Subsidy Project of Decommissioning and Contaminated Water Management
in the FY2015 Supplementary Budgets

Development of Technology for Investigation inside RPV

Final Report

March 2018

International Research Institute for Nuclear Decommissioning (IRID)

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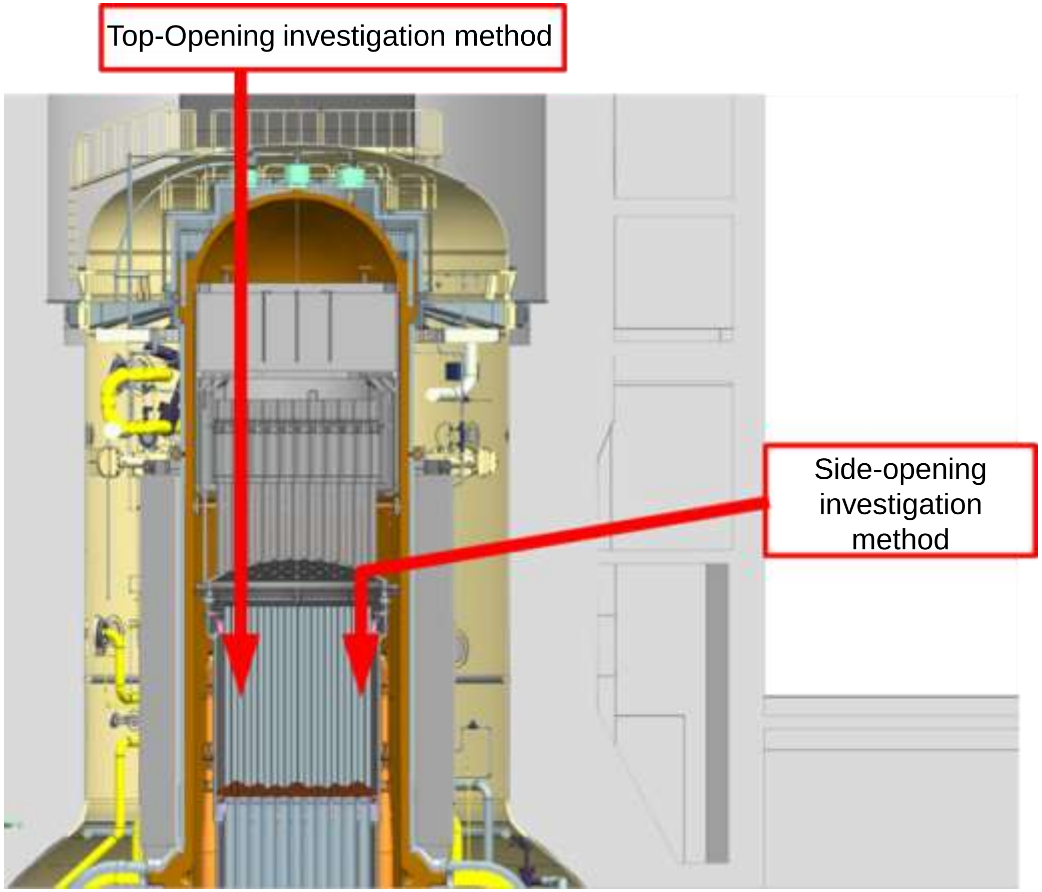
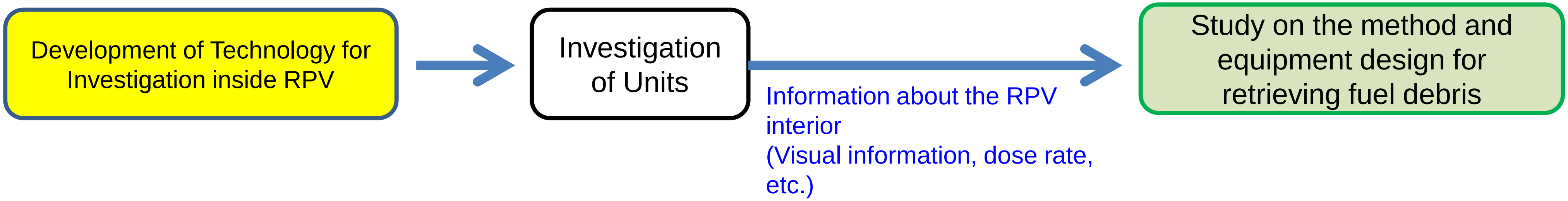
1. Research Background and Purposes

[Purpose of investigateing the inside of the RPV]
Obtain basic information about the inside of the RPV toward fuel debris retrieval (fuel debris distribution, dose, structure conditions, etc.).

[Purpose of the technical development]
Clarify investigation needs and targets to develop the technology that enables the investigation.

[Use of the Project's achievements]
Conduct the investigation at the Units using the technology developed under the R&D project and thereby obtain information that will contribute to the study on fuel debris retrieval and criticality control.





Development of Technology for Investigation inside RPV

Investigation of Units

Information about the RPV interior (Visual information, dose rate, etc.)

Study on the method and equipment design for retrieving fuel debris

2. Project Goals

What to do	Target achievement index
Generate and update investigation and development plans	Multiple ideas on the RPV-interior investigation processes are studied and compared, optimal technology is selected, and the investigation and development plans are generated toward the selection of a fuel debris retrieval method and the fuel debris retrieval operation or toward the obtainment of permissions and authorizations for the operation. (Excluded from the “TRL” technology readiness level for the sake of easier information organization)
Develop equipment to access the reactor core	-
6.1 Development of equipment to access from the top	-
6.1.1 Development of opening equipment to access down to the RPV head	The Unit application feasibility of the opening equipment to access down to the RPV head is evaluated. (Target TRL as of completion: Level 4)
6.1.2 Development of boundary maintenance equipment and access equipment for operations	The Unit application feasibility of the boundary maintenance equipment and access equipment for operations is evaluated. (Target TRL as of completion: Level 4)
6.1.3 Development of the inside-reactor opening equipment	The Unit application feasibility of remote-control technology to make holes at reactor internals is evaluated. (Target TRL as of completion: Level 4)
6.2 Development of equipment to access from the side	The feasibility of the method to investigate the reactor core through the RPV side-opening is evaluated, the method concept is designed based on the evaluation results, and the Unit applicability of the method is evaluated. (Target TRL as of completion: Level 3-4)
6.3 Development/Selection of method to investigate to the reactor core	The feasibility of the Unit application of the method for investigateing to the reactor core is evaluated through the use of the findings from the project “Development of the Basic and Generic Technology to Retrieve Fuel Debris and Reactor Internals (Visual and Measurement Technology)”, etc. (Target TRL as of completion: Level 4)
6.4 Designing the entire investigation equipment system and planning the investigation	Safety requirements and responses thereto that would need to be regulated and discussed are identified, and the entire work flow from the equipment installation at the R/B operation floor to the on-site surveys and the post-investigation treatment is in place. (Excluded from the “TRL” technology readiness level for the sake of easier information organization)

3.1 Implementation Items in the Research Project

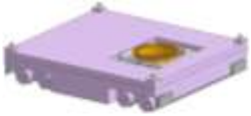
No.6

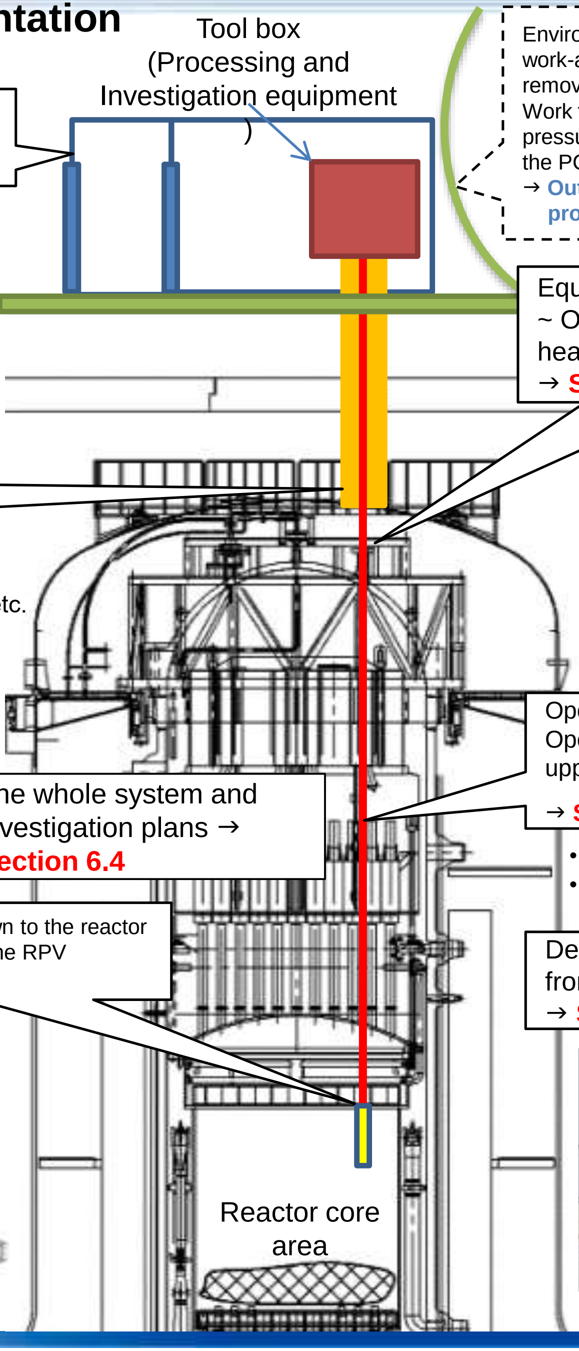
#	Items	Achievements up to FY2015	Items implemented in FY2016-2017	Action policy/Solutions
-	Generate and update investigation and development plans	• investigation flowchart generated • Studied the needs identified in other projects and drew up investigation and development plans	• Studied the viability of the side-opening investigation method	• Desk-study the side-opening investigation method in FY2016-2017.
6.1.1	Opening equipment to access the part down to the RPV head	• Studied the concept of the equipment to open the part between well cover and the RPV head • Conducted an elemental test in FY2014	• Planned the remote-control works (positioning and installation/anchoring) • Explored a method to prevent a hydrogen explosion from happening during processing work • Method to prevent the fall of fragments from processing work and the methods to fixate and collect them • Studied and understood the migration behavior of radioactive materials including radioactive dust	• Equipment design and element test (FY2016-2017) ➢ Confirm, through partial prototyping, the procedures and equipment for remote-control works
6.1.2	Boundary maintenance equipment	• Drew up the basic concept; and conducted a test on sealing to verify the basic structure in FY2015	• Established the remote-control procedures for installing and anchoring the boundary maintenance equipment and made seismic design • Method for verifying the installation and post-investigation treatment	• Equipment design and element test (FY2016-2017) ➢ Verify, through partial prototyping of the equipment, the method and equipment ➢ Verify the compatibility with the opening equipment
	Access equipment for operations (work cell)	• Studied the concept in FY2015	• Structural (seismic) and shielding designs • Conducted a study on handling tools • Air (conditioning) system • Monitoring plan (for door opening/closing and during the occurrence of an abnormality)	• Equipment design (FY2016-2017) ➢ Verify the compatibility with the opening equipment
6.1.3	Development of the technology to make holes inside the reactor (the part down to the upper grid plate)	•Conducted an element test and confirmed the feasibility of processing work to make holes in reactor internals inside the RPV, the key process to access the reactor core •Studied the concept in FY2015	• Tool head and the mechanism to remove fragments from processing work (Access from the top: for narrow or complicated shapes) • Guide pipe insertion and the tool transfer mechanism (Access from the top: approx. 20 m below) • Remote control and collection of equipment	• Equipment design and element test (FY2016-2017) ➢Decide whether it's necessary to prototype the equipment and conduct a verification test on the equipment or method after designing the equipment and, if necessary, conduct the test
6.2	Development of the equipment to access from the side	-	• Determined the viability of the side-opening investigation method • Designed the concept of side-opening investigation method • Designed equipment for side-opening investigation method	➢ Establish a method focusing on securing boundaries ➢ Conduct a study on the equipment specifications
6.3	Development of the technology to investigate the reactor core and RPV bottom part	• Studied the concept in FY2015	• Narrowed down investigation instruments such as cameras and detectors • Method to access the reactor core (wire, telescope, guide pipe, etc.) • Rescue methods at the time of failure • Studied methods to investigate the reactor core and the RPV bottom part and on their precision requirements	• Equipment design and element test (FY2016-2017) ➢ Verify investigation method using partial elements (shroud head, upper grid plate, etc.)
6.4	Designing the investigation equipment system and planning the investigation methods	-	• Elaborated investigation flow using equipment mentioned in Sections 5.1-5.3 and its work plans (area decontamination, processes from preparation to completion, and equipment retrieval/decontamination /maintenance, etc.) • Studied safety requirements	➢ Build HP, scrutinize exposure assessment conditions, and confirm the investigation viability in a slightly -positive-pressure environment ➢ Generate investigation flowcharts

3.2 Relationships among Implementation Items

- Study on utility functions and systems
- Study on the method/carrier to carry in/out the equipment


Overview of the Top-Opening Investigation method


Tool box transport cart



Work cell
→ **Section 6.1.2**

Environment adjustment and work-area making after fuel removal from the pool
Work for creating a negative pressure environment inside the PCV, etc.
→ **Outside the scope of this project**

Equipment for processing work ~ Opening down to the RPV head
→ **Section 6.1.1**

- Opening equipment
- Equipment to make small-diameter holes, etc.

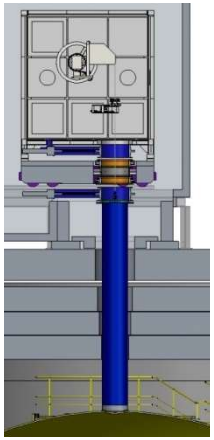

Equipment to perform processing work for the PCV head

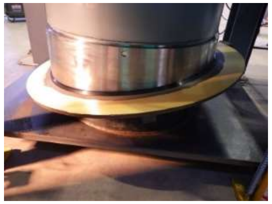

Equipment to perform processing work for the heat-retention material


Equipment to perform processing work for the RPV head

Boundary maintenance equipment
→ **Section 6.1.2**

- Tool box
- Guide pipe
- Sealing mechanism (resin packing), etc.


System configuration for boundary maintenance


Guide pipe sealing part

The whole system and investigation plans → **Section 6.4**

Opening equipment for reactor internals ~ Opening inside the reactor (down to the upper grid plate)
→ **Section 6.1.3**

- Tool head (abrasive water jet nozzle)
- Access equipment (stored in the tool box) , etc.


Access equipment for the opening of reactor internals

Equipment to investigate down to the reactor core and the bottom part of the RPV
→ **Section 6.3**

- Suspension lowering equipment
- Camera
- Dosimeter
- Horizontal-motion mechanism, etc.

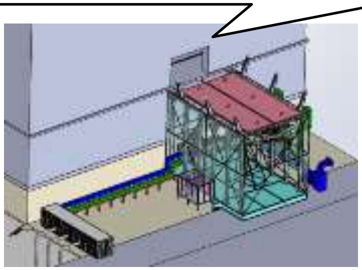

For Prior Confirmation

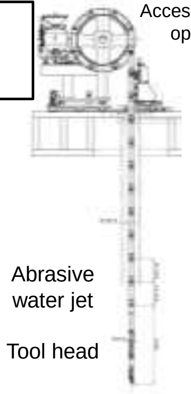

For the full-scale investigation

investigation equipment


Access (suspension lowering) equipment

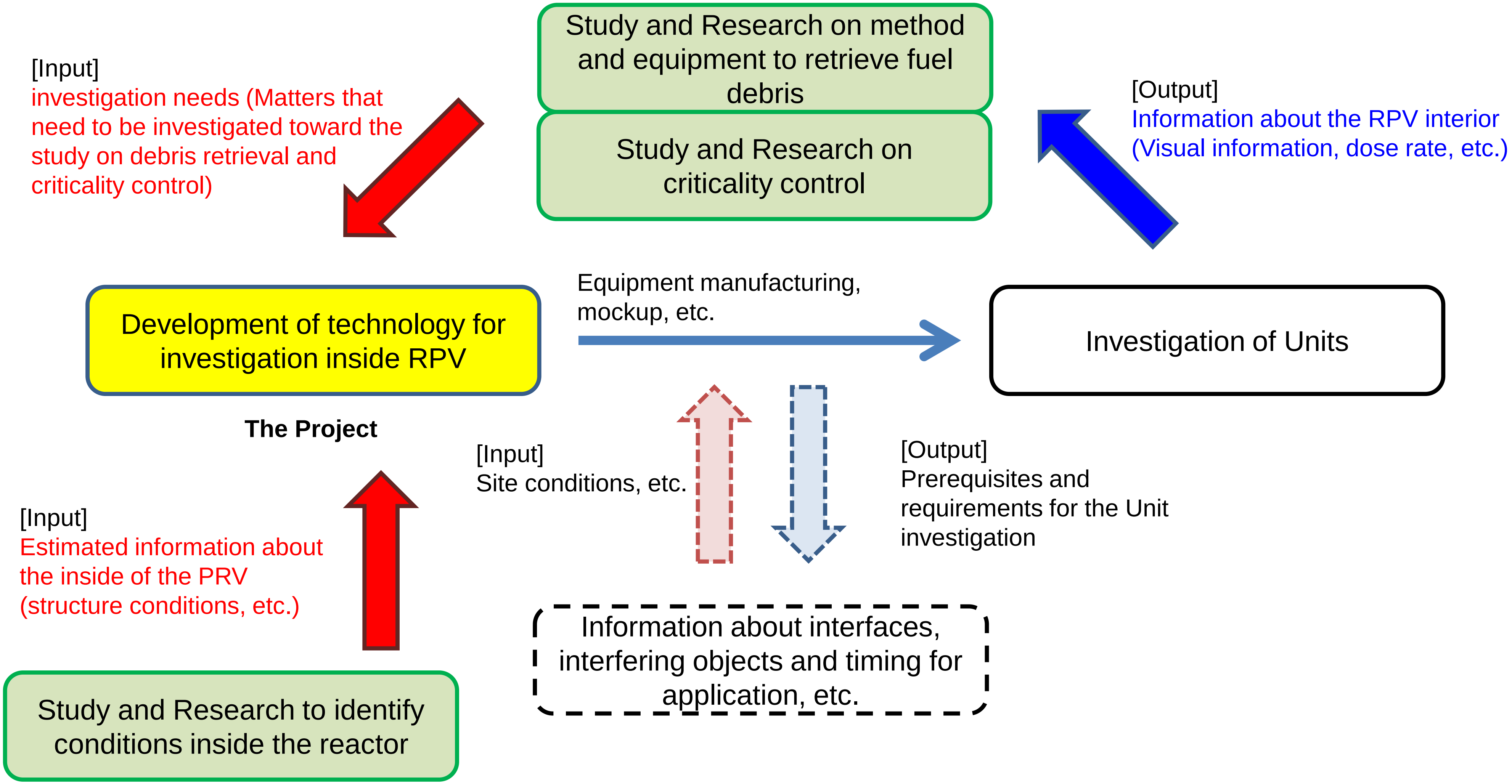
Development of equipment to access from the side
→ **Sections 6.2 and 6.3***


Overview of the side-opening investigation method



*investigation tools (such as camera, dosimeter and the like only)

3.3 Relationships with Other Research



Study and Research on method and equipment to retrieve fuel debris

Study and Research on criticality control

[Input]
investigation needs (Matters that need to be investigated toward the study on debris retrieval and criticality control)

[Output]
Information about the RPV interior (Visual information, dose rate, etc.)

Development of technology for investigation inside RPV

The Project

Equipment manufacturing, mockup, etc.

Investigation of Units

[Input]
Site conditions, etc.

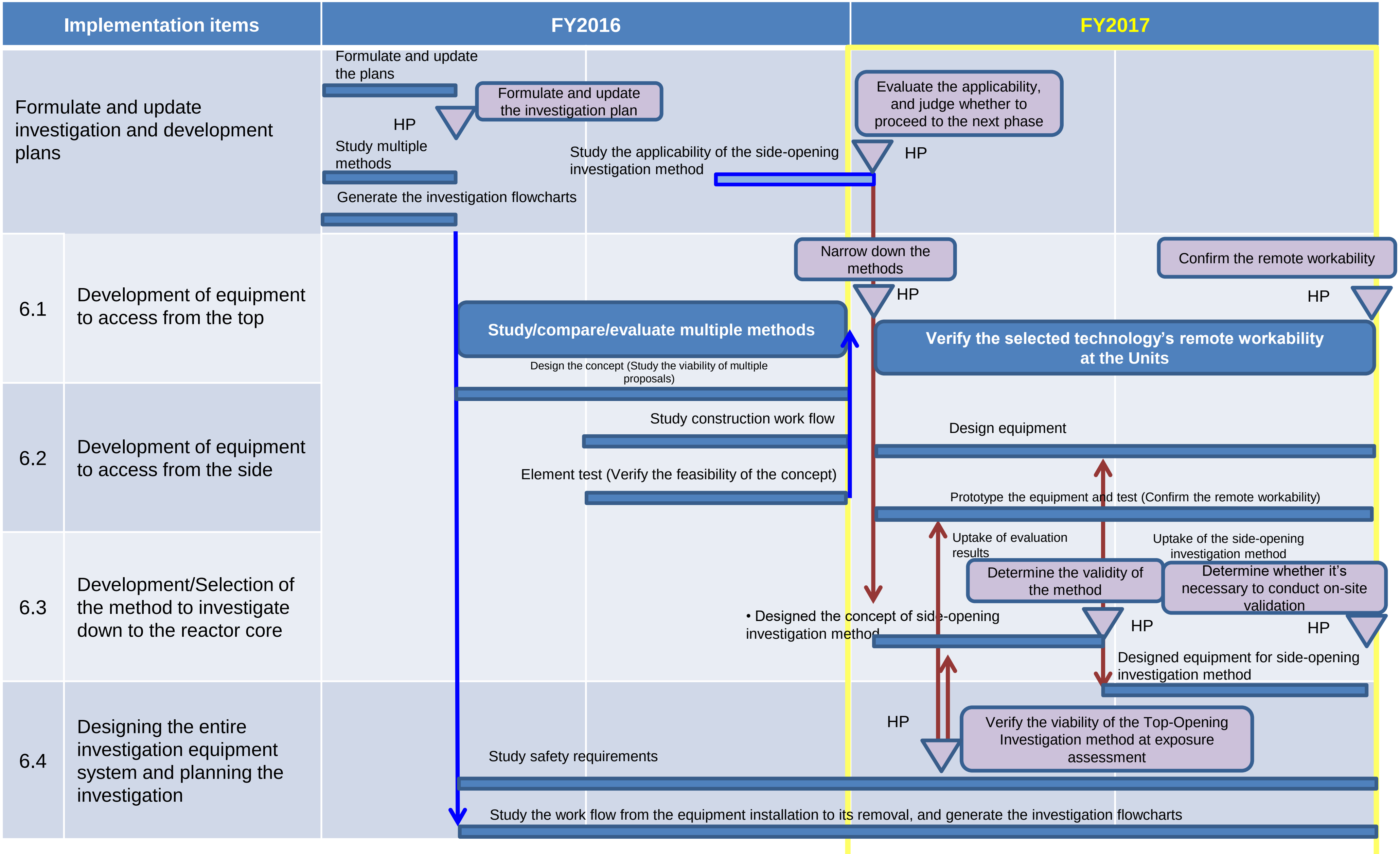
[Output]
Prerequisites and requirements for the Unit investigation

[Input]
Estimated information about the inside of the PRV (structure conditions, etc.)

Study and Research to identify conditions inside the reactor

Information about interfaces, interfering objects and timing for application, etc.

4. Schedule



Implementation items		FY2016	FY2017
Formulate and update investigation and development plans		Formulate and update the plans Formulate and update the investigation plan HP Study multiple methods Study the applicability of the side-opening investigation method Generate the investigation flowcharts	Evaluate the applicability, and judge whether to proceed to the next phase HP
6.1	Development of equipment to access from the top	**Study/compare/evaluate multiple methods** Design the concept (Study the viability of multiple proposals)	Narrow down the methods HP Confirm the remote workability HP **Verify the selected technology's remote workability at the Units**
6.2	Development of equipment to access from the side	Study construction work flow Element test (Verify the feasibility of the concept)	Design equipment Prototype the equipment and test (Confirm the remote workability)
6.3	Development/Selection of the method to investigate down to the reactor core	• Designed the concept of side-opening investigation method	Uptake of evaluation results Uptake of the side-opening investigation method Determine the validity of the method Determine whether it's necessary to conduct on-site validation HP HP Designed equipment for side-opening investigation method
6.4	Designing the entire investigation equipment system and planning the investigation	Study safety requirements Study the work flow from the equipment installation to its removal, and generate the investigation flowcharts	HP Verify the viability of the Top-Opening Investigation method at exposure assessment

5. Project Organization Chart

(Main) official in charge: International Research Institute for Nuclear Decommissioning (IRID)
(Deputy) official in charge: Toshiba Energy Systems & Solutions Corporation (International Research Institute for Nuclear Decommissioning)

Tokyo Electric Power Company Holdings, Inc.

International Research Institute for Nuclear Decommissioning (Head Office)

- ○ Integral planning and technical supervision
- ○ Management of technical development and its progress

Toshiba Energy Systems & Solutions Corporation

1) Generate and update investigation and development plans
2-1) Develop the equipment to access the reactor core from the top
(i) Develop the opening equipment to access down to the RPV head
(ii) Develop the boundary maintenance equipment and the access equipment for operations
(iii) Develop opening equipment for upper grid plate
3) Develop/Select method to investigate down to the reactor core
4) Design entire investigation equipment system and plan the investigation

IHI Corporation
- 2-1) (i) Develop opening equipment to access the RPV head

IHI Corporation
- 2-1) (ii) Develop boundary maintenance equipment

KIMURA CHEMICAL PLANTS CO., LTD.
- 2-1) (ii) Develop access equipment for operations

Hitachi-GE Nuclear Energy, Ltd.

1) Generate and update investigation and development plans
2-1) Develop the equipment to access the reactor core from the top
(iii) Develop opening equipment for upper grid plate
4) Design entire investigation equipment system and plan the investigation

Hitachi Power Solutions Co.,Ltd.
- 2-1) (iii) Support design and tests in the development of opening equipment for upper grid plate

Hitachi Power Solutions Co.,Ltd.
- 2-1) (iii) Design, manufacture and conduct a test of element test machines for the development of opening equipment to the upper grid plate

Mitsubishi Heavy Industries, Ltd.

1) Generate and update investigation and development plans
2-2) Develop the method and equipment to access the reactor core from the side

AREVA ATOX
D&D SOLUTIONS Co., Ltd. (ANADEC)
- 2-2) Develop method and equipment to access the reactor core from the side

SHIMIZU CORPORATION
- 2-2) Evaluate integrity of Unit 1's R/B through an access to the reactor core from the side

Kajima Corporation
- 2-2) Evaluate integrity of the R/Bs of Units 2 and 3 through an access to the reactor core from the side

Cooperating development project teams

- Upgrading the Comprehensive Identification of Conditions inside Reactor
- Development of Fundamental Technology for Retrieval of Fuel Debris and Internal Structures; Upgrade the Approach and Systems; and Conduct Sampling
- Development of Technology for Collection, Transfer and Storage of Fuel Debris
- Development of Technology for Criticality Control Methods
- Grasp the Fuel Debris Characterization
- Development of Technology for Investigation inside PCV
- R&D for Treatment and Disposal of Solid Radioactive Waste
- Development of Repair Technology for Leakage Points inside PCV

Note: Organized companies were selected by competitive bidding.

6. Implementation Items: (1) Prerequisites (and Items Implemented in and before FY2015)

Items	Content
Investigation needs (Items implemented in and before FY2016)	• Early access to the reactor core and data collection will allow us to reflect the data in the specific design of debris retrieval equipment. • The following two pieces of data need to be collected: visual information and dose rate.
Target Unit (Items implemented in and before FY2016)	• Top-opening: Unit 3 • Side-opening: Unit 2
Access route (Items implemented in and before FY2016)	• Top-opening: right above the RPV spare nozzle • Side-opening: rooftop of the air conditioning room east to the R/B
Assumed air dose rate (Max.)	Drywell: 16 Sv/h Inside the reactor (in the vicinity of the steam dryer and steam separator): 800 Sv/h Inside the reactor (in the vicinity of the reactor core): 5,000 Sv/h
Assumed structure conditions	part between well cover and shroud head: (Presumably) in a sound condition part below the upper grid plate: it may have major damage; the structures below the upper grid plate were defined as debris and processing work for the part to the shroud head was performed before conducting the investigation. The deepest part of the bottom part of the RPV was accessed based on the assumption that the melting of the fuel, structures, etc. in the reactor core starts at their center.
Light penetration rate (in fog/mist)	46% (the absorption coefficient value for Unit 1 measured under stricter conditions than the internal PCV investigation ones: 0.511)
Work site and remote operability	Work site: operation floor Assumed work area: 1.3m above the operation floor Assumed work area environment: 1 mSv/h Equipment installation: manually by workers Processing work and investigation: remotely-operated
Fragments from processing work	From aspect of criticality control, the top priority is to prevent fragments from falling into the reactor core.
Boundary (Items implemented in and before FY2016)	A boundary is built in the PCV. A negative pressure environment is created inside the work cells that are installed on the operation floor and at the rooftop of the air conditioning room to prepare for a situation where radioactive materials leak toward their openings.

6. Implementation Items (2) Required Safety Requirements

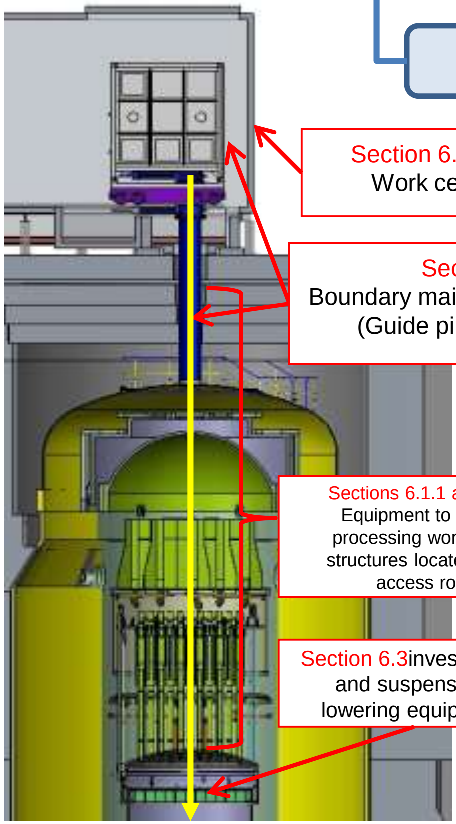
Safety requirements	Assumed events	Responses and their policies
Prevent radioactive materials from leaking to the gas phase	Migration of radioactive materials to the gas phase during an operation	Build a boundary in the PCV. Create a negative pressure environment for the work area as a measure against contamination spread. Monitor works, ventilate the R/B, etc. during operation. Assess public exposure doses at the site boundaries and worker exposure doses inside the R/B based on the radioactive dust amounts that would be generated from the cutting of structures in the PCV, RPV and reactor. Conduct Top-Opening Investigation after creating a negative pressure environment in the PCV, given the possibility of the inside of the R/B getting contaminated during processing work. For side-opening investigation, confirm if the exposure standard value will be satisfied even when the PCV has, as it does currently, a slightly-compressed environment.
Prevent radioactive materials from leaking to the liquid phase	Migration of radioactive materials to the liquid phase during operation	Continue to study, while referring to the study on the water system, how to assess the concentrations when water containing radioactive materials flows to the outside of the PCV → to the torus room or into the PCV → to the inside of the pedestal.
Maintain the fuel debris cooling function	Loss of the fuel debris cooling function	Select an access route that avoids the piping currently in use.
Control criticality and maintain sub-criticality.	Occurrence of criticality resulting from a change in a fuel debris shape due to the fall of a fragment from processing work	Find an access route and method that will have less processing objects and cause less falls of fragments in the reactor core. Explore, for the side-opening investigation, an approach that enables the shroud head to be cut into as tiny pieces as possible and thereby reduces the risk of recriticality due to the fall of a fragment in the reactor. Continue to conduct a study, in cooperation with the criticality control project, on the evaluation of the weight of fragments from the cutting work that would affect criticality.
Prevent fire or explosion	Hydrogen explosion during a processing work	Introduce, for the top-opening investigation, anti-hydrogen measures for the work to make small-diameter holes at the PCV head and the RPV head.
Prevent the fall of a heavy weight object	Dispersion and diffusion of radioactive materials resulting from the fall of a heavy weight object	Design equipment that does not cause the fall of a heavy weight object (multiplexing, diversification, etc.).
Prevent the collapse of the R/B during the construction work for the investigation	Collapse of the R/B due to the installation of equipment	Design the support structure in such a way that the floor slab of the air conditioning room (above which a work cell is to be installed for the side-opening investigation) withstands the load of the work cell and other equipment. Evaluate the seismic resistance of the R/B walls against the investigation hole perforation and make sure that the impact of the work will be minor.

6. Implementation Items: (3) Required Functions and Equipment for the Top-Opening investigation

The diagram below shows the functions and equipment necessary to conduct the investigation all the while ensuring safety (Evaluation items are omitted there.)

Purpose	Required functions		Required equipment (Development items)	Main capabilities/Element technology
Investigate the RPV interior	Obtain basic information about the RPV interior	Obtain visual information Obtain dose rate data	Section 6.3 investigation and suspension-lowering equipment	•Accessibility to narrow areas •Visibility in fog/mist •Radiation resistance
		Establish the access route	Sections 6.1.1 and 6.1.2 Equipment to provide processing work for the structures located on the access route	•Workability at narrow areas •Remote operability •Down-size of the access equipment
	Ensure safety	Confine radioactive materials	Section 6.1.2 Boundary maintenance equipment (Guide pipe and tool box)	•Sealing performance at the interfaces
		Prevent contamination spread	Section 6.1.2 Work cell	• Negative pressure control • Instruments for handling equipment in the cell
		Prevent hydrogen explosion	Section 6.1.1 Equipment to make small-diameter holes	• Processing method that does not use fire
		Monitor the work environment	Monitor dusts, criticality, etc. Outside the scope of this project	

🟩	Element tests conducted in FY2017
⬚	Desk-studied in FY2017 or applied other research achievements



Section 6.1.2
Work cell

Section 6.1.2
Boundary maintenance equipment
(Guide pipe and tool box)

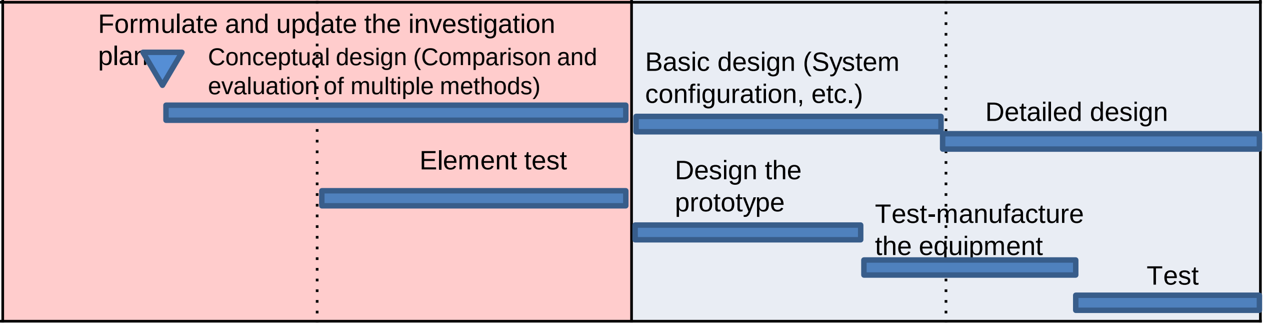
Sections 6.1.1 and 6.1.2
Equipment to provide processing work for the structures located on the access route

Section 6.3investigation and suspension-lowering equipment

6.1 Development of Access Device from the Top to the Reactor Core

6.1.1 Development of the Opening Device for Accessing the RPV Head

○ Outline of schedule



#	Items	Achievements up to FY2015	FY2016	FY2017
6.1.1	Opening equipment to access the part down to the RPV head	• Studied the concept of the equipment for opening well cover, PCV head, RPV heat-retention frame, and PRV head • Conducted an elemental test in FY2014	Formulate and update the investigation plan Conceptual design (Comparison and evaluation of multiple methods) Element test	Basic design (System configuration, etc.) Detailed design Design the prototype Test-manufacture the equipment Test

○ Items implemented in and before FY2016

- The RPV spare nozzle part was selected as the access route for its workability and the amount of processing-work objects thereon.
- The policy to collect fragments from processing work in a tool box was adopted, instead of storing them in a container, and to dispose of them with the tool box.
- The following structure-processing methods were selected.

Structure	Method	Notes
Well cover	Core boring	
PCV head	Small-diameter opening: machining* Large-diameter opening: abrasive water jet (AWJ) ⇒ The finding of the PCV Maintenance Technology Project was referred to.	*Method that takes account of residual hydrogen
Heat-retention material	AWJ	
RPV head (spare nozzle part)	Small-diameter opening: machining* Large-diameter opening: AWJ ⇒Verified in an element test in FY2017.	*Method that takes account of residual hydrogen

○ Items implemented in FY2017

<Equipment design>

•Opening equipment for the well cover, PCV head*, RPV heat-retention frame and RPV head was designed.

•The design was elaborated to take account of its relationships with the boundary maintenance equipment and the access equipment for operations.

<Test-manufacturing and testing the equipment>

•A test was conducted using a partial mockup of the actual size and the workability of the RPV spare Nozzle Removal method was confirmed.

⇒ Remote operability was confirmed in a test assuming that the guide pipe and the spare nozzle would be located about 100 mm away from the center.

○ Remaining issues

•Streamline the structure and method to attain higher workability

•Conduct a study on the access route other than the RPV spare nozzle part (and the study on the processing method for the RPV heat-retention material and RPV head) and conduct an element test to verify the viability

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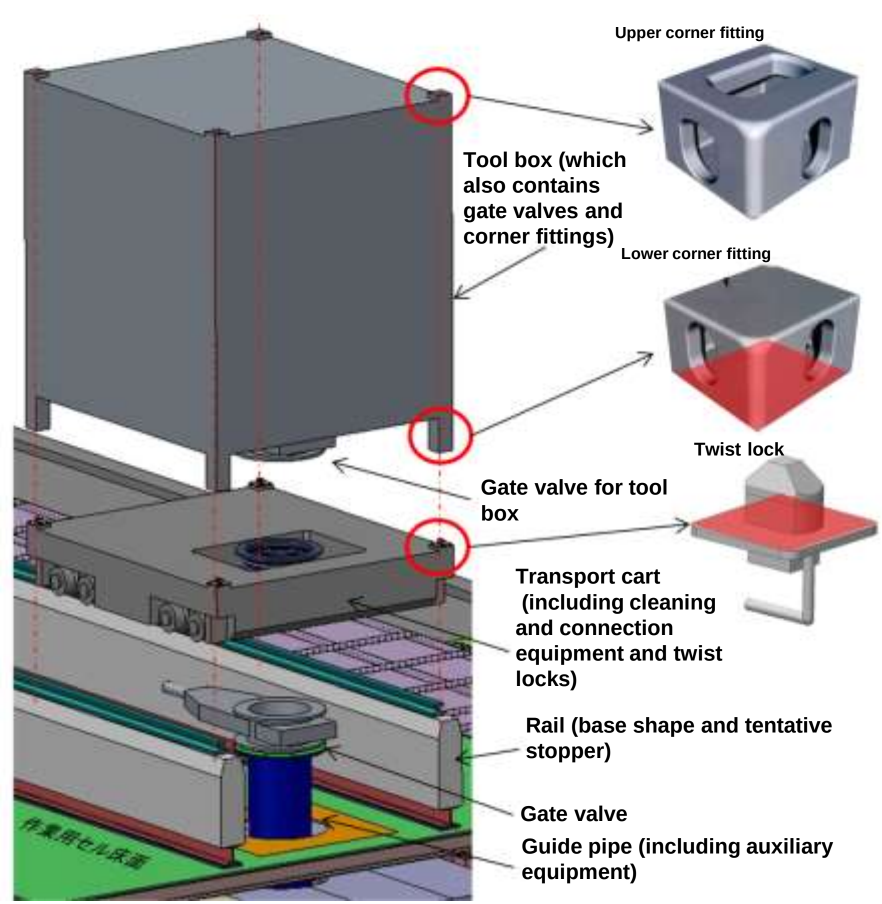
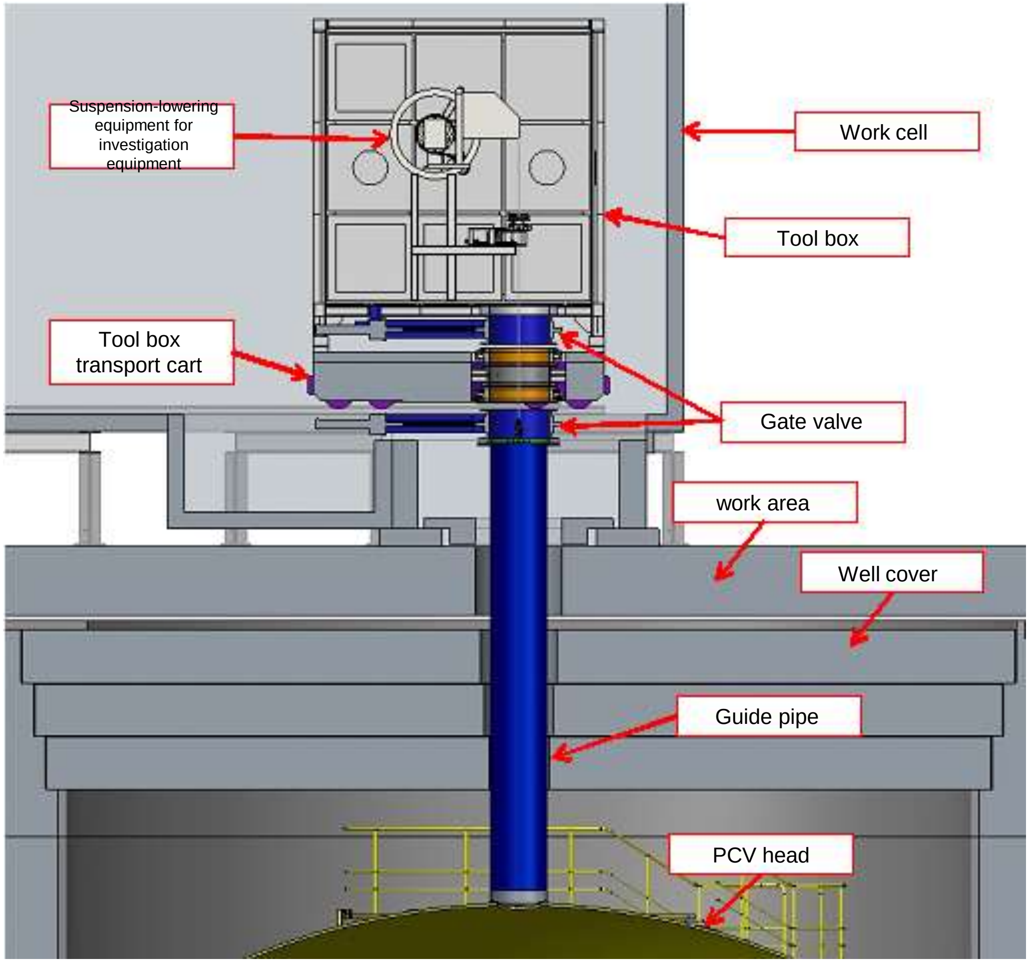
*For the PCV head small/large-diameter hole processing method, the findings of a test conducted in the PCV Maintenance Technology Project were referred to.

6.1.1 Development of Access Device from the Top to the Reactor Core

(1) Joint between Tool Box and Guide Pipe

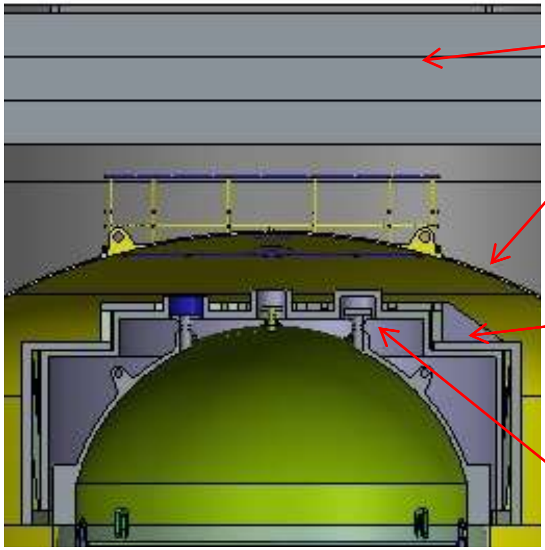
Each processing and investigation equipment are set with the access device(suspension-lowering device), and stored in a tool box which has an air tight function. Then, a work cell is placed on a transport rail cart and transported to the upper part of the guide pipe. A tool box is carried into a work cell for each step and replaced to install on the guide pipe.





6.1.1 Development of Access Device from the Top to the Reactor Core

(2) Processing device to the RPV Head



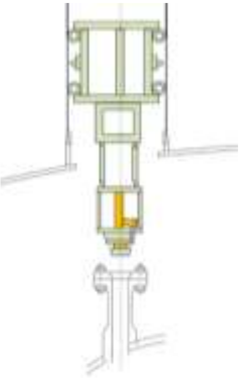
Well cover: element test conducted in FY2014

PCV head: element test conducted in FY2014; the similar technology developed in the PCV Maintenance PJ

RPV heat-retention material: element test conducted in FY2014

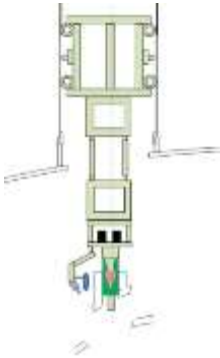
RPV head (spare nozzle part): element test conducted in FY2014 to confirm whether it can be processed with AWJ

Open the flange



Remove the flange

Remove the nozzle



Equipment to process the RPV head spare nozzle

Flange opening equipment

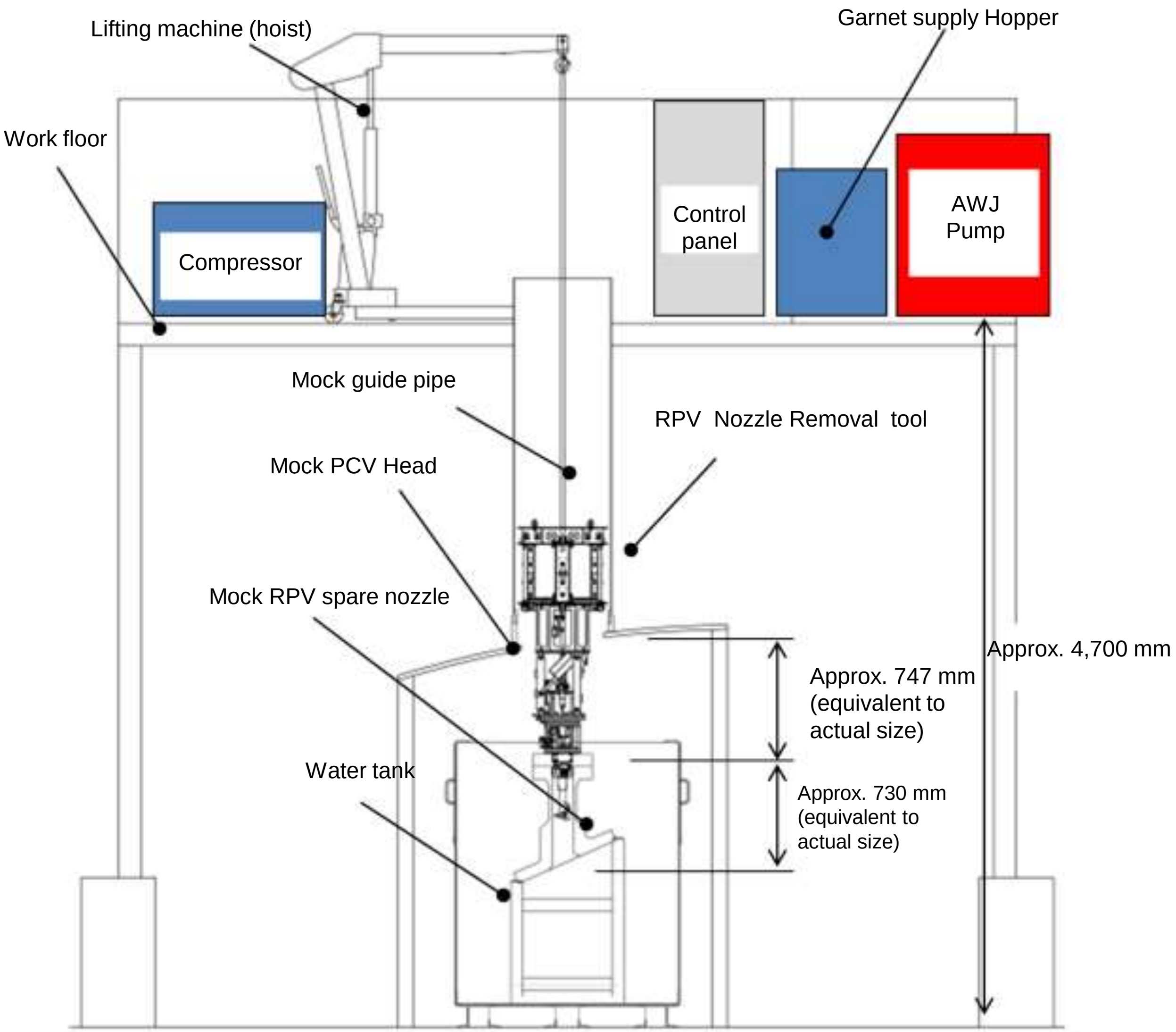
Equipment to severe the inner flange

Equipment to severe the outer nozzle

The feasibility of the processing methods is already confirmed at element tests conduced in the previous fiscal year(s). A test in FY2017 was conducted to confirm the remote operability of the method for removing the RPV head spare nozzle, which was the most difficult work.

6.1.1 Development of Access Device from the Top to the Reactor Core

(3) Testing the RPV Head Spare Nozzle Removal

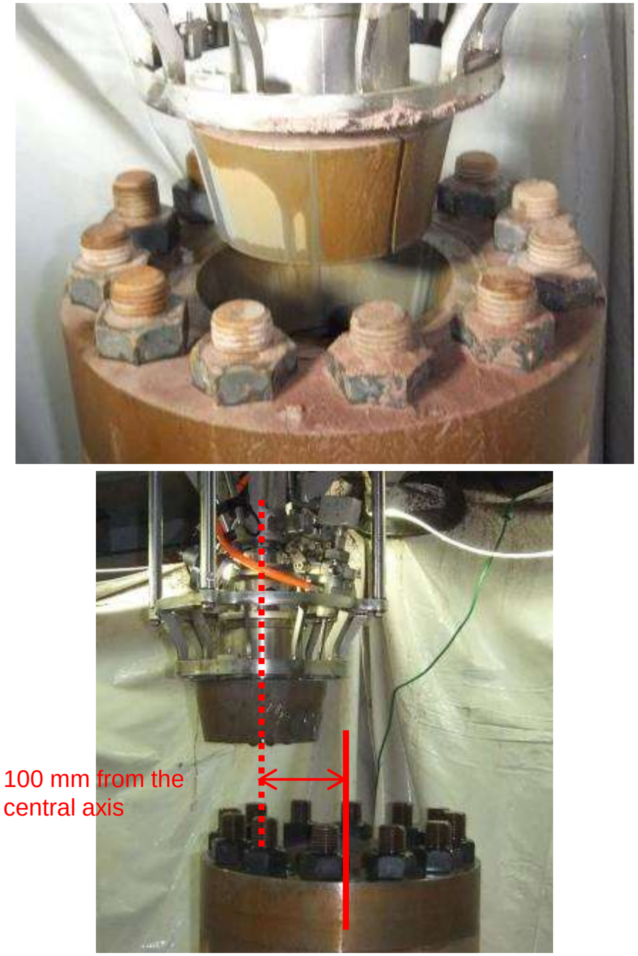


Overview of the test facility

Mock processing specimen

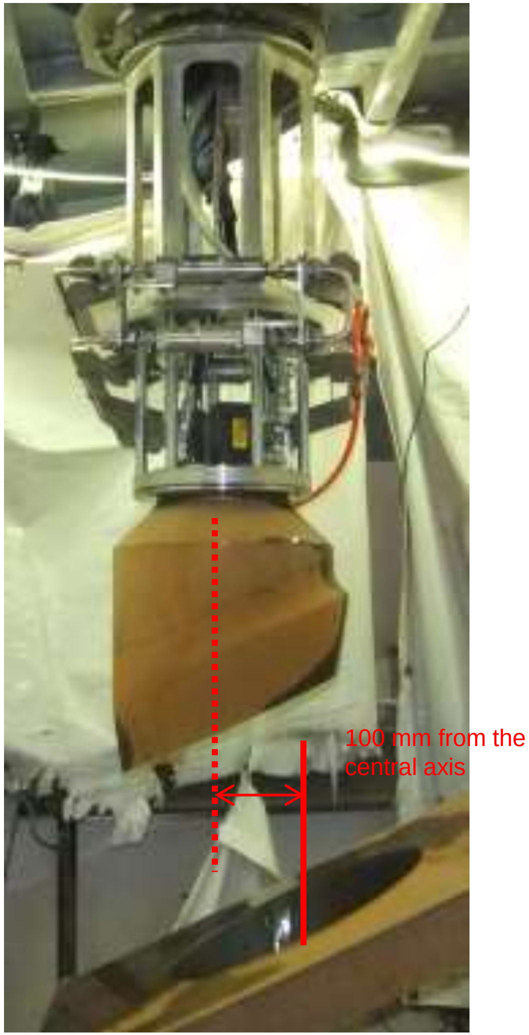
6.1.1 Development of Access Device from the Top to the Reactor Core

(4) Results of the RPV Head Spare Nozzle Removal Test



Removal of the RPV nozzle flange

Removal of fragments of the (upper) RPV nozzle

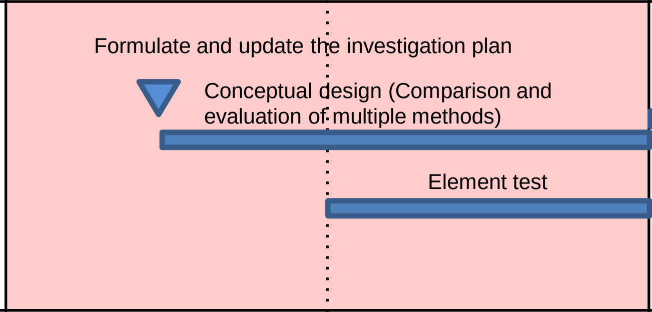
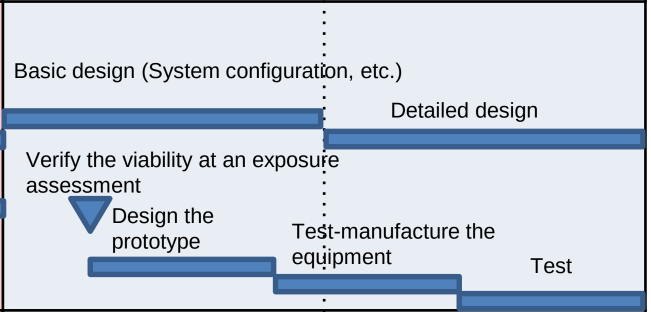
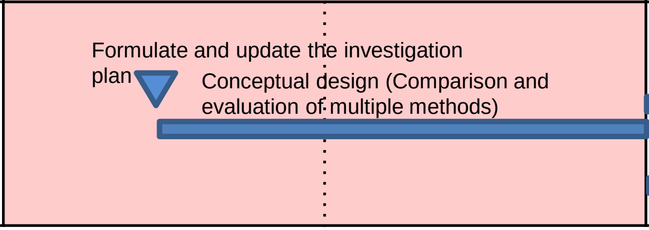
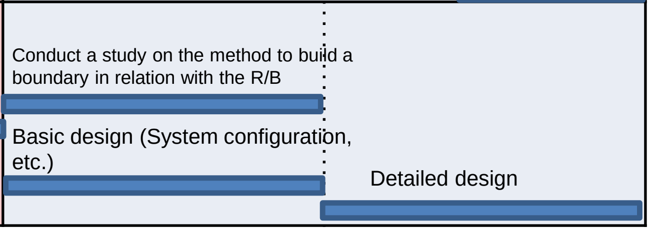


Removal of fragments of the (root part of) RPV nozzle

Processing and removing function tests using prototype equipment were conducted by remote-operation. The tests verified that the RPV spare nozzle removal method can be remotely operated, including that equipment can be off-set to work even when the nozzle is 100 mm deviate from the central axis.

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

○ Outline of schedule

#	Items	Achievements up to FY2015	FY2016	FY2017
6.1.2	Boundary maintenance device	• Formulate the basic concept • Conduct a test on the sealing function in FY2015 to confirm the basic structure	 Formulate and update the investigation plan Conceptual design (Comparison and evaluation of multiple methods) Element test	 Basic design (System configuration, etc.) Detailed design Verify the viability at an exposure assessment Design the prototype Test-manufacture the equipment Test
	Access device for operations (Work cell)	• Study the concept in FY2015	 Formulate and update the investigation plan Conceptual design (Comparison and evaluation of multiple methods)	 Conduct a study on the method to build a boundary in relation with the R/B Basic design (System configuration, etc.) Detailed design

○ Items implemented in FY2016

•Concepts of the opening equipment to access the part down to the RPV head, the boundary maintenance equipment and the access equipment for operations, were designed.

•A summary evaluation concerning the exposure during a processing work for reactor internals under the current slightly-compressed environment was conducted, it was found that it would be impossible to work in the R/B.

○ Items implemented in FY2017

<Equipment design>

•The exposure assessment conditions were scrutinized to determine whether it's possible to conduct the assessment when the PCV has a slightly-positive pressure environment.

The Top-Opening Investigation⇒ The PCV should have a negative pressure environment.

The side-opening investigation ⇒ The PCV should have a slightly-positive pressure environment.

•A seismic problem will arise if a work cell is installed on the shield that is currently in use at Unit 3 because of the acceptable maximum load of the operation floor and also because the shield is not anchored. ・If the investigation at Unit 3 is conducted, therefore, the shield needs to be remodeled or have a work area different from the current one.

- A study on the system to control negative pressures for a work cell and on the method to carry in/out the equipment was conducted.

<Test-manufacturing and testing the equipment>

•The guide pipe of the actual size for the boundary maintenance equipment was test-manufactured and a test was conducted, confirming the workability of the installation angle adjustment process.

•A test to confirm the sealing property of the actual-sized guide pipe was conducted and slight leakage was observed; however, it is thought that the PCV can maintain its negative pressure environment with the sealing.

○ Remaining issues

•Streamline the equipment structures and methods to attain higher workability

•Rationalize the layout plan for a work cell and its surroundings, and clarify the work-cell installation method and interface conditions.

•Conduct a detailed study on the system for maintaining negative pressures inside a work cell.

•Confirm the sealing (confinement) between guide pipe and tool box, and optimize the guide pipe seal structure (element test).

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

(1) Exposure Assessment Results and Future Investigation Policies

- The side-opening investigation method (No change made to the policy)
  - Target values are satisfied for activity concentration and site boundary dose.
    ⇒ The investigation can be conducted in a slightly-positive pressure environment (No problem with the concentration level inside the R/B).
  - Measures, such as dust monitoring and installation of a filter exhaust facility in the R/B will be introduced.

- The Top-Opening Investigation method (Changes made to the policy)
  - The activity concentration level at the (outdoor) vicinity of the R/B is within the limit for personnel. The site boundary dose is also within the limit.
  - If, however, processing work for structures located below the steam dryer is performed, the inside of the R/B will be contaminated, making it impossible for anybody, even in a full-body mask, to enter.
    ⇒ The investigation takes place in a negative pressure environment.
    (The investigation will be conducted in the negative pressure environment created for the side entry fuel debris retrieval.
    → The investigation schedule needs to be adjusted.)
  - Dust monitoring will be performed during the investigation.

⇒The following changes will arise if the investigation is conducted in a negative pressure environment.

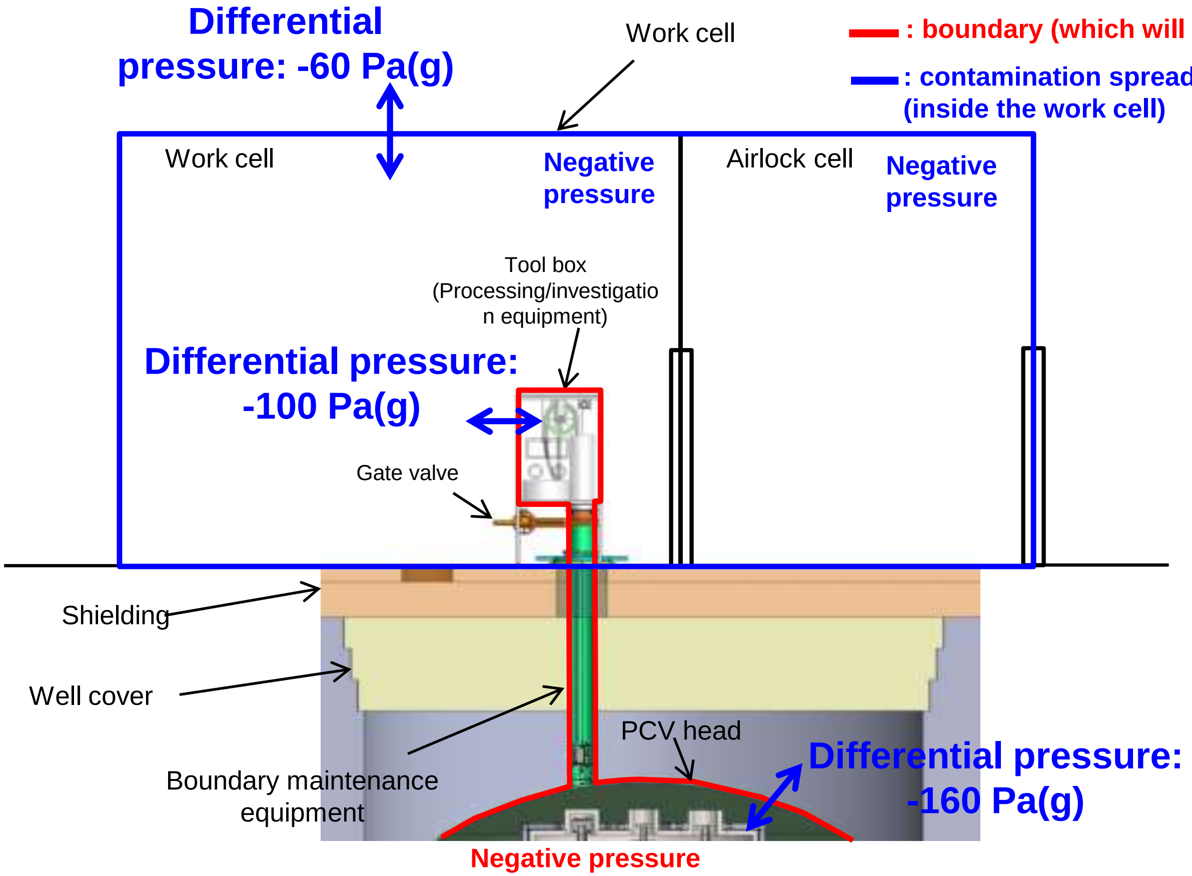
(i) Structure change of the resin packing for the guide pipe that will be installed at the PCV head

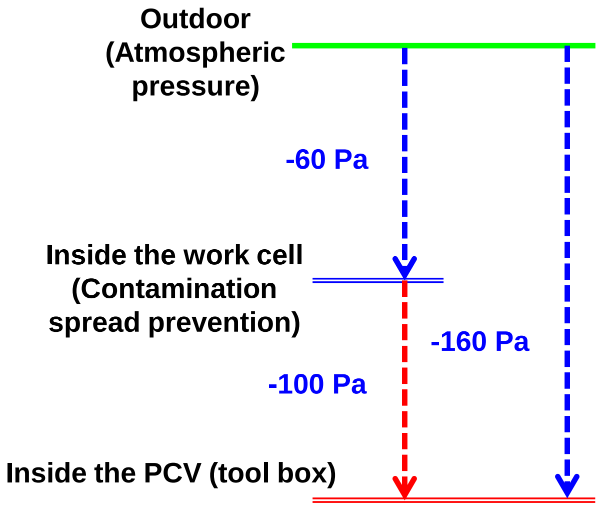
⇒Confirmed by an element test.

(ii) Change from the N2 purge system to an exhaust system ⇒ Study on the design.

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

(2) Work Cell and the Plan for Preventing Contamination Spread (under Negative Pressure Environments in the PCV)



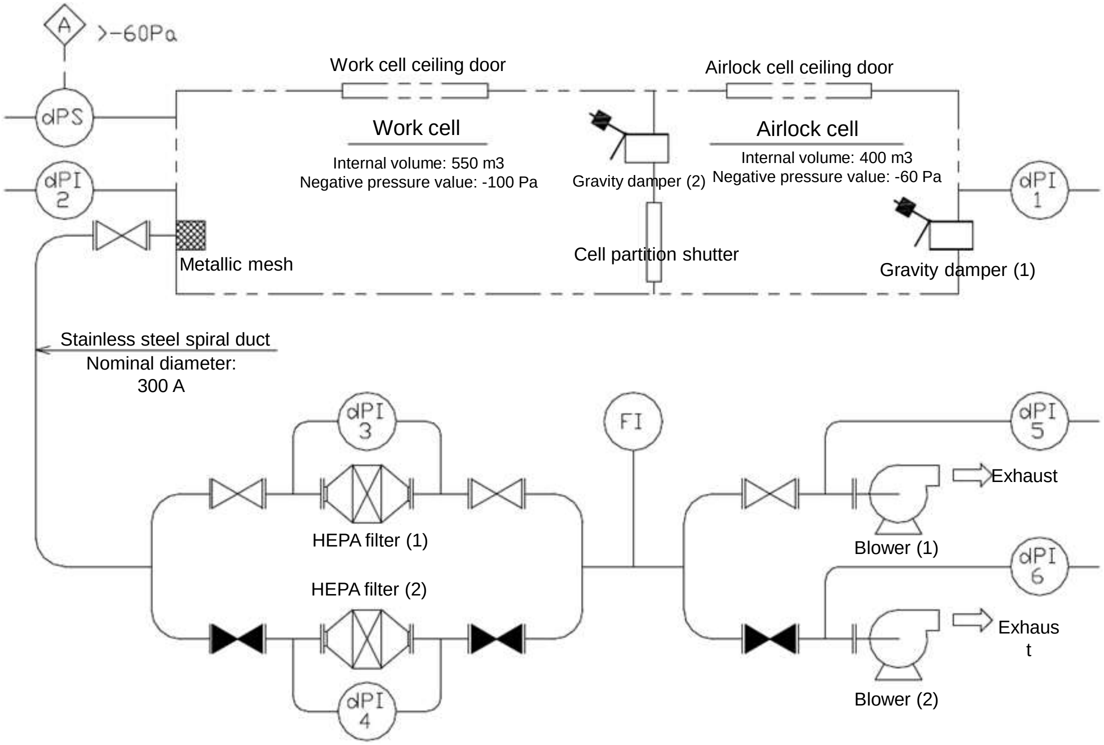


Pressure relations among the PCV inside, the work cell, and the inside/outside (atmospheric air) of the R/B

To prevent radioactive materials from leaking outside, the inside of a work cell shall have a negative pressure environment. (The RPV interior investigation, which does not involve fuel debris retrieval, will only use the primary boundaries, which has a function different from the second boundaries that will be used for the fuel debris retrieval.)

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

(3) Study on the Method to Control Negative Pressures inside a Work Cell



Summary diagram of the negative pressure control system

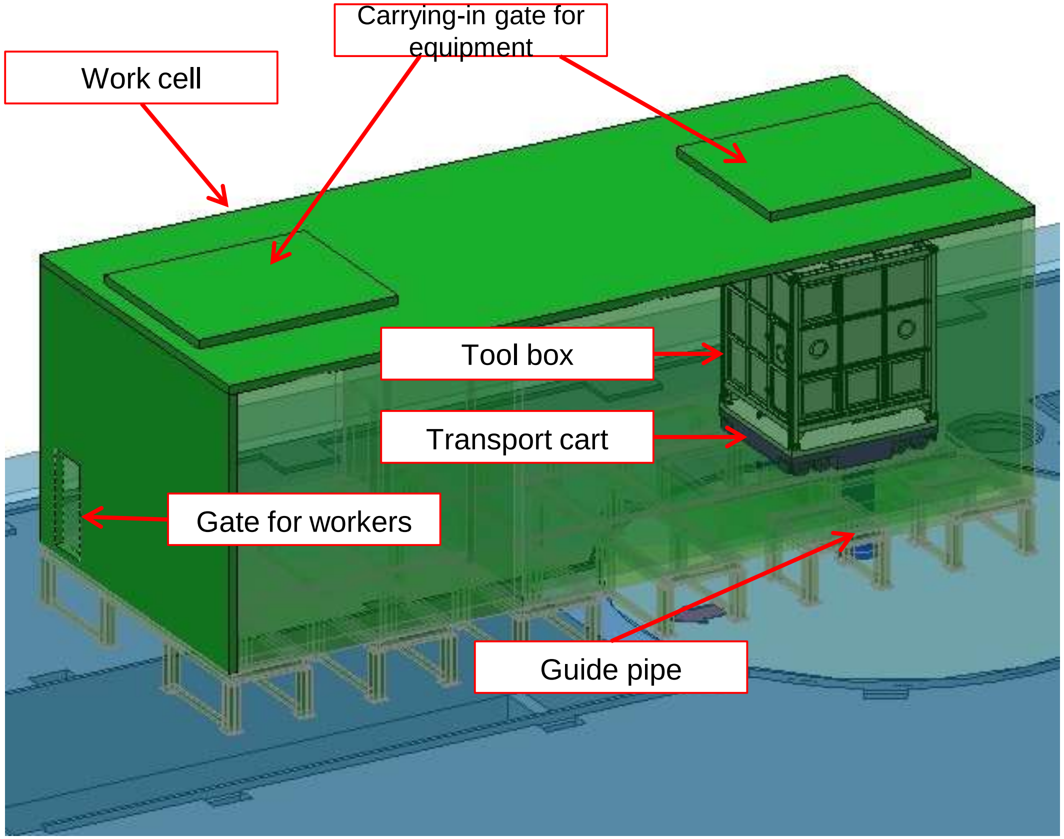
A system required to create a negative pressure environment inside the work cell was studied.

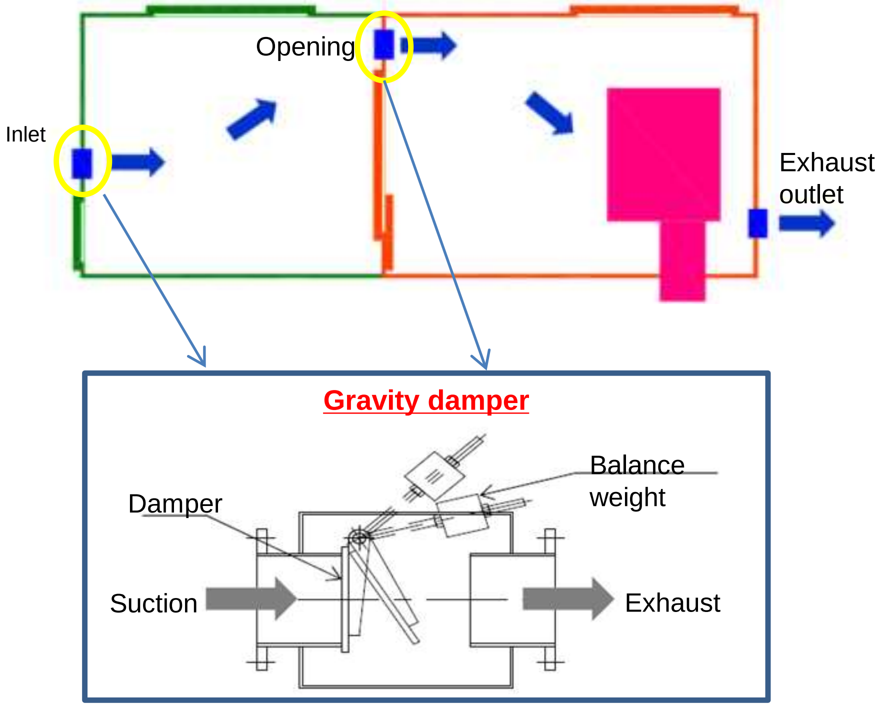
Summary of specifications of the system for controlling negative pressures

Symbol	Function	Summary of specifications
Gravity damper (1)	Automatically adjust negative pressures inside the airlock cell (the “L” area)	Set value -60 Pa
Gravity damper (2)	Automatically adjust negative pressures inside the work cell (the “M” area)	Set value -40 Pa
HEPA filters (1)(2)	Collect radioactive powder dust contained in exhaust air (one of the filters is a spare for replacement)	Collection efficiency: 0.3 µm or higher, 99.7% Rated airflow: 70 m^3/min
Blowers (1)(2)	Absorb and exhaust air in/from the cell (one of the blowers is a spare for failure)	Airflow: 100 m^3/min Static pressure: 2.15 kPa
dPI (1)	Monitor negative pressures inside the airlock cell	
dPI (2)	Monitor negative pressures inside the work cell	
dPIs (3)(4)	Monitor the clogging of the HEPA filter	
dPIs (5)(6)	Monitor the integrity of the blower	
dPS	Alert an abnormal negative pressure	Set value: -60 Pa
FI	Monitor the exhaust airflow	

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

(4) Work Cell Appearance





Install a “gravity damper” at an air inlet to control the gas flow at the area.

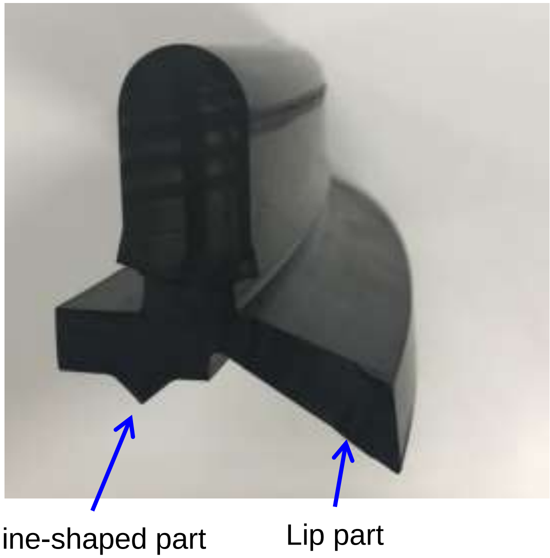
Remaining issues

Adjust the method for Connecting the equipment with the work cell area; optimize the layouts for the work cell and its surroundings; optimize the equipment structures for higher workability; and elaborate the system for maintaining negative pressures inside a work cell.

6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

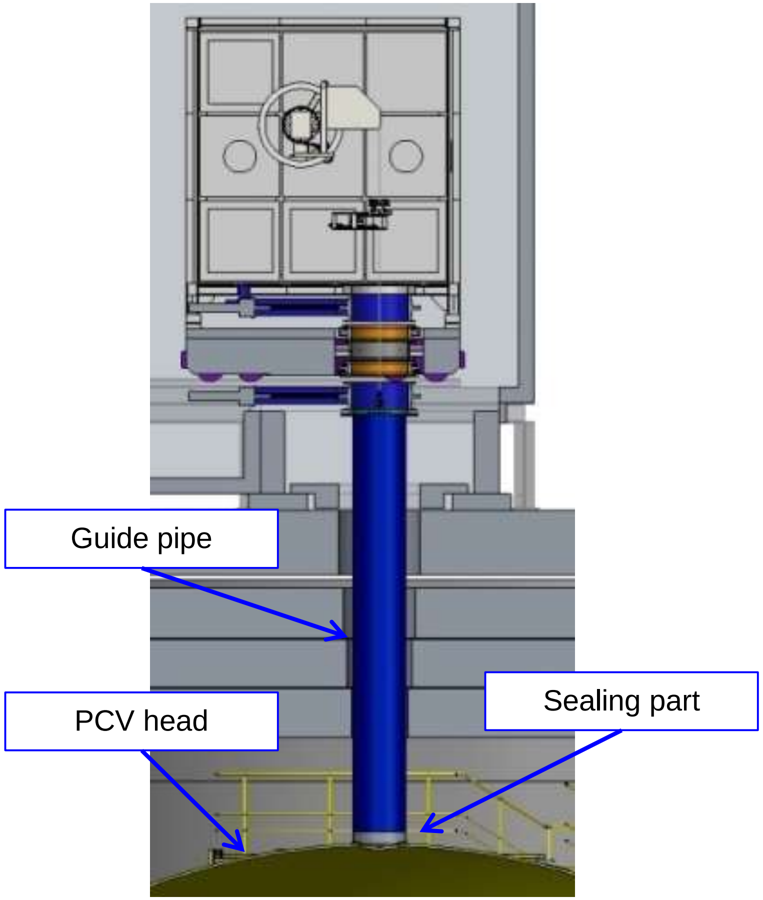
(5) Changes to the Guide Pipe Seal Structure

Until FY2016, a packing structure was explored on the assumption that the PCV would have a slightly-positive pressure environment and the feasibility of its sealing at an element test was confirmed, but the structure was changed to respond to the change to the negative pressure environment inside the PCV.


Mine-shaped part

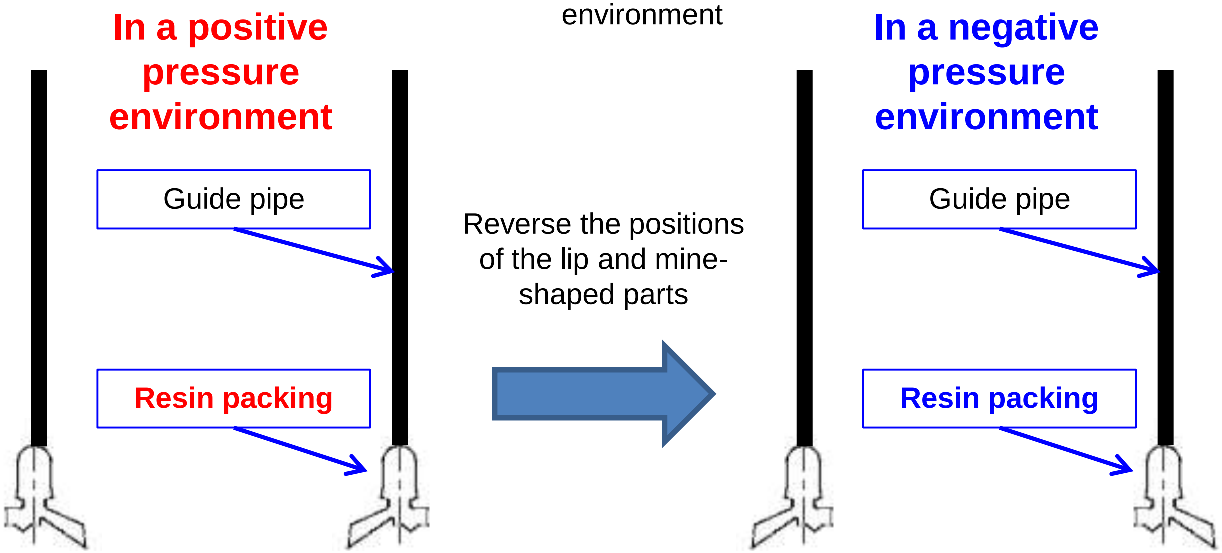
Lip part

Cross-section of the resin packing for a negative pressure environment


Guide pipe

PCV head

Sealing part


In a positive pressure environment

Guide pipe

Resin packing

Reverse the positions of the lip and mine-shaped parts

In a negative pressure environment

Guide pipe

Resin packing

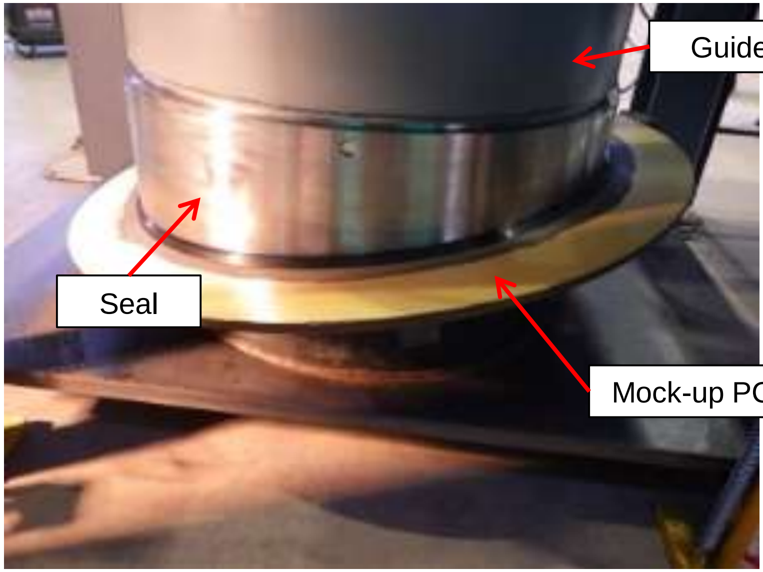
6.1.2 Development of the Boundary Maintenance Device and the Access Device for Operations

(6) Results of the Guide Pipe Sealing Test

The sealing performance was confirmed by using an actual-sized guide pipe (approx. 5 m long) against a condition where the sealing material (ethylen-propolindiene EPDM rubber) was irradiated (10^6 Gy).

A test was also conducted assuming the occurrence of displacement or inclination in order to figure out the required precision level for the guide pipe installation and the result was reflected in the equipment specifications. A test was conducted for the endpoint of not creating any pressure change during a 10-minute holding period under - 200 Pa(g).

During the 10-minute holding period under -200 Pa (g), the sealing for the use in a negative pressure environment experienced a pressure change of up to -145 Pa(g), resulting in a small amount of leakage; however, since it will be an in-leak inside the PCV which will have a negative pressure environment, no leakage of radioactive materials will occur even when the sealing function is lost due to an earthquake, etc. No influence on the sealing function from either the presence or absence of the irradiation was observed.



Sealing part

Remaining issue

Optimize the sealing structure so that it will have higher reliability for the use in a negative pressure environment

6.1.3 Development of Opening Equipment inside the Reactor

○ Outline of schedule

#	Items	Achievements up to FY2015	FY2016	FY2017
6.1.3	Development of technology for drilling holes inside the reactor (to the upper grid plate)	•An element test was conducted to confirm the feasibility of processing work for opening holes in reactor internals in the RPV, the key process to access the reactor core •Conceptual study was conducted in FY2015.	Formulate and update the investigation plan Conceptual design Element test	Basic design Detailed design Design the prototype Test-manufacture the equipment Test

○ Studies conducted in and until FY2016

The conceptual study on equipment for opening holes in the reactor

- Studied the non-contact method(small processing reaction force), positioning and opening the narrow parts of the reactor internals using the Abrasive Water Jet (AWJ) that is easy to re-process (combination cutting).
- Confirmed process-ability and workability of a small-sized AWJ nozzle by an element test and evaluate its feasibility.
- Studied an access route with small risk of criticality (with less risk of the fall of fragments from processing work) and the investigation plan.

○ Items implemented in FY2017

Basic and detailed designs for equipment of opening holes in the reactor (including the work plan)

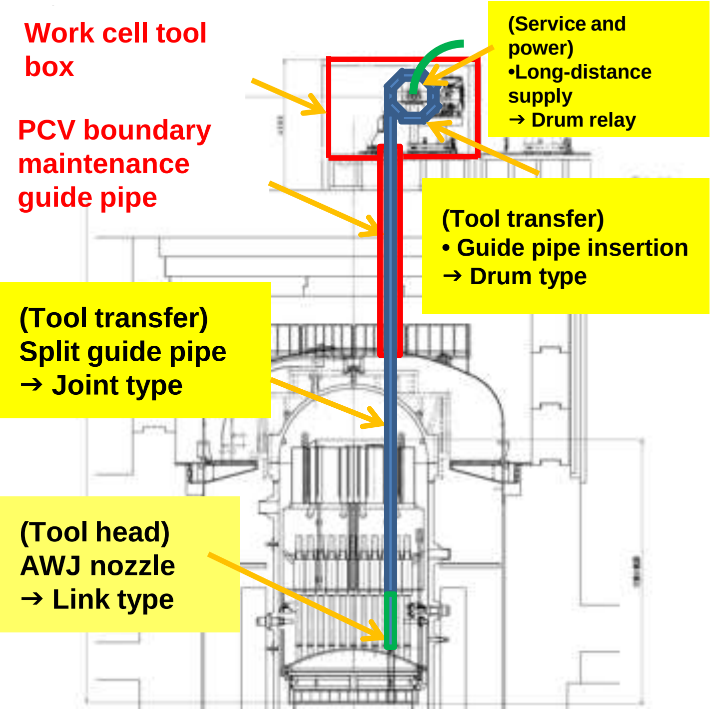
- Studied the dividing-up of the guide pipe and the down-sized insertion mechanism (joint/drum methods).
- Studied correction of the position deviations of the tool head AWJ nozzle (link method).
- Studied a longer supply line of services (high-pressure water and abrasive) (drum relay).
- Produced a prototype equipment and evaluated the remotely-operated cutting performance to verify remote operability by an element test (including simulation of actual layout.

Equipment composition

■Tool head: severe structures and remove fragments from the top to open holes

■Tool transfer system: insert the guide pipe into the lower part of the RPV spare nozzle

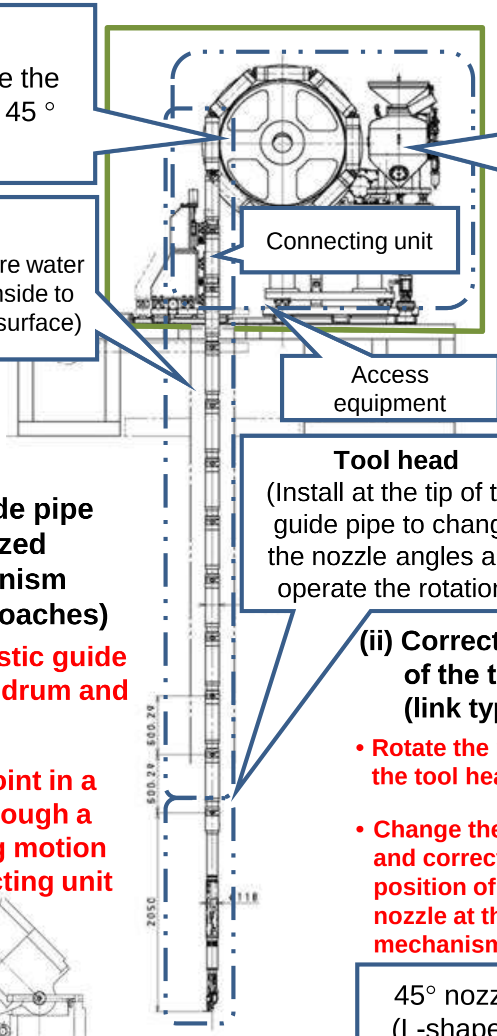
■Remote control/monitoring system, and service/power supply



Concept about the core access

6.1.3 Development of Opening Equipment inside the Reactor

(1) Study on Design of Opening Equipment inside the Reactor



Drum
(Remotely replace the drums for 0° and 45 ° nozzles)

Guide pipe
(Store the high-pressure water and abrasive hoses inside to protect from a cutting surface)

Connecting unit

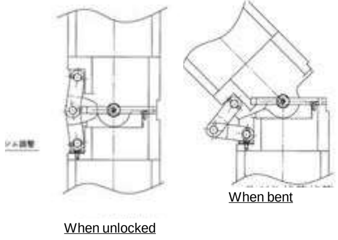
Access equipment

Abrasive tank
(Pressure-Supply abrasive to the tool head via the rotating joint inside the drum)

Tool head
(Install at the tip of the guide pipe to change the nozzle angles and operate the rotation)

(i) Dividing the guide pipe and the down-sized insertion mechanism (joint/drum approaches)

- Use an joint elastic guide to roll up to the drum and store therein
- Lift/Lower the joint in a fixated state through a toggle clamping motion with the connecting unit

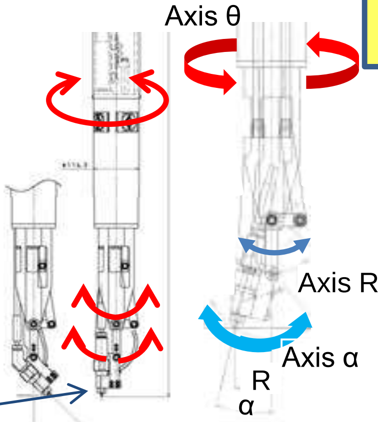


(iii) Make longer the supply line of services (high-pressure water and abrasive)(drum relay)

- Relay long-distance hoses and cables at the rotating joint inside the drum (and store them in the drum)
- Use a regulator inside the tool head to relay the abrasive pressure-fed (0.3 MPa) from the drum

(ii) Correct the position deviations of the tool head's AWJ nozzle (link type)

- Rotate the nozzle at the tool head
- Change the angle and correct the position of the AWJ nozzle at the link mechanism



45° nozzle
(L-shaped)

0° nozzle
(Straight)

Nozzle driving axes

Main equipment specifications
(Access equipment)
- **Drum: height up to 4 m (to be stored in the tool box)**
- **Guide pipe**
  - **- Insertion length at 18 m; speed at 3.5 m/min (provisional)**
  - **- Structure divided into 32 parts (600 mm × 8 sections × 4 volumes at height 4 m)**
  - **- Outside diameter: φ140mm**

(Tool head)
- **AWJ nozzle (0°/45° nozzle)**
  - **- High-pressure water flow rate: 3.7 ℓ/min; pressure: 342 MPa**
  - **- Abrasive garnet sand**
- **Drive mechanism's drive axes: α (angle), R (position), θ (rotation)**
- **Regulator**
  - **- Abrasive capacity: 1 kg**
  - **- Pressure Supply (receiving): 0.3 MPa (standard)**
  - **- Abrasive supply volume: max. 500 g/min**

(Other equipment)
- **High-pressure water pump: flow rate at 3.7 ℓ/min; pressure at 342 MPa**
- **Air pressure: 0.2~0.3 MPa (standard)**

•The guide pipe was down-sized by rolling up with a drum.

•The tool head needs to be down-sized to take account of its relation with the component (tool box) on the operation floor.

[Remaining issue]
Down-size the tool head by dividing it up (at joints into the parts with a length of 600 mm) to store it in the tool box (whose height is 4 m or lower provisionally)

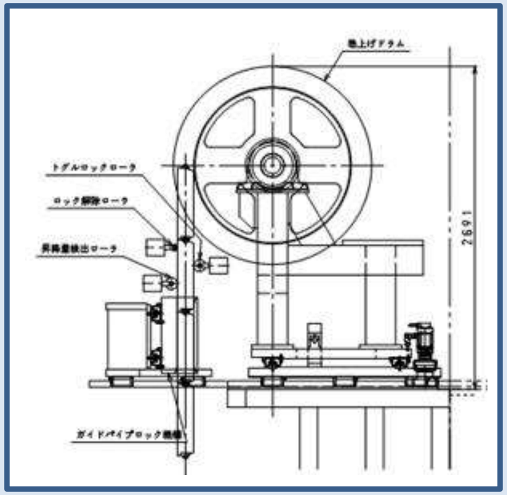
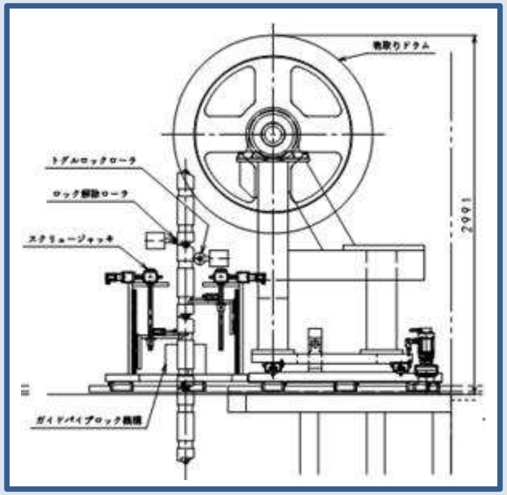
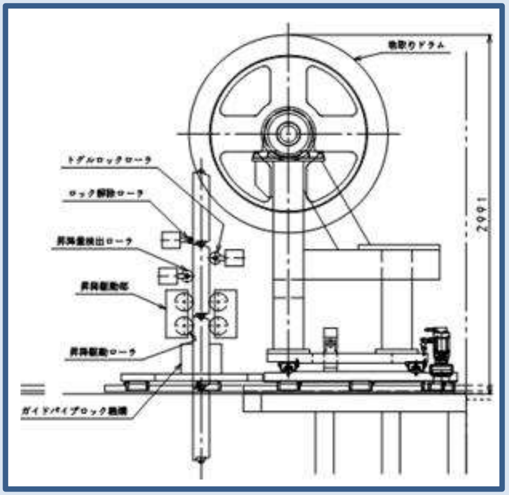
6.1.3 Development of Opening Equipment inside the Reactor

(1) Study on Design of Opening Equipment inside the Reactor

(i) Dividing the guide pipe and the down-sized insertion mechanism : 1) Drum structure

- Elevate/Lower the tool head to the processing position and keep it at the position: insertion length at 18 m; speed at 3.5 m/min
- Divide up the guide pipe at joints and stored due to height limit inside work cell: height of 4m

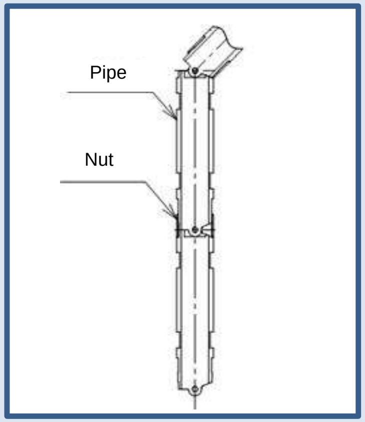
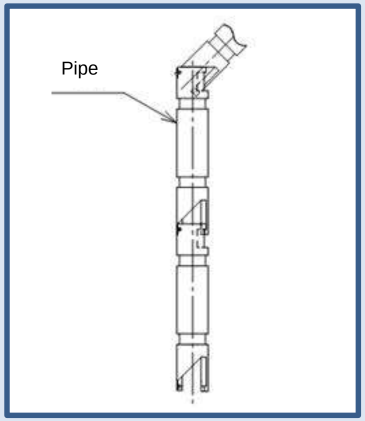
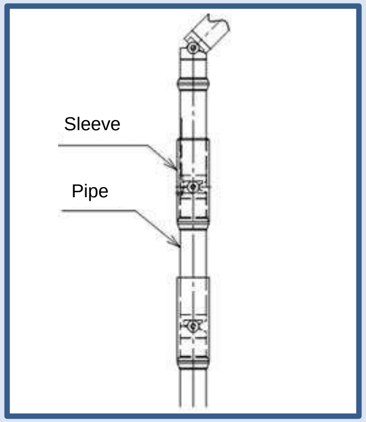
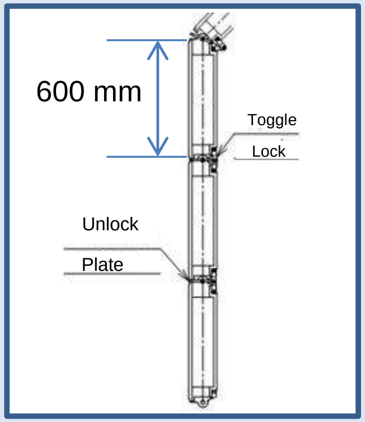
  (Store the extra part of the guide pipe in the drum as the guide pipe is lifted/lowered: 600 mm × 8 sections × 4 volumes=19.2 m)
- Extract and adjust the guide pipe's center core to severe multiple nozzle angles in combination: target deviation within 5 mm

Evaluation item	Drum roll-up	Drum roll-up + jack lifting/lowering	Drum roll up + elevating/lowering roller
Connecting structure	Roll up the guide pipe with drum  	Lift/Lower the guide pipe with jack and store it in drum  	Lift/Lower the guide pipe with roller and store it in drum 
Anchoring performance	× The guide pipe rattles and deviates	○ (Jack) does not loosen	△ (Roller pressing) does not easily loosen
Positioning	× Not anchored (rattles and deviates)	○nchored	△ (Roller pressing) contact surface
Workability	○ Not long time needed	× Long time needed	○ Not long time needed

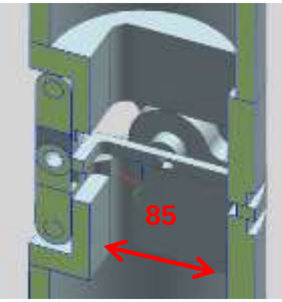
6.1.3 Development of Opening Equipment inside the Reactor

(1) Study on Design of Opening Equipment inside the Reactor

(i) Dividing the guide pipe and the down-sized insertion mechanism : 2) Guide pipe structure

Evaluation item	Nut anchoring	Self-weight retention	Sleeve anchoring	Toggle anchoring
Connecting structure	Stabilize stretch with locknut 	Retain stretch with self-weight 	Stabilize stretch with sleeve 	Stabilize stretch with toggle clamp 
Anchoring performance	○ (Screw) does not easily loosen	× Weak against external force	△ (Taper) loosens	○ (Toggle) does not easily loosen
Positioning	○ No rattling at the screw fastening part	△ Not anchored (Precision required for the processing)	△ Contact surface (Precision required for the processing)	△ Contact surface (Precision required for the processing)
Workability	△ Nut's rotation △ Long time required (for screw)	○ No anchoring work required	△ Sleeve's up/down motion ○ Not long time needed	○ Lock mechanism easy to open/close ○ Not long time needed

- Anchor with toggle clamp
- Twist the joint by about 1.5° by rolling up the guide pipe with drum and aligning it to the skew (twisting) angle
- Tilt the drum by about 2° to insert the guide pipe vertically



Locked

Unlocked

Joint twisting

Drum tilting

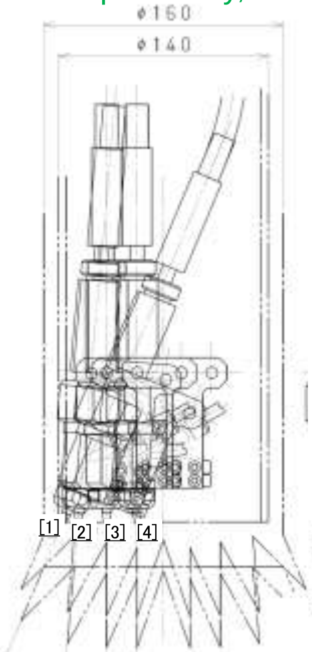
6.1.3 Development of Opening Equipment inside the Reactor

(1) Study on Design of Opening Equipment inside the Reactor

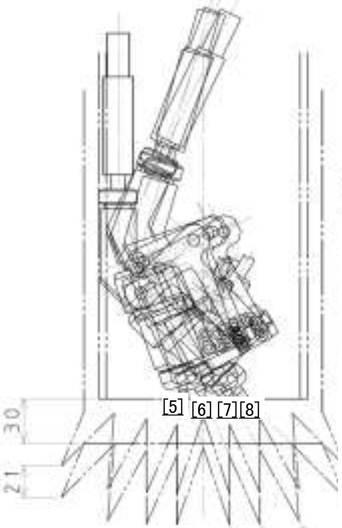
(ii) Correcting the position deviations of the tool head’s AWJ nozzle mechanism: 1) Nozzle structure

- To open holes in reactor internals and thereby allow the guide pipe to pass, the nozzle mechanism must have φ140 mm.
- The nozzle mechanism must be storable inside the guide pipe so narrow reactor internals can be cut with the mechanism, or more specifically, so the cutting work can be conducted by using multiple nozzle angles in combination.

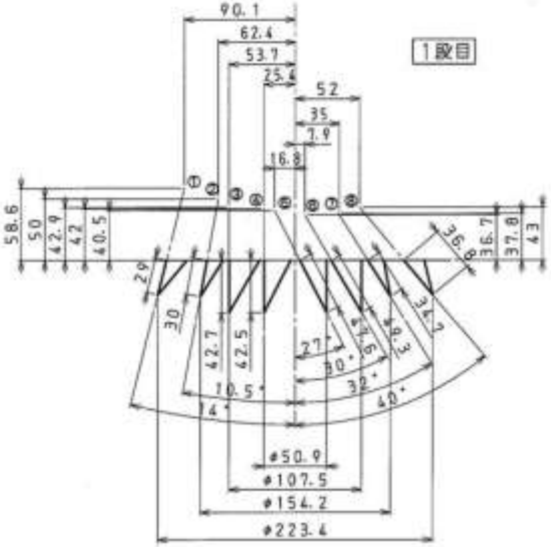
(If the work space allows, both simple-cutting and combination-cuttingapproaches will be employed to prevent the falling of fragments.)



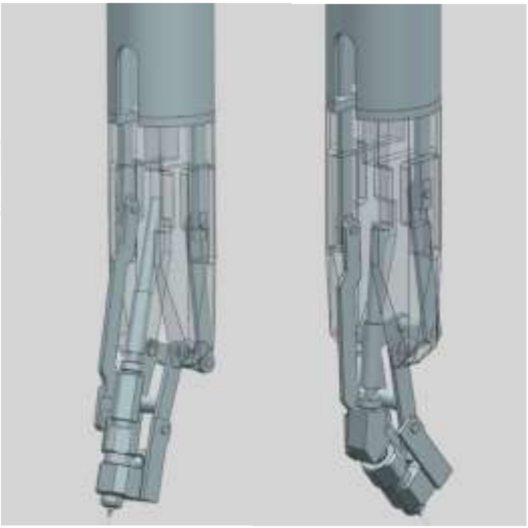
Conditions [1]~[4]:
(0° nozzle head)



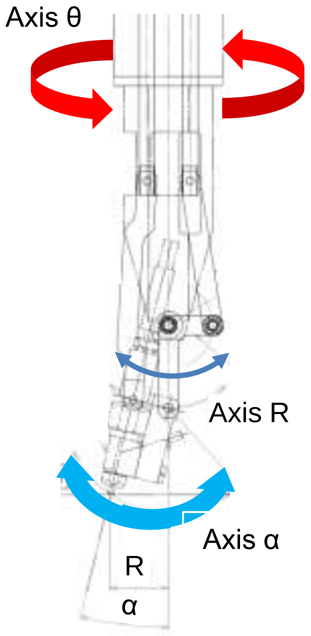
Conditions [5]~[8]:
(45° nozzle head)



Combined-cutting plan



Tool head’s link structure

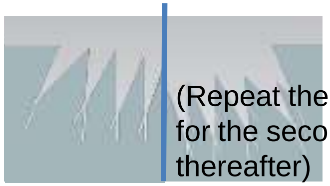


Nozzle driving axes

(i) cutting at angles [1]~[4]

(ii) cutting at angles [5]~[8]

(iii) cutting for the first level complete



(Repeat the same process for the second level and thereafter)

- Change the nozzle angle by driving the α axis
- Correct the nozzle position deviation in the diameter direction by driving the R axis

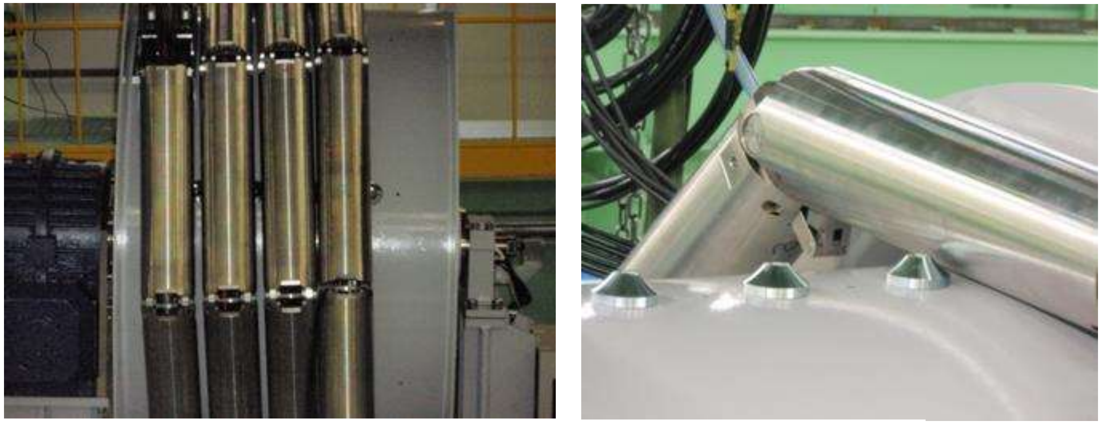
6.1.3 Development of Opening Equipment inside the Reactor

(2) Assembly of the Prototype Inside-Reactor Opening Equipment

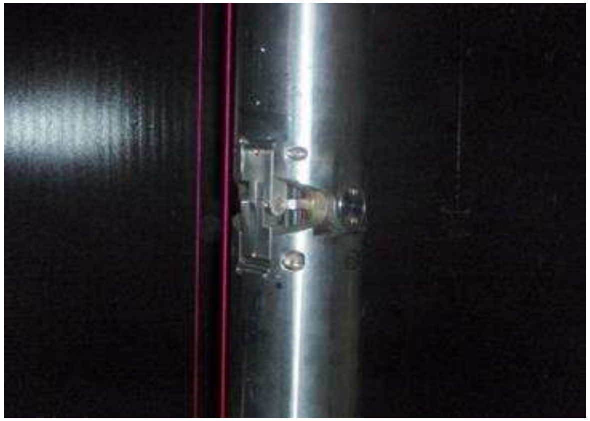
(a) Drum and guide pipe

(b) Drum and abrasive tank

(c) Tool head



(d) Guide pipe’s skew guide

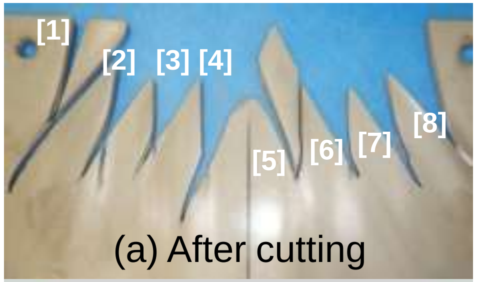


(e) Guide pipe’s toggle lock

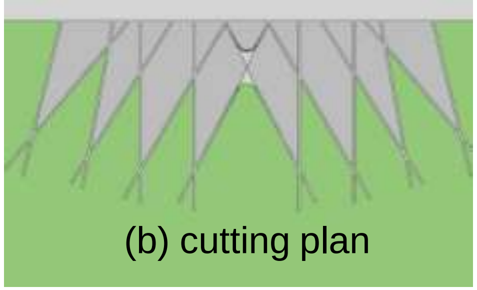
6.1.3 Development of Opening Equipment inside the Reactor

(3) Elemental Test

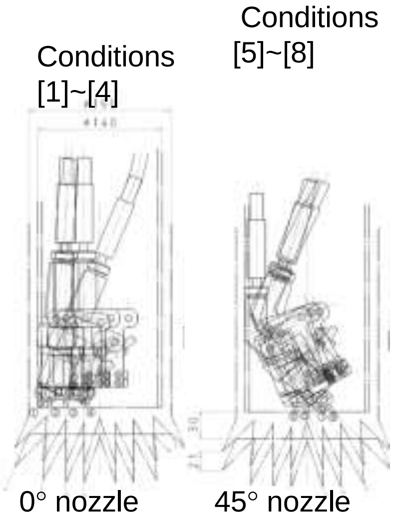
(i) Verification test on the cutting conditions (Combination-cutting of a simulated steam dryer upright plate (6 tons)



(a) After cutting



(b) cutting plan



(c) Combined-cutting

Prototype inside-reactor opening equipment

Platform for the mock specimen
(inside the test tank)

Conditions	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Notes
cutting speed (mm/min)	3	1.8	2	1.8	10	7	5	3	**High-pressure water supply: 3.7 ℓ/min** **Abrasive consumption: 200 g/min**

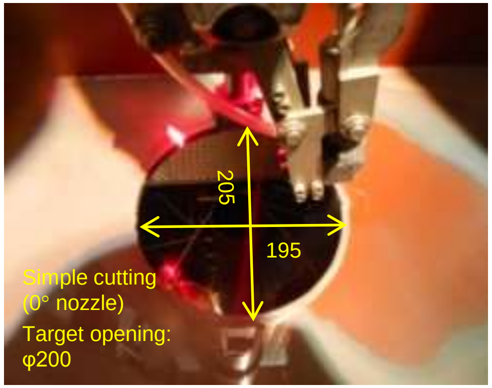
- **The remote operability of the combination-cuttingwith AWJ was confirmed; some parts were left uncut and required re-processing. (The nozzle's horizontal position deviation of 4 mm and vertical position deviation of 1 mm were taken into account; abrasive consumption at 200 g/min.)**
- **It was confirmed whether the tool head position can be corrected. (The precision level will be sought to be improved through the anchoring of the guide pipe joints and by reviewing the adjustment structure.)**

[Remaining issues] Review the AWJ cutting conditions (combination angles, positions, etc.) and improve the equipment toward a higher precision level for remotely-opened diameters and a less chance of re-processing. Stabilize the supply of services (abrasive up to 500 g/m).

6.1.3 Development of Opening Equipment inside the Reactor

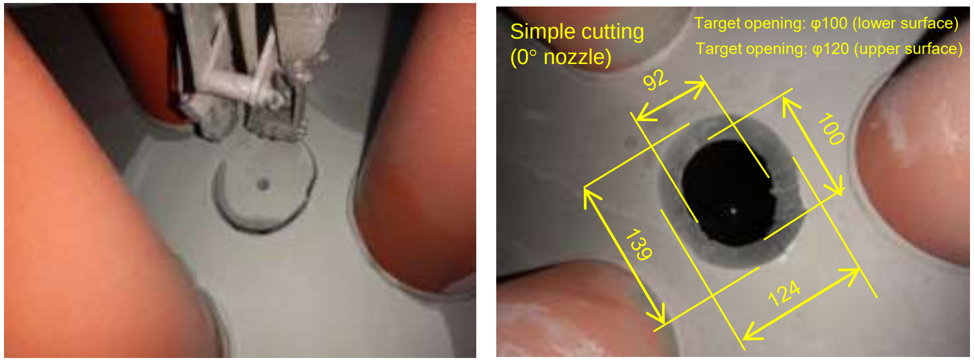
(3) Elemental Test

(ii) Verification test (using a mock specimen) on remote operability



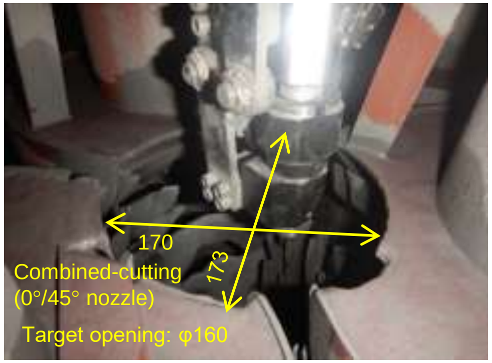
(a) Steam dryer (bottom plate)

(b) Steam separator (connecting rod)

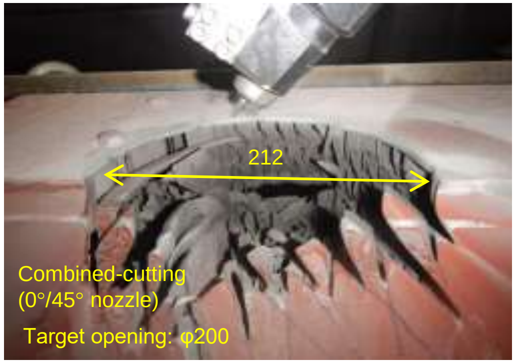


i. cutting surface

ii. When opened



(c) Steam separator (triple cylinder center)



(d) Steam dryer (corrugated plate)

iii. Fragment from processing work (upper surface)

iv. Fragment from processing work (lower surface)

(e) Shroud head

- **It was confirmed whether the cutting can be remotely conducted and a hole was made in a mock Unit layout setting, it was found that the opening diameters varied and required re-processing.**
  ➔ Need to improve the cutting precision, access accuracy and workability (by adjusting the nozzle positions and stabilizing abrasive).
- **It was confirmed that fragments from the processing work of the shroud head can be collected and removed. (Fragments from the cutting work fell on the shroud head or in the stand pipe).**

6.1.3 Development of Opening Equipment inside the Reactor

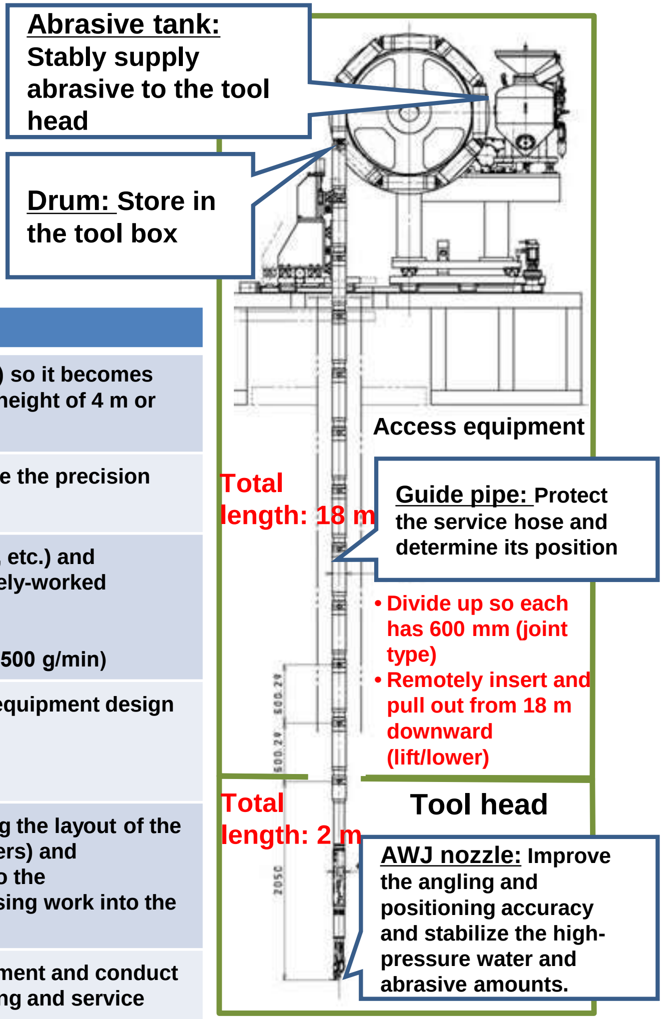
[Remaining issues**]**

- The design of the equipment structures, the making of element prototypes continues to be worked on, and element tests conducted, in order to address the technical issues identified in the studies conducted in FY2017 (see below), and the Unit applicability of those designs was confirmed.
- The concretization and rationalization of the designs of the equipment and systems are sought and the preparation of component specifications, assembly diagrams, systematic charts, etc., are being prepared.

[Issues]

- The tool head needs to be made more compact because of the its relation with the component (tool box) on the operation floor.
- The remotely-conducted AWJ combination-cuttingresulted in some parts being left uncut and requiring re-processing.
- The diameters of the remotely-worked openings varied in the mock Unit layout setting and needed to be re-processed.
  → Improve the cutting precision, access accuracy and workability.
- Some fragments other than those from the processing work of the shroud head fell into the stand pipe; need to compromise the limit concerning the fall of fragments.

Items	Implemented items	Issues/Policy proposals
[Equipment structure design]	**Down-size the tool head**	• **Divide up the tool head (at joints into the length of 600 mm each) so it becomes more compact and can be stored in the tool box (which has the height of 4 m or less provisionally).**
	Reduce the guide pipe's vibration	• **Anchor the joints, review the adjustment structure and concretize the precision improvement to reduce the tool head's position deviations.**
	Improve the cutting precision, access accuracy and workability	• **Review the AWJ cutting conditions (combination angle, position, etc.) and sophisticate the equipment toward higher accuracy of the remotely-worked opening diameters and less chance of re-processing.** • **Stabilize the service supply (abrasive consumption: 200 → max. 500 g/min)**
[Element prototyping and testing]	**Study the methods for preventing interferences inside the reactor and how to determine the opening positions**	• **Rationalize the remote operations and monitoring based on the equipment design (positioning of processing work targets and openings).**
	Study the equipment in light of assumed reactor conditions	• **Formulate the processing work and investigation flows (including the layout of the processing work targets, opening positions and opening diameters) and rationalize the investigation method and equipment to respond to the compromised limit concerning the fall of fragments from processing work into the reactor.**
	Confirm the workability of the equipment and systems at the Unit(s).	• **Make a prototype combining the tool head and the access equipment and conduct a partial mockup test to confirm the remote operations, monitoring and service management.**



Abrasive tank: Stably supply abrasive to the tool head

Drum: Store in the tool box

Access equipment

Total length: 18 m

Guide pipe: Protect the service hose and determine its position

- Divide up so each has 600 mm (joint type)
- Remotely insert and pull out from 18 m downward (lift/lower)

Tool head

Total length: 2 m

AWJ nozzle: Improve the angling and positioning accuracy and stabilize the high-pressure water and abrasive amounts.

6.2 Development of Equipment to Access the Reactor Core from the Side

○ Outline of schedule

#	Items	Achievements up to FY2015	FY2016	FY2017
2.4	Development of the equipment to access from the side	-	Study the applicability	Evaluate the applicability Determine the method feasibility Conceptual design Design equipment

○ Implementation items

(Second half of FY2016)

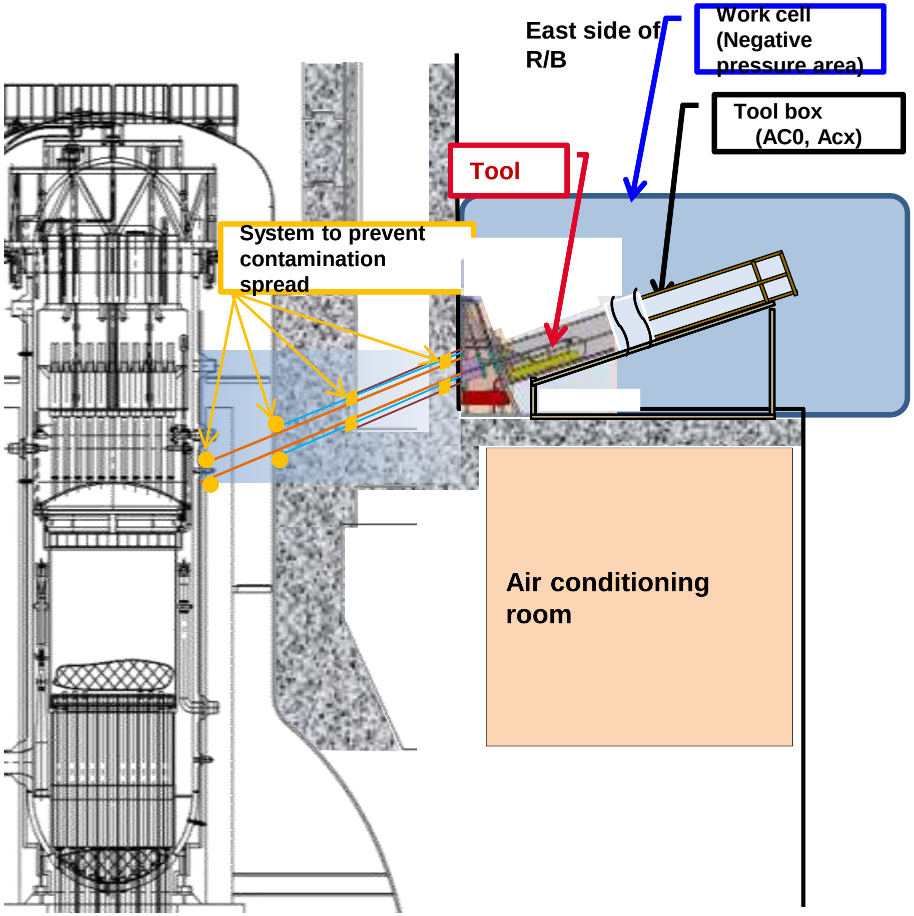
- ➢It was decided to additionally seek a method to access from the side (the side-opening investigation method) and the development plan was drawn-up and a study launched.

(First half of FY2017)

- ➢The applicability of the method was evaluated in early FY2017.
- ➢The applicability to the Units was examined and it was concluded that the priority should go to Unit 2.
- ➢Working on the conceptual design was started and the concept of the investigation method concretized with particular focus on securing the boundaries.
- ➢An exposure assessment was conducted concerning the construction work for the investigation, it was confirmed that the investigation is applicable under the current PCV condition (nitrogen substitution) even when an exposure increase occurs due to the dispersion of radioactive dust.

(Second half of FY2017)

- ➢Specifications of equipment was summarized based on the conceptual design.

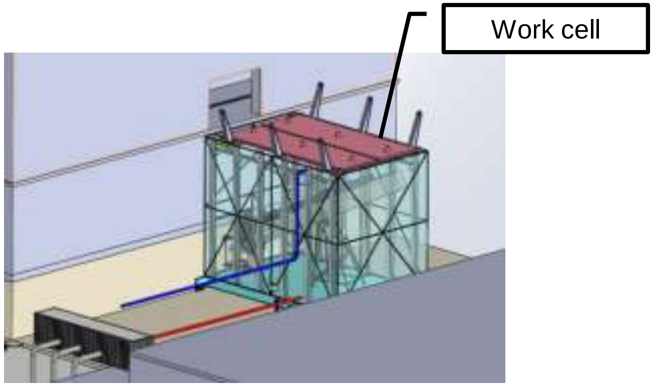


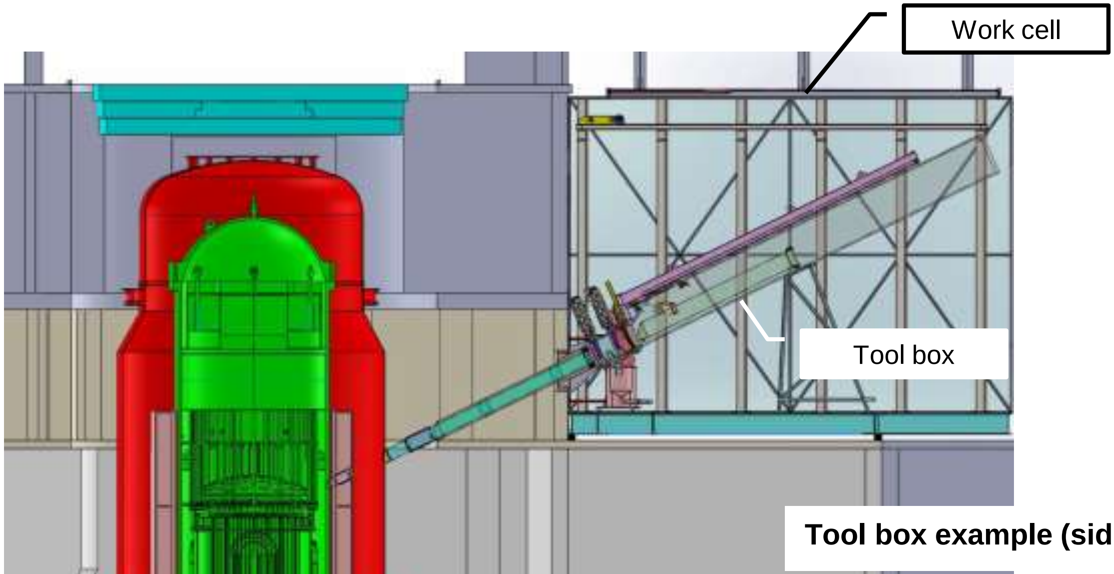
6.2 Development of the Equipment to Access the Reactor Core from the Side

(1) Results of the Study on the Equipment Concepts

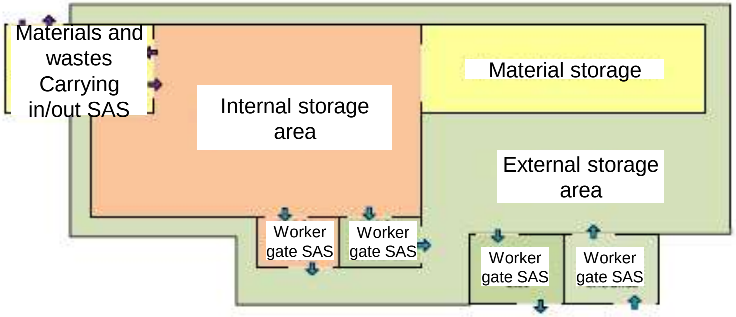
- A tool box (Acx) stored necessary tools (for drilling, inserting guide-tube and installing seal) is fixed in the tool box space on the east side wall of the reactor building (R/B). The tool box is connected one to another for the side-opening investigation.
- A work cell is installed (in a negative pressure environment) to cover the tool box. The layout should be considered for dust leakage from the tool box.
- Pre-preparation and post-treatment for the tool box is conducted at the "maintenance unit" installed on the ground level.

The work cell has an openable ceiling, which will be opened/closed for the replacement of tool boxes.





Maintenance unit (floor plan)

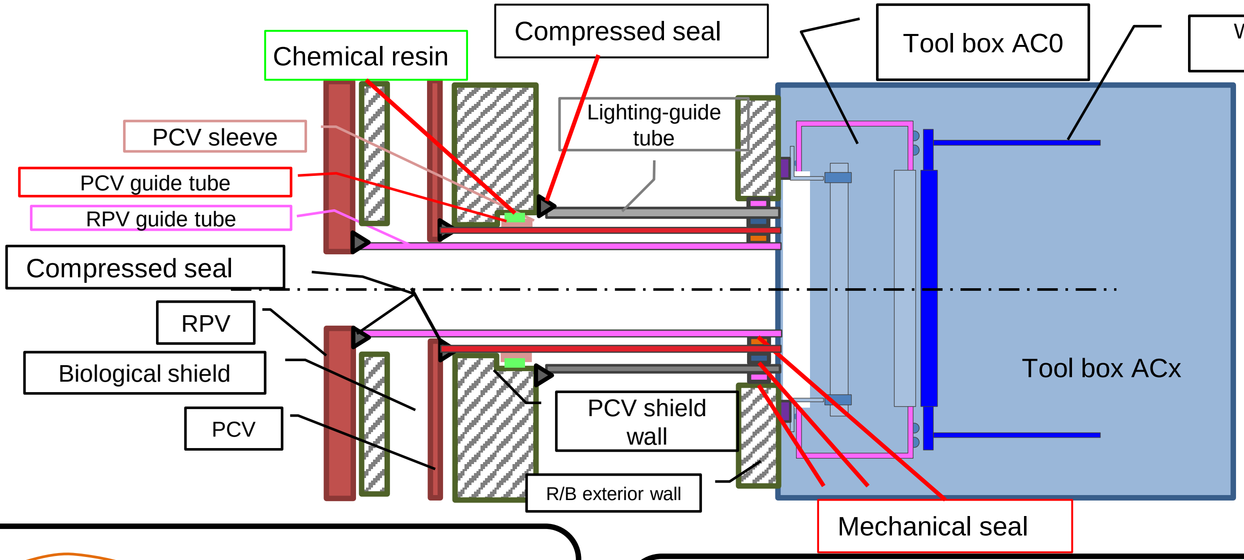


Tool box example (side view)

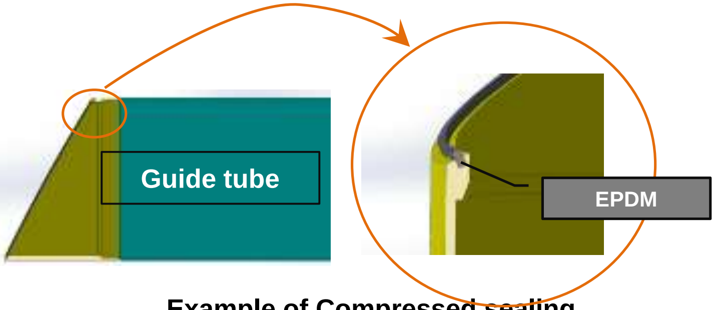
6.2 Development of the Equipment to Access the Reactor Core from the Side

(2) Boundary Formation

- Use mechanical seals and compressed seals in combination to make a boundary.
- Install a work cell (with a negative pressure environment) in such a way as to wrap the tool box (AC0 and/or ACx) as a preventive measure.

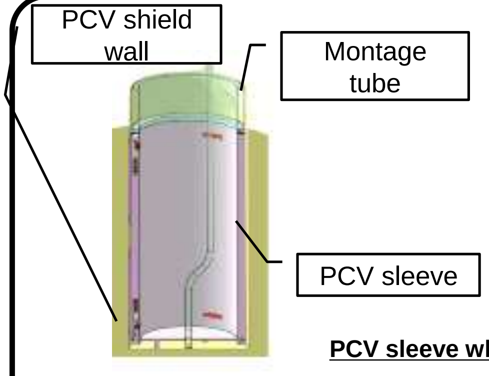


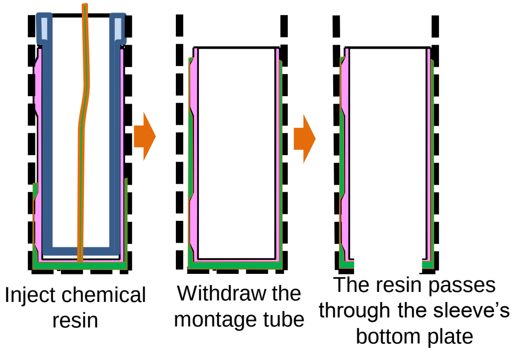
Example of Mechanical sealing



Example of Compressed sealing

Issue: sealing performance with the surface of cylinder structures
↓
Needs to conduct an element test to confirm the sealing performance.





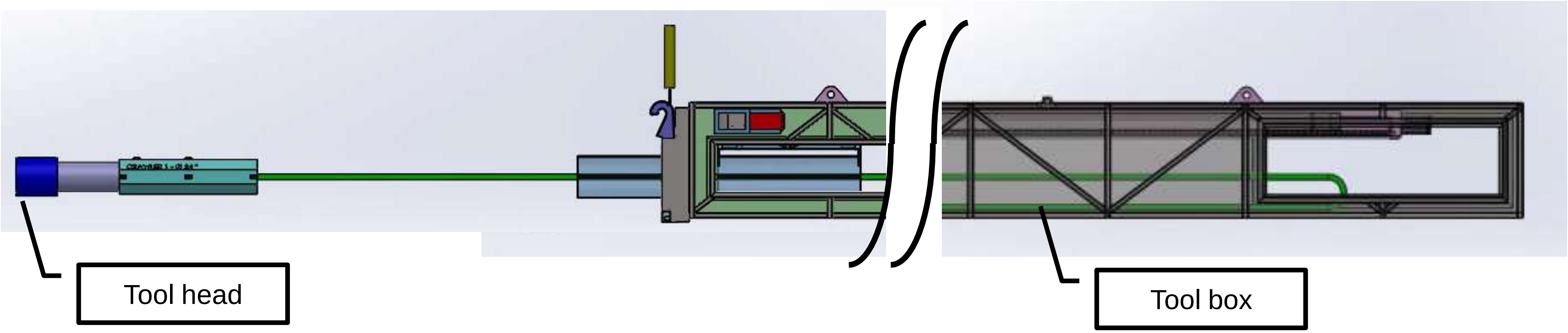
PCV sleeve when installed

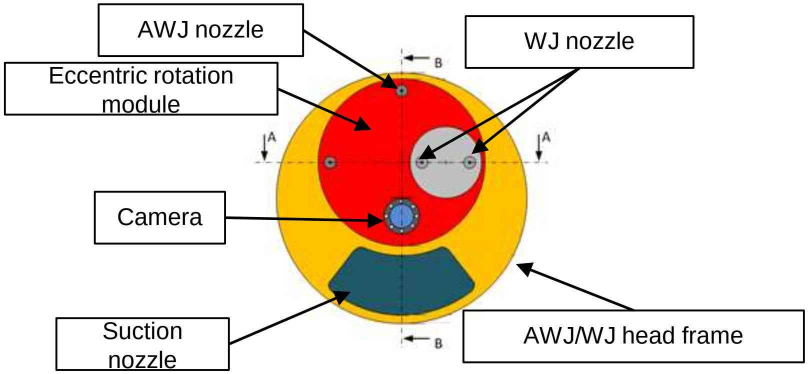
Issue: joint strength at the cutting surface of chemical resin concrete.
↓
Needs to conduct an element test to confirm the joint strength.

6.2 Development of the Equipment to Access the Reactor Core from the Side

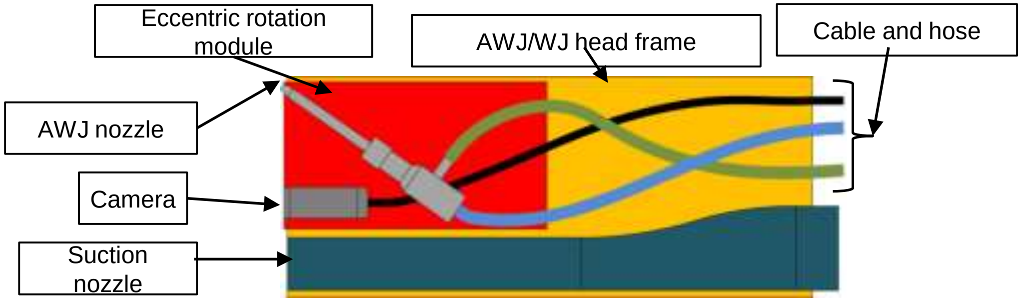
(3) Drilling of investigation Holes

- Use a hybrid head with a water jet (WJ; used to drill concrete) and abrasive water jet (AWJ; used to drill rebars and steel plates) to open the holes.





Tool head (plan view)



Tool head (side view)

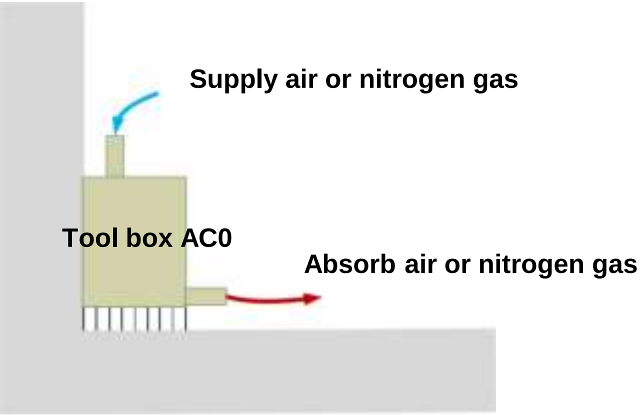
Issue: whether capable of cutting the reinforced concrete used for the reactors in Fukushima?
↓
Needs to conduct an element test to confirm the cutting capability (against a coarse surface).

Issue: how to collect and drain treated water (and fragments from cutting work)
↓
Needs to conduct an element test to confirm the waste treatment performance (and the collection and separation of fragments from cutting work).

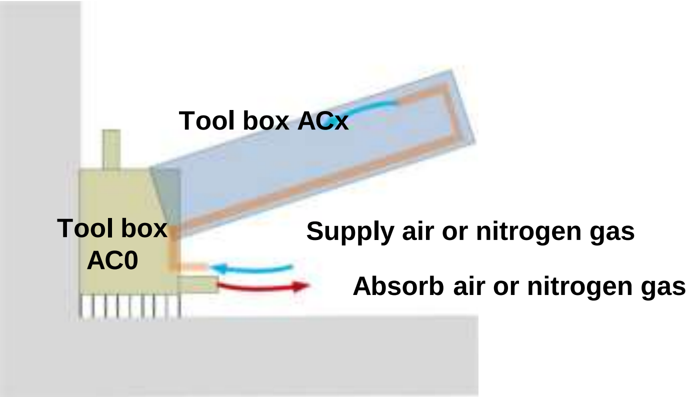
6.2 Development of the Equipment to Access the Reactor Core from the Side

(4) Concepts of the Boundary Maintenance(Preventing Dust Diffusion)

- Prevent contaminated dust from diffusing after the PCV opening by Supplying air or nitrogen gas into the tool box (AC0 or ACx) and thereby keeping the pressure inside the tool box (AC0 or ACx) higher than the pressure inside the PCV.



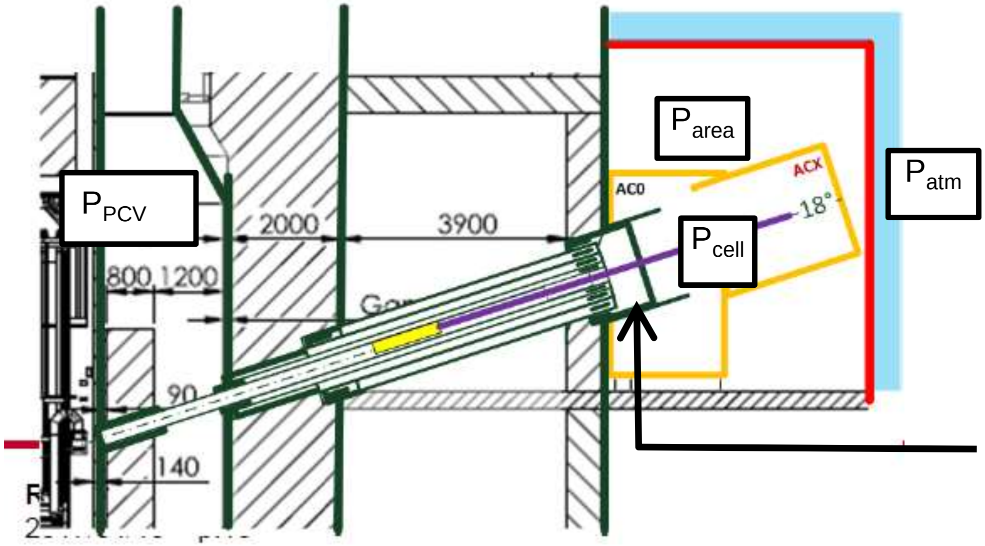
When the **AC0 tool box** is alone.



When the **AC0 tool box** is connected **Acx.**

- ➢ Establish a negative pressure area outside the tool box (AC0 and/or ACx) which has a slightly-positive pressure, as a measure against contamination spread.

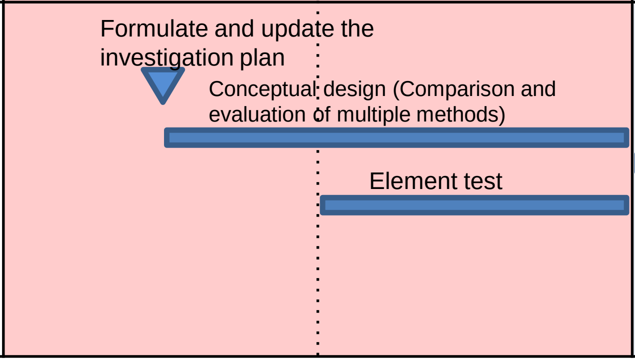
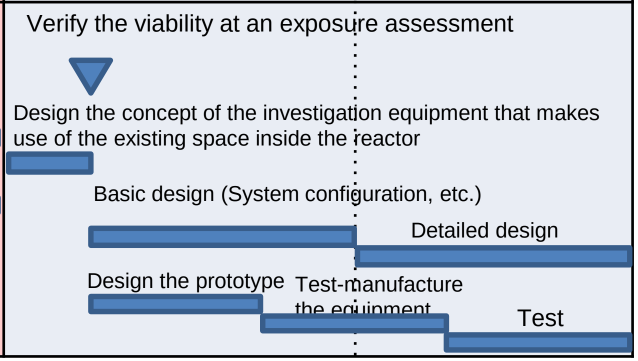
$P_{PCV} < P_{cell} > P_{area} < P_{atm}$



Slightly-positive pressure by Supplying nitrogen gas or air

6.3 Development/Selection of the Investigation Method for the Reactor Core

○ Outline of schedule

	Items	Achievements up to FY2015	FY2016	FY2017
6.3	Development/Selection of the method to investigate the part to the reactor core	-	 Formulate and update the investigation plan Conceptual design (Comparison and evaluation of multiple methods) Element test	 Verify the viability at an exposure assessment Design the concept of the investigation equipment that makes use of the existing space inside the reactor Basic design (System configuration, etc.) Detailed design Design the prototype Test-manufacture the equipment Test

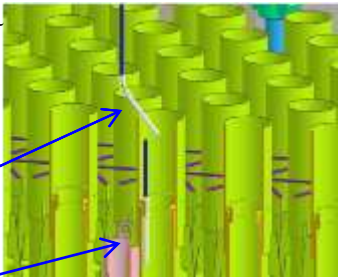
○ Items implemented in FY2016

- The concepts of the investigation equipment and the access equipment were designed. Based on the results of an element test, it was decided to use either an imaging tube or CID camera as part of the investigation equipment.

○ Items implemented in FY2017

<Equipment design>

- Based on the summary composition of the investigation equipment studied in FY2016, it was decided to employ the following investigation equipment.
  - A: Equipment for Prior Confirmation that will be injected through small-diameter openings
  - B: Equipment for the Full-Scale Investigation that will be injected through large-diameter openings
  - C: Equipment that moves horizontally inside the shroud head toward the center of the RPV to investigate the deepest part of the RPV
- A study on whether/how to bundle investigation instru
  dosimeter and thermometer was also conducted.
  A study on the cable composition was also conducted.



Passage inside the steam separator

<Test-manufacturing and testing the equipment>

•The following at an element test was conducted:

✓ Verification test on the access-ability of the investigation equipment

⇒ The test was conducted using test mock-ups and each equipment's remote operability was confirmed.

✓ Verification test on the visibility of fiber scopes and industrial-use endoscopes

⇒ It was confirmed that the equipment A met the visibility required for Prior Confirmation.

✓ Test on the viability of the prototype of the horizontal-motion mechanism

⇒ The viability was confirmed in the assumed real-life environment.

✓ Test on the radiation resistance of the thermometer

⇒ It was confirmed that it can be used in the assumed real-life environment.

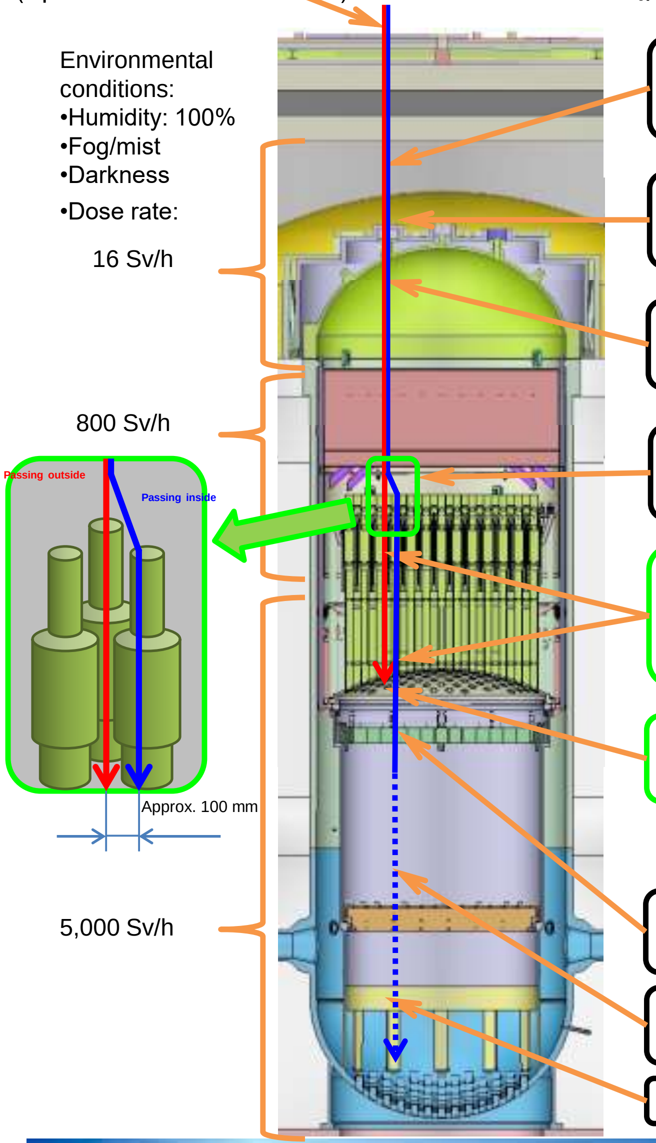
○ Remaining issues

- Improve the operability and visibility (image processing) of the investigation equipment
- Conduct another element test and a study to address the issues identified in the element test
- Estimate the inside-reactor conditions from the findings of the investigation at the Units and use the estimate for the development of the fuel debris retrieval equipment
- Reflect the progress of the inside-reactor investigation equipment design in the design of the access equipment for the side-opening investigation

6.3 Development/Selection of the Investigation Method for the Reactor Core

(1) Investigation Equipment A for Prior Confirmation: Investigation Specifications and Requirement Specification of Equipment

Required specifications for investigation equipment A



Investigation route
(Spare nozzle's central axis)

Environmental conditions:
- Humidity: 100%
- Fog/mist
- Darkness
- Dose rate:

16 Sv/h

800 Sv/h

5,000 Sv/h

Investigation flow & location	Limit of size
Preliminary investigation inside the well cover	Diameter of the well-cover opening: **φ40 mm**
Preliminary investigation inside the PCV head	Diameter of the PCV head opening: **φ40 mm**
Preliminary investigation inside the RPV head	Diameter of the spare nozzle opening: **φ40 mm**
Preliminary investigation of the steam separator	Diameter of the steam dryer bottom plate opening: **φ40 mm**
Preliminary investigation of the **outside** of the steam separator and the upper part of the shroud head	Min. gap outside steam separator: 67 mm; gap between supporting rods: 37 mm
Preliminary investigation of the **inside** of the steam separator	Vanes inside the steam separator: **screw-shaped with a gap of approx. 79~21 mm between them**

After passing through the steam separator

- Preliminary investigation of the reactor core (Upper grid plate)
- Preliminary investigation of the reactor core (Core support plate)
- Investigation of the bottom part of the RPV

Investigation Equipment (AS)
External diameter: φ30 mm or less
Dose: up to 5,000 Sv/h
investigation items:
- Visual information: foreign objects of φ50 mm or larger
- Dose: precision level necessary for orders to be processed
- Temperature: accuracy of ±2^{o}C

investigation route: on the central axis of the spare nozzle(for the part down to the upper part of the shroud head)
Max. descent distance: 16.2 m
Other: protection against water drops, fall prevention, and securing of collection capability at the time of failure

Investigation equipment (AB)
External diameter: φ20 mm or less; Length: 100 mm or less
Dose: up to 5,000 Sv/h
investigation items:
- Visual information(*1): foreign objects of φ50 mm or larger

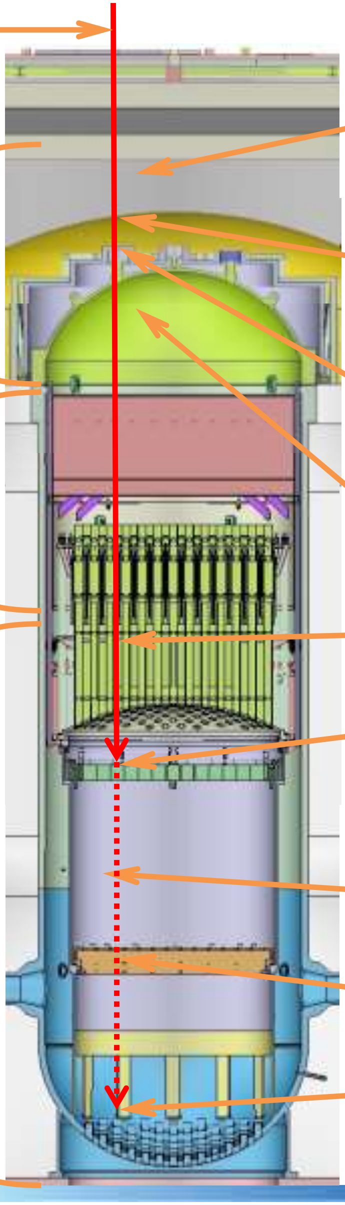
investigation route: From the spare nozzle's central axis (up to the steam dryer) to the inside of the steam separator (down to the bottom part of the RPV)(*2)
Max. descent distance: 26.9 m
Other: protection against water drops, fall prevention, and securing of collection capability at the time of failure

(*1) Priority is given to the easiness-to-pass of the steam separator vanes through narrow areas for the purpose of obtaining information about the reactor core before processing the shroud head. Neither thermometer nor dosimeter is installed on the equipment AB because the data can be collected with the investigation equipment AS or can be measured, after the processing work, with the investigation equipment B.

(*2) Through a remote operation, curvature of the off-set amount (approx. 100 mm) is given to the investigation equipment so it can enter the steam separator through the hole that will be opened at the steam dryer bottom plate.

6.3 Development/Selection of the Investigation Method for the Reactor Core

(2) Investigation Equipment B (for the Full-Scale Investigation): Investigation Specifications and Requirement Specification of Equipment



investigation route (Spare nozzle's central axis)

Environmental conditions:
- Humidity: 100%
- Fog/mist
- Darkness
- Dose rate: 16 Sv/h

800 Sv/h

5,000 Sv/h

Investigation flow & location

- Investigation of the inside of the well cover
- Investigation of the inside of the PCV head
- Preliminary investigation inside the RPV heat-retention material
- Investigation inside the RPV head
Diameter of the steam separator opening: φ140 mm
- Steam separator (After processing)
- Upper grid plate
- After passing the upper grid plate
- Investigation inside the reactor core
- Core support plate
- Investigation of the bottom part of the RPV (Straight descending route)

Limit of size

- Diameter of the well cover opening: φ700 mm
- Diameter of PCV head opening: φ500 mm
- Diameter of the RPV heat-retention material opening: φ680 mm
- Diameter of the RPV opening: φ300 mm (Remove the spare nozzle)
- Diameter of the steam separator opening: φ140 mm
- Diameter of the shroud head opening: **φ110 mm**

Required specifications for investigation Equipment B

Investigation Equipment B

External diameter: φ100 mm or less

Dose: up to 5,000 Sv/h

investigation items:
- Visual information: fuel rod of φ10 mm
- Dose: precision level necessary for orders to be processed
- Temperature: accuracy of ±2°C

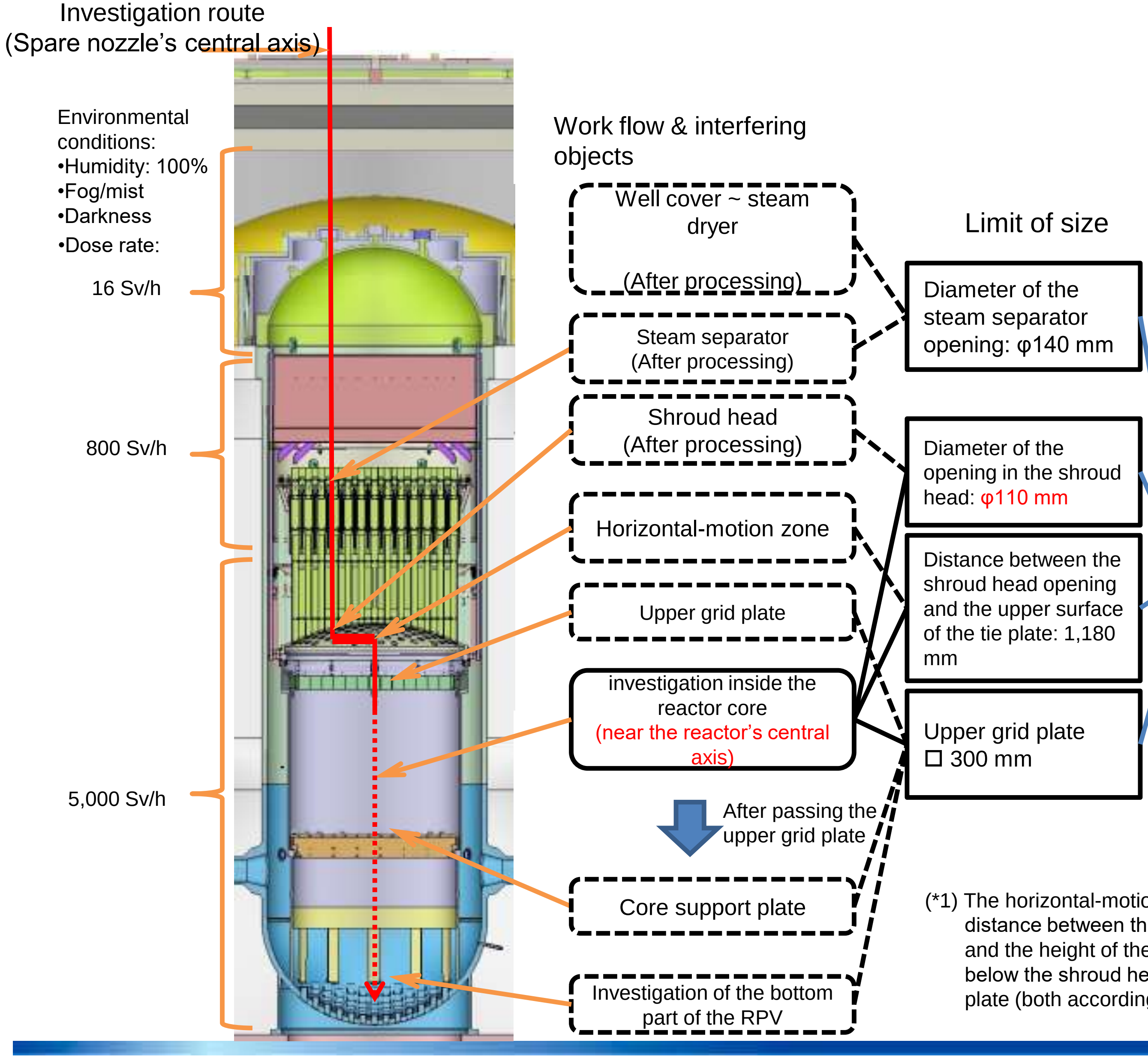
investigation route: On the spare nozzle's central axis (the part down to the bottom part of the RPV)

Max. descent distance: 26.9 m

Other: protection against water drops, fall prevention, and securing of collection capability at the time of failure

6.3 Development/Selection of the Investigation Method for the Reactor Core

(3) Investigation Equipment C (Which Moves Horizontally): Investigation Specifications and Requirement Specification of Equipment



Investigation route
(Spare nozzle's central axis)

Environmental conditions:
- Humidity: 100%
- Fog/mist
- Darkness
- Dose rate:

16 Sv/h

800 Sv/h

5,000 Sv/h

Work flow & interfering objects

- Well cover ~ steam dryer (After processing)
- Steam separator (After processing)
- Shroud head (After processing)
- Horizontal-motion zone
- Upper grid plate
- investigation inside the reactor core (near the reactor's central axis)

After passing the upper grid plate

- Core support plate
- Investigation of the bottom part of the RPV

Limit of size

- Diameter of the steam separator opening: φ140 mm
- Diameter of the opening in the shroud head: φ110 mm
- Distance between the shroud head opening and the upper surface of the tie plate: 1,180 mm
- Upper grid plate ☐ 300 mm

Required specifications for investigation Equipment C

Investigation Equipment C
External diameter: φ100 mm or less
Dose: up to 5,000 Sv/h
investigation items:
- Visual information: fuel rod of φ10 mm
- Dose: precision level necessary for orders to be processed
- Temperature: accuracy of ±2°C

investigation route:
on the spare nozzle's central axis (to the shroud head) and on the reactor's central axis (from the upper grid plate to the bottom part of the RPV) (*1)
Max. descent distance: 26.9 m
Protection against water drops, fall prevention, and securing of collection capability at the time of failure

(*1) The horizontal-motion amount below the shroud: approx. 1,220 mm, which is the distance between the spare nozzle's central axis and the reactor's central axis; and the height of the space available for offset adjustment: the distance between below the shroud head opening and the upper end of the fuel assembly's fuel plate (both according to our study conducted in FY2016).

6.3 Development/Selection of the Investigation Method for the Reactor Core

(4) Study Results

Type	Access equipment	Investigation Equipment (for visual information collection)		Overview	Diameter of the equipment
A	Suspension lowering + X-Y position adjustment mechanism (+ middle inflection mechanism)	Low dose area (~ 10^2 Gy)	Industrial-use endoscope	**Equipment injected through small-diameter openings for Prior Confirmation.** They are equipped with a dosimeter and thermometer. The one used for the investigation of the inside of the steam separator will also be equipped with a middle inflection mechanism so that it can access narrow areas.	φ30 mm or φ20 mm
	Suspension lowering + X-Y position adjustment mechanism (+ middle inflection mechanism)	High radiation area (10^3 Gy ~)	Fiber scope + movable tip mechanism		
B	Suspension + X-Y position adjustment mechanism	Low dose area (~ 10^2 Gy)	Camera (CCD) + pan tilt mechanism	**Equipment injected through large-diameter openings for Full-Scale Investigation. They are equipped with a dosimeter and thermometer. The straight-descending one will have a camera with a pan tilt or powered mirror so that it will fully cover the investigation area.**	φ100 mm
		High radiation area (10^3 Gy ~)	Camera (CID and imaging tube) + pan tilt mechanism		
C	Connecting drum + horizontal-motion mechanism	High radiation area (10^3 Gy ~)	Camera (CID and imaging tube) + pan tilt mechanism	**Equipment injected through large-diameter openings for the Full-Scale Investigation. They will be equipped with a dosimeter and thermometer and have a horizontal-motion mechanism for an access to the center of the reactor.**	φ100 mm

Investigation equipment

Fiber scope

Industrial-use endoscope (for the investigation of the inside the PCV)

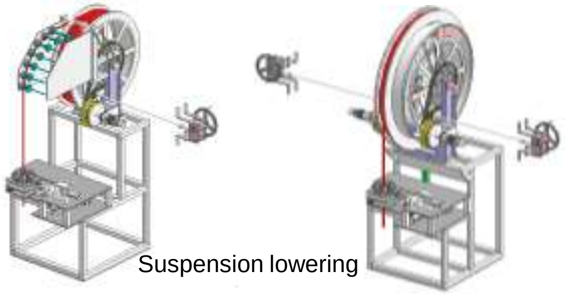
CCD (for the investigation of the inside of the PCV A2′)

CID (in colors)

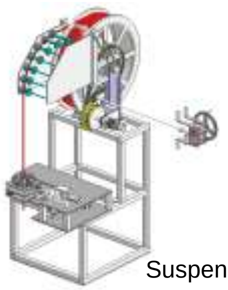
Imaging tube (in black and white)

Imaging tube (in black and white)

Access equipment

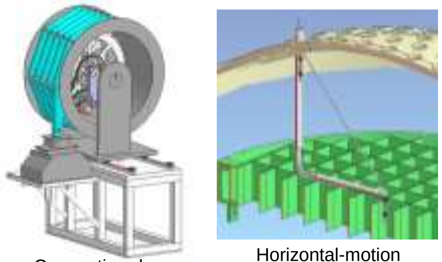


Access method employed for the investigation equipment A



Suspension lowering

Access method employed for the investigation equipment B



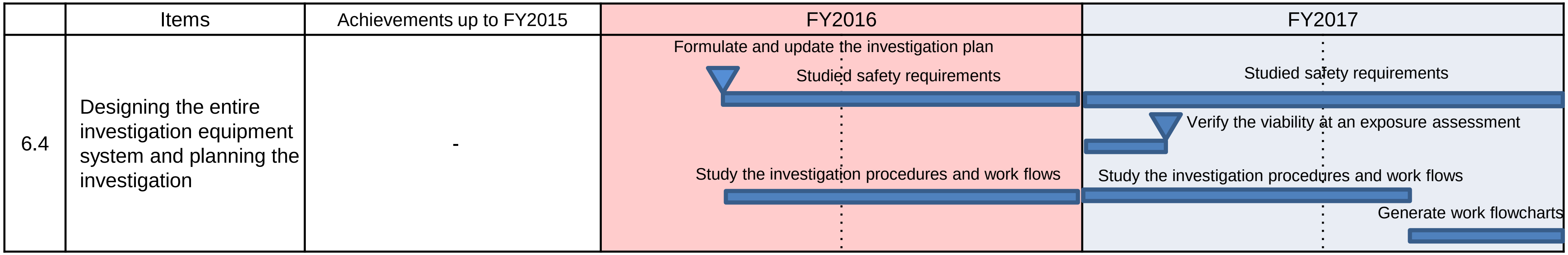
Connecting drum

Horizontal-motion mechanism

Access method employed for the investigation equipment C

6.4 Designing the Entire Investigation Equipment System and Planning the investigation

○ Outline of schedule



	Items	Achievements up to FY2015	FY2016	FY2017
6.4	Designing the entire investigation equipment system and planning the investigation	-	Formulate and update the investigation plan Studied safety requirements Study the investigation procedures and work flows	Studied safety requirements Verify the viability at an exposure assessment Study the investigation procedures and work flows Generate work flowcharts

○ Items implemented in FY2016

- •In order to develop safe and secure investigation methods and access routes despite having no information about the state of the reactor well inside, structures, reactor core or dose rates, the access operation flow was broken down and a study conducted on the implementation plan.

○ Items implemented in FY2017

- •A study on the investigation procedures and work flows was conducted.
- •Safety requirements were organized, which would need to be discussed with the regulatory authority.
- •The specifications required for each equipment were put together and investigation flowcharts and layout drawings were generated.

○ Remaining issues

- •Rationalize the work and investigation flows; assess the impact of fragments from the processing work of structures; and conduct an exposure assessment.
- •Estimate the conditions inside the reactor and environmental conditions from other project findings.
- •Organize the relations between safety and function requirements and reflect the findings in the designs of the equipment.
- •Clarify when to introduce the supplementary systems necessary to conduct investigation (e.g., gas control, nitrogen supply, negative pressure control, dust monitoring, criticality control system) and what specifications those systems should have, and conduct a study on the applicability of those systems (and the systems that are being studied in other projects).
- •Conduct a study on the operation guidelines for the real-time dust monitoring system.
- •Establish a utility supply system for each tool.

<Required Safety Requirements>

Safety requirements	Assumed events
Prevent radioactive materials from leaking to the gas phase	Migration of radioactive materials to the gas phase during an operation
Prevent radioactive materials from leaking to the liquid phase	Migration of radioactive materials to the liquid phase during an operation
Maintain the fuel debris cooling function	Loss of the fuel debris cooling function
Control criticality and maintain sub-criticality.	Occurrence of criticality resulting from a change in a fuel debris shape due to the fall of a fragment from processing work
Prevent fire or explosion	Hydrogen explosion during a processing work
Prevent the fall of a heavy weight object	Dispersion and diffusion of radioactive materials resulting from the fall of a heavy weight object
Prevent the collapse of the R/B during the construction work for the investigation	Collapse of the R/B due to the installation of equipment

6.4 Design of Whole Investigation Equipment System and Plan of the Investigation Method

(1) Study on the Processing and (Top-Opening) Investigation Flows

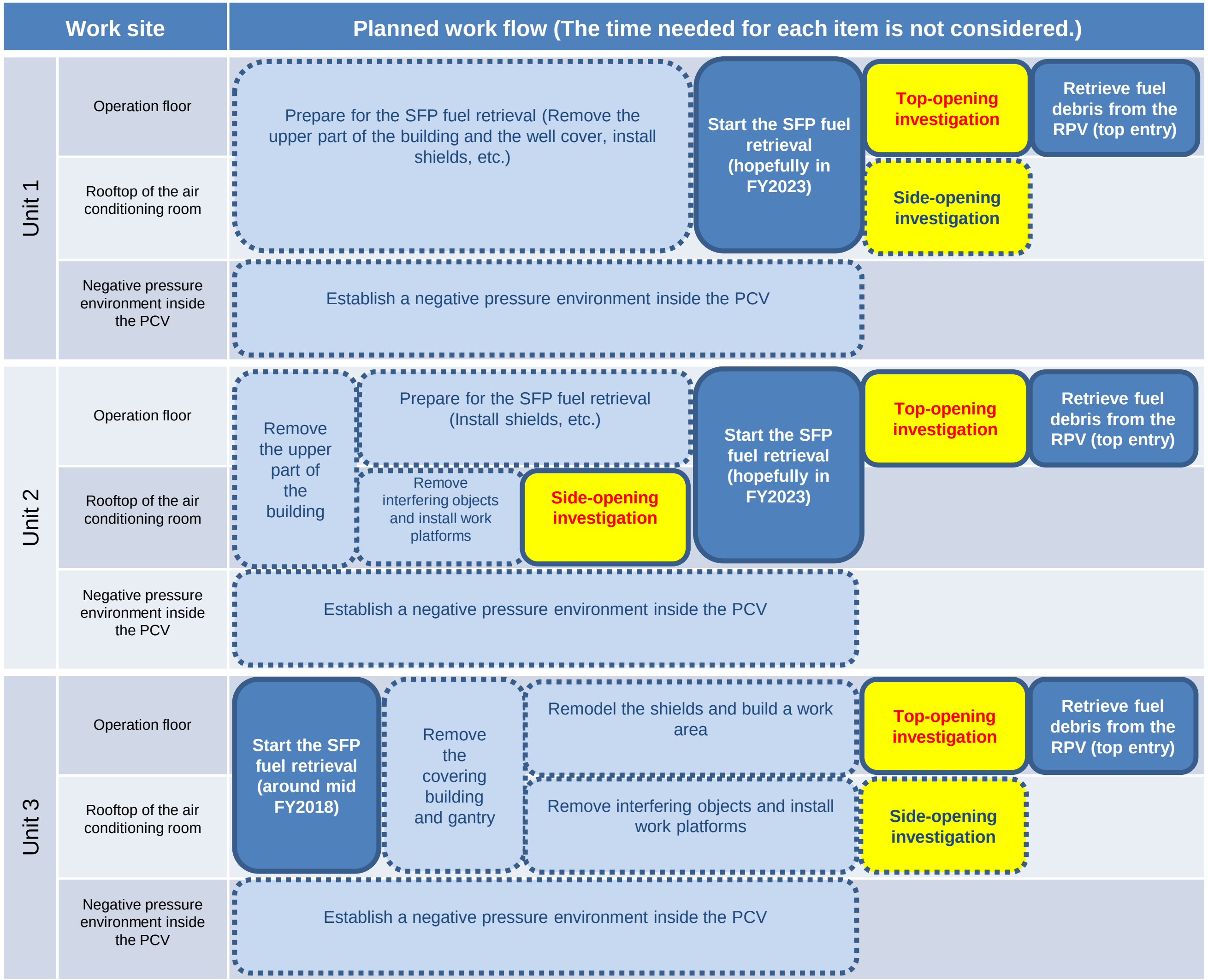
The processing and investigation flow steps are as below. Prior to the opening of large-diameter holes, small-diameter holes are planned to be opened for preliminary confirmation to determine the next step for investigation.

No.	Flow steps	Processing work/Applicable investigation equipment	Notes
1	Process the well cover	Make small-diameter holes (φ40 mm)	Use a core boring for the processing work. Fragments from the processing work will fall.
2	Preliminarily investigate the inside of the well cover	Investigation Equipment A	Prior-confirm the PCV head; confirm only its immediate underneath. Determine whether it’s possible to install and process the guide pipe.
3	Process the well cover	Make large-diameter holes (φ700 mm)	Use a core boring for the processing work. Fragments from the processing work are collectable.
4	Investigate the inside of the well cover	Investigation Equipment B	Investigate the inside of the reactor well. Confirm the conditions of the structures.
5	Process the PCV head	Make small-diameter holes (φ40 mm)	Open by machining as a measure against hydrogen explosion. Fragments from the work will fall.
6	Preliminarily investigate the inside of the PCV head	Investigation Equipment A	Confirm the upper part of the RPV heat-retention material; confirm only its immediate underneath. Determine whether it’s possible to conduct the processing work.
7	Process the PCV head	Make large-diameter holes (φ500 mm)	Use AWJ to conduct the processing work. Fragments from the processing work are collectable.
8	Investigate the inside of the PCV head	Investigation Equipment B	Investigate the space between PCV and RPV heat-retention material. Confirm the conditions of the structures.
9	Process the RPV heat-retention material	Make large-diameter holes (φ680 mm)	Use AWJ for the processing work. Fragments from the processing work will fall.
10	Preliminarily investigate the inside of the RPV heat-retention material	Investigation Equipment B	Prior-investigate the RPV head spare nozzle. Determine whether it’s possible to conduct the processing work.
11	Process the RPV head (spare nozzle)	Make small-diameter holes (φ40 mm)	Open by machining the center of the spare nozzle closing flange as a measure against hydrogen explosion. Fragments from the processing work will fall.
12	Preliminarily investigate the inside of the RPV head	Investigation Equipment A	Prior-confirm the conditions of the dryer; confirm only the immediate underneath of the dryer. Determine whether it’s possible to conduct the processing work.
13	Process the RPV head (spare nozzle)	Make large-diameter holes (φ300 mm)	Use AWJ to conduct the processing work. Remove the spare nozzle. Fragments from the processing work are collectable.
14	Investigate the inside of the RPV head	Investigation Equipment B	Investigate the inside of the RPV head. Confirm the conditions of the structures and the state of the space.
15	Process the steam dryer bottom plate	Make small-diameter holes (φ40 mm)	Use AWJ to conduct the processing work. Perform the processing for corrugated plates, etc. at a safer location. Fragments from the processing work will fall.
16	Preliminarily investigate the steam separator	Investigation Equipment A	Prior-investigate the conditions of the upper part of the steam separator; confirm only its immediate underneath. Determine whether it’s possible to conduct the processing work.
17	Process the steam dryer bottom plate	Make large-diameter holes (φ140 mm)	Use AWJ for the processing work. Fragments from the processing work will fall.
18	Preliminarily investigate the outside of the steam separator	Investigation Equipment A	The equipment will pass through the outside of the steam separator to prior-investigate the conditions of the part down to the shroud head. Determine whether it’s possible to conduct the processing work.
19	Preliminarily investigate the inside of the steam separator	Investigation Equipment A	The equipment will pass through the inside of the steam separator. Investigate the part down to the reactor core if the equipment can pass through the vane part. Determine whether it’s possible to conduct the processing work.
20	Process the steam separator	Make large-diameter holes (φ140 mm)	Use AWJ for the processing work. Fragments from the processing work will fall.
21	Process the shroud head	Make large-diameter holes (φ110 mm)	Use AWJ to conduct the processing work. Fragments from the processing work are collectable.
22	investigation inside the reactor core	Investigation Equipment B	The equipment will make a straight descent to the point it can reach to investigate the parts from the upper grid plate to the reactor core and also (if reachable) to the RPV bottom part.
23	Investigate the inside of the reactor core (horizontal-motion)	Investigation Equipment C	The equipment will horizontally move in the shroud head toward the center of the reactor and then go down to and investigate the deepest bottom (possible to access).

6.4 Designing the Entire Investigation Equipment System and Planning the investigation

(2) (Draft) Integral Planning

<Prerequisites> ・The side-opening investigation will be conducted only when it can be carried out prior to the top-opening investigation
• Schedule of the major flow steps should not be planned at the same timing.
• The top-opening investigation will be set after removing fuels from the SFP and building a negative pressure environment



Work site | **Planned work flow (The time needed for each item is not considered.)**

Unit 1

- Operation floor / Rooftop of the air conditioning room: Prepare for the SFP fuel retrieval (Remove the upper part of the building and the well cover, install shields, etc.) → **Start the SFP fuel retrieval (hopefully in FY2023)**
- Operation floor: **Top-opening investigation** → **Retrieve fuel debris from the RPV (top entry)**
- Rooftop of the air conditioning room: **Side-opening investigation**
- Negative pressure environment inside the PCV: Establish a negative pressure environment inside the PCV

Unit 2

- Operation floor / Rooftop of the air conditioning room: Remove the upper part of the building
- Operation floor: Prepare for the SFP fuel retrieval (Install shields, etc.)
- Rooftop of the air conditioning room: Remove interfering objects and install work platforms → **Side-opening investigation**
- Operation floor / Rooftop of the air conditioning room: **Start the SFP fuel retrieval (hopefully in FY2023)**
- Operation floor: **Top-opening investigation** → **Retrieve fuel debris from the RPV (top entry)**
- Negative pressure environment inside the PCV: Establish a negative pressure environment inside the PCV

Unit 3

- Operation floor / Rooftop of the air conditioning room: **Start the SFP fuel retrieval (around mid FY2018)** → Remove the covering building and gantry
- Operation floor: Remodel the shields and build a work area → **Top-opening investigation** → **Retrieve fuel debris from the RPV (top entry)**
- Rooftop of the air conditioning room: Remove interfering objects and install work platforms → **Side-opening investigation**
- Negative pressure environment inside the PCV: Establish a negative pressure environment inside the PCV

Issues/Matters that need to be studied or considered

○ Common among the Units
•Perform on-site pre-surveys
•Priority of works
•Duration of work for each item
•Timing for creating a negative pressure environment

○ Unit 1
•Plan the SFP fuel debris retrieval and coordinate post-investigation works on the operation floor toward fuel debris retrieval
→ How to establish the work area after removing the well-cover?
→ How to reflect investigation findings about the SFP fuel retrieval work area into the facilities?

○ Unit 2
・Determine when to remove the interfering objects on the rooftop of the air conditioning room
・Plan the SFP fuel debris retrieval and coordinate post-investigation works on the operation floor toward fuel debris retrieval
→ How to reflect investigation findings about the SFP fuel retrieval work area into the facilities?

○ Unit 3
•Plan the SFP fuel debris retrieval and coordinate post-investigation works on the operation floor toward fuel debris retrieval
→ Find out how much the well cover is damaged and judge whether it’s possible to process it
→ How to reflect investigation findings about the work area into the remodeling of the shield toward fuel debris retrieval

⇒ The Top-Opening Investigation will probably start with a delay. The flow of the “Connecting” work needs to be rationalized more (conducted at the operation floor) while taking account of the pre- and post-investigation plans (per Unit) and the entire operation flow up until the fuel debris retrieval.

7. Summary

7.1 Development of equipment to access the reactor core from the top

- An exposure assessment was conducted and the policy to perform the investigation in a negative pressure environment adopted.
- A verification test on the boundary maintenance equipment's sealing in a setting that simulated a negative pressure environment for the inside of the PCV was conducted.
- Equipment for removing the RPV spare nozzle was prototyped and an element test conducted.
- Equipment for making holes at narrow reactor internals (combination-cutting of the steam separator, etc.) was prototyped and an element test was conducted.

⇒ For the method to establish an access route by opening the upper part of the RPV, studies were conducted on the plans/specifications of the equipment (and systems); its prototype was made and an element test conducted; its design elaborated; and its remote operability confirmed.

7.2 Development of equipment to access the reactor core from the side

- A study on the equipment's applicability to each Unit was conducted and the data showing the validity of applying it to Unit 2 earlier than the other units was put together.
- An exposure assessment was conducted and it was confirmed whether the method would cause no problems even when radioactive dust disperses.
- The concept was studied and a method for securing a boundary established .

⇒ A method for cutting the PCV shield wall , PCV and RPV without compromising a boundary was established; the work flow was clarified; the specifications compiled; and the application feasibility to the Units confirmed.

7.3 Development/Selection of the method to investigate down to the reactor core

- Studies were conducted, per each investigation flow, on the specifications of the two types of equipment: the one to preliminarily confirm the access route after making small-diameter holes; and the other to perform the Full-Scale Investigation after making large-diameter holes.
- A study on the specifications of the investigation equipment which has a horizontal-motion mechanism was conducted.
- A verification test on the access capability was conducted and the remote operability confirmed.

⇒ The equipment was prototyped and a verification test conducted, by using mockup openings, on the equipment's access capability and its remote operability confirmed.

7.4 Designing the entire investigation system and planning the investigation

- A study on the processing/investigation flows was conducted and the entire investigation flow organized.
- A study on the action policy for each Unit that responds and corresponds to the pre- and post-investigation state and plan was conducted.

⇒ The entire work flow was generated from the equipment installation on the R/B operation floor through to the on-site surveys and to the post-investigation treatment.

⇒ A study on the necessity of conducting the following pre-investigation on-site surveys aimed at heightening the equipment system's and plan's applicability to the real-life situations was conducted.

- **•Survey on the inside of the reactor well (for the top-opening investigation)**
- **•Survey at the third floor of the Unit 2's R/B (for the side-opening investigation)**