Locating Fuel Debris inside the Unit 3 Reactor Using a Muon Measurement Technology at Fukushima Daiichi Nuclear Power Station

September 28, 2017

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Tokyo Electric Power Company Holdings, Inc.

The contents of this document is what TEPCO carries out as a part of the project developed by the International Research Institute for Nuclear Decommissioning (IRID)

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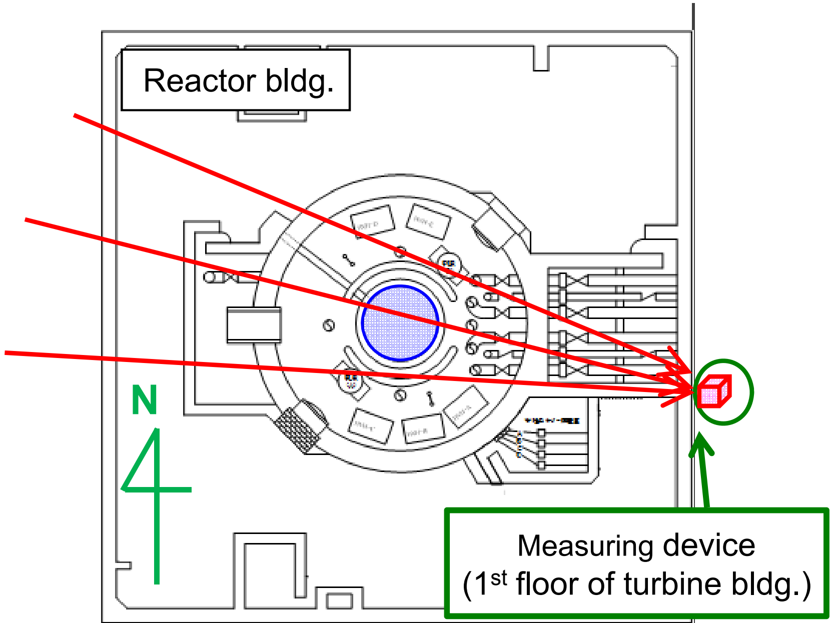
- As the step of gathering information about fuel debris distribution toward a removal of fuel debris, muon measurement using a transmission method that obtains quantitative distribution in the Reactor Pressure Vessel (RPV) from transmittance of muon particles which have passed through the reactor have been carried out in Unit 1 and 2.
  - Unit 1 : No massive fuel in the core area (Feb.-May., May.-Sept., 2015)
  - Unit 2 : High-density materials that is considered fuel debris at the lower area of RPV (Mar.-July., 2016)

- Unit 3 muon measurement has been carried out from May to September, 2017. The result is reported. (Measurement was completed on September 8.)



Installation location of
muon measuring device

Installation of muon measuring device
(small-sized unit, approx.1m × 1m × 1.3m(height))

Measurement principle of the muon transmission method

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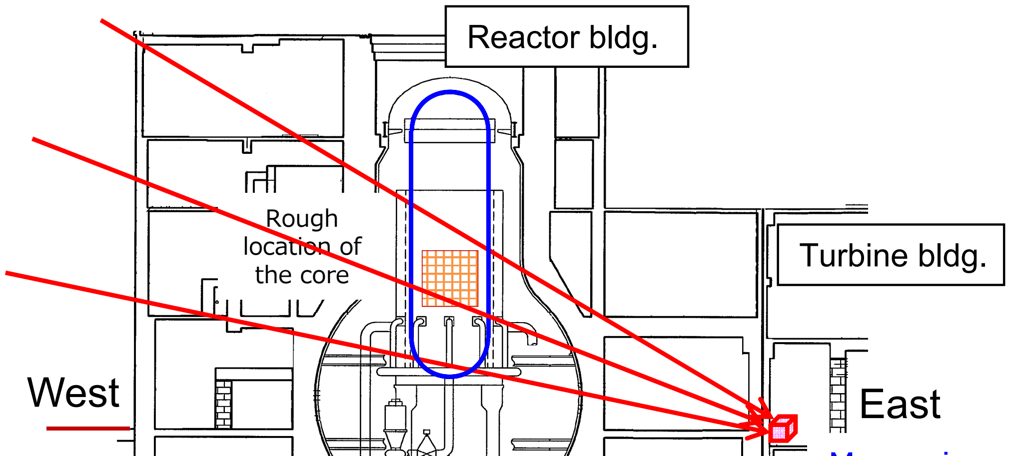
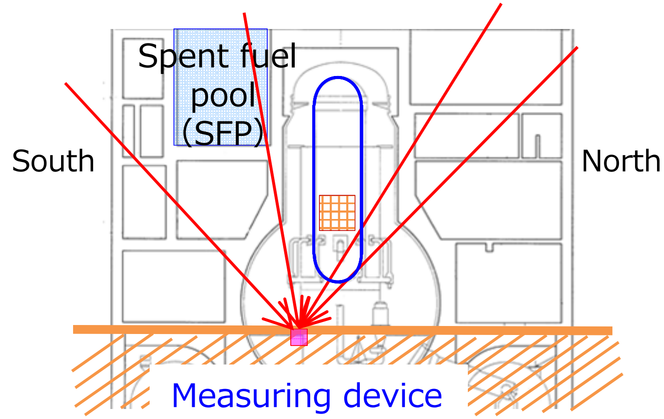
- Muon is the secondary cosmic ray generated in the collision of cosmic ray from space with atmosphere. Muon has high energy and characteristics to pass through materials.

- By measuring muon particles which have passed through the reactor building, images of fuel debris distribution inside the RPV are captured like X-ray pictures from their transmittance. (Higher density materials that less muon can pass through make darker shadow.)



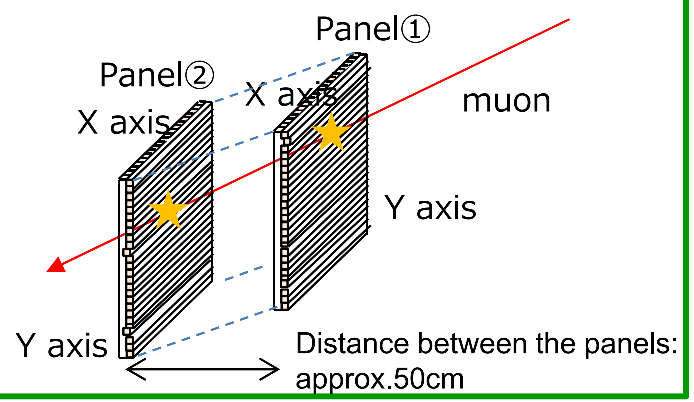
Measurement image of muon particles that pass through the reactor building (East-west cross section)



Measurement image of muon particles that pass through the reactor building (North-south cross section)

Measurement principle of the muon transmission method (image)

Two panels (plastic scintillators) inside the muon measurement device detects incoming cosmic rays muon and calculate their trace on where they have pass through from the coordinates on the panels.



Result image using the muon transmission method

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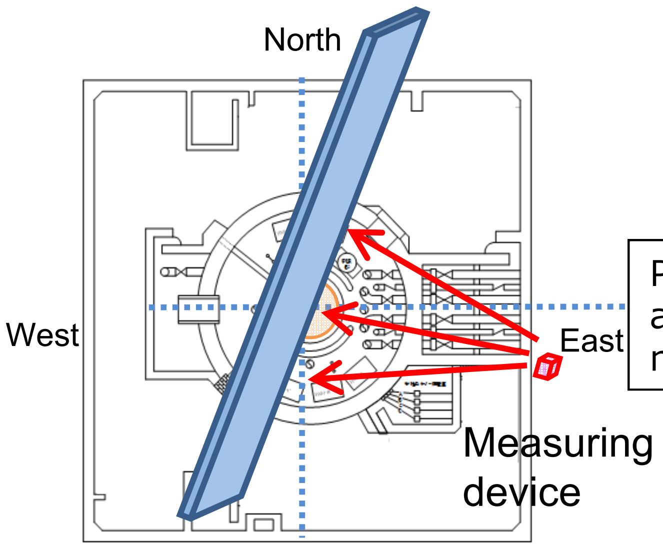
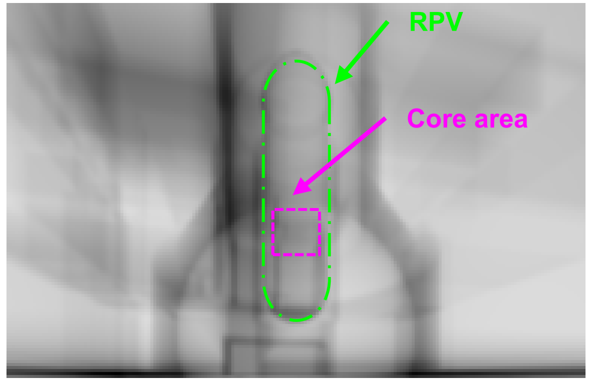
- By measuring muon particles which have passed through the reactor building, the reactor building is seen through.
- By projecting on the cross section though the reactor, images of fuel debris in the reactor core and the bottom of RPV are captured like X-ray pictures.



Projected image

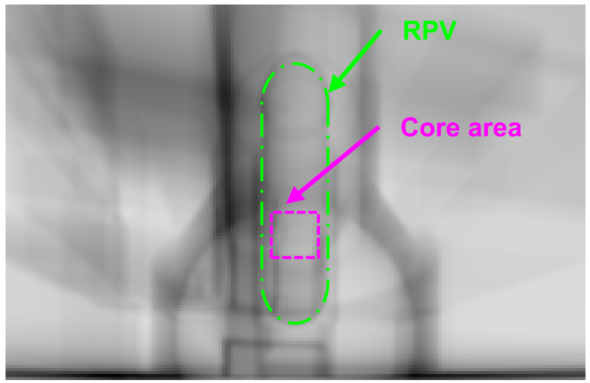
Projected images by muon are simulated from structure map of the reactor building

Simulation (with fuel)



Simulation conditions
・Reactor core and lower area of RPV：With fuel
・Inside SFP：Filled with water

Simulation (without fuel)



Simulation conditions
・Reactor core and lower area of RPV：Without fuel
・Inside SFP：Filled with water

Result of Unit 3 muon measurement (Quantitative distribution)

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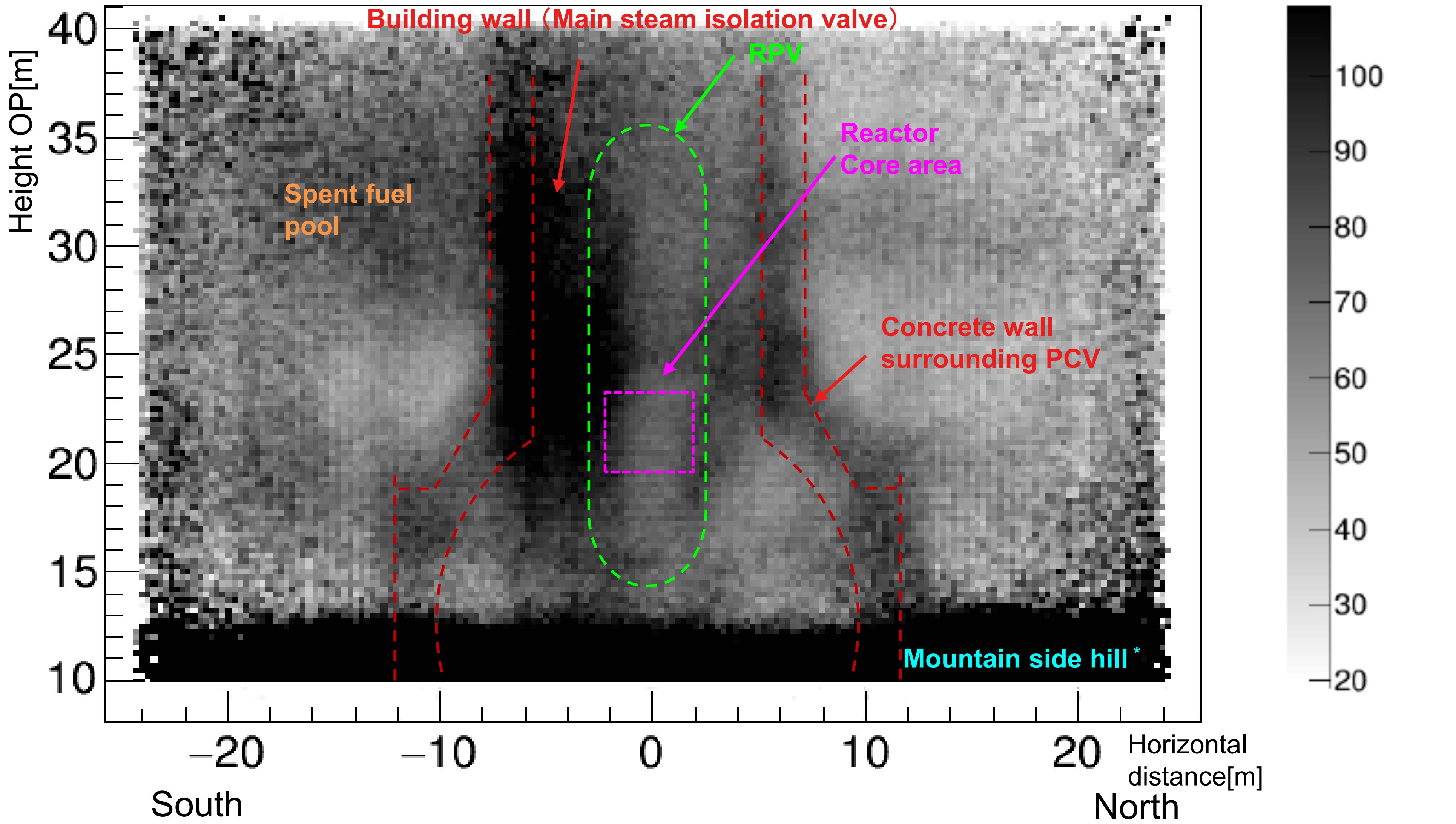
- Quantitative distribution of unit 3 from measurement up to date is as the picture bellow. (The interpretation is shown on the following pages.)

(As of September 8, 2017)



Main structure in the reactor building (comparison with simulation)

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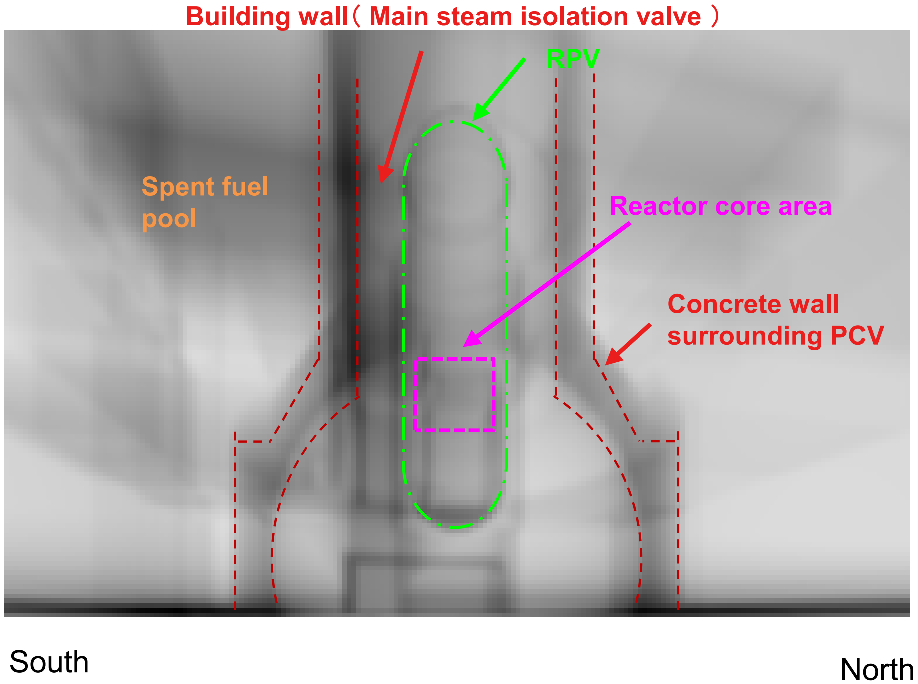
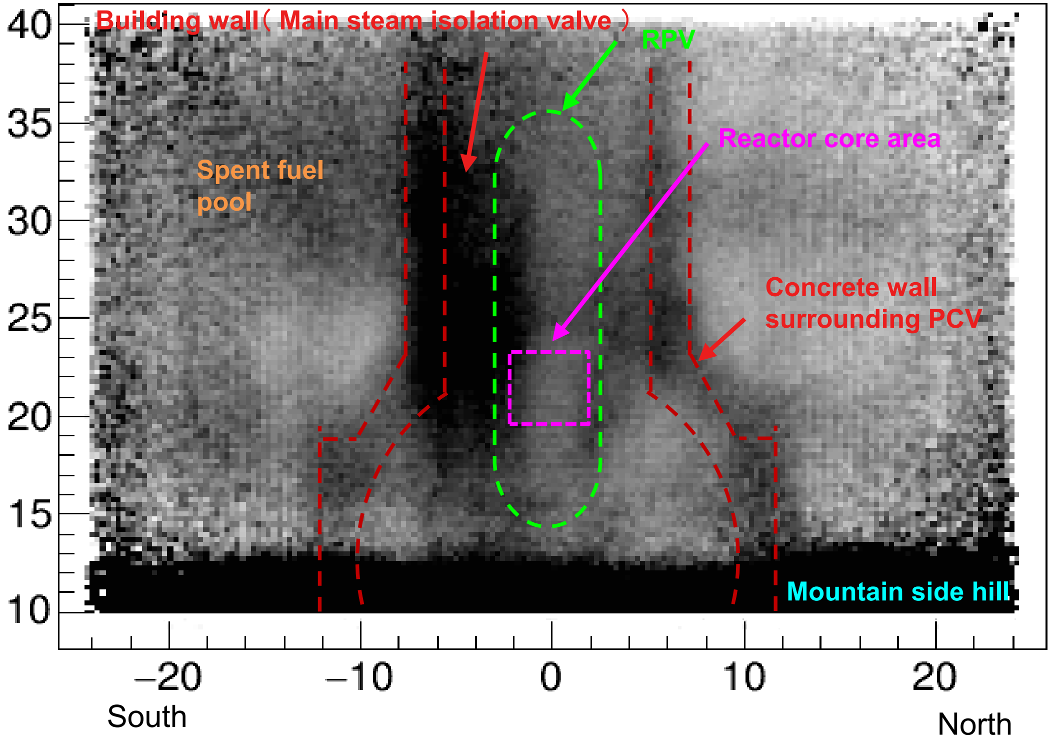
- By measuring muon particles which passed through the reactor building, main structures in the reactor building including the concrete wall surrounding PCV, the spent fuel pool and wall of building were recognized.

(As of September 8,2017)



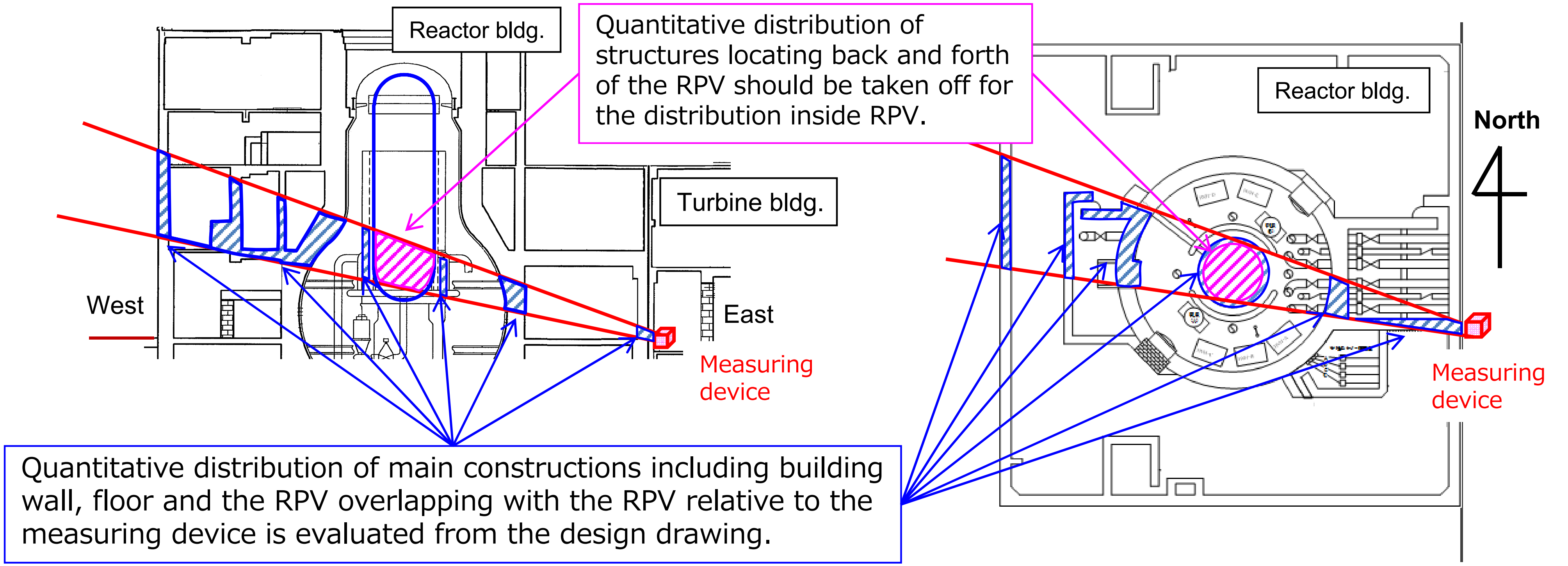
Quantitative distribution by simulation (Case with fuel debris in core area and at lower area of reactor)



Quantitative distribution by muon measurement

Evaluation of quantity inside the RPV

- Quantitative distribution obtained from the muon measurement includes some effects of structures such as building wall, floor and the RPV itself.
- These effects should be taken out for the true quantitative distribution inside the RPV.
- Evaluate quantitative distribution of structures which exist front and behind of RPV by identifying design drawing and simulation in order to exclude it from measurement result.



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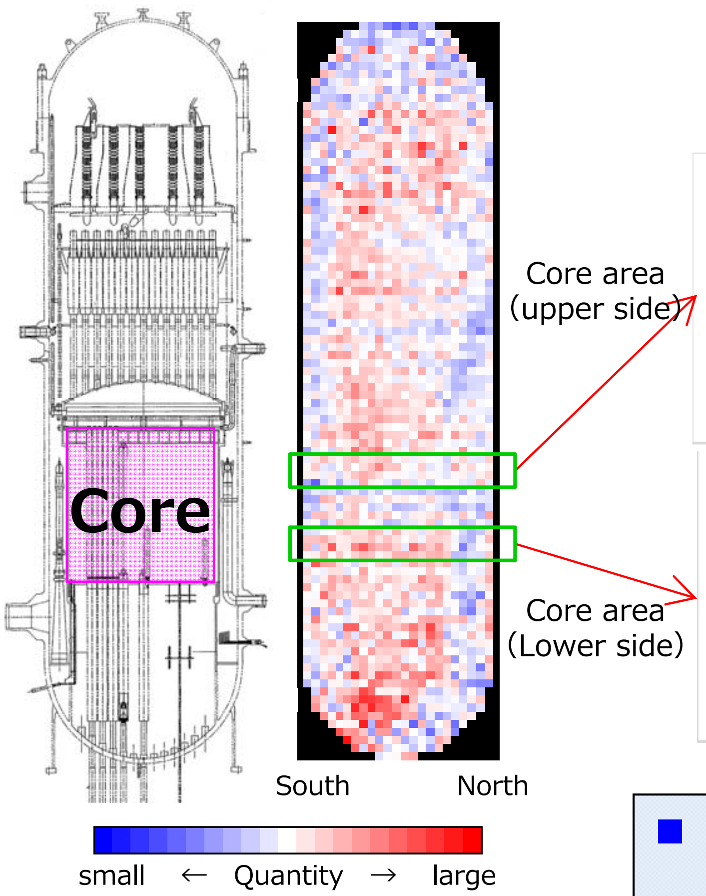
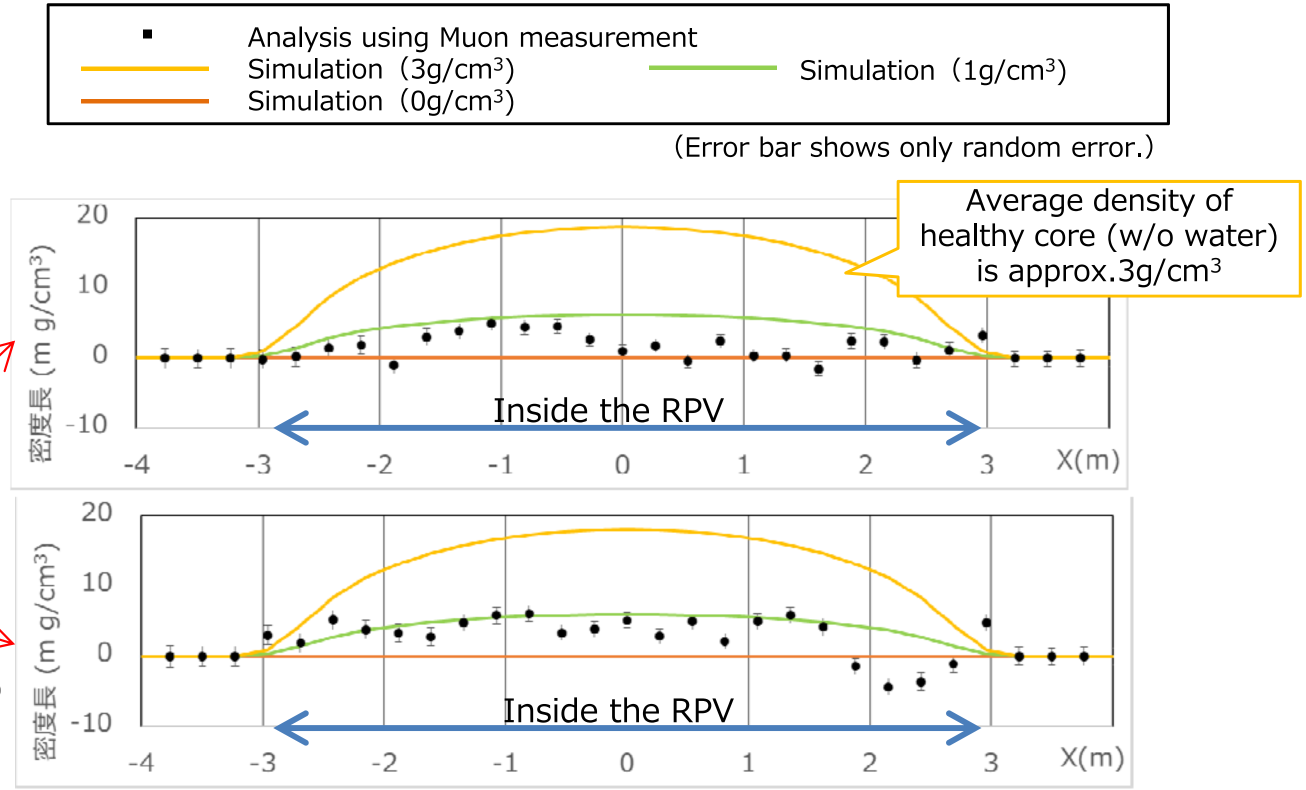
- Quantity of structures such as building wall, floor and the RPV was taken off from the measurement result based on simulation.
- Status of fuel is evaluated by comparing the true distribution with simulation result for the case that the RPV is filled with a hypothetical material with uniform density.

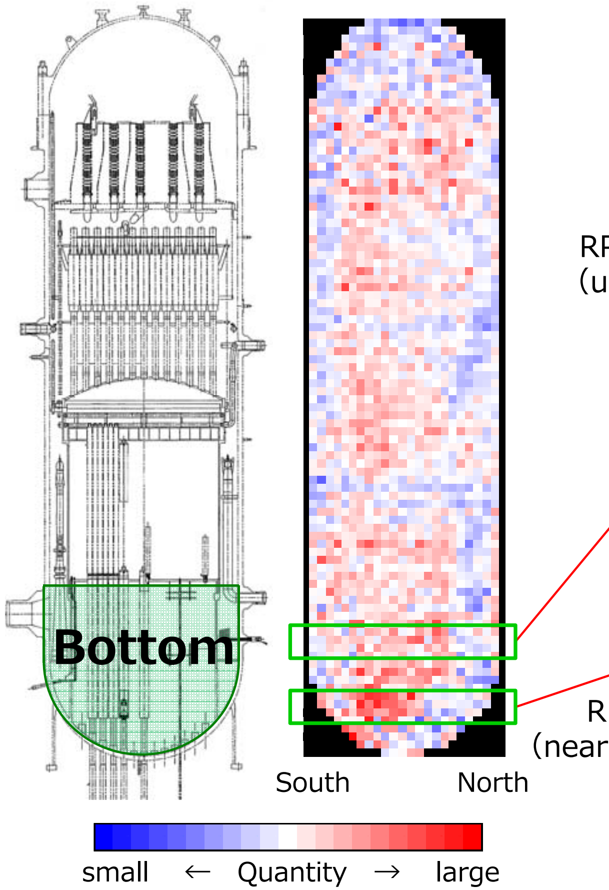


Quantitative distribution inside the RPV
(inside of the inner wall)

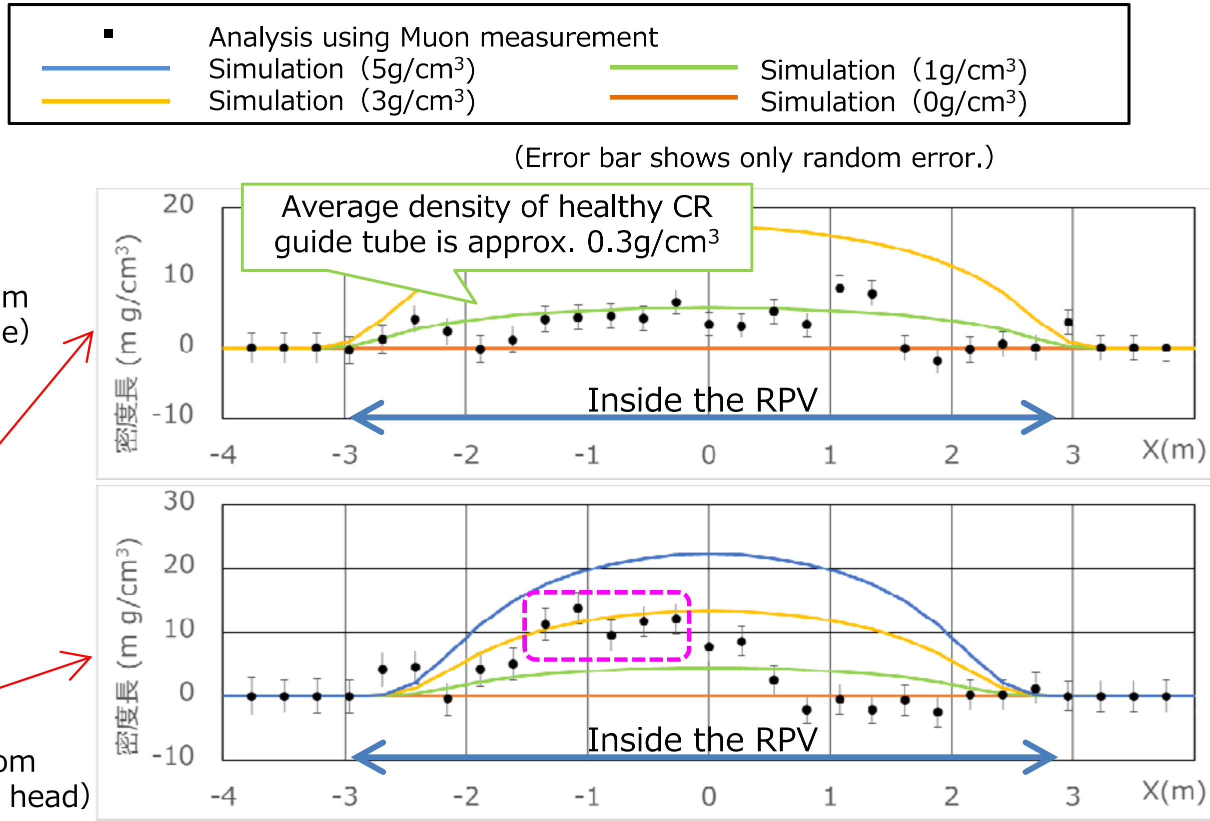


- Quantity in core area is distributed in average density lower than 1g/cm³. Quantity greatly decreased.

Quantitative distribution inside the RPV（②RPV bottom)

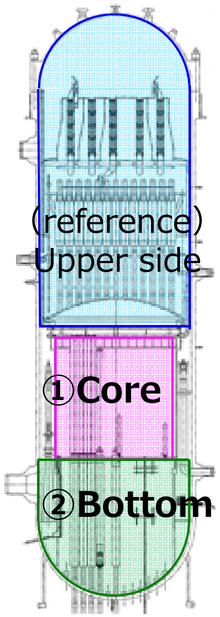


Quantitative distribution inside the RPV
(inside of the inner wall)



- There is more quantity at the RPV bottom (near bottom head) than usual in some locations.

Quantitative evaluation inside the RPV



<Result>

(As of September 8, 2017)

	quantity [ton]	Error [ton]		(Reference) quantity before the accident[ton]
		Random error	Systematic error	
(Reference)Upper side	Approx.120	±Approx.6	Dozens	Approx.80 (structures)
① Core area	Approx.30	±Approx.3		Approx.160 (fuel assembly) Approx.15 (control rod) Approx.35 (constructions)
② Bottom of the RPV	Approx.90	±Approx.5		Approx.35 (constructions) Without effect of water

<Evaluation of fuel debris distribution>

① Quantity of the core area greatly decreased. It is considered that the bulk of fuel and structures moved to lower side. And it is considered there is no massive fuel.

② Quantity of the RPV bottom increased compared to quantity before the accident. There is a possibility that some of fuel debris remain.

<Evaluation of systematic error>

Systematic error is evaluated about ±15～±25 ton considering a resolution limit of the detector to specify the location of targets.
However, there might be several times error more from the factors that simulation could not cover including reinforcing bar inside concrete and constructions installed after the accident.

- By measuring muon particles which passed through the reactor building, main structures such as the concrete wall surrounding the PCV, the spent fuel pool and wall of the reactor building were recognized.

- Evaluation results for the fuel debris distribution inside the RPV by Unit 3 muon measurement are as follows:

  - There is no massive fuel debris in the core area.

  - There is a possibility that some fuel debris remain at the RPV bottom, though it is uncertain.

- These results and other knowledge obtained from PCV internal investigation are leveraged towards fuel debris removal in the future.

(Reference) Comparison between Unit 1-3 muon measurement results and estimation of fuel debris distribution

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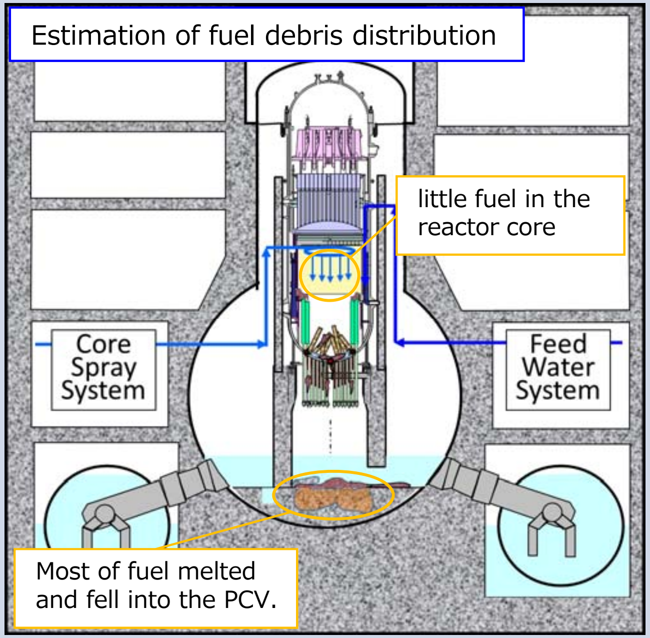
Results

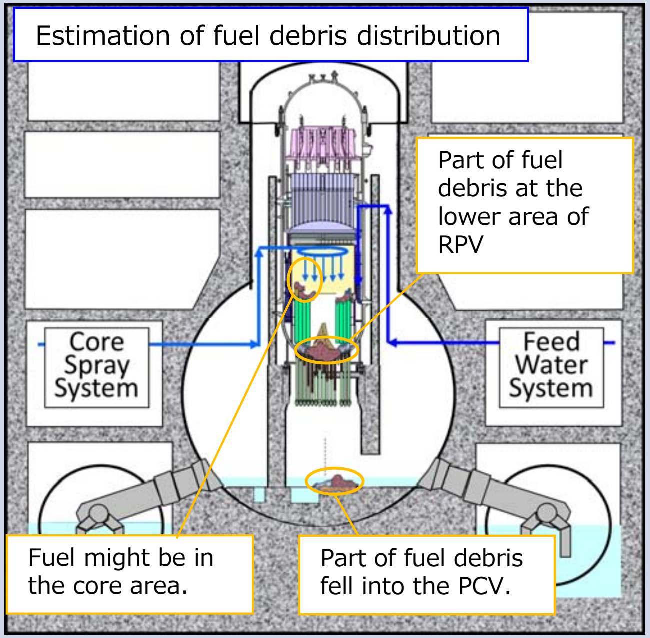
Unit 1	Unit 2	Unit 3 (flash report)
・No massive fuel in the core area. (Lower area of the RPV is not measured.)	・High density materials that is considered fuel debris were found at the lower area of the RPV. ・Part of fuel possibly exists in the reactor core area.	・No massive fuel in the core area. ・There is a possibility that some of fuel debris might remain at the RPV bottom, though it is uncertain.
Reflect the result to estimation of fuel debris distribution	Reflect the result to estimation of fuel debris distribution	Results of PCV internal investigation and Muon measurements will be reflected to estimation of fuel debris distribution

Current estimation of fuel debris distribution (*)

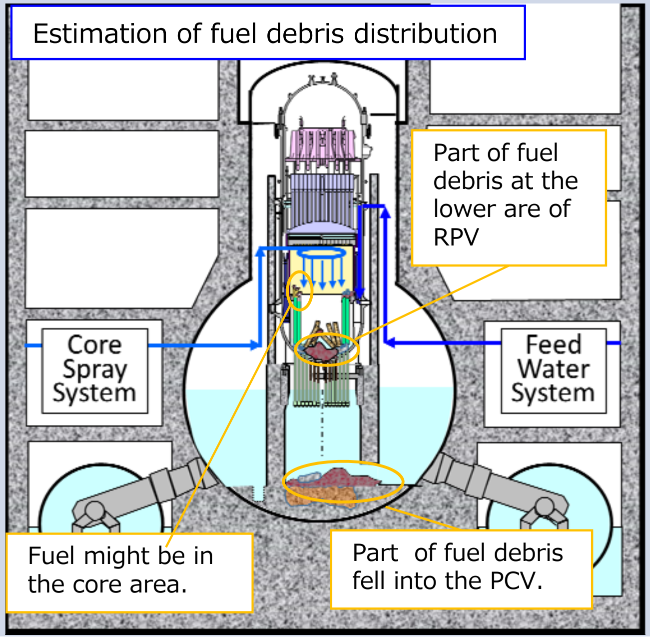
Unit 1



Unit 2



Unit 3



Unit 1:
- Most of melted fuel fell into the PVC and there is little fuel in the reactor core.

Unit 2 and Unit 3:
- Part of melted fuel fell into the lower plenum of RPV and the PCV, and part of fuel remain in the reactor core.
- More fuel debris might fall into PCV in Unit 3 than Unit 2.

*"Project of Decommissioning and Contaminated Water Management (Upgrading level of grasping state inside reactor)" (IRID, IAE)
From the document of the 2nd international forum on the decommissioning of the Fukushima Daiichi NPS on July 3, 2017
http://ndf-forum.com/program_en/day2.html

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