 FY2021 Implementation Policy

[Narrowing down combinations of machining technologies]

From the evaluation results (slide No. 29) based on the results of simple tests, the 2 patterns of machining technology combinations were narrowed down as shown in the following table.

Combination of machining technologies	No. 1 (*1)		No. 2 (*2)	
	Vertical	Horizontal	Vertical	Horizontal
	AWJ	AWJ	Laser	AWJ

(*1) Corresponds to the No. in the table on Slide No. 15.

[FY2021 Implementation Policy]

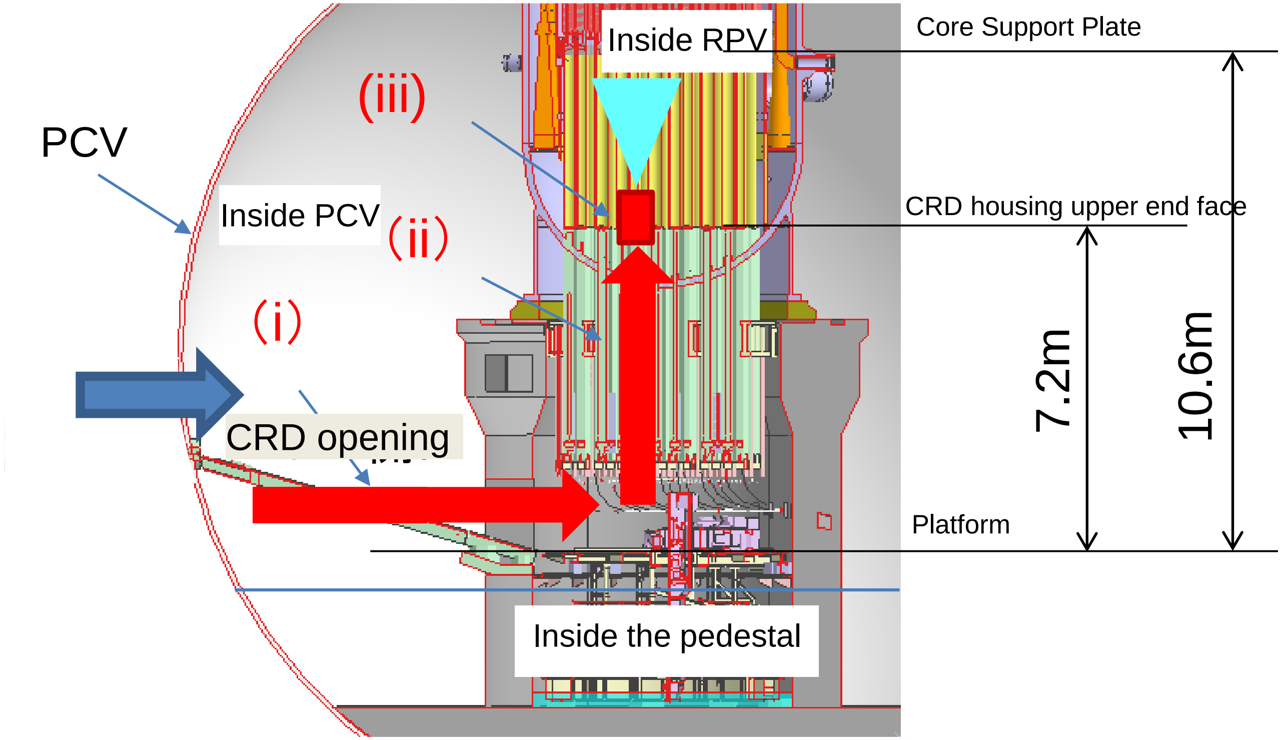
The FY2021 implementation policy on the machining technologies (AWJ & laser) that have been narrowed down are shown below.

Machining technology	Implementation Details	
AWJ	①	Study on application to parts other than the main body of steam separator
	②	Study on further reducing the volume of abrasive (revision of cutting parameters)
	③	Elemental tests concerning ① and ② as may be required (Nozzle life will be verified during the elemental tests.)
Laser	①	Study on applications other than the steam separator
	②	Study on application to cutting in the horizontal direction (study on downsizing the head)
	③	Elemental tests concerning ① and ② as may be required
	④	Identification of issues in actual application and study of measures

(2) Development of the bottom access investigation method

Definition of development items: Definition of access equipment and investigation equipment

The technology to be applied to the method of investigating inside RPV from the bottom was divided into the following 3 parts and studied.



(i) Equipment for access to the inside of the pedestal
(ii) Equipment for access to the inside of the RPV from inside the pedestal
(iii) Investigation equipment

6. Implementation Details

Common for Units 1, 2 and 3

(2) Development of the bottom access investigation method

① Planning of the bottom access / investigation and the development for the access / investigation equipment

The study process is shown below.

1. Drafting of the investigation plan

Implementation items	Unit 1	Unit 2	Unit 3
A. Organization of investigation needs	⇒ Verification of investigation needs with TEPCO and NDF ・Information such as image data and dose rate needs to be obtained by accessing the inside of the RPV early on. ・Existing technological development results will be utilized for early implementation.		
B: Organization of preconditions	Preconditions will be organized based on results of investigation inside PCV, etc.		
C: Organization of applicable technologies ⇒ Equipment that have been developed in preceding projects that are currently in development and preparation, and which can be applied for this purpose will be put together. ⇒ Study conditions will be set based on the results of "B: Organization of preconditions"	(i) Equipment for access to the inside of the pedestal ⇒ Access equipment used for Detailed Investigation inside PCV will be used.	(i) Equipment for access to the inside of the pedestal ⇒ Arm type access equipment for fuel debris retrieval will be used.	(i) Equipment for access to the inside of the pedestal ⇒ Similar to Unit 2, arm type access equipment for fuel debris retrieval will be used , since the plan is to reduce the PCV water level.
	(ii) Equipment for access to the inside of the RPV from inside the pedestal (using a drone) ⇒ Since it has been evaluated that most of the fuel debris has fallen to the pedestal bottom, study will be carried out afresh presuming that there is an opening of diameter about 1m in the central part of the lower hemispherical dome of the RPV.	(ii) Equipment for access to the inside of the RPV from inside the pedestal (using telescopic mechanism) ⇒ Study will be carried out afresh presuming that there is an opening in the RPV bottom part above the location where the upper tie plate had fallen, and that the dimensions of the opening are such that the tie plate can pass through it.	(ii) Equipment for access to the inside of the RPV from inside the pedestal (using telescopic mechanism) ⇒ Study will be carried out afresh presuming that there is an opening in the RPV bottom part that is about the size of the CRGT based on the investigation result that CRGT had fallen.
	(iii) Investigation equipment ⇒ Study will be conducted on application of the equipment developed so far including those developed in other PJs, for each Unit.		

6. Implementation Details

Common for Units 1, 2 and 3

(2) Development of the bottom access investigation method

① Planning of the bottom access / investigation and the development for the access / investigation equipment

Implementation items	Unit 1	Unit 2	Unit 3
1. Drafting of the investigation plan (continued)			
D: Study of feasibility evaluation items	・Applicable elemental technologies will be identified from the conditions in A, B and C respectively and potential equipment specifications will be put forth. ・Since there are uncertainties concerning the status inside PCV, multiple specifications will be studied to deal with the uncertain conditions. ・A comparative evaluation of the investigation specifications for each condition will be conducted, and potential elemental technologies will be narrowed down.		
2. Feasibility study (test)			
E: Implementation of tests, etc.	・Issues in the potential elemental technologies will be identified, and the evaluation items necessary for evaluating feasibility will be set. ・Following the evaluation items, a test plan necessary for evaluating feasibility will be drafted. ・Tests will be conducted based on the plan.		
3. Feasibility evaluation			
F: Evaluation based on the test results, etc.	・Feasibility evaluation will be carried out based on the test results, and the investigation method to undergo conceptual study next year, will be selected. ・Investigation plan and development plan related to the selected investigation method will be developed.		

② Conceptual study of the bottom access / investigation equipment (FY2021)

6. Implementation Details

(2) Development of the bottom access investigation method

Unit 1: Development of equipment for accessing the inside of the RPV using a drone

<Purpose>

To perform simple tests on the method of accessing the inside of RPV from inside the pedestal using a drone (wired, wireless), and to evaluate its feasibility as a bottom access investigation method for Unit 1.

<Implementation details>

① A simple flight test of the drone (wired, wireless) was performed for evaluating feasibility.
- Drone unit test
- Combination test with extension rod, etc. in an environment with simulated CRD opening / RPV opening

② Study on response plan for FY2021 based on the simple tests results

<Results>

① Data (size, payload, battery life) contributing to the conceptual study in FY2021 and the essential points of the investigation (ability to pass through the opening, investigation procedures) were verified through simple tests.

② It was determined that the following structure of the drone (wired, wireless) is applicable.
- Wired drone: The structure consisting of a drone and a cable drum was selected.
- Wireless drone: The structure consisting of a drone and an extension rod was selected.

<Remaining issues>

① Wired drone: Stable supply of feeding voltage, lack of flight level due to voltage drop in the power supply cable.
② Wireless drone: Extended flight duration
③ Common: Evaluation of the site applicability (radiation resistance, darkness and rainfall environment)

6. Implementation Details

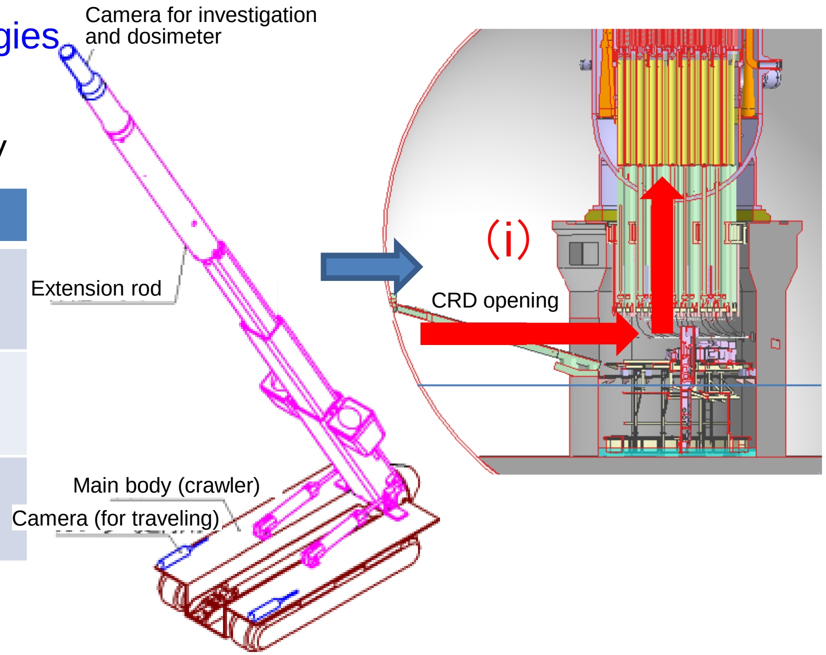
(2) Development of the bottom access investigation method

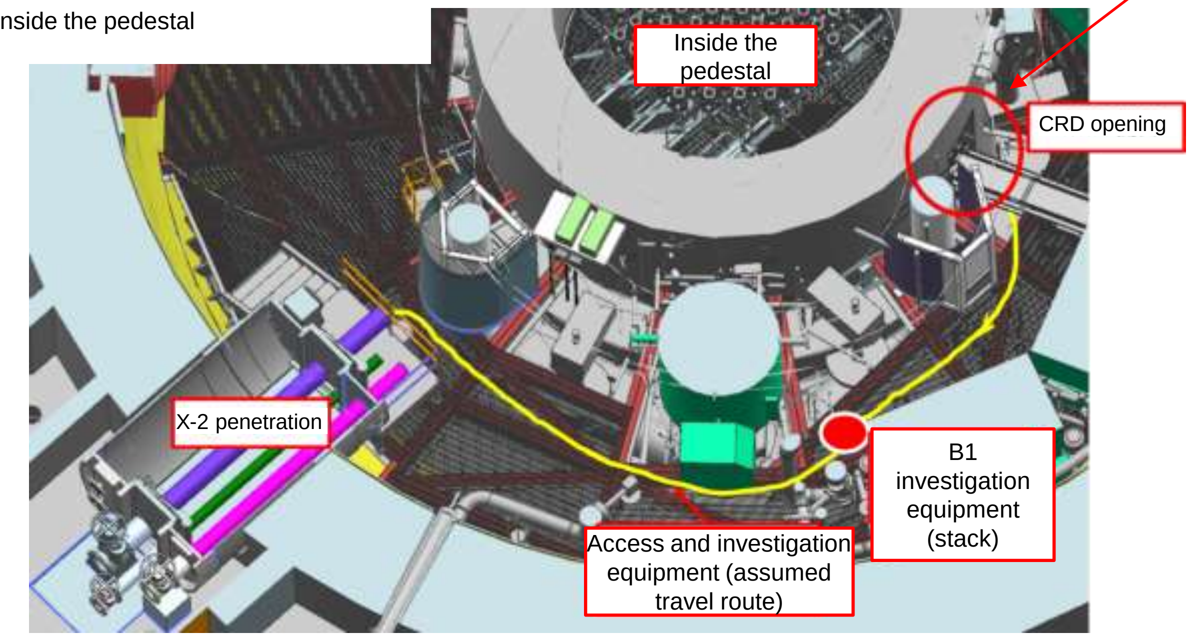
1. Drafting of the investigation plan C: Organization of applicable technologies

(i) Equipment for access to the inside of the pedestal

Unit 1: Status of study and development concerning detailed investigation inside PCV

Items	Status of study and development
Location for access inside the PCV	① X-2 penetration → outside the pedestal (basement) → exploring the basement ② X-2 penetration → traveling over the grating → entering inside pedestal (investigation)
Location for access to the inside of the pedestal	① Worker access port (underwater) ② CRD opening (in air)
Equipment for access to the inside of the pedestal	① ROV for inside the pedestal: Width 20cm, length 45cm ② Equipment for investigating inside the pedestal: Length of extension rod 5m





Under development as equipment for access to the inside of the pedestal

① Accessing the CRD opening with a crawler
② Providing access to the camera for investigation and the dosimeter into the pedestal by drawing out the extension rod

The extension rod is effective as a means for providing the bottom access equipment with access into the pedestal or as a means for providing assistance to the bottom access equipment inside the pedestal.

6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D：Study of feasibility evaluation items

<Investigation Overview>

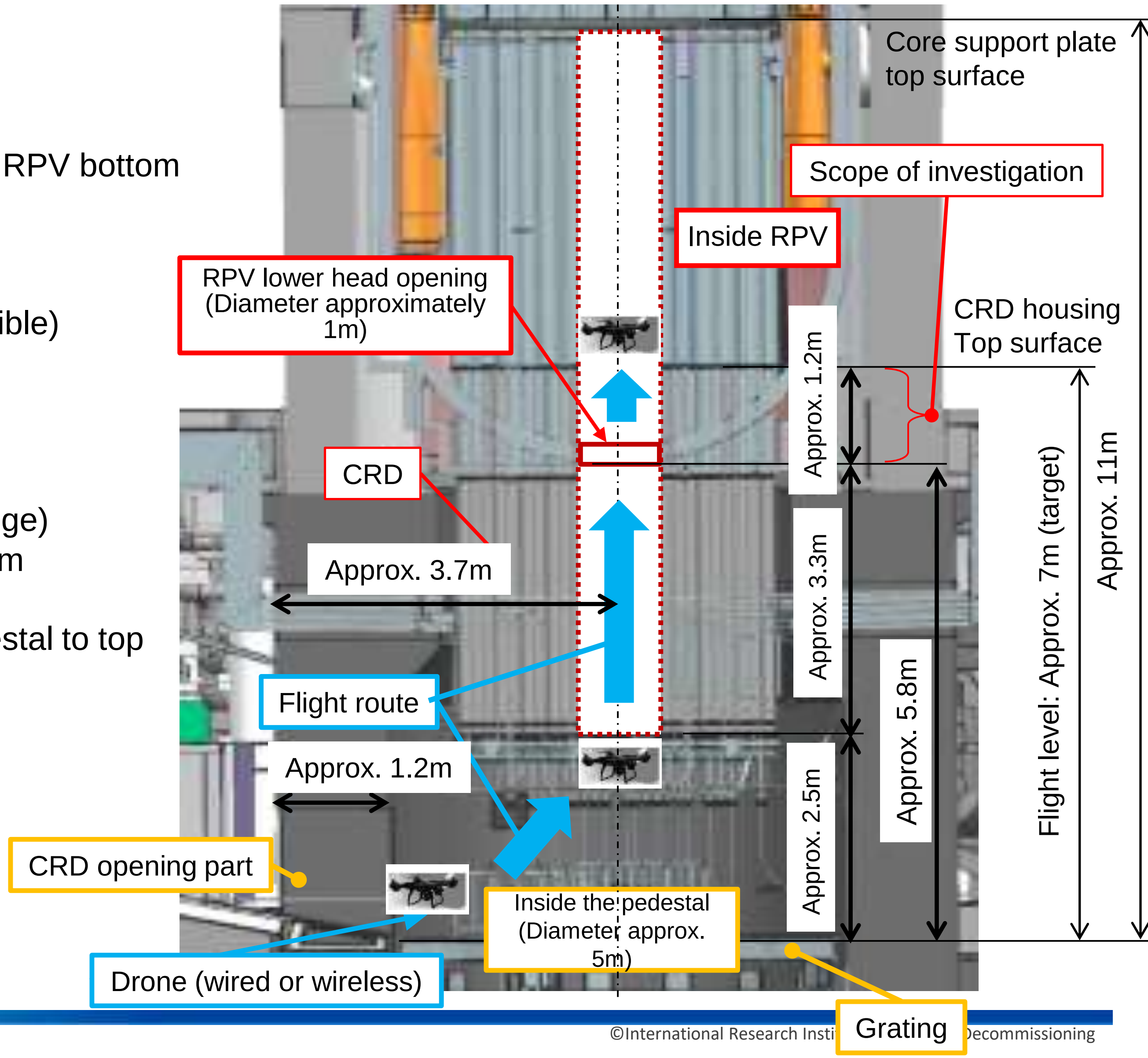
(1) Purpose of investigation
Verification of the status inside of the RPV bottom

(2) Investigation items
① Acquisition of image data
② Measurement of dose rate (if possible)

(3) Investigation equipment
Drone (wired or wireless)

(4) Scope of investigation (drone flight range)
① Scope of investigation：RPV bottom
② Target flight level: Approx. 7m
(Top surface of grating in the pedestal to top surface of CRD housing)

(5) Drone landing and take-off location
CRD opening outside the pedestal



6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Investigation Overview>

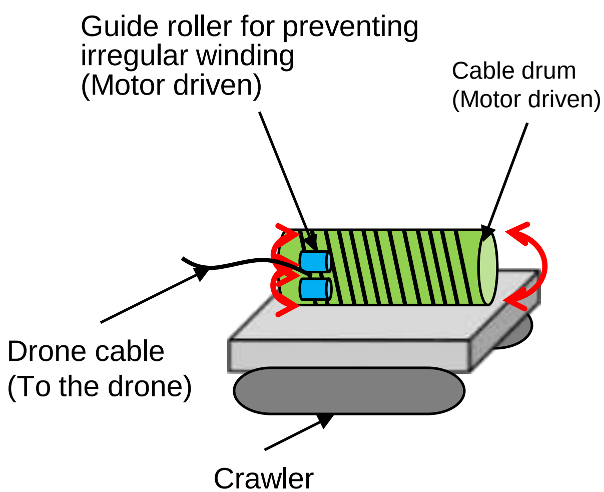
(6) Auxiliary equipment (installed in front of the CRD opening part)

1) Cable drum (only for wired drone)

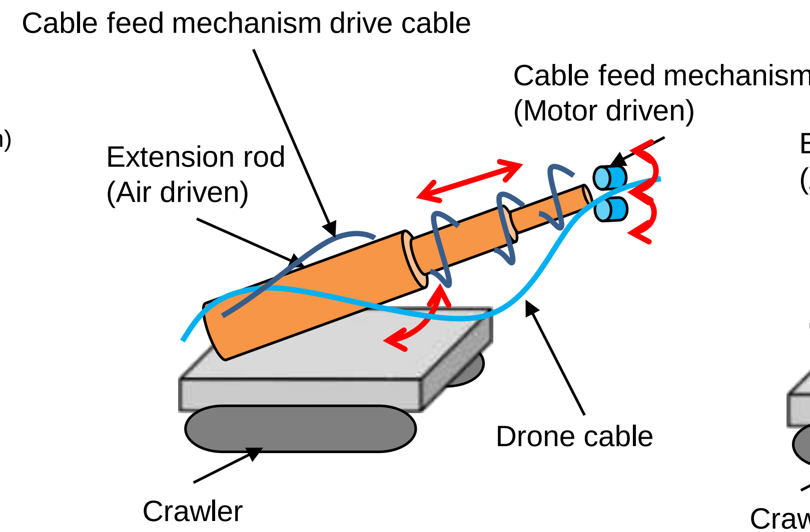
- Feeding and retraction of the wired drone cable is carried out with the cable drum.

2) Extension rod (utilizing the technology being developed as part of Investigation inside PCV)

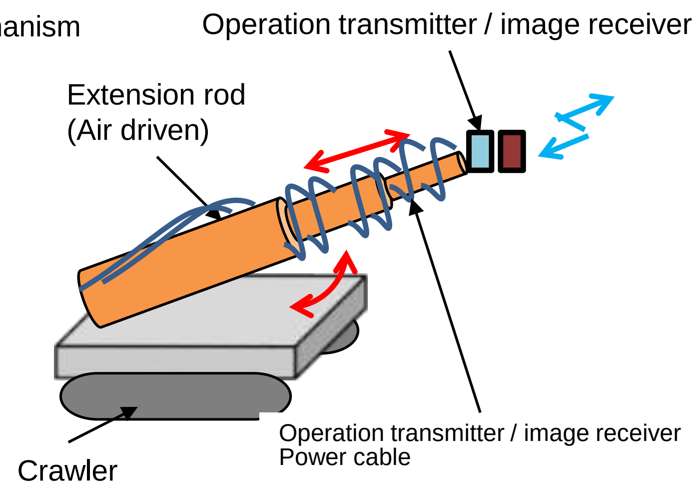
- In the case of wired drone: The cable feed mechanism is installed at the tip of the extension rod, it is ensured that the wired drone cable does not get entangled in the cables of existing equipment inside the pedestal and the load on the drone resulting from the cable mass is reduced.
- In the case of wireless drone: The operation transmitter / image receiver are installed at the tip of the extension rod to communicate with the wireless drone inside the pedestal.



Cable drum



Cable feeding mechanism and extension rod



Transceiver and extension rod

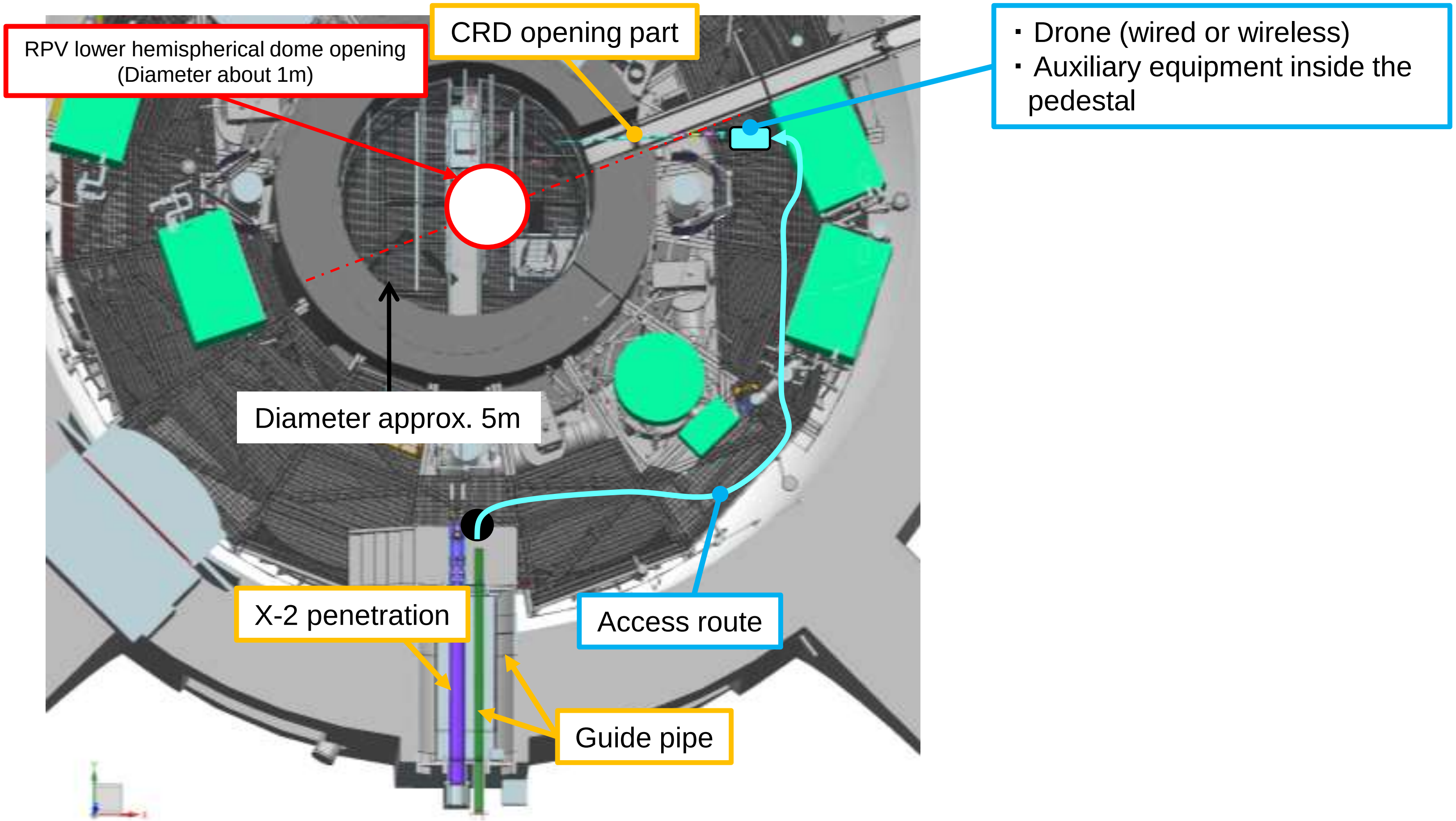
6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Access route up to the pedestal (CRD opening part)>

In the demonstration test concerning the investigation inside Unit 1 PCV, the PCV is accessed from the guide pipe of the X-2 penetration and from there the CRD opening part is accessed by moving anti-clockwise inside PCV.



6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Travel route of the equipment (drone, auxiliary equipment)>

Solid red arrow: Travel path of the equipment
Dashed red arrow: Location up to which the tip of the extension rod is drawn out

		X-2 penetration	CRD opening part	Inside the pedestal	Inside RPV
Pattern 1	[Wired drone]	→	→	→	→
	[Crawler (with cable drum)]	→			
	[Crawler (with extension rod)]	→	- - → (Drawing out the extension rod)		
Pattern 2	[Wired drone]	→	→	→	→
	[Crawler (with cable drum)]	→			
Pattern 3	[Wireless drone]	→	→	→	→
	[Crawler (with extension rod) (*1)]	→	- - → (Drawing out the extension rod)		
Pattern 4	[Wireless drone]	→	→	→	→
	[Crawler (with transceiver)]	→			

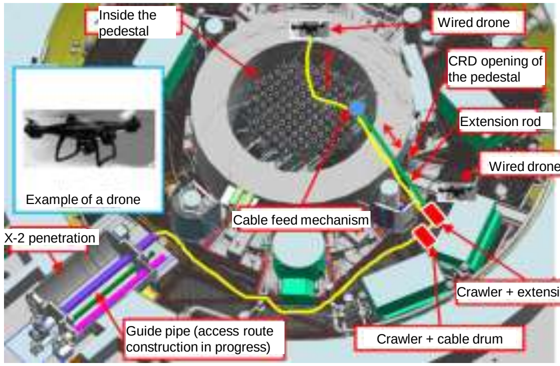
The drone travels from X-2 penetration to the inside of the RPV.
The auxiliary equipment travels from X-2 penetration to the CRD opening part.

(*1) For Pattern 1 the cable feed mechanism is mounted at the tip of the extension rod and for Pattern 3 the transceiver is mounted at the tip.

<Merits and demerits of the drone (wired, wireless)>

Type of drones	Merits	Demerits
Wired drone	・Stable power supply ・Stable communication	・Large cable load ・Cable likely to get entangled
Wireless drone	・No cable load ・No risk of cable getting entangled	・Battery life ・Communication likely to be unstable

Example of Pattern 1

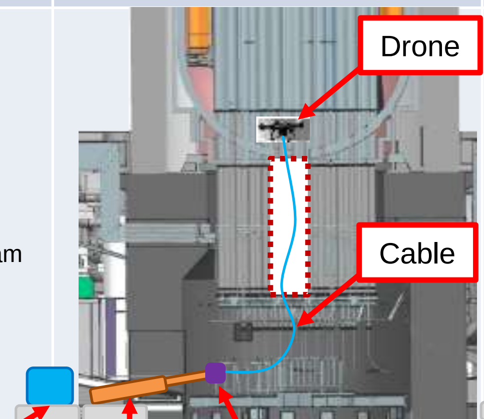
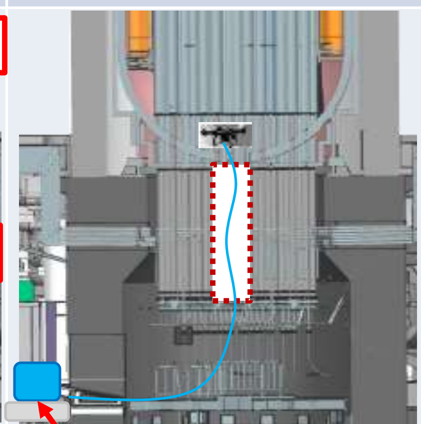
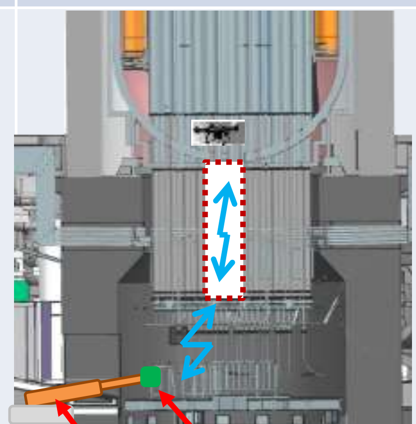
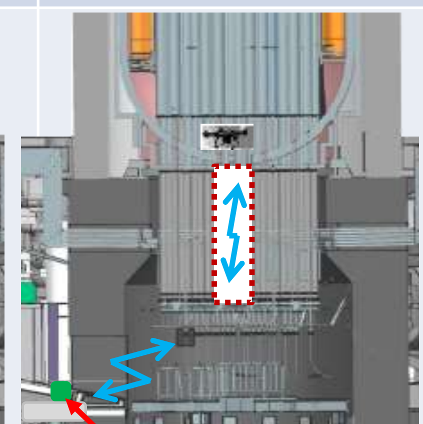


6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Investigation pattern using drones (wired and wireless)>

No.	Pattern 1 Wired drone and extension rod	Pattern 2 Only wired drone	Pattern 3 Wireless drone and extension rod	Pattern 4 Only wireless drone
Investigation equipment	Wired drone	Wired drone	Wireless drone	Wireless drone
Auxiliary equipment	① Cable feed mechanism ② Extension rod ③ Cable drum	① Cable drum	① Extension rod ② Transceiver	① Transceiver
Outline of investigation	• Auxiliary equipment (①②③) are installed in front of the CRD opening part. • The extension rod extends inside the pedestal before or after the drone flies. • The inside of the RPV is investigated by means of the flying drone.	• Auxiliary equipment (①) is installed in front of the CRD opening part. • The inside of the RPV is investigated by means of the flying drone.	• Auxiliary equipment (①②) are installed in front of the CRD opening part. • The extension rod extends inside the pedestal during or after the drone flies. • The inside of the RPV is investigated by means of the flying drone.	• Auxiliary equipment (①) is installed in front of the CRD opening part. • The inside of the RPV is investigated by means of the flying drone.
Conceptual diagram				

6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Required specifications and preconditions for the actual investigation>

Required specifications:

①: Should be able to reach the top surface of CRD housing (height 7m).

②: Should be able to verify the inside of the RPV bottom in the range of tilt: ±90°, pan: ±180° by operating the drone or the mounted camera.

<Preconditions>

Items		Conditions	
Dimensional conditions	Location for access inside the PCV	・Guide pipe for inserting the equipment for investigation inside PCV being established in the X-2 penetration ・Guide pipe inner diameter: φ314mm (usable space: φ290mm)	[Maximum permissible size] Φ290mm (*1) (*1) The size of the opening at the bottom part of RPV is assumed to be φ1000mm, however, due to access route constraints the maximum permissible size is φ 290mm. In future, the position control performance, etc. of the access equipment will be evaluated and the regions that can be investigated will be studied.
	Location for access inside of the pedestal	・CRD opening part ・Dimensions of the opening part: width 790mm × thickness 1200mm × height 1173mm (from the top of the grating)	
	Outer diameter of the opening at the bottom of the RPV	・φ1000mm ・It is assumed that there is a cylindrical space of φ1000mm below the RPV opening.	
	Location of the RPV bottom opening	・Center of the RPV	
Environmental Conditions	Dose rate	・Dose rate: 100 Gy/hr (tentative), Cumulative dose: 1000Gy	
	Temperature	・Assumed to be 80°C or less	
	Humidity	・Assumed to be 100%	
	Other	・Darkness ・Cooling water injection in progress (rainfall) ・Since it is assumed that there is damage caused on the grating inside the pedestal due to the impact of falling of fuel debris, as far as possible the equipment should not come in contact.	

6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Overview of the investigation equipment and auxiliary equipment (specifications and functions)>

<table>
<tr><th colspan="2"></th><th colspan="4">Mounted equipment / specifications and functions</th></tr>
<tr><th colspan="2">Equipment name</th><th>Pattern 1</th><th>Pattern 2</th><th>Pattern 3</th><th>Pattern 4</th></tr>
<tr><td>Investigation equipment</td><td>Drone</td><td colspan="2">・Type : Wired drone
・Size : within φ290mm
・Flight level: 7m
・Investigation equipment:
(1) Camera
(2) Dosimeter
(3) Motor for oscillating the camera</td><td colspan="2">・Type : Wireless drone
・Size : within φ290mm
・Flight level: 7m
・Investigation equipment: (1) Camera
(2) Conceptual image transmitter for camera
(3) Dosimeter
(4) Transmitter for dosimeter
(5) Motor for oscillating the camera</td></tr>
<tr><td rowspan="4">Auxiliary equipment</td><td>Cable Drum</td><td colspan="2">・Feeding and winding the drone cable
・Length of cable that can be stored: approx. 15m</td><td colspan="2">—</td></tr>
<tr><td>Cable feed mechanism</td><td>・Feeding the drone cable
・Motor driven</td><td>—</td><td colspan="2">—</td></tr>
<tr><td>Extension rod</td><td>・Introducing the cable feed mechanism into the pedestal
・Extension length approx. 5.3m
・Air driven</td><td>—</td><td>・Introducing the wireless transceiver into the pedestal
・Extension length approx. 5.3m
・Air driven</td><td>—</td></tr>
<tr><td>Transceiver</td><td colspan="2">Wired (operation / image)</td><td colspan="2">Wireless (operation: 2.4Ghz, image: 5.7GHz)</td></tr>
</table>

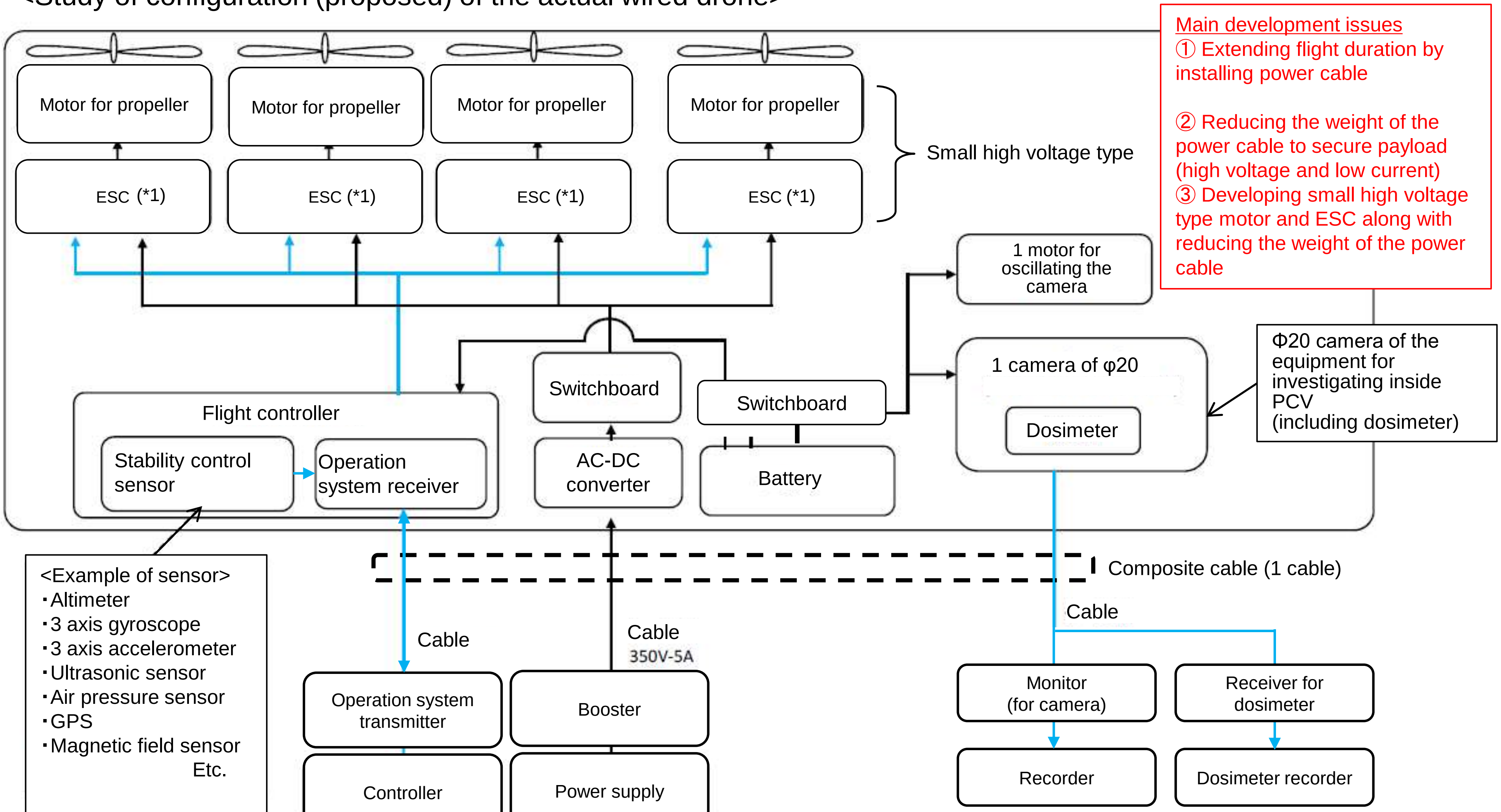
6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Study of configuration (proposed) of the actual wired drone>

← : Flow of electric current
← : Flow of signal



(*1) ESC: Electric Speed Controller (controls the motor speed)

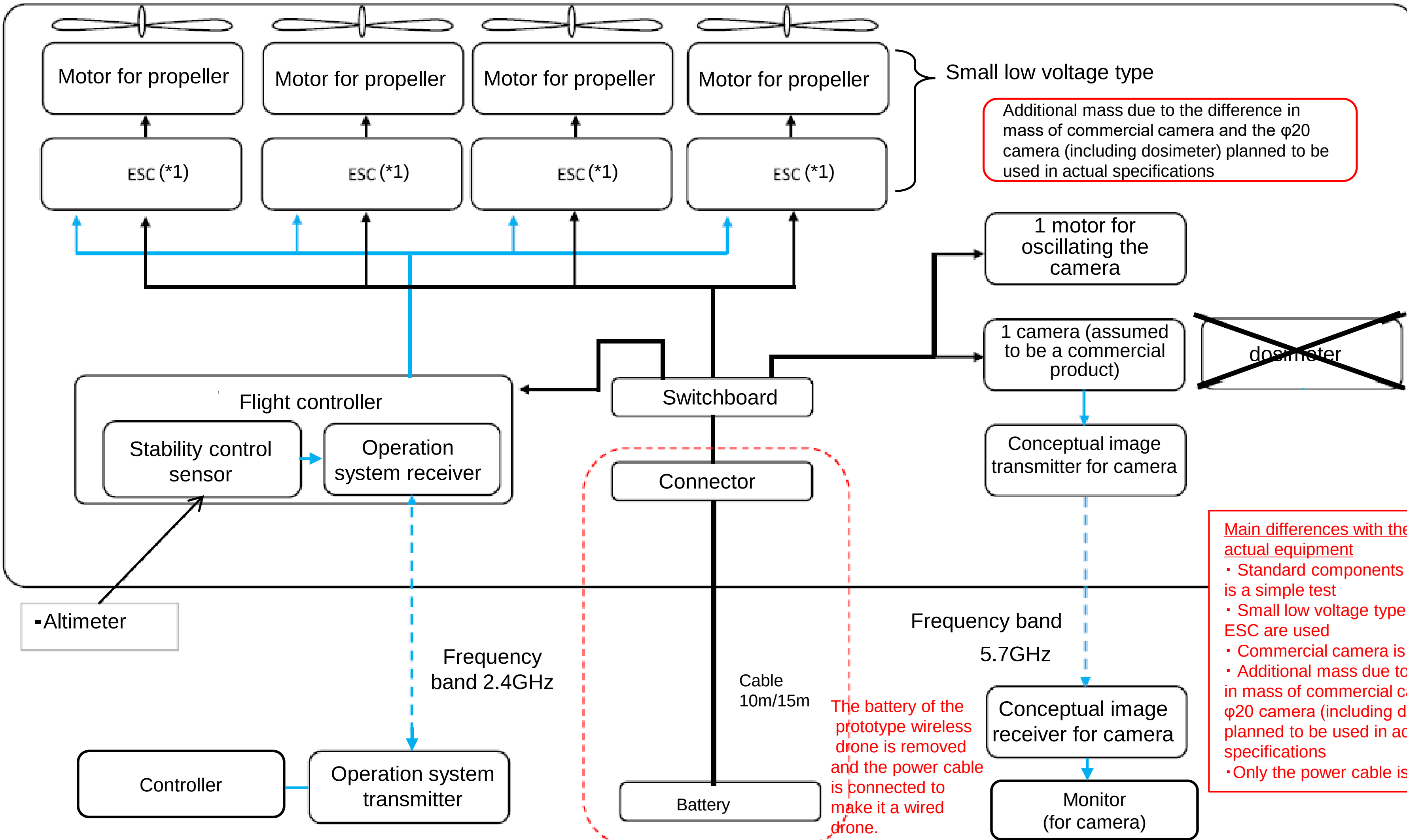
6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Result of studying the configuration of the wired drone for the test>

← : Flow of electric current
← : Flow of signal (solid line: wired, dotted line: wireless)



Main differences with the proposed actual equipment
・Standard components are used as it is a simple test
・Small low voltage type motor and ESC are used
・Commercial camera is used
・Additional mass due to the difference in mass of commercial camera and the φ20 camera (including dosimeter) planned to be used in actual specifications
・Only the power cable is wired

(*1) ESC: Electric Speed Controller (controls the motor speed)

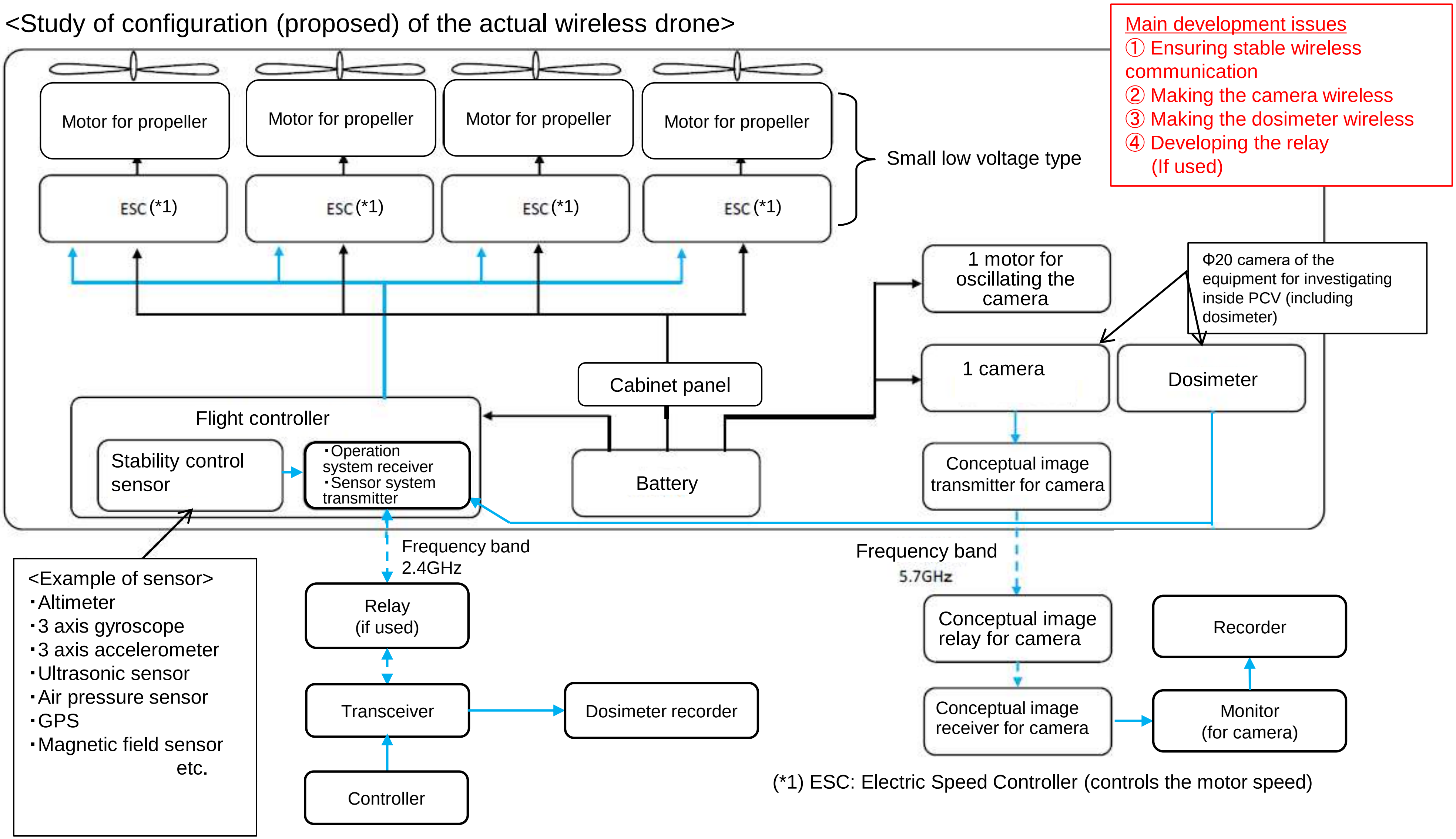
6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Study of configuration (proposed) of the actual wireless drone>

← : Flow of electric current
← : Flow of signal (solid line: wired, dotted line: wireless)



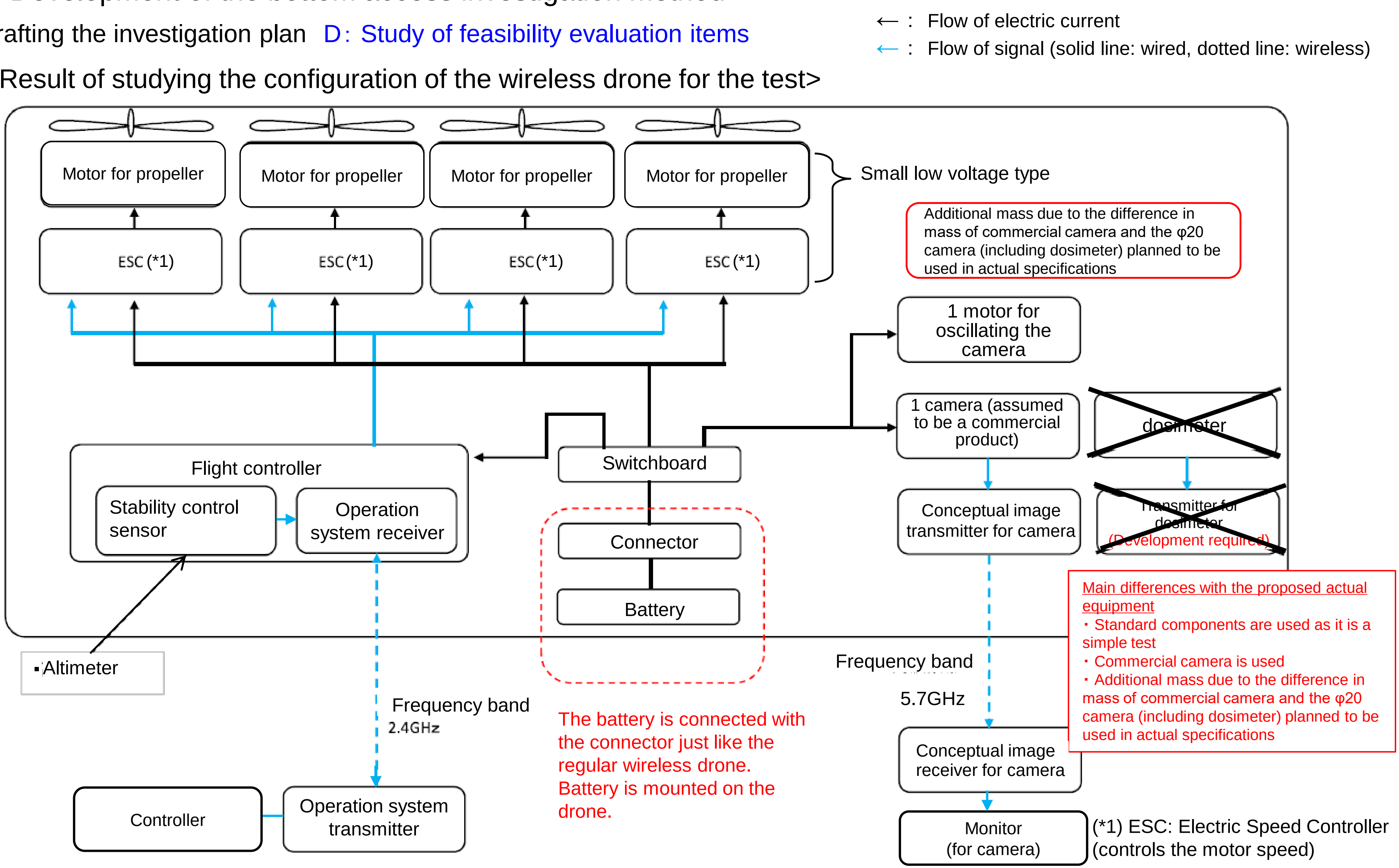
(*1) ESC: Electric Speed Controller (controls the motor speed)

6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting the investigation plan D: Study of feasibility evaluation items

<Result of studying the configuration of the wireless drone for the test>



6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone]

<Development issues concerning wired drones, response policy (target specifications) and simple test details>

Classification	Development issues	Response policy (target specifications)	Simple test	Items to be verified	Test No.	Study results
Main body of wired drone	Size	Shall be structured so that it can pass through the inner diameter of guide pipe (φ290mm)	Single unit test	Size	1-1	Refer to No. 47
	Payload	The combined weight of the drone main body and the cable shall be such that it can be hauled.	Single unit test	Payload, flight level	1-1	Refer to No. 47
	Flight stability	Shall be able to fly through a 1000mm diameter opening and shall be controlled only with the help of the image from the mounted camera.	Combined test	Ability to pass through CRD / RPV opening	1-5 1-6	Refer to No. 51 and 52
	View area (Scope of investigation)	・Shall be able to fly up to the top surface of CRD housing (height 7m) ・Shall be able to view 90° vertically and 360° horizontally	Single unit test	Ability to rotate	1-2	Refer to No. 48
Cable	Stable power supply	Power supply of 350V shall be possible at 50m	–	–	–	Only specifications were studied (detailed study planned to be conducted in FY2021)
	Stable communication	Shall be able to be controlled even at the farthermost location. And, images shall be uninterrupted.				
Cable Drum	Propriety of cable feeding / winding	Assuming that the drone flies up to the interior of the RPV, 15m of cable shall be able to be fed / wound remotely	Single unit test	Propriety of cable feeding / winding	1-3	Refer to No. 49
	Size	Size shall be smaller than a semi-circle of φ290mm as it is mounted on to the crawler.				
	Structure	Shall be able to be operated remotely. Shall be motor-driven.	–	–	–	Detailed study planned to be conducted in FY2021
	Torque	Assuming that the drone flies up to the interior of the RPV, the torque shall be able to haul a 15m cable. (Trial evaluation needs to be conducted)	–	–	–	Detailed study planned to be conducted in FY2021
Cable feed mechanism	Propriety of cable feeding / winding	Shall be mounted at the tip of the extension rod and shall be able to feed / wind 7m of cable remotely in order to make the drone fly up to the RPV interior.	Single unit test	Propriety of cable feeding / retracting	1-4	Refer to 50.
	Structure	The basic structure shall have a passive pulley.				
Extension rod	Structure	Multistage CFRP (*1) rods shall be drawn out by means of air drive.	–	–	–	Technology developed as part of other subsidized projects is used.
	Size	Size shall be smaller than a semi-circle of φ290mm when not extended, as it is mounted on to the crawler.				
	Payload	Cable feed mechanism shall be able to be mounted at the tip.				

(*1) CFRP: Carbon Fiber Reinforced Plastics

6. Implementation Details

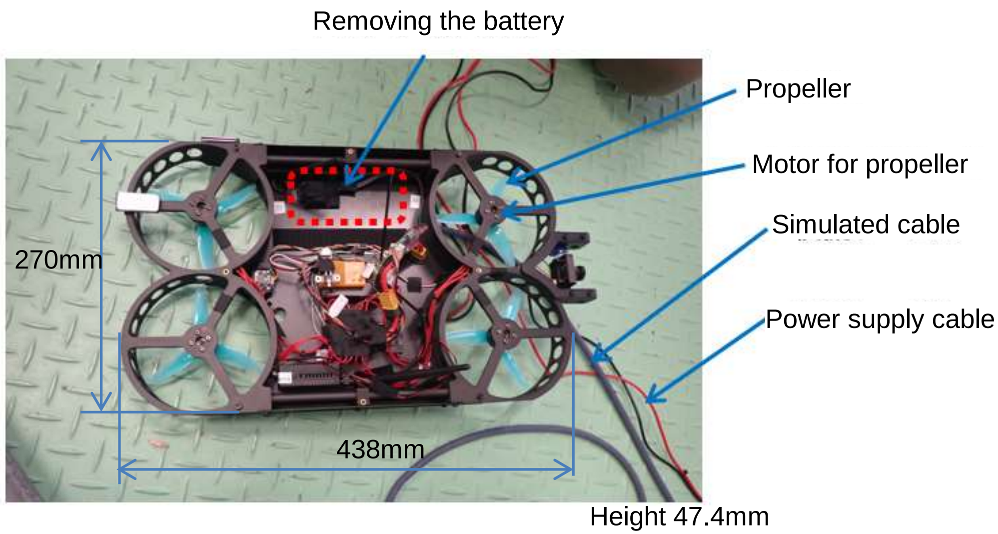
(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-1

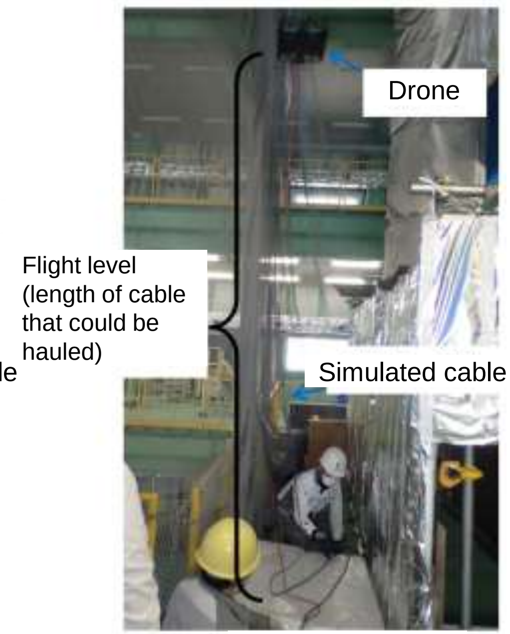
<Unit test: Wired drone (size, payload, flight level)>

[Overview] (1) The size of the wired drone was verified.
(2) The payload of the wired drone was verified.
・A simulated cable for measuring the flight level was installed on the drone, the drone was flown up to a height to which the cable could be raised, the length of the cable that could be hauled was measured, and the payload was calculated based on the unit weight of the cable.

[Result] (1) The size of the drone was length 438mm, width 270mm and height 47.4mm, and it could pass through the inner diameter of the guide pipe which was less than φ290mm.
(2) The flight level was about 3 to 5 m, and the payload calculated from the length of cable hauled was 465 to 800g.
Due to a voltage drop in the power supply cable, the target flight level of 7m could not be reached. Hence the specifications of the power supply cable need to be revised.



External appearance of the drone (*1)



Test condition

(*1) A wireless drone was simulated with the specifications of a wired drone and the test was conducted.

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-2

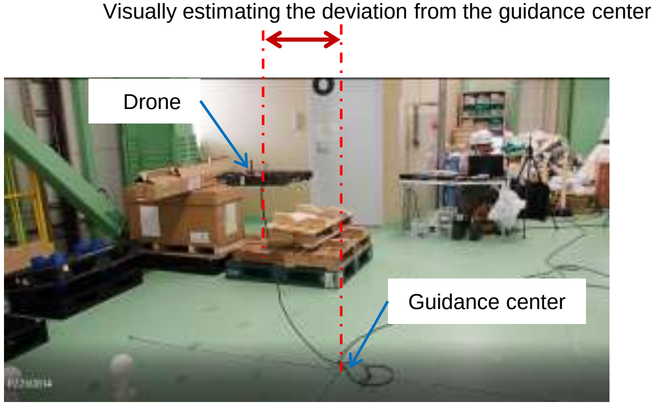
<Unit test: Wired drone (ability to turn)>

[Overview] (1) Since the panning function of the camera is supposed to work for the turning movement of the drone, the deviation from the guiding center was verified to confirm turning performance.

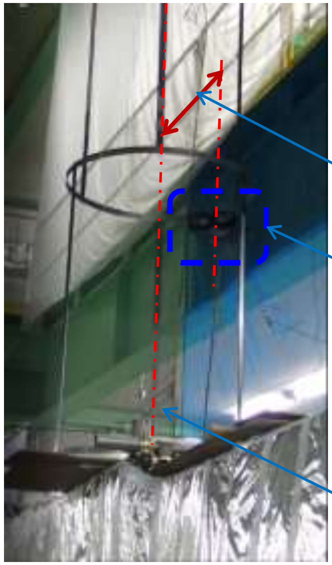
[Result] (1) The drone turned φ2 to φ2.5m at a flight level of 1 to 2m, and φ1 to φ1.5m at a flight level of 4 to 5m, which is larger than the size of the RPV opening, which is φ1. Hence it would not be able to turn within φ1m.

(2) In order to enhance the turning performance of the drone, it is necessary to change the current arrangement of the 4 propellers from their current rectangular placement to a more square shaped placement so that the propellers become equidistant, however, this is difficult to achieve due to dimensional constraints.
(If the propellers are arranged at long equal intervals along the length of the drone, the inner diameter of the guide pipe becomes φ290mm or more and hence this arrangement is not possible. And, if the propellers are arranged at short equal intervals along the width of the drone, the space available for mounting equipment such as flight controller, etc. is reduced and the required equipment cannot be mounted.)

(3) Due to the above-mentioned factors, measures to enhance turning performance will not implemented, and the method of not making the drone turn inside the RPV opening as far as possible will be applied but investigating the status inside the RPV bottom, which was going to be verified by turning the drone, from a height in the vicinity of the top surface of the CRD housing, by installing a camera with a pan-tilt mechanism on the under surface of the drone, will be studied.



Test conditions (flight level: 1 to 2m)



Test conditions (flight level: 4 to 5m)

6. Implementation Details

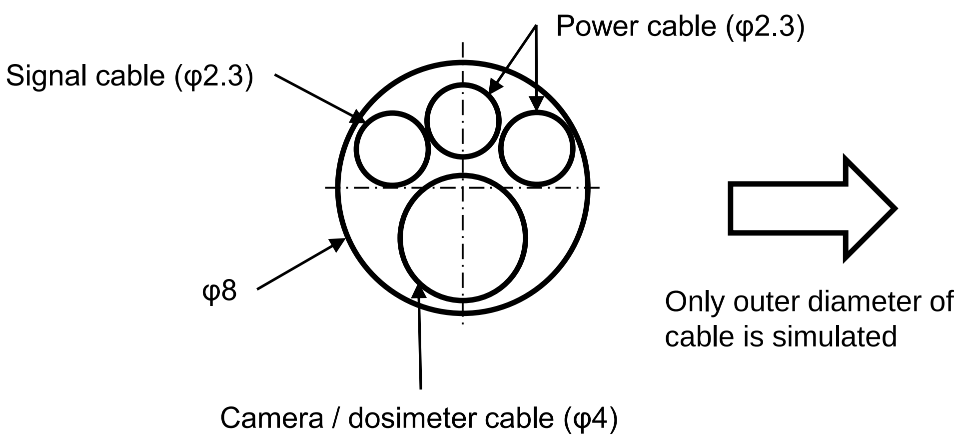
(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-3

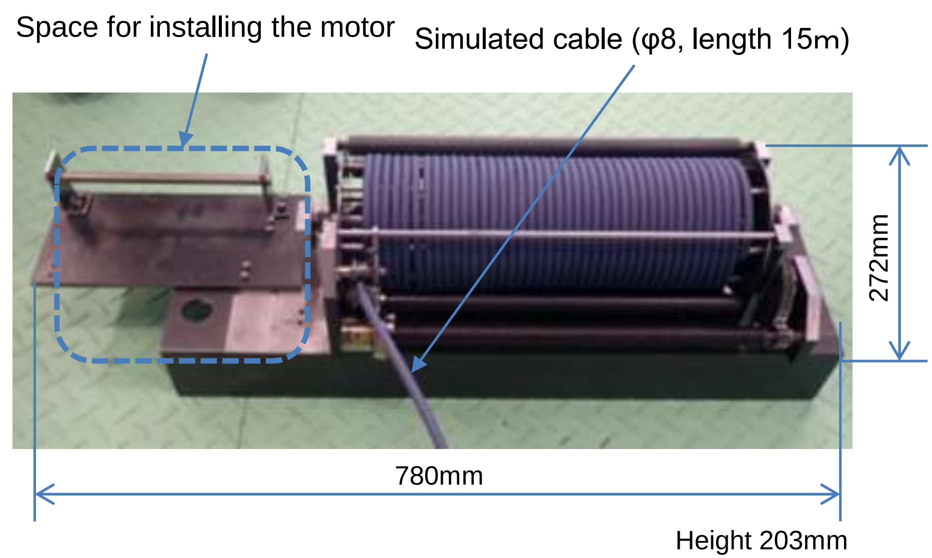
<Unit test: Cable drum (propriety of cable feeding / winding)>

[Overview] (1) Availability of cable feeding and winding was verified when a 15m long cable is stored in the cable drum (manual).

[Result] (1) The outer diameter of the composite cable for the wired drone was studied, and a manual cable drum was test manufactured.
(2) Availability of cable feeding and winding was verified and a 15m long cable can be stored in a size of φ290mm.



Study on outer diameter of the composite cable for the drone



External appearance of the cable drum

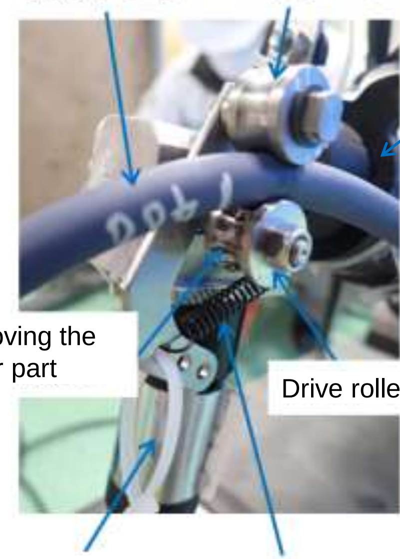
6. Implementation Details

(2) Development of the bottom access investigation method

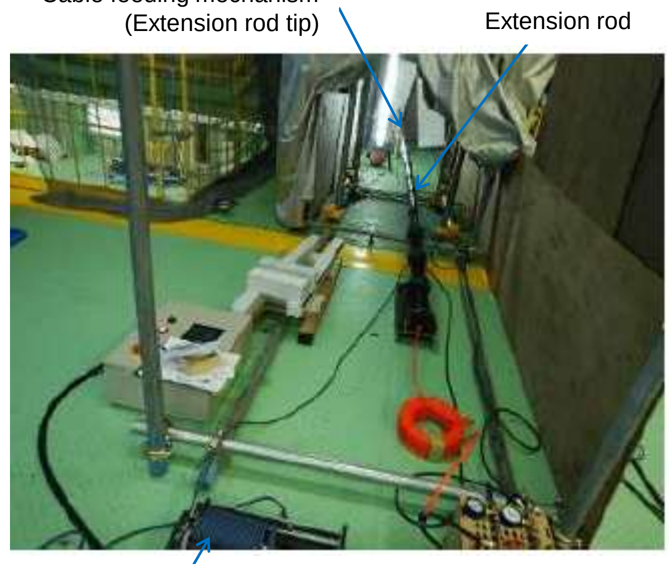
2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-4

<Unit test: Cable feed mechanism (propriety of cable feeding / retracting operation)>

[Overview] (1) Availability of cable feed/pullback operation with cable feed mechanism was verified
[Result] (1) It was verified that cable feed mechanism can feed a cable in 7m length required for the drone and pullback a cable.



Cable feeding mechanism



Test condition

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-5

<Combination test with the extension rod, etc.: Ability to pass through the CRD / RPV opening part, whether or not the cable gets entangled, investigation / movement pattern>

[Overview] (1) The wired drone, cable feed mechanism, extension rod and cable drum were combined and the movement was verified by simulating the CRD opening part and the RPV opening part.

(2) The movement was confirmed for the following 2 patterns as per the movement procedures during investigation.

・Movement pattern A: Onward path — Flying the drone to right below the RPV opening part (hovering on stand-by) → drawing out the extension rod → moving the drone upwards / investigating

Return path — Lowering the drone to right below the RPV opening part (hovering on stand-by) → drawing in the extension rod → flying the drone outside the CRD opening part

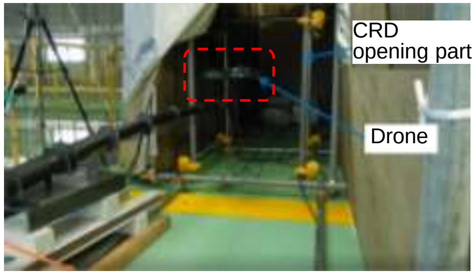
・Movement pattern B: Onward path — Drawing out the extension rod → flying the drone to right below the RPV opening part → moving the drone upwards / investigating

Return path — Flying the drone outside the CRD opening part → drawing in the extension rod

[Result] (1) Movement pattern A is suitable considering the risk of the drone cable getting caught in the extension rod.

[Evaluation legend] ○: No problem, △: There is concern, ×: Not possible

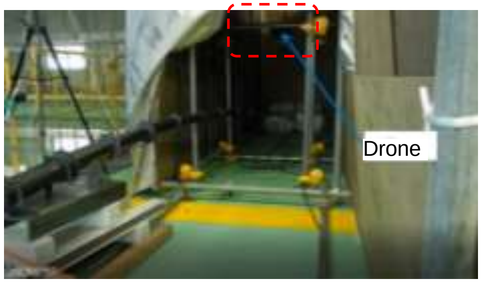
No.	Ability to pass through CRD opening part	Ability to pass through RPV opening part	Cable getting caught	Conceptual image from the camera while flying	Remarks
Movement pattern A	○	○	○	○	・The cable came in contact with the floor while the drone was being lowered from the RPV opening part.
Movement pattern B	○	○	△	○	・The cable came in contact with the floor while the drone was being lowered from the RPV opening part. ・On the return path, there was an event of the cable being caught in the extension rod.



[Flying state]

[Camera image]

Test condition (while passing through the CRD opening part)



[Flying state]

RPV opening

[Camera image]

Test condition (while passing through the RPV opening part)

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wired drone] Test No.: 1-6

<Combination test with the extension rod, etc.: Ability to pass through the CRD / RPV opening part, whether or not the cable stuck, investigation / movement pattern>

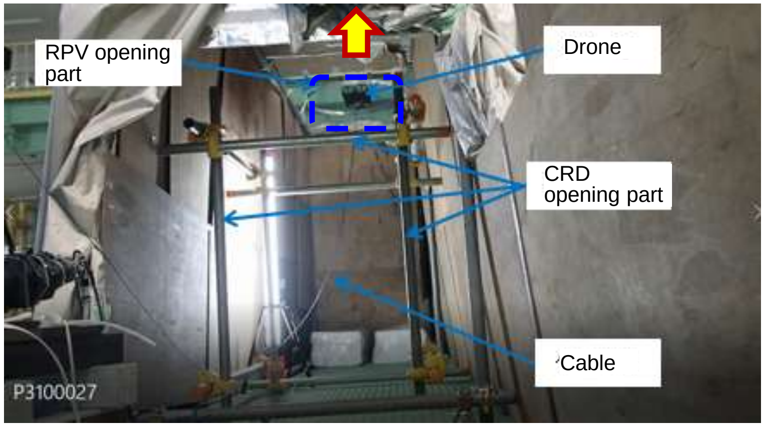
[Overview] (1) The wired drone and cable drum were combined and the movement was verified by simulating the CRD opening part and the RPV opening part.

[Result] (1) The drone flight may be possible inside the pedestal and RPV even if not using the cable feed mechanism and the extension rod for preventing the cable from getting caught in the CRD opening part, etc., which is designed to reduce the load resulting from cable mass. However, it is necessary to consider measures to prevent the contact of the floor (by synchronizing the drone flight and cable drum winding operation) as the cable contacts with the floor while the drone is being lowered.

[Evaluation legend] ○: No problem, △: There is concern, ×: Not possible

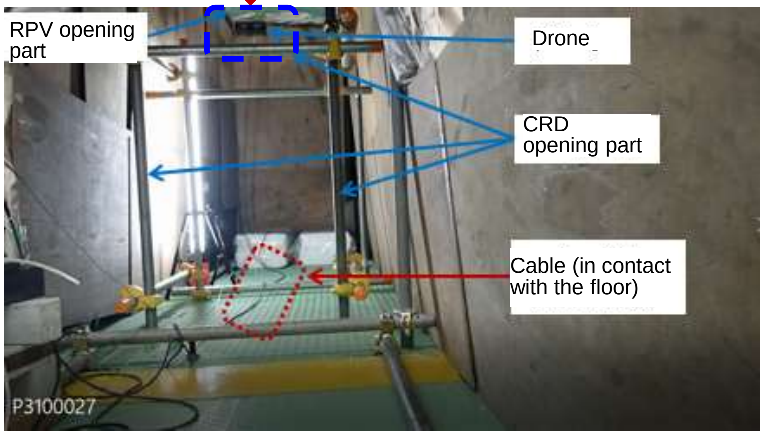
No.	Ability to pass through CRD opening part	Ability to pass through RPV opening part	Cable stuck	Conceptual image from the camera while flying	Remarks
1	○	○	○	○	The cable came in contact with the floor while the drone was being lowered from the RPV opening part.

Flying direction of the drone (upwards)



Test condition (while moving upwards to the RPV opening part)

Flying direction of the drone (downwards)



Test condition (while moving downwards from RPV opening part)

6. Implementation Details

Unit 1

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wireless drone]

<Development issues concerning wireless drones, response policy (target specifications) and simple test details>

Classification	Development issues	Response policy (target specifications)	Simple test	Items to be verified	Test No.	Study results
Main body of wireless drone	Size	Shall be structured so that it can pass through the inner diameter of guide pipe (φ290mm)	Single unit test	Size	2-1	Refer to No. 54
	Payload	The weight of the drone main body can be hauled	Single unit test	Payload, flight level	2-1	Refer to No. 54
	Battery life	Flight ability for 10 minutes (tentative) (Assuming that the investigation time is 1 min - 4 minutes and the time for flying a round trip is 6 minutes)	Single unit test	Flight duration	2-2	Refer to No. 55
	Flight stability	Flight ability in a range of 1000mm diameter and shall be controlled only with the help of the image from the mounted camera.	Combined test	Ability to pass through CRD / RPV opening, etc.	2-5	Refer to No. 58
	View area (Scope of investigation)	・Flight ability up to the top surface of CRD housing (height 7m) ・Visual confirmation of 90° vertically and 360° horizontally	Single unit test	Ability to rotate	2-3	Refer to No. 56
Wireless system	Communication stability	Communication ability in environments through the entire or part of the PCV concrete, control rod drive mechanism and lower head of RPV, even if the signal strength reduces.	Single unit test	Verification of communication performance	2-4	Refer to No. 57
Extension rod	Structure	Multistage CFRP (*1) rods shall be extended with the air drive.	–	–	–	Technology developed as part of other subsidized projects is used.
	Size	Size shall be smaller than a semi-circle of φ290mm when stored, as it is mounted on to the crawler.				
	Payload	Transceiver can be mounted at the tip.				

(*1) CFRP: Carbon Fiber Reinforced Plastics

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wireless drone] Test No.: 2-1

<Unit test: Wireless drone (size, payload, flight level)>

[Overview] (1) The size of the wireless drone was verified.

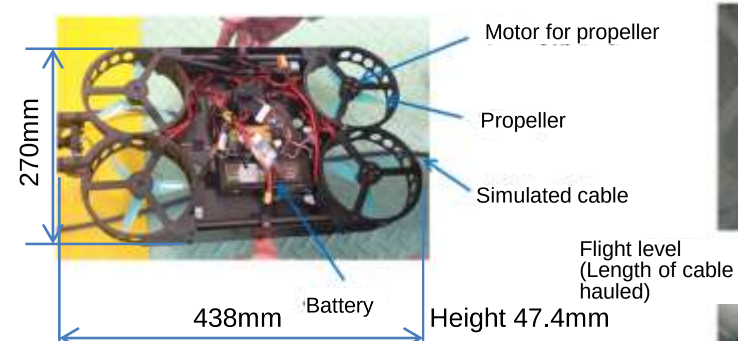
(2) The payload of the wireless drone was verified.

- A simulated cable for measuring the flight level was installed on the drone, the drone was flown up to a height to which the cable could be raised, the length of the cable that could be hauled was measured, and the payload was calculated based on the unit weight of the cable.
- The upper limit of the payload was verified by adding weight to the lower part of the wireless drone and making it fly.

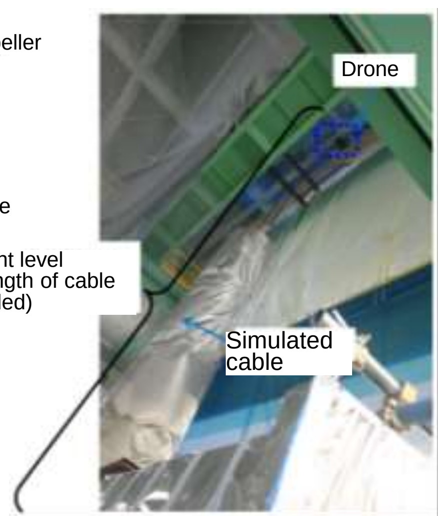
[Result] (1) The drone with the size of 438mm length, 270mm width and 47.4mm height passed through the inner diameter of the guide pipe which was less than φ290mm.

(2) The flight level was approximately 9 ~ 10m, and the payload calculated from the length of cable traction was 882g on an average.

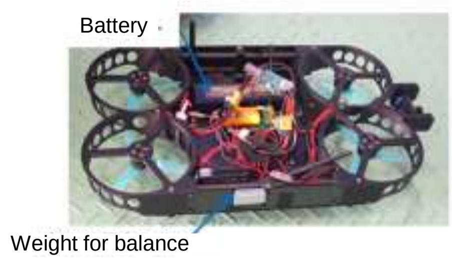
(3) When a weight of 900g, 1000g, 1100g and 1200g was added to the drone, there was no problem until the weight added was 1100g. When 1200g of weight was mounted on the drone, upward flight was possible but wobbling of the drone increased and as the current value of the propeller motor exceeded 80A as against the battery current (3.5A), due to which the battery could get damaged, the upper limit of payload for this drone was considered to be 1100g.



[External appearance of the drone: top surface]

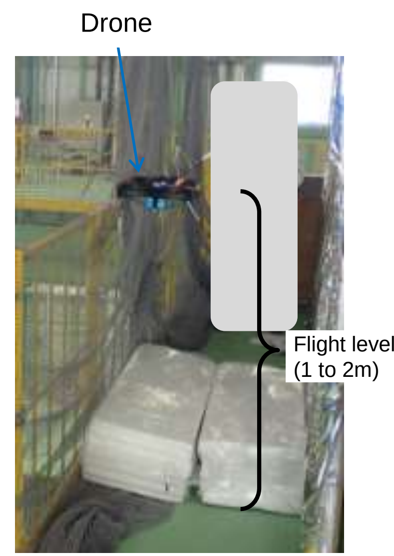


Test condition (measurement of cable traction length)



[External appearance of the drone: top surface]

[External appearance of the drone: underside]



Test condition (verification of upper limit of payload)

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wireless drone] Test No.: 2-2

<Unit test: Wireless drone Continuous flight duration (battery life))>

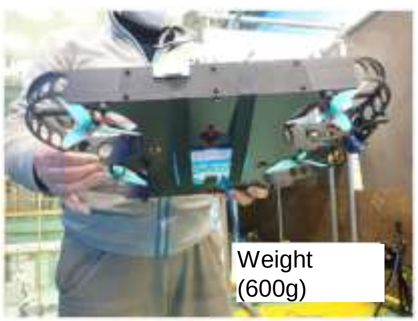
[Overview] (1) Continuous flight duration of the wireless drone (battery life) was verified.

[Result] (1) Following are the results of verifying the continuous flight duration (battery life) of the wireless drone.

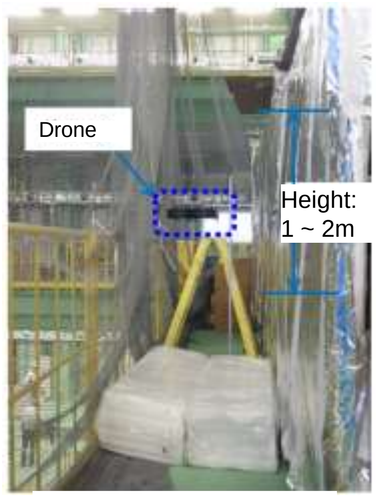
- Hovering: 4min 23s to 4min 40s
- Repeating upward and downward movement: (round trip between 1 to 7m) 2min 26s to 2min 36s, (round trip between 1 to 2m) 2min 35s to 3min 22s

(2) If the investigation time inside RPV is 10min (tentative) (assuming that the investigation time is 1 - 4 minutes and the time for flying a round trip is 6 minutes), since there is no margin in the flight duration, measures such as increasing the size of the battery or installing multiple batteries are needed.

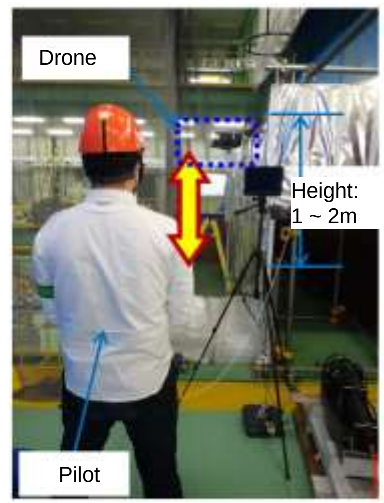
[External appearance of the drone: top surface]



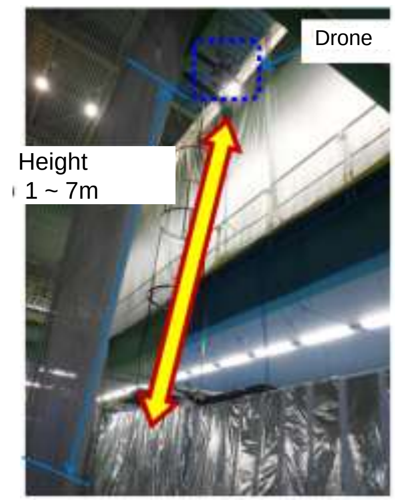
[External appearance of the drone: underside]



[Hovering
: Flight level 1 to 2m]



[Repeating upward and downward movement
: Round trip of flight level 1 to 2m]



[Repeating upward and downward
: Round trip of flight level 1 to 7m]

Test condition

2. Feasibility study E: Performing tests, etc. [Wireless drone] Test No.: 2-3

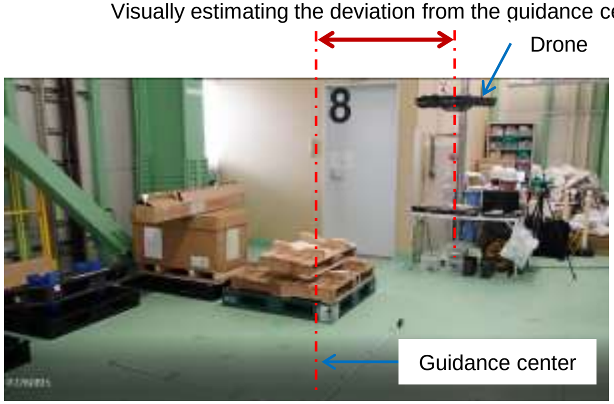
<Unit test: Wireless drone (ability to turn)>

[Overview] (1) Since the panning function of the camera is supposed to work by means of the turning movement of the drone, the deviation from the guiding center was verified to confirm turning performance.

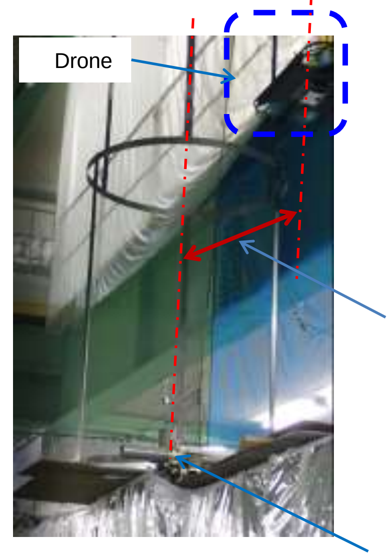
[Result] (1) The drone turned φ2m at a flight level of 1 ~ 2m, and φ4 to φ7m at a flight level of 4 ~ 5m, which is larger than the size of the RPV opening, which is φ1. Hence it would not be able to turn within φ1m.

(2) In order to enhance the turning performance of the drone, it is necessary to change the current arrangement of the 4 propellers from their current rectangular placement to a more square shaped placement so that the propellers become equidistant, however, this is difficult to achieve due to dimensional constraints.
(If the propellers are arranged at long equal intervals along the length of the drone, the inner diameter of the guide pipe becomes φ290mm or more and hence this arrangement is not possible.
And, if the propellers are arranged at short equal intervals along the width of the drone, the space available for mounting equipment such as flight controller, etc. is reduced and the required equipment cannot be mounted)

(3) Due to the above-mentioned factors, measures to enhance turning performance will not implemented, and the method of not making the drone turn inside the RPV opening as far as possible will be applied but investigating the status inside the RPV bottom, which was going to be verified by turning the drone, from a height in the vicinity of the top surface of the CRD housing, by installing a camera with a pan-tilt mechanism on the under surface of the drone, will be studied.



Test conditions (flight level: 1 ~ 2m)



Test conditions (flight level: 4 ~ 5m)

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. [Wireless drone] Test No.: 2-4

<Unit test: Wireless drone (verification of ability to communicate)>

[Overview] (1) The ability to communicate based on the position of the drone and the transceiver was verified. (The drone was placed inside the RPV (plate thickness 200mm) and the transceiver was placed inside the pedestal, and the ability to communicate from an assumed RPV opening of φ1000mm was verified.)

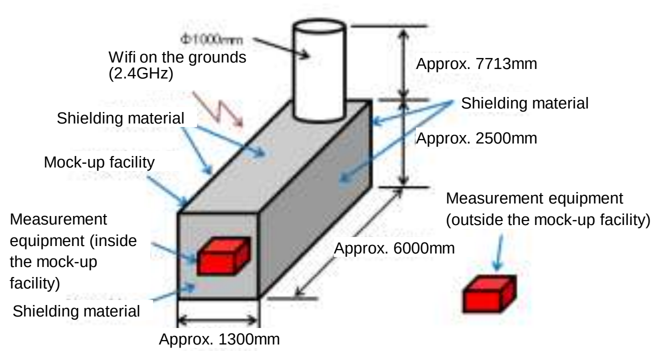
[Result] (1) A transceiver was placed inside a mock-up facility with radio shielding and the drone was flown through a simulated opening of φ1000mm. The drone was operated at any location regardless of the location of the transceiver and the φ1000mm opening. At this time, the normal signal intensity of -45dBm became about -57dBm due to the radio shielding on the mock-up facility.

(2) In order to measure the signal intensity that would result in the drone not being able to fly, the drone was placed inside a metal container with plate thickness 28mm and a radio shielding unit test was conducted. It was confirmed that the signal was attenuated up to about -85dBm, but the drone was still operated. It is presumed that signal leaked through a small gap in the container and thus complete radio shielding was not achieved.

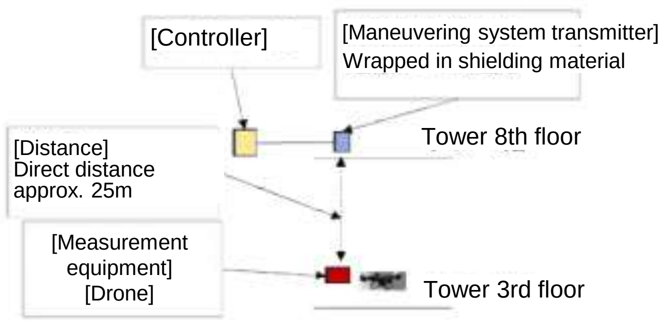
(3) The drone was not operated when the transmitter was wrapped in 2 layers of shielding sheet and the drone was placed on a different floor at a distance of approx. 25m to 30m.
However, radio waves other than the drone signal were measured and since these were difficult to be distinguished from the drone signal, the signal intensity was not measured.

(4) Based on the above, it is presumed that the drone was operated in (1) since radio shielding comparable to the 200mm plate thickness of RPV was not achieved and signal had been leaking.

(5) In the actual equipment, although the radio waves are completely shielded in the RPV, it is believed that the drone is operable depending on the location of the φ1000mm opening part, and the drone & transceiver. Hence testing methods and conditions in which radio shielding equivalent to the actual RPV can be achieved, need to be studied, tested and verified.



Test image (verification of the attenuation effect in the testing facility)



Test image (verification of the attenuation effect when shielding methods are combined)

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E : Performing tests, etc. [Wireless drone] Test No.: 2-5

<Combination test with the extension rod, etc.: Ability to pass through the CRD / RPV opening part, investigation / movement pattern>

[Overview] (1) The wireless drone and extension rod (with transceiver mounted on its tip) were combined and the movement was verified by simulating the CRD opening part and the RPV opening part.

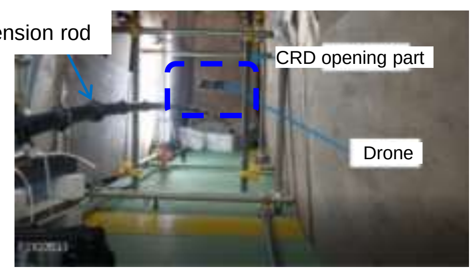
(2) The movement was verified for the following 2 patterns as per the movement procedures during investigation.

- Movement pattern A: Onward path — Flying the drone to right below the RPV opening part (hovering on stand-by) → drawing out the extension rod → moving the drone upwards / investigating
  - Return path — Lowering the drone to right below the RPV opening part (hovering on stand-by) → drawing in the extension rod → flying the drone outside the CRD opening part
- Movement pattern B: Onward path — Drawing out the extension rod → flying the drone to right below the RPV opening part → moving the drone upwards / investigating
  - Return path — Flying the drone outside the CRD opening part → drawing in the extension rod

[Result] (1) Although there was no significant difference in movement pattern A and B, considering the flight duration (battery life), movement pattern B was found to be suitable since there was no hovering on stand-by time.

[Evaluation legend] ○ : No problem, △ : There is concern, × : Not possible

No.	Ability to pass through CRD opening part	Ability to pass through RPV opening part	Cable getting caught	Conceptual image from the camera while flying	Remarks
Movement pattern A	○	○	–	○	During the downward movement from the RPV opening part, there was an error in operation and the drone crashed.
Movement pattern B	○	○	–	○	



[Flying state]

[Camera image]

Test condition (passing through the CRD opening part)

[Flying state]

[Camera image]

Test condition (passing through the RPV opening part)

6. Implementation Details

(2) Development of the bottom access investigation method

3. Feasibility evaluation F: Evaluation based on the test results

<Evaluation of the simple tests results>

[Evaluation result legend] ○: Applicable, △: Can become applicable upon revising the specifications, etc., ×: Application is difficult, ー: Out of scope of evaluation

Outline of investigation		Pattern 1		Pattern 2		Pattern 3		Pattern 4 (*1)	
Investigation equipment		Wired drone		Wired drone		Wireless drone		Wireless drone	
Auxiliary equipment		① Cable feed mechanism ② Extension rod ③ Cable drum		① Cable drum		① Extension rod ② Transceiver		① Transceiver	
Evaluation items	Flight level	△	Cannot fly to the required height of 7m due to drop in voltage.	△	Same as on the left	○	Can fly to the required height of 7m.	○	Same as on the left
	Flight duration (Battery life)	○	Unlimited.	○	Same as on the left	△	Limited.	△	Same as on the left
	Communication stability	—	No wireless communication	—	Same as on the left	△	Difficult to completely block the radio waves (same is presumed for actual equipment as well).	△	Same as on the left
	Ability to pass through CRD opening part	○	Does not come in contact with simulated CRD opening part.	○	Same as on the left	○	Does not come in contact with simulated CRD opening part.	○	Same as on the left
	Ability to pass through RPV opening part	△	Sometimes there is contact with the simulated RPV opening part and the flight is not smooth.	△	Same as on the left	△	Sometimes there is contact with the simulated RPV opening part and the flight is not smooth.	△	Same as on the left
	Combination with auxiliary equipment inside the pedestal	△	The cable may get caught in the drawn out extension rod.	―	Not applicable	○	No problem in particular.	―	Not applicable

(*1) The test results of pattern 4 are an estimation from the test results of pattern 3.

Although flight level is a challenge, the wired drone that does not have a limit on flight duration will be used. (Pattern 2 that does not have the risk of the cable getting caught, and which has fewer equipment configurations, will be used.)
And, the wireless drone will be considered as a back-up for the wired drone. (Pattern 3 will be used assuming there is the risk of radio shielding in the actual equipment.)

(2) Development of the bottom access investigation method

3. Feasibility evaluation F: Evaluation based on the test results

[Proposed Response Policy for FY2021]
Based on the results of the simple tests, the issues will be studied in FY2021.

Classification	Issues	[Proposed Response for FY2021]
Wired drone (Pattern 2)	Stable supply of feeding voltage	・Selecting a DC-DC converter that can drive the motor for the propeller
	Lack of flight level due to voltage drop in the power supply cable	・Reducing the weight of the power supply cable (with high voltage and low current specifications) ・Test manufacturing the composite cable (operation system, power supply, camera) ・Test manufacturing the small high voltage type motor and ESC along with reducing the weight of the power supply cable (it is surmised that the small low voltage type used this time can be used if a DC-DC converter that can convert high voltage to low voltage can be mounted)
Wireless drone (Pattern 3)	Extension of flight duration	・Increasing the battery capacity and the no. of batteries mounted
Common (Environmental conditions)	Radiation resistance	・Irradiation test at the component level and desk study
	Darkness, rainfall	・Considering conducting tests in darkness ・Selecting equipment in accordance with water-proofing standards

6. Implementation Details

(2) Development of the bottom access investigation method

Unit 2 & 3: Development of equipment for accessing the inside of the RPV using telescopic mechanism

<Purpose>

To perform simple tests on the method of accessing the inside of RPV from inside the pedestal by mounting an access equipment that uses telescopic mechanism, on to the arm type access equipment for fuel debris retrieval, and to evaluate its feasibility as a bottom access investigation method for Unit 2 and 3.

<Implementation details>

The following 3 types of simple tests were implemented.

- ○ CFRP bonded part strength verification test
- ○ Sealing performance verification test
- ○ Behavior verification test

<Results>

The basic performance (stretching movement, extension) of the 14 stage telescopic access equipment, the design of which is being studied, was verified through simple tests using a three-stage telescopic pipe. Issues such as high sliding resistance or leakage from the sealed portion came forth, however, it was evaluated that the mechanism itself was feasible.

<Remaining issues>

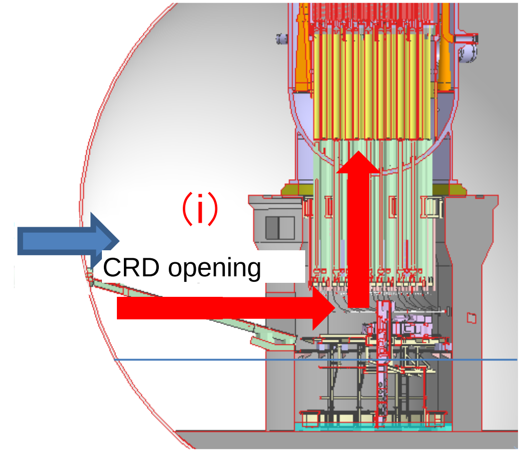
- ･Reducing the sliding resistance and the amount of leakage from the sealed portion
- ･ Coordinating the specifications and working with arm type access equipment being developed under other projects

6. Implementation Details

(2) Development of the bottom access investigation method

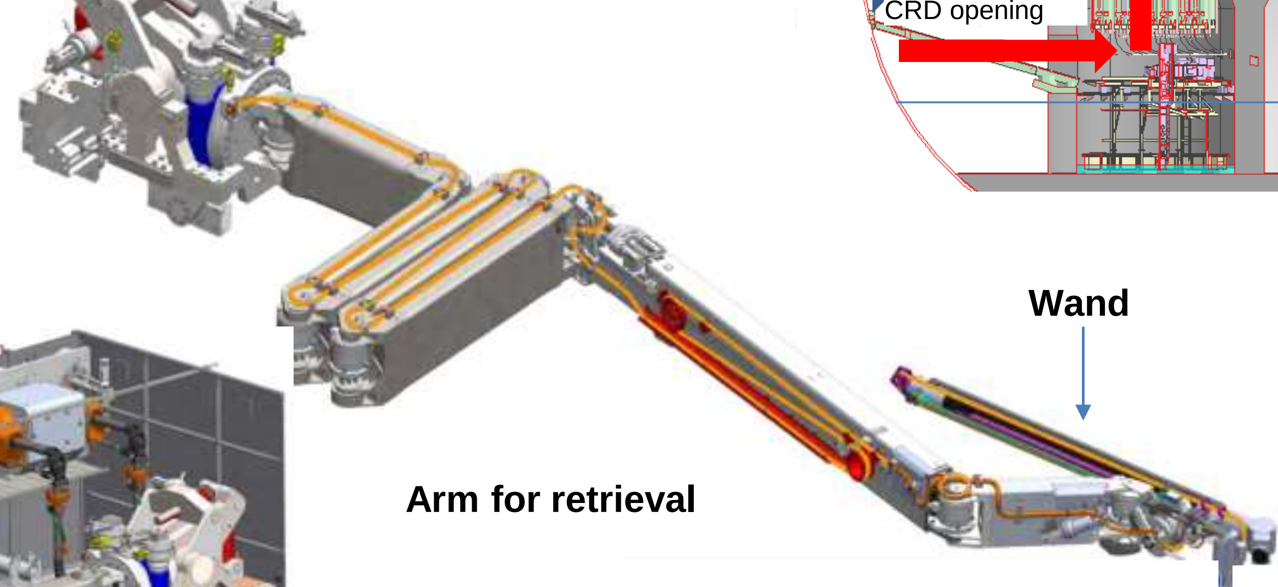
1. Drafting of the investigation plan C: Organization of applicable technologies

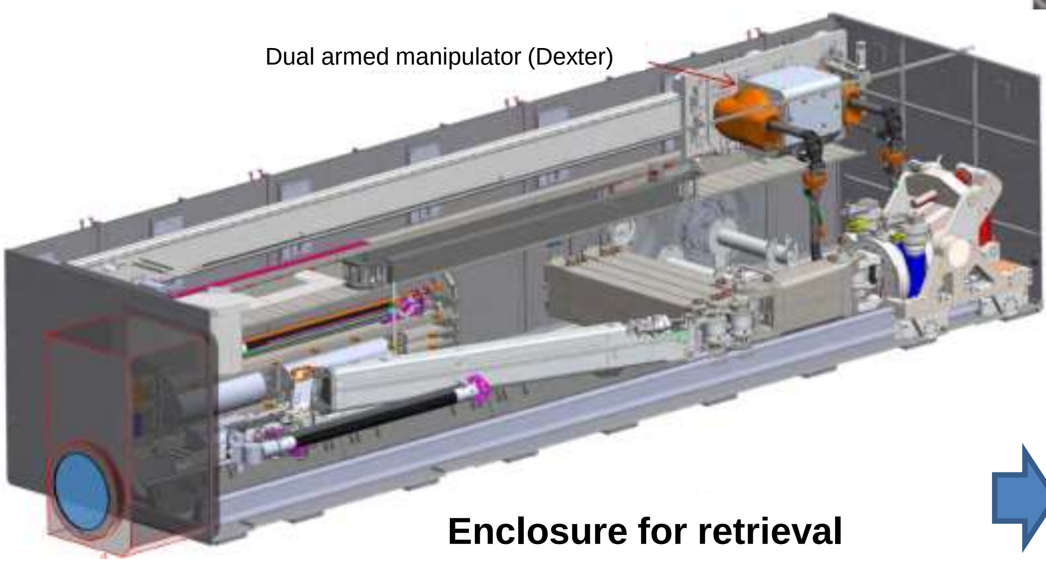
(i) Equipment for access to the inside of the pedestal



Unit 2 : Status of development of the technology for increasing the scale of fuel debris retrieval in stages

Items	Specifications
Location for access inside the PCV	X-6 penetration
Location for access to the inside of the pedestal	CRD opening (in air)
Equipment for access to the inside of the pedestal	Arm for retrieval





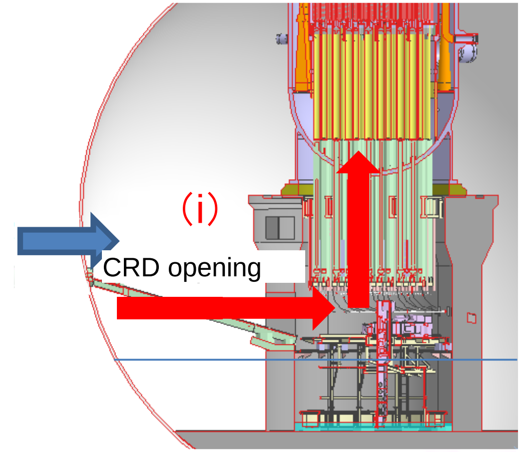
It is anticipated that the access equipment for retrieval (arm, enclosure, etc.) can be used as the equipment for access to the inside of the pedestal

6. Implementation Details

(2) Development of the bottom access investigation method

1. Drafting of the investigation plan C: Organization of applicable technologies

(i) Equipment for access to the inside of the pedestal

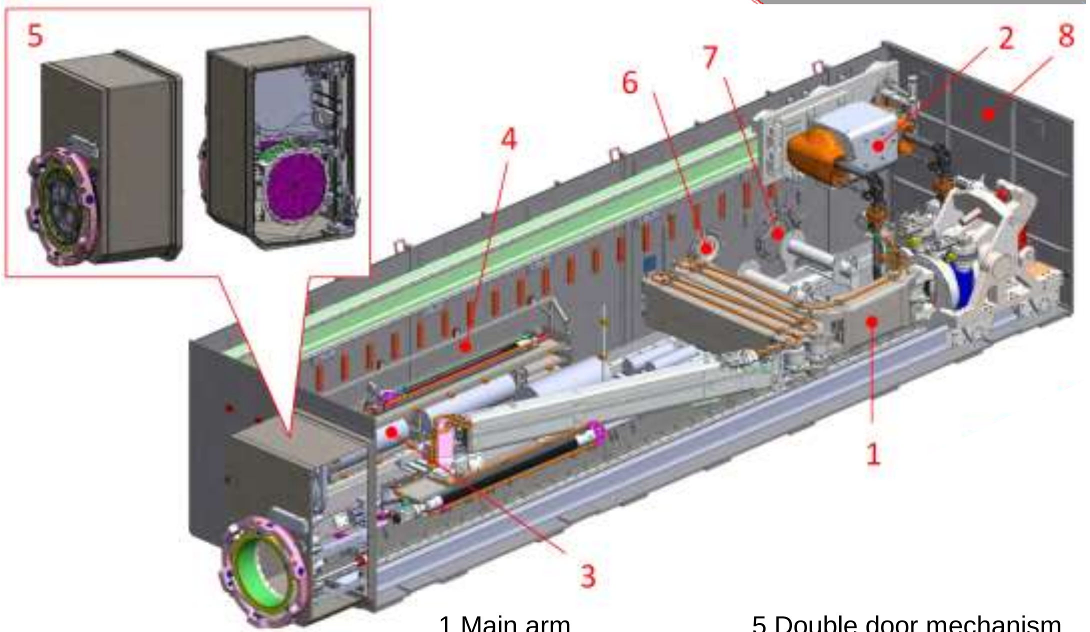


Unit 2： Status of development of the technology for increasing the scale of fuel debris retrieval in stages

Using the arm-type access equipment being developed under the “Development of Technology for Increasing the Scale of Fuel Debris Retrieval in Stages” project was considered, and a meeting was held for coordinating with said project so as to be able to make the equipment work without making any modifications, etc. as far as possible.

The operation of the tip tool (main working conditions if absolutely no modifications will be made) is described below.

- The tip tool shall be connected to the arm at the tool changer part at the tip of the arm for retrieval.
- As far as dimensional constraints are concerned, the total length of the tip tool inside the enclosure shall be 700mm.
- While removing the contaminated tool from the enclosure, the tool must be placed in a container called DPTE350, but as the depth of the container is approx. 400mm, it should be possible to break up the tool being mounted on the arm so that it fits in the container.
- With regards to dimensional constraints, the diameter of the equipment shall be φ250mm and the cross-sectional shape of the equipment shall be such that it can pass through X-6 penetration.
- The conveyable weight of the arm shall be 15kg.
- The utilities that can be supplied to the tool at the tip are restricted due to the specifications of the cable installed on the arm.
- The tool at the tip shall be handled by dual armed manipulator (Dexter). And, a hoisting tool needs to be installed.　Etc.



1 Main arm
2 Dexter manipulator
3 Tools
4 Tool storage rack
5 Double door mechanism
6 DPTE270 (Padirac) port
7 DPTE350 port
8 Back panel

The restrictions are rigid. Conditions for relaxing those restrictions will be developed by taking operation related actions or other minor changes.

6. Implementation Details

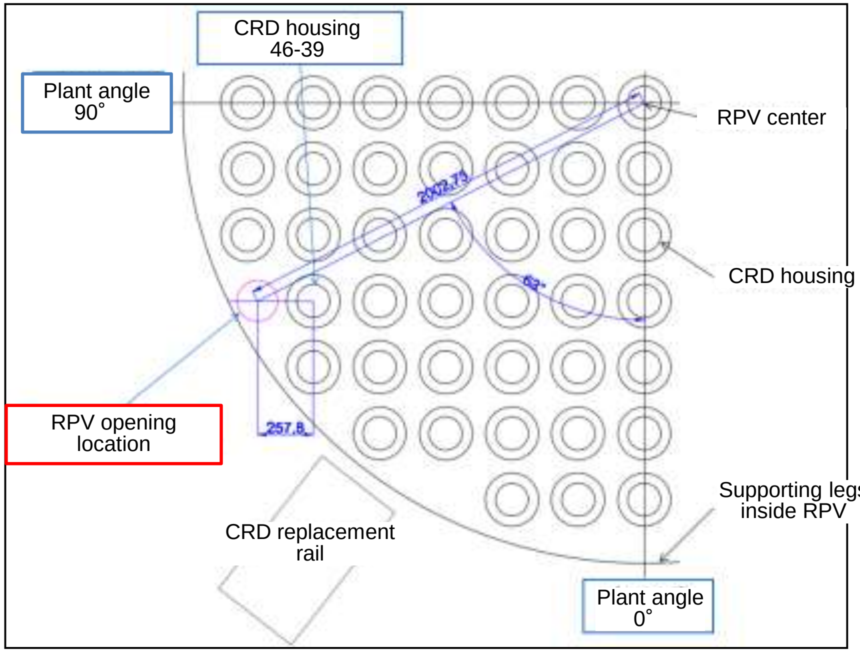
Unit 2 & 3

(2) Development of the bottom access investigation method

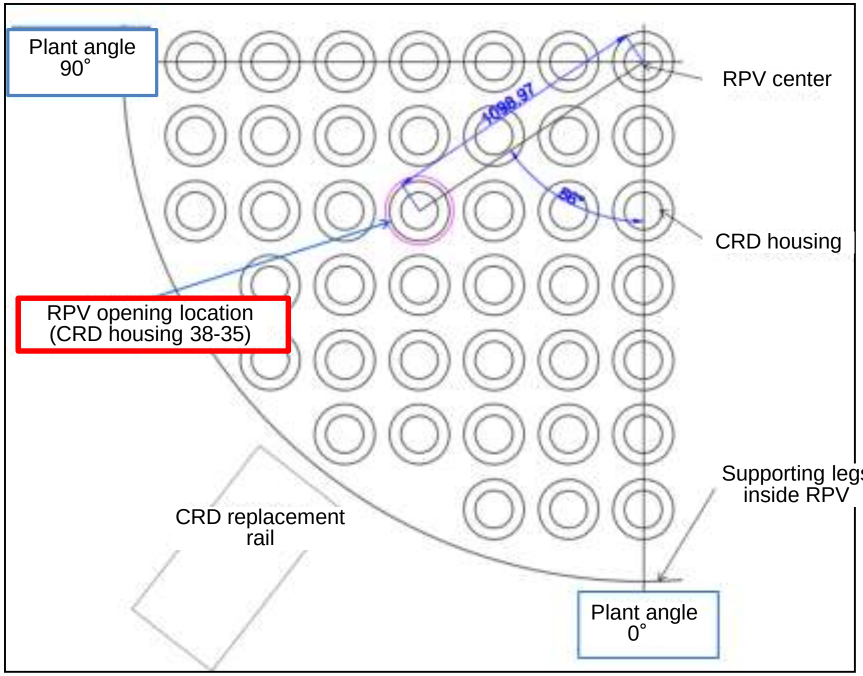
2. Feasibility study D: Study of feasibility evaluation items

Environmental conditions and preconditions pertaining to the bottom access investigation method for Unit 2 and 3

- Dose rate: 100Sv/h
- Temperature: 50° C
- Humidity: 100%
- Other: Darkness, rainfall, fog
- Location for temporarily setting up the RPV bottom opening part
  - ･Unit 2: In the vicinity of CRD housing 46-39
  - ･Unit 3: At CRD housing 38-35
- Outer diameter of the opening at the bottom of the RPV
  - ･Unit 2: 187mm (based on the upper tie plate dimensions)
  - ･Unit 3: 284mm (based on the external dimensions of the CR guide tube)
- Status of the structures below the location for temporarily setting up the RPV bottom opening part:
  - ･Unit 2: There is a cylindrical space of φ187mm below RPV bottom opening part
  - ･Unit 3: There is a cylindrical space of φ284mm below RPV bottom opening part



Unit 2 Location of bottom opening



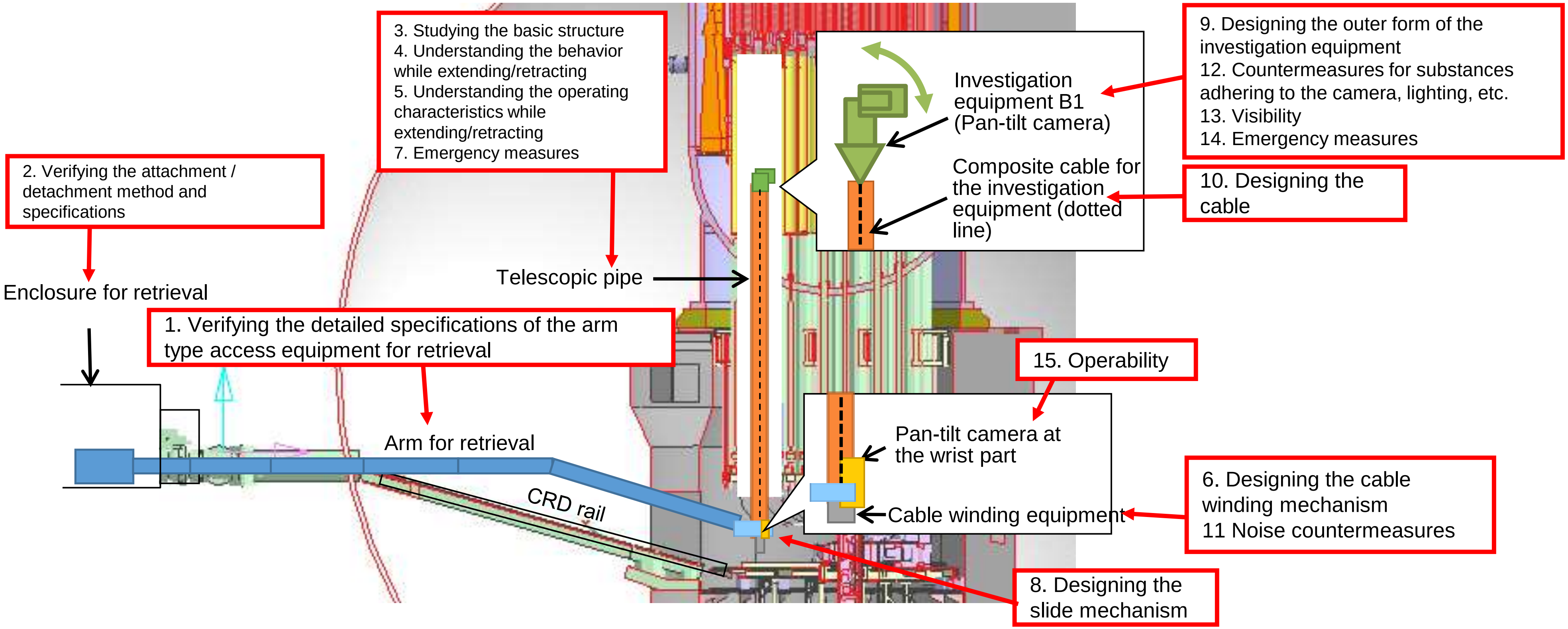
Unit 3 Location of bottom opening

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study D: Study of feasibility evaluation items

Overview of issues pertaining to the bottom access investigation method for Unit 2 and 3



<Rough specifications of the telescopic pipe>

- When retracted: approx. 1m When extended: approx. 8m
- Pipe size: 14 stage configuration from φ97 to 32mm
- Material: CFRP
- Thickness: 1mm
- Weight: approx. 12kg (with camera and cable drum)

In order to be able to extend up to approx. 8m within the dimensional constraints of φ100mm and length approx. 1m, a thin walled telescopic pipe with multi-stage configuration needs to be developed.

6. Implementation Details

Unit 2 & 3

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc.

Issues pertaining to the bottom access investigation method for Unit 2 and 3 (1/2)

Content in red: Items to be verified through simple tests

No.	Major items	Medium items	Minor items	Development issues	Response Policy for FY2020
1	Equipment for access to the inside of the pedestal	Verifying the connection with the arm type access equipment for retrieval	Verifying the detailed specifications of the arm type access equipment for retrieval	・Accuracy in determining the location at the tip ・Deflection and vibrations of the arm ・Range of movement of each shaft ・Conveyable weight ・Specifications of the cable installed outside the arm ・Emergency response policy	・Confirmation with the "Increasing the Scale of Retrieval in Stages" PJ for information that would contribute to the study on equipment specifications
2			Verifying the attachment / detachment method and specifications	・Verification of the feasibility of the transportation container and the procedures for transfer in and out of the enclosure ・Method of installing and removing using Dexter	・Confirmation with the "Increasing the Scale of Retrieval in Stages" PJ for information that would contribute to the study on equipment specifications
3	Equipment for access to the inside of the RPV from inside the pedestal	Designing the telescopic access equipment	Studying the basic structure	・Viability of the structure given the dimensional constraints associated with handling by means of the arm type access equipment for retrieval	・Design study Understanding the impact of environmental conditions on the strength of the telescopic pipe at the location where the CFRP rods are attached, along with wall thinning of the pipe, through test manufacturing and demonstration.
4			Understanding the behavior while extending/retracting	・Accuracy in connecting the sections (pipe inclination) ・Vibrations while extending (investigation equipment part) ・Extent of gap with the tip when the vertically installed mechanism is extended (backlash, deflection) ・Verification of the extension retraction behavior when the telescopic mechanism is tilted ・Verification of the extension retraction movement when something gets stuck (Can the telescopic mechanism be extended when it is stuck, can it be retracted when the investigation equipment is stuck) ・Impact of adhered substances on the extension retraction behavior	・Design study Understanding the behavior through test manufacturing and demonstration using a multi-stage telescopic mechanism for information that would contribute to the equipment specifications study
5			Understanding the operating characteristics while extending/retracting	・Air pressure required while extending ・Ability to control position determination ・Sliding resistance of the air packing and telescopic mechanism ・Sliding resistance of the rotation control guide of the telescopic mechanism	・Design study ・Understanding the impact on the sealing performance and sliding resistance under environmental conditions (dose, temperature) assumed as a result of test manufacturing and demonstration, for information that would contribute to the equipment specifications study. Understanding the behavior through test manufacturing and demonstration using a multi-stage telescopic mechanism for information that would contribute to the equipment specifications study

6. Implementation Details

Unit 2 & 3

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc.

Issues pertaining to the bottom access investigation method for Unit 2 and 3 (2/2)

Content in red: Items to be verified through simple tests

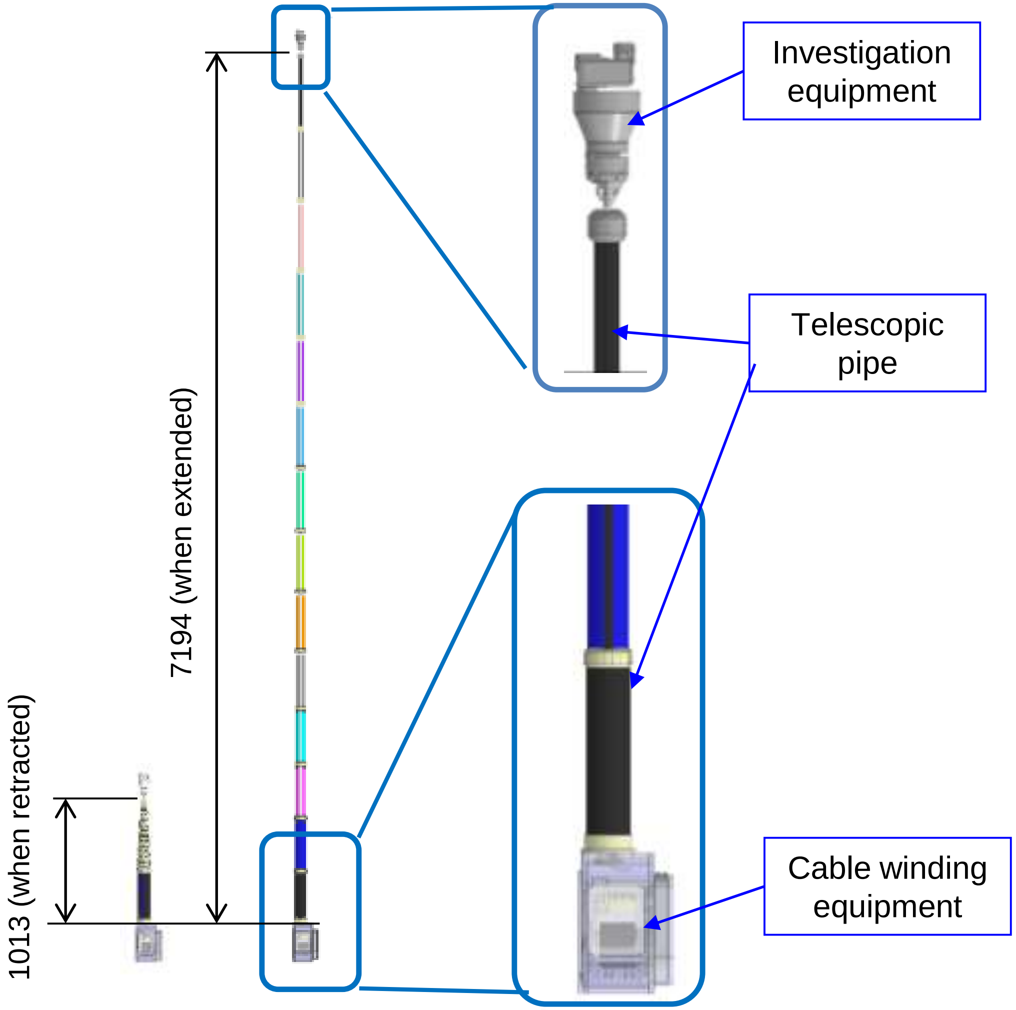
No.	Major items	Medium items	Minor items	Development issues	Response Policy for FY2020
6	Equipment for access to the inside of the RPV from inside the pedestal	Designing the telescopic access equipment	Designing the cable winding mechanism	･Accuracy in measuring the wire tension (propriety of detecting sagging) ･Coordinated control of air pressure and tension while winding the cable when the telescopic mechanism is being extended/retracted ･Limit detection ･Placement of the mechanism (passing through X-6 penetration, interference with the arm) ･Pressure resistant box design (about 0.1MPa)	･Design study Understanding the behavior through test manufacturing and demonstration using a multi-stage telescopic mechanism for information that would contribute to the equipment specifications study
7			Emergency measures	･Handling of power cutoff (disconnection, etc.), loss of control (software crash), control line disconnection, etc.	⇒ Will be studied after the overall equipment configuration has been determined.
8			Designing the slide mechanism	･Placement of the mechanism (passing through X-6 penetration, interference with the arm)	･Design study
9	Investigation equipment	Investigation equipment designing	Designing the outer form of the investigation equipment	･Interference with the X-6 penetration, reactor internal structures	･Design study
10			Cable design	･Achieving a small diameter (targeting φ6 or less) ･Tensile strength	･Design study
11			Noise countermeasures	･Noise while rotating when the slip ring is used (dosimeter)	⇒ Will be implemented after the design of the cable winding mechanism shapes up based on the results of the behavior verification test
12			Countermeasures for substances adhering to the camera, lighting, etc.	･Design study	⇒ Will be implemented in FY2021 along with the study on the application of a CMOS camera using a cable with a smaller diameter
13			Visibility	･Verification of the visibility of the back side when there are structures or mechanisms in the vicinity of the camera ･Understanding the characteristic of reduced visibility due to noise resulting from radiation dose	⇒ Will be implemented in FY2021 along with the study on the application of a CMOS camera using a cable with a smaller diameter
14			Emergency measures	･Handling of power cutoff (disconnection, etc.), loss of control (software crash), control line disconnection, etc.	⇒ Will be studied after the overall equipment configuration has been determined.
15	Other	Operability	Operability using a camera	･Can the operation be performed by determining the status such as status of contact with structures, etc. by means of the camera on the wrist part or the investigation equipment camera	⇒ Will be studied after the specifications of the arm type access equipment for retrieval are finalized.
16		Emergency measures	Examination of assumption items	･Which events such as earthquake, power outage, etc. are assumed?	⇒ Will be studied after the overall equipment configuration has been determined. ⇒ Will be studied after the specifications of the arm type access equipment for retrieval are finalized.

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study D: Study of feasibility evaluation items

Telescopic access equipment: Rough specifications



Items	Specifications	Remarks
No. of stages	14 stages	
Material	Pipe: CFRP, aluminum Other parts: aluminum parts	
Driving source	Extension: air Retraction: Cable winding equipment Various motors: power supply	
Pipe thickness	1mm	
Dimensions when retracted (Only telescopic pipe)	1100mm or less	
Dimensions when extended (Only telescopic pipe)	7100mm or more	
Outer diameter	Base: φ97mm Tip: φ37mm	
Air pressure	At maximum extension: 0.1MPa	The plan is to apply air pressure gradually according to the no. of stages
Maximum conveyable weight	2kg (when air pressure is 0.1MPa)	
Cable	Built into the telescopic pipe	
Cable handling	Controlled by the rotation of the reel of the cable winding equipment at the base	
Clearance between the pipes	0.2mm	
Sealant	NBR	Radiation resistance: Cumulative resistance 1 MGy

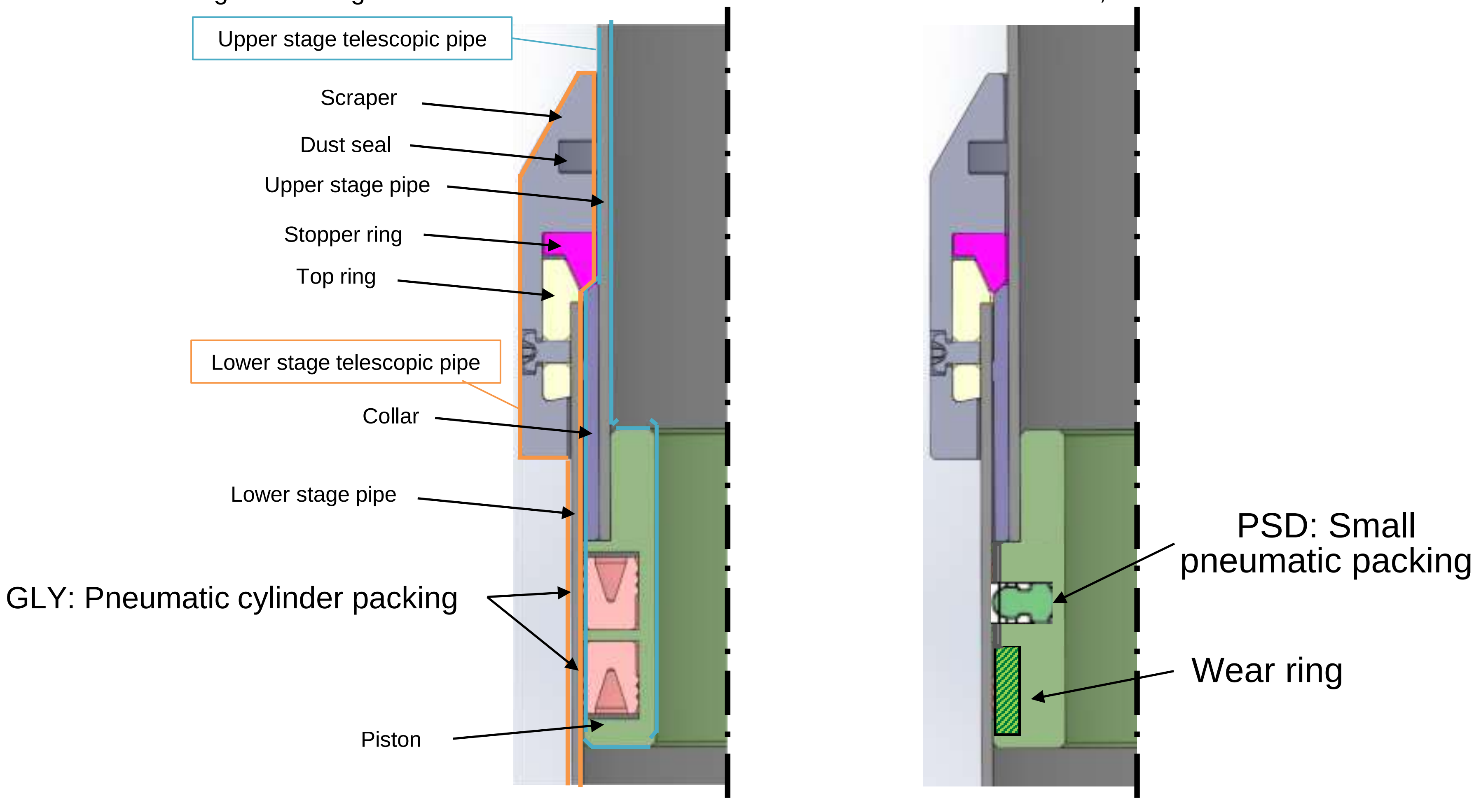
6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study D: Study of feasibility evaluation items

Telescopic access equipment: Seal structure

- A seal structure using a wear ring was studied in addition to the seal structure with a track record, in order to control inclination.



A: Regular (pneumatic cylinder) B: Controlled inclination type

6. Implementation Details

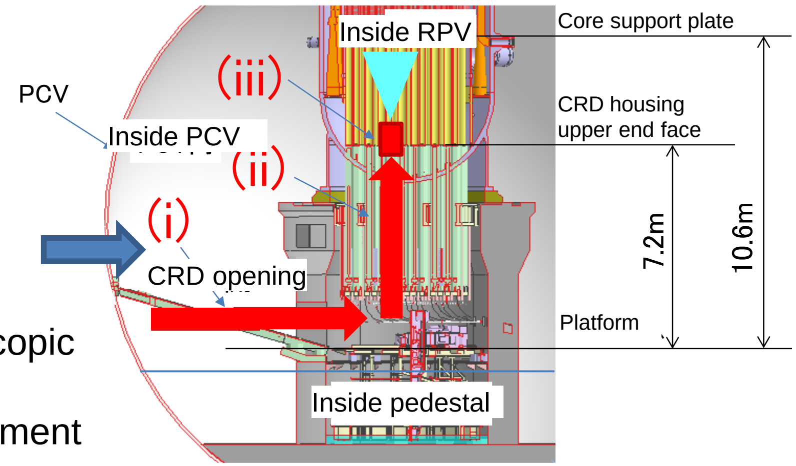
Unit 2 & 3

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc.

➢Feasibility evaluation (test)
3 types of tests were conducted on the telescopic access equipment studied as the "(ii) Equipment for access to the inside of the RPV from inside the pedestal".

(1) Test for verifying the strength of the CFRP bonded part of the telescopic access equipment
(2) Sealing performance verification test of the telescopic access equipment
(3) Behavior verification test of the telescopic access equipment



(i) Equipment for access to the inside of the pedestal
⇒ Arm type access equipment for fuel debris retrieval will be used
(ii) Equipment for access to the inside of the RPV from inside the pedestal
⇒ Will be newly developed (telescopic access equipment)
(iii) Investigation equipment
⇒ Equipment studied under "Development of Technology for Investigation inside RPV" in the previous year will be used.

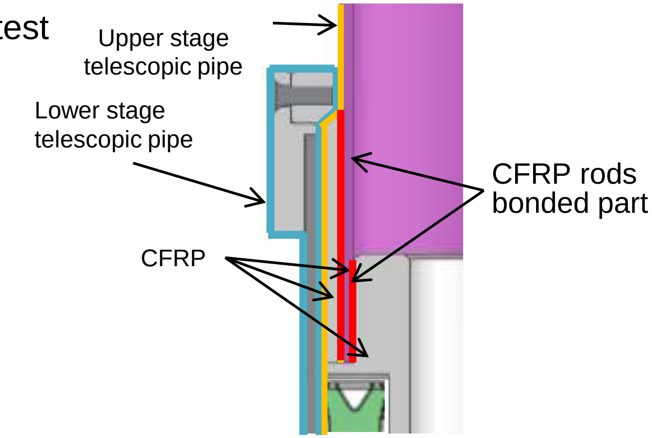
Items to be verified through the tests (Minor items in No. 66 and 67)	Corresponding feasibility evaluation tests
3. Studying the basic structure	(1) Test for verifying the strength of the CFRP bonded part of the telescopic access equipment
4. Understanding the behavior while extending/retracting	(3) Behavior verification test of the telescopic access equipment
5. Understanding the operating characteristics while extending/retracting	(2) Sealing performance verification test of the telescopic access equipment (3) Behavior verification test of the telescopic access equipment
6. Designing the cable winding mechanism	(3) Behavior verification test of the telescopic access equipment

6. Implementation Details

Unit 2 & 3

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (1) CFRP bonded part strength verification test



<Purpose>
To verify the strength of the location where the CFRP rods are bonded, under assumed environmental conditions.

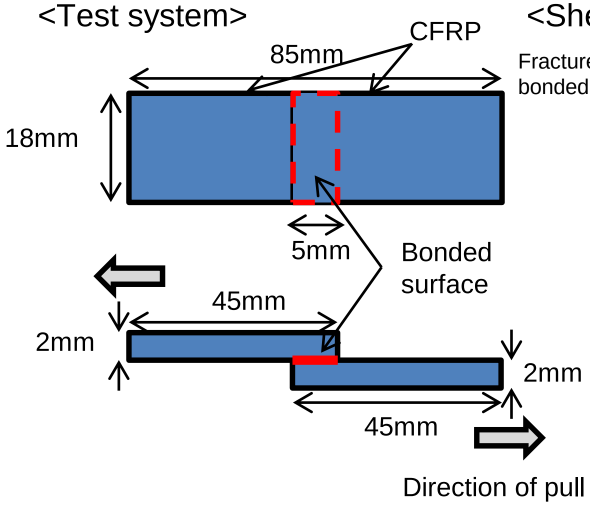
<Test overview>
Using a sample piece of a small CFRP, shear load was applied to the bonded part, and fracture stress was verified. The radiation environment was simulated by using a CFRP rods bonded part already exposed to radiation as a test piece. Further, the impact of environmental conditions was verified by conducting the test under 0Gy (unirradiated) and 1000Gy (assuming 10 hours under 100Gy/h) exposure conditions.
Furthermore, ISO19095 (resin-Metal bonding characteristics evaluation test method) was used as reference for the test method (Same as the test method for verifying the strength of the CFRP and aluminum bonded part evaluated in the past).

<Evaluation items, etc.>

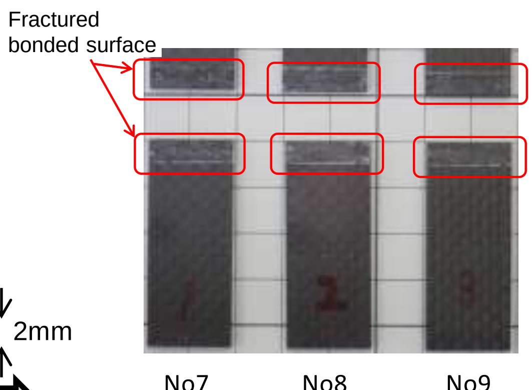
No.	Name of the test	Evaluation item	Target (criteria)	Verification method
1	CFRP rods bonded part strength verification	・Fracture stress when shear load is applied to the bonded part of the CFRP rods	・The fracture stress when shear load is applied shall be 4.7MPa or more (*1).	Shear load is applied to the irradiated sample and the unirradiated sample, the load is increased gradually and the stress when the sample fractures is measured.

(*1)The maximum stress at the bonded part becomes 0.26MPa based on the maximum piston thrust of approx. 709N (air pressure: 0.1MPa x maximum area of load (second level slider part)) and area of the bonded part: 2743mm 2.
Multiplying the impact of reduction in the bonding strength due to length of the bonding area: 3 and the safety factor: 6: the target shall be 4.7MPa or more

<Test system>



<Shear failure>



Result of the shear failure test after letting to stand for 24 hours under cumulative exposure 1000Gy, 50℃, humidity: 95%

<Scope of simulation of test system>

Simulation target	Simulated	Not simulated	Reason for not being simulated
CFRP rods bonded part	・Material ・Adhesive	・Area of the bonded part	As measurement can be performed from the fracture stress per area.
		・Plate thickness of test piece	As there is no impact on fracture stress
Surrounding environment	・Exposure dose	・Darkness	As there is no impact on fracture stress

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (1) CFRP bonded part strength verification test

<Test results>

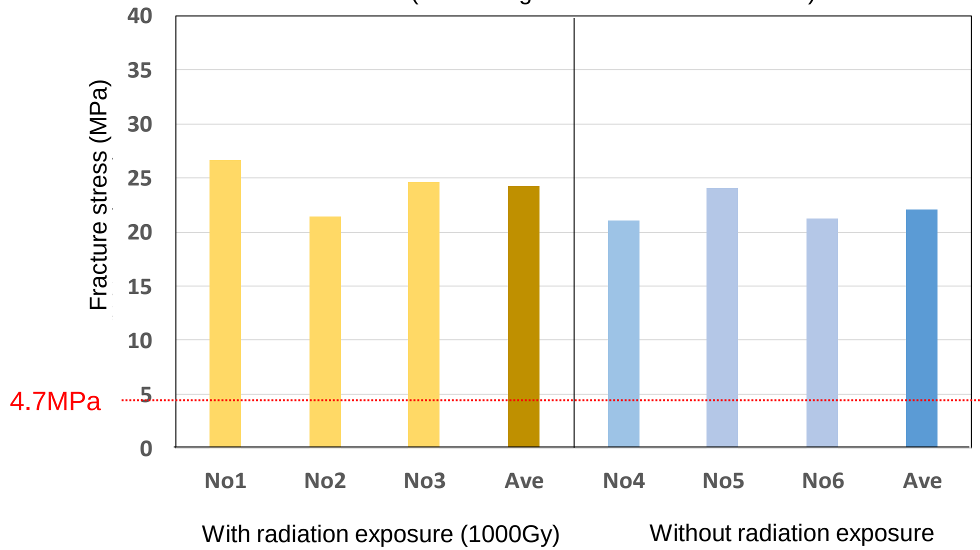
○ Indoor environment

The shear failure stress after radiation exposure was 21.4 to 26.7 [MPa], that is on an average: 24.2 [MPa], as against 21.0 to 24.0 [MPa], that is on an average: 22.1 [MPa] for the unirradiated sample. Thus there was no major difference in the bonding strength. And, in case of both, the irradiated test piece and the unirradiated test piece, there was a cohesion failure wherein a fracture occurred inside the adhesive layers and hence it is believed that the adhesive did not degrade due to radiation exposure.

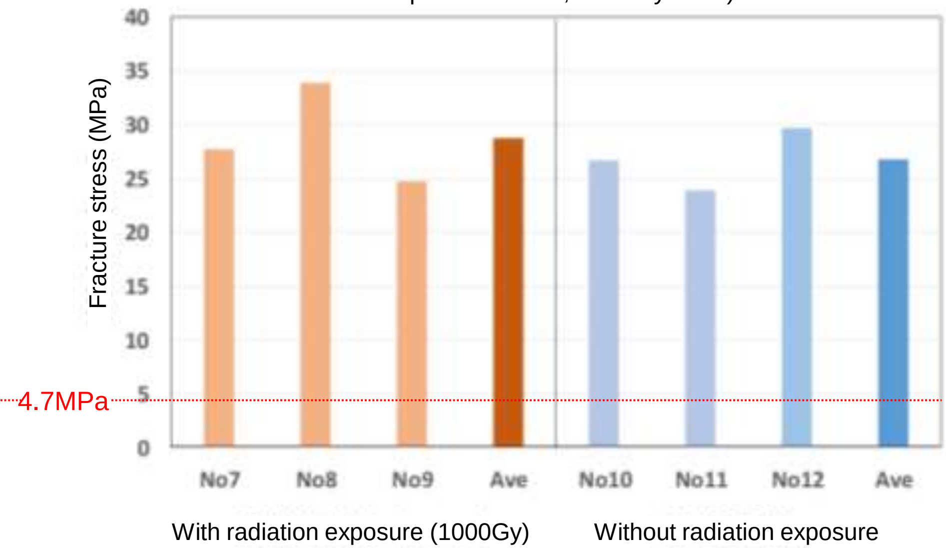
○ Constant temperature environment with temperature: 50℃ and humidity: 95%.

The shear failure stress after radiation exposure was 24.7 to 33.9 [MPa], that is on an average: 28.8 [MPa], as against 23.9 to 29.7 [MPa], that is on an average: 26.8 [MPa] for the unirradiated sample. Thus there was no major difference in the bonding strength. And, in case of both, the irradiated test piece and the unirradiated test piece, there was a cohesion failure wherein a fracture occurred inside the adhesive layers and hence it is believed that the adhesive did not degrade due to radiation exposure.

Fracture stress at the CFRP bonded part
(after being left in indoor environment)



Fracture stress at the CFRP bonded part (after leaving for 24 hours under temperature: 50℃, humidity: 90%)



Based on the above results it was evaluated that there is no degradation of the CFRP bonded part due to shear failure stress if it is left for less than 24 hours (*1) under an environment with temperature: 50[℃], humidity: 90%, dose rate: 100[Gy/h] assumed while investigating inside RPV.

(*1) Based on the result that there was cohesion failure, it was evaluated that strength can be retained even when kept under a radiation exposure environment for about 24 hours, just like the results of a similar bonding strength test conducted in FY2019.

6. Implementation Details

Unit 2 & 3

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (2) Sealing performance verification test

<Test overview>

The test was conducted with the purpose of verifying sealing performance and sliding resistance of the telescopic access equipment under environmental conditions assumed on the site. The 2 types of structures of the sealed part as shown in the figure on the right were used for the test.

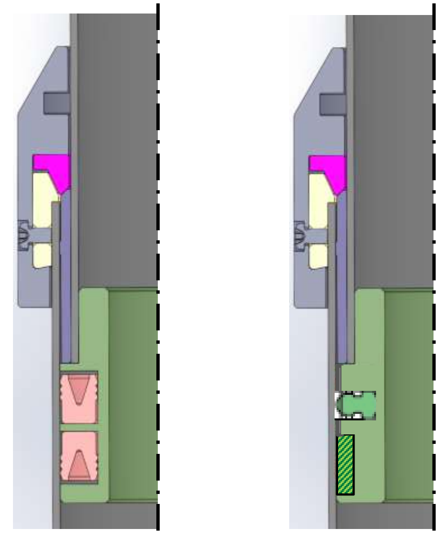
Dose conditions were 0Gy (unirradiated) and 1000Gy (assuming 10 hours of investigation under 100Gy). And, the test was conducted under 25℃ (room temperature) and 50℃ respectively and the difference in impact depending on the environmental conditions was verified.

<Test system>

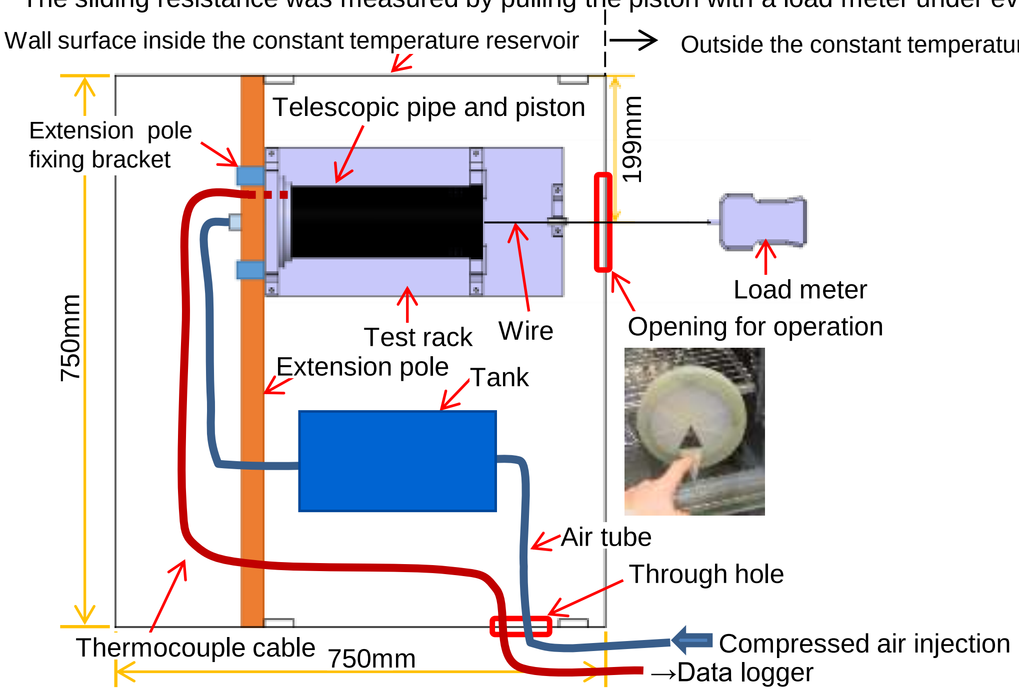
A constant temperature reservoir was used for simulating the temperature conditions. A thermocouple was installed inside the telescopic pipe to monitor temperature so as to ensure that there is no difference in the temperature inside the constant temperature reservoir and inside the telescopic pipe. And, a sealant that was already exposed to radiation was used for simulating the radiation dose environment.

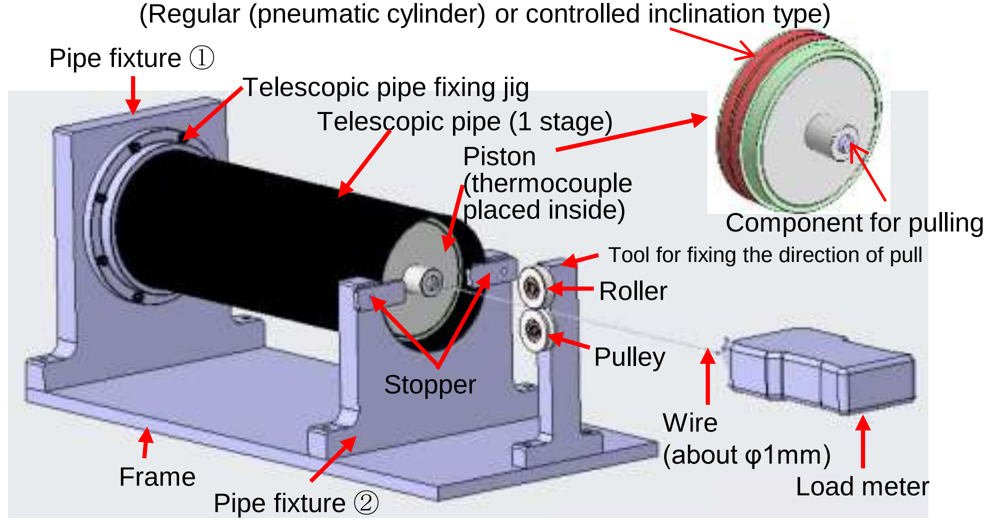
The sealing performance was verified by subjecting the telescopic pipe to 0.1MPa of air, applying soapy water to the area around the piston part and confirming whether or not there was any leakage.

The sliding resistance was measured by pulling the piston with a load meter under every test condition.



Structure of sealed part





6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (2) Sealing performance verification test

<Test Item>

The following 2 types of tests were conducted for the "Telescopic access equipment sealing performance verification test".

① Leakage check

② Seal sliding resistance comparison test

<Purpose>

① Leakage check

⇒ To confirm whether or not the seal can prevent leakage of air under the radiation dose and temperature conditions in the investigation area.

② Seal sliding resistance comparison test

⇒ To confirm whether or not the sliding resistance of the seal changes under the radiation dose and temperature conditions in the investigation area.

<Evaluation items, etc.>

No.	Name of the test	Evaluation item	Target (criteria)	Verification method
①	Leakage confirmation	Presence of air leakage	Air shall clearly not be leaking	Visually confirmation for formation of foam in the soapy water applied at the surface of the tip of the telescopic pipe (performed once for every condition)
②	Seal sliding resistance comparison test	Sliding resistance	Shall be equal to or less than the maximum tensile force of the cable winding equipment (Roughly) 50N or less	Measuring the sliding resistance by pulling the piston that installs the seal inside the telescopic pipe, with the load meter (performed 5 times for every condition)

<Scope of simulation of test system>

Simulation target	Simulated	Not simulated	Reason for not being simulated
Telescopic pipe	・Outer diameter / inner diameter (1st stage portion) ・Shape of the seal (1st stage portion)	・Length	As it is sufficient as long as just the length required for verifying the sliding resistance is secured.
		・Shape of the site where the seal is installed	As it is sufficient as long as the contact between the telescopic pipe and the seal are simulated, and the shape of the site for installing the seal does not need to be simulated (In the actual equipment, the component for pulling that is removed from the piston will be installed at the lower tip of the second stage of the telescopic mechanism)
Surrounding environment	・Exposure dose ・Temperature	・Humidity	As it is assumed that the environmental conditions are such that the characteristics of the seal cannot be changed significantly.
		・Darkness	As the environmental conditions are such that the characteristics of the seal cannot be changed.

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (2) Sealing performance verification test

① Leakage check

<Test results>

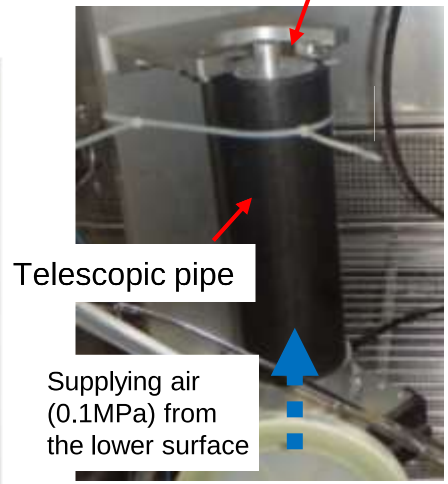
- When 0.1 MPa, which is assumed to be the maximum pressure supplied inside the telescopic pipe, was supplied, there was leakage under all conditions, and it was found that the difference in the dose and temperature conditions did not have an impact on the air sealing function.
- There was leakage from the entire circumference of the regular seal under all conditions. There was leakage from some parts of the controlled inclination type seal under all conditions, but the quantity of leakage was less in the controlled inclination type seal which has stronger adhesion.
- In order to reduce the quantity of leakage, inner surface of the telescopic mechanism needs to be improved such as by reducing its roughness (making it smoother), etc.
- The impact of leakage from each type of sealed part structures on the extension/retraction movement of the telescopic access equipment was verified by conducting a telescopic access equipment behavior verification test

Result of leakage check

No.	Structure of sealed part	Exposure dose	Temperature	Result of verification
1	Regular	0Gy (Unirradiated)	25℃ (room temperature)	Leakage present
2			50℃ or more	Leakage present
3		1000Gy	25℃ (room temperature)	Leakage present
4			50℃ or more	Leakage present
5	Controlled inclination type	0Gy (Unirradiated)	25℃ (room temperature)	Leakage present
6			50℃ or more	Leakage present
7		1000Gy	25℃ (room temperature)	Leakage present
8			50℃ or more	Leakage present

Regular

Controlled inclination type



Telescopic pipe fixed on to the test rack

Verification of leakage in the regular seal under 0Gy (unirradiated) and 50℃ conditions

Verification of leakage in the controlled inclination type seal under 0Gy (unirradiated) and 50℃ conditions

6. Implementation Details

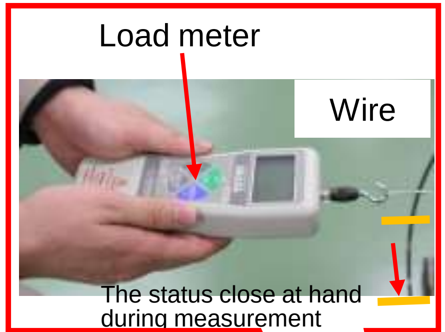
(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (2) Sealing performance verification test

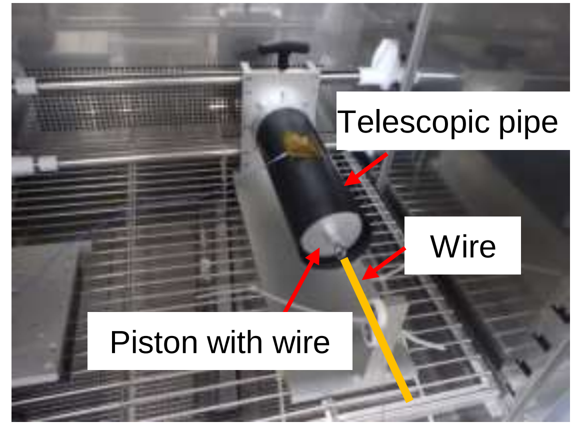
② Seal sliding resistance comparison test

<Test results>

- It was found that the sliding resistance tends to increase in the regular seal when it is irradiated and heated.
- The sliding resistance decreased in the controlled inclination type seal when it was irradiated, but it was found that the sliding resistance tends to increase when it is irradiated and heated, similar to the regular seal.
- As the rated tensile force of the cable winding equipment is 83N, the pipe of the regular seal can be retracted, however, it may not be possible to retract the pipe of the controlled inclination type seal.
- In order to reduce the sliding resistance, inner surface of the telescopic mechanism needs to be improved such as by reducing its roughness, etc.



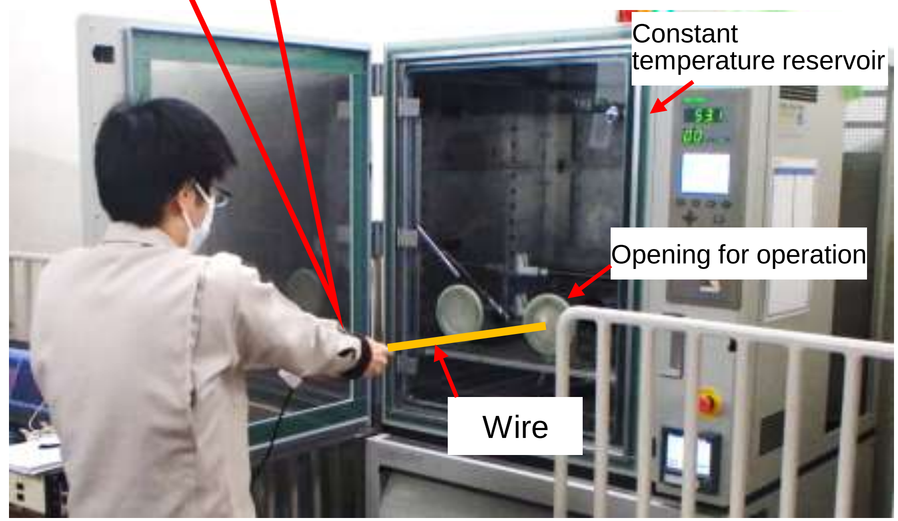
The status close at hand during measurement



The test rack affixed inside the constant temperature reservoir

Sliding resistance measurement results

No.	Structure of sealed part	Exposure dose	Temperature (average) [° C]	Range of maximum sliding resistance under each condition [N]	Average value under each condition [N]
1	Regular	0[Gy] (No irradiation)	23	30.0 to 37.7	34.9
2			52	35.6 to 43.7	39.1
3		1000[Gy]	23	33.0 to 42.9	38.3
4			51	45.8 to 54.3	51.0
5	Controlled inclination type	0[Gy] (No irradiation)	23	95.5 to 114.4	102.8
6			51	89.8 to 119.7	104.4
7		1000[Gy]	23	80.4 to 95.2	85.7
8			51	104.5 to 122.0	115.0



Measurement of sliding resistance under 50℃ environment

6. Implementation Details

(2) Development of the bottom access investigation method

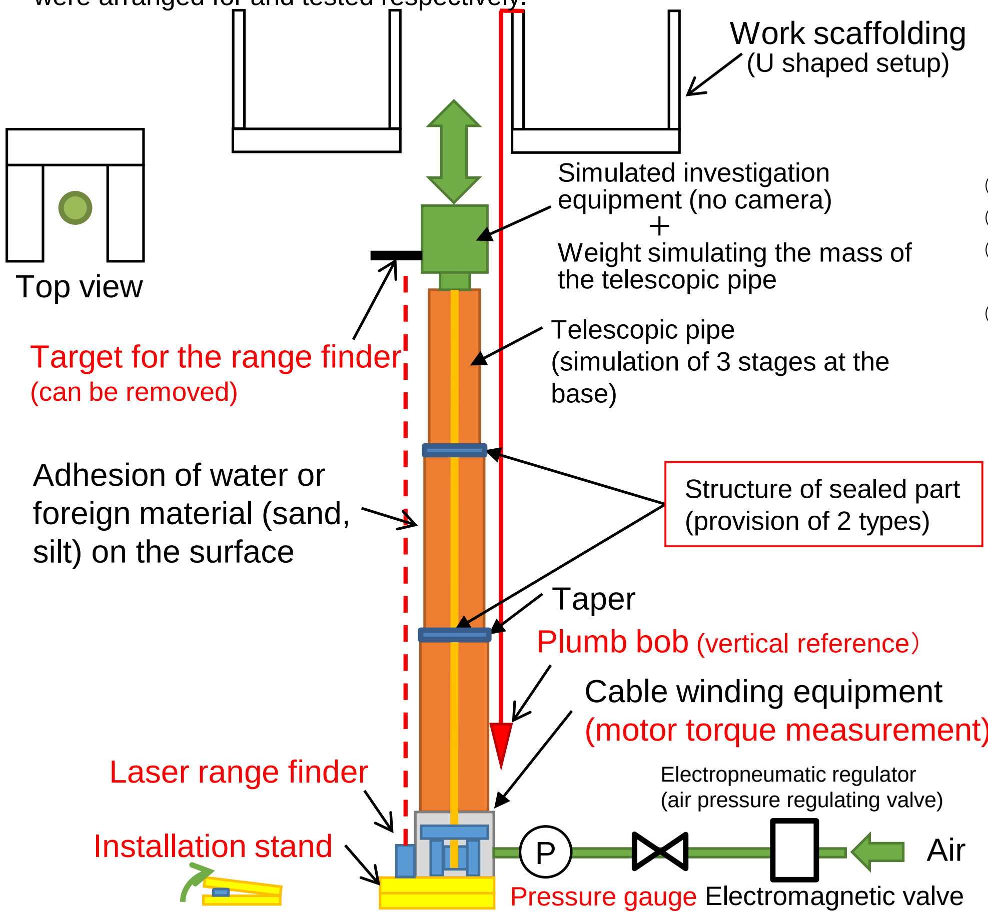
2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

<Test overview>

Elemental tests of the telescopic pipe with the entire 14 stage structure are planned to be conducted in FY2021. Directed towards these tests, the movement of the telescopic pipe was verified in FY2020 by partial test manufacturing a 3 stage structure, the smallest structure that can facilitate simulation of the base, middle section and the seal structure at the tip. Information contributing to designing the equipment was obtained by evaluating the behavior observed during the test.

<Test system>

The purpose of this test was to verify the extension and retraction movement of the pipe. The 3 stages at the base were simulated for the test since the entire load of the 14 stage structure was to be applied to a 3 stage structure. And, both types of seal structures - the regular (pneumatic cylinder) and the controlled inclination type were arranged for and tested respectively.



<Test items>

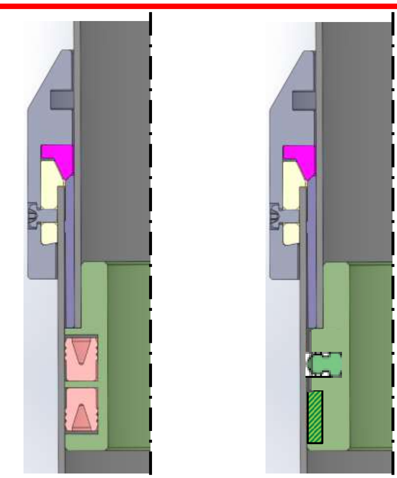
The following 4 types of tests were conducted for the “Telescopic access equipment behavior verification test” using a 3 stage telescopic pipe. An overview of each of these tests is provided on the following slides.

① Telescopic pipe extension retraction movement verification test

② Extension retraction movement test when the telescopic pipe is inclined

③ Behavior verification test when the telescopic pipe / investigation equipment get caught in the structures

④ Extension retraction movement verification test when foreign material adheres to the telescopic pipe



A: Regular (pneumatic cylinder)

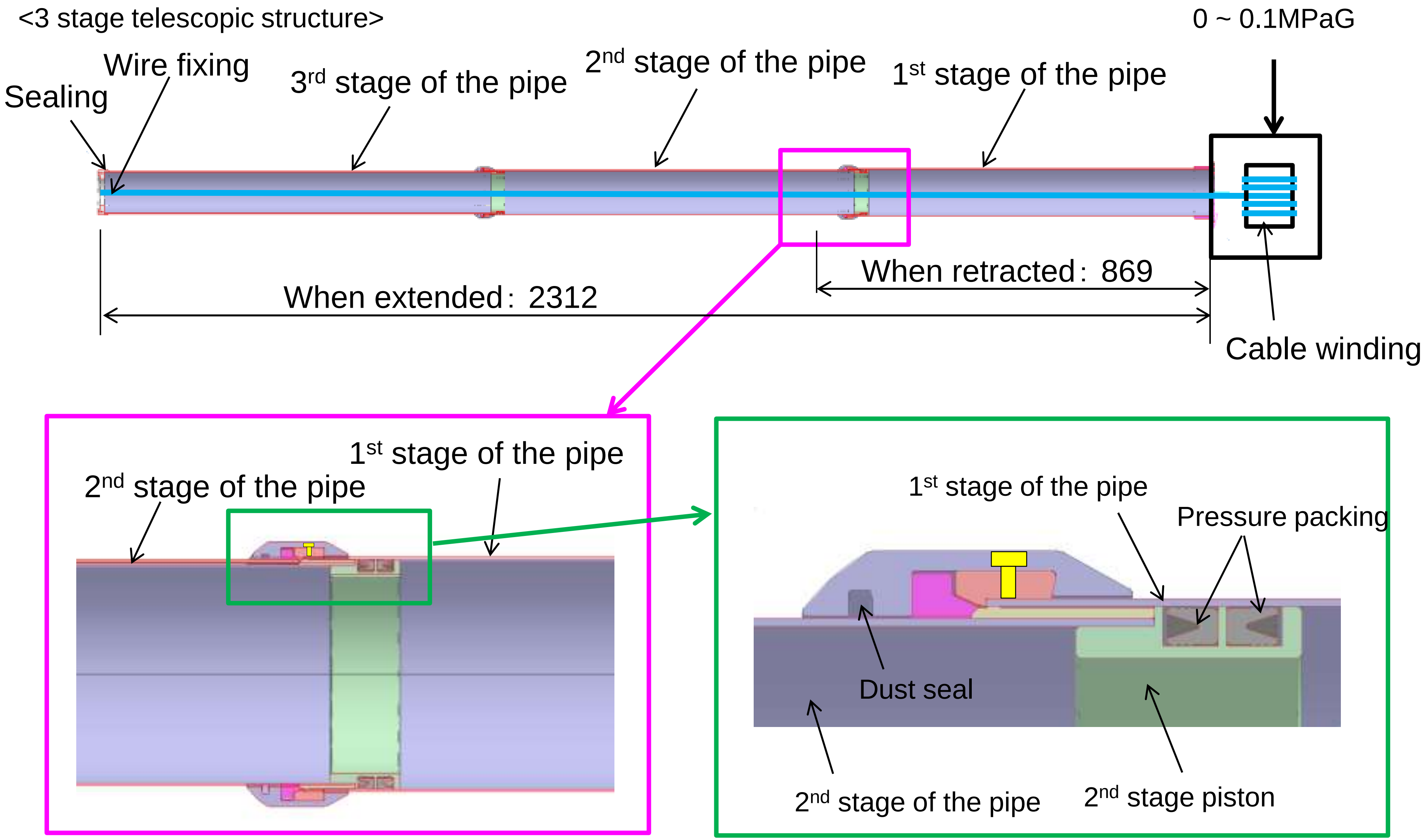
B: Controlled inclination type

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

<3 stage telescopic structure>



6. Implementation Details

Unit 2 & 3 No. 80

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

<Scope of simulation of test system>

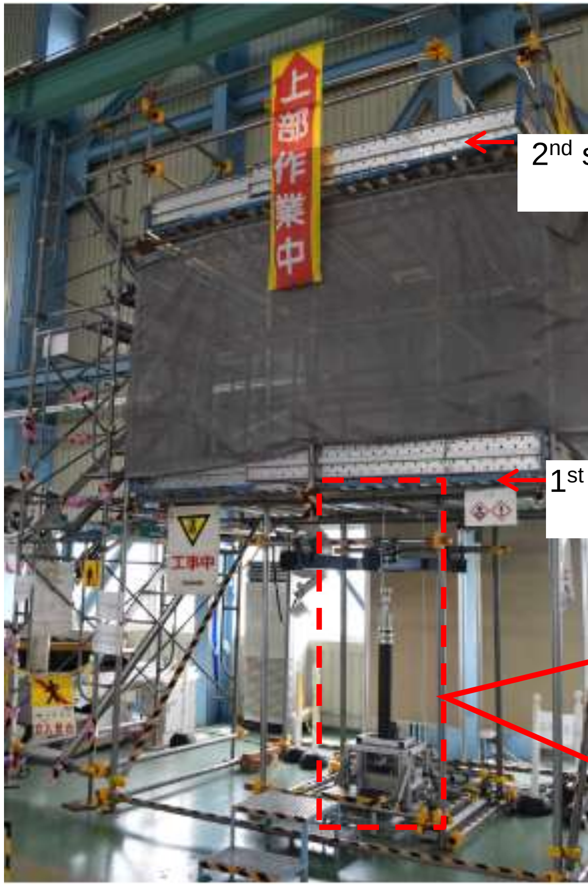
Simulation target	Simulated	Not simulated	Reason for not being simulated
Environmental Conditions	・RPV opening size	Humidity, fog	As the test is under wet conditions (not simulated as an environment)
		Dose rate	CFRP strength and bonding strength has already been tested in the past. Only the sealed portion is simulated for the test.
		Temperature	Only the sealed portion is simulated for the test.
		Darkness	As there is no impact on the movement behavior of the telescopic pipe
		Structures below the RPV bottom opening part	The movement behavior of the telescopic pipe is verified in this test. Movement when the structures are simulated is planned to be verified during the mock-up test implemented prior to the on-site investigation.
Investigation equipment	・Mass ・Tapering shape	Camera not mounted	As the presence/absence of the camera image does not impact the extension retraction movement.
		Shapes other than the tapering shape	As the shape of the investigation equipment does not impact the extension retraction movement.
		Mechanism (No tilting movement, no extension of illumination	As the impact of change in the center of gravity of the investigation equipment when the mechanism is moved, on the extension retraction movement will be verified when the 14 stage telescopic pipe is test manufactured.
Telescopic pipe	・Shape (3 stage, tapering) ・Mass (equivalent to that of 14 stages (simulated with partial weight)) ・Mechanism (seal, etc.)	Entire length (14 stages)	The movement and behavior of the telescopic pipe is verified in this test. The length-wise impact of the inclination, vibrations and deflection when the telescopic mechanism is gradually extended, will be verified when the 14 stage telescopic pipe is test manufactured next year.
Cable winding equipment	・Winding mechanism ・Pressure resistant case ・Torque measurement function ・Thickness of the investigation equipment cable	Flexural rigidity of the investigation equipment cable	As it is believed that the flexural rigidity of the cable does not impact the extension retraction movement and since it will be verified when the 14 stage telescopic pipe is test manufactured next year.
		Tensile strength of the investigation equipment cable	As the required tensile force for the investigation equipment cable is verified in this test

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

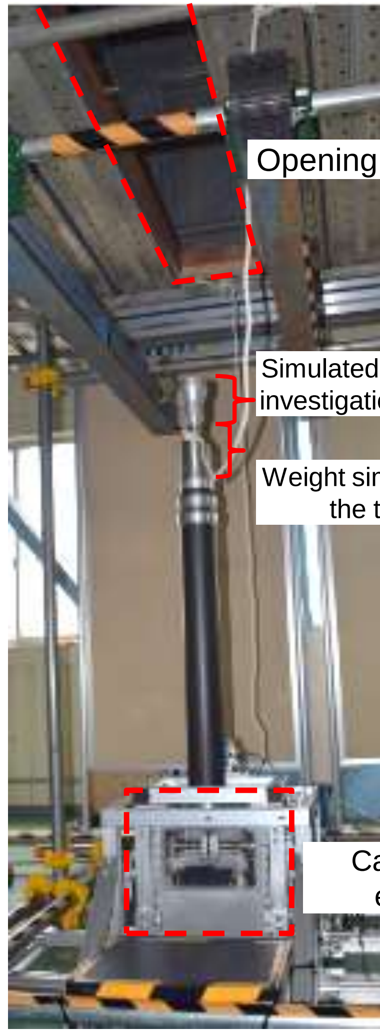
<Test apparatus>



2nd stage scaffolding (height 4m)

1st stage scaffolding (height 2m)

Complete view of work scaffolding



Opening

Simulated weight of the investigation equipment

Weight simulating the mass of the telescopic pipe

Cable winding equipment

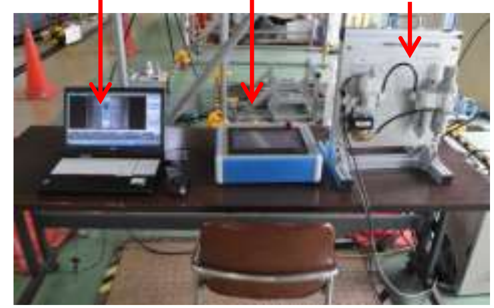
3 stage telescopic pipe (when completed retracted)

3 stage telescopic pipe (when completed extended)

PC camera for verifying vibrations

Operation panel

Pressure operation panel



Console

6. Implementation Details

(2) Development of the bottom access investigation method

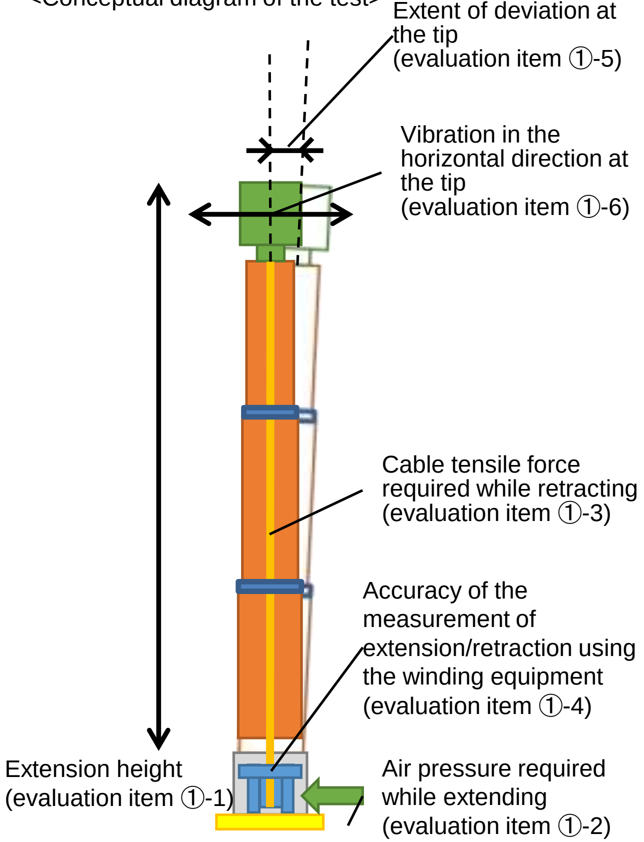
2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

① Telescopic pipe extension retraction movement verification test

<Purpose>

To confirm whether extension retraction movement in the vertical direction is possible when the 3 stage telescopic pipe and cable winding equipment are combined and a heavy object weighing as much as the investigation equipment is mounted at the tip of the telescopic pipe, and to verify the movement characteristics under those circumstances.

<Conceptual diagram of the test>



<Evaluation items, etc.>

(*1) Numerical values obtained when the test is performed using a 3 stage telescopic pipe are listed.

No.	Evaluation item	Target (criteria)	Policy for setting target values	Verification method	Other items to be verified
①−1	Extension height	Equivalent to 3 stages	Maximum extension of the telescopic pipe that is test manufactured	Measurement using a laser range finder	・Method of coordinated control of air pressure reduction and tensile force required for winding when the telescopic mechanism is being retracted ・Whether or not there is irregular winding by the winding equipment ・Whether or not the limit of extending the telescopic pipe can be determined based on the cable tensile force (if it cannot be determined, a soft limit is applied based on the valued obtained when the extension/retraction is measured). ・ Measurement is conducted 3 times.
①-2	Air pressure required while extending	0.1MPa or less	Maximum design pressure or less	Measurement of pressure of air injected at each stage, using a pressure gauge	
①-3	Cable tensile force required while retracting	50N or less	Equal to or less than the maximum tensile force of the cable winding equipment	Evaluated based on the cable winding equipment drum driven motor torque	
①-4	Accuracy of the measurement of extension/retraction using the winding equipment	Error ±30mm or less	The maximum error so that at least 1/4 of the images overlap, when the camera moves in the vertical direction so that 1/3 of the images overlap, while generating images through the cylinder.	At every 0.5m the value obtained from the measurement by means of the winding equipment and the actual value measured by the laser range finder are compared.	
①-5	Extent of deviation at the tip (backlash)	Approx. 16mm or less (*1) (at full length: 65mm or less)	The permissible deviation when 3 stages are extended is set such that the 9th stage of the telescopic pipe (φ57mm) does not come in contact with the reactor bottom opening (φ187mm).	Horizontal load sufficient to eliminate the backlash is applied to the tip at each stage of the telescopic pipe to verify the displacement by means of the plumb bob.	
①-6	Vibration in the horizontal direction at the tip	Convergence time and vibration cycle	If the telescopic pipe vibrates, extension/retraction is performed after the vibrations stop	The presence of vibrations, convergence time and vibration cycle are verified based on the image from the bird's eye view camera	

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

① Telescopic pipe extension retraction movement verification test

<Results using the regular seal>

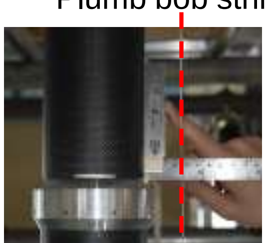
- It was confirmed that extension retraction movement is possible with the tensile force of the cable winding equipment and under maximum design pressure or less.
- There were no vibrations during the extension and the retraction and the extent of deviation due to backlash was within the permissible range.
- The error in the accuracy of the measurement of extension/retraction increased as the telescopic pipe extended, but this issue is expected to be resolved by controlling the extension with the help of the reinforced cable being planned.
- The tensile force was 220N at maximum (momentary force / can be reproduced when the retraction of second pipe starts) as against the targeted 50N, but the pipe was retracted. The force during retraction was about 50N to 130N.

<Results using the controlled inclination type seal>

- The sliding resistance was unexpectedly high, the motor torque was insufficient, and the pipe was not retracted. Hence extension was verified only once.
- The extent of deviation at the tip was half of that using the regular seal and it was found that a wear ring is useful.

<Test picture>

Plumb bob string



Measuring the backlash

Telescopic pipe during extension

<List of results>

No.	Evaluation item	Target (criteria)	Result		
①−1	Extension height	Equivalent to 3 stages	Regular	1st time to 3rd time: equivalent to 3 stages (maximum 2300mm)	○
			Controlled inclination type	1st time: equivalent to 3 stages (maximum 2300mm)	○
①−2	Air pressure required while extending	0.1MPa or less	Regular	1st time to 3rd time: 0.04MPa	○
			Controlled inclination type	1st time: 0.05MPa	○
①-3	Cable tensile force required while retracting (determined based on the value from the motor torque monitor)	50N or less	Regular	1st time: Maximum 120N 2nd time: Maximum 220N 3rd time: Maximum 220N	△ (The pipe can be retracted, but the tensile force while retracting may exceed the rated value of 83N.)
			Controlled inclination type	—	x
①-4	Accuracy of the measurement of extension/retraction using the winding equipment	Error ±30mm or less	Regular	1st time: 29mm 2nd time: 22mm 3rd time: 20mm	○
			Controlled inclination type	1st time: 23mm (error only during extension)	○
①-5	Extent of deviation at the tip (backlash)	16mm or less (at full length: 65mm or less)	Regular	1st time: 5.5mm 2nd time: 7mm 3rd time: 6mm	○
			Controlled inclination type	1st time: 3.5mm	○
①-6	Vibration in the horizontal direction at the tip	Convergence time and vibration cycle	Regular	No vibrations (There are no vibrations even if it is bent by deliberately applying load)	○
			Controlled inclination type	No vibrations (behavior only while extending)	○

6. Implementation Details

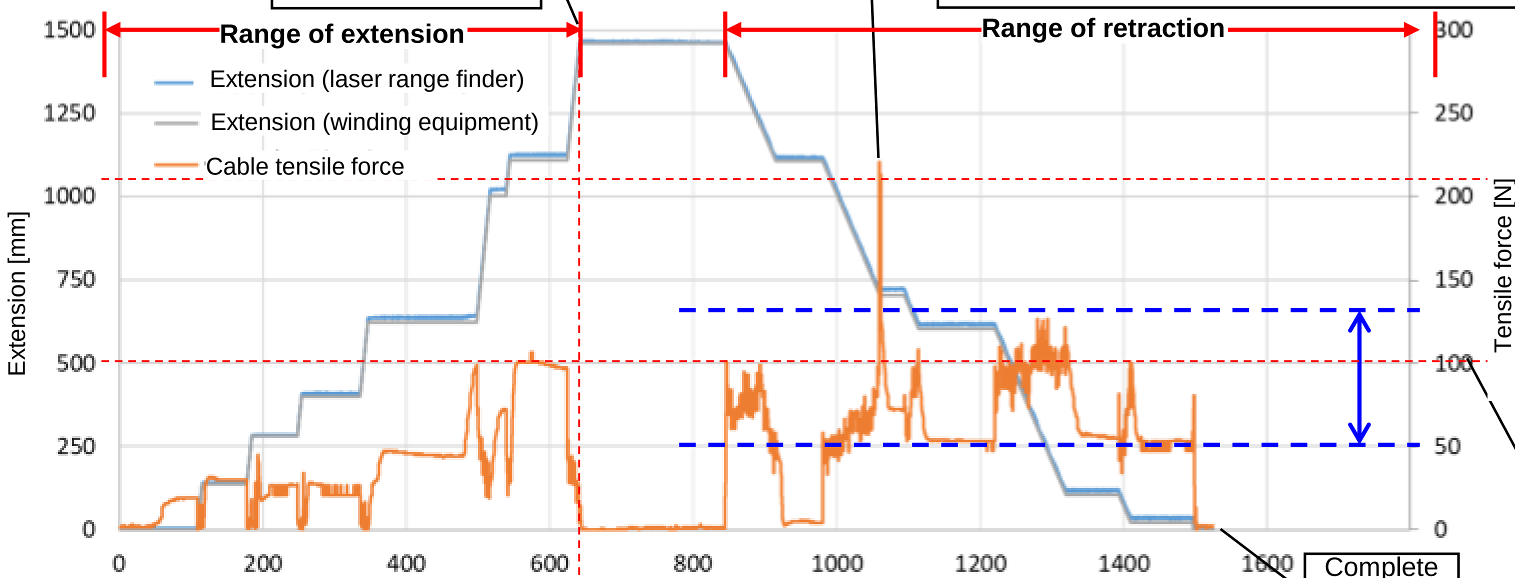
(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

① Telescopic pipe extension retraction movement verification test (regular seal)

Maximum extension

Momentary force: 220N
(The time when retraction of the 2nd pipe starts)



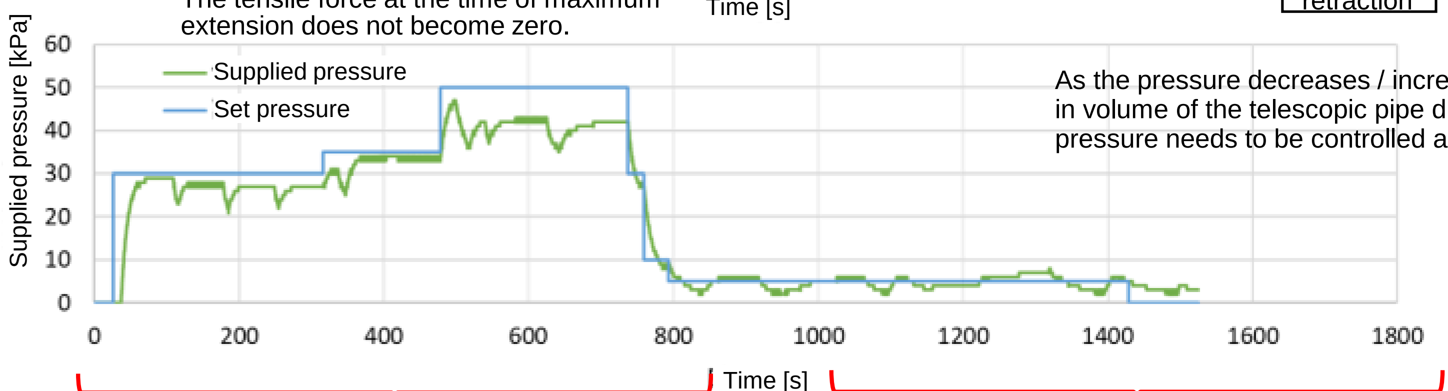
Upper tensile limit: 208N

Rated tensile force: 83N

Tensile force while retracting: In the range of roughly 50N ~ 130N

Complete retraction

The tensile force at the time of maximum extension does not become zero.



As the pressure decreases / increases depending on the change in volume of the telescopic pipe during extension / retraction, the pressure needs to be controlled according to the movement.

While extending the pressure supplied is 30kPa ~ 40kPa

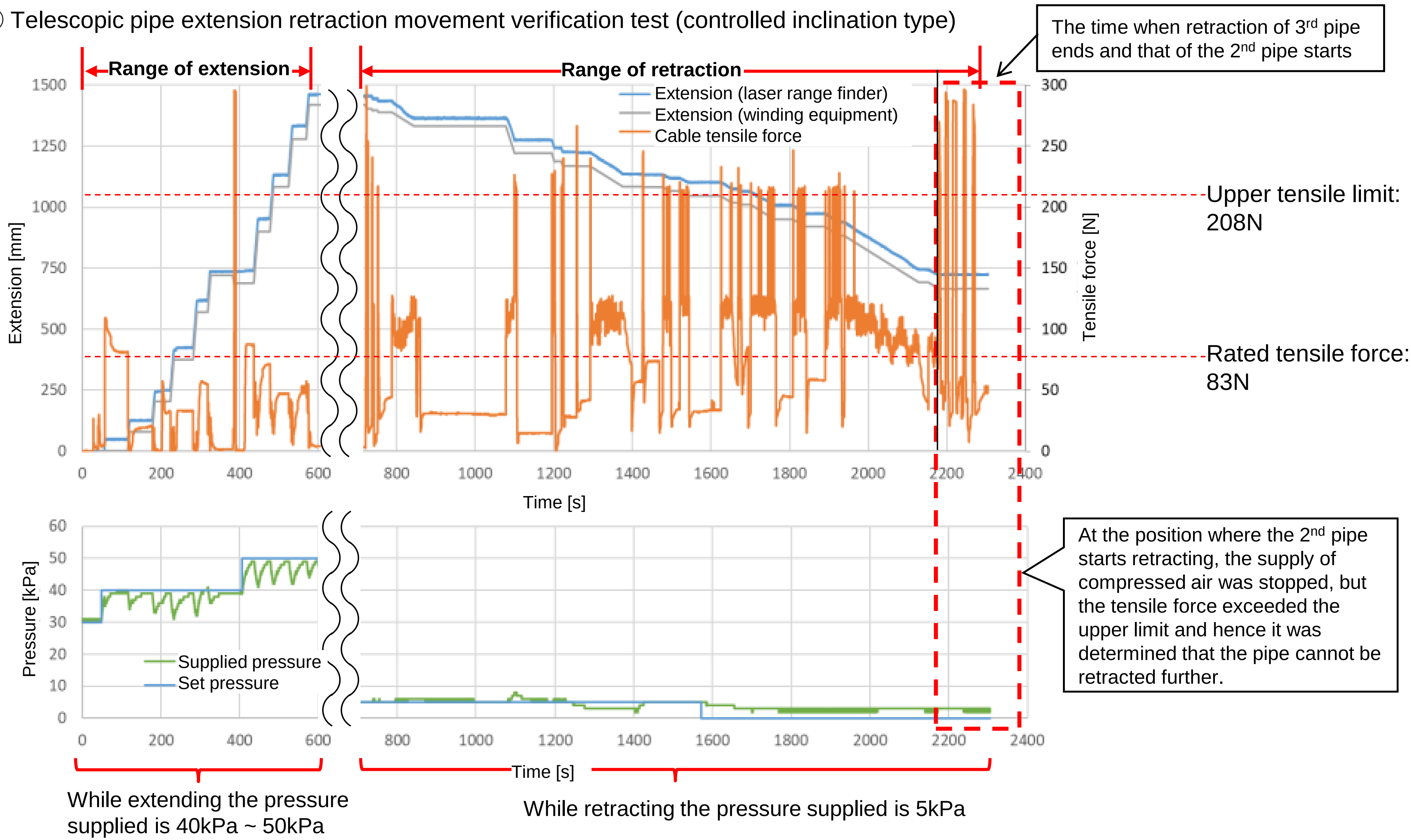
While retracting the pressure supplied is 5kPa

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

① Telescopic pipe extension retraction movement verification test (controlled inclination type)



(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

① Telescopic pipe extension retraction movement verification test

<Summary of the extension retraction movement verification test>

- The test was conducted 3 times for the telescopic pipe with the regular seal and it was confirmed that the required air pressure, cable tensile force and extension/retraction measurement accuracy can be reproduced.
- While retracting the telescopic pipe, with the regular seal, the pipe needed to be retracted while exceeding the rated tensile force. In order to be able to retract the telescopic pipe with a tensile force that is equal to or lower than the rated tensile force, measures need to be taken to reduce the sliding resistance between the inner surface of the telescopic pipe and the packing.
- While extending the telescopic pipe, with the regular seal, it was found that the gap between the set pressure of the electropneumatic regulator installed on the air supply line and the supplied pressure tends to increase with the extension of the telescopic pipe. Meanwhile, with the controlled inclination type seal, there is no gap between the set pressure and the supplied pressure even when the telescopic pipe is extended. It is presumed that this is because of the difference in the amount of leakage from the compressed gas packing supplied inside the telescopic pipe.
- The plan was to determine that extension has been completed when the tensile force becomes zero, but it was found that the tensile force does not become zero simultaneously with the completion of extension. Detection of completion of extension of the telescopic pipe needs to be studied including cases when the telescopic pipe does not have to be extended to the maximum.
- It was found that even if the tensile force exceeds the upper limit when the telescopic pipe is retracted, by resuming retraction after the pressure inside the telescopic pipe (supplied pressure) decreases, retraction can be continued by reducing the required tensile force. (At the time of retracting the telescopic pipe, the pressure inside the telescopic pipe goes on increasing during retraction, but when retraction is stopped, the pressure decreases due to the electropneumatic regulator (air pressure regulating valve).)

6. Implementation Details

(2) Development of the bottom access investigation method

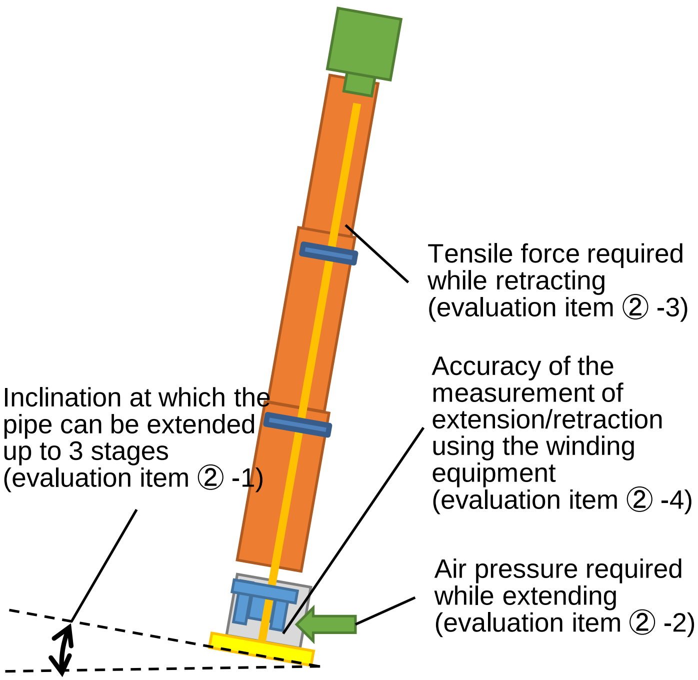
2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

② Extension retraction movement verification when the telescopic pipe is inclined

<Purpose>

To ascertain the maximum inclination at which the telescopic pipe can be extended/retracted, with the same configuration as "① Telescopic pipe extension retraction movement verification test"

<Conceptual image of the test>



<Evaluation items, etc.>

No.	Evaluation item	Target (criteria)	Policy for setting target values	Verification method	Other items to be verified
②−1	Inclination at which the pipe can be extended/retracted up to 3 stages	Can be extended/retracted	As the telescopic pipe has been designed on the premise of being able to extend and retract vertically based on the investigation conditions, the inclination at which the pipe can be extended/retracted shall be verified without setting the target value (maximum 5°)	The inclination of the installation stand of the telescopic pipe is verified by means of an angle meter.	・Whether or not there is irregular winding by the winding equipment ・Detecting when the telescopic pipe has been extended to its full length: depends on the accuracy of the measurement of extension/retraction
②−2	Air pressure required while extending	0.1MPa or less	Maximum design pressure or less	Measurement of pressure of air injected at each stage, using a pressure gauge	
②−3	Tensile force required while retracting	50N or less	Shall be equal to or less than the maximum tensile force of the cable winding equipment	Evaluated based on the cable winding equipment drum driven motor torque	
②−4	Accuracy of the measurement of extension/retraction using the winding equipment	Error ±30mm or less	The maximum error so that at least 1/4 of the images overlap, when the camera moves in the vertical direction so that 1/3 of the images overlap, while generating images through the cylinder.	Value obtained from the measurement by means of the winding equipment and the actual value measured by the laser range finder are compared.	

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

② Extension retraction movement verification when the telescopic pipe is inclined

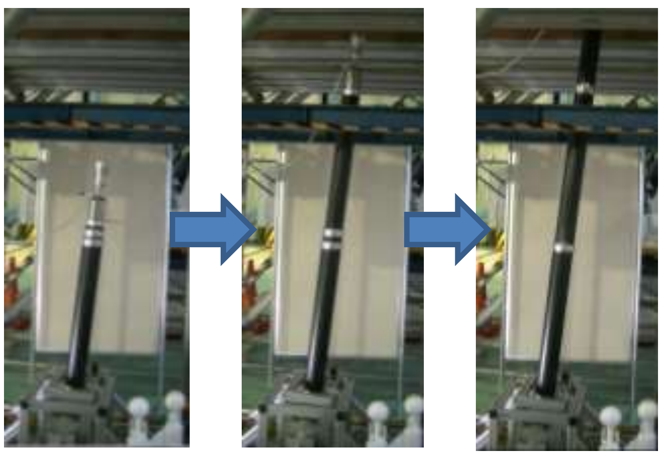
<Results using the regular seal>

- It was found that the pipe can be extended even with an inclination of 5° (upper limit of test). It is conceivable that the lower end of the pipe would get caught due to the moment resulting from self weight, and that the tensile force required for retraction increases as compared to vertical movement, but it was found that the pipe can be retracted at an inclination of 3° . This is expected to be resolved by changing the seal structure and controlling the backlash. Additionally, the allowable angle of inclination is expected to increase by further reducing the sliding resistance of the seal.

<Results using the controlled inclination type seal>

- When the vertical extension retraction movement was verified, the sliding resistance was unexpectedly high, the motor torque was insufficient, and the pipe was not retracted. Hence this test was not performed.

<Pictures of testing>



Extension of a telescopic pipe at an inclination of 5°

<List of results> Conducted only once for each condition (regular)

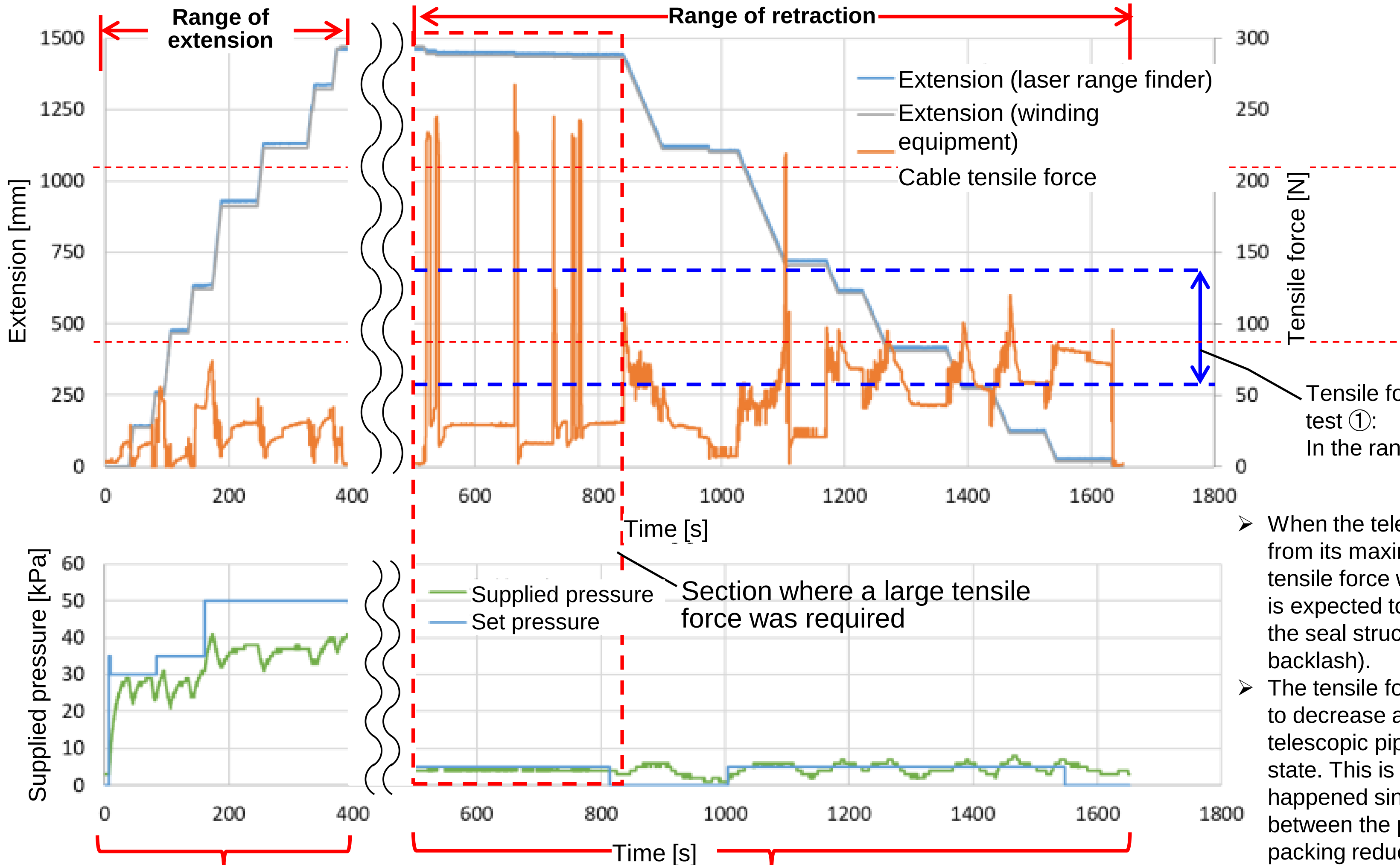
No.	Evaluation item	Target (criteria)	Result		
②−1	Inclination at which the pipe can be extended/retracted up to 3 stages	Can be extended/retracted	Regular	Inclination 3°: Can be extended/retracted Inclination 4°: Can be extended only Inclination 5°: Can be extended only	○ (Precondition for operating the telescopic pipe vertically)
			Controlled inclination type	—	—
②−2	Air pressure required while extending	0.1MPa or less	Regular	Inclination 3°: 0.04MPa Inclination 4°: 0.04MPa Inclination 5°: 0.04MPa	○
			Controlled inclination type	—	—
②−3	Tensile force required while retracting	50N or less	Regular	Inclination 3°: Maximum 270N Inclination 4°: Cannot be retracted Inclination 5°: Cannot be retracted	△ (The pipe can be retracted, but the tensile force while retracting may exceed the rated value of 83N.)
			Controlled inclination type	—	—
②−4	Accuracy of the measurement of extension/retraction using the winding equipment	Error ±30mm or less	Regular	Inclination 3°: 26mm Inclination 4°: Not evaluated (*1) Inclination 5°: 15mm	○
			Controlled inclination type	—	—

(*1) Not evaluated as the characteristics can be ascertained by evaluating the upper limit / lower limit under test conditions.

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

② Extension retraction movement verification when the telescopic pipe is inclined (regular seal, angle of inclination 3°)



While extending the pressure supplied is 30kPa ~ 40kPa

While retracting the pressure supplied is 5kPa

- When the telescopic pipe was retracted from its maximum extension, a large tensile force was required, however, this is expected to be resolved by changing the seal structure (controlling the backlash).
- The tensile force while retracting tended to decrease as compared to when the telescopic pipe was retracted in a vertical state. This is presumed to have happened since the contact surface between the pipe inner surface and the packing reduced when the pipe was tilted thereby weakening the sliding resistance.

6. Implementation Details

Unit 2 & 3 No. 90

(2) Development of the bottom access investigation method

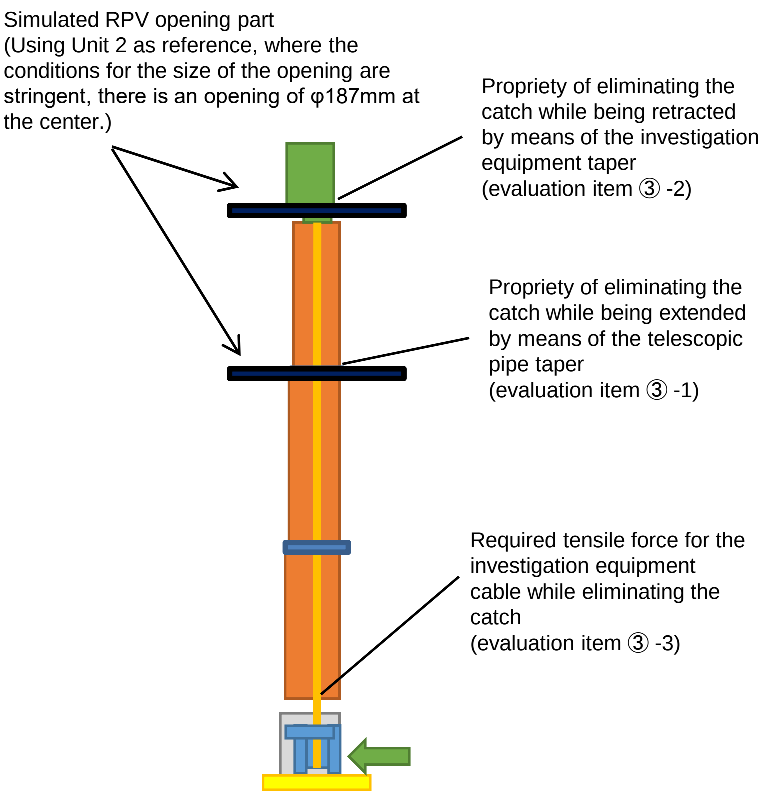
2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

③ Behavior verification test when the telescopic pipe / investigation equipment get caught in the structures

<Purpose>

To verify that with the same configuration as “① Telescopic pipe extension retraction movement verification test” when the telescopic pipe gets caught in the structures while being extended, the catch can be eliminated by following the precedent of the taper installed on the telescopic pipe or the investigation equipment.

<Conceptual diagram of the test>



<Evaluation items, etc.>

No.	Evaluation item	Target (criteria)	Policy for setting target values	Verification method	Other items to be verified
③−1	Propriety of eliminating the catch while being extended by means of the telescopic pipe taper	Elimination	Verifying that there is no problem with the designed taper angle	Visual confirmation	・Whether or not the pipe will get caught at other locations where the taper has not been provided
③−2	Propriety of eliminating the catch while being retracted by means of the investigation equipment taper	Elimination	Verifying that there is no problem with the designed taper angle	Visual confirmation	
③−3	Required tensile force for the investigation equipment cable while eliminating the catch	50N or less	Shall be equal to or less than the maximum tensile force of the cable winding equipment	Evaluated based on the cable winding equipment drum driven motor torque	

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

③ Behavior verification test when the telescopic pipe / investigation equipment get caught in the structures

<Results using the regular seal structure>

- The location where the opening rubs against the pipe (interference of telescopic pipe taper of 8.5mm and investigation equipment taper of 11mm) and the location that reduces the interference between the taper and the opening (interference of telescopic pipe taper of 3mm and investigation equipment taper of 7mm), were evaluated for the location for the opening.
- Since the telescopic pipe has little backlash and deflection, the pipe cannot be extended/retracted if it was placed such that it rubs against the opening. When the interference was reduced, although it was extended, it was not retracted.
- Since the 14 stage telescopic pipe becomes quite long and thus becomes less rigid, evaluation will be performed during the 14 stage telescopic pipe test as well. And, as the arm-type access equipment for retrieval is likely to pass through due to its deflection during actual operation, the rigidity characteristics of the access equipment will be verified in future and the demonstration method will be studied.

<Results using the controlled inclination type seal structure>

- When the vertical extension retraction movement was verified, the sliding resistance was unexpectedly high, the motor torque was insufficient, and the pipe was not retracted. Hence this test was not performed.

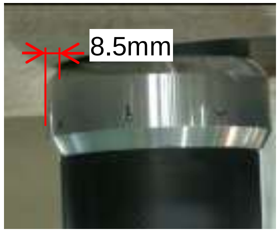
<List of results>Conducted only once for each condition (regular)

No.	Evaluation item	Target (criteria)	Result		
③−1	Propriety of eliminating the catch while being extended by means of the telescopic pipe taper	Elimination	Regular	Interference 8.5mm: Cannot be extended Interference 3mm: Can be extended (required pressure 0.04MPa)	x (The arm type access equipment is likely to pass through due to its deflection.)
			Controlled inclination type	—	—
③−2	Propriety of eliminating the catch while being retracted by means of the investigation equipment taper	Elimination	Regular	Interference 11mm: Cannot be retracted Interference 7mm: Cannot be retracted	x (The arm type access equipment is likely to pass through due to its deflection.)
			Controlled inclination type	—	—
③−3	Required tensile force for the investigation equipment cable while eliminating the catch	50N or less	Regular	— (The catch was not eliminated under any of the conditions)	x (Motor torque needs to be increased)
			Controlled inclination type	—	—

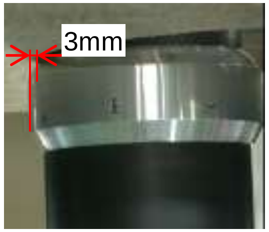
<Test picture>

Simulated opening

Simulated opening created



Location where the opening rubs against the pipe



Location where the interference is reduced

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

④ Extension retraction movement verification test when foreign material adheres to the telescopic pipe

<Purpose>

To verify whether or not the telescopic pipe can be retracted when its outer surface is wet or when foreign material is adhered to it, with the same configuration as "① Telescopic pipe extension retraction movement verification test".

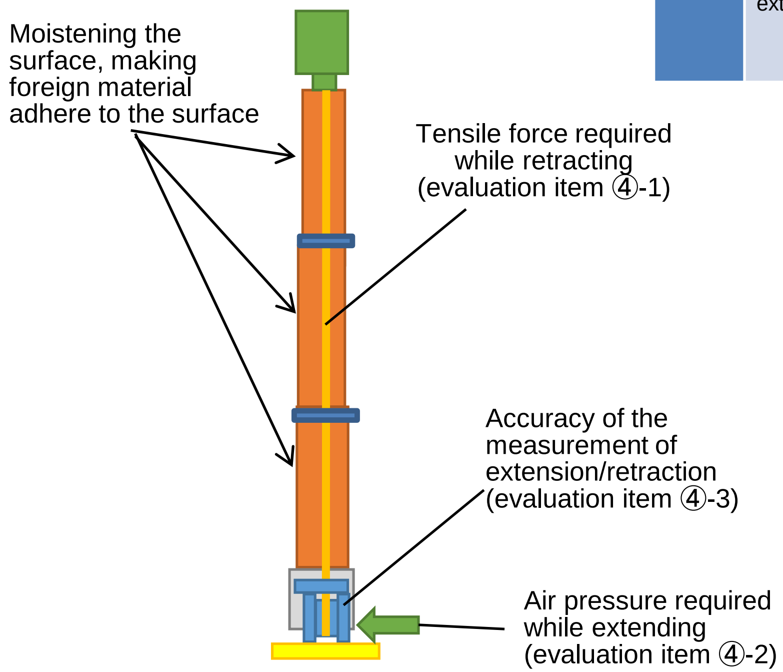
The following 2 types of particle sizes were selected as particles that enter the gap (200μm) between the pipes.

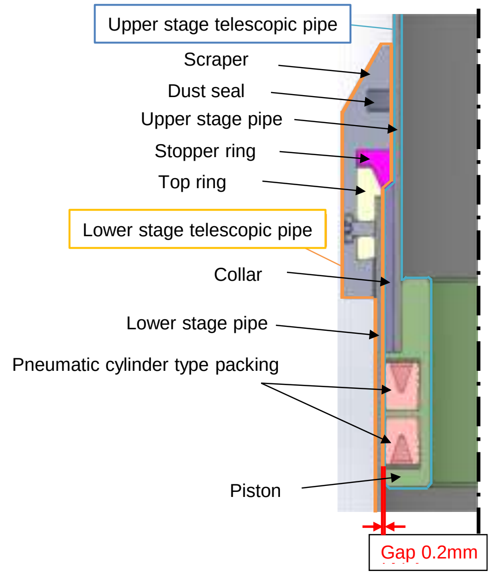
(a) Particle size 15μm (soil)
(b) Particle size 100μm (alumina)

<Evaluation items, etc.>

No.	Evaluation item	Target (criteria)	Policy for setting target values	Verification method	Other items to be verified
④-1	Tensile force required while retracting	50N or less	Shall be equal to or less than the maximum tensile force of the cable winding equipment	Evaluated based on the cable winding equipment drum driven motor torque	・Whether or not there is irregular winding by the winding equipment
④-2	Air pressure required while extending	0.1MPa or less	Maximum design pressure or less	Measurement of pressure of air injected at each stage, using a pressure gauge	
④-3	Accuracy of the measurement of extension/retraction	Error ±30mm or less	The maximum error so that at least 1/4 of the images overlap, when the camera moves in the vertical direction so that 1/3 of the images overlap, while generating images through the cylinder.	At every 0.5m the value obtained from the measurement by means of the winding equipment and the actual value measured by the laser range finder are compared.	

<Conceptual diagram of the test>





6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

④ Extension retraction movement verification test when foreign material adheres to the telescopic pipe

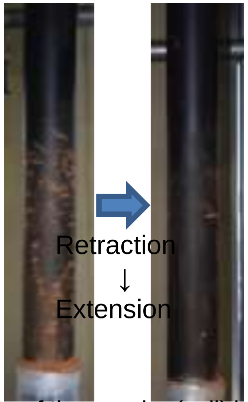
<Results using the regular seal>

- Particles of (a) size 15μm (soil) and (b) size 100μm (alumina) were made to adhere to the 2nd stage pipe and the pipe was extended and retracted. (150Mm gap between the pipes)
- There was no change in behavior even when the pipe was extended and retracted while powder a and powder b adhered to it. The tensile force while retracting was also in the range of roughly 50N to 130N and thus it was found that there was no difference compared to when no powder adhered to the pipe surface.
- When the telescopic pipe was disassembled and checked, it was found that the powder had not entered the seal part or inside the pipe and thus it was confirmed that the dust seal was effective.

<Results using the controlled inclination type seal>

- When the vertical extension retraction movement was verified, the sliding resistance was unexpectedly high, the motor torque was insufficient, and the pipe was not retracted. Hence this test was not performed.

<Test picture>



State of the powder (soil) before and after the test

Inside the 1st stage of the pipe after the test

<List of results> Conducted only once for each powder (regular)

No.	Evaluation item	Target (criteria)	Result		
④-1	Tensile force required while retracting	50N or less	Regular	Powder a: Maximum 230N Powder b: Maximum 130N Retraction possible in either case	△ (The pipe can be retracted, but the tensile force may exceed the rated value of 83N.)
			Controlled inclination type	—	—
④-2	Air pressure required while extending	0.1MPa or less	Regular	Powder a: 0.04MPa Powder b: 0.04MPa (Can be extended just like when no foreign material is adhered)	○
			Controlled inclination type	—	—
④-3	Accuracy of the measurement of extension/retraction	Error ±30mm or less	Regular	Powder a: 22mm Powder b: 14mm	○
			Controlled inclination type	—	—

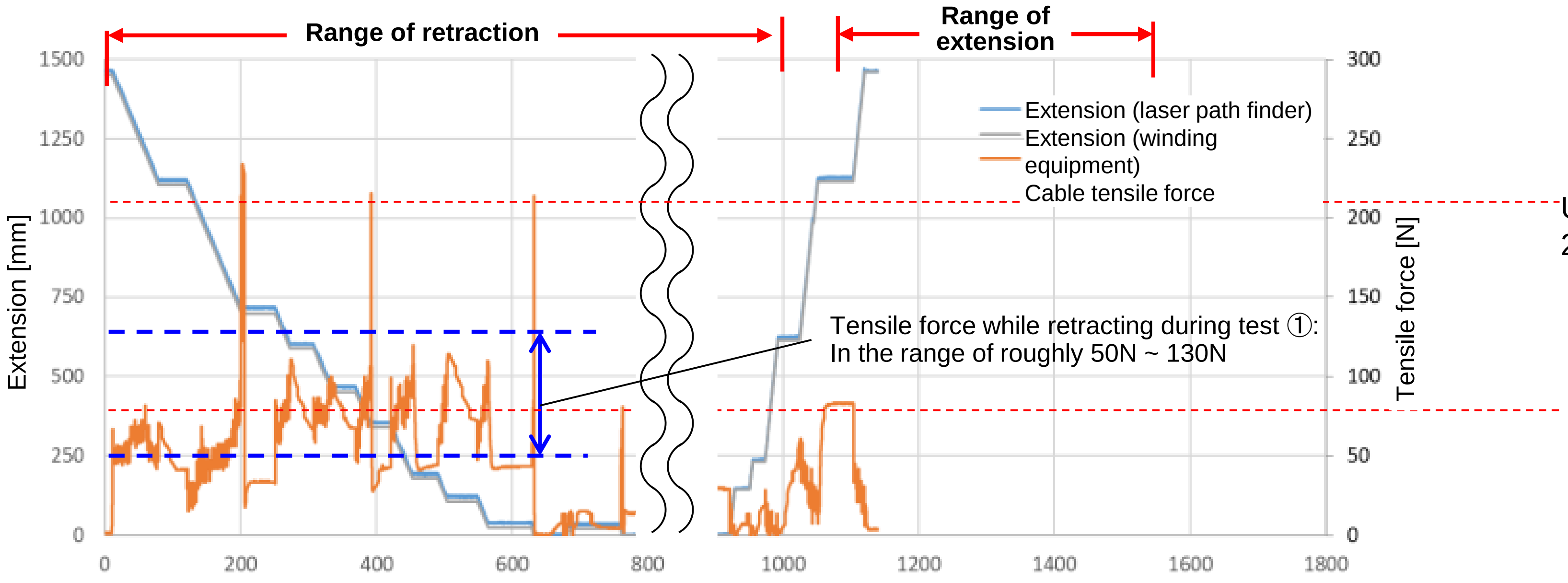
Powder deposited on to the outer peripheral surface of the pipe at the 2nd stage Power (b) has a larger particle size and hence the surface is moistened and then powder is deposited.

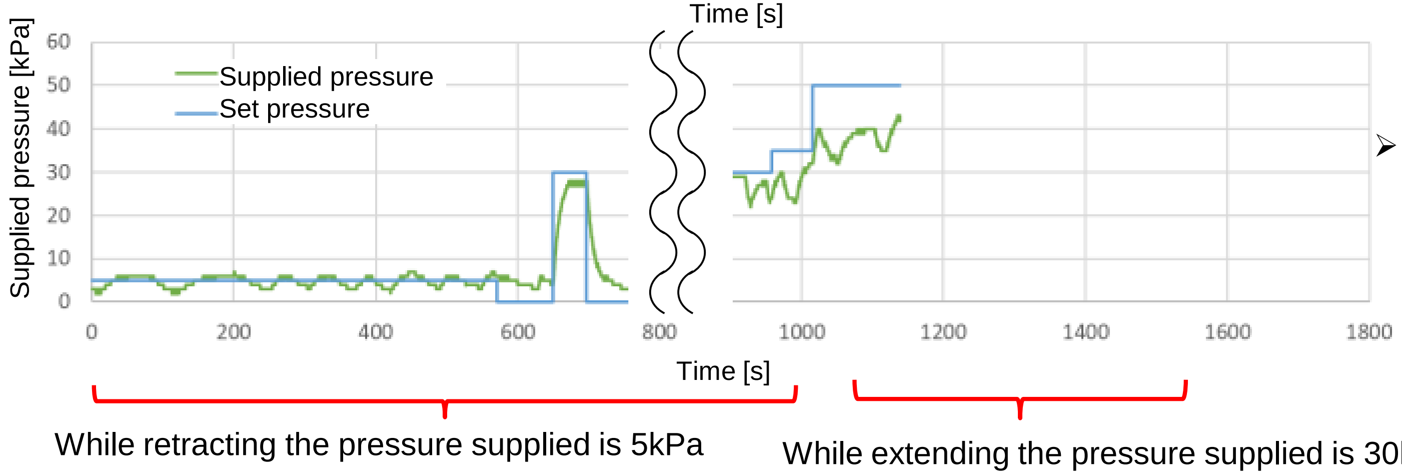
6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

④ Extension retraction movement verification test when foreign material adheres to the telescopic pipe (regular seal, soil)





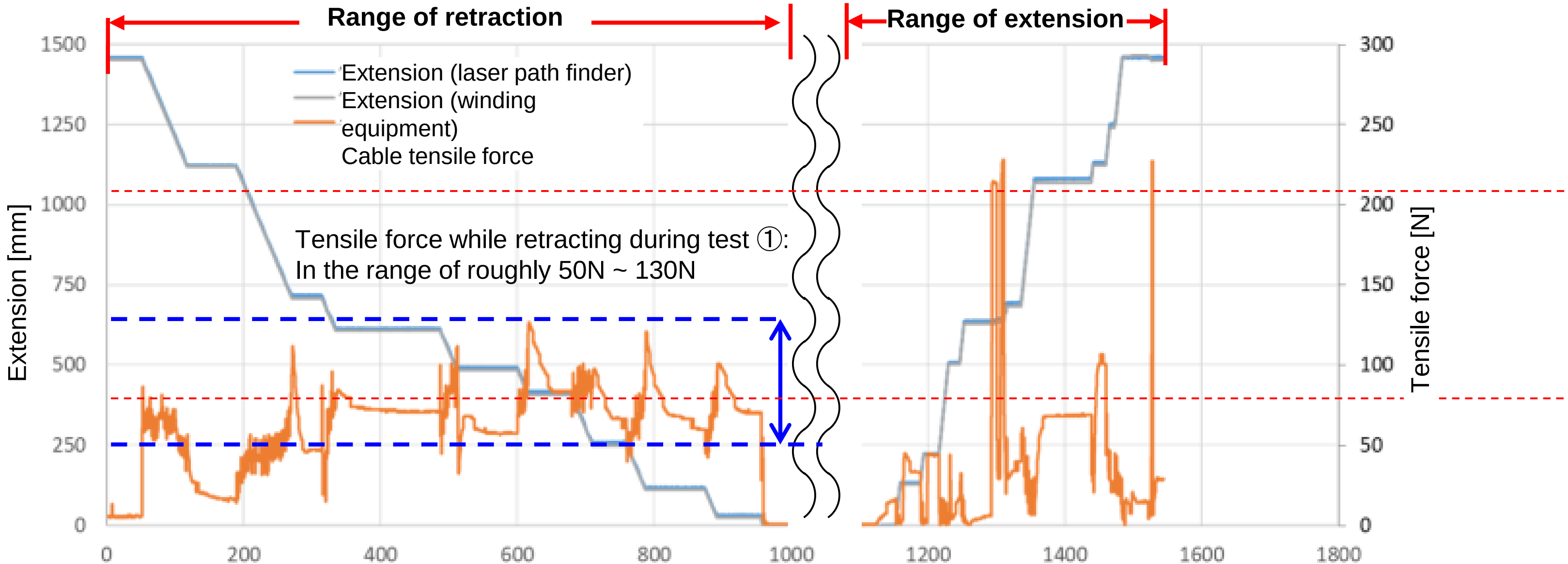
- There was no major difference in the supplied pressure during extension and the tensile force during retraction, as compared to when the powder is not deposited.

6. Implementation Details

(2) Development of the bottom access investigation method

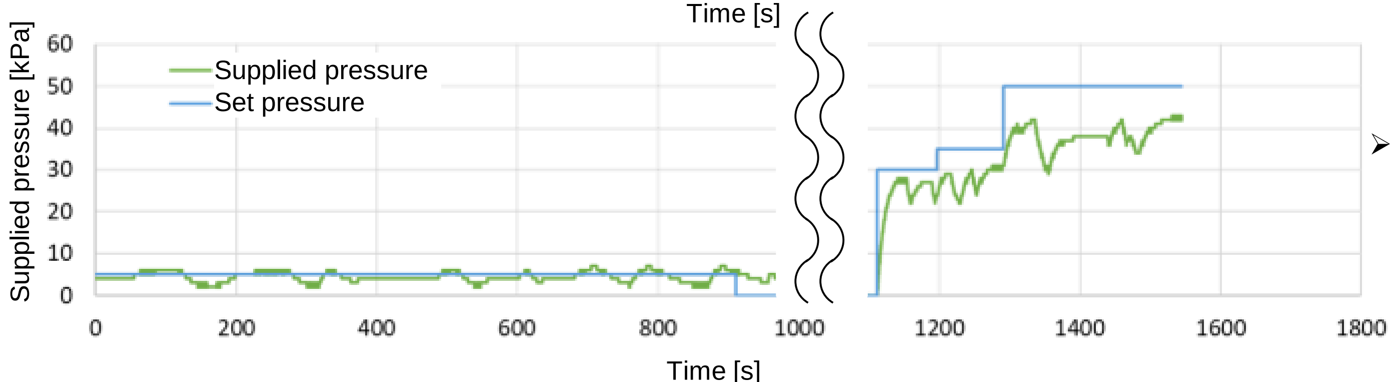
2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

④ Extension retraction movement verification test when foreign material adheres to the telescopic pipe (regular seal, alumina)



Upper tensile limit: 208N

Rated tensile force: 83N



- There was no major difference in the supplied pressure during extension and the tensile force during retraction, as compared to when the powder is not deposited.

While retracting the pressure supplied is 5kPa

While extending the pressure supplied is 30kPa to 40kPa

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. (3) Behavior verification test

Summary (regular seal)

- It was verified that the telescopic pipe can be extended/retracted with the configuration of the telescopic pipe and cable winding equipment being considered (Leakage did not have any impact). However, as the maximum required tensile force when the telescopic pipe is vertical was 230N as against the tensile force of 83N resulting from the rated torque of the motor of the cable winding equipment, it became evident that the sliding resistance of the seal of the telescopic pipe needs to be reduced.
- As it was confirmed that the telescopic pipe can be extended/retracted at an inclination of 3° , the error in installation by means of the arm type access equipment for retrieval will be verified in future and measures will need to be studied as necessary.
- Even if foreign material (powder) adhered to the telescopic pipe, the powder did not get stuck inside the pipe and there was no major difference in the required tensile force. Thus the effectiveness of the dust seal was verified.

Summary (controlled inclination type seal)

- The sliding resistance was unexpectedly high, the motor torque was insufficient, and the pipe was not retracted. Hence it was only verified whether or not the pipe was extended.

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study E: Performing tests, etc. Feasibility of the 14 stage telescopic pipe

No.	Items	Evaluation	Reason
1	Extension movement	Acceptable	It was verified that a 3 stage telescopic pipe can be extended with a pressure of 0.04MPa or less when there is regular packing. However, as the telescopic pipe is extended and gets longer, the gap between the supplied pressure and the adjusted pressure increases. When the 14 stage telescopic pipe continues to be extended, the supplied pressure may not rise even if the set pressure is increased. This increase in gap is not seen in case of the controlled inclination type seal structure in which there is less leakage as compared to the regular seal. Hence it is believed that the leakage from the packing is the cause. ⇒Issue ①: Reducing the amount of leakage
2	Retraction movement	Acceptable	A 3 stage telescopic pipe was retracted when there was regular packing. However, it was found that the tensile force while retracting exceeds the rated tensile force of the motor. The sliding resistance needs to be reduced in order to reduce the required tensile force. ⇒ Issue ②: Reducing the sliding resistance
3	Ability to pass through φ187mm opening	Good	When the 3 stage telescopic pipe was completely extended and horizontal load was applied, there was misalignment resulting from the backlash of 3mm in case of the controlled inclination type seal structure and a backlash of 7mm in case of the regular seal. The pipe that passes through the φ187mm opening assumed to be present at the RPV bottom is the 9^{th} stage (φ57mm). The misalignment due to the backlash when the pipe is extended up to the 9^{th} stage (length 6.9m) is 21mm in case of the regular seal and 10mm in case of the controlled inclination type seal. Hence it was verified that telescopic pipe backlash does not affect passing through the φ187mm opening in the case of the regular seal, with which the 3 stage telescopic pipe was extended/retracted. Further, the misalignment caused by the backlash when the 14 stage telescopic pipe is extended (length 10.4m) is 31mm in the case of the regular seal and 10mm in the case of the controlled inclination type seal.
4	Catch elimination performance	Acceptable	The catch was not eliminated even with a regular packing in a 3 stage telescopic pipe. The sliding resistance of the packing structure needs to be reduced in order to make it easier to eliminate the catch during retraction. Further, when using the actual equipment, since the arm type access equipment bends, it is expected to become easier to eliminate the catch as well. ⇒ Issue ② : Reducing the sliding resistance

Issues such as high sliding resistance or leakage from the sealed portion came forth, however, it was evaluated that the mechanism itself was feasible.

6. Implementation Details

(2) Development of the bottom access investigation method

2. Feasibility study F: Evaluation based on the test results, etc.

<Implementation Plan for FY2021>

・The following proposals are being studied in response to issues ①: Reducing the amount of leakage and its issue ②: Reducing the sliding resistance.

○ Changing the folds on the inner surface of the CFRP so that they are in a single direction

The inner surface of the current pipe is not smooth as it is made of a plain carbon fiber weave. Hence the tensile force required while retracting the telescopic pipe and the amount of leakage from the packing contact area need to be reduced by smoothening. Therefore, changing the orientation of the folds so that they face a single direction in order to smoothen the inner surface of the pipe that comes in contact with the packing, will be studied.

○ Changing the seal structure

A structure combining the pneumatic cylinder packing (GLY) of the regular seal in which there is less sliding resistance and the wear ring in which there is less misalignment of the tip, will be studied.

・In addition to the above-mentioned issues, increasing the torque (cable winding force) as much as possible while considering dimensional constraints of the cable winding equipment will be included in the design study as well.

・As an alternative plan in case issues ① and ② cannot be resolved, the use of aluminum pipes that have a proven track record and have a less rough surface will be considered, and basic data will be obtained through a seal function verification test. However, using aluminum material has its demerits from the viewpoint of strength, and, the equipment becomes heavier as well. These will need to be considered if aluminum is to be used.

➡ The effect of sealing performance will be verified by means of a verification test considering measures for reducing the amount of leakage and the sliding resistance, and the feasibility of the method is planned to be verified through elemental tests using a 14 stage telescopic pipe.

6. Implementation Details

Unit 2 & 3

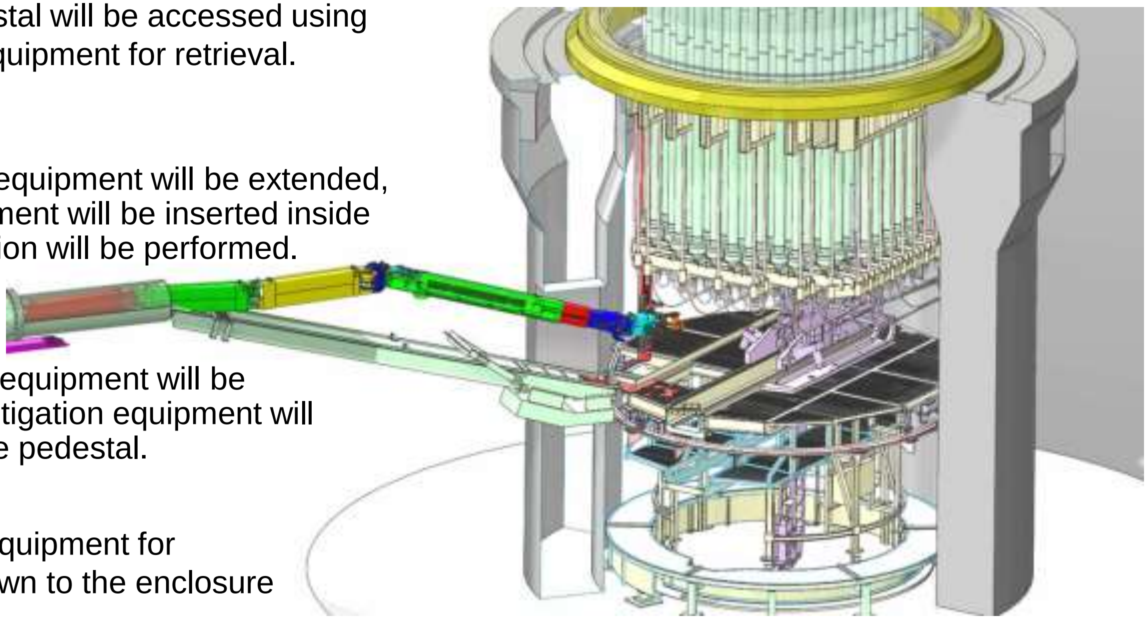
(2) Development of the bottom access investigation method

2. Feasibility study F: Evaluation based on the test results, etc.

<Investigation plan>

The plan is to perform the investigation using the telescopic access equipment following the steps mentioned below. The plan is scheduled to be executed in FY2021.

Installation of the equipment for investigation inside RPV on to the arm type access equipment for fuel debris retrieval	This investigation will be performed by removing the wand part of the arm type access equipment for fuel debris retrieval and installing equipment for investigation inside RPV on it.
Access to the inside of the pedestal	The inside of the pedestal will be accessed using the arm type access equipment for retrieval.
Access and investigation inside the RPV	The telescopic access equipment will be extended, the investigation equipment will be inserted inside RPV and the investigation will be performed.
Withdrawal from inside the pedestal	The telescopic access equipment will be retracted and the investigation equipment will be withdrawn inside the pedestal.
Withdrawal from the enclosure for retrieval	The arm type access equipment for retrieval will be withdrawn to the enclosure for retrieval.



Conceptual image of bottom access investigation in Unit 2

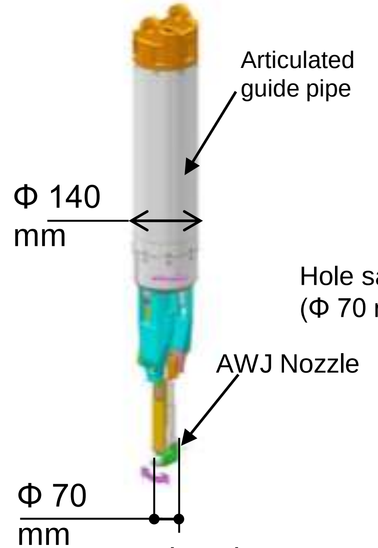
7. Summary

(1) Advancement of machining technology for the top access investigation method

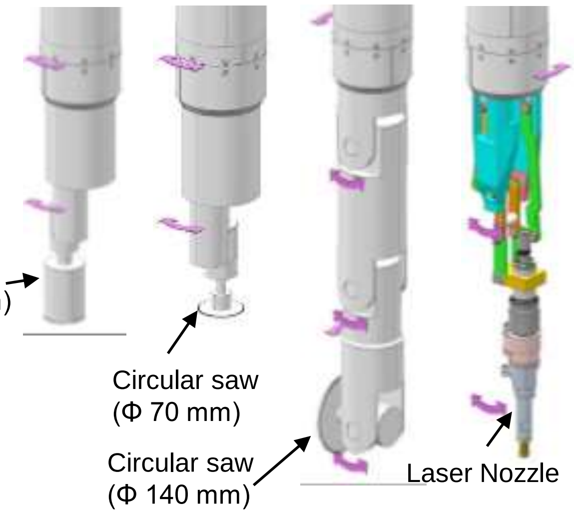
- Alternative machining technologies were investigated and evaluated, and machining technology in which hole saw cutting, circular saw cutting and laser cutting are added to the AWJ cutting technology was selected as machining technology that reduces the generation of secondary waste.

- Reducing the size of the nozzle used in AWJ, optimizing machining parameters such as the jet spray angle, the cutting location, etc., were studied. In addition, equipment and tools required if hole saw cutting, circular saw cutting and laser cutting were to be used, were studied as well.

- Simple tests for verifying the cutting performance of the machining technologies were conducted and it was determined that there are prospects of AWJ cutting and laser cutting being applied (Refer to the table on the right for the combinations of cutting direction and method).

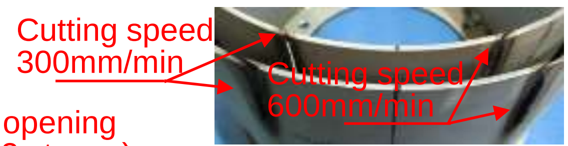


AWJ head

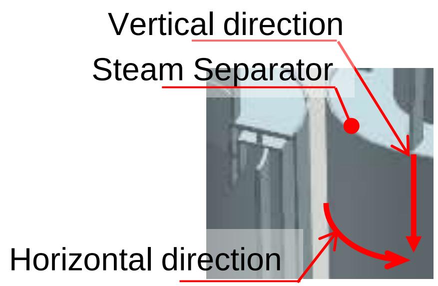


Examples of tool heads

Results of the simple tests (AWJ)



Results of the simple tests (laser)



Conceptual image of the cutting direction

Table Selected method and its combination

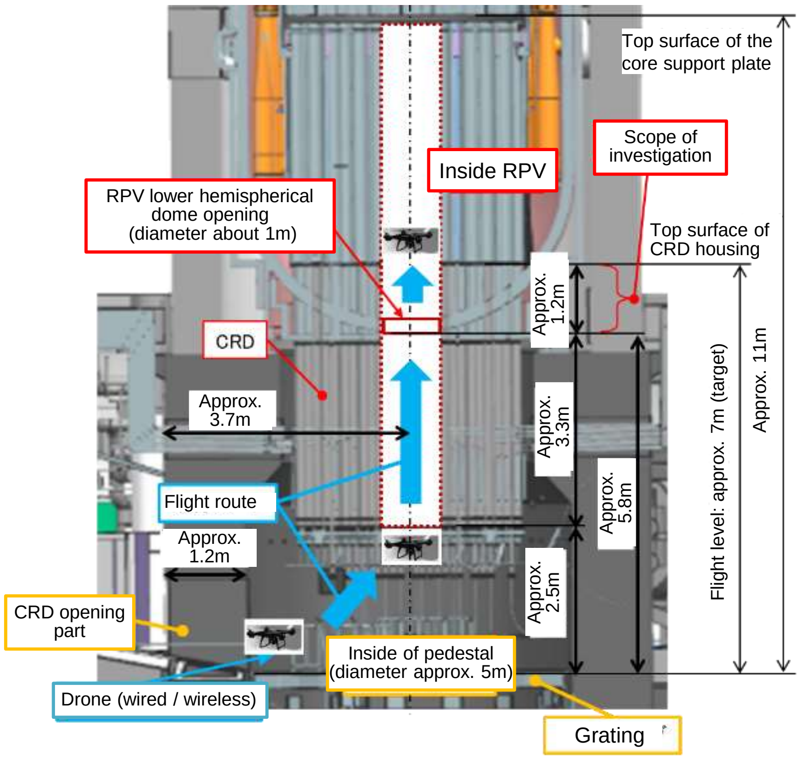
Machining technology combination	No. 1		No. 2	
	Vertical	Horizontal	Vertical	Horizontal
	AWJ	AWJ	Laser	AWJ

IRID

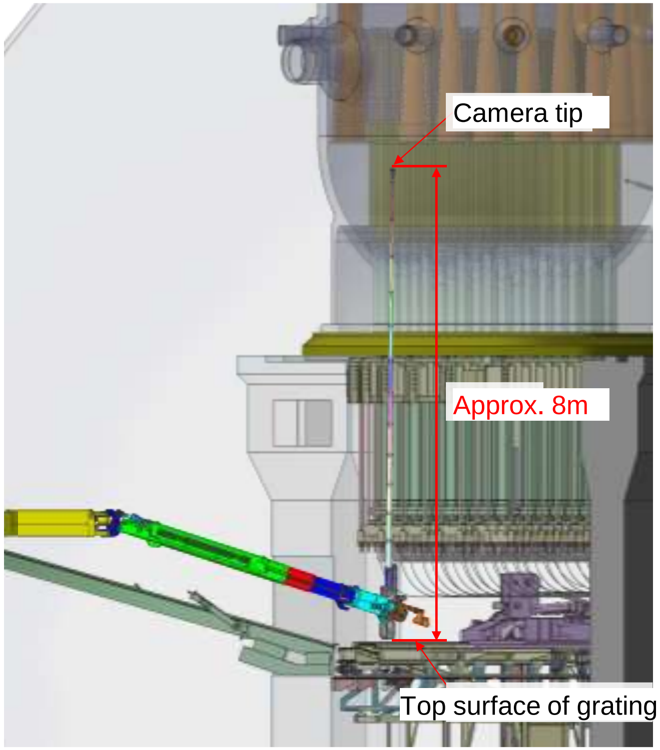
7. Summary (2) Development of the bottom access investigation method

- In Unit 1, since the size of opening at the RPV bottom is assumed to be large, it was decided to develop a method of accessing the inside of the RPV by means of a drone (wired/wireless) by using the crawler type access equipment being developed as part of the Detailed Investigation inside PCV PJ. Simple flight tests were performed for evaluating the feasibility of accessing inside RPV by means of a drone. A wired drone consisting of a drone and a cable drum and a wireless drone consisting of a drone and extension rod were selected.

- In Unit 2 and 3, since the size of the opening at the RPV bottom is assumed to be small, it was decided to develop a method of accessing inside RPV by mounting a telescopic pipe on the arm type access equipment for fuel debris retrieval, the scale of which was gradually increased. Simple tests were performed for evaluating the feasibility of the telescopic access equipment.



Unit 1: Conceptual image of access using a drone



Unit 2 & 3：Conceptual image of access using a telescopic pipe

7. Summary

Remaining issues and plan for FY2021

(1) Advancement of machining technology for the top access investigation method

Application of the machining technologies (AWJ/Laser) narrowed down based on the results of simple tests, besides the steam separator, are planned to be studied, issues in applying the technologies to actual equipment and further improvement items are planned to be identified and related measures are planned to be implemented.

(2) Development of the bottom access investigation method

・Based on the results of simple tests, conceptual designing and elemental tests on drones (wired/wireless) for Unit 1 are planned to be conducted in FY2021.

・According to the results of simple tests the telescopic access equipment for Unit 2 & 3 can be extended, however, the sliding resistance is unexpectedly high and hence further improvement is needed. Conceptual designing considering measures for reducing sliding resistance and amount of leakage will be undertaken and elemental tests using a 14 stage telescopic pipe are planned to be implemented in FY2021.

Additionally, information on the connection with the arm type access equipment for fuel debris retrieval, design information, etc. is planned to be verified and reflected.