IRID

R&D for Fuel Debris Retrieval
at
Fukushima Daiichi Nuclear Power Station

June 2018

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(IRID)

This achievement is obtained from the Subsidy Project of Decommissioning and Contaminated Water Management by Ministry of Economy, Trade and Industry (METI).

Overview of Units 1-4

Main decommissioning works and steps

All fuel has been removed from Unit 4 SFP by December 22, 2014. Work continues toward fuel removal and debris (Note 1) retrieval from Unit 1-3.

(Note 1) Fuel assemblies having melted through in the accident.

Fuel Removal from SFP: Rubble removal & dose reduction (Units 1 & 2) → Installing a Fuel removal handling Machine (Unit 3) → Fuel removal (Unit 4) → Storage and handling

Unit 1: Fuel removal scheduled to start in FY2023
Unit 2: Fuel removal scheduled to start in FY2023
Unit 3: Fuel removal scheduled to start around mid-FY2018
Unit 4: Fuel removal completed in 2014

Fuel Debris Retrieval: Capturing the status inside the PCV/ examining the fuel debris retrieval method, etc. (Note 2) (Unit 1-3) → Fuel debris retrieval → Storage and handling

(Note 2) The method employed to retrieve fuel debris for the first unit will be confirmed in FY2019.

Dismantling Facilities: Scenario development & technology consideration → Design and manufacturing of devices / equipment → Dismantling

Unit 1

Unit 2

Unit 3

Unit 4

Organizational Information of IRID

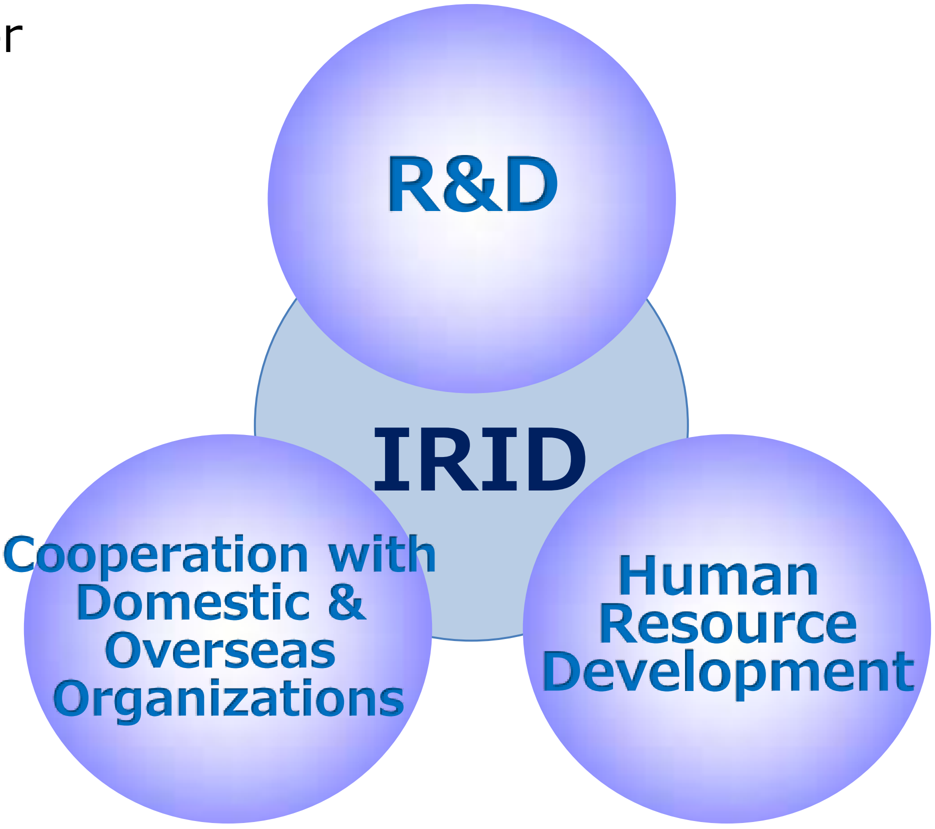
Research and development of technology for the current, most urgent challenge,

- The decommissioning of the Fukushima Daiichi NPS -

1. Name
   International Research Institute for Nuclear Decommissioning(IRID)
   http://www.irid.or.jp/en/

2. Date of Establishment
   August 1, 2013

3. Membership (18 organizations)
   - 2 Research Institutes
     - JAEA etc.
   - 4 Manufacturers
     - Toshiba, Hitachi-GE,MHI etc.
   - 12 Electric Utilities, etc.
     - TEPCO etc.



Boiling Water Reactor (BWR) Mark-I

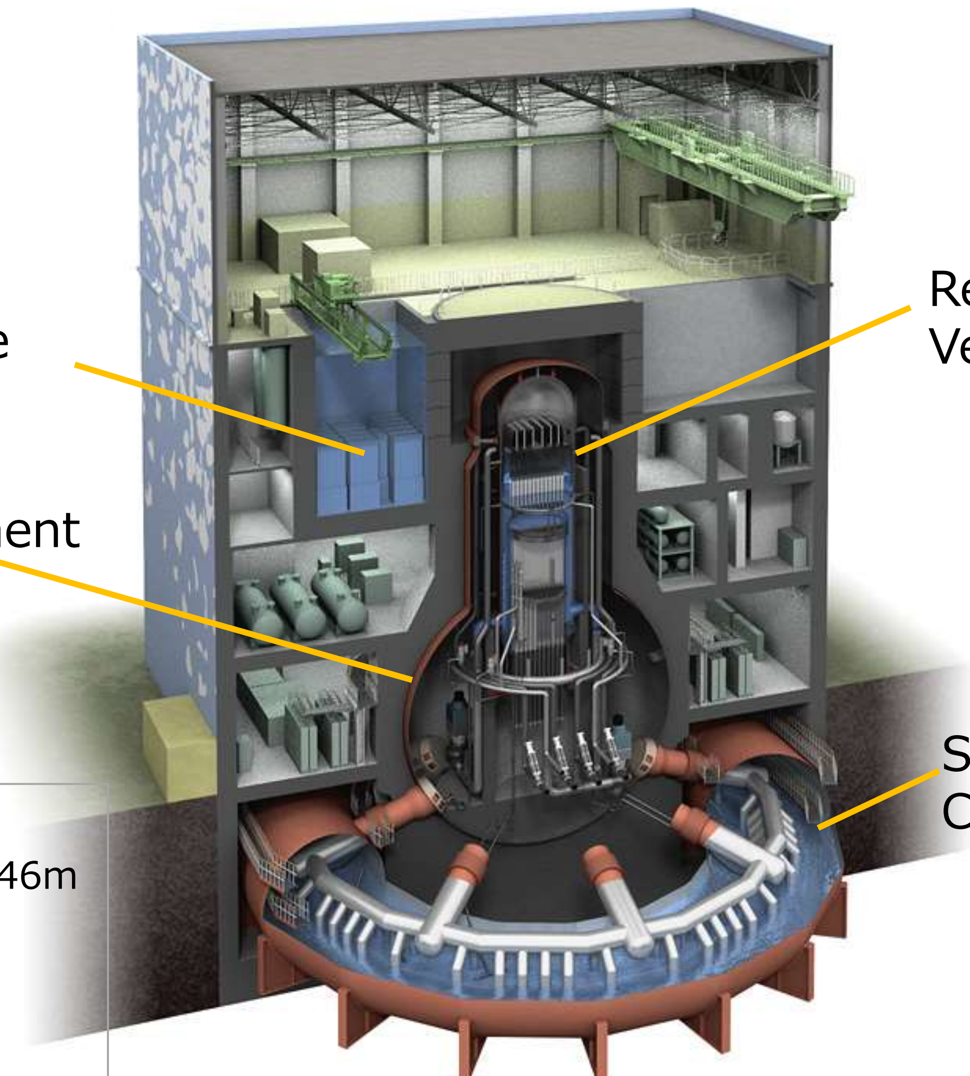
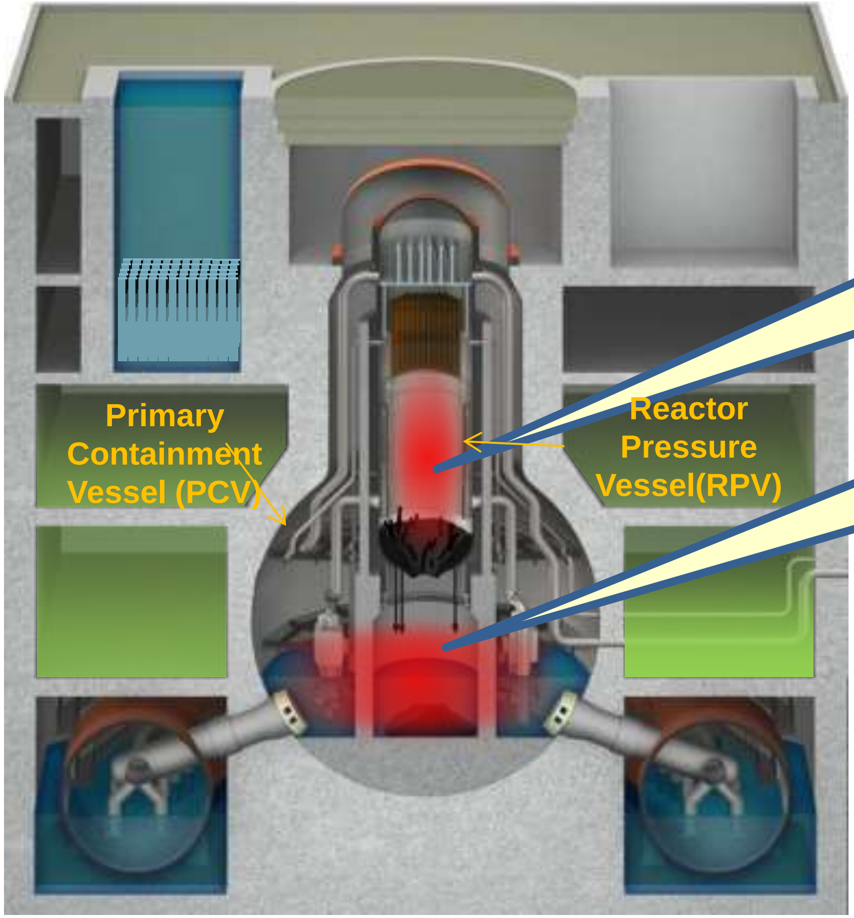


Image of the reactor building

Reactor building
Height × width: 46m×46m

PCV
Height × dimension: 34m×20m

Where is Damaged or Melted Fuel?



Cross-sectional image of the reactor building (R/B)

Fuel assemblies that constitute the nuclear reactor core, and core support structures had melted due to extreme temperatures of nuclear fuel (residual heat + decay heat) caused by the radioactive cooling function loss.

Parts of molten fuel and core structures might have flown out of the RPV and fallen to the PCV.

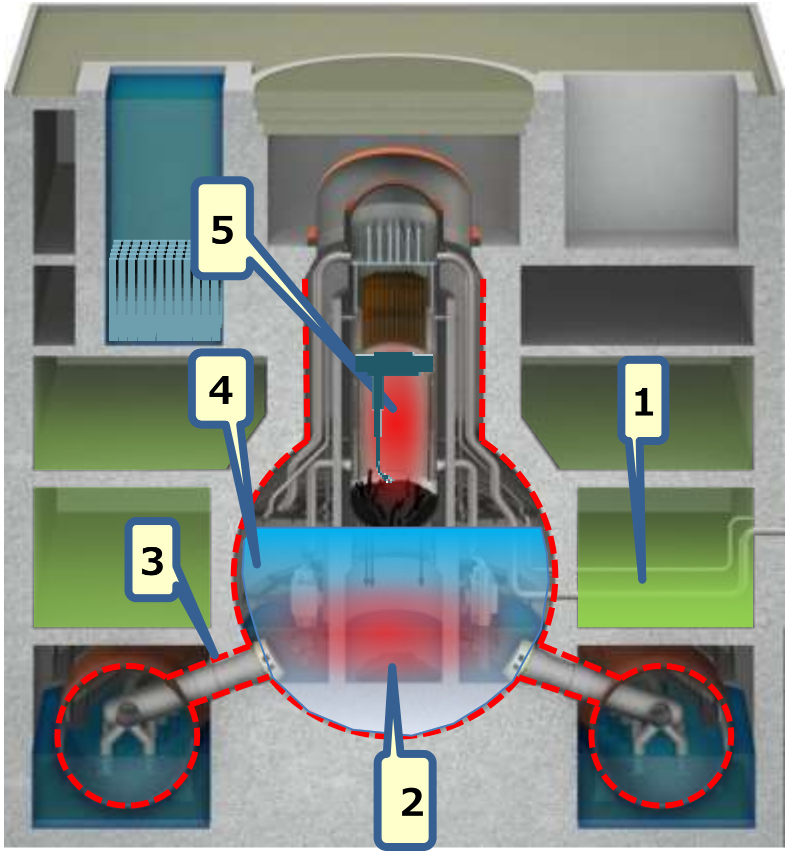
Decay heat

- Decay heat is released as a result of radioactive decay and produced energy of radiation to heat surrounding materials.
- This heat will decrease as radioactive elements change into stable nuclides.
- At the moment of reactor shut down, the heat will be newly generated about 7% of the operation power after a second. After a day, the heat will be still released about 0.6% falling as T 0.2.
- **More than 7 years has passed after shutdown, the heat is currently less than 100 kW.**

IRID R&D Projects

1. Decontamination and Dose Reduction

- Technology for a remote operation



2. Detection of Fuel Debris

◎Indirect methods
- By analysis
- Using cosmic ray MUON

◎Direct methods
- Inside PCV and RPV

3,4. PCV Repair

- Development of Technology
- A full-scale test

5. Debris Retrieval

Developments of
- Fundamental Technology
- Access methods and systems
- Criticality control methods

6.Debris Transfer and Storage

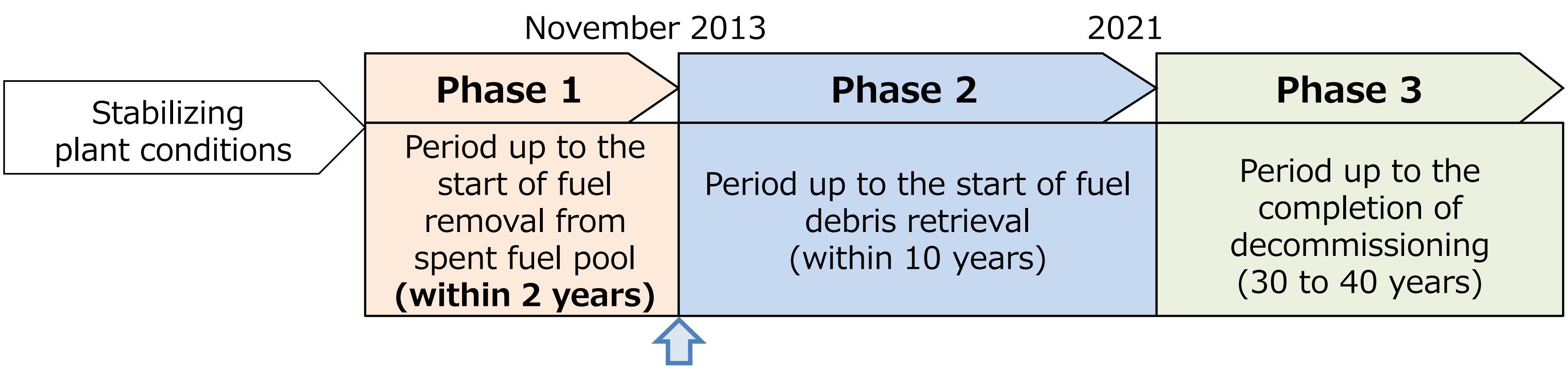
- Development of technology for collection, transfer and storage of debris

Expectation toward Fuel Debris Retrieval

- "The Mid-and-Long-Term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station (NPS)" indicates that **a period between the completion of decommissioning and the start of fuel debris retrieval will be around 30-40 years.** [1)]

- Fuel debris retrieval method for the first implementing unit will be determined in FY2019 and fuel debris retrieval will start within FY2021

- "The NDF Technical Strategic Plan" indicates that Fukushima Daiichi NPS has **maintained in the stable condition** by tentative measures, and fuel debris retrieval policy is intended to **drastically improve the current situation.**[2)]



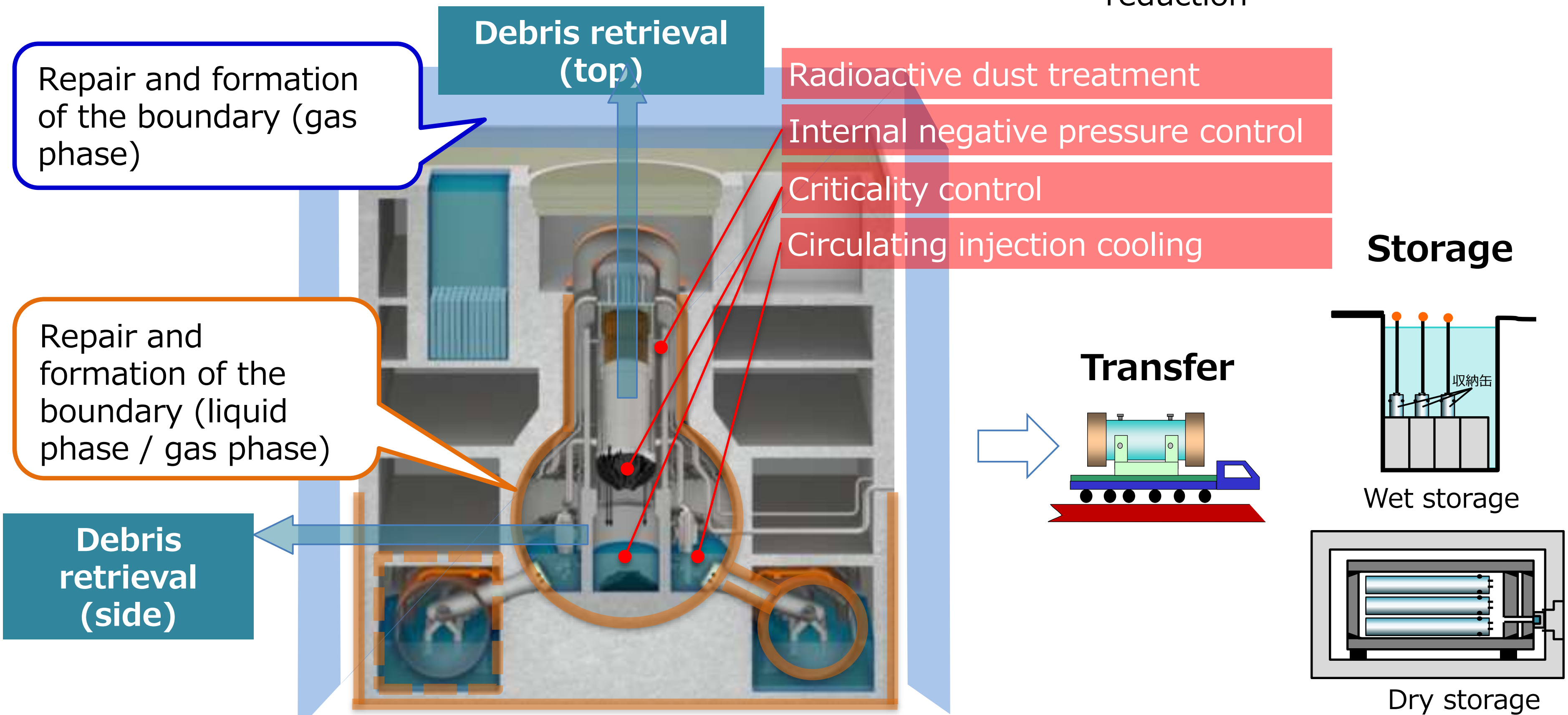
Start of fuel removal from the Unit 4 spent fuel pool on November 18, 2013

1) Ministerial Committee on Countermeasures for Decommissioning and Contaminated Water Treatment, TEPCO Holdings Inc. The Mid-and-Long-Term Roadmap towards the Decommissioning of Fukushima Daiichi NPS
2) Nuclear Damage Compensation and Decommissioning Facilitation Corporation, TEPCO Holding Inc.., Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi NPS.

Fuel Debris Retrieval: What are expected preparations.

1. **Ensuring nuclear safety (implementation of defense in depth)**
   - Suppressing a diffusion of radioactive materials
   - Prevention of re-criticality and impact control
   - Fires and other accidents
   - Robustness of external events, impact control, etc.

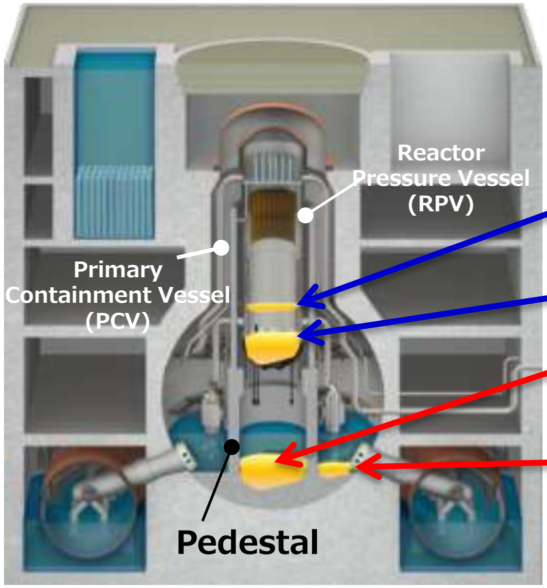
2. **Fuel debris retrieval work**
   - Access to debris
   - Cutting and collection
   - Transfer and storage
   - Remote operation and dose reduction



Investigation of the Fuel Debris Distribution

Code Analysis Results of Fuel Debris Distribution

Reactor Building (R/B)



: Inside the RPV　　: Outside the RPV　　(unit: ton)

	Unit 1	Unit 2	Unit 3
Location	Representative value*	Representative value*	Representative value*
Reactor Core	0	0	0
RPV bottom	15	42	21
Inside the Pedestal	157	146	213
Outside the Pedestal	107	49	130
Total	279	237	364

"Representative value": a value that is most likely to be certain as of now.
"Assumed weight": fuel + melted and solidified structural materials (including concrete component)

- Comprehensive analysis and evaluation based on analysis results and actual investigation data (temperature data, measurement through Muon technology and investigation inside the PCV , etc.).

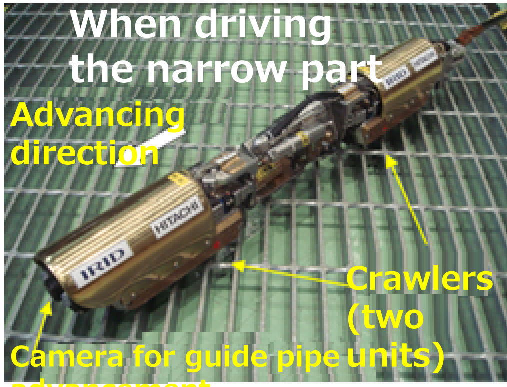
Assuming that most of debris exists at the bottom of pedestal.

Investigation of
Primary Containment Vessel (PCV)

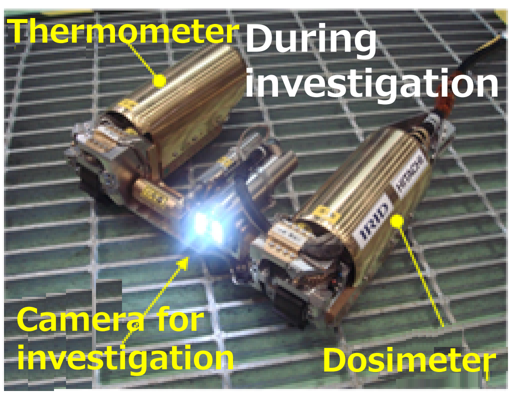
Investigation of inside PCV by using Robots

Investigation of outside the pedestal (Unit 1)

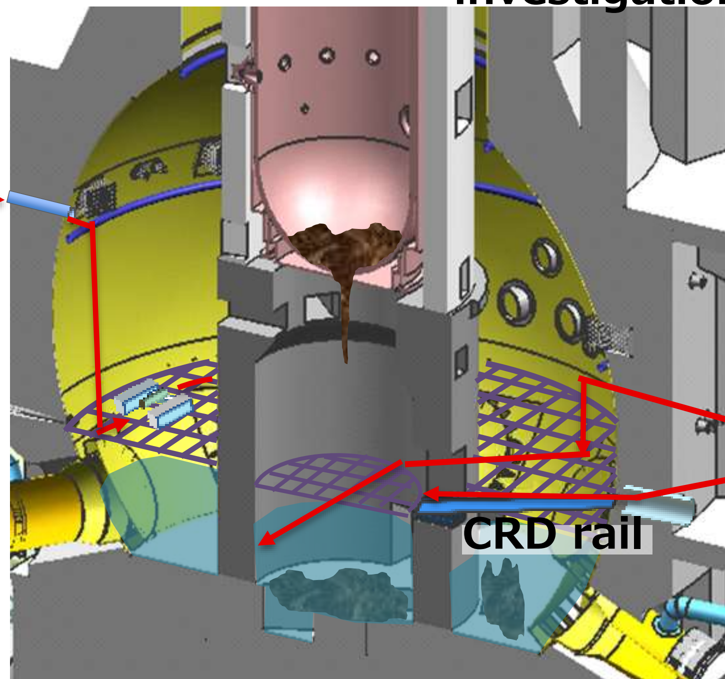
○Shape-changing robot (B1,B2 investigation)



Shape changing

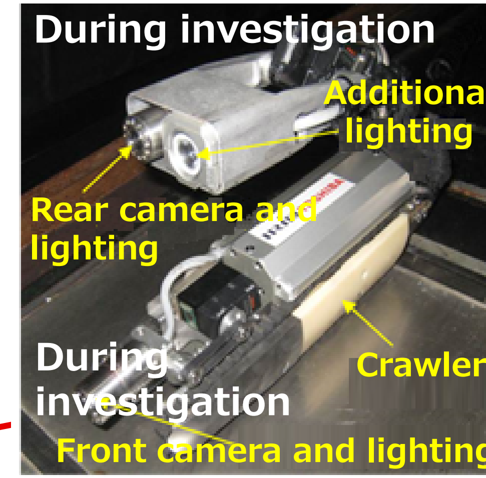


(Note) The robot for B1 investigation is shown in the above photos



Investigation of inside the pedestal (Unit 2)

○Remotely operated crawler robot for investigation (A2 investigation)



○Hanging camera on extension rod

Investigation of inside the pedestal (Unit 3)

Thruster for up-and-down

Thruster for driving

Light

Front camera

○Submersible Crawling Robot

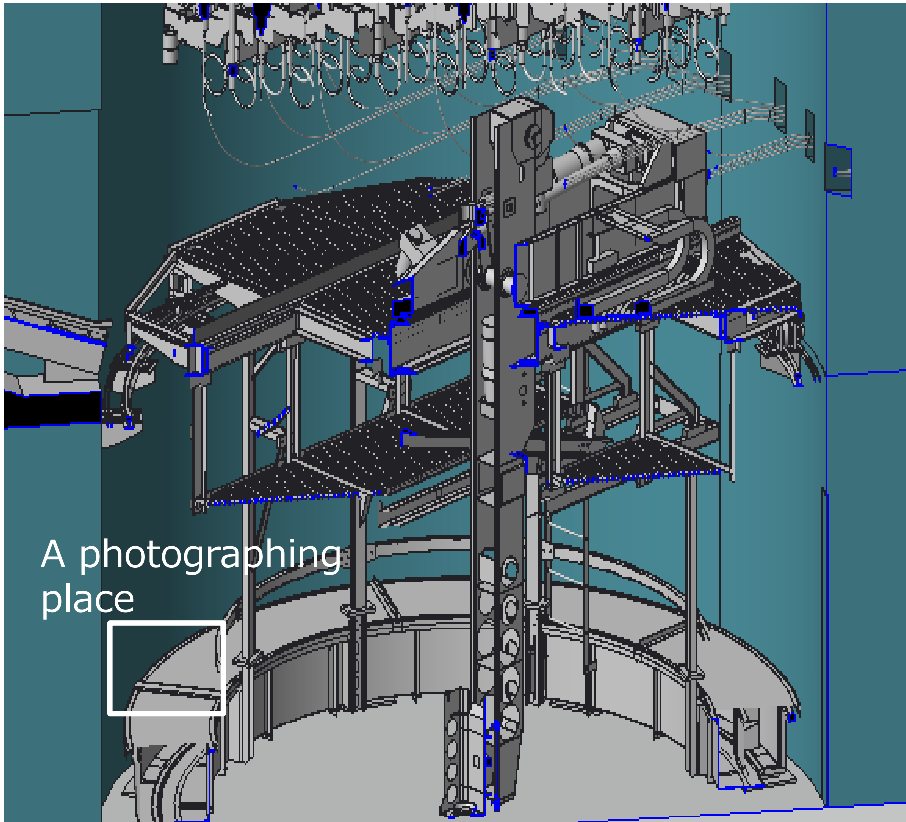
A2 Investigation at Unit 2

Inside the pedestal (after processing image data)

Pedestal area below RPV

Before the accident

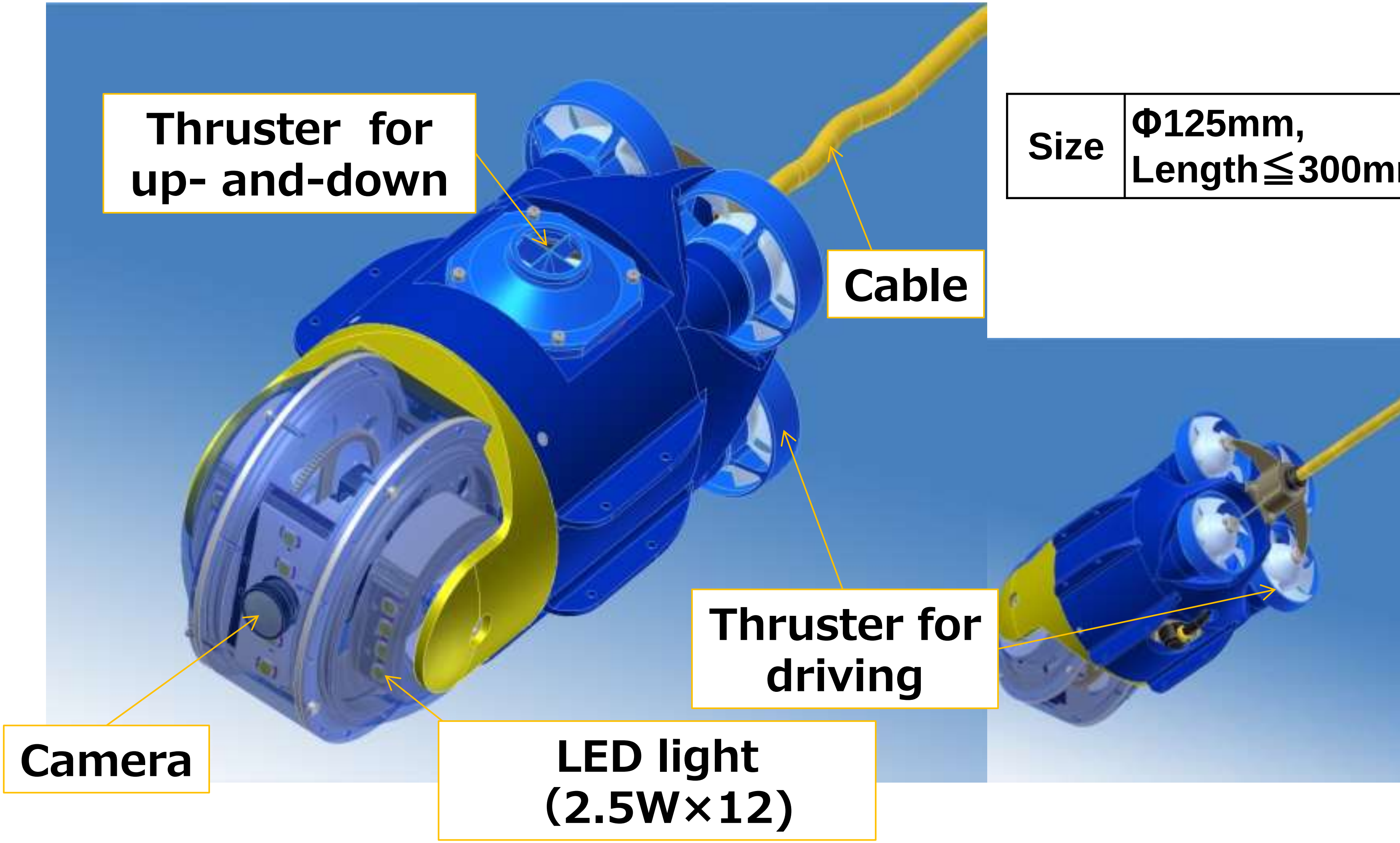
Investigation for Unit 2 Pedestal Floor



Bottom of the Unit 2 PCV
(An overhead image)

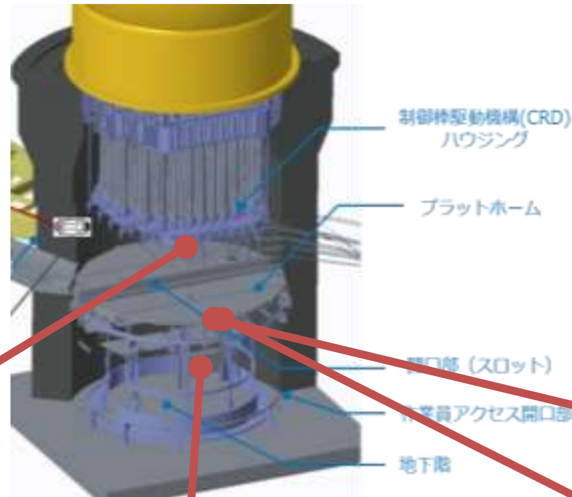
Pedestal floor and wall
Fuel debris? and a fuel assembly handle

Investigation Robot for Unit 3 (Mini-mambo)



Size	Φ125mm, Length≦300mm

Investigation at Unit 3: Pedestal and Underwater



No.16

No.17

No.18

No.19

・Molten materials were confirmed, which may have been solidified at the lower part of the pedestal and on the structures inside the pedestal.

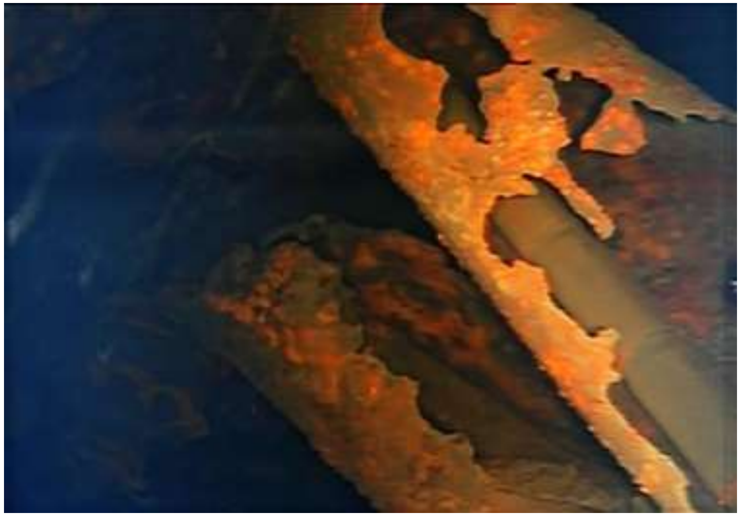
* Reference: the Tokyo Electric Power Company Holdings, Inc.

Investigation at Unit 3: Pedestal and Underwater


CRD (Control Rod Drive system) flange

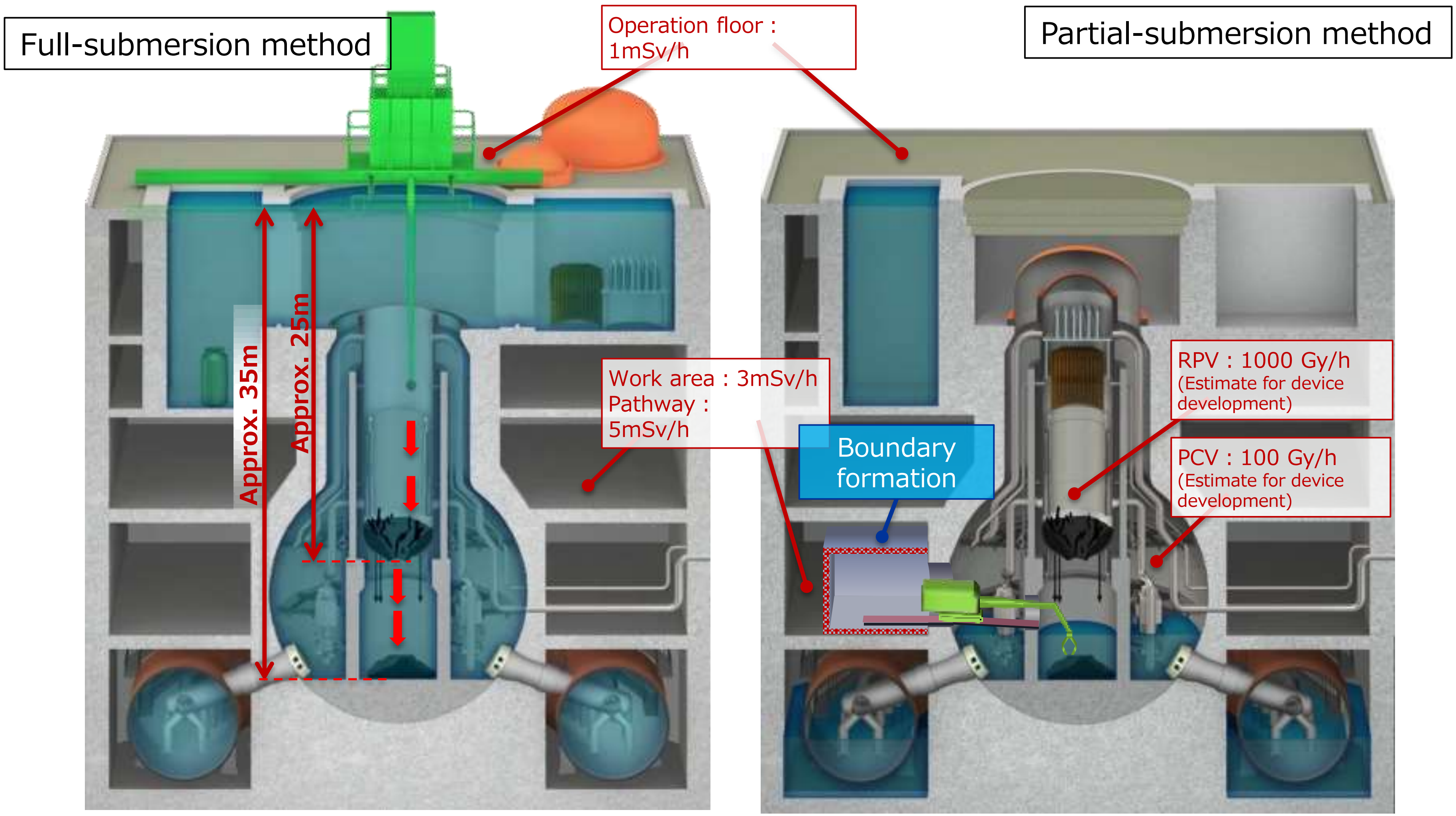

Control rod ?


Fuel debris?


A control rod guide tube

Debris Retrieval Design

Study on Fuel Debris Retrieval Methods



Fuel Debris Retrieval Policy

- "The Mid-and-Long-Term Roadmap towards the Decommissioning of Fukushima Daiichi NPS" [1)] describes a fuel debris retrieval policy as below.

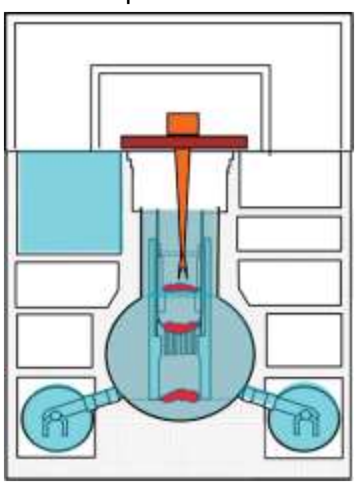
Focused on Partial-submersion method

- Full-submersion method is technically difficult in the current situation.
- Estimated radiation dose is high during working for stopping water leakage at the upper part of PCV.

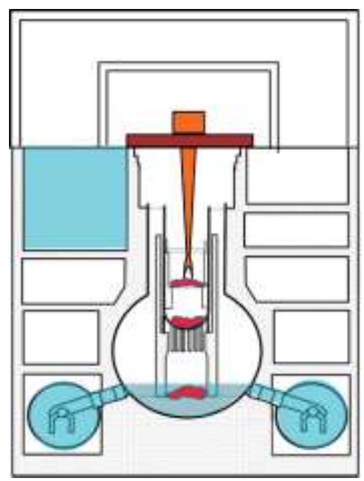
Accessing from the side at the bottom of PCV

- Suppressing increased risks associated with retrieval work.
- Reducing risks of fuel debris without delay

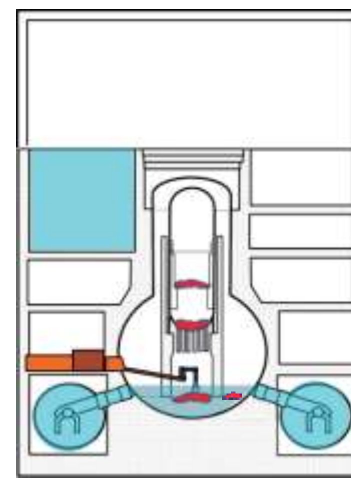
a. Submersion-Top Access method



b. Partial submersion-Top access method



c. Partial submersion-Side access method



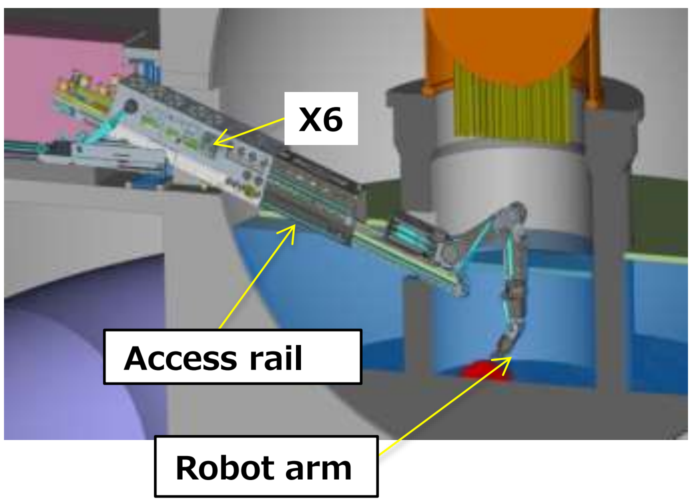
1) Mid-and-Long-Term Roadmap towards the Decommissioning of Fukushima Daiichi NPS, TEPCO Holding Inc., Ministerial Committee on Countermeasures for Decommissioning and Contaminated Water Treatment.

Fuel Debris Retrieval

Technical issues (example)

- Confinement of radioactive dust
- Remote operation under a high level gamma radiation environment
- Reduction of radiation dose and prevention of spreading of contamination

Partial submersion – Side access



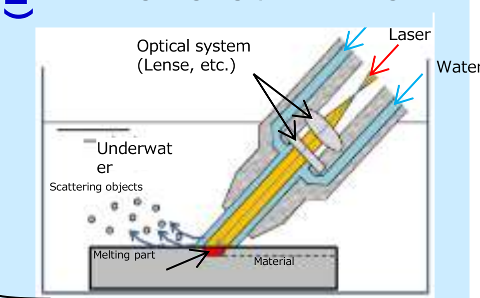
Development of key technology

Robot arm

Cutting technology (Example)

Core boring process

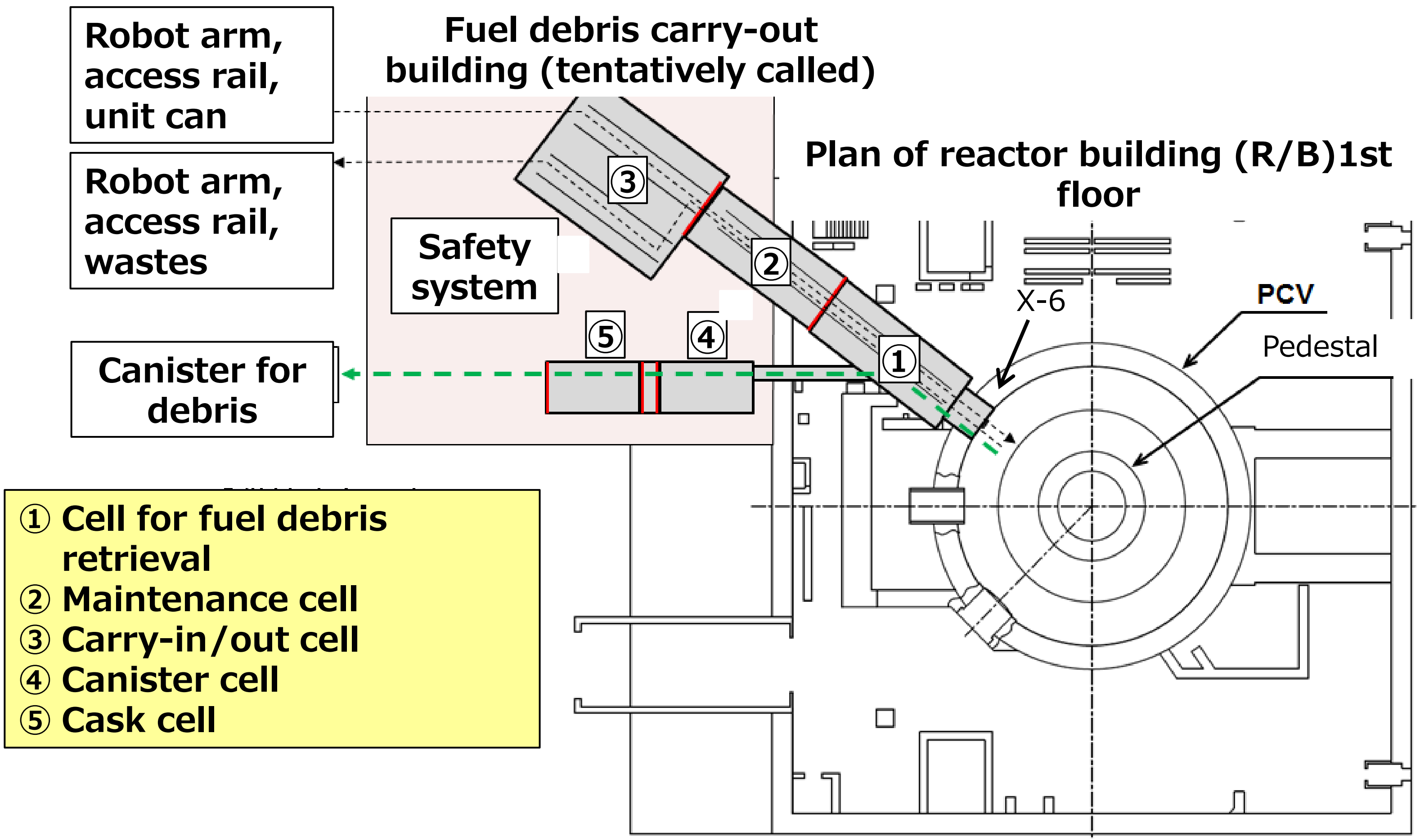
Laser gouging processing



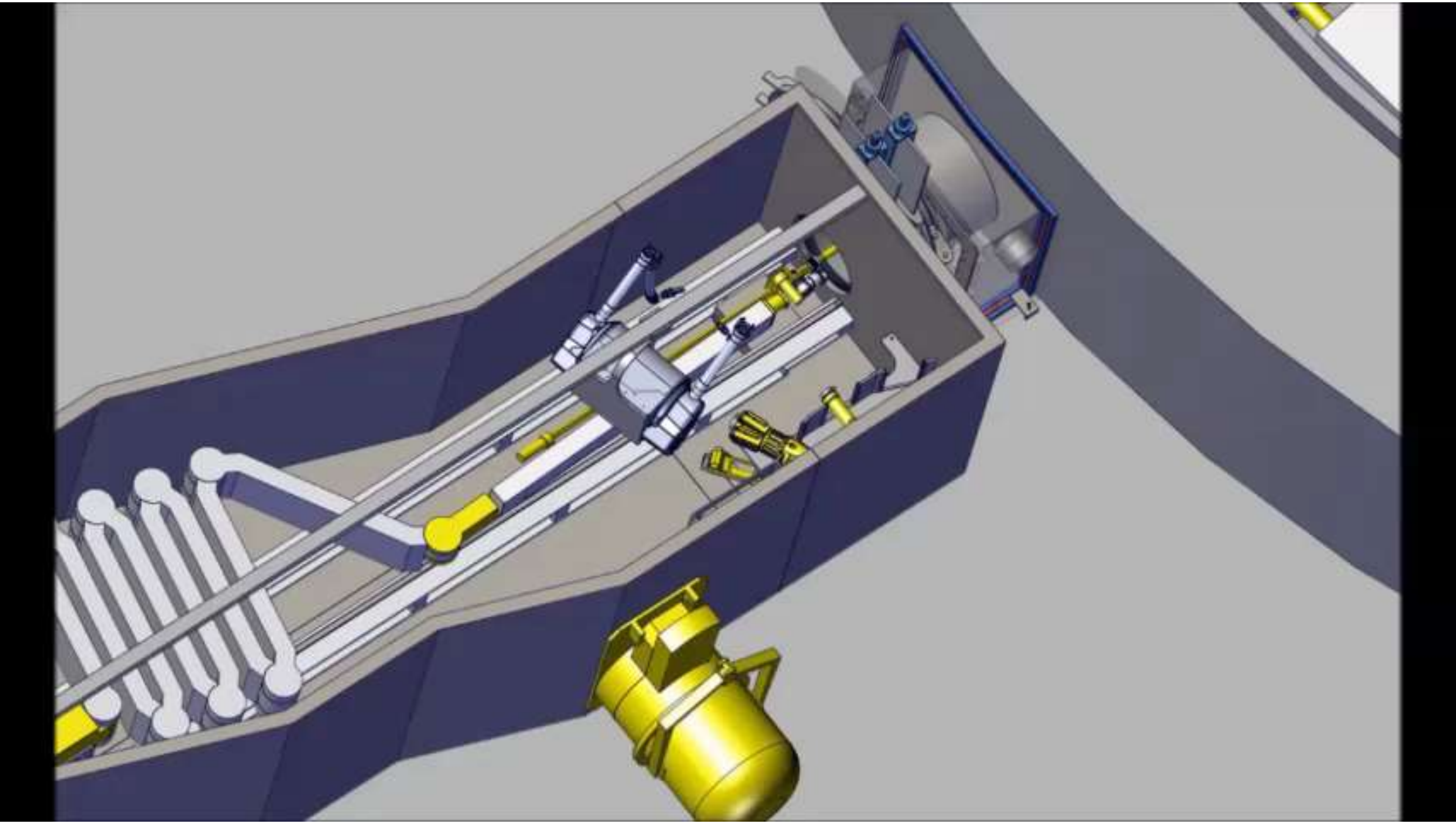
Access Rail Method: Layout

Layout

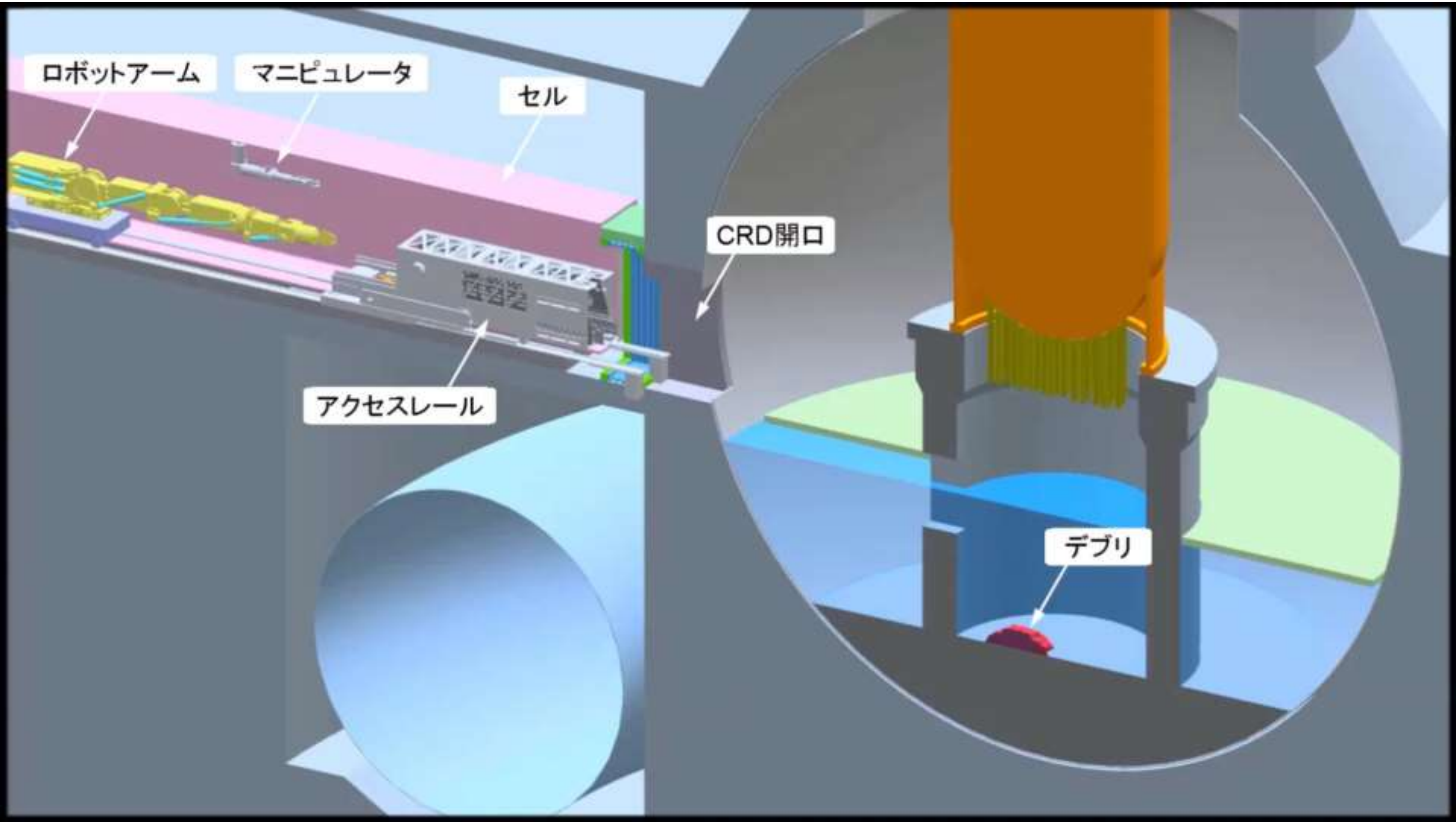
- **Multiple cells** with airtightness/shielding functions are **connected** and installed on the R/B 1st floor.
- **An additional building for fuel debris carry-out (tentatively called) is built on the side of R/B.** Safety systems are also installed.



Preliminary Access to Fuel Debris for Sampling



Access Rail: Side Access



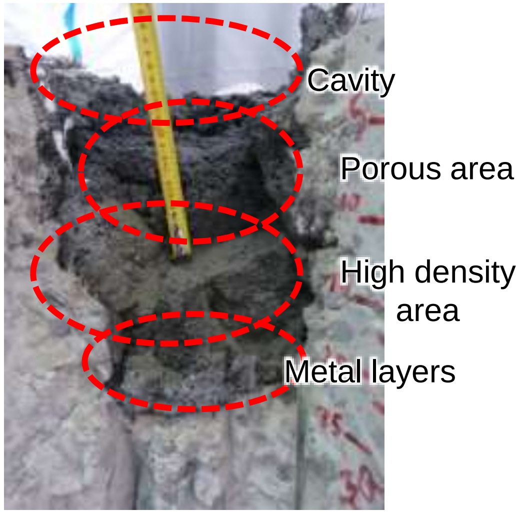
Access Tunnel / Side Access

Cutting and Collection Works for Fuel Debris

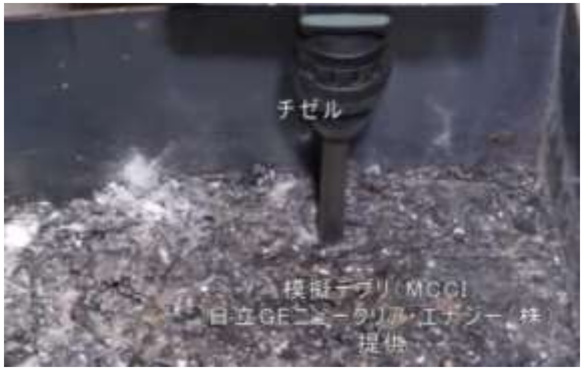
- Fuel debris cutting
  - Crushing hard fuel debris
    Selecting methods of crushing/processing based on debris properties.
  - Canister（Ex.:Φ220~400mm）
    Process for changing size to fit in a canister

- Collection
  - Result of processing / crushing: Particle size
  - Gripping, picking, sucking and absorbing
  - Separation / collection by sucking powder and particles with water.

- Remote operation
  - All the work including operation and monitoring must be remotely operated due to s high radiation environment.
  - Throughput
  - **Radiation resistance: Life-time / exchange frequency of device**



MCCI[1] Test
Molten fuel interacted with concrete



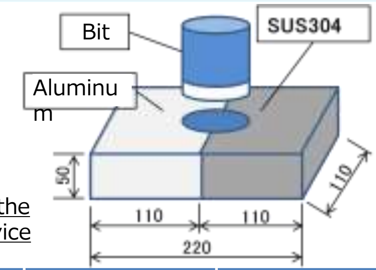
Preliminary testing for processing chisel

1) Molten Core Concrete Interaction,

Cutting and Collection Works for Fuel Debris

- Estimating a composition/property of fuel debris for each reactor system.
  - Further investigation and sampling will clarify.
- Study on cutting capacity, processing speed, crushing properties, scattering, downsizing, required payload, remote operation and others.
  - Core boring
  - Disk sorter
  - Wire saw
  - Hand saw
  - Ultrasound core drill
  - Hydraulic cutter
  - Chisel
  - Abrasive water jet
  - Laser gouging
  - Plasma arc
  - Plasma jet
  - Gas
  - Ark saw, etc.

Core Boring Process Test



Specifications of the common test device

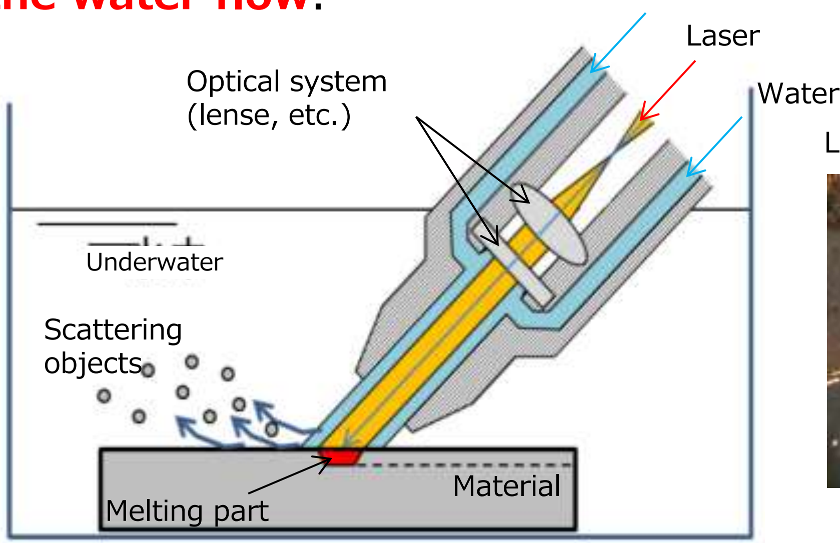
■ The result of the common cutting test specimen for the improved bit (impregnated bit).

No.	Shape of bit	Photos of bit	Supply pressure (kN)	Number of rotations (min^{-1})	Result of processing (ceramic/SUS)	Stability of the initial cutting	Discharging efficiency of chips	Remarks
1	Outer height taper 1		15	150		**Good**	**Good**	**There is a problem with the forward movement of cutting due to differences in the cutting easiness of materials.**
2	Outer height taper 1		15	225		**Good**	**Good**	**The same as above**
3	Outer height taper 1		10	150		**Good**	**Good**	**The same as above**
4	Outer height taper 1		10	225		**Good**	**Good**	**The same as above**

Laser Gouging Cutting Test

[Principles of Laser gouging]

- By transmitting the laser in the water flow, the surface of material is irradiated by the laser **with the water flow and laser as the same axel**.
- Laser irradiated area is heated and melted and **molten material is removed by the water flow**.



Laser chipping under the wate

Schematic diagram of laser chipping process

FY2014 test result

[Characteristics of laser chipping process]

- More than 99% of molten materials that removed can be deposited under water or in the water tank, and **only small amount of process waste is scattered in the air**.
- Process method **that is not influenced by the hardness of fuel debris**
- **It is difficult to eject the water flow in the air** that the laser can be transmitted (the current problem).

Laser Gouging Cutting Test (Videos)

Safety Requirements, Function requirements

Prevention of radioactive exposure to the public

Safety principles	Safety requirements
Prevention of generation/additional release of radioactive materials	A:Decay heat removal B:Maintaining sub-criticality

Safety principles	Safety requirements
Confinement of radioactive materials	C:Prevention of gas leakage D:Prevention of liquids leakage E:Boundary damage prevention

Prevention of radioactive exposure to workers*

Safety principles	Safety requirements
Protection from environmental radiation	F:Environmental radiation dose reduction

Required functions

(Required systems(tentatively called)

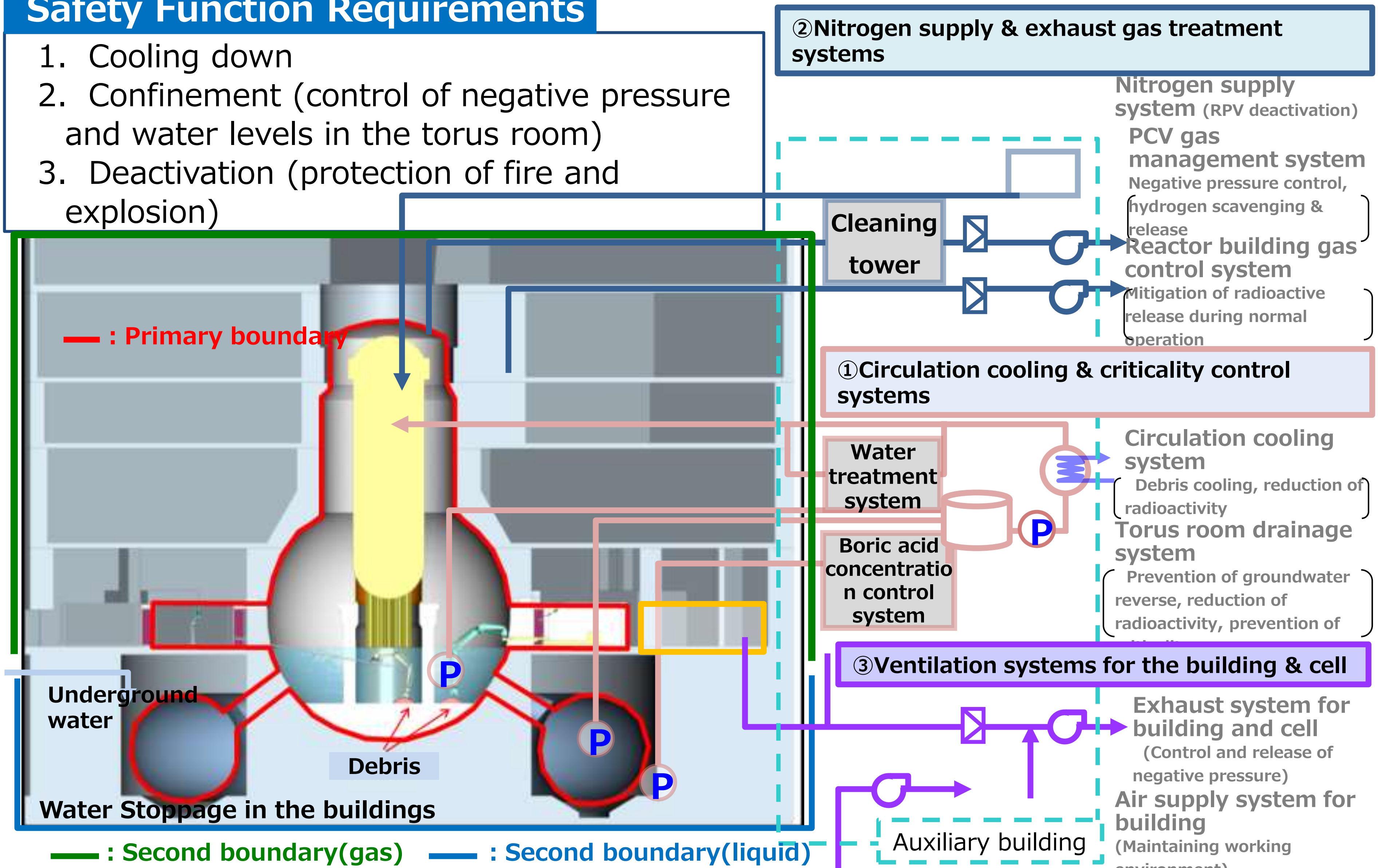
- **Cooling** (Circulation cooling system)
- **Criticality prevention/mitigation** (Criticality control)
- **Maintaining negative pressure/purification** (Gas control system)
- **Water levels monitoring/purification /transfer**
- **Fire/explosion prevention** (Nitrogen supply system)
- **Decontamination, shielding, etc.**

*Debris retrieval/decommissioning work. Exposure to workers (on-site) during accidents will be evaluated in accordance with the public.

Safety Function

Safety Function Requirements

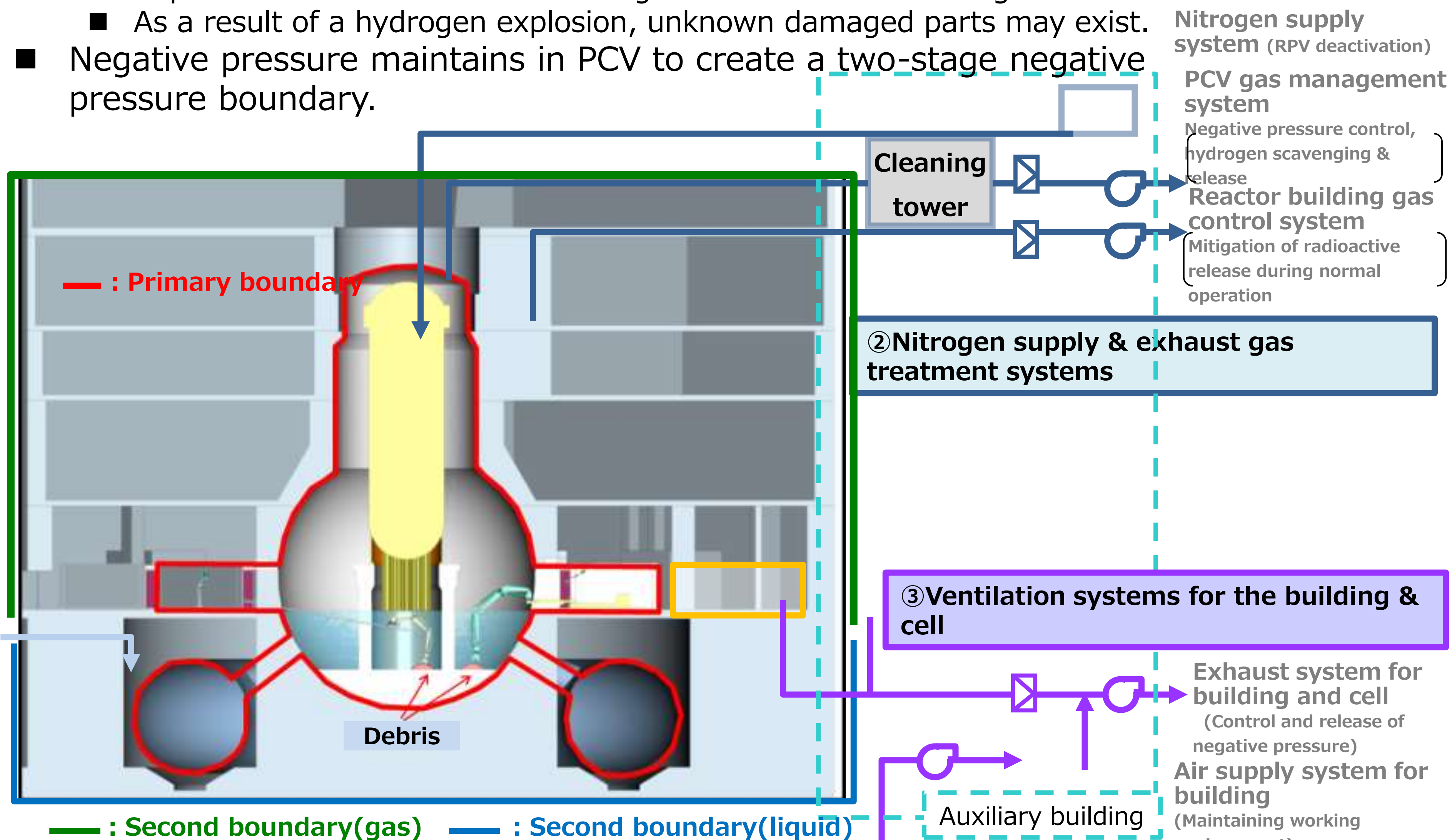
1. Cooling down
2. Confinement (control of negative pressure and water levels in the torus room)
3. Deactivation (protection of fire and explosion)



Nitrogen Supply & Exhaust Gas Treatment Systems

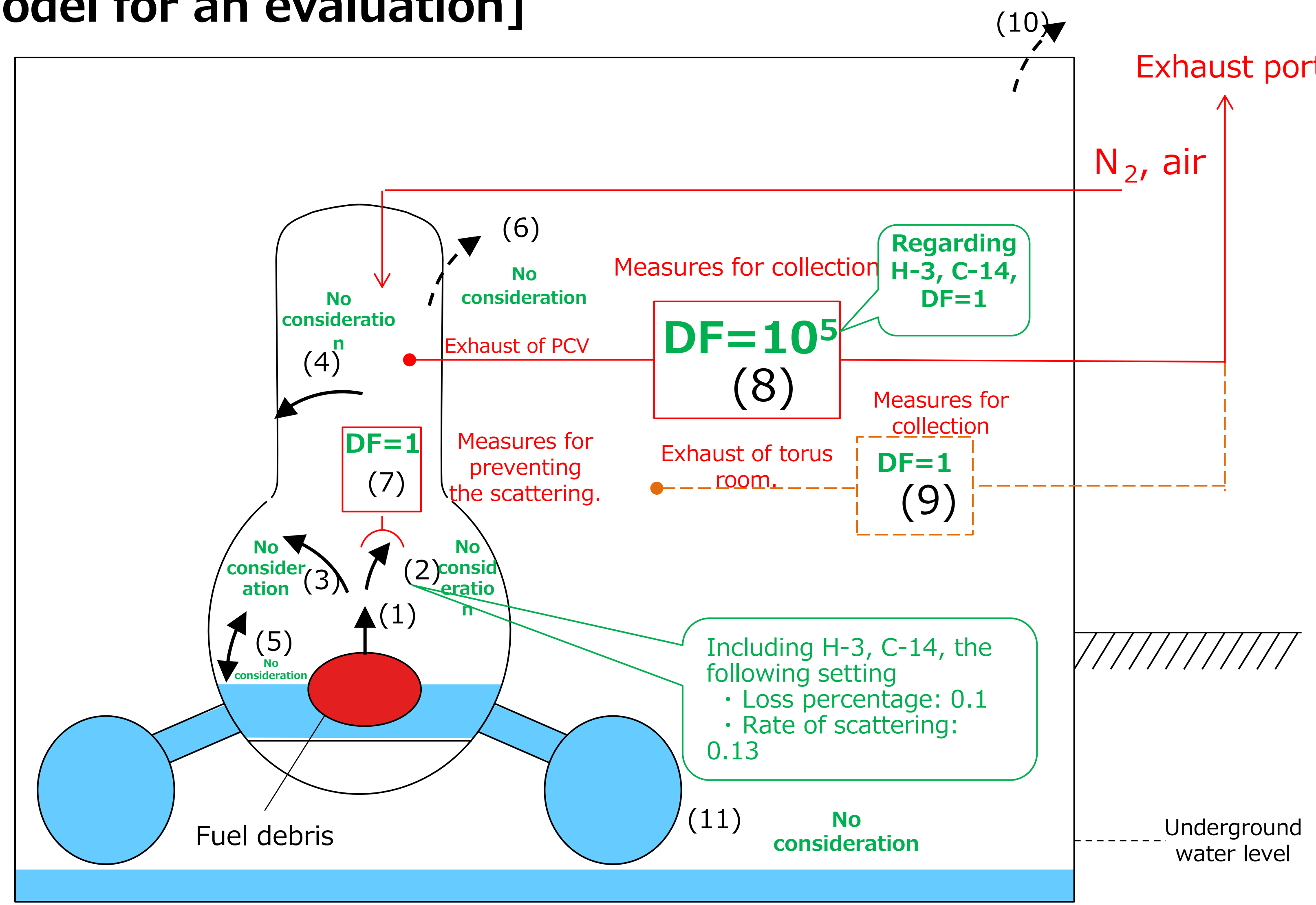
Boundary

- A static boundary formation in PCV has difficulty.
  - Many penetrations such as piping and electricity.
  - Repair works are limited due to a high radiation in the building.
  - As a result of a hydrogen explosion, unknown damaged parts may exist.
- Negative pressure maintains in PCV to create a two-stage negative pressure boundary.



Assessment of Non-emergency Exposure

[Model for an evaluation]



Annual radiation level due to the release : About 8.4 μSv/year at the site boundary.

Summary

- The conditions of fuel debris are becoming clear by investigations inside PCV. Detailed investigations of fuel distribution and PCV damaged conditions are being planned.
- Fuel debris retrieval is planned to start with a side-access method to retrieve fuel that has fallen below the lower part of RPV.
- A key point of safe retrieval work is maintaining of sub-criticality and prevention of α dust diffusion.
- Therefore, the exhaust purge system with a negative pressure gradient boundary is being studied.

End of presentation