The 7th International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station @Iwaki Performing Arts Center Alios

Historical challenges to understand the in-reactor and containment status of Units 1 to 3

August 28, 2023

TEPCO

What is accident progression analysis method?

- High level of radioactivity inside the reactor buildings made it difficult to directly confirm the situation of the damaged reactors just after the accident.
- Understanding the in-reactor and containment status of units 1 to 3 which suffered core damage and meltdown is crucial in decommissioning the plant.
- Thus, we started the accident progression assessment using analysis code, which led us to assess the situation of damages inside reactors and PCV s.

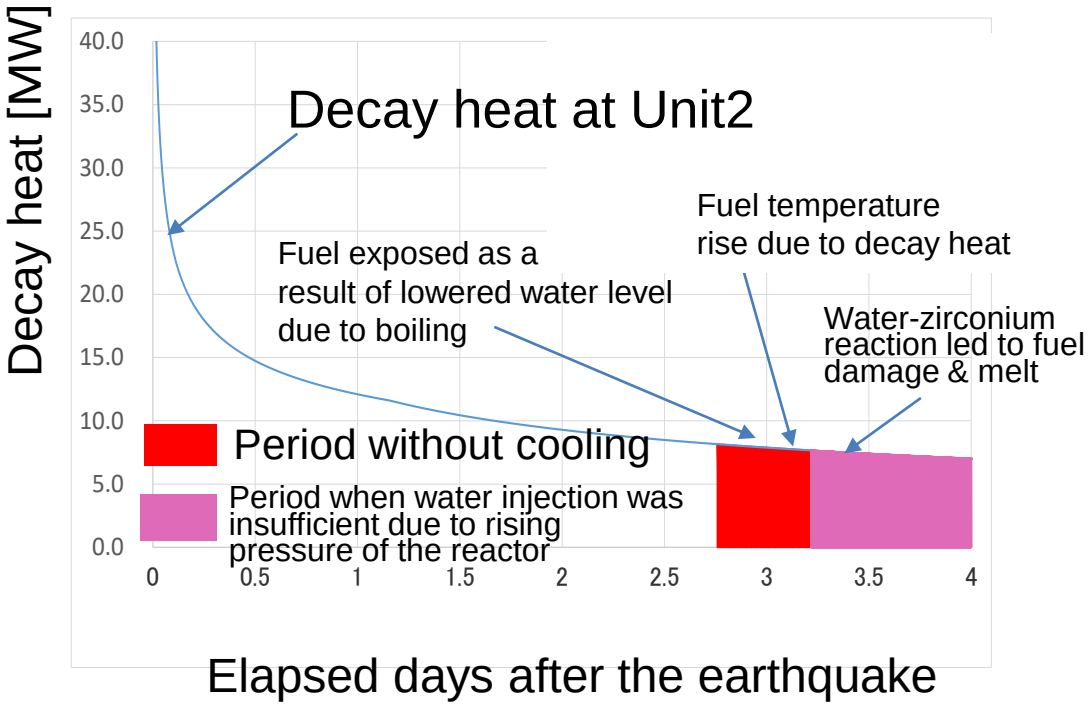
Assessment using analysis code

○ **Sufficient knowledge of the reactor design** and **research findings on the accident obtained so far** were incorporated into analysis code, which has enabled us to assess the damage of fuel, reactors and PCVs.
As of 2011, we had reached the basic conclusion on the accident that its severity was in the order of Unit 1 ＞Unit 3＞Unit 2

×
- The actual BWR accident was unprecedented and is beyond the knowledge of technicians who have never witnessed the actual plant,
- The analytical results using analysis code are not able to cover all the aspects of the damaged reactors, because it doesn't consider all of the structures and phenomena.

Findings by analysis code assessment

The accident at Units 1 to 3 was due to the inability to remove decay heat, i.e. the energy from decay heat melted fuel and damaged reactors.

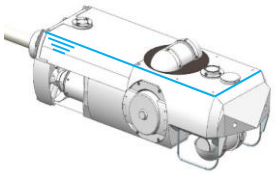


Analysis code assessment is to analyze accident progression by assessing how the accumulated energy is harnessed during the period without cooling (red part).

①Water boiling→Water lost
②Rise in fuel temperature
③Chemical reaction
（heat generation/heat absorption）
④Fuel melt
⑤Heat transfer from melted fuel to structures & accompanying structure damage / melt

What is PCV internal investigation?

- As the dose on the premises and inside the R/Bs decreased gradually due to decay, TEPCO became capable of conducting hands-on investigation after 2012.
- R&D started after the accident, resulting in the development of robotics and measuring instruments. These were applied on the site and the situations inside the PCVs started to be gradually uncovered.



<u>Hands-on observation by internal investigation</u>

○
- Seeing is believing
- Actual status including structures and phenomena which are not assessed by analysis code can be obtained as footage and dosimetry data. That means hands-on investigation is indispensable to understand the in-reactor and containment status.

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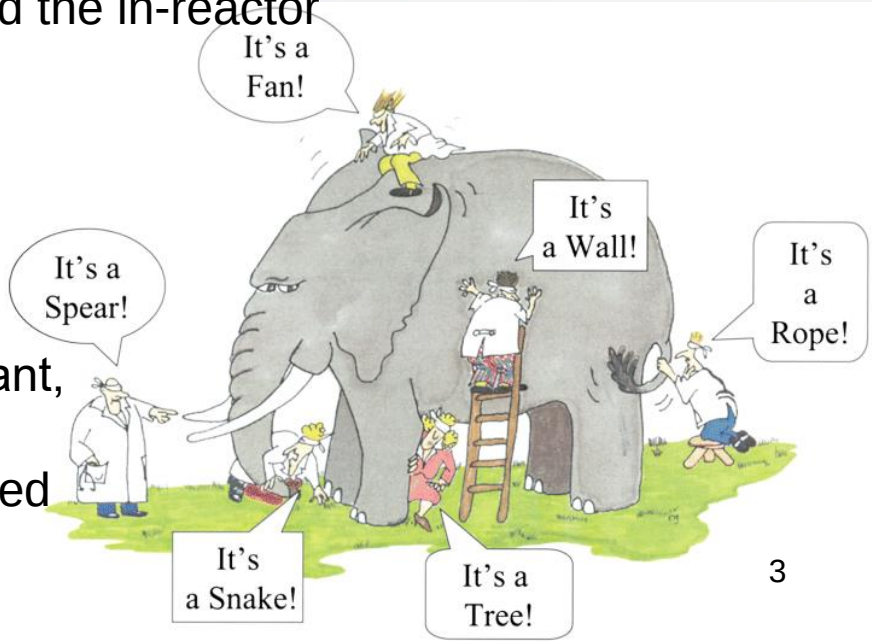
- Accessible areas are limited.
- You cannot observe without cameras.
- Relying on remote technology for observation creates the situation like "Blind men who touch just part of an elephant, and try to describe the whole animal".

Thus, interpretation of what has been observed tends to become a challenge.



Inter-disciplinary approach between accident progression analysis and internal investigation to understand the in-reactor & PCV status

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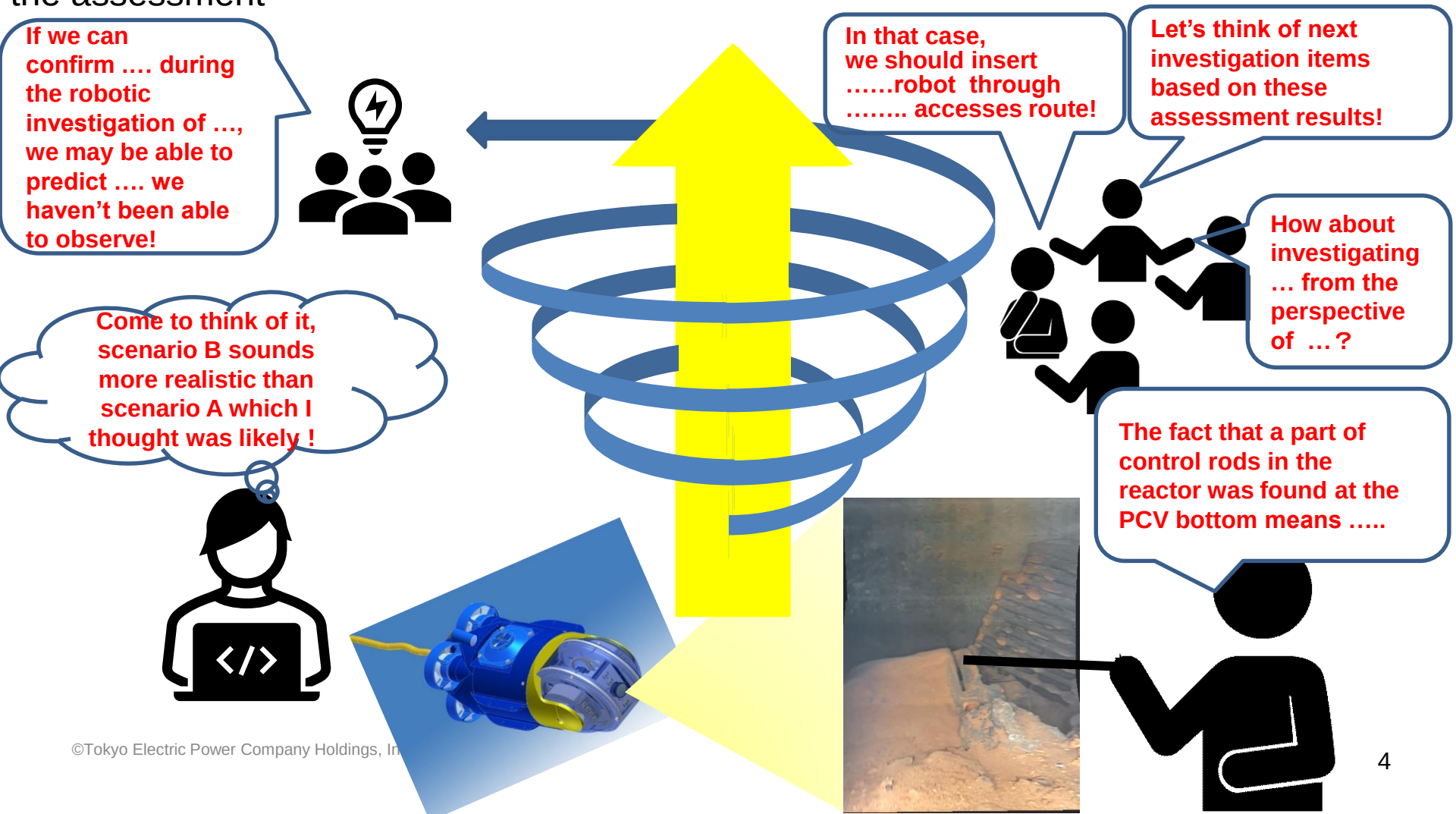
An accident progression analyst is akin to an expert on elephants who has never seen an elephant, while a person in charge of internal investigation is like someone blindfolded, compelled to deduce something solely based on their tactile experience with the elephant. They both cooperated and complemented each other, contributing to an upward spiral in the assessment



History since the accident

Internal Investigation

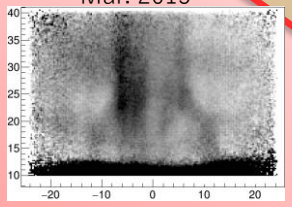
Investigation of torus room in Unit 2 (Apr.2012)

Unit 1 PCV internal investigation (Oct. 2012)

Unit 1 PCV interna investigation (Mar. 2017)

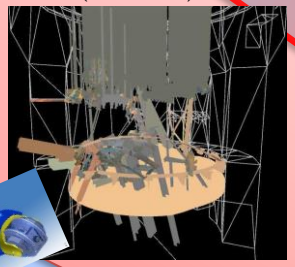
Visiting overseas countries which experienced fuel debris retrieval for training in fuel debris analysis
1) TMI 2 knowledge transfer work shop @ Idaho
2) Chornobyl fuel debris analysis seminar @ Khlopin Radium Institute

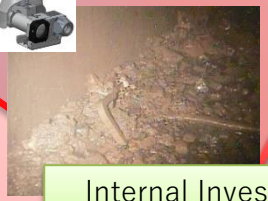
Muon investigation Mar. 2015



Accident Progression Analysis

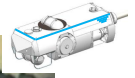
Unit 3 PCV internal investigation (Jul. 2017)

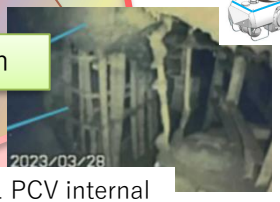




Unit 2 PCV internal investigation (Jan. 2018)

Internal Investigation



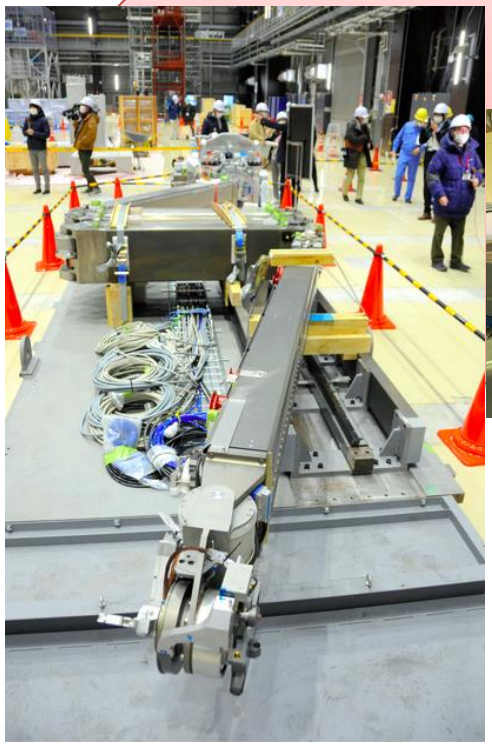


Unit 1 PCV internal investigation (Mar. 2023)

Path toward fuel debris retrieval

Fuel debris retrieval

Preparation toward trial retrieval at Unit2



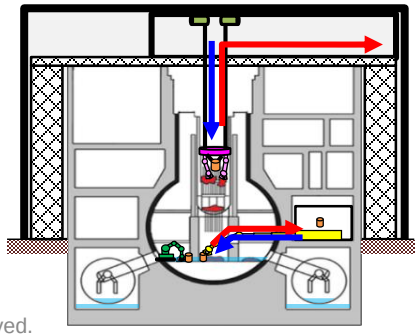
Retrieval in stages

Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods

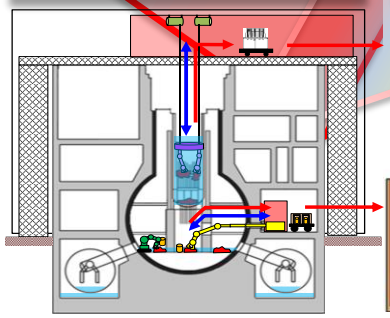
- 1st committee held on Mar. 29, 2023
- Discussions to continue, with the latest 5th committee having been held on Jul. 19.

Expansion of retrieval in scope

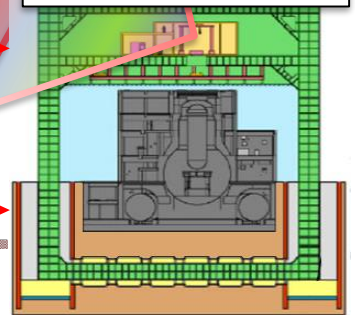
Dry method



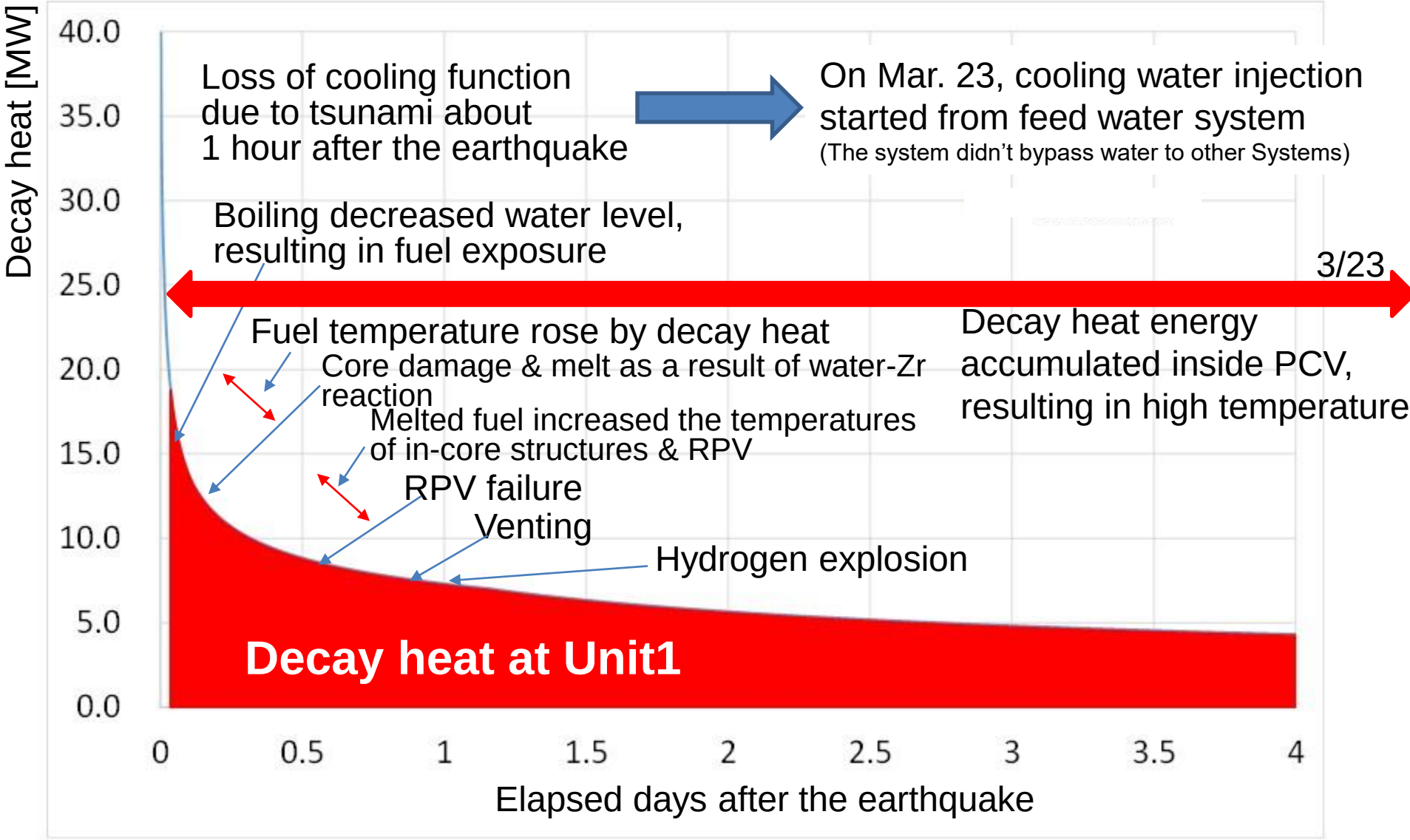
An option of dry method



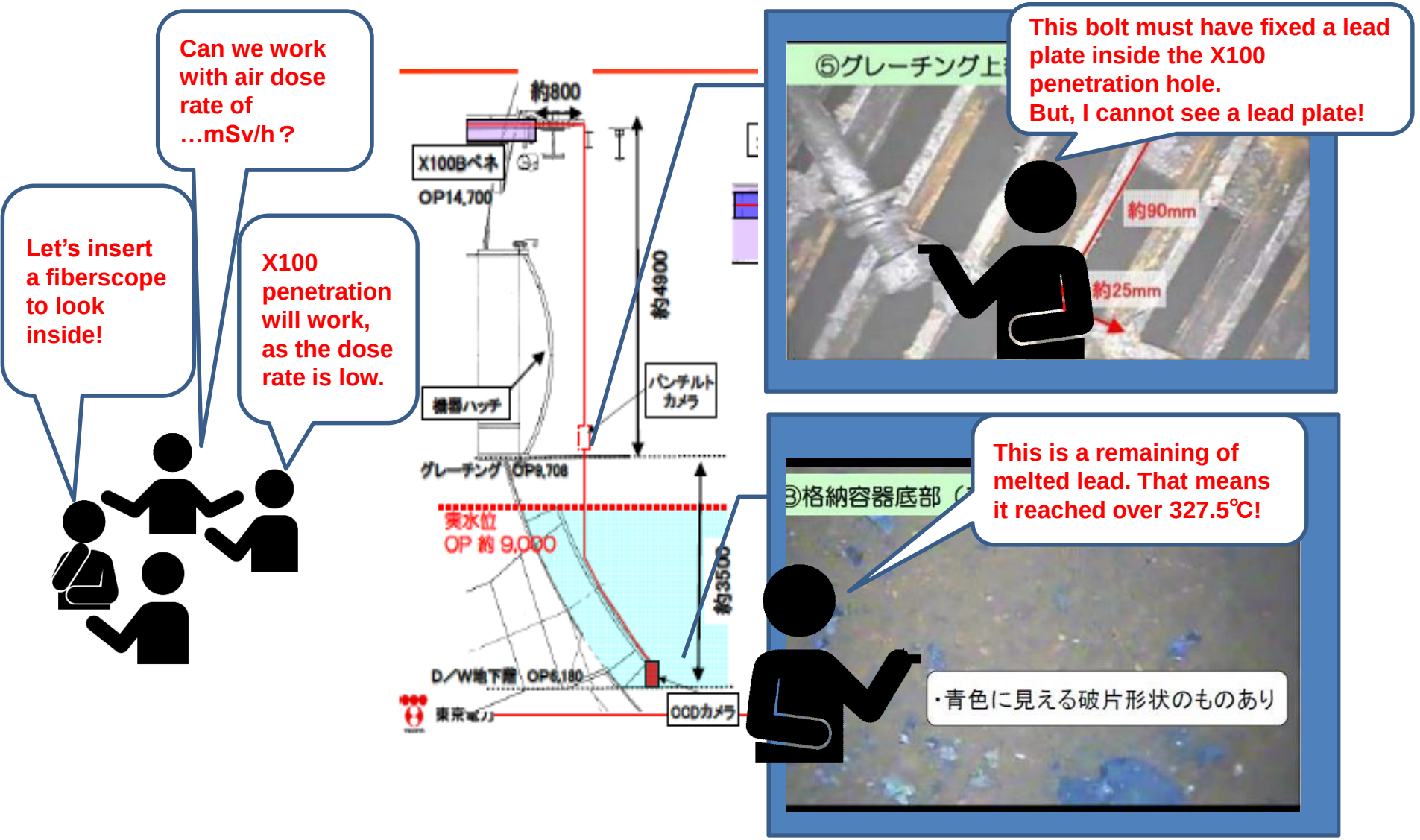
Submersion method



Accident progression at Unit 1

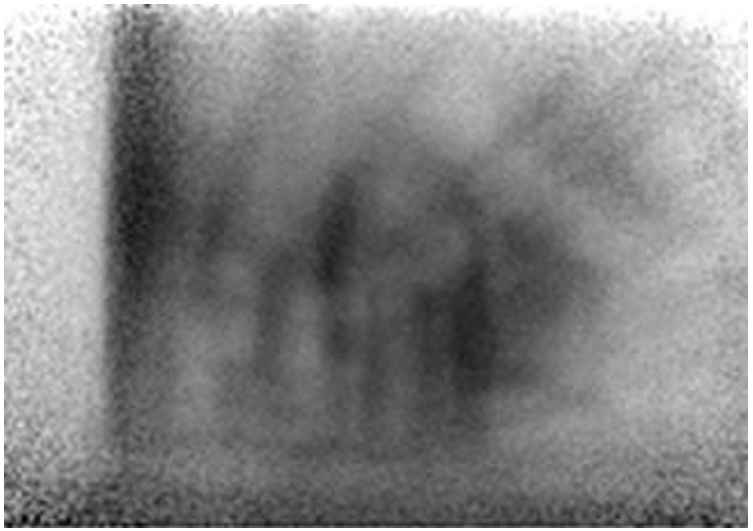


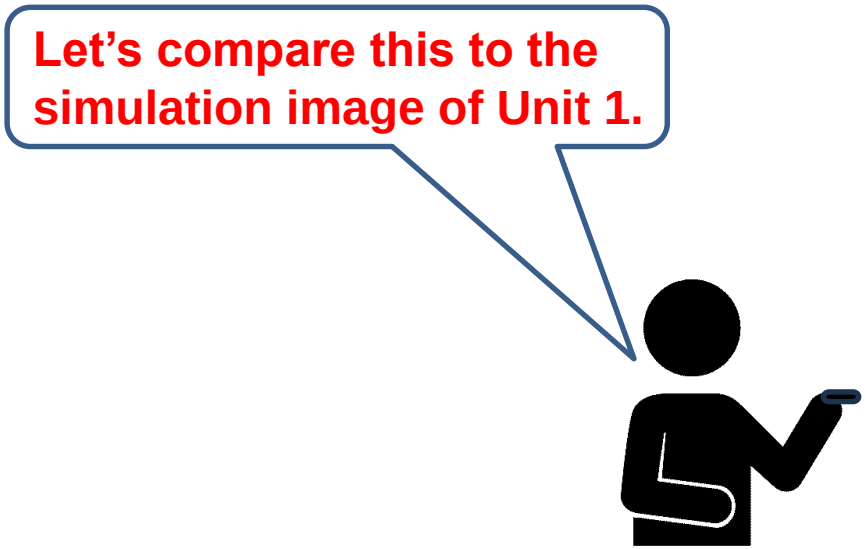
Unit 1 PCV investigation in Oct. 2012



Muon investigation results at Unit 1 in 2015

Clarification of Muon investigation results at Unit 1 in 2015





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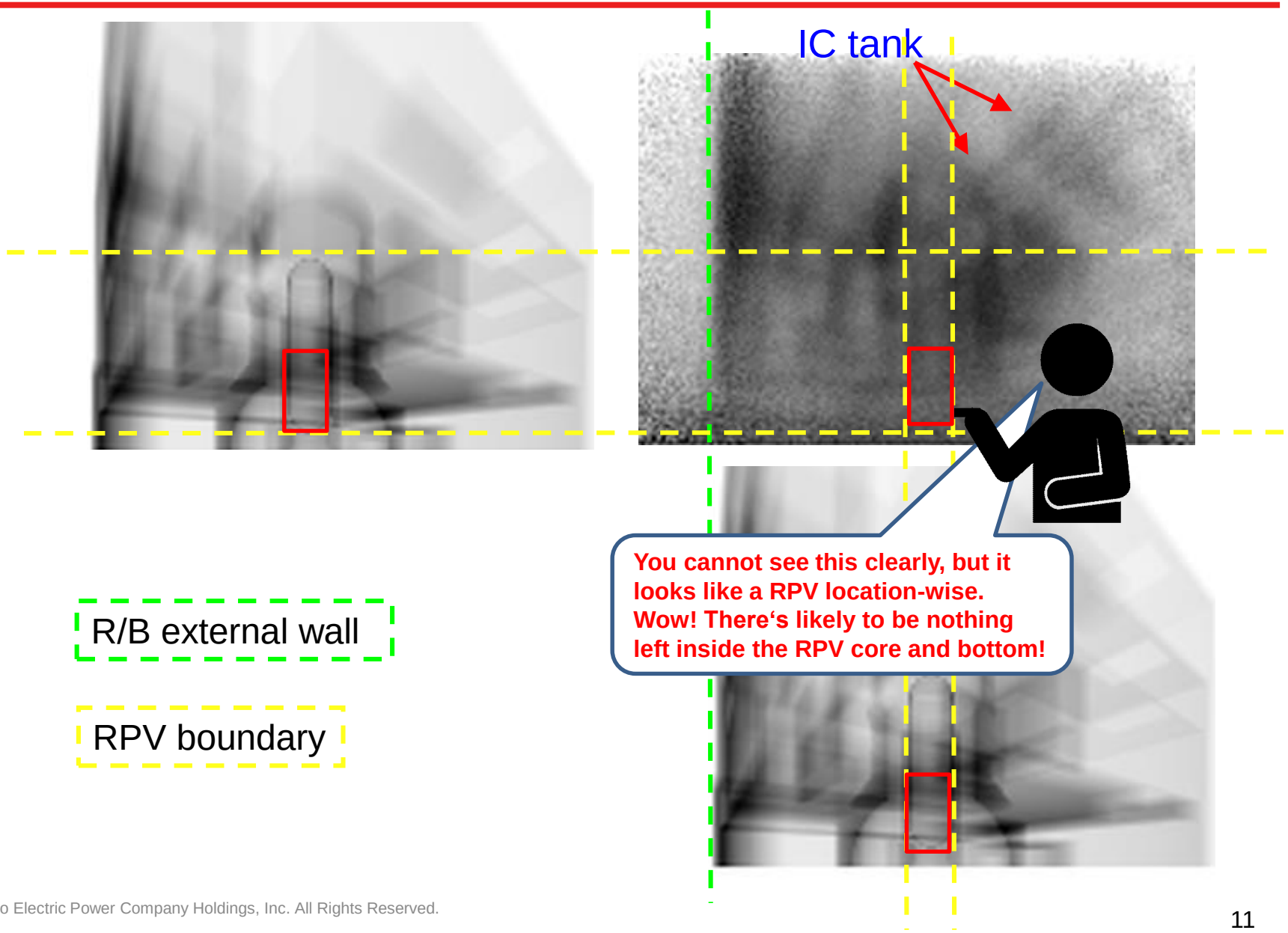
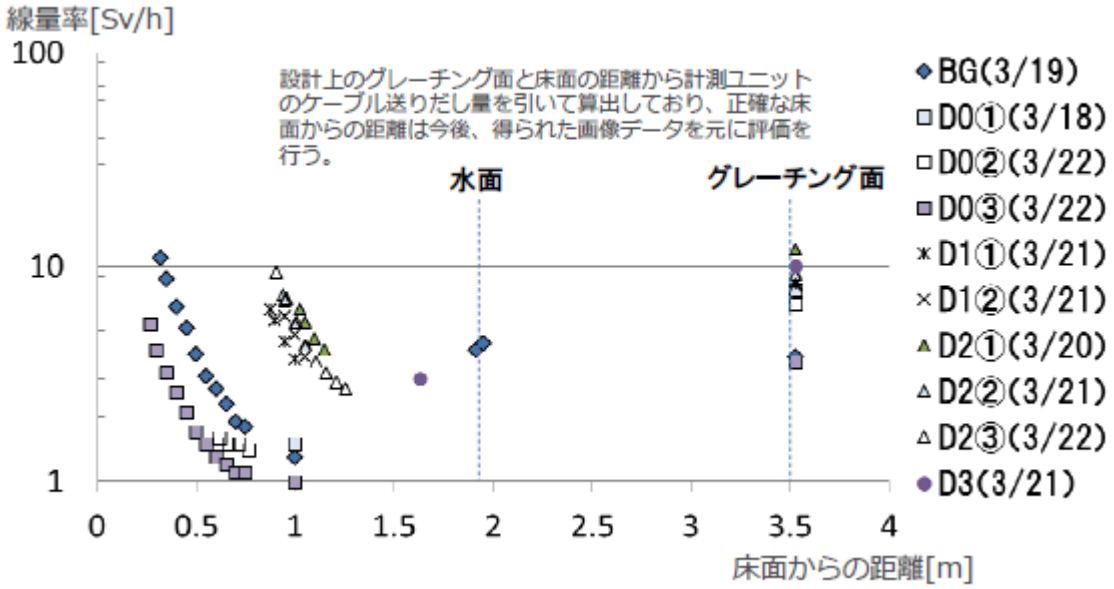
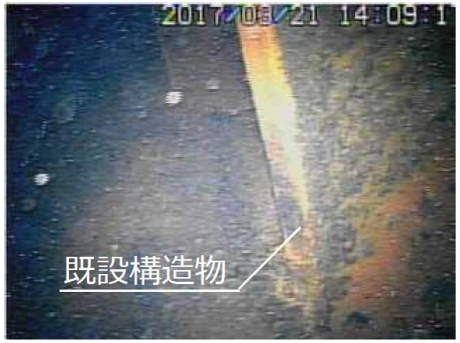


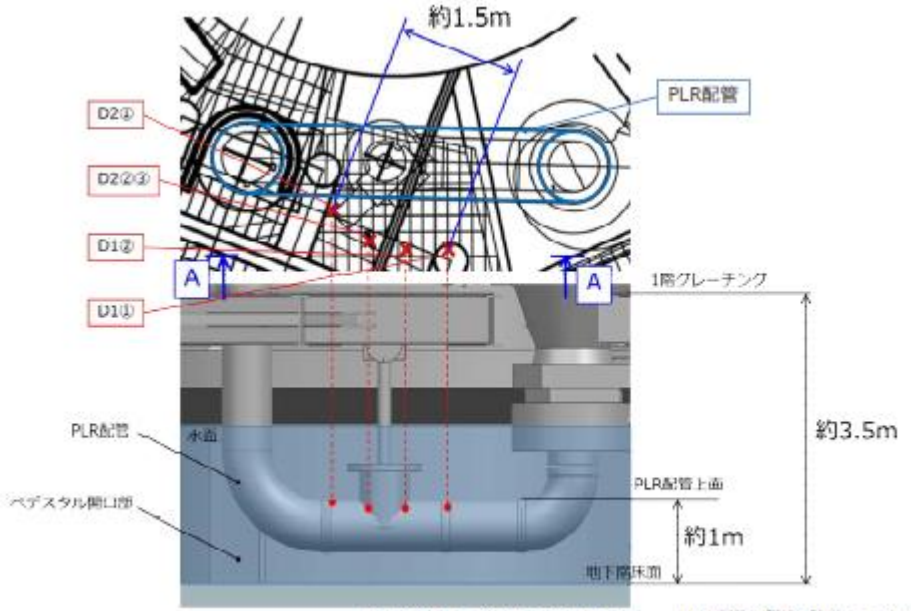
PCV internal investigation using a shape-changing robot at Unit 1 in March 2017





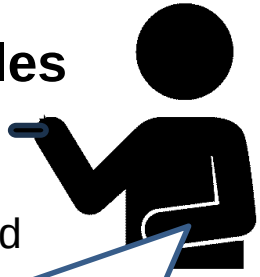
3/21　D3　最下点近傍の画像

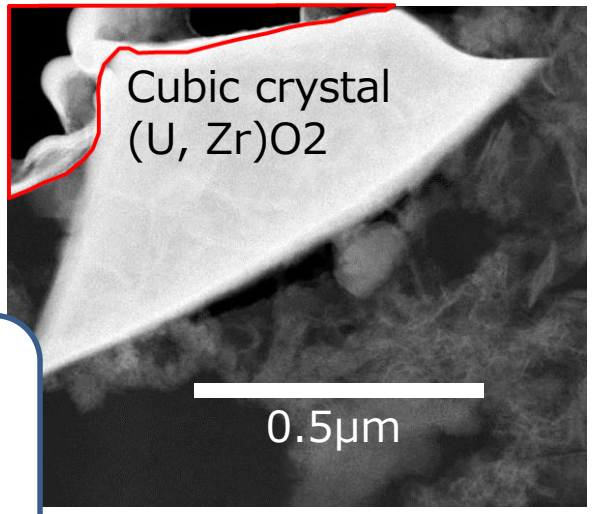
3/20　D2①　最下点近傍の画像



Information obtained from the sample analysis at Unit 1

- **Observation results of the samples as a whole**
  - SEM-EDS analysis results show a mixture of U bearing particles with the rust.
  - But, the average concentration of U in the observation area (about 300μm×200μm) is low and undetected.
  - ICP-MS analysis results show Fe is the largest in constituent, followed by Al, Cu, Zn, Pb, U etc.
- **Observation results of U particles**
  - Cubic crystal rich in U(U, Zr)O2, cubic crystal rich in Zr (Zr, U)O2, & monoclinic crystal ZrO2 were observed





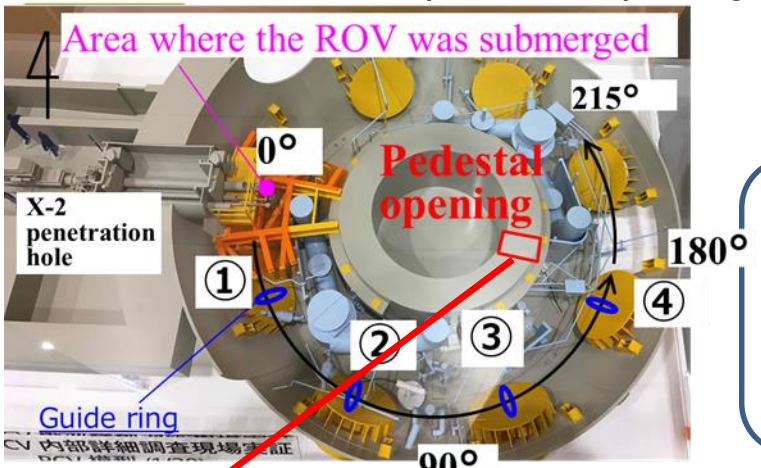
These were also observed in the TMI-2 fuel debris. That indicates the samples experienced extremely high temperature and ZrO2 cooled down slowly, which is in line with the accident progression assumption.
It is promising for future retrieval that chemically unstable U3O8 and UO3 have not been observed.

Crucial information regarding the fuel debris distribution for its retrieval in the future.

Even though the proportion is small, it indicates that U-containing materials have been found outside the pedestal.

Findings by ROV investigations at Unit 1 in 2022 to 2023 (1)

A. Near the pedestal opening



Previous MCCI experimental results

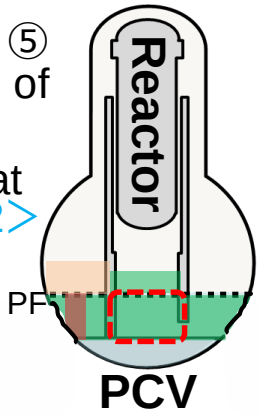
The MCCI knowledge obtained through the past experiments suggested if melted fuel drops to the concrete, it eats away the concrete vertically and then horizontally.
The situation of the pedestal at Unit 1 is quite different from that!

It was confirmed that the lower part of concrete was lost and rebars were exposed at the opening of the pedestal.

This is a new piece of information for accident progression analysis and its implications for the decommissioning should be considered.

Findings by ROV investigations at Unit 1 in 2022 to 2023 (2)

- The ROV couldn't reach points ⑧, ⑨, and ⑩. But the footage taken at point ⑤ and the one taken during its movement enabled us to ascertain the base parts of pedestal. <Photo1,2>
- The observed base parts look similar to other investigation points with concrete at the lower inner part of the pedestal partially lost and rebars exposed. <Photo1,2>



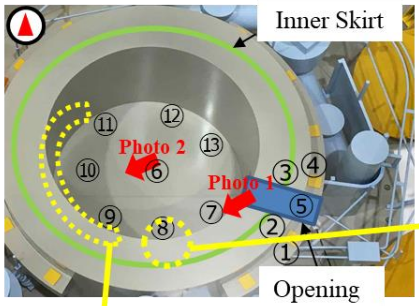
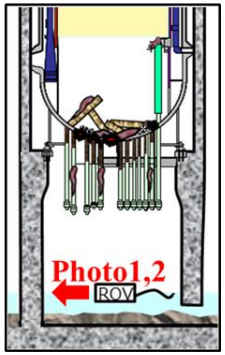


Photo 1: Point ⑧ at pedestal base



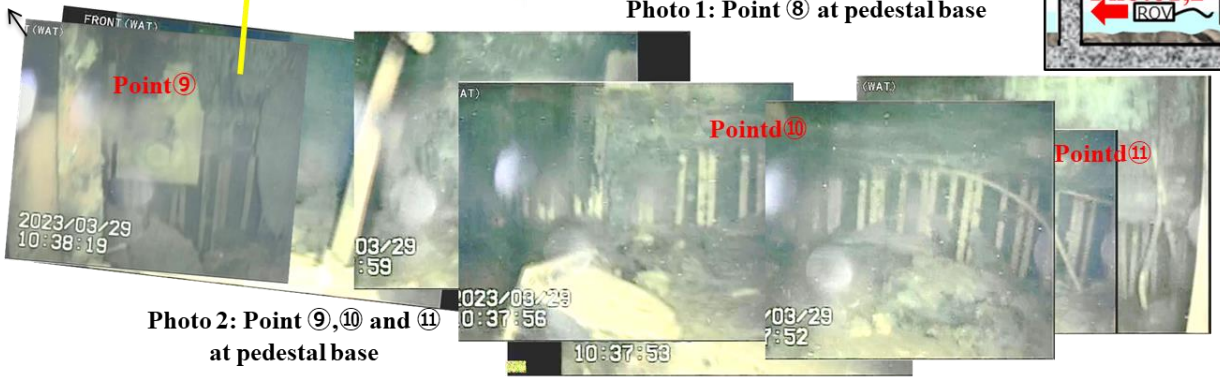


Photo 2: Point ⑨,⑩ and ⑪ at pedestal base

The concrete has been confirmed to be lost along all circumference inside the pedestal.

Findings by ROV investigations at Unit 1 in 2022 to 2023 (2)

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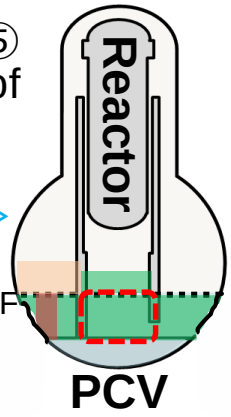


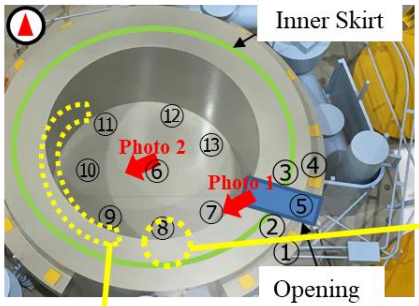
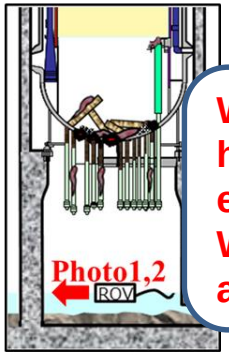


Photo 1: Point ⑧ at pedestal base



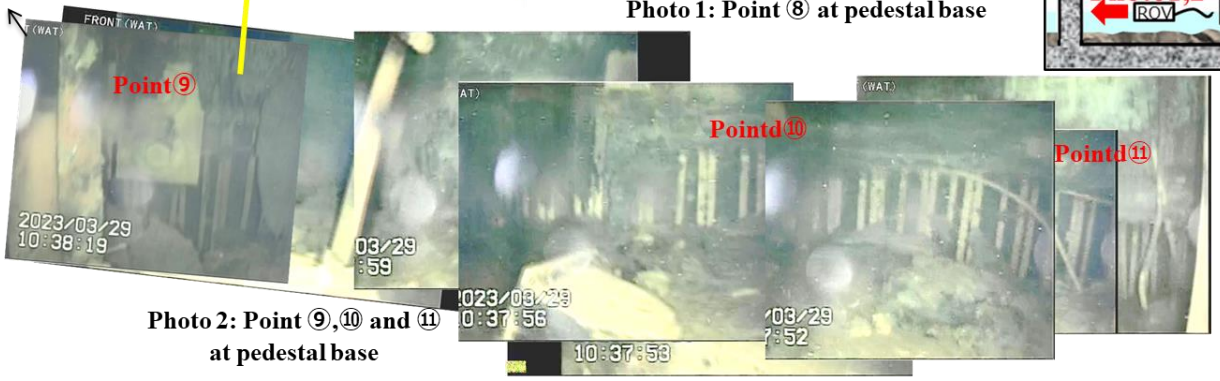


Photo 2: Point ⑨,⑩ and ⑪ at pedestal base

Why is it that pedestal concrete has been lost around almost its entire circumference?
Why are the missing sections all approximately the same height?

The concrete has been confirmed to be lost along all circumference inside the pedestal.

Integrity of the pedestal at Unit 1

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- Three steps are being taken, considering that the concrete has been lost at the lower part of the pedestal.

1. Assessment of the effects have been conducted by evaluating the strength of the inner skirt remaining in the pedestal. The result shows, even with the Mar. 2011 class earthquake, the structure will not suffer large scale collapse.

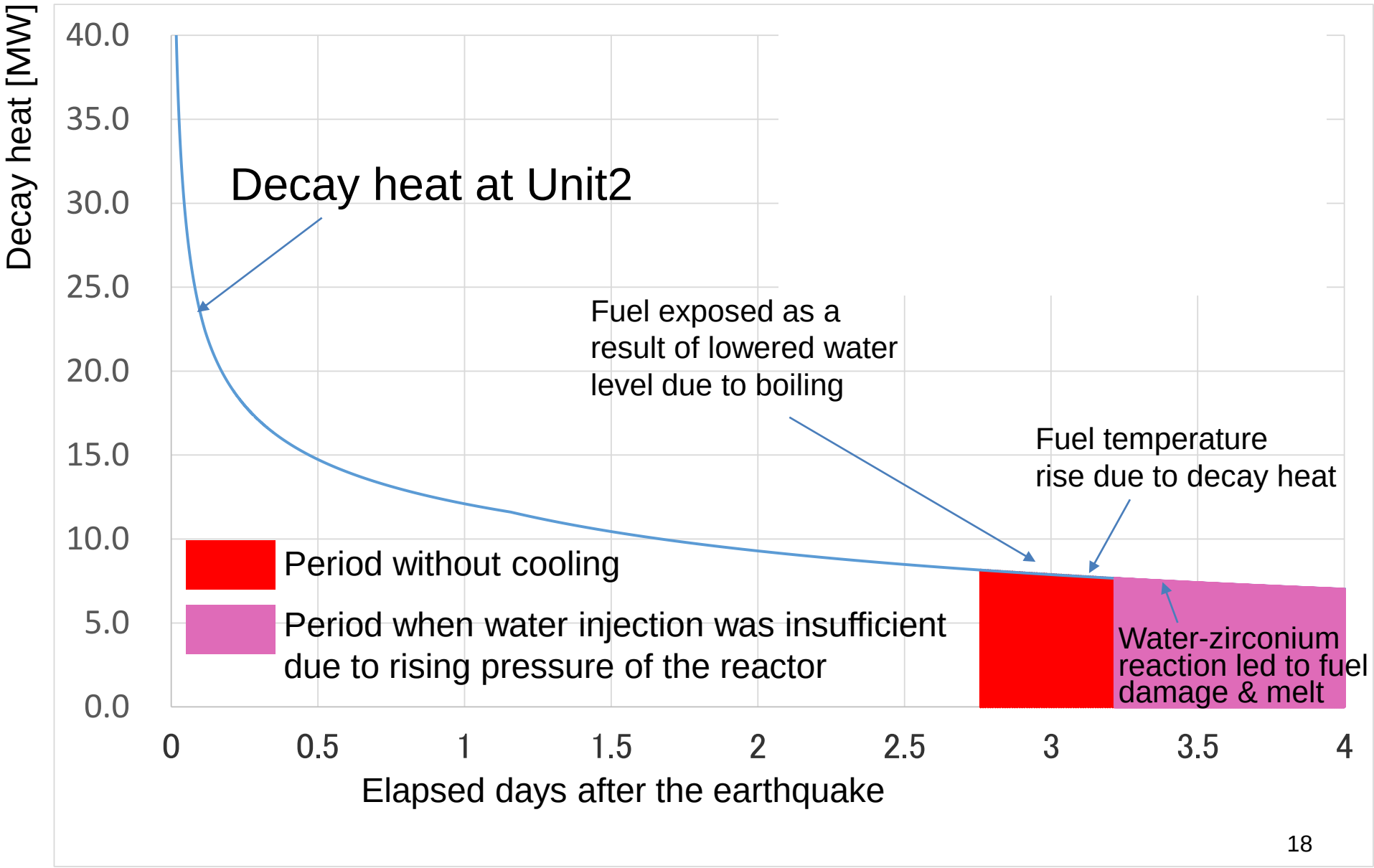
   ⇩ But, we shouldn't be complacent with the assessment result.

2. Assuming that the support function of the pedestal has deteriorated, a conservative scenario has been made. The result shows 0.03～0.04mSv per incident at the site boundary, which is much lower than 5mSv per incident, the criteria for accident scenarios.

   ⇩ Mitigation measures to be prepared in case of emergency

3. In case of loss of the supporting function, measures to prevent the radioactive dust from dispersing will be in place.
   - Preparation to stop injecting nitrogen in case of emergency based on the idea that the amount of nitrogen injected should be smaller than that of exhaust for ease of controlling the dust leakage.
   - Agile responses (Restoration of exhaust facilities using mobile equipment etc.)

Accident progression at Unit 2



PCV internal investigation at Unit 2 in March 2012

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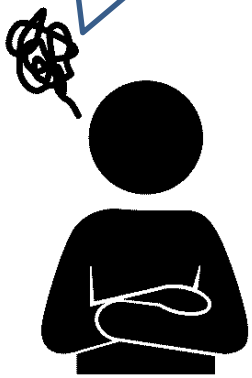
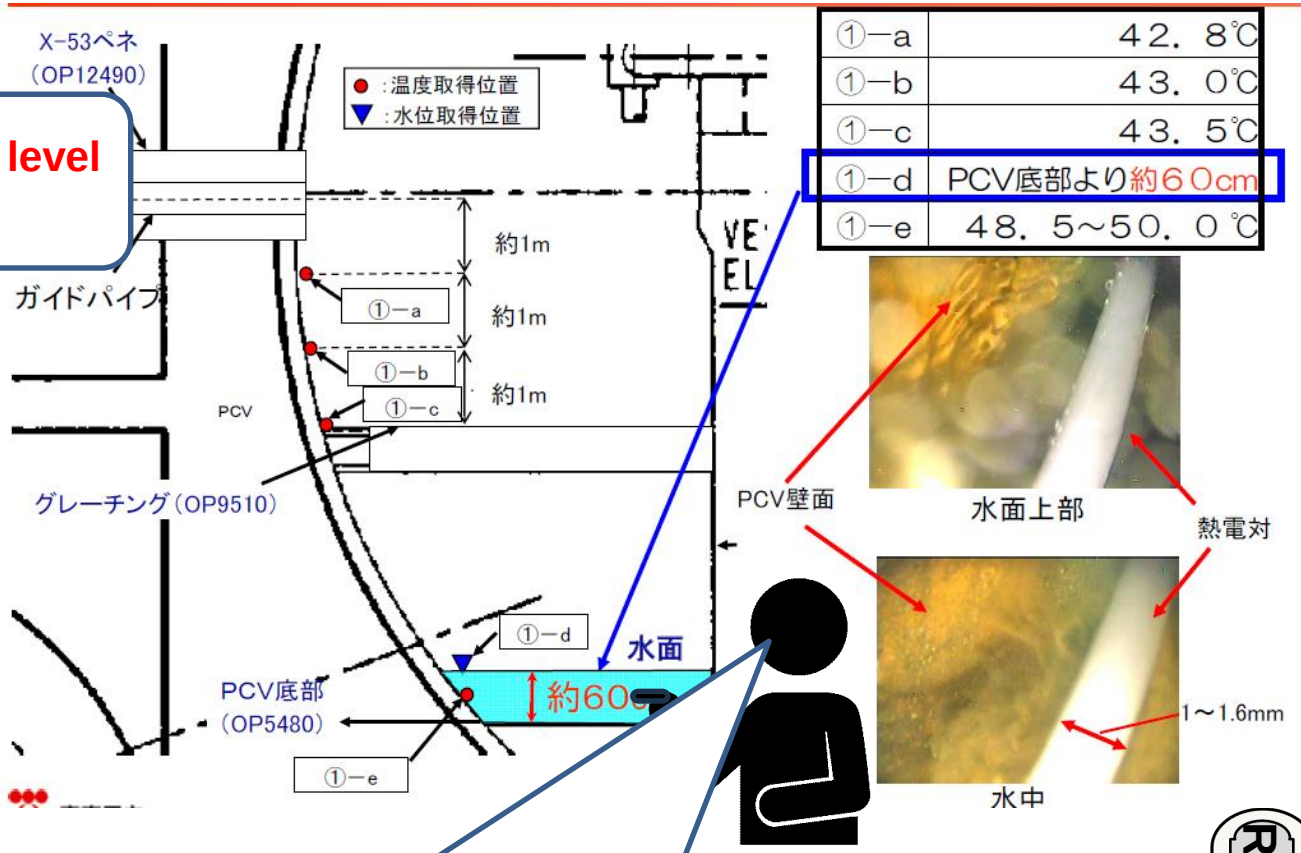
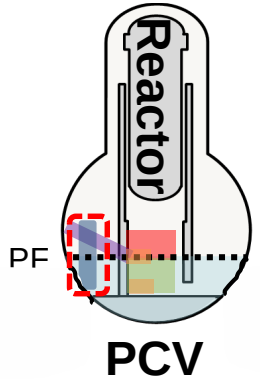
Why is the water level in Unit 2 so low?



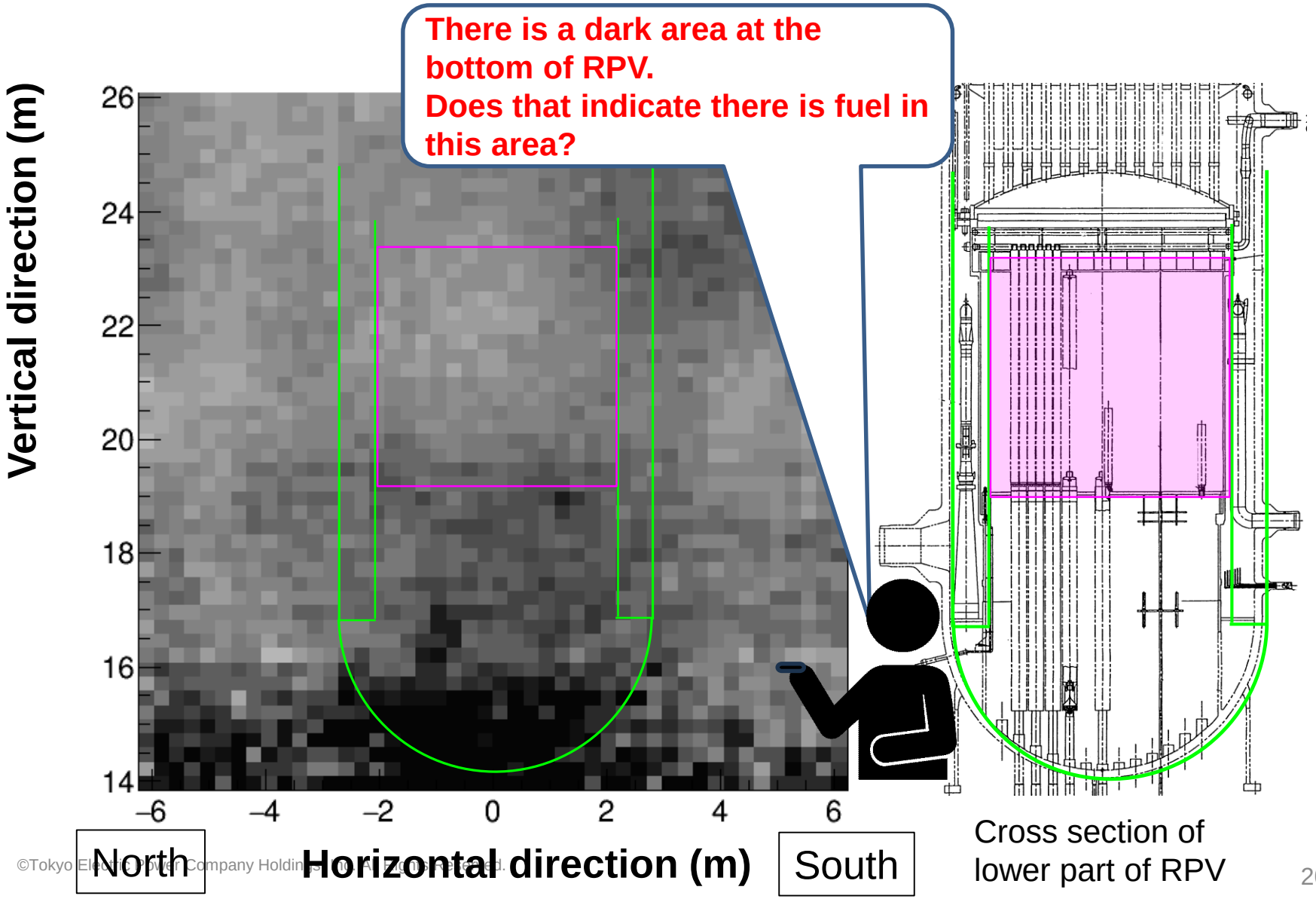


①−a	42．8℃
①−b	43．0℃
①−c	43．5℃
①−d	PCV底部より約60cm
①−e	48．5～50．0℃

The PCV water level is no higher than the one in the venting piping that leads to suppression chamber.
Does that mean water leakage from venting piping or suppression chamber?



Results of muon investigation conducted at Unit 2 in 2016



An investigation inside the pedestal at Unit 2 PCV using a camera robot in 2018

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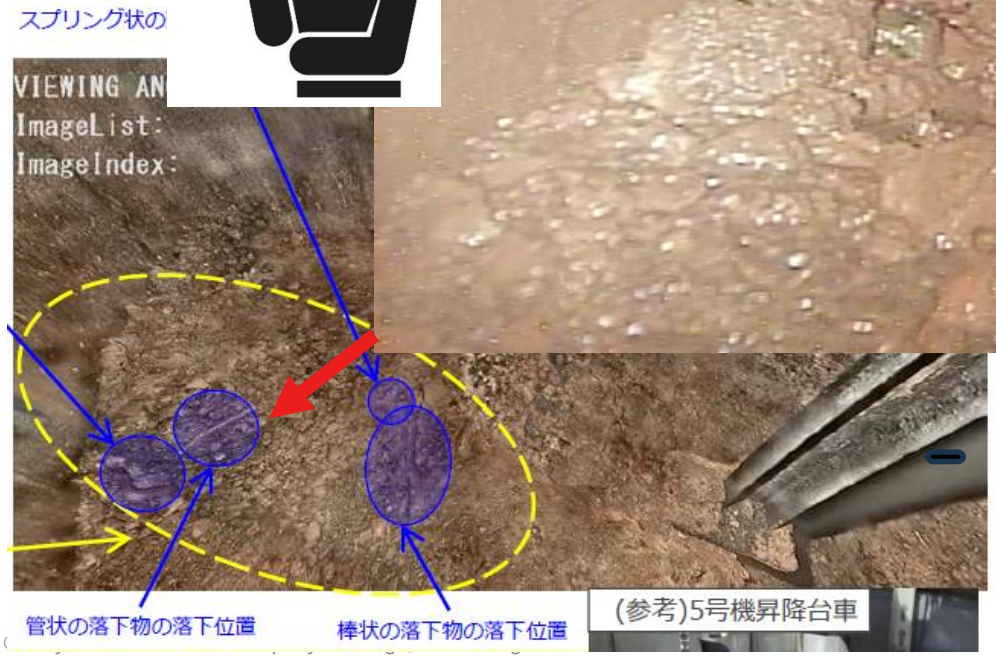
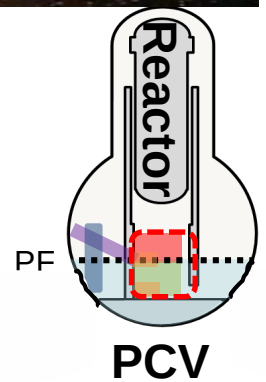
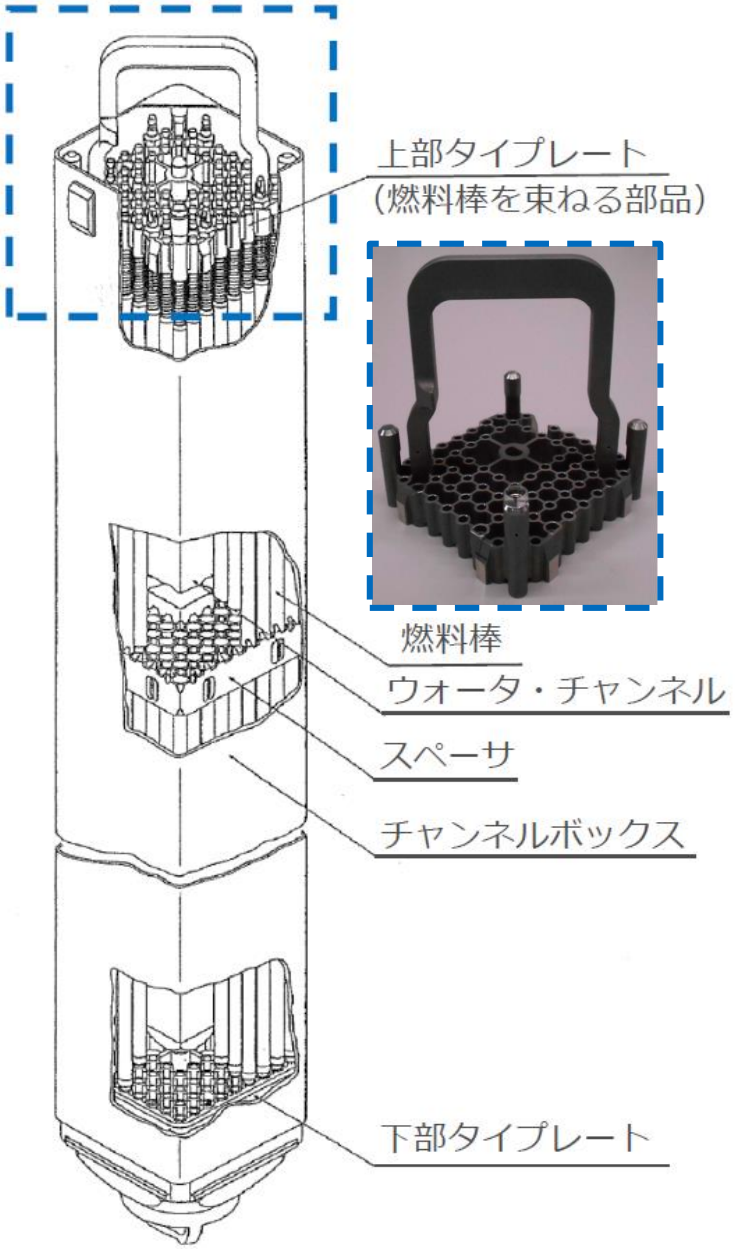
Pebble-like deposits spread all over the floor inside the pedestal. Moreover, there are a couple of places where deposits are accumulated higher than others

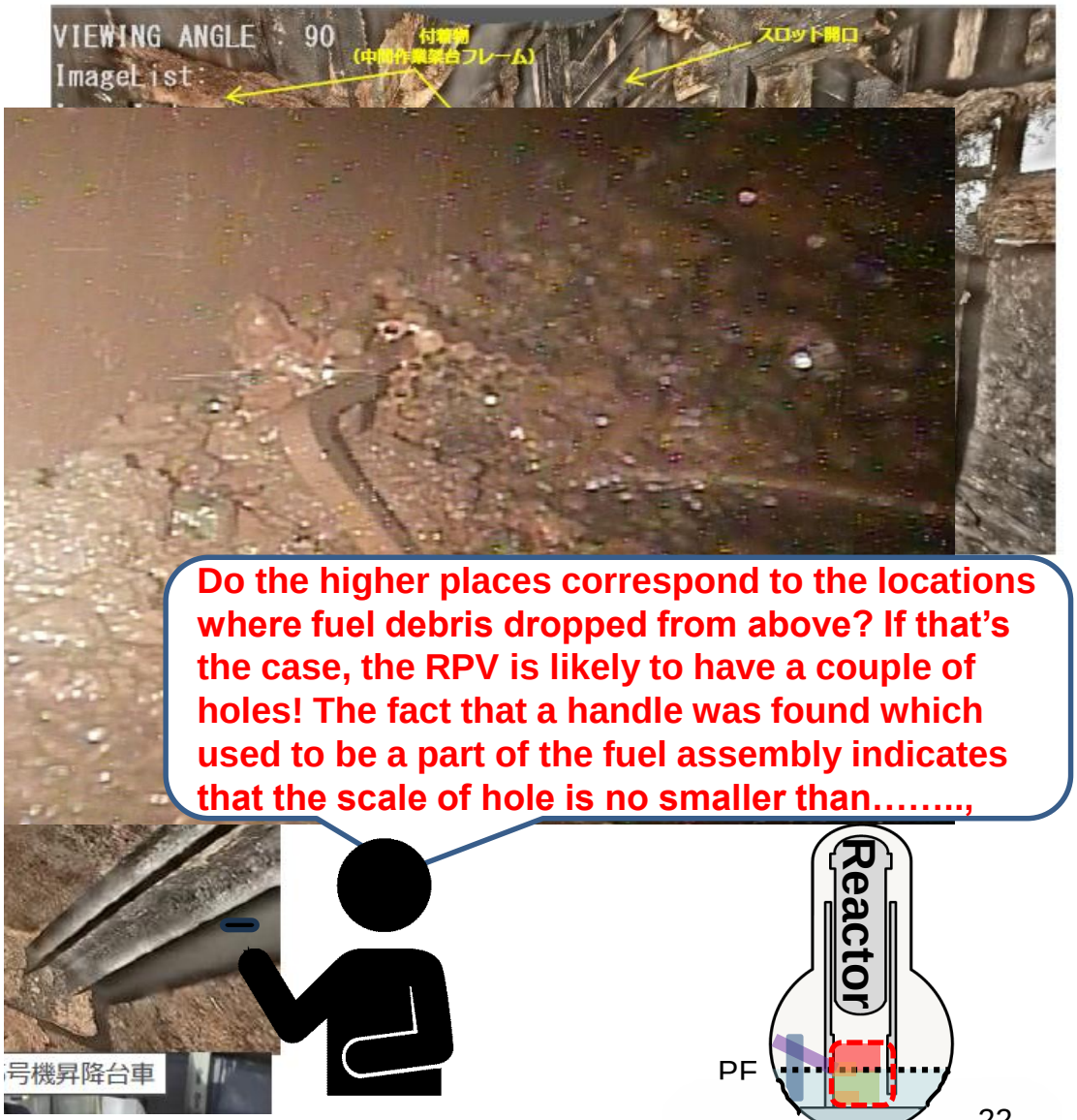




An investigation inside the pedestal at Unit 2 PCV using a camera robot in 2018

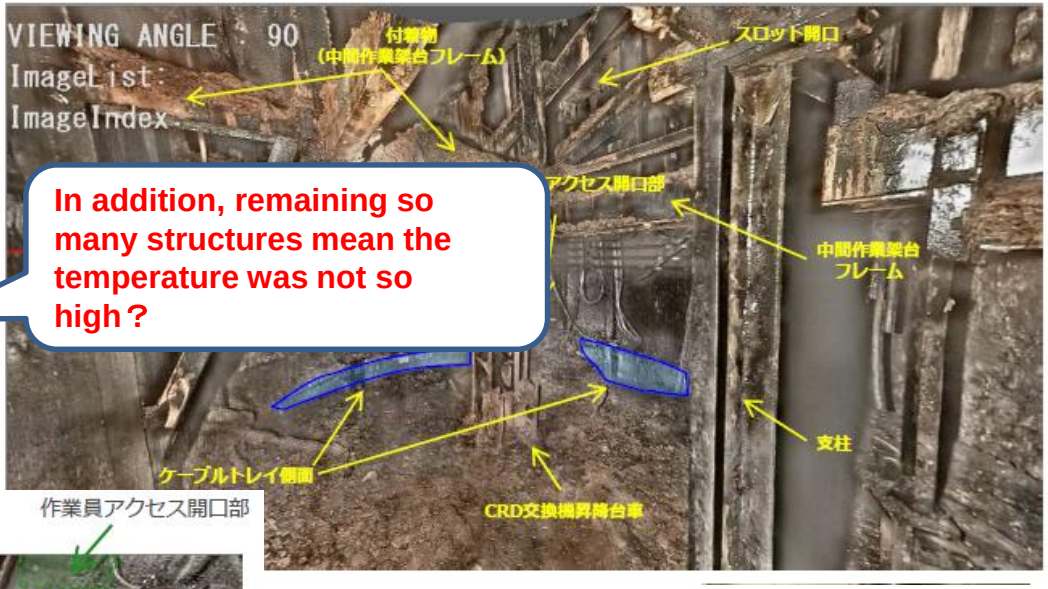
TEPCO



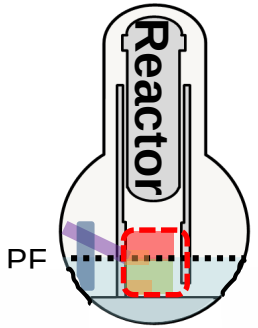


An investigation inside the pedestal at Unit 2 PCV using a camera robot in 2018

TEPCO

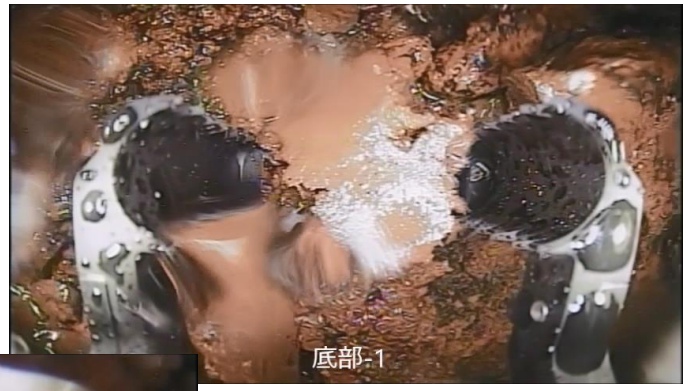


In addition, remaining so many structures mean the temperature was not so high？

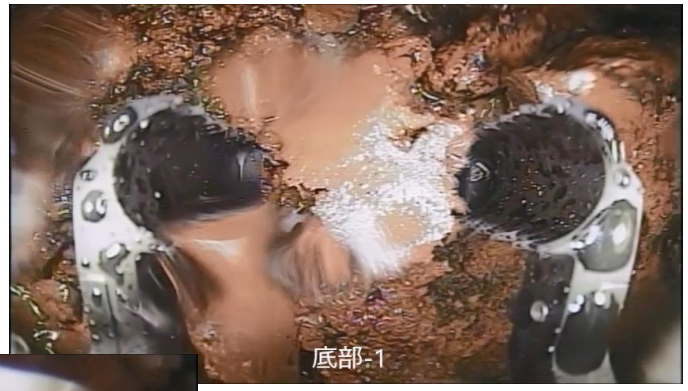


Deposit-contact investigation inside the pedestal at Unit 2 PCV using an improved camera robot in 2019

Can we retrieve pebble-like deposits? How about plate-like or rock-like deposits？ Let’s touch them using a robot!



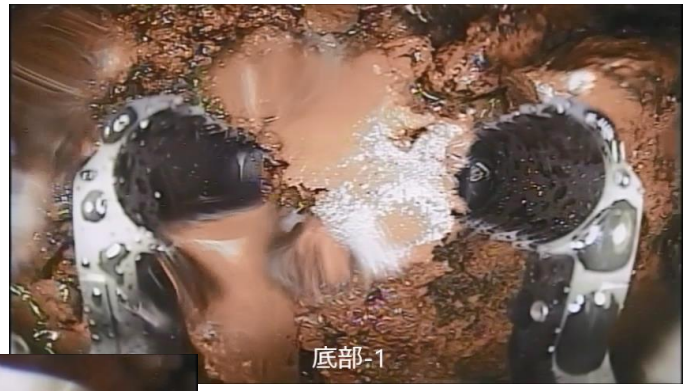
Deposit-contact investigation inside the pedestal at Unit 2 PCV using an improved camera robot in 2019



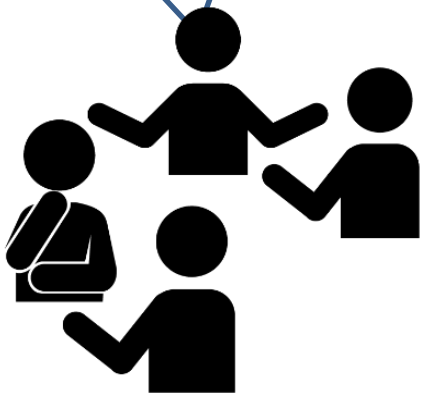
Pebble-like or plate-like deposits can be moved.

But, rock-like deposits can't be moved.

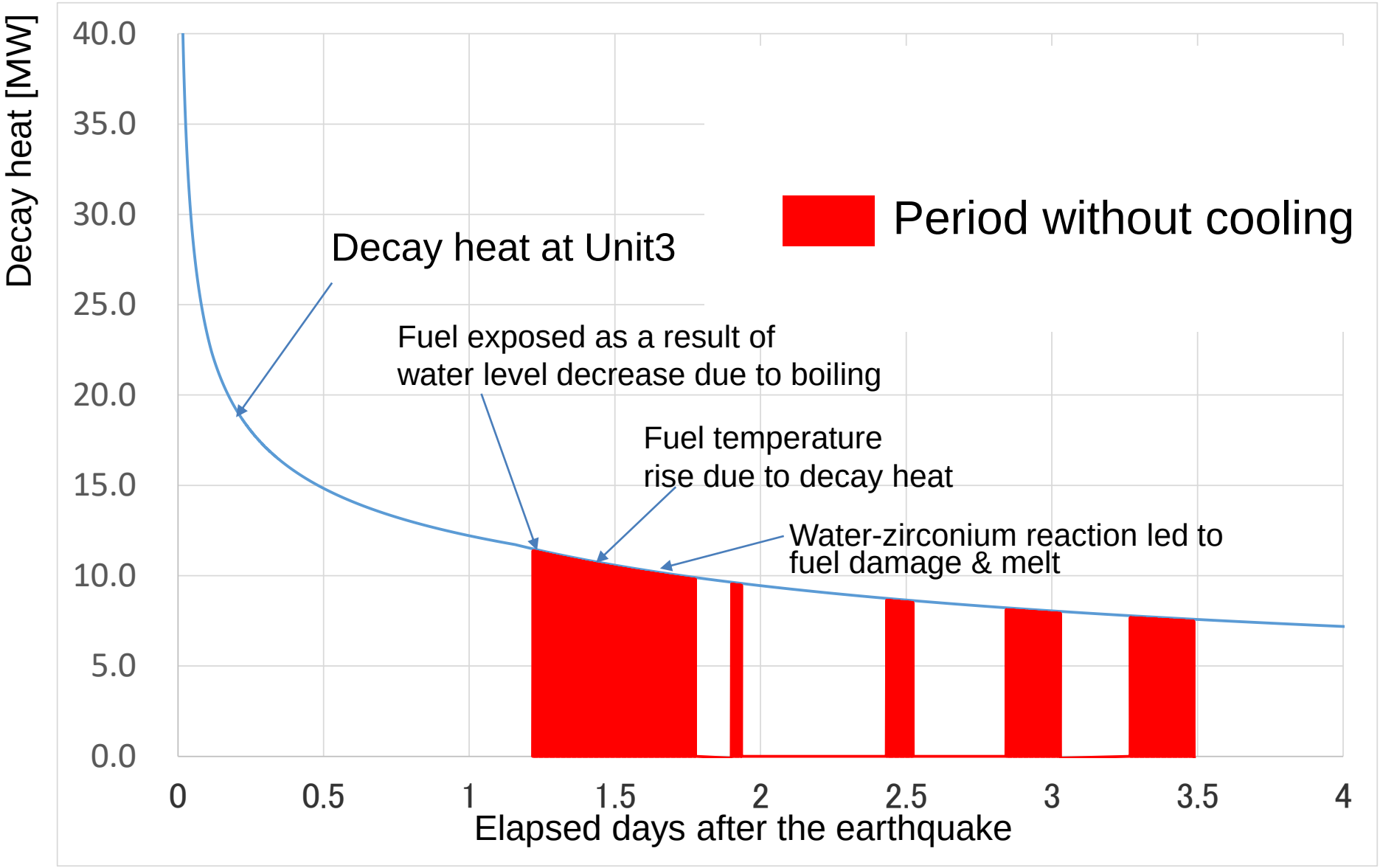
Deposit-contact investigation inside the pedestal at Unit 2 PCV using an improved camera robot in 2019



You can pick up pebble-like or plate-like ones. Those should be retrieved as well!

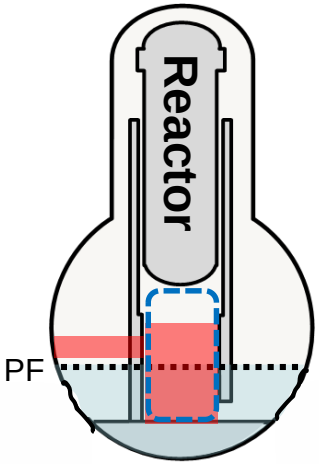


Accident progression at Unit 3



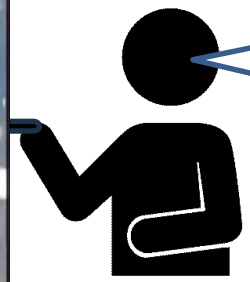
An investigation inside the pedestal at Unit 3 PCV using an underwater ROV in 2017 (1)

Status of CRD housing support before the Accident at Unit 3



An investigation inside the pedestal at Unit 3 PCV using an underwater ROV in 2017 (1)

Status of CRD housing support before the Accident at Unit 3



Wavering water surface indicates water coming down from the reactor

An investigation inside the pedestal at Unit 3 PCV using an underwater ROV in 2017 (2)

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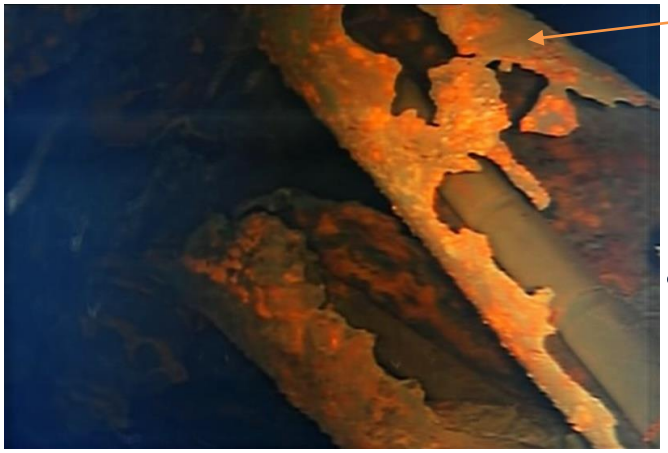
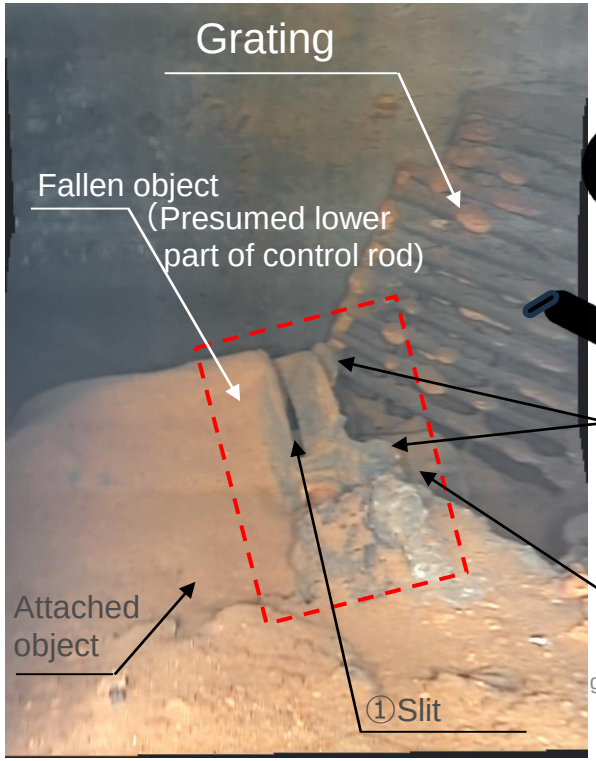
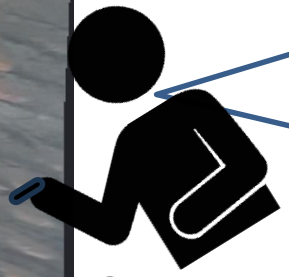
A cylinder-like structure（presumed CR guide tube）

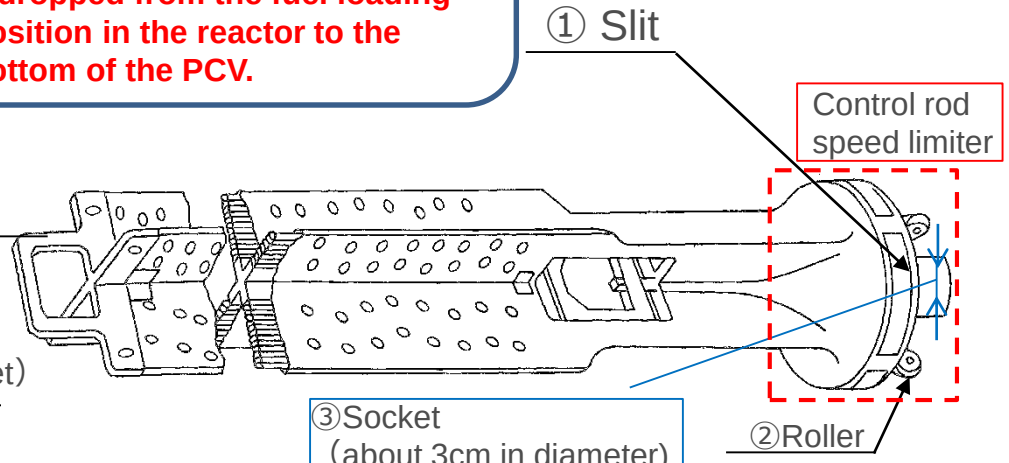


It looks like an index tube which is responsible for inserting a control rod into a core. Structures that had been present in the reactor dropped to the bottom of PCV.

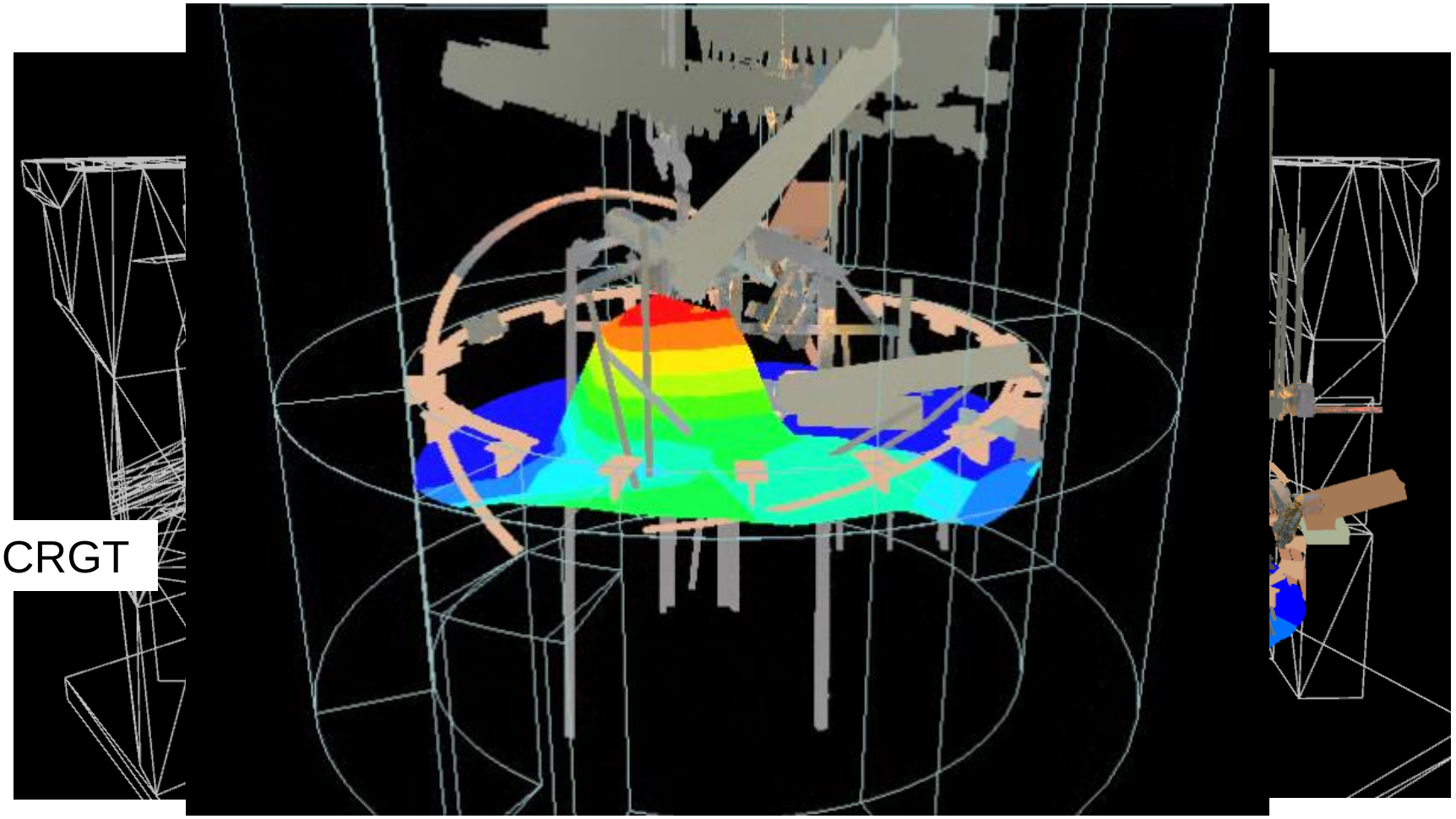




Referring to the figure of control rod, this really looks like a speed limiter that is at the lower part of the control rod.
It dropped from the fuel loading position in the reactor to the bottom of the PCV.



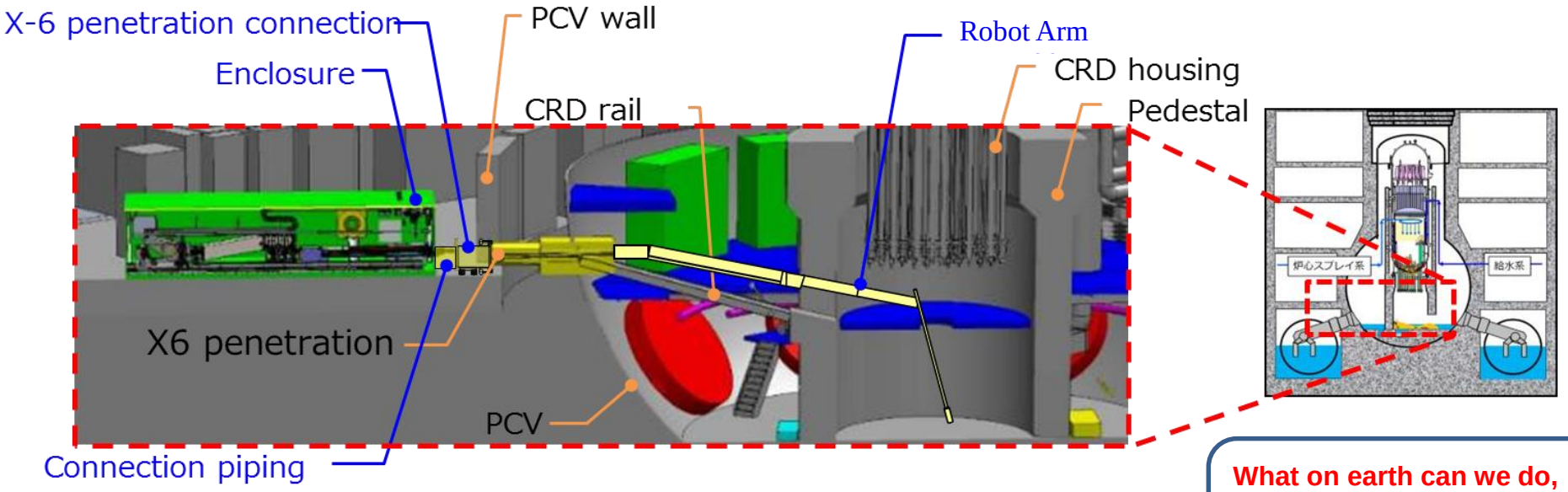
An investigation inside the pedestal at Unit 3 PCV using an underwater ROV in 2017 (3)



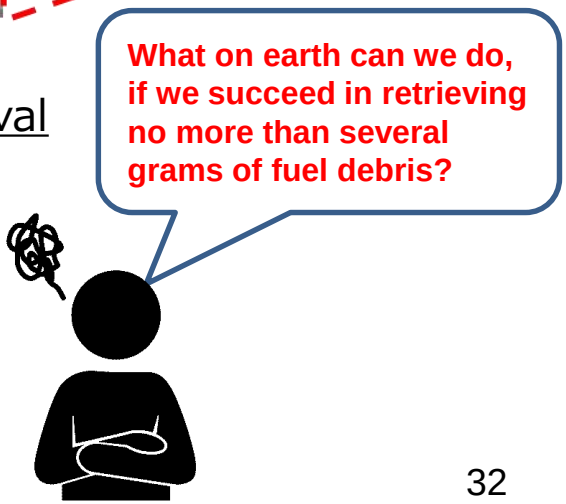
Deposits at the bottom of the pedestal are accumulated higher towards the center.

Unit 2 PCV internal investigation & trial debris retrieval

- We'll insert an arm-type device into the PCV through the X-6 penetration, remove obstacles in the PCV, and conduct internal investigation and trial retrieval.
- Several grams of fuel debris are planned to be retrieved.



Outline of Unit 2 PCV internal investigation & trial debris retrieval



Expectations for the trial retrieval of several-gram samples

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The practice of analyzing minute particles at the μm scale will enable us to analyze materials even when they amount to only several grams.

I'll hear opinions of experts from other fields.

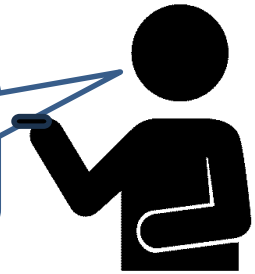
We know that pebble-like or plate-like fuel debris are movable. But, which fuel debris should we sample first?

Fuel debris retrieval should be started with pebble-like debris.

This is our first fuel debris analysis. So, let's do it from as many aspects as possible.

This is our first and crucial step in the fuel debris retrieval.
So, let's achieve it, while remaining steady and ensuring safety!

Could you assess how the fuel debris was formed, using the analysis results?



The accuracy of accident progression analysis should improve, if you grasp the concentration of uranium in the fuel debris.

Let's maintain proper records of the information gathered during sampling to ensure smooth progress in analysis and transportation

Thank you for your attention.