The 7th International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station

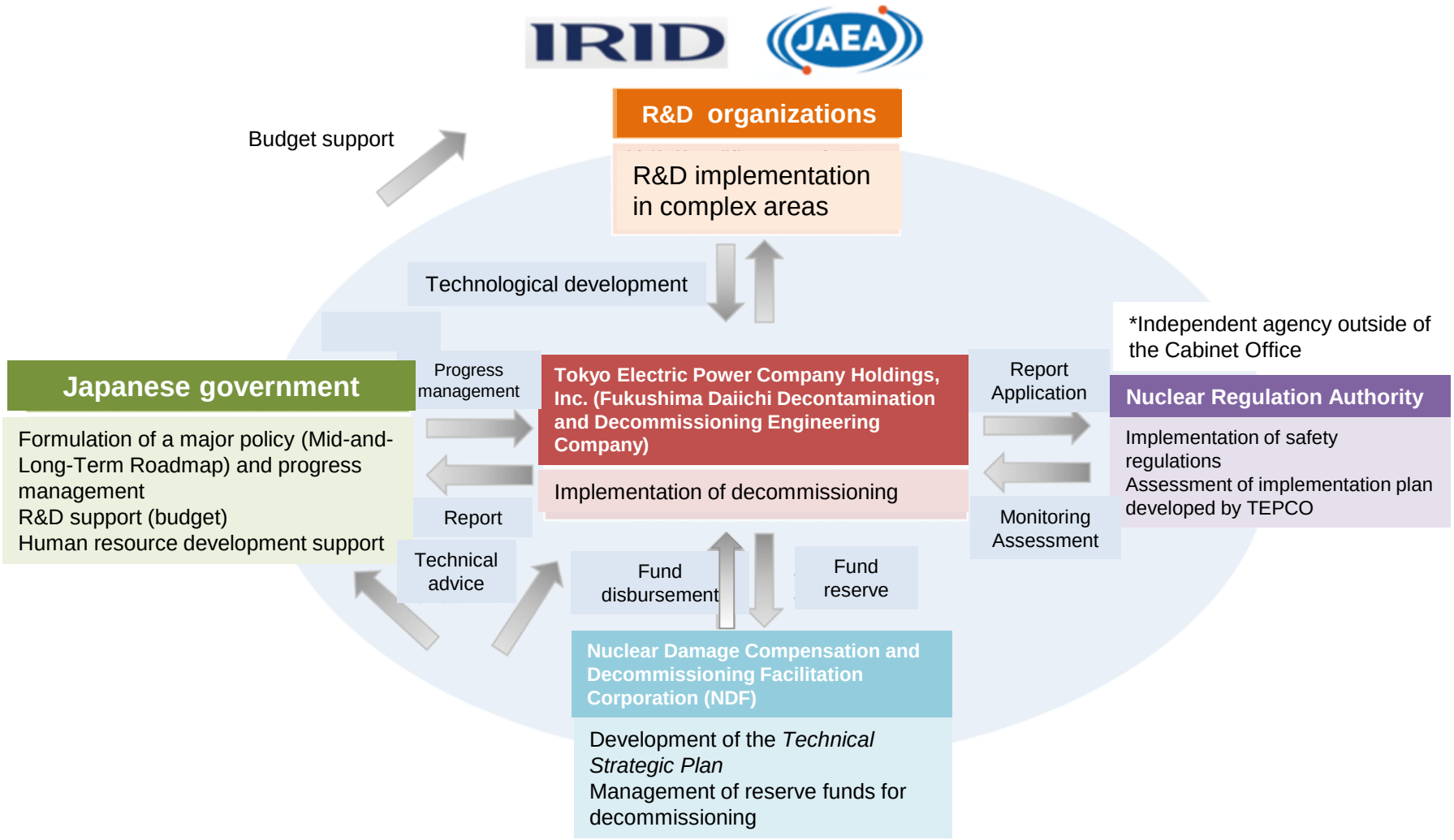
IRID's R&D Results for Fukushima Daiichi Decommissioning and Future Challenges and Expectations

28 August 2023

Toyoaki Yamauchi
President of International Research Institute for Nuclear Decommissioning (IRID)

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

Roles of Organizations in Decommissioning of Fukushima-Daiichi



Reference: "Important Stories on Decommissioning 2021," The Agency of Natural Resources Energy, Ministry of Economy, Trade and Industry of Japan website

Overview of IRID

[Basic principles]

IRID commits to research and development of technology **for the decommissioning of the Fukushima Daiichi Nuclear Power Station as a current urgent issue** from the standpoint of strengthening the foundation of nuclear decommissioning technology

■ **Name of organization:** International Research Institute for Nuclear Decommissioning (IRID)

■ **Establishment:** August 1, 2013 (approved by the Minister of Economy, Trade and Industry of Japan)

■ **Member organizations:** **Number of IRID members: 766 people**
(As on March 31, 2023, excluding directors)

- **Research Institutes: 2 Organizations**
  Japan Atomic Energy Agency (JAEA), National Institute of Advanced Industrial Science and Technology (AIST)
- **Manufacturers, etc.: 5 Companies**
  TOSHIBA Energy Systems & Solutions Corporation, Hitachi-GE Nuclear Energy, Ltd., Mitsubishi Heavy Industries, Ltd., ATOX Co., Ltd., Tousou Mirai Technology, Co. Ltd.
- **Electric Utilities, etc.: 12 Companies**
  Hokkaido Electric Power Co., Inc., Tohoku Electric Power Co., Inc., Tokyo Electric Power Company (TEPCO) Holdings, Chubu Electric Power Co., Inc., Hokuriku Electric Power Company, Kansai Electric Power Co., Inc., The Chugoku Electric Power Co., Inc., Shikoku Electric Power, Incorporated, Kyushu Electric Power Co., Inc., The Japan Atomic Power Company, Electric Power Development Co., Ltd., Japan Nuclear Fuel Ltd.

■ **Project costs**

Unit: 100 million Yen

Fiscal year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Project costs	46	122	147	143	148	140	142	145	170	155

R&D projects conducted by IRID

1. R&D for fuel removal from spent fuel pool

Evaluation of **Long-term Structural Integrity** of Fuel Assemblies Removed from Spent Fuel Pool

3 R&D for Radioactive Wastes

Technology for **Proceeding Process Methods** of Radioactive Wastes

Treatment and **Disposal of Solid** Radioactive Wastes

2 R&D for Fuel Debris Retrieval

Technology for Decontamination and Dose Reduction

Remotely Operated Decontamination Technology in R/B

Fuel Debris Retrieval Technology

Retrieval Technology for Fuel Debris and Internal Structure:
Criticality Control/Fundamental Technology/ Small Neutron Detector

Development of Retrieval Technology and Method For Fuel debris and Internal Structures

Dust collection System for Retrieval of Fuel debris and Internal structures

Technology for **Containment, Transfer And Storage** of Fuel Debris

Development of Safety System for fuel Debris retrieval

Technology for Environmental Improvement

<Ensuring of the stable state>

Corrosion Control Technology in RPV/PCV

Full-scale test for Repair Technology for PCV Leak Points

Full-scale Test for Water Circulation Technology in PCV

Investigation and Analysis Technology

<Indirect Investigation> <Direct Investigation>

Fuel debris detection Technology for RPV

Upgrading for **Identifying Conditions Insides the Reactor**

Technology for **Detailed Investigation Inside PCV**

Investigation Technology Inside the RPV

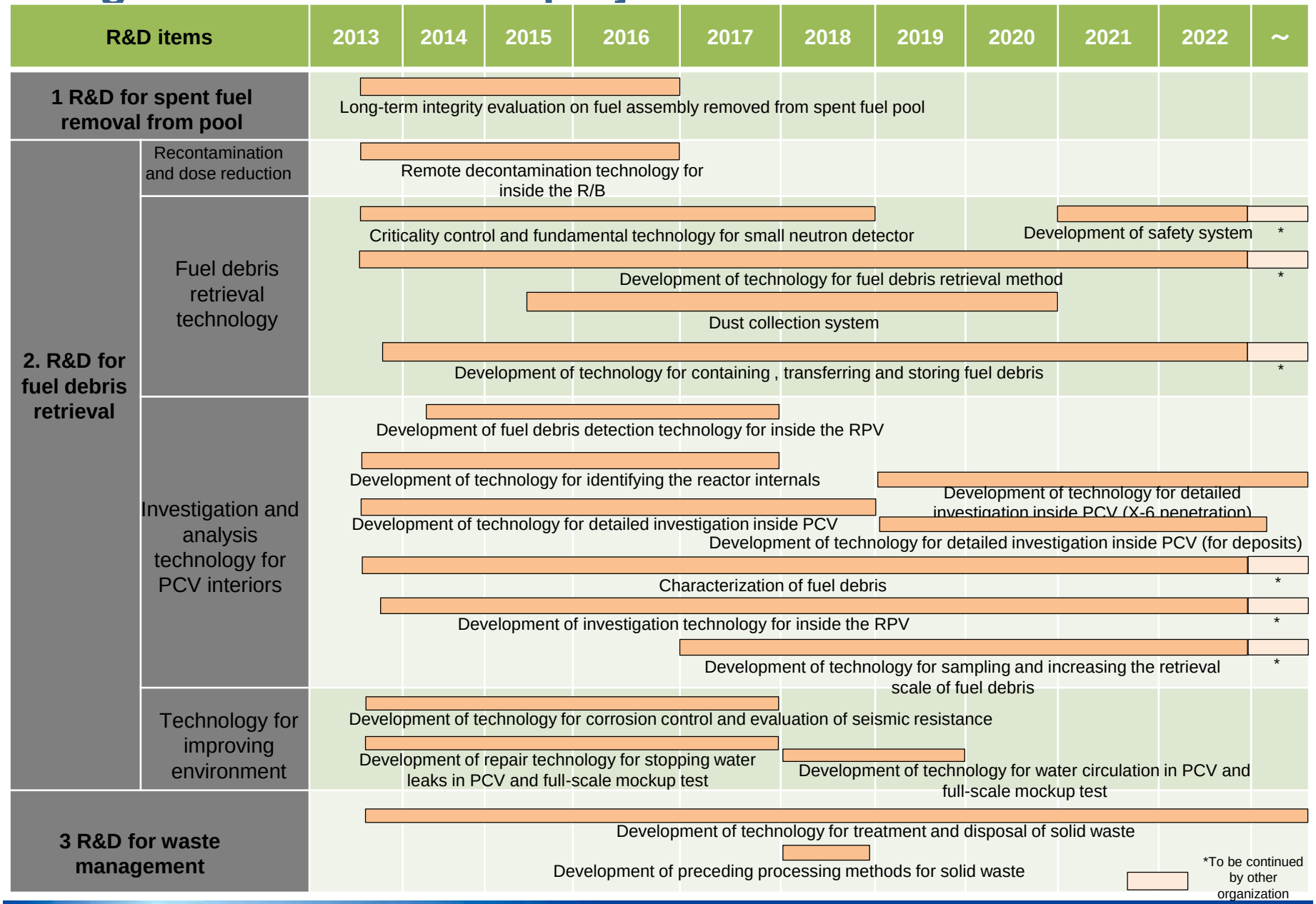
PCV detailed Investigation: **Demonstration Through X-6 penetration**

PCV Detailed Investigation: **Demonstration of Deposits**

Fuel Debris Characterization and Analysis

Fuel Debris Sampling Technology/ /Increase of Retrieval Scale for Fuel Debris

Progress of IRID's R&D projects

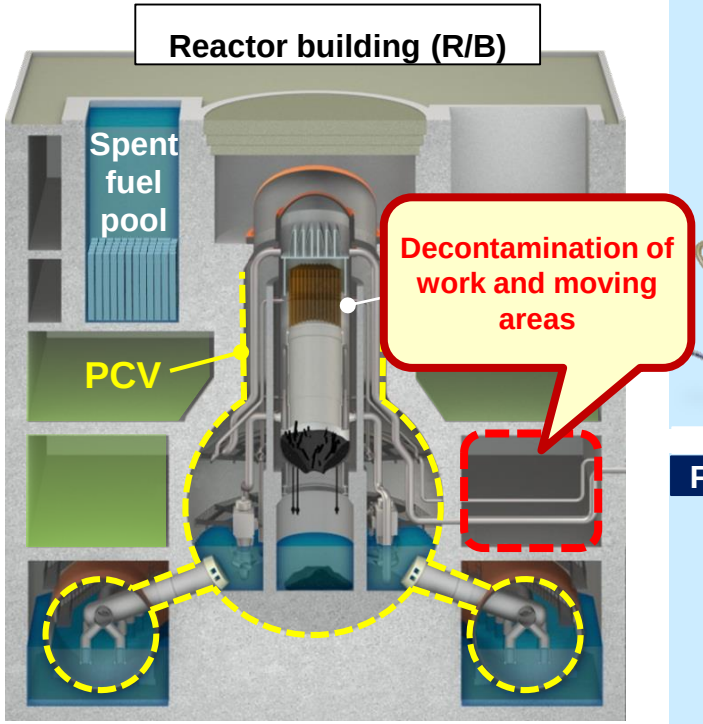


Technologies for decontamination, dose reduction and environmental improvement (repairing PCV to stop water leaks)

Remote Decontamination Technology

Needs for technological development

Humans cannot access the R/B because radiation levels are high in the R/B. It is necessary **to improve work environments (dose reduction).**



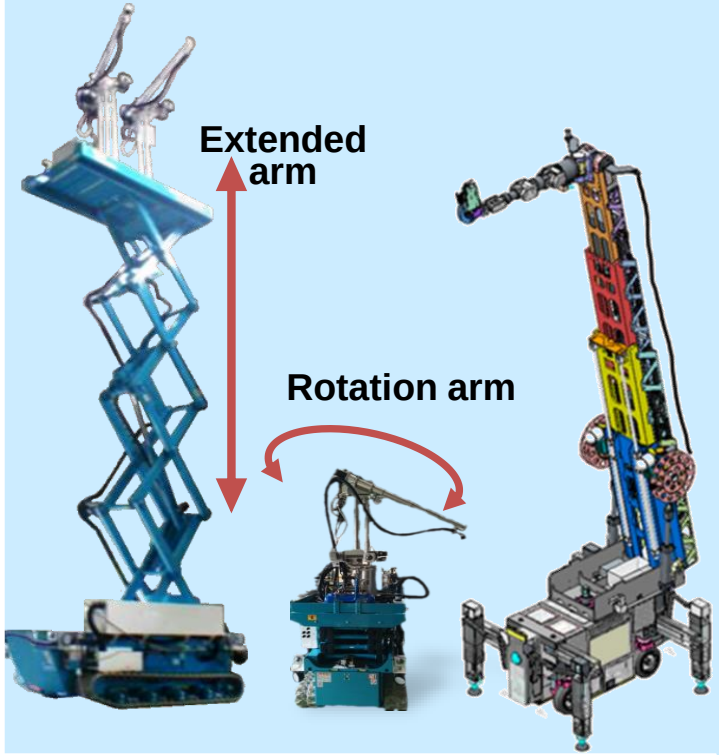
For low places (floors and lower part of walls)

Suction and blast

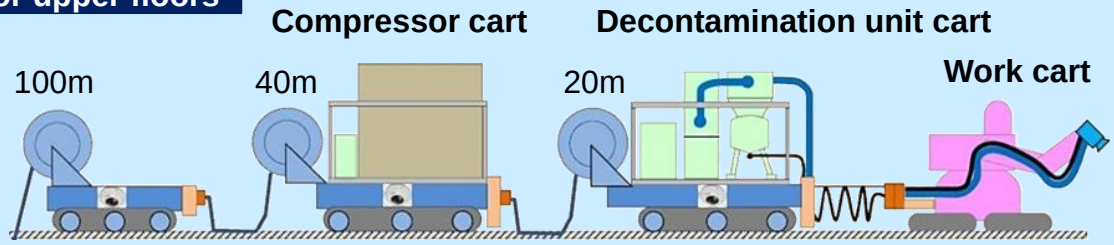
High pressure water injection

Dry ice blast

For high places

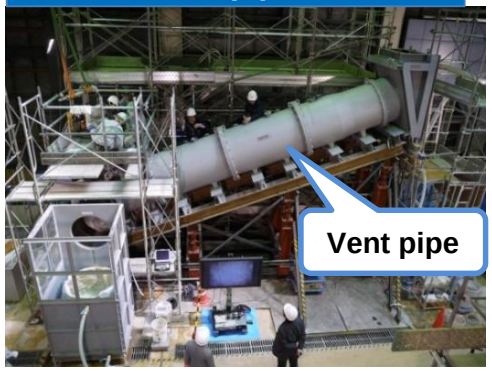


For upper floors



Technology for repairing the primary containment vessel (PCV) and stopping water leaks

Test for stopping water leaks in vent pipe

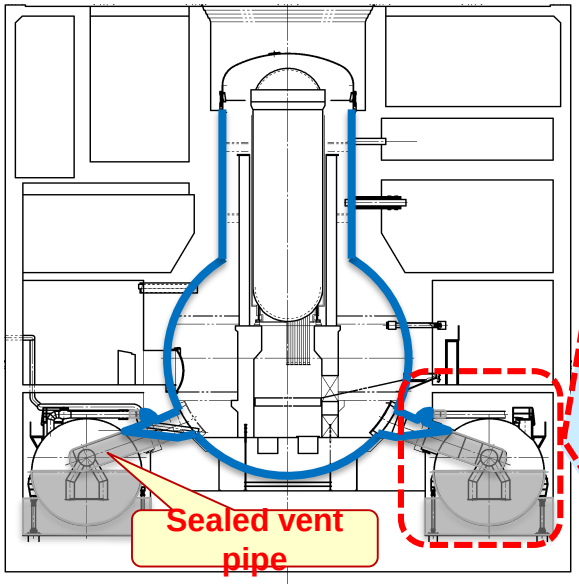


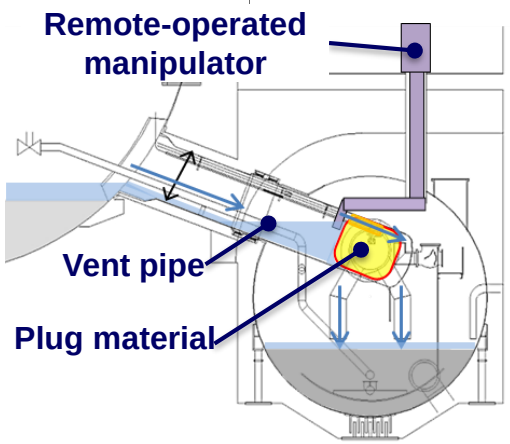
Performance of water stops was confirmed by using the 1/2 scale test facility (in-factory test).

Test for stopping water leaks using plug material

Performance of water stops using a plug material was confirmed by using the 1/2 scale facility (outdoor test).

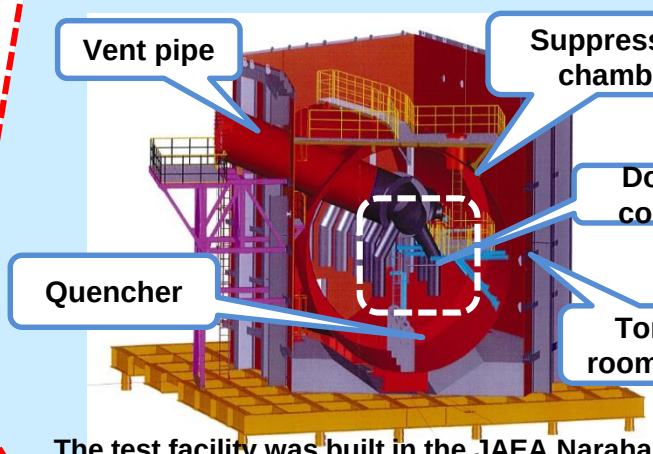
:Area for repairing PCV and stopping water leaks





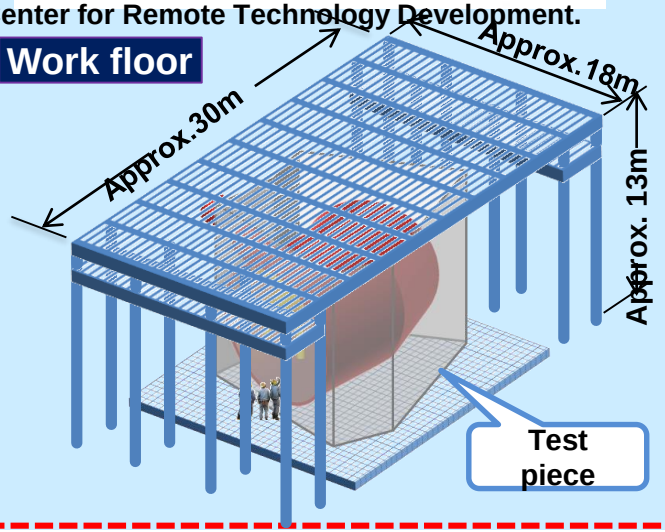
Test using a full-scale test facility

Full-scale test facility (1 / 8 sector)



The test facility was built in the JAEA Naraha Center for Remote Technology Development.

Work floor



Verification procedures of full-scale mock-up facility (JAEA Naraha Center for Remote Technology Development)

Purpose

- This test aims to create a procedure manual considering an actual work and **evaluate the onsite applicability** by using a full-scale mock-up facility.

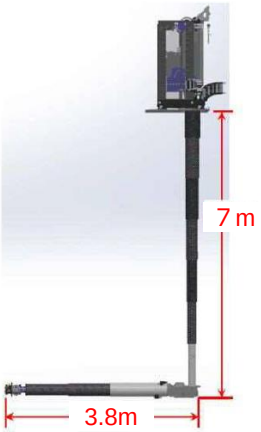
Main approach

- Focusing on the following three methods for stopping water leaks, work procedures are confirmed by conducting tests of the workability and concrete placement.
  - ① Water stops for vent pipes
  - ② Water stops by filling in the S/C
  - ③ Strengthening the S/C support column S/C

Mock-up facility

Inside of the mock-up facility (S/C interior)

Verification test of strengthening workability of the S/C support column



Remote-operated manipulator

Investigation technology for inside the PCV*and investigation results

*PCV: Primary containment vessel

Muon transmission measurement to identify the location of fuel debris

- Muons are secondary cosmic rays, which generate when radiation from space collides with the atmosphere of the Earth. The cosmic ray muons are high-energy particles and can pass through materials.
- Muon tomography can measure the number of muons that pass through the reactor building to image the density of materials such as X-ray. It can be used to image the distribution of fuel debris in the reactor pressure vessel (RPV). (Smaller number of muons will pass through high density regions so higher density regions show dark shadow).

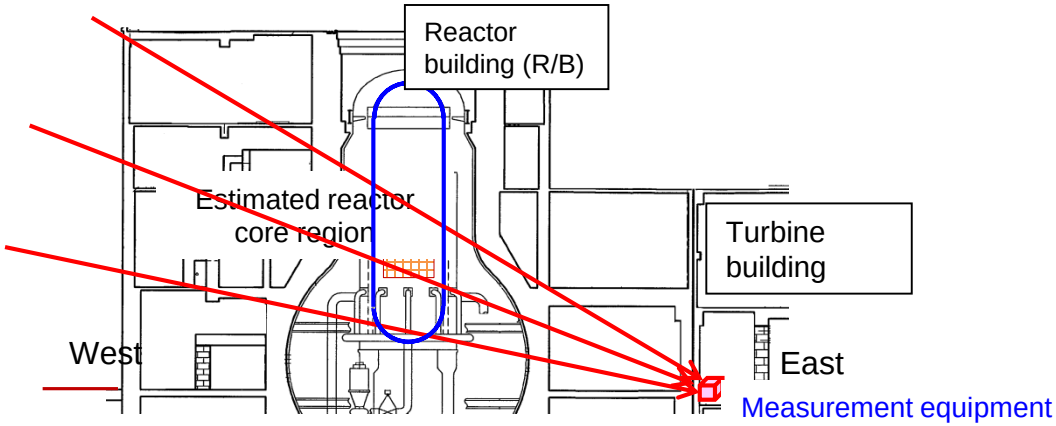


Illustration of measuring muons passing through the reactor building (horizontal cross section)

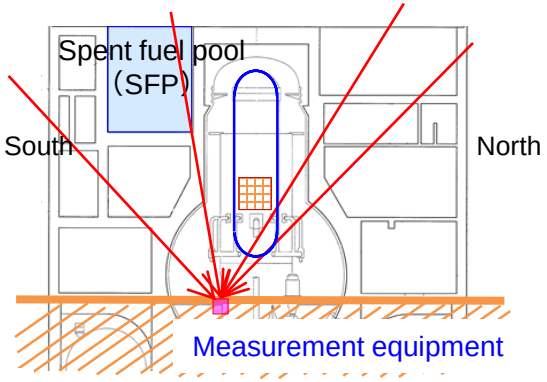
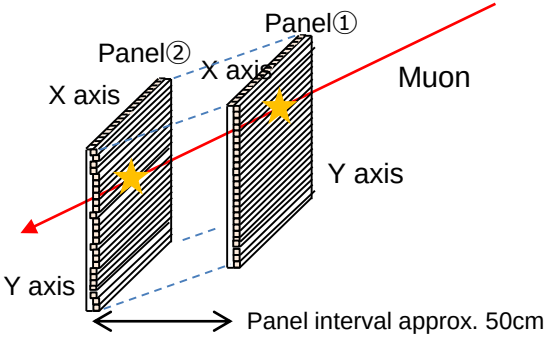


Illustration of measuring muons passing through the reactor building(vertical cross section)

<Measurement principle of the muon transmission method (illustration)>

Two panel detectors (plastic scintillator) that are placed in the measurement equipment can detect muons falling from space and calculate their trace on where they have passed through from the coordinates (X and Y axes) on the panel.



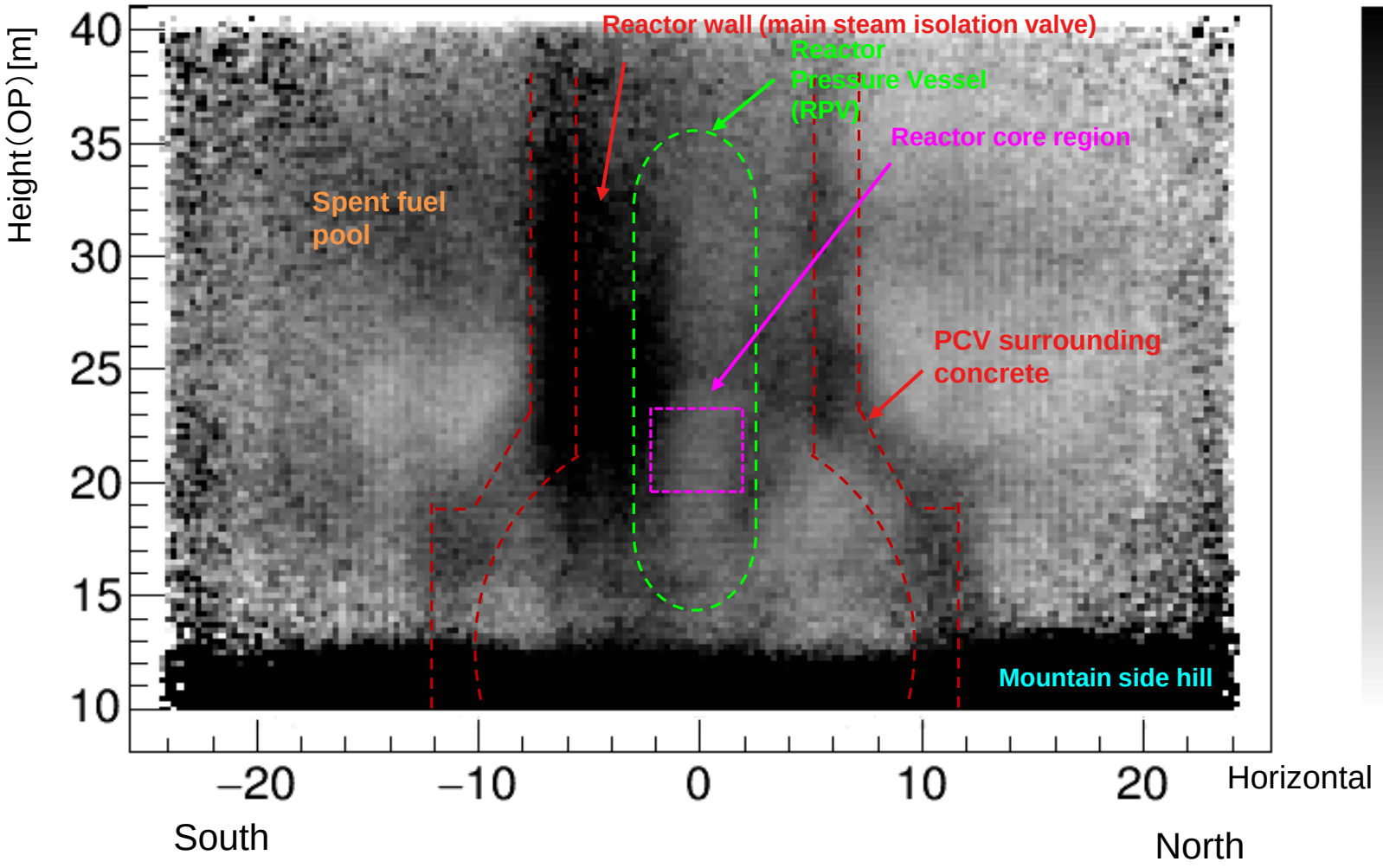
Reference: The TEOCO Holdings, Inc. website

Measurement results of the muon transmission method (2014 - 2017)

No high-density substances were confirmed in the core region of the Fukushima Daiichi Units 1-3.

Measurement image of inside the unit 3

(As of September 8, 2017)

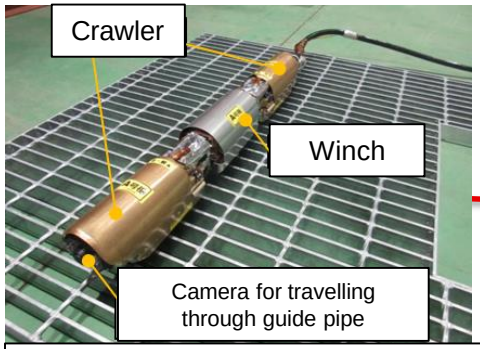


Reference: The TEPCO Holding Inc. website.

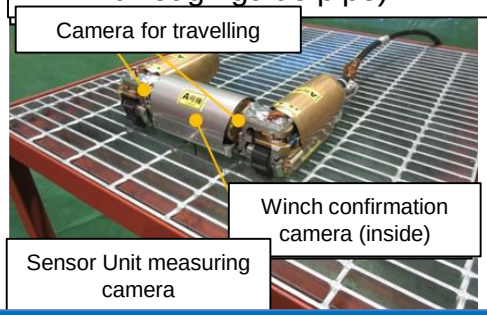
Robots developed for investigation of PCV interiors

Investigation of outside the pedestal (Unit 1)

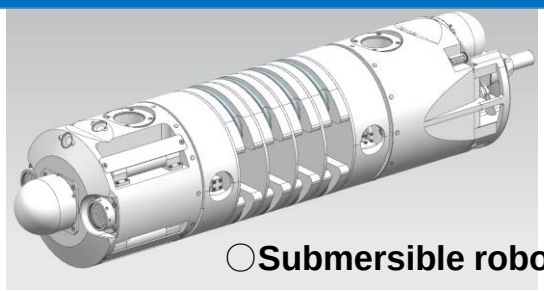
○ **Shape-changing robot (B2 investigation)**



Type Ⅰ (when travelling through guide pipe)



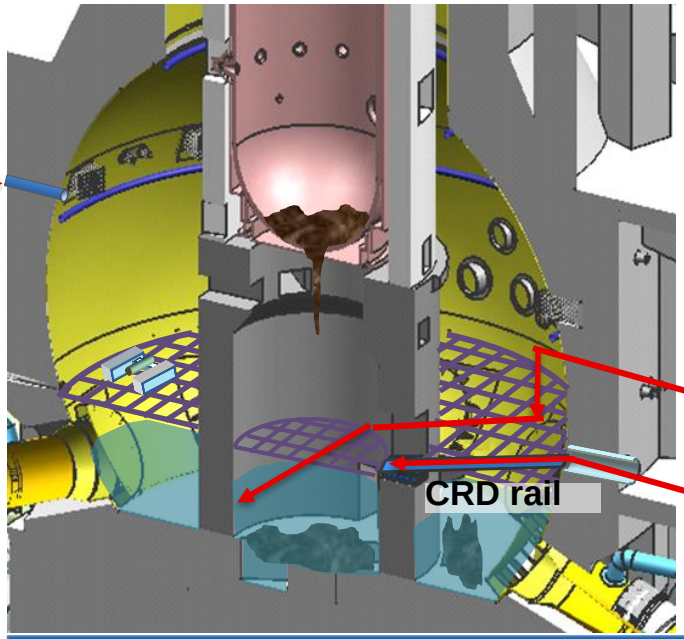
Investigation of inside the pedestal (Unit 1)

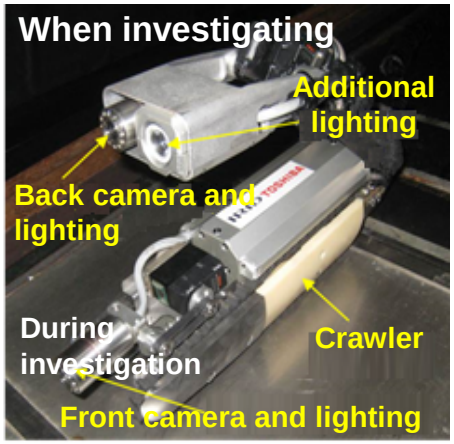


○**Submersible robot**

Investigation of inside the pedestal (Unit 2)

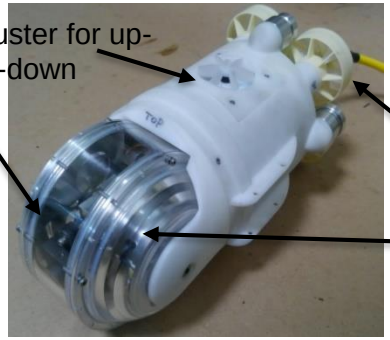
○ **Crawler type remote-operated investigation robot (A2 investigation)**





○**Suspension type investigation equipment (A2' investigation)**

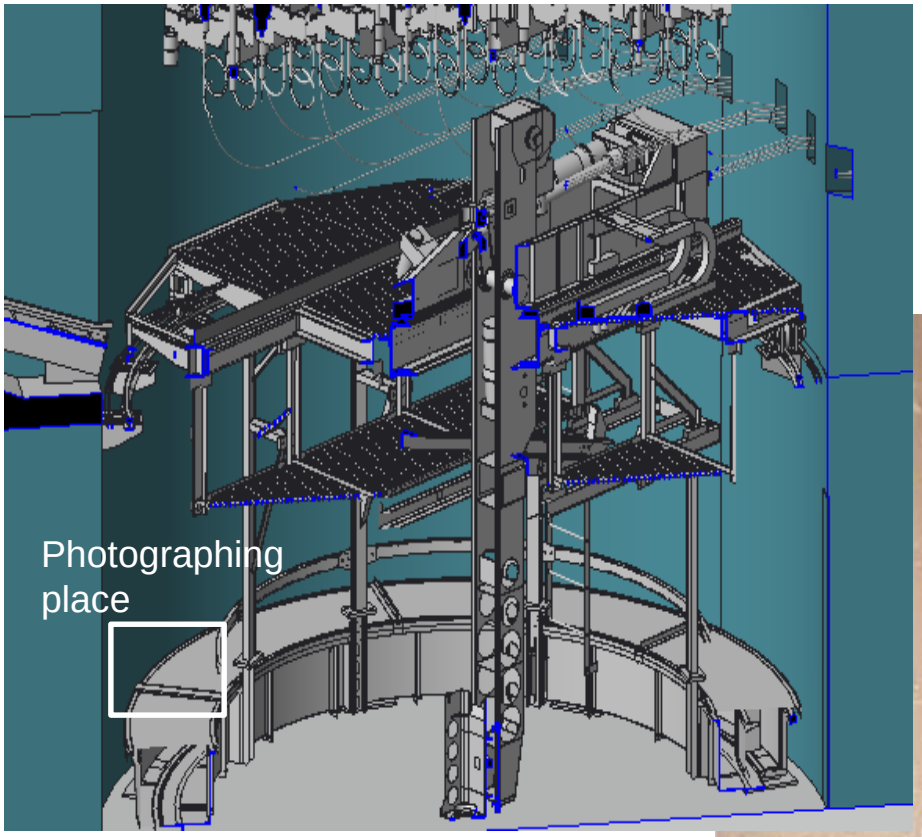
Investigation of inside the pedestal (Unit 3)



○**Submersible robot**

Investigation results of the Unit 2 lower pedestal interior

(A2' investigation on Jan.2018)



The Unit 2 PCV bottom
(An overhead view)

Photo: Near the pedestal inner wall
at the Unit 2 PCV bottom

(A fuel assembly handle was found.)

Reference: The TEPCO Holding Inc. website.

Investigation results of the Unit 2 upper pedestal interior

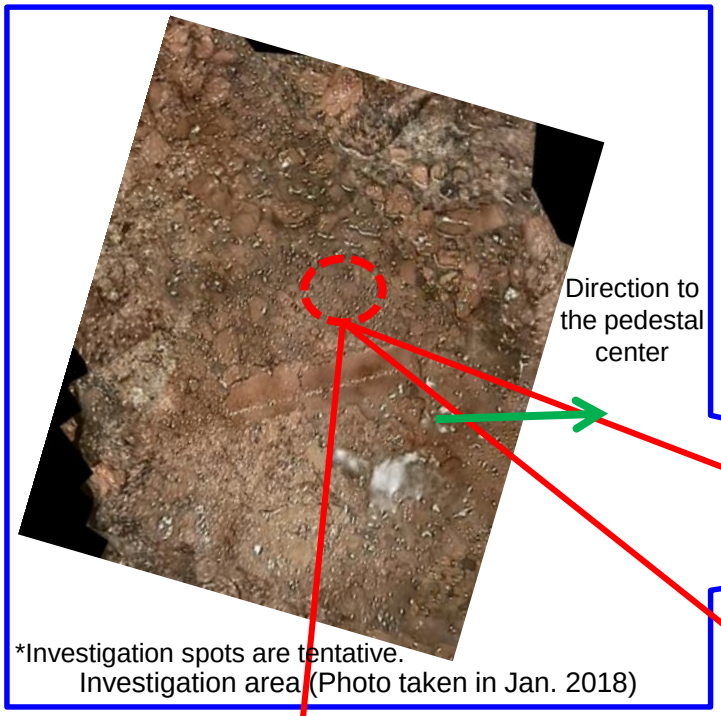
(A2 investigation: January – February 2017)

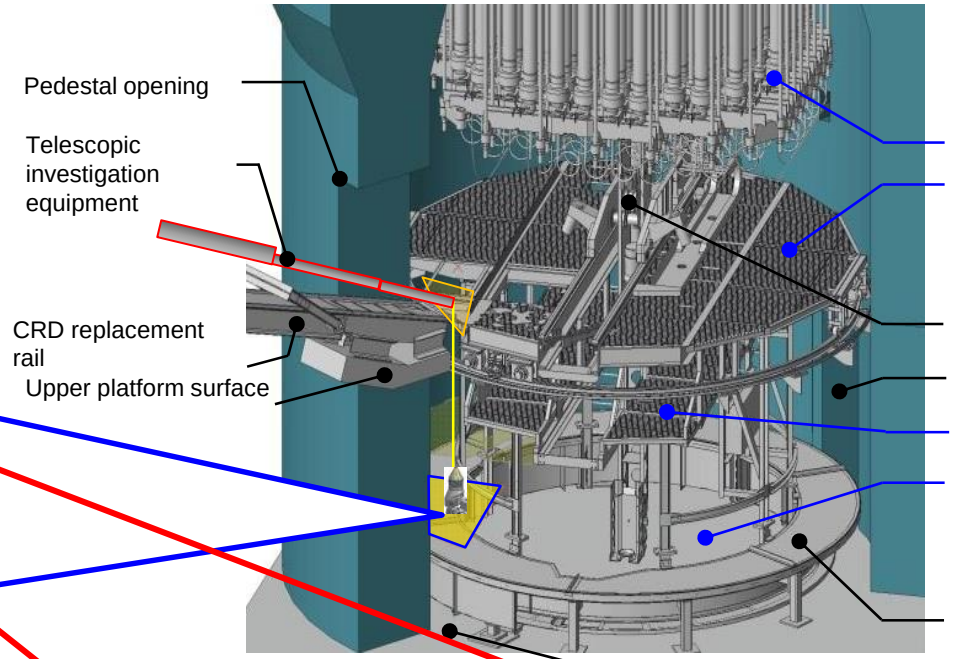
Upper pedestal interior (after image processing)

Reference: The TEPCO Holding Inc. website.

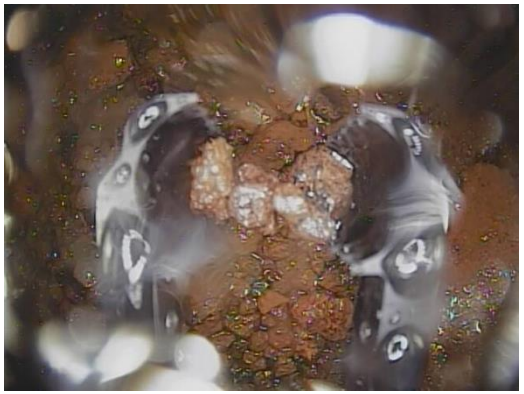
Investigation results of the Unit 2 pedestal floor

(February 2019)





Before touching deposits



Touching deposits

After touching deposits

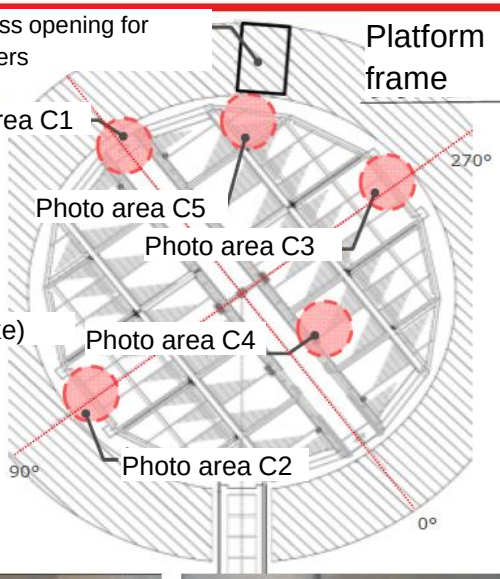
Reference: The TEPCO Holding Inc. website.

Investigation results of the Unit 3 PCV interior (in July 2017)

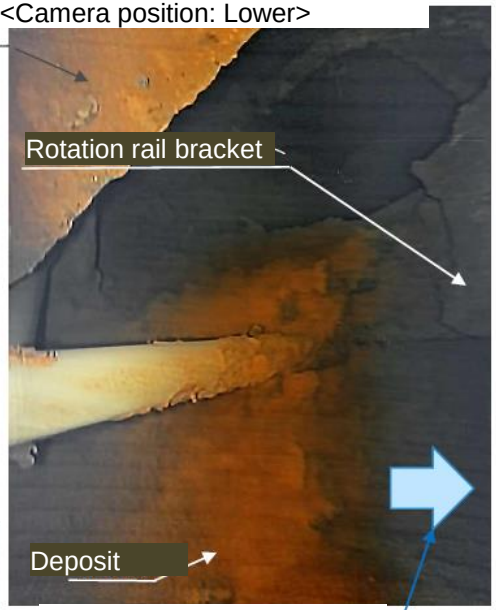
2. Investigation results
2.3. The lower pedestal

Area C1 where a photo was taken
<Camera position: Lower>

Deposit (pebble-like)



Area C5 where a photo was taken
<Camera position: Lower>



Area C2 where a photo was taken
<Camera position: Horizontal>

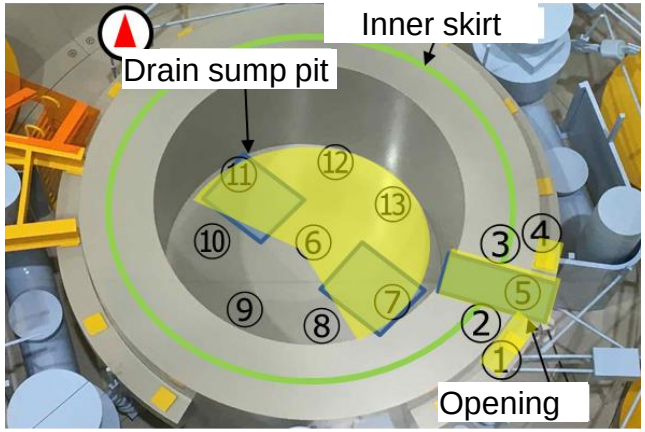
Area C3 where a photo was taken
<Camera position: Upper>

Area C4 where a photo was taken
<Camera position: Lower>

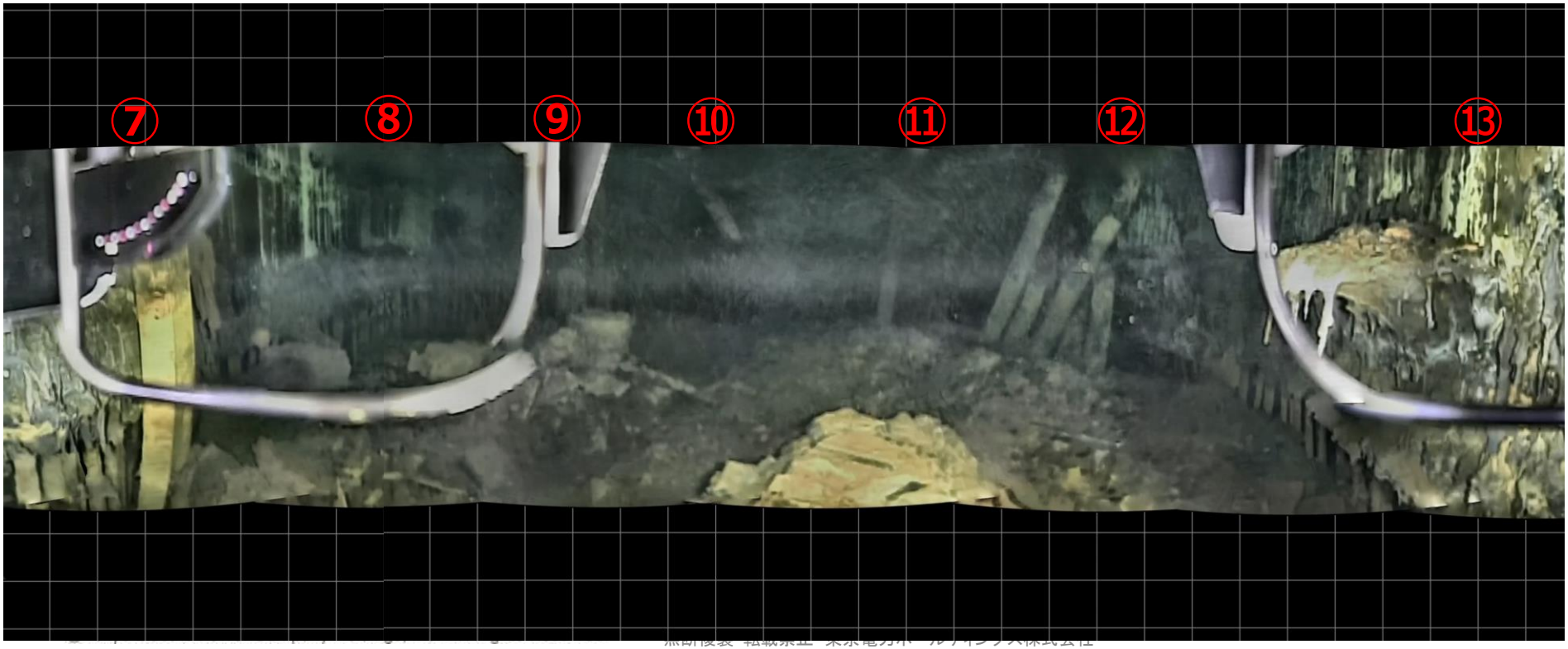
- The investigation has revealed that deposits in sandy, pebble-like and massive form has accumulated.
- The access opening for workers was not confirmed visually (Deposits were found nearby the pedestal).

Reference: The TEPCO Holding Inc. website

Investigation results of the Unit 1 pedestal interior



A panoramic view of the pedestal interior (image processing by TEPCO HD)



Reference: The TEPCO Holding Inc. website.

Investigation results of the Unit 1 pedestal floor (March 2022)

Tokyo Electric Power Company (TEPCO) Holdings, Inc. investigated the pedestal opening. The first-half investigation on March 2022 confirmed that the pedestal wall of the opening part was damaged. The second-half investigation on March 2023 confirmed that the entire circumference of the pedestal interior was also damaged.

- TEPCO assumes that the lost concrete area of the pedestal inner wall (only concrete remains) is approximately 1meter in height and 50cm in depth.
- The lost of the pedestal outer wall opening would be limited.

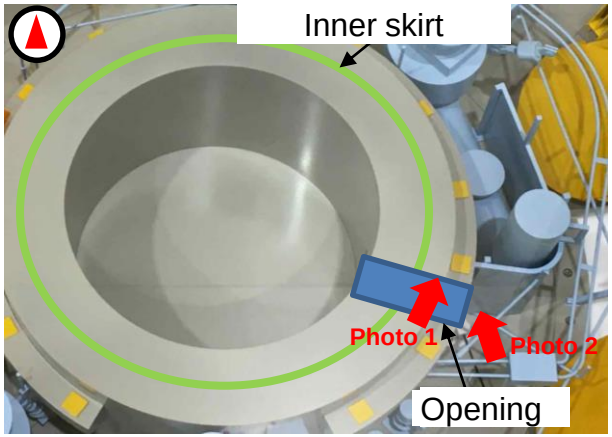


Photo 1: Concrete remains seen from the pedestal opening

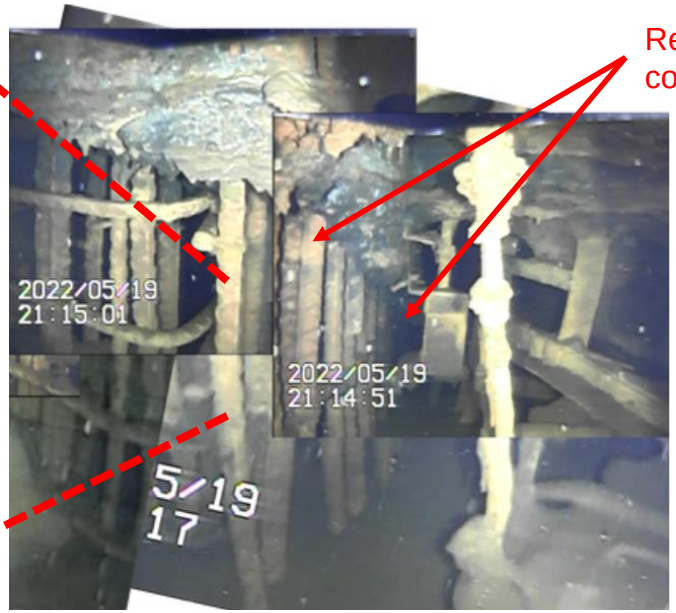


Photo 2: Concrete remains seen from the pedestal opening

Reference: Study committee of monitoring and evaluating specific nuclear facilities (the 107th), April 14, 2023

Photos processed by TEPCO Holdings Inc.

Development for future investigation technology inside Reactor Pressure Vessel (RPV)

- In addition, elemental technology for accessing the RPV from the side has been developed.
- The elemental technology for accessing the RPV from the top and investigating the inside has been verified for future prototypes.

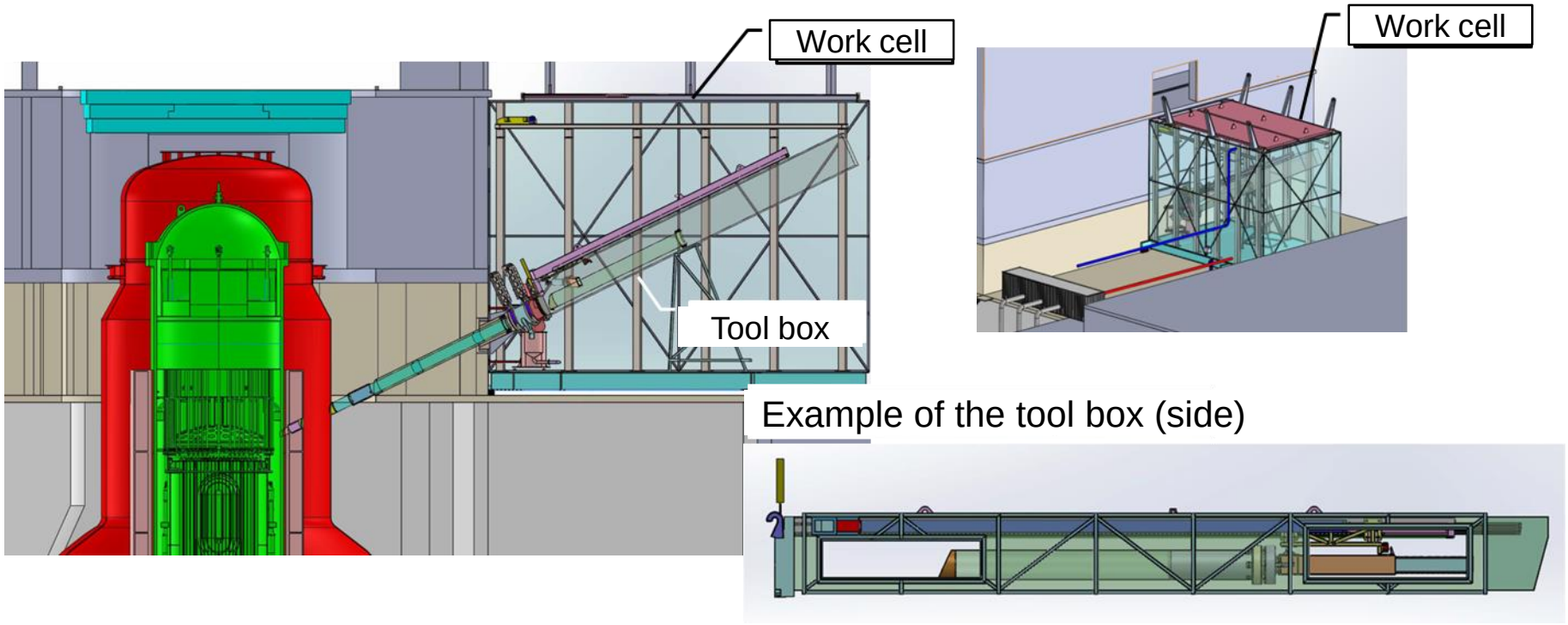
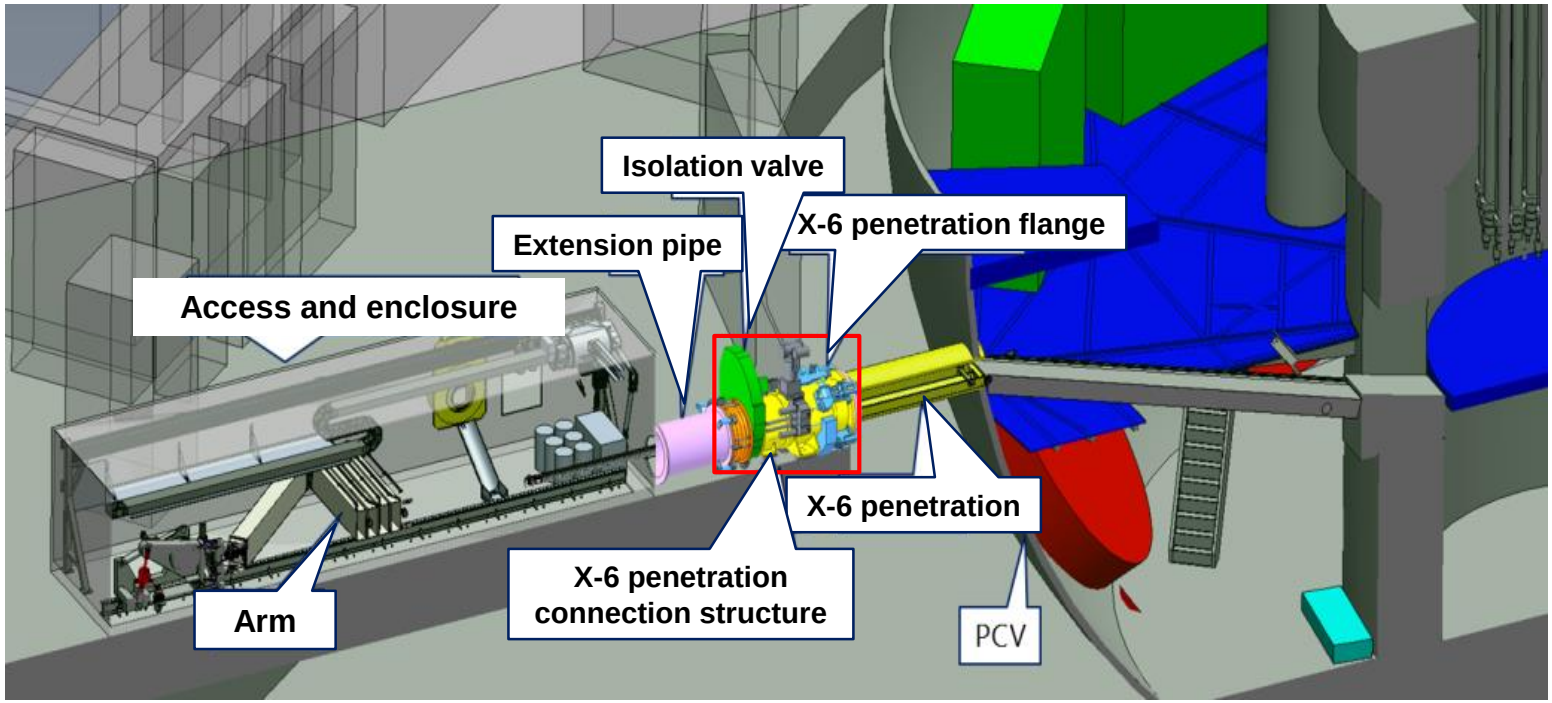


Illustration of the side opening investigation method

Technological development for fuel debris retrieval

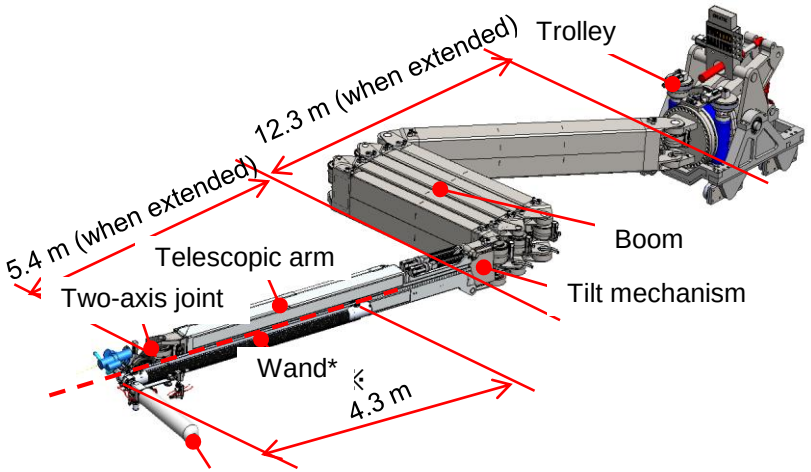
A concept of fuel debris retrieval for the Unit 2 of Fukushima Daiichi



- A long cantilever arm with 22 meter in length and 4.6 ton in weight is designed to pass through a narrow X-6 penetration (55 cm in inner diameter and some deposits have accumulated inside the X-6 penetration).
- Fuel debris which is located on the pedestal floor 5 and 10 meters below the X-6 penetration end can be retrieved by using a tool operated with the program control system.
- Collected fuel debris will be stored in a container designed for duel debris, which is remotely operated in the enclosure.

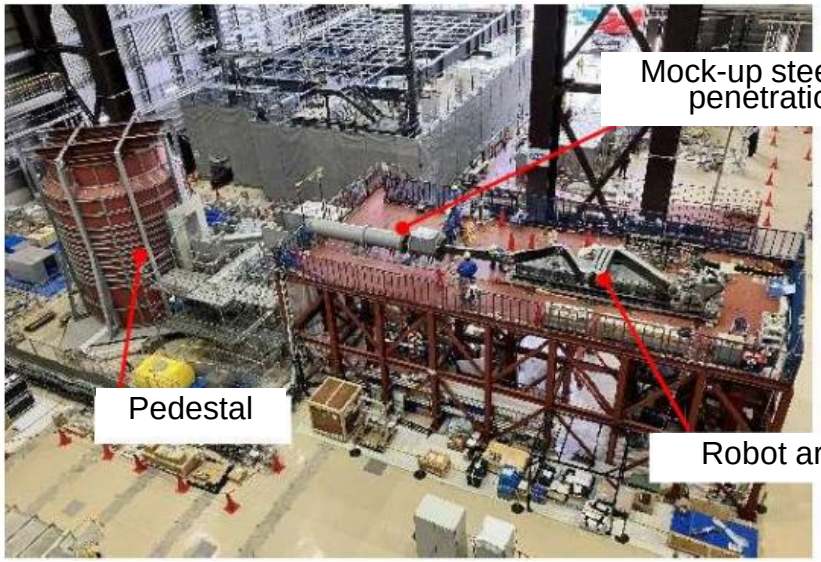
Development and demonstration of the robot arm

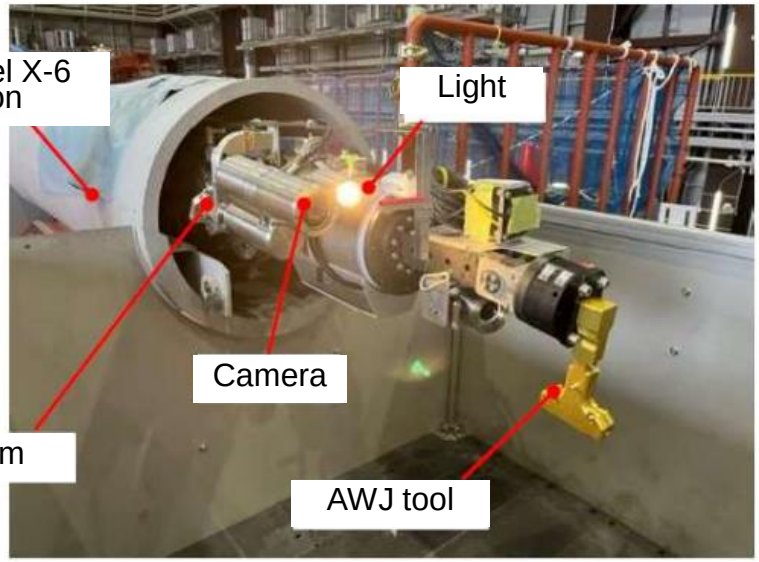
- The arm type access equipment was manufactured which can access on a wide range through the PCV penetration for maintenance of a control rod drive mechanism.
  - Total length of the arm: Approx. 22m
  - Investigation equipment up to 10kg can be loaded.



*The wand can be replaced an alternative tool.

Demonstration test at the JAEA Naraha Center for Remote Technology Development





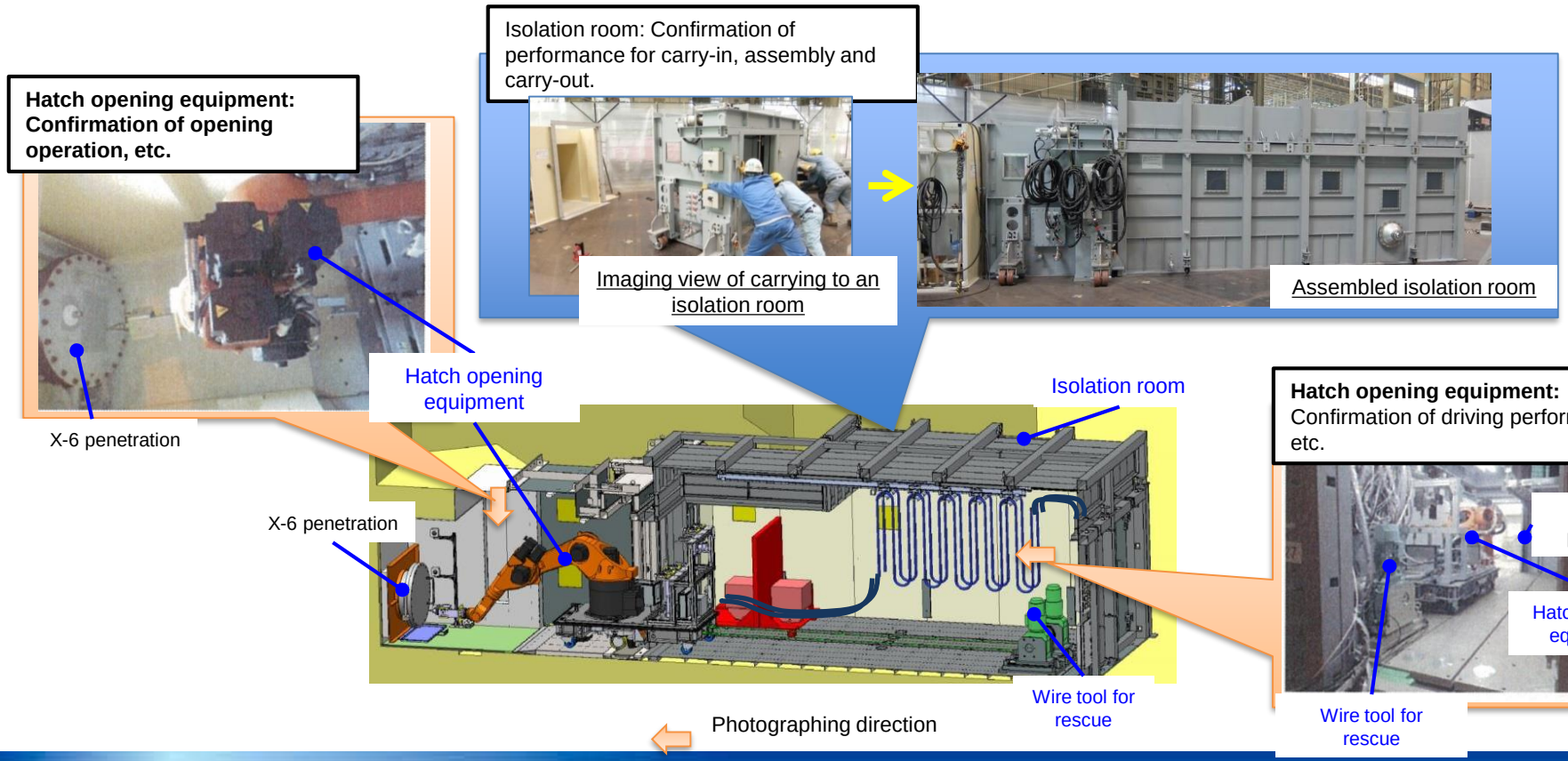
Reference: Report of the preparation status of investigation inside the Unit 2 PCV and trial retrieval of fuel debris issued by the Team Meeting and Countermeasures for Decommissioning and Contaminated Water Treatment Conference (the 115th).

Hatch opening of the Unit 2 PCV penetration

■ Opening of the PCV penetration (X-6 penetration)

Technology for opening the X-6 penetration was developed to insert the arm type access equipment.

- ✓ **Confinement functions when opening the hatch**
- ✓ **Hatch opening by remote operation**

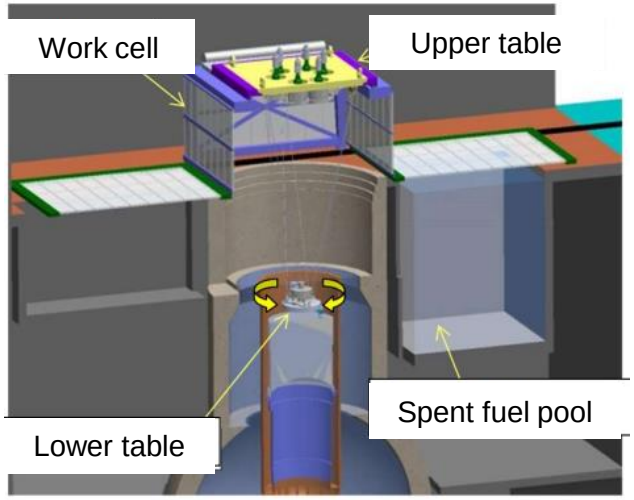


Development of fuel debris retrieval methods

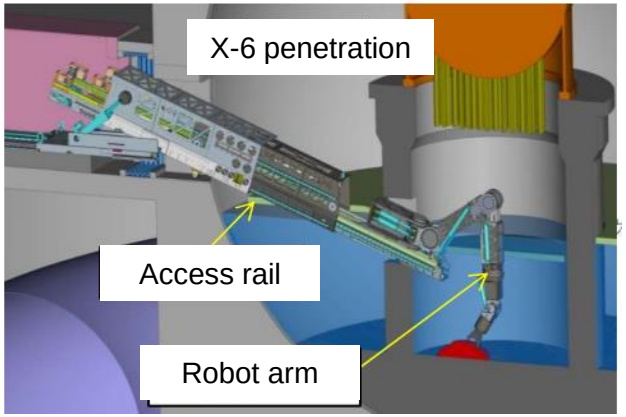
Technological issues

- Ensuring **confinement functions of radioactive dust**
- Establishing **remote-operation** technology
- Establishing technologies for **reducing radiation exposure and preventing the spread of contamination**

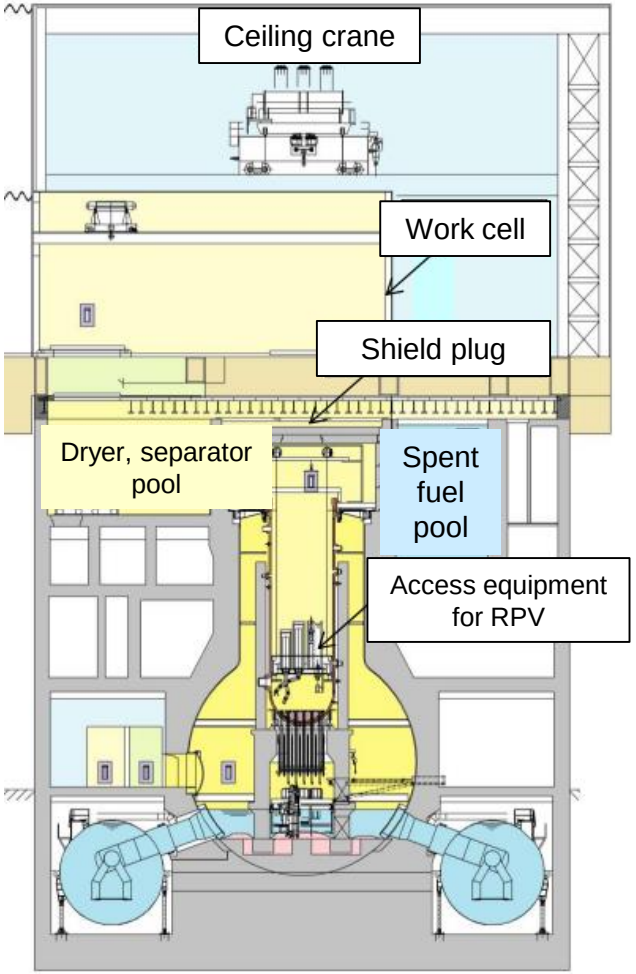
Full-submersion top access method (concept)



Partial-submersion side access method (concept)



Partial-submersion top access method (concept)



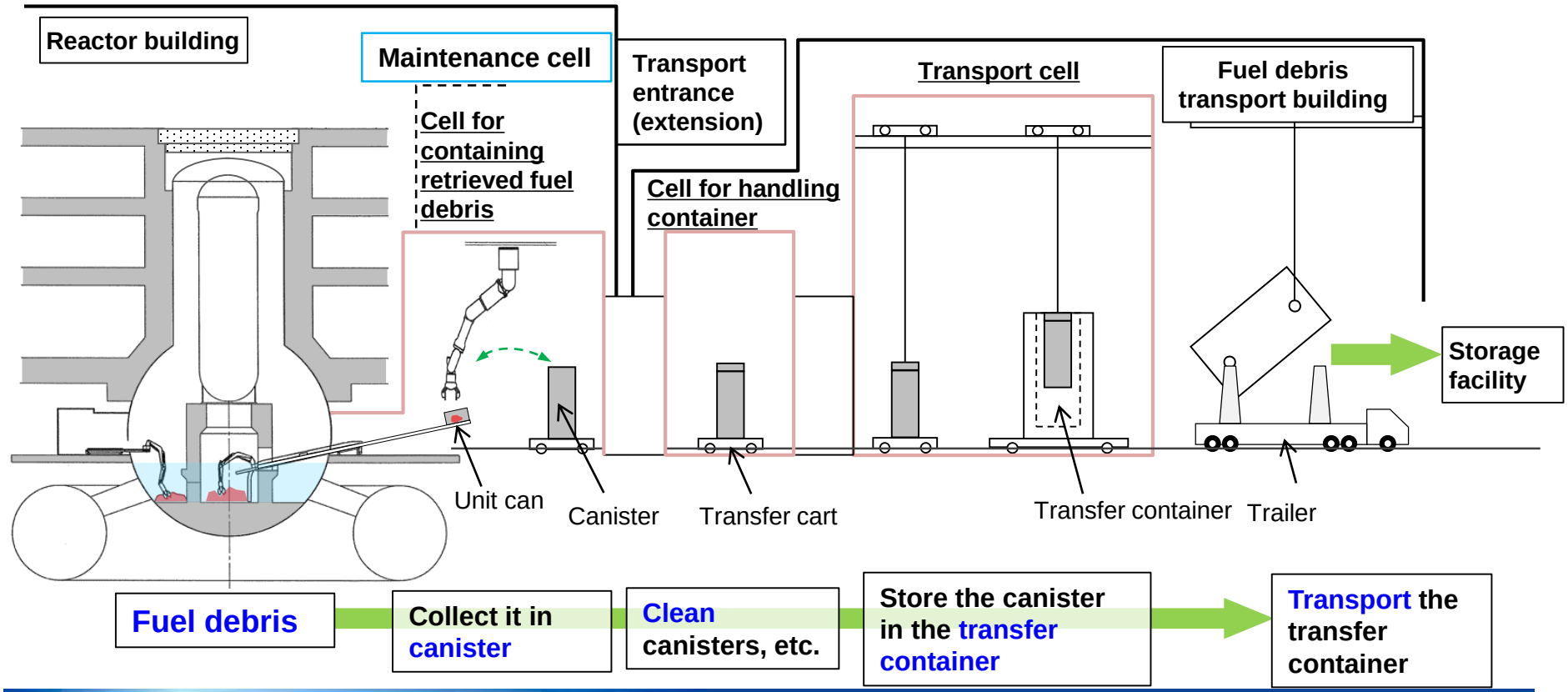
Development of technology for containing, transferring and storing fuel debris

Design of canister

⇒**Responding to issues specific to Fukushima Daiichi**

- High burnup and concentration level → **High reactivity**
- Molten products mixed with concrete → **Hydrogen generation** caused by radiolysis of water containing in concrete
- Sea water injection and molten with instrumentation cables, etc. → Effect from **salt contents** and mixture of **impurities**

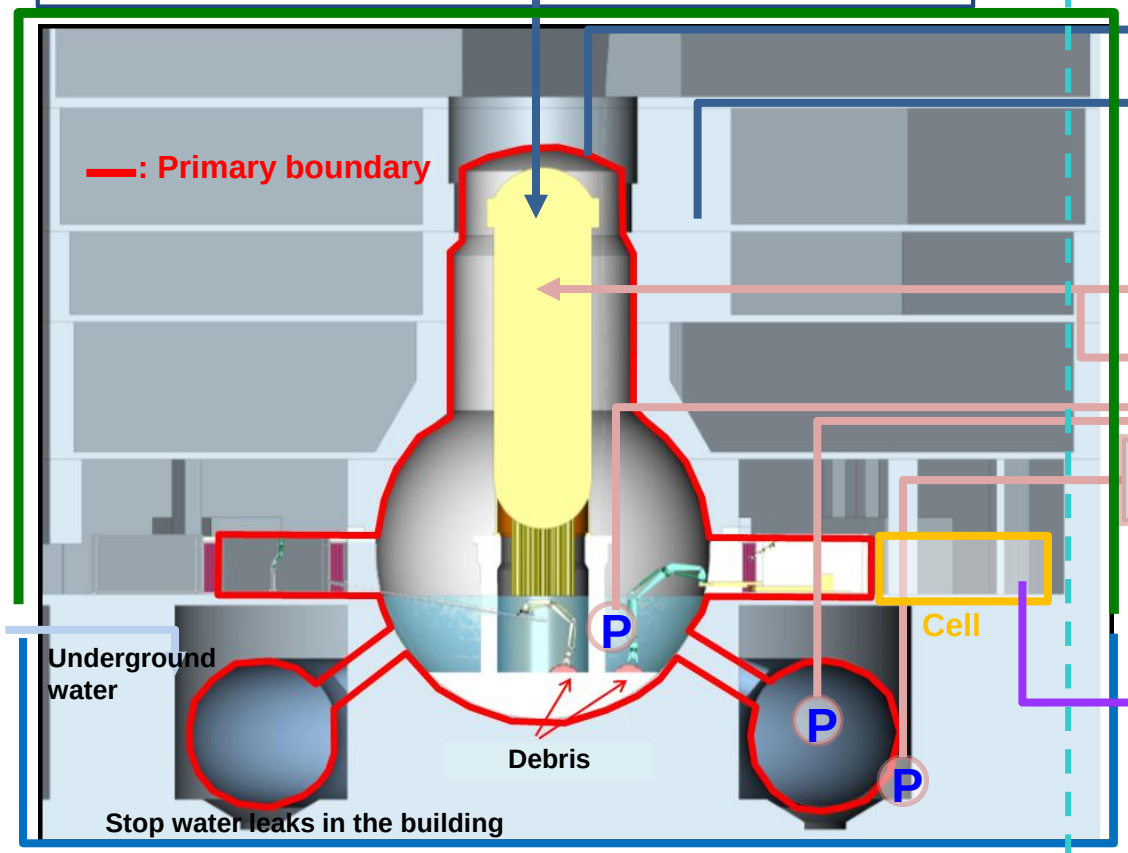
Transfer method (Ex. Partial-submersion side-access method)



Concepts of ensuring the safety when retrieving fuel debris and system design

Necessary safety functions

1. Cooling
2. Confinement (negative pressure and water level control of the torus room)
3. Inactivation (fire and explosion prevention)
4. Sub-criticality



②Nitrogen supply and gas emission processing apparatus

Nitrogen supply system
((RPV inactivation)

Cleaning tower

PCV gas control system
Negative pressure control, hydrogen scavenging)

Reactor building gas control system
Mitigation of radioactive release at ordinary times

①Circulation cooling and criticality control apparatus

Water treatment equipment

Boric acid concentration adjusting equipment

Circulation cooling system
Debris cooling and radioactive concentration reduction

Torus room discharge water system
Underground water level reverse prevention, radioactive concentration reduction, criticality prevention (boric acid concentration)

③Ventilation for the building and cells

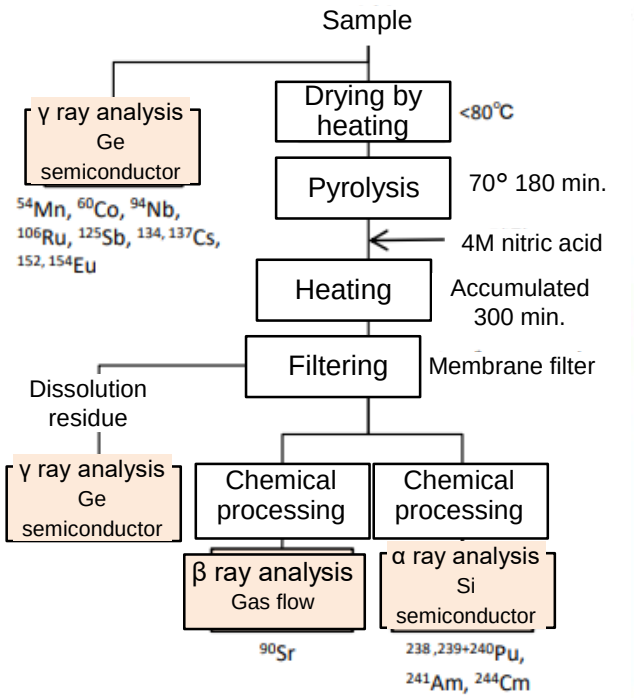
Air exhaustion system for the building and cell
(negative pressure control and control air exhaustion)

Air supply system for the building
(to maintain work environments)

In the auxiliary building

Technology for waste management

Waste characterization : Analysis and database establishment

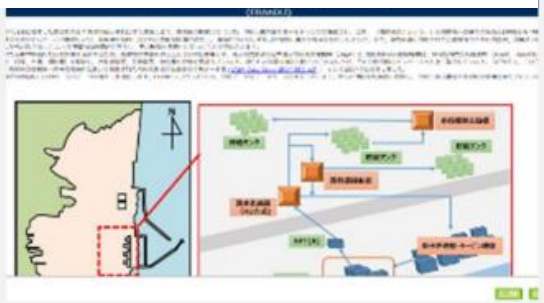


KURION

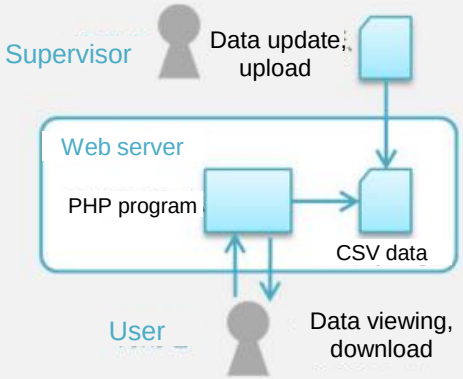
Sample collection equipment

FRAnDLi（Fukushima Daiichi Radwaste Analytical Data Library）
https://frandli-db.jaea.go.jp/FRAnDLi/

Debris-Wiki
The Debris-Wiki is a simple data interface to narrow the search from classification of waste and analysis items. It is easy to use for beginners. The Japan Atomic Energy Agency (JAEA) has developed the wiki-style database platform.



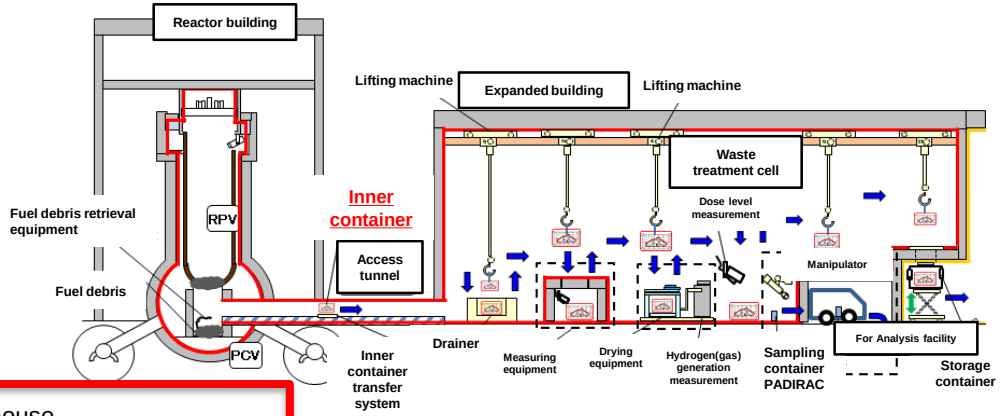
The FRAnDLi top page and search performance



Configuration and functions of FRAnDLi

Technology for storing and handling high level radioactive waste

Contamination measurement by using α camera



Process flow from retrieving fuel debris to storing it (excerpt)

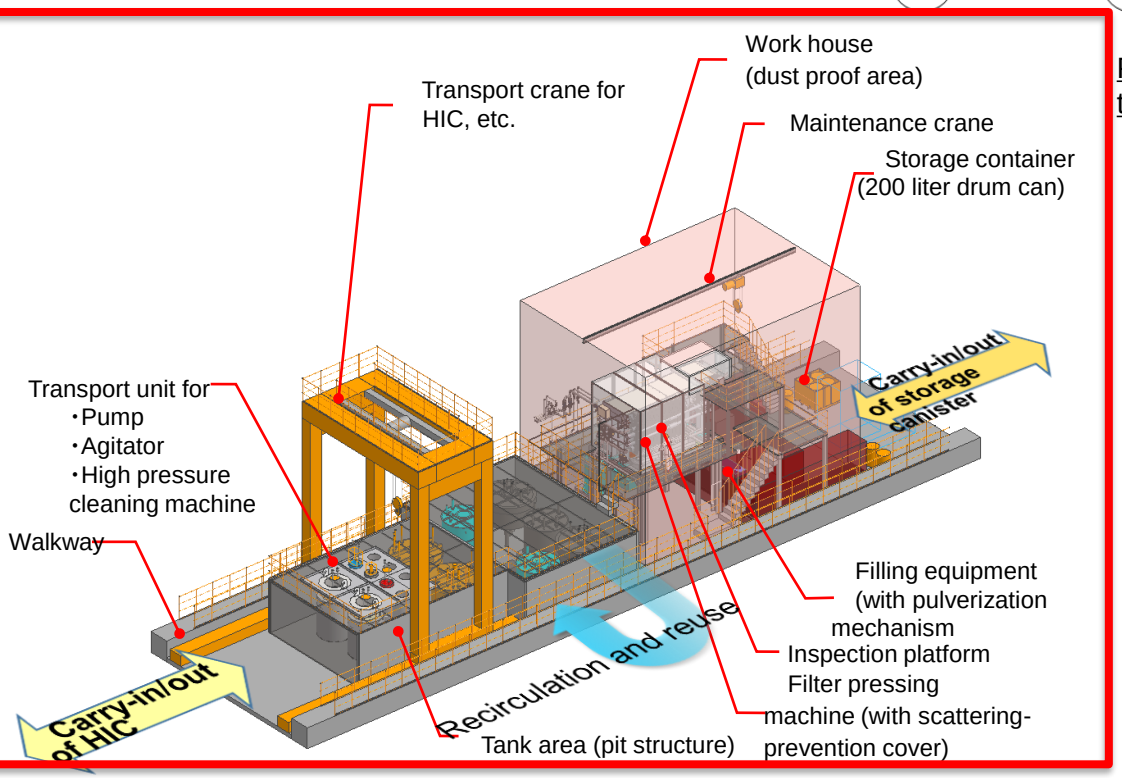
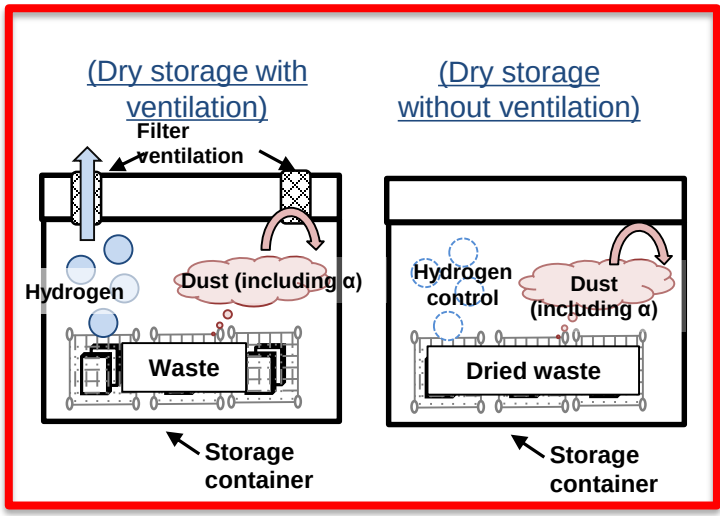


Illustration of pressurized compression filtering method system



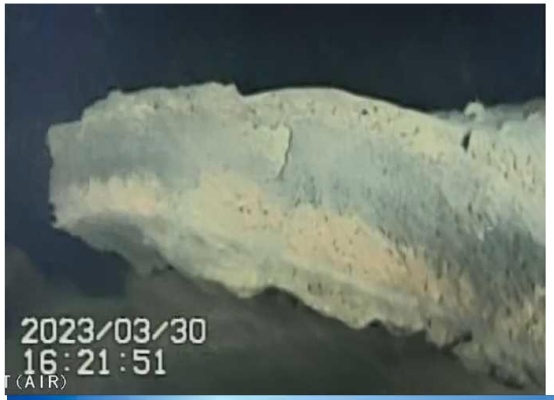
Example of storing high level radioactive waste in Japan (illustration of storage methods)

Summary

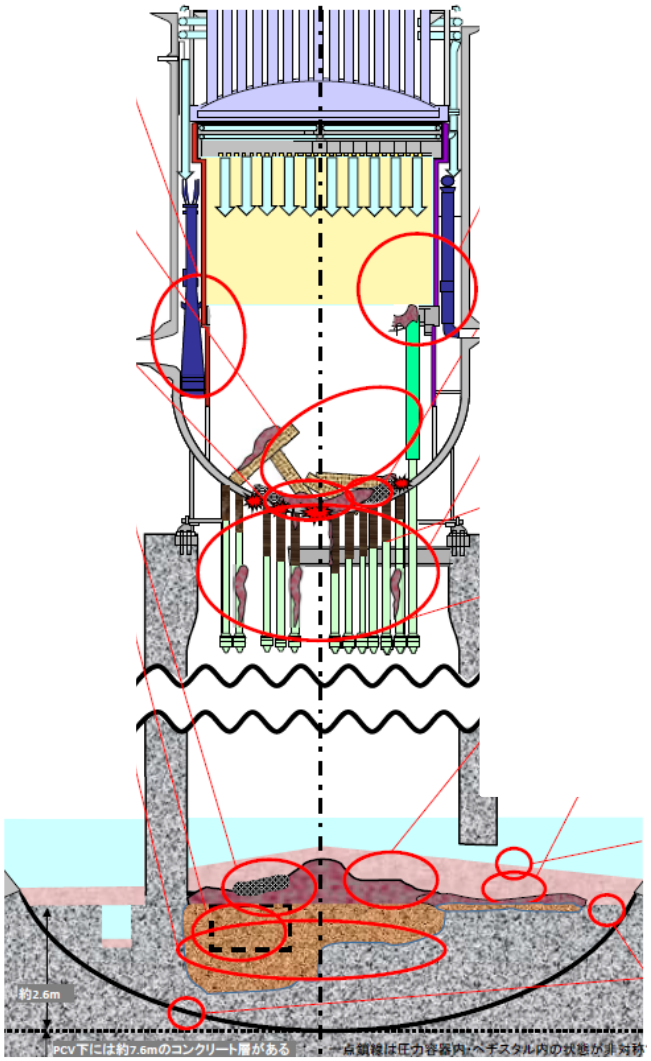
Summary of the investigation results until now (Unit 1)

・Unit 1 has almost no fuel in the RPV, and deposits have spread outside the pedestal. The inner walls of the pedestal were also damaged.
(The Unit 1 reactor core was damaged about eight hours after the loss of power.)

Composite image of the Unit 1 entire pedestal floor
(Reference: the TEPCO Holdings website)



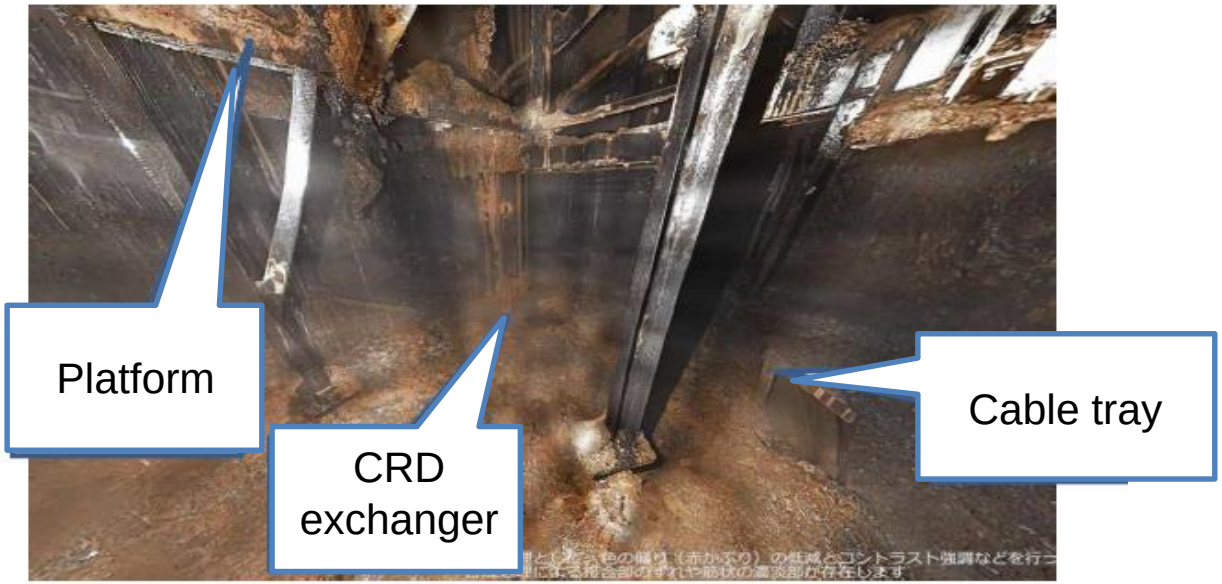
Shelf-shaped deposit outside the Unit 1 pedestal
(Reference: TEPCO Holdings website)



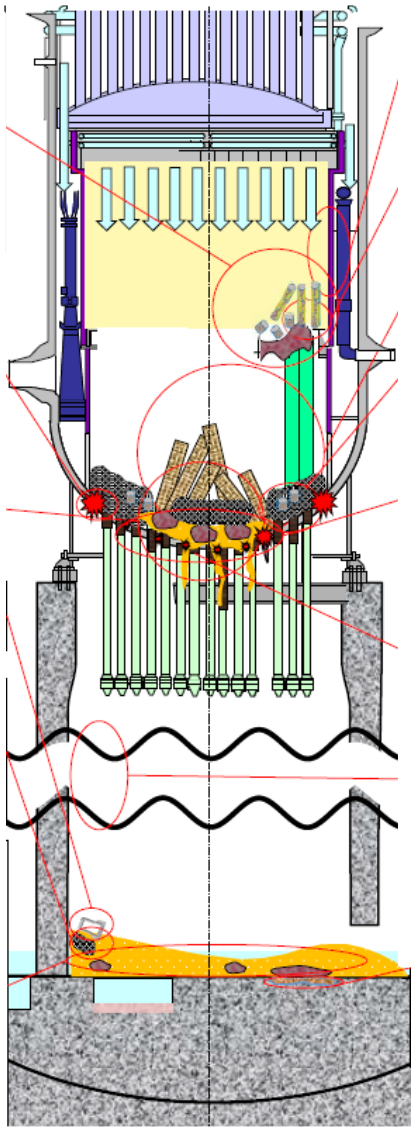
Damage estimation of the Unit 1 RPV/PCV
(From TEPCO website)

Summary of the investigation results until now (Unit 2)

・Unit 2 has a lot of fuel left in the reactor pressure vessel (RPV). Although there is 1 meter-deposit on the pedestal floor. The RPV substructure retains its original form.
(The Unit 2 reactor core was damaged about 3 days after the loss of power.)



Wide angle photo of the Unit 2 entire pedestal floor
(Reference: the TEPCO Holdings website)



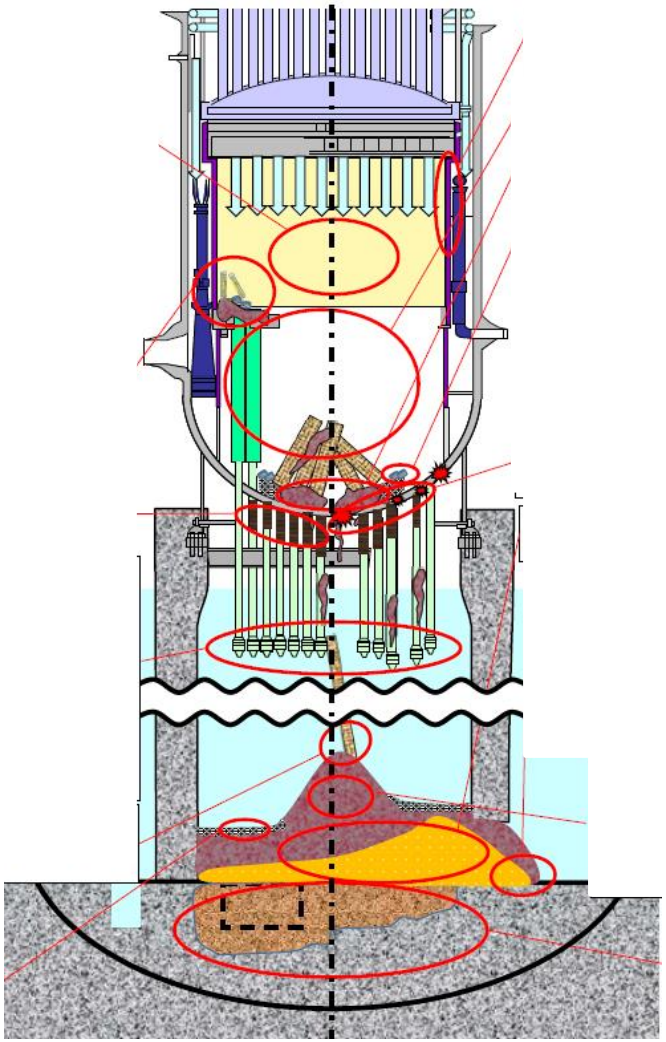
Damage estimation of the Unit 2 RPV/PCV
(From TEPCO HP)

Summary of the investigation results until now (Unit 3)

・Unit 3 have some fuel left in the RPV. There is 2-3 meters of deposits on the pedestal floor.
(The Unit 3 reactor core was damaged about one and half day after the loss of power.)

Photos taken from investigation inside the Unit 3 pedestal

(Reference: the TEPCO Holdings website)



Damage estimation of the Unit 3 RPV/PCV
(From TEPCO HP)

Future Challenges and Expectations

- IRID has been conducting research and development for the investigation of inside the PCVs. The results of R&D revealed that the situation of inside the PCVs was clarified by photography taken by camera.

- Further investigation and clarification of the accident occurrence are needed to develop the future plan and to proceed with engineering for the decommissioning.

- We will continue working together for the decommissioning of the Fukushima Daiichi by sharing knowledge and experience with relevant parties from Japan and overseas.

- Clarification of the accident occurrence would be useful for responding to an accident during operating reactors and designing the safety system for new reactors. We will continue sharing these useful information with the world to contribute the safety of the nuclear power plant.

Thank you for the attention.

IRID's R&D reports are available on the following IRID website.

https://irid.or.jp/en/research/

A booklet *"The 10-year path of research development for the decommissioning"* was released in July 2023.

*Only Japanese version is available.