The 1st International Forum on the Decommissioning of the Fukushima Daiichi NPS

Fuel debris retrieval strategy for Fukushima Daiichi Nuclear Power Station

April 11th, 2016

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About fuel debris

What are "Fuel debris“ ?

“Solidified melted fuel distributed among fuel assemblies, control rods and some other reactor materials”

Fuel debris of TMI-2

Fuel debris of Chernobyl

Fuel debris of Windscale

- Features

  Mixed with other materials not contained in the cladding such as nuclear fuel materials.
- Risks to be considered with the plant status.
  - Criticality, decay heat, containment, radiation, hydrogen explosion, support structure
- Difficulties in risk management for the fuel debris
  - Uncertainty: Lack of information on in-vessel conditions
  - Instability: Fuel melted and facilities damaged by the accident
  - Lack of risk management: Difficulty in accessing due to severe radiological environment
- Institutional requirements and the rules

Current condition of fuel debris

- **Fuel debris inventory (Bq)**

  Reduced to **one several hundredth** from the days of the accident

  【Reasons】

  - Release of volatile radionuclides by meltdown
  - Release of soluble radionuclide by cooling water circulation and injection
  - Radioactive decay over time

- **Situation estimated by plant parameters**

  Reactor (fuel debris) in a stable state from the macroscopic observation

  - Sub-criticality maintained: Noble gas concentration monitored by PCV gas control system and sub-criticality confirmed
  - Cooling: In-vessel temperature maintained by cooling water circulation and injection (20-40°C)
  - Containment
    - Release of radioactive materials (gas phase): Maintain PCV pressure slight positive, 0.003mSv/year at site boundary (Estimated additional dose)
    - Contaminated water (water phase): Contain water leakage from PCV by the buildings.(Water level difference between inside and outside the building)
  - Prevention of hydrogen explosion: Inert PCV by nitrogen injection
  - Corrosion prevention: Inject corrosion inhibitor while filling the PCV with nitrogen

Fuel debris risk reduction strategy

- **Two angles for fuel debris risk reduction**
  - Short & Mid-term risk reduction

    Degradation of containment function, abnormal event initiated by instability of internal condition such as possible criticality and flow out of radionuclide which may arise in a short & medium period of time.
  - Long-term risk reduction

    Prevent risks to the environment for a long period of time.

- **Strategy for short & mid-term risk reduction**

  1) To understand fuel debris properties (decrease in uncertainty)
  2) To improve in-vessel conditions through fuel debris retrieval work (elimination of instability)
  3) To manage the storage of fuel debris in a stable state (improvement of risk management level)

- Our Goal → "Assured, stable, and managed state"

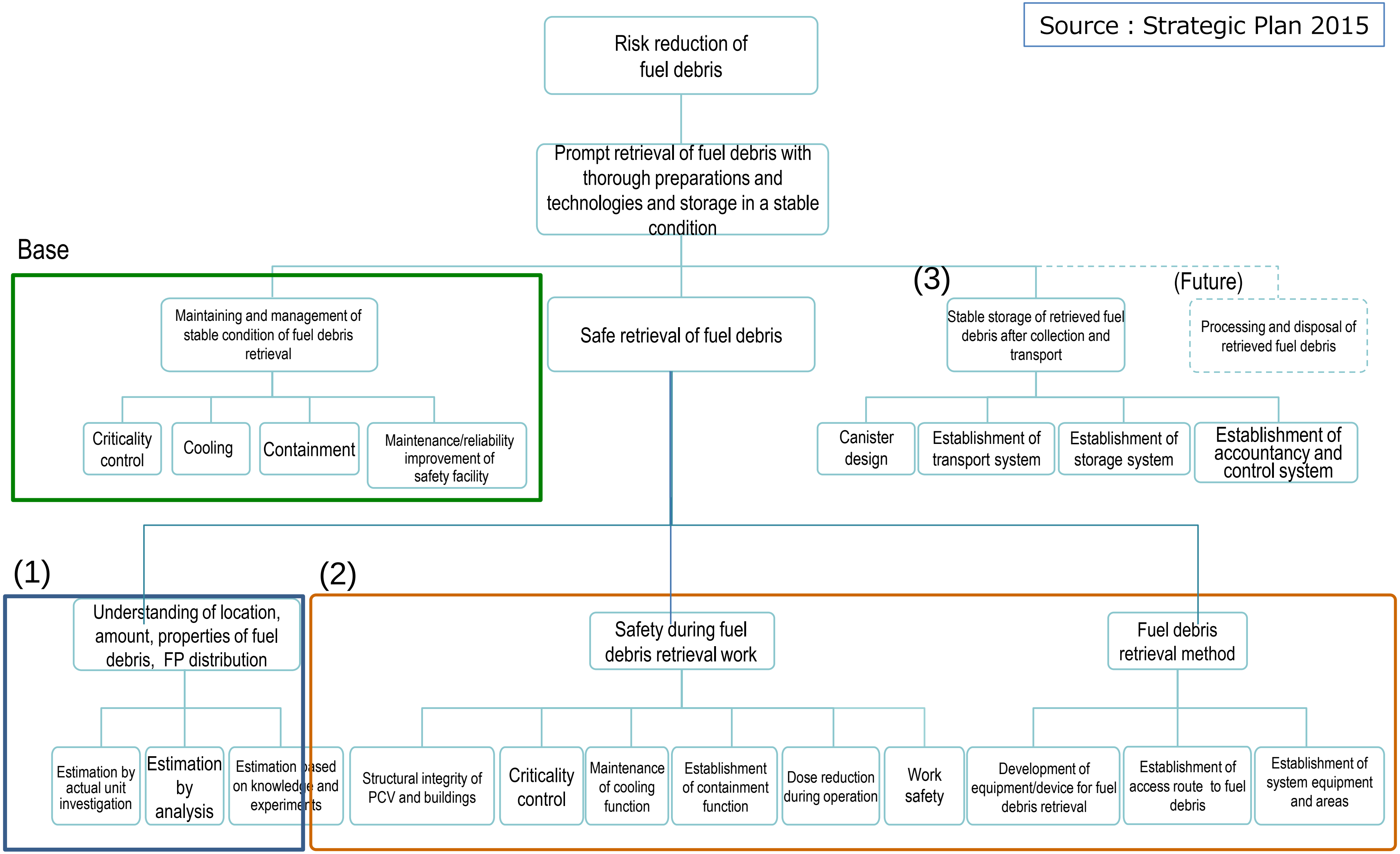
  However risk suppression during fuel debris retrieval work important.

"If you know your enemies (fuel debris) and know yourself (feasibility of technique), you will not be put at risk even if you have a hundred battles (fuel debris retrieval).

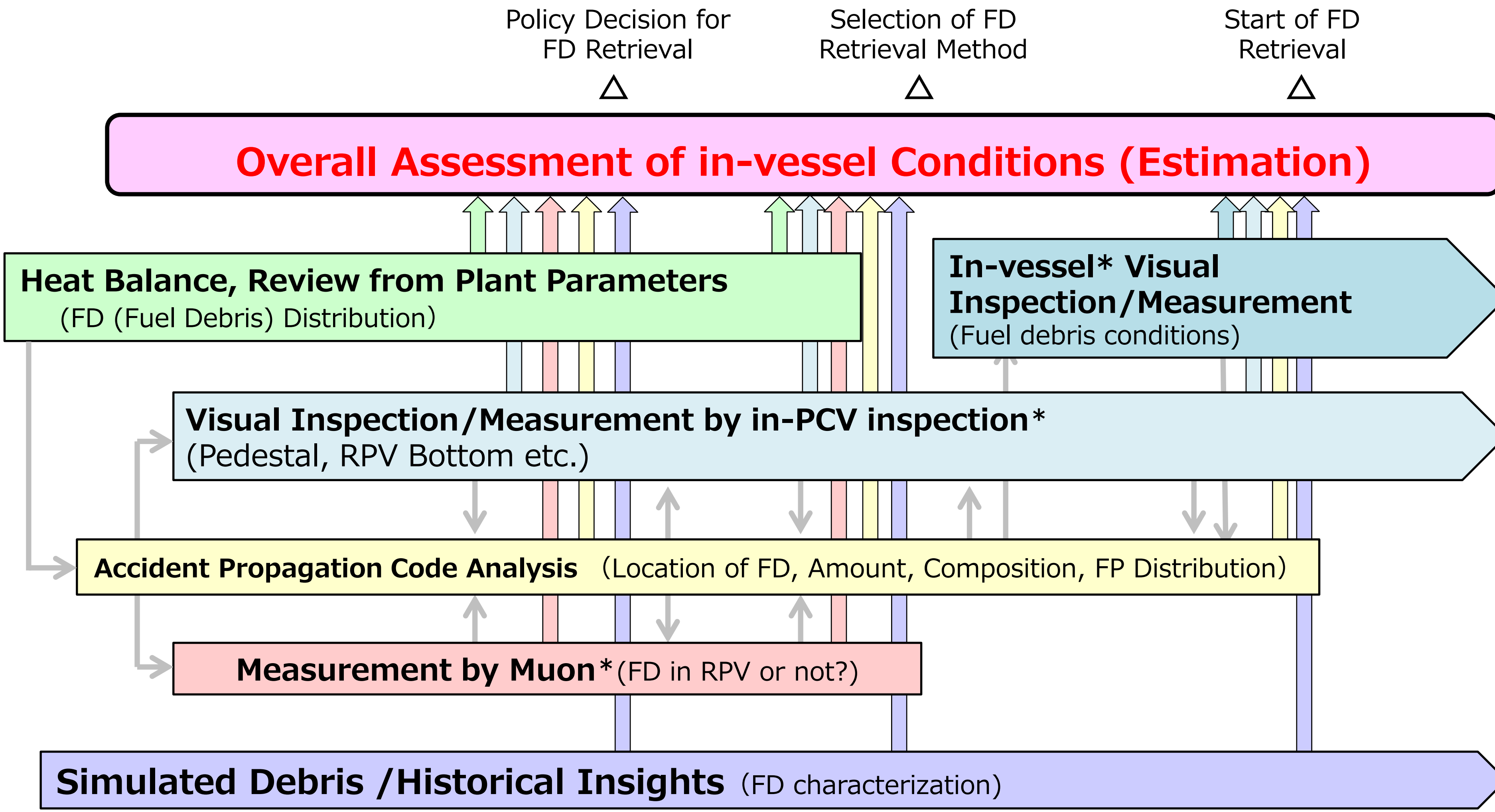
(Sun Zi's Art of War)

Logic tree for fuel debris risk reduction

Source : Strategic Plan 2015



Strategy on the in-vessel Investigation (comprehensive evaluation/estimation)



*Investigation depends on the Balance between Cost of Development and Investigation, Time needed and Dose Rate vs. Information obtained

- **“How sure is sure enough?” is the function for decision.**

Prioritization in the fuel debris retrieval method assessment

Information needed for fuel debris retrieval method

- ✓ **Location of the fuel debris (rough estimation)**
- ✓ **Presence of fuel debris with higher risk**
- ✓ **Damage condition of structures**

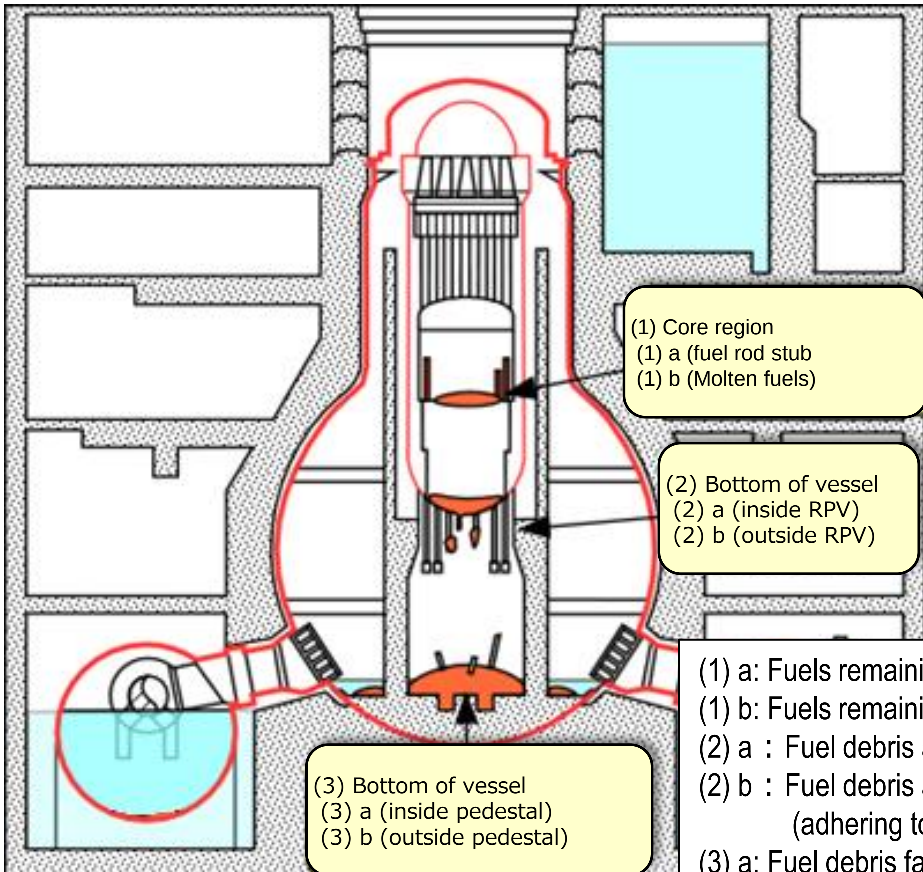


Fig. Estimated located where fuel debris are distributed

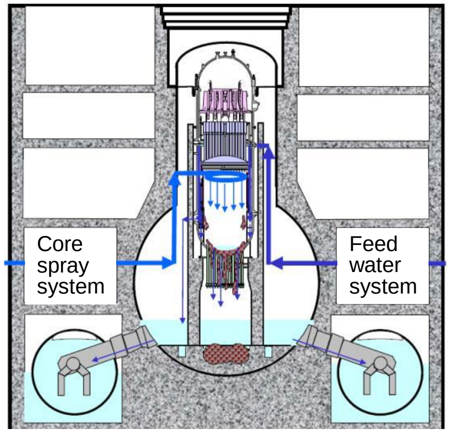
- ➢ Rough fuel debris estimation;
  core regions, bottom of the vessels (in/outside the vessels), bottom of the PCV (in/outside the pedestal).
- ➢ Unsolved fuel (fuel rod stub) at core periphery
  Criticality risk.
- ➢ Status of MCCI at the bottom of PCV and RPV pedestal damage

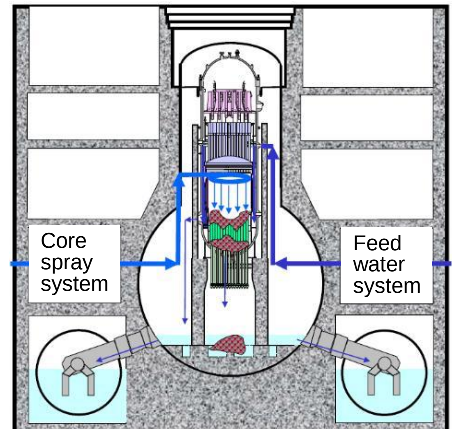
(1) a: Fuels remaining in the core region without being melted (fuel rod stub)
(1) b: Fuels remaining in the core region that melted with cladding etc.
(2) a ： Fuel debris accumulated on the inner side of the bottom of RPV
(2) b ： Fuel debris accumulated on the outer side of the bottom of RPV
(adhering to the CRD housing etc.)
(3) a: Fuel debris fallen on the bottom of PCV and accumulated inside the pedestal
(3) b: Fuel debris fallen on the bottom of PCV and leaked to the outside of pedestal

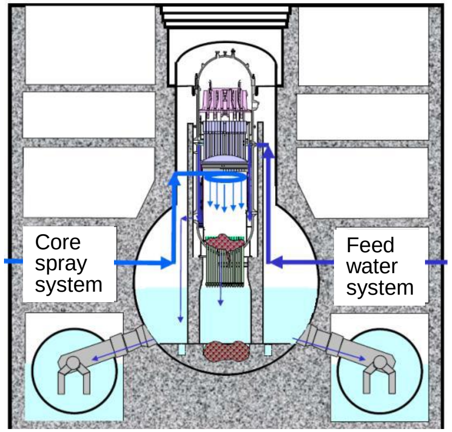
Plant inspection status and estimated fuel debris locations

Current estimated plant status

Source : Strategic Plan 2015







Unit	Unit 1	Unit 2	Unit 3
Plant investigation situation	-D/W water level approx. 3 m from PCV bottom. -S/C is mostly filled with water. -Leakage from the sand cushion piping identified -Leakage from the expansion-joint cover of the vacuum break line connected to the W/W venting piping confirmed. -Hot dose rate (several Sv/h) spot in the southeast area of the reactor building 1st floor.	-D/W water level approx. 30 cm from PCV bottom. -S/C water level close to the center, almost the same water level to that of the torus. -No evidence of leakage in the torus upper section. -Photo of RPV pedestal inside taken from the opening confirms the structure of RPV lower region, which shows that the vessel failure will not be so large.	-D/W water level approx. 6.5 m from PCV bottom. (estimated from the pressure differential of D/W and S/C) S/C mostly filled with water. -Leakage from the expansion-joint of the main steam piping D confirmed.
Estimated fuel debris location	-Almost all molten fuel dropped down to the RPV lower plenum and no fuel debris remains in the core. -Dropped fuel debris into the lower plenum fallen on the RPV pedestal bottom. -Dropped fuel debris in the pedestal bottom flew outside of the pedestal (probable attack to the shell).	-Some molten fuel dropped to the RPV lower plenum and on the pedestal floor, and the remaining stays in the core (no fuel debris estimated outside the pedestal).	

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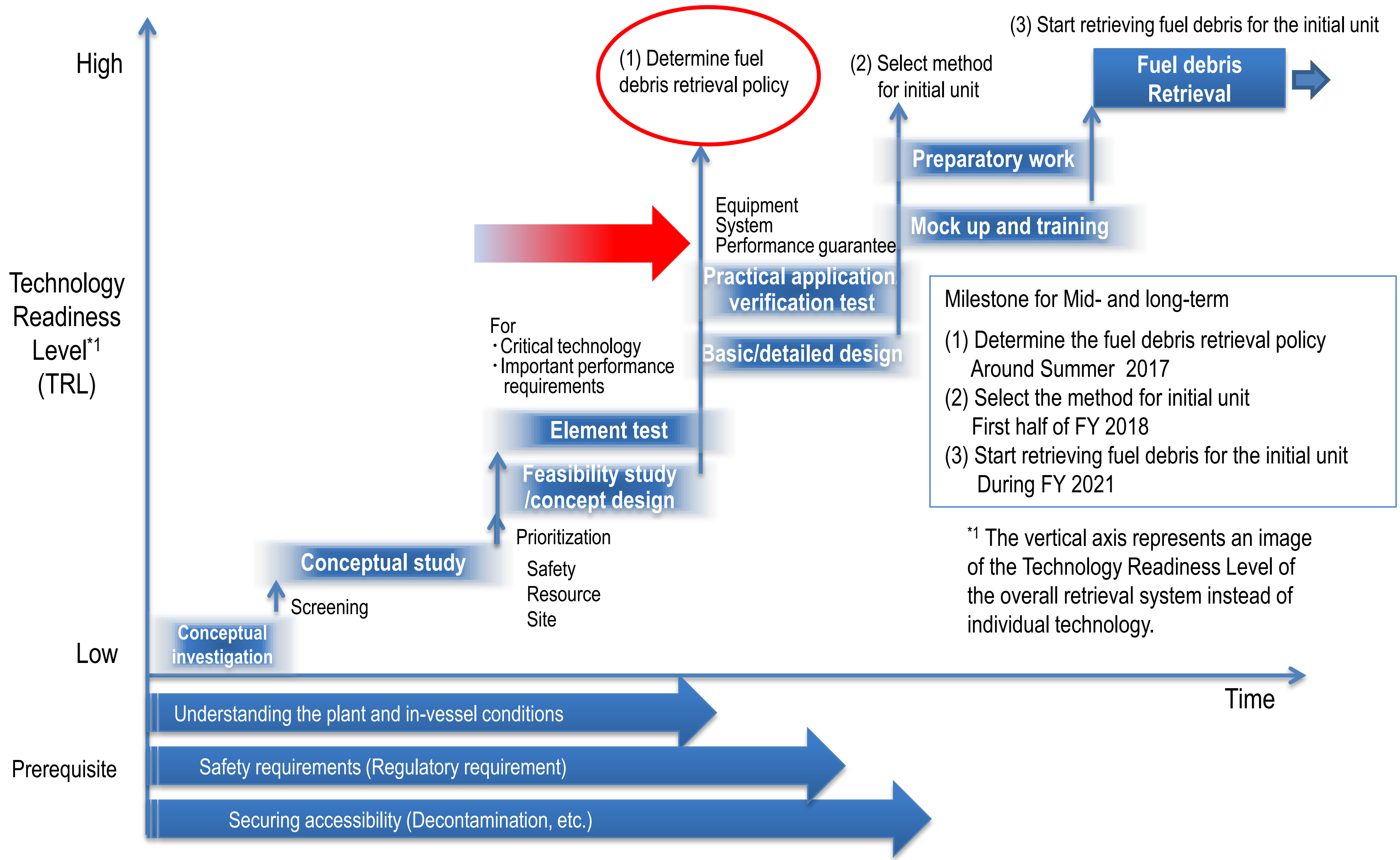
Road to achieve the fuel debris retrieval



Milestone for Mid- and long-term

(1) Determine the fuel debris retrieval policy
Around Summer 2017

(2) Select the method for initial unit
First half of FY 2018

(3) Start retrieving fuel debris for the initial unit
During FY 2021

*1 The vertical axis represents an image of the Technology Readiness Level of the overall retrieval system instead of individual technology.

Toward the selection of fuel debris retrieval method

- **Method of fuel debris retrieval consists of :**
  - Access route and systems
    (including decontamination and securing the space)
  - Transportation of equipment
  - Visualization and measurement
  - Cutting and dust collection
  - Packaging and transfer
- **Safety functions required when retrieving the fuel debris**
  - ✓ To control Sub-criticality
  - ✓ To maintain cooling function
  - ✓ To provide the containment function
    - Liquid phase (Prevention of the contaminated water leakage)
    - Gas phase (Dust dispersion prevention)
  - ✓ To secure structural integrity for PCV/buildings
  - ✓ Occupational dose reduction (shielding)
  - ✓ To ensure industrial safety
- **Five Guiding Principles for debris fuel selection method:**

  "Safe," "Proven," "Efficient," "Timely" and "Field-oriented"

Water level inside PCV for debris retrieval

- **Water level inside PCV critical for selecting fuel debris retrieval method**
  - ➢ Advantage of increase of water level inside the PCV up to the upper part of the core (To flood fuel debris etc by cooling water is an ordinary and assured method.)
    - ✓ Dust dispersion prevention (when cutting fuel debris)
    - ✓ Dose reduction by water shielding (activated Co, Cs contamination, fuel debris)
    - ✓ Margin for cooling function
  - ➢ Disadvantage of increase of water level inside the PCV (advantage of not to increase the level)
    - ✓ Large scale and difficult PCV repair work (water leak blockage) required
    - ✓ Measures assuming large-scale leakage accident required (relating to the contaminated water management).
    - ✓ Sub-criticality during the increase of water level required.
    - ✓ Verification of structural integrity during the earthquake required for the increase of the water load.
- **Water level inside the PCV to be determined by the balance of the advantage and disadvantage of the increase of water level inside the PCV, their feasibilities and fuel debris distribution.**

Access direction and water level inside the PCV

- Alternative directions (side/bottom) should be studied considering that the fuel debris may have been dispersed to the bottom of the PCV in addition to normal access to the core fuels from the operating floor.
- Method should be selected focusing on feasibility

  Combination of <u>access direction</u> and <u>water levels inside PCV</u>

  *(Full submersion, Submersion, Partial Submersion, and Dry) methods to be studied for the feasibility are narrowed down as follows.

Combination of <u>access direction</u> and <u>water levels inside PCV</u>

		Entry direction		
		Top	Side	Bottom
Water level	Full submersion	a.		
	Submersion	a.		
	Partial submersion	b.	c.	
	Dry			

: Possibility of water flowing out from the openings (shaded: Side and Bottom under Full submersion and Submersion; Bottom under Partial submersion)

: Difficulty of constructing new access route (green dashed: Bottom)

: Difficulty of evaluating cooling performance (orange dashed: Partial submersion/Dry boundary)

Selection of the methods based on the above.

<u>Methods to be focused</u>

a. Full submersion/Submersion method – top entry method → "Submersion –Top entry"
b. Partial submersion– top entry method → "Partial submersion – Top entry"
c. Partial submersion – side entry method → "Partial submersion – Side entry"

*Definition of water level inside the PCV

<u>Full submersion</u>
Water is filled up to the reactor well

<u>Submersion</u>
Fuel debris are submerged
The portion above the lower part of the core is submerged (mage)

<u>Partial submersion</u>
Partial fuel debris are exposed to the air
Only the bottom of the PCV is submerged (image)

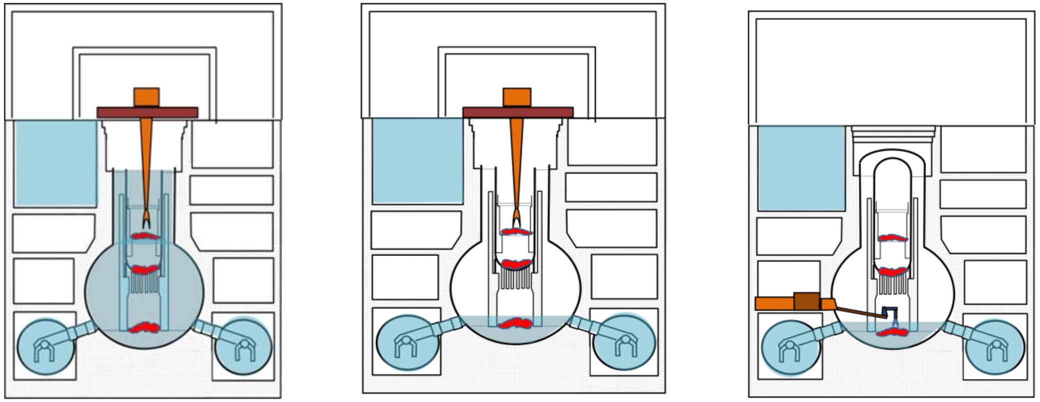
<u>Dry</u>
No water

Development of fuel debris retrieval method

- For each step (e.g. rise of PCV water level, removing upper structures, and retrieving fuel debris retrieval) of three methods requires to:
  - ✓ **Extract systems** to secure the safety
  - ✓ Investigate the **concept of required equipment/device** for fuel debris retrieval work
  - ✓ **Select and implement element test** to confirm the feasibility of the functions required for equipment/device above

- Request for proposal (RFP) with multiple manufacturers in Japan and overseas to review the on-site applicability
  - ✓ Partial submersion method (top/side entry method)
  - ✓ Cutting/dust collection and visualization and measurement technologies commonly used for the methods.

Three methods to be focused on

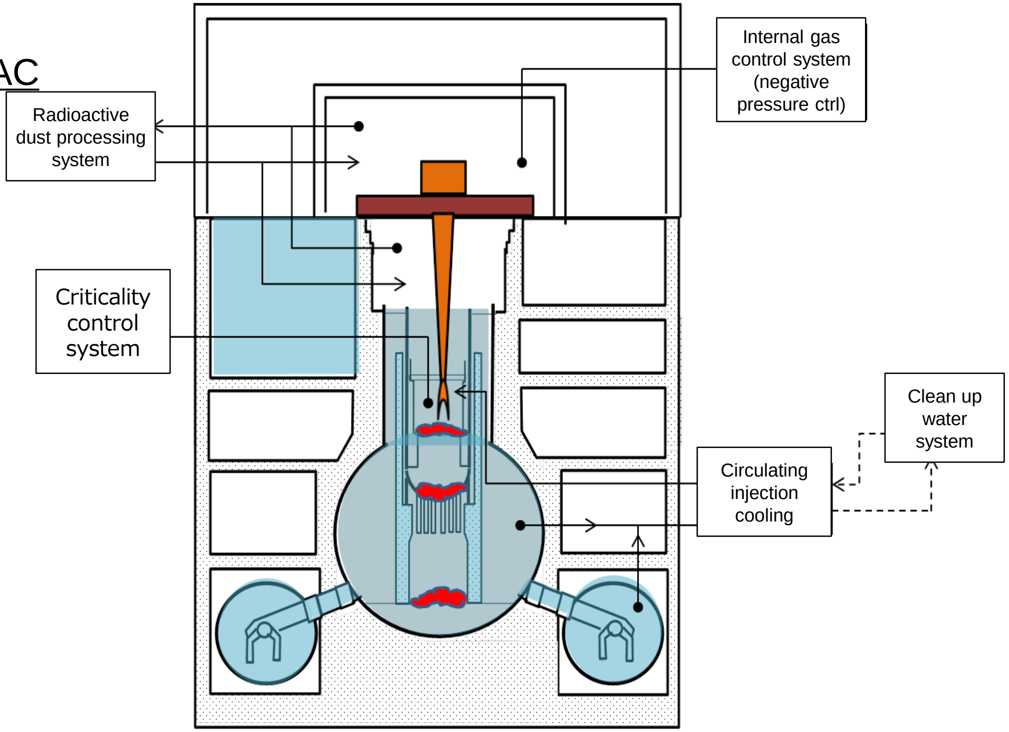


Submersion –Top entry | *Partial submersion –Top entry* | *Partial submersion –Side entry*

Feasibility study for the overall fuel debris retrieval system

- Systems constituting the fuel debris retrieval method (for three major methods) :

  - ✓ Radioactive dust processing system
  - ✓ Negative pressure management system/HVAC
  - ✓ Cooling water recirculates and injection system (including leakage water collection/purification)
  - ✓ Criticality control system (monitoring system/boron injection)
  - ✓ Contaminated water treatment system
  - ✓ Plant data measuring system
  - ✓ Communication system
  - ✓ Electrical system etc.



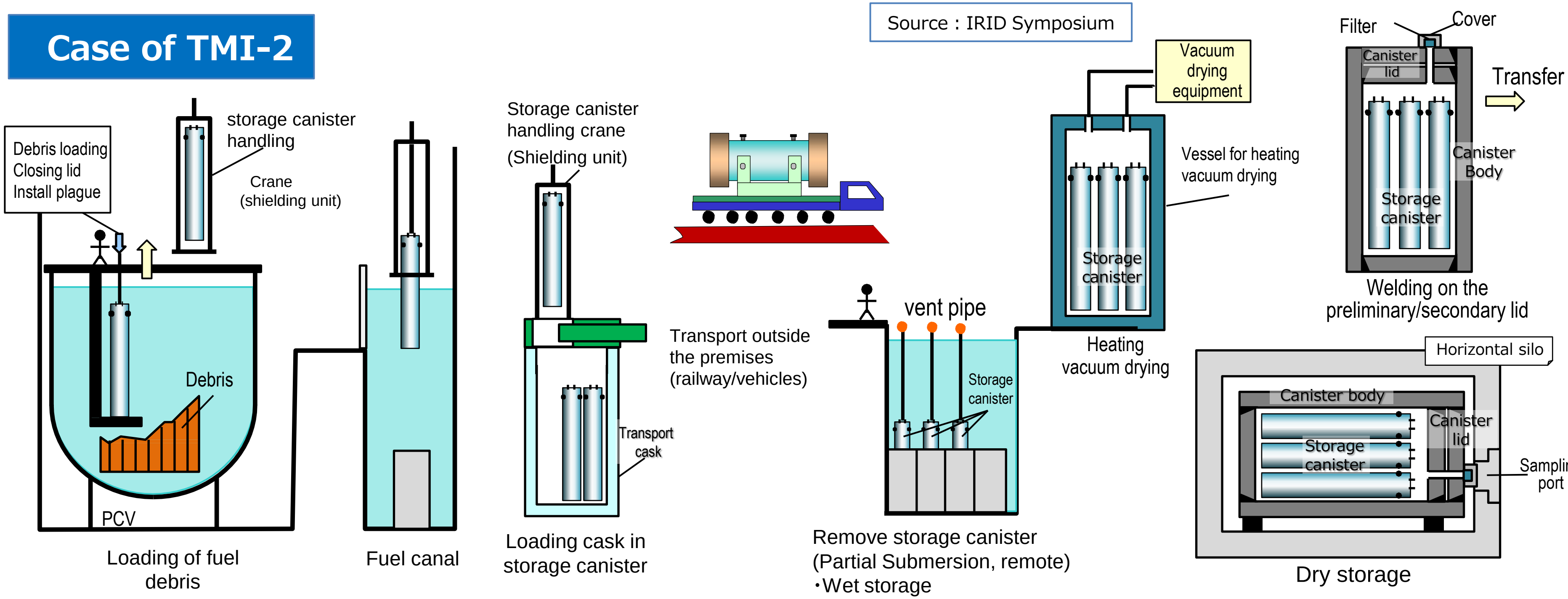
- Review the required safety technical specification underlined above and feasibility and possible placement

Each system will be required for three major methods but its scale/type are subject to change depending on the method. Feasibility for each method will be confirmed.

Toward the stable storage of fuel debris

Case of TMI-2

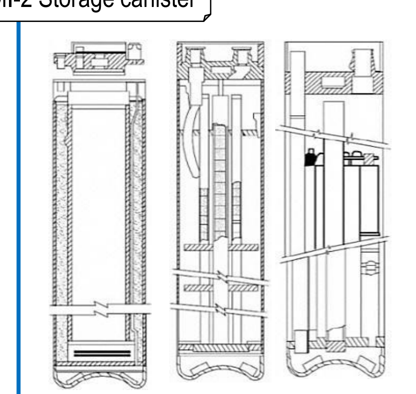
Source：IRID Symposium



Issues toward stable storage

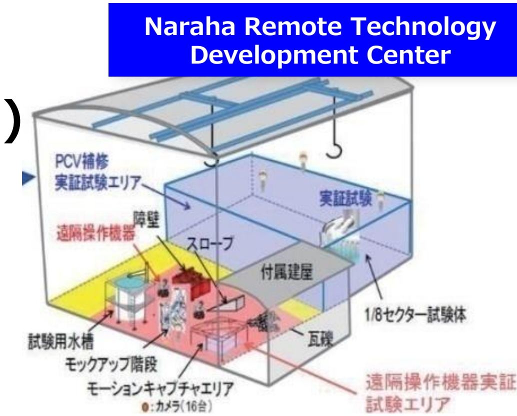
- Difference from TMI-2
  - ✓ High burn-up and concentration
  - ✓ MCCI products are expected to exist.
  - ✓ Melting with seawater injection, instrumentation cable etc.
- Storage method and place for fuel debris
- Method for safeguard and counting of fuel debris

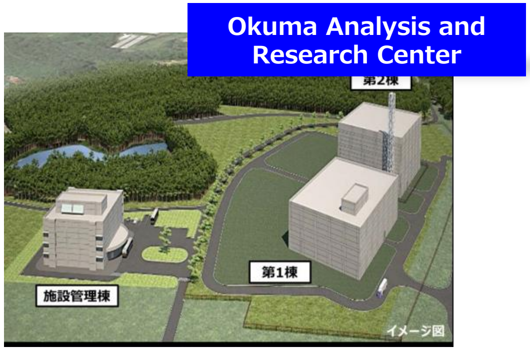
TMI-2 Storage canister



R&D promoted for the fuel debris retrieval

- **R&D for the practical/on-site application (e.g. IRID)**
  - R&D leads to the comprehensive evaluation of in-vessel conditions
  - R&D regarding the fuel debris retrieval technology
- **Decommissioning R&D Partnership Council (Secretariat of NDF)**
  - Integrated management of the development from the basic and fundamental to the practical technology.
  - Clarification and matching of on-site needs and R&D seeds
  - Human resource development
- **Development of R&D center (JAEA)**
  - Naraha Remote Technology Development Center
  - Okuma Analysis and Research Center
  - CLADS*





Conclusion

- **Risk reduction for fuel debris will be promoted in short and mid-term as below aiming at the "assured, stable and managed state."**
  - To understand the status and characteristics (decrease in uncertainty)
  - To improve in-vessel conditions by the fuel debris retrieval (elimination of instability)
  - To manage the storage of fuel debris at a stable state (improvement of risk management level)
- To have comprehensive analysis and assessment of in-vessel situation and to challenge to upgrade the accuracy of estimation in pursuit of successful fuel debris retrieval
- The most appropriate fuel debris retrieval method to be selected based on the conditions of each unit, securing the safety functions and in line with the fundamental philosophy ("Safe," "Proven," "Efficient," "Timely" and "Field-oriented") .
- R&D for the fuel debris retrieval including stable storage of the fuel debris. Integrated alliance is to be promoted among the related organizations for both the development of basic and fundamental technologies and establishment of the centers to support the R&D.