Technical Challenges and the Direction of the Decommissioning of Fukushima Daiichi NPP

NRC RIC Meeting March. 14, 2019

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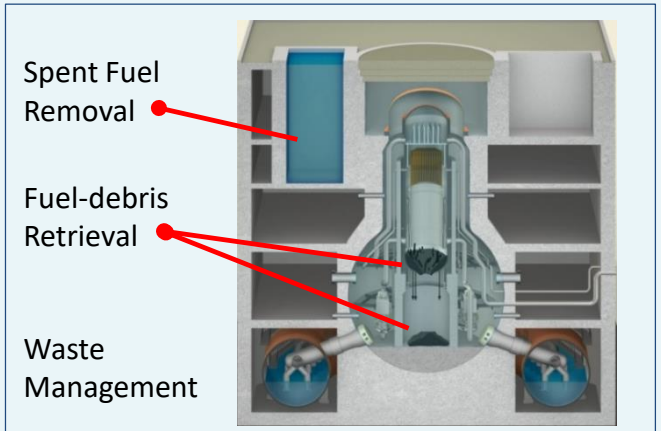
Where we are now, and what we are going to do

D&D process for accident nuclear facility generally understood (IAEA NW-T-2.7)

Fukushima Daiichi D&D

Urgent stabilization of the damaged facilities (Core cooling, highly contaminated water removal, etc.)	Contaminated water measures, ensuring cooling circulation, rubble removal, spent fuel removal, improvement of working environment	**Mid- and Long-term operations** • Spent fuel removal (extended) • **Fuel-debris retrieval** • **Waste storage and treatment** • Ground water management (continued)	Demolishing and waste disposal



Schedule

Unit-1

(Massive rubbles: being removed)

Unit-2

(Operating floor: being investigated)

Unit-3

(SF removal will start shortly)

	Phase-1		Phase-2							Phase-3				
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
New milestones by the revised Mid and Long-term Roadmap	Spent fuel removal								Unit 3 removal					Unit 1 removal start Unit 2 removal start	
	Fuel-debris retrieval									Decision on the method for the 1st unit				Fuel-debris retrieval for the 1st unit	Starting from small scale
	Waste management													Prospect of processing & disposal	

Pictures: https://photo.tepco.jp/en/index-e.html

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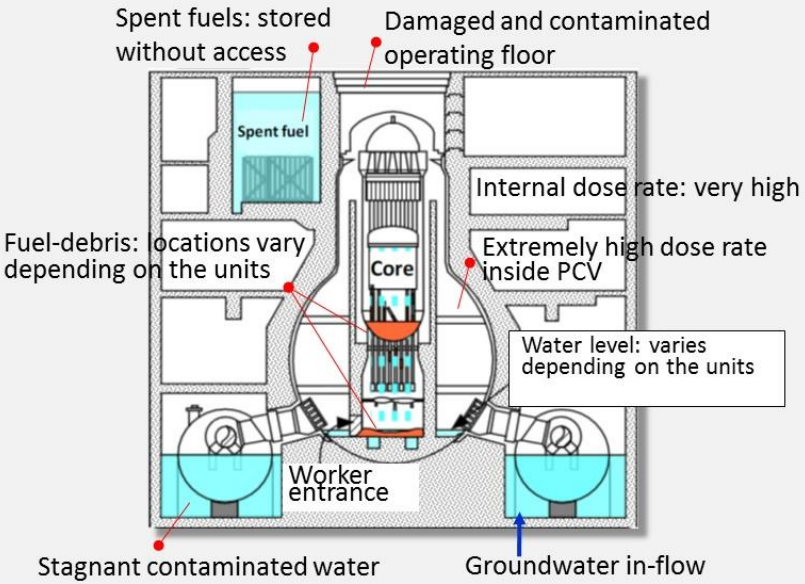
Fuel-debris retrieval: a daunting challenge

Associated difficulties

- **Uncertainty in the property of fuel-debris**
- **Uncertainty in the internal situation**
- **Uncertainty in the behavior of radioactive materials**
- **Difficult accessibility to the fuel materials**
- **Extremely severe internal environment**
- **Complexity in the water management**
- **Uncertainty in the long-term effect**



Technical Elements Needed

- **Internal inspection technique under extreme condition inside PCV and RPV**
  Instrumentation, remote manipulators, robotics, radiation-resistant electronics, etc.
- **New techniques and devices for fuel-debris retrieval**
  Retrieval machinery for fuel-debris, canister for retrieved fuel-debris, etc.
- **Water management**
  Processing of contaminated water, groundwater management, stoppage of leaks in reactor vessels, etc.
- **Waste management**
  Minimization, safe storage, treatment, disposal etc.
- **Environmental control**
  Reduction of atmospheric release, site remediation, etc.
- **Safety/Risk assessment and safety control**
  Risk analysis, safety case, probabilistic analysis, etc.
- **Analysis of unknown materials**
  Characterizing recovered fuel-debris and solid waste, non-destructive analysis, etc.

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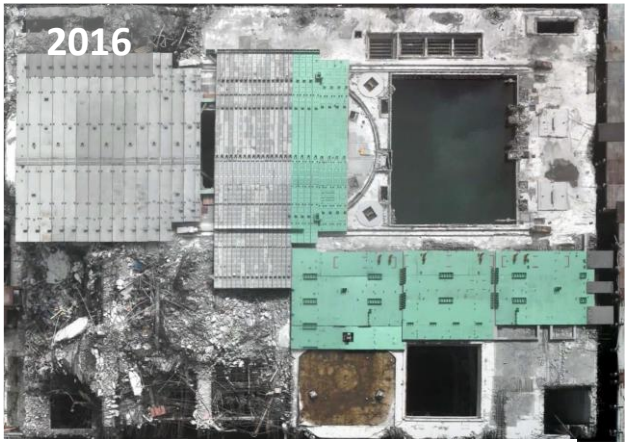
Large-scale remote operation enabled the SF recovery (Unit-3)

Operation floor damaged by hydrogen explosion (appearance)

Operation floor damaged by hydrogen explosion (from the above)

Clearing up high dose rubbles

Removal of large rubbles fallen down into the pool



Installation of radiation shielding

Installation of building cover and remote fuel handling system

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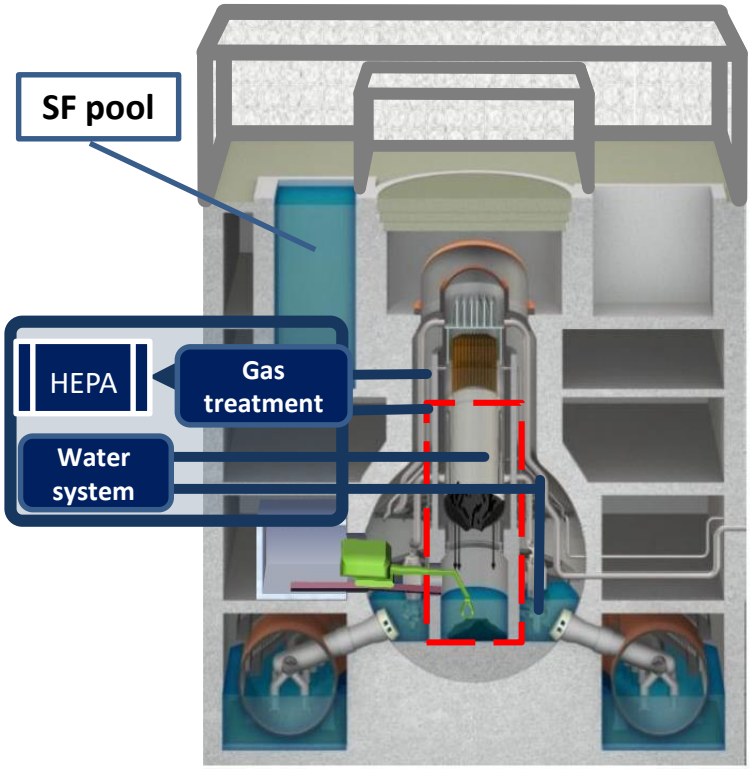
Fuel-debris retrieval strategy

Careful preparation is necessary for the fuel debris retrieval

1. Ensure containment
2. Minimize exposure to workers
3. Safe retrieval of fuel debris

Partially-submerged plus horizontal access method



Requirements

- Seismic integrity
- Workers safety
- Lower radiation dose
- Confinement of radioactive materials
- Confinement and access to the debris (Horizontal access)
- Fuel debris handling machine
- Prevention of re-criticality
- Water level control at PCV and building

Final selection of the fuel debris retrieval method

- Horizontal Access
- Partially-submerged

Rationales;

Too many penetrations at upper part of PCV
- Technically difficult for water stoppage
- causing too high dose to workers

More information available on lower part of PCV through recent remote inspections

Possible to work with SF removal in parallel

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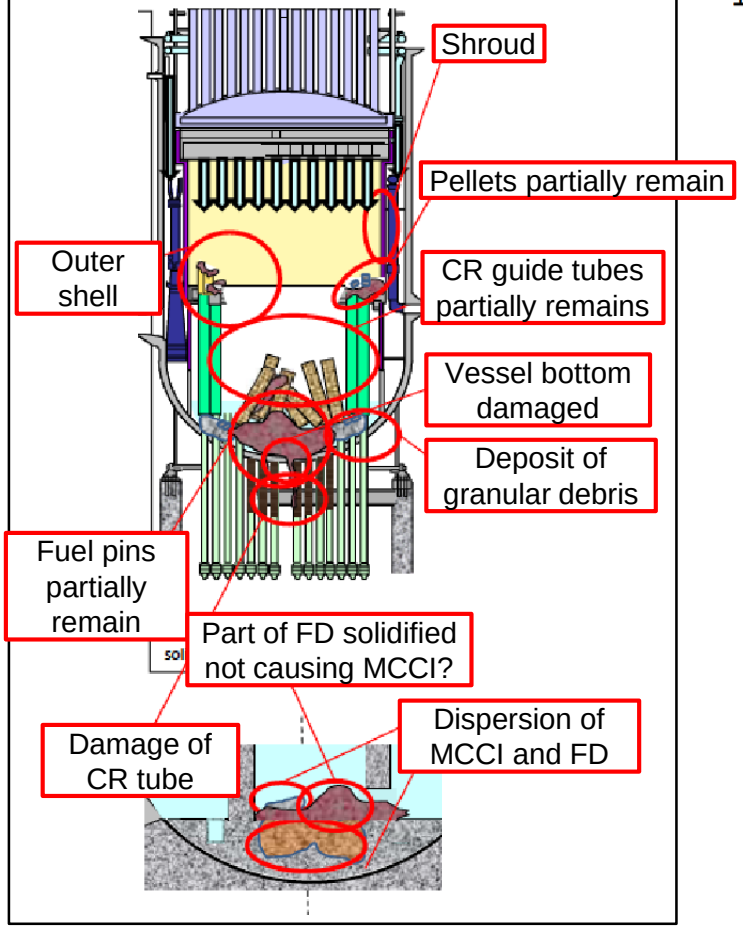
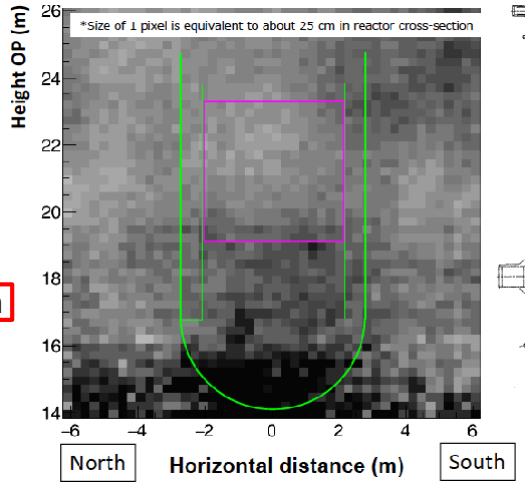
Remote inspection techniques adopted

SA Analysis

Estimation by MAAP/SAMPSON



Muon measurement

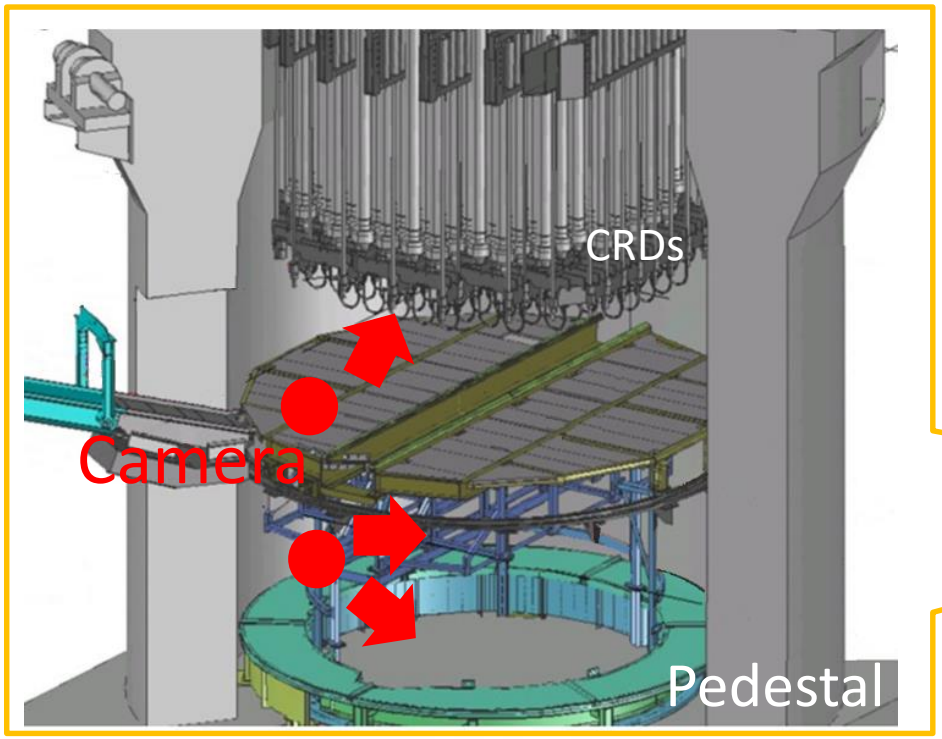


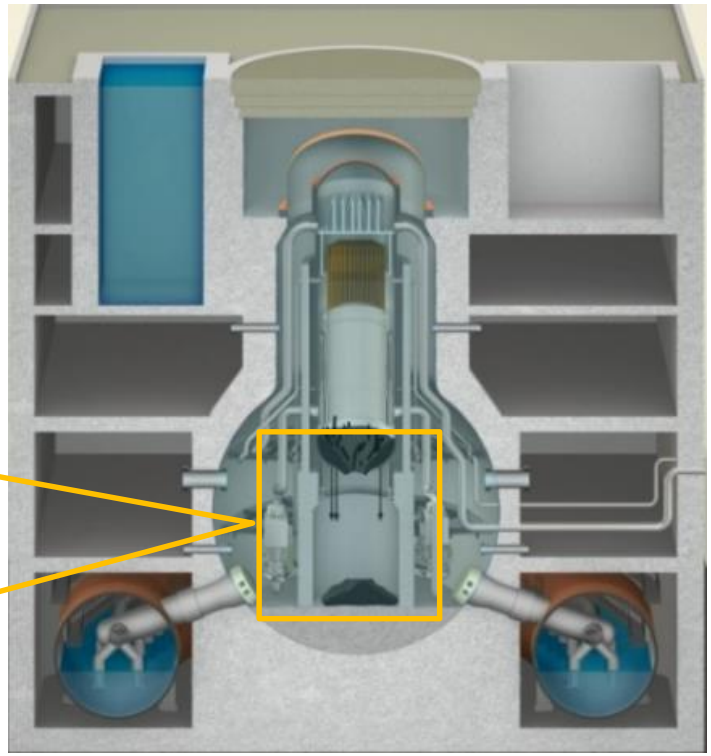
http://photo.tepco.co.jp/en/index-e.html

Remote survey

Photographic images inside the pedestal of Unit-2

Internal inspection of Unit-2 PCV（Jan. 2018）





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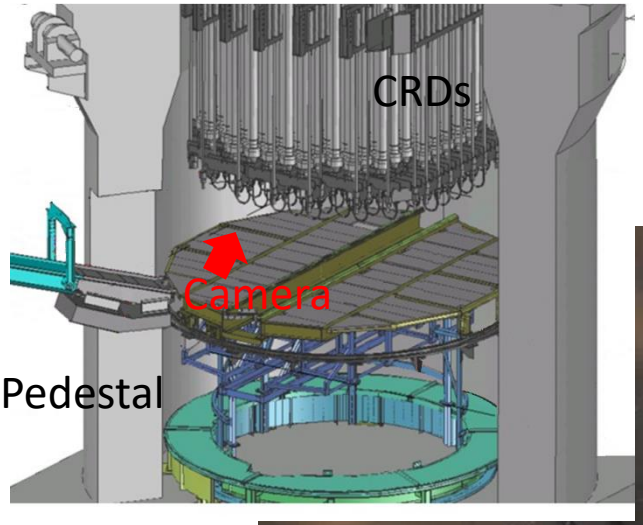
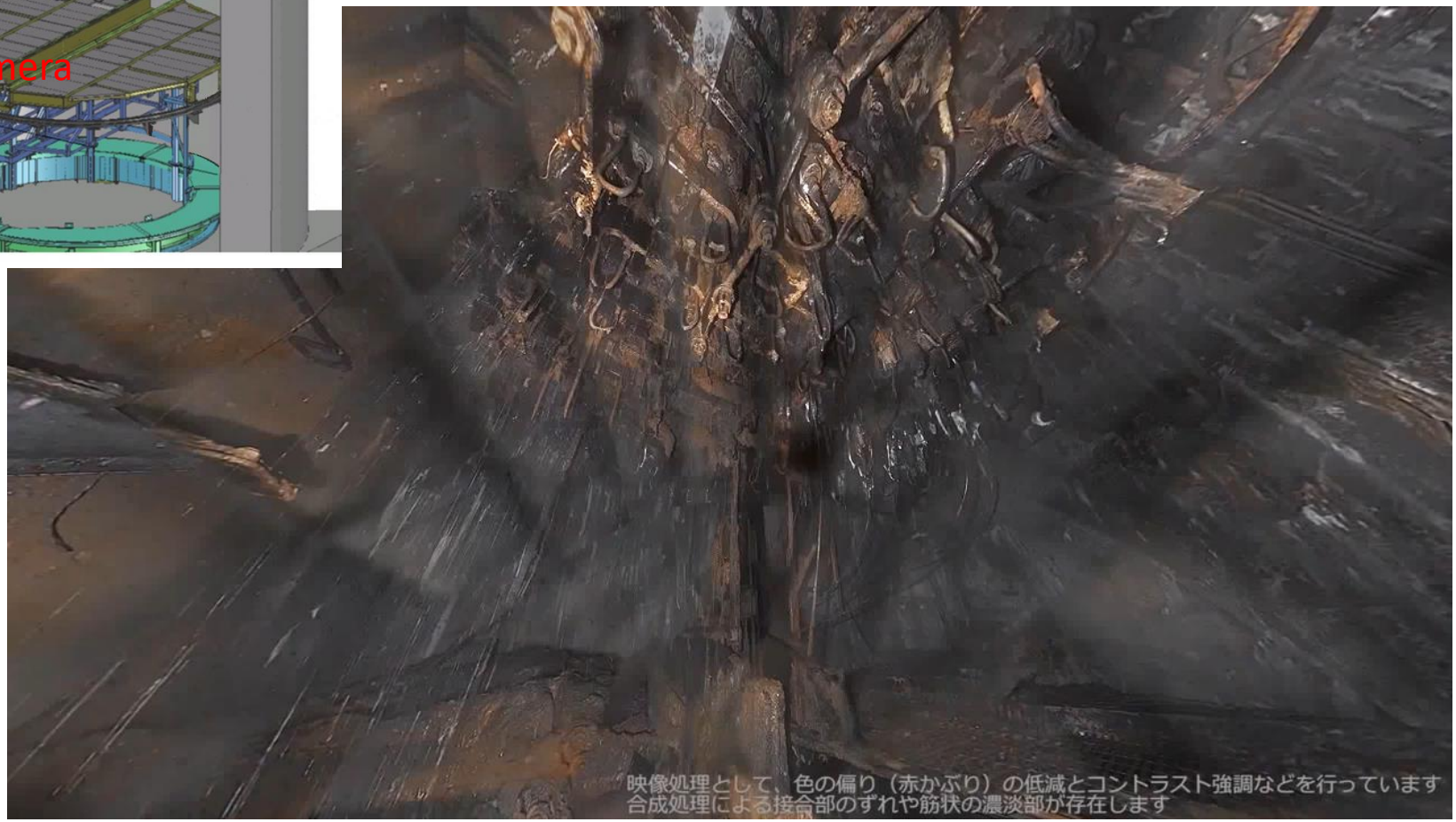


(1) Upward direction to lower part of RPV (CRD housings)



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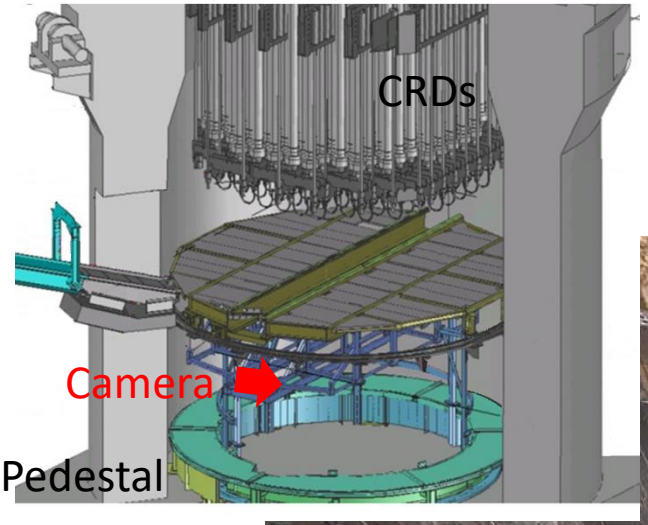
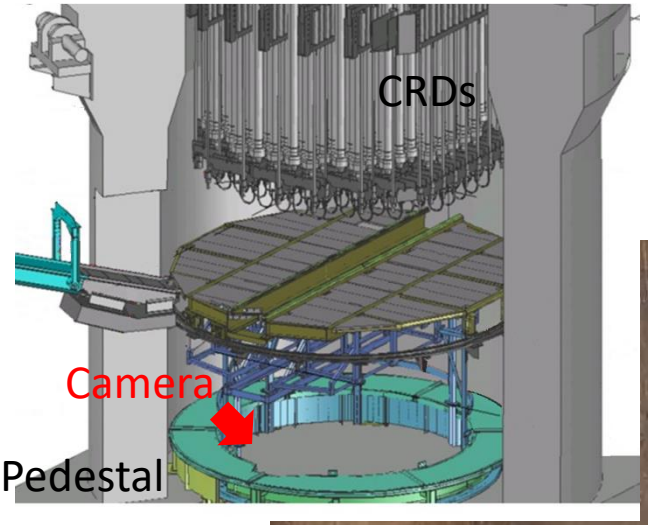


(2) Downward direction of PCV; inside Pedestal

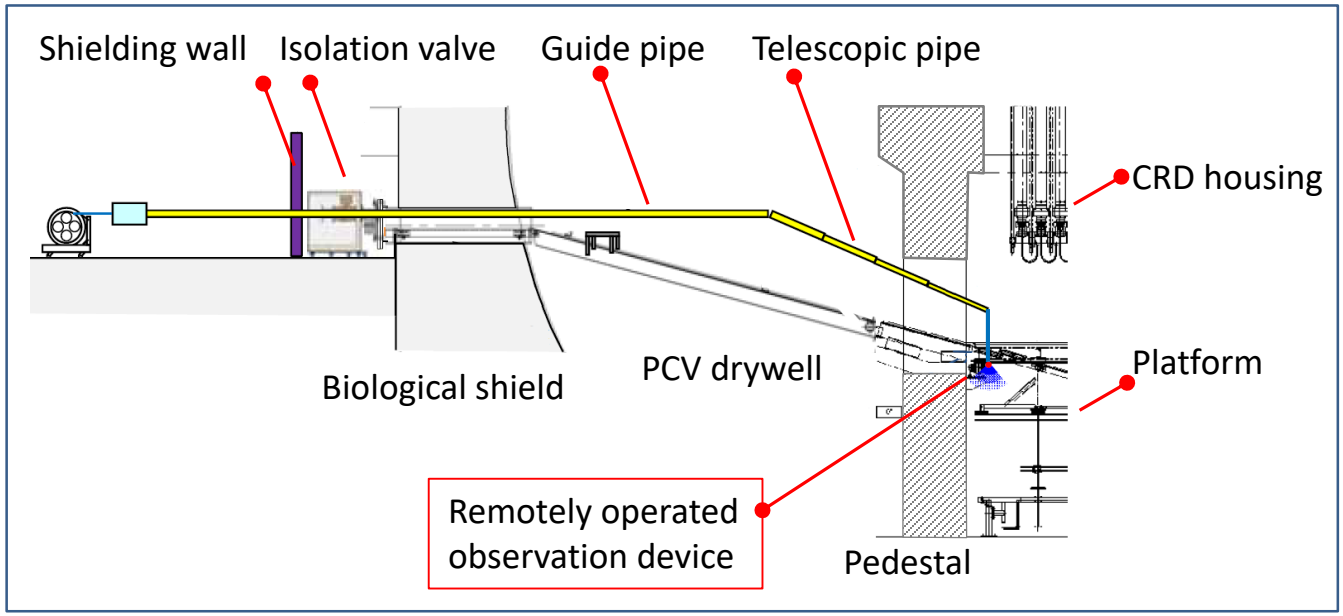
Internal inspection of Unit-2 PCV（Jan. 2018）



(3) Bottom of PCV; inside Pedestal

Newest observation by remote inspection (Unit-2)

Drawn by referring from press release by TEPCO, Feb. 13/2019



Pictures: tepco.co.jp/decommissioning.information/newsrelease/referemce/pdf/2019/1h/rf_20190213_1.pdf

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Newest observation by remote inspection (Unit-2)

Drawn by referring from press release by TEPCO, Feb. 13/2019

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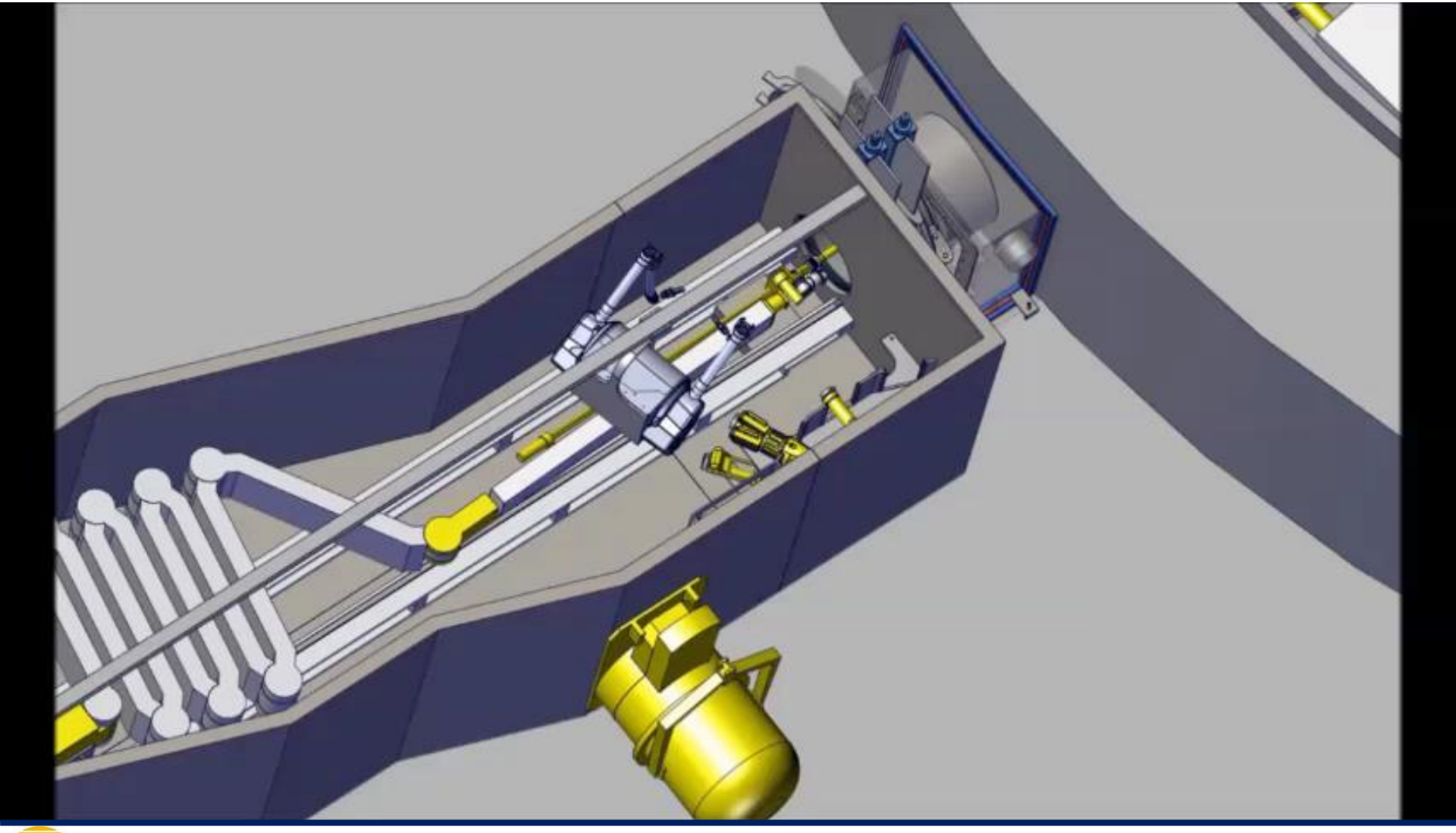
Planned internal inspection using an advanced remote arm

(1) Access to PCV through an existing penetration

Courtesy of IRID



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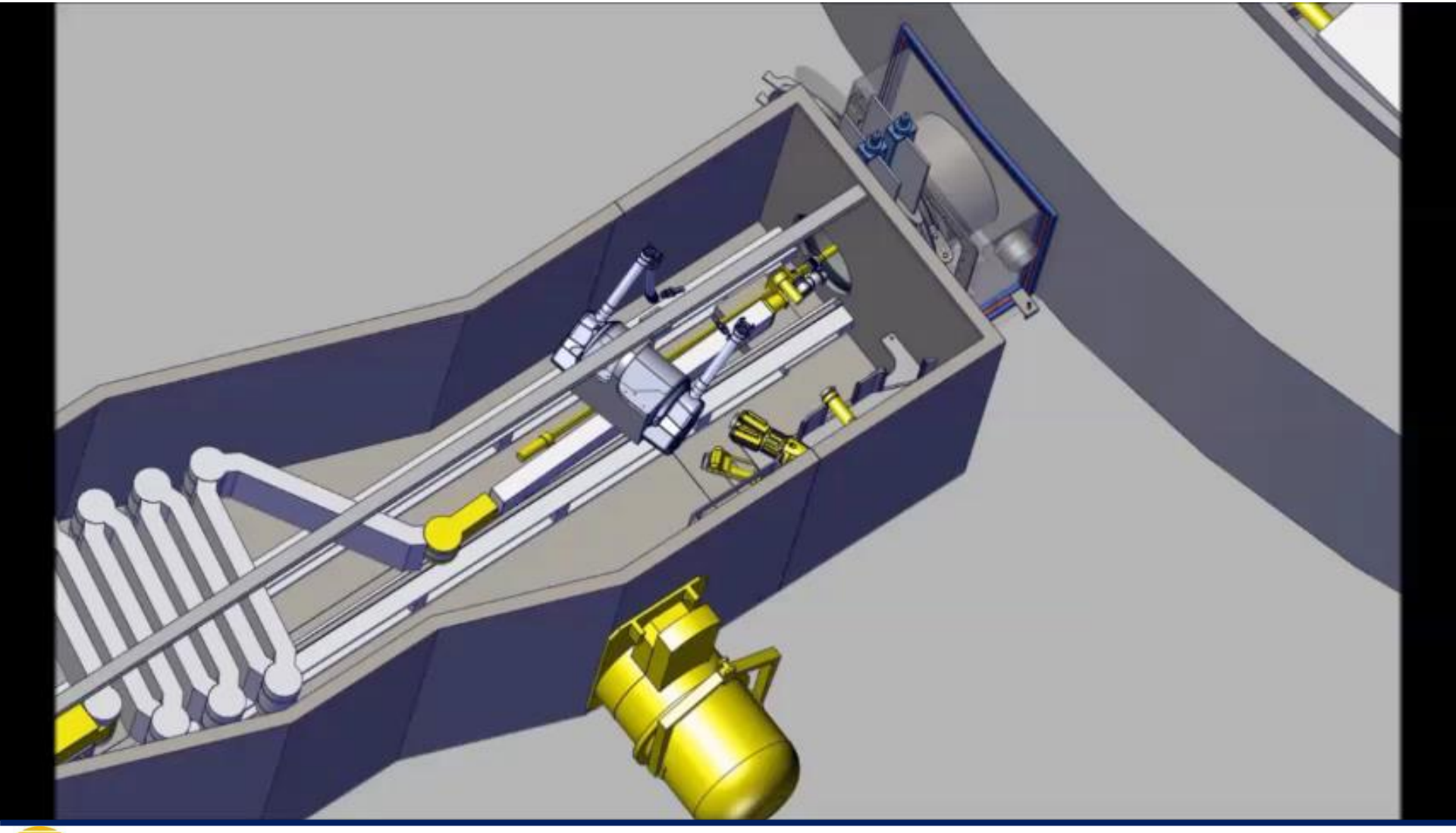
Planned internal inspection using an advanced remote arm

(2) Sample transfer to canister

Courtesy of IRID



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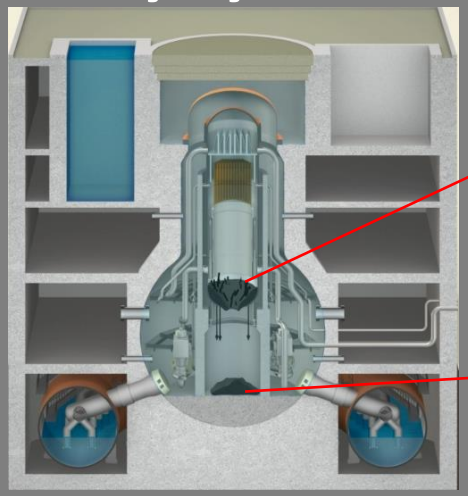
Fuel-debris at Fukushima-Daiichi requires more investigation

1F-1,2,3



Fuel-debris

$(U,Zr)O_x$, $(U,Zr,M)O_x$,
$(Fe, Cr, Ni)_x(U, Zr)$,
$(Fe, Cr, Ni)_xB$, ・・・・・

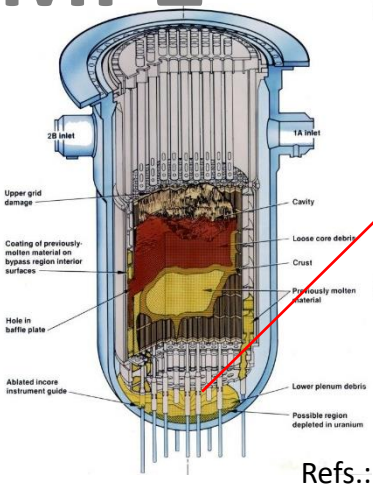
MCCI product

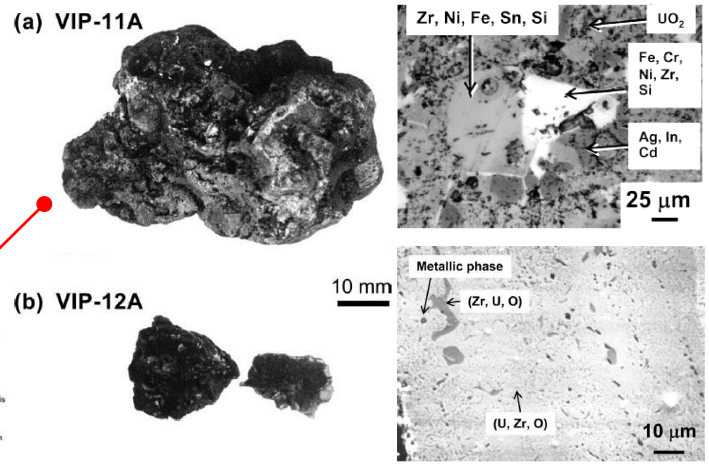
$(Zr, U, Ca)O_2$,
Al-Ca-O
Fe-Si-(Zr,U)-Al

Fuel-debris of 1F-1,2,3, as features;

- Consists of fuel (UO_2, PuO_2 and Zircalloy) and control rods (B_4C and stainless steel)
- May have reacted with concrete to form MCCI product
- May have reacted with salt coming from sea water injected during accident
- Formed through unclear core disruption process with complicated dynamics of thermal and chemical conditions

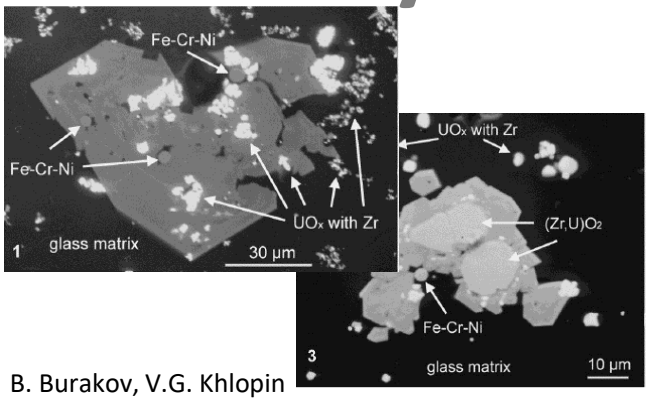
TMI-2





Refs.: Nagase et. al., J. Nucl. Sci. Mater., Vul. 49, No.1 (2012)

Chernobyl-4



B. Burakov, V.G. Khlopin Radium Institute, Handout of the 2nd Int. Forum on the Decommissioning of Fukushima Dai-ichi NPS (2017).

Reinforcement of analytical capability

Radioactive Material Analysis and Research Facility being constructed

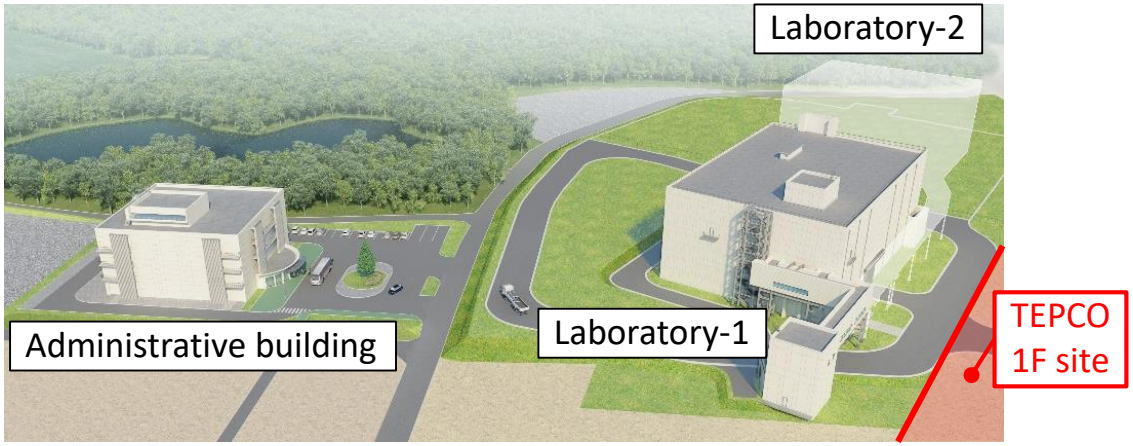
- World unique facilities specific to severely-damaged nuclear reactors
- 300 workers including facility operators, engineers, analysis technicians and radiochemists
- To be built at the site next to 1F site

Reducing uncertainty of materials and wastes will improve ;

- Efficiency and design of the devises and process
- Safety assessment and operation procedures
- Waste packaging design
- Waste disposal assessment
- Accountability in Safeguard

Necessary enhancement of analytical function for;

- Analytical throughput
- Accuracy of the analysis
- Timeliness and less dependence on the transportation

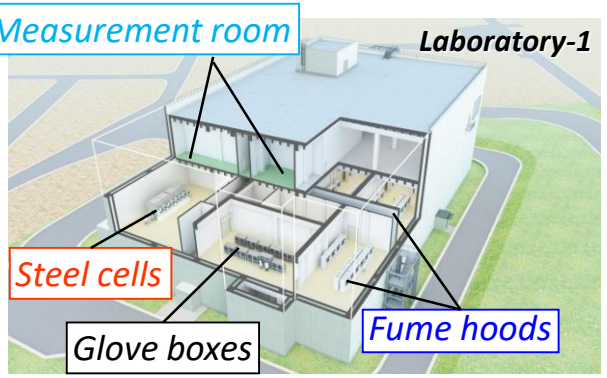


Laboratory- 1 (FY 2019)

For characterization of low- and medium-level radioactive wastes (≤ 1 Sv/h)

ca. 200 samples per year

4 steel hot cells, 10 GBs, 50 FHs



Courtesy of JAEA

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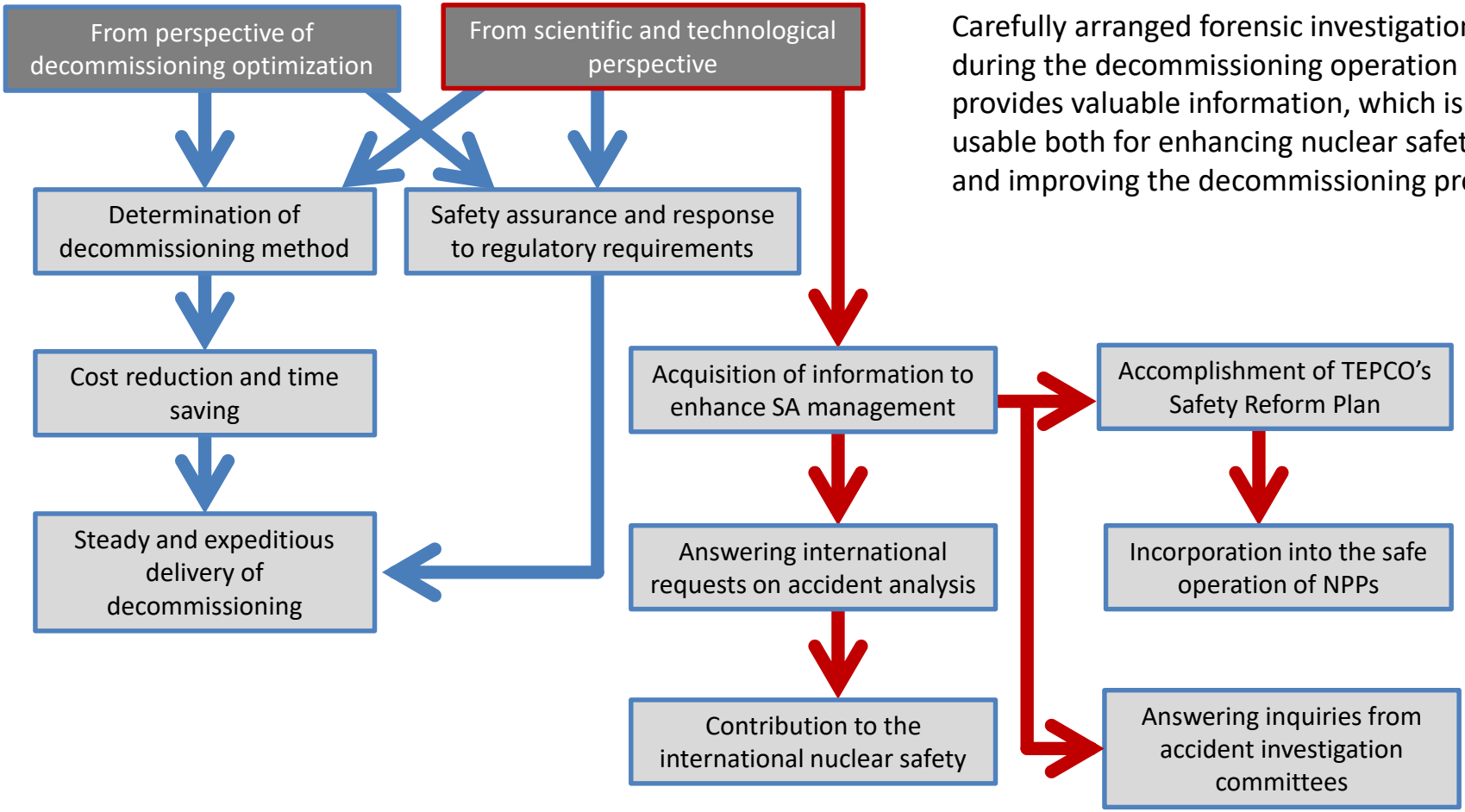
Forensic investigations in D&D operation will give us advantages



Carefully arranged forensic investigations during the decommissioning operation that provides valuable information, which is usable both for enhancing nuclear safety and improving the decommissioning process.

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Desired evolution of safety regulation

Fukushima Daiichi is regulated as a “specified nuclear facility” (accident reactor) with exemption from the NPP regulation. No regulatory standard is directly applicable, resulting in improvised regulatory requirements.

Desired and encouraged approach

- The concept of ALARP to be adopted to optimize the balance of safety, cost, time, goal, etc.; it should be shared by stakeholders including regulatory authority
- Dialogue among stakeholders including the regulatory authority with its independence most surely ensured
- Learning from safety regulations adopted to the worldwide legacy sites

Desired way of safety assessment and regulatory judgement

- Risk-informed perception on the decommissioning methods
- Safety assessment assisted with probabilistic considerations
- Need of flexible and tailored regulation on the existing conditions, that enables quick reduction of the existing risks

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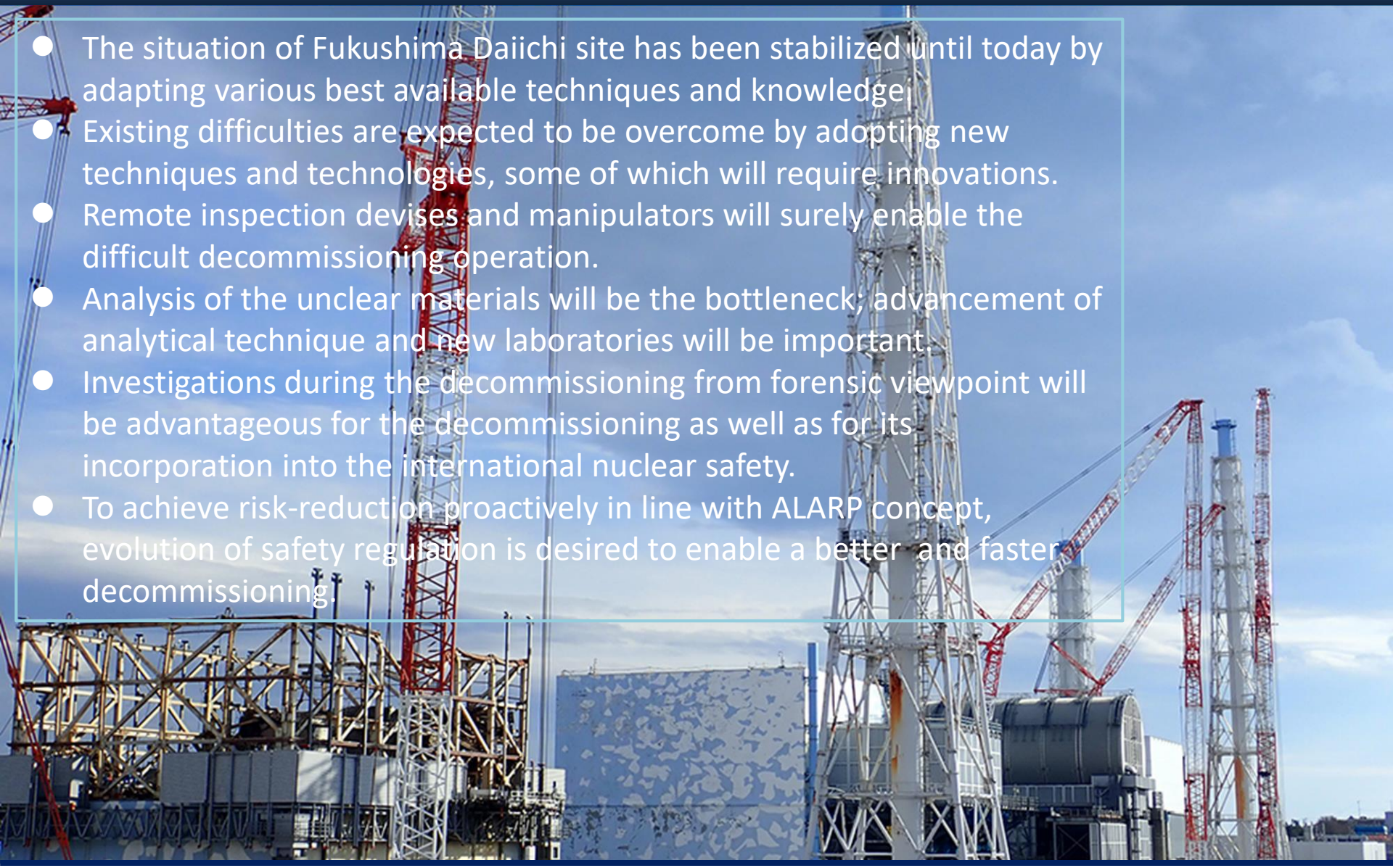
Conclusions



- The situation of Fukushima Daiichi site has been stabilized until today by adapting various best available techniques and knowledge.
- Existing difficulties are expected to be overcome by adopting new techniques and technologies, some of which will require innovations.
- Remote inspection devises and manipulators will surely enable the difficult decommissioning operation.
- Analysis of the unclear materials will be the bottleneck; advancement of analytical technique and new laboratories will be important.
- Investigations during the decommissioning from forensic viewpoint will be advantageous for the decommissioning as well as for its incorporation into the international nuclear safety.
- To achieve risk-reduction proactively in line with ALARP concept, evolution of safety regulation is desired to enable a better and faster decommissioning.

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