IAEA International Experts' Meeting on Strengthening Research and Development Effectiveness in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant

R&D activities related to the fuel debris retrieval from the Fukushima Daiichi NPS

International Research Institute for Nuclear Decommissioning (IRID)

February 19, 2015

*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 2013 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.

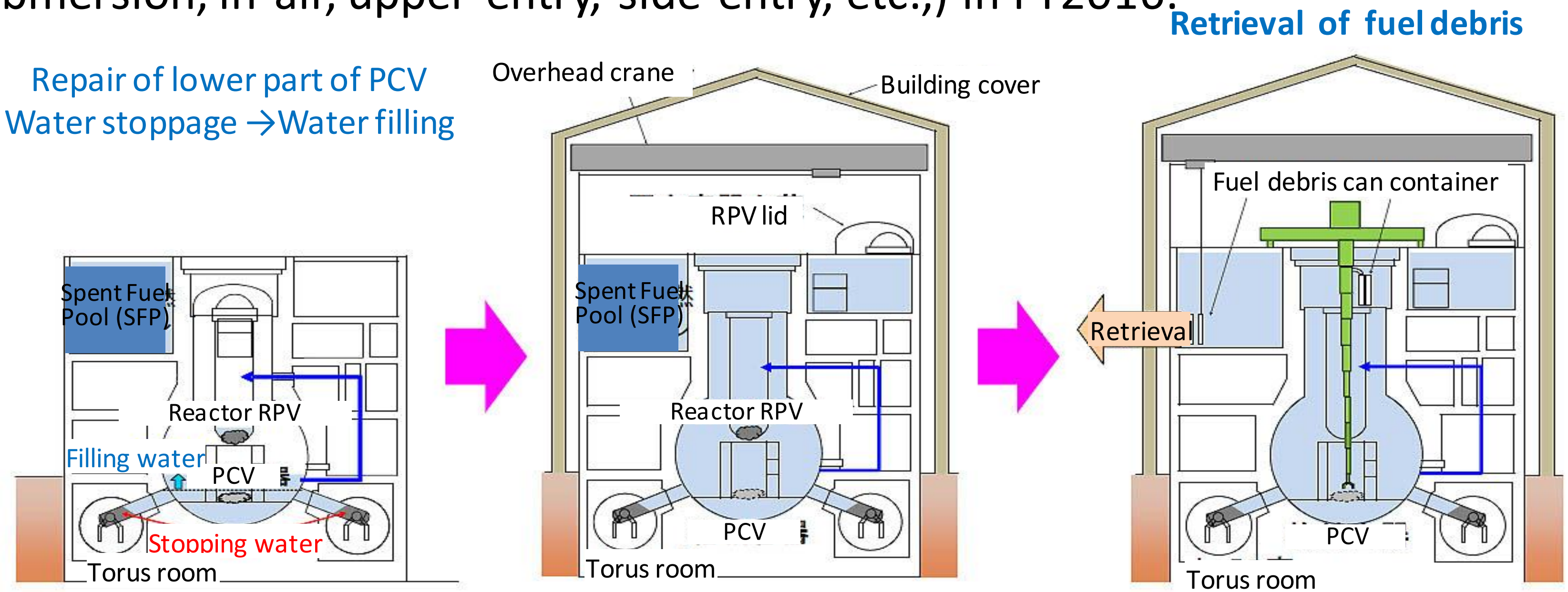
Concept image of work steps for fuel debris retrieval

■Retrieving the fuel debris submerged in water is a favorable approach from the standpoint of minimizing exposure of workers.

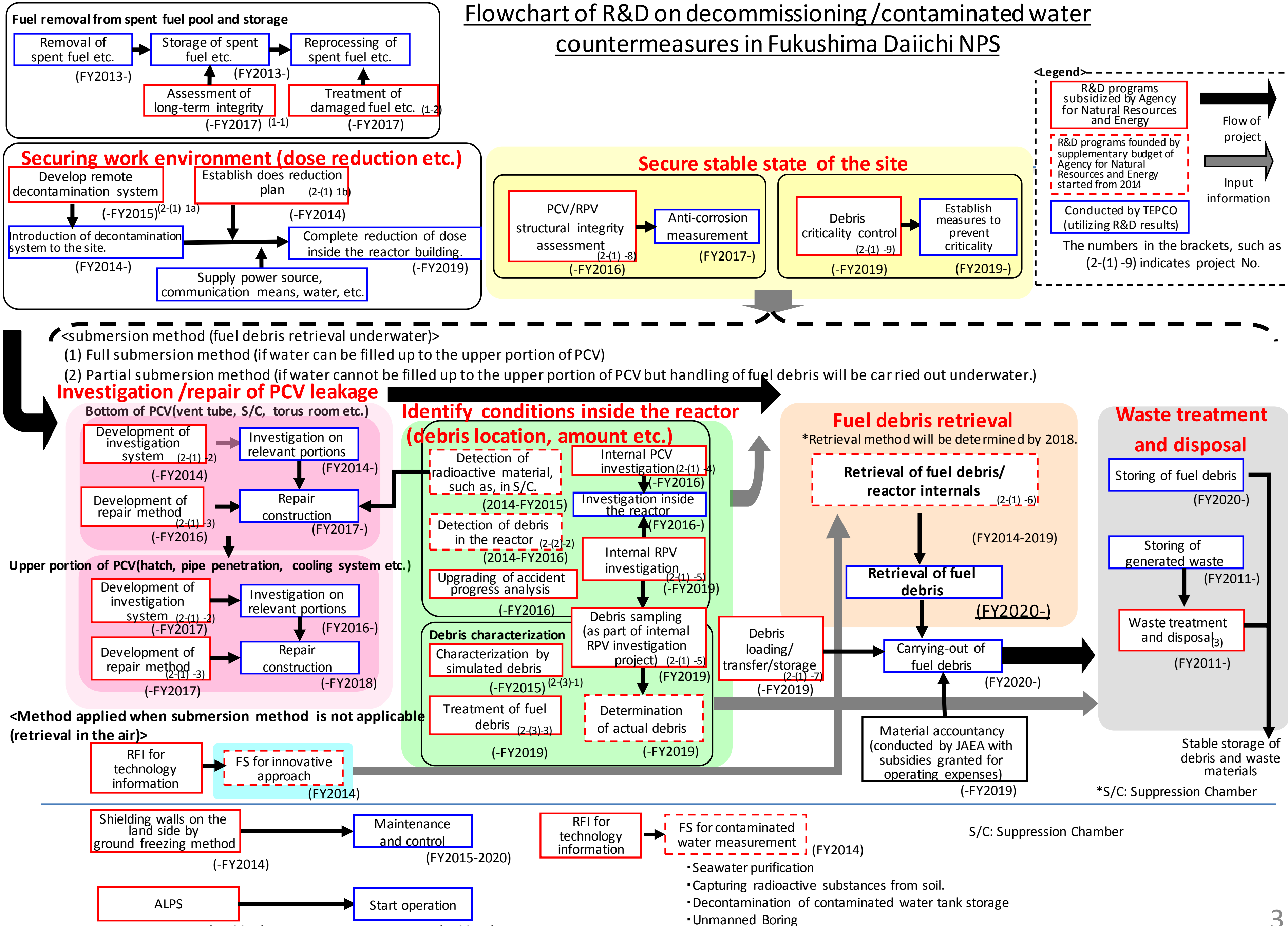
■Investigation and repairing methods for filling the PCV with water have been studied.

■ Furthermore R&D for the retrieval, packing and storage of fuel debris is in progress.

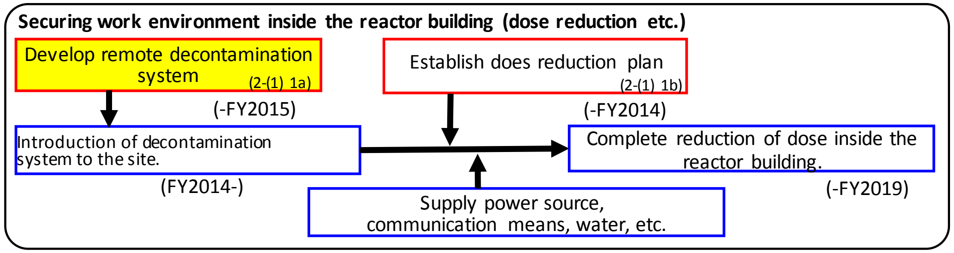
■Retrieval method will be chosen from among candidate methods (submersion, in-air, upper-entry, side-entry, etc.,) in FY2016.



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



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

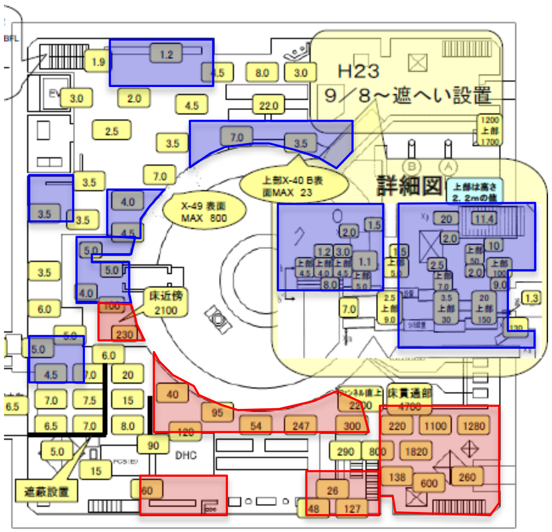
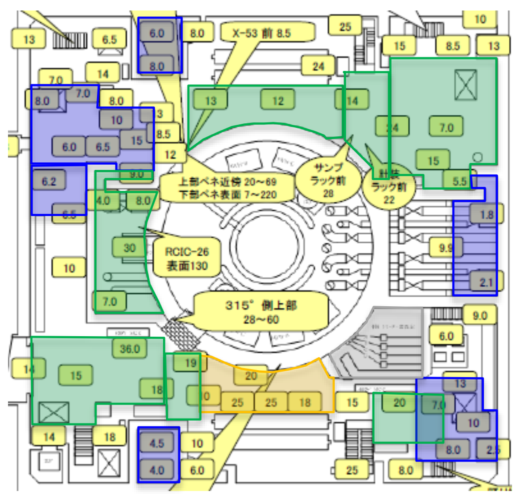
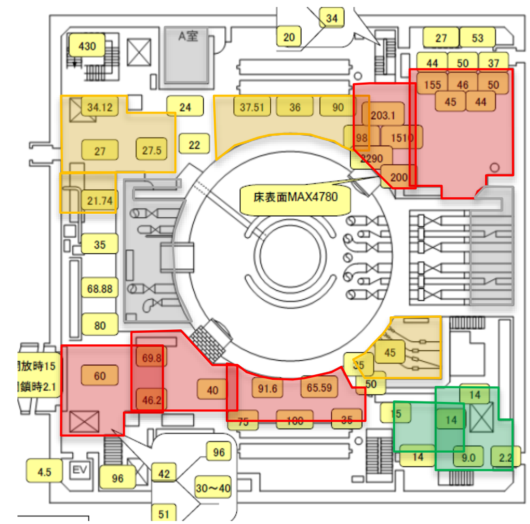


Dose rate goal for decontamination equipment

◆ Development goal of the decontamination equipment

(the needs for PCV leakage investigation repairing work, and overall dose reduction scenario)

3 mSv/h for work area　　　5 mSv/h for access route

	Unit 1	Unit 2	Unit 3
Needs for dose reduction* and the dose rate			
Building conditions	The dose rate s are low in whole; **about 1 to 10mSv/h** The rates have been high in south area, some parts in southeast area measures **5,000mSv/h**	Used to be 2〜60mSv/h (In 2014 Oct, the rates were about **5~10mSv/h** because of decontamination in lower/middle parts and shielding)	The dose rates are high in whole; about **20〜100mSv/h**

＊mapping results of the dose rates at planned operation area(with needs of dose reduction) derived from PCV investigation and repair project

- Blue: 3mSv/h to10mSv/h
- Green: 10mSv/h to 20mSv/h
- Yellow: 20mSv/h to 50mSv/h
- Red: more than 50mSv/h
- Grey: out of study due to the lack of data

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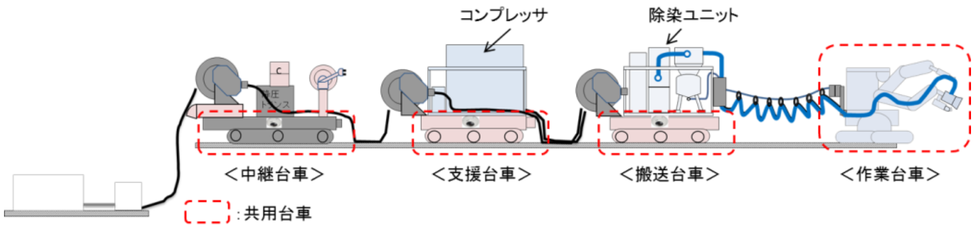
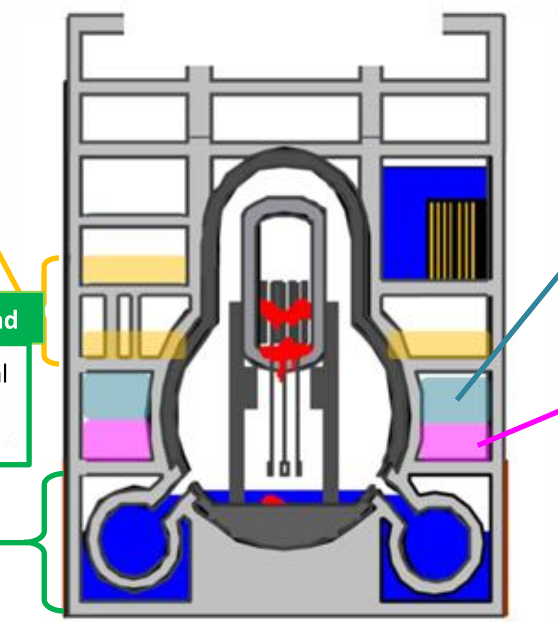
Overall Plan（Developed decontamination equipment and development status）

Decontamination equipment for upper floors

・FY2013 : design
・FY2014-2015 : production, verification test, applicability study of actual device



上部階用除染装置の概念図（ブラスト装置を搭載した例）

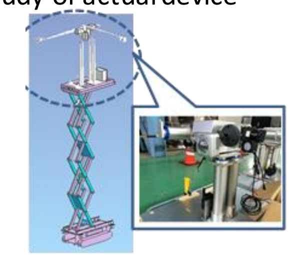


Equipment for underground

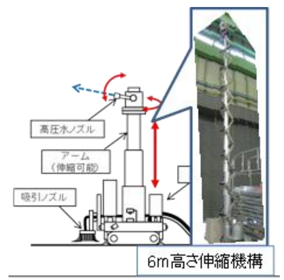
・FY2014 : Study of technical challenges ,development planning

Decontamination equipment for high places

・FY2013 : design, production
・FY2014-2015 : improvement, verification test, applicability study of actual device



Dry ice blast

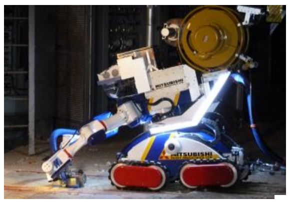


High pressure water jet

Suction /blast

Decontamination equipment for low places＜Development completed＞

・FY2011-2012 : design, production, test in 2F
・FY2013 : improvement, verification test (factory, 1F)

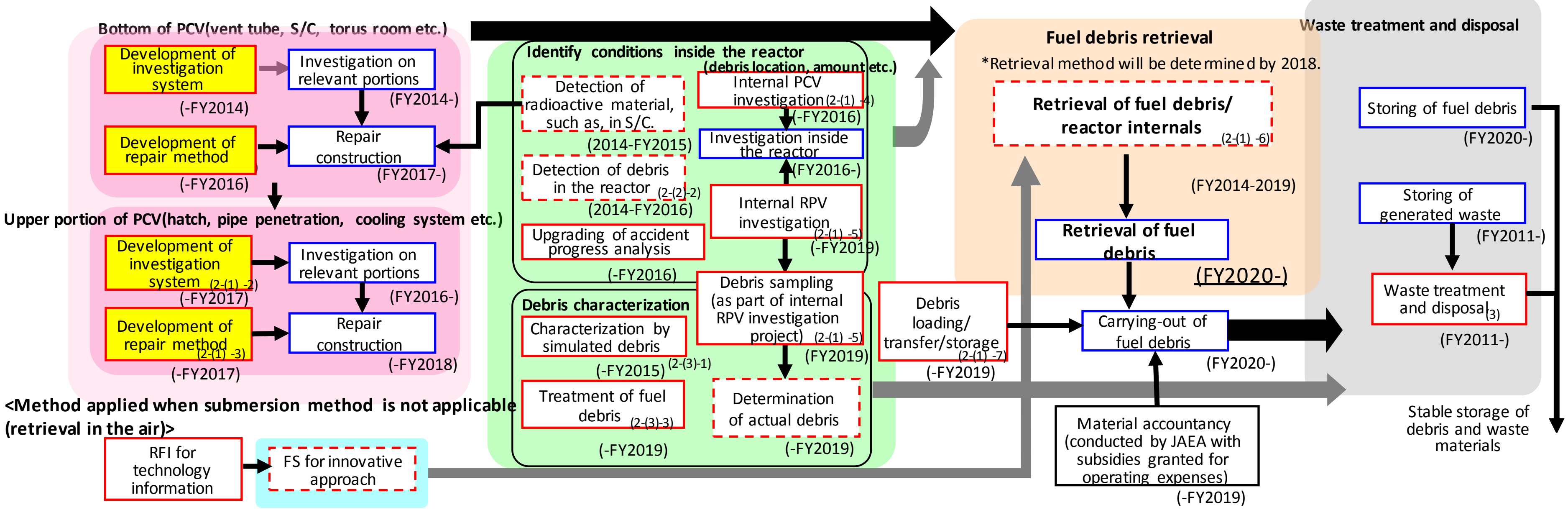


Suction /blast

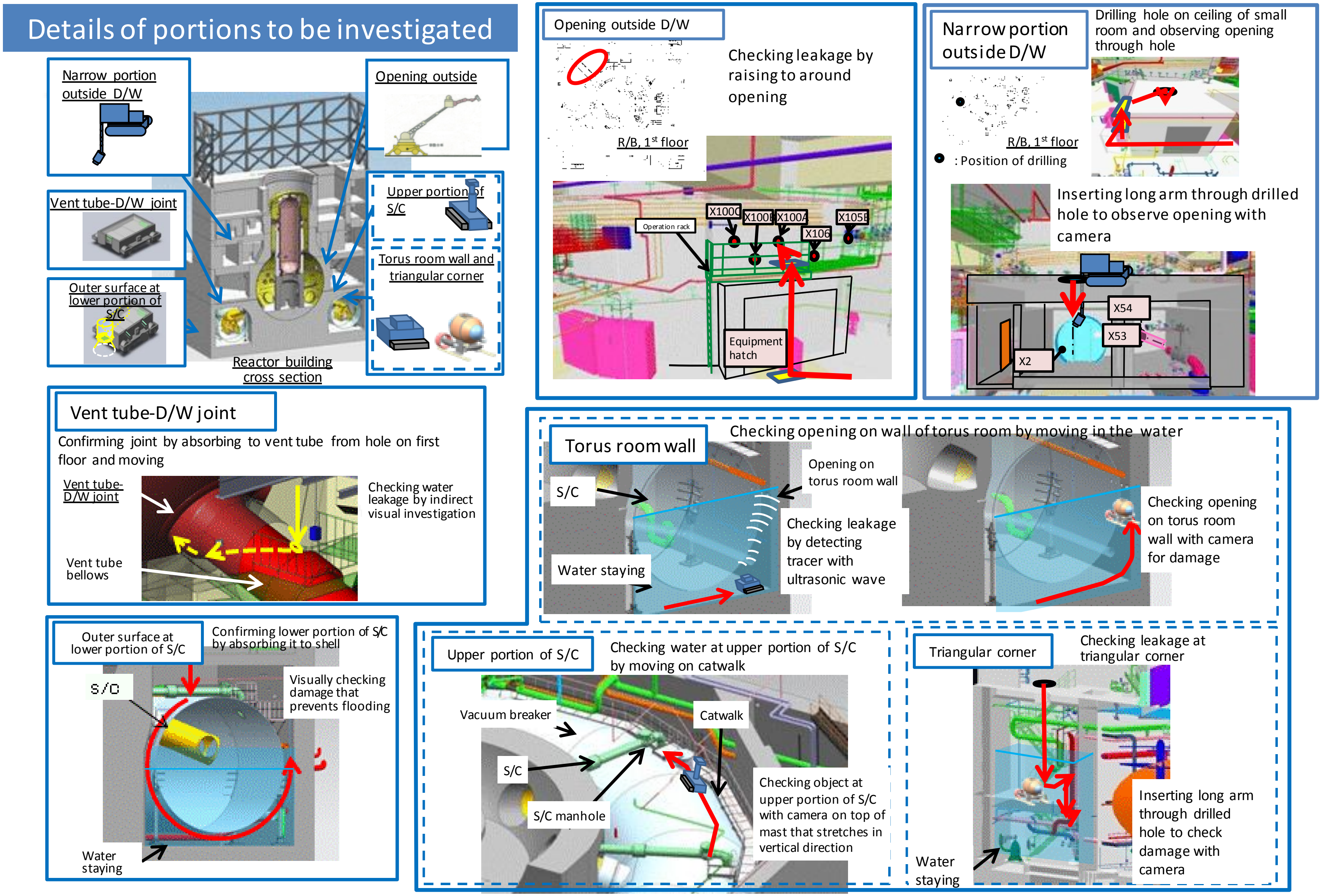
High pressure water jet

Dry ice blast

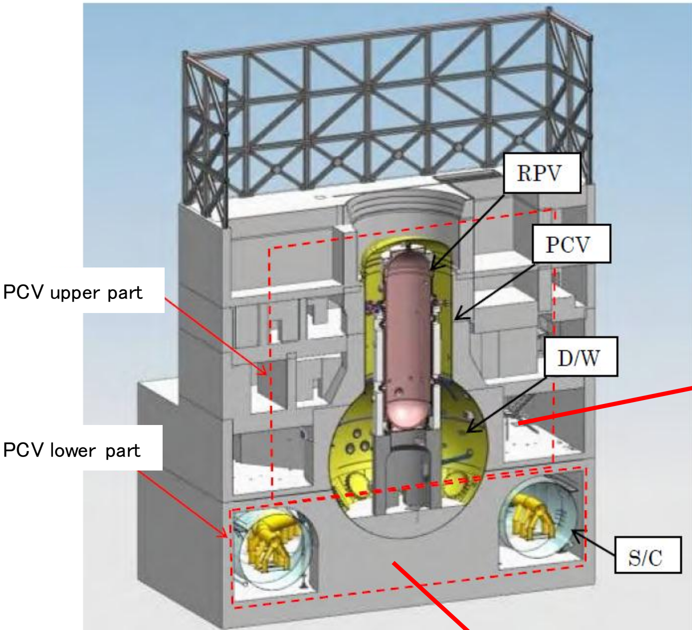
Development of technologies for investigation and repair (stopping water) toward filling PCV with water (2-(1)-2 & 3)

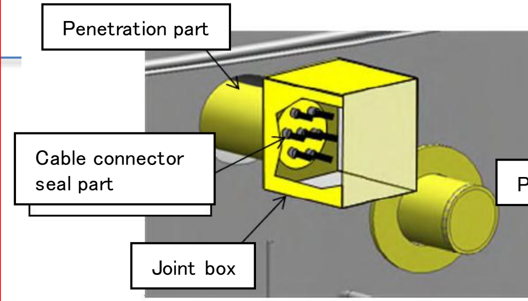


Development of investigation equipment for PCV water leakage

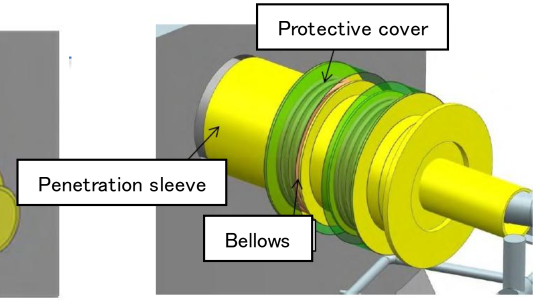


Development of PCV repair technology





Electric wiring penetration



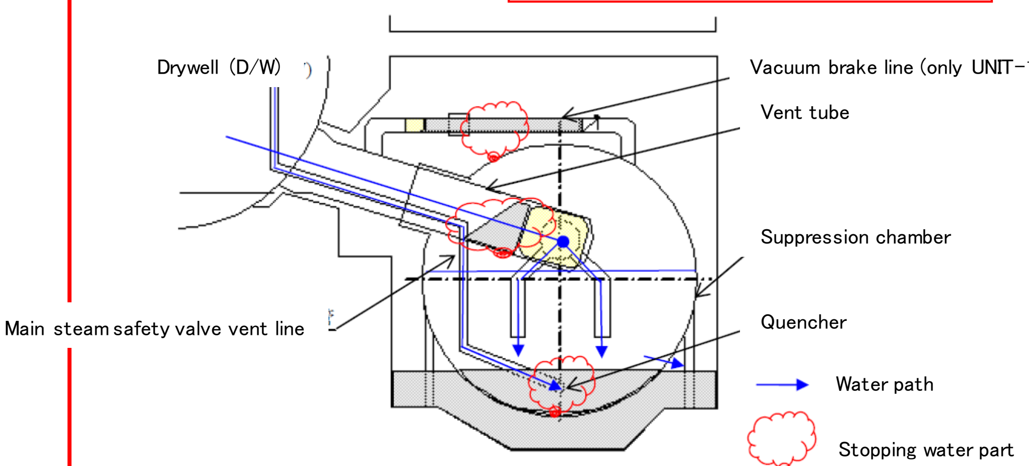
Bellows of tube penetration

Part for repair of PCV upper part

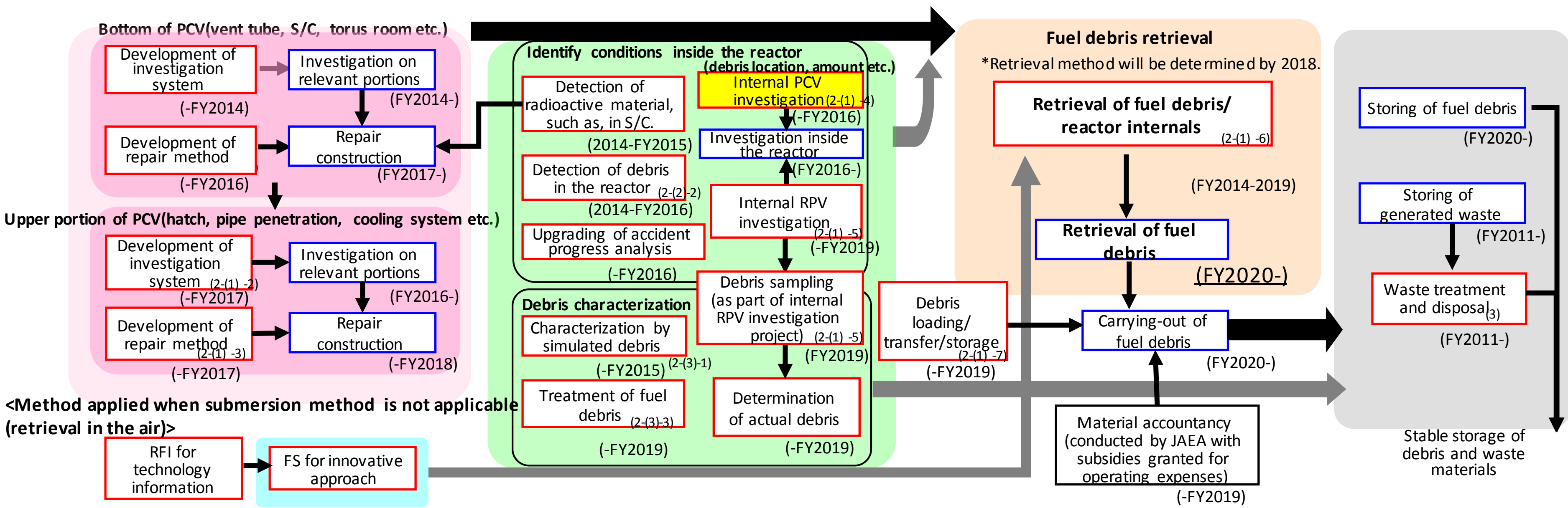
PCV upper part

Apparatus hatch

Part for repair of PCV lower part



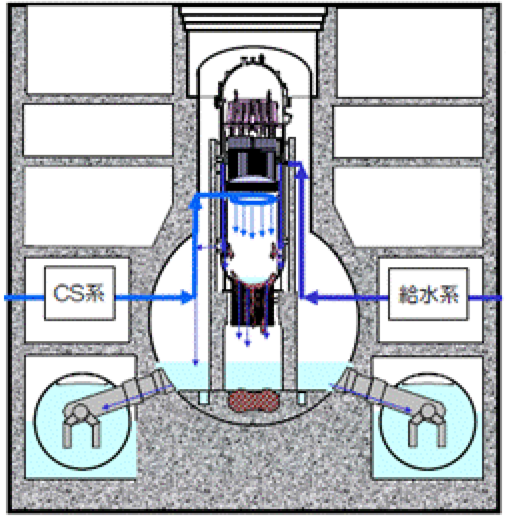
Development of technologies for investigating inside of PCV(2-(1)-4)



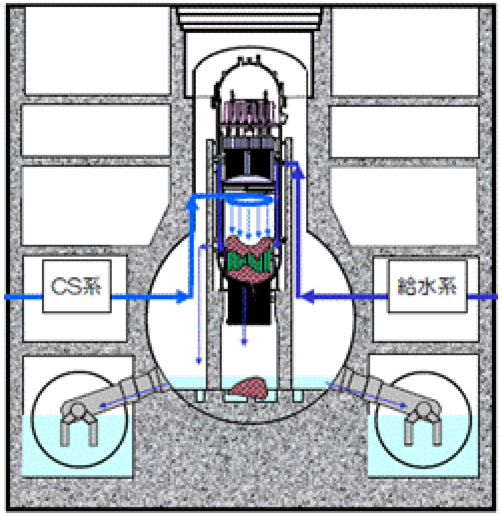
Development plan for investigation method and device

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

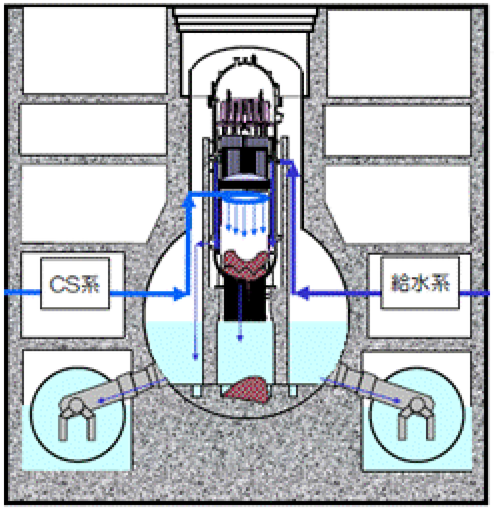
Unit 1



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.

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*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"

Development Steps of Each Unit (Unit 1)

[Investigated area] : **- Outside the pedestal on the basement floor**
- Near the access entrance of RPV pedestal

(1) Investigations from the X-100B penetration（～FY2015）: B1, B2

(Currently, dose rate near the X-6 penetration is very high.)

(2) Investigation from X-6 (FY2016～FY2017): B3

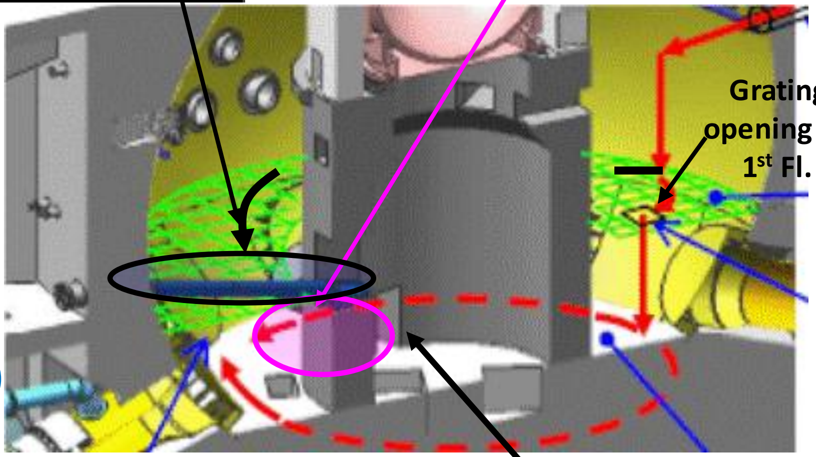
(After decontamination near X-6 penetration)

Investigation to obtain information using debris shape measurement apparatus outside the pedestal on the basement Fl.

B1. Investigation outside the pedestal on the first Fl (grating).

B2. Investigation outside the pedestal on the basement Fl.

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



B3. Investigation outside the pedestal on the basement Fl. And workers entrance

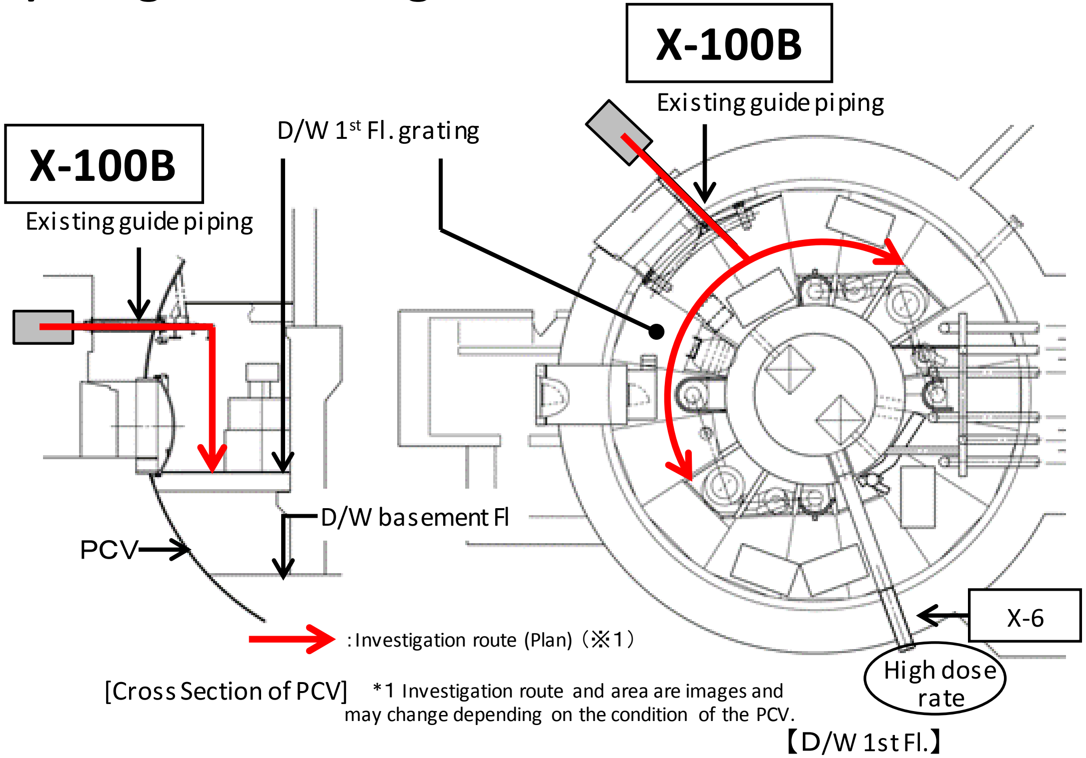
Investigation inside the pedestal may be conducted depending on the investigation of Unit 2.

Status of Development (Equipment for outside pedestal)

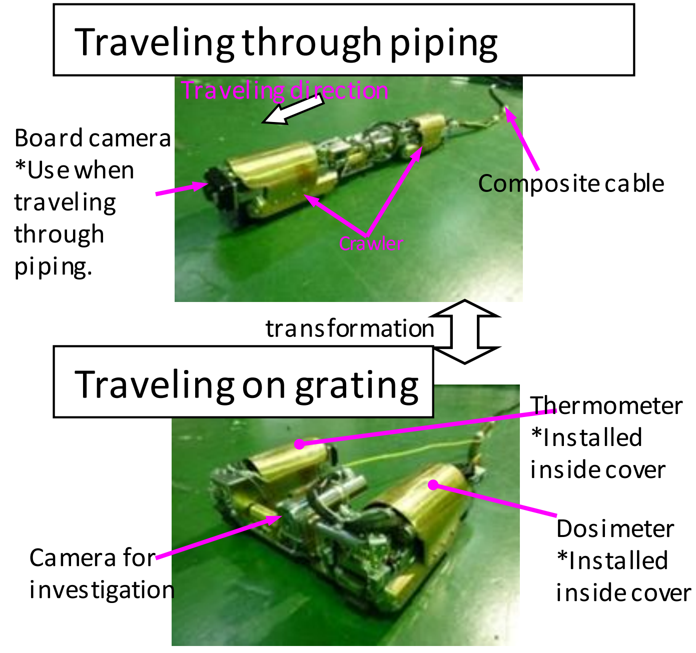
(1)Overview of equipment

- Shape-changing crawler equipment
- Inserted from the narrow access entrance (X-100B penetration : ϕ100mm)
- Travel on grating stably.

(2) Image of investigation route



Internal PCV investigation route (Plan)



Features of equipment

Development Steps of Each Unit (Unit 2)

[Investigated area] : - On the platform (Upper surface of platform, CRD housing)
- Basement floor

(1) Investigation from X-6 penetration（Φ115mm)（Early FY2015）: A2

(2) Investigation from X-6（Enlarge hole）（FY2016～2017）: A3,A4

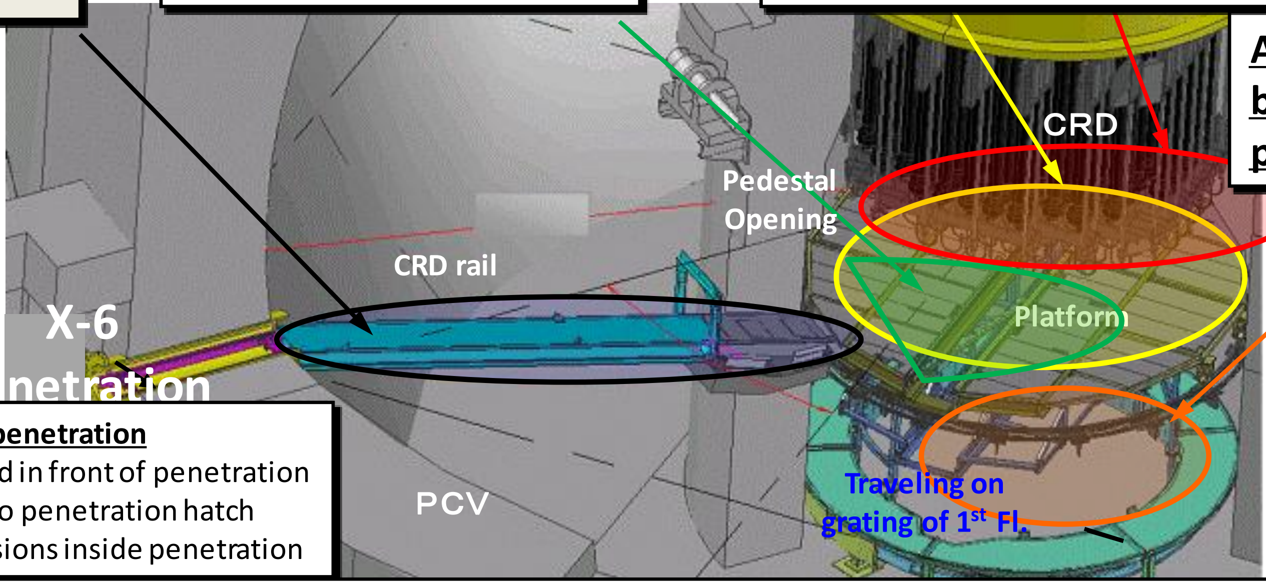
・Insert debris visualization system, investigate inside pedestal.

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

A2. Investigation on platform inside pedestal

A3. Investigation of CRD Hsg and on platform (detail)

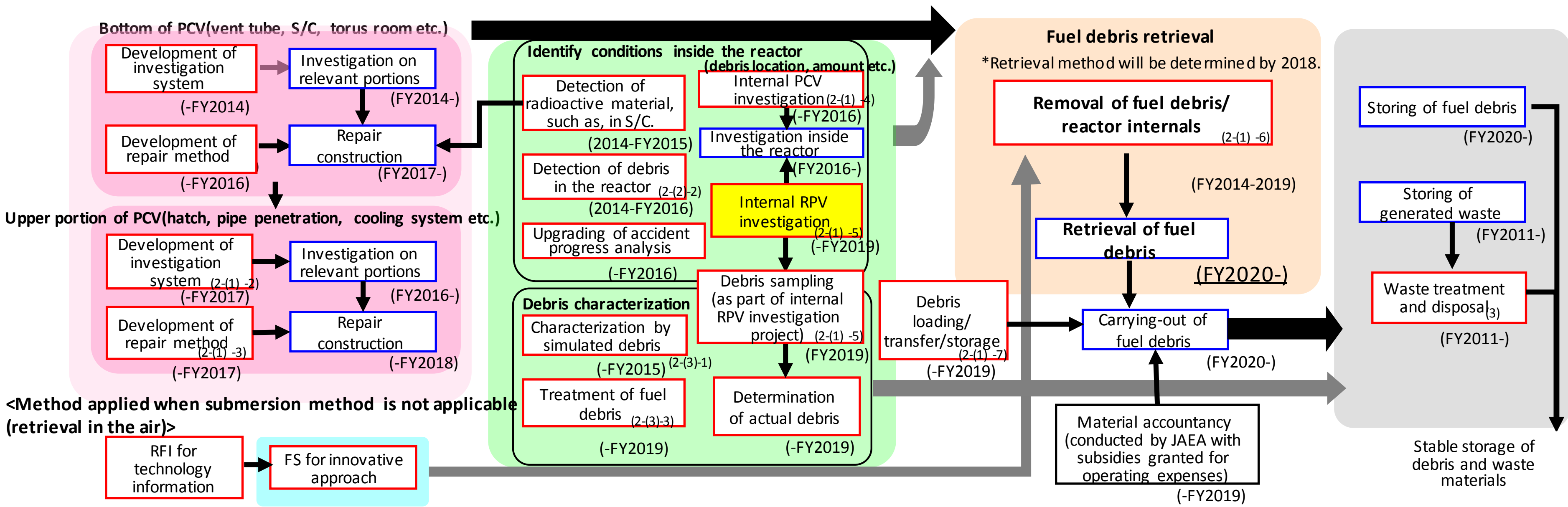
A4. Investigation on basement inside pedestal



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

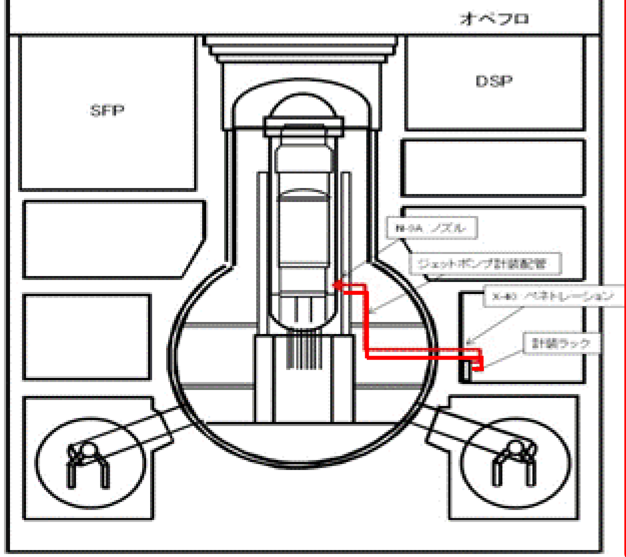


Study of access route to inside RPV

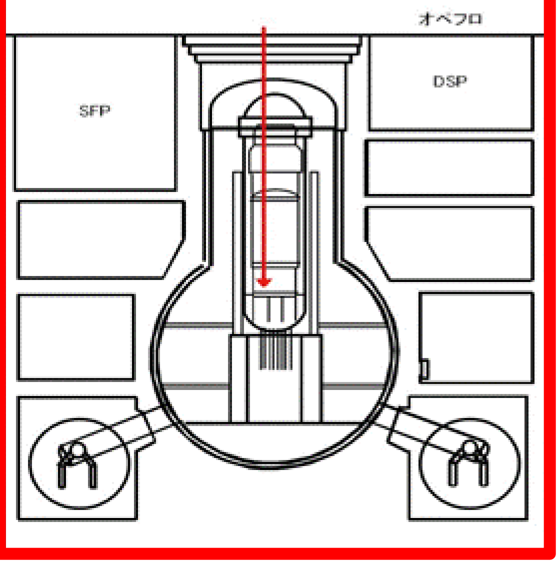
Table Development plan of access technology (sample of access by drilling on the upper section of RPV)

No	Development technology element	Issues	2014	2015	2016	2017	2018
1	Boring technology	Creating access hole for the steam dryer and separator					
2	Tube hole 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 constructing technology	Boundary constructing on the operation floor (sealed plug)					

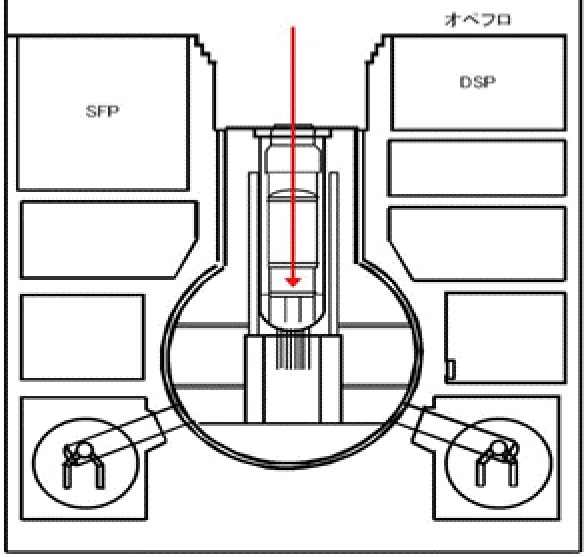
Access through piping systems



Access via drilling hole on the upper section of RPV

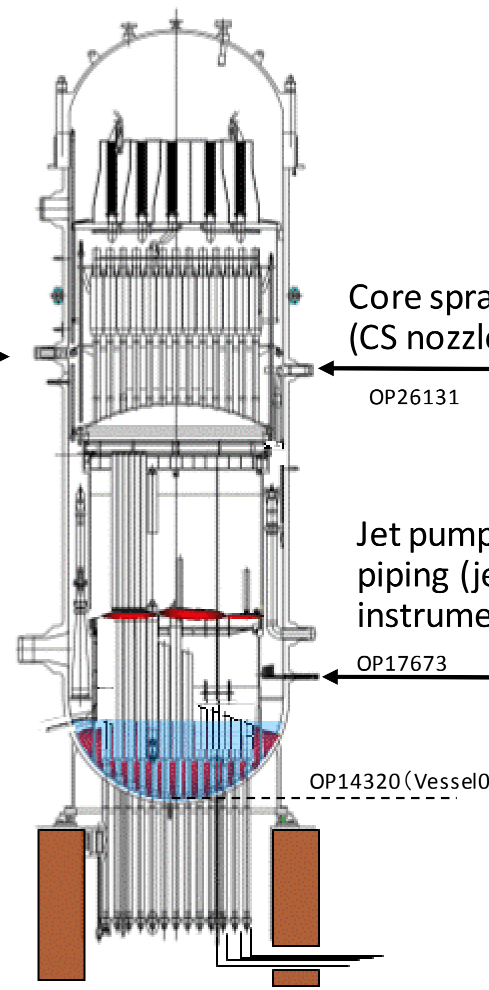


Access after RPV opened



Access route to investigate inside RPV

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

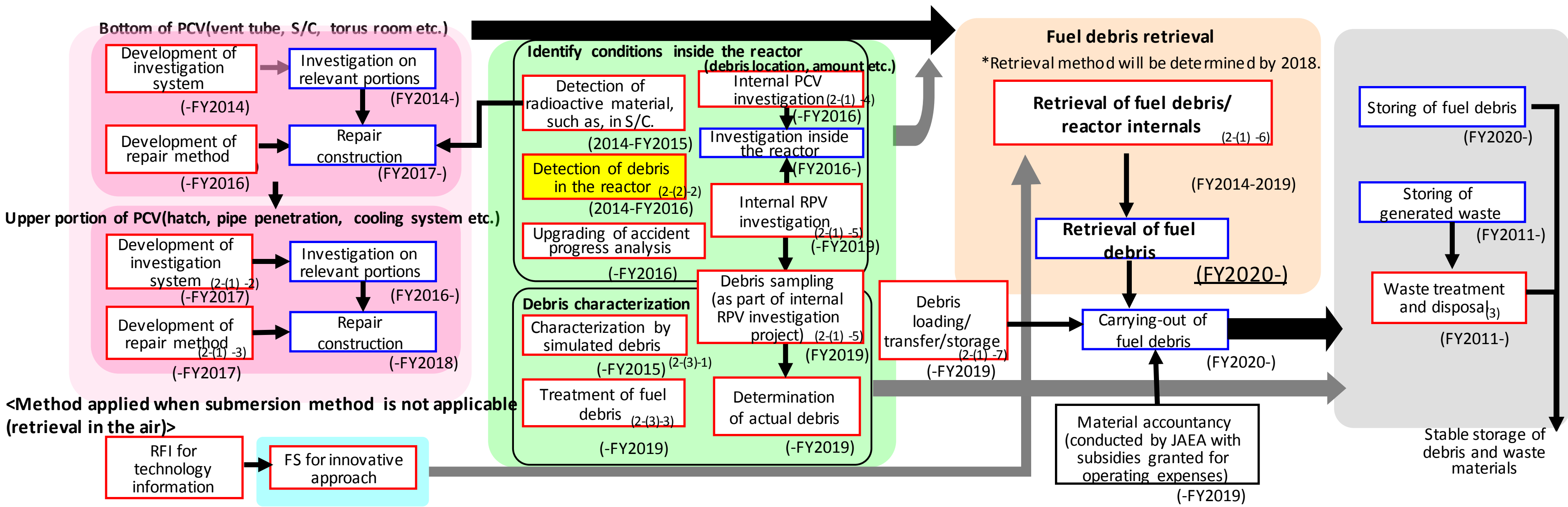


<u>Result of selection (example of Unit 3)</u>

- As systems that have opening to RPV,
  - jet pump instrument line,
  - feed water piping
  - core spray piping, etc.

- The challenges are
  - bending of the system piping
  - opening or closing of the valves of access piping
  - securing dimensions that allow passage

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



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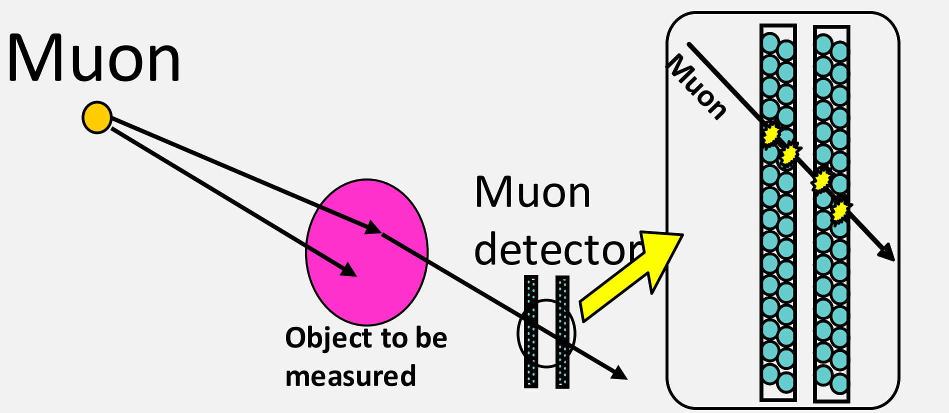
Overview of muon project (muon observation technology)

Transmission method



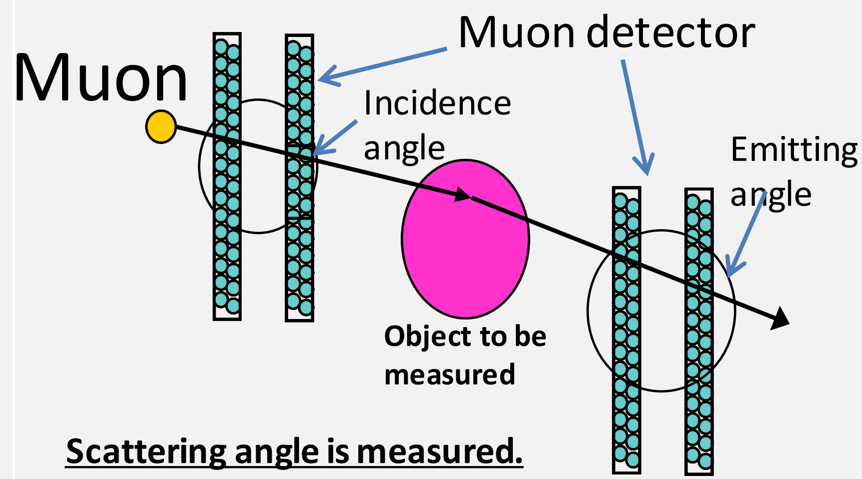
o : Detection element

Transmission ratio is measured.

Identifying ability (fuel debris): About 1 m

Small-size muon detectors (applicable early)

Scattering method



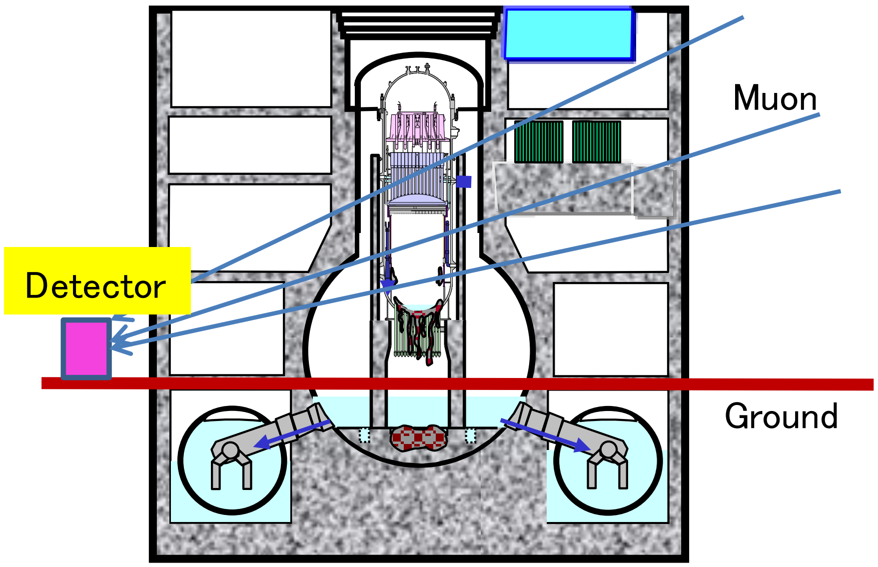
Scattering angle is measured.

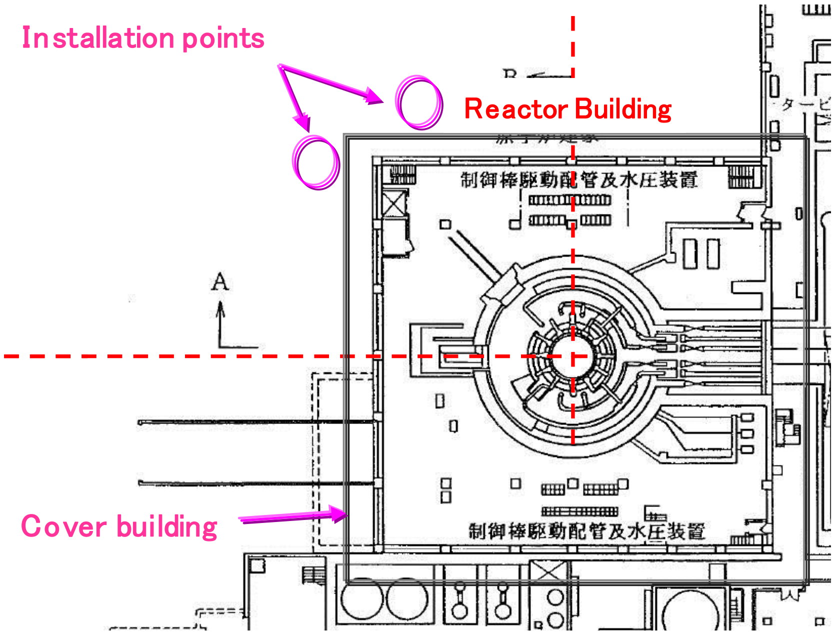
Identifying ability (fuel debris) : About 30 cm

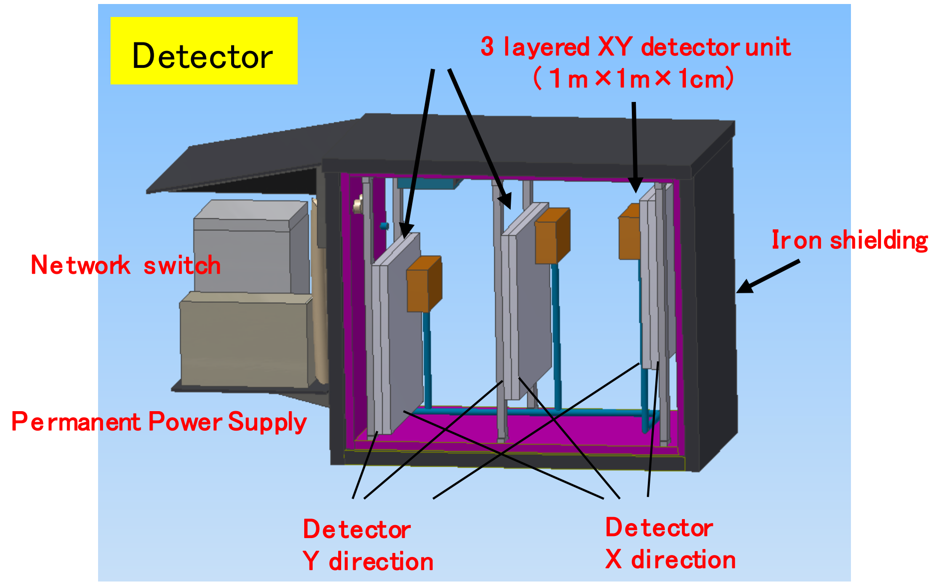
Large-size muon detectors

【Ref.】Installation image of Transmission method

- Two detectors were installed at the corner of north side and northwest side of the Unit 1 R/B
- Measurement will start in February, 2015.
- Detectors are shielded by 10cm-thick iron plate.

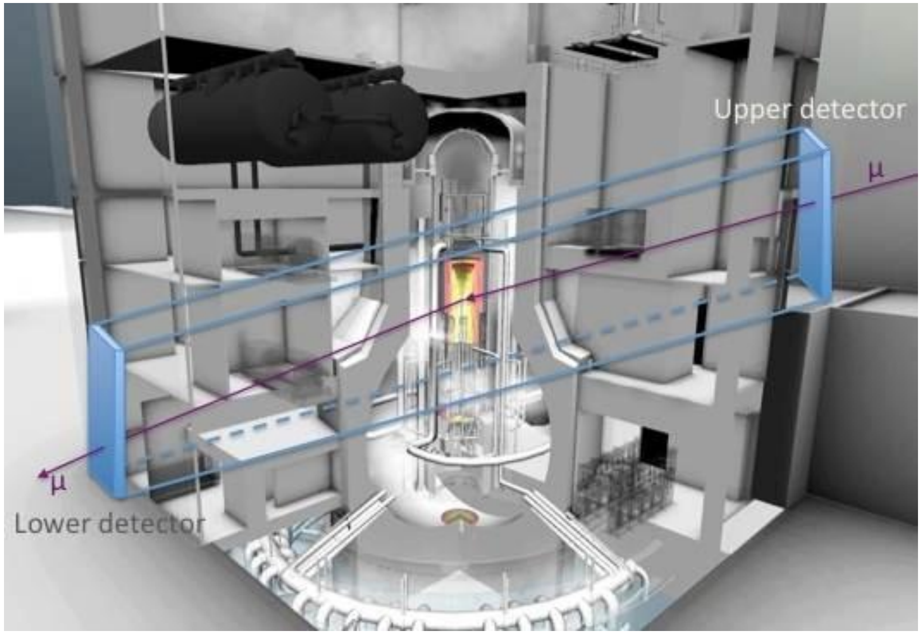


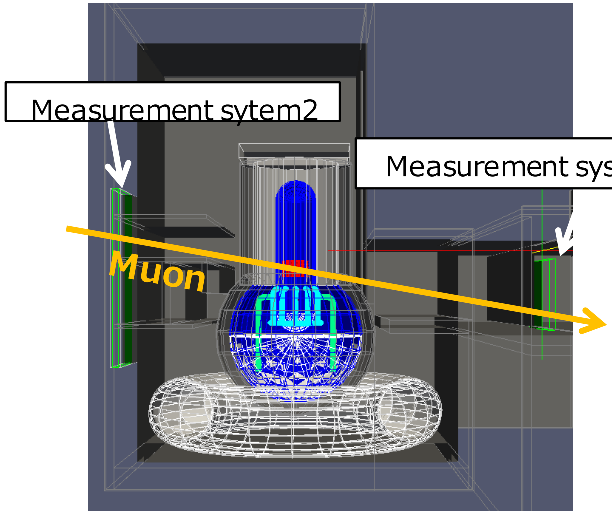


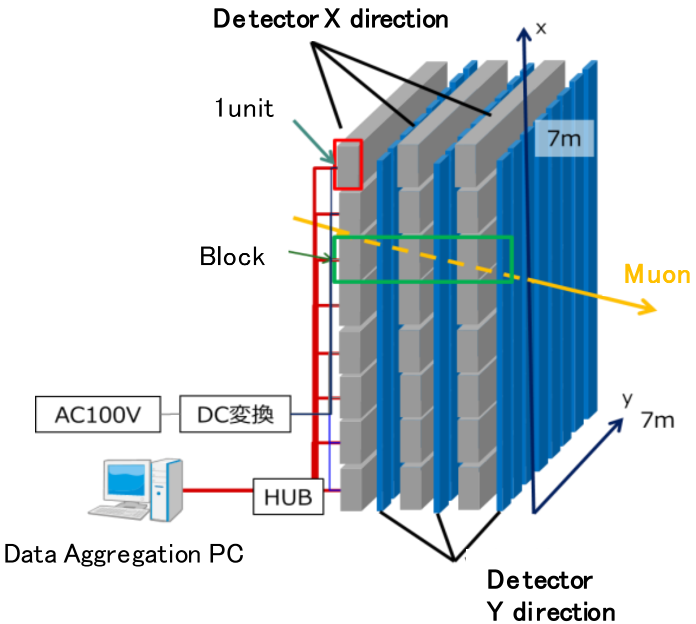


【Ref.】Installation image of Scattering Method

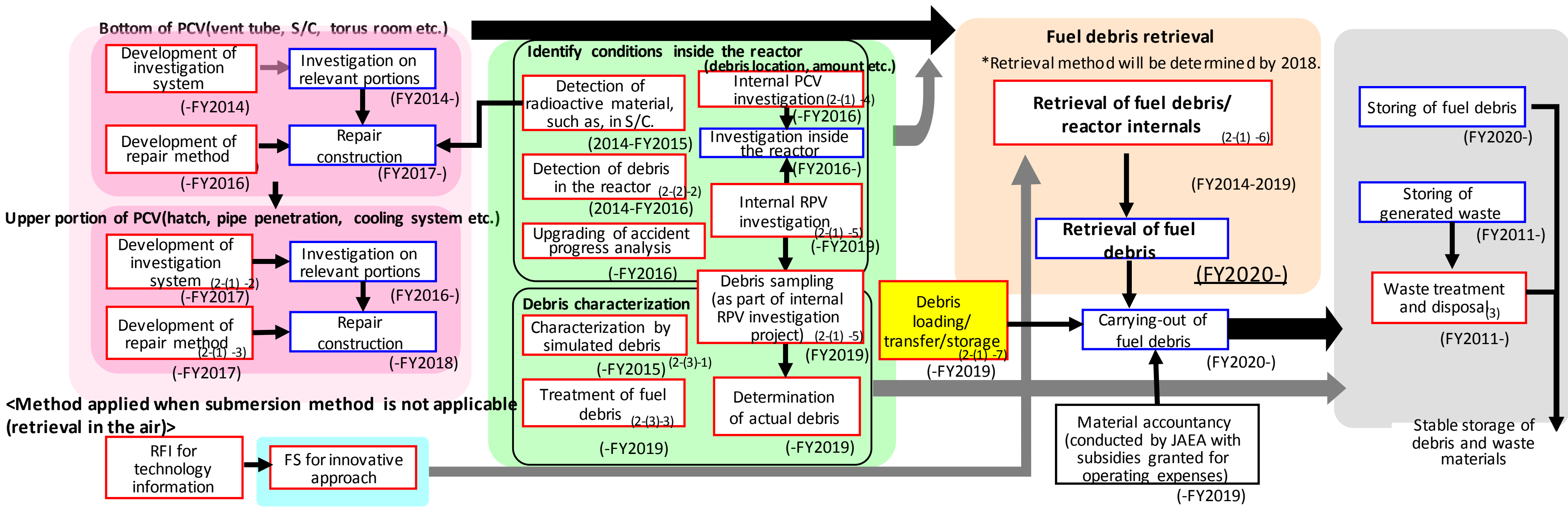
- Detectors will be installed in front of the R/B and 2nd Floor in T/B (Operation Floor) at Unit 2
- Background radiation should be eliminated by shielding and algorism.
- The detector in front of the R/B should be shielded by 8cm-thick iron plate.
- Shielding material will not be used in T/B 2nd Floor because of the low background radiation.







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



Comparison : Fuel debris in Fukushima Daiichi and TMI 2

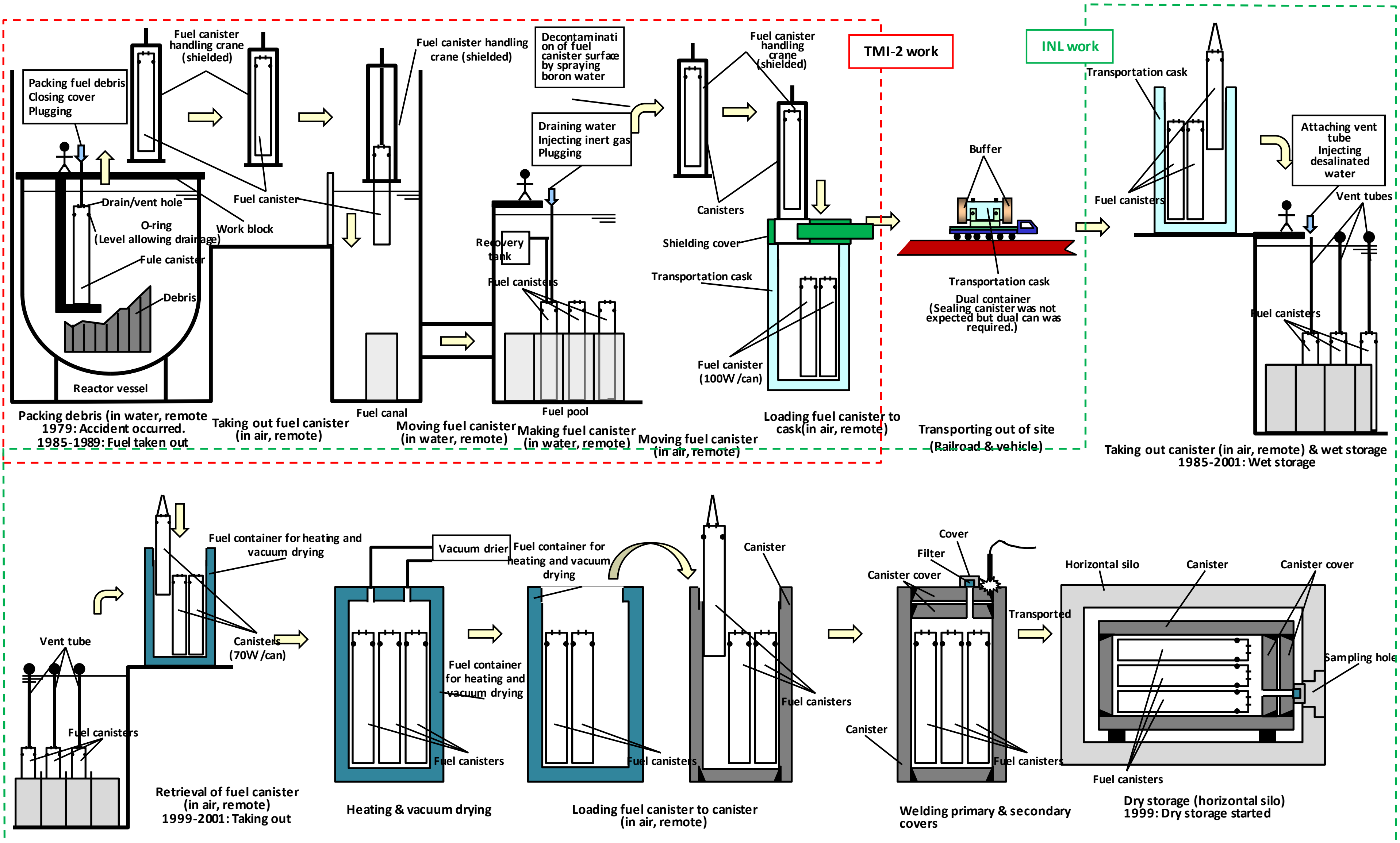
- Burnup and enrichment are higher in 1F
  - ⇒*Radiation, decay heat and reactivity are higher*
- Fuel debris in 1F contain molten core concrete interaction product
  - ⇒*Concern of hydrogen generation due to water radiolysis in concrete*
- Seawater injection to the reactor, melting along with the instrumentation cables
  - ⇒*Effect of salt and kinds of impurities contaminated in the fuel debris*

Need to be addressed when designing fuel debris loading, transfer and storage system

		1F	TMI-2
Burnup（Reactor core average）		About 25.8GWd/t	approx. 3.2GWd/t
Enrichment（bundle average(max)）		3.7 wt%	2.96 wt%
Cooling period（minimum）		About 9 years (as of June 2020）	About 6 years
Fuel debris location		Inside RPV and PCV（supposition） ⇒Molten interaction with concrete and instrumentation cables as well as fuel constructional material and internal structures are supposed to exist.	Inside RPV ⇒Molten interaction with fuel constructional material and internal structures.
Quantity	Debris	—	134.4t
	（Fuel Assembly）	About more than 450t in total of 3 units	About 122t
	（Uranium）（unirradiated）	About more than 260t in total of 3 units	About 82t
Others		Seawater was injected to the reactor	—

Containing, transfer and storage of damaged fuel at TMI-2

(Overview of fuel debris handling at TMI-2)



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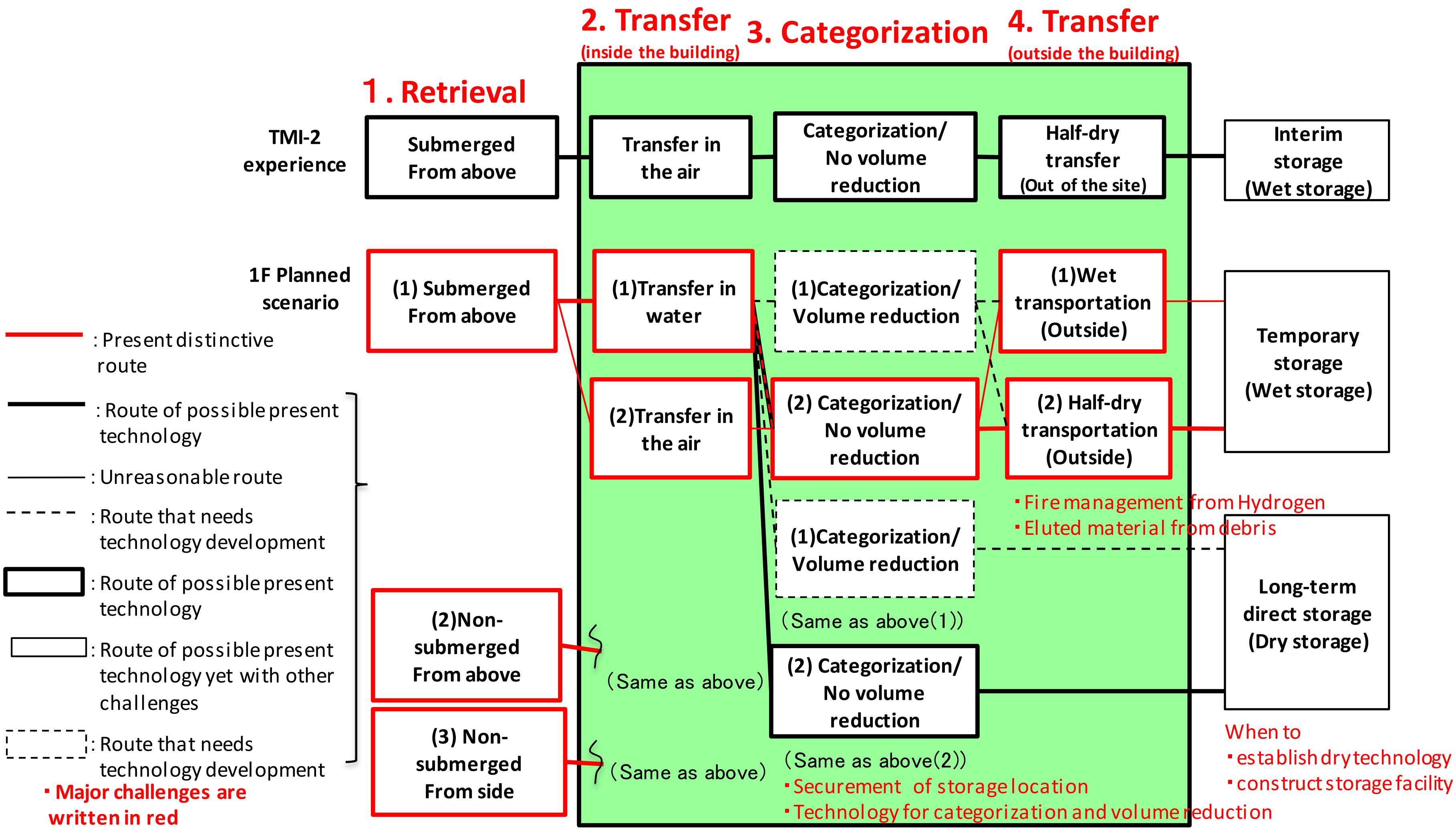
【Ref.】Scenario for fuel debris loading, transfer and storage (1/2)



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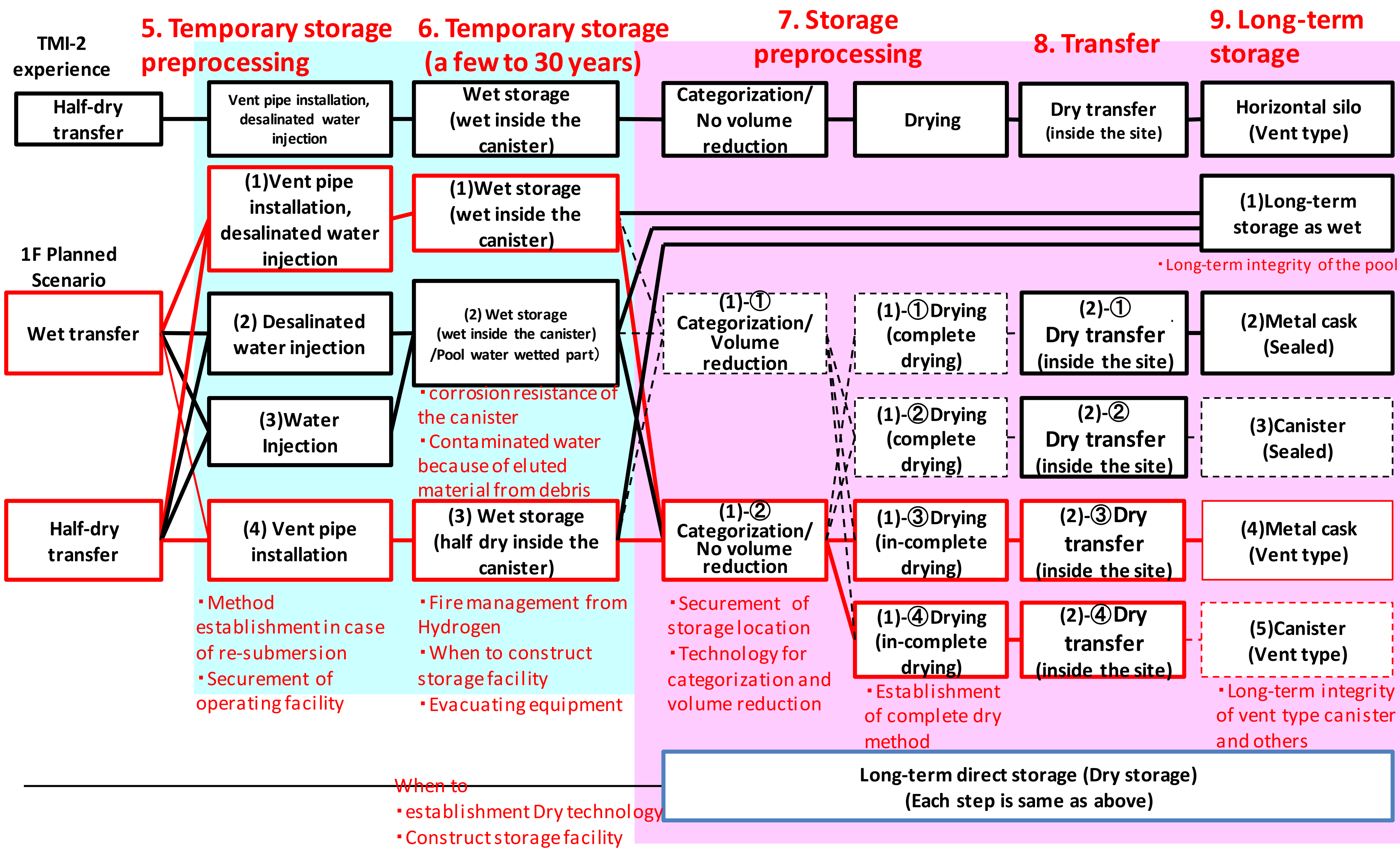
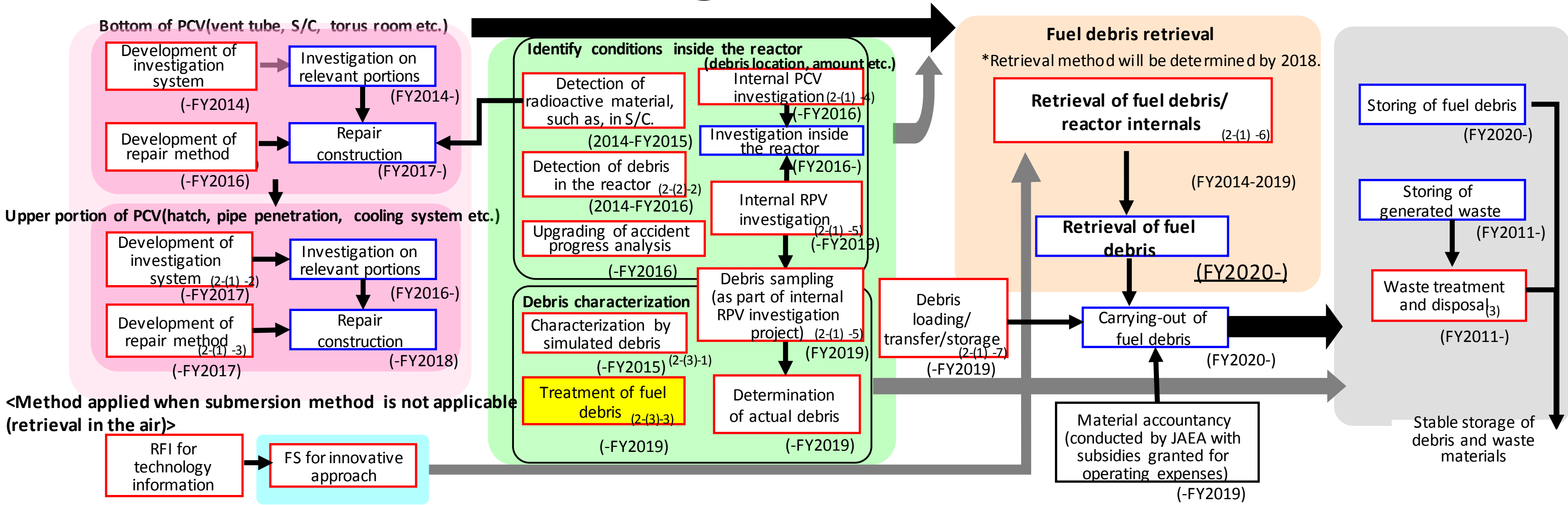
【Ref.】Scenario for fuel debris loading, transfer and storage (2/2)



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



Analysis of characteristics by using simulated fuel debris

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

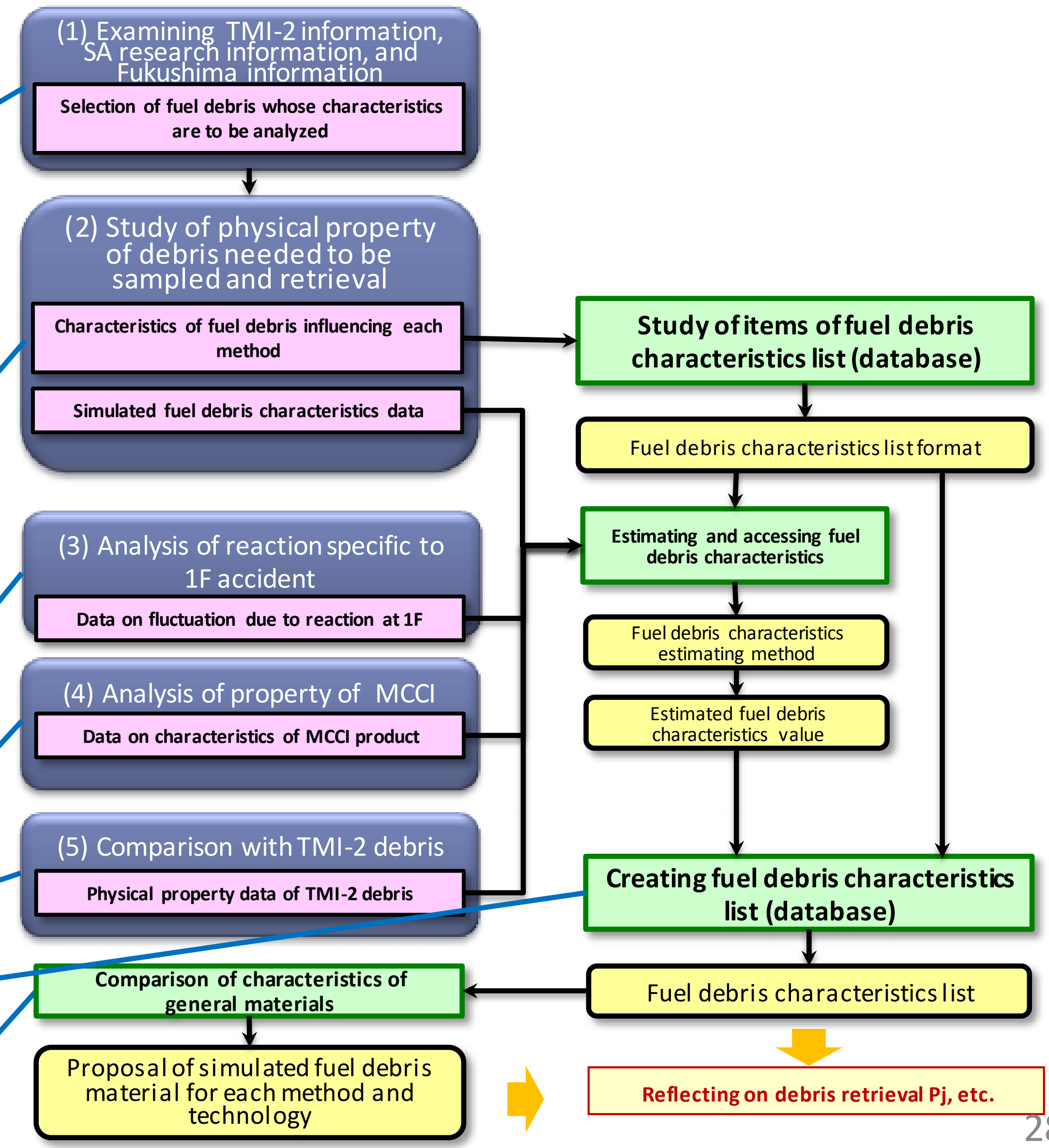
- Getting information on MCCI phenomenon and products by effectively using information and opinions from overseas and international cooperation

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

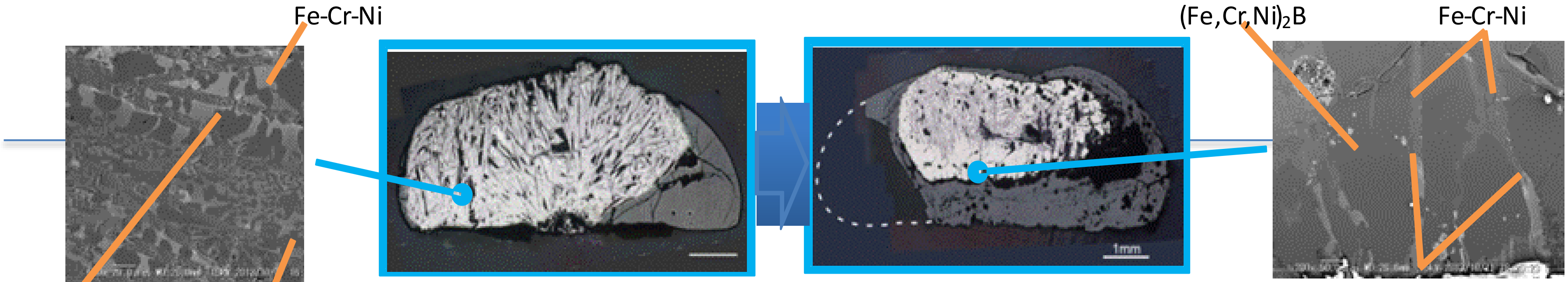
- Estimating fuel debris characteristics based on data and information gathered to create a characteristics list

- 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



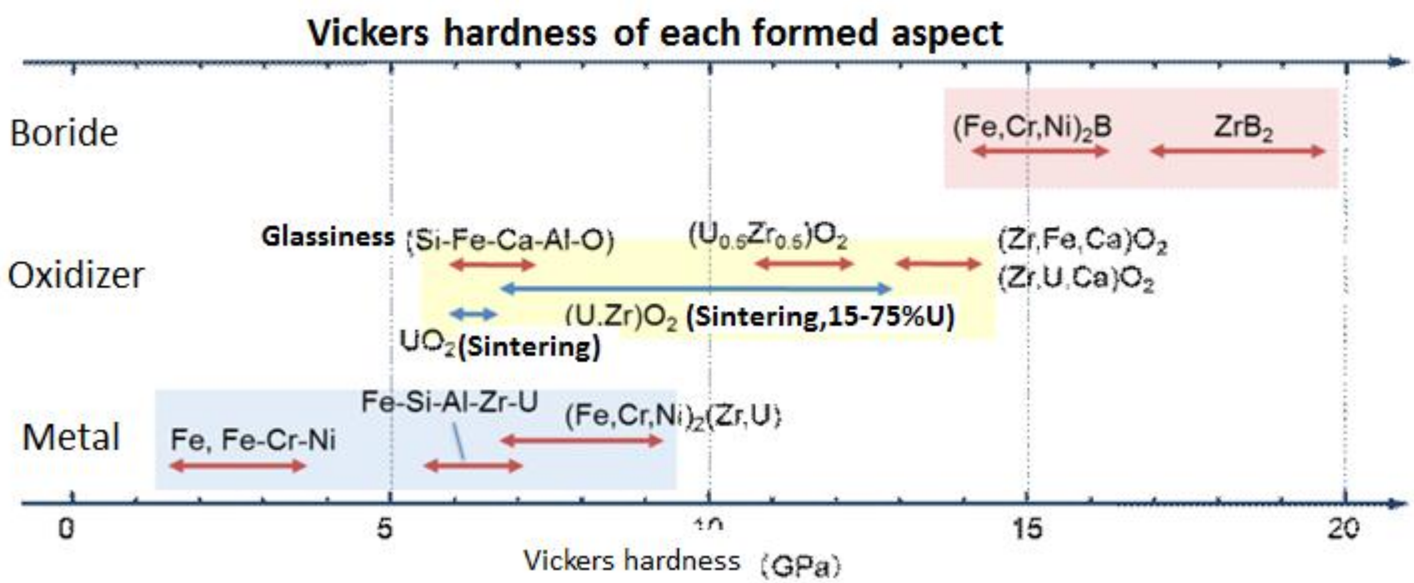
【Ref.】Analysis of characteristics by using simulated fuel debris



ZrB_2（Foil-like or flat crystal structure） $(Fe,Cr,Ni)_2(Zr,U)$ (Fe_2ZrType Cubic） Arc melting Oxidative atmosphere(annealing) （Ar-0.1%O_2,1500℃） $(Zr,U)O_2$ (Zr-rich) （Alloy and ZrB_2 Oxidized）

Reaction with control material (B_4C+SUS)（Example of the melt-solidified material from sectional observation image

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



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

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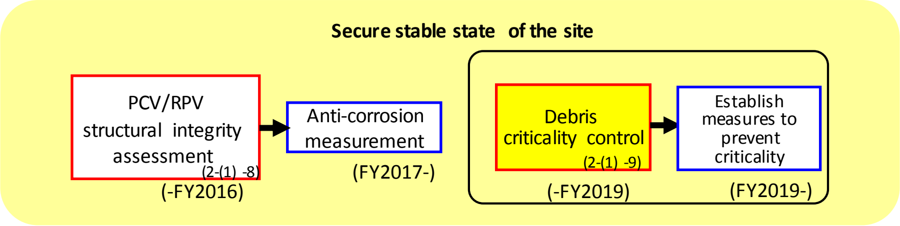
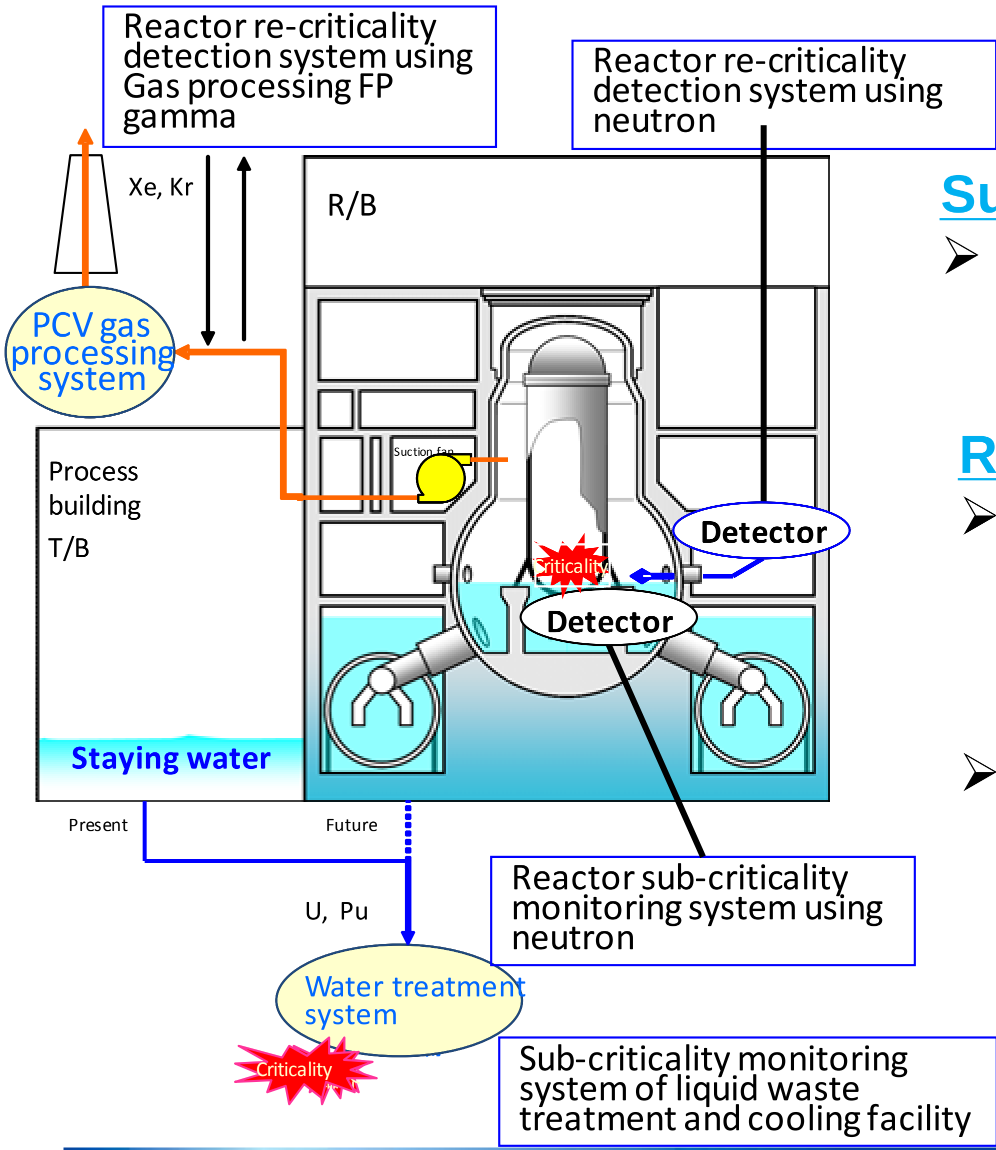
Development of the criticality management of fuel debris(2-(1)-9)



Monitoring sub-criticality and detecting re-criticality

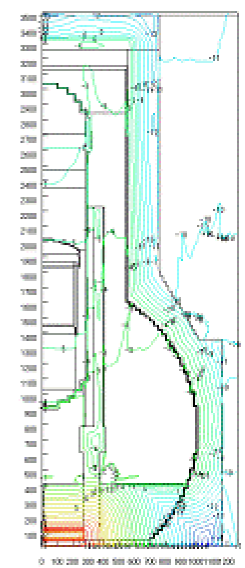


Sub-criticality monitoring

- Workers should be protected from risk of exposure due to criticality.

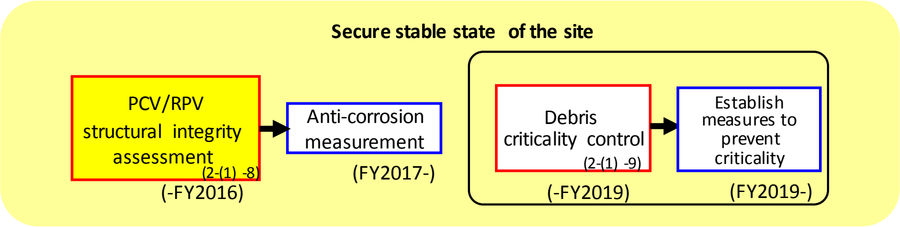
Re-criticality detection

- Even if criticality is reached in PCV/RPV, risk of exposure is extremely low.
- Still, monitoring the situation in a relatively wide range is important.



Neutron beam distribution in case criticality in PCV

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



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 equipment with low allowable value be damaged

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

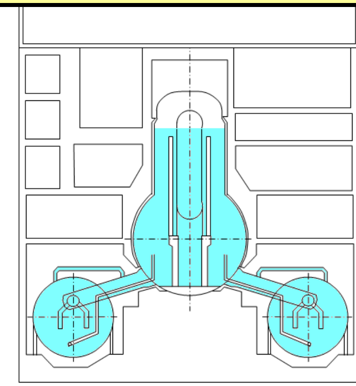
**Study by experts in equipment design and structure is indispensable and current research and development system should be reviewed.

[blue box]: Done in 2012

[red box]: Conducted or to be conducted from 2012 to 2015

Outline flow of remaining life assessment (example)

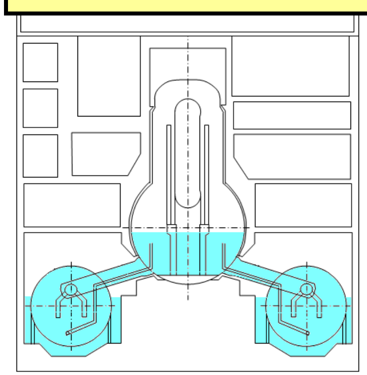
(a) PCV flooding status (example) (assessed in 2012)



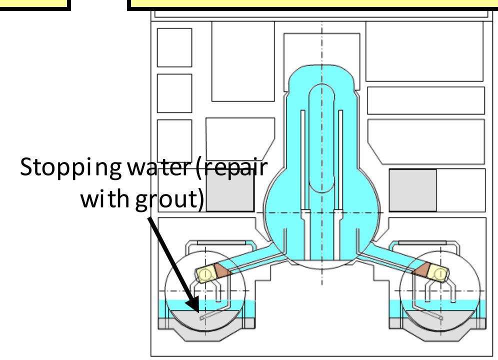
Putting in order items to be checked and results expected by conducting examination when conditions leading to improvement of accuracy of remaining life assessment, such as damage of buildings and current water level (coordination with other projects such as to inspect inside PCV is needed.)

[red dashed box]: Assessed in 2013

(b) Plant condition assumed at present (example)



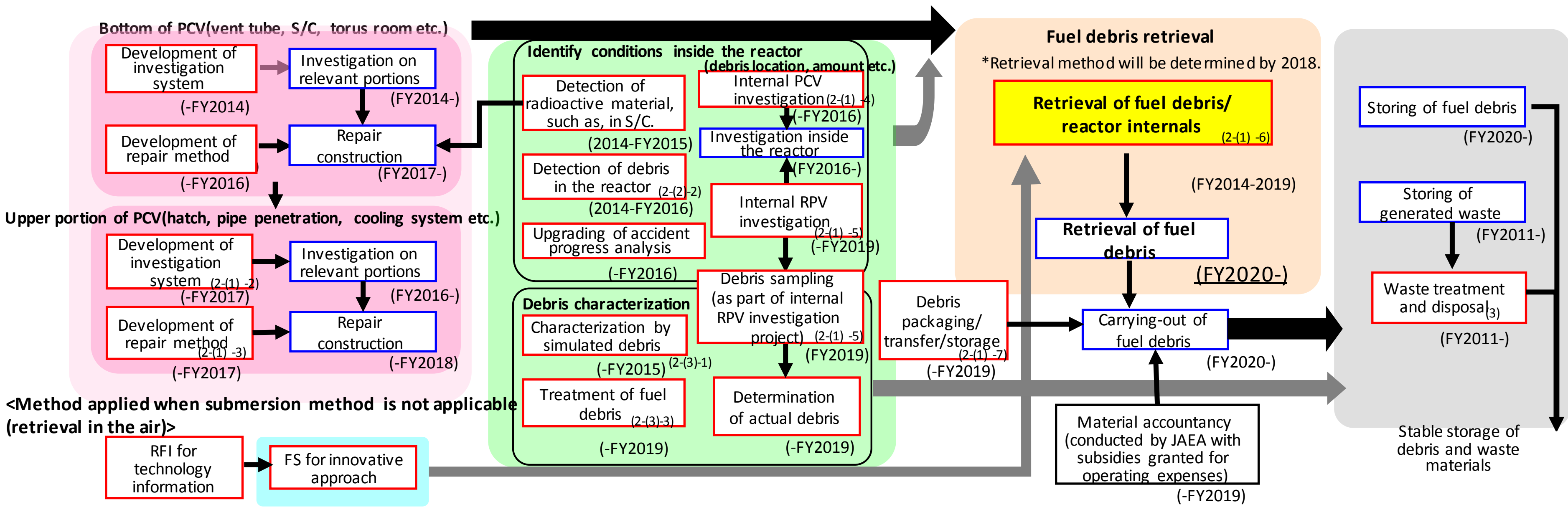
(c) Plant condition assumed until PCV flooding (example)***



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

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

Development of technologies for retrieval of fuel debris and reactor internals (2-(1)-6)



R&D policy

1 Method for fuel debris retrieval

The status differs from unit to unit.

→In addition to the method in which the PCV is submerged(full submersion),partial submersion (the upper part of the PCV is not submersed) or retrieval in the air (partial in-air, full in-air) should be evaluated for comparison.

→ After sorting out the status and presumption, applicability of each method for the each unit will be evaluated.

2 Technologies for fuel debris retrieval

There is not evidently applicable or confirmed technologies to the plants in Fukushima daiichi NPS.

→There are some examples such as the fuel debris retrieval conducted in TMI-2 and large repair works in domestic plants. Proven technologies will be focused.

→ However, since the core internals might not be in the form of the original design, development of applicable technologies will be implemented presuming such situation.

Development of technologies for retrieving fuel debris and core internals

◎ Retrieval 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

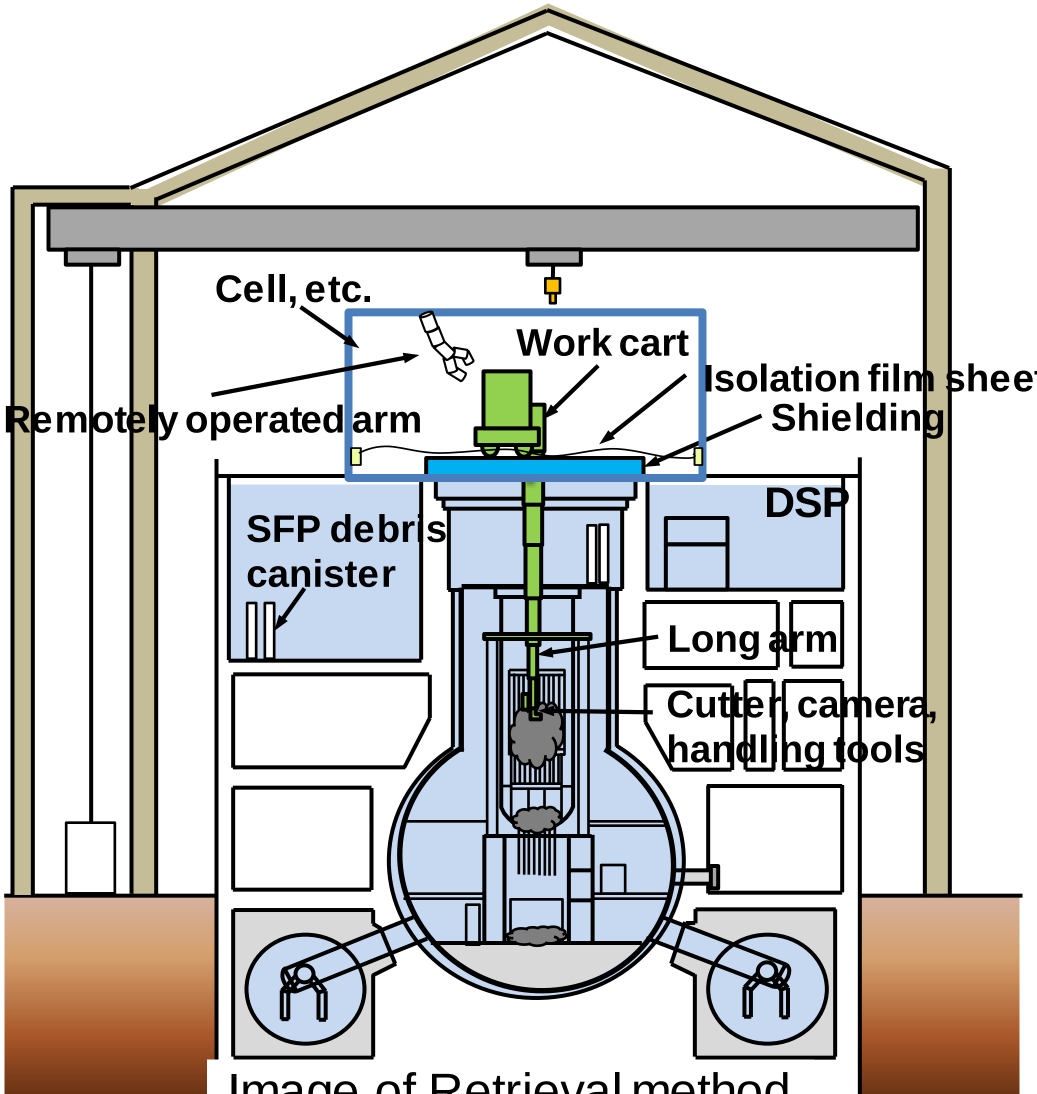
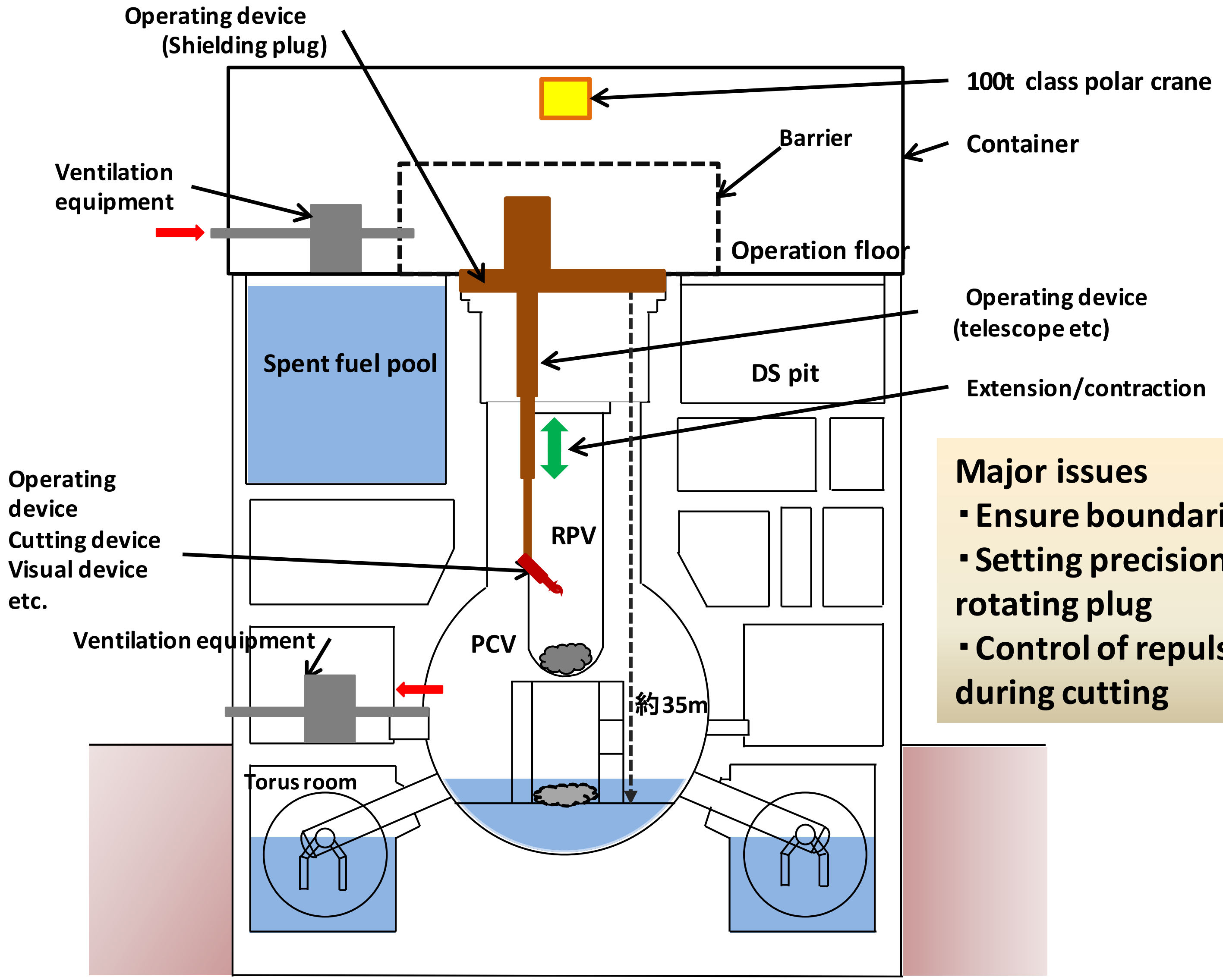


Image of Retrieval method

Fuel Debris Retrieval

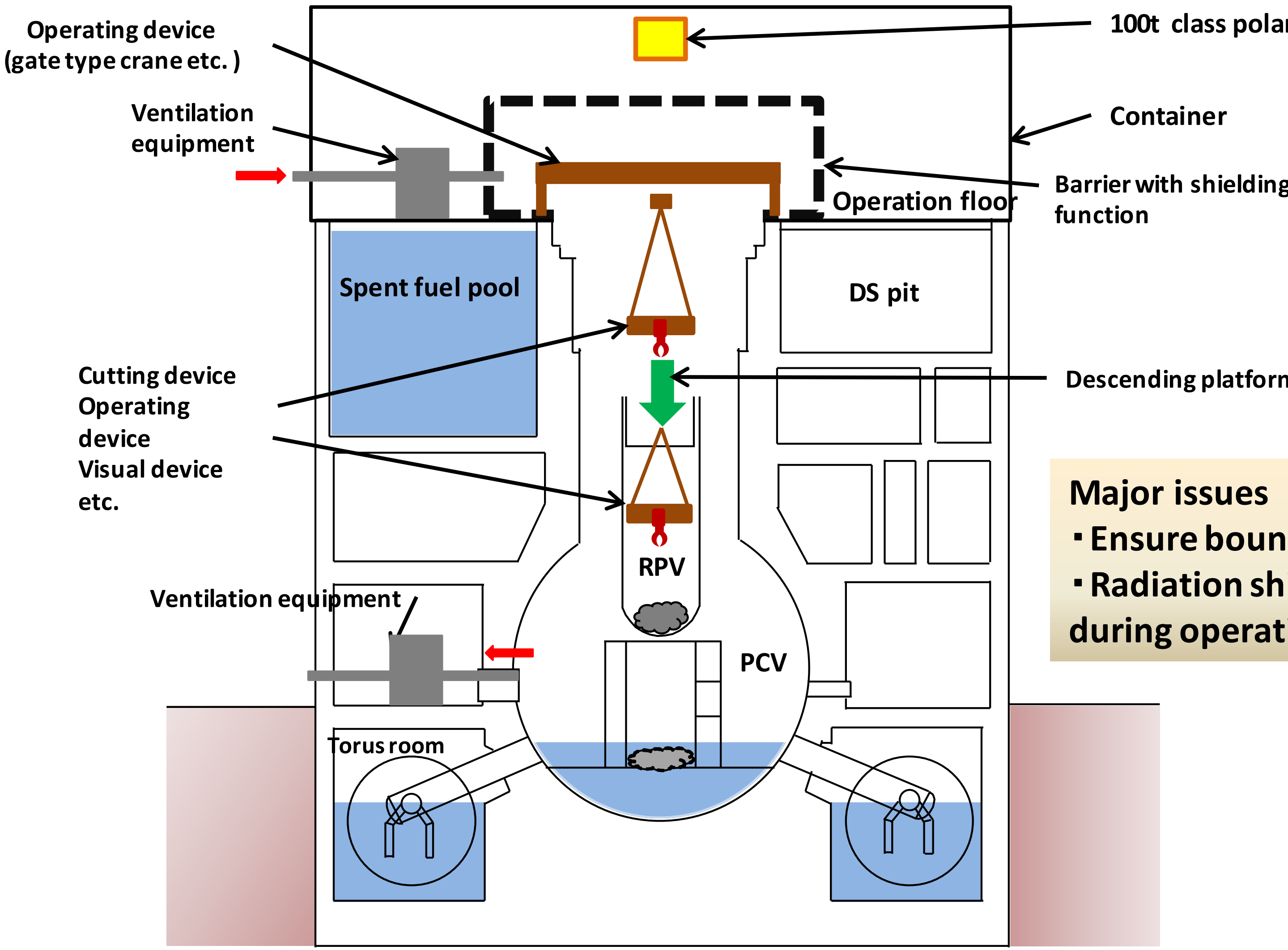


Major issues

- 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**

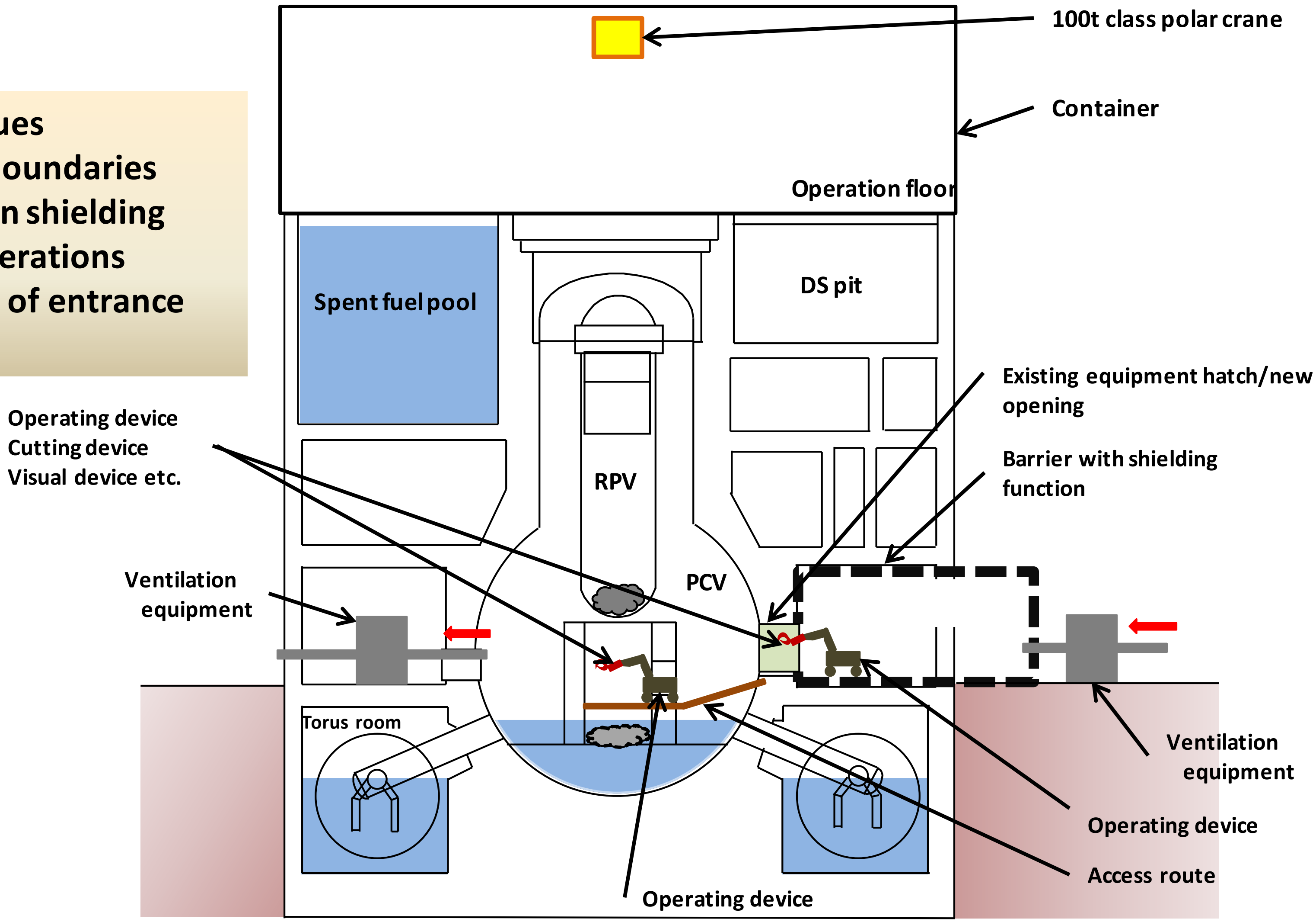


Fig. Method to retrieve fuel debris in air from the side

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.

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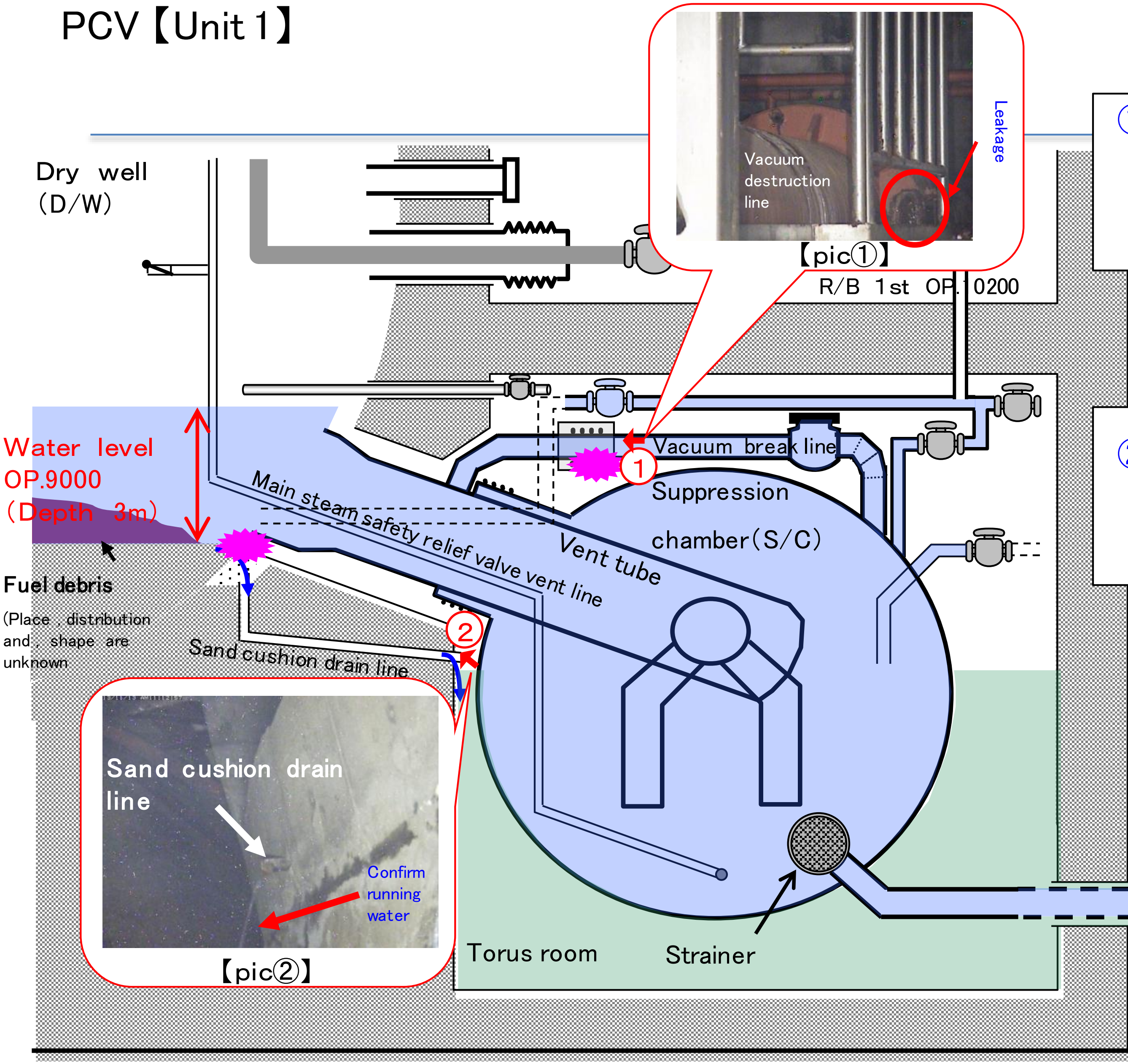
Backup Material

Current status of lower part of PCV【Unit 1】



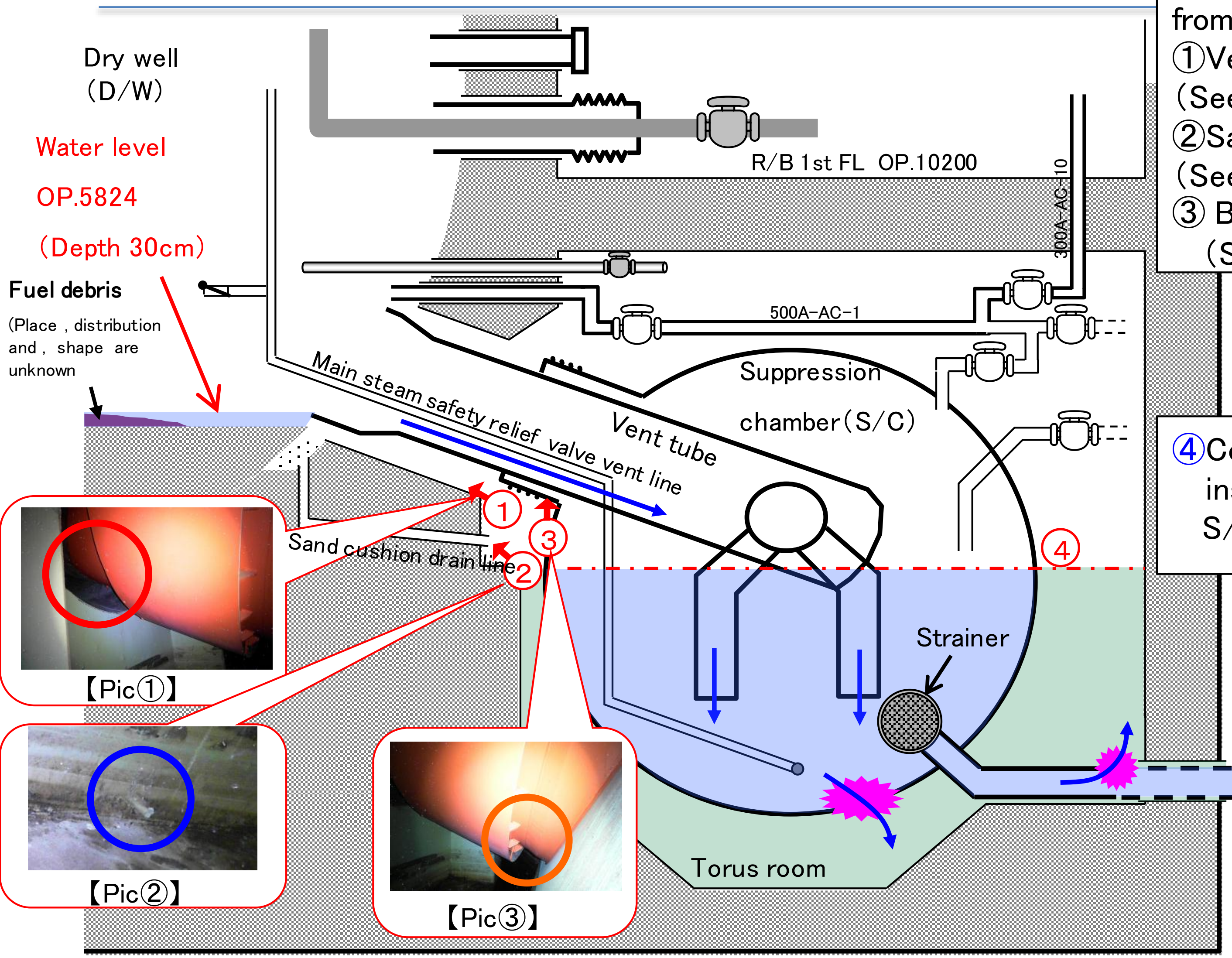
①Confirm Leakage from the bellows portion of vacuum break line (See pic①)

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

→To pump
(R/B basement FL)

TEPCO data

Current status of lower part of PCV【Unit 2】

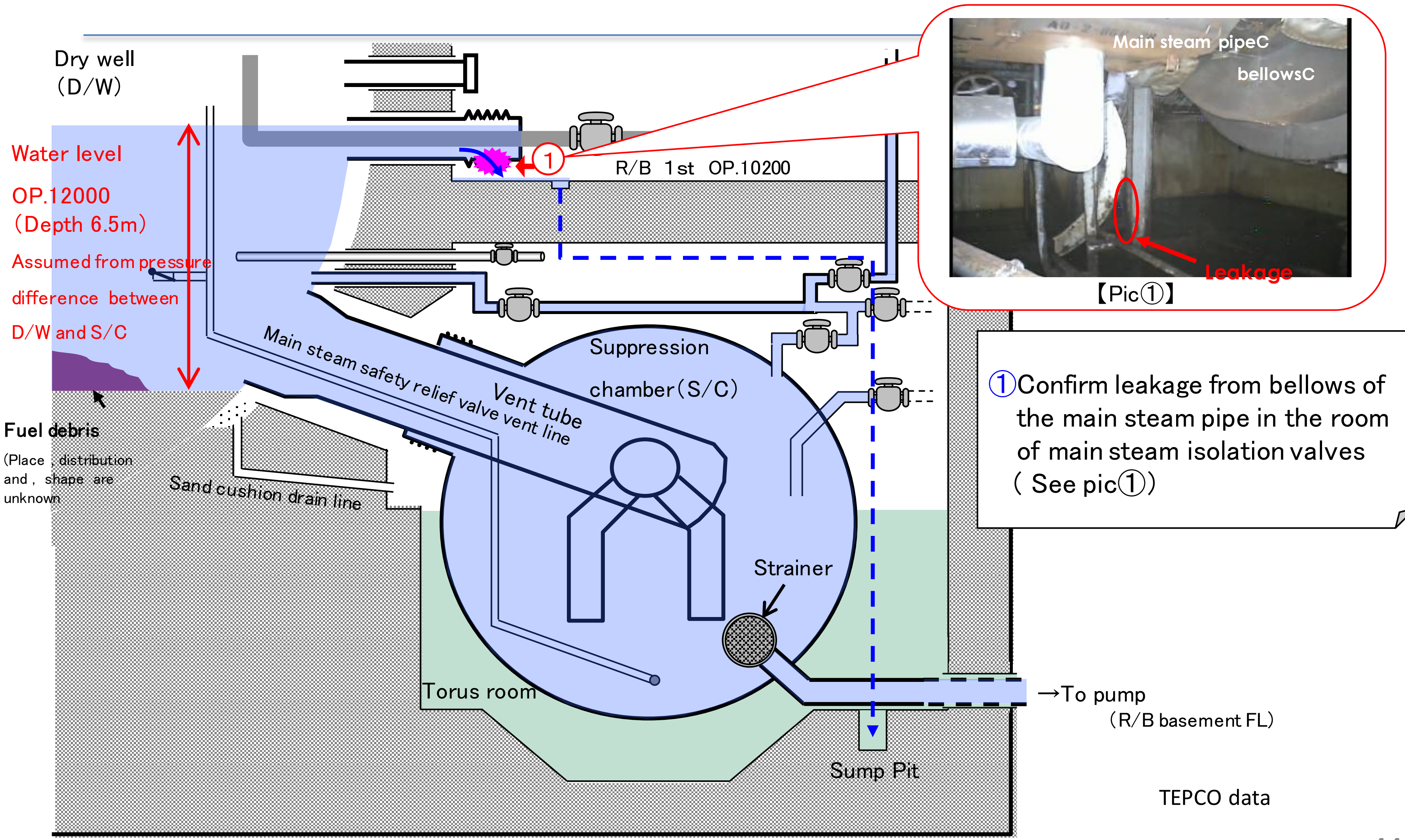


Not confirm running water leakage from
①Vent tube sleeve
(See pic①)
②Sand cushion drain line
(See pic②)
③ Bellows cover
(See pic③)

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】



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

TEPCO data