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Advanced Technologies for Fuel Debris Retrieval towards Fukushima Daiichi Decommissioning

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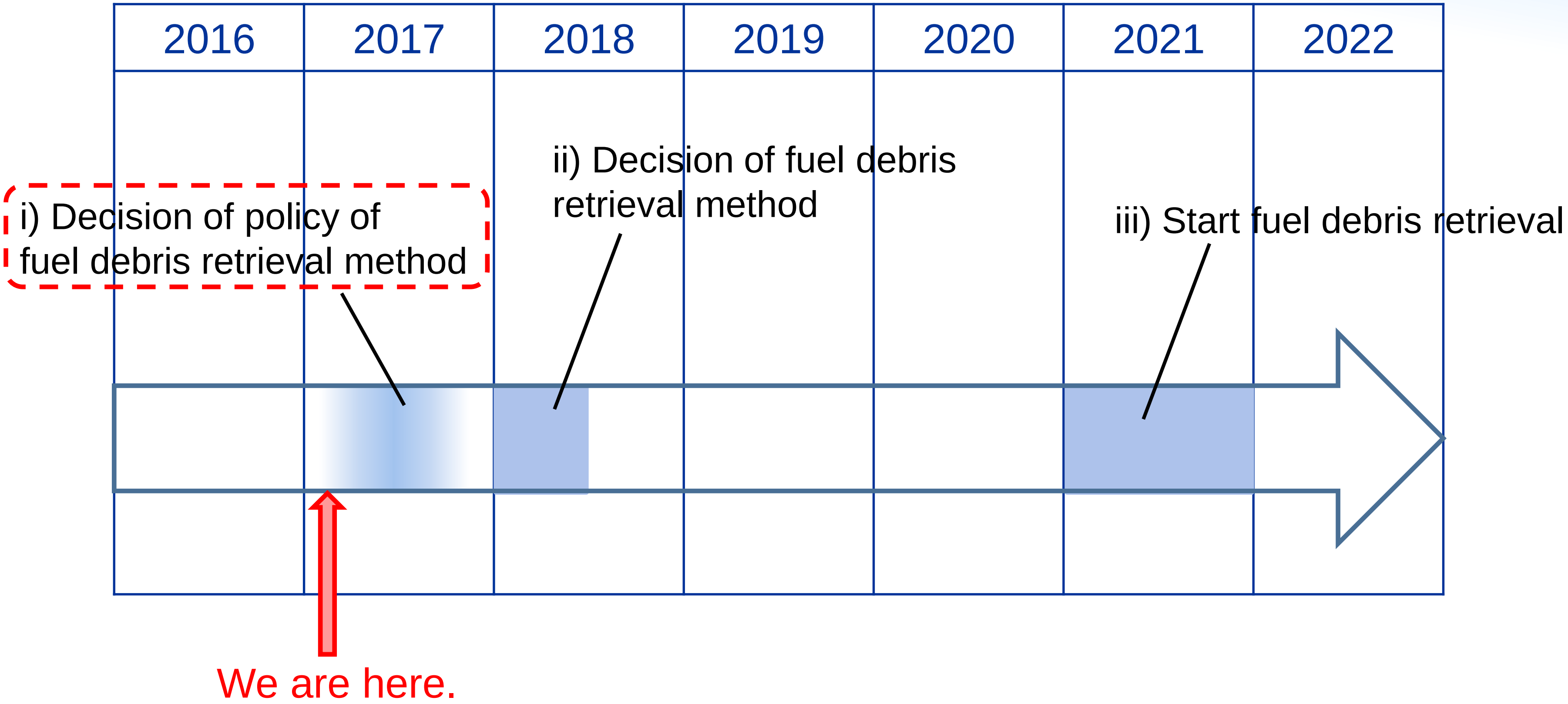
Where are We in the Road Map?



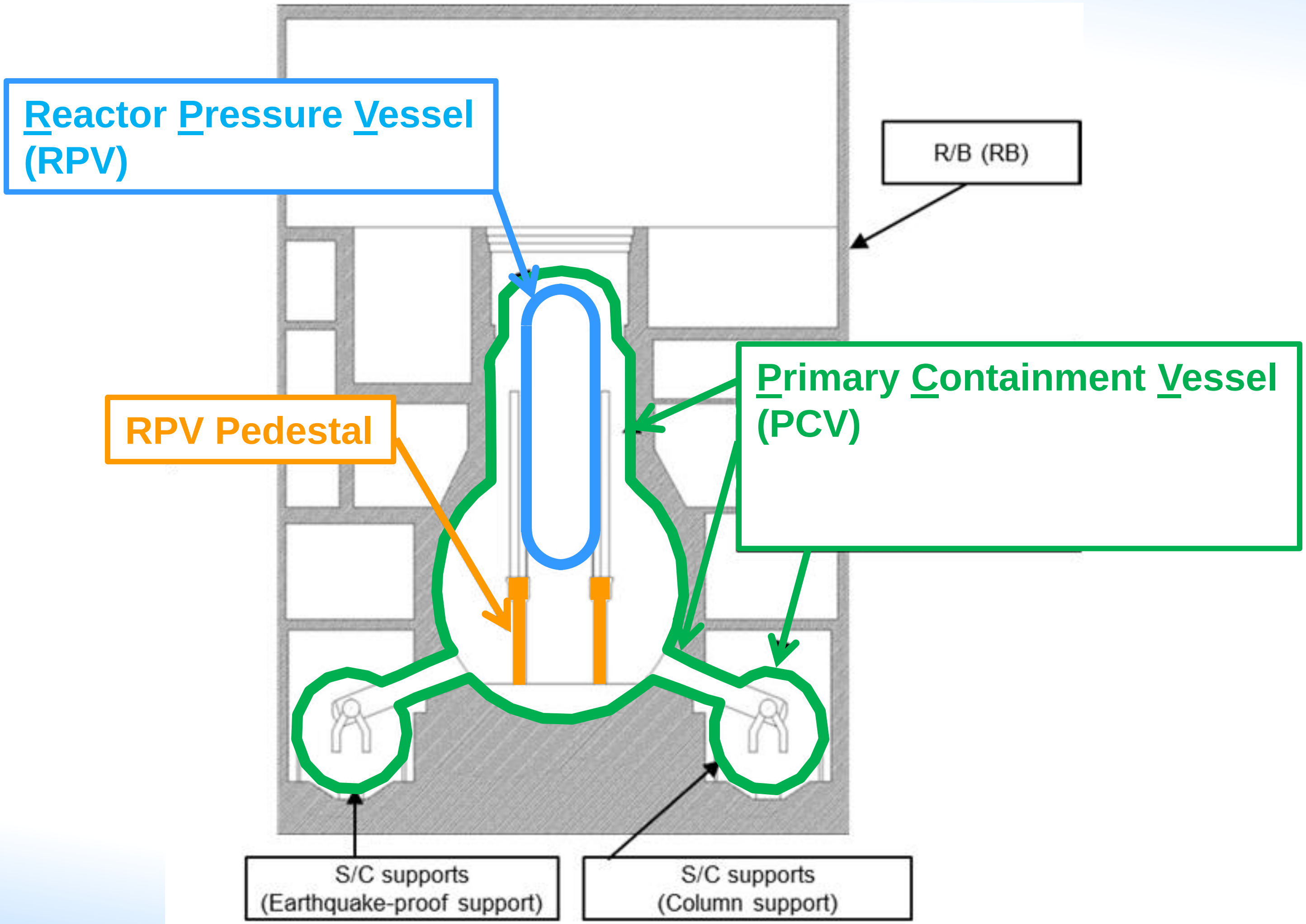
Source: " Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", the Japanese Government

Fundamental Question

- **Where is debris?**
- **How much debris is there?**
- **What is its condition?**

We cannot see debris directly.

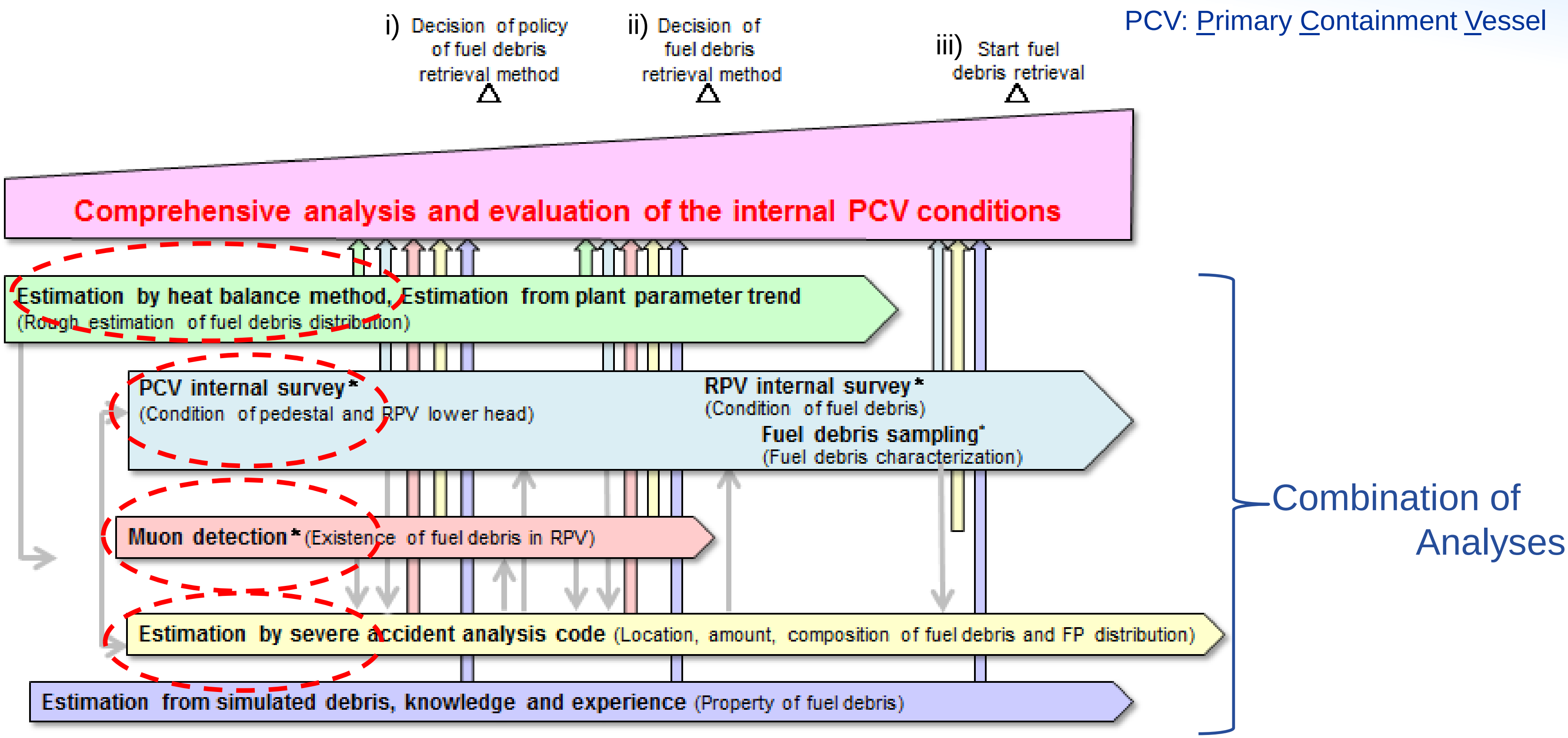
PCV, RPV and RPV Pedestal



Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Evaluation of the internal PCV conditions

It is extremely important to carry out the studies on the fuel debris retrieval method to understand the internal PCV conditions including plant conditions and fuel debris.



* Determine the survey contents considering the balance of cost of development/survey, period, exposure dose and the obtained information

➢ **Based on the new findings, continuously improve the comprehensive analysis/evaluation**

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

PCV/RPV internal survey (1/2)

- Thermometer, CCD camera, dosimeter

  To measure the overall condition in PCV/RPV

- Robot

  - A small robot which is remote-controlled, movable, transformable and heavy-duty
  - The results of the survey at unit 1 are,

    (1) No large damage on the existing facility (e.g. PLR pump, PCV inner wall and HVH)

    (2) Dose rate was approximately 10 Sv/h.

    (3) PRL piping shielding unit confirmed fallen.

    (4) The access route to the bottom of the D/W was confirmed but the deposits are scattered over a wide range.

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

PCV/RPV internal survey (2/2)

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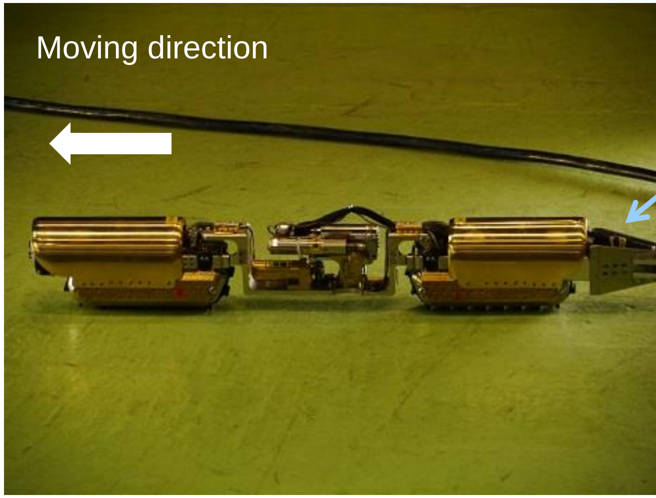
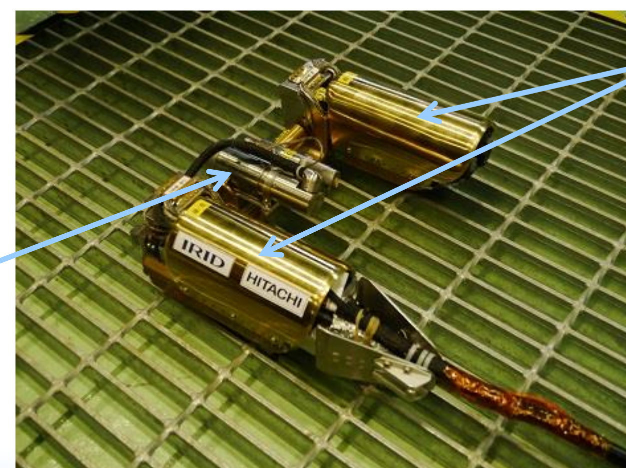


【The Robot's Form at Going into PCV】

Connected with Cable

Transforming

【The Robot's Form at Moving inside PCV】



Thermometer

Camera

Source: IRID website (http://www.irid.or.jp/research/20150203/)

Muon Detection (1/2)

- Muon Radiography:

  Technology to obtain an image like X-ray photograph by measuring muon particles which pass through something

- Strong capability to pass through material

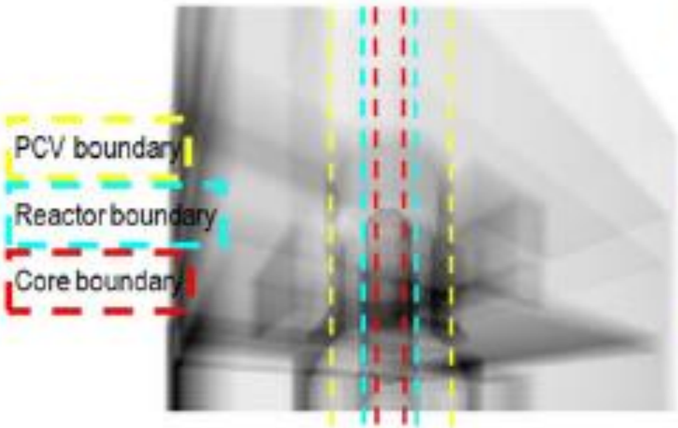
  High density material is shown as black shadow in the image

- Very rough measurement method

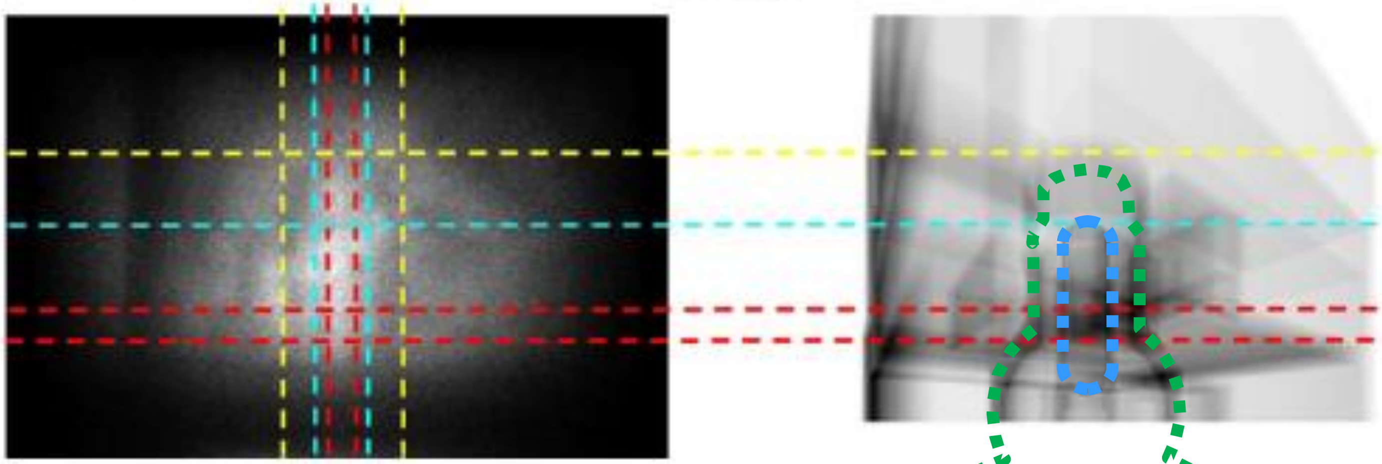
  However, it’s still useful for speculating the location of fuel debris

Source: ”Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Muon Detection (2/2)



- Measured data, though it does not clearly indicate, shows that equipment, etc. are detected at locations where they are supposed to exist based on the design documents
- The boundaries of the PCV and the RPV in the image acquired from measurement matches those in the image drawn from design data.
- High density material (fuel) is not detected at the area where the reactor core was originally located.



The image above is obtained at Unit 1. Similar result was gotten at Unit 2 as well.

Source: Quick Report on the Measurement Results for Unit 1 from Development of Technology for Detecting the Fuel Debris Location inside Nuclear Reactors from TEPCO

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Estimation by severe accident analysis codes

- The amount, locations and composition of fuel debris and FP distribution are to be estimated using severe accident analysis codes. (MAAP and SAMPSON)
- Furthermore, the estimation of internal PCV conditions is being performed in OECD/NEA BSAF project.
- Analysis results have been examined continuously to improve the codes.

Table: Analysis results using the severe accident analysis code (Unit: ton)

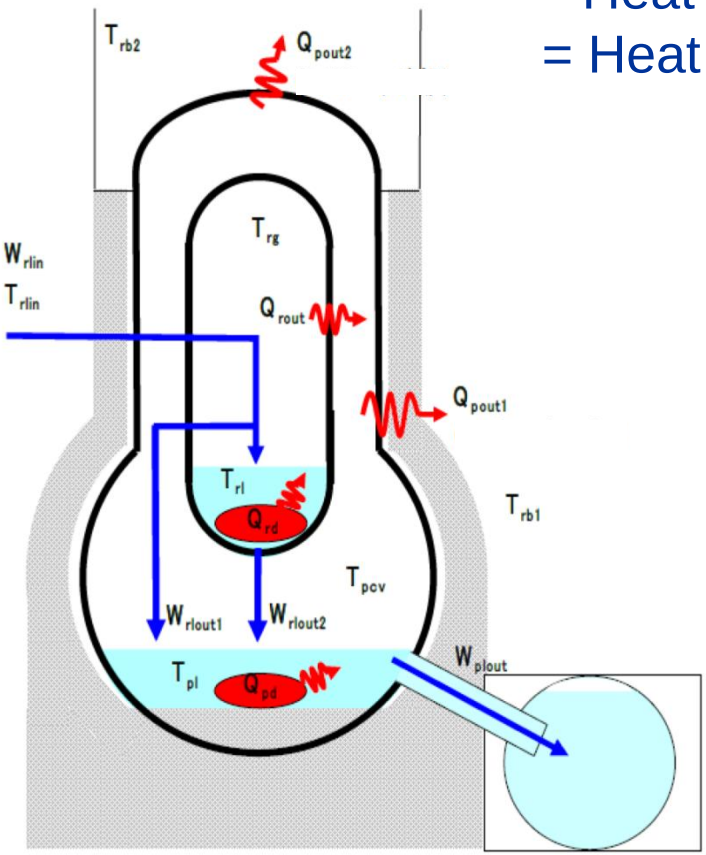
Locations	Unit 1		Unit 2		Unit 3	
	MAAP	SAMPSON	MAAP	SAMPSON	MAAP	SAMPSON
Core region	0	0	0	13	0	29
Bottom of the RPV	15	10	25	58	25	79
Inside the pedestal	109(78)	79(130)	92(37)	76(14)	103(51)	53(20)
Outside the pedestal	33(52)	52(0)	102(4)	5(0)	96(6)	0(0)
Total amount (concrete included)	287	271	260	166	281	181

Note: The weight inside and outside the pedestal is the weight of fuels/structural materials (excluding the weight of concrete). The weight of concrete is indicated in ( ).

Source: IRID Completion report for "Improvement of recognition regarding the internal PCV condition using severe accident progression analysis and actual plant data"

Source: ”Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Estimation by Heat Balance Method



Heat Input (heat of the injected cooling water and decay heat)

= Heat radiation (heat radiated out to the building or into the air through the PCV walls and cooling-water temperature rise caused by fuel debris)

Unit	Estimation results
Unit 1	Heat source equivalent to the decay heat of approx. 45% may exist in the PCV. (Evaluated assuming no heat source exist in the RPV based on the results of the analysis using MAAP code (, which is no decay heat in the RPV))
Unit 2	30-60% heat source (fuel debris) may exist in the RPV.
Unit 3	20-70% heat source (fuel debris) may exist in the RPV. The amount of debris exist in the RPV as a heat source is, however, likely to be fewer since the temperature of RPV accumulated water does not follow the temperature of injected water.

Note: This estimation includes the uncertainties of the decay heat of the fuel debris that fell to the bottom of the PCV (according to the evaluation performed by the JAEA, it will be reduced to about 60% if all of the highly volatile nuclide are released), possibility of heat conductance from the fuel debris to the floor concrete, and uncertainties in the evaluation of heat transfer rate in the heat emittance from the PCV side to the outside. (Provided by IRID)

Source: IRID Completion report for "Improvement of recognition regarding the internal PCV condition using severe accident progression analysis and actual plant data"

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Summary of status on fuel debris

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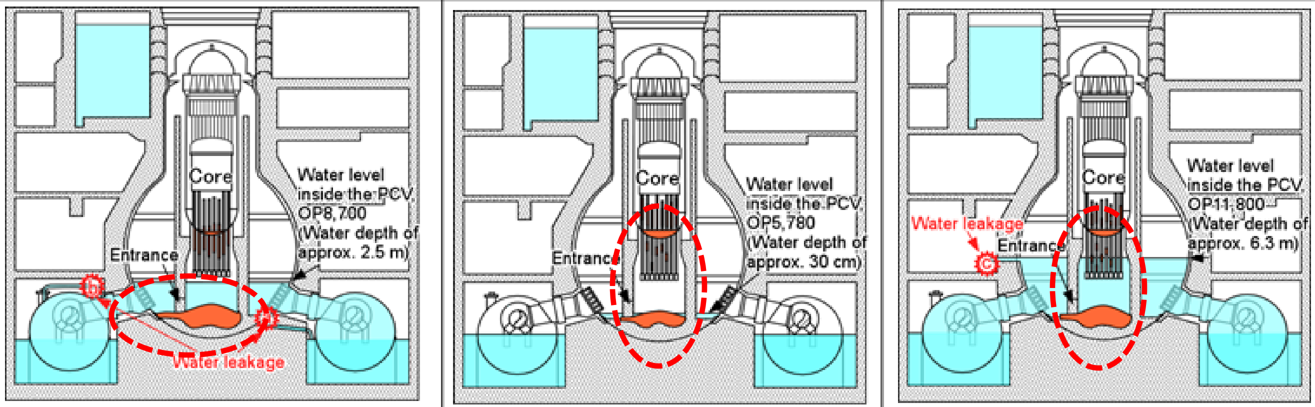
- **Plant conditions of Units 1-3 (including the estimation of fuel debris distribution)**

Unit 1	Unit 2	Unit 3



[Unit: ton]

	Location	Unit 1 Range of Estimation*1	Unit 1 Typical Value*2	Unit 2 Range of Estimation*1	Unit 2 Typical Value*2	Unit 3 Range of Estimation*1	Unit 3 Typical Value*2
Estimated Distribution	Core	0-3	0	0-51	0	0-31	0
	RPV Lower Head	7-20	15	25-85	42	21-79	21
	Inside RPV Pedestal	120-209	157	102-223	145	92-227	213
	Outside RPV Pedestal	70-153	107	3-142	49	0-146	130
	Total	232-357	279	189-390	237	188-394	364
Current Status	Dose Rate measured in PCV	Approx. 5-10 Sv/h (measured on Apr. 10-16, 2015, in gas phase of 0.7 m from the water level, on the grating)		Approx. 31-73 Sv/h (measured on Mar. 27, 2012, in gas phase of 3.7 to 6.7 m from the water level, around X-53 penetration)		Approx. 0.75-1 Sv/h (measured on Oct. 20, 2015, in gas phase of 0.55 m from the water level, around X-53 penetration)	
	Observed water leakage points	Water flows were detected from one sand cushion drain pipe (ⓐ) and one expansion joint cover (ⓑ) of the S/C vacuum break line.		It is expected water flow from somewhere below water level inside the torus room, since there is no trace of water leakage in gas phase.		Water flow was detected from the expansion joint (ⓒ) of the MS Line D in the MSIV room.	
	PCV internal survey	-No large scale damage on the existing facilities (e.g. PLR pump, wall inside the PCV and HVH). -Deposits are scattered over a wide range. -PLR piping shielding units fallen.		-The structures of the RPV bottom was confirmed by the photographs taken from RPV pedestal opening. Breakage of the RPV bottom is unlikely to be a large.		-PCV internal survey using inspection device inserted from PCV penetration indicated that no damage of the walls and PCV was found within the scope of the survey.	

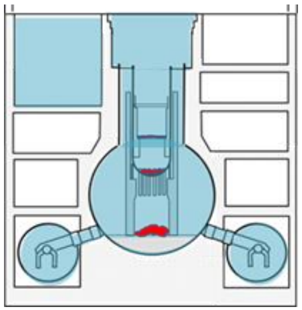
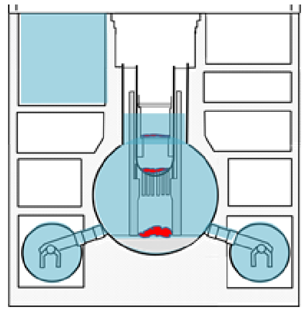
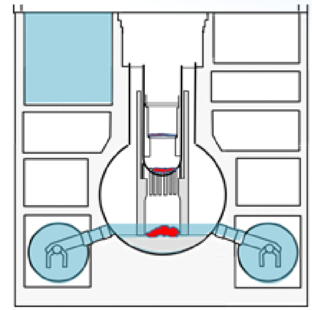
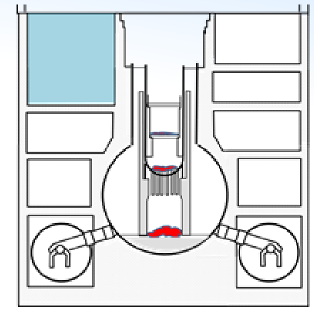
*1: Range of results based on Severe Accident codes
*2: The most reliable value by a plurality of analysis results in the current

Note: Fuel debris distribution: Based on the document provided by IRID
Plant investigation status: Based on the document released by TEPCO

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Possible options for retrieval

- **Narrow down of the methods based on the PCV water level and access direction**

		Full submersion	Submersion	Partial submersion	Dry
Water level		 A method in which water fills to the top of the reactor well.	 A method in which the water fills to a level above the highest point of the fuel debris distribution	 A method in which the water is filled t o a level below the highest part of the fuel debris distribution. (with poring water to the fuel debris)	 All the areas where fuel debris is scattered are exposed to the air, and neither water cooling nor water pouring is involved
Access direction	**Top**	a.	a.	b.	
	Side			c.	
	Bottom				

Methods to be focused

a. Submersion method (including full submersion)[1]

b. Partial submersion – Top access method

c. Partial submersion – Side access method[2]

(gray): Possibility of water flowing out from the openings

(green dashed): Difficulty of constructing new access route

(blue dashed): Difficulty of evaluating cooling performance

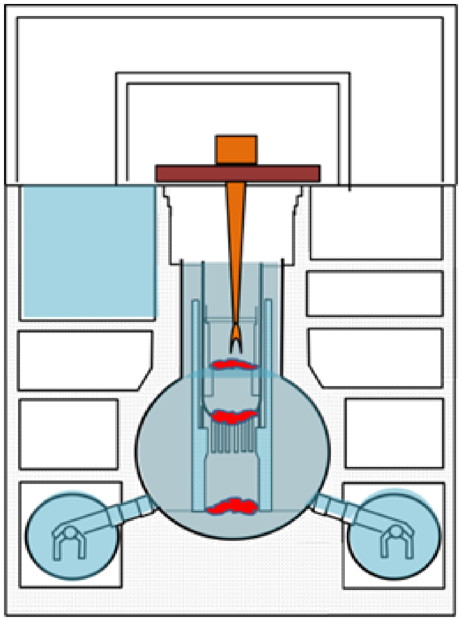
1 : Including the Full submersion

2 : The water level is lower than the access hole.

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

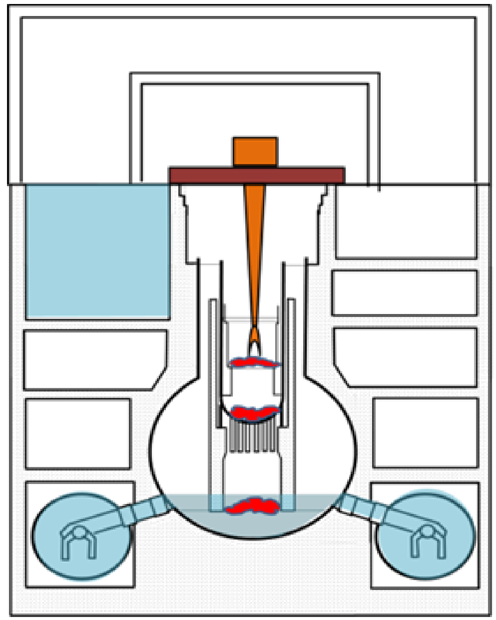
Three Methods of Fuel Debris Retrieval to be focused

Individual method from the following three methods or combined method will be applied according to the distribution of the fuel debris.



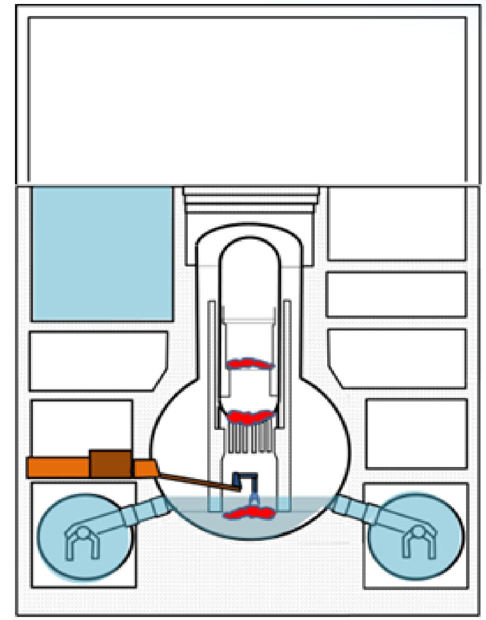
Submersion-Top access method

Assuming the in-core structures above the fuel debris are removed



Partial submersion -Top access method

Assuming that the in-core structures above the fuel debris are removed



Partial submersion - Side access method

Assuming that the equipment and other objects outside the RPV pedestal in PCV are removed

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Consideration toward the determination of retrieval policies

(1) Evaluate the effect of risk reduction

(2) Evaluate access route and retrieval method

(3) Select the first fuel debris to be retrieved and its method

(4) Consideration on the fuel debris other than those retrieved at first

And further consideration…

- Interim storage in stable condition
- Treatment and disposal in longer-term
- Management of arising waste

…..

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

Safety Issues

In any method, safety must be ensured to protect (1) Residents and environment, and (2) Workers from the impact caused by radioactive materials. Issues are follows;

1. Securing the structural integrity of the PCV and R/B
2. Criticality control
3. Maintaining the cooling function (PCV repair (water sealing))
4. Ensuring containment function (Radioactive prevention of radioactive dust scattering)
5. Reducing workers' exposure during operation
6. Ensuring work safety

Source: "Technical Strategic Plan 2016 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

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