

The 8<sup>th</sup> International Forum on the Decommissioning of  
the Fukushima Daiichi Nuclear Power Station

# Initiatives for Fuel Debris Retrieval at Fukushima Daiichi Nuclear Power Station

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Naoto Iizuka

Chief Technology Officer for D&D

Fukushima Daiichi Decontamination and Decommissioning Engineering Company,  
Tokyo Electric Power Company Holdings, Inc.

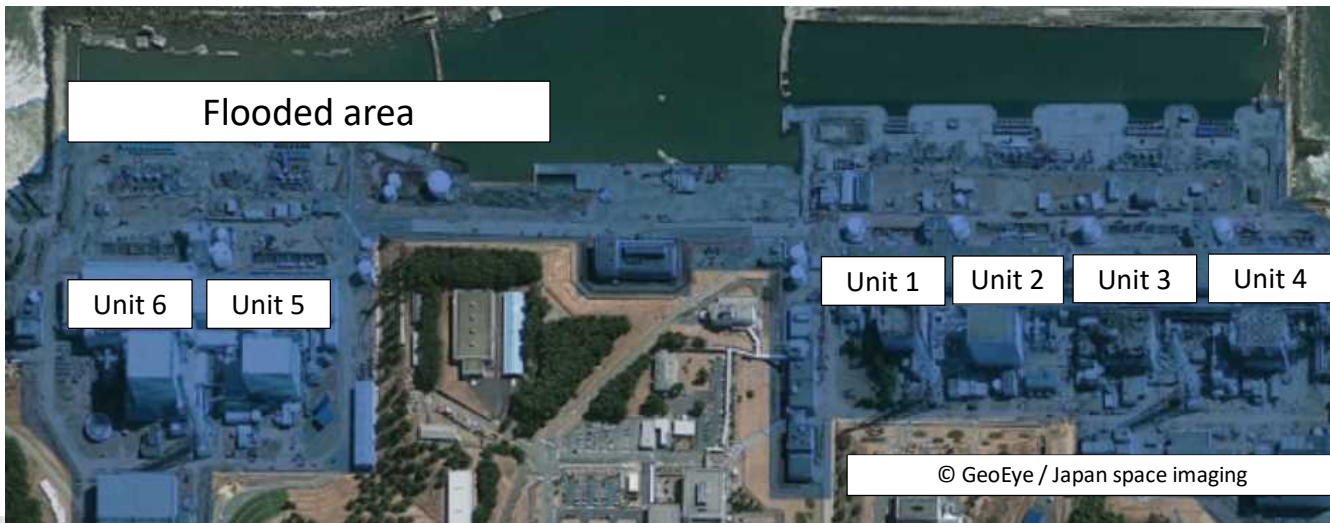
# Introduction



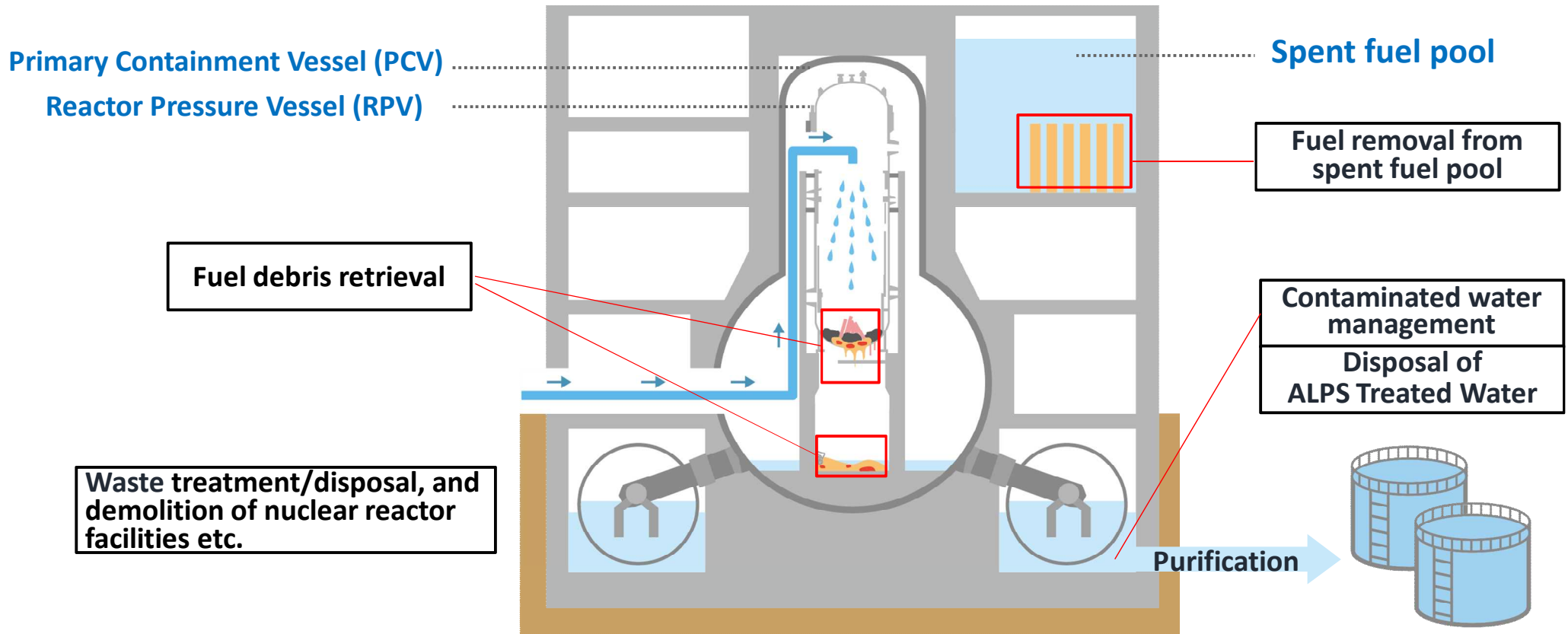
# Accident at Fukushima Daiichi in March 2011

Unit	1	2	3	4	5	6
Operating on Mar. 11	●	●	●	—	—	—
Meltdown	●	●	●	—	—	—
Explosion	●	—	●	●	—	—

Currently, Units 1 to 3 are in cold shutdown status

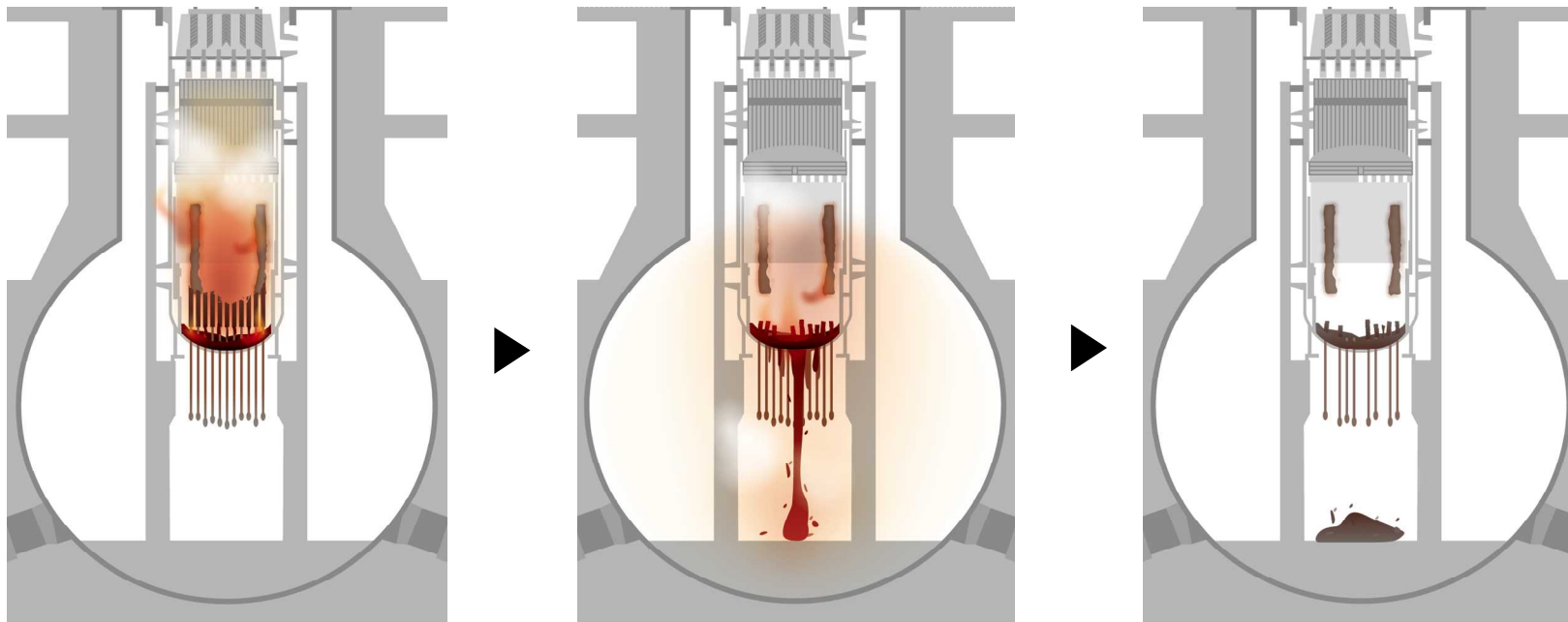


■ Decommissioning work is being carried out to reduce the risk of radioactive materials affecting local people and the environment.



## What is fuel debris?

- Fuel debris is a substance that has cooled and re-solidified while being mixed with various materials, after the reactor fuel became damaged and melted as a result of the loss of cooling function.



A photograph of a reactor core, showing a central fuel assembly and surrounding fuel elements. The image is somewhat blurry and has a dark, industrial appearance. The text is overlaid in white, bold font.

**Initiatives to assess the internal conditions of reactors**

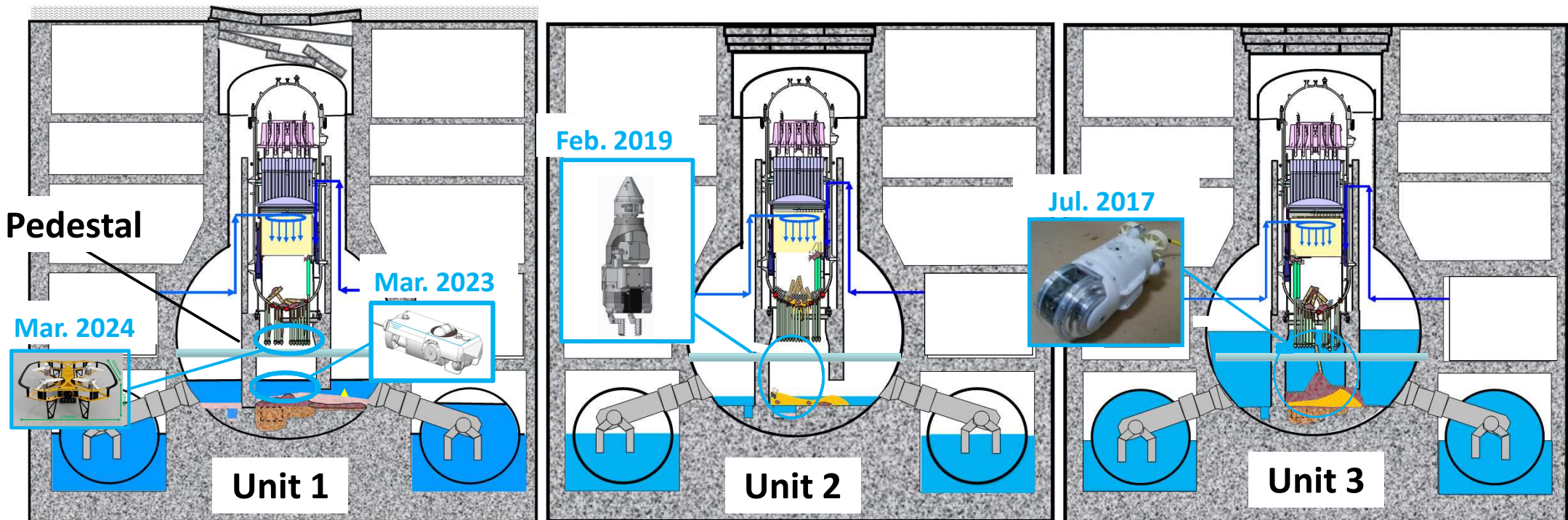
## Why is internal investigation necessary?

- Internal investigation to assess the conditions of fuel debris and surrounding structures is a necessary step for fuel debris retrieval. However, the high level of radioactivity makes it difficult for workers to go inside.
- Robotic explorations, assessment using analysis codes and a muon survey have been conducted.

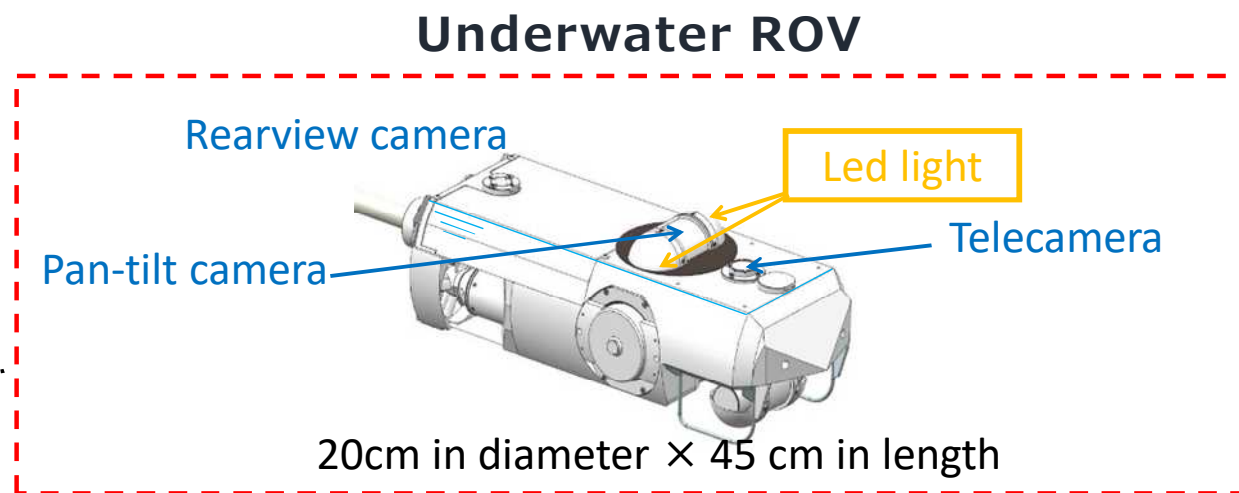
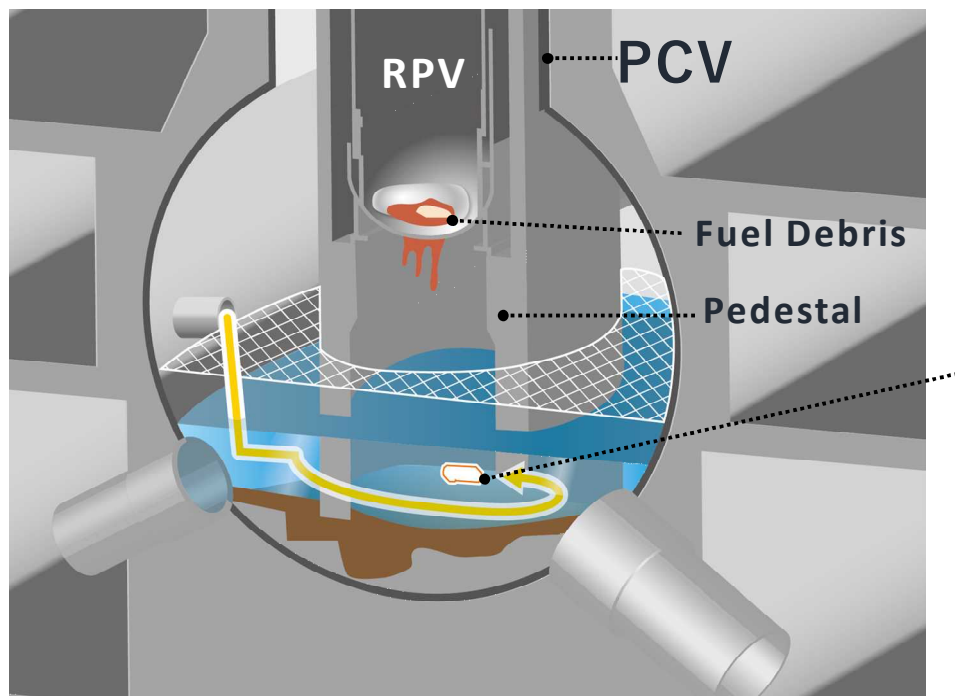
### Robotic exploration

### Analysis of accident progression

### Muon Survey

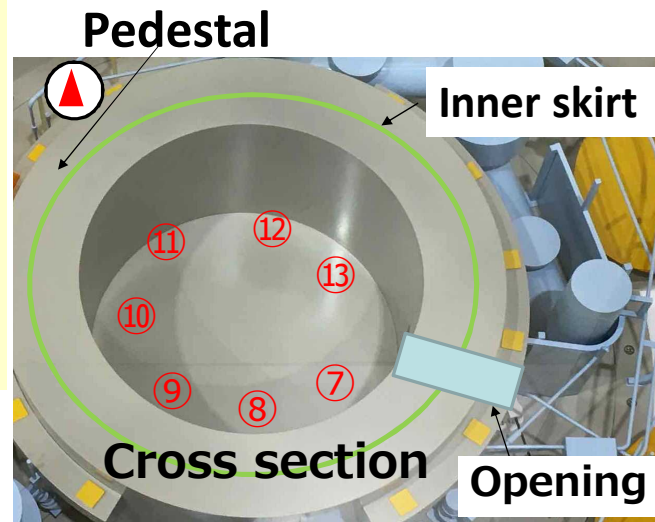


- Detailed images of the interior and opening of the pedestal were obtained using cameras.
- Further accident progression analysis and assessment of pedestal integrity were conducted based on the information obtained from the investigation.



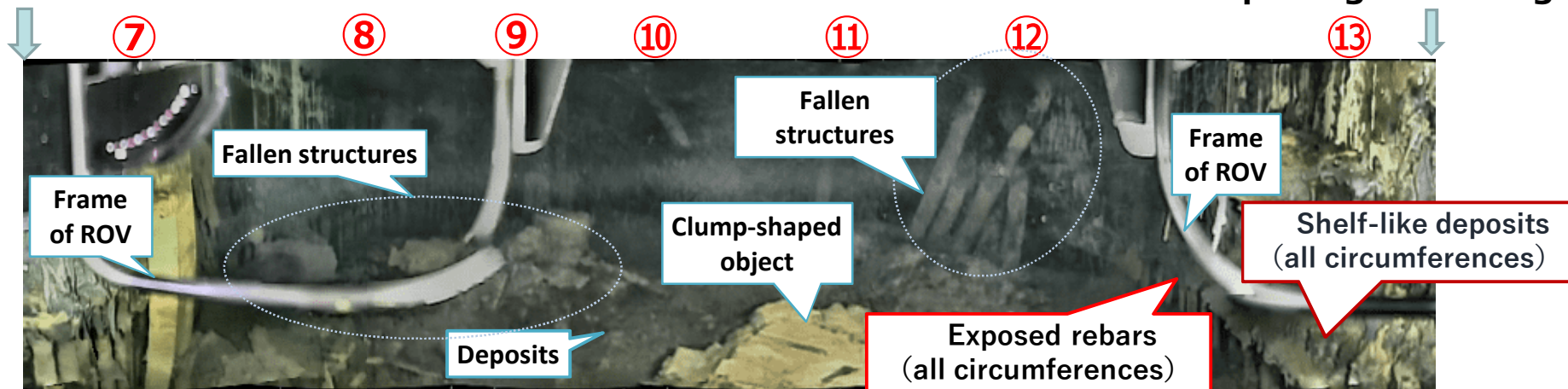


- Shelf-like deposits were found 1 meter from the floor, with concrete missing and rebars exposed around the entire pedestal's circumference beneath this level.
- Deposits rising up to 1 meter were observed across the floor.
- Structures that fell from the upper side were identified.



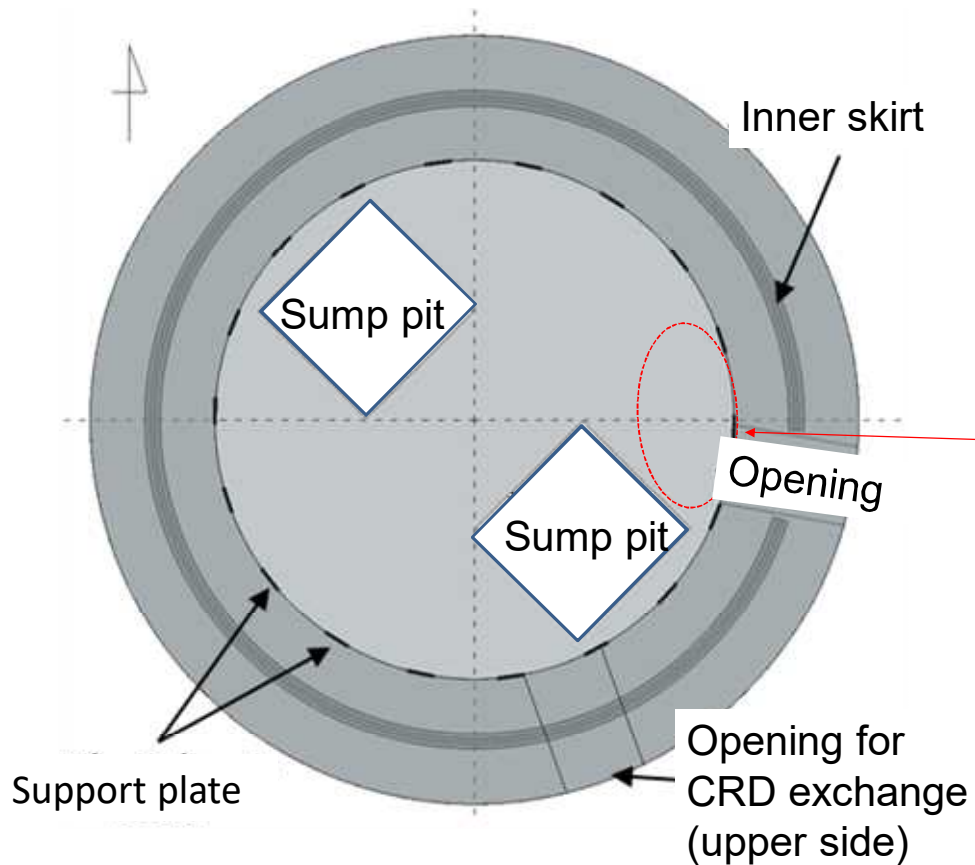
Opening on the left side

Opening on the right side

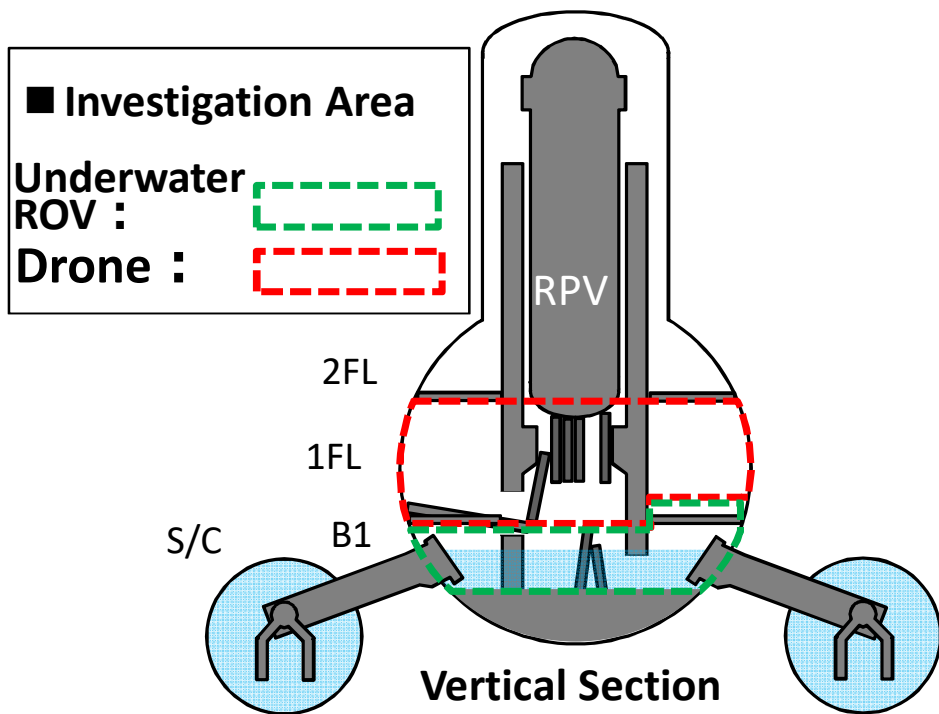


Source : International Research Institute for Nuclear Decommissioning (IRID)

- In contrast to the lower part, the upper part of the pedestal has been found to remain intact.



■ To gain a comprehensive understanding of Unit 1 PCV as part of the efforts toward fuel debris retrieval, an investigation of the first floor was conducted, following the one on the basement floor.



### Small drone

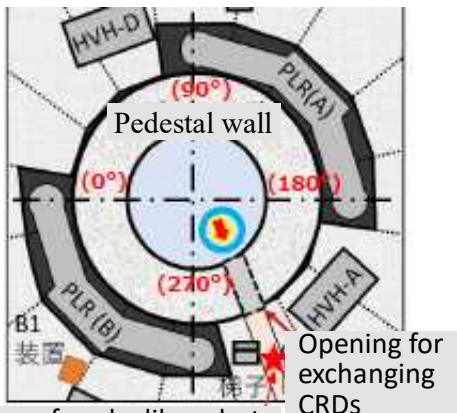


Use : Filming  
 Scale : 191×179×54[mm]  
 Weight : 185[g](including a battery)  
 Flight duration : about 8 minutes  
 Installed devices :  
 -Light (90lm(45lm×2)),  
 -Ultrahigh-sensitivity camera (front only)

### Snake-type robot for wireless relay

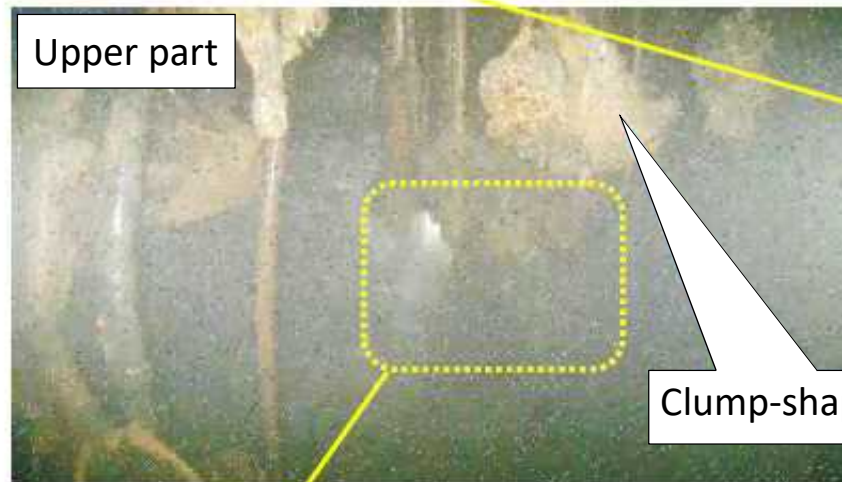


Use : Carrying of wireless relay device & dose measurement  
 Scale : 2,900×180×165[mm]  
 Weight : about 25[kg]  
 Installed devices :  
 -wireless relay device for drones  
 -CMOS camera×2  
 -dosimeter



Standby position of snake-like robot

Rough sketch of the 1<sup>st</sup> floor inside pedestal

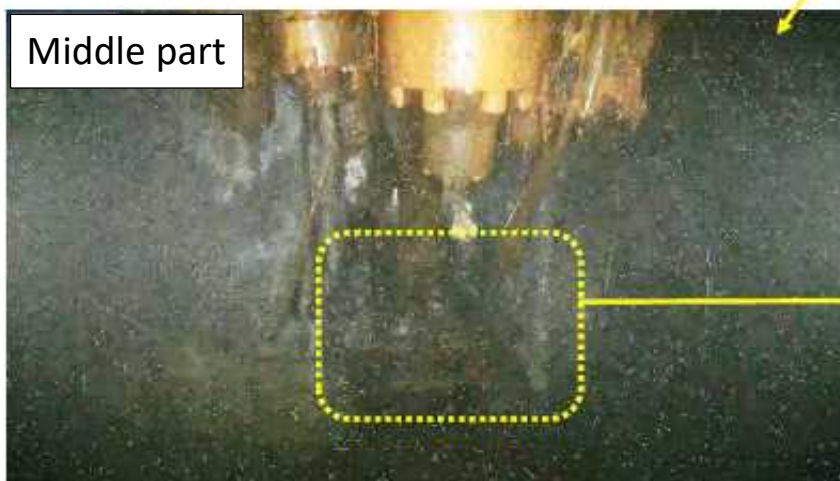


Upper part

Clump-shaped object



Icicle-shaped clump



Middle part

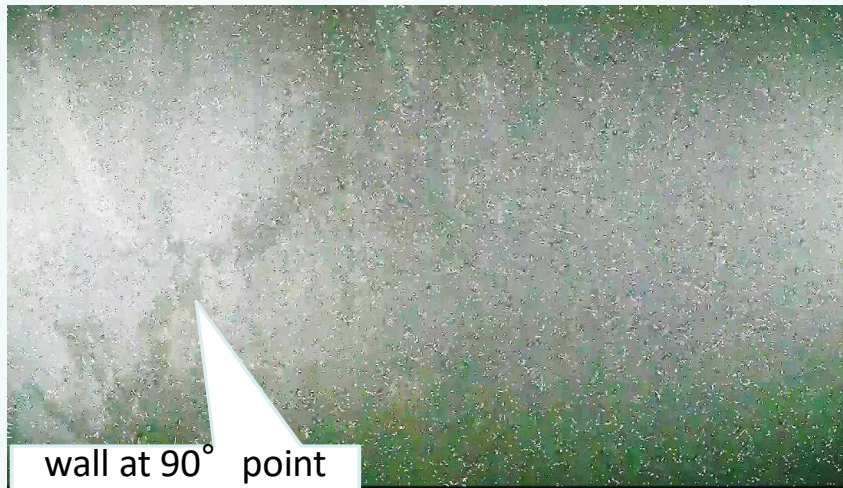


Lower part

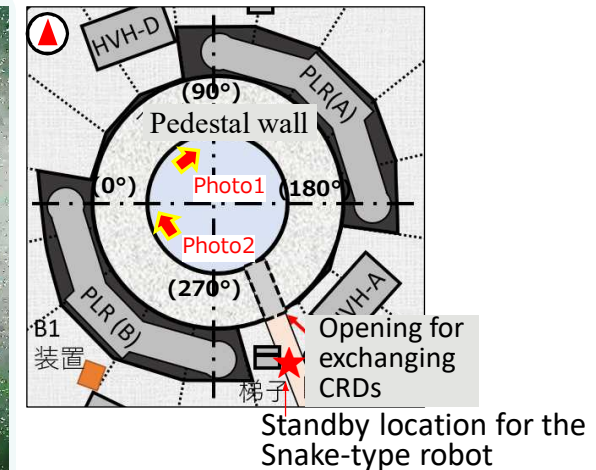
CRD exchanging rail

**Photo1** : Wall at 90° Point inside the pedestal

- No significant damage was confirmed despite a color change, and the concrete remains intact.
- No equipment was observed, as there has been none since before the accident.

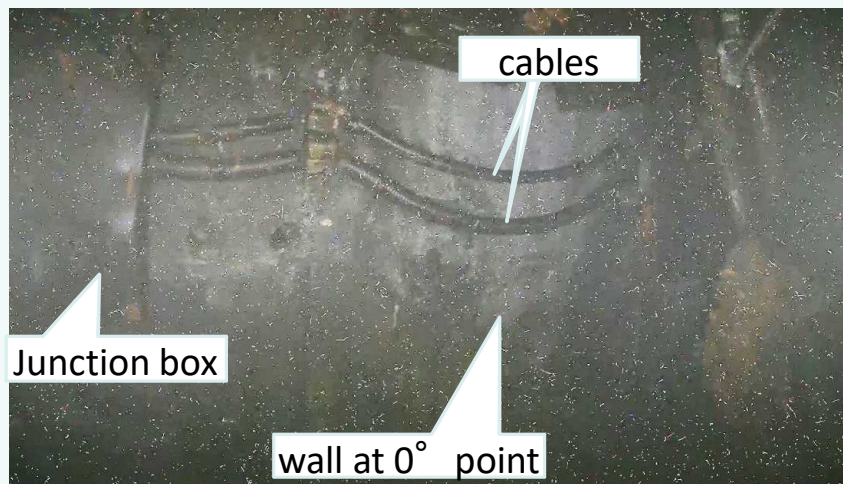


**First floor inside Unit 1 PCV**

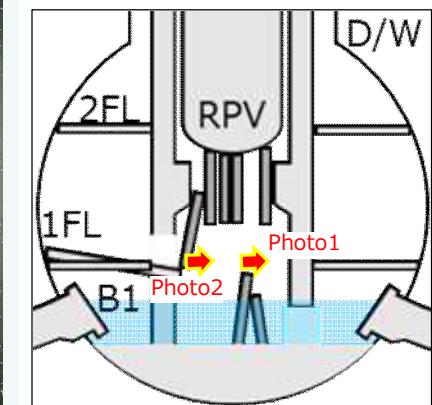


**Photo2** : Wall at 0° Point inside the pedestal

- Like photo 1, No significant damage was confirmed despite a color change, and the concrete remains intact.
- Objects including a junction box for cables were observed. It is presumed to have changed in color and shape.



**Vertical section of Unit 1 PCV**



Images rendered by TEPCO Holdings

# Focal points of the future internal investigation into Unit 1

- As the investigation into the conditions of existing structures and the atmosphere has progressed, the focus will shift to a comprehensive understanding of the distribution of the deposits and their component analysis.
- Confirming the conditions of the interior of the RPV and the vent pipe, as well as the sampling and analysis of deposits on the basement floor inside the pedestal, will be prioritized.



**[Atmosphere]**

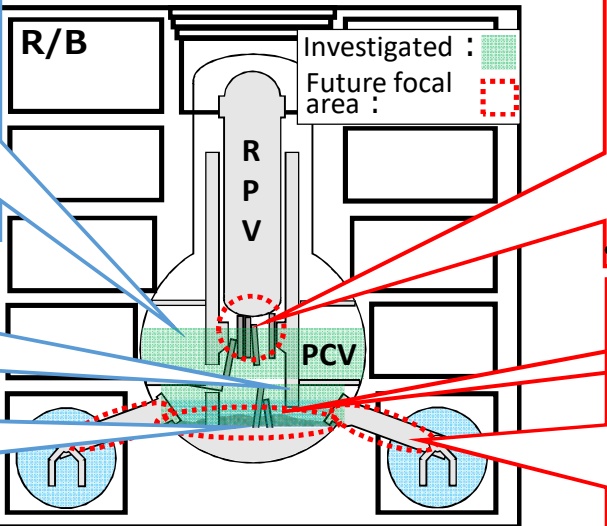
- Air dose rate**  
MAX: about 10Gy/h, Areas with 5Gy/h or less are predominant
- Water level in PCV**  
Initially 2 meters from the bottom, but its lowering is progressing
- Steams found in dark or humid areas

**[Structures]**

CRD related equipment has fallen in multiple places. Concrete at the base part of interior side of pedestal is missing within a range of 1 meter from the floor.

**[Deposits]**

Deposits is accumulated inside the pedestal, but moved outside as well. About 0.1 to 1 meters from the bottom.



**[RPV internal investigation]**

- Employing small drone to investigate bottom**
  - If a hole allowing access to the interior is found at the RPV bottom, an investigation will be conducted.
- Employing other methods to investigate**
  - Investigation methods will be studied based on the results of RPV investigations at other units.
  - Through existing piping
  - Through damaged part at the bottom
  - Through upper part

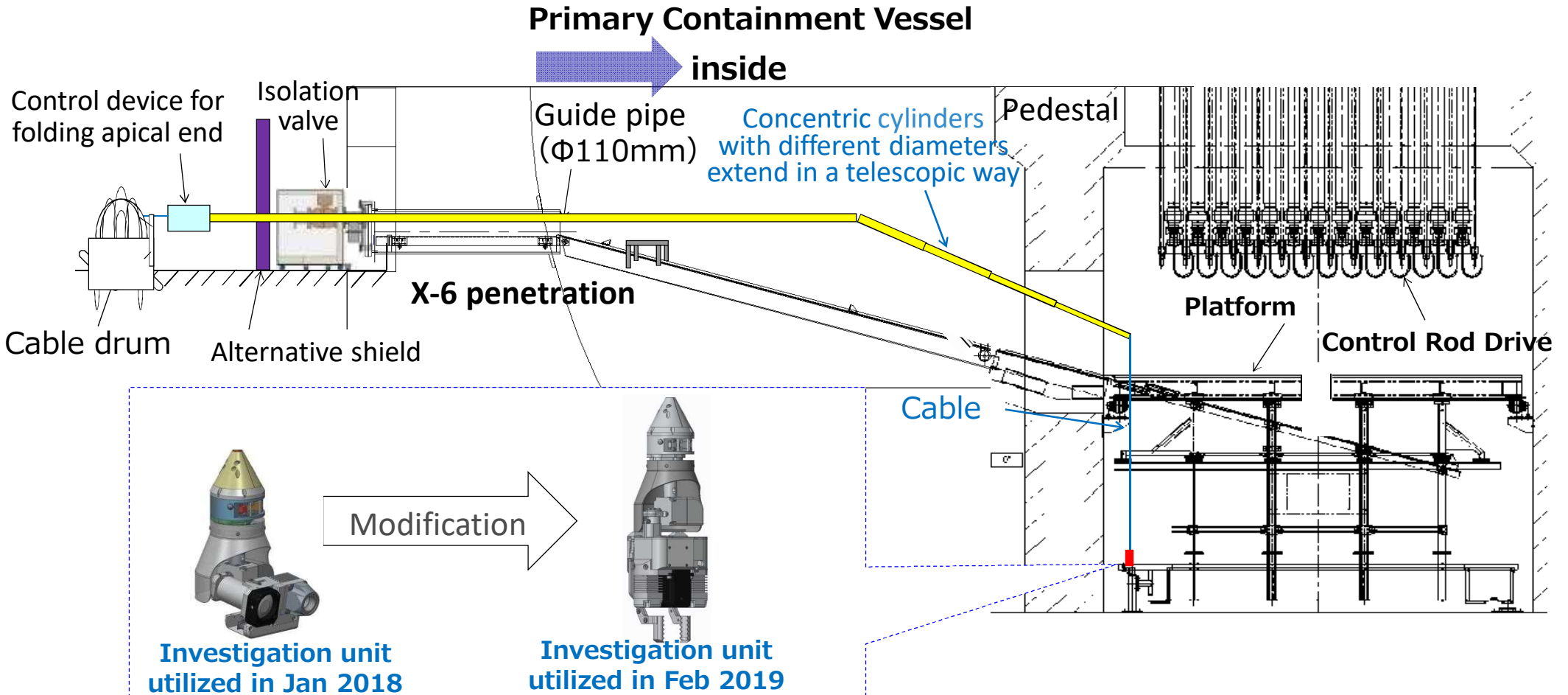
RPV Bottom  
Hole  
Investigation image

**[Deposits sampling/analysis]**

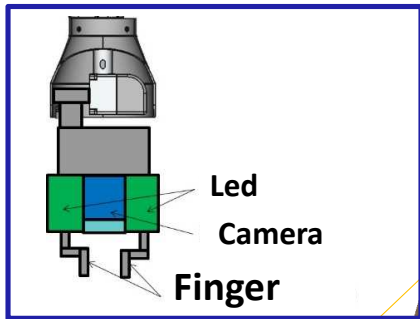
- Employing small drone to sample deposits**
  - Attaching an end effector to the drone to sample deposits on basement floor inside/outside the pedestal
  - Performing component analysis
- Investigation inside the vent pipe**
  - Employing small drone to investigate inside**
    - Launching a drone from D/W into vent pipe
    - Lowering water level and securing wireless relay method should be conducted in advance

Deposits  
Bottom of PCV  
Investigation image

■ Investigation unit used in January 2018 was modified to confirm whether deposits located inside can be gripped or not.

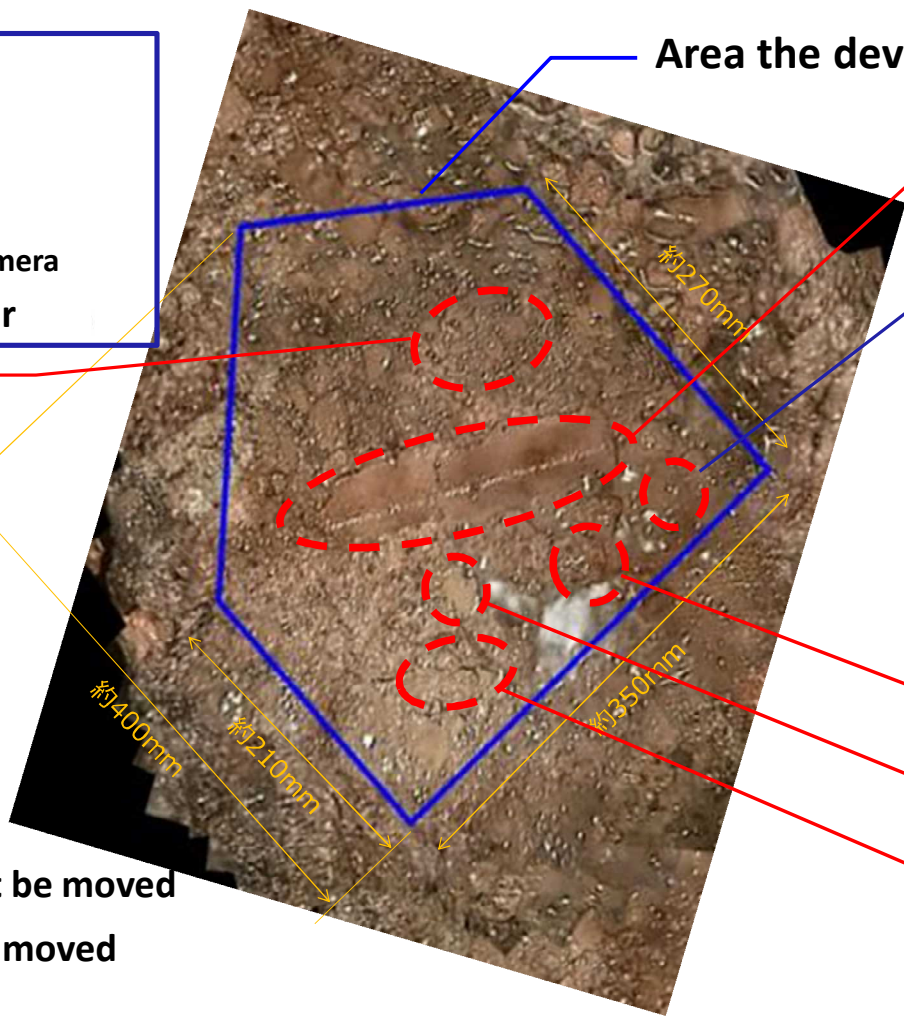


Tip of device



No. 2

Area the device was able to approach at the bottom of PCV



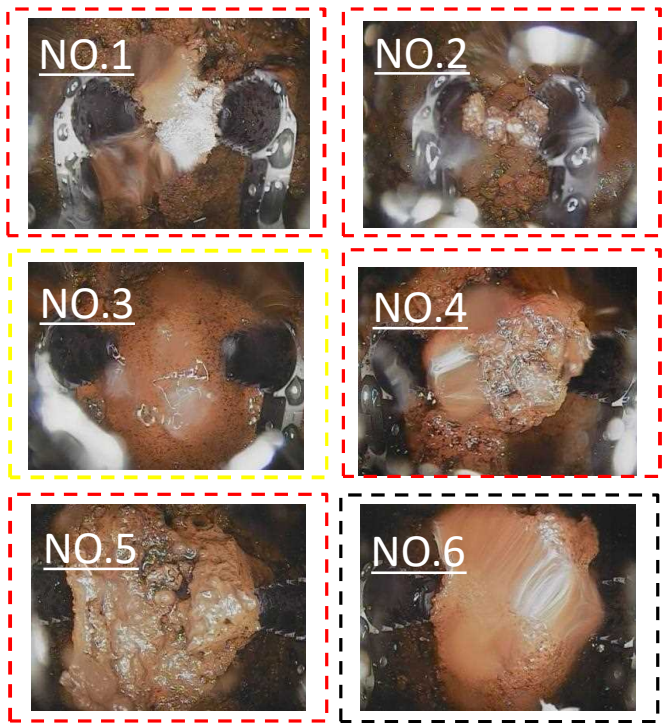
No. 6



No. 3

No. 4

No. 1

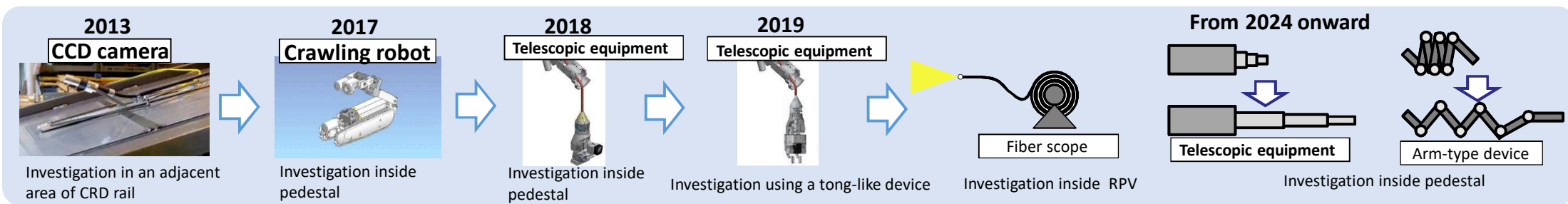
No. 5



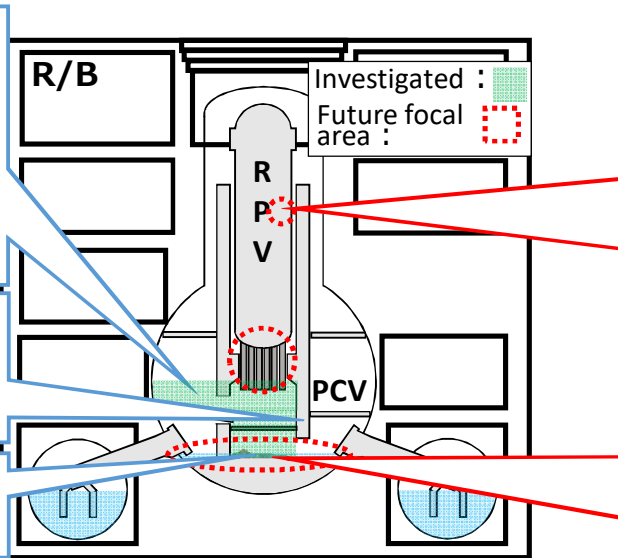
 : Cannot be moved  
 : Can be moved



- Fuel debris retrieval and detailed internal investigation using the arm-type device will be conducted.
- The plan will be implemented to initiate an internal investigation into the RPV, marking the first such investigation among Units 1 to 3.



- 【Atmosphere】**
  - **Air dose rate**  
 MAX: Somewhere between 70 and 80 Gy/h  
 About 10Gy/h inside the pedestal
  - **Water level in PCV**  
 The lowest among the 3 reactors, almost as low as bottom of D/W
  - Steams found in dark or humid areas
- 【Structures】**  
 No significant damage confirmed despite a color change. A part of platform in the pedestal dropped with deposits attached to it.
- 【Deposits】**  
 Small amount of deposits at the bottom inside the pedestal



**【RPV internal investigation】**

- **Investigation using existing instrumentation piping**
  - Employing a fiberscope inserted through the RPV's water level gauge piping that leads to the internal of RPV and confirming the conditions

The diagram shows a piping system with a nozzle (P) and a valve (V). A fiber scope is inserted through a penetration (X-28C) into the RPV. A newly installed boundary valve (under consideration) is shown near the penetration. An 'Investigation Image' is shown as a small inset.

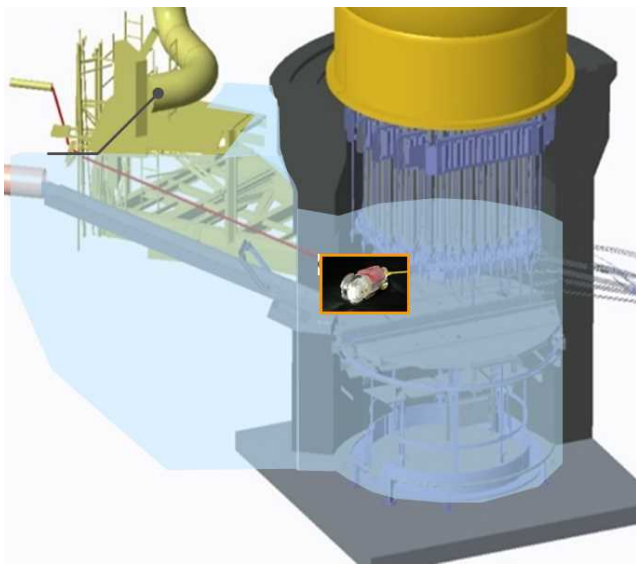
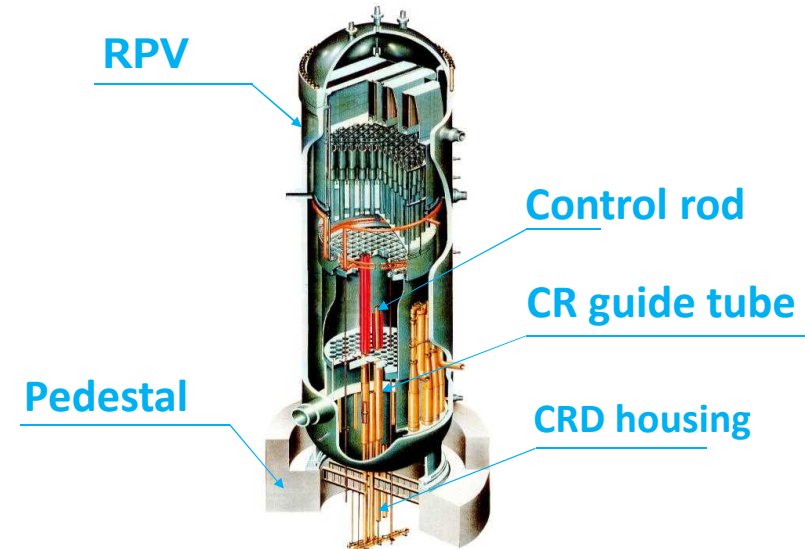
**【Trial fuel debris retrieval】**

- **Employing telescopic equipment through X-6 penetration**
  - Several grams of fuel debris to be sampled and analyzed
- **Employing arm-type equipment**
  - An Investigation to be conducted as well, covering wider area than the telescopic equipment

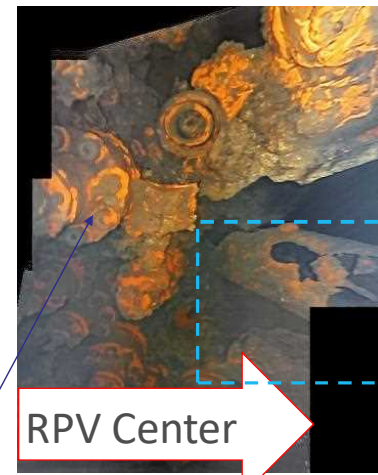
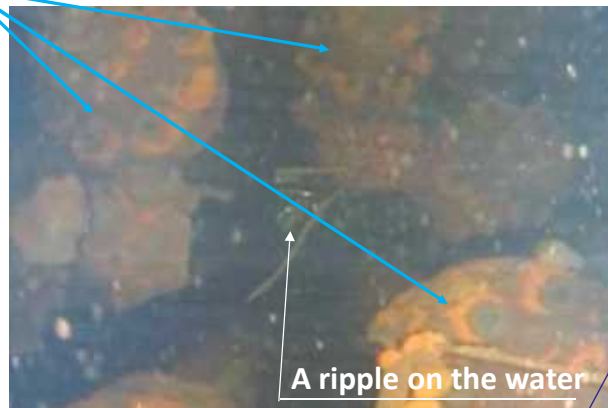
Two diagrams show equipment being used for debris retrieval. The first shows a telescopic device with an 'Image' inset. The second shows an arm-type device with an 'Image' inset.

**Key Findings**

- ✓ Damage to multiple structures/solidified molten-objects stuck to structures
- ✓ Deposits that look like sand, pebbles, or clumps inside the pedestal
- ✓ Fallen in-core structures such as CR guide tubes
- ✓ Locations where levels and intervals of CRD housing are different



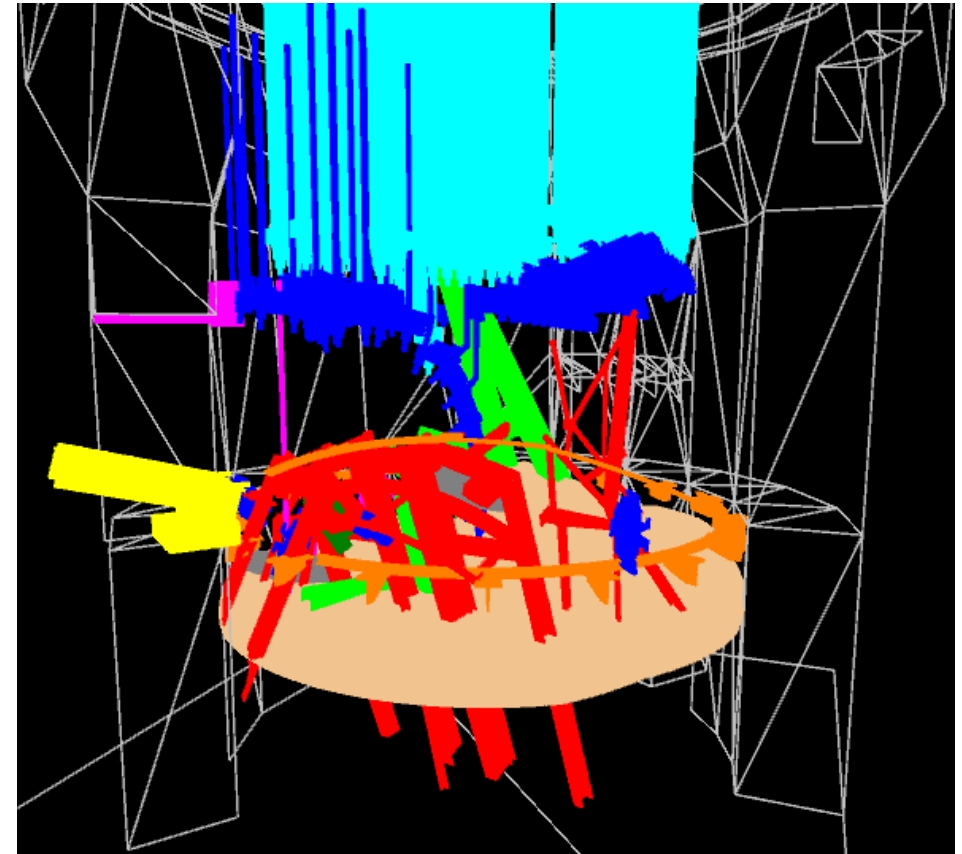
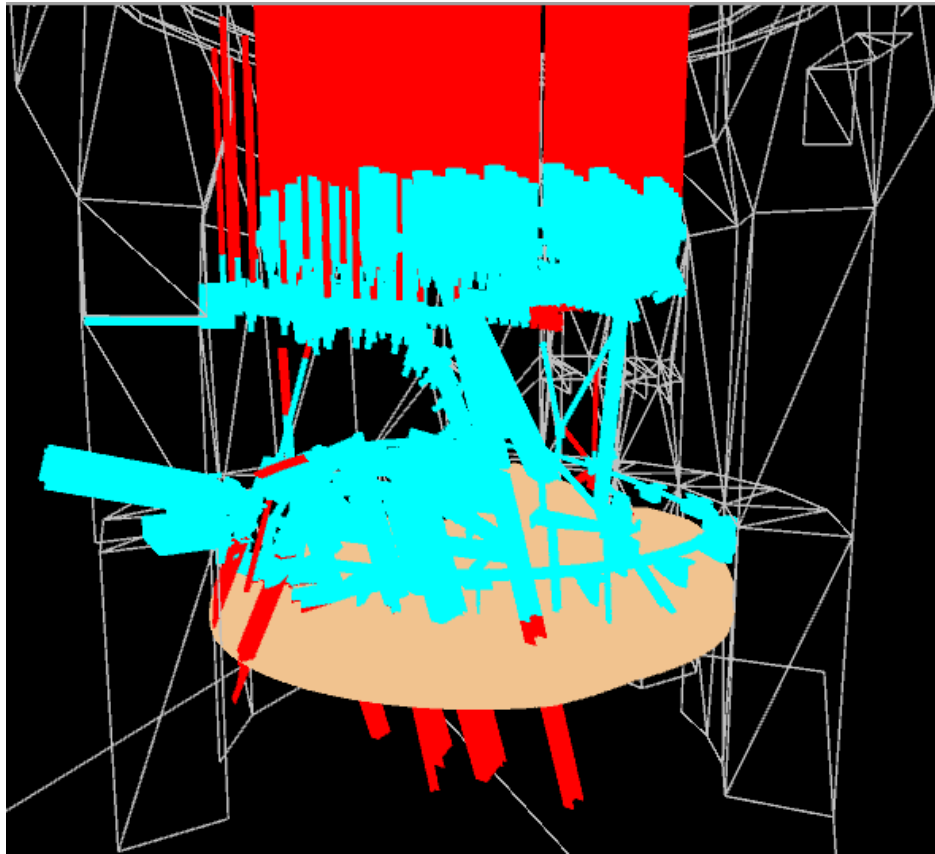
**Levels and intervals of adjacent CRD flanges are different**



**A cylindrical structure (presumed to be a CR guide tube)**



**Flange of CRD housing**



**Cyan** : Structures whose images were taken through investigation

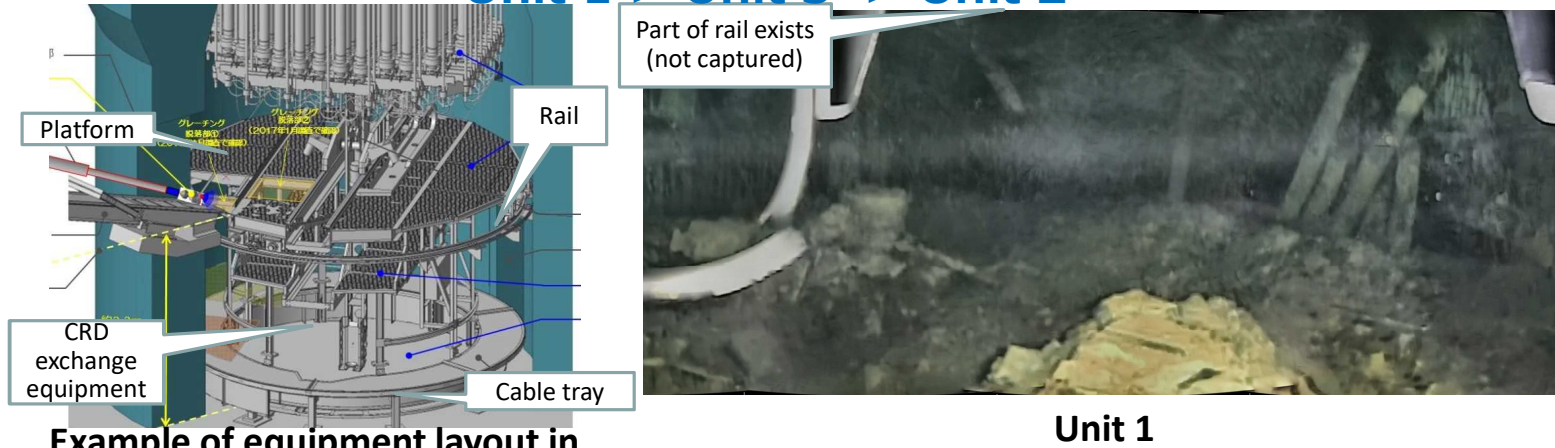
**Red** : Structures whose images were not taken through investigation (presumed from design information)

**Red** : Platform/Cradle, etc.  
**Green** : Motor for revolving platform  
**Blue** : CRD housing support  
**Cyan** : CRD housing

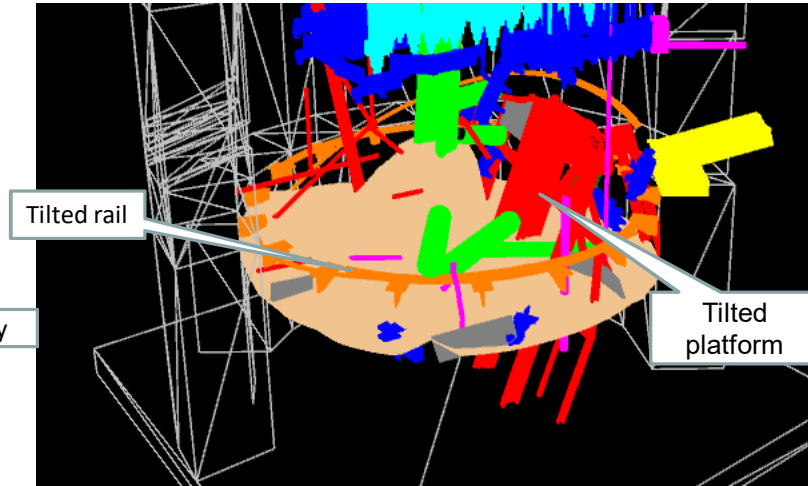
**Green** : CR guide tube  
**Yellow** : CRD exchange rail  
**Orange** : Rail for revolving platform, Support clasp  
**Magenta** : Terminal box, Conduit, Piping  
**Grey** : Grating

# Comparison of inside of pedestals at Units 1-3

The degree of damage in the pedestal is in the order of  
**Unit 1 > Unit 3 > Unit 2**

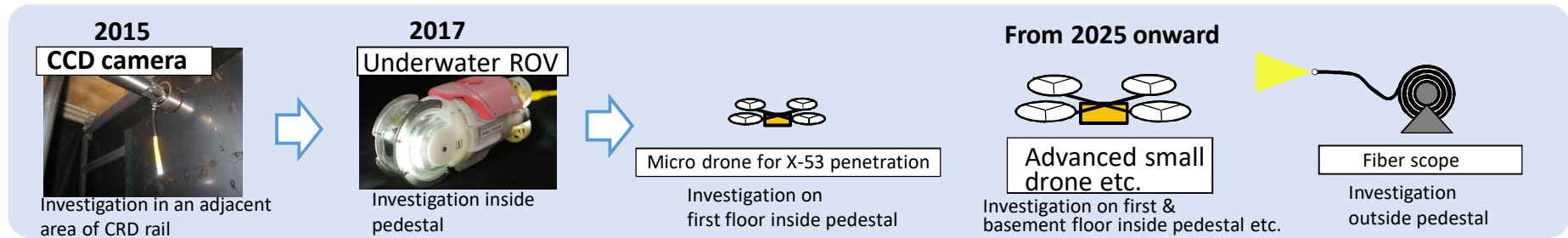


Example of equipment layout in Mark-I containment vessel



## Focal points of the future internal investigation into Unit 3

- As the investigation into the interior of the pedestal has progressed, the focus will shift to an understanding of the conditions of places other than inside the pedestal and component analysis of deposits.
- Confirming the conditions of the exterior of pedestal and the interior of RPV, both of which are uninvestigated, as well as the sampling and analysis of deposits inside the pedestal, will be prioritized.



**【Atmosphere】**

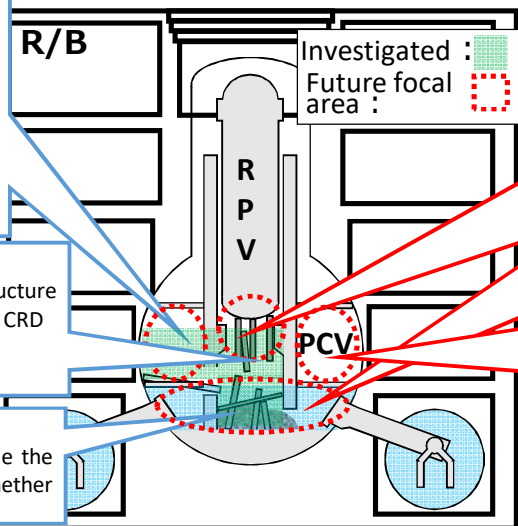
- **Air dose rate**  
 MAX: about 1Gy/h  
 As the current measured area is limited to around X-53 penetration area, the scope will be expanded.
- **Water level in PCV**  
 The highest among the 3 reactors, as high as the grating on the first floor
- Steams found in dark or humid areas

**【Structure】**

Unlike Unit 1, the original shape of the structure has remained unchanged. However, fallen CRD housing and a deformed platform were observed.

**【Deposits】**

There is a large amount of deposits inside the pedestal. It has not been confirmed whether they have flowed outside.



**【RPV internal investigation】**

- **Studying investigation methods**
  - Investigation methods will be studied based on the results of RPV investigations at other units.
  - Through existing piping
  - Through damaged part at the bottom
  - Through upper part

**【Investigation on the status of deposits outflow from inside the pedestal】**

- **Investigation using a fiberscope**
  - Employing a fiberscope inserted through a penetration hole for TIP, and confirming the status of deposits outflow from the pedestal's opening for workers.

Image

**【Investigation inside/outside the pedestal】**

- **Employing a micro drone through X-53**
  - Obtaining images
- **Employing an advanced small drone**
  - After arranging an existing penetration hole as an access route for the drone, it will be launched to obtain useful information.

X-53

PCV wall

Micro drone

Image

X-53

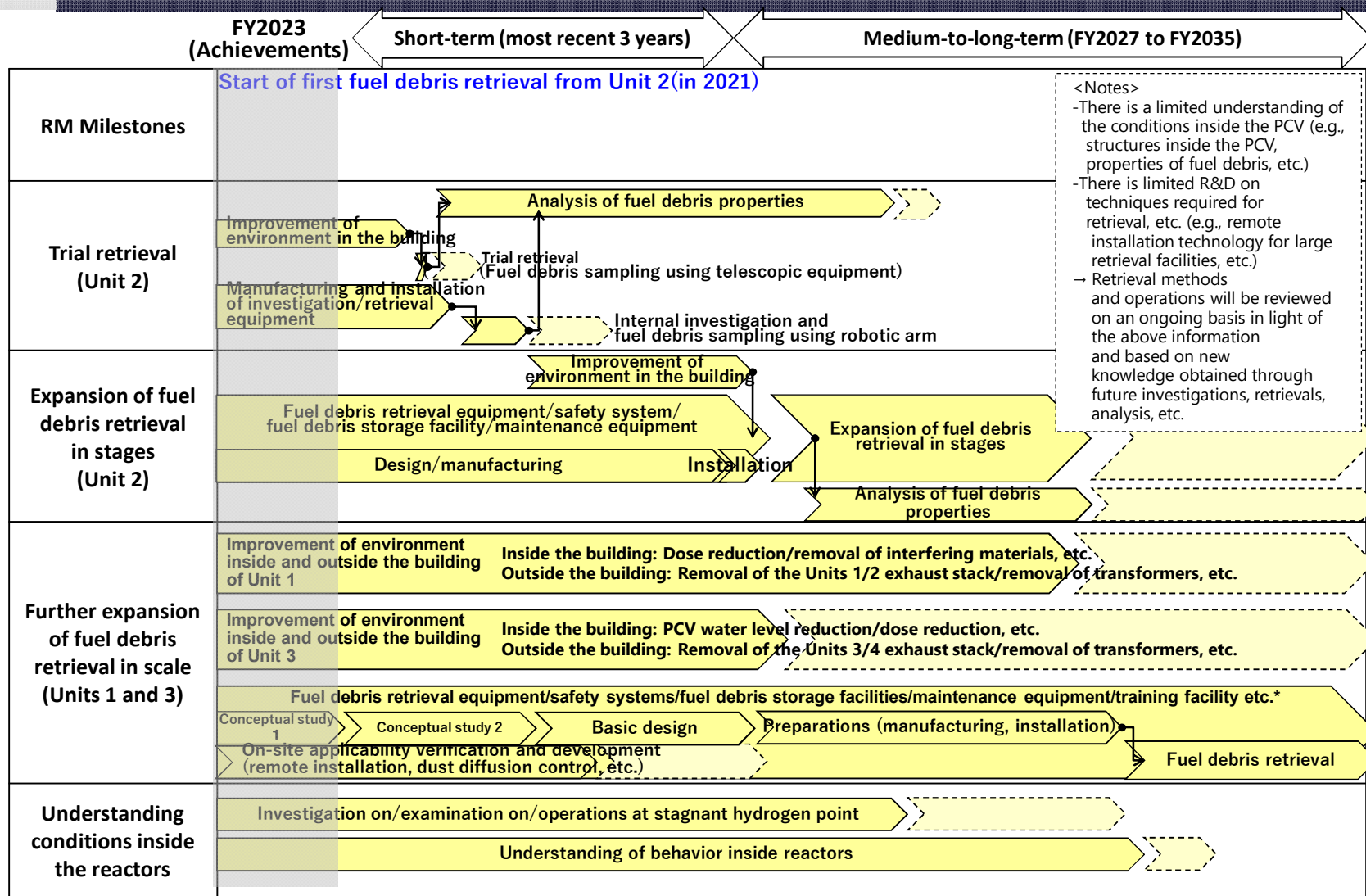
X-6, X-2 etc.

A high-angle photograph of two workers in blue uniforms and yellow hard hats working on a large, horizontal industrial shaft. The shaft is supported by a metal frame and has various cables and components attached to it. The workers are positioned on either side of the shaft, appearing to be inspecting or working on it. The background shows a concrete floor and some equipment.

# Trial Fuel Debris Retrieval at Unit 2

IRID has contributed to some work shown here

# Mid-and-Long-Term Decommissioning Action Plan 2024 (Fuel debris retrieval)

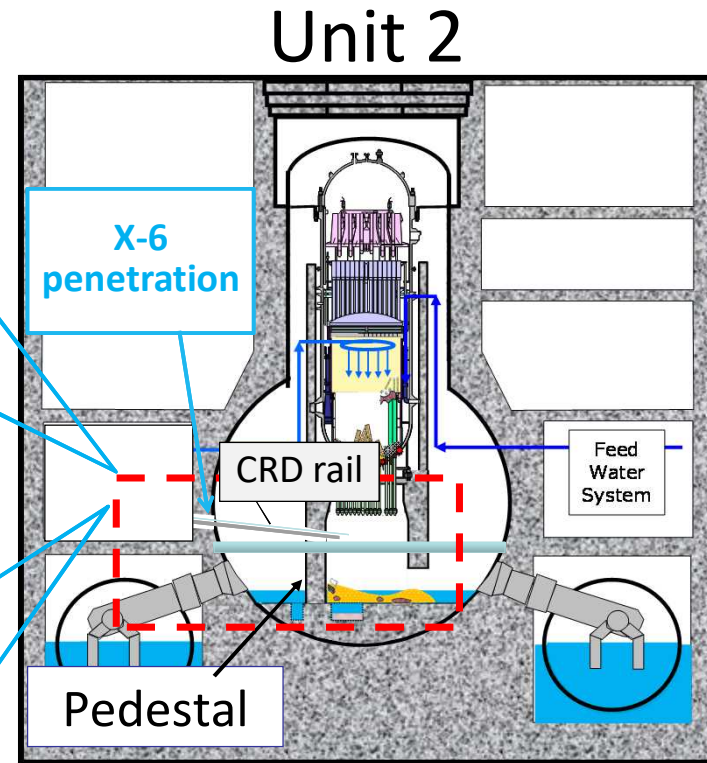
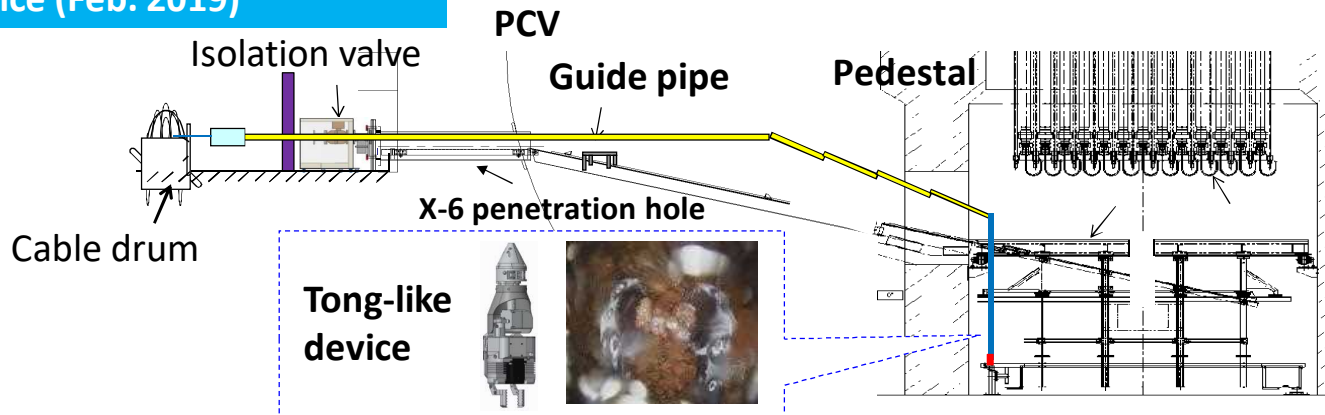


\*Based on the assumption that studies will be carried out giving precedence to Unit 3, followed by Unit 1.

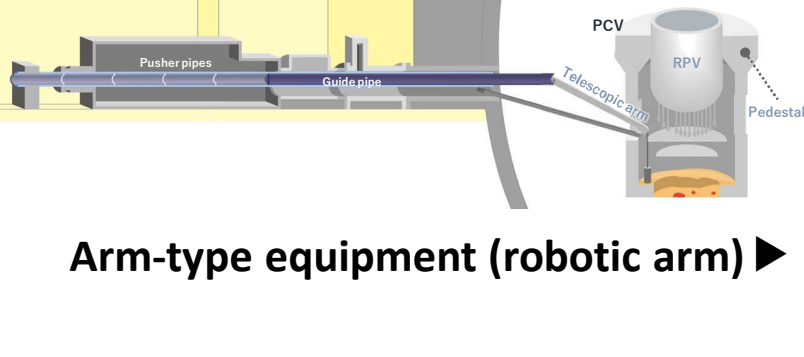
# Trial fuel debris retrieval at Unit 2

- We will insert retrieval equipment through the same access route as the investigation in 2019.
- The plan is to sample several grams of fuel debris, using an end effector attached to the tip of the equipment.

## Investigation using a tong-like device (Feb. 2019)



## Trial fuel debris retrieval



◀ Telescopic equipment

Arm-type equipment (robotic arm) ▶

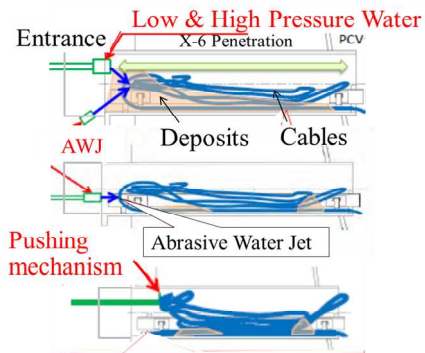


# Steps for trial fuel debris retrieval at Unit 2

1. Installing Isolation Chamber

2. Opening X-6 Penetration Hatch

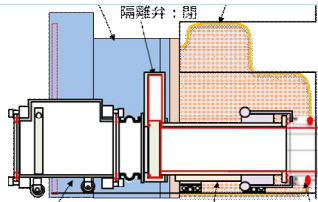
3. Remove deposits (incl. cables) inside X-6 penetration hole



- Squeezing deposits with low and high pressure water
- Removing cables using AWJ
- Pushing cables with pushing mechanism

4. Installing connection structure etc. for X-6 penetration hole

Isolation chamber etc.

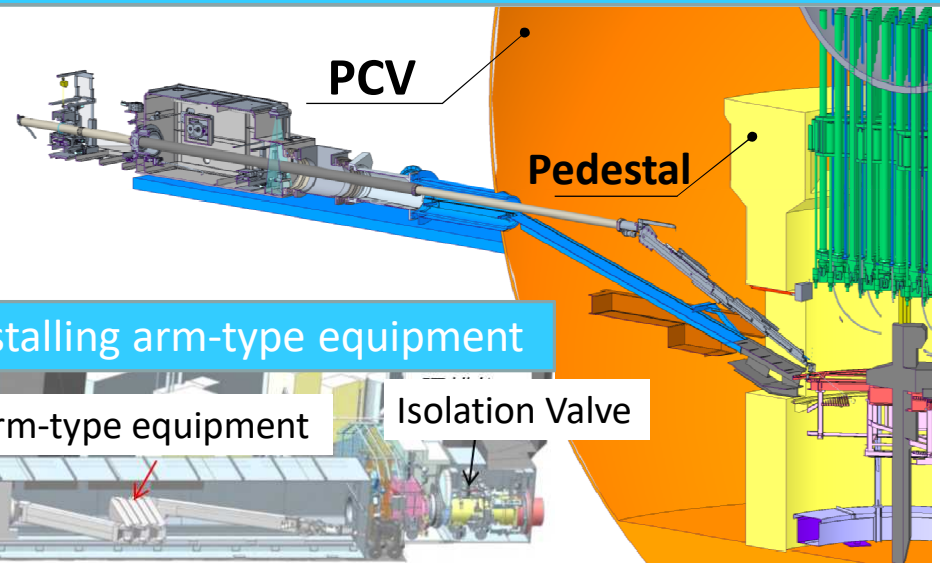


Connection structure etc.

X-6 penetration hole

5. Installing telescopic arm

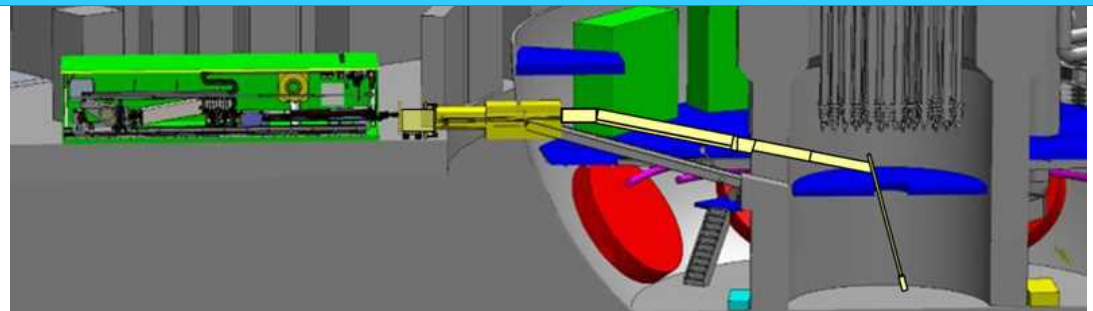
6. Trial fuel debris retrieval using telescopic arm



7. Installing arm-type equipment

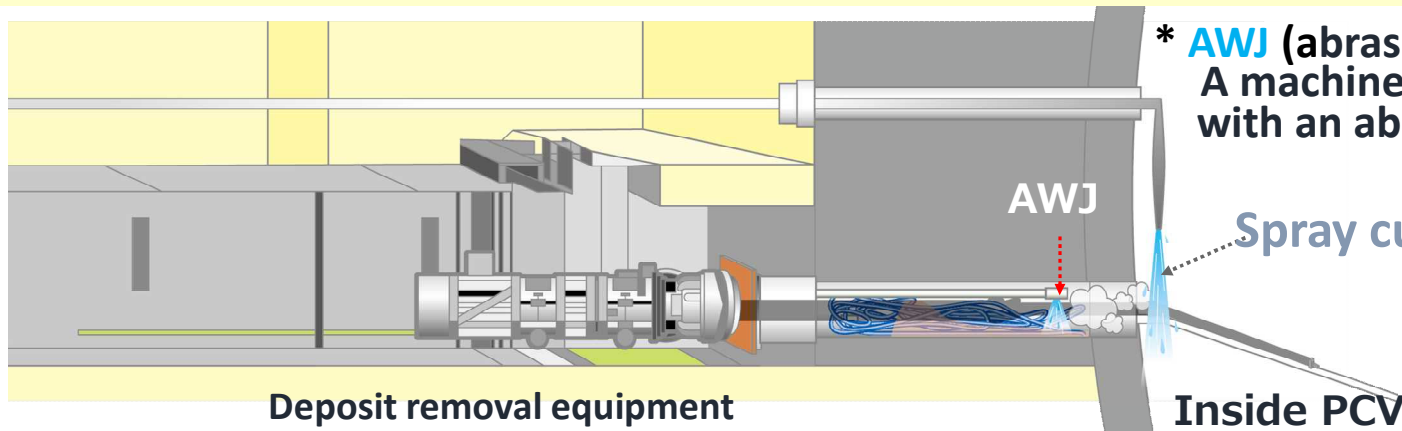


8. Internal investigation & trial fuel debris retrieval using arm-type equipment



# Removal of deposits inside X-6 penetration hole

- Deposit removal equipment was installed to secure the access route for trial retrieval equipment.
- By squeezing deposits using low and high-pressure water and cutting cables using AWJ\*, the whole process was completed in May 2024.



\* **AWJ** (abrasive water jet):  
A machine using high-pressure water mixed with an abrasive agent to flush and cut materials.

Opening hatch

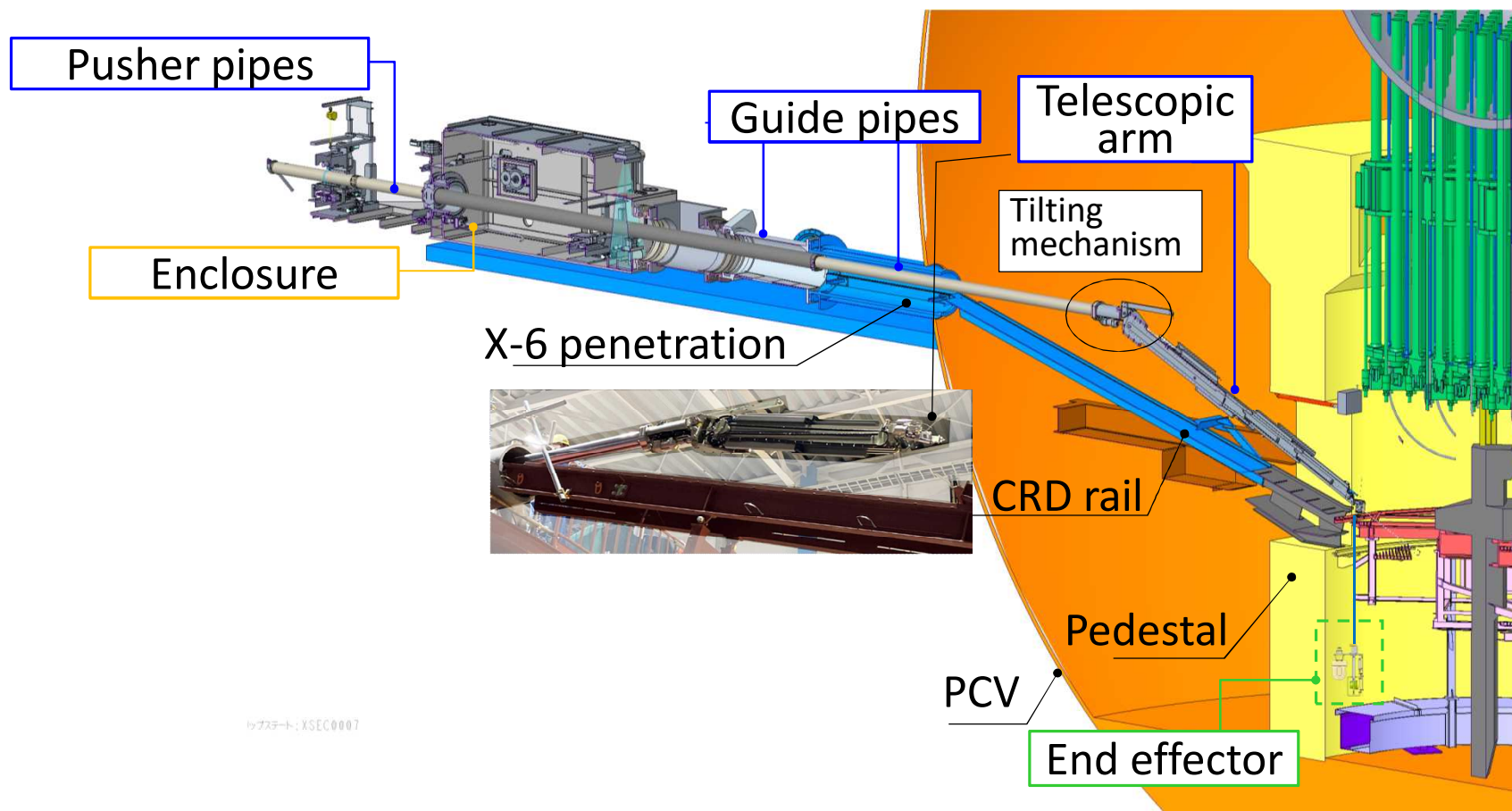


Removal of deposits completed

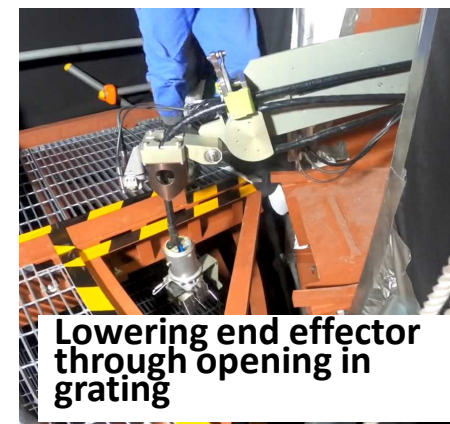
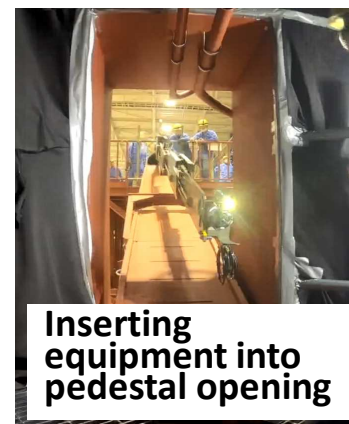
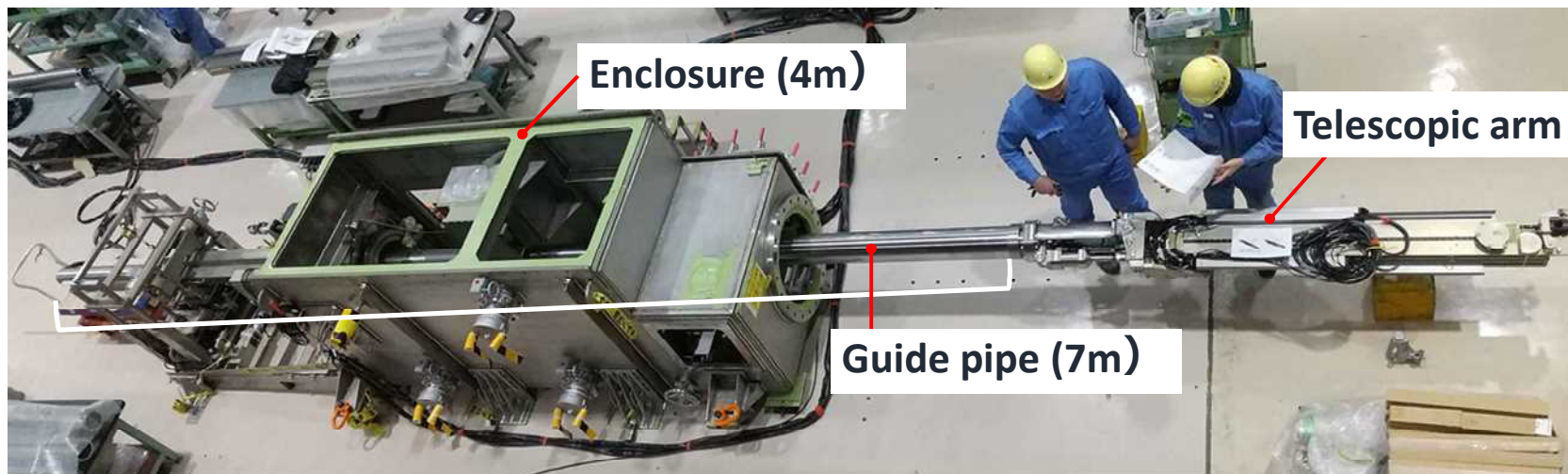


## Telescopic equipment for trial fuel debris retrieval

- The pusher pipes help the guide pipes move in, and then the telescopic arm, manipulated by the tilting mechanism, goes inside the pedestal.
- The end effector, lowered from the telescopic arm, works to sample the fuel debris.



レポート: XSEC0007



- Delivery of the equipment into the Unit 2 building commenced on July 19, once the appearance confirmation and preparatory work had finished.
- Connection between telescopic equipment and existing connection structure/connection pipe began on July 24 and the installation was completed on July 25.



**Operations**



**Connection completed between telescopic equipment & connection structure / connection pipe  
(Scene from above)**

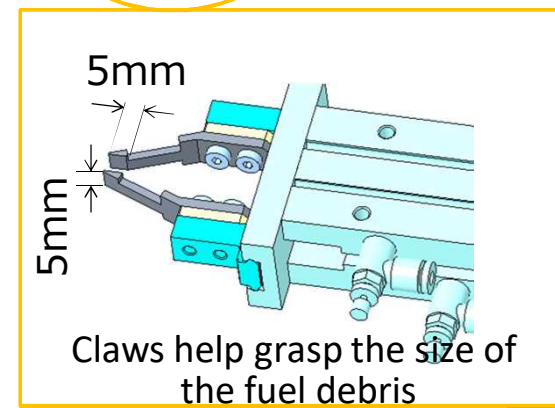
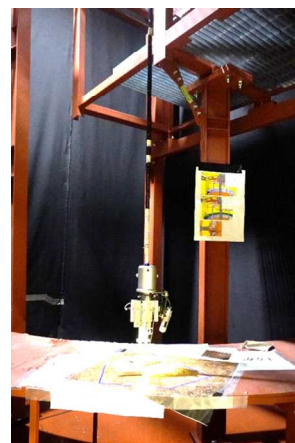
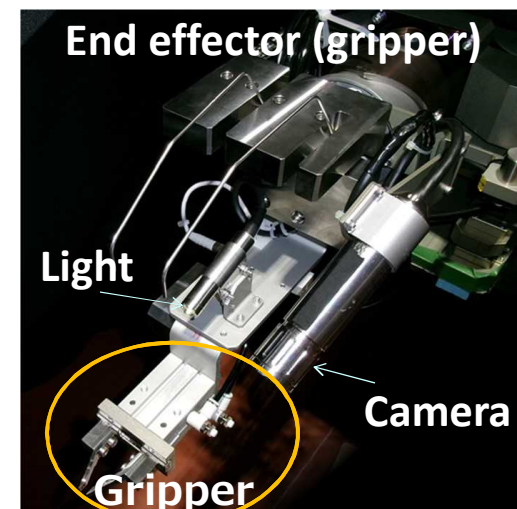
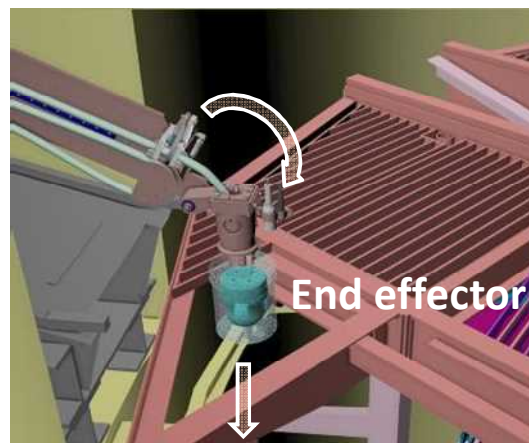
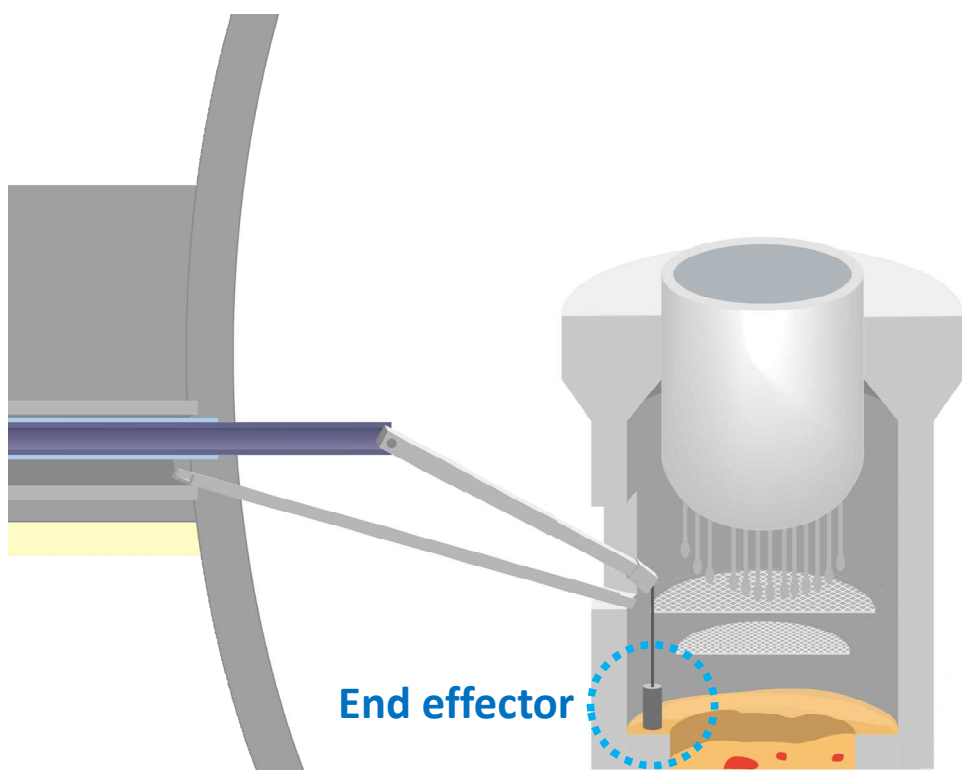
Connection pipe



Telescopic equipment

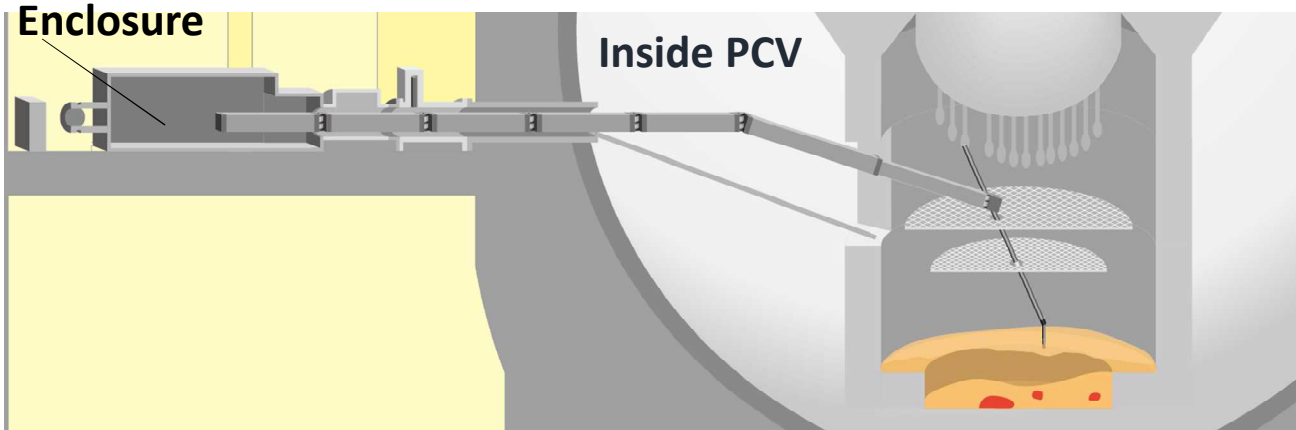
**(Photos taken on Jul. 25, 2024)**

- The plan is to sample granular fuel debris weighing 3 grams or less by lowering an end effector (gripper) to the bottom.
- The mounted camera can determine the size of the fuel debris to be sampled.



- The equipment has a foldable structure with sophisticated controllability, allowing it to pass through narrow spaces such as the X-6 penetration hole.
- A remote-controlled dual-arm manipulator, which will be installed in the enclosure, is responsible for tasks such as placing the retrieved fuel debris into a container.

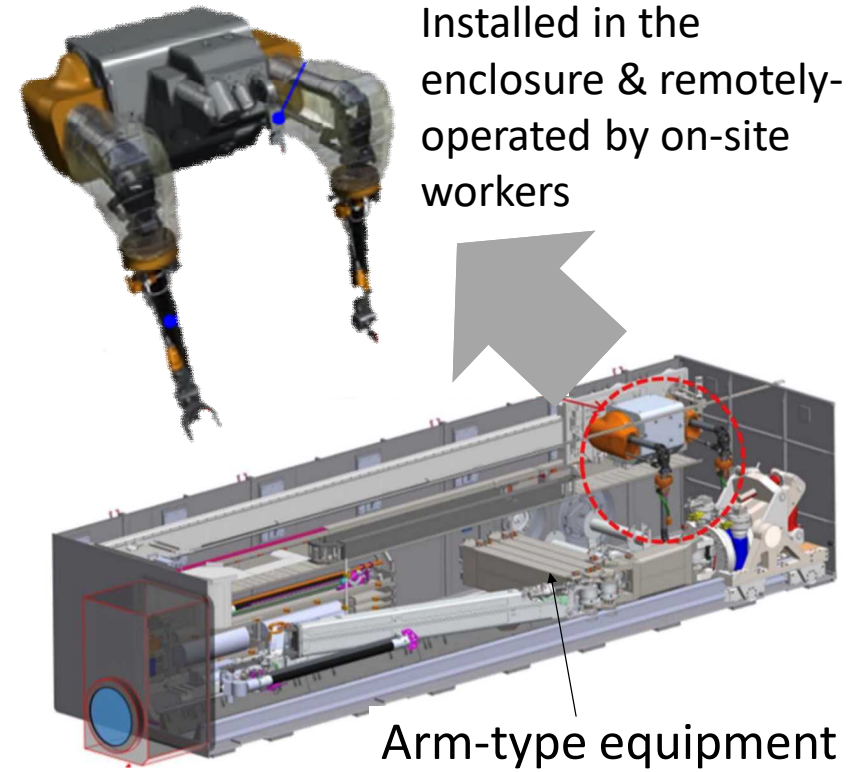
**Extended into the pedestal (22m in length)**



**Folded in the enclosure**



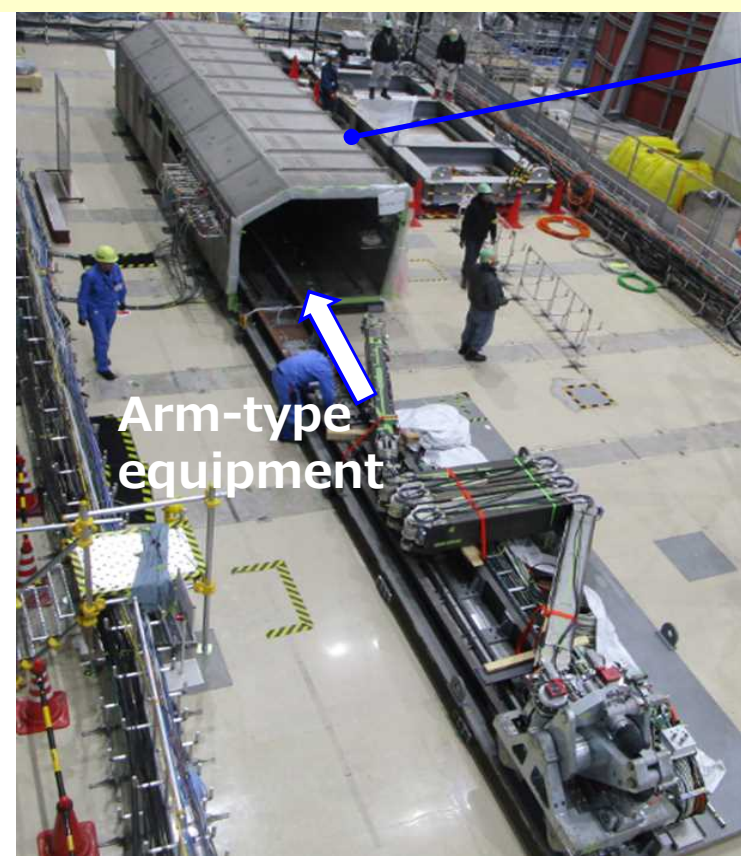
**Dual-arm manipulator**



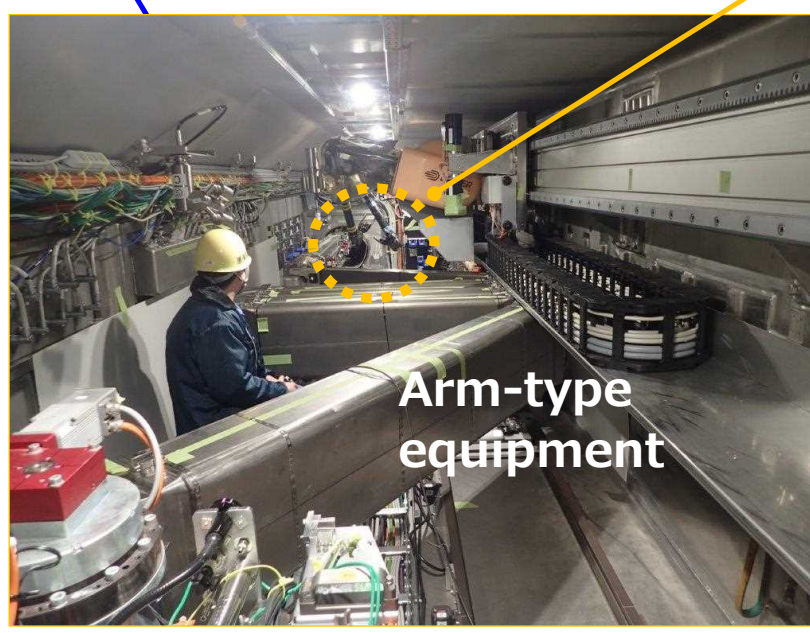
Installed in the enclosure & remotely-operated by on-site workers

Arm-type equipment

- A mock-up test simulating the on-site situation has been conducted using mock-up facilities set up by JAEA in Naraha.
- After the incorporation of the equipment into the enclosure was completed, a manipulation test of the dual-arm manipulator in the enclosure was conducted.

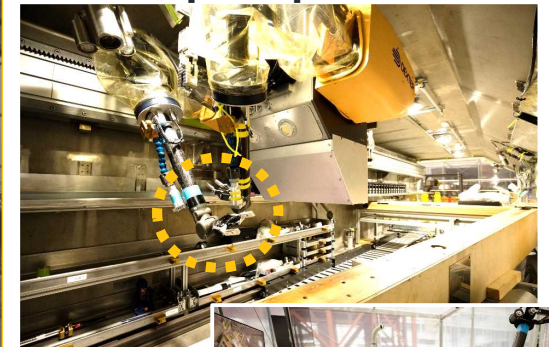


Enclosure  
(housing the equipment)



## Dual-arm manipulator

Similar movement as in manual work



Remote operation for handling radioactive materials

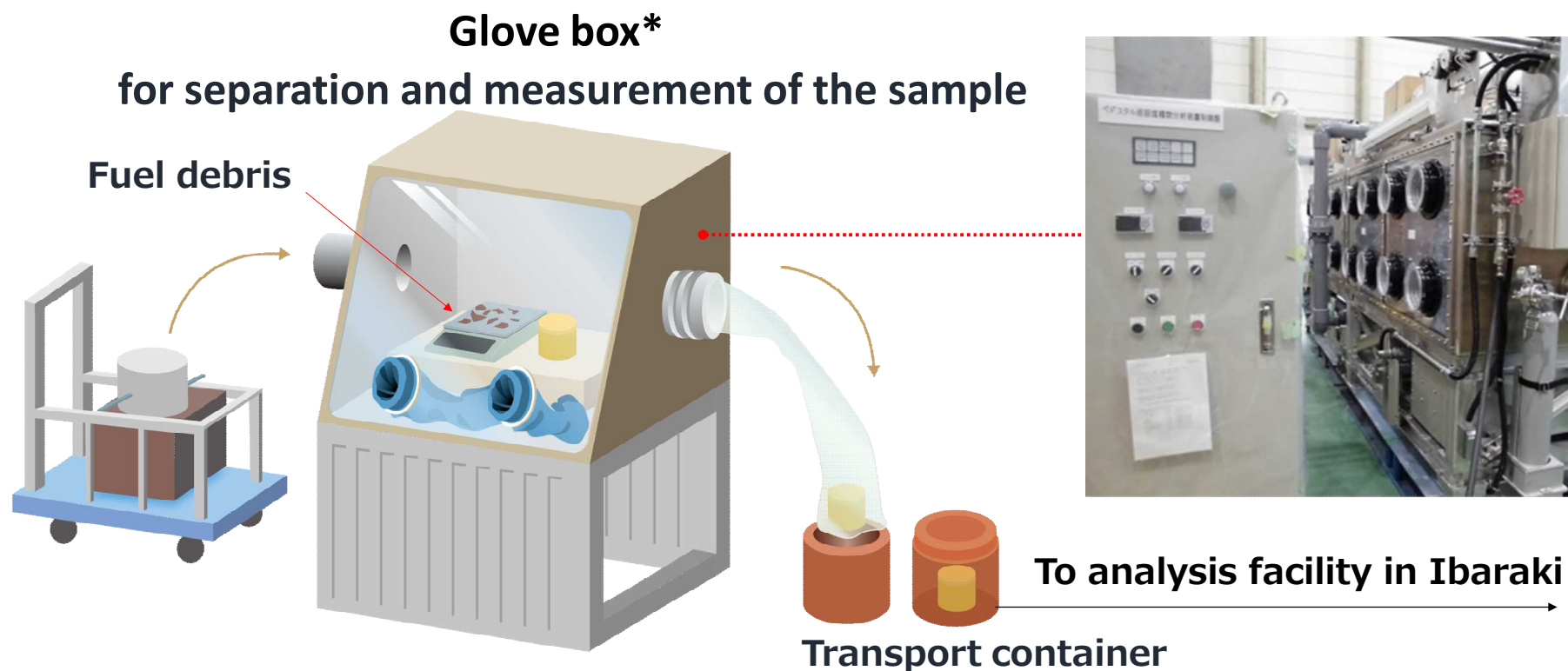




A photograph of a large industrial building, possibly a power plant or refinery, with a tall metal structure on the right side. The text "Property analysis of fuel debris" is overlaid in white.

# Property analysis of fuel debris

■ Fuel debris (up to several grams) obtained through a trial retrieval is set to be stored in a container, and then transported to an analysis facility in Ibaraki, south of Fukushima, where a property analysis etc. will be conducted.



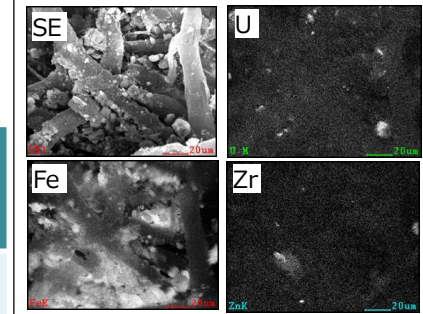
\*Glove box: Airtight container for radioactive materials, made of stainless steel and resin

- Components analysis, radiation analysis, and analysis to understand the local property will be conducted.
- The analysis of the properties of fuel debris is crucial for determining methods to retrieve and store it, as well as for understanding the progression of the accident

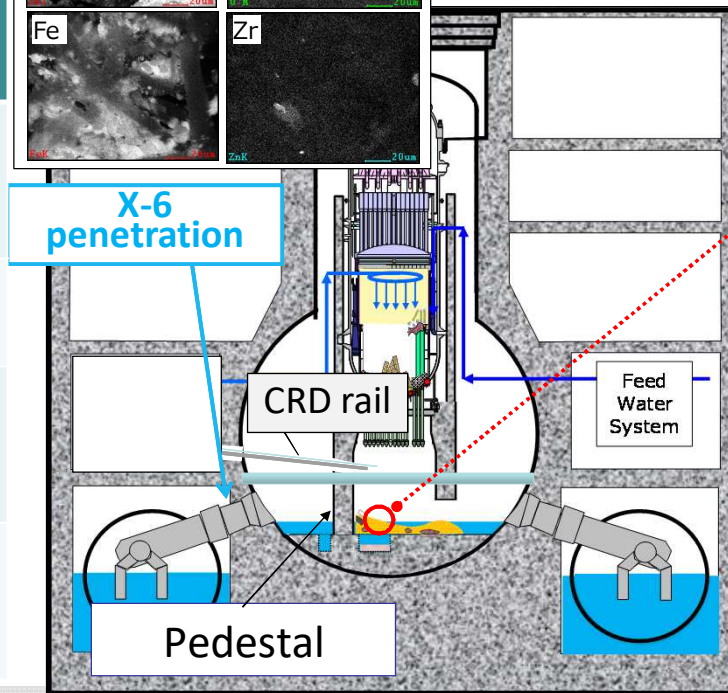
**Key analysis items**

Item	Analysis method	Information to be gained
Components	ICP-AES ICP-MS	Content percentage of Uranium/structure materials, Isotope ratio
Elemental distribution	SEM-EDX SEM-WDX	Compound presence
Radiation concentration	$\gamma$ , $\alpha$ spectrometer	Presence of volatile Cs, Presence of non-volatile Eu, Cm
Crystal structure	TEM electron diffraction	Presumed temperature and atmosphere fuel debris underwent

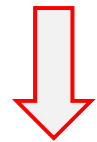
Materials attached to devices deployed in X-6 penetration



Distribution of fuel debris has been presumed based on various investigations and analyses. However, the available information on its properties remains limited.



Detailed analysis of fuel debris



Understand properties of fuel debris around the sampling points



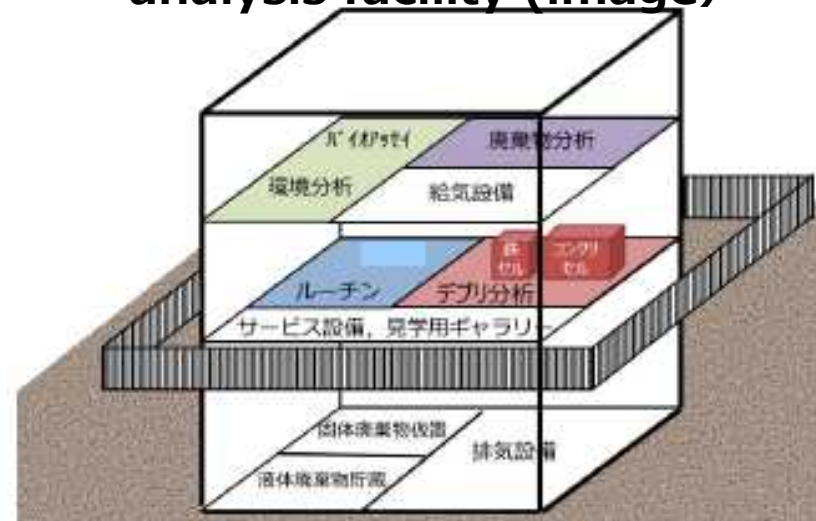
Continue analytical efforts to understand wider range

- Laboratory-2 of JAEA's Okuma Analysis and Research Center is being prepared to start operations in 2026.
- TEPCO's comprehensive analysis facility is scheduled for construction in the latter half of the 2020s.

**JAEA's Okuma Analysis and Research Center**



**TEPCO's comprehensive analysis facility (image)**



Thank you for your attention

TEPCO

