# Request for Information (RFI) of Innovative Approach for Fuel Debris Retrieval

## Technological Aspects of RFI

December 16th, 2013

International Research Institute for Nuclear Decommissioning

1 Current Situation of Fukushima Daiichi NPS

2 Mid and Long Term Roadmap

3 Ongoing R&D Projects

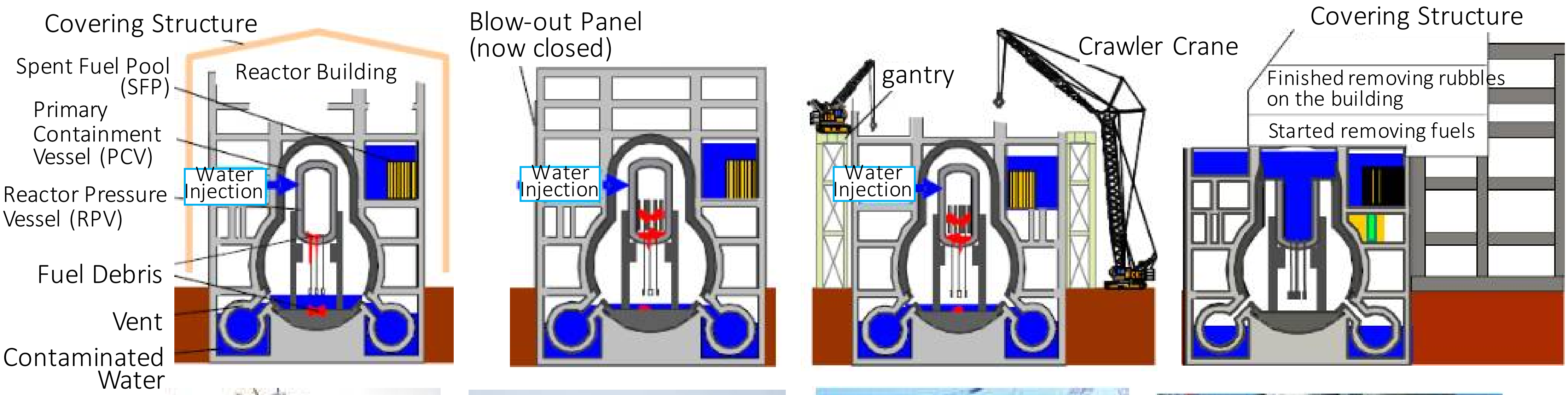
# 1 Current Situation of Fukushima Daiichi NPS

# Overview of Units 1-4



- The state of progress for decommissioning varies with each unit.
- Removing spent fuels from SFP at unit 4 started from November 18.

Unit 1 | Unit 2 | Unit 3 | Unit 4

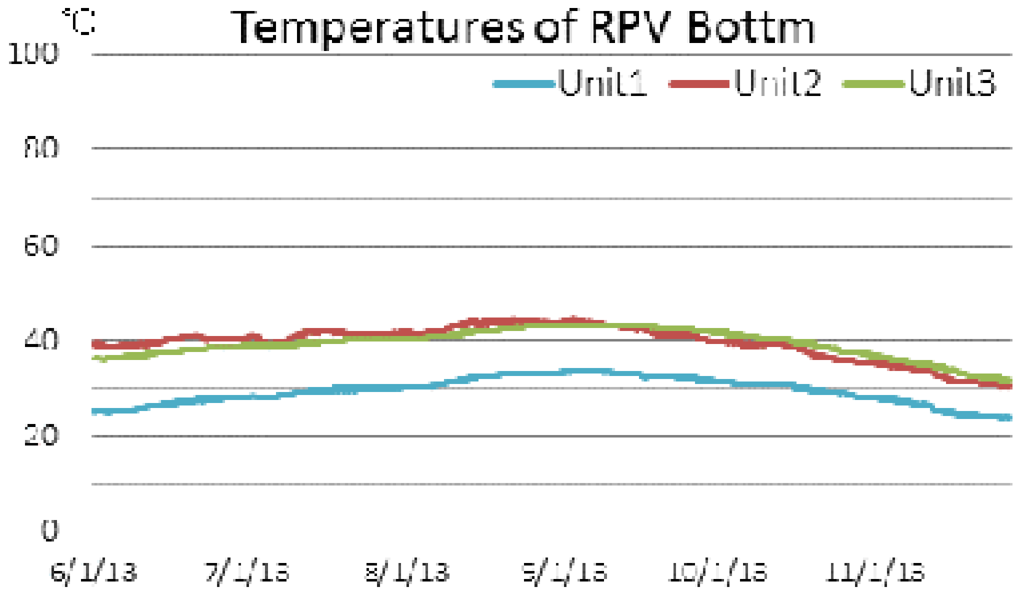


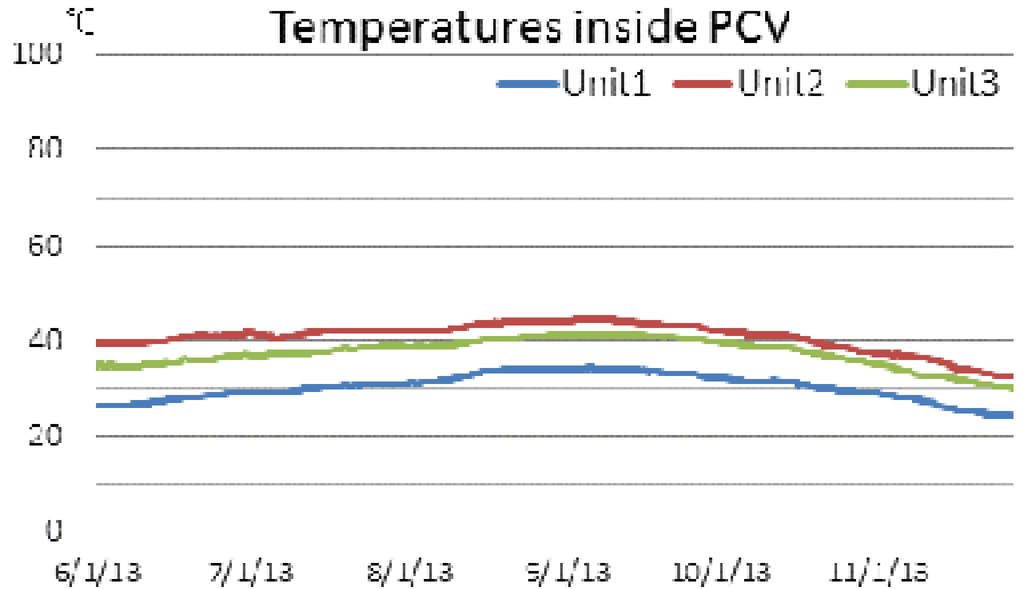

| Electrical output | 460MW | 784MW | 784MW | 784MW |
|---|---|---|---|---|
| Date of commercial operation | 1971/3 | 1974/7 | 1976/3 | 1978/10 |

# Status of Core and Spent Fuel Pool of Units 1-6



- The temperature of RPV bottom and inside the PCV each of Unit 1 to 3 has been maintained in a stable condition.

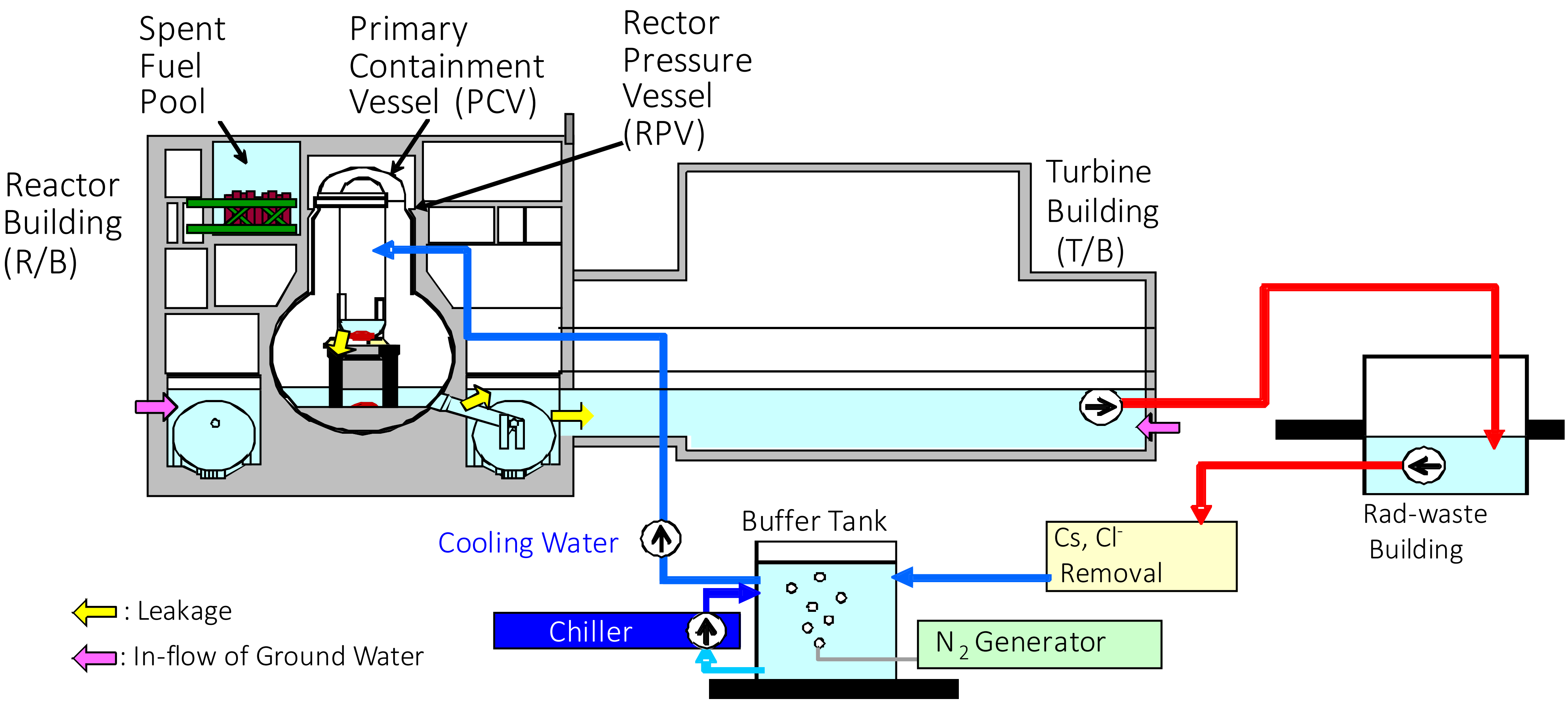



| | | Unit1 | Unit 2 | Unit 3 | Unit 4 | Unit 5/6 |
|---|---|---|---|---|---|---|
| Shutdown | | ○ | ○ | ○ | (Shutdown for Outages in 3/11 2011) | |
| Cooling | Reactor | ○ Cooled by Circulation Water System | | | — | ○ Cold Shutdown |
| | Spent Fuel Pool | ○ Cooled by air-cooled heat removal system | | | | ○ |
| Containment | | △ Contaminated water accumulated in building | | | | ○ |

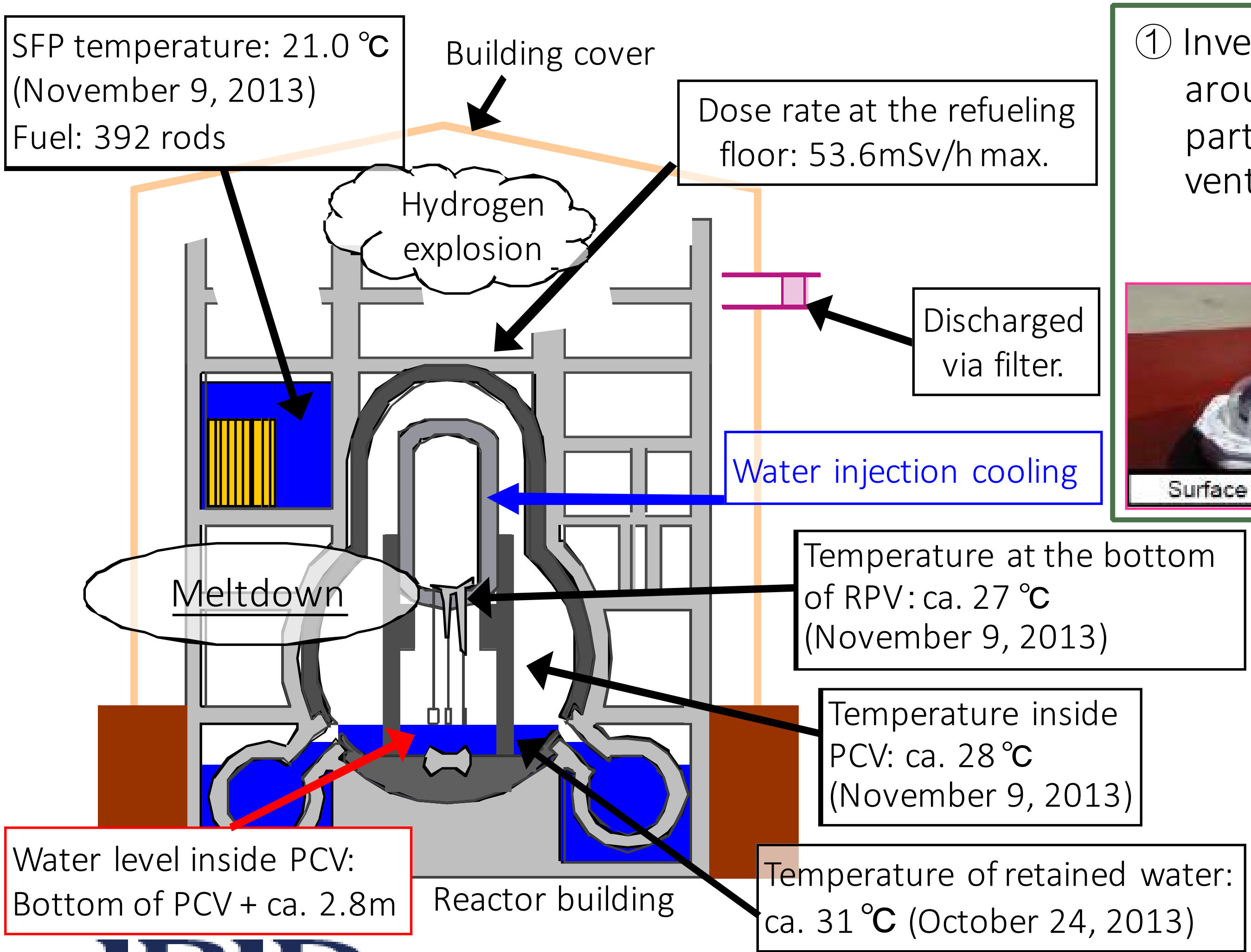
# Status of Circulating Water Cooling of Units 1-3

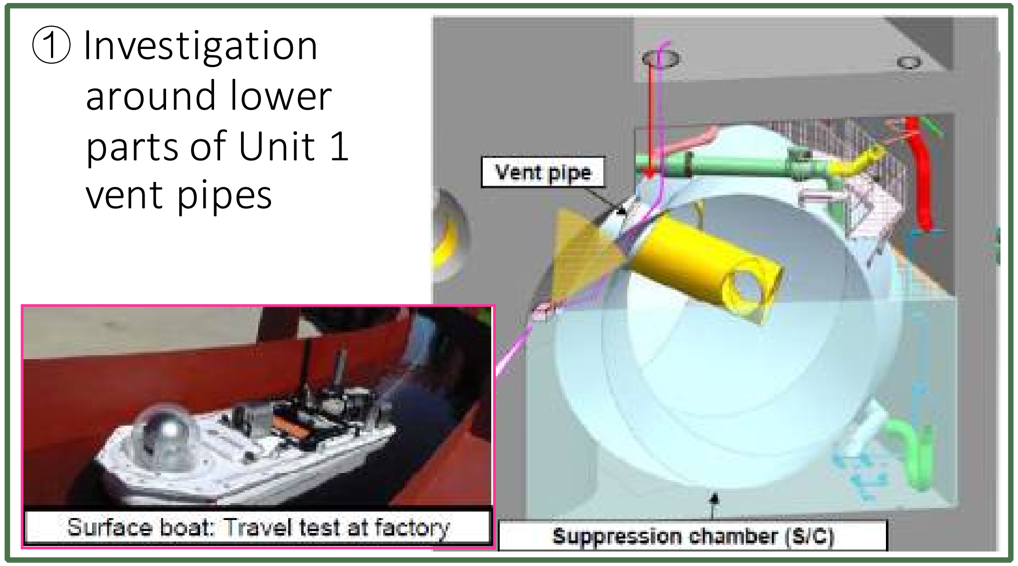
- Cooling water is leaking from RPV, PCV and R/B to T/B.
  Accumulated water in T/B is re-used as a coolant after cleaned with Cs & Cl removal system.
- In-flow of ground water is increasing the amount of "contaminated water" to be processed by multiplex, diversity, independency systems.

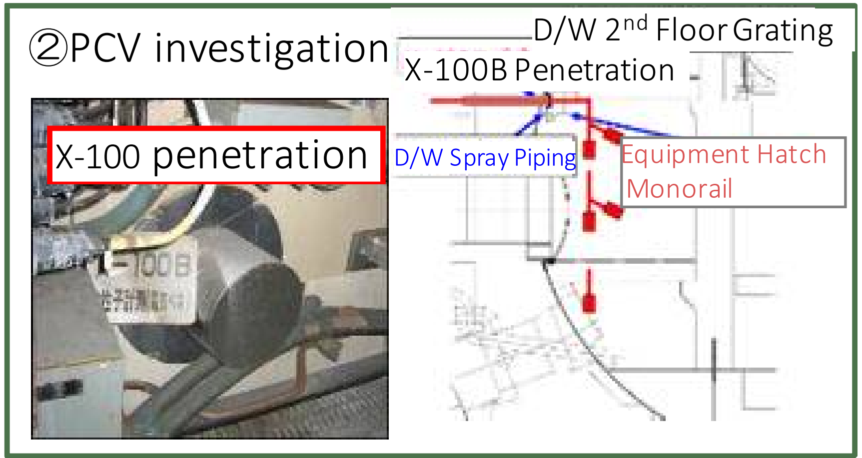


# Current Status of Unit 1

- Estimated location of debris: Most of the fuel has fallen down into the PCV.
- Investigation of torus room and vent pipes of Unit 1 (2013/11) [figure ①]
  - Leakage locations was detected. (Sand cushion drain pipe, Sand cushion ring header)
- PCV investigation with CCD camera (2012/10) [figure ②]
  - Water level: Approx. 2,800 mm above PCV bottom, water temperature: Approx. 35 ℃



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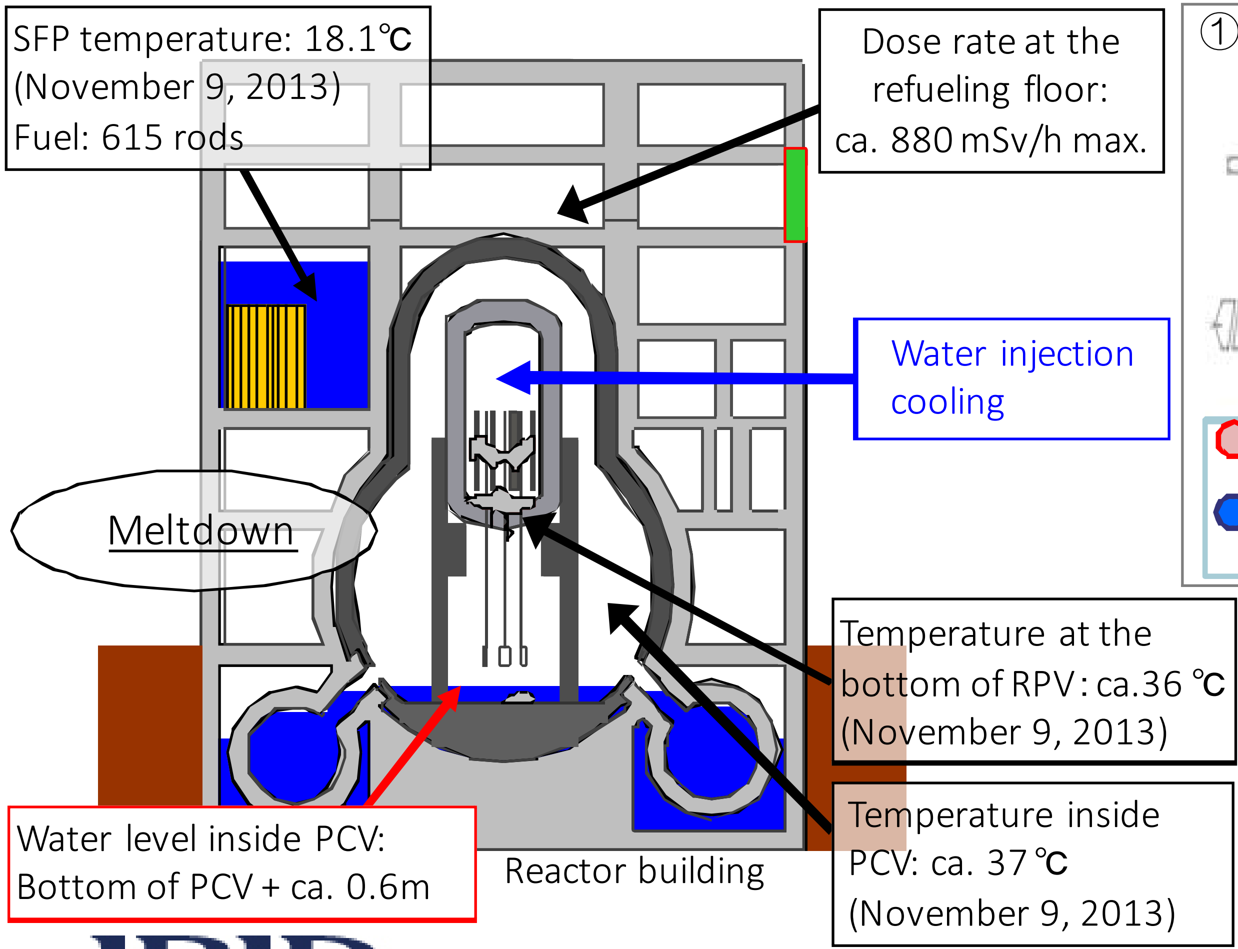
*Plant-related parameter(except temperature)indicates the value as of December 14, 2012

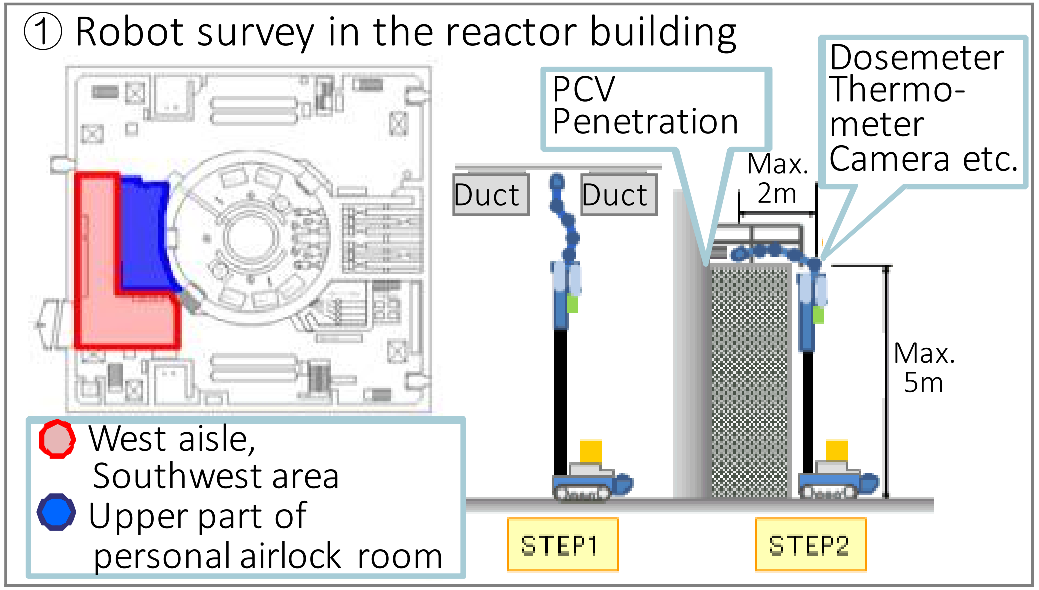
# (Movie) PCV Investigation of Unit 1

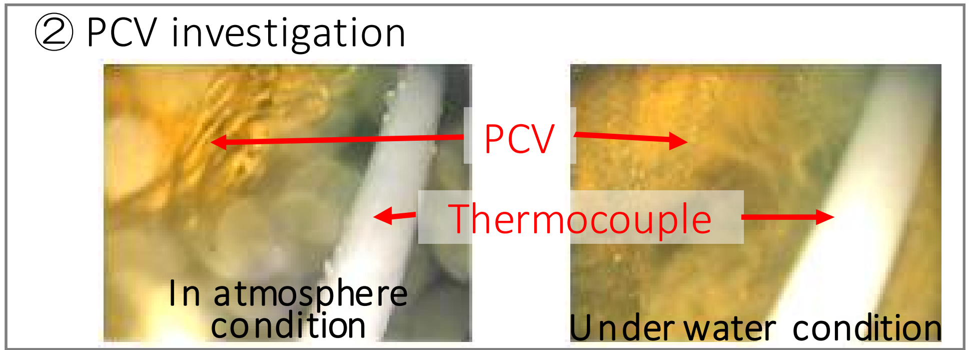
# Current Status of Unit 2



- Estimated locations of debris: Existing the core part, lower plenum and PCV, but the ratio among these locations is unknown.
- Robot survey in the reactor building on 1st floor. (2013/6) [figure ①]
- PCV investigation by borescope. (2012/1, 3) [figure ②]
  Water level: Approx. 600 mm above PCV bottom, water temperature: Approx. 50 ℃
- Water level measurement in the torus room. (2012/6)
  Torus room water level OP* 3,270 (*OP: Tide level at Onahama. Groundwater level)





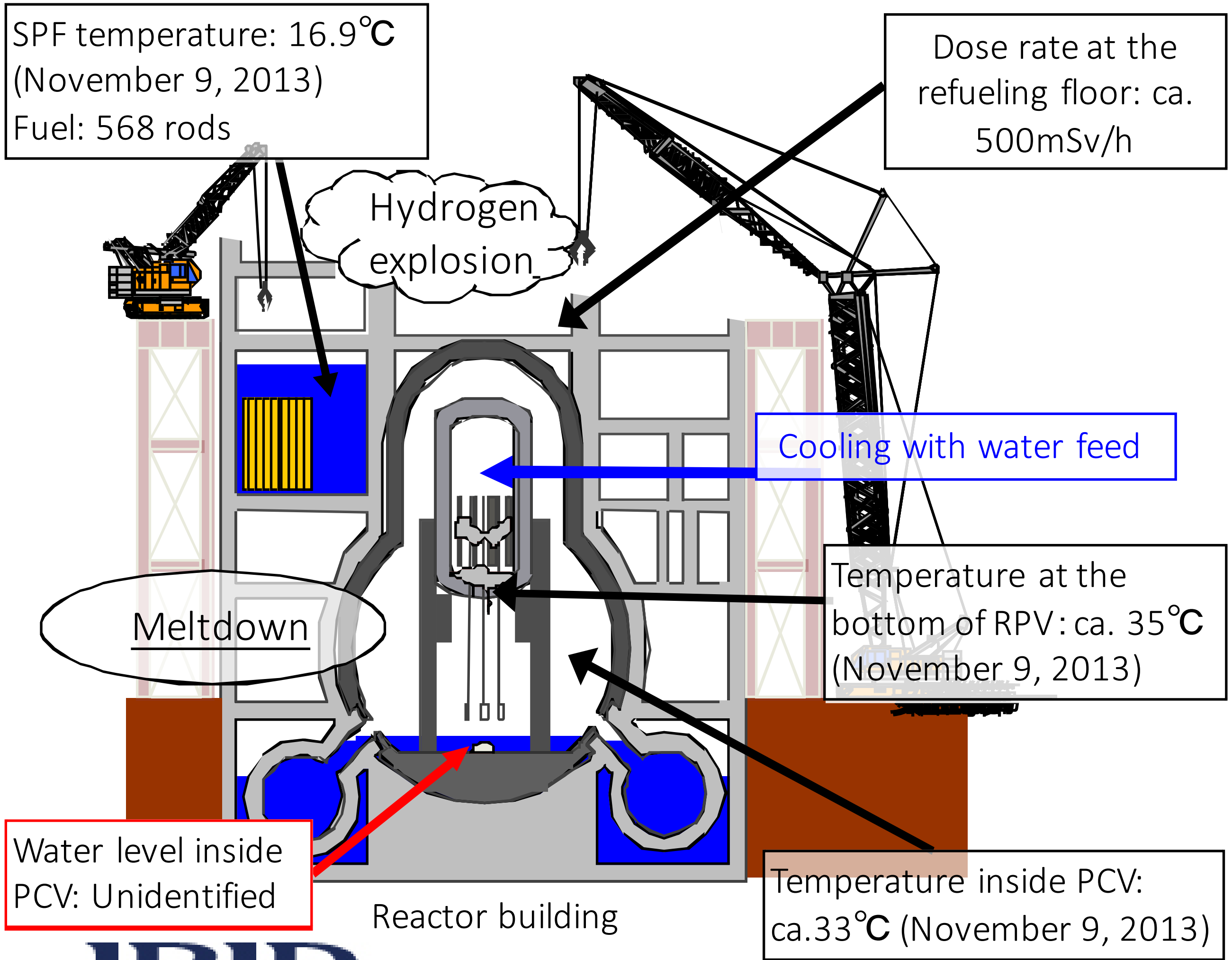

*Plant-related parameter(except temperature)indicates the value as of December 14, 2012

# (Movie) PCV Investigation of Unit 2

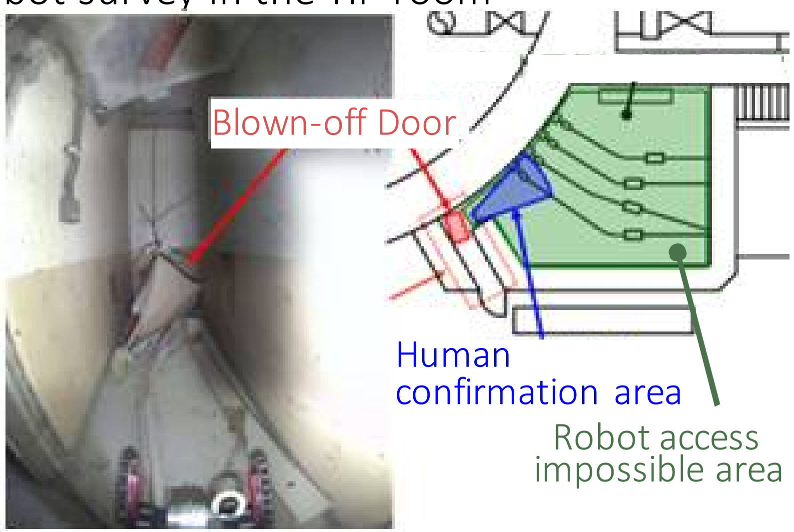
# Current Status of Unit 3



- Estimated locations of debris: Fuel is estimated to exist in the core part, lower plenum and PCV, but the ratio among these locations is unknown.
- Robot survey in the TIP room in the reactor building.(2012/3)
- Water level measurement in torus room. (2012/6, 7)
  torus room water level: Approx. OP 3,370.




Robot survey in the TIP room




Water level survey in torus

| | Water level |
|---|---|
| Torus room | OP 3,370 |
| Staircase area | OP 3,150 |

Northwest staircases area



*Plant-related parameter(except temperature)indicates the value as of December 14, 2012

# Current Status of Unit 4



- The cover for fuel removal was installed in order to improve the work environment and to prevent radioactive materials from scattering and releasing during the work.
- Started fuel removal at Unit 4 at Nov. 18, 2013.

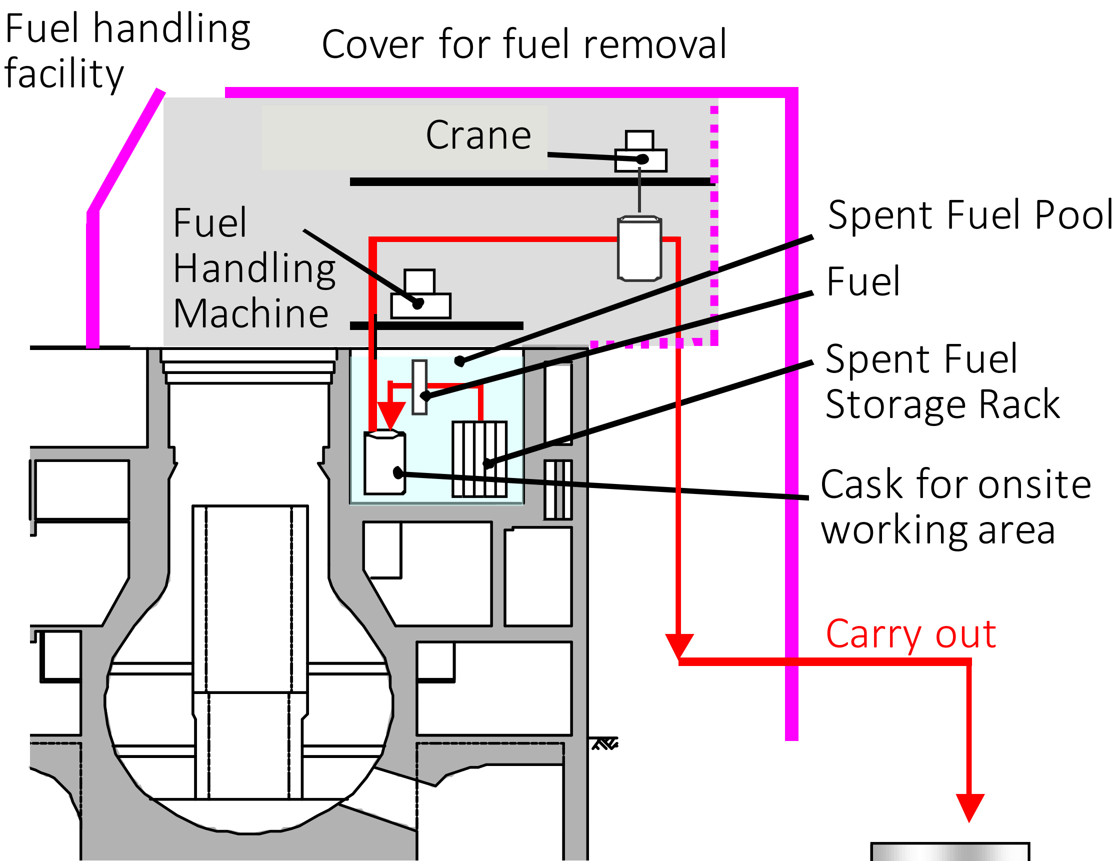



Image of fuel removal

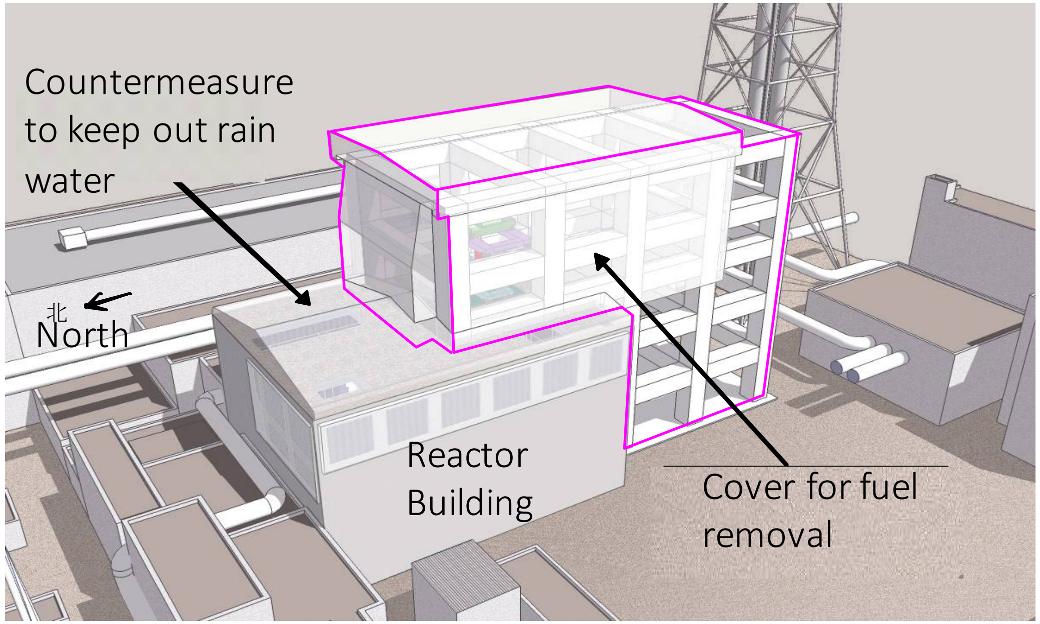
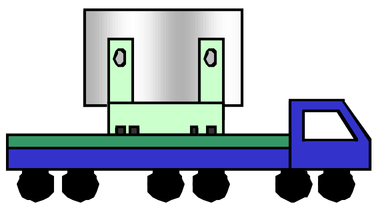
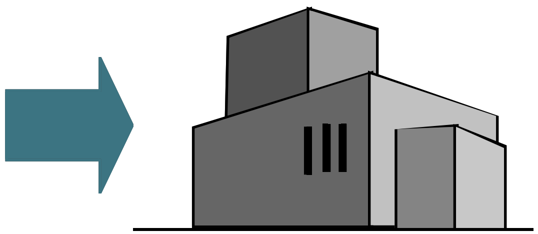



Image of the cover for fuel removal in Unit 4
(This picture shows only a image of the general plan.)



Move onsite



Common pool

# 2 Mid and Long term Roadmap

# Outline of Mid and Long Term Roadmap



- Mid and long term roadmap was revised in June 2013.
- Phased approach was confirmed.
- Fuel removal from unit 4 SFP started from November 2013.

December 2011 (Step 2 Achieved) | November 2013 | 1st half of 2020 (fast case) | 30 to 40 years in the future

| Efforts to stabilize plant condition | Phase 1 | Phase 2 | Phase 3 |
|---|---|---|---|
| <Cold shutdown achieved><br>•Achieve cold shutdown<br>•Significantly reduce radiation releases | Period up to the commencement of the removal of the fuel from the spent fuel pool (within 2 years) | Period up to the commencement of the removal of the fuel debris (within 10 years) | Period up to the completion of decommissioning measures (30 to 40 years in the future) |

Started first fuel assembly removal from Unit 4 SFP on Nov. 18, 2013

“Mid-to-long term roadmap on Decommissioning of Fukushima Daiichi NPS” was revised on June 27, 2013.

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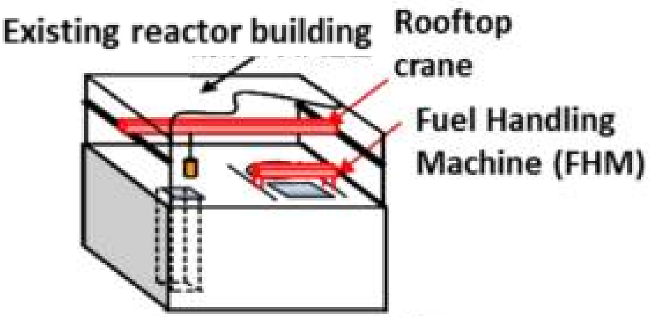
# Multi Plans for Removing Fuel Debris (e.g. Unit 2)



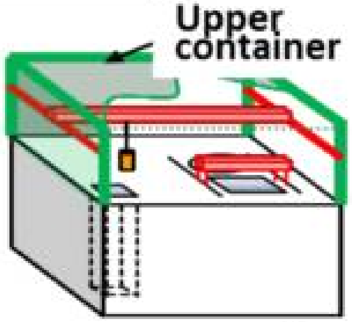
- Several plans are considered and operated in parallel to accelerate removal of fuel debris.




<Plan 1>
When the existing reactor building can be decontaminated and the FHM can be restored

**First half of FY2020**
**(one-and-a-half years earlier than the initial plan)**

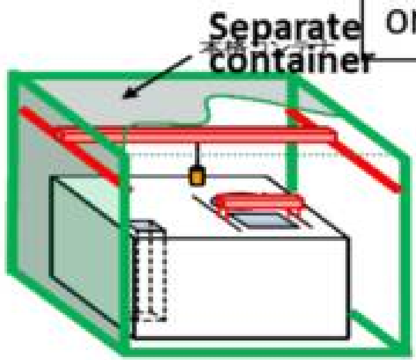
Commencement of the removal of the fuel debris




<Plan 2>
When the reactor building has sufficient seismic resistance for a container to be constructed on its upper level

**First half of FY2021**
**(6 months earlier than the initial plan)**

Commencement of the removal of the fuel debris




<Plan 3>
When the reactor building lacks sufficient seismic resistance, necessitating the construction of a separate container

**First half of FY2024**

Commencement of the removal of the fuel debris

# Planned Schedule for Unit 1-4

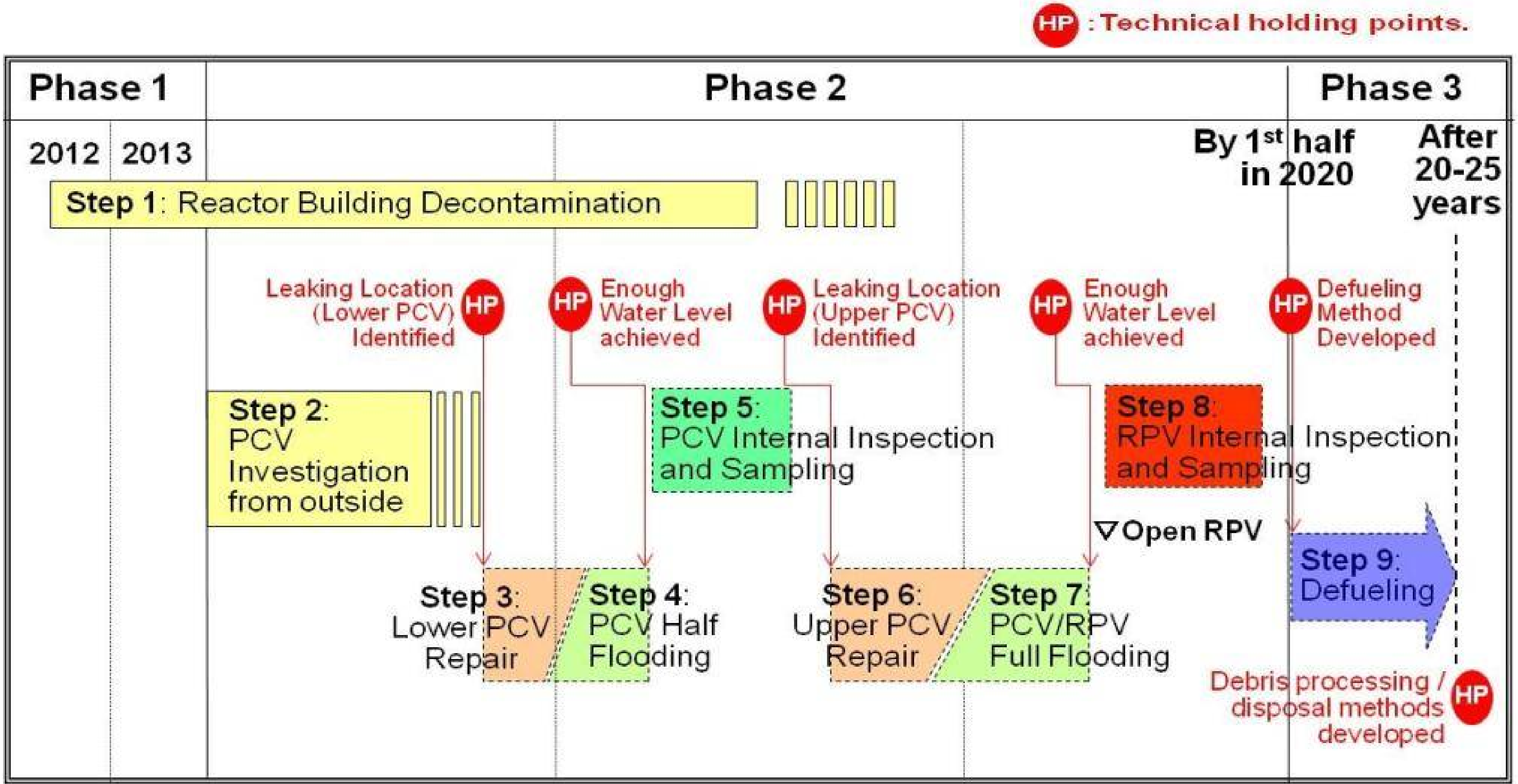


- Removal of fuel at Unit 4 was started from November 2013 (one month earlier than the initial plan).
- Removal of debris will be started from the first half of FY 2020 (the earliest case).

| | Fuel rods removal from SFPs (Target schedule) | Fuel debris retrieval (Target schedule) |
|---|---|---|
| Unit 1 | First half of FY2017 (the earliest case) ~ Second half of FY2017 | First half of FY2020 ~ Second half of FY2022 |
| Unit 2 | Second half of FY2017 (the earliest case) ~ First half of FY2023 | First half of FY2020 ~ First half of FY2024 |
| Unit 3 | First half of FY2015 | Second half of FY2021 (the earliest case) ~ Second half of FY2023 |
| Unit 4 | November 2013 (one month earlier than the initial plan) | — |

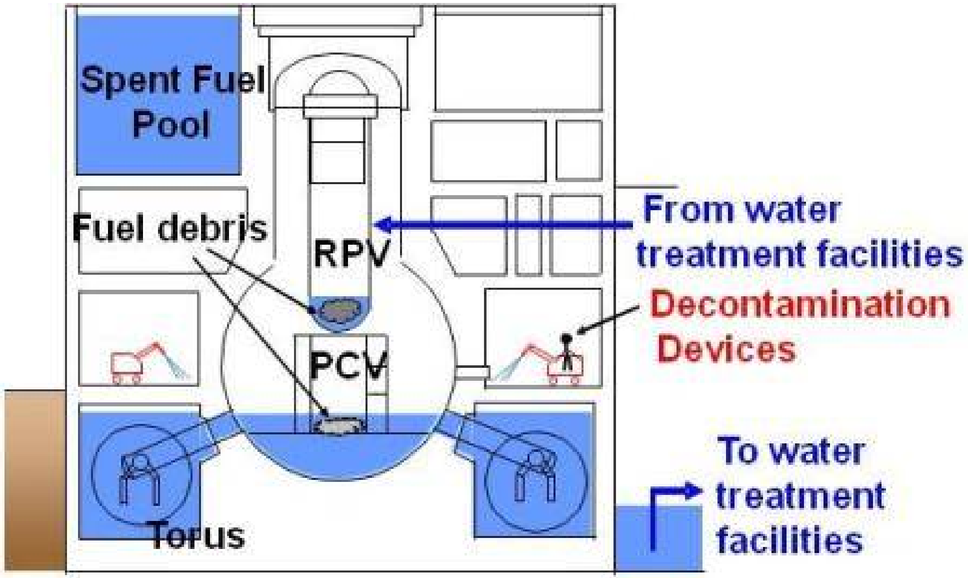
# Steps for Fuel Debris Removal premised on of the Existing Flooding Method

- The most reliable method of fuel debris removal at present is considered to remove the fuel debris by keeping them covered with water to reduce the risk of radiation exposure during the work process.



# Step 1: Reactor Building Decontamination

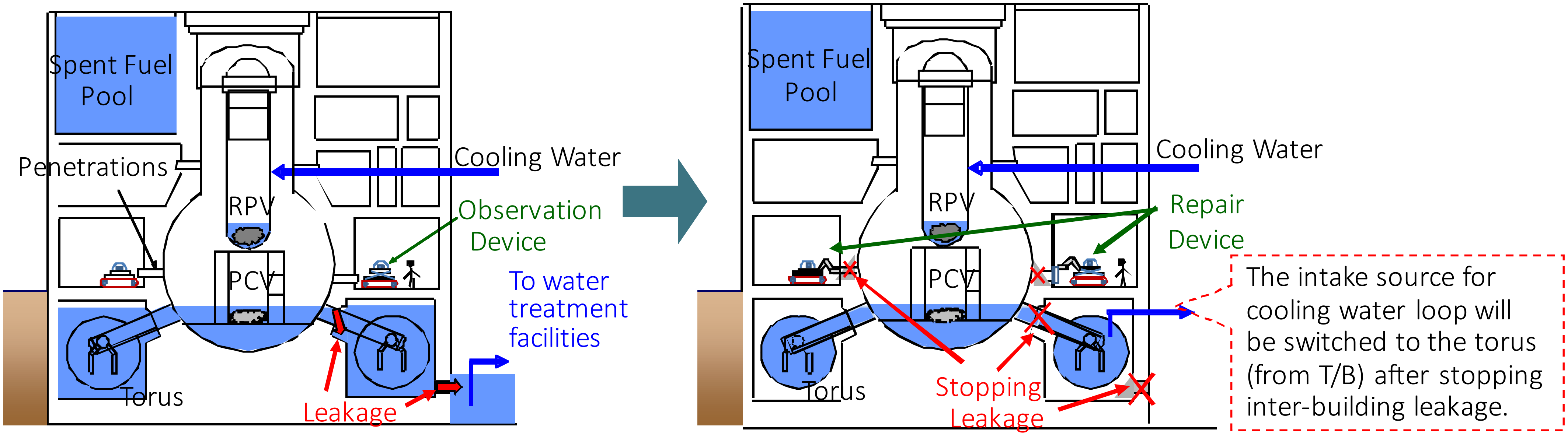





- Decontamination of the area is essential to the following procedures.
  - Feasibility of high-pressure washing, coating, scraping and etc. are investigated in the national R&D program.
  - Combined usage of shielding may be necessary.
- Major challenges and dfficulties:
  - High dosage (~ 5 Sv/h ).
  - Obstacles like rubble scattered in R/B.
  - Smaller space due to the compact design of BWR 4.

# Steps 2,3: Identification and Repair of the Leakage Points of PCV

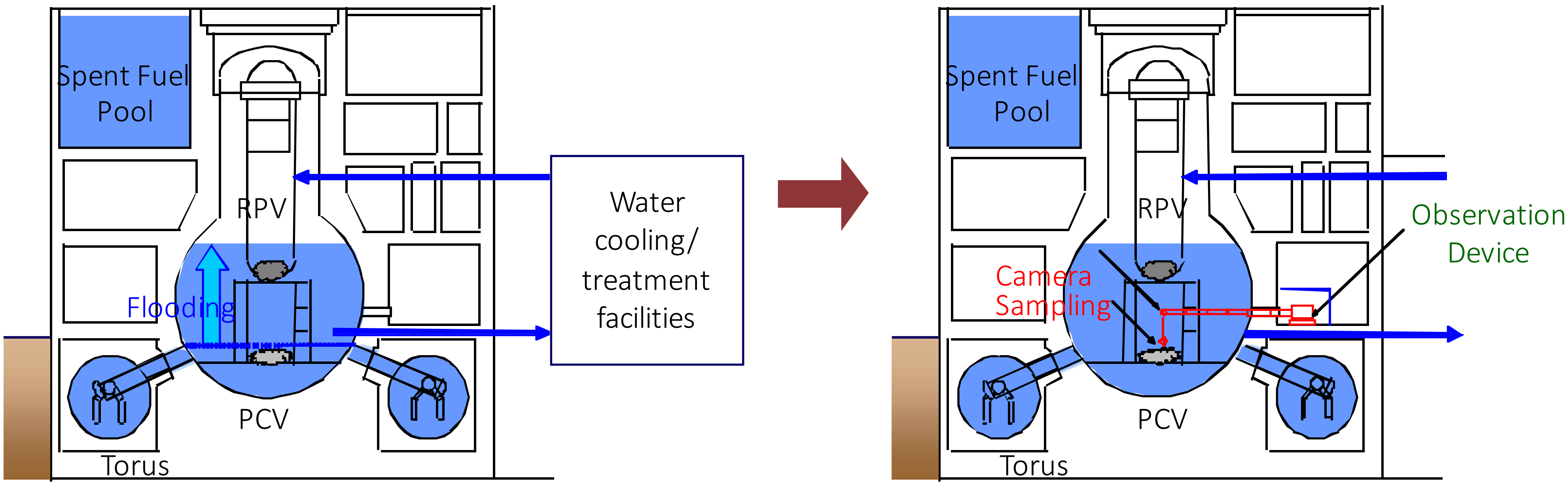





- Leaking locations will be investigated from outside of PCV and will be repaired.
- Major challenges and difficulties:
  - High dose rate and humidity of PCV inside.
  - Major part of "suspicious locations" are underwater with poor visibility.
  - Repair work has to be conducted while highly radioactive cooling water is running for continuous fuel cooling.

# Steps 4,5: Flooding of the Lower PCV , PCV Inspection & Sampling

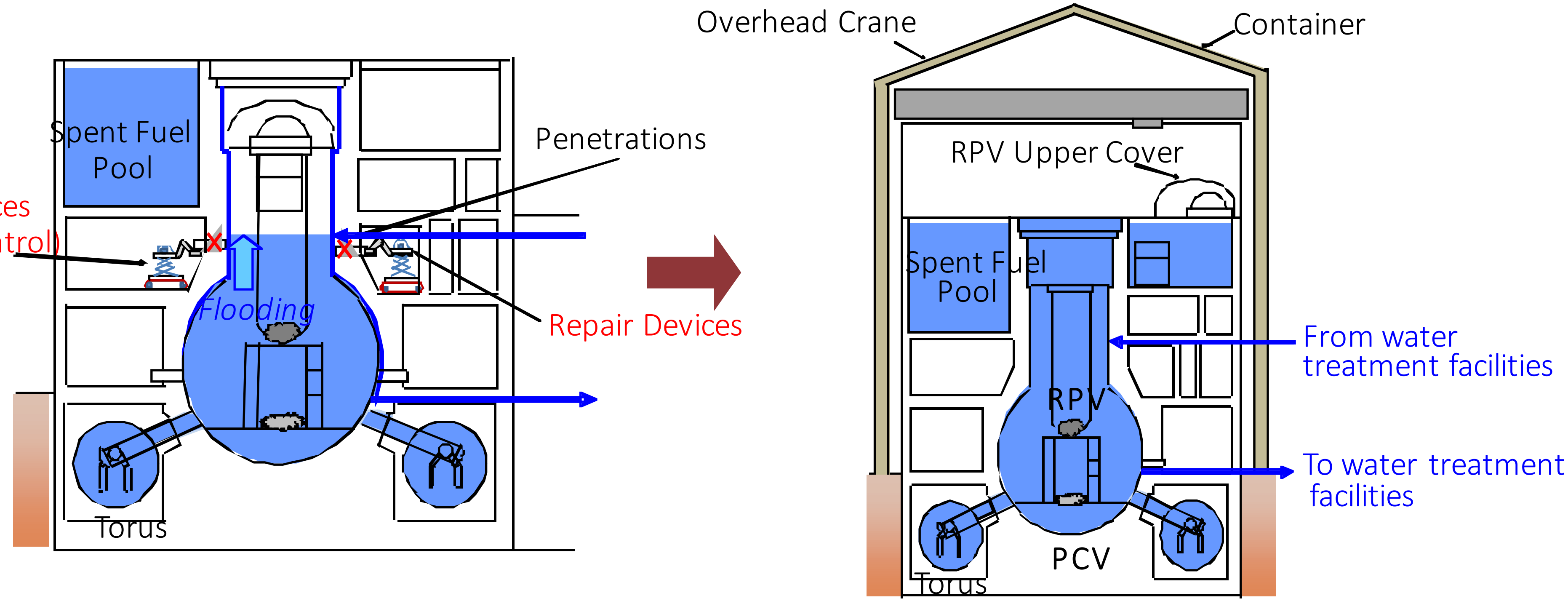





- Filling the lower PCV with water (Flooding).
- Distribution and characteristic of fuel debris will be investigated.
- Major challenges and difficulties:
  - High dose rate, limited accessibility and poor visibility.
  - Leak-tight penetration is required for the investigation device once PCV flooding is achieved.
  - Subcritical assessment.

# Steps 6,7: Upper PCV repair, Flooding of Entire Reactor Well

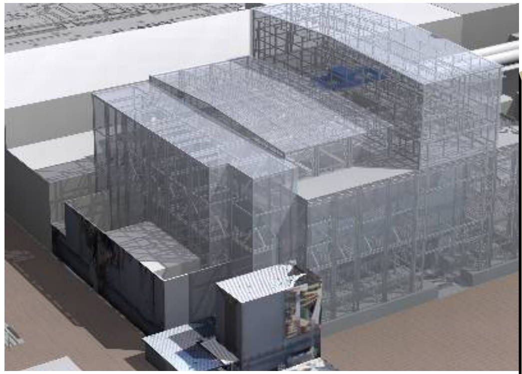


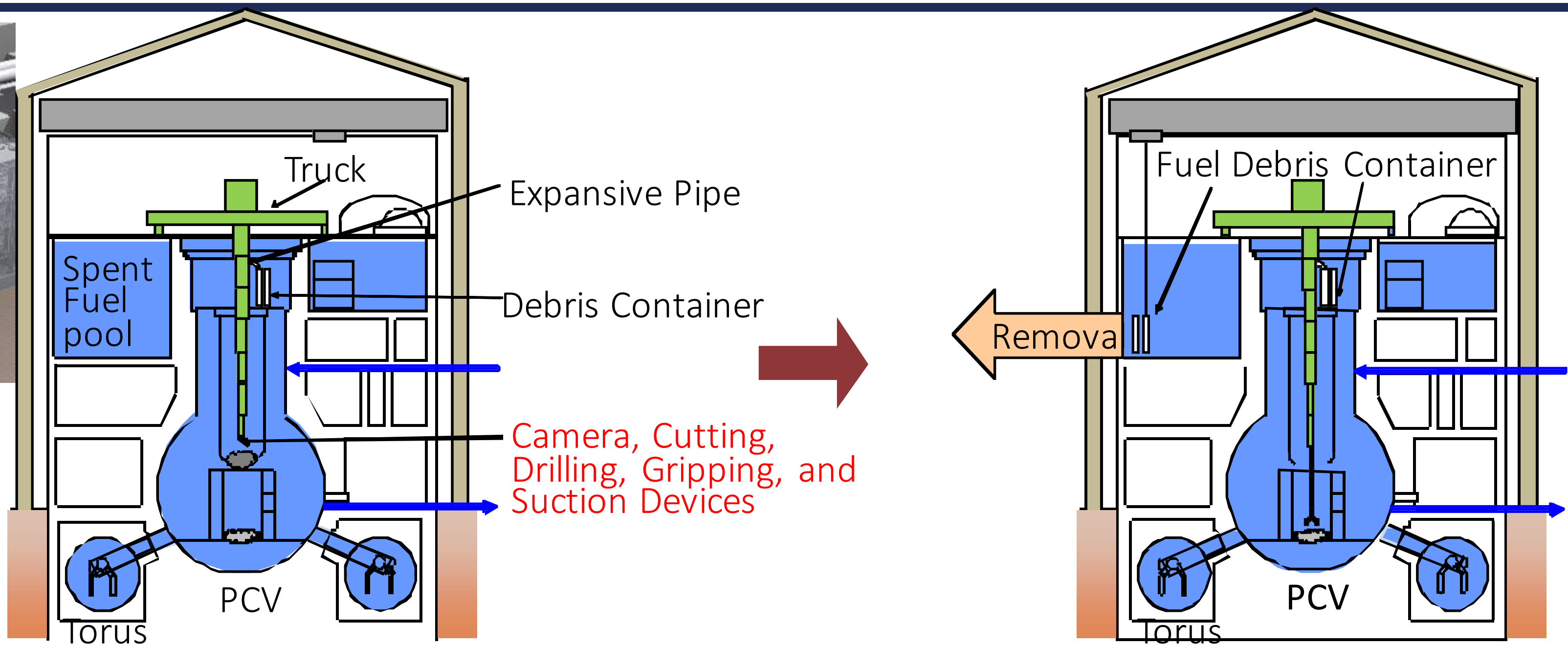



(1) Filling entire PCV/RPV with water after repairing upper PCV.
(2) R/B container and overhead crane will be installed for defueling.
(3) RPV/PCV top heads will be removed after sufficient water is attained.

- Major challenges and difficulties:
  - High dose rate, limited accessibility.
  - Seismic stability after flooding has to be maintained considering quantity of water.
  - Prevent radioactive substances from releasing from PCVs.
  - Subcritical assessment.

# Step 8, 9 : Internal RPV Inspection & Sampling, Defueling from RPV and PCV






- Condition of RPV internal and fuel debris will be investigated.
- Fuel debris and RPV internal structure will be removed
- Major challenges and difficulties:
  - High dose rate, limited accessibility and poor visibility
  - Development of necessary device
  - Subcritical assessment
  - Storage of the removed debris
  - Fuel debris is assumed to have fallen onto the complicated RPV bottom structure (BWR is much more complicated than PWR)
  - Debris may have fallen even out of RPV (Debris remained in RV in TMI-2)
  - Diverseness of neutronic-, mechanical- and chemical- property of debris mixed with different types of metal and concrete

# Major Challenges in the Existing Decommissioning Procedures



- Final goal is to defuel from the Reactor Building (R/B).
- Defueling procedure would be much more complicated than TMI-2 case due to differences like:

| | TMI-2 | Fukushima Daiichi |
|---|---|---|
| R/B Damage | Limited | Damaged by $H_2$ explosion (Units 1,3,4) |
| Water Boundary | RV remained intact | Both RPV/PCV have been damaged (Units 1-3) |
| Fuel Debris Location | Remained in RV | Possibly Fallen out from RPV |
| Bottom of the Vessel | No structure | Complicated structure with Control Rod Drives |

- TMI-2 experience can be utilized more efficiently for post-defueling procedures in decommissioning.

# 3 Ongoing R&D Projects

# R&D Programs for Decommissioning



Red: will be explained in slides below

## 1. Removal of spent fuel from spent fuel pool

- 1.1 Long-term Integrity of spent fuel assemblies (FY2011–2017)
- 1.2 Damaged spent fuel processing (FY2013–2017)

## 2. Preparation for removal of fuel debris

- 2.1 Fuel debris removal using remote control equipment and devices
  - 2.1.1a Development of remote decontamination technology for the inside of the reactor building (FY2011–2014)
  - 2.1.1b Formulation of a comprehensive plan for dose reduction (FY2012–2013)
  - 2.1.2&3 Development of technology for Inspection and repair (stop leakage) for filling water in the PCV (FY2011–2017)
  - 2.1.4 Investigation of the PCV Interior (FY2011–2016)
  - 2.1.5 Investigation of the RPV Interior (FY2013–2019)
  - 2.1.6 Removal of fuel debris and internal structures in the reactor (FY2014–2020)
  - 2.1.7 Containment, transport and storage of reactor fuel debris (FY2013–2019)
  - 2.1.8 Assessment of RPV/PCV integrity (FY2011–2016)
  - 2.1.9 Controlling fuel debris criticality (FY2012–2019)
- 2.2 Ascertaining and analyzing reactor core status
  - 2.2.1 Analysis of accident progression to estimate reactor status (FY2011– 2020)
- 2.3 Ascertaining the characteristics of and preparing to process fuel debris
  - 2.3.1&2&3 Grasping of characteristics using simulated debris and development of fuel debris treatment technology (FY2011–2020)
  - 2.3.4 Establishment of a new accountancy method for Fuel Debris (FY2011–2020)

## 3. Processing and disposal of radioactive waste

(FY2011-)

# Building Contamination Survey at Unit 1-3 (2.1.1a)



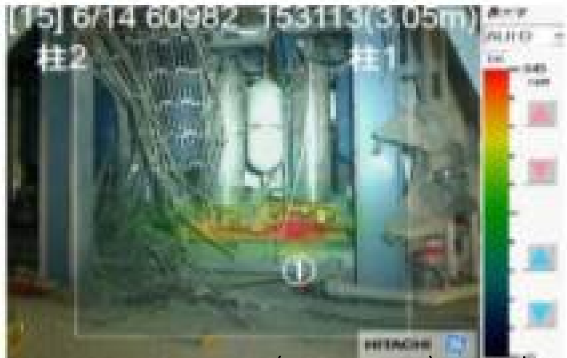
- Dose level/radiation source surveys of the Units 1 through 3 reactor buildings, and analysis of contamination samples have been conducted in order to formulate a decontamination plan.

| | | | Remote survey using robot | | | Survey by workers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Contamination status survey | | | | |
| | | | | | | Floating surface contamination survey / Deposited surface contamination survey | | | Permeated contamination survey | |
| | Plant | Floor (reactor building) | Dose rate survey | Radiation source survey | Surface conditions survey | Floor | Equipment | Walls | Floor | Walls |
| Survey scope | Unit 1 | 1F | ● | ● | ● | ● | ● | ● | ● | ● |
| | | 2F | | | | ● | | | | |
| | | 3F | | | | ● | | | | |
| | Unit 2 | 1F | ● | ● | ● | ● | | | ● | |
| | | 2F | | | | ● | | | | |
| | | 3F | | | | ● | | | | |
| | Unit 3 | 1F | ● | ● | ● | ● | | | ● | |
| Survey objectives | | | Confirmation of dose rate distribution inside the building | Confirmation of relative dose rate distribution | Confirmation of surface conditions of floor, walls, and equipment services | Contamination distribution confirmation | | | Contamination distribution confirmation | |
| Survey details | | | Measurement of dose rate at heights of 0.05 m and 1.5 m above floor in approximately a 3m mesh | Measurement of dose rate distribution using a gamma camera | Videography of floor surfaces, wall services, and equipment services using a camera | Collection of surface sediments with brush, etc., and adhered sediments with paint stripper, for analysis | | | Concrete core sampling and analysis | |

## Does/radiation source survey results

●Dose rate survey results
Unit 1 : 3.2-8.9mSv/h
Unit 2 : 6.8-30.3mSv/h
Unit 3 : 15.8-124.7mSv/h

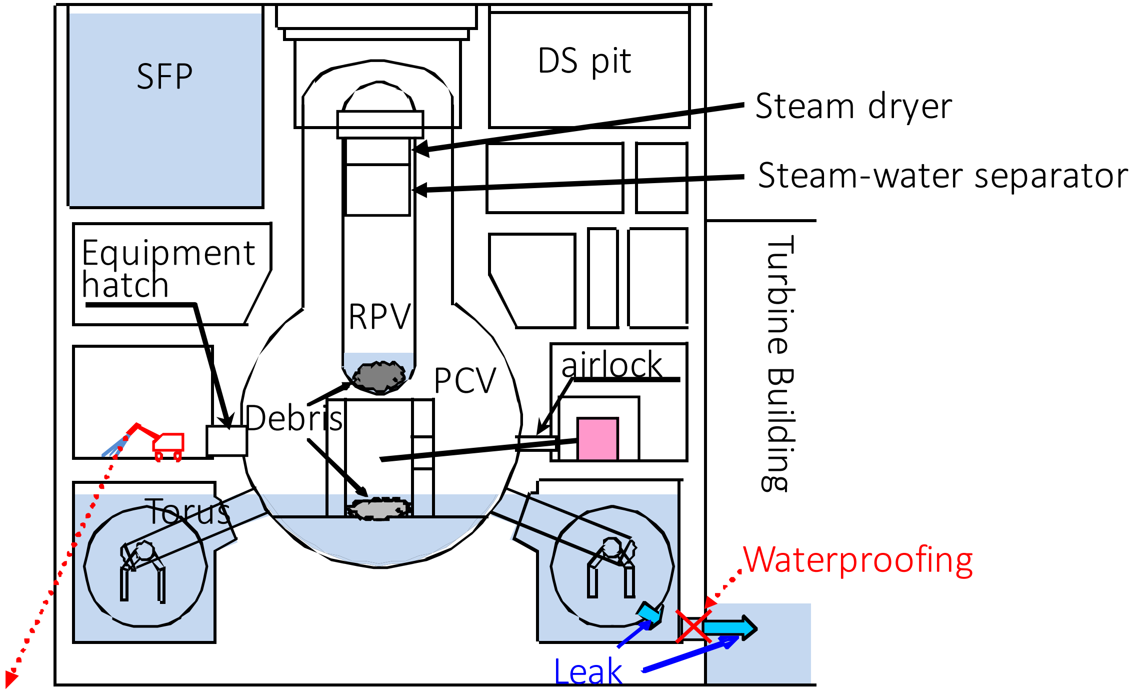
●Radiation source survey results
the primary hotspots are containment vessel penetration seals, water pressure control units (HCU) and the Unit 3 equipment hatch



Radiation source survey(γ camera) results example (Unit 3 South side HCU)

# Building Internal Decontamination (2.1.1a)

- Development of remotely operated decontamination devices that meet the contamination conditions in the field in order to improve the work environment such as surveying and repairing leaks in the PCV to prepare for fuel debris removal.





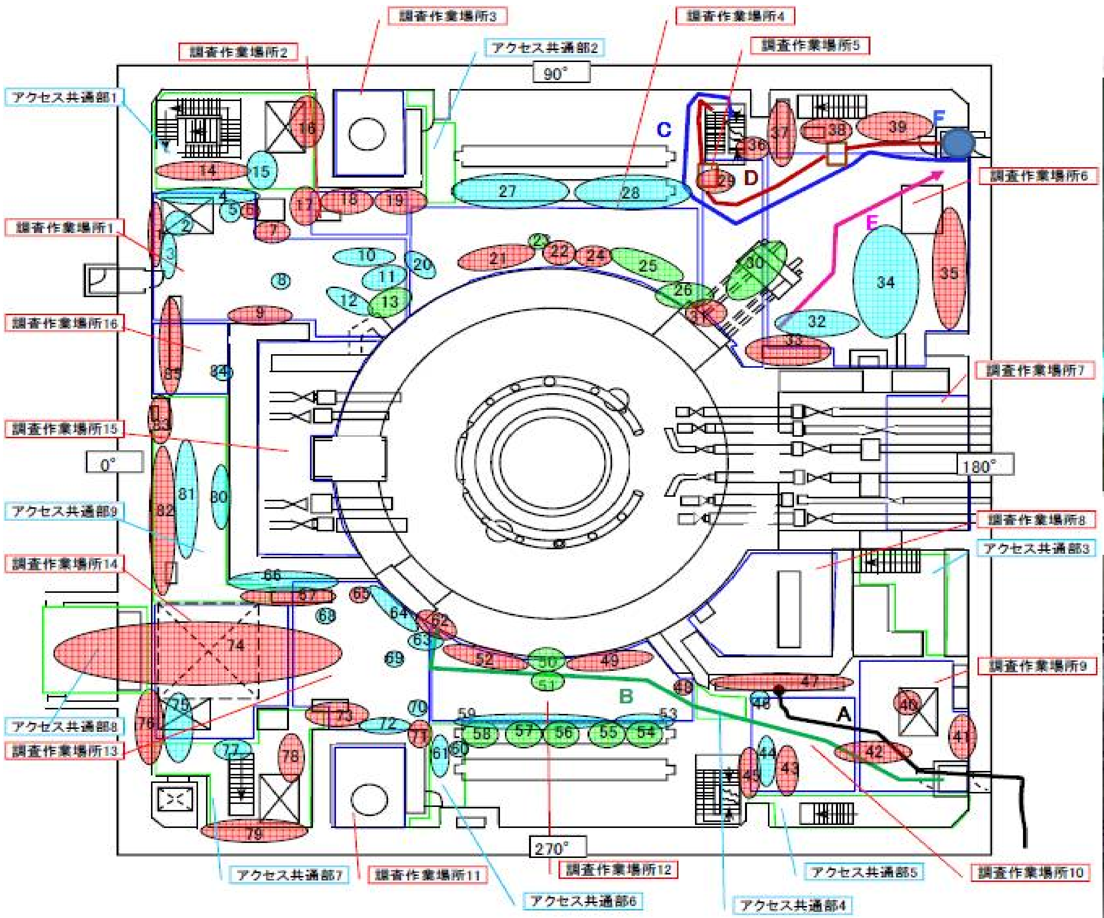
High-pressure water jet decontamination device


Dry ice blast decontamination device


Blasting/collecting decontamination device

# Building Internal Decontamination (e.g. Unit 3) (2.1.1a)

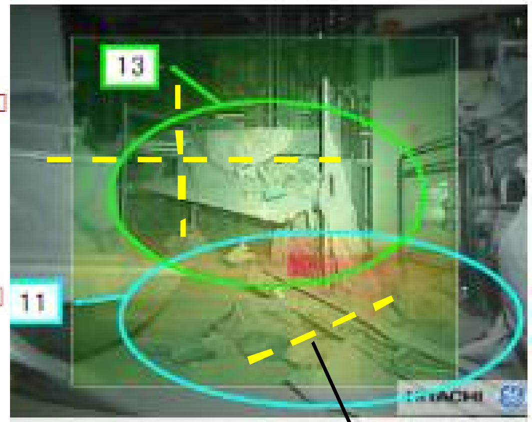
- Retrieval of rubbles in Unit 3 is planned as below;




Access route obstacle
Dose reduction
Decontamination work obstacle

Unit 3 1FL

Image of rubbles




Equipment


N2 hose and HCU fence

Hoses and cables
→ Need to be organized

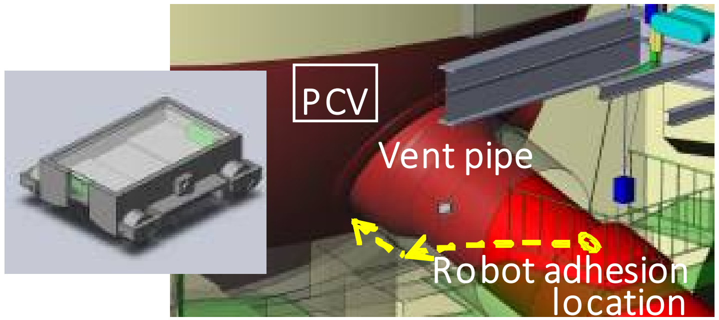
Fallen duct

Large objects and objects attached to supports
→ Need to be cut free

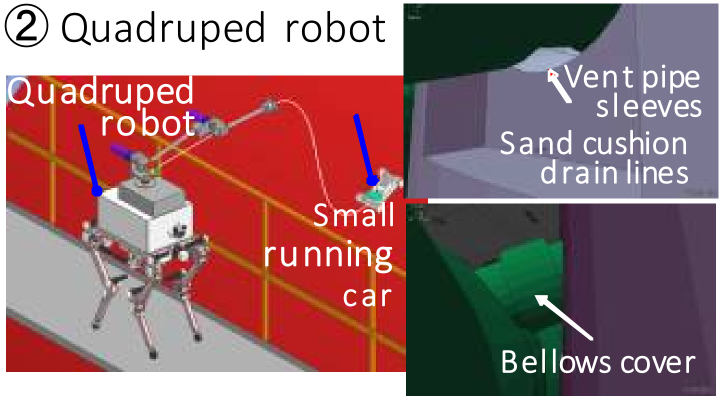
# Open air Robot for Inspection and Repair of PCV (2.1.2&3)

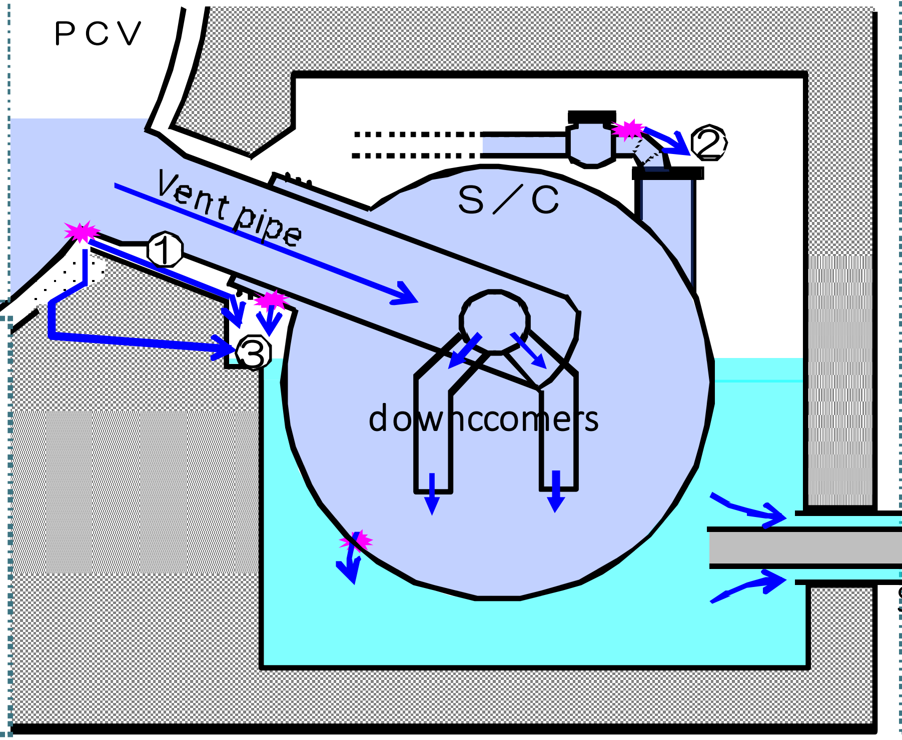
| Device | Characteristics |
|---|---|
| ① Survey robot of Vent pipe joint | This robot adheres itself to the surface of the outside of the vent pipe and approaches joints between bent pipes and the D/W from between the vent pipe and concrete wall in order to survey the damage. |
| ② Robot for surveying the upper part of the S/C | This robot checks for leaks from structures at the top of the S/C, which is high up (Approx. 3m at its highest), after accessing it from the catwalk outside the Torus. |
| ③ Quadruped robot (&small running car) | This robot is used to ascertain conditions (advance survey) inside the S/C, such as the presence of leaks, within the scope that can be photographed from near the area beneath the vent pipe.<br>Unit 1's triangular corners are currently submerged and cannot be accessed. |

## ① Survey robot of Vent pipe joint

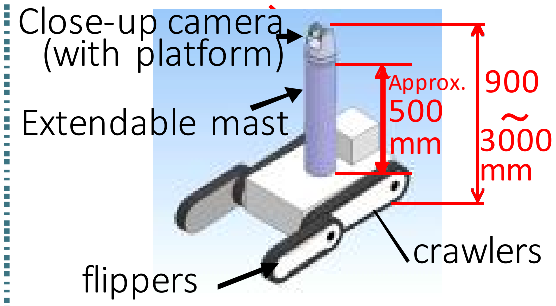


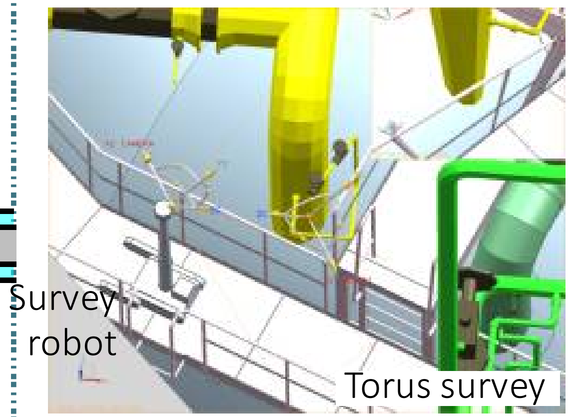

## ② Quadruped robot




## ③ Robot for surveying the upper part of the S/C

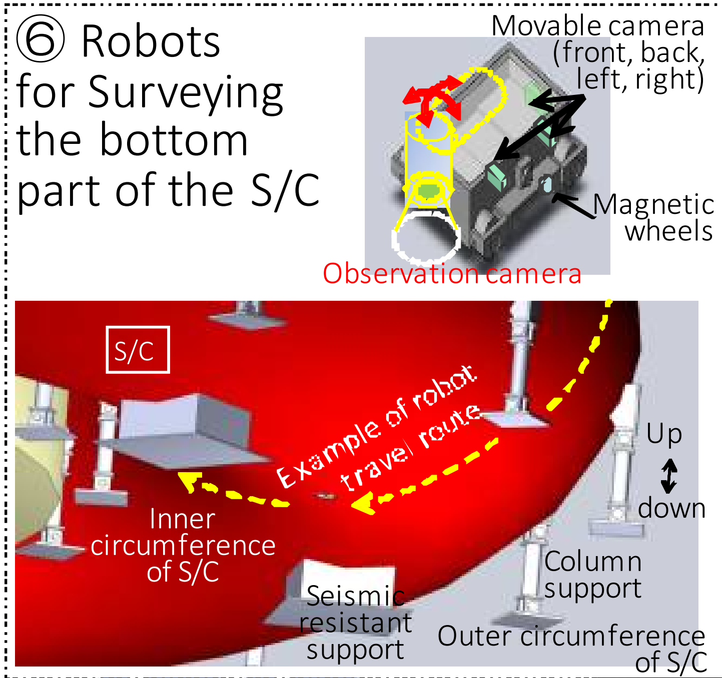


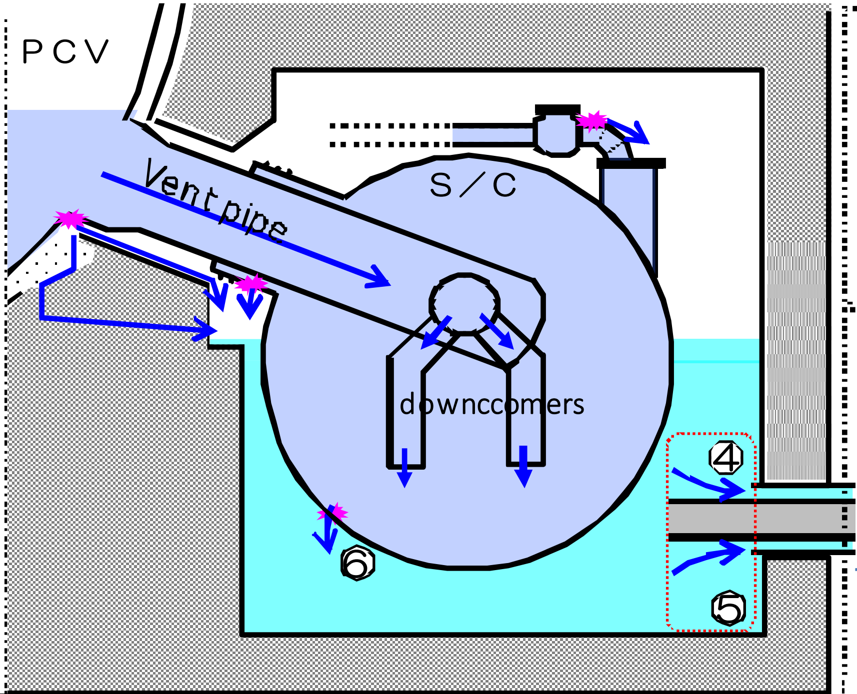



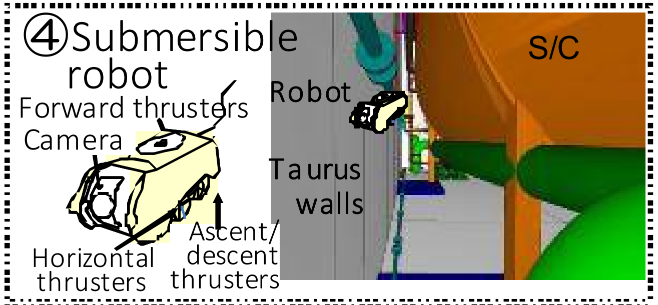
# Submersible Robot (2.1.2&3)

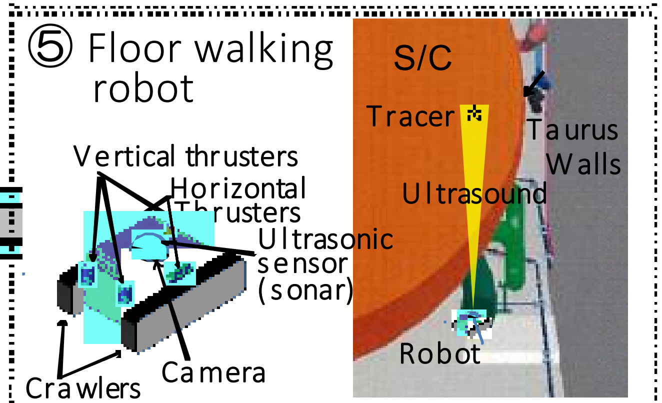


| Develops device | | Characteristics |
|---|---|---|
| Robot for surveying submersed torus walls | ④ Submersible robot | This submersible robot is remotely operated (used in very narrow places) by an operator viewing a video screen and will be used to check for damages at building penetration seals (this robot is expected to be put into use during the second half of fiscal year 2013). |
| | ⑤ Floor walking robot | This robot walks on the floor underneath the water and uses ultrasound to check for leaks in distant places. |
| ⑥ Robots for surveying the bottom part of the S/C | | This robot adheres itself to the outer surface of the S/C to check for damages on the outside of the S/C, on structures on the outside and on penetration pipes. |
| ⑦ Development of basic technology for “self-location”, “ long cable processing” and “ shape/flow detection” that submersible robots are to be equipped with ( elemental technology shall be reflected in government PJ as suitable). | | |
| ⑧ Development of technology related to “nondestructive measurement of water levels inside steel containers”, “ movement on curved steel surfaces” “self-location” and “torus access” that is needed to measure the water level inside the S/C. | | |



# Submersible Robot and S/C Water Level Measurement Robot (2.1.2&3)

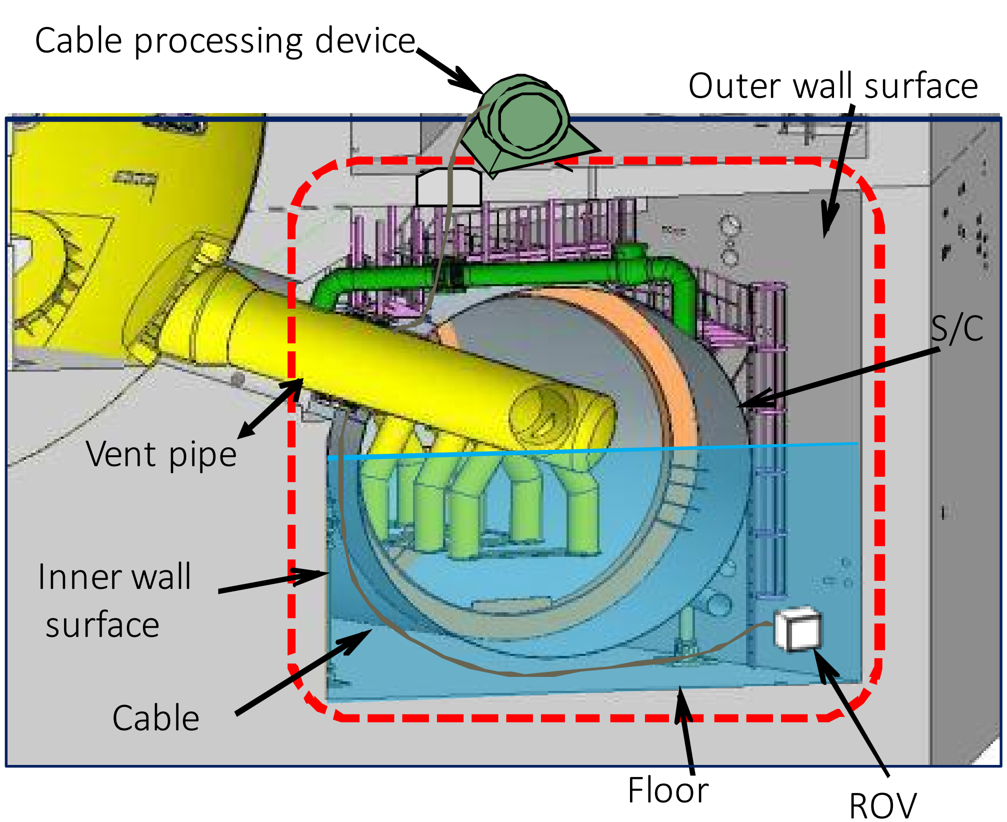
## ⑦ Submersible Robot

### Required equipment

- Submersible robot

### Required technology

- Self-location technology
- Long cable processing technology
- Shape/water flow detection technology




## ⑧ S/C water level measurement robot

### Required equipment

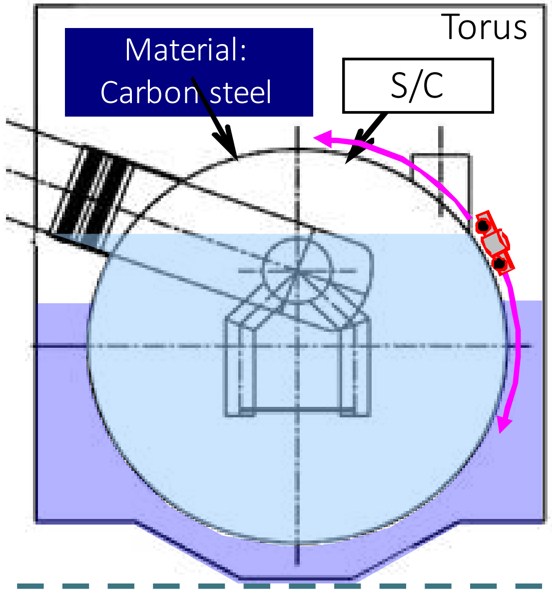
Water level measurement robot that can move on curved steel surfaces

### Required functions

Must be able to measure the water level inside the S/C from outside the S/C

### Required technology

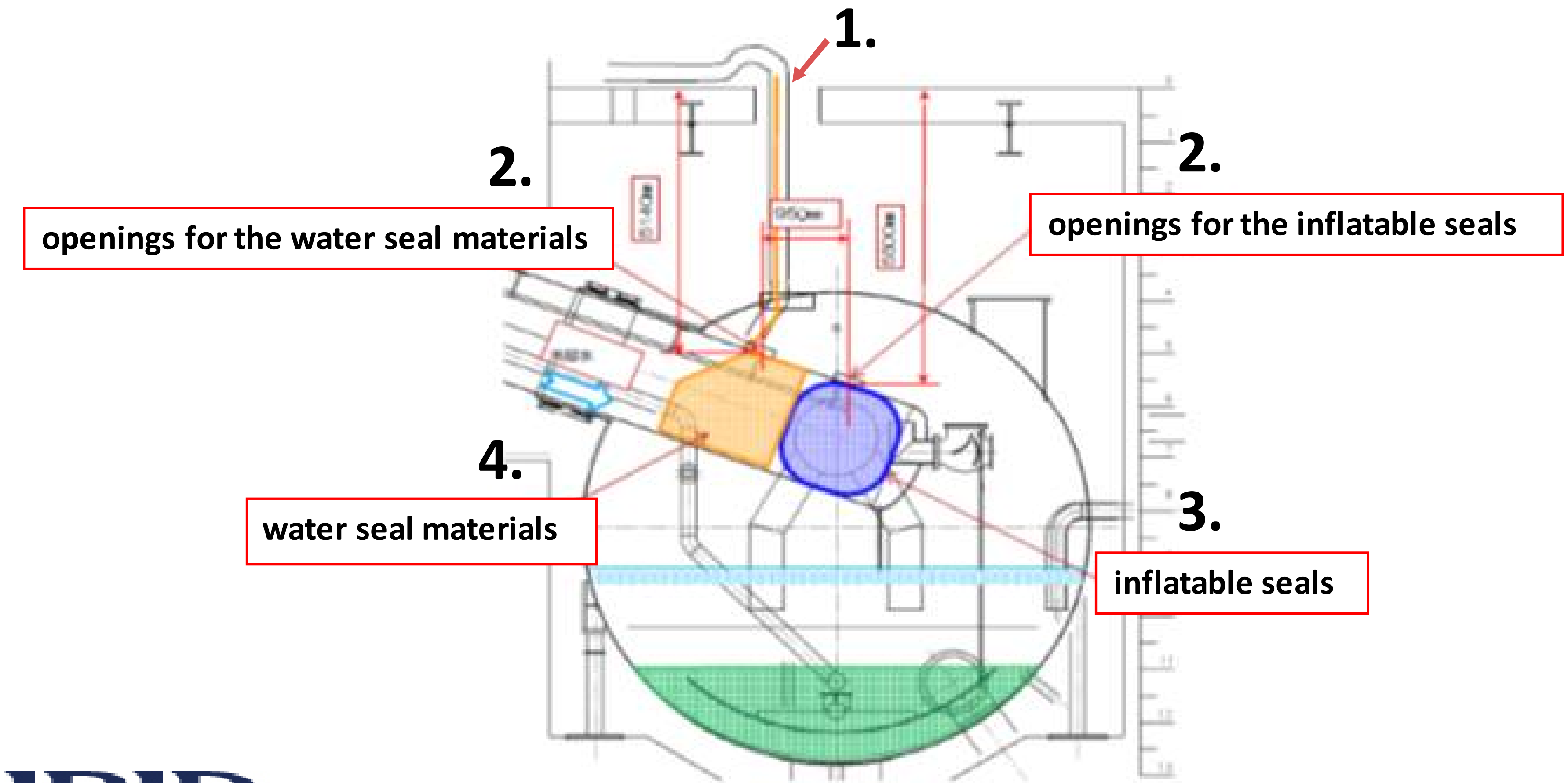
Technology for nondestructive measurement of water levels inside steel containers
Technology for moving on curved steel surfaces
Self-locating technology
Technology related to accessing the Torus



# Repair (stop leakage) concept for lower part of PCV (2.1.2&3)

## Repair Method of S/C [plugging vent pipe and isolating S/C]

1. Make openings on the slab of the ground floor.
2. Make openings on the S/C shells and the vent pipes.
3. Install the inflatable seals tip on the vent pipes.
4. Pour the water seal materials into the vent pipes upper side of the inflatable seals.

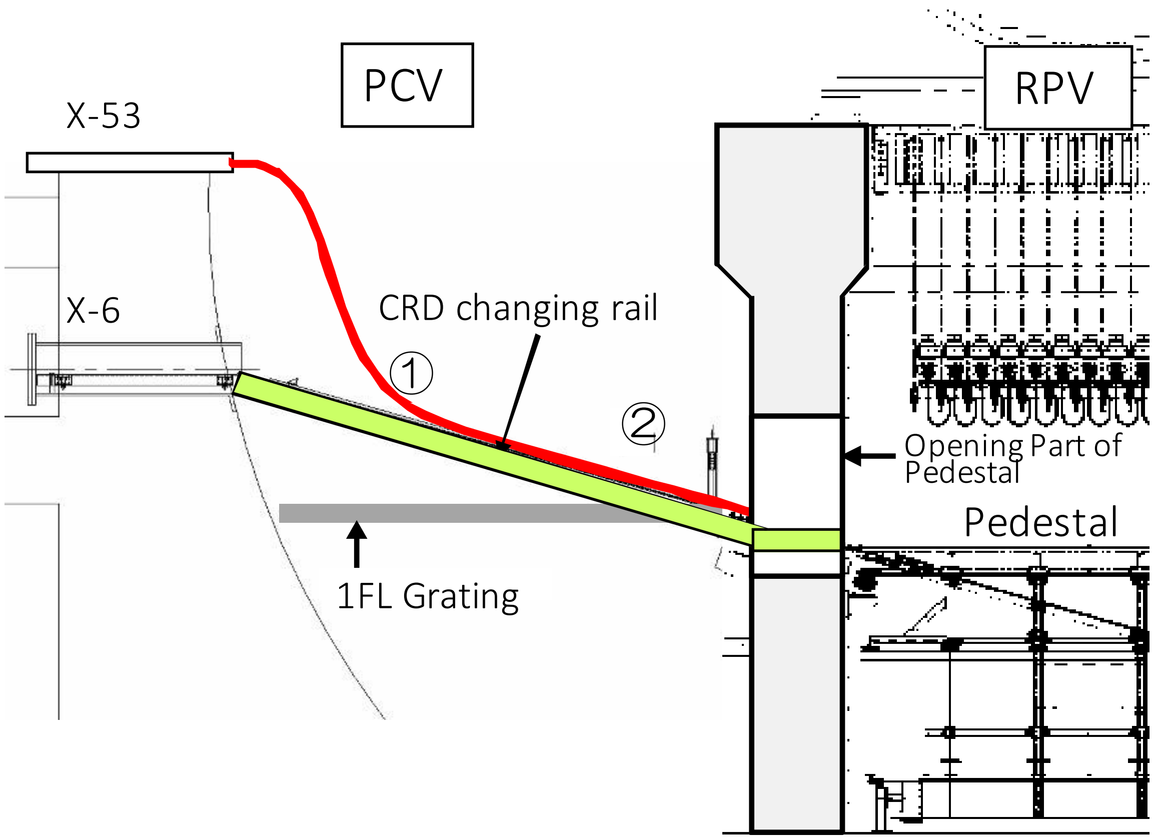


# Investigation of the PCV Interior (Results at present) (2.1.4)

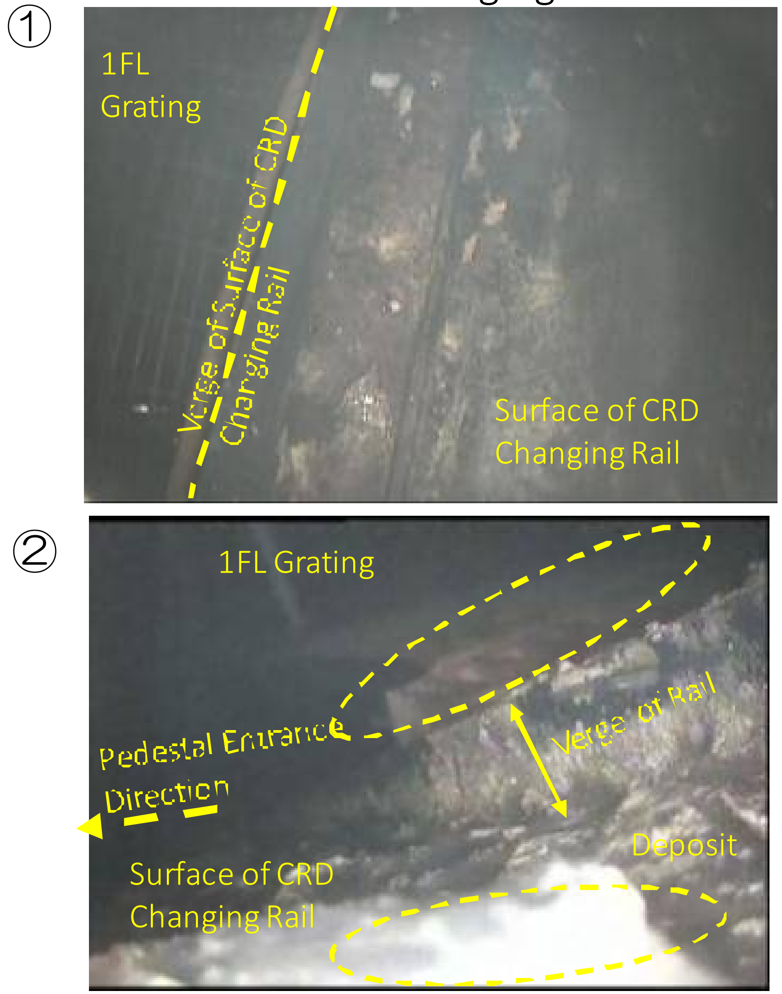


- A thermometer, CCD camera, dosimeter, leak sensor, etc. were inserted into the PCV through penetration seal X-100B at Unit 1.
- Thermometer, endoscope and dosimeter inserted into the PCV through penetration seal X-53 at Unit 2.

Measurement location of ambient radiation dose and temperature



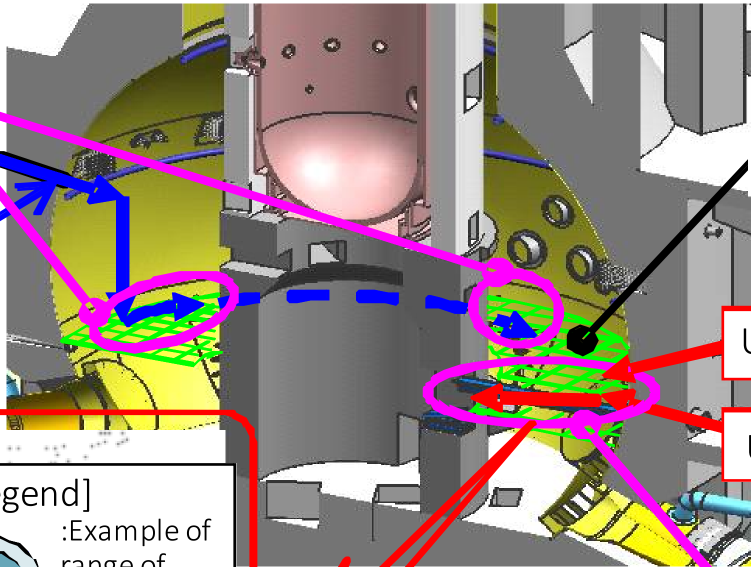

Unit 2 CRD Changing Rail

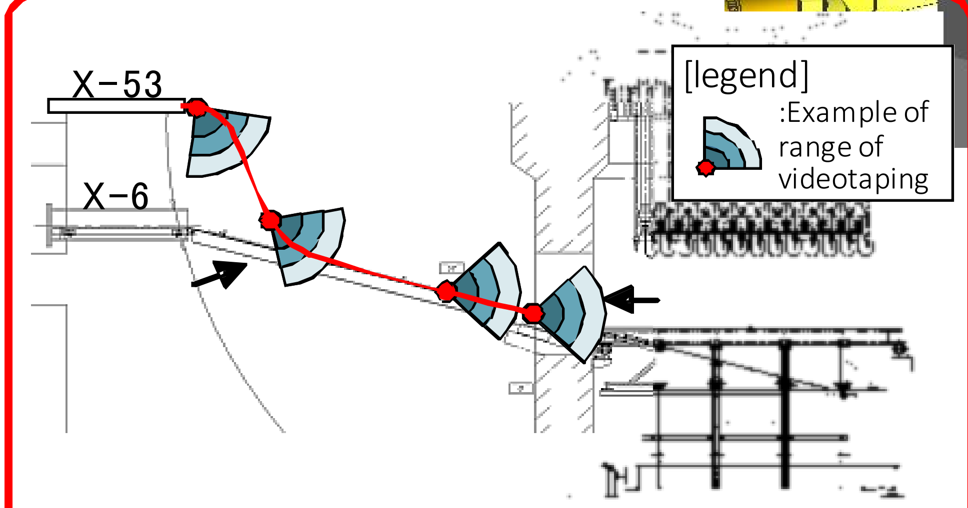



The image processing is conducted for ① and ②.

# Investigation of the PCV Interior (Future Plans(1)) (2.1.4)

- Unit 1: Server devices inserted into the PCV from spare penetration seal (X-100B) equipment moved to above the first floor grating to survey the outside of the pedestal
- Unit 2 : CRD exchange rail and the vicinity of pedestal opening to be surveyed from penetration seal (X-53).
  And also, the survey equipment will be inserted through the CRD equipment hatch (X-6)



Scope of advanced survey from X-53

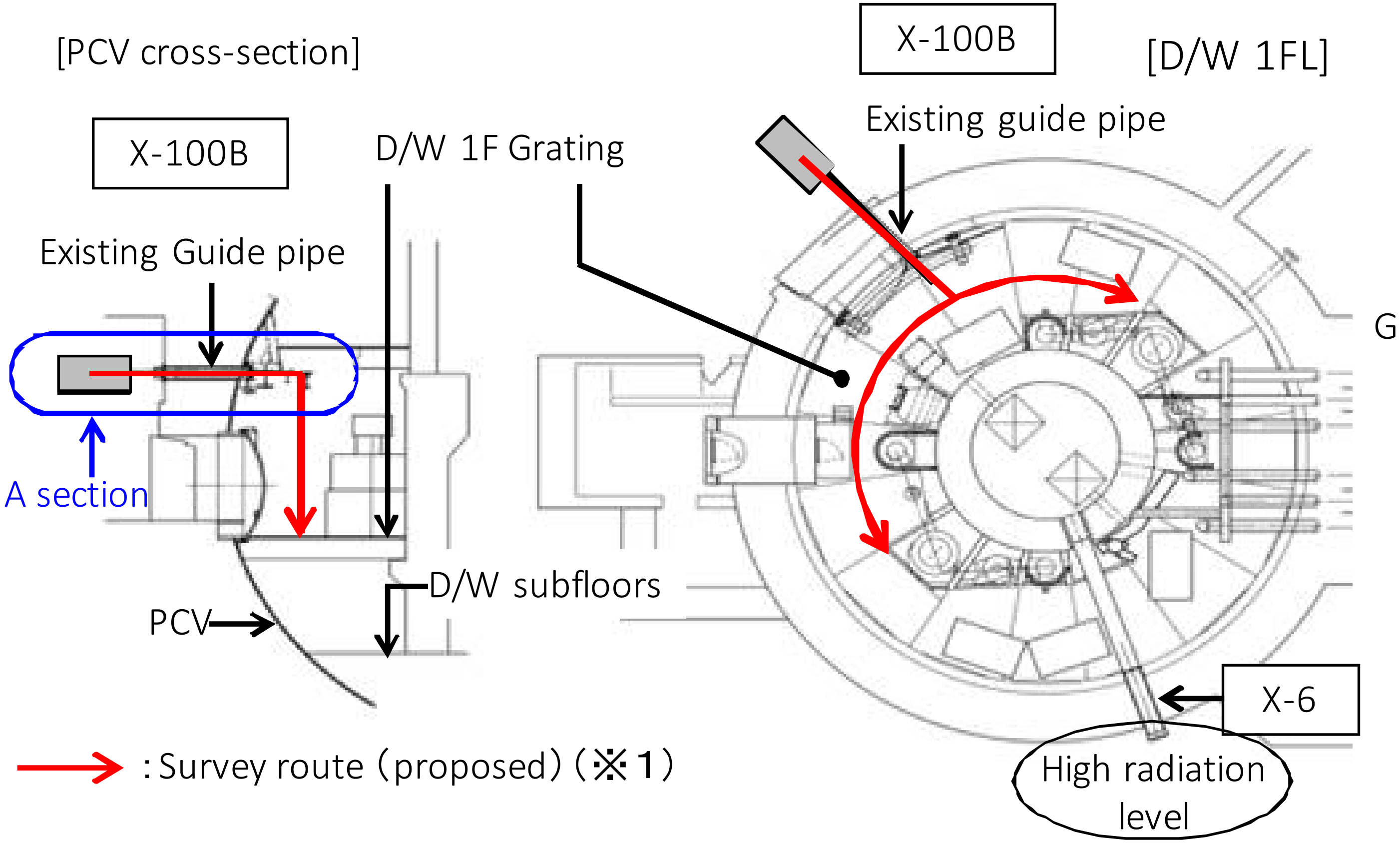
<u>Preliminary survey implementation items and accessories</u>

Advance survey: Survey on inside of PCV in preparation for detailed survey (survey to ascertain the location of fuel debris)

# Investigation of the PCV Interior (Future Plans(2)) (2.1.4)

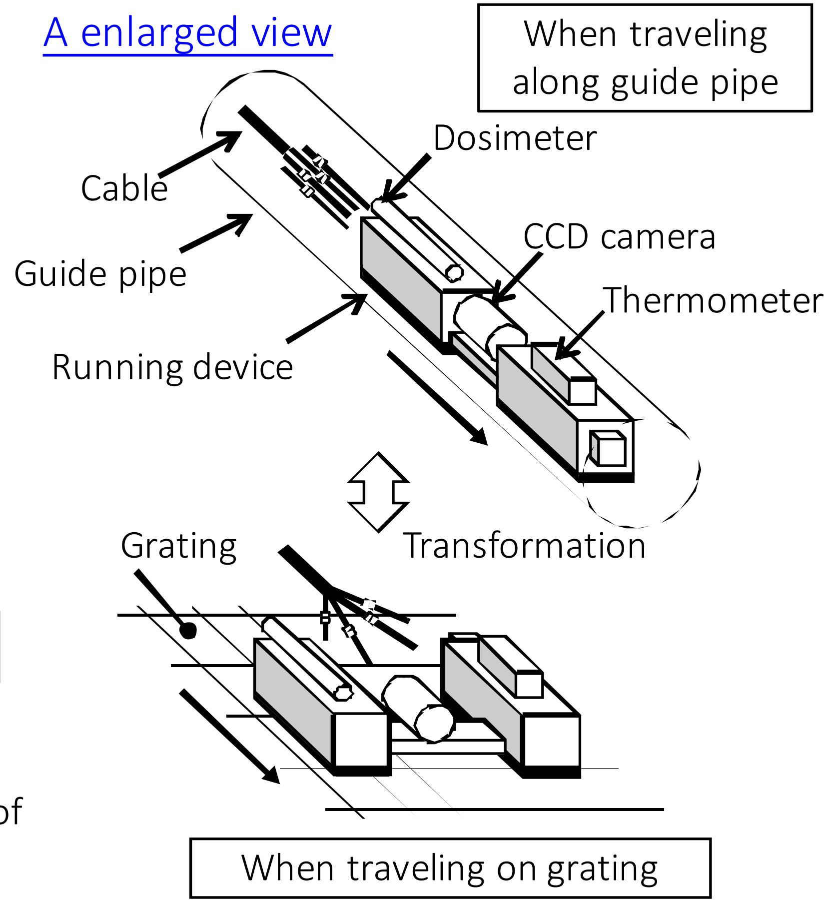


- Inserting survey equipment through Unit 1 X-100B
  - A crawler device that can transform and move along gratings stably after being inserted into the PCV from narrow access pipe (X-100B penetration seal: inner diameterφ100mm).




※1) this is a concept image of the root. The actual survey route and scope of the survey will be determined based on site conditions.

PCV internal survey route (proposed)




Device concept image

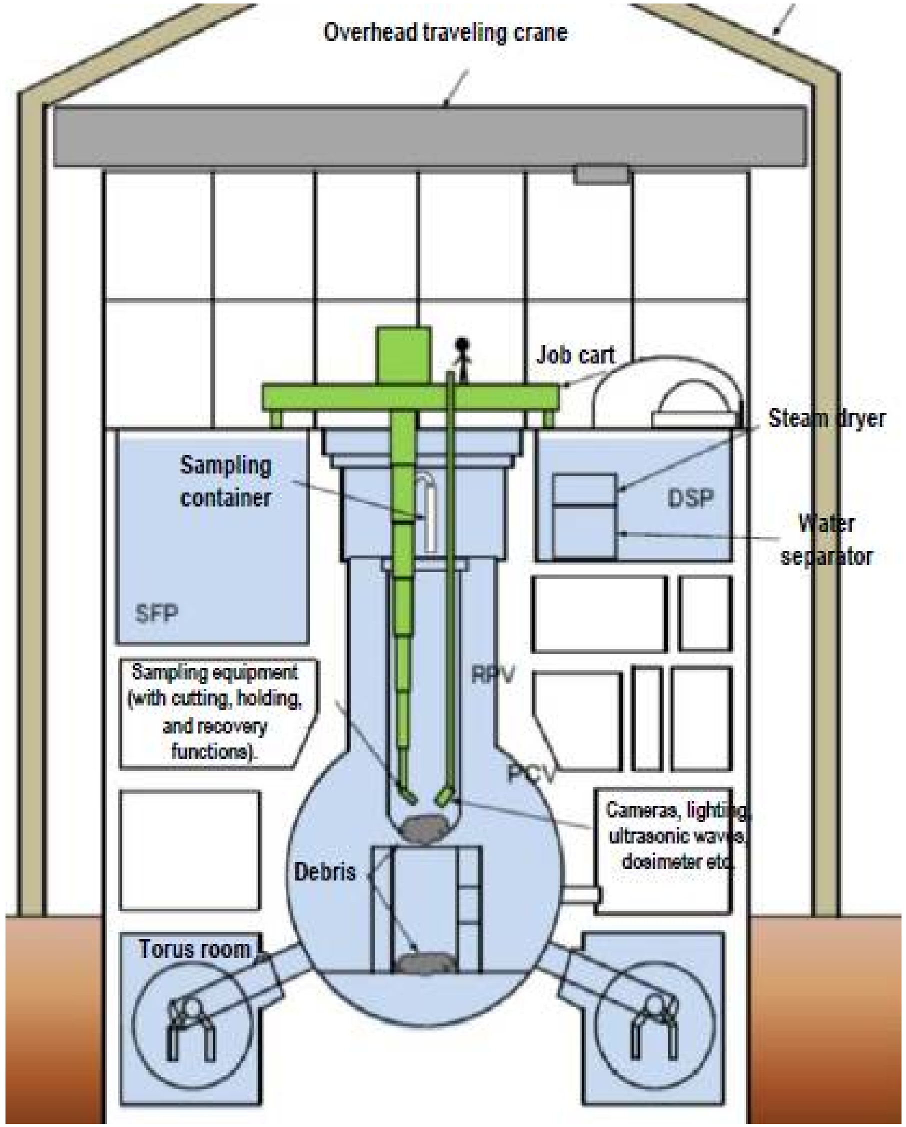
# Investigation of the RPV Interior (Future Plans) (2.1.5)

The survey inside the RPV will be conducted to obtain information inside the RPV prior to the removal of fuel debris.

- reviewing the scenarios of methods to take out fuel debris.
- Clarification of the objectives of the survey based on the scenarios.
- deciding the items and target parts of the survey.

## Schedule


▽1 (2018 Latter half): Defining the method for surveying inside the RPV
▽2 (2019 Latter half): Commencement of surveys inside the RPV



# Analysis of Accident Progression to Estimate Reactor Status(2.2.1)



Using the current severe accident analysis code to perform accident progression analysis.

- Identifying code improvement items based on comparison with actual parameters and also PIRT.
- Advancing improvement items in the accident progression analysis code.
- Using an advanced analysis code to estimate and identify core and PCV status.