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IRID Annual Symposium 2014

Status of R&D Projects Related to Fuel Debris Retrieval

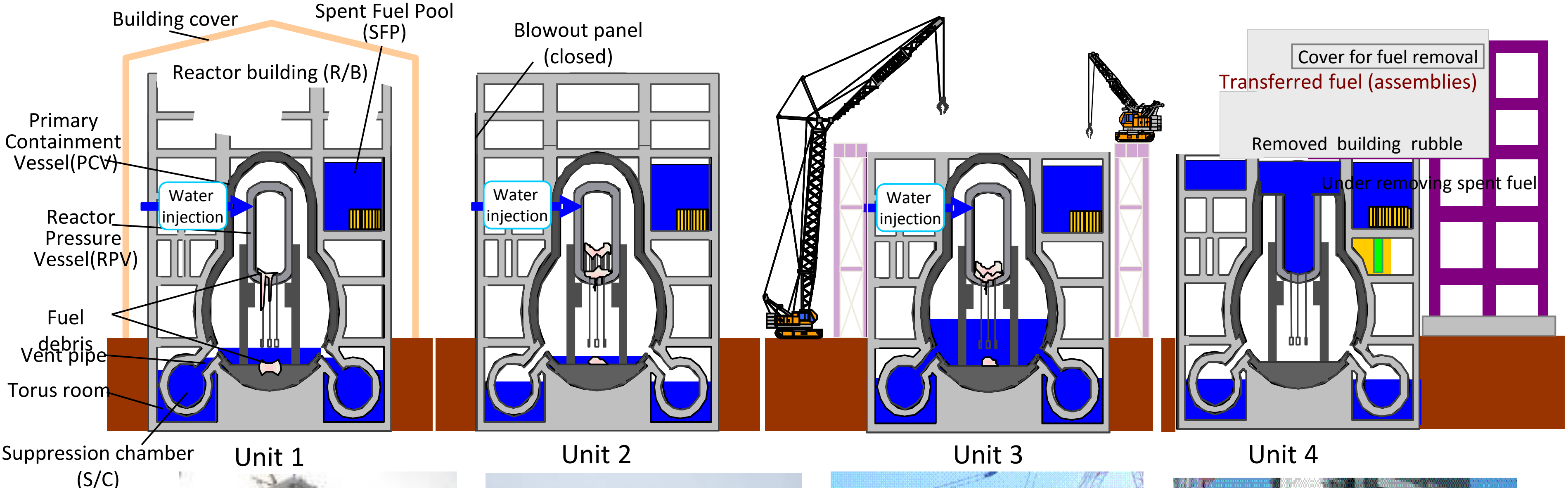
July 18, 2014

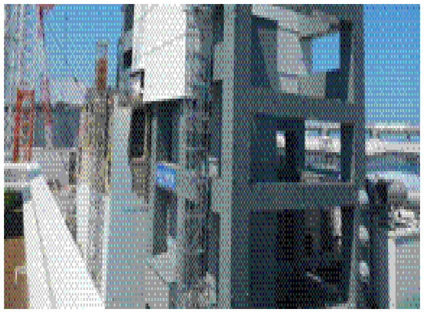
International Institute for Decommissioning

*The contents of this presentation include the results of "Establishment of basic technology for decommissioning and safety of nuclear reactors for power generation in 2013 (technological study and research concerning forming an idea for processing and disposing of radioactive waste resulting from the accident)", a project commissioned by the Ministry of Economy, Trade and Industry, and the 2014 subsidiary for decommissioning and contaminated water measures (development of technologies for processing and disposing of waste resulting from the accident).
*Plant information included in this document is taken from TEPCO's official website.

Overview of Units 1-4

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





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

Outline of Mid-to-Long Term Roadmap

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

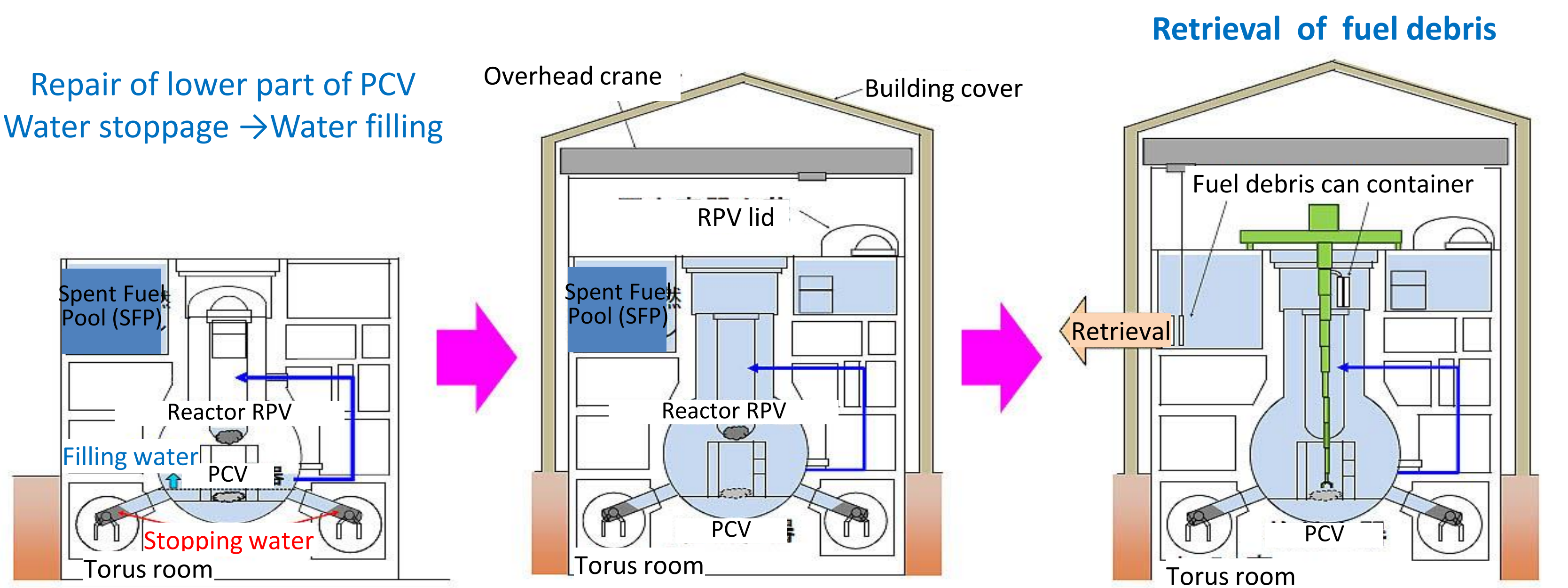
Efforts to stabilize plant condition	Phase 1	Phase 2	Phase 3
December 2011 (Step 2 Achieved)	November 2013	1st half of 2020 (fast case)	30 to 40 years in the future
<Cold shutdown achieved> •Achieved cold shutdown •Significantly reduced radiation releases	Period up to the commencement of the removal of the fuel from the spent fuel pool (within 2 years)	Period up to the commencement of the retrieval 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.

Concept image of work steps for fuel debris retrieval

■The approach of retrieving the fuel debris submerged in water is the safest approach from the standpoint of minimizing exposure of workers.
■Technologies for investigations and repairing methods for filling the PCV with water has been conducting. Furthermore R&D for the retrieval, packing and storage of fuel debris will be implemented.
■Request for information(RFI) on alternative methods for the fuel debris retrieval was conducted.



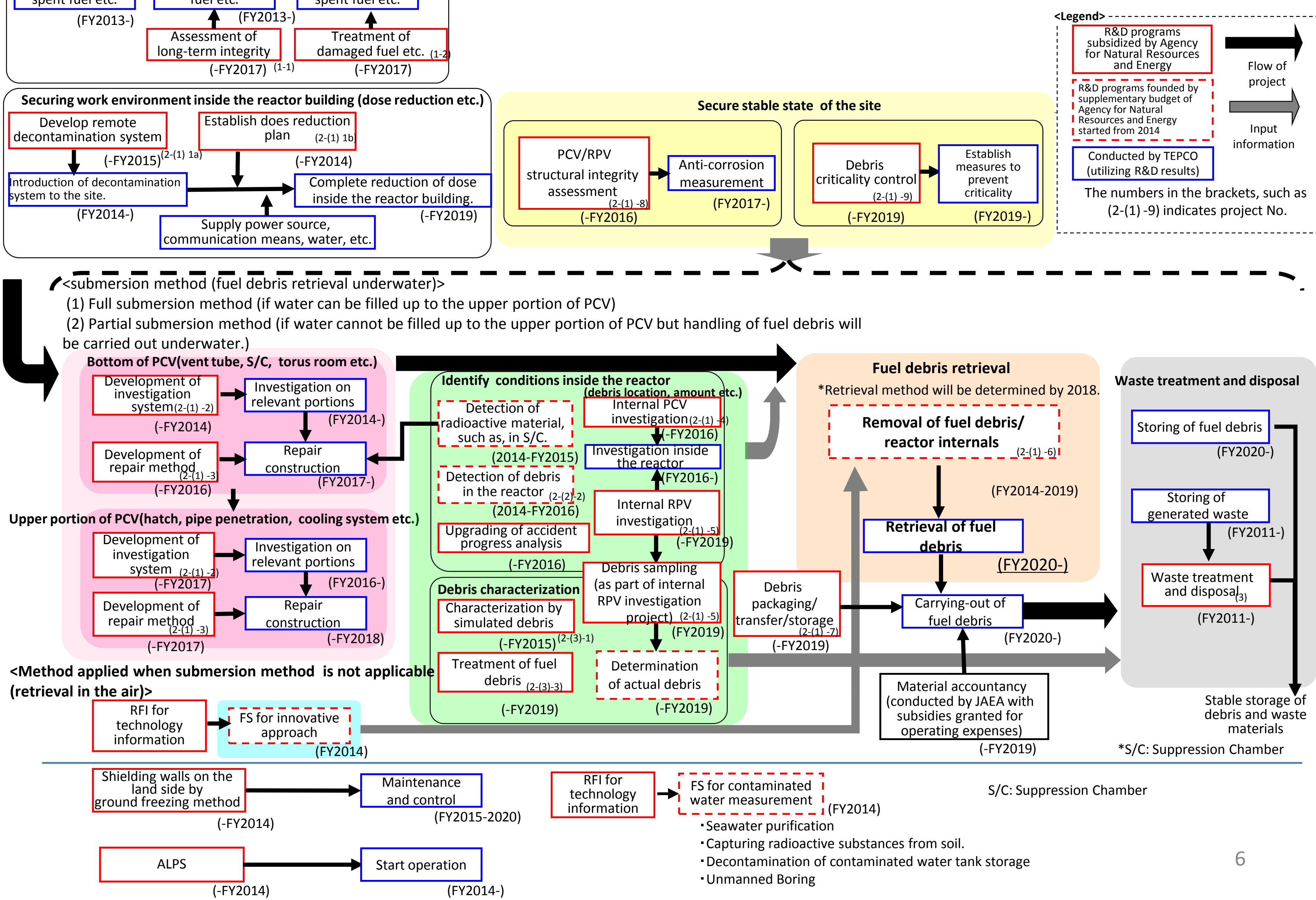
Major Challenges in the Existing Decommissioning Procedures

- **Final goal is to remove all fuels from Reactor Building (R/B).**
- **Removing 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 are damaged (Units 1-3)
Fuel Debris Location	Remained in RV	Possibly fallen out from RPV
Bottom of the Vessel	No structural components	Complicated structure including Control Rod Drives

- TMI-2 experience can be utilized more effectively for procedures after removal of fuels in decommissioning.

Flowchart of R&D on decommissioning /contaminated water countermeasures in Fukushima Daiichi NPS



Research & development projects related to removal of fuel debris

1. Research and development related to removal of fuel from spent fuel pool
(1-1) Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool
(1-2) Study of methods to process damaged fuel removed from spent fuel pool

2. Research and development related to preparations for retrieving fuel debris
(2-(1)-1) Development of technology for remote decontamination of inside of reactor building
(2-(1)-2 & 3) Development of technologies for investigation and repair (stopping water) toward filling PCV with water
(2-(1)-4) Development of technologies for investigating inside of PCV
(2-(1)-5) Development of technologies for investigating inside of RPV
(2-(1)-6) Development of technologies for retrieval of fuel debris/core internals
(2-(1)-7) Development of technologies for fuel debris containing/transfer/storage
(2-(1)-8) Development of technologies for assessing structural integrity of RPV/PCV
(2-(1)-9) Development of technologies for criticality management of fuel debris
(2-(2)-1) Analysis of core status by advanced technologies for analyzing progression of accident
(2-(2)-2) Development of technologies for detecting fuel debris in reactor
(2-(3)-1 & 3)Fuel debris characterization by using simulated debris and development of fuel debris processing technologies

1. Research and Development related to removal of fuel from spent fuel pool

Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool (1-1)

(1-1) Assessment of long term structural integrity of fuel assemblies removed from spent fuel pool

○ Objective of research

It was confirmed by investigating new fuels in the spent fuel pool (SFP) and simulation of water quality conducted prior to removing fuel from Unit 4 that the peculiar environment (seawater injection and fall of rubble) did not influence the fuel removal work. The objective of this research and development is to study methods to assess and store the structural integrity of fuel assemblies over a long time, taking into consideration the peculiarity such as seawater injection and mixing of rubble.

○ Problems for assessment of long-term structural integrity of fuel assemblies at 1F site

The following peculiarity should be considered when assessing the structural integrity of the fuel assemblies at 1F:

- Changes in quality of water in SFP due to injection of seawater
  - Mixing seawater components such as chloride ion and increase in electric conductivity
- Mixing of rubble into SFP
  - pH increase (alkalization) , damage of fuel assemblies (such as scratch and deformation)

Long-term structural integrity of 1F fuel will be assessed by gathering demonstrative data through experiments using actual fuels, specifying conditions along with existing data.
In addition, irradiation effects and acceleration test methods will be studied through the basic test.

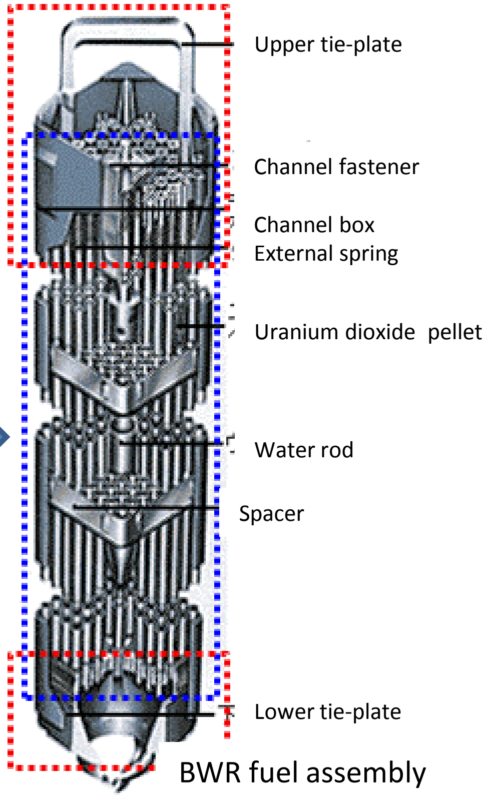
(1-1) Assessment of long term structural integrity of fuel assemblies removed from spent fuel pool

○Adaptabiity of store of fuel assembly in the interim storage / treatment facility for long term after transferred from the spent fuel pool to the common pool.
Structural integrity ⇒ Load transfer paths meet the required structural strength
Fuel cladding scalability ⇒ Effect evaluation caused by fission products(FP) leaking from fuel cladding
（For example, below the criteria of dry cask storage.)

<u>Structural integrity</u>
•Handle
•Upper Tie-Plate
•Fastening of Tie Rod Bolt

<u>Sealability of fuel cladding</u>
•Fuel cladding

<u>Structural integrity</u>
•Lower Tie-Plate



BWR fuel assembly

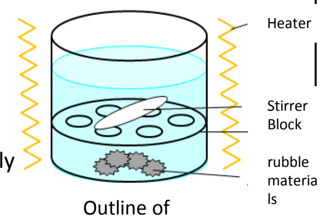
(1-1) Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool (2013 result - 1)

Objective

Since there were concerns that seawater and concrete components dissolved from rubble affect the quality of water in the channel box locally, tests to assess the influences on the water quality of such components collected from Unit 4 when new fuels had been checked were conducted.

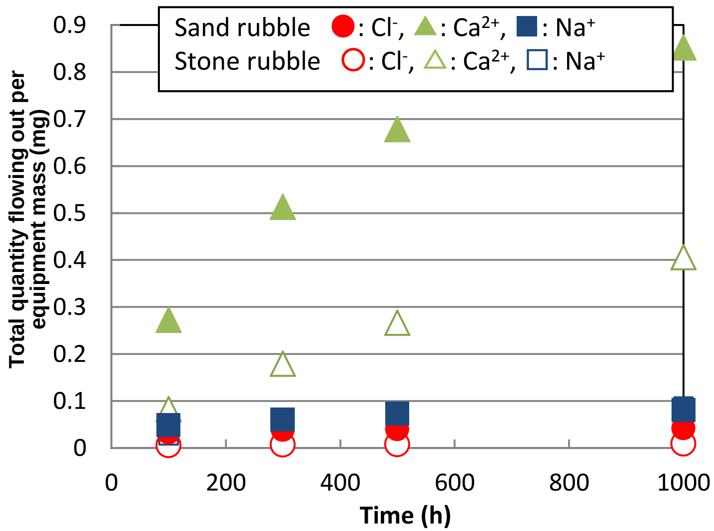
Immersion test using rubble mixing with fuel in SFP of Unit 4

- Test conditions
  - Shape of rubble: Stone or sand shape
  - Quantity of solution: 100 mL
  - Immersion temperature: 60°C
  - Immersion time: 1,000 hr (solution to be sampled after 100, 300, and 500 hr)
  - Atmosphere: Released to atmosphere
  - Measuring method: Ion Chromatographs, inductively coupled plasma mass spectrometry (ICP-MS)



Outline of immersion test

- Test result



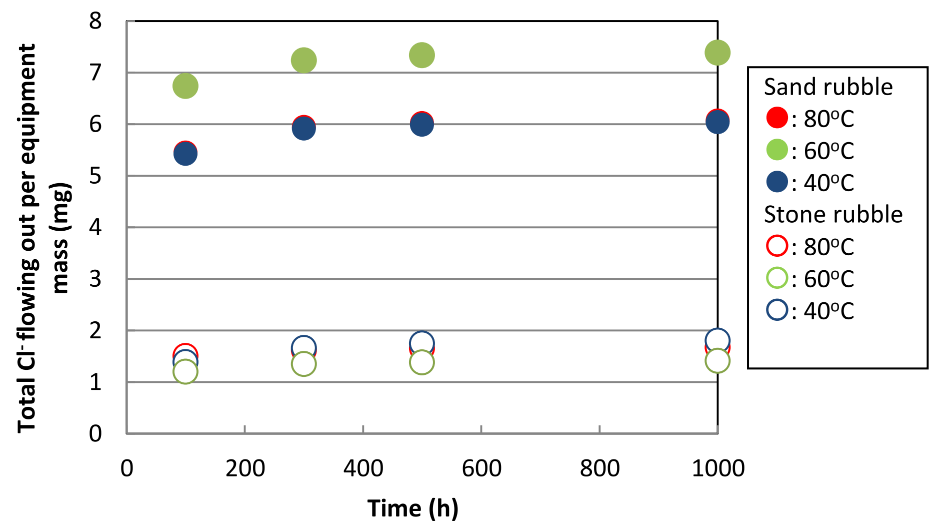
Total quantity of Cl^-, Ca^{2+}, and Na^+ dissolved from rubble at 1F

- ◆ Seawater components Cl^- and Na^+, and concrete component Ca^{2+} were detected.
- ◆ Chloride ion concentration tended to saturate with immersion time.

Immersion test with simulated rubble

- Test conditions
  - Simulated rubble: rubble of commercially available concrete immersed in simulated seawater solution of a chloride ion concentration of about 6,000 ppm and a temperature of 90°C
  - Shape of rubble: Stone or sand shape
  - Quantity of solution: 100 mL
  - Immersion time: 1,000 hr (solution to be sampled after 100, 300, and 500 hr)
  - Immersion temperature: 40, 60, and 80°C
  - Measuring method and atmosphere are equivalent to those of the SFP fuel rubble immersion test.

- Test result



Total Cl^- concentration in solution in which simulated rubble is immersed

- ◆ Total chloride ion concentration tended to saturated with immersion time.
- ◆ No dependency on temperature of the quantity of chloride ion was observed.

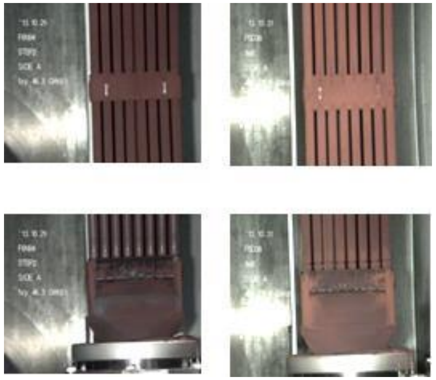
(1-1) Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool (2013 result - 2)

Objective

Data for comparison were collected for future research by using spent fuel rods stored in a common pool and measuring their oxide film thickness and inspecting their appearance. Fuel rods were selected taking into account the types and the use history of the fuel rods, and production conditions of the cladding.

Selection of fuel rod to be checked

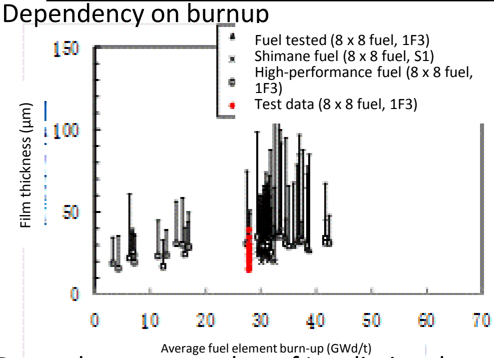
Fuel No.	Manufacturer	Fuel type	Burn-up (GWd/t)	Cy	Irradiation days	Remarks
F2RN1	NFI	STEP Ⅱ	45.1	4	1586	High burn-up
F6N94	GNF-J	STEP Ⅱ	46.3	5	1688	High burn-up
F6M40	GNF-J	STEP Ⅱ	44.9	6	2118	About 2,000Irradiation days
F5D38	GNF-J	8x8	27.8	4	1339	High burn-up
F5C23	GNF-J	8x8	27.8	5	1659	Equivalent burn-up range but many irradiation days

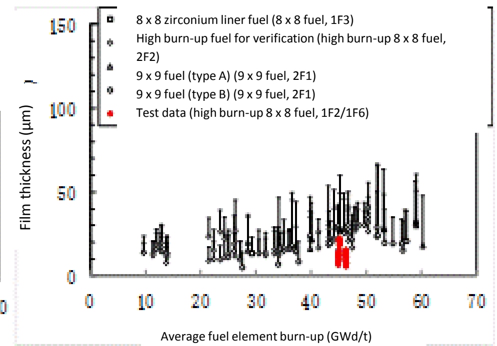


Appearance of fuel assembly

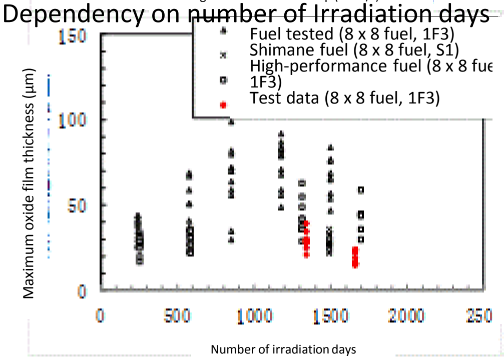
Oxide film thickness measurement

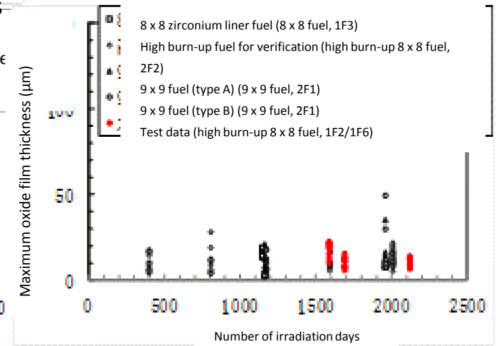
Dependency on burnup





Dependency on number of Irradiation days





Japan Nuclear Energy Safety Organization, “2005 Report on High Burn-up 9 x 9 Type Fuel Reliability Demonstration Result”, July 2006
Japan Nuclear Energy Safety Organization, “2006 Report on High Burn-up 9 x 9 Type Fuel Reliability Demonstration Result”, December 2007

- **The fuel rods appeared to be covered with uniform brown clad and no special corrosive behavior was observed. Nor was local collection of rust suggesting crevice corrosion due to increase in chloride ion observed.**
- **Result of measuring the thickness of the oxide film was compared with existing data but the measurement result was within the range of the existing data and no special corrosive behavior was confirmed.**

(1-1) Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool (2013 result - 3)

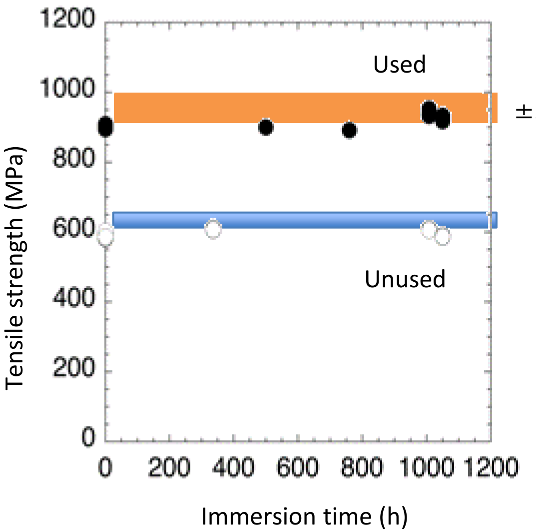
<u>Objective</u>

(1) To assess influences of the environment history of the pool at the initial stage of the accident on the mechanical strength of cladding by conducting a ring type tensile strength test of cladding immersed in seawater at 80°C

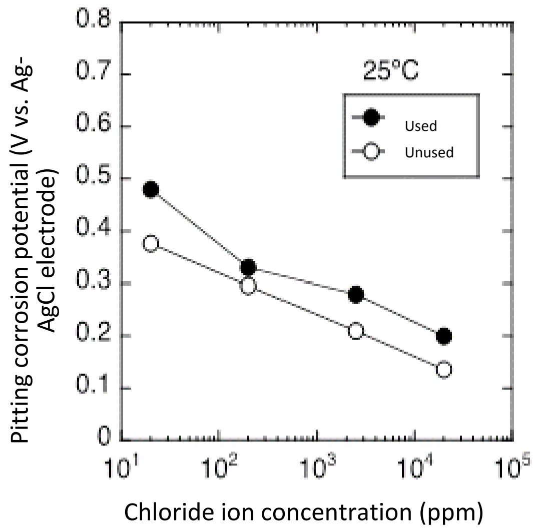
(2) To check influences of oxide film of pitting corrosion on used cladding by measuring pitting corrosion potential in artificial seawater

(3) To assess influences of radiation field (highly oxidized environment) on pitting corrosion of unused cladding by measuring pitting corrosion potential with gamma ray irradiation

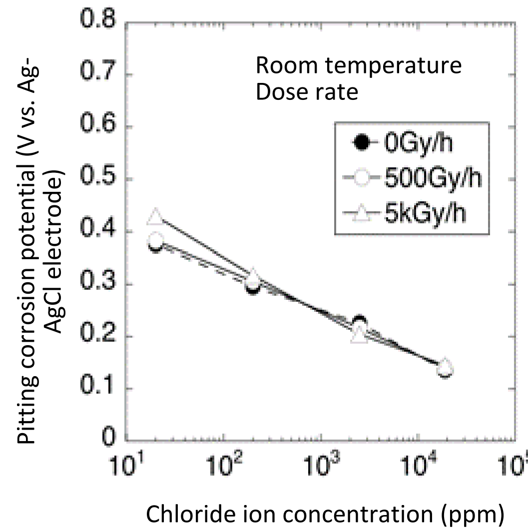
(1) Tensile strength of used cladding immersed in seawater at 80°C for 1,000 hours



(2) Pitting corrosion potential of unused and used cladding in diluted artificial sea water



(3) Influence of gamma ray irradiation (water quality change) on pitting corrosion potential of unused cladding in diluted artificial seawater



<u>Test result (outline)</u>

(1) History of immersion in high-temperature seawater for a short time does not affect the strength characteristics

(2) Existence of oxide film suppresses generation of pitting corrosion of cladding.

(3) Pitting corrosion potential of cladding does not drop in radiation field.

<u>Summary</u>

It is considered that possibility of pitting corrosion on fuel cladding is low in the spent fuel pool environment and cladding not damaged keeps integrity from the viewpoint of corrosion.

*Conducted by JAE with subsidiary from the education ministry

(1-1) Assessment of long-term structural integrity of fuel assemblies removed from spent fuel pool (2014 plan)

Main goal of 2014

Reflecting the results of the projects in 2013, a plan for post-radiation tests using the materials of fuel removed from SFP will be made. Corrosion test and strength test will be conducted on simulated fuel materials not irradiated to select Items to assess influences of rubble on corrosion and judge long-term structural integrity of the materials when they are stored in a wet environment (water quality data, etc.). These items for assessment will also be checked for validity by assessing with underwater camera the fuel assemblies transferred from Unit 4 to the common pool, and the scale of influence of each item will be confirmed through test. In addition, seawater component transfer assessment and corrosion test using spent fuel cladding will also be conducted as basic tests related to long-term structural integrity assessment.

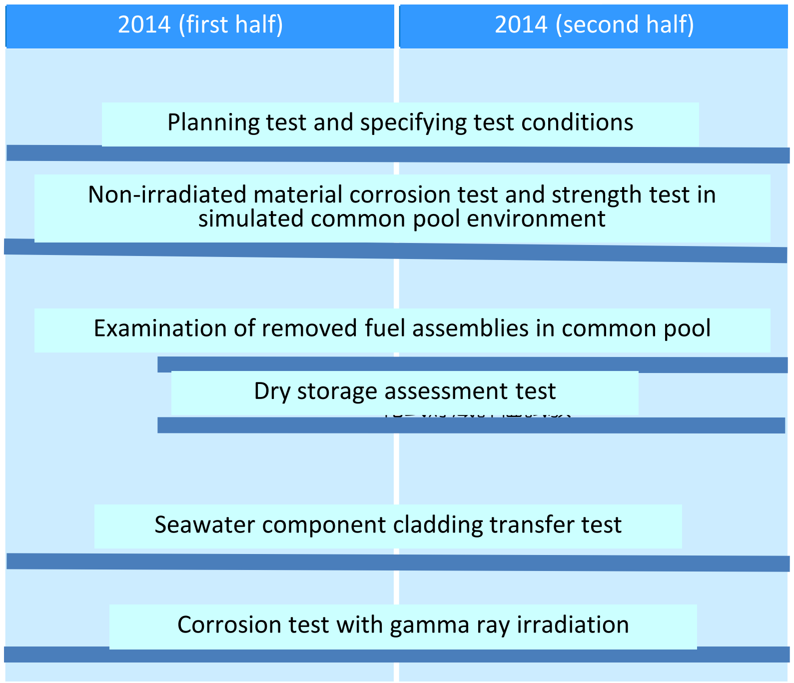
Objectives in 2014

1. **Development of technologies for assessing long-term structural integrity of fuel assemblies**
   (1) Study of test conditions for long-term structural integrity assessment
   - A plan of a test using the materials of fuel taken out of SFP will be made. The results of water quality influence assessment and corrosion tests conducted in 2013 will be reflected. In addition, a plan for transporting fuel materials will be studied and incorporated into the above plan.

   (2) Development of technologies for assessing long-term structural integrity of fuel structures
   - Corrosion and strength tests using non-irradiated specimen simulating the structure of fuel will be conducted to assess influences of rubble to be brought into the common pool on corrosion and influences of damage to cladding on corrosion.
   - Assessment of 1F-4 spent fuel stored in the common pool will be evaluated and the thickness of oxide film will be measured to assess corrosion of the fuel.
   - Tests will be conducted to assess influences of damages from falling rubble and water content, on the assumption that spent fuel taken out of the SFP will be stored in a dry environment.

2. **Basic tests related to long-term structural integrity assessment**
   (1) A chloride ion transfer test using simulated cladding will be conducted to assess absorption of seawater component at the surface cladding of spent fuel.
   (2) Tests to check corrosion of the cladding of spent fuel will be conducted with solution containing seawater and rubble components and with gamma ray irradiated, to assess influences on corrosion of local changes in water quality.

Schedule (2014)



1. Research and Development related to removal of fuel from spent fuel pool

Study of methods to process damaged fuel removed from spent fuel pool (1-2)

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(1-2) Study of method to process damaged fuel removed from spent fuel pool (2013 result – 1)

○ Objective of research

It is planned to store spent fuels removed from the spent fuel pool in the common pool of the power plant for the time being, but it is necessary to decide a policy toward the future processing and disposal of the fuel. Therefore, technical problems over reprocessing and solutions to them will be organized by examining cases where damaged fuels, were handled, both domestically and internationally. In addition, information necessary for organizing indexes to decide on implementing processing and disposal and problems will also be organized.

○ Actions

(1) Studying cases of handling of damaged fuels both domestically and internationally

Domestic cases where damaged fuel was handled will be referred to from materials and documents made public, such as reports on laws and regulations, in order to identify problems of transporting and storing damaged fuels in a reprocessing facility and find solutions to them. In addition, overseas cases will also be studied by checking documents on damaged fuels from international organizations such as IAEA and the database of the International Nuclear Information System (INIS).

(2) Study of requirements and criteria for handling damaged fuel, etc., in other countries

Other countries' documents on check items for identifying fuel damage status, criteria, fuel investigation method, etc., will be studied.

(3) Study of methods and cases of handling damaged fuel, etc., in reprocessing facility

Descriptions on handling spent fuels under the current license of a domestic reprocessing facility will be organized.

(4) Organizing decision criteria and technical problems toward reprocessing

Based on the above results, information necessary for preparing indexes to make decision on whether reprocessing can be implemented, problems, and technical issues related to handling damaged fuels will be removed and countermeasures will also be investigated.

○ Decision indexes and technical problems toward reprocessing

- **Major factors making it difficult to handle damaged fuels at a reprocessing facility**
  - Leakage of radioactive substances: Contamination of pool water
  - Deterioration of mechanical strength: Influences on removing and handling channel box
  - Deformation: Interference with channel box removal and equipment
  - Accompanying impurities: Influences on chemical processing, etc.
- **Possible countermeasures (Depends on condition and degree of damage.)**
  - Can container (sealed (exhaust/drain functions)/unsealed)
  - Repair and reinforcement
  - Reassembly
- **Major technical problems**
  - Influences on handling (including influences on channel box, can container, repair, and reinforcement)
  - Influences on chemical processing, etc. (corrosion, products, waste, process operation)
- **Possible decision indexes (permissible range at reprocessing facility)**
  - Ratio of leakage of radioactive substances
  - Degree of deformation
  - Quantity of accompanying impurities
  - Structure, dimensions, etc., of can container

(1-2) Study of method to process damaged fuel removed from spent fuel pool (2014 plan)

<u>Objectives in 2014</u>

- To conduct corrosive tests on cans containing liquid waste at high concentration and liquid waste tanks to assess the concentration of impurities permissible for both the cans and tanks
- To analyze influences of impurities on U and Pu products and anion on U and Pu removal through removal test under FP and impurity coexisting conditions
- To complete analysis of influences of impurities on basic glass property values (such as glass transfer temperature) by producing glass specimen that takes impurities into consideration
- To comprehensively extract and sort out the influences on processing damaged fuel, etc., at a reprocessing facility

<u>Actions in 2014</u>

Study of influences of damaged fuels on chemical processing

(1) Assessment of influences of impurities on corrosion of reprocessing equipment s

Corrosion tests (immersion test and electrochemical corrosion test) using simulated solution that takes FP components into consideration will be conducted on high-level liquid waste tanks, the representative equipment that handles high-level liquid waste, to assess influences of impurities on corrosion.

(2) Assessment of in-process behavior of impurities

Impurities will be removed under condition where FP coexists to confirm transfer of the impurities to the U and Pu products. U and Pu will be removed under condition where anion coexists, to confirm the influences of the impurities on U and Pu removal.

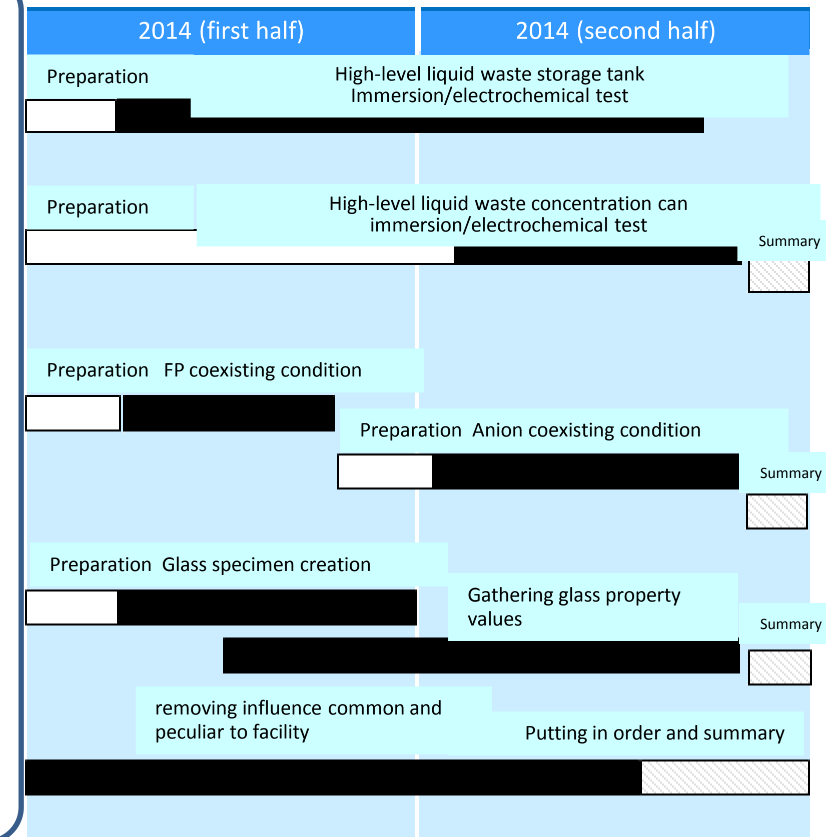
(3) Assessment of influences of impurities on liquid waste

To assess influences of impurities on vitrified objects, glass specimen will be created by using powder materials based on the composition of high-level liquid waste to gather glass property values such as density, glass transfer temperature, and expansion coefficient.

(4) removal and outlining other influences

Influences expected at reprocessing facility will be comprehensively removed and necessary research elements will be decided.

Schedule (2014)



2. Research and development related to preparations for retrieving fuel debris

Development of technology for remote decontamination of inside of reactor building (2-(1)-1)

(2-(1)-1) Development of technology for remote decontamination of inside of reactor building (2013 result – 1)

Main goals of 2013

(1) To confirm contamination situations on the upper floors (second and upper floors of the reactor building excluding the floors damaged by explosion) and at the high places on each floor (dose rate, radiation source, and contamination distribution).

(2) To share and study the specifications of remote equipment for upper floors for common use, and design and produce remote decontamination equipment for the high places on each floor

(3) To create shield necessary for the hot spots on the first floor of the reactor building and verify to confirm if it can be remotely installed

Actions taken in 2013

1. Gathering basic data on contamination conditions

Dose rate ~~was measured and contam~~ination distribution, surface contamination, contained radiation source, and penetration of contamination were checked mainly on the upper floors and at high places of each floor of the reactor buildings of Units 1 to 3. To check penetration of contamination, penetrated contamination (concrete core) samples collected were analyzed at the site to assess the amount of radioactivity. Some samples were transported to JAEA for detailed analysis of penetration contamination.

Unit	Floor/area	Item to be checked					Remarks
		Dose rate (dose rate meter)	Contamination distribution (γ camera)	Surface contamination (β-ray dose rate meter or accumulative dose rate meter)	Contained radiation source (accumulative dose rate meter)	Penetration of contamination (core analysis)	
1	First floor/both sides	○	○	○ -2	-	○	
	First floor/high place	○	○	-	-		
	Second floor/whole area -1	○	○	-	-		
	Second floor/whole area -1	○	○	-	-		
2	First floor/high place	○	○	○ -2	○ -2		
	Second floor/whole area -1	○	○	-	-		
	Second floor/whole area -1	○	○	-	-		
	Fifth floor (operation floor)/whole area -1	○	○	○	-	○	
3	First floor/high place	○	○	-	-		
	Second floor/whole area -1	○	○	-	-		Second floor cannot be accessed because rubble piles up on the stairs.

*1: Investigation into small rooms was not included.

*2: Surface contamination of core sample was investigated. *3: To be implemented at the northwest corner *4: Sample sent to JAEA for analysis

2. Adjusting decontamination technologies and study of concept of decontamination

Based on the situation of contamination investigated in 2012, decontamination technologies suitable for decontamination of the upper floors were selected (by reviewing the result of narrowing down on decontamination technologies, which was conducted in 2012), and a basic policy for decontaminating the upper floors and the high places on each floor was considered.

3. Design and production of remote decontamination equipment and verification of remote decontamination

Specifications for common use of a remote decontamination equipment that would be applied to the upper floors were considered and designed. In addition, a remote decontamination equipment that would be applied to decontamination of the high places on each floor was designed and manufactured. The system demonstrated in 2012 was remodeled to verify its application to the real plant.

4. Verification of shielded installation of real plant

Necessary shields were created for the hot spots on the first floor of the reactor building and verification was conducted to confirm that the shields could be remotely installed.

(2-(1)-1) Development of technology for remote decontamination of inside of reactor building (2013 result – 2)

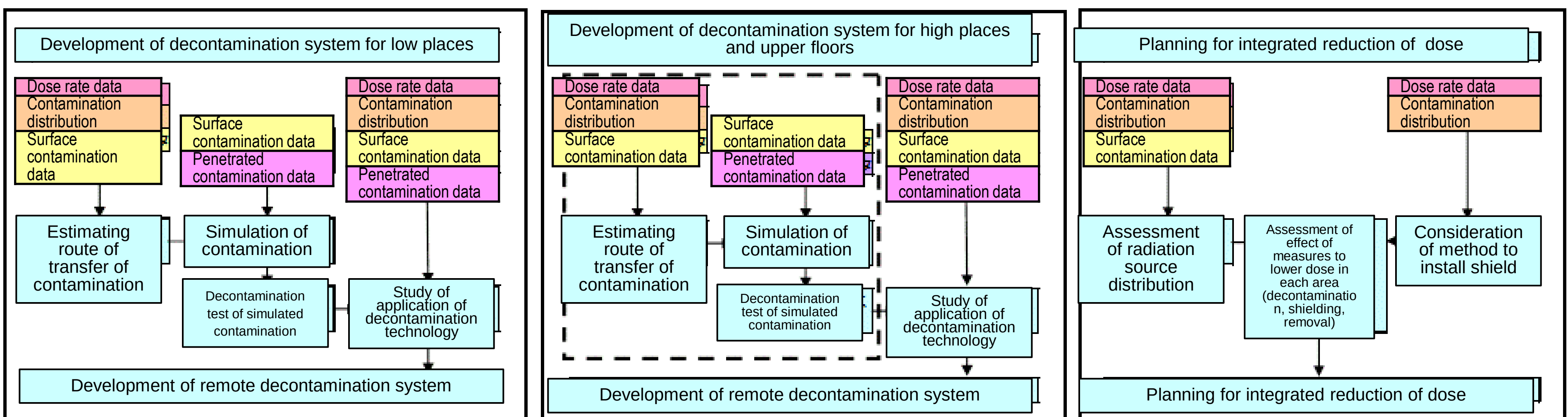
[Schedule for collecting basic data]

Place checked		Dose rate check	Contamination distribution check	Surface contamination check	Penetrated contamination check	Applicable decontamination system
Unit 2, 5th floor		○	○	○	○	Decontamination system for upper floors
Unit 1, 2nd & 3rd floors		○	○	-	-	Decontamination system for upper floors
Unit 2, 2nd & 3rd floors		○	○	-	-	Decontamination system for upper floors
Unit 3, 2nd floor		○	○	-	-	Decontamination system for upper floors
Units 1 to 3, 1st floor	Low place	●	●	●	●	Decontamination system for low places
	High place	○	○	○	-	Decontamination system for high places
Unit 1, south		○	○	○	○	Decontamination systems for low and high places
Basement		-	-	-	-	

●: Investigated in 2012
○: Investigated in 2013

: Basic data of 2012 will be used.

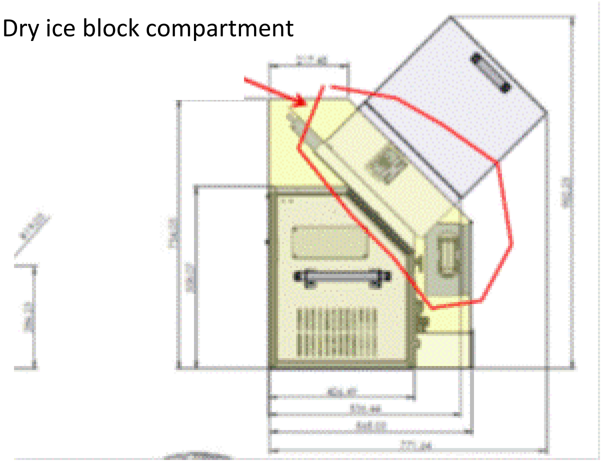
[Plan to apply result obtained by collecting basic data]



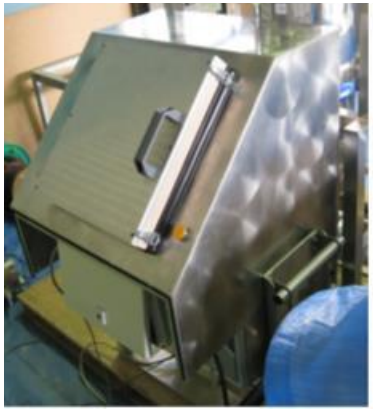
Development of technology for remotely decontaminating floor on the wall (lower portion) and the first floor of reactor building – 1
[Improvement of dry ice blast decontamination equipment]

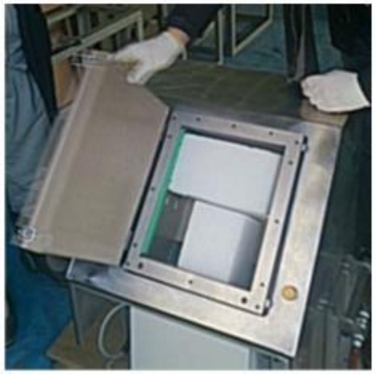
(1) Improvement of decontamination time
To extend decontamination time by increasing dry ice blocks to be filled

Dry ice block compartment



Tripling blast time
Blast time was 30 minutes before, which was increased to 1.5 hour after remodeling.

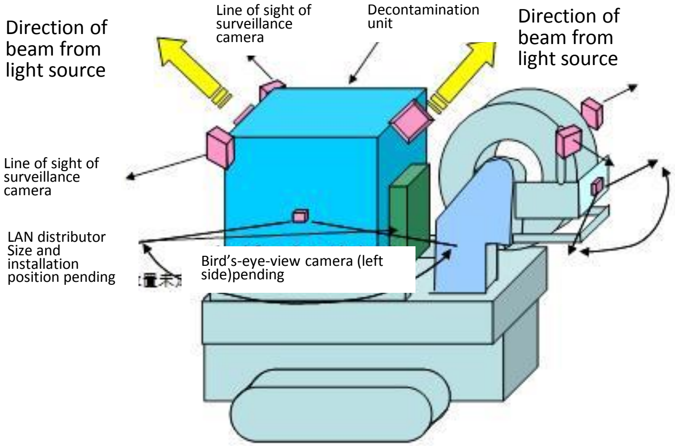




(2) Improvement to safely increase moving speed (to enhance efficiency in operating camera and employ optical LAN)

◆ New around-view camera is mounted so that interference from all the directions of a moving cart can be viewed on a single screen (or on multiple screens by increasing the number of surveillance cameras).

Image from bird's-eye-view camera

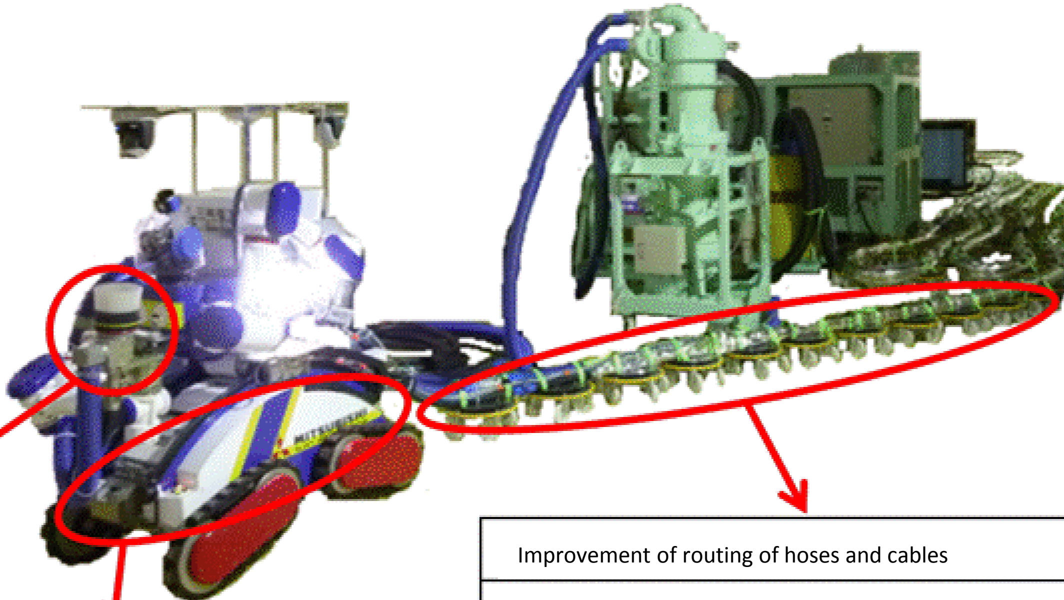


The number of cameras increased from four to nine per cart.

Development of technology for remotely decontaminating floor and wall (lower portion) on first floor of reactor building – 2
[Improvement of blast/collecting equipment]

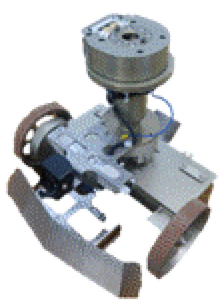
Improvement of operability

- Improvement of screen (introduction of around-view monitor)
- Increasing size of monitor
- Improvement of software (reuse of arm teaching data)

Production of collecting decontamination head

Wide head for decontamination with a rotary brush was produced.

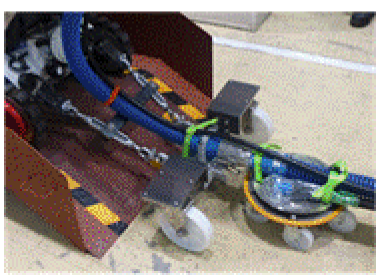


Improvement of visibility

Placement of cameras and lighting instruments was reviewed.


Improvement of routing of hoses and cables

- Adjustments were made to decrease the distance between casters of the cart so that hoses and cables do not interfere with corners of pillars and others.
- The specifications of the first cart on casters were changed to improve the follow-up performance.



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Development of technology for remotely decontaminating ceiling and wall (upper portion) on first floor and roof of reactor building – 3

[Result of investigation at south side of Unit 1 (1)]

<u>investigation with gamma camera into contamination condition</u>
Date: December 22 to 24, 2013 (3 days)
Area: South area of first floor of reactor building of Unit 1
Operations: (1) Dose rate measurement (1,500 mm and 50 mm above floor)
(2) Shooting with gamma camera

Measurement points
●: Only dose rate was measured.
X: Measurement with gamma camera (dose rate also measured9
←: Measurement with gamma camera (Angle of elevation changed only for measurement in the direction indicated by the arrow.)
▲: Measurement with gamma camera (Measurement focused on the southern direction only at elevation angle of 0 (or 10 degrees in some cases).

Legend
Blue: Measured on December 22
Orange: Measured on December 23
Red: Measured on December 24

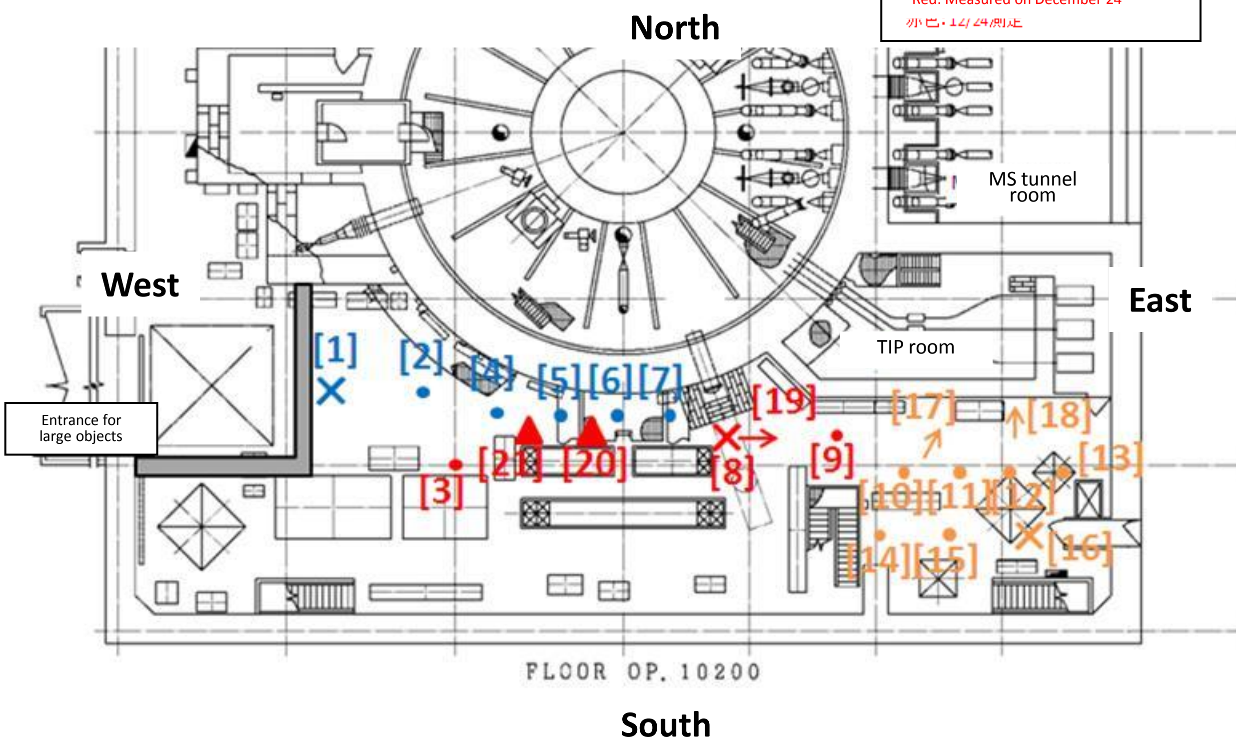


Figure: Position of investigation of contamination conditions at the south side of first floor of Unit 1

Table: Result of dose rate measurement

Measurement point	Dose rate measurement (mSv/h)	
	Height: 1,500 mm	Height: 50 mm
[1]	12.97	15.87
[2]	30.84	20.19
[3]	105.5	–
[4]	61.95	40.83
[5]	65.17	42.99
[6]	25.52	31.85
[7]	41.65	17.55
[8]	52.32	30.64
[9]	–	–
[10]	1661.79	185.92
[11]	1096.64	330.98
[12]	510.51	274.30
[13]	313.57	244.23
[14]	139.11	38.17
[15]	91.31	35.44
[16]	166.98	133.37
[17]	659.38	157.75
[18]	202.94	144.04

Development of technology for remotely decontaminating ceiling and wall (upper portion) on first floor and roof of reactor building – 4

[Result of investigation at south side of Unit 1 (2)]

<u>Result of investigation by gamma camera at south side of first floor of Unit 1 (assessment of outline of inert gas piping</u>

Piping in the southeast area was confirmed by the photographs shot by the gamma camera to be highly contaminated.
(Vapor went through the piping because the PCV was vented at the time of accident.)
It was estimated through assessment that the dose rate at a position 50 cm from the surface of the inert gas piping was about 900 mSv/h.

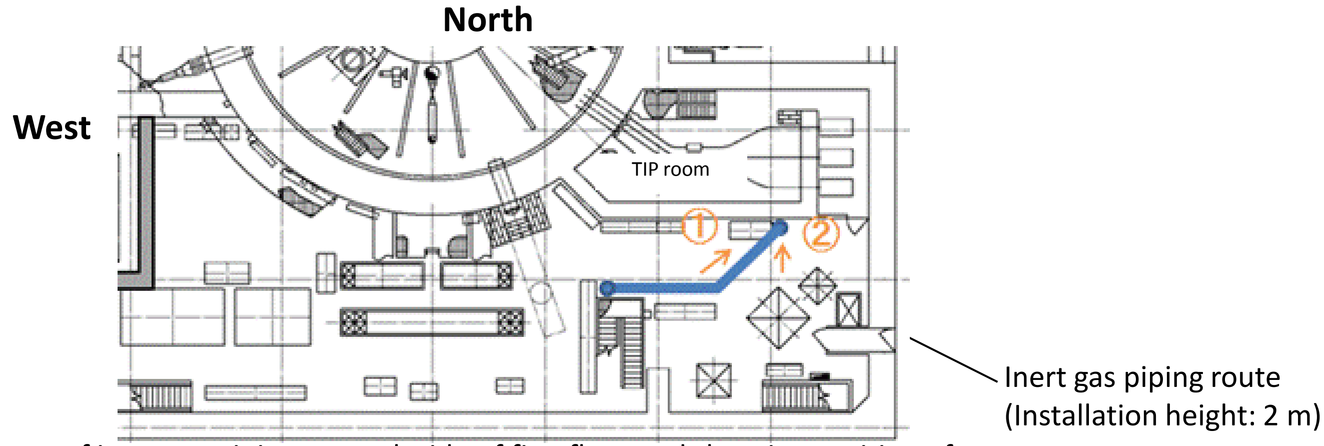


Figure: Route of inert gas piping at south side of first floor and shooting position of gamma camera

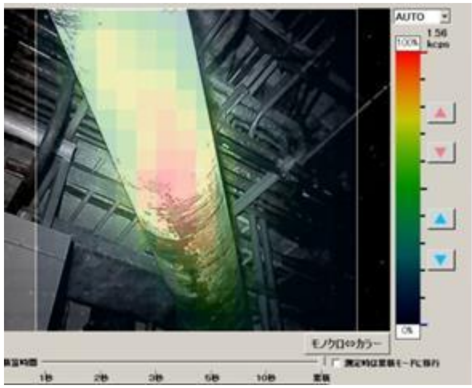


Figure: Shooting position (1) (from above)

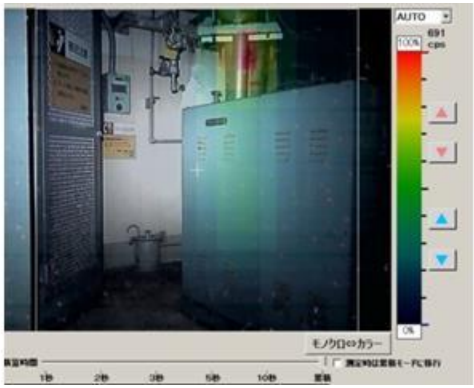


Figure: Shooting position (1) (wall side)

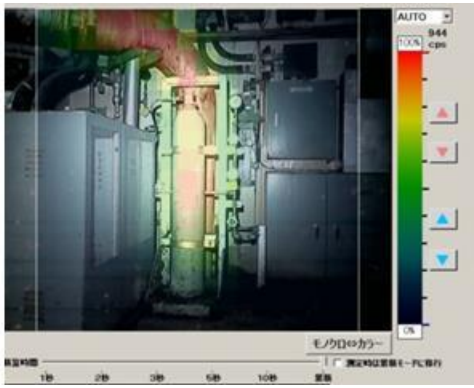


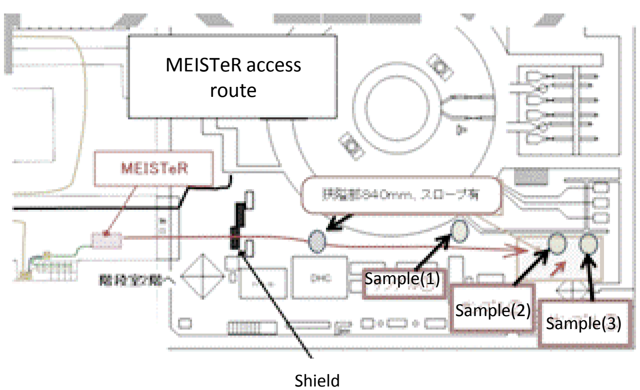
Figure: Shooting position (2) (wall side)

Development of technology for remotely decontaminating ceiling and wall (upper portion) on first floor and roof of reactor building - 5

[Result of investigation at south side of Unit 1 (3): Core sampling investigation]

- The following three positions where high dose was obser were selected for sampling.
- Core size: Φ45 mm × 60 to 70 m

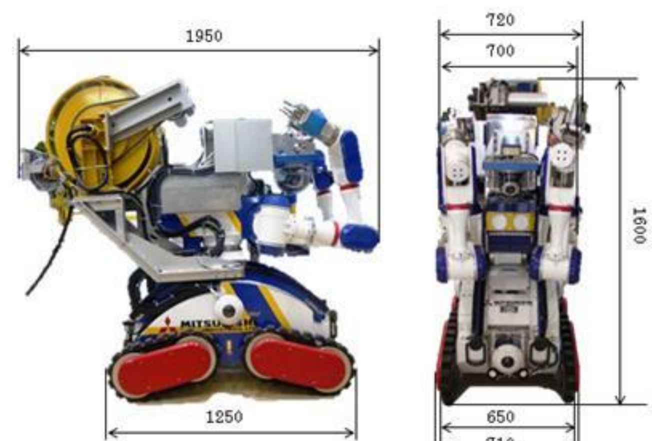
	Situation of sampling location	Sampling situation
Around X-6 penetration		
Around opening of inert gas piping		
Left wall of TIP room door		



	Sample (1)	Sample (2)	Sample (3)
Sampling location	Around X-6 penetration (between penetration and piping)	Around water mark at bottom of AC piping	Around left wall of TIP room door
Sample appearance			
Surface dose rate (coating side)	0.10 mSv/h	0.27 mSv/h	0.09 mSv/h
Sample shape	About 45 mm dia. x 60 to 70 mm (partially diagonal)		
Remarks		Surface partially missing (about 5 mm × 20 mm)	

Core sampling equipment

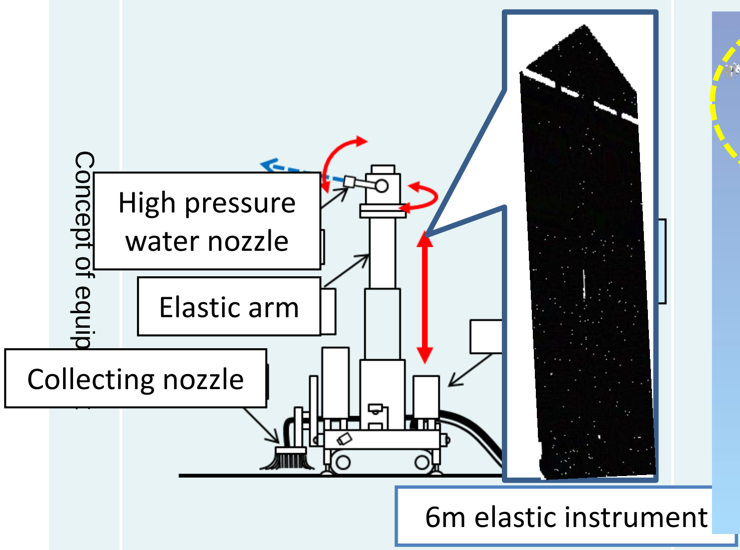
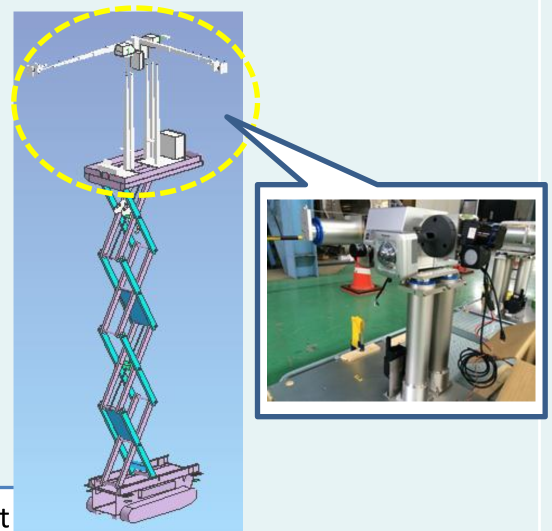
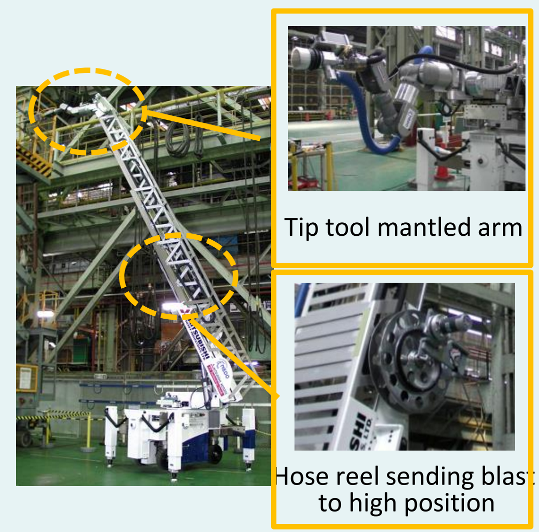
- A core drill was mounted to the left arm of MHI-MEISTeR, which was used as a robot for decontamination, and a core recovery handle was mounted to the right arm.
- Power and communications cables were supplied and recovered by a cable drum.



Development of technology for remotely decontaminating ceiling and wall (upper portion) on first floor and roof of reactor building – 6

[Basic policy of high-place decontamination equipment]

- Possible sources of radiation at high places are radioactive vapor adhering to the duct, piping, supports, and electric appliances, and radioactive substances that have penetrated into the concrete on the ceiling and wall. They are considered to be contaminated by straying, adhering, and penetrating radioactive substances.
- High-place decontamination equipment of different functions, such as to remove radioactive substances adhering to complicated shapes and chip away concrete at high places, needs to be developed.
- Based on the above, the concept of equipment that combines "suction/blast", "high-pressure water", "dry ice", and a high-place work cart was designed.

	High-pressure water	Dry ice blast	Absorption/blast
Concept of equip			
Decontamination method	Substances adhering to it are removed by spraying high-pressure water to the object.	Dry ice blocks are shaved and shaved dry ice is sprayed onto the surface of the object to be decontaminated to remove contaminant from the surface.	**[Suction]** Contaminant is removed and collected by the collecting mechanism mounted to the decontamination head. **[Blast]** Abrasives are sprayed by compressed air to the object to be decontaminated to remove contaminant from the surface of the object.

(2-(1)-1) Development of technology for remote decontamination of inside of reactor building (2014 plan)

Major goals of 2014

(1) Method to decontaminate portions immersed in contaminated water will be considered. In addition, measures for preventing dispersion of dust when those portions dry up will also be studied.

(2) Specifications to produce and share remote decontamination equipment for the upper floors will be studied and designed. Equipment that decontaminates the high places on a floor will be designed and manufactured.

Actions in 2014

1. Gathering basic data on contamination conditions

Considering the conditions of contamination of portions immersed in contaminated water and the portions to be decontaminated, measures for preventing dispersion of dust when those portions dry up will be considered. In addition, a test to confirm the effect of suppressing generation of dust will be conducted by simulating contamination.

2. Adjusting decontamination technologies and studying concept of decontamination

Concept of decontaminating portions immersed in contaminated water will be studied. In doing so, specific portions of the real plant will be assumed.

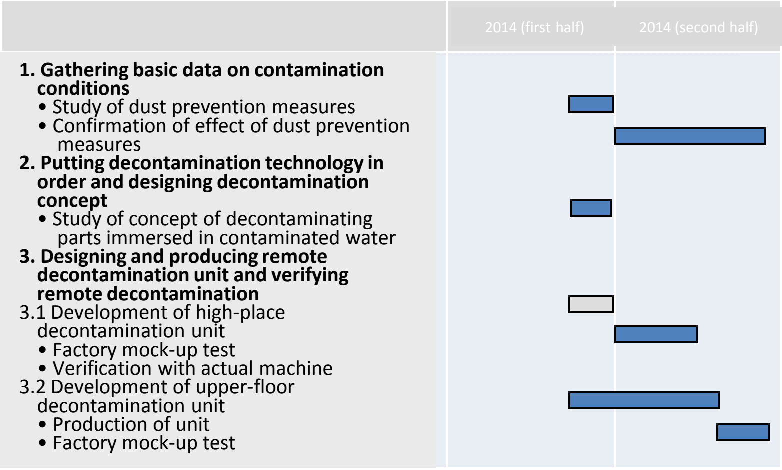
3. Designing and producing remote decontamination equipment and verifying remote decontamination

3.1 Development of decontamination equipment for high places

Mock-up of the high-place decontamination equipment produced in 2013 will be tested in factory. Part of a high place of the real plant will be simulated for the factory mock-up test. In addition, verification with the real plant will be conducted at high places on the first floor of the reactor building of Unit 1 to 3 at Fukushima Daiichi nuclear power plant.

3.2 Development of upper-floor decontamination equipment

Mock-up of the upper-portion decontamination equipment designed in 2013 will be tested in factory.



2. Research and development related to preparations for removing fuel debris

Development of technologies for investigation and repair (stopping water) toward filling PCV with water(2-(1)-2 & 3)

(2-(1)-2 & 3) Development of technologies for investigation and repair (stopping water) toward filling PCV with water

- **Investigation: For the lower portion, equipment has been designed and mock-up for factory test has been created, and equipment performance test and assessment of applicability of the real plant have been completed.**
  For the upper portion, equipment has been designed, produced, and checked for performance, for each portion checked.
- **Repair: For the lower portion, repair technique and water-stopping materials have been studied in detailed and tested toward designing and production of equipment.**
(Stopping water) For the upper portion, results of tests, etc., have been reflected on the detailed designing of water-stopping materials toward production of repair equipment that will be applied to places heavily damaged.

Actions

1. Development of technology for investigating PCV

1.1 Development of equipment to inspect lower portion of PCV

･Equipment that inspect the lower portion of the PCV and detect leakage of water from a reactor building to the adjacent buildings are produced. Factory mock-up test equipment has been created and its performance has been confirmed.

･A plan to assess applicability of the real plant (on-site verification) has been drawn up and on-site verification has been completed.

1.2 Development of equipment to inspect upper portion of PCV

･PCV upper portion investigation equipment has been designed, produced, and checked for performance for each portion to be inspected. Basic type, small-diameter penetration has been conducted for a device that identifies leakage of the dry well outer opening investigation equipment.

･A plan to assess applicability of the real plant has been drawn up. On-site verification is slated for 2015.

2. Development of PCV repair (water-stopping) technology

2.1 Development of PCV lower portion repair equipment

･Details of the repair technique is studied toward designing and production of repair equipment that makes up a boundary by using a vent tube and a suppression chamber.
Completion of (detailed study of water-stopping materials through water-stopping test and optimization of auxiliary closing materials)

2.2 Development of PCV upper portion repair equipment

･Results of water-stopping test will be reflected on detailed study and design of water-stopping materials in order to produce repair equipment to be applied to places that are highly likely damaged (hatch flange, bellows of opening, and electric penetration) may have been damaged.

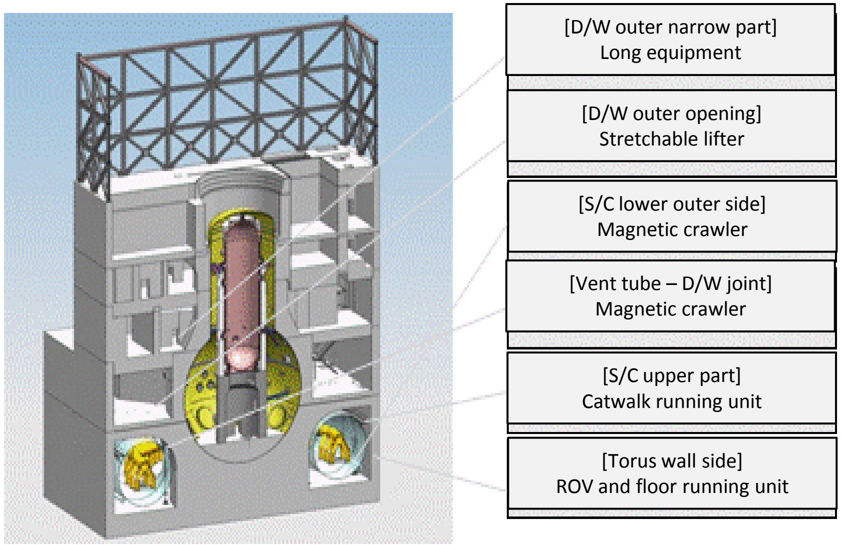
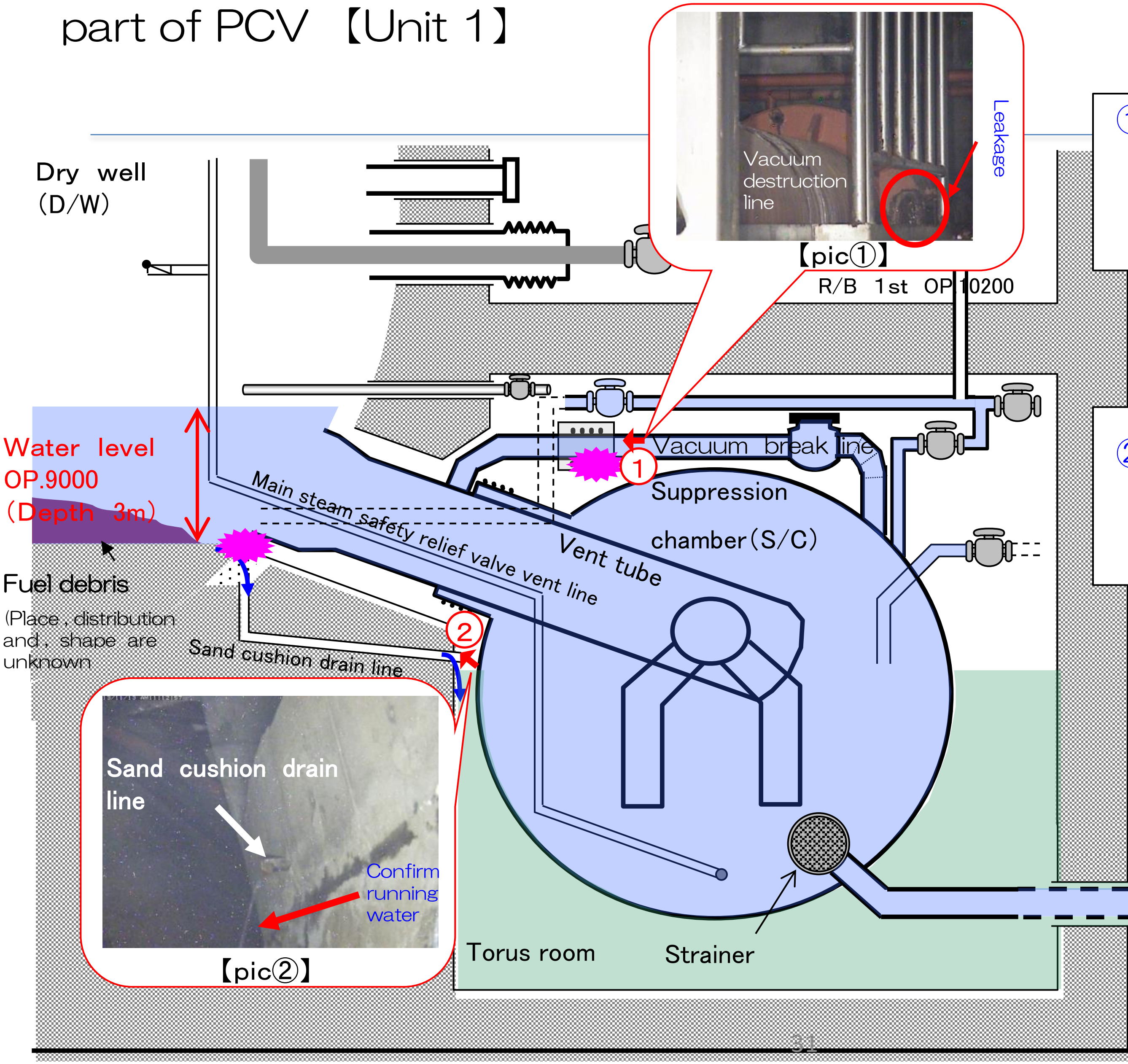


Figure: Location where investigation/investigation equipment is used

Current status of lower part of PCV 【Unit 1】

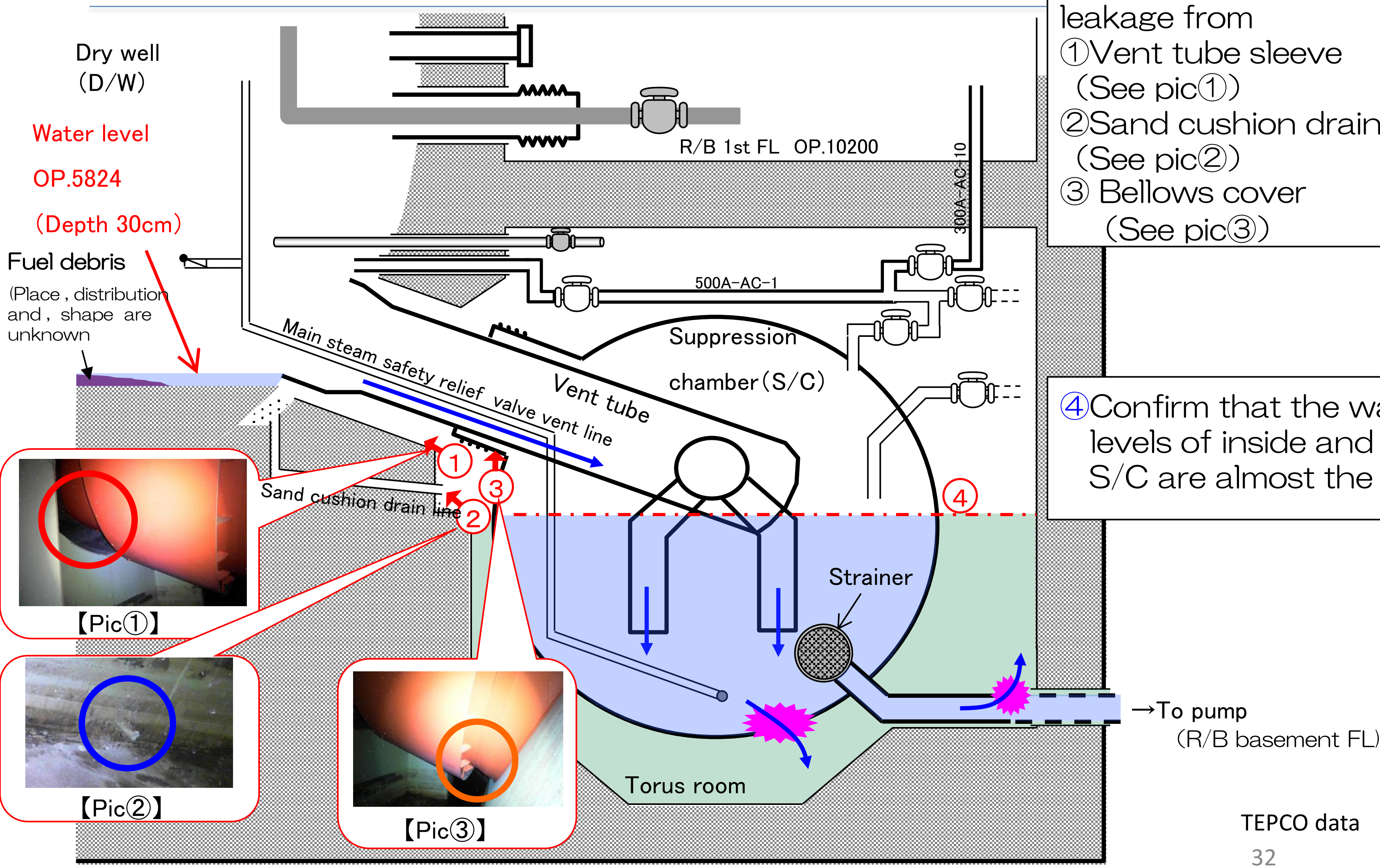


①Confirm Leakage from the bellows portion of vacuum break line (See pic①)

②Confirm running water from the sand cushion drain line (See pic②)

TEPCO data

Current status of lower part of PCV 【Unit 2】

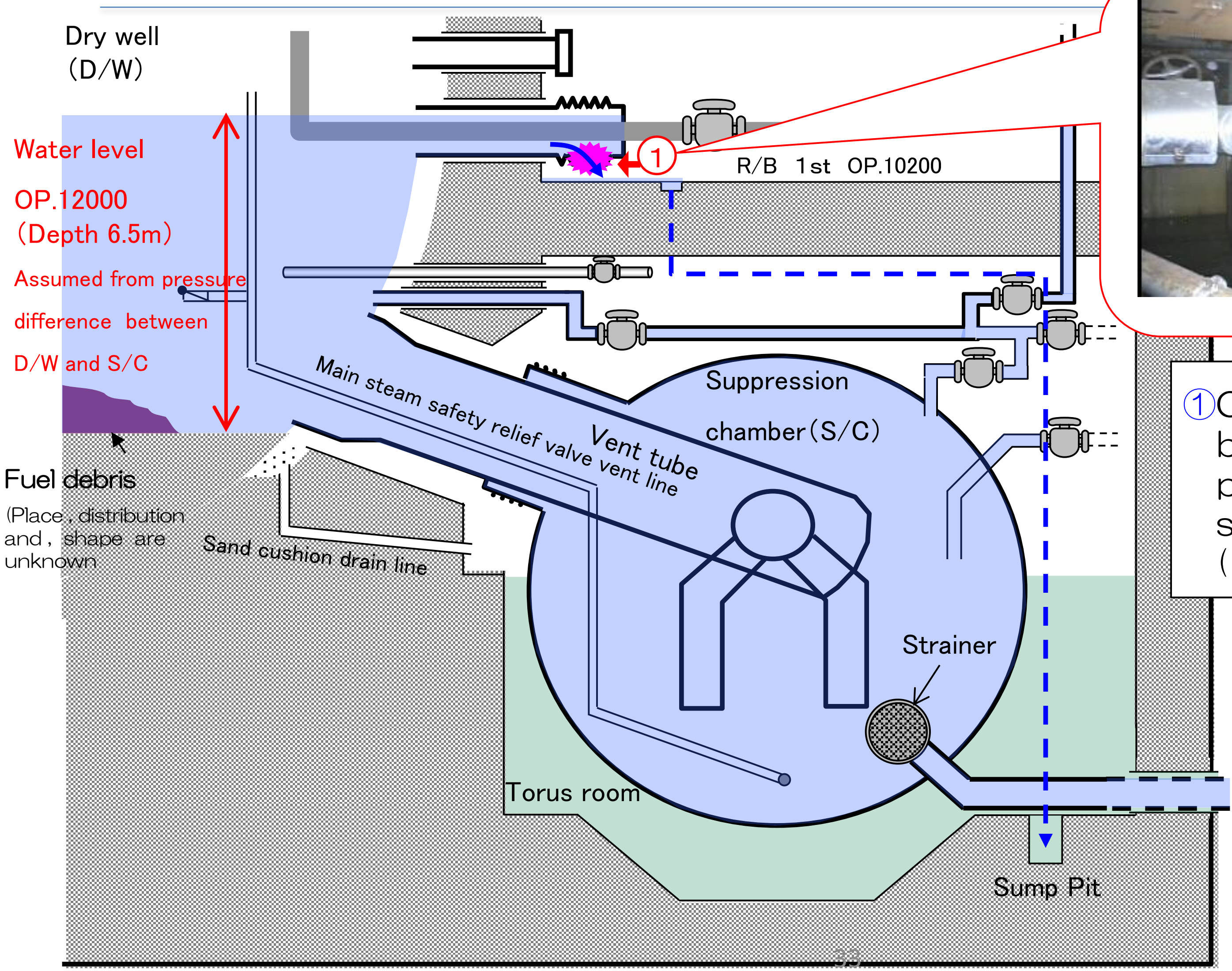


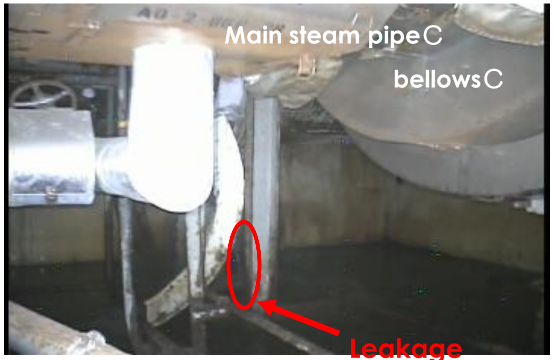
Not confirm running water leakage from
①Vent tube sleeve
(See pic①)
②Sand cushion drain line
(See pic②)
③ Bellows cover
(See pic③)

④Confirm that the water levels of inside and outside S/C are almost the same

TEPCO data

Current status of lower part of PCV 【Unit 3】



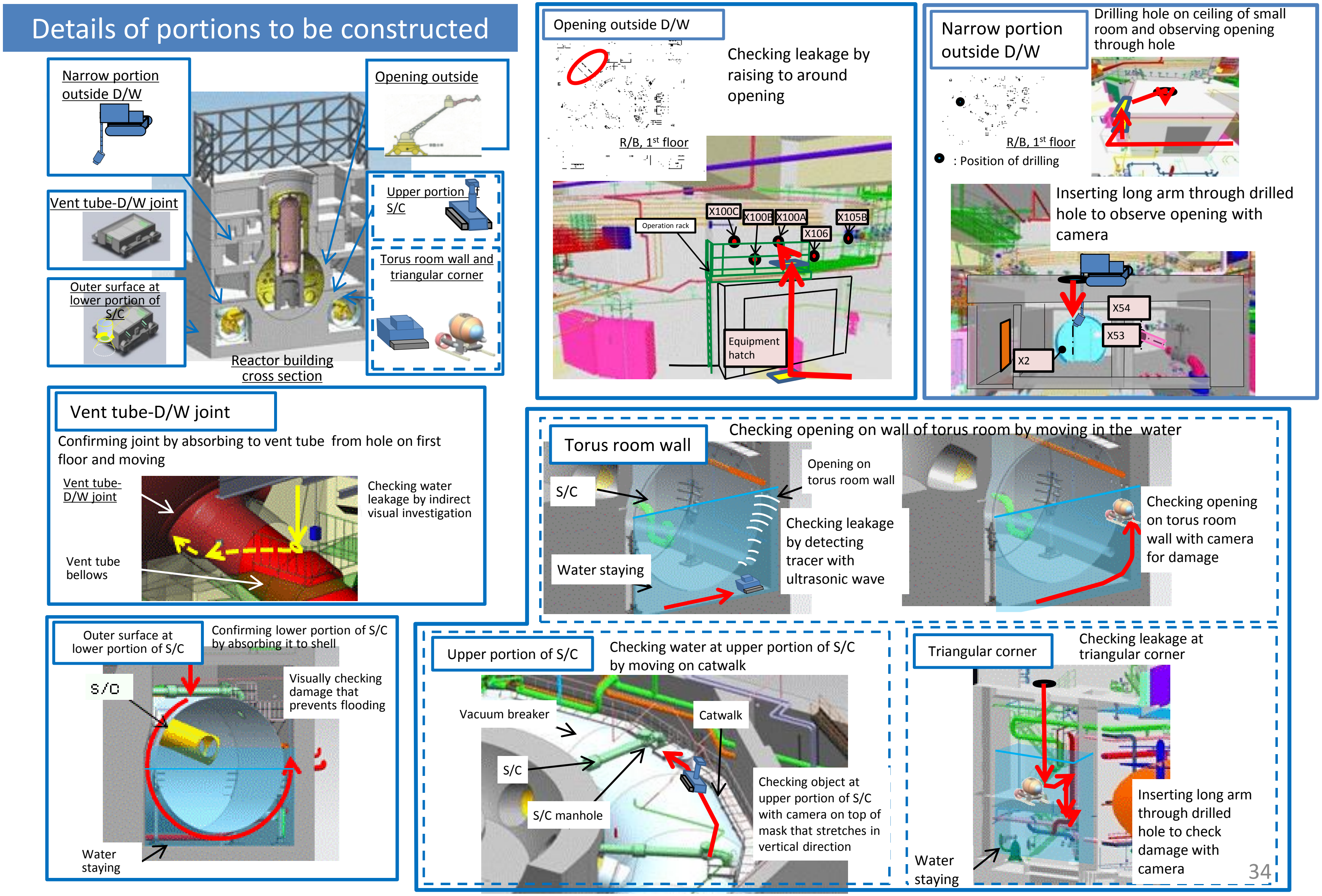


【Pic①】

①Confirm leakage from bellows of the main steam pipe in the room of main steam isolation valves
(See pic①)

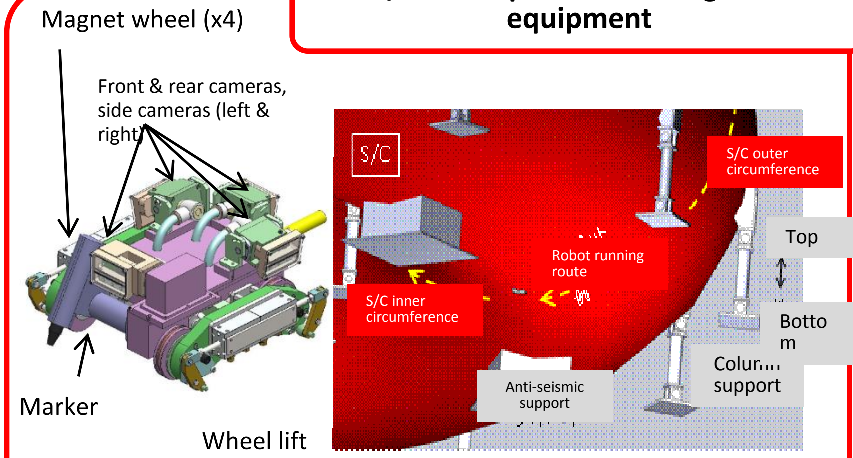
TEPCO data

Development of investigation and investigation equipment (1) (portions subject to construction)

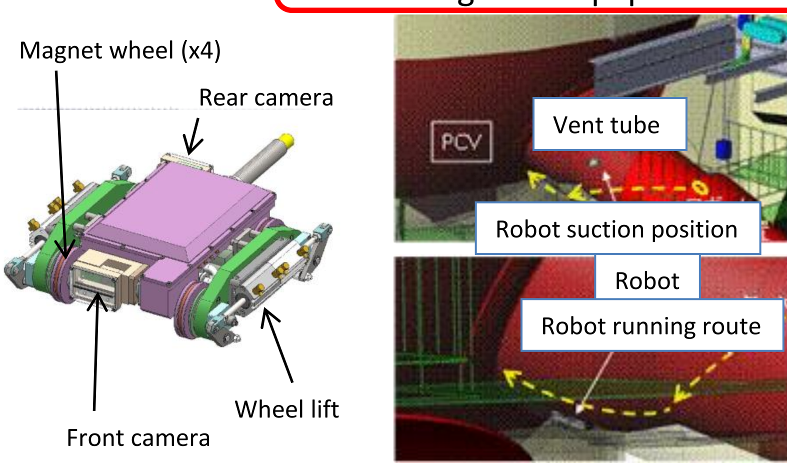


Development of investigation equipment (2)
(vent tube-D/W joint and S/C lower portion investigation equipment)

S/C lower portion investigation equipment

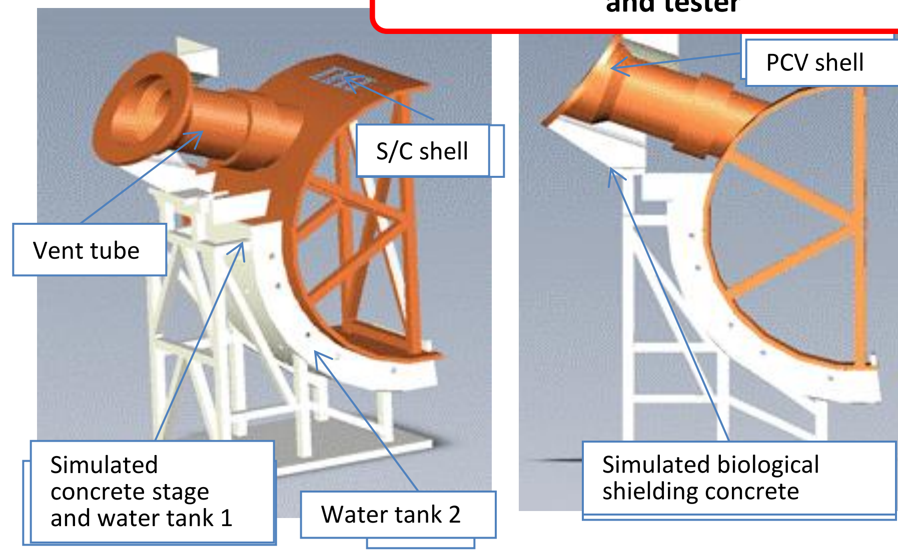


Vent tube-D/W joint investigation equipment



- The equipment can suck the vent tube and S/C at any position.
- It can get over a difference in step of about 5 mm in height and 15 mm in width.
- The equipment can move at any position and posture without wheel lifting.

Vent tube & S/C upper portion simulator and tester



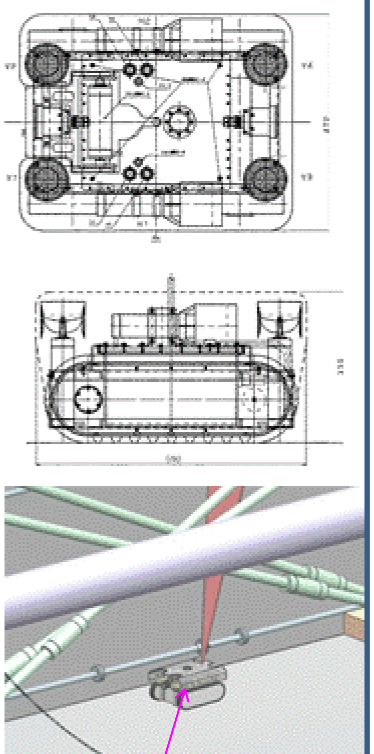
S/C shell and water tank assembly status

Underground pin installation status

Vent tube and concrete sleeve (vertical installation)

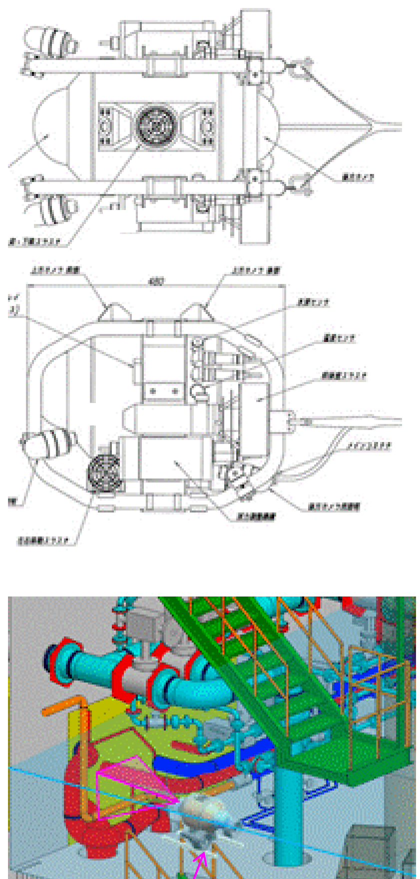
Development of investigation equipment (3) (Torus room wall, S/C upper portion, and D/W outside narrow portion investigation equipment

V1 to V4 & H1 to H2
Four vertical thrusters and two horizontal thrusters



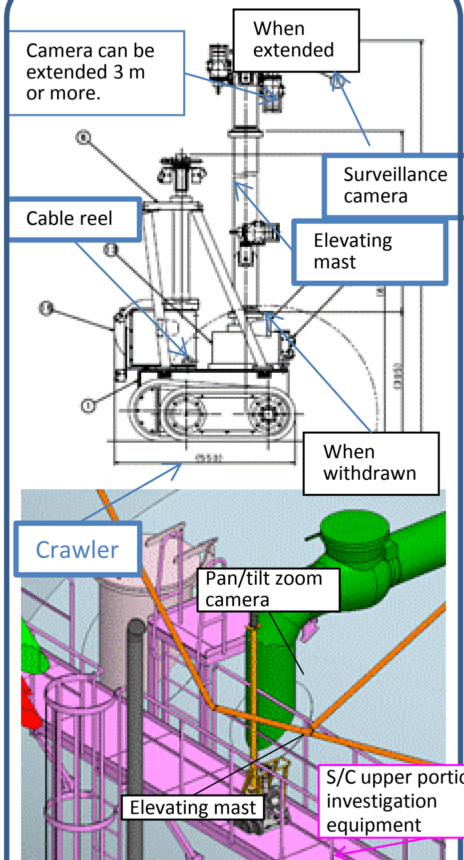
Horizontal floor moving equipment

- Small investigation equipment that can move on floor and move under water
- Equipped with sonar and can check leakage under water



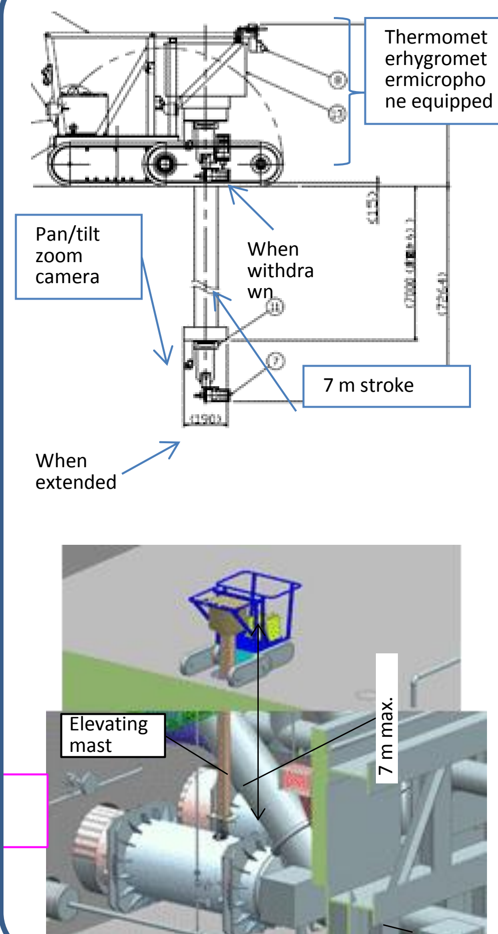
Underwater swimming equipment

- Thruster has long life and easy to maintain by using magnet coupling.
- Camera can move up/down and left/right about 90° to have wide view angle.



S/C upper portion investigation equipment

- Camera can be extended 3 m or more to inspect structure at upper portion of S/C.
- Equipment measures 600 mm square and can move on catwalk at upper portion of S/C.



D/W outer narrow portion investigation equipment

- Camera is extended (up to 7 m) and inserted into room to check objects inside
- The equipment can voluntarily move with camera withdrawn.

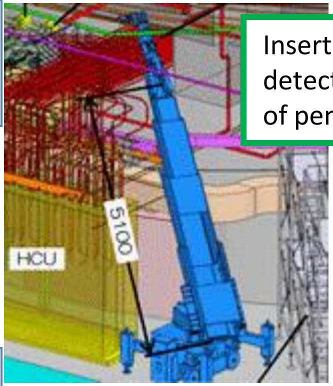
Development of investigation equipment (4) (D/W outer opening investigation equipment)

investigation method

Checking leakage by accessing PCV penetration at high place

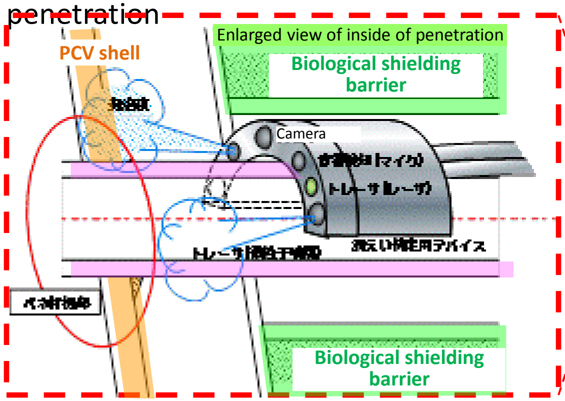
Typical penetration to be checked

CRDM macaroni piping

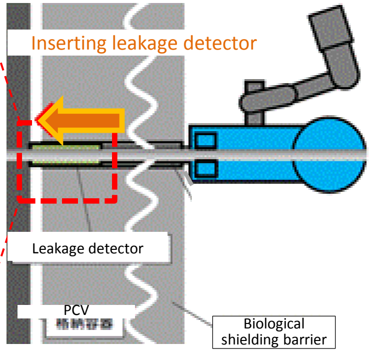


Inserting leakage detector to base of penetration

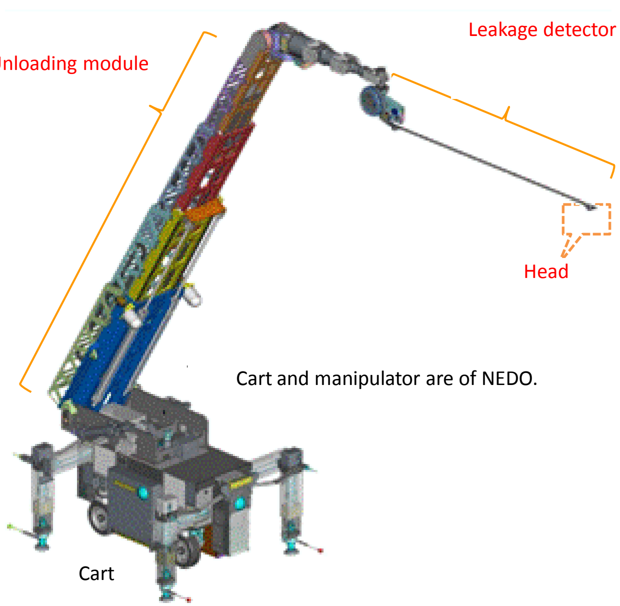
Image of investigation at base of penetration



Detecting flow of nitrogen gas in atmosphere

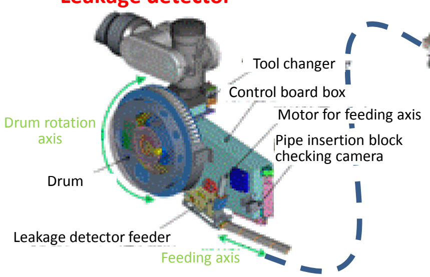


Overview of equipment (Red: Range of production)

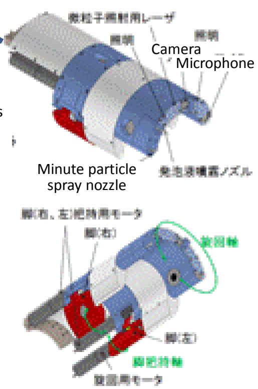


Design and production status of equipment

Leakage detector



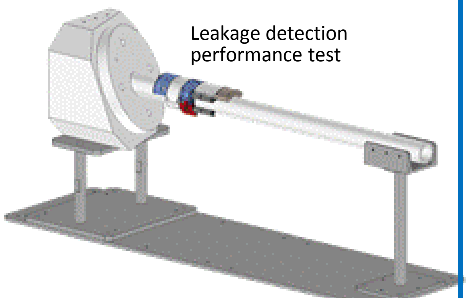
Head



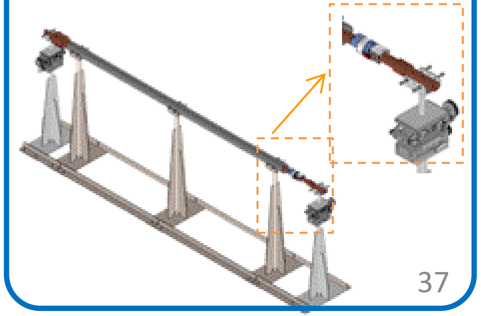
Unloading module (under production)

Leakage detector (head)

Actual machine simulation test (under preparation)

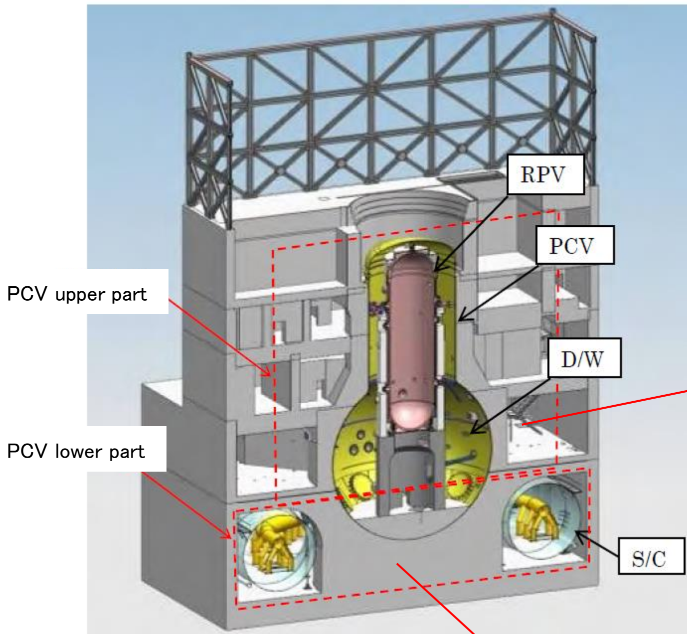


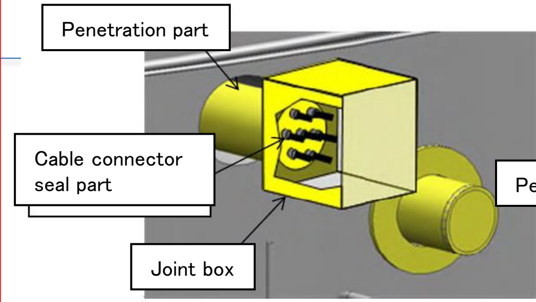
Leakage detection performance test



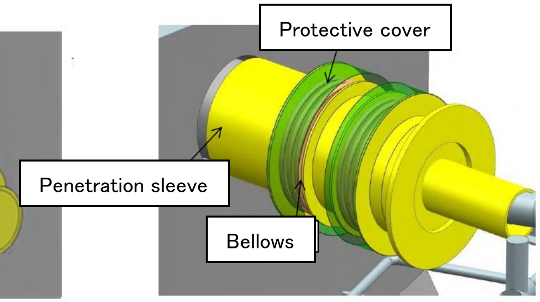
Driving performance verification test

Development of PCV repair technology(1)(Part for repair)





Electric wiring penetration



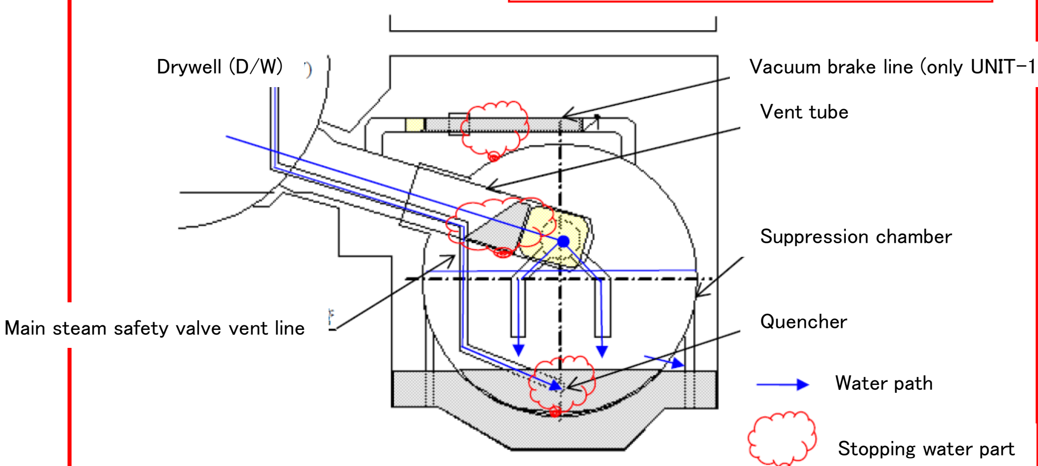
Bellows of tube penetration

Part for repair of PCV upper part

PCV upper part

Apparatus hatch

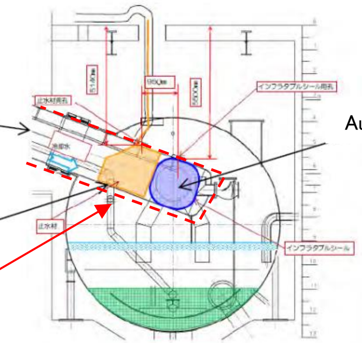
Part for repair of PCV lower part



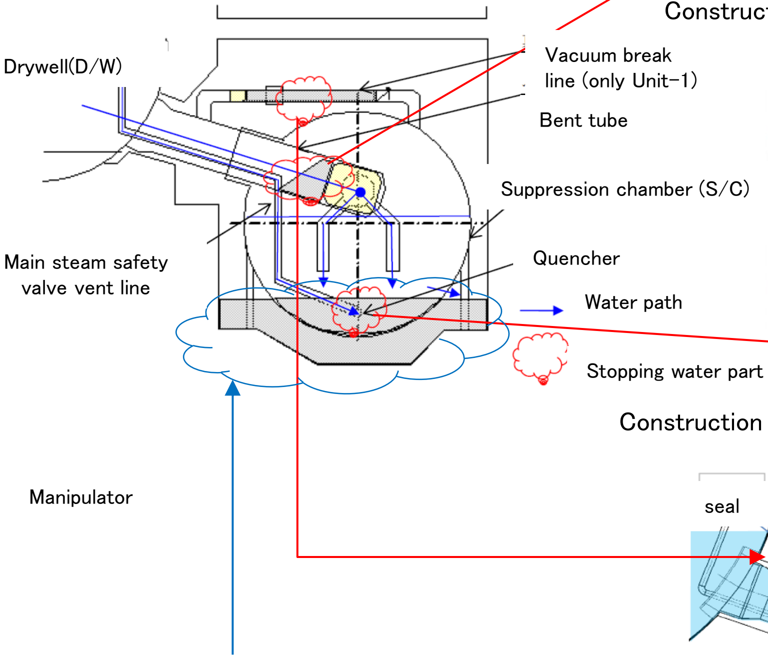
Development of PCV repair technology (2) (PCV lower part)

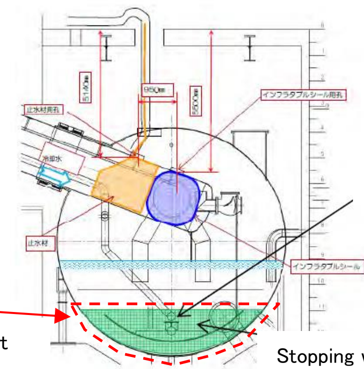
Result of 2013 (example)

Concept of construction method of PCV lower part repair

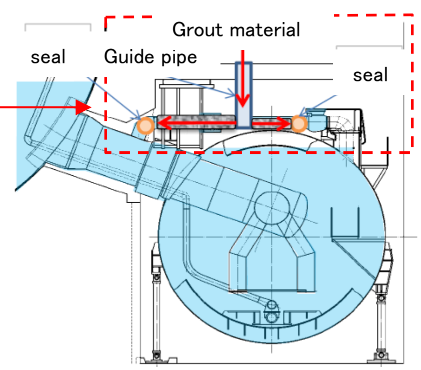


Construction method of stopping water at vent tube

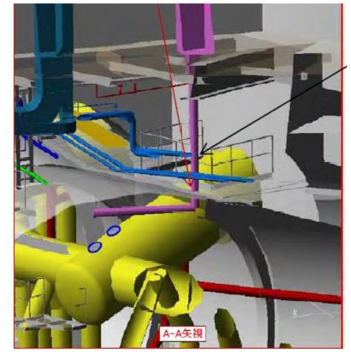




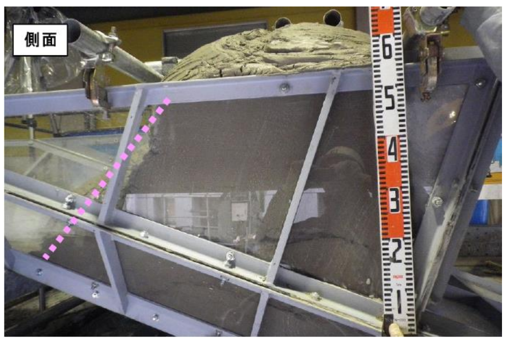
Construction method of stopping water at quencher seal



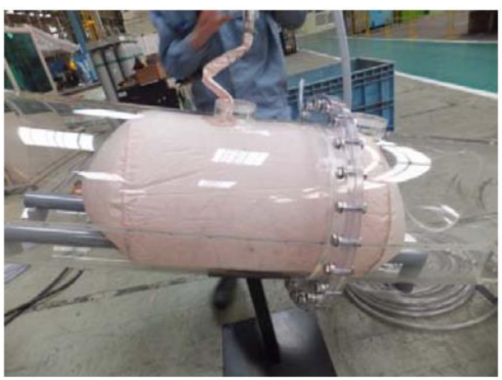
Construction method of stopping water at vacuum break line



Concept of PCV lower part repair equipment



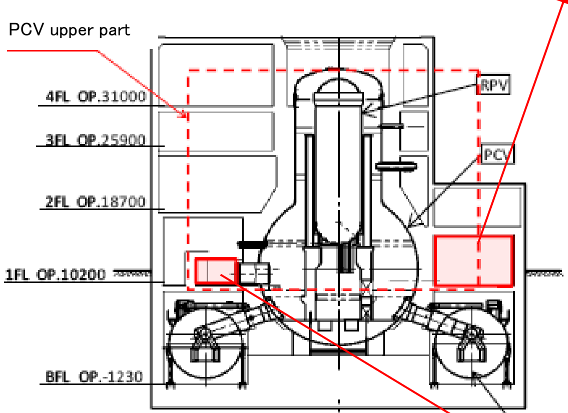
Element test of stopping water material at vent tube

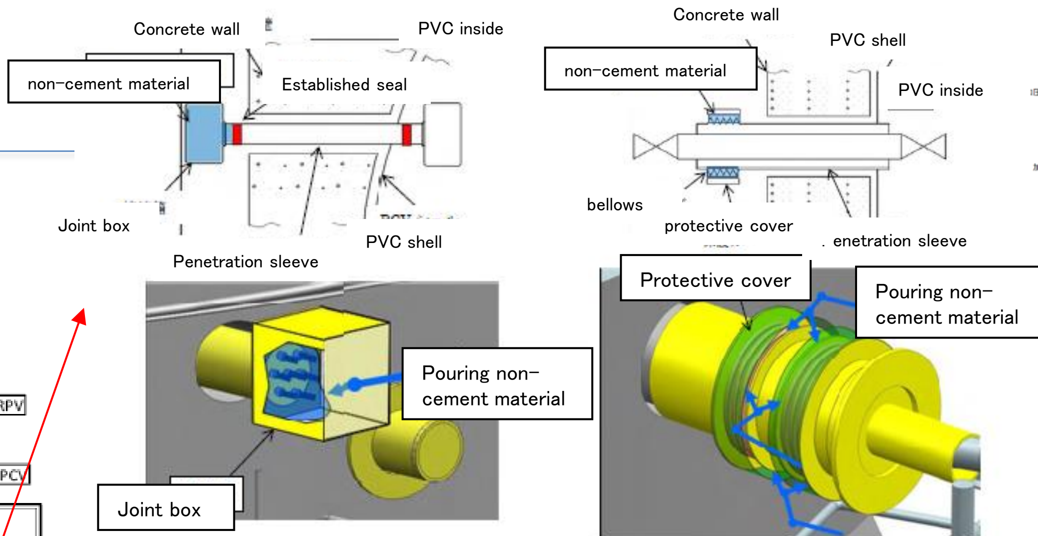


Element test of auxiliary maerial

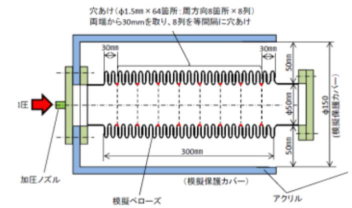
Development of PCV repair technology (3) (PCV upper part)

Concept of construction method of PCV upper part repair

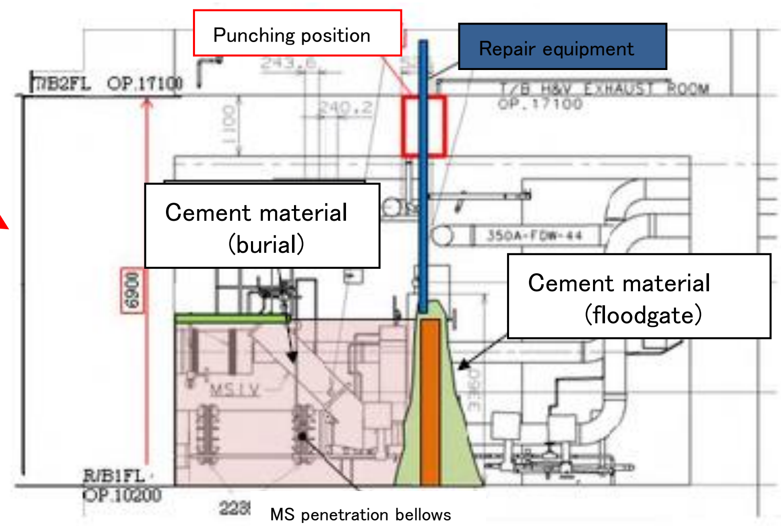




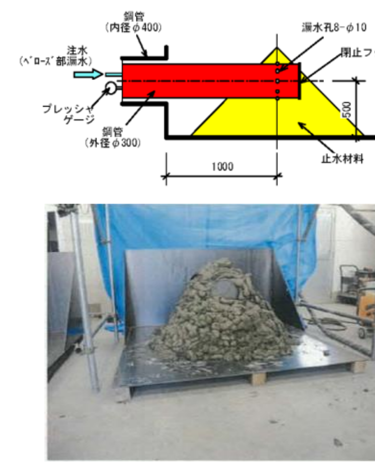
Construction method of repair at the open part of D/W outside




Element test of stopping water material at the open part of D/W outside



Construction method of repair at the narrow part of D/W outside



Element test of stopping water material at the narrow part of D/W outside

(2-(1)-2 & 3) Development of technologies for investigation and repair (stopping water) toward filling PCV with water (2014 plan draft)

Major goals of 2014

[Development of PCV investigation technology]

- Of the PCV upper portion investigation equipment, study of improving the specifications of the dry well outer narrow portion investigation equipment will be completed based on the record of accessing the targeted portion last year. Study of improving the specifications of the dry well outer opening investigation equipment will be completed based on the result of a factory mock-up test. Study of the concept of the leakage detector of the dry well outer opening investigation equipment will be completed as a series of equipment improvement study work because of the special penetration (penetration substantially deviating from the large-diameter penetration and positioned at the center of the penetration group).
- Study of the concept of equipment for inspecting new portions (knuckle portion of the PCV) will be completed.

[Development of PCV repair (water stopping) technology]

- As water-stopping techniques that can be applied at the site, (1) detailed designing of the PCV lower portion repair (water stopping) equipment and drawing up an element test method will be completed, and (2) study of improving the specifications of the PCV upper portion repair (water stopping) and drawing up an element test method will be completed.

Actions in 2014

[Development of PCV investigation technology]

1. Development of lower portion check/investigation equipment

- Development was completed by works in 2013

2. Development and improvement of upper portion check/investigation equipment

- Study of improving the specifications of the dry well outer narrow portion investigation equipment will be completed based on the result and record of accessing the targeted portions last year. Study of improving the specifications of the dry well outer opening investigation equipment will be completed based on the result of a factory mock-up test. Basic design of a device for special penetration will be completed.
- Study of the concept of the PCV knuckle portion investigation equipment, which was newly needed, will be completed.

[Development of PCV repair (water stopping) technology]

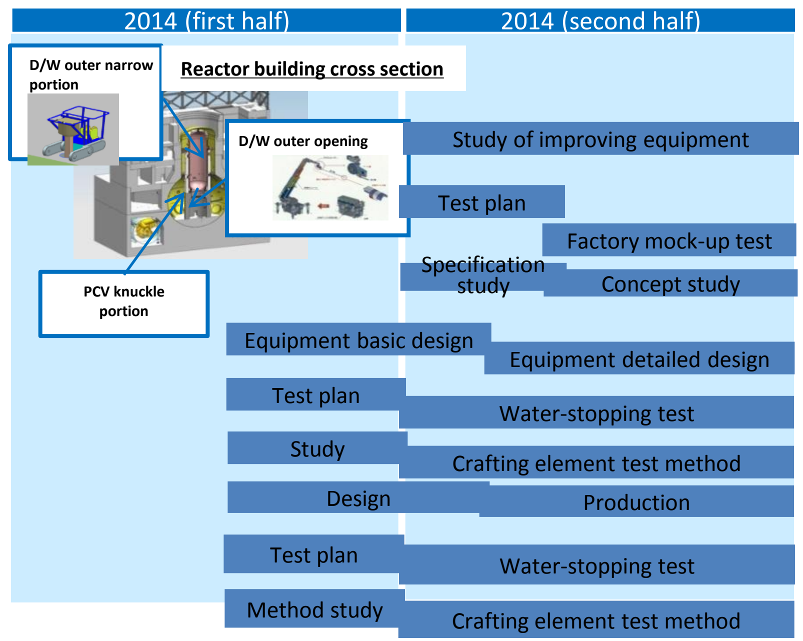
1. Development of PCV lower portion repair (water stopping) technique and equipment

- Detailed designing of a repair equipment for boundary configuration with a vent tube, quencher, down-comer, suppression chamber, S/C joint tube, and others will be completed. Applicability of water-stopping materials that are used to repair these portions will be confirmed by conducting a water-stopping test in 1/2 scale. Portions of the torus room wall, triangular corner, and sleeves between buildings where water must be stopped and water stopping methods will be considered and an element test method will be created.
- Specimen for a mock-up test and test equipment will be designed and produced.

2. Development of PCV upper portion repair (water stopping) technique and equipment

- A water-stopping test in about ½ scale will be conducted to check portions that may have been heavily damaged (such as hatch flange, opening bellows, and electric penetration) and the applicability will be confirmed. As necessary, an element test method will be created.

Schedule (2015)



2. Research and development related to preparations for retrieving fuel debris

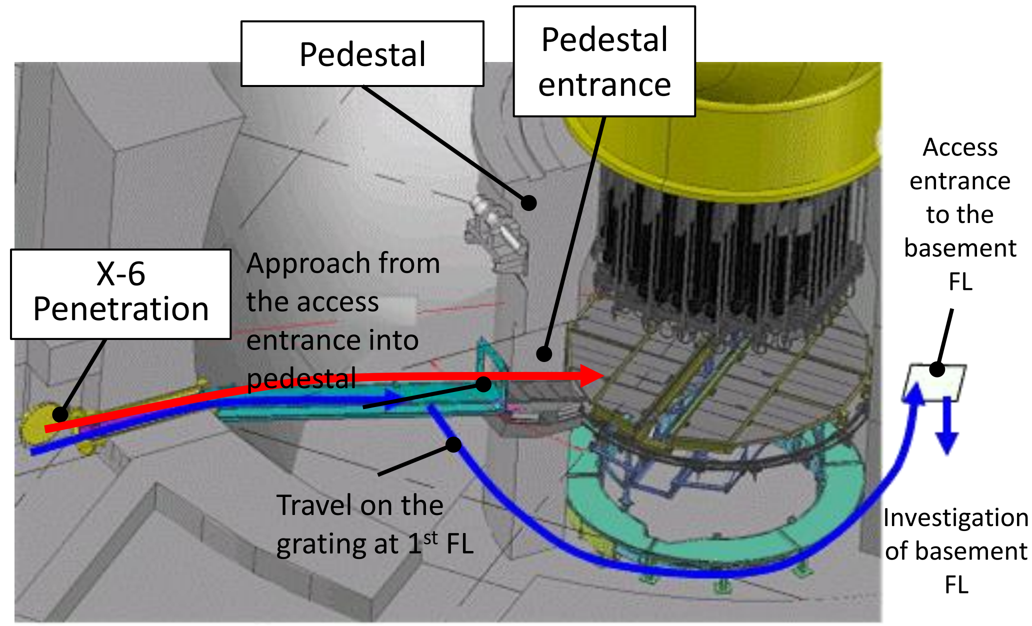
Development of technologies for investigating inside of PCV(2-(1)-4)

Overall plan (Objective and goal of internal PCV investigation technology)

[Objective of internal PCV investigation technology]
To develop the investigation technology to grasp internal PCV status required for fuel debris retrieval

[Goal of PCV investigation]
As Fuel debris is assumed to exist inside PCV, development of device to take picture and detect meltage that may include fuel debris, and the device to approach to the survey target area are set as a goal.

The ultimate goal is;
1. Develop the measuring device to detect meltage
2. Develop the device to approach inside the pedestal
3. Develop the device to approach outside the pedestal
4. Implement feasibility tests on the above devices



Access route inside pedestal
Access route outside pedestal

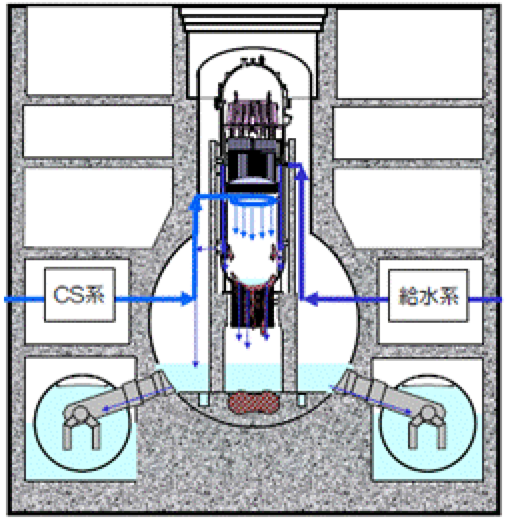
Image of approach for investigation : *1

*1: This access route may be changed depending on the future examination

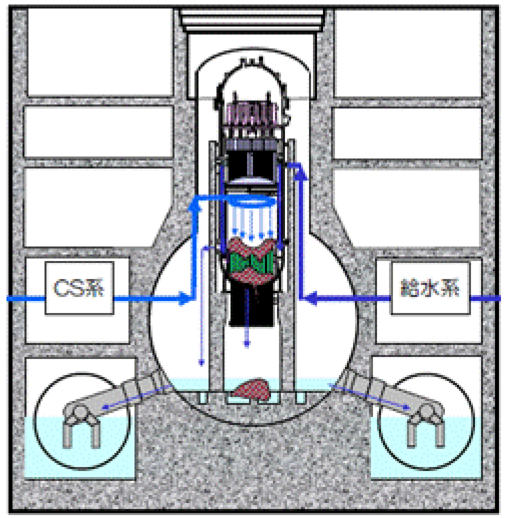
Development plan for investigation method and device

Set the development plan based on estimated condition of RPV and PCV of Unit 1 to Unit 3 (*1)

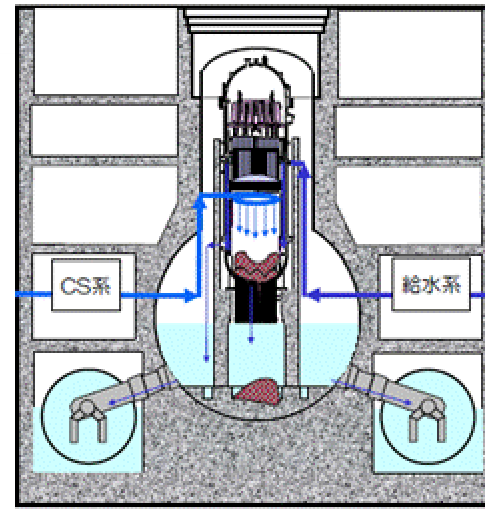
Unit 1



Unit 2



Unit 3



・Almost all of melted fuel have been fallen down to the bottom of RPV plenum and little fuel have left in RPV.

⇩ Development plan

・There is a possibility that fuel debris exists even outside of the pedestal, and investigation outside the pedestal should be conducted as priority.

・While some part of melted fuels has fallen down to the bottom of RPV lower plenum and PCV pedestal, the other part may have been left inside RPV.

・Presumed that more fuel than having estimated may have fallen down to PCV in Unit 3.

⇩ Development plan

・As the possibility that fuel debris spread outsides the pedestal is lower compare with Unit 1, investigation inside the pedestal should be developed as priority.

・As in Unit 3, the water level inside the PCV is high, penetration which will be used in Unit 1 and 2 must be submerged, other methods should be examined.

*1. [Reference] TEPCO's webpage Dec. 13, 2013 "The first progress report related to estimated state of reactor core and RPV of Fukushima Daiichi NPS Unit 1, 2 and 3, and unsolved issues"

(2-(1)-4) Development of technology for investigation of inside of PCV (2013 result)

- Investigation equipment for unit 1 was produced and its function verification test was completed as for pre-survey of outside of the pedestal (image of PCV, dose, temperatures etc., obtained). Equipment manufacturing for removing shielding block of Unit 2 and its verification test is planned to be completed in the preliminary investigation inside the pedestal.
- Basic verification and element test for additional investigation equipment for the accessing point will be completed to be prepared for full scale investigation in/outside of the pedestal where debris may be existing (distribution state of fuel debris and measurement of shape).

<u>Contents of implemented measures</u>

<u>1. Development of equipment for preliminary investigation of internal PCV:</u>

Development of equipment below is ongoing for demonstration test to be conducted next year.

(1) Investigation equipment inserted from X-100B (Unit 1)

Completed manufacturing of equipment and function verification test. Improvement items removed by function investigation will be conducted by FY2014.

(2)Equipment for removing X-6 shielding block(Unit 2)

Manufactured components (manipulator, end effector etc.) of equipment, and equipment assembly is ongoing. Measures on the handling objective with large weight found from the results of on-site investigation is under the verification to be reflected to the development plan.

(3) Investigation equipment inserted from X-6 penetration (Unit 2)

As for the results obtained from the investigation conducted through X-53 in the previous year and issues, they are to be verified for changes in the equipment structure of transfer mechanism, and reflected to the development. Manufacturing of equipment / function verification test is planned to be conducted by FY2014.

<u>2. Development of access method and equipment</u>（Access equipment in/out side the pedestal)

Verified concept of access equipment for inside/outside of the pedestal, and establishment of specification of element making is ongoing. Also, verified is concept for access equipment required for prevention of dispersion of radioactive material when sending equipment into PCV.

Element making/test done by FY 2017.

<u>3. Development of investigation equipment and technology</u>（Debris measurement apparatus）

Established equipment system structure for technology of measuring shape by optical-cutting method. Also, element test for measurement simulating disturbance environment (spray, rain etc.) inside the PCV is ongoing.

Development Steps of Each Unit (Unit 1)

[Investigated area] : Outside the pedestal on the basement Fl. Near the access entrance
[Investigation and steps to develop equipment]
(1) Investigation from the X-100B penetration（～FY2015）
As high dose rate was detected near the X-6 penetration, investigation is planned from penetration X-100B (Φ100mm) .
①To obtain information on the grating inside the PCV 1st Fl. (ex. Investigation on usability of CRD rail) : B1
②Based on the result of investigation in the torus room implemented in Nov. 2013, investigation to obtain picture outside the pedestal on the basement Fl. is planned(near the access entrance and around the vent piping) : B2
(2) Investigation from X-6 (FY2016～FY2017)
①Further investigation to gather information using debris shape measurement apparatus outside the pedestal on the basement Fl. will be conducted ：B3

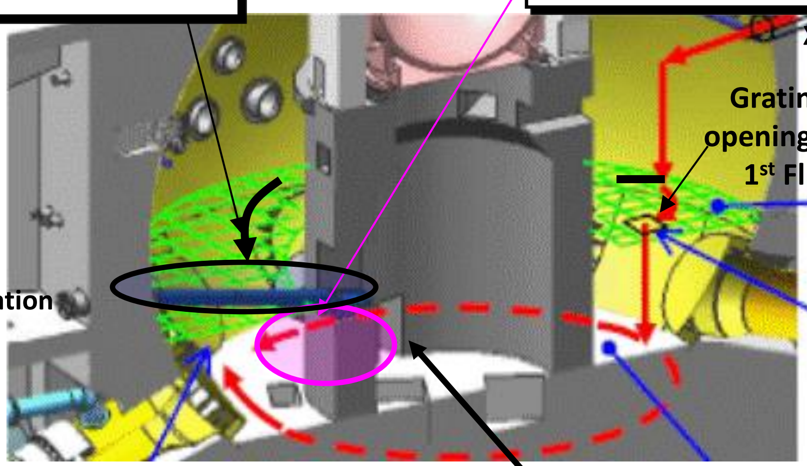
Examine necessity of additional investigation

B1. Investigation on the grating outside the pedestal on first Fl.
（Planned in later FY2014) : use X-100B

B2. Investigation outside the pedestal on the basement Fl.
（Planned in FY2015）: X-100B

Depending on result of B2 investigation, B3 test may be conducted.

B3. Investigation on outside pedestal on the basement Fl. And workers entrance
(Planned in FY2016～17) : Use X-6



Investigation inside the pedestal may be conducted depending on the investigation of Unit 2.

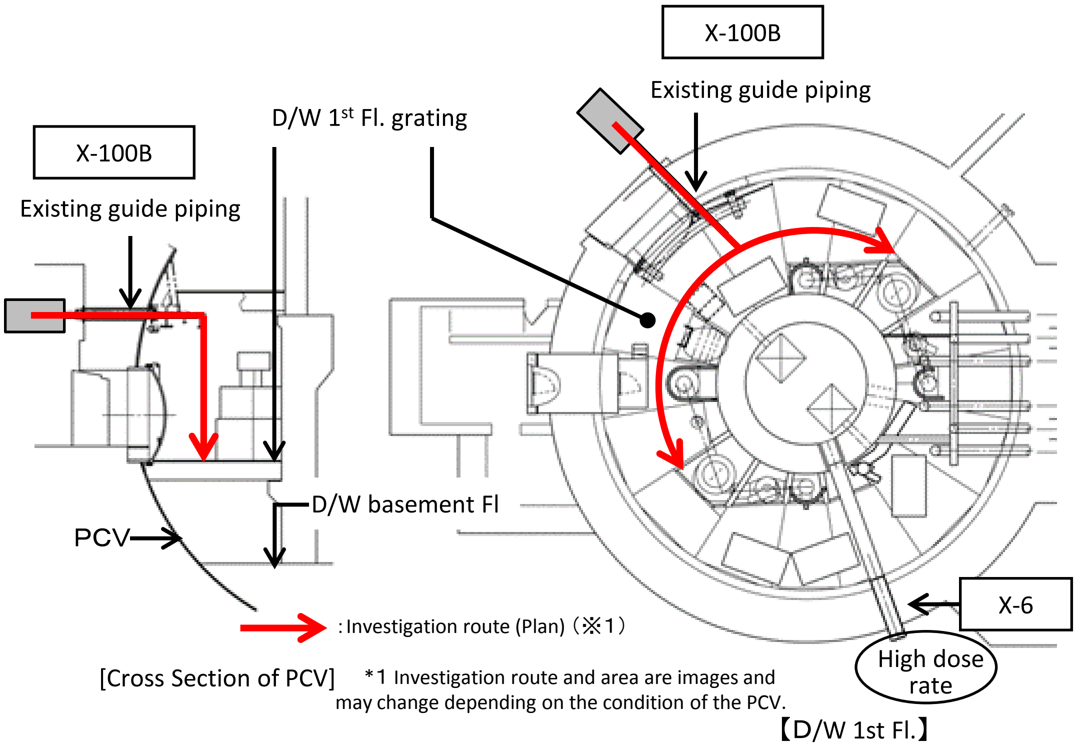
Status of Development (Equipment for outside pedestal)

3.3.1 Investigation equipment of grating on the 1st floor outside pedestal

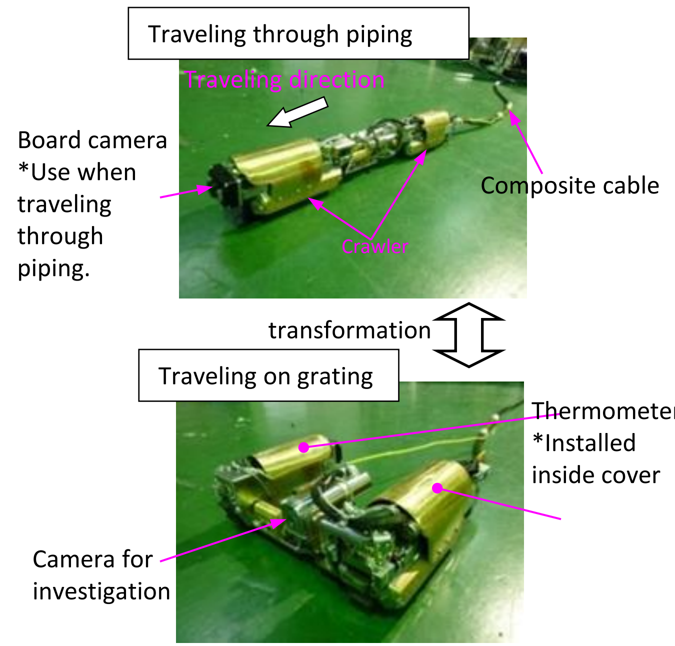
(1)Overview of equipment

Shape-changing crawler equipment is inserted from the narrow access entrance (X-100B penetration opening : ϕ100mm) and safely travel on grating stably.

(2) Image of investigation route and equipment



Internal PCV investigation route (Plan)



Features of equipment

(3) Status of development

①Extract improvements from stand alone/combination test held in the year before and to be applied

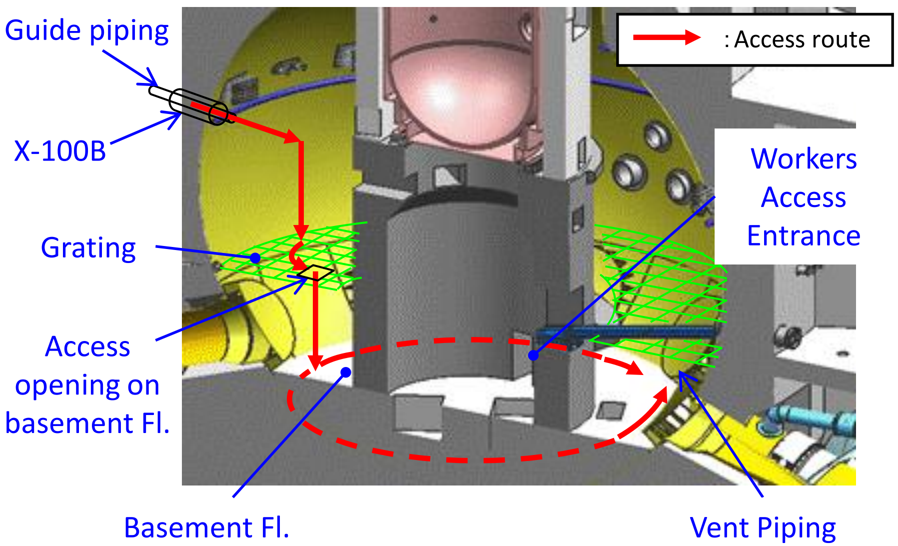
②Toward the function verification test scheduled in Feb., form a test plan and design and manufacture full scale model.

Additional Study based on result of investigation from a boat at Unit 1

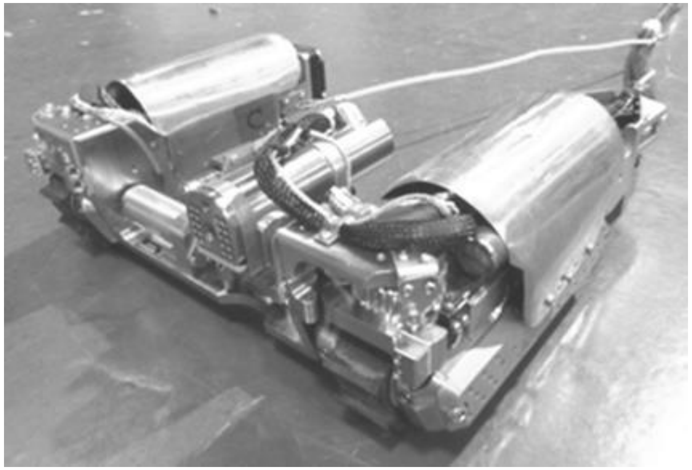
・When Unit 1 was investigated from a boat at Unit 1, water leakage from the sand cushion drain pipe was found out. As early investigation on debris inside PCV should be required, additional investigation is planned.

・Equipment is inserted from the X-100B penetration to the basement Fl. outside pedestal, and approached around workers access entrance which is assumed that debris had spread.

・Plan to modify the shape-changing crawler equipment which is under development to investigate outside pedestal on the 1st Fl. And it can be applied to basement Fl.



Whole picture of access route



Developing shape-changing crawler equipment

Development Steps of Each Unit (Unit 2)

[Investigated area] : On the platform(Upper surface of platform, Bottom of CRD housing) and basement (Basement Fl.)

[Investigation and steps to develop equipment]

(1) Investigation from X-6 penetration（Φ115mm)（within FY2014）

・Plan investigation of inside pedestal platform from X-6 in later FY2014 : A2

(2) Investigation from the X-6（Enlarge hole or penetration）（FY2015～2016）: A3～A4

・Insert debris visualization system, investigate inside pedestal.

A1. Investigation on CRD rail(Conducted in Aug.2013)

A2. Investigation on platform inside pedestal (later FY 2014)

A3. Investigation on bottom of CRD and platform (later FY2015)

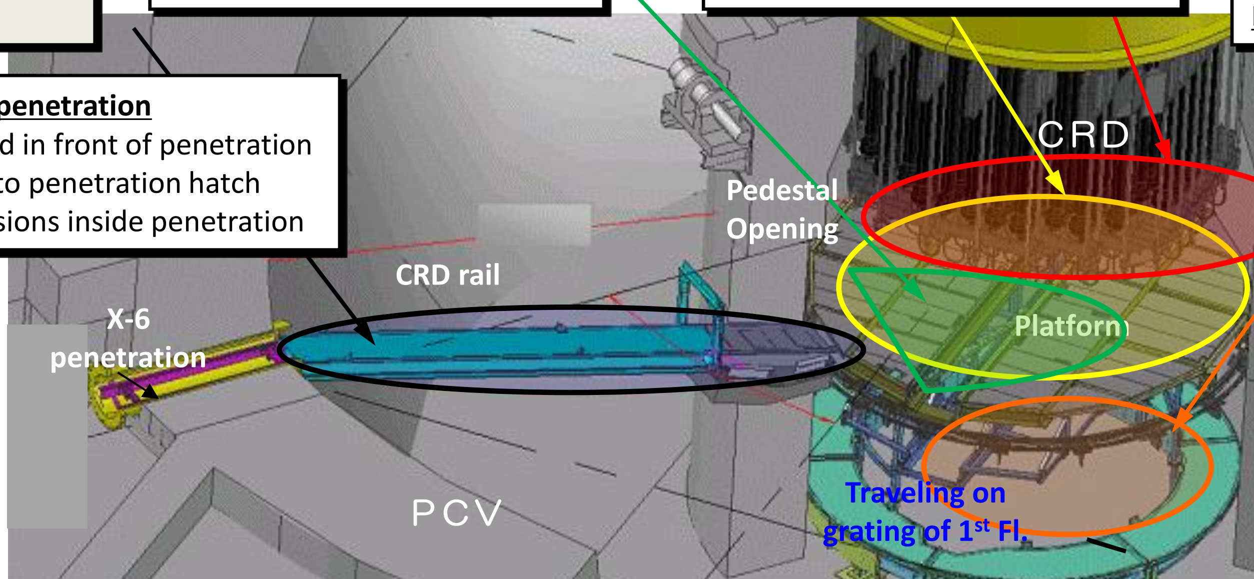
A4. Investigation of pedestal on the basement (later FY2016)

Step to use X-6 penetration

・Remove shield in front of penetration

・Pierce a hole to penetration hatch

・Remove inclusions inside penetration



Based on the result of internal investigation from A2 to A4, investigation outside pedestal may be conducted.

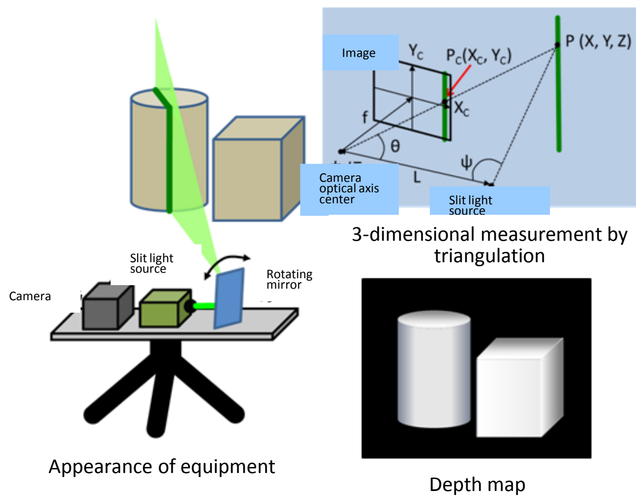
Development status (Fuel debris measuring equipment)

(1) Objective of development

To develop measuring equipment that analyzes the position and distribution of fuel debris and expected molten materials

(2) Actions

- Basic design of the equipment will be decided based on the optical-cutting method selected in 2012.
- The performance will be confirmed by element tests under the operating conditions to assess the validity of the basic design.
- Additional examination of measuring techniques other than the optical-cutting method (such as component measurement) will be conducted and feasibility of equipment using those techniques will be assessed.



Principle of optical-cutting measurement

No.	Category	Measuring technique
1	Temperature distribution measurement	Probe thermometer
2		Radiation thermometer
3	Dose measurement	Dosimeter
4		Gamma ray detector
5		Compton camera
6	Component measurement (direct measurement)	Laser-induced fluorescence method
7		Laser-induced breakdown emission spectrographs
8	Component measurement (sampling)	Gas sampling
9		Solid sampling

Measuring techniques other than those for measuring appearance and shape

(3) Elements of development

- Measurement performance and resistance to radioactivity in foggy atmosphere, rain drop-containing atmosphere, and water
- Small and lightweight so that the equipment can be mounted on access equipment, while maintaining high measurement performances

(2-(1)-4) Development of technologies for investigating inside PCV (2014 plan draft)

Major objectives of 2014

A verification test with actual investigation device for advance investigation (to obtain pictures, dose rate and temperature data) of inside PCV under an environment of high dose rate 100 Gy/h will be completed. In addition, basic design of investigation device that will access for full scale investigation the inside and outside pedestal in PCV where fuel debris is expected to exist and production of some parts will be completed.

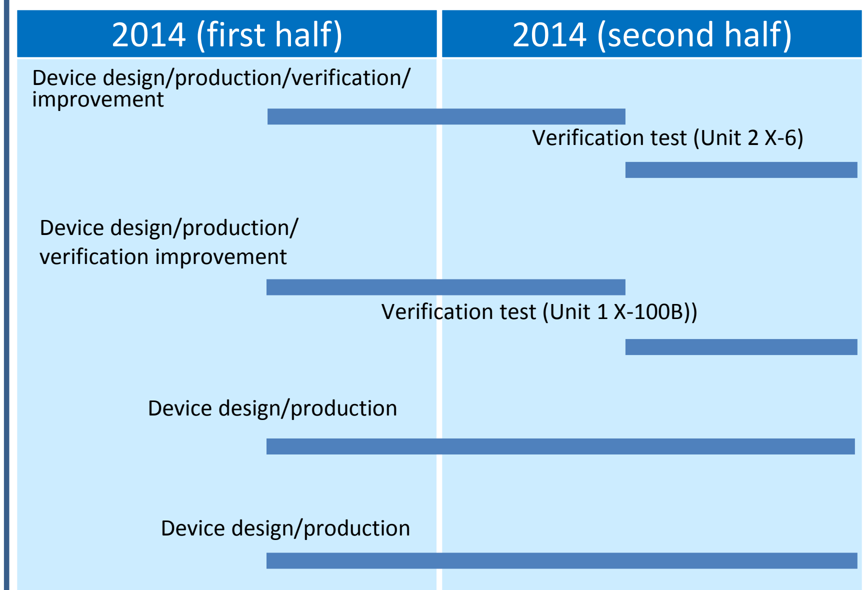
Actions in fy2014

*1 and 2 are for pre-investigation (to obtain images, dose rate, temperature and obstacles) and 3 and 4 are for full scale investigation (to measure distribution and shape of fuel debris).

1. **Development and verification test of device to investigate situations of the platform inside pedestal**
   (1) Development of the device will be completed based on development of last year and by conducting verification tests and making improvements.
   (2) Verification tests through X-6 penetration of Unit 1 will be conducted. (The device includes investigation device which remotely removes the shielding block in front of X-6 penetration, device which drills a hole on the hatch of X-6 penetration, and device which accesses inside PCV.)
2. **Development and verification test of device to investigate outside pedestal**
   (1) Development of the device will be completed based on development of last year and by conducting verification tests and making improvements.
   (2) Verification tests using X-100B penetration of Unit 1 will be conducted. (The device accesses inside PCV through X-100B.)
3. **Development of device toward further investigation inside and outside pedestal**
   Basic design of device that accesses portions where fuel debris is expected to exist (on platform, pedestal basement, and near the worker access openig) will be completed and production of some equipment will be started (completion is slated for March 2016).

4. Development of debris measurement device
Study of mounting fuel debris measurement device that uses a measurement technique such as optical-cutting method to device in 3 above will be conducted and design and production will be started.

Schedule (2014)

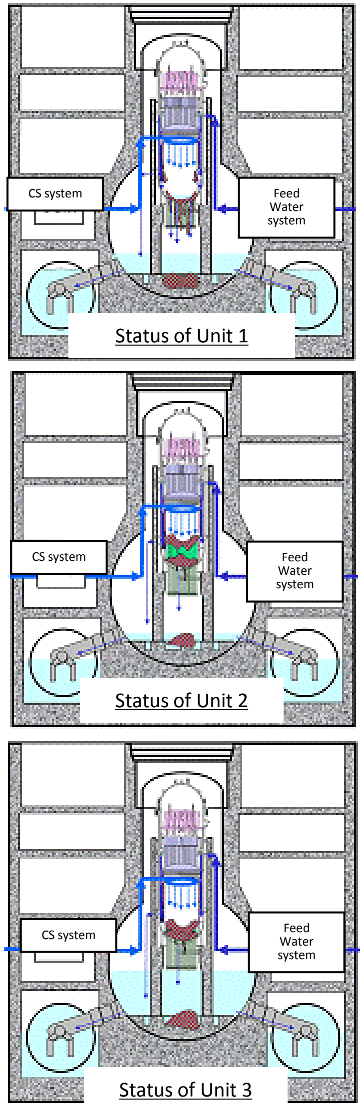


2. Research and development related to preparations for retrieving fuel debris

Development of technologies for investigating inside of RPV(2-(1)-5)

Project overview (Objective of investigation of inside RPV)

[Objective of investigation of inside of RPV]
The purpose of investigation of inside RPV is to identify the position of fuel debris inside RPV, estimate damage of core internals, and measure temperature and dose rate inside RPV.
In this project (to investigate inside RPV), technologies that enable the above investigation will be developed.



[Estimated damage to reactor]

[Examples of expected results]
Information to be obtained inside RPV and expected results are listed below.

Information to be obtained	Expected result
• Images of fuel debris and core internals • Dose rate of reactor atmosphere and fuel debris • Temperature of reactor atmosphere and fuel debris	The situation inside the plant can be directly confirmed, which can be fed back to a fuel debris removal plan and device development.
• Sampling of fuel debris	At present, details of fuel debris are not known. However, by sampling and analyzing a small quantity of fuel debris, the composition of the fuel debris can be confirmed.

(2-(1)-5) Development of technologies for investigating inside of RPV (fy2013 results)

To identify the position of fuel debris in RPV and damages to core internals, and to measure the dose rate and temperature in RPV, methods of accessing to the investigation portions, investigating, and sampling have been considered and technologies for inspecting in RPV, where dose rate is high (preliminarily estimated at 1,000 Gy/h), have been arranged, and development of technologies for investigating inside RPV have been planned (to develop technologies for investigating via piping systems in fy2015 and fy2017, those for drilling a hole on top of RPV for investigation in fy2018, and those for investigation in fy2019 after the reactor opened).

Actions

1. Planning for investigation of inside RPV

◆ **Selection of major items to be investigated and period of investigation**

Items to be investigated inside RPV were selected and the period of investigation was considered. As a result, the plan for technological development (to develop technologies for inspecting via piping systems in fy2015 and fy2017, those for drilling a hole on top of RPV for investigation in fy2018, and those for investigation in fy2019 after the reactor opened) has been drawn up.

◆ **Selection of access route**

Candidate access routes to investigate inside RPV, such as a route to access through piping, one to drill a hole on top of RPV to gain an access, and one for accessing after the reactor opened, were selected. Accessibility of each route was assessed and a candidate route was decided .

2. Planning development of technologies

◆ **Access technology**

Based on the result of selection of a route to access inside RPV, the existing technologies were examined and issues to development, such as how to go through obstacles, were removed.

◆ **investigation technology (radiation-resistant camera, dosimeter, etc.)**

Applicability was considered by examining the existing technologies and issues such as how to resist radiation were removed.

◆ **Sampling technology**

Concept of sampling technique was examined by surveying the existing technologies, issues were organized, and a development plan was formulated.

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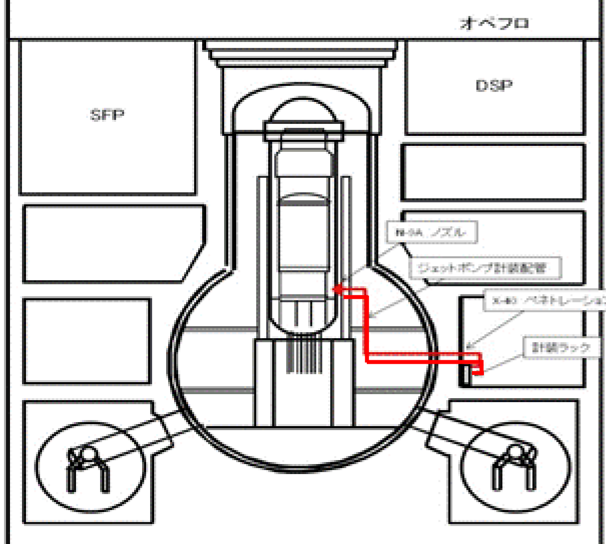
Study of access route to inside RPV

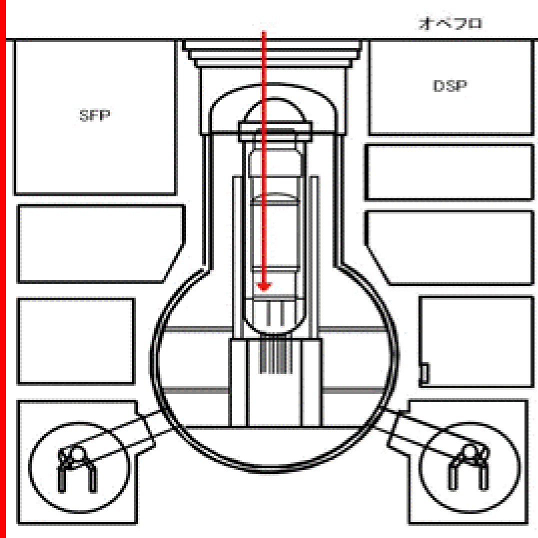
Table Development plan of access technology (sample of access by drilling on the upper section of RPV)

No	Development technology element	Issues	2014	2015	2016	2017	2018
1	Boring technology	Creating access hole for the steam dryer and separator	■	■	■	■	■
2	Tube expansion technology	Tube expansion for the hole diameter of steam dryer and separator	■	■	■	■	■
3	Remote control technology	Monitoring the passing on the curve and narrow part of access route, and operating condition	■	■	■		
4	Boundary forming technology	Boundary reforming on the operation floor (sealed plug)	■	■	■		

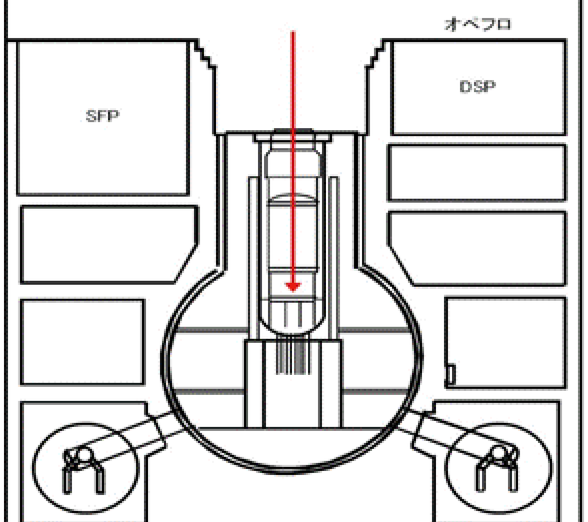
Access through piping systems

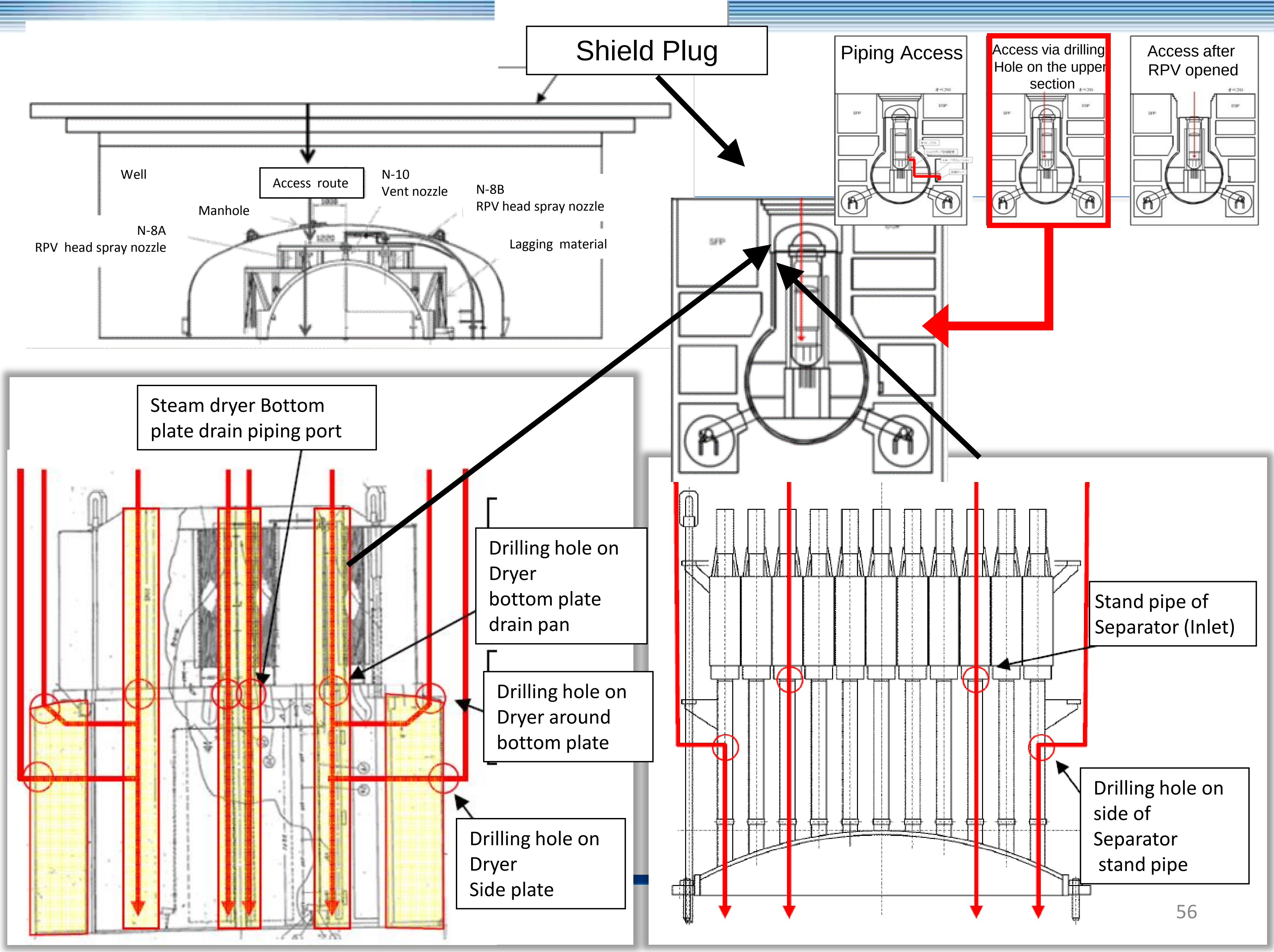


Access via drilling hole on the upper section of RPV



Access after RPV opened





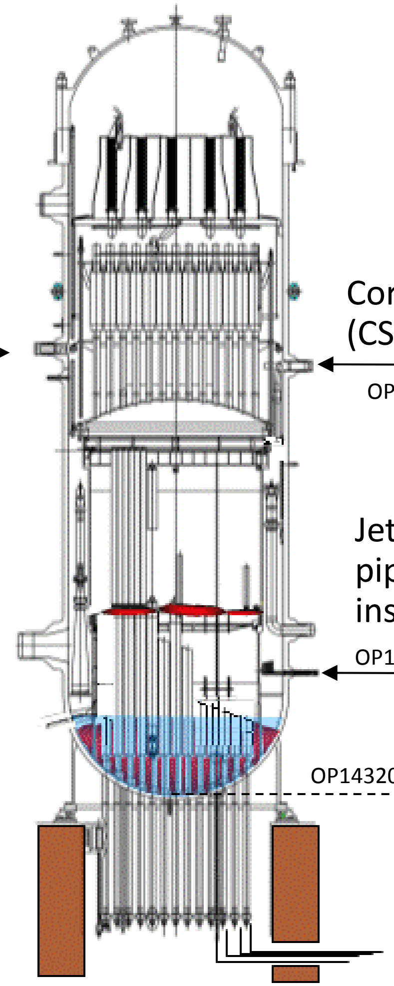
Shield Plug
Piping Access
Access via drilling Hole on the upper section
Access after RPV opened
Well
Access route
N-10
Vent nozzle
N-8B
RPV head spray nozzle
Manhole
N-8A
RPV head spray nozzle
Lagging material
SFP
Steam dryer Bottom plate drain piping port
Drilling hole on Dryer bottom plate drain pan
Drilling hole on Dryer around bottom plate
Drilling hole on Dryer Side plate
Stand pipe of Separator (Inlet)
Drilling hole on side of Separator stand pipe

Access route to investigate inside RPV

Planning investigation of inside RPV (route for accessing via piping systems)

Feed water system A
(Feed water supply nozzles N4A and B)
OP26601

Core spray (CS) system A
(CS nozzle N5A)
OP26131



Jet pump instrumentation piping (jet pump instrumentation nozzle N8)
OP17673

OP14320（Vessel0）

Result of selection (example of Unit 3)

- As systems that have opening to RPV, the jet pump instrument line, feed water piping, core spray piping and others were removed.

- The challenges are at bending of the system piping, opening or closing of the valves of access piping, and securing dimensions that allow passage in accordance with design concept of equipment, among others, and will be further narrowed down in accordance with the design of equipment.

(2-(1)-5) Development of technologies for investigating inside of RPV (fy2014 plan)

Major objectives of fy 2014

- To develop technologies for investigating inside RPV (to develop technologies for investigating via system piping in fy 2015 and fy2017, those for drilling a hole on top of RPV for investigating in fy2018, and those for investigation in fy 2019 after the reactor is opened), system design and basic design of access devices, investigation devices, and sampling devices that takes photographs and measure the dose rate and temperature inside RPV (access device) where dose is as high as 1,000 Gy/h (preliminarily estimated value) will be completed.
- Trial production and test operation of element technologies by which to produce the access device, investigation device, and sampling device will be completed.

Actions in 2014

1. Development of access device

(1) Technologies for accessing inside the RPV via piping will be completed by designing the system of device and experimentally producing and testing element technologies that constitute the device.
Toward early realization of access to the inside RPV, basic design and detailed design of the device will be completed, using the dimensions, weight, etc., of the investigation device to be developed in 2 below as input.

(2) System design of device will be performed by using technologies to gain an access from the top of RPV (technologies to drill a hole on top of RPV and make an access after the reactor is opened), and experimental production and test of element technologies that constitute the device will be completed. In addition, basic design and detailed design of the device will be completed, using the dimensions, weight, etc., of the investigation device to be developed in 2 below as input.

2. Development of investigation device

System design of equipment, such as a camera, will be completed, taking into consideration the dimensional constraints of the investigation device and access route. Basic design of the investigation device will be performed and input information that contributes to study of the access device in 1 above, such as dimensions and weight, will be proposed.

3. Development of sampling device

System design and basic design of the sampling device will be performed, taking into consideration the methods to process and recover sampled fuel debris.

Schedule

Item/year	1st half of 2014	2nd half of 2014
1. Development of access technologies		
Piping access		
・System design of device		
・Basic design of device		
・Detailed design of device		
・Trial production and test of elements		
RPV upper portion access		
・System design of device		
・Basic design of device		
・Trial production and test of elements		
2. Development of investigation technologies		
・System design of device		
・Basic design of device		
・Trial production and test of elements		
3. Development of sampling technologies		
・System design of device		
・Basic design of device		
・Trial production and test of elements		

2. Research and development related to preparations for retrieving fuel debris

Development of technologies for retrieval of fuel debris/core internals (2-(1)-6)

Overall plan (objective and system)

Major objective in fy 2014

Purpose: To estimate situations of inside RPV and dispersion of fuel debris to contribute to decommissioning of Fukushima Daiichi nuclear power plant

Estimate of inside RPV situation and field of analysis

Actual measurement of plant situation and remote visualization (TEPCO)

[Project commissioned by Agency of Natural Resources and Energy]

Project for preparing technological base for safely decommissioning reactor for power generation, etc.
(Estimating situation of inside RPV by using severe accident analysis code)

- ➢ Improvement of analysis code and analysis of actual plant accident
  - ▪MAAP Group (Toshiba, Hitachi GE)
  - ▪SAMPSON Group (Institute of Applied Energy)
- ➢ Assessment of individual events by heat flow analysis, etc.
- ➢ International cooperation: OECD/NEA benchmark analysis PJ (BSAF), etc.

JAEA: Mock-up test (such as seawater heat transfer test, from fy 2013)

AESJ: "Severe accident assessment" research expert committee

(2-(2)-1) Estimating situation of inside RPV by advancing technologies for accident progression analysis (fy 2013 result)

Accident progression analysis technologies for estimating the reactor conditions, such as the position of fuel debris, were advanced (by improving a reactor damage progression model, fuel debris behavior model in a lower plenum and others). Study to estimate the conditions of the reactor was conducted by using the result of the advanced accident progression analysis technology and based on new information obtained from on-site operations, and it was estimated that the ratio of debris that fell into the PCV was the maximum at Unit 1 and lower than or equal to that at Units 2 and 3

Actions

1. Validity Confirmation of improvement of code and addition of model

Ranking of the importance of PIRT (Phenomena Identification and Ranking Table) completed in fy2012 was newly confirmed and revised. Its importance rank by sensibility analysis.

2. Improvement and advancement of analysis codes

Analysis codes (MAAP and SAMPSON) were improved to enhance the analysis accuracy, based on information gathered through operations at the site, result of existing simulation test, and newest information and opinions.

3. Analysis with improved codes (MAAP and SAMPSON)

Based on the latest version of the improved codes and database built up, accident progression and reactor conditions of Units 1 to 3 were analyzed to confirm the influences of improvement of the model.

4. Analysis of individual phenomena by CFD

A test to analyze spreading fuel debris was conducted by using cast simulation codes to confirm applicability of the codes to fuel debris diffusion behavior assessment with the real plant.

5. Mock-up test

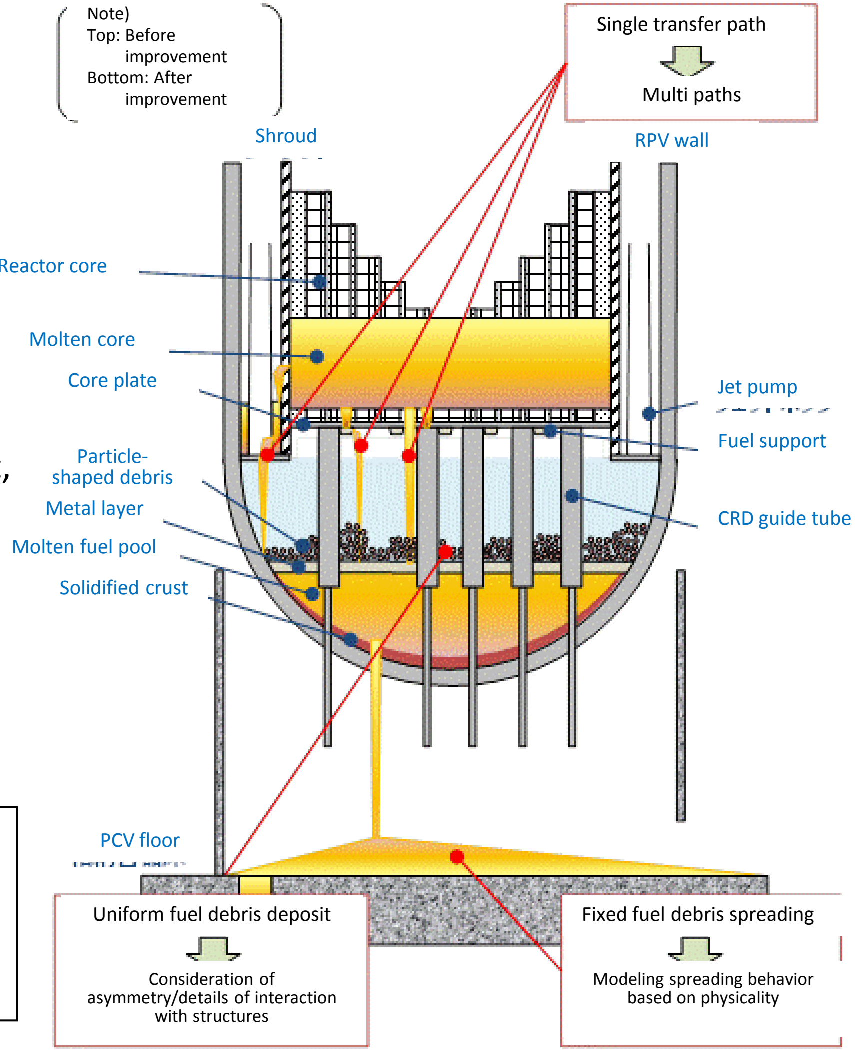
Simulated tests contributing to detailed analysis of severe accident phenomenon progression (such as seawater heat transfer test and molten fuel drop behavior test) were conducted to confirm applicability of the existing heat transfer assessment equations at a time of seawater injection.

Improvement and addition of model of MAAP

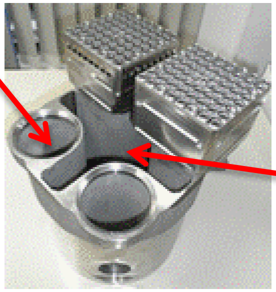
Enhancing assessment accuracy in estimating fuel debris position and plant behavior by improving MAAP code

■ Improvement and verification of MAAP5 code

- Improvement of code was commissioned to EPRI in the U.S. based on the following improvement items and their advancement specifications:
  - Improvement of reactor damage progression model (Migration pathways of molten material were considered.)
  - Improvement of lower plenum fuel debris behavior model (Deposit form, interaction of structures)
  - Improvement of PCV fuel debris behavior model (Spreading behavior, concrete interaction)
- Verification of improved code
  - Model of individual phenomenon was verified by element test, etc.
  - Overall plant behavior was verified by actual-plant test, etc.



Added route (1)
Fuel debris fell into hole of fuel supported.



Added route (2)
Fuel debris falling into a hole into which a control rod was inserted (cross-shaped).

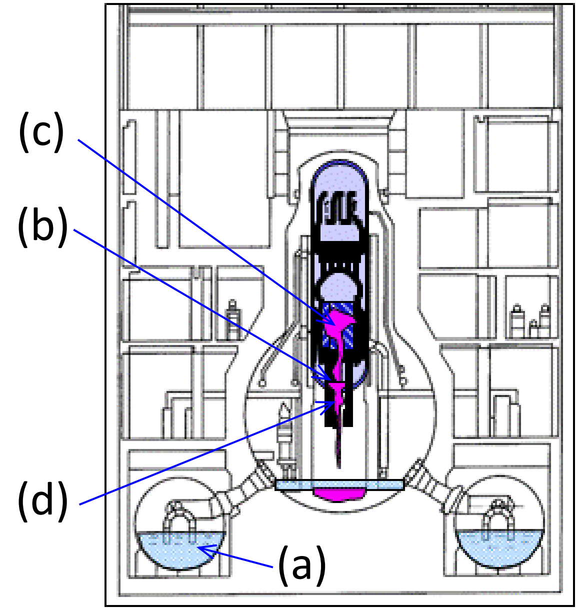
Addition and improvement of model of SAMPSON

(a) Modeling thermal stratification phenomenon in PCV suppression chamber
- Three-dimensional flow model to solve natural circulation of water was developed (coordinate system: Descartes/cylindrical) ）
- Analysis capability of the model when RCIC operated was verified by analysis of Unit 2.

(b) Improvement of model of outflow to lower plenum and interaction model between molten materials and structures/coolant at lower plenum
- Route for molten core materials to flow out to lower plenum was studied through analysis and model was improved.
- Interaction model between molten materials and structures/coolant was developed and its function was verified.

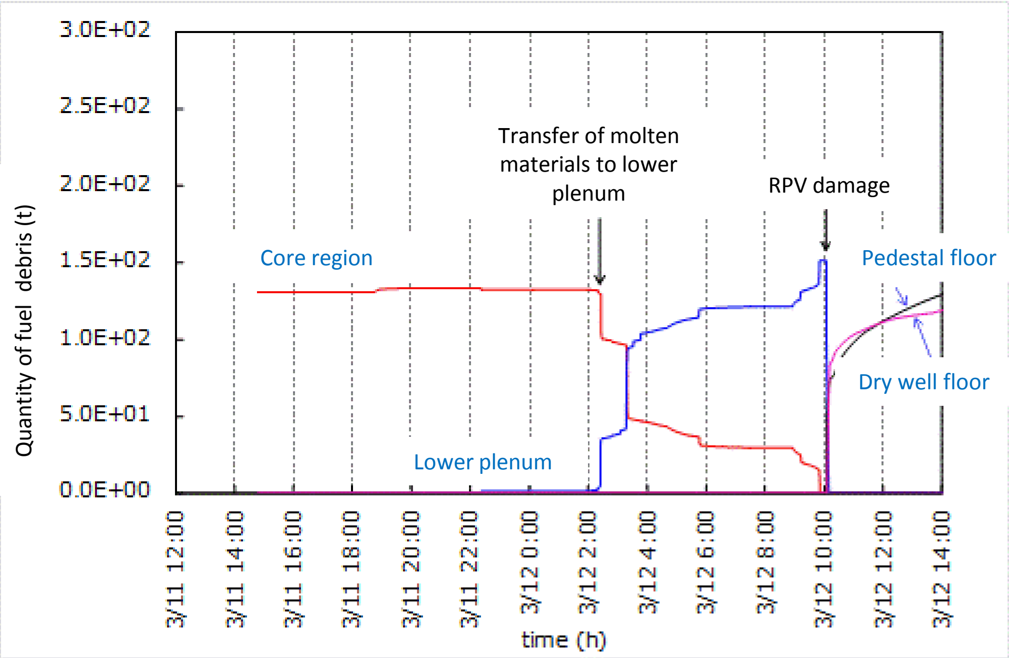
(c) Models of eutectic reaction and oxidation reaction at high temperatures were improved.
- Models of B_4C and ion oxidation reaction was added.
- Models of B_4C and ion eutectic reaction was developed and their function were verified.

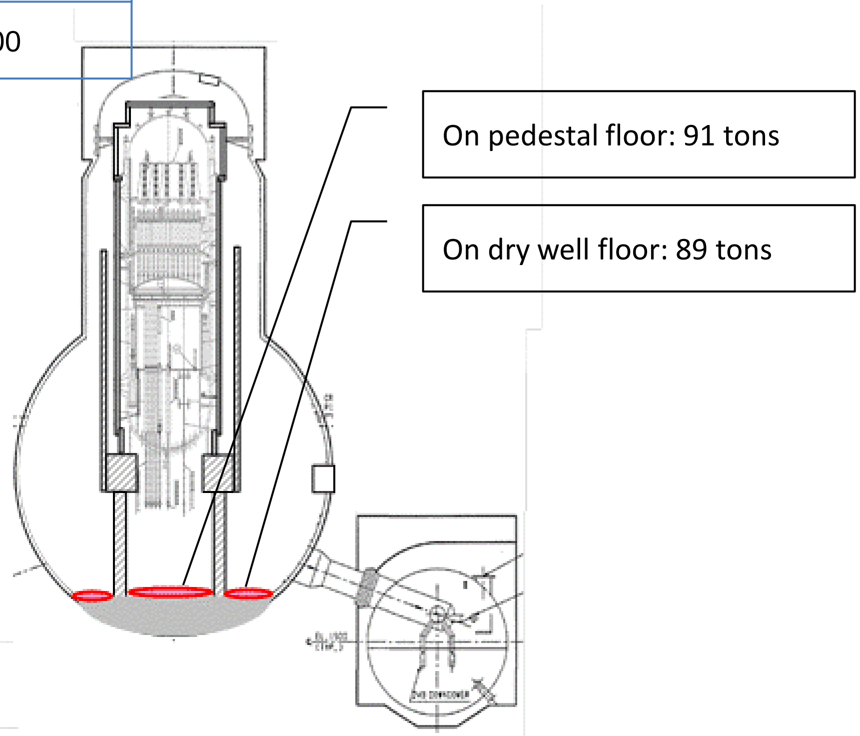
(d) Model of interaction between molten materials and structures at lower part of RPV
- Interaction model was developed and its function was verified.



Accident analysis at Unit 1 by MAAP code

Event	Time of occurrence
Reactor water level ≦ Top of active fuel	2011/3/11 around 17:50
Core damage (fuel rod maximum temperature ≧1,200°C)	2011/3/11 around 18:40
Core melting (fuel rod maximum temperature≧2,200°C)	2011/3/11 around 18:50
RPV damage	2011/3/12 around 10:00

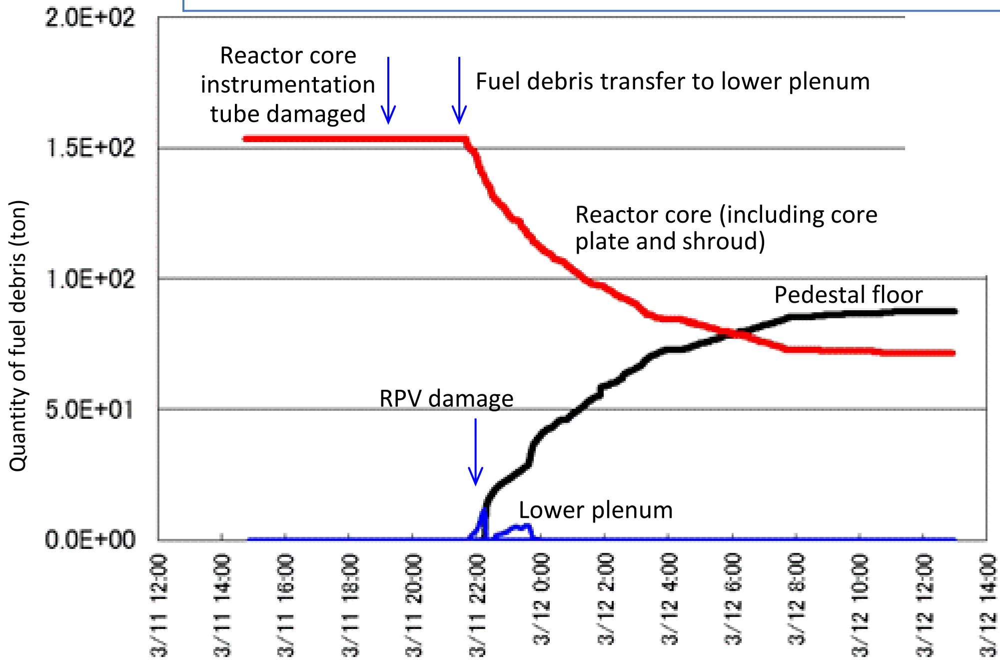


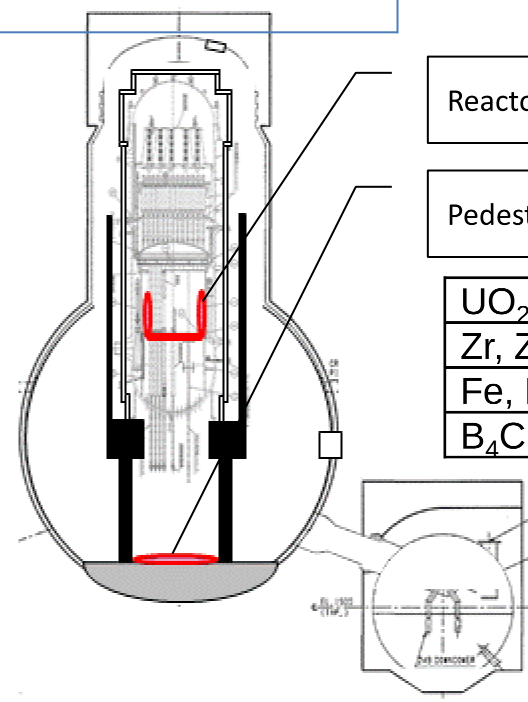


(Note) Quantity of fuel debris at around 13:00, March 12, 2011 (fuel and structures)

Accident analysis at Unit 1 by SAMPSON code

Event	Time of occurrence
Reactor water level Top of active fuel	2011/3/11 around 17:50
Core damage (fuel rod maximum temperature ≧1,200°C)	2011/3/11 around 19:40
Core melting (fuel rod maximumt temperature≧2,200°C)	2011/3/11 around 22:00
RPV damage	2011/3/11 around 22:10





Reactor core:72 tons

Pedestal floor: 88 tons

UO_2, U_3O_8	33.6 wt%
Zr, ZrO_2	34.2 wt%
Fe, Fe_2O_3	31.3 wt%
B_4C	0.9 wt%

(Note) Quantity of debris at around 13:00, March 12, 2011 (fuel and structures)

IRID

International cooperation: OECD-NEA BSAF project

Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF)

Period: November 2012 to October 2014

Objectives: (1) To obtain information and opinions on accident progression and reactor situations by gathering knowledge and opinions from experts
(2) To contribute to advancement of analysis techniques and codes

Official in charge of international cooperation at Agency of Natural Energy and Resources ↔ Operation organization: JAEA ← (Cooperation) → TEPCO, Institute of Applied Energy, Toshiba, Hitachi GE

Operation organization: JAEA ↕ Participants

Participants:

Japan: JAEA, JNES, Central Research Institute of Electric Power Industry, Institute of Applied Energy
USA: USNRC and others France: IRSN, CEA Germany: GRS South Korea: KAERI
Russia: ROSATOM, IBRAE Switzerland: PSI Spain: CSN

Information sharing through international project conference* and website (https://fdada.info/index)

* ･Preparatory conference: June 18-20, 2012 in Paris (NEA headquarters)
･First conference: November 6-8, 2012 in Tokyo
･Second conference: October 15-17, 2013 in Paris (NEA headquarters)
･Third conference: June 2014 in Tokyo
･Fourth conference (final): October 2014 in Paris (NEA headquarters)

2. Research and development related to preparations for retrieving fuel debris

Development of technologies for detecting fuel debris in Reactor(2-(2)-2)

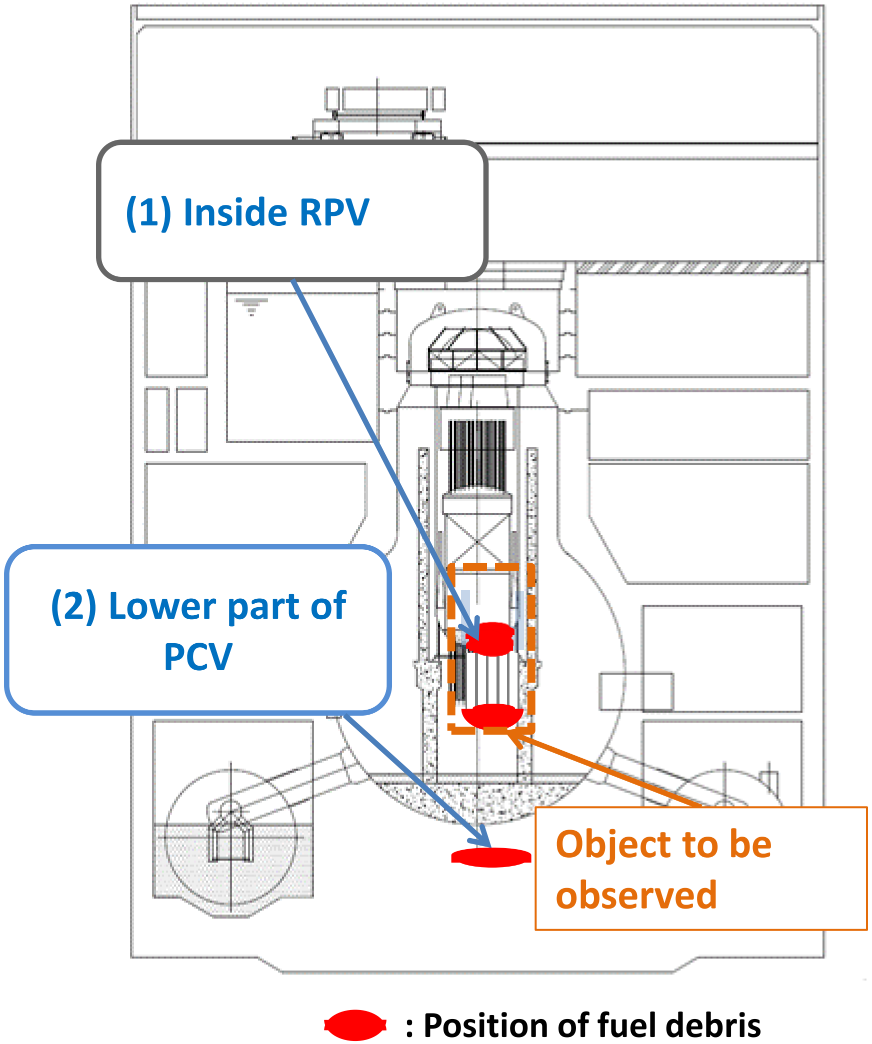
Overview of project

- Identifying position and quantity of fuel debris in RPV (1) and lower part of PCV (2) is important.
  - Damage to fuel assemblies
  - Inflow of molten fuel to narrow space
  - Detailed distribution such as density of fuel debris

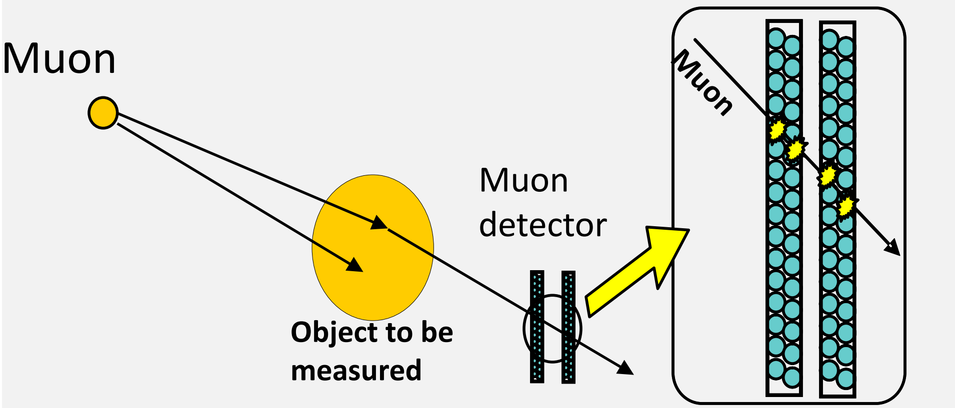
→ Specific retrieval procedures and techniques

High dose rate inside RPV makes difficult to access.

Early supply of fuel debris distribution information to IRID by using see-through technology using muon

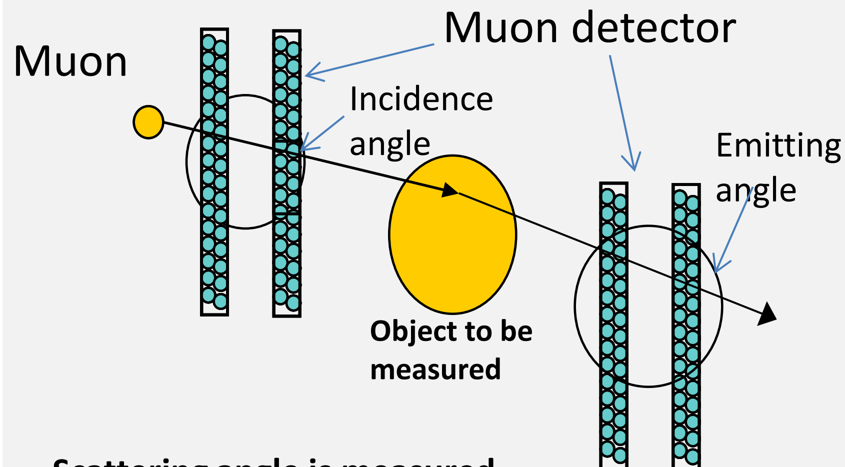


Overview of project (muon observation technology)



: Detecttion element

<u>Permeation ratio is measured.</u>



<u>Scattering angle is measured.</u>

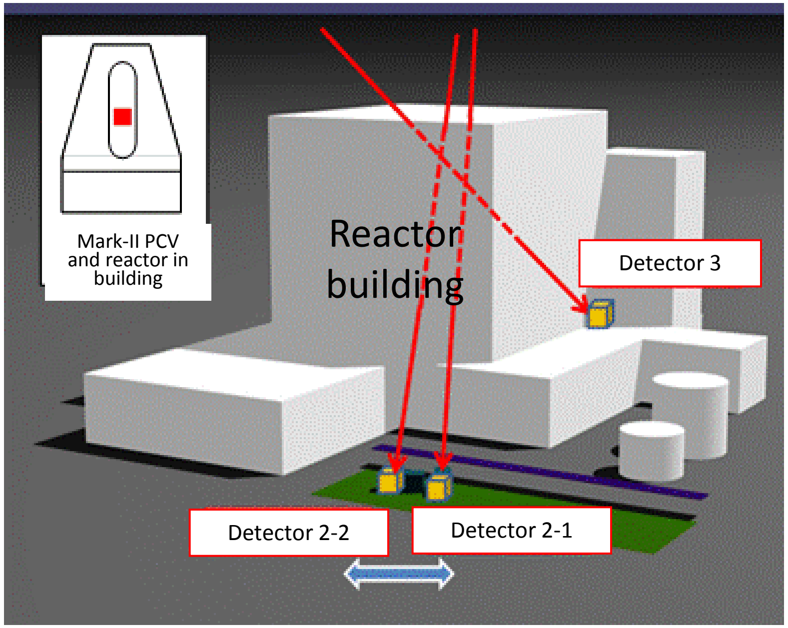
Permeation method	Scattering method
Presence of matters in coming direction (two-dimensional)	**Presence of matters at scattering position (three-dimensional)**
Identifying ability (fuel debris): About 1 m	**Identifying ability (fuel debris)：About 30 cm**
One small-size muon detector (applicable early)	Two large-size muon detectors (need to be developed)
	Can identify heavy elements such as uranium.

IRID

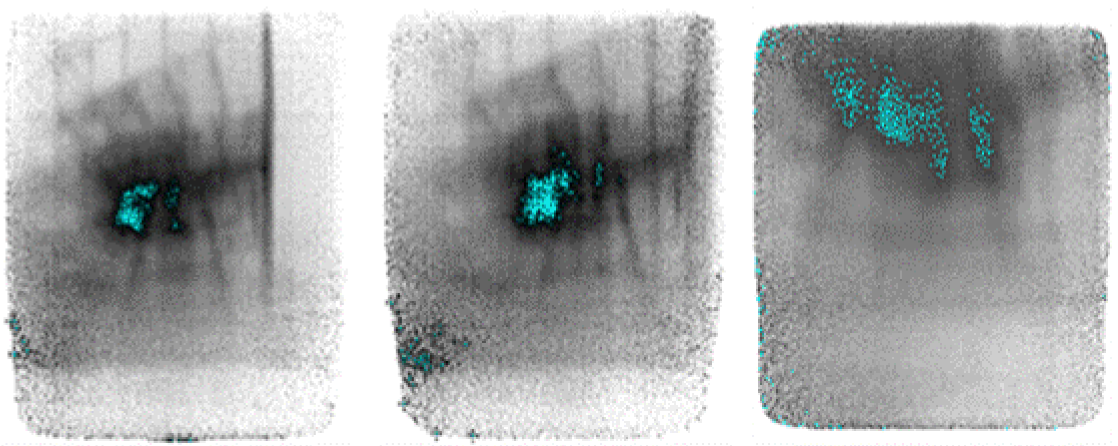
Outline of past result (muon permeation method)

Results of measurement with equipment in the same scale at Tokai No. 2 nuclear power plant of the Japan Atomic Power Company:

- **<u>No fuel in nuclear reactor</u>**
- **<u>Fuel existed in spent fuel pool</u>**



<u>Measurement positions at Tokai No. 2 nuclear power plant:</u>
<u>(3 points)</u>



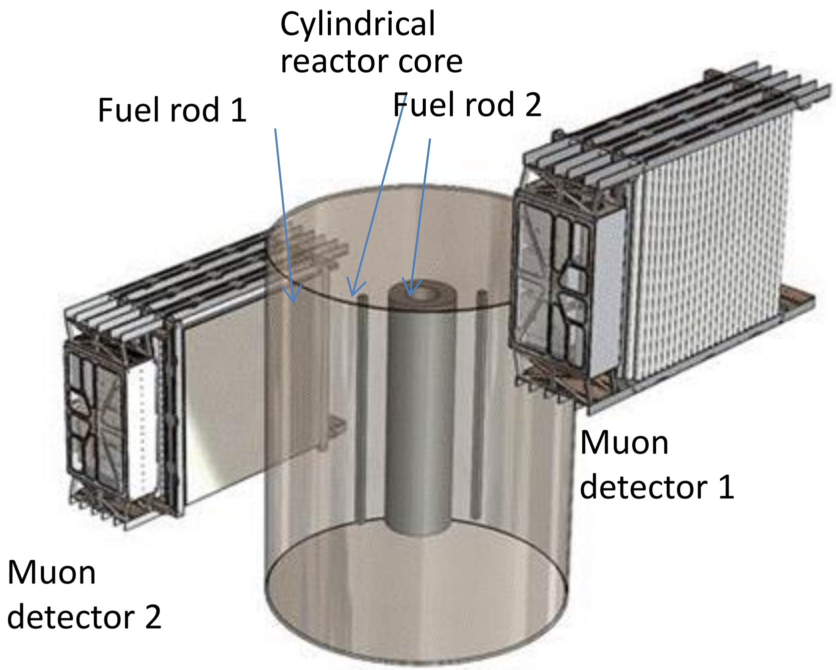
Detector 2-1　Detector 2-2　Detector 3

<u>Measurement result at each point</u>
High-density substance existed outside bell-shaped PCV

KEK(High Energy Acceleration Research Organization)data

Past result (muon scattering method 1/3)

- **Uranium identifying test in research reactor in scale of 1/10 of Fukushima Daiichi nuclear power plant**
- **Simulation and experiment value matched within 3%.**
- **Aimed at achieving identifying ability of 30 to 40 cm at Fukushima Daiichi**



Measurement system

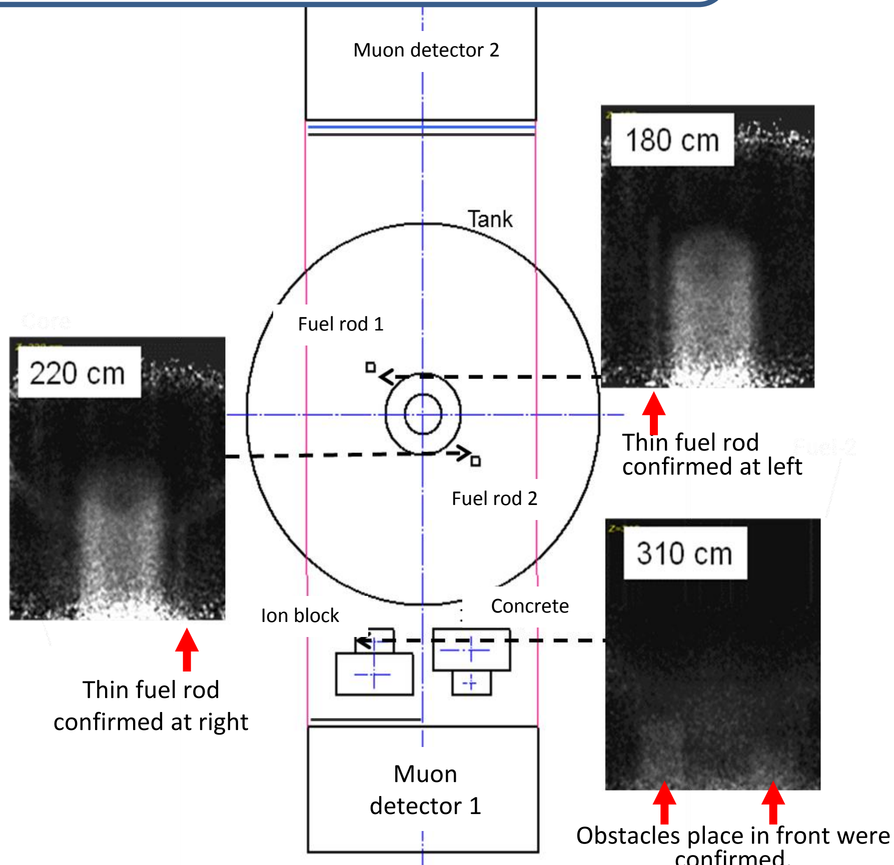
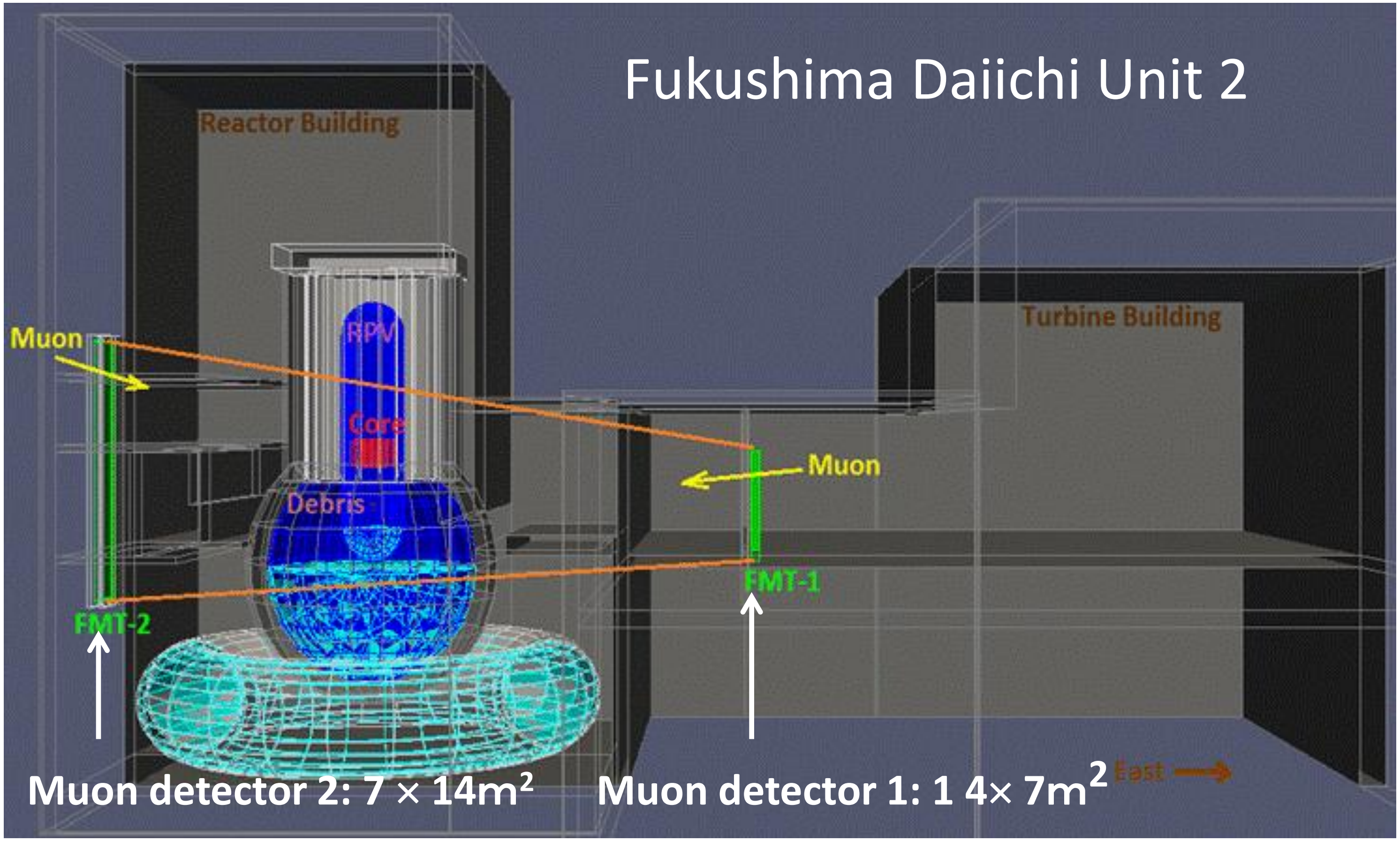


Image of each cross section measured three-dimensionally

TOSHIBA Data

Past result (muon scattering method 2/3)



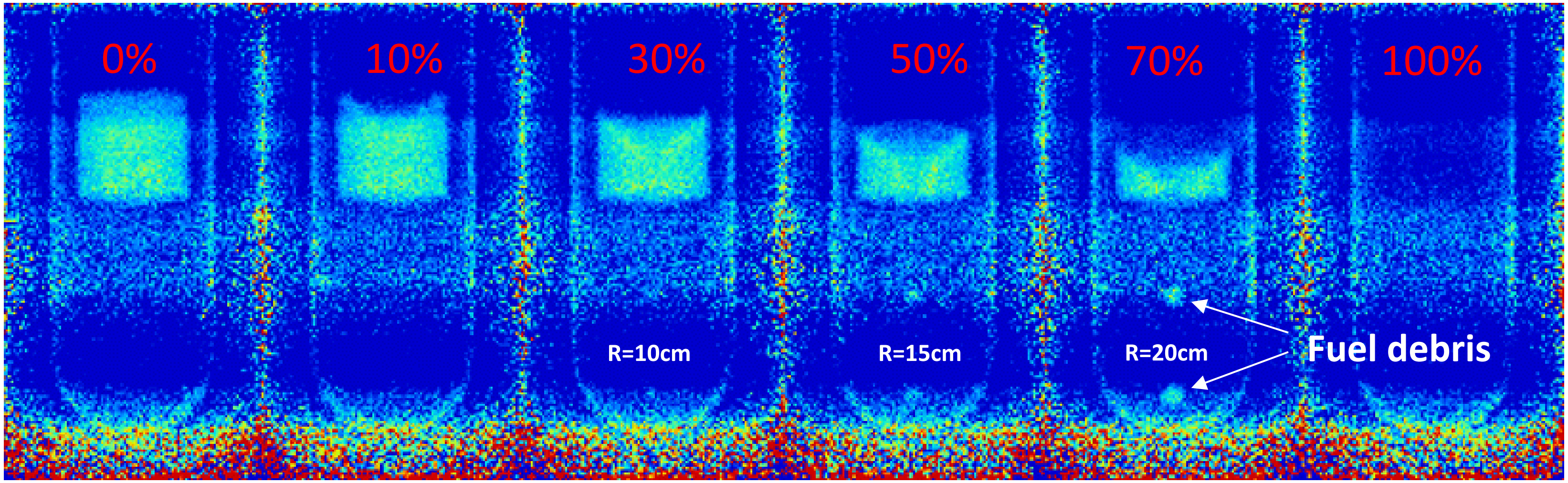
Numerical simulation was conducted in actual scale of Unit 2.

TOSHIBA Data

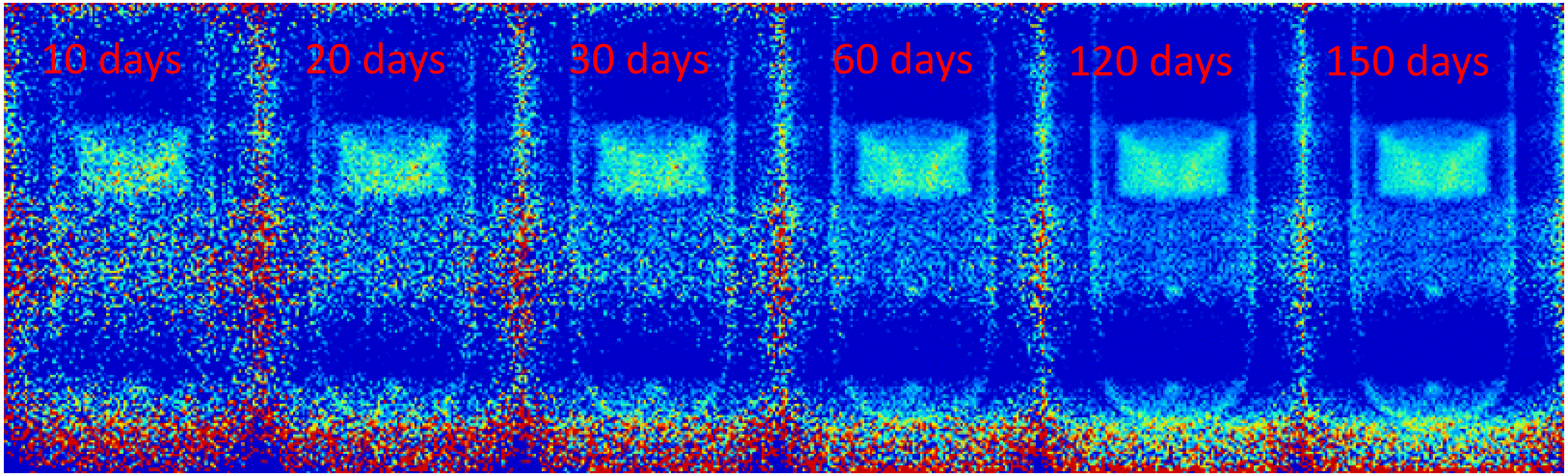
Past result (muon scattering method 3/3)

(Result of numerical simulation)

Simulation of reactor core molten 0 to 100%, measured for 90 days



Simulation of reactor core molten 50%, measured for 10 to 150 days



TOSHIBA Data

2. Research and development related to preparations for retrieval of fuel debris

Development of technologies for fuel debris containing/transfer/storage (2-(1)-7)

Overall plan (objective and goal)

[Purposes of development of technologies for fuel debris packing, transfer, storage]

1F has the following differences in condition fromTMI-2:

- **Fuel debris of 1F-1 to 3 exists at lower portion of RPV and in PCV. Its position and property are unknown.**
- **Dose rate is high in the building and make access difficult.**
- **Fuel is higher in burn-up and concentration than that of TMI-2 and difficult for fuel debris packing, transfer, storage.**
- **There is a concern that corrosion has progressed by injection of seawater into reactor.**

Exclusive canisters were developed for TMI-2, which were used for fuel debris packing, transfer, storage. For fuel debris packing, a work block was installed on top of RPV and fuel debris was packed in canister in RPV.

This research is for development of technologies to create fuel debris canisters suitable for the situation of 1F and handle the canisters, by referring to the records of TMI-2.

[Goals of development]

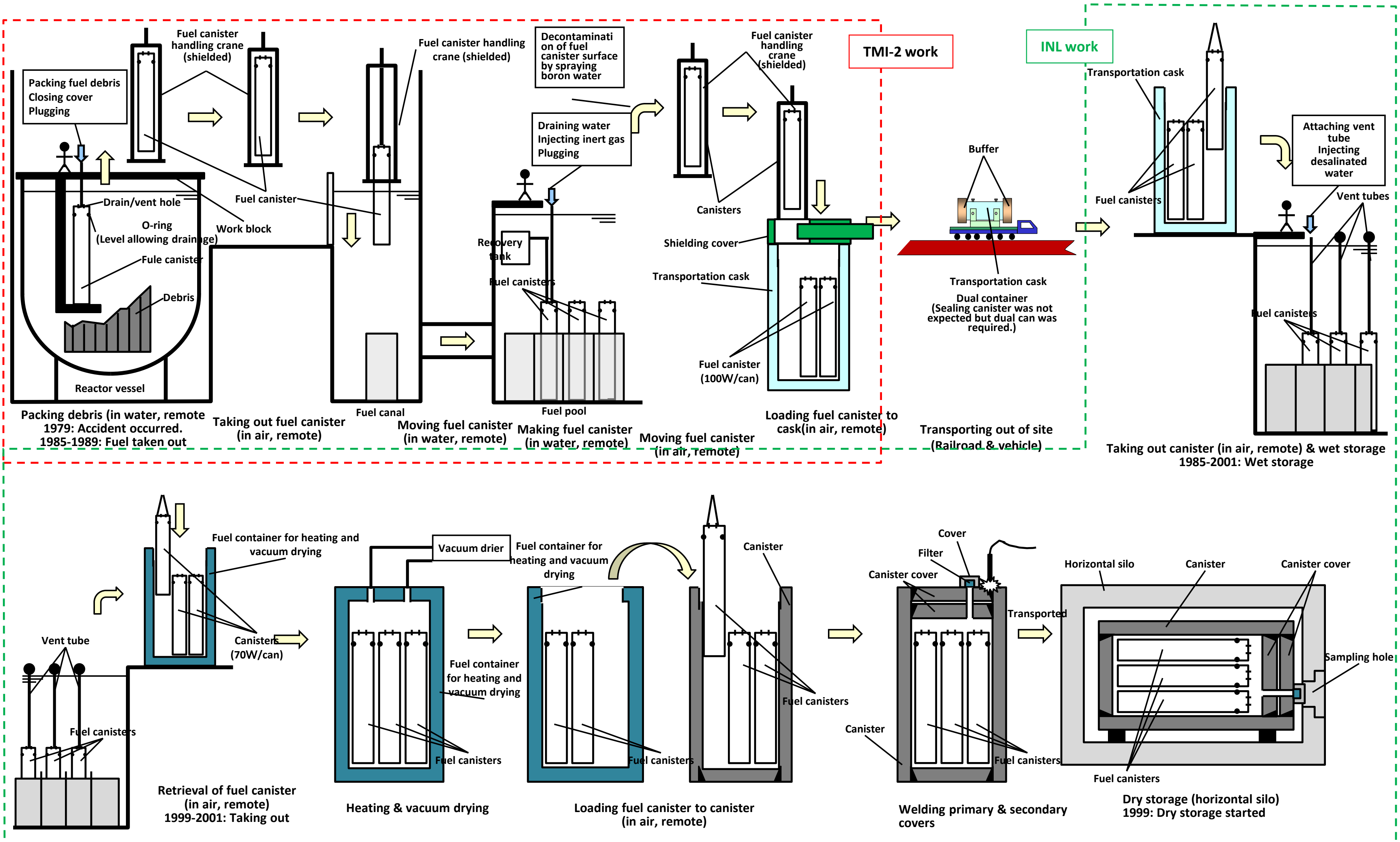
Fuel debris must be safely retrieval while keeping it well below critical point, prevented from scattering, appropriately shielded, cooled, and stored in accordance with the 1F execution plan, and safety of workers and inside and outside the site must be ensured.

- **Deciding specifications required for canisters suitable for 1F fuel debris packing, transfer, and storage, and selecting their materials**
- **Development of technologies for assessing the safety of the fuel debris canister**
- **Design and production of canister for a mock-up test for retrieval of fuel debris**

IRID

Research on transfer and storage of damaged fuel (1)

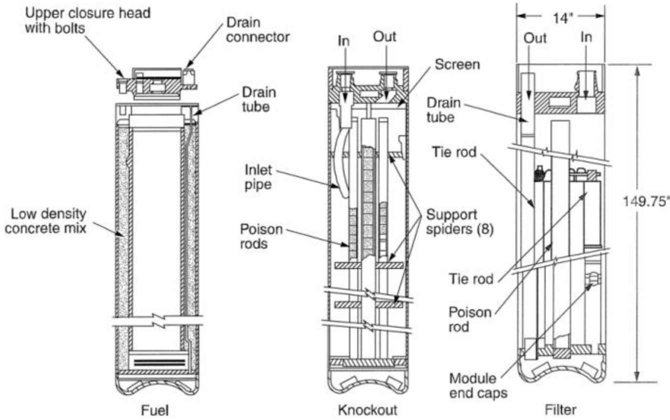
(Overview of fuel debris handling at TMI-2)



Research on transfer and storage of damaged fuel (2)

Outline of result research on transfer and storage of damaged fuel

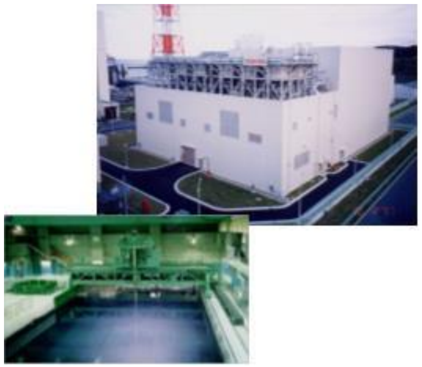
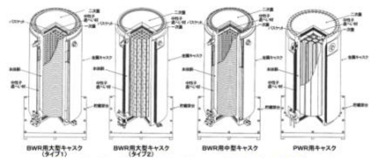
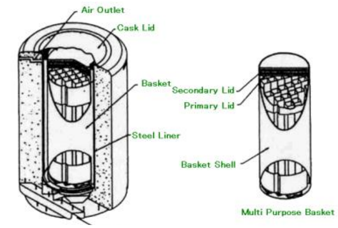
		Example at TMI-2 (fuel debris transfer)	Example at TMI-2 (fuel debris storage)	Example at Paks	Transfer of damaged fuel in France
Object contained		Fuel debris (molten fuel)	Same as left	Damage to cladding (fuel not molten)	Pin-hole leak
Wet or dry		Semi-dry (Only water was drained and drying processing was not performed.)	Dry	Wet	Dry
Fuel canister		Used	Used	Used	Not used (Fuel debris transported in same way as sound fuel)
Basic safety design	Containment	Fuel canister was constructed so that hydrogen generated is always vented through screen filter on cover while can was in storage. Cask for transporting can is sealed and generation of hydrogen was controlled by hydrogen recombination medium.	Fuel canister had no sealing function. Hydrogen generated was vented through HEPA filter attached to canister.	Fuel canister was always vented through cover having vent mechanism.	Canister was not used. Cask was selected by analyzing and assessing hydrogen concentration during transportation. Hydrogen concentration was measured before transportation.
	Shielding	Shielding was secured by peripheral equipment. Thickness of canister was determined by factors such as structure.	Same as left	Same as left	Secured by cask
	Criticality	Quantity of fuel debris to be stored in fuel canister was conservatively decided by optimum deceleration (debris of one fuel assembly or less was stored in can. Operation is managed in same way.)	Criticality was assessed with 12 fuel canisters storing new fuel of maximum concentration to full capacity loaded to canister.	Conservative setting of optimum deceleration in canister	Same as sound fuel
	Heat removal	Assessed by maximum quantity of debris stored in one fuel canister	Same as left	Only heat removal capacity was described (details unknown).	Assessed with sound fuel



Example of fuel debris canister used at TMI-2, USA (reference)
Source: DOE/SNF/REP-084 TMI Fuel Characteristics for Disposal Criticality Analysis (2013)

Fuel debris storage system at TMI-2, USA (reference)
Source: Andrew P. Szilagyi, Three Mile Island Unit 2 Overview and Management Issues, OECD-Nuclear Energy Agency – 12th Meeting of the WPDD, France (2011i)

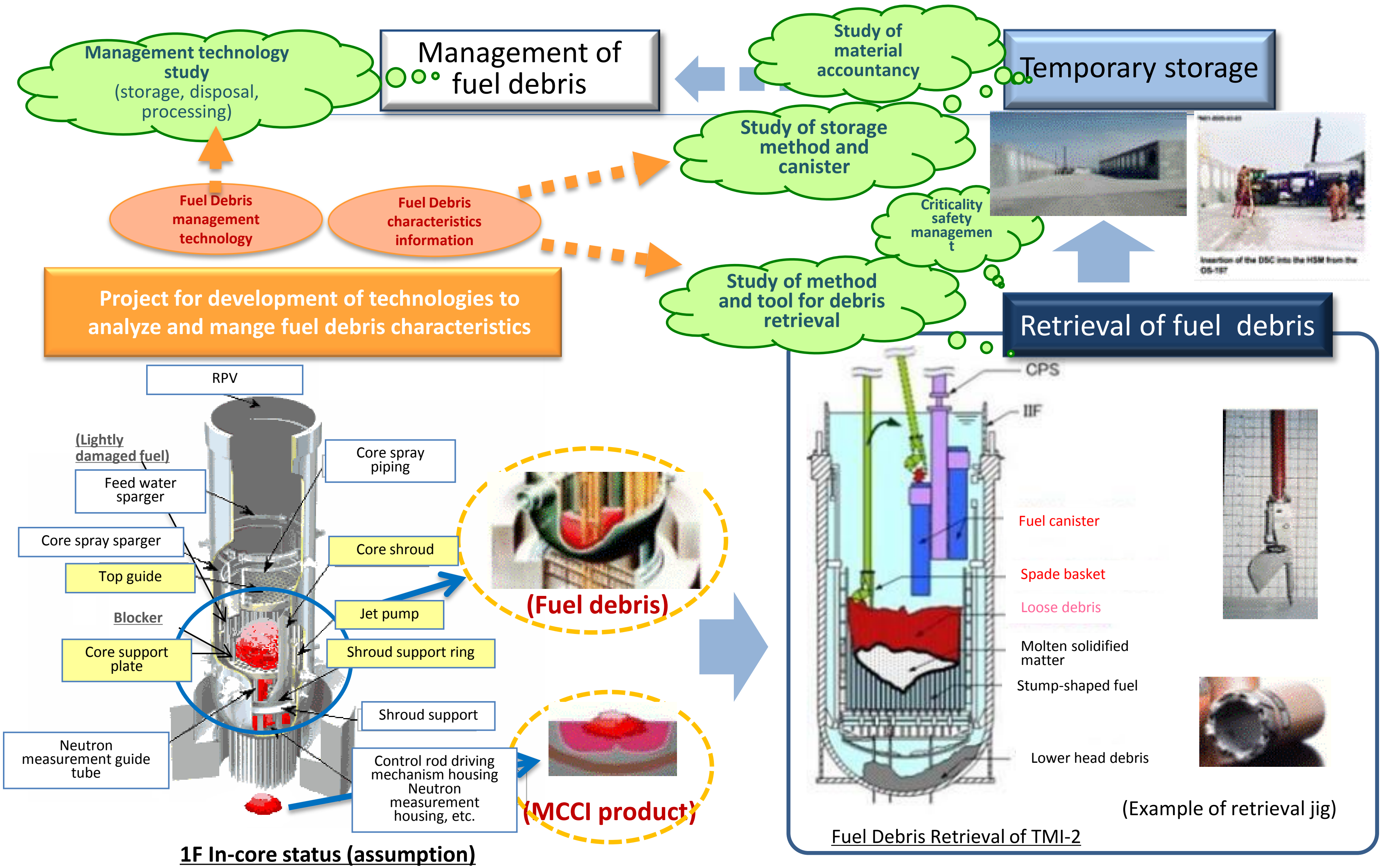
Study of storage system

Storage method		Wet	Dry		
		Pool	**Metal cask**	**Concrete shielding** (including horizontal silo)	**Vault**
Overview			 From HP of Recyclable Fuel Storage Company  Figure 8. Metal cask to be used at Recycle Fuel Storage Center [Source]	 (2) Concept of concrete cask (U.S.A.: VSC24) Figure 13. Concept of horizontal silo and concrete cask [Source] Takuya Yanagishita, Tosiari Saegusa, Chihiro Ito, Shinichi Komatsu, Eiji Yoshimura: Overseas Trend of Spent Fuel Intermediate Storage Technology, Atomic Energy Society of Japan magazine, Vol. 42., No. 11, 72 (2000)	 Jenny Morris, Contingency Options for the Dry Storage of Magnox Spent Fuel in the UK, ICEM 09/DECOM(2009)
Ensuring safety function	Sealing	･Pool water and reactor building	･Metal gasket of primary and secondary covers	･Welded primary and secondary covers of canister	･Same as left
	Screening	･Pool water and reactor building	･Metal cask (combination of steel and neutron screening materials) and building	･Concrete cask (combination of steel and concrete)	･Building (concrete)
	Criticality prevention	･Geometrical arrangement of fuel rack (fuel rack materials as necessary)	･Geometrical arrangement of metal cask basket (basket materials as necessary)	･Geometrical arrangement of canister and basket (basket materials as necessary)	･Same as left
	Heat removal	･Circulative cooling by pool water	･Natural cooling of metal cask surface	･Natural cooling of canister surface	･Same as left
Merits & demerits	Transportation	･Object to be stored must be stored in transportation cask.	･Transportation and storage cask was developed and cask can be transported as is.	･Canister must be moved from storage cask to transportation cask (transportation and storage canister may be used in some cases).	･Canister must be put in transportation cask.
	Easy to check	･Object to be stored can be easily taken out and checked for status because it is stored in water as is.	･Because object to be stored is stored in cask, object must be checked in pool or hot cell, which is more disadvantageous than pool.	･Object to be stored is stored in canister sealed by welding and must be checked in pool.	･Same as left
	Needed area	･Storage density is high and installation area may be small.	･Storage density is lower than pool.	･Storage density is lower than metal cask (installation area for storage is large).	･Storage density is higher than cask.
	Expandability	･New building must be constructed to increase capacity, needing large-scale operation.	･Cask, which accounts for large part of cost, can be increased, so that system can be gradually expanded.	･Same as left	･New building must be constructed to increase capacity, needing large-scale operation.
	Maintenance cost	･High cost as cooling function and water quality management are needed	･Low cost as only maintenance of electric system is needed	･Same as left	･Same as left
	Laws & regulations	･There are domestic records and laws and regulations are established.	･Same as left	･There are overseas records but not domestic records, and laws and regulations are not established.	･Same as left

2. Research and development related to preparations for retrieval of fuel debris

Understanding of characteristics by using simulated fuel debris and development of fuel debris processing technologies (2-(3)-1 & 3)

Outline of fuel debris characteristics study



IRID

Purpose of analyzing fuel debris characteristics

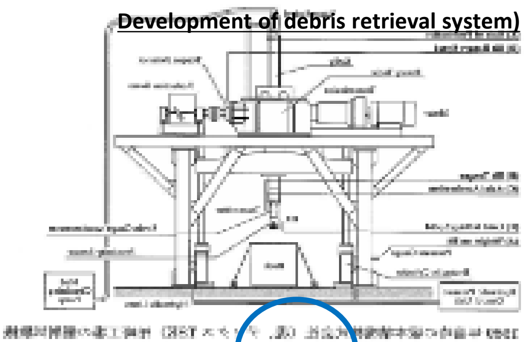
(Reflecting physical property information on other projects)

Storage & preservation project

Criticality control project

Material Accountancy project

Development of debris retrieval system)



(Image of drilling element test)

Cold specimen

Cold specimen

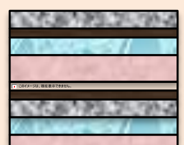
・Study of influences on cutting and drilling
・Reflecting information of physical property data on cold simulation specimen

Fuel Debris retrieval PJ

・Study of debris retrieval method
・Development of retrieval jig, etc.

Single phase specimen

or



Specimen of composite materials

Study of cold simulation specimen

Compound specimen in Kazakhstan also used for reference

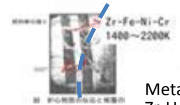
Fuel Debris characteristics information

<Analyzing characteristics with simulated debris>

(Physical property data)

・Mechanical characteristics: Hardness, elasticity, fracture toughness, etc.
・Thermal characteristics: Melting point, thermal conductivity, specific heat, etc.
・Others: Particle diameter, shape, porosity, density, chemical form, etc.

Gathering physical property information on each part



Pellet of not molten fuel

Metallic compound (SUS-Zr-U alloy, ZrB_2, etc.)

Oxide (U, Zr)O2, etc.)

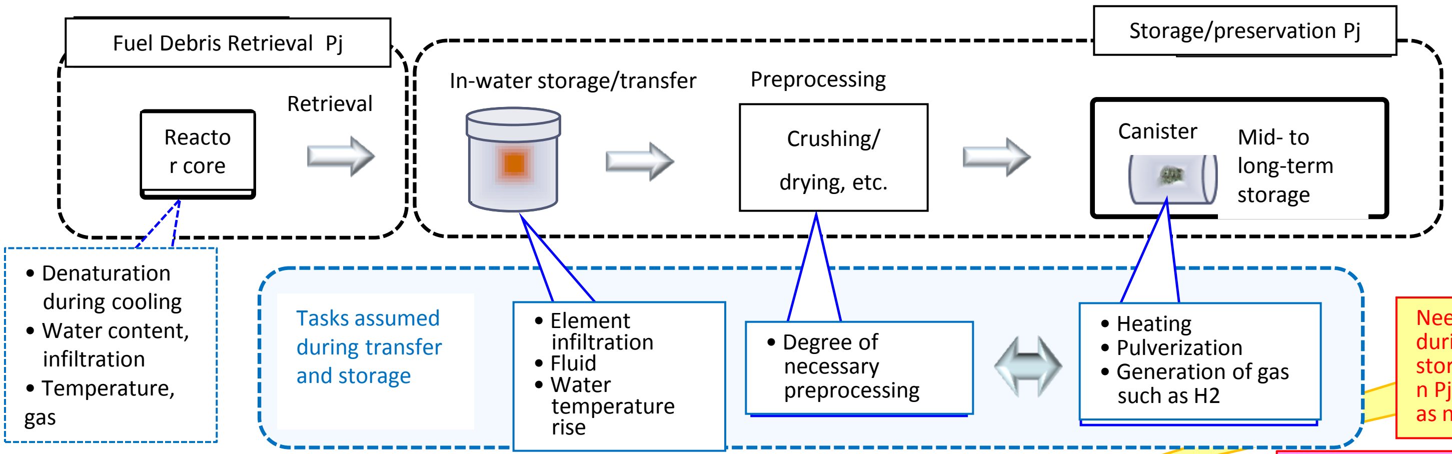
Crystal of boride

Structure material (metal)

Reactant with concrete (silicate compound, etc.)

Example of actual fuel debris sample (image)

Purpose of development of fuel debris management technology



Needs generated during storage/preservation Pj to be reflected as necessary

Concerns about storage/preservation Pj → Needs

Item	Category
Quantity of water absorbed to fuel debris	Water content, dehydration
Quantity (speed) of water released when debris is dried at room temperature	Water content, dehydration
Quantity (speed) of water released when debris is heated and dried	Water content, dehydration
Quantity (speed) of radioactive substances flowing out when debris is submerged	Denaturation (in water)
Quantity (speed) of halogen element flowing out when debris is submerged	Denaturation (in water)
Quantity of radioactive substances released when debris is stored in atmosphere	Denaturation (in air)
Quantity of radioactive substances released when debris is stored in vacuum	Denaturation (in air)

Needs to be reflected as necessary depending on progress of work at site and other projects

Debris Pj (2014)

[Details of study]

- Assessment of factors influencing on tasks and concerns
- Study of assessment method (samples, parameters, assessment items)
- Examining known document information and similar examples in general industries

[Development item] … Problems of development anticipated at present

→ Assessment of water content and dehydration behavior
(Assessment with sample whose shape is known)

→ Assessment of characteristics when submerged in water
(Referring to result of soaking test of spent fuel, etc., or hot test)

→ Denaturation test in gas phase

IRID

(2-(3)-1 & 3) Analysis of characteristics by using simulated fuel debris and development of fuel debris processing technologies

Data on fuel debris, such as the hardness, were gathered by producing a material simulating the characteristics of actual debris (simulated fuel debris) to estimate the actual debris characteristics so that technologies for taking out fuel debris can be considered. In addition, to study a scenario to manage the fuel debris after retrieval, applicability and technical issues of the existing fuel processing technologies were removed and alternatives available were compared to clarify gains and losses.

Actions

Analysis of debris characteristics (2-(3)-1)

(1) Study of physical properties necessary for developing technologies for fuel debris retrieval

- Influences of various simulated materials, such as machinability and hardness, were analyzed.
- Mechanical characteristics of simulated fuel debris containing (U, Zr)O_2 in a high Zr region and Fe were measured and each chemical form of the measured values was reflected on estimation of physical property distribution, on the assumption that metallic materials had mixed in reactor.

(2) Analysis of reaction specific to accident at 1F

- Possibility of generation of alloy phase and boride through reaction with control materials was confirmed. Trend that oxide (glassy) and alloy layer separate in reaction (MCCI) with concrete was also confirmed. The hardest substance was estimated to be boride.
- Influences of Gd contained in some fuel on the thermal characteristics of oxide simulated debris ((U, Zr)O_2) and their range were confirmed.

(3) Estimating actual debris characteristics

- From the above results, a list of characteristics of fuel debris (preliminary version) was created.

Development of fuel debris management technologies (2-(3)-3)

(1) Deciding technical requirements toward creating fuel debris management scenario

- Alternatives of scenario for managing fuel debris retrieval that out was compared to clarify gains and losses.
- Applicability of the existing spent fuel transportation canister was evaluated. It was judged that water content of fuel debris, which influences storage, was important.

(2) Study of element technologies needed for analyzing fuel debris

- Basic data of fusion process, preprocessing technology of analysis, were collected from each type of simulated fuel debris containing MCCI product.

(3) Study of applicability of existing fuel processing technology

- Basic data on applicability of simulated fuel debris to wet and dry processing were gathered.

IRID

(2-(3)-1) Analysis of characteristics by using simulated fuel debris (how to proceed with research and development)

Basic policy

- Estimating chemical form of fuel debris in reactor, reflecting the results of the latest plant data at 1F and event progression analysis
- Reviewing items to meet needs by exchanging information with site and fuel debris retrieval project (same applies to (2) to (5))
- Reviewing necessary items in light of needs of other projects under adjustment (storage/preservation, criticality safety, measurement management)
- Reflecting information and opinions from overseas (SA research, TMI-2, etc.)

- Studying physical properties heavily influencing necessary methods (such as for drilling) and selecting physical properties that serve as criteria for selecting simulated fuel debris suitable for methods
- Collecting mechanical property data from major materials of fuel debris, by using simulated fuel debris
- Gathering wide range of data including composition and influences of impurities
- Collecting wide range of data in advance, taking various possibilities into consideration, as many data are needed in early stage

- Assessing influences of reaction specific to 1F by using simulated fuel debris
- Collecting wide range of data, taking various possibilities into consideration, as analysis of situations in reactor proceeds in parallel

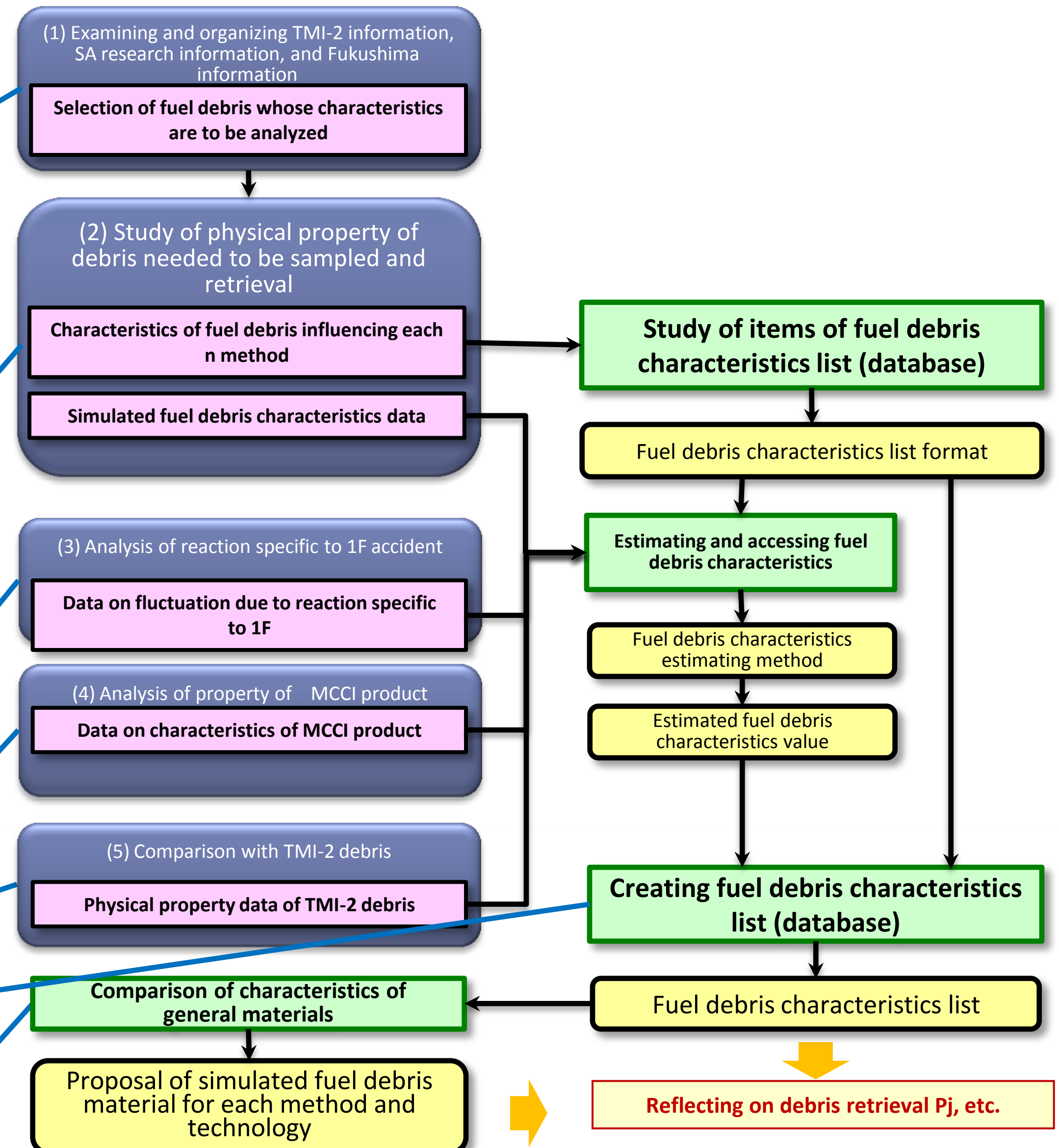
- Getting information on MCCI phenomenon and products by effectively using information and opinions from overseas and international cooperation

- Obtaining physical property data by using fuel debris from TMI-2

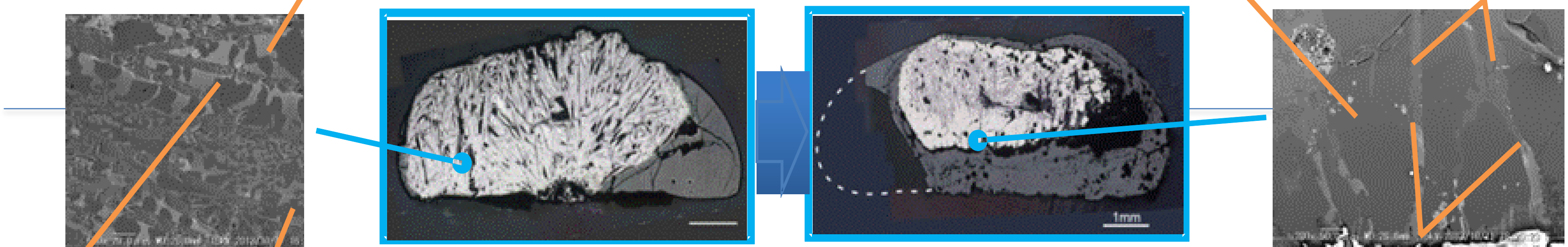
- Estimating fuel debris characteristics based on data and information gathered to create a characteristics list

- Proposing simulated fuel debris materials for each method and technology by selecting general materials with similar characteristics that have heavy influence

How to proceed with research



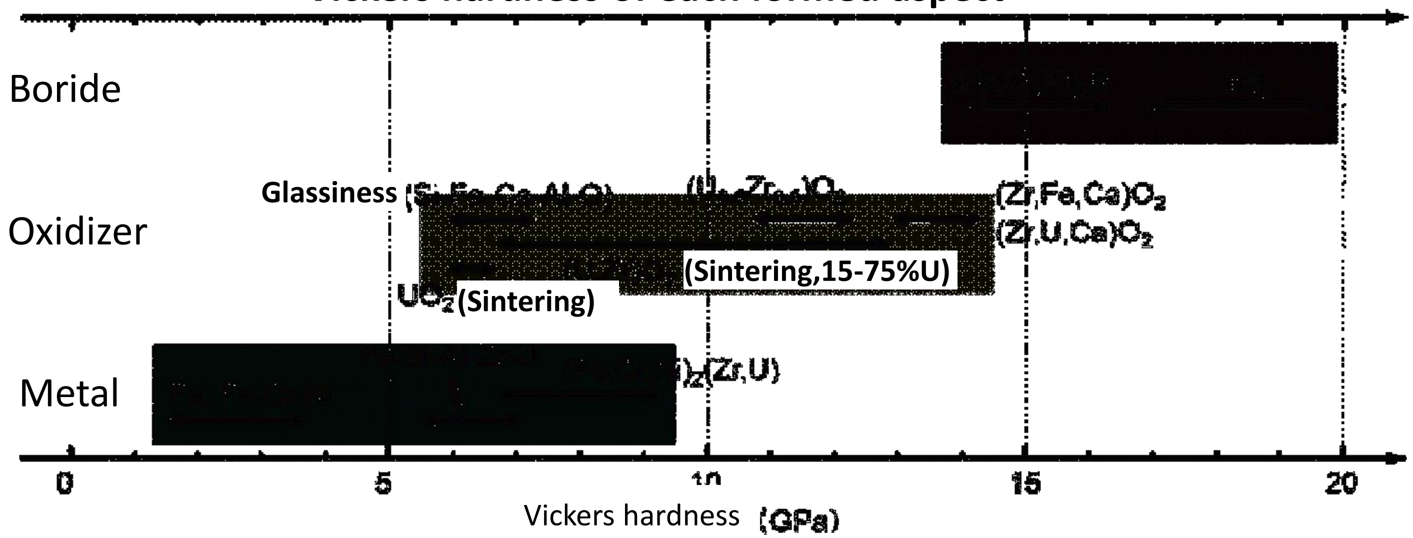
(2-(3)-1) Analysis of characteristics by using simulated fuel debris (Result of study in FY 2013)



Reaction with control material (B_4C+SUS) (Example of the fusion solidification abstaining from side observation image

(Obtained knowledge regarding the composition of solidified material generated when control rod and molten fuel)

Vickers hardness of each formed aspect



(Estimate hardness distribution for each chemical system of fuel debris (boride, oxide, metal))

(2-(3)-1) Analysis of characteristics by using simulated fuel debris (plan for 2014)
- Production and assessment of characteristics of metal/ceramic molten solidified substance -

- **To test and assess the characteristics of materials for producing a mock-up for developing equipment and decides a method to produce a mock-up, by creating metal/ceramic uneven molten solidified substance considered difficult to be processed by retrieval equipment**

[Major result]

➢ **Macro/micro observation and chemical analysis of boundaries between metal and ceramic, and gathering data such as on hardness and fracture toughness**

Background

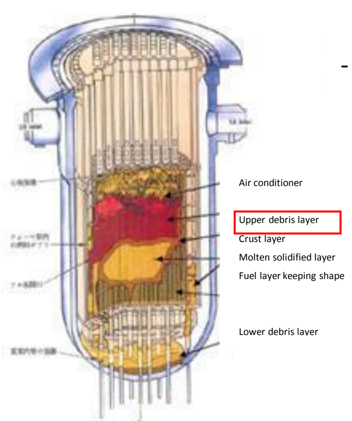
TMI-2: Formation of crust layer of solidified metal/ceramic[1,2]

→ Difficult crushing and cutting due to compound of metal with high toughness and hard but fragile oxide

→ At 1F, it is estimated that molten fuel fell on metal structures, partially melting them, and then solidified and generated compound mixing oxide and metal

→ It is necessary to analyze the characteristics of the uneven compound.

Debris distribution at TMI-2



Crust layer
- Metal + ceramic unevenly solidified

Cross-sectional structure

Method

(1) Metal/ceramic molten solidified substance production test

Falling molten UO_2 + Zr compound (60 kg) onto stainless structure.

Producing molten solidified substance of metal and ceramic unevenly and rapidly cooled

(2) Material assessment

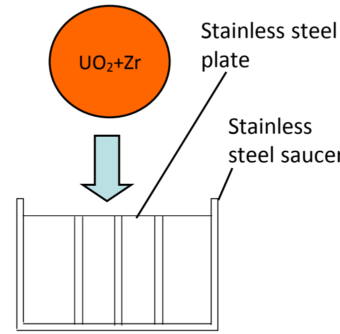
Conducting macro/micro observation of cross section, chemical component analysis, and measurement of hardness and fracture toughness by focusing on boundaries between metal and ceramic and their perimeter

(3) Designing mock-up of metal/ceramic molten solidified substance

Deciding on production specifications by selecting materials for and designing mock-up for developing equipment

Setting production conditions from result of estimating debris characteristics at 1F based on existing information and opinions

Reflection on retrieval fuel debris



Specimen

[1] Research activity report by Japanese Committee of US-Japan WR Research (March 1991)
[2] Tokai et al., Nuclear Magazine, Vol.32 No.4 (1990)388.

2. Research and development related to preparations for fuel debris retrieval

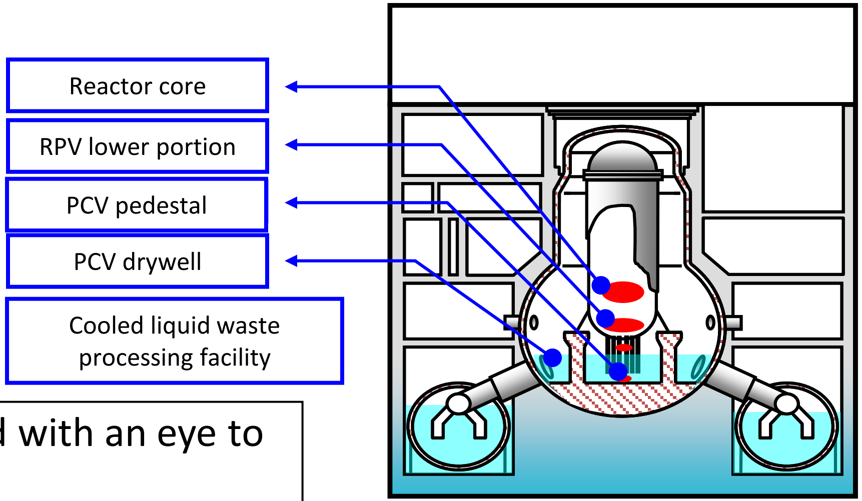
Development of the criticality management of fuel debris(2-(1)-9)

Overall plan (objective and goal)

[objective of development of criticality control technology]
It is believed that fuel debris has not reached criticality at present but technologies for controlling and monitoring criticality will be developed so as to prevent re-criticality even if the fuel debris shape or water quantity changes while fuel is being retrieved.

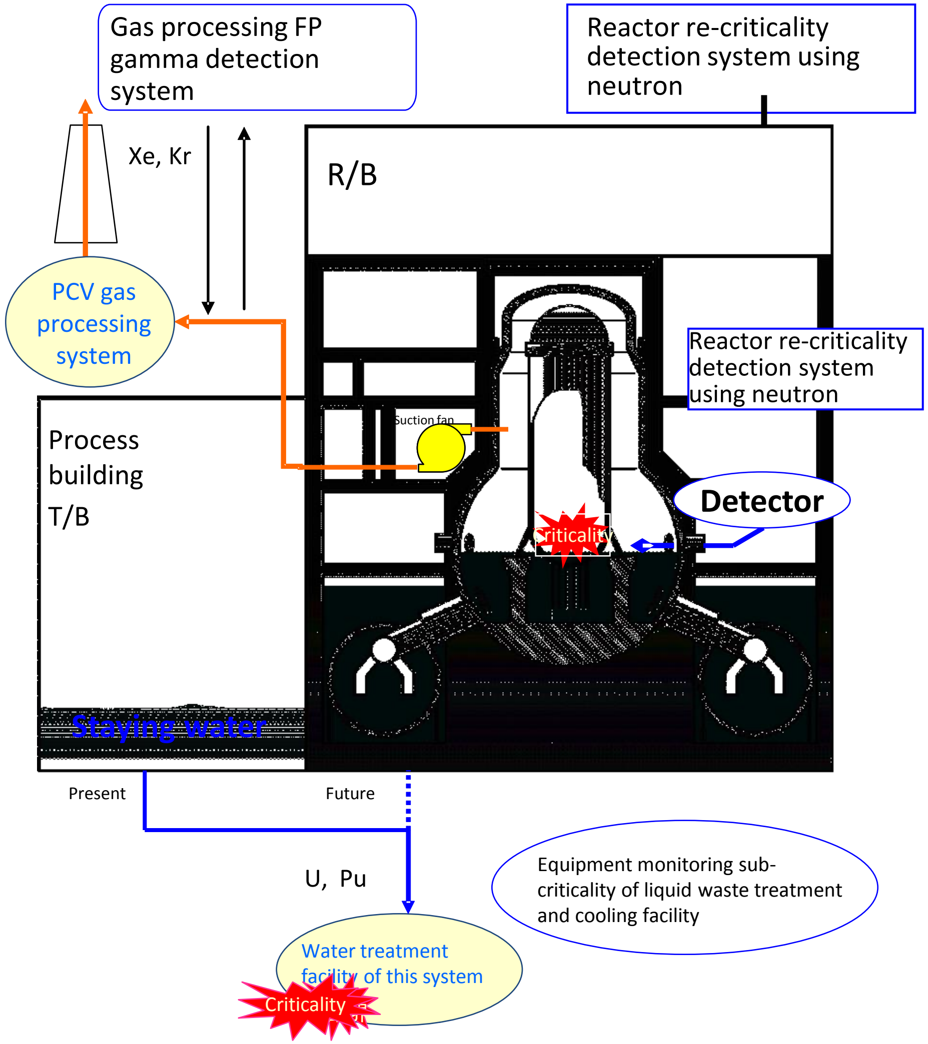
[Goal of development of criticality control technology]
Fuel debris is considered to exist in PCV via RPV. Development of technologies to access and monitor criticality and neutron absorbent to prevent re-criticality when fuel debris is removed will be aimed.

Roadmap: Following technologies will be developed with an eye to retrieve fuel debris in the first half of 2020:
(1) Criticality assessment technology
(2) Liquid waste/cooling facility sub-criticality control technologies
(3) Reactor re-criticality detection technology
(4) Criticality prevention technology

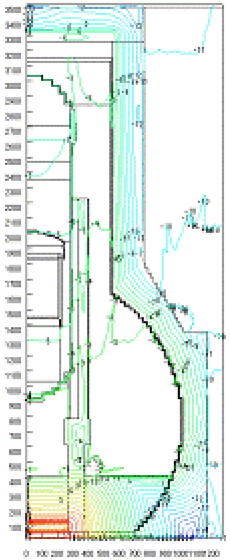


Assumed position of fuel debris

Outline of monitoring sub-criticality and detecting re-criticality



- Since requirements for controlling criticality differs between inside and output PCV, sub-criticality monitoring or re-criticality monitoring is used depending on the purpose (before fuel debris is retrieved).
- Workers who maintain facilities for treating liquid waste and cooling outside PCV should be protected from risk of exposure due to criticality.
  → sub-criticality monitoring
- Even if criticality is reached in PCV/RPV, risk of exposure is extremely low because radiation does not directly reach the outer wall of PCV. On the other hand, however, monitoring the situation in a relatively wide range is important.
  → Re-criticality detection



Neutron beam distribution in case criticality in PCV

Development of technologies to detect re-criticality in reactor

Objective of development: To develop a re-criticality detection system using neutron and FPγ ray to detect a case where fuel debris has reached re-criticality in RPV or PCV

Result of developing in 2013 [Re-criticality detection system using neutron]

- Consideration of specifications of re-criticality detection system
  - Specifications of a system that detects neutron to be emitted when fuel debris reaches re-criticality in RPV or PCV were drawn up.
  - Based on the result of analysis of neutron dose distribution inside and outside of PCV and on the assumption that the system will be installed in PCV:
    - Detector was selected (^{10}B proportional counter tube, fission ionization chamber for reactor).
    - System was designed, trial system was manufactured, and feasibility test was conducted.
  - Feasibility was assessed through γ resistance test of ^{10}B proportional counter tube and system test [by using a facility of National Institute of Advanced Industrial Science and Technology].

Development was completed in 2013. The system was tested for its performance to detect re-criticality when PCV was filled with water, and was used for criticality management.

Result of development in 2013 [Re-criticality detection system using FPγ ray]

- Kr-87/88, as well as Xe-135, could not be measured as a nuclide to be monitored, to shorten the detection time.
- Optimum system configuration was considered according to conditions because Kr-87/88 substantially differs in concentration depending on the location where the system was to be installed.
- It was confirmed that Xe-135 (nuclide that had been measured) could also be measured while Kr-87/88 was being measured.
- Effect of simultaneous counting, a method to improve the sensitivity, was verified.
- Recommended system configuration was studied based on the estimated concentration of spontaneous fission at 1F-1.
  - Effect of shortening the time to fill water was evaluated.
  - Sub-criticality estimation method using a Kr/Xe ratio was studied.
  - Including the system in the criticality control procedure was studied.

Development of re-criticality prevention technology

Objective of development
・To develop soluble and insoluble neutron absorbent as a means to prevent re-criticality when fuel debris is retrieved

Results of development in 2013 [Insoluble neutron absorbent]

・Study of basic characteristics test items of candidates (absorbent, binder)
・Trial production/procurement of candidate materials. Their applicability to fuel debris removal work was assessed based on the basic characteristics. Candidate materials had no problems in mechanical and thermal characteristics and were screened by solubility.
・Deciding on future development policy (planning test to confirm the resistance to radiation)

Second screening by conducting radiation resistance test. An application method was studied to secure homogeneity when the material was applied and the result was reflected on the criticality control method.

Results of development in 2013 [Soluble neutron absorbent]

・Putting in order problems and making a study plan on soluble neutron absorbents (such as sodium pentaborate)
- Study of influences on corrosion resistance of materials in reactor , selection of contents to be added for galvanic corrosion tests
- Irradiation test (gamma ray irradiation test at JAEA Takasaki laboratory) was conducted to confirm influences on hydrogen generation of radiation decomposition accompanying mixing of boron and chlorine.
- Influences on nuclide removal performance of liquid waste treatment methods and methods to separate or recover neutron absorbent were studied.

In additional corrosion test was conducted to decide on a method of applying the soluble absorbent and the result was reflected on the criticality control method. Influences on the fuel debris canister were evaluated.

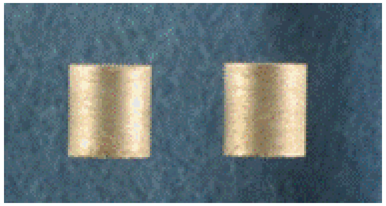
Development of criticality prevention technology

(example,Insoluble neutron absorbent)

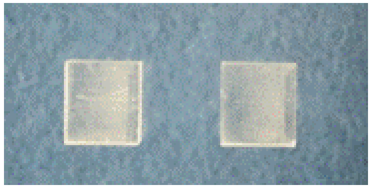
Result of screening candidate materials by solubility

Category	Neutron absorbent candidate	Radiation resistance test	Policy
Solid	B_4C/sintered metal material	Done	Base metal selected according to cost as necessary
	B or Gd-contained glass material	Done	Zinc borate with low solubility selected
	Hollow boron	Pending*	Solubility needs to be improved. (Candidate material for specific method (underwater drift))
	Gd_2O_3 particle	Done	
Liquid → Solid	Cement/ Gd_2O_3 particle	Done	
	Water glass/ Gd_2O_3 particle	Pending*	Solubility needs to be improved.
Liquid	B_4C gel material	Pending*	Solubility needs to be improved.
	Slurry/ Gd_2O_3 particle	Done	

Pending*: Radiation resistance test to be conducted after characteristics are improved

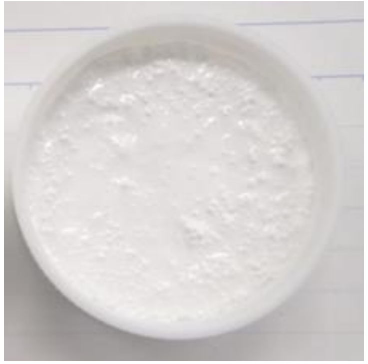


B_4C/sintered metal material



B/Gd-contained glass

10mm



Slurry/Gd_2O_3 particle

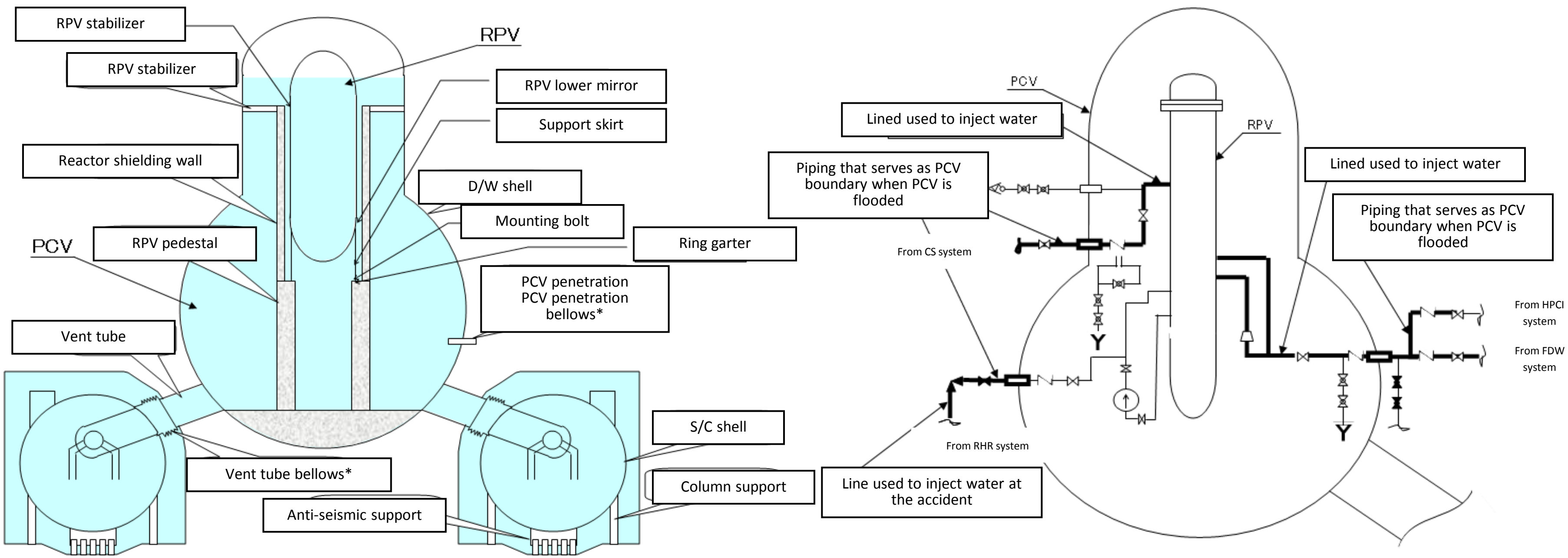
Figure: Candidate materials screened

2. Research and development related to preparations for retrieval of fuel debris

Development of technologies for assessing structural integrity of RPV/PCV(2-(1)-8)

Overall plan (objective and goal)

- Quantitative data on corrosion rate will be collected for RPV ,PCV, RPV pedestal, and reactor water injection pipe after the severe accident, in order to evaluate aseismatic strength, taking into consideration long-term wall thinning by corrosion.
- Corrosion inhibition to secure the integrity of structural over long time will be studied and its effect will be confirmed. Applicability of the method to the real plant will be assessed. to contribute to keep the structural integrity components.



:RPV-related facility
:PCV-related facility

* **Because these are made of stainless steel and may already be cracked by SCC, they will not be evaluated and a method to exclude them from repair or flooding boundary is under study.**

Bold line range: Reactor water injection pipe

<u>Example of portions to be checked for structural integrity (remaining life assessment)</u>

Overall structural integrity assessment flow

Building behavior analysis* (building damage simulation)

*Input condition proposed by Tepco.

Building-equipment coordination behavior analysis

Organizing loading conditions

Equipment strength assessment

Listing & updating list of equipment with low permissible value

Application of corrosion inhibition

No effect

Model creation

- Water level
- Basis ground motion Ss
- Damage to equipment
- Influence of corrosion

Assessment condition

- Allowable value
- Corrosion wall thinning (test data)
- High-temperature strength deterioration (test data)

Study of scenario and risk assessment in case equipments with low allowable value be damaged

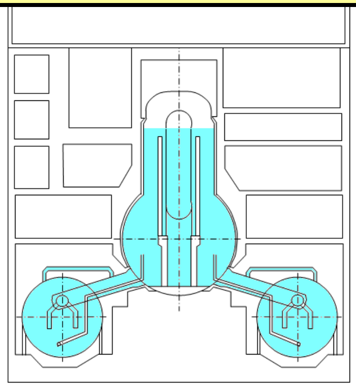
Inputting information to other projects (requesting study of internal investigation and repair method**)

**Study by experts in equipment design and structure is indispensable and current research and development system should be reviewed.

: Done in 2012

: Conducted or to be conducted from 2012 to 2015

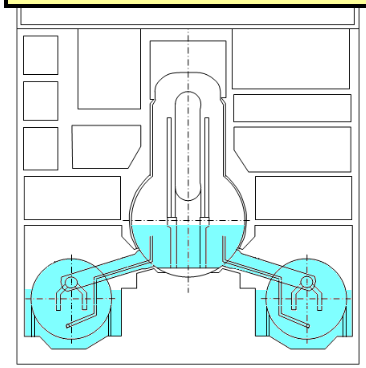
(a) PCV flooding status (example) (assessed in 2012)



Putting in order items to be checked and results expected by conducting examination when conditions leading to improvement of accuracy of remaining life assessment, such as damage of buildings and current water level (coordination with other projects such as to inspect inside PCV is needed.)

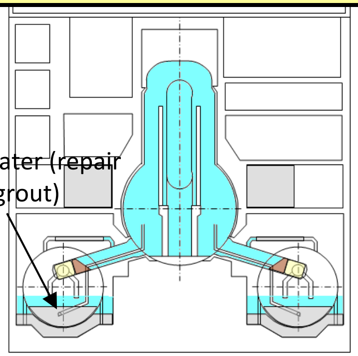
: Assessed in 2013

(b) Plant condition assumed at present (example)



(c) Plant condition assumed until PCV flooding (example)***

Stopping water (repair with grout)



***Information input from other project "development of technologies for stopping water leaking from reactor building and repairing lower portion of PCV"

Outline flow of remaining life assessment (example)

Water level in PCV estimated from present situation and until PCV is flooded (example)

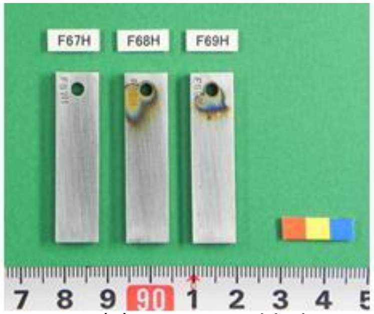
Development of corrosion inhibision - Result of test to add sodium nitrite -

Purpose
To gather quantitative data by conducting corrosion tests by using sodium nitrite, which has a been used for coolant bearings at a real plant, in order to check the effect of suppressing corrosion of PCV (carbon steel SGV480 for PCV). In addition, additive density considered appropriate for application to the real plant will be studied based on the gathered data.

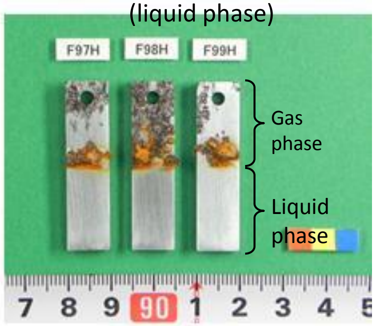
Sodium nitrite addition test matrix
(50°C, seawater diluted 200-fold, saturated atmosphere)

Sodium nitrite density (ppm)	Gas-liquid phase environment	Test time			
		50h	100h	500h	2000h
Density (1) (200)	Liquid phase	●	●	● (1)	—
Density (2) (400)	Liquid phase	●	●	● (2)	●
Density (3) (2000)	Liquid phase	●	●	●	—
Density (2) (400)	Gas-liquid interface	●	●	● (3)	—


Without anti-rust agent (liquid phase)


(1) 200 ppm added (liquid phase)


(2) 400 ppm added (liquid phase)



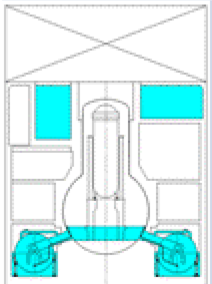
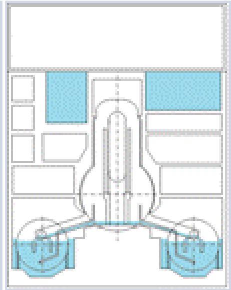
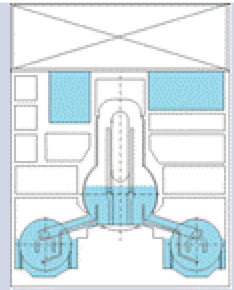
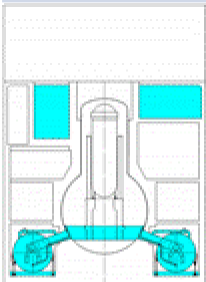
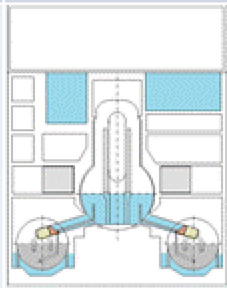
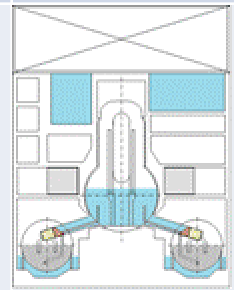
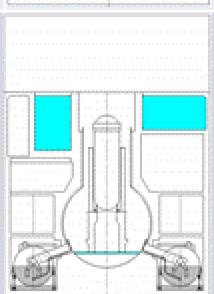
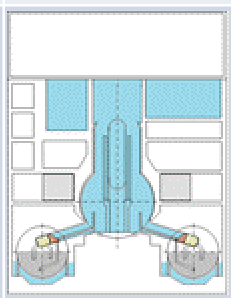
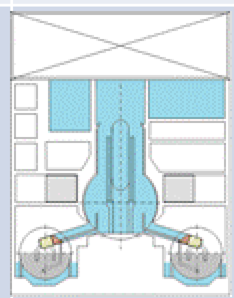
(3) 400 ppm added (gas-liquid interface)

Test result
- **Corrosion in liquid phase was prevented when sodium nitrite was added 400 ppm or more.**
- **Corrosion in liquid phase was prevented on gas-liquid interface but corrosion in gas phase was observed.**

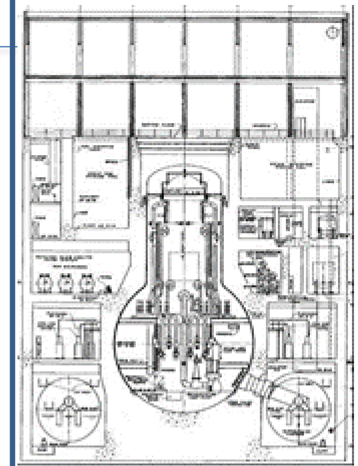
Appearance of specimen after test (example)

Policy for evaluating aseismatic strength

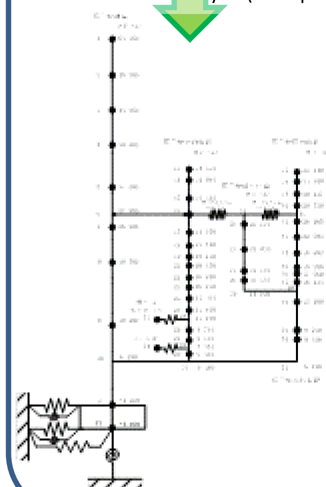
Strength of each unit of equipment was evaluated from the load of seismic response analysis in plant conditions (three cases at each plant) assumed to have a higher priority when methods of fuel debris retrieval was studied.

Plant/ case	1F-1		1F-2		1F-3	
H25-1		**O Present assumption** • Building damaged • D/W water level: About 2.9 m • S/C: Full of water • Vent tube: Full of water • Vacuum destruction tube: full of water • Torus room water level: OP3680		**O Present assumption** • Building sound • D/W water level: About 0.6 m •S/C: OP3100 • Vent tube: Water flowing at bottom • Torus room water level: OP3200		**O Present assumption (3 years after accident)** • Building damaged • D/W water level: About 6.5 m • S/C: Full of water • Vent tube: Full of water • Torus room water level: OP3200
H25-2		**O Torus room water level control** • **Building damaged** • Equipment on stairs of operation floor: About 5,100 t • D/W water level: About 2.9 m • S/C: Full of water • Vent tube: Full of water • Vacuum destruction tube: Full of water • Torus room water level: OP-300		**O PCV partially flooded** • Equipment on stairs of operation floor: About 5,500 t • Small room buried • D/W water level: About 5 m • S/C: Concrete OP1900 • Vent tube: Repair considered • Torus room water level: OP-300		**O PCV partially flooded** • Equipment on stairs of operation floor: About 3,900 t • Small room buried • D/W water level: About 6.5 m • S/C: Concrete OP1900 • Vent tube: Repair considered • Torus room water level: OP-300
H25-3		**O S/C reinforced** • Building damaged • Equipment on stairs of operation floor: About 5,100 t • D/W water level: About 0.3 m • S/C: Concrete OP3570 • Vent tube: Air • Vacuum destruction tube: Air • Torus room water level: OP-300, concrete OP-485		**O PCV flooded** • Equipment on stairs of operation floor: About 5,500 t • Small room buried • D/W water level: About 35 m • S/C: Concrete OP1900 • Vent tube: Repair considered • Torus room water level: OP-300		**O PCV flooded** • Equipment on stairs of operation floor: About 3,900 t • Small room buried • D/W water level: About 35 m • S/C: Concrete OP1900 • Vent tube: Repair considered • Torus room water level: OP-300

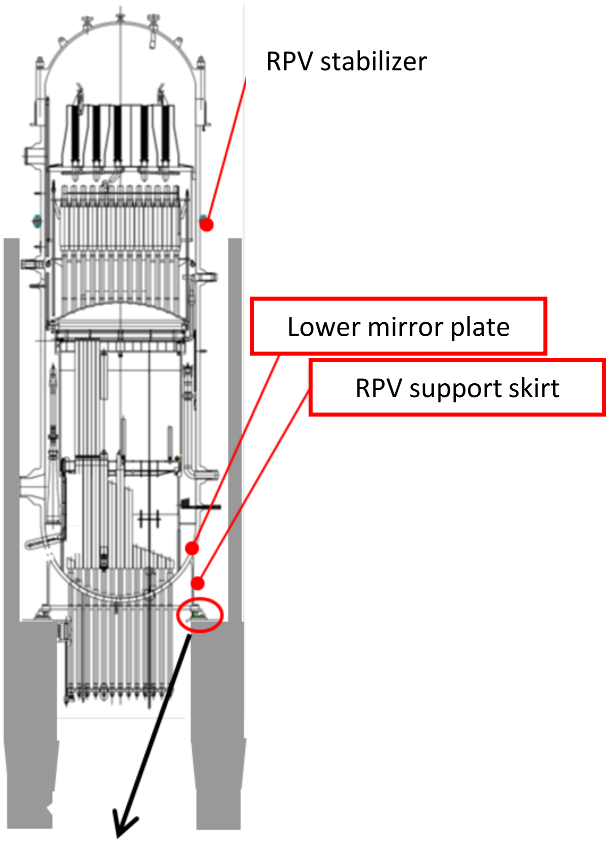
Seismic response analysis



Modeling building-equipment coordinated analysis (example)



Result of evaluation of structural integrity of RPV structures (example)



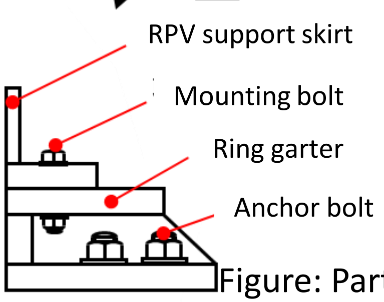


Figure: Parts evaluated

Support skirt (primary stress) (MPa)

Case	Unit 1		Unit 2		Unit 3	
	Stress	Permissible value	Stress	Permissible value	Stress	Permissible value
25-1	58	360	39	360	38	360
25-2	59		40		39	
25-3	59		71		61	

Support skirt (compression)

Case	Unit 1		Unit 2		Unit 3	
	Buckling*	Permissible value	Buckling*	Permissible value	Buckling*	Permissible value
25-1	0.188	1	0.113	1	0.112	1
25-2	0.192		0.118		0.115	
25-3	0.191		0.213		0.182	

*Left member of inequality expression of buckling: = αB(P/A)/fc +αB(M/Z)/fb (source: JEAC4601-2008)

Lower mirror plate (primary stress) (MPa)

Case	Unit 1		Unit 2		Unit 3	
	Stress	Permissible value	Stress	Permissible value	Stress	Permissible value
25-1	195	540	105	540	130	540
25-2	227		110		133	
25-3	227		104		124	

*: Strength of stress in this table indicates a value multiplied by a coefficient in accordance with the stress strength required for filing an application for factory license and taking the plant conditions into consideration.

Stress generated at all portions assessed was equal to or lower than the allowable stress.

Result of evaluation of structural integrity of PCV structures (example)

Evaluation result (Unit 1)

Conditions:

- Seismic condition: Ss wave
- Temperature: 50°C
- Service condition: Ds
- Corrosion wall thinning: See tables on the right.

<Evaluated cases>
Case 25-1: Equivalent to corrosion after 10 years
Case 25-2: Equivalent to corrosion after 15 years
Case 25-3: Equivalent to corrosion after 15 years

Estimated thinning of Unit 1 dry well (single side) (mm)

After accident	10 years	15 years
Estimated thinning	2.15	2.44

Estimated thinning of Unit 1 suppression chamber (single side) (mm)

After accident	10 years	15 years
Estimated thinning	1.09	1.36

(1)-1 Result of primary stress evaluation of D/W shell (part evaluated: Sand cushion) (thinning on both sides considered)

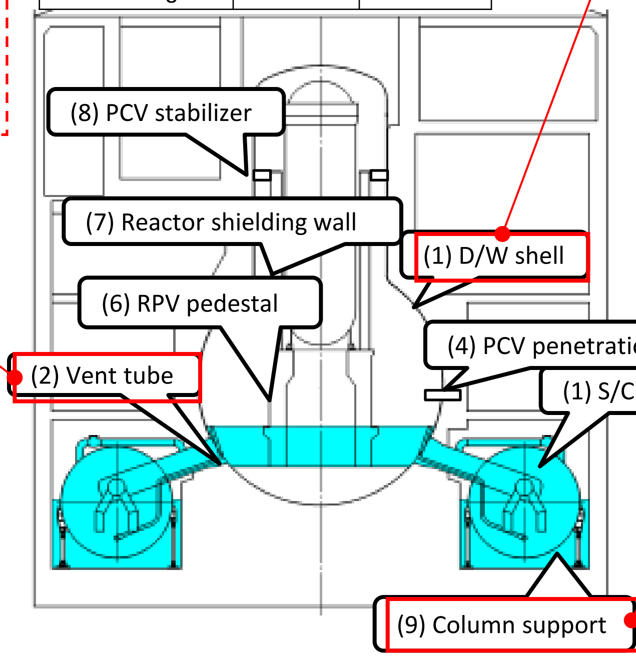
Case	Stress strength (MPa)	Permissible value (MPa)	Tolerance
25-1	124	423	3.41
25-2	140	423	3.02
25-3	128	423	3.30

Note: Allowable stress (fc and fb) of column support was evaluated with value F assumed to be value Su at room temperature (value F was 1.2Sy at compression).

Evaluation result:

(2) Result of evaluation of primary stress on vent tube (part evaluated: Joint between vent tube and D/W body

Case	Stress strength (MPa)	Permissible value (MPa)	Tolerance
25-1	117	423	3.61
25-2	142	423	2.97
25-3	144	423	2.93



Equipment evaluated (example: case 25-1)

(9) Result of evaluation of primary stress on column support (part evaluated: Outer column support)

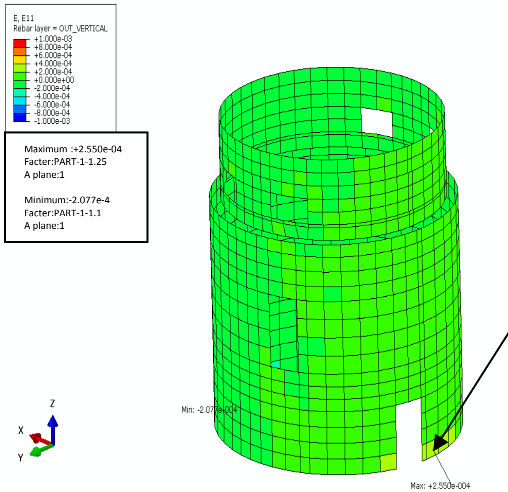
Case	Combined stress (compression + bend) $\Sigma_c/f_c + {}_c\sigma_b/f_b$	Permissible value	Tolerance
25-1	1.083	1	0.92
25-2	0.946	1	1.05
25-3	2.354	1	0.42

Generated stress of the parts evaluated as PCV boundary function was lower than the allowable stress but that of the suppression chamber support structures was higher. Countermeasures for detailed evaluation and reinforcement (such as burying the torus chamber with cement materials, etc.) will be studied in the future.

Result of evaluation of structural integrity of RPV pedestal (example)

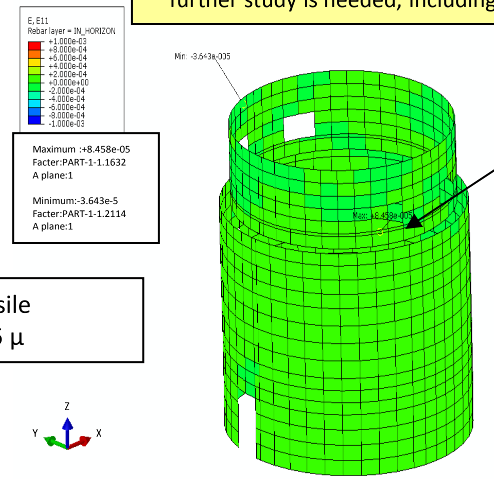
Evaluation result (Unit 1)

- Generated stress and distortion on all items evaluated were less than the evaluation criteria.
- At present, however, influences of corrosion by molten fuel debris are not taken into account and further study is needed, including how corrosion influences should be considered.



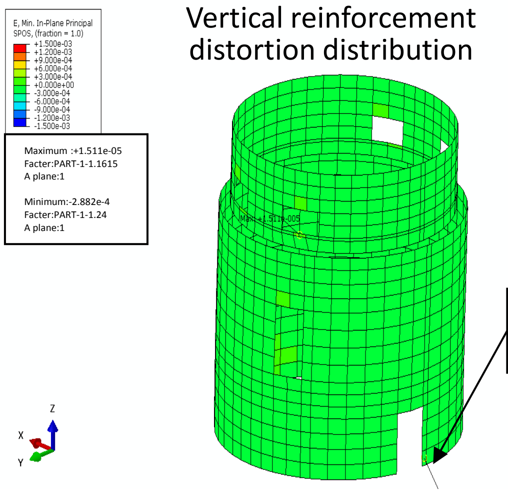
Maximum tensile distortion: 256 μ

Vertical reinforcement distortion distribution



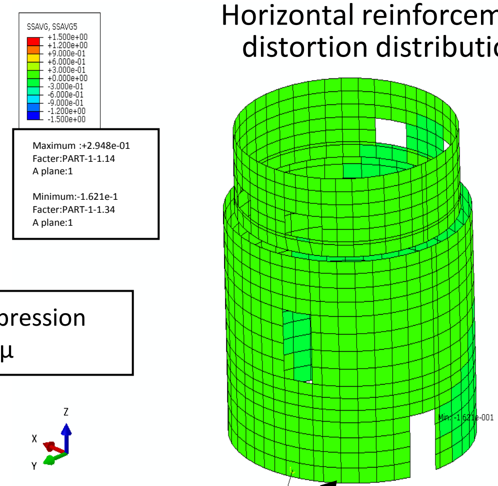
Maximum tensile distortion: 85 μ

Horizontal reinforcement distortion distribution



Maximum compression distortion: 289 μ

Distribution of major distortion of concrete



Distribution of antiplane shear stress

Maximum antiplane shear stress: 0.30 N/mm²

Evaluation result (case H25-2)

Item	Generated stress/ distortion	Criteria*1
Concrete distortion	289×10^{-6}	3000×10^{-6}
Reinforcement distortion	256×10^{-6}	5000×10^{-6}
Antiplane shear stress	354N/mm	1823N/mm

*1: Criteria were calculated based on "Standards of Nuclear Facilities for Power Generation – Concrete Reactor PCV Standards JSME S NC1-2003" of Japan Society of Mechanical Engineering.

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Actions in 2014 to 2015

Flow of feasibility assessment of PCV flooding method

(1) Preparing repair (reinforcement) measures in case tolerance was found not to be secured by equipment assessment in2013

[Equipment with no or lower tolerance]

- 1F-1: Column support
- 1F-2/3: Reactor shielding wall, column support, earthquake-resistance support

Consultation with developer of PCV repair technology

(2) Creating and analyzing seismic response analysis model (building-equipment coordination) with new plant information such as repair (reinforcement) and fuel retrieval equipment added

[Conditions of seismic response analysis]

- Two cases based on H25-2 and H25-3 of 2013
- Basic ground motion Ss (conventional Ss: Maximum acceleration of 600 Gal)
- Reactor building seismic response analysis model: Model used in 2013 to be reused

(3) Evaluation of earthquake resistance of equipment under calculated loading conditions

[Equipment to be evaluated]

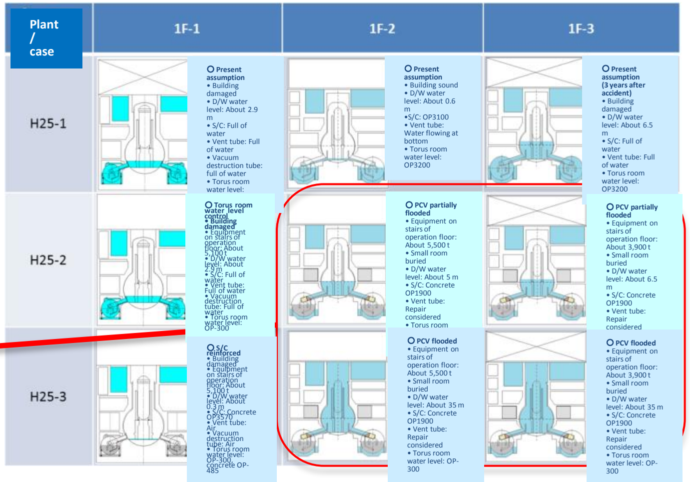
- Equipment to maintain functions of PCV flooding boundary and water-injection cooling equipment
- Excluding equipment to be repaired by development of PCV repair technology

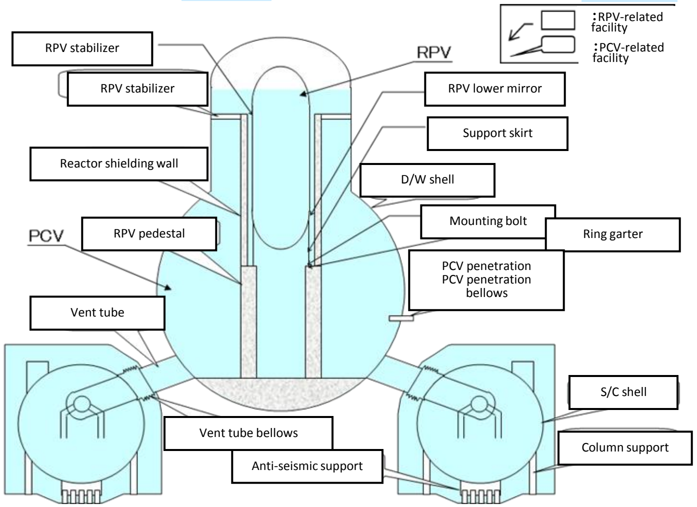
(4) Details of evaluation of equipment with low tolerance

[Detailed evaluation method]

- Evaluation simulating real plant by finite-element method, etc.
- Criteria (setting of allowable stress, etc.): Criteria that allow achieving maintenance of the functions required of equipment, without emphasizing current codes & standards, will be set up.

Seismic response analysis case conducted in 2013





Equipment to be evaluated (example)

2.Research and development related to preparations for retrieving fuel debris

Development of technologies for fuel debris containing/transfer/storage (2-(1)-6)

Explanatory CG for Submersion Method for Fuel Debris Retrieval

(2-(1)-6) Overview of development of technologies for retrieving fuel debris and core internals

◎ Technical method study

Based on required information on the plant status, development of related technologies, and investigation results, etc.., to study total scenario.

→ Many information will be comprehensively evaluated and unclear points should be assumed.
→ To be studied by the national project , including existing technical investigation.

◎ Problems to development of technologies to retrieve fuel debris

Problems common to retrieval of fuel debris, regardless of the technical methods, are as follows:

1) Cutting fuel debris
2) Remote operation
3) Prevention of expansion of contamination
4) Shielding
5) Criticality prevention

◎ Element test

Of the above problems, elements for cutting fuel debris, remote operation, and prevention of expansion of contamination to be tested.

(1) Cutting fuel debris
 1) Test to cut ceramic specimen
 2) Production of specimen
(2) Remote operation
 1) Long arm control technology
 2) Test models production of remote operated arm (including in cell)
(3) Prevention of expansion of contamination
 1) Selection of isolation film sheet

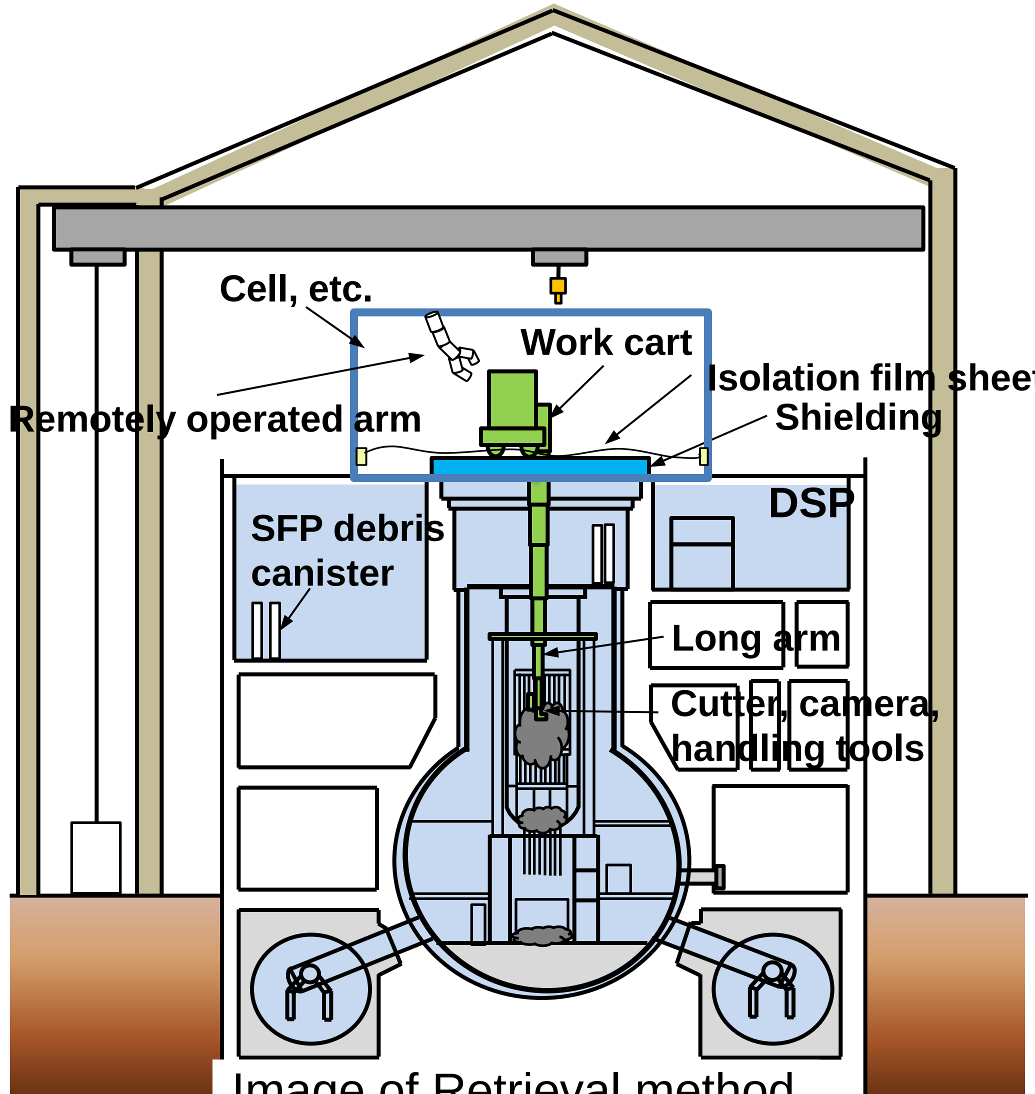


Image of Retrieval method

(2-(1)-6) Overview of development of technologies for retrieving fuel debris and core internals (2014 plan)

Major goal for 2014
To assess and plan a fuel debris retrieval technologies and plan research and development after examining and putting in order existing technologies for retrieving fuel debris from RPV or PCV up to 35 m beneath from the operation floor. Development of device will be started if possible.

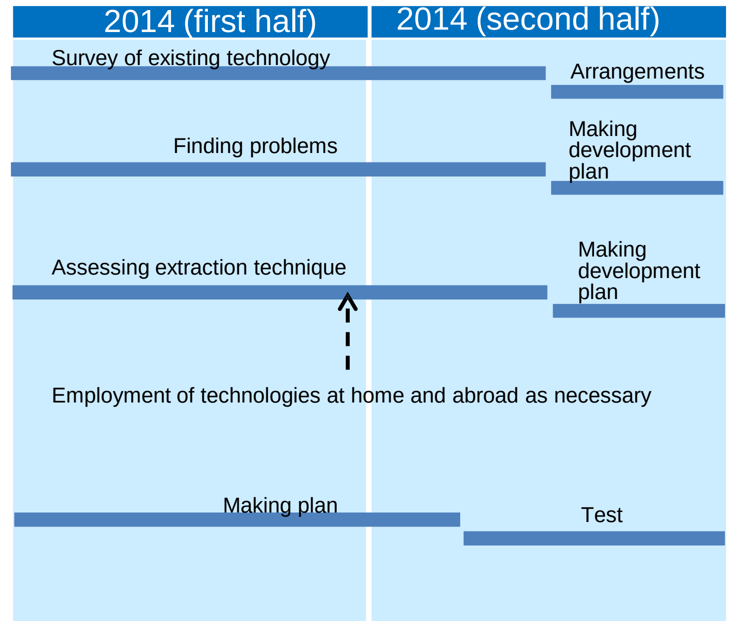
Actions in 2014

1. Examining existing technologies
   Examining and putting in order existing technologies (including equipment that experienced at TMI) necessary for retrieving fuel debris while referring to existing catalogs

2. Planning fuel debris retrieval technique and development
   Techniques for retrieval of fuel debris from RPV and PCV (such as a system to cool water when fuel debris is retrieved, radiation shielding, radioactive substance dispersion prevention measure, and method to contain fuel debris in canisters and transport the canisters, etc.) will be assessed and a development plan will be made.
   In making the plan, image processing systems and electronic devices will be evaluated, taking into consideration the fact that high radiation is emitted from fuel debris.
   * Research and development will be performed by eagerly adopting proposals on useful technologies and techniques, by using a mechanism to invite proposals on retrieving fuel debris from both Japan and abroad.

   * Techniques to retrieve fuel debris and core internals in water/air while taking into consideration the assumed environmental conditions, including the present plant conditions and the status of filling water at the upper part of PCV.

3. Development of equipment to retrieve fuel debris/element test
   Device test and device development will be started, reflecting the result of survey of existing technologies and development plan above. A test plan to process ceramic specimen simulating fuel debris will be made with technologies used at TMI to process and cut fuel debris and core internals, and a test to process ceramic specimen will be conducted.



Request for provision of information on alternative methods for fuel debris retrieval from home and abroad

Contents of RFI

Topic A: Internal PCV/RPV investigation

A-1:Conceptual study of method (following are samples)

1. Method of inserting investigation device such as cameras inside.
   a. Utilize current throughbore such as piping/penetration.
   b. Create new throughbore .
   c. Methods of Shielding penetrations and of equipment operation in terms of reduction of radiation exposure.
2. Method of detecting fuel debris location by measurement outside, etc.

A-2:Required technologies (following are samples)

1. Advanced measurement technology (camera, dosimeter, thermometer etc.)
   a. High performance optical equipment(camera etc.), other measurement technology (ultrasonic, laser etc.)
   b. Control technology of measuring instrument, and information transmission technology .
2. Technology to detect whether the substance in the reactor is fuel debris or not.

Topic B: Fuel debris retrieval

B-1:Conceptual study of method (following are samples)

1. Access to fuel debris from the top of PCV underwater
2. Access to fuel debris from the top of PCV in the air[*1]
3. Access to fuel debris from the side of PCV in the air[*1]
4. Access to fuel debris from the bottom of PCV in the air[*1]

*1 including partial submergence

B-2:Required technologies (following are samples)

1. Technology regarding fuel debris retrieval (cutting, suction).
2. Equipment/device such as remote control manipulator, with superior control capability from long distance.
3. Technology of shielding against fuel debris with high radiation.
4. Device and equipment under the high radiation environment.
5. Equipment/device to create a borehole on the building concrete and PCV to access from the side or bottom of the PCV.
6. Technology to store fuel debris safely in PCV/RPV before retrieving.

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Results of RFI

About 60% of information was provided from Japan, and about 40% from overseas countries.

	•Field of information for RFI	Total	Breakdown by country JPN	US	UK	GER	FRA	BEL	CAN	RUS
Topic A Internal PCV/RPV investigation	A-1：Conceptual study for the method.	33	20	7	3	-	2	-	1	-
	A-2：Required technology	58	32	6	10	6	2	2	-	-
Topic B Fuel debris retrieval	B-1：Conceptual study for the method	43	23	8	3	2	5	-	1	1
	B-2：Required technology	60	41	7	3	4	2	2	-	1
	Total (No. of items of information)	**194**	116	28	19	12	11	4	2	2

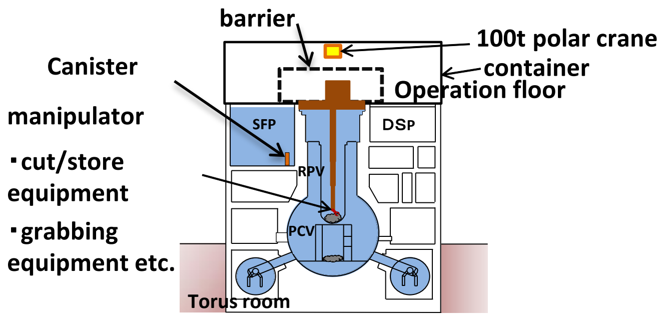
About 60% of responses comes from inside Japan
and 40% of responses from overseas

Comparison of Submersion and Dry method

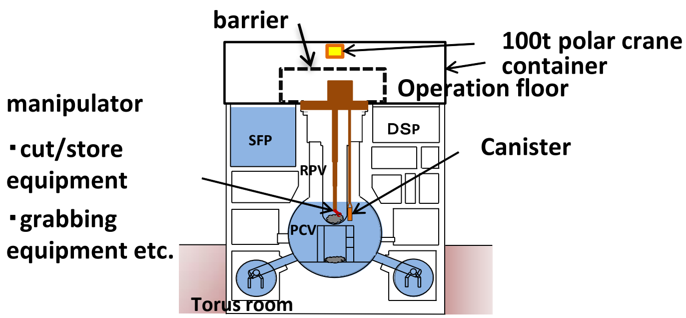
<u>Submersion method</u>　Method to retrieve fuel debris in a submerged condition in which fuel debris is cut and stored under water.
<u>Dry method</u>　Alternative method, in which fuel debris is cut and stored in air, or cut underwater but stored in air, against the Submersion method.

Examples

Submersion method

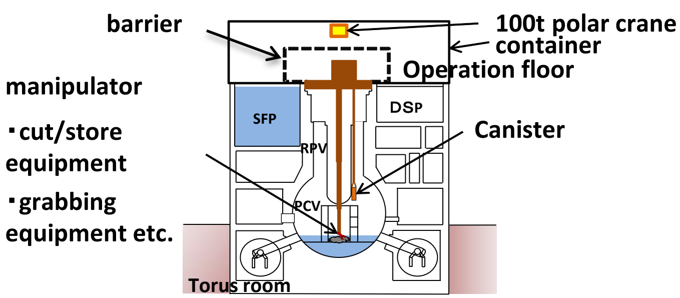


Fuel debris cut and stored under water

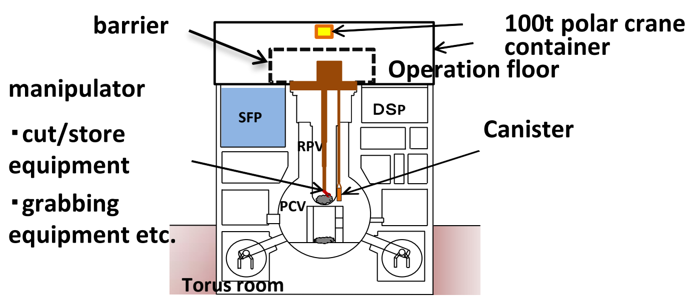


Fuel debris cut and stored under water (PCV partial submersion)

Dry method



Fuel debris stored in air



Fuel debris cut and stored in air

Categorizing Provided Information

A: PCV/RPV internal investigation

A-1: Conceptual study

1st tier classification	No.	2nd tier classification	Number of responses
Placing equipment in PCV/RPV	1	From top (through new boreholes)	1
	2	From side (through existing penetrations)	3
	3	From side (through new boreholes)	3
Measurement from outside of PCV	4	From side	2
	5	From bottom	1

A-2: Support technology

1st tier classification	No.	2nd tier classification	Number of responses
Direct measurement	6	Radiation	8
	7	Thermal	1
	8	Element analysis	2 (2)
Direct observation	9	Camera	10
	10	Fiber scope	2
	11	Ultrasonic waves	6
	12	Laser scanner	2
	13	Others	1
Indirect measurement	14	Muon	4
	15	X-rays, γ-rays and neutron	3
	16	AE method	1
Work environments maintenance	17	Criticality control & exposure simulation	5
	18	Water level	2
	19	Hot cell	1
	20	Lighting	1
Access technology	21	Manipulator	5
	22	Robot (underwater)	2
	23	Robot (land)	6
	24	Robot (amphibious)	6
	25	Cutting and boring tools	6
	26	Radiation-resistant components	10

∗ Category of topics may be different from the one registered by applicant since IRID individually re-evaluates the information. The number in the bracket is the one of RFI submitted for Contaminated water issue, which is re-evaluated from the viewpoint of RFI for fuel debris.

Categorizing Provided Information

B: Debris retrieval from PCV/RPV / C：Others

B-1: Conceptual study

1st tier classification	No.	2nd tier classification	Number of responses
Submersion method	27	From top	5
	28	From bottom	2
Dry method	29	From top	7
	30	From top - from side (combined approach)	7
	31	From side	7
	32	From bottom	4 (1)
Others	33	Chemical method	3
	34	Other than PCV/RPV	2
	35	Others	2 (6)

B-2: Support technology

1st tier classification	No.	2nd tier classification	Number of responses
Debris cutting	36	Mechanical	5 (2)
	37	Thermal (plasma)	1
	38	Thermal (laser)	8 (1)
Debris retrieval	39	Sorting	4
	40	Category	1
	41	Container (for temporary storage)	4
Work environments maintenance	42	Exposure management	2
	43	Shielding	5 (1)
	44	Decontamination of containers	3
	45	Water stoppage	2 (2)
	46	Water treatment	3
Access technology	47	Manipulator	12
	48	Robot (for debris retrieval)	3 (1)
	49	Cutting and boring tools	1

C：Others

1st tier classification	No.	2nd tier classification	Number of responses
Outside the scope of RFI	50	Outside the scope of RFI	7

- Submersion method (both processes of cutting off fuel debris and storing into storage container are carried out underwater).
- Dry method (either or both processes of cutting and storing fuel debris is carried out in the air).

Example of RFP Responses

\- Representative Method -

Internal Investigation

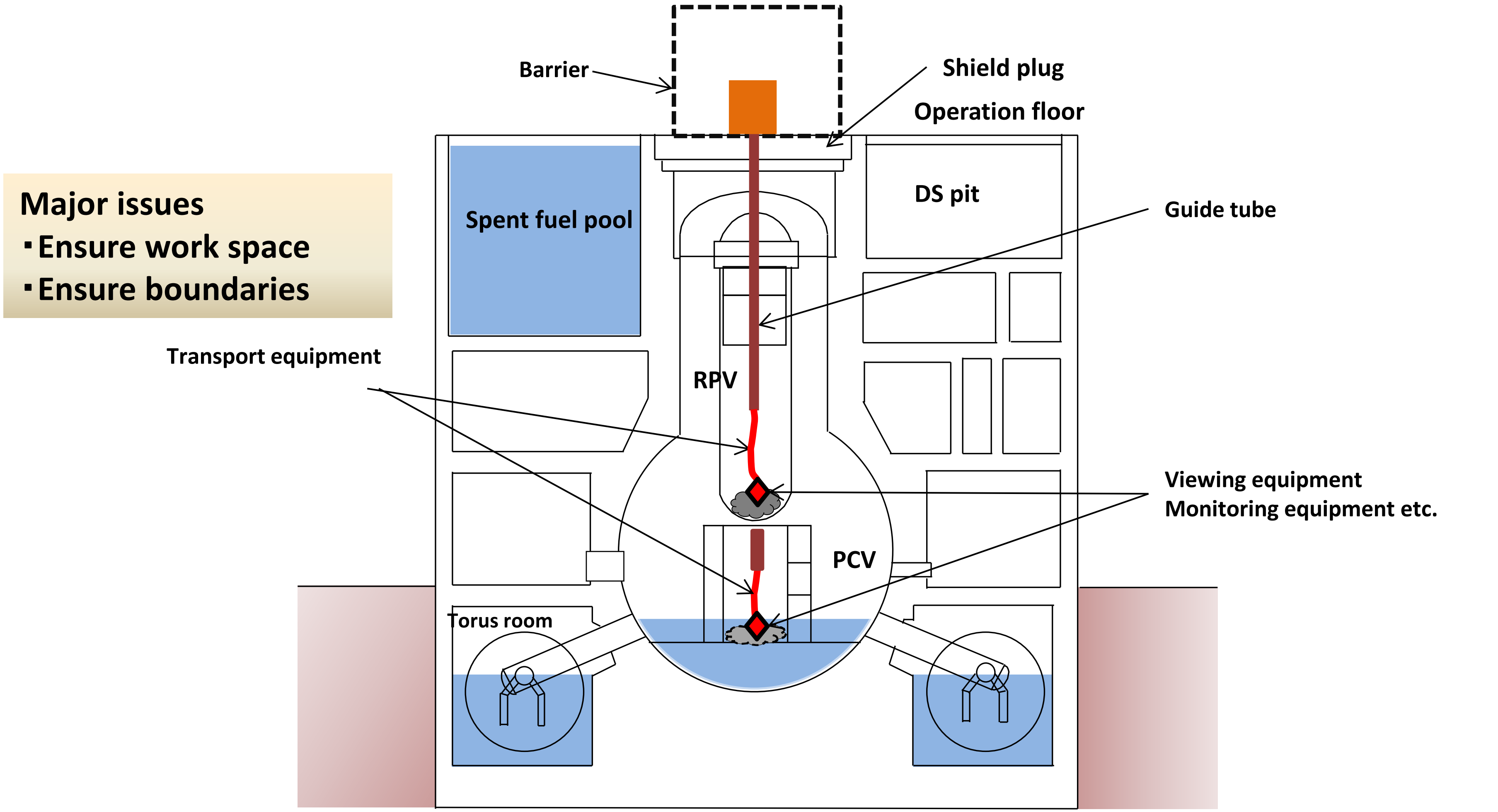
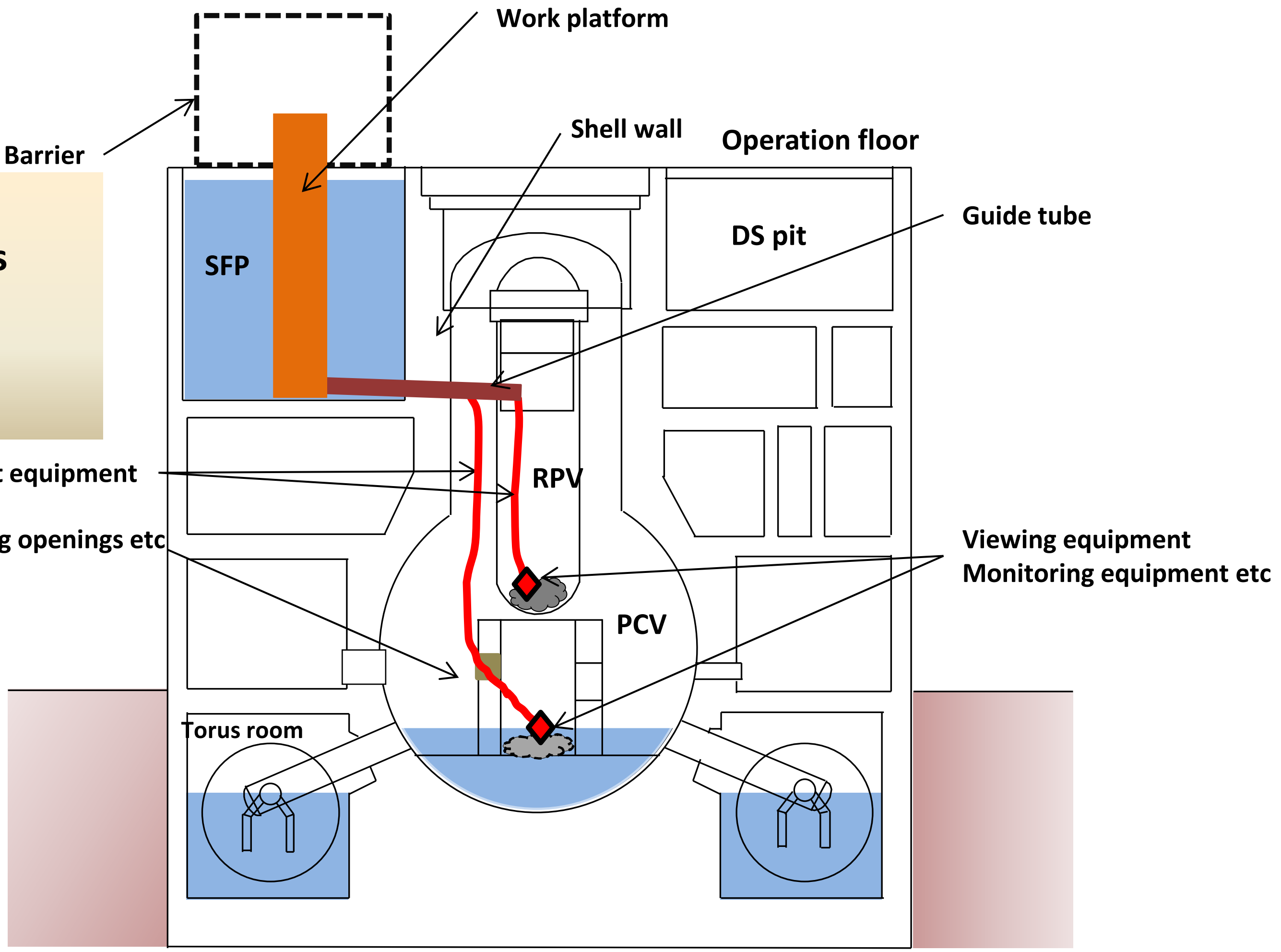


Fig. Method to drill from the top (from shield plug)

Internal Investigation



Major issues
- **Ensure boundaries**
- **Location of drilling/drilling technology**

Fig. Method to drill from the top (from SFP)

Internal Investigation

Major issues

- **Access distance**
- **Access method to RPV**

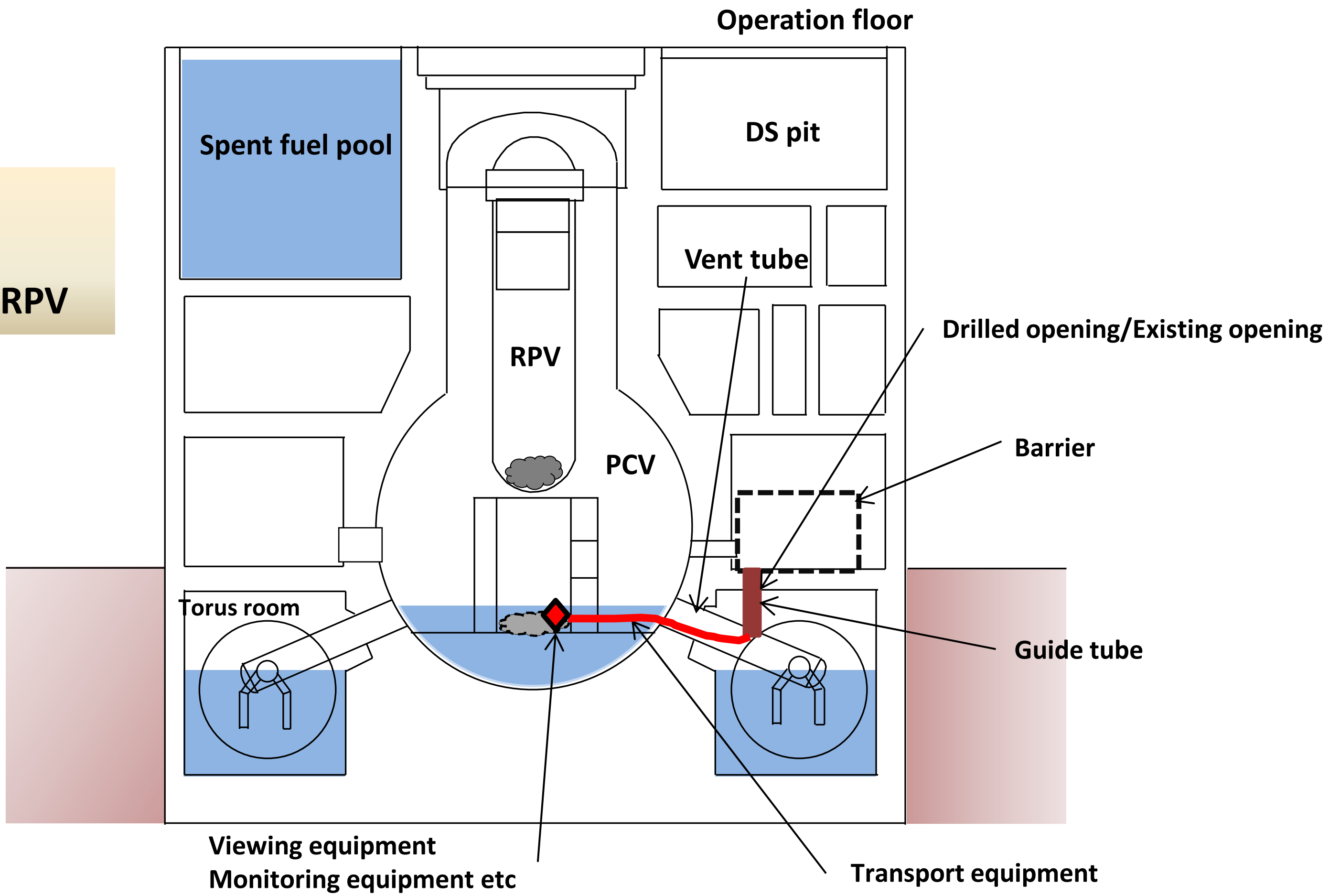
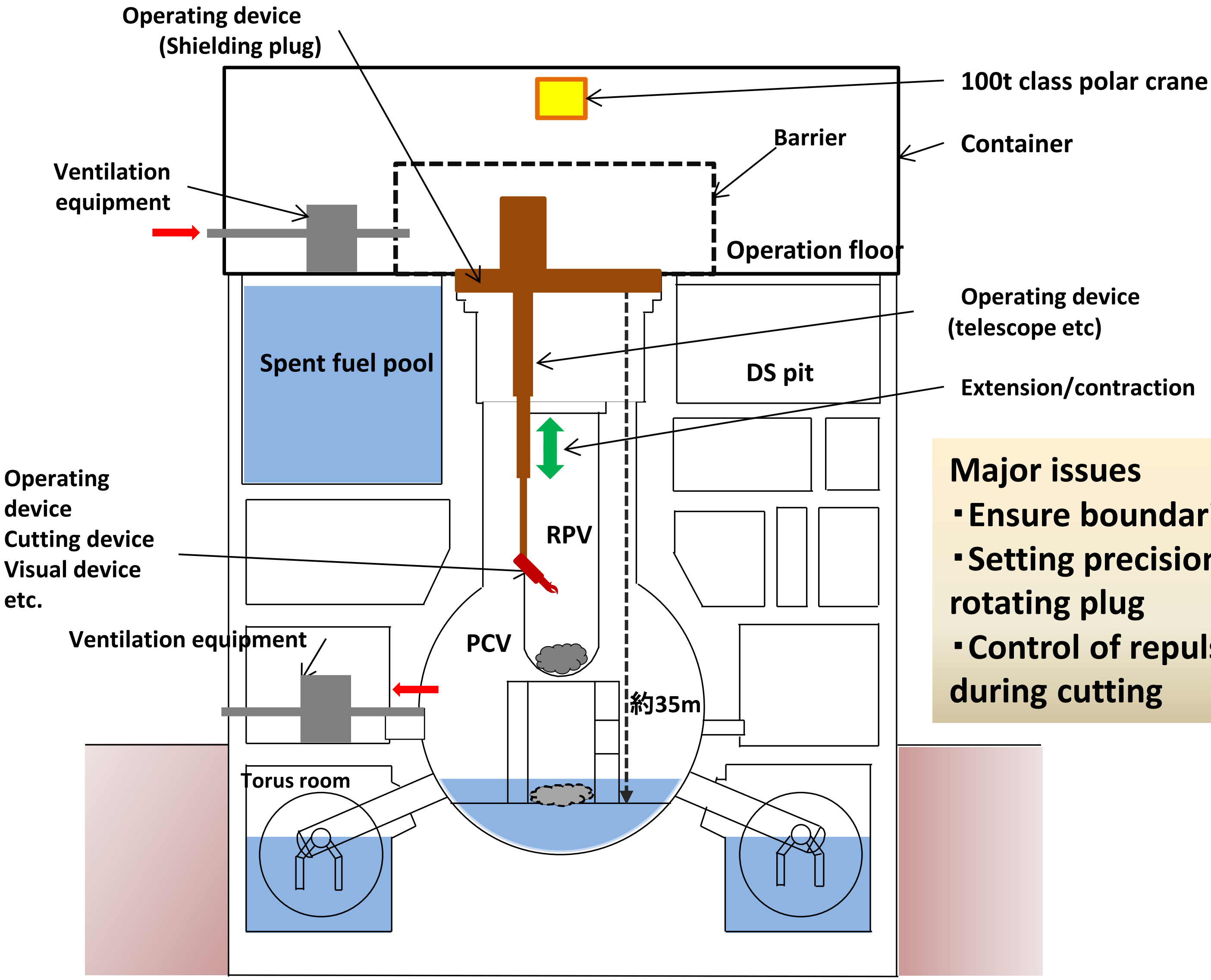


Fig. Method to survey lower PCV from vent

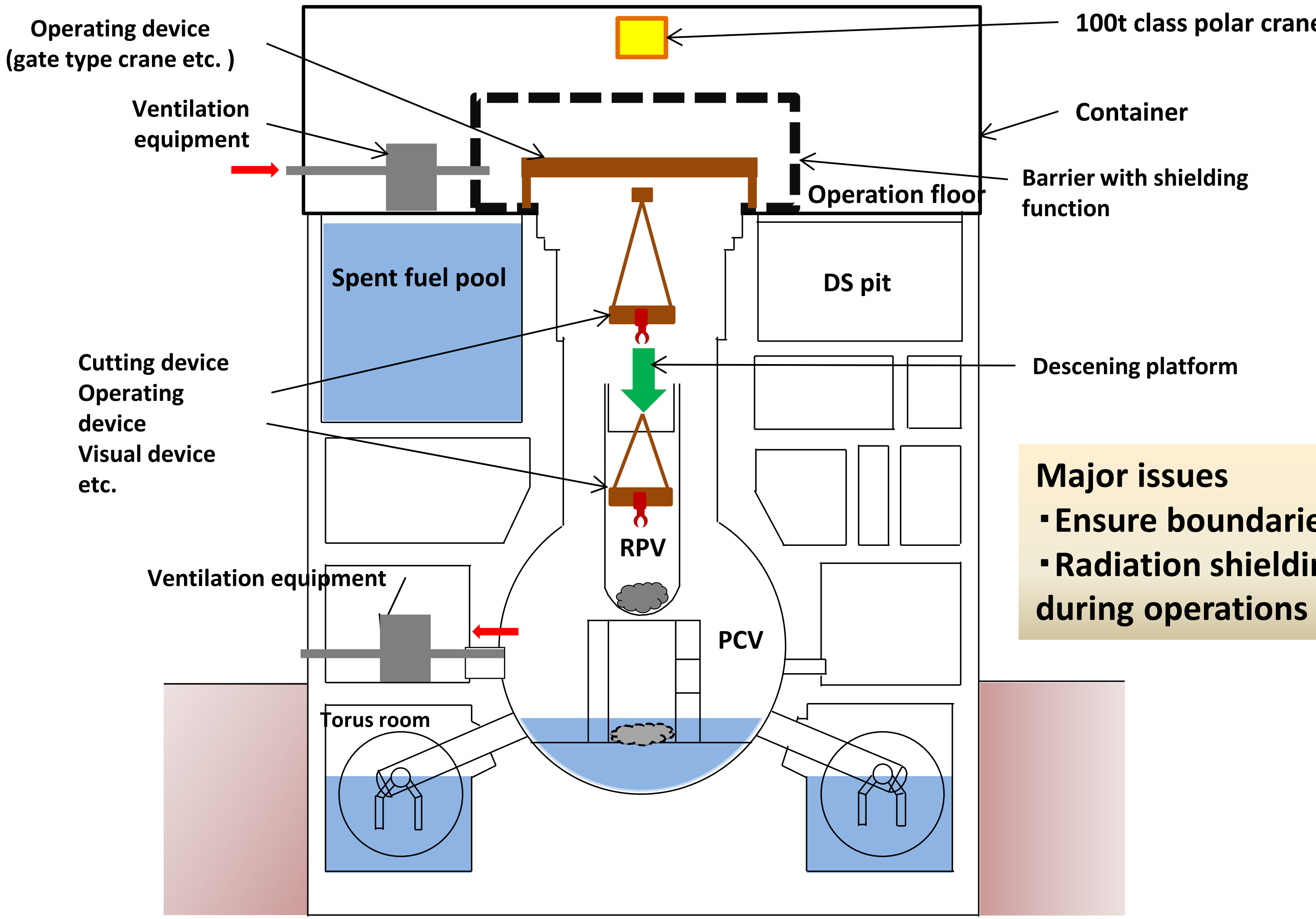
Fuel Debris Retrieval



Major issues
- Ensure boundaries
- Setting precision of the rotating plug
- Control of repulsive force during cutting

Fig. Method to retrieve fuel debris in air by rotating plug

Fuel debris retrieval



Major issues
- **Ensure boundaries**
- **Radiation shielding during operations**

Fig. Method to retrieve fuel debris in air by descending work platform

Fuel debris retrieval

Major issues
- **Ensure boundaries**
- **Radiation shielding during operations**
- **Location of entrance opening**

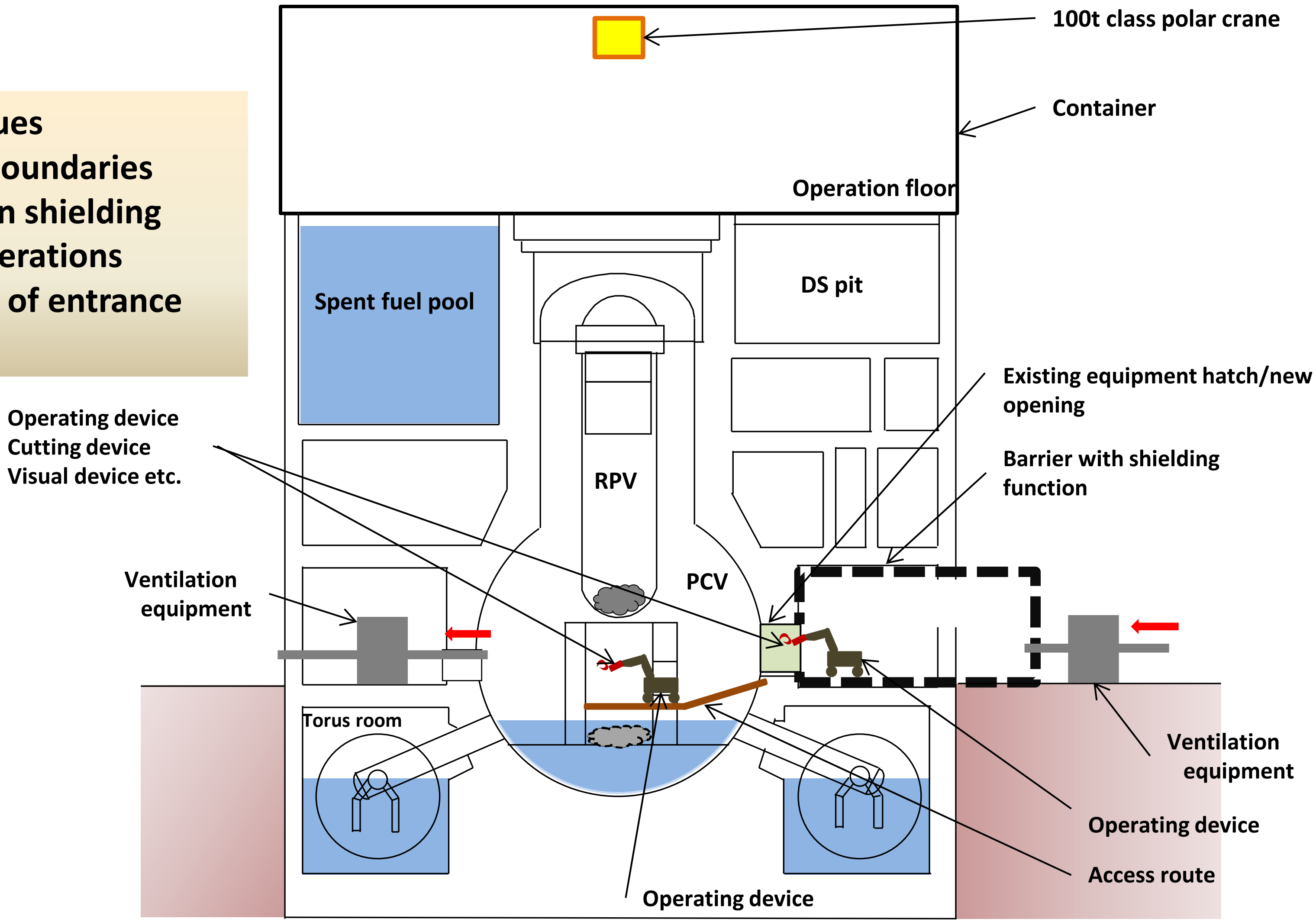


Fig. Method to retrieve fuel debris in air from the side

RFP for Conceptual Study of Innovative Approach for Fuel Debris Retrieval and Feasibility Study of Essential Technology

RFP has been processing by MRI since 27 June.
Fuel debris investigation team of IRID is performing technical support.

Description of the projects	
Project 1: Conceptual Study of Innovative Approach of Fuel Debris Retrieval	To conduct conceptual study for the method to retrieve the fuel debris in the air in a safe and stable condition
Project 2: Feasibility Study of Visual and Measurement Technology for Innovative Approach	To conduct feasibility study of technology to realize practical application of compact and light-weighted visual equipment with lighting function, and measurement equipment to characterize the properties of the objects both of which can be used under the very high radiation environment
Project 3: Feasibility Study of Fuel Debris Cutting and Dust Collection Technology for Innovative Approach	To conduct feasibility study of technology to realize practical application of the equipment capable of cutting the fuel debris (with dust collection function)

Remarks) Proposal of technologies for transfer debris or cutting the concrete / steel wall surface will be requested as necessary when the specific method is adopted.

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Finally, - Toward retrieving fuel debris -

- Retrieving fuel debris of Fukushima Daiichi is expected to be more difficult than TMI-2. It is therefore necessary to gather knowledge and information domestically and internationally for developing overall strategy for fuel debris retrievable.

- To retrieve fuel debris, it is necessary to make a plan best-suited for the entire related projects and to develop technologies flexibly while making clear the purpose and goal of each project.

- To formulate a strategy, it is important to consider the end state (what should be done in the end) and study various feasible options. As a result, it is important always to prepare alternatives, as well as the first idea.