Subsidy Project of Decommissioning and Contaminated Water Management

Development of Technology for Gradually Increasing the Scale of Fuel Debris Retrieval

Accomplishment Report for FY2021

August 2022

International Research Institute for Nuclear Decommissioning (IRID)

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1. Research Background and Purpose
1.1 Reasons why this research is necessary

- Information on fuel debris properties is needed for equipment development and criticality evaluation to retrieve fuel debris from Units 1 through 3 of the Fukushima Daiichi Nuclear Power Station (NPS). Until now, values estimated from the accident data or analysis results of the Three Mile Island (TMI) or Chernobyl accidents has been used. However, for appropriate development of the equipment, the on-site fuel debris needs to be retrieved and analyzed so as to verify whether or not the estimated values are valid (including whether or not the values are on the safer side).

- Hence, in continuation from FY2021, in FY2022 as well, mainly the following work has been implemented.
  - Creation and update of the development plan of retrieval technology for gradually increasing the scale of fuel debris retrieval, and the retrieval plan.
  - Detailed designing, prototype manufacturing, and various verification tests of the equipment and systems for fuel debris retrieval

- Based on the outcomes of the above-mentioned work, newly found challenges and the recent circumstances at the Fukushima Daiichi NPS, retrieval technology for gradually increasing the scale of fuel debris retrieval needs to be developed while reviewing the positioning or objectives of fuel debris retrieval, which is being implemented through this research.

1.2 Reflection of results and contribution thereof

Project commenced in FY2021
Project commenced in FY2020

Project of Development of Technology for Investigation inside PCV*1
(Development of technology for investigation inside PCV)

Results of the investigation inside PCV*1 will be reflected.

Project of Development of Technology for Detailed Investigation inside PCV*1
(On-site demonstration of the technology for detailed internal investigation using X-6 penetration)

The development progress of investigation equipment will be reflected.

***1: PCV = Primary Containment Vessel**

Project of "Development of Technology for Gradually Increasing the Retrieval Scale of Fuel Debris" (this project)

Creation of the retrieval technology development plan for gradually increasing the scale of fuel debris retrieval, and the retrieval plan

Development of equipment and systems for gradually increasing the scale of fuel debris retrieval

Project of gradually increasing the retrieval scale of fuel debris and analysis

Physical property data such as hardness, etc. Cutting speed, status of dust scattering

Component data such as U, Pu, Gd, etc.

Fuel debris distribution data

Component data such as amount of hydrogen generated, etc.

Waste inventory data

Project for Development of Technology for Further Increasing the Scale of Retrieval of Debris and Internal Structures (including criticality control)

Upgrading of approach and systems for retrieval of fuel debris and internal structures,
Upgrading of fundamental technology for retrieval of fuel debris and internal structures,
Upgrading of criticality control technology for fuel debris

- **Reflection into the system design of the retrieval cell**
- **Designing and improvement of fuel debris retrieval tools**
- **Validity check of criticality evaluation**

Project for Development of Analysis and Estimation Technologies for Fuel Debris Characterization

Advancement of understanding of the in-core conditions through accident progression analysis and actual equipment data, etc.

Verification of the reliability of the in-core analysis results

Project for Development of Technology for Collection, Transfer and Storage of Fuel Debris

Development of technology for collection, transfer and storage of fuel debris

Verification of canister safety

Project for R&D for Treatment and Disposal of Solid Wastes

Research and development for treatment and disposal of solid waste

Reflection in the overall plan for waste

Research projects concerning detailed designing of the fuel debris retrieval methods and equipment, etc.

Gradually increasing the scale of fuel debris retrieval
(Planned to be implemented at TEPCO HD)

Detailed designing of equipment for gradually increasing the scale of fuel debris retrieval

2. Project Goals (1/2)

Project commenced in FY2020

Implementation items started in FY2020

No.	Project details	Target Technology Readiness Level (TRL) as of FY2021
6.1	**Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)**	6.1.1 Element technology to be installed on the retrieval arm Prototypes of the horizontal offset mechanism, telescopic mechanism, and the wand were manufactured, combination tests were conducted using dummy tip tools, and the force applied on the fuel debris while pressing the tip tool, and the passing ability through the opening on the platform were verified. (Target TRL at completion: Level 5)
		6.1.2 Element technology to be installed on the enclosure for retrieval A prototype of the double door system was manufactured, and the following items were verified by means of the unit performance tests. ・Airtightness when opening and closing of the double door ・Airtightness when opening and closing of the isolation door ・Effectiveness of the emergency drive system in the event of motor failure (Target TRL at completion: Level 5)
6.2	**Development of remotely controlled transport cart for fuel debris canisters**	Development of remotely controlled transport cart for fuel debris canisters A prototype was manufactured, and the following items were verified by means of in-factory verification tests. ・ Traveling performance and stopping accuracy of the cart, ・Connection and separation of the simulated enclosure and fuel debris canisters ・Workability of emergency retrieval in the event of a failure and workability of maintenance (Target TRL at completion: Level 5)

2. Project Goals (2/2)

Implementation items started in FY2021

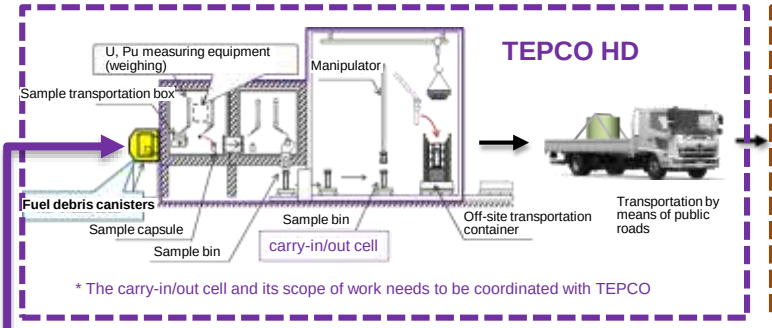
No.	Project details	Target Technology Readiness Level (TRL) as of FY2022
6.3	Update of the retrieval technology development plan	The retrieval technology (retrieval equipment and systems, etc) development plan for gradually increasing the scale of fuel debris retrieval, created as part of previous project (project commenced in FY2019), based on the information obtained from investigation and Others inside PCV of Unit 2, was updated as necessary. Besides, latest findings were reflected and updated as needed into the scenarios related to gradually increasing the scale of fuel debris retrieval. (This is not included in setting the Technology Readiness Level (TRL) to organize information.)
6.4	Development of the retrieval equipment and combination tests	6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.) The access equipment for retrieval (arm and enclosure, etc.) were manufactured and its applicability was verified through in-factory verification tests based on the detailed design of the access equipment for retrieval (arm and the enclosure, etc.) conducted in the previous project (project commenced in FY2020). (Target TRL at completion: Level 5)
		6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems The manufactured access equipment for retrieval (arm and enclosure, etc.) and the equipment developed until FY2021 during the previous project (project commenced in FY2019) were combined and their applicability of the system was verified. (Target TRL at completion: Level 5)

3. Implementation Items, their Correlation and Relations with Other Research

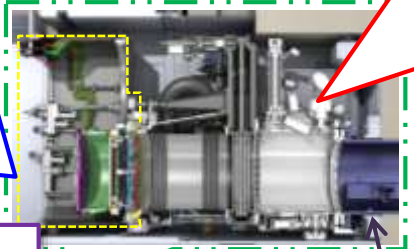
Project commenced in FY2021

Project commenced in FY2020

No.6



Double door mechanism
(Developed as part of the project commenced in FY2020)



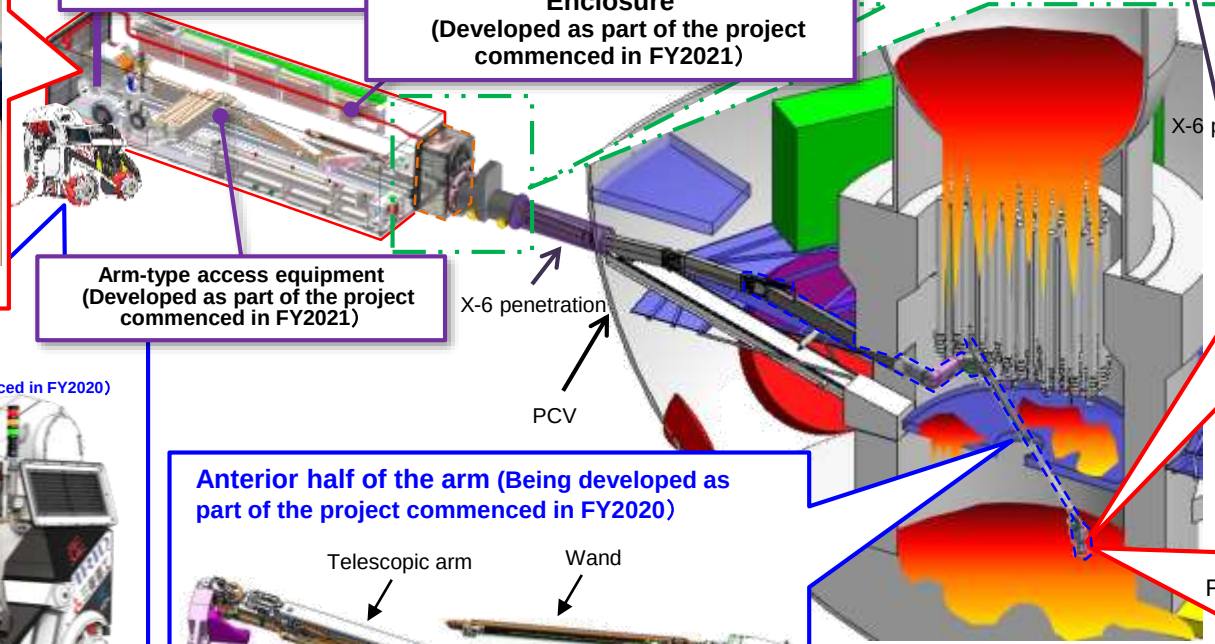
Equipment for constructing access route (X-6 penetration connection structure)

(Manufactured as part of the project commenced in FY2019)

Dual arm type manipulator

(Manufactured as part of the project commenced in FY2019)

Fuel debris collection scenario

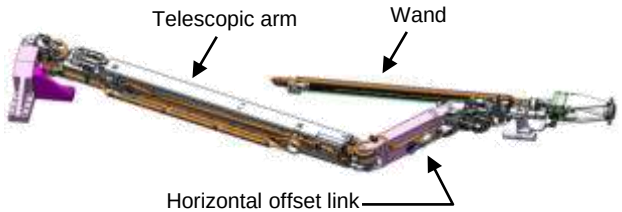


Fuel debris cutting and collection equipment

(Manufactured as part of the project commenced in FY2019)

Remotely controlled transport cart for fuel debris canisters
(Developed as part of the project commenced in FY2020)

Anterior half of the arm (Being developed as part of the project commenced in FY2020)



Neutron monitor (for monitoring approach to criticality, etc.)

(Manufactured as part of the project commenced in FY2019)

3. Implementation Items, their Correlation and Relations with Other Research
3.1. Implementation items of this research (1/2)

Project commenced in FY2020

Implementation items started from FY2020

No.	Implementation items		Scope of implementation in FY2021	Page
6.1	Development of element technology for the access equipment for fuel debris retrieval (arm enclosure, etc.), and designing	6.1.1 Element technology to be installed on the retrieval arm	• Manufacturing the prototypes of the front-end arm such as the horizontal offset mechanism, telescopic mechanism, wand, etc. • In-factory verification test of the prototypes	13-15
		6.1.2 Element technology to be installed on the enclosure for retrieval	• Manufacturing the prototype of the double door system • In-factory verification test of the prototype	16-18
6.2	Development of remotely controlled transport cart for fuel debris canisters	Remotely controlled transport cart for fuel debris canisters	• Manufacturing the prototype of the remotely controlled transport cart • In-factory verification test of the prototype	19-22

Blue: Testing **Red: Manufacturing**

3. Implementation Items, their Correlation and Relations with Other Research
3.1. Implementation items of this research (2/2)

Project commenced in FY2021

Implementation items started from FY2021

No.	Implementation items		Scope of implementation in FY2021	Page
6.3	Update of the retrieval technology development plan		• Updating the development plan at the time of commencement in FY2021 (examination of the timing of reflecting the results of the verification tests of the arm for detailed investigation inside PCV and the points to be focused on during the reflection, and examination of the contents of the verification tests conducted by combining various developed equipment)	23-26
6.4	Development of the retrieval equipment and combination tests	6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)	• Designing and manufacturing of the base of the arm, and integrating it with the front-end arm • Designing and manufacturing of the enclosure	27-29
		6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems	• Study of the combination test plan • Preparations for the combination tests	30-32

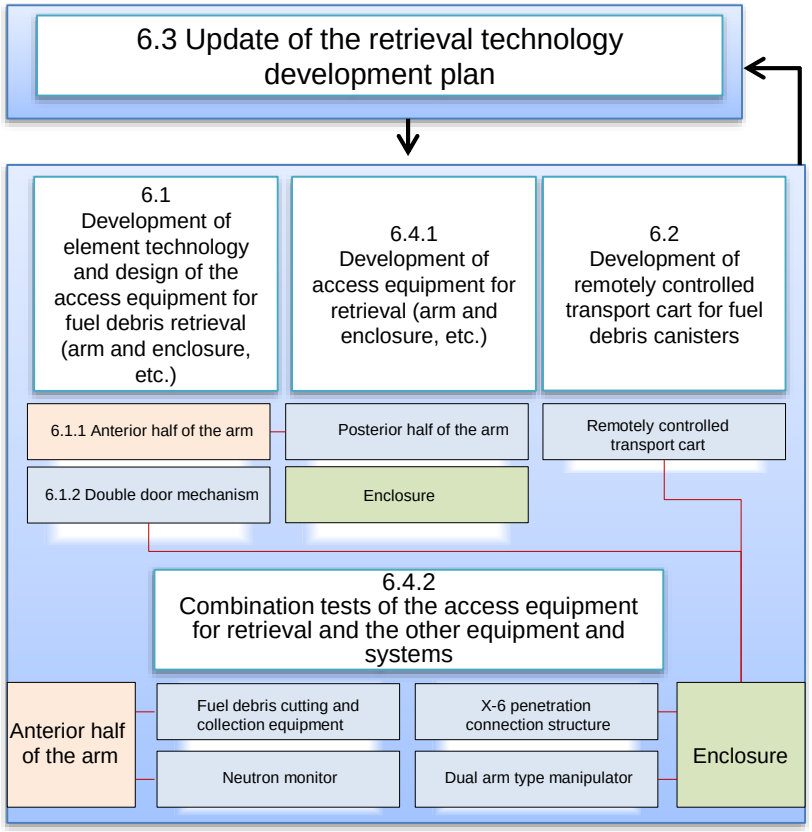
Black: Desk study **Red: Manufacturing**

3.2 Correlation between implementation items and with other research (1/2)

Project commenced in FY2020

Project commenced in FY2021

No.	Related implementation items	Details of collaboration	Relationship
6.1.1	6.4.1 Retrieval arm	Integration of the anterior half and posterior half of the arm	Performance of passing through the X-6 penetration is considered while integrating the newly designed anterior half and posterior half of the arm.
6.1.2	6.4.1 Enclosure	Overall assembly of the enclosure	The method of accurately installing the double door mechanism on the enslosure is considered.
6.2	6.4.1 Enclosure	Docking interface for the fuel debris canisters (PADIRAC)	An interlock for identifying the installation location of the PADIRAC port of the enclosure, detecting docking, and preventing accidental docking cancellation is considered.
6.3	6.1.1 to 6.4.2	Reflection of technological challenges in the development plan	The plan is updated with the new technological challenges that became evident through the in-factory verification test of the prototype, as part of this project.
6.4.1	6.1.1 Anterior half of the arm 6.1.2 Double door mechanism	Same as 6.1.1, 6.1.2	Same as 6.1.1, 6.1.2
6.4.2	6.1.1 Anterior half of the arm 6.1.2 Double door mechanism 6.2 Remotely controlled transport cart 6.4.1 Arm 6.4.1 Enclosure	Verification of interface by means of combination verification Identification of challenges in the extent of coordination between systems	6.1.1: It is checked whether or not there is room for improving the equipment in terms of the interface or linkage with the fuel debris cutting and collection equipment or the neutron monitor. 6.1.2: It is checked whether or not there is room for improving the equipment or process in terms of the interface or linkage with the X-6 penetration connection structure or the dual arm type manipulator. 6.2: It is checked whether the same verification results as those obtained in France are obtained when the operation is performed by Japanese operators. 6.4.1 (arm): Performance of passing through the X-6 penetration is verified. 6.4:1 (enclosure): It is checked whether or not there is room for improving the equipment or process in terms of the interface or linkage with the dual arm type manipulator.



3.2 Correlation between implementation items and with other research (2/2)

Project commenced in FY2020

Project commenced in FY2021

■ Work flow for fuel debris retrieval from inside PCV and the main connections with related PJs

Work flow for fuel debris retrieval from inside PCV

Equipment related to fuel debris retrieval from inside PCV

Enclosure

Double door mechanism

Dual arm type manipulator

Equipment for constructing the access route

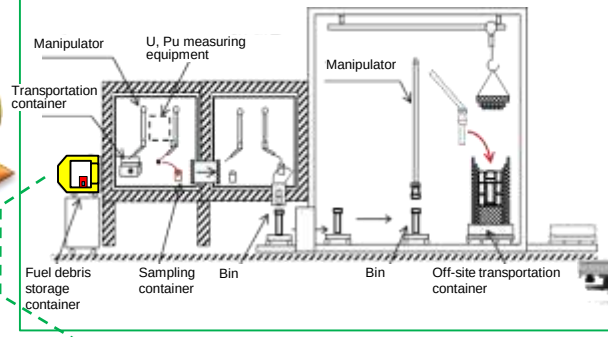
Fuel debris cutting and collection equipment

Arm-type access equipment

Neutron monitor

Remotely controlled transport cart

Equipment related to the carry-in/out cell



Existing analysis facility

Off-site transportation

Project for Development of Technology for Gradually Increasing the Scale of Fuel Debris Retrieval

TEPCO HD

Fuel Debris Characterization PJ

Main connections with related PJs

[PCV Detailed Internal Investigation PJ]
・Reflection of the image of the condition inside PCV into the design
・Sharing of information on development of the arm for investigating inside PCV
・Sharing of development challenges pertaining to the detailed investigation inside PCV

[PCV Detailed Internal Investigation PJ]
・Sharing of information on development of enclosure for investigating inside PCV
・ Sharing of remote operation procedures to be followed during the investigation inside PCV
[TEPCO HD]
・ Reflection of related technologies into fuel debris retrieval, the scale of which is gradually increased

[Fuel Debris Characterization PJ]
・Fuel debris acceptance interface coordination
[Fuel Debris Retrieval PJ]
・ Fuel debris sampling requirements
・Fuel debris cutting technology related information sharing
・Criticality prevention measures at the time of fuel debris cutting

[TEPCO HD]
・ Coordination of the maintenance area in the Reactor Building

[TEPCO HD]
・Sharing of information on fuel debris canister (PADIRAC)
・Coordination with the transfer area in the Reactor Building
・ Reflection of needs pertaining to technologies to be utilized, into fuel debris retrieval, the scale of which is gradually increased

Fuel debris retrieval plan

[Fuel Debris Characterization PJ]
・ Questioning about analytical capabilities of the existing analysis facilities and its reflection in the fuel debris retrieval plan
[TEPCO HD]
・ Discussion on fuel debris transfer route and its reflection in the fuel debris retrieval plan

4. Implementation Schedule

Project commenced in FY2020

Project commenced in FY2021

: Project commenced in FY2020 : Project commenced in FY2021

Large classification	Small classification	Remarks (Latest status)
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)	6.1.1 Element technology to be installed on the retrieval arm	
	6.1.2 Element technology to be installed on the enclosure for retrieval	
	Overall designing of the access equipment for retrieval (arm and enclosure, etc.)	
6.2 Development of remotely controlled transport cart for fuel debris canisters		
6.3 Update of the retrieval technology development plan		
6.4 Development of the retrieval equipment and combination tests	6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)	
	6.4.2 Combination tests of the access equipment for retrieval with the entire system	
Major milestones		

FY2020: Apr May Jun Jul Aug Sept Oct Nov Dec Jan Feb Mar

FY2021: Apr May Jun Jul Aug Sept Oct Nov Dec Jan Feb Mar

FY2022: Apr May Jun Jul Aug Sept Oct Nov Dec Jan Feb Mar

Manufacturing and in-factory verification of the front-end arm ⇒Extension due to the impact of the COVID-19 pandemic

Detailed designing

Manufacturing and in-factory verification

Assembly and coordination

Testing

Elemental tests on the double door system

Manufacturing and in-factory verification of the double door mechanism ⇒ Completed

Detailed designing

Manufacturing and in-factory verification

Detailed designing

Manufacturing and in-factory verification of the remotely controlled transport cart ⇒ Completed

Detailed designing

Manufacturing and in-factory verification

Crystallization of the development plan ⇒ Implemented as per the plan

Development of the retrieval arm ⇒Manufacturing in progress

Manufacturing and integration of the retrieval arm

Development of the enclosure for retrieval ⇒ Manufacturing in progress

Manufacturing and in-factory verification of the enclosure for retrieval

Improvement of the dual arm type manipulator ⇒ Manufacturing in progress

Combination tests of the front-end arm and the fuel debris cutting and collection equipment ⇒ Preparations for testing are underway

Combination tests of the entire arm (in-factory verification)

Combination tests of the enclosure and the X-6 penetration connection structure / remotely controlled transport cart for the fuel debris canisters

Verification test of the remotely controlled attachment and detachment mechanism for the dual arm type manipulator cable, emergency handling of the double door mechanism

Interim report

Annual report

Interim report

Final report

5. Project Organization

Project commenced in FY2020
Project commenced in FY2021

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

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

Project teams to cooperate for technological development

- Development of Technology for Detailed Investigation inside PCV (Field validation of the technology for detailed internal investigation using X-6 penetration)
- Development of technology for further increasing the scale of retrieval of fuel debris and reactor internals
- Development of technology for collection, transfer and storage of fuel debris
- Research and development for treatment and disposal of solid waste
- Development of analysis and estimation technology for characterization of fuel debris

Mitsubishi Heavy Industries, Ltd.

Implementation items started in FY2020

6.1 Development of element technology for the access equipment for fuel debris retrieval (arm enclosure, etc.), and designing
- 6.1.1 Element technology to be installed on the arm for retrieval
- 6.1.2 Element technology to be installed on the enclosure for retrieval

6.2 Development of remotely controlled transport cart for fuel debris canisters

Implementation items started in FY2021

6.3 Update of the retrieval technology development plan

6.4 Development of the retrieval equipment and combination tests
- 6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)
- 6.4.2 Combination tests of the access equipment for retrieval with the entire system

VEOLIA NUCLEAR SOLUTIONS:
・Designing and test manufacturing of the element technology to be mounted on the retrieval arm

Sojitz Machinery Corporation + CLEO:
・Elemental tests on the double door system
・Designing and test manufacturing of element technology to be mounted on the retrieval enclosure
・Manufacturing and in-factory verification of the remotely controlled transport cart for fuel debris canisters

VEOLIA NUCLEAR SOLUTIONS (VNS):
・Test manufacturing of access equipment for retrieval
・Combination tests on the access equipment for retrieval

Sojitz Machinery Corporation CLEO:
・Test manufacturing of the attachment and detachment mechanism for the dual arm type manipulator cable
・Preparation and assistance for the combination tests on the double door mechanism
・Preparation and assistance for the combination tests on on remotely controlled transport cart for fuel debris canisters

Jacobs:
・Preparation and assistance for the combination tests on pebble-shaped and sandy debris collection equipment (bucket type)

ORANO:
・Preparation and assistance for the combination tests on pebble-shaped and sandy debris collection equipment (flexible gripper type)

6. Implementation Details

Project commenced in FY2020

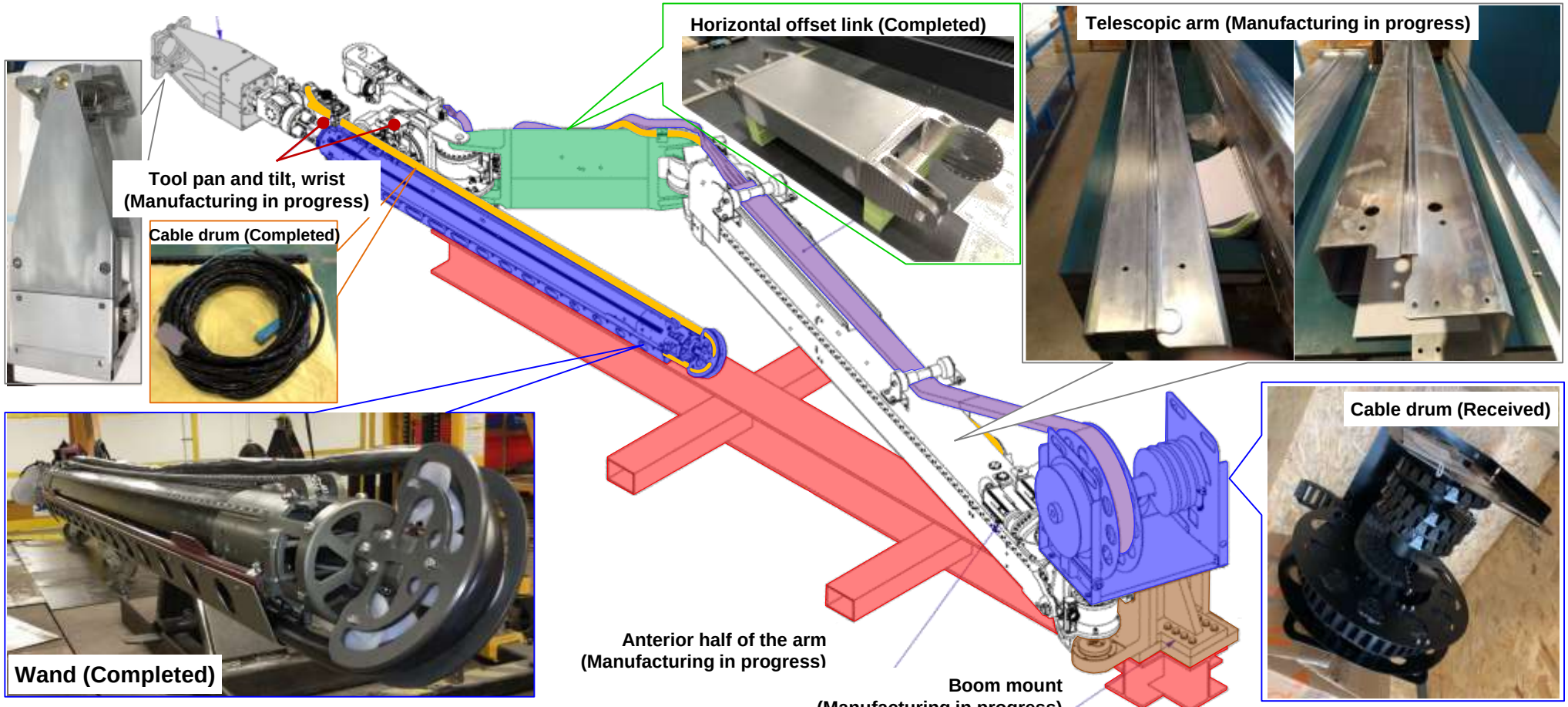
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)

6.1.1 Element technology to be installed on the retrieval arm

[Achievements for FY2021 1/2]

✓ The front-end arm including the telescopic arm and wand is being manufactured considering the counterforce from the horizontal offset mechanism or the fuel debris cutting and collection equipment. (The development period was extended due to the impact of the COVID-19 pandemic)

Dummy tip tools simulating the fuel debris cutting and collection equipment (Completed)



6. Implementation Details

Project commenced in FY2020

6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)

6.1.1 Element technology to be installed on the retrieval arm

[Achievements for FY2021 2/2]

- ✓ Plan for the in-factory verification test to verify the performance of the front-end arm was developed.
- ✓ A test rack simulating the structure inside the PCV was fabricated for verifying the performance of the front-end arm.

Simulated pedestal

Simulated pedestal and test rack used in the in-factory verification test

Note: VR simulation
A 3-dimensional model of the arm is displayed on the computer screen, and how it will move is calculated by operating it, to get the location that it is expected to reach. (Refer to the next slide)

In-factory verification test details

No.	Name	Details	Material used	Criteria
1	Basic performance test 1	Investigating the range of motion, and the maximum/minimum target speed	Test rack, dummy tip tool	Should be the prescribed range of movement and speed.
2	Basic performance test 2	Investigating the ability of the load meter embedded in the foot of the horizontal offset link	Test rack, simulated pedestal	Should be able to apply a pressing force of 1kN on the foot.
3	Basic performance test 3	Investigating the ability to pass through the opening on the platform	Test rack, simulated pedestal	Should not come in contact with the opening
4	Dummy tip tool test 1	Verifying the ability of the dummy tip tool to pass through the platform opening	Test rack, dummy tip tool, simulated pedestal	Should not come in contact with the opening
5	Dummy tip tool test 2	Verifying the ability of the dummy tip tool to be positioned on the debris		Should stop momentarily 100mn from the floor, and not collide with the target surface. Should be able to position the tip tool vertically (less than ±5°) at 100N or less.
6	Dummy tip tool test 3	Verifying the ability of the dummy tip tool to press against the debris, acquiring data on application of load, measuring the required time		Should be able to apply a pressing force of 1kN. Arm should not have any problems while pressing.
7	Control accuracy verification test	Comparing with the VR simulation		The location of the representative site should be within ±100mm.

6. Implementation Details

Project commenced in FY2020

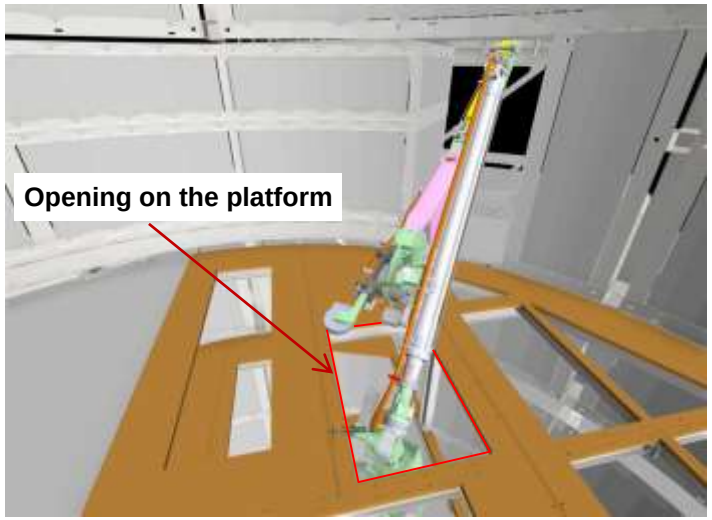
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)

6.1.1 Element technology to be installed on the retrieval arm

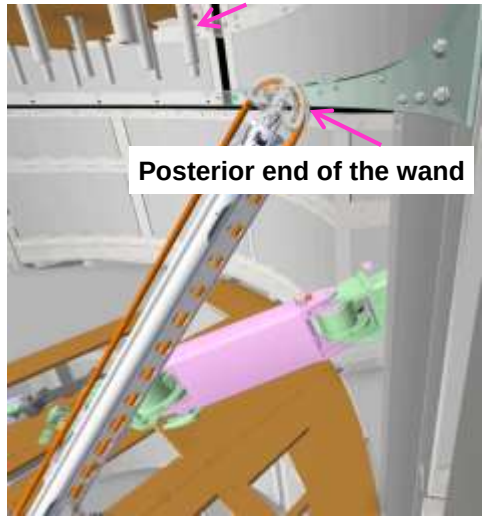
[Issues]

- ✓ The risk of the posterior end of the wand interfering with the structures inside the pedestal when the fuel debris cutting and collection equipment descends from the opening on the platform, was identified. Note that, as a countermeasure, the descending route needs to be checked in advance by means of the VR simulation so that the equipment does not get damaged. Also, it needs to be ensured that there isn't a large gap between the result of the VR simulation and the positional relationship of the actual arm and structures.
  (A method of adjusting the positions should be prepared.)

Inside the Unit 5 pedestal (from the TEPCO HD website)



Structures inside the pedestal



[Future plans]

- ✓ Manufacturing and assembly of the front-end arm will be completed, and the ability to pass through the opening inside the PCV will be verified in the factory by means of the horizontal offset mechanism, and the pressing force of the fuel debris cutting and collection equipment will be verified in the factory by means of the wand.
- ✓ Subsequently, combination verification tests with the prototypes of the fuel debris cutting and collection equipment and the neutron monitor will be conducted as part of the project commenced in FY2021.
- ✓ After conducting the above-mentioned combination verification tests, the front-end arm will be integrated with the posterior half of the arm, and in-factory verification of its function as the retrieval arm will be conducted.

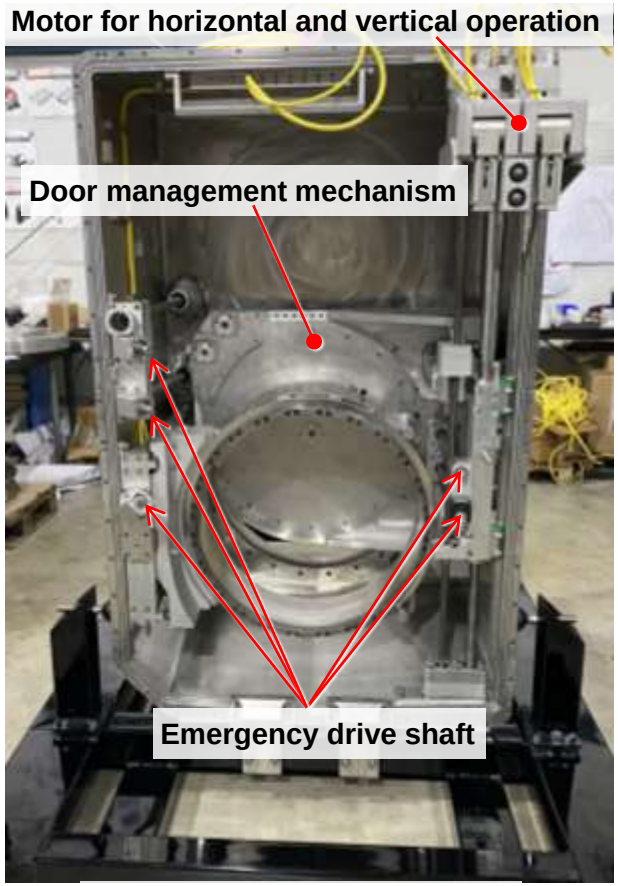
6. Implementation Details

Project commenced in FY2020

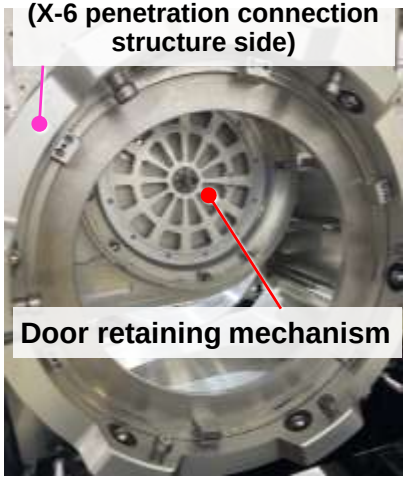
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)
6.1.2 Element technology to be installed on the enclosure for retrieval

[Achievements for FY2021:1/3]

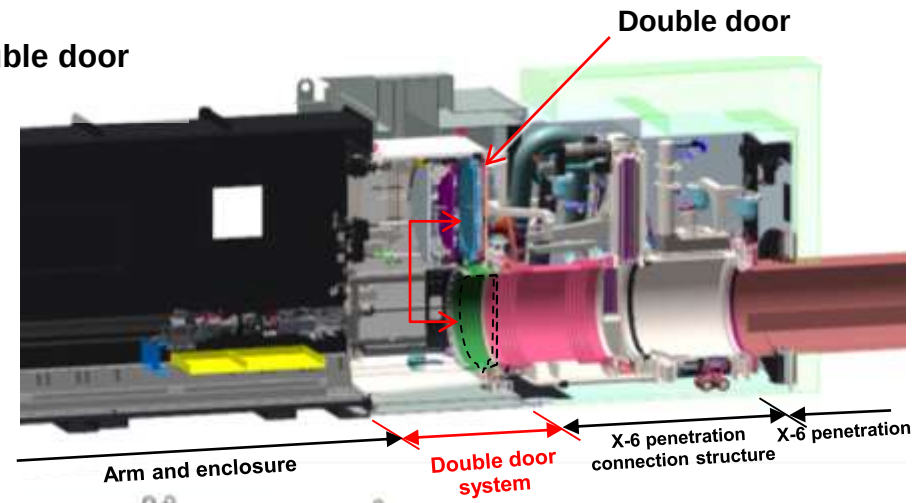
✓ **A prototype of the double door system that opens and closes the double door was manufactured as scheduled.**

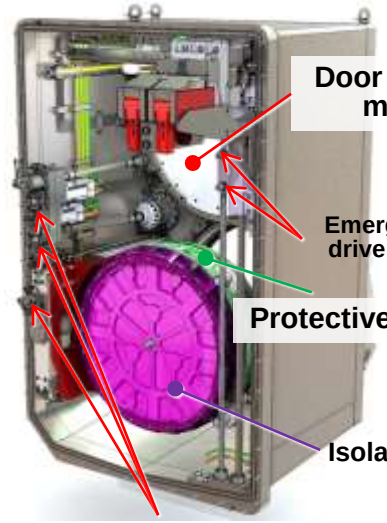


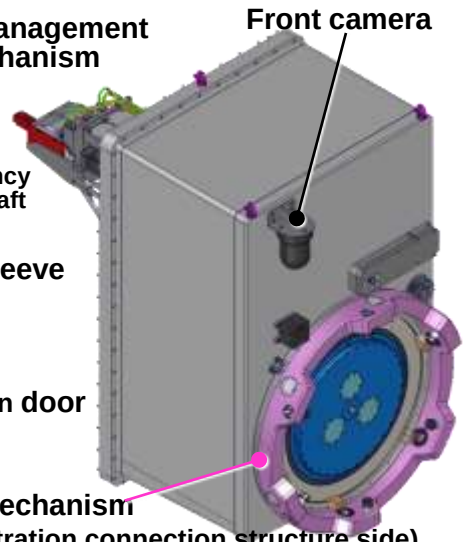
Arm and enclosure side



Protective sleeve
(With the isolation door removed)







6. Implementation Details

Project commenced in FY2020

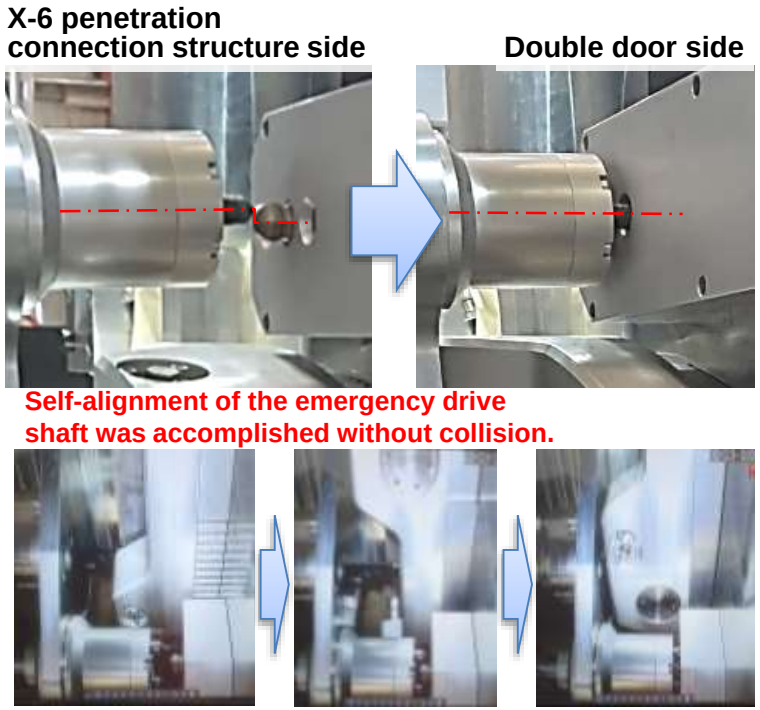
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)
6.1.2 Element technology to be installed on the enclosure for retrieval

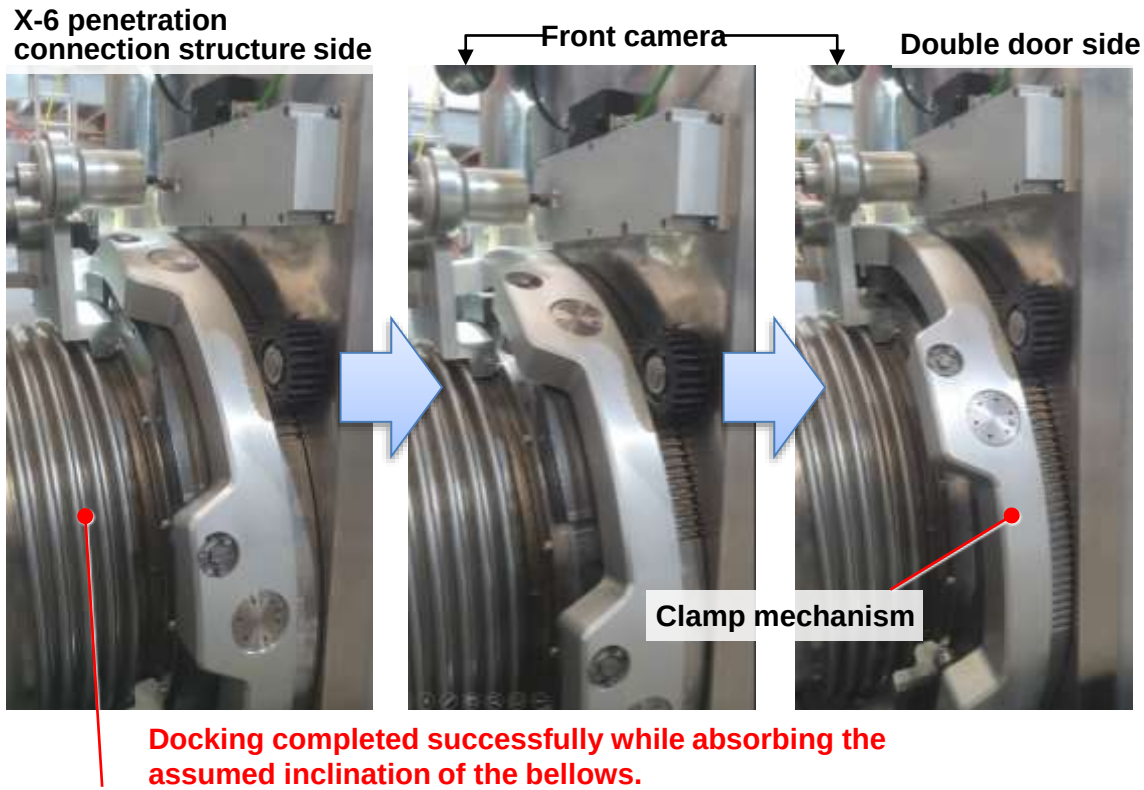
[Achievements for FY2021: 2/3]

✓ **In-factory verification test of the prototype was conducted, and it was confirmed through the following tests [1] to [3] that the problems about which there were concerns no longer persist.**

[1] Linkage function with the X-6 penetration connection structure (avoiding collision by self-aligning, absorbing bellows inclination error and satisfactory view from cameras)

Linkage test with the X-6 penetration connection structure





Bellows simulating the X-6 penetration

6. Implementation Details

Project commenced in FY2020

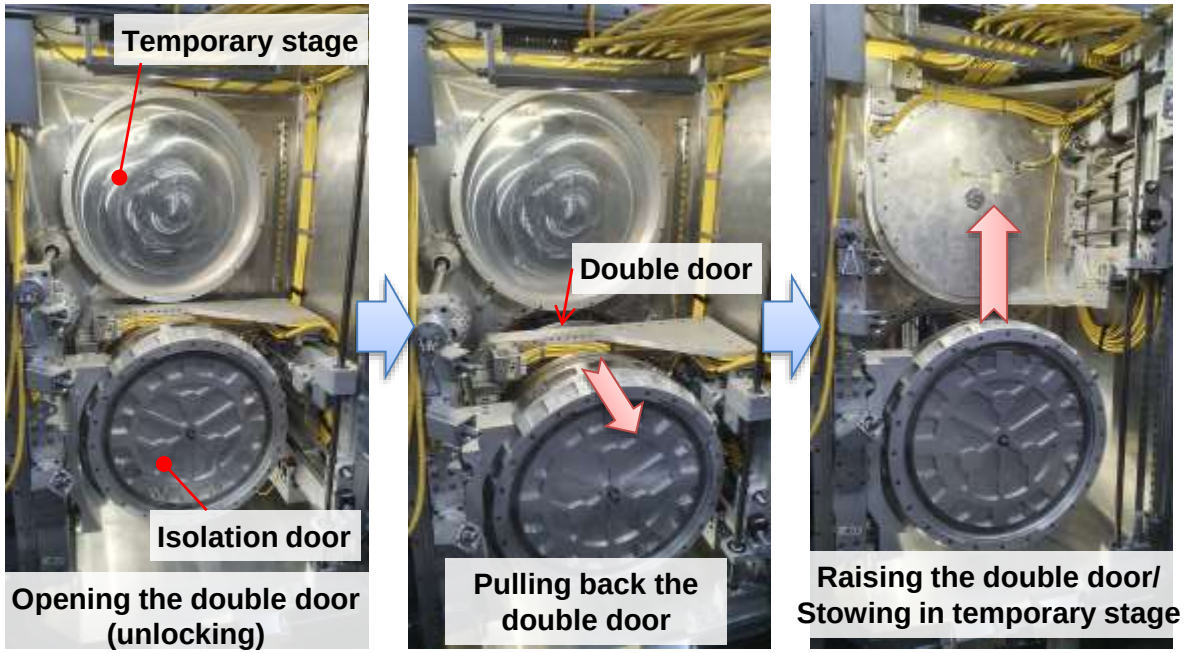
6.1 Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)
6.1.2 Element technology to be installed on the enclosure for retrieval

[Achievements for FY2021: 3/3]

✓ In-factory verification test of the prototype was conducted, and it was confirmed through the following tests [1] to [3] that the problems about which there were concerns no longer persist.

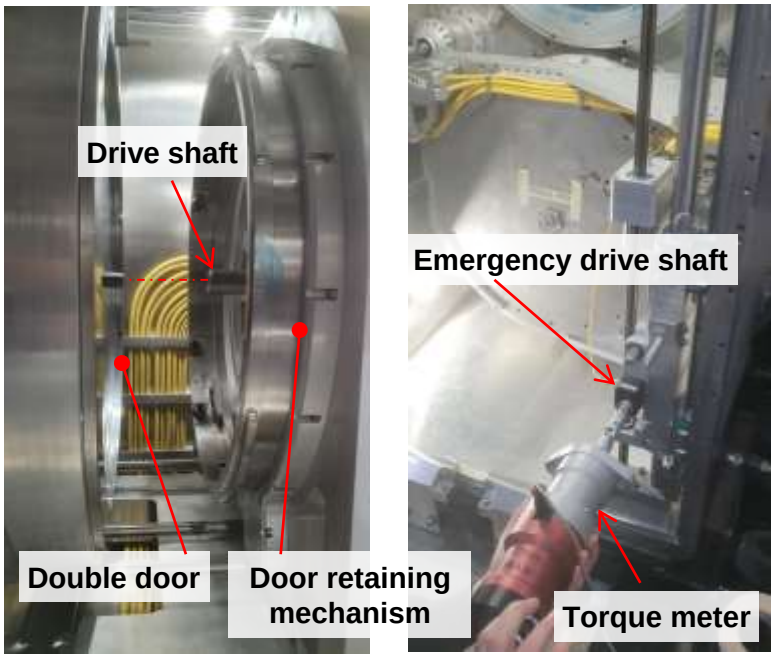
[2] Double door opening/closing and air-tight function (Leakage rate 0.1vol%/h) [3] Emergency drive function in the event of motor failure (Rotational torque 12.8Nm or lower)

Double door opening / closing test



The operation of removing and temporarily storing the double door was performed without any problem, and the test for leakage rate was passed as well.

Operational test by means of the emergency drive system in the event of motor failure



It was projected that operation with the dual arm type manipulator was possible.

[Issues and future plans]

✓ Since system verification still remains as an issue, the double door system will be incorporated into the enclosure and combination tests, etc. with the X-6 penetration connection structure will be conducted during the project commenced in FY2021.

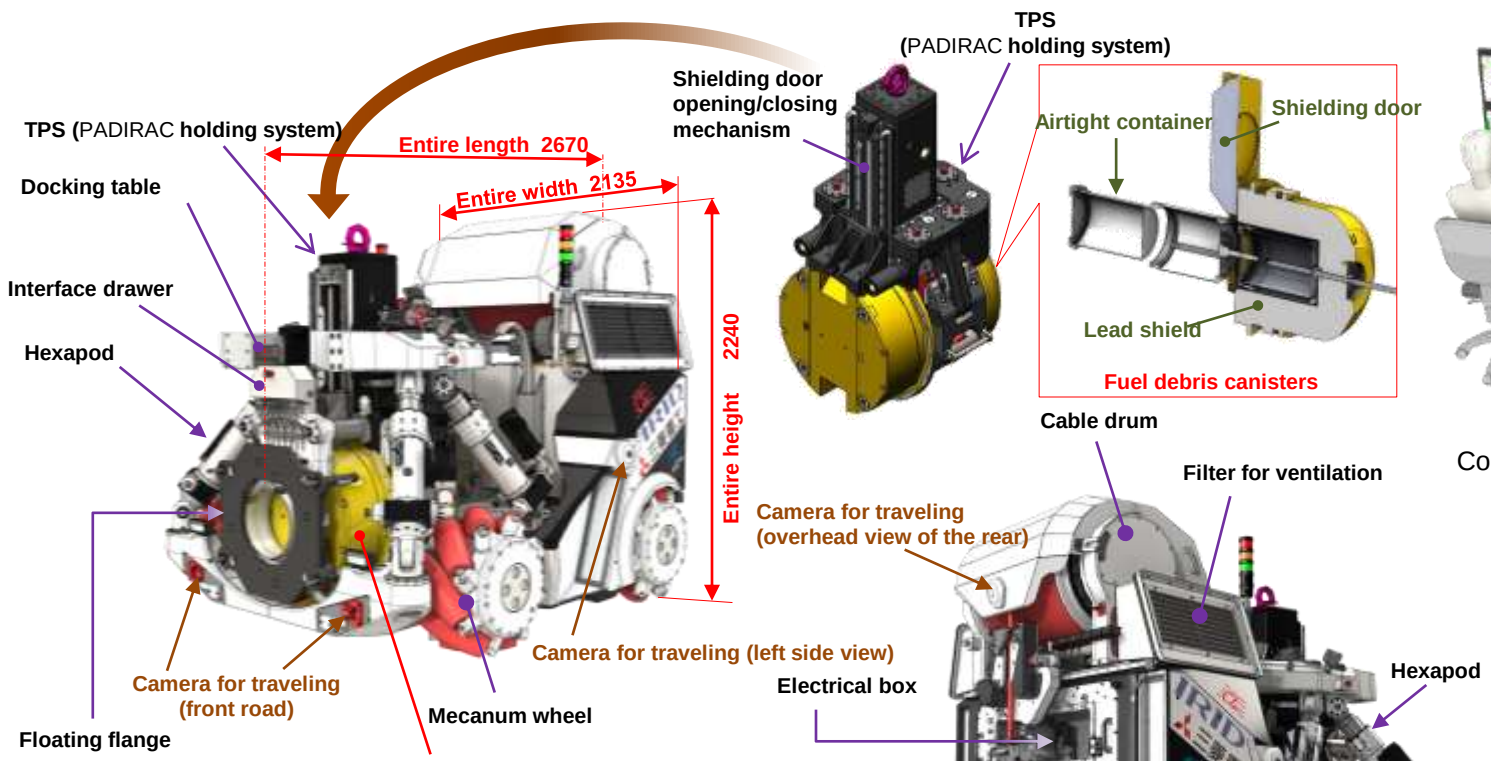
6. Implementation Details

Project commenced in FY2020

6.2 Development of remotely controlled transport cart for fuel debris canisters

[Achievements for FY2021: 1/4]

✓ **A prototype of the remotely controlled transport cart (cart, control panel and operating facility, etc.) for fuel debris canisters (PADIRAC) was manufactured.**



Fuel debris canisters: PADIRAC RD-20 (weight 4 ton) (*1)

(*1) PADIRAC … Product name of the shield transportation system and container manufactured by GETINGE La Calhene, France

External appearance of the remotely controlled transport cart (Weight of the body of the cart: 12 ton)

Control system for the assistant operators and monitoring personnel

Relay board

Control unit for the operators

6. Implementation Details

Project commenced in FY2020

6.2 Development of remotely controlled transport cart for fuel debris canisters

[Achievements for FY2021: 2/4]

- ✓ **The setting work of the remotely controlled transport cart for fuel debris canisters (PADIRAC) was performed wearing protective clothing, and it was verified that the work can be performed in accordance with the work procedures.**

TPS (PADIRAC holding system) (*1)

(*1) TPS：Tool PADIRAC System

Fuel debris canister (PADIRAC)

Main body of the cart

Setting the TPS + PADIRAC on to the cart

Traveling preparations completed

6. Implementation Details

Project commenced in FY2020

6.2 Development of remotely controlled transport cart for fuel debris canisters

[Achievements for FY2021: 3/4]

✓ **In-factory verification test of the remotely controlled transport cart was conducted and the following performance and functions were verified. Hence it was projected that it can be used on site.**

No.	Items	Implementation details	Results	Judgment	Remarks
1	Hexapod positioning performance	Data on hexapod positioning performance while holding PADIRAC is acquired, and whether or not the value meets the design requirements and conditions is evaluated and studied.	It was confirmed that positioning accuracy required for connection to the transfer port was met.	Pass	Figure 1 Photo 1
2	Mecanum wheel Traveling performance	Traveling performance with respect to the following is verified. 1) Performance with respect to rough position adjustment (braking distance) 2) Traveling on slopes 3) Impact of the conditions of the pathways (obstacles, accumulated water, sand, etc.) 4) Camera visibility Etc.	It was confirmed that required traveling performance in all respects was met.	Pass	Photos 2 to 4
3	Airtight container connection test	It is confirmed that the docking table, shielding door opening/closing mechanism, etc. operate according to the design, and that the airtight container fits properly into the transfer port and can be attached and detached.	It was confirmed that the airtight container can be properly attached and detached.	Pass	Photo 5
4	Comprehensive verification test	It is confirmed that the series of operations from installing PADIRAC - traveling - fitting the airtight container to the simulated double door - attaching/detaching it - traveling - removing PADIRAC can be performed smoothly.	It was confirmed that the series of work can be performed smoothly.	Pass	
5	Rescue test	It is confirmed that rescue measures can be carried out wherein the transport cart is moved to the truck bay door in the event of failure of motor, etc.	It was confirmed that the planned rescue measures can be implemented.	Pass	Photo 6
6	Maintenance verification test	It is confirmed that the work of replacement and maintenance of failed components can be carried out under site conditions (wearing radiation protective clothing). (Verification of maintenance work with representative components)	It was confirmed through verification using a typical example that maintenance can be carried out as planned in all respects.	Pass	Photo 7

Required positioning performance values

Tx= ±0.5mm Rx= ± 1°
Ty= ±1mm Ry= ± 0.17°
Tz= ±1 mm Rz=± 0.17°

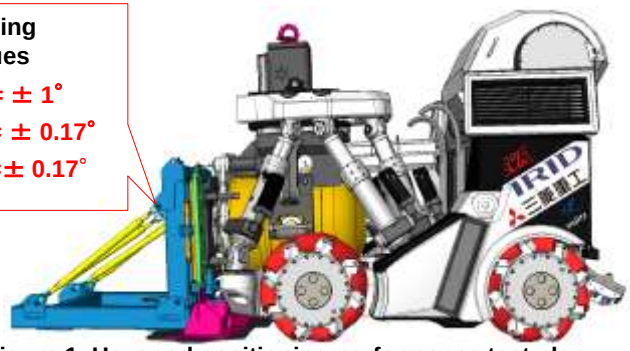


Figure 1 Hexapod positioning performance test plan

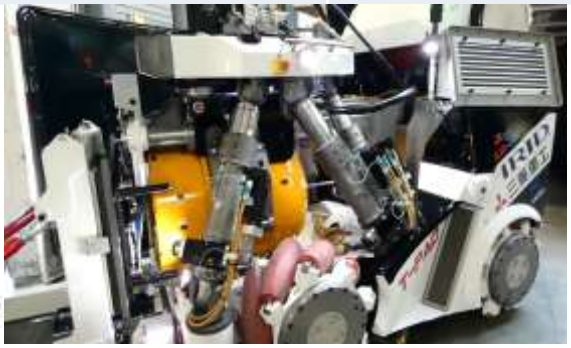


Photo 1 Hexapod positioning performance test

6. Implementation Details

Project commenced in FY2020

6.2 Development of remotely controlled transport cart for fuel debris canisters

[Achievements for FY2021: 4/4]

Photo 2 Traveling test (traveling over a slope)

Photo 3 Traveling test (traveling through narrow spaces)

Photo 4 Traveling test (traveling over sand)

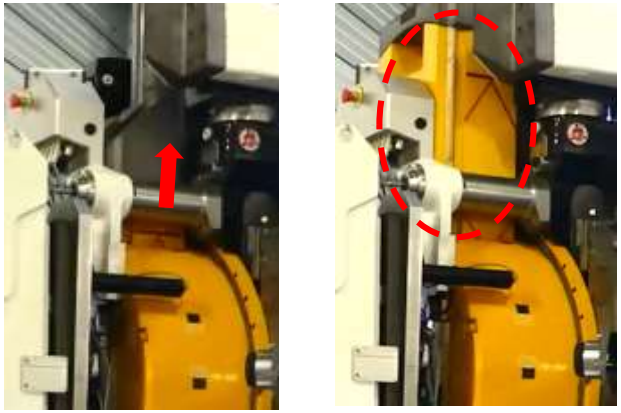


Photo 5 Connection test (opening/closing of shielding door)

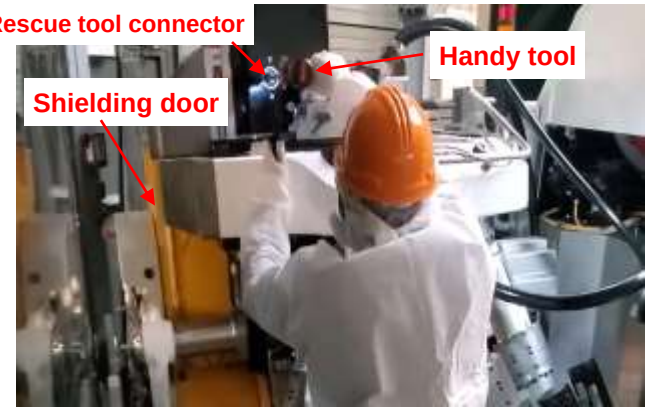


Photo 6 Rescue test (when motor for closing the shielding door fails)

Photo 7 Maintenance test (replacement of travel motor)

[Issues and future plans]

- ✓ **Since system verification still remains as an issue, re-verification tests and combination verification tests with the enclosure will be conducted in Japan as part of project commenced in FY2021.**
- ✓ **Selection of the maintenance area during work using actual equipment, and the method of managing carryin-in/out of the remotely controlled transport cart from the Reactor Building need to be studied.**

6. Implementation Details

Project commenced in FY2021

6.3 Update of the retrieval technology development plan

[Achievements for FY2021:1/3]

- ✓ **Development plan of the retrieval technology (retrieval equipment and systems, etc.) for gradually increasing the retrieval scale of fuel debris created until FY2020 was updated.**
- ✓ **Based on the information obtained from the manufacturing tests and combination tests of the access equipment for investigation inside PCV, the time period of reflection into the project development plan, the reflection items and specific details were examined.**

Information planned to be acquired	Time period of acquisition Time period of reflection	Items to be reflected in the development	Specific implementation details and implementation method	Status of reflection
Operating speed of the arm for investigation inside PCV	November 2021 to January 2022	Review of the expected performance of the retrieval arm, study on the possibility of improving speed, study on the possibility of changing the operating method	The expected performance is reviewed considering the disparities in the weight, gear ratio and motor torque of the retrieval arm. If the expected performance of operating 5 round trips a day is not met, the possibility of improving the speed by increasing the motor torque is studied. If it is evaluated that there isn't sufficient room for improving the speed, the possibility of changing the operating method such as by reducing the applied load or number of round trips, or reducing the time required by reviewing the operating procedures, is studied.	**The following speeds need to be improved.** **・Forward and reverse speed of the carriage** **・Telescopic arm extension speed** **For the former, the improvements from the PCV investigation project will be followed. For the latter, the results of testing the front-end arm will be evaluated.**
Attenuation properties of the arm for investigation inside PCV	November 2021 to January 2022	Review of the expected behavior of the retrieval arm, study on the possibility of reducing vibrations, study on the possibility of changing the operating method	The expected behavior in terms of the vibrations is reviewed considering the disparities in the length and weight of the retrieval arm. If the expected vibrations of the arm have a negative impact on the passing ability through the X-6 penetration or the platform opening, or if the vibrations when the tip tool approaches fuel debris exceeds 100mm, the possibility of reducing vibrations by means of low speed operation is studied. If it is evaluated that there isn't sufficient room for reducing vibrations, the possibility of controlling vibrations by reviewing the operating procedures, is studied.	**Was 4% or more (as expected) horizontally.** **Was less than 1% vertically. As stabilization of the vibrations required time, it is determined that the arm needs to come to a resting position inside the pedestal.** **The acquired data will be utilized in the future for mechanism analysis.**
Workability of removing the external cable using the dual arm type manipulator	November 2021 to January 2022	Review of the cable fixing structure or the cable drum structure of the retrieval arm, study on the necessity of special tools for the installation work, study on the possibility of improvement in the external cable	The cable fixing structure or the cable drum structure is reviewed for improving the workability of remote operation by means of the dual arm type manipulator. And, whether or not special tools can be used for supporting the installation work, is studied. Also, whether or not improvements can be made to make it easier to handle the external cable itself using the dual arm type manipulator, is studied.	**Although verification is still not completed, 2 issues are evident.** **In the future, the possibility of additional tests and development during this project will be studied.**

6. Implementation Details

Project commenced in FY2021

6.3 Update of the retrieval technology development plan

[Achievements for FY2021: 2/3]

- ✓ **A chart was developed indicating the positioning, verification items, and goals to be achieved pertaining to the combination tests of equipment developed during the project commenced in FY2019 and the project commenced in FY2020.**
- ✓ **Preliminary work for the "[1] Combination tests of the front-end arm and the fuel debris cutting and collection equipment" has started.**

Combination test items [Place of implementation]	Positioning	Validity	Items to be verified	Goals to be achieved
[1] Combination tests of the front-end arm and the fuel debris cutting and collection equipment [UK]	The method and procedure for operating inside the pedestal to bring the fuel debris cutting and collection equipment and the neutron monitor in close proximity to the target location in the designated position, is verified. Until now, the study was conducted using VR simulation, but verification is required considering the vibrations arising from acceleration/deceleration and rigidity of the arm.	Since the front-end arm that is beyond the telescopic arm is used, the vibrations arising from the posterior half of the arm cannot be simulated, but issues can be ascertained early on (*). Full-scale pedestal simulation facility can be used. (*) After the entire arm is completed, as adjusting the motor drive of the boom link requires time, it is not possible to move on to testing immediately.	Vibrational amplitude of the arm and deceleration time Visibility of the camera installed on the arm in motion Workability of operation of the front-end arm (wand in particular) Method of getting closer to the target location in the designated position	Vibrational amplitude: 100mm or less Deceleration time: less than 5 minutes The camera image recording must not hinder arm operation. There must not be any steps wherein it is difficult to operate the arm. Must not collide with the surroundings Must be able to get closer to the target location in the designated position.
[2] Combination tests of the arm and the simulated X-6 penetration [UK]	The passing ability of the retrieval arm through the X-6 penetration is verified by spreading out the boom link and forward movement of the carriage. The vibrating properties are verified by operating the front-end arm beyond the telescopic arm while the boom link is spread out.	Since the structure of the boom link is different than the arm for PCV investigation, it needs to be verified using the retrieval arm as well. Since the front-end arm gets involved in the movement of the arm after it passes through x-6 penetration, the results of the combination tests of the front-end arm conducted in [1] above can be effectively used upon ascertaining the vibration properties by operating the anterior half of the telescopic arm, etc. while the boom link is spread out.	Verification of passing through X-6 penetration Measurement of the deflection of the arm Vibration properties of the telescopic arm by operating the wand while the arm is extended	Must be able to pass while maintaining a clearance of 10mm or more. (including vibrations) Arm deflection must be equivalent to or under the value assumed in the design. Amplitude must be within 30mm.

Continued on the next slide

6. Implementation Details

Project commenced in FY2021

6.3 Update of the retrieval technology development plan

[Achievements for FY2021: 3/3]

✓ **Table continued from the previous slide**

Combination test items [Place of implementation]	Positioning	Validity	Items to be verified	Goals to be achieved
[3] Combination tests of the enclosure (double door mechanism) and X-6 penetration connection structure [Japan]	It is verified that docking of the double door mechanism and the X-6 penetration connection structure can be performed as per the design, while installing the enclosure on site. Layout of the camera is verified considering workability of remote operation, particularly since workers are unable to access the narrow space inside the airtight door where the double door connection is performed.	Weight is simulated by installing a dummy arm, etc. inside the enclosure. Therefore, efficiency of simulation is ensured.	Eccentricity at the time of installation Clamp torque at the time of docking Stop position accuracy View from camera	Must be within the permissible eccentricity. Must be lower than the motor design torque. Must be within the permissible dimensions. Laser pointer must be visible.
[4] Combination tests of the enclosure and the remotely controlled transport cart [Japan]	Work of docking the fuel debris canister (PADIRAC) in the enclosure is verified, and the rescue method in the event of an accident is verified.	Efficiency of simulation is ensured by simulating the interfering objects around the enclosure.	Docking operation of both Work efficiency in the event of rescue operation	Must be able perform docking without any problems. Must be able to perform rescue operation.
[5] Combination tests of the dual arm type manipulator and the simulated double door mechanism [Japan]	A simulated double door mechanism equipped with a rescue interface is placed in the simulated enclosure that is used in the dual arm type manipulator verification test, and it is verified that the operation of restoring the double door mechanism using the dual arm type manipulator and special auxiliary tools can be performed.	Simulation of the relative position of the dual arm type manipulator and the simulated double door mechanism, the interference objects, form of the rescue interface, and the required torque, is enabled. Therefore, efficiency of simulation is ensured.	Visibility of the camera Performance of access of the arms of the dual arm type manipulator Efficacy of the special tools	Must be able to observe the operation of special tools and the status of movement of the double door. Must be able to install the special tools. The arms of the dual arm type manipulator must be able to support the rotational torque.
[6] Combination tests of the dual arm type manipulator and the remotely operated cable attachment/detachment mechanism [Japan]	The operation of the cable attachment/detachment mechanism of the dual arm type manipulator is verified inside the simulated enclosure used in the dual arm type manipulator verification test. Test is conducted with the dual arm type manipulator, its dedicated cart and its rail combined.	Efficiency of simulation is ensured by simulating the interfering objects inside the enclosure. The remotely controlled transport equipment (equipment collection box) of the dual arm type manipulator is not simulated, but the remotely controlled attachment/detachment mechanism is a technology that is used for the maintenance of the dual arm type manipulator regardless of the presence of the equipment collection box, and is effective in ascertaining issues early on.	Electrical connectivity Driving force of the actuator Driving force of the brake	Must be able to have an electrical connection at all terminals. Driving force of the actuator and brake must be adequate.

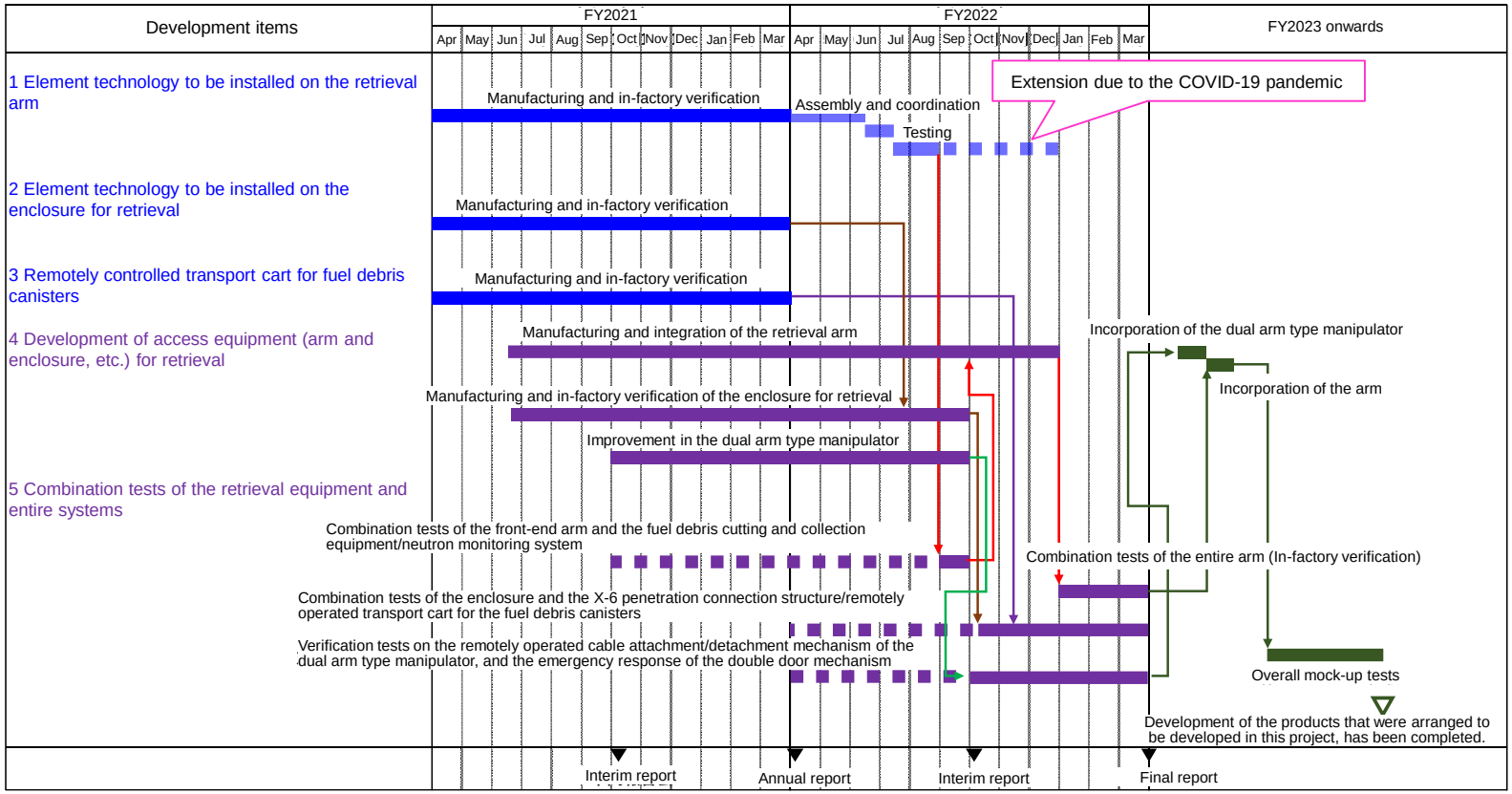
6. Implementation Details

Project commenced in FY2021

6.3 Update of the retrieval technology development plan

[Issues]

- ✓ **It is necessary to keep to a schedule for developing the retrieval arm due to the extension of the front-end arm.**
- ✓ **The verification of the overall mock-up test needs to be considered after the completion of this project.**



[Future plans]

- ✓ **The retrieval technology (retrieval equipment and systems, etc.) development plan for gradually increasing the retrieval scale of fuel debris, will be updated as required.**
- ✓ **The latest findings will be reflected and updated into the scenarios related to gradually increasing the scale of fuel debris retrieval as needed .**

6. Implementation Details

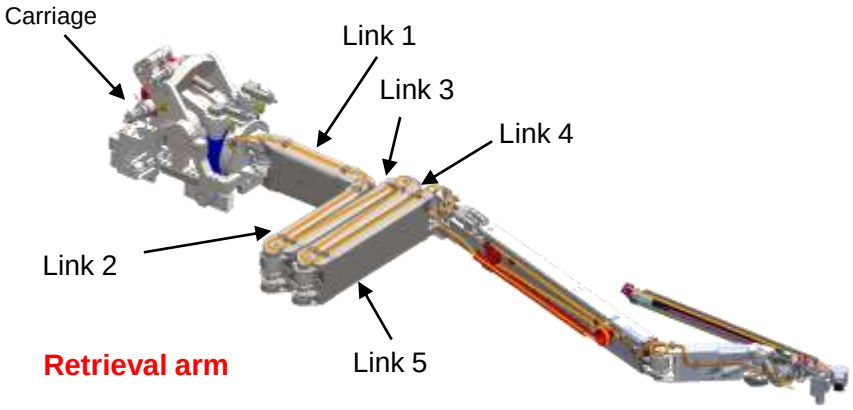
Project commenced in FY2021

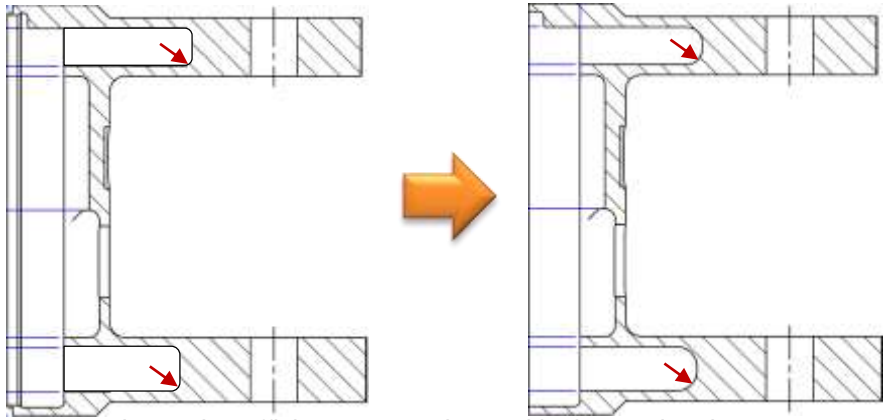
6.4 Development of the retrieval equipment and combination tests

6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)

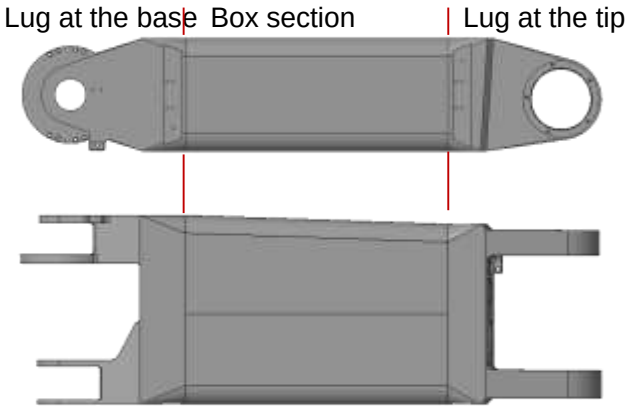
[Achievements for FY2021 (arm) : 1/2]

- ✓ **Boom links 1 to 5 are being manufactured in Japan.**
- ✓ **Manufacturing drawings of the boom links were revised to improve manufacturing efficiency.**

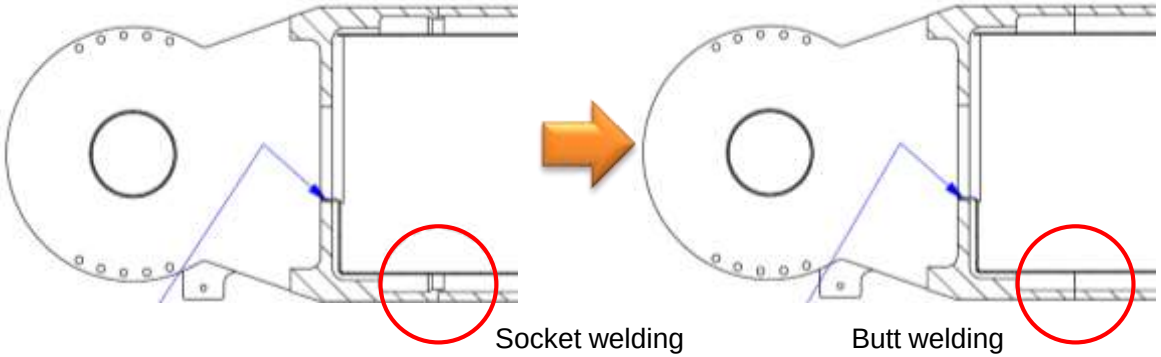




The cutting efficiency was enhanced by increasing the corner radius of the counterbore part inside the lug.



Structure of boom link 1



Improvement in the method of welding the lug and the box section

6. Implementation Details

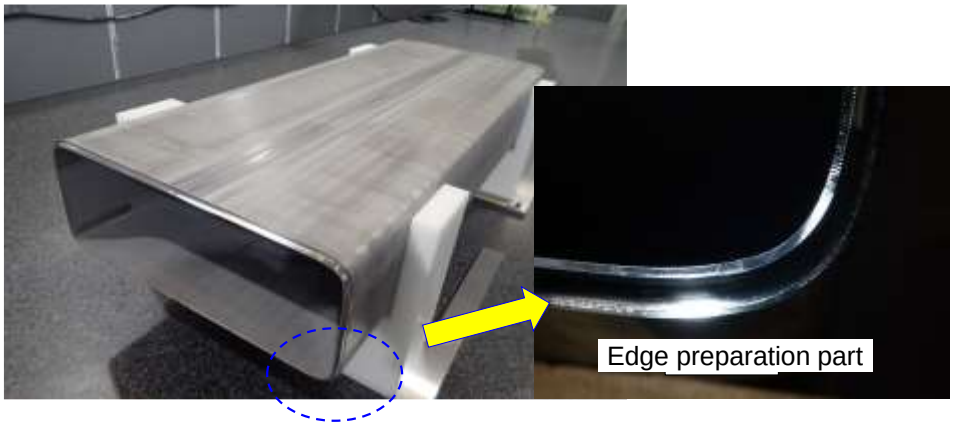
Project commenced in FY2021

6.4 Development of the retrieval equipment and combination tests

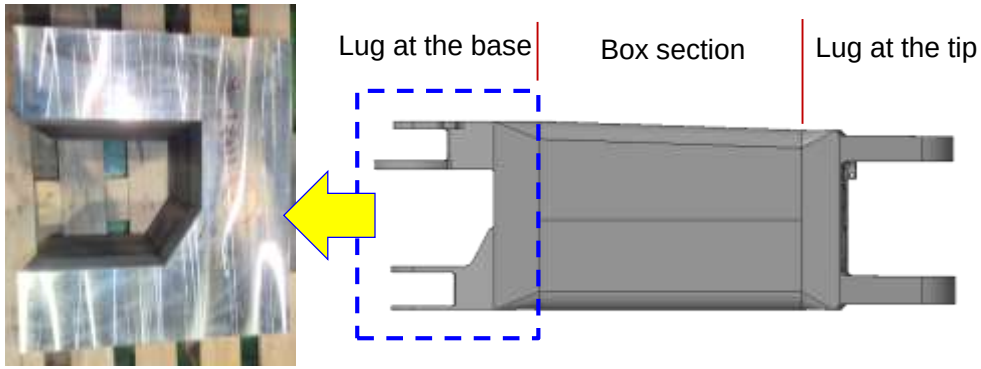
6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)

[Achievements for FY2021 (arm) : 2/2]

- ✓ **The material for the boom links has been arranged for in Japan, and processing has commenced.**
- ✓ **Veolia Nuclear Solutions (VNS) in UK has started preparations for arranging products such as the carriage that will be delivered for a long period.**



Status of processing the box section of Link 2



Status of processing the lug at the base of Link 1

[Issues (arm)]

- ✓ **Improvement points(preventing deformation during thermal processing) obtained from the experience of manufacturing the horizontal offset link need to be reflected.**
- ✓ **The quality of the arm needs to be ensured while some process that require time such as acid cleaning, etc. are simplified to retain the overall schedule.**

[Future plans (arm)]

- ✓ **The components of the posterior half of the arm will be supplied for VNS (UK) to assemble the whole arm and the function of the retrieval equipment will be verified in combination with the front-end arm and the enclosure.**

6. Implementation Details

Project commenced in FY2021

6.4 Development of the retrieval equipment and combination tests

6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)

[Achievements for FY2021 (enclosure)]

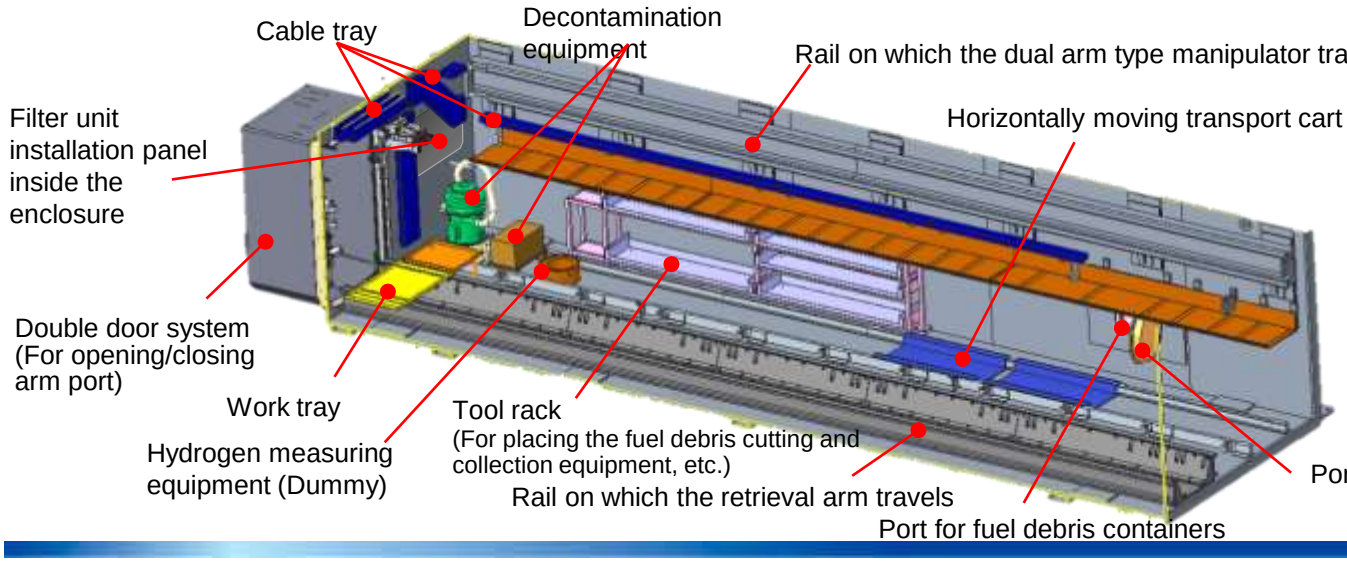
- ✓ **The manufacturing drawings were examined in preparation for fabricating the enclosure for the verification test. (Main body and ancillary equipment)**
- ✓ **The arrangements of components has commenced. (Main component used for the boundary part, SUS material for the interior equipment, etc.)**
- ✓ **Manufacturing of the remotely operated cable attachment/detachment mechanism that was improved dual arm type manipulator was started.**

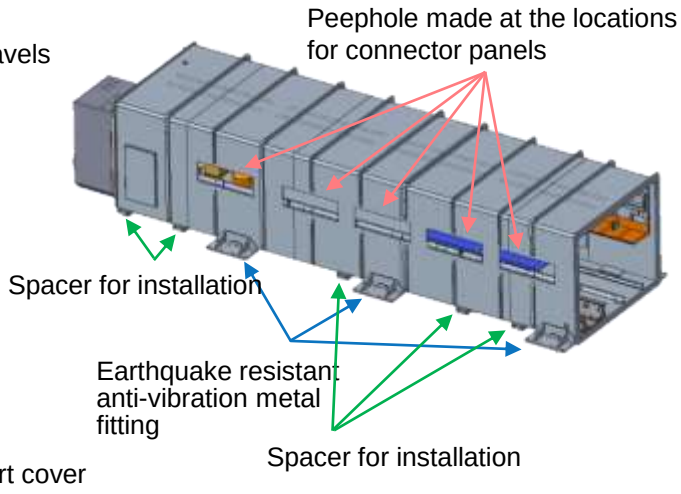
[Issues (enclosure)]

With the regard to the positioning of the double door system and the rail for the retrieval arm when installing in the enclosure, it is necessary to consider the standard setting to satisfy the accuracy requirements.

[Future plans (enclosure)]

After manufacturing is completed, the double door system will be incorporated and combination tests with the X-6 penetration connection structure and the remotely controlled transport cart will be conducted.





Arm and dual arm type manipulator are not shown.

6. Implementation Details

Project commenced in FY2021

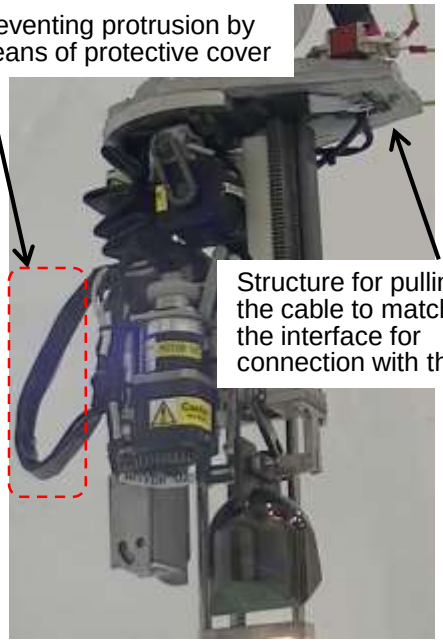
6.4 Development of the retrieval equipment and combination tests

6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems

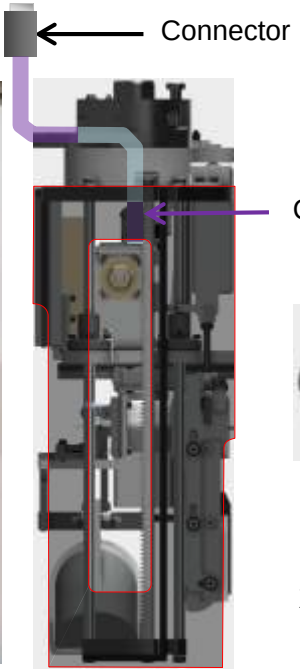
[Achievements for FY2021 (Bucket type debris collection equipment)]

- ✓ **Maneuverability of the bucket type debris collection equipment cable was studied in preparation for the combination test with the front-end arm, and it was designed so that the cable does not protrude on the outside.**
- ✓ **Installing a protective cover was considered to prevent interference while passing through narrow spaces.**
- ✓ **The structure of the equipment was improved based on the above-mentioned design.**

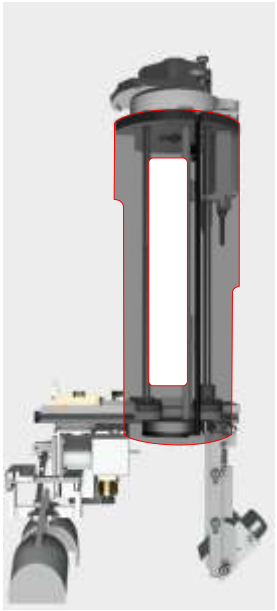
External appearance of the equipment developed as part of the project commenced in FY2019



Status of preparations for the tests



Position while passing through X-6 penetration



Position when spread out

Consideration of installing a protective cover

[Issues (Bucket type debris collection equipment)]

- ✓ **It is necessary to verify the scenario of approaching fuel debris when combined with the arm.**

6. Implementation Details

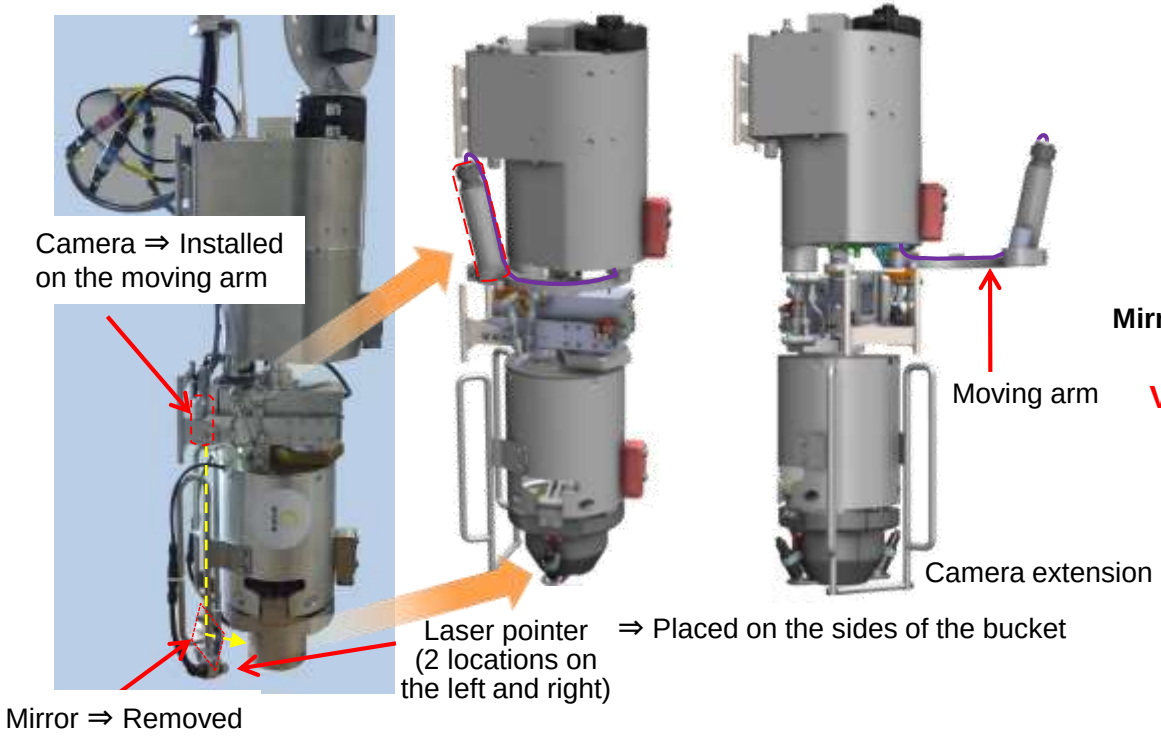
Project commenced in FY2021

6.4 Development of the retrieval equipment and combination tests

6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems

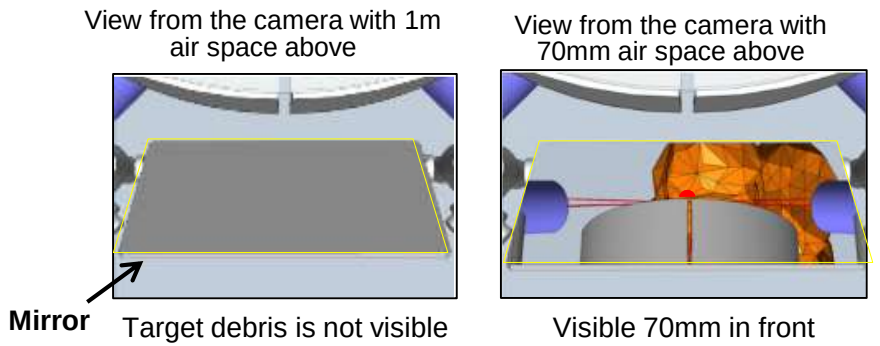
[Achievements for FY2021 (Flexible gripper type debris collection equipment)]

- ✓ **A design for ensuring visibility by extending the camera outside was adopted, in order to enhance visibility when the flexible gripper type debris collection equipment approaches fuel debris, in preparation for the combination test with the front-end arm.**

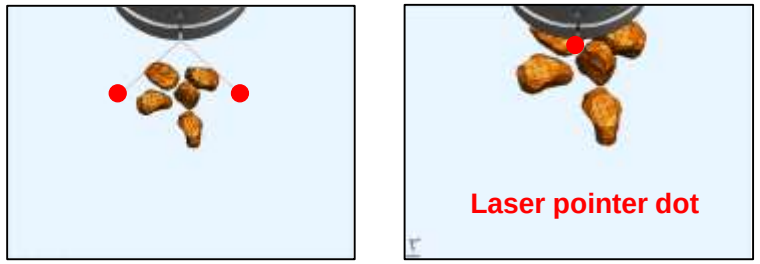


Study of change in position of the camera

Current state



View from camera expected during the combination test



Result of verification of the view from camera

[Issues (Flexible gripper type debris collection equipment)]

- ✓ **It is necessary to verify the scenario of approaching fuel debris when combined with the arm.**

6. Implementation Details

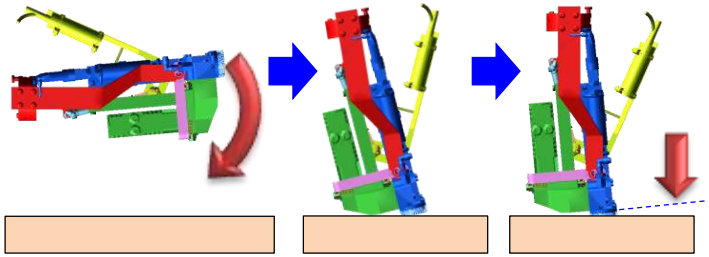
Project commenced in FY2021

6.4 Development of the retrieval equipment and combination tests

6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems

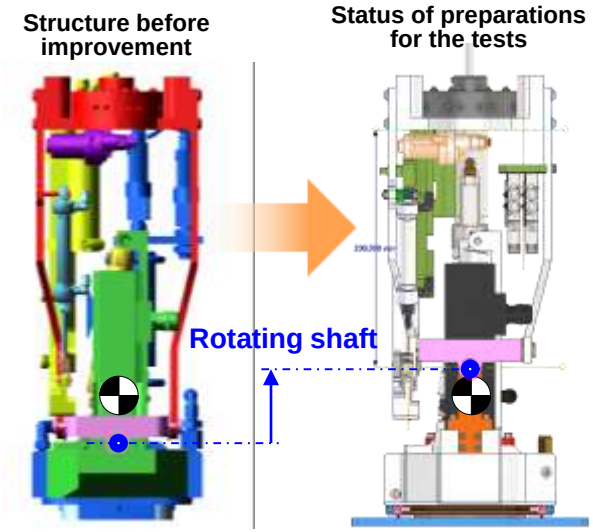
[Achievements for FY2021 (Cutting powdery fuel debris collection equipment)]

- ✓ **The design of the gimbal mechanism was reviewed in order to ensure accessibility of the fuel debris on the platform, in preparation for the combination test with the front-end arm.**

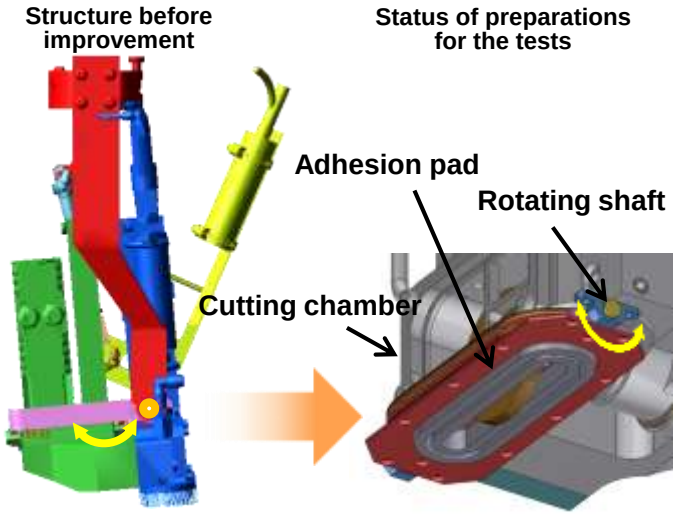


Since the rotating shaft is located below the focal point, the target debris is approached in an inclined position.
The cutting chamber cannot be set up unless it is thrust with strong force.

Issues of approaching fuel debris



Moving the rotating shaft above the focal point



Integration of the rotating gimbal in the cutting direction with the cutting chamber

[Issues (Cutting powdery fuel debris collection equipment)]

- ✓ **The scenario of approaching fuel debris when approaching the platform beam needs to be verified.**
- ✓ **The thrust and cutting performance when combined with the arm needs to be verified.**

[Future plans (Bucket type debris collection equipment, flexible gripper type debris collection equipment, cutting powdery fuel debris collection equipment)]

- ✓ **The equipment will be modified based on the studies, in preparation for the combination tests.**
- ✓ **The approach scenario will be verified and the arm behavior and debris collection performance will be confirmed through the combination test with the front-end arm.**

7. Summary and Future Action

Project commenced in FY2020
Project commenced in FY2021

Summary of the scope of implementation in FY2021, and the future actions are given below.

No.	Implementation items		Summary of the scope of implementation in FY2021	Future action
6.1	Development of element technology and design of the access equipment for fuel debris retrieval (arm and enclosure, etc.)	6.1.1 Element technology to be installed on the retrieval arm	• Manufacturing of prototypes of the front-end arm such as the horizontal offset mechanism, telescopic mechanism, wand, etc. is being continued. • The plan for in-factory verification test of the prototypes has been created and preparations for the testing facility have been completed.	Fabrication of the front-end arm will be completed, and the performance of the prototypes will be verified through in-factory verification tests.
		6.1.2 Element technology to be installed on the enclosure for retrieval	• Manufacturing of the prototype of the double door system has been completed. • The appropriateness of the linkage function, airtightness, restoration method in the event of a failure is confirmed by means of the in-factory verification test of the prototypes.	The equipment will be transported to Japan, will be incorporated into the enclosure, and combination tests, etc. with the X-6 penetration connection structure will be conducted, to verify the system.
6.2	Development of remotely controlled transport cart for fuel debris canisters	Remotely controlled transport cart for fuel debris canisters	• The prototype of the remotely controlled transport cart has been manufactured. • That the work of moving the fuel debris canisters can be performed, or that the performance of the remotely controlled transport cart and the maintenance method are appropriate, is confirmed.	The equipment will be transported to Japan, re-confirmation tests and combination verification tests with the enslosure will be conducted in Japan.
6.3	Update of the retrieval technology development plan		• The development plan is updated, the timing and points to • be focused on while reflecting the results of the verification test of the arm for detailed investigation inside PCV, into the development plan is examined, and the details of the combi nation verification tests on various developed equipment ar e examined.	The development plan will be updated as required. The latest findings, etc. will be reflected and updated as needed into the scenarios related to gradually increasing the scale of fuel debris retrieval.
6.4	Development of the retrieval equipment and combination tests	6.4.1 Development of access equipment for retrieval (arm and enclosure, etc.)	• Designing and manufacturing of the base of the arm and integrating it with the front-end arm are being continued. • The enclosure has been designed, manufacturing is being continued.	In-factory verification test will be conducted upon completion of the access equipment. After enclosure is completed, the double door system will be incorporated, and combination tests with the X-6 penetration connection structure and the remotely controlled transport cart will be conducted.
		6.4.2 Combination tests of the access equipment for retrieval with the other equipment and systems	• The study of the combination test plan is being continued. • Preparations for the combination tests are being continued.	The equipment will be modified in preparation for the combination tests. The approach scenario will be verified and the arm behavior and debris collection performance will be confirmed through the combination test with the front-end arm.

Black: Desk study Blue: Testing Red: Manufacturing