Decommissioning of the Fukushima Daiichi NPP
The Holistic Approach of Japan

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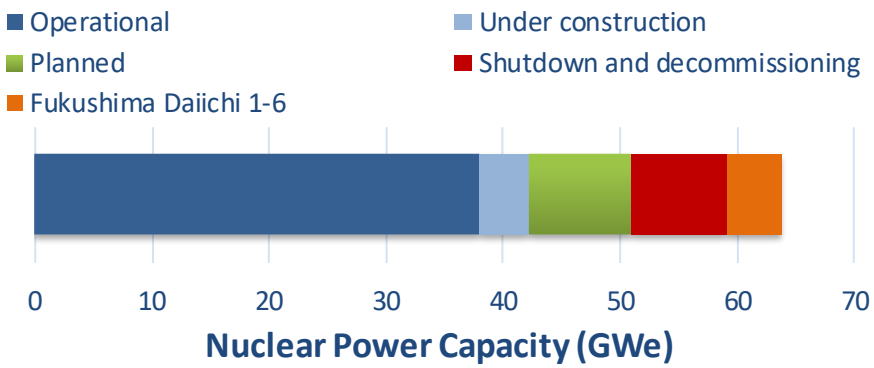
Ground of the decommissioning of the Fukushima Daiichi NPP

Nuclear power generation in Japan

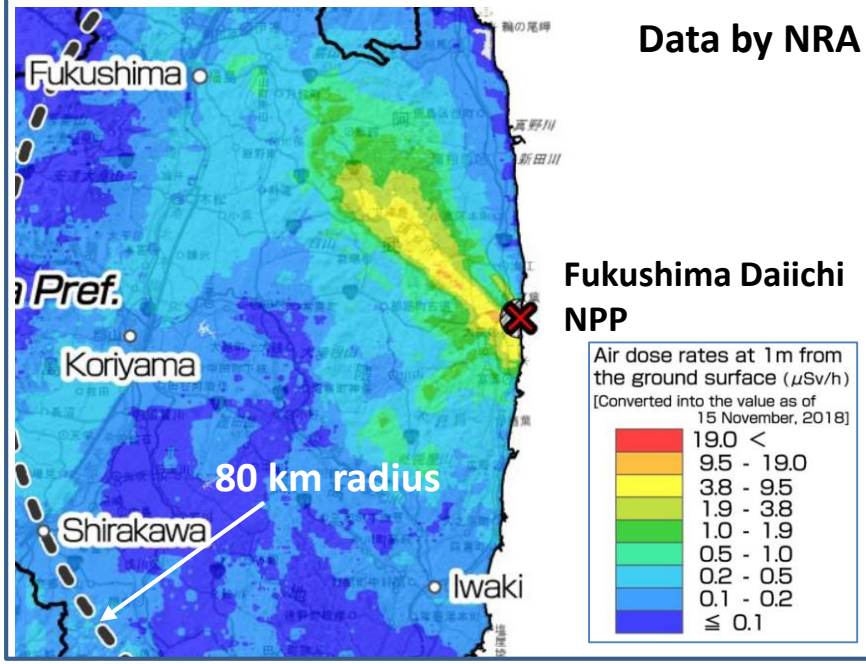
- Current capacity: 38 commercial reactors operational; 38 GWe
- Re-started: 8 reactors in power generation
- Public's mood: · Disinclined for nuclear power
  · Anxiety on radiation safety



D&D of Fukushima Daiichi Reactors

- Successful decommissioning of the four damaged units of Fukushima Daiichi is an indispensable prerequisite for Japanese energy policy
- Eliminating people's anxiety on the NPP site is necessary for the revitalization of the suffered society
- Risk reduction of Fukushima Daiichi NPP, strongly required by regulatory authority

Air Dose Rate as of Nov. 2018



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

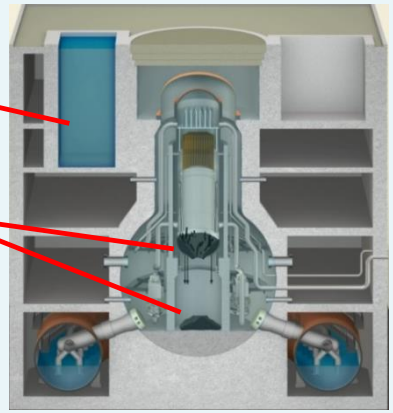
D&D process for accident nuclear facility generally understood (IAEA NW-T-2.7)

Radioactive waste management

Accident → **Emergency response** → **Stabilization** → **Clean-up** → **Safestore (Optional)** → **Demolishing and remediation**

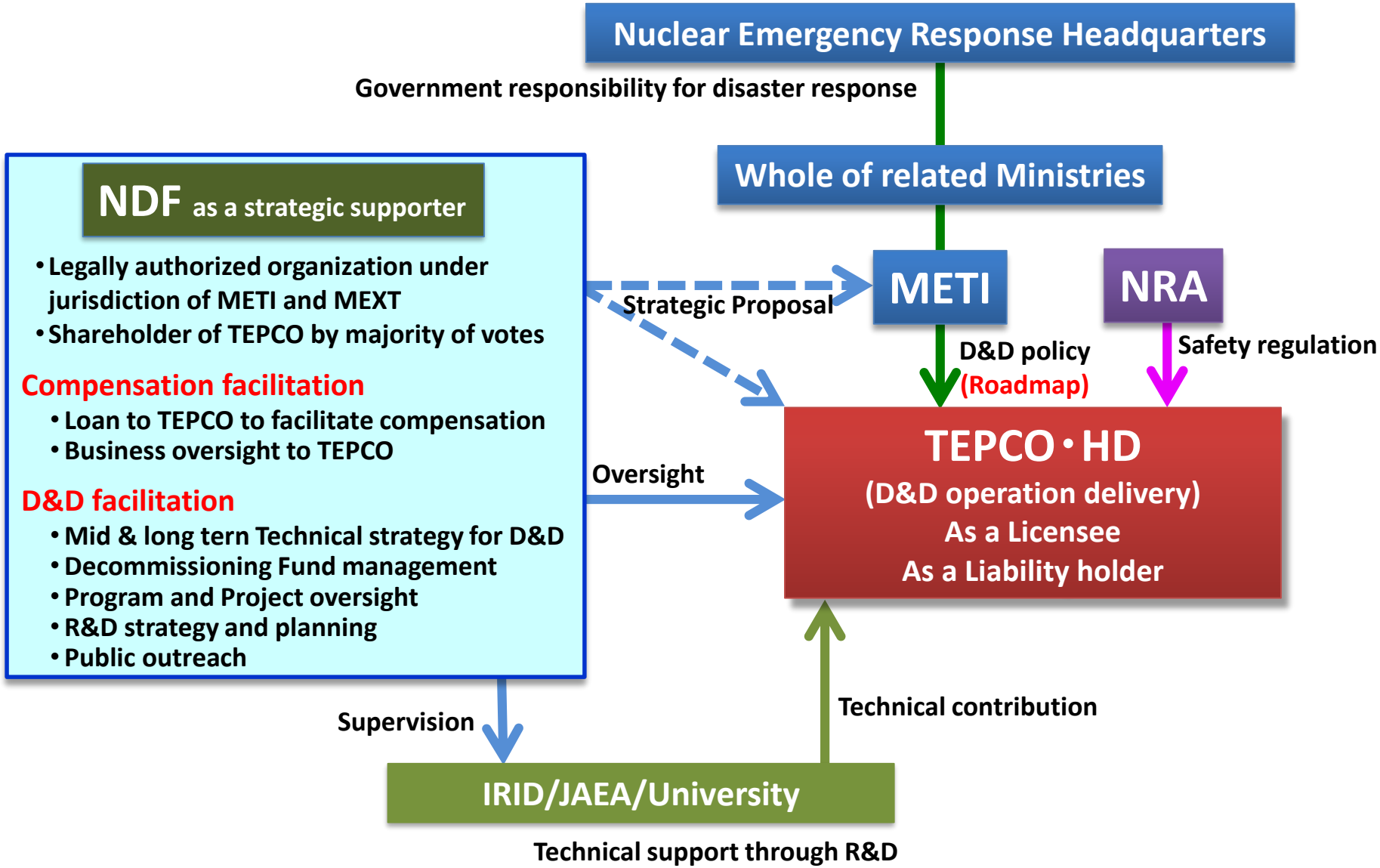
Fukushima Daiichi D&D

- 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



Pictures from TEPCO

Organizational structure addressing 1F Decommissioning

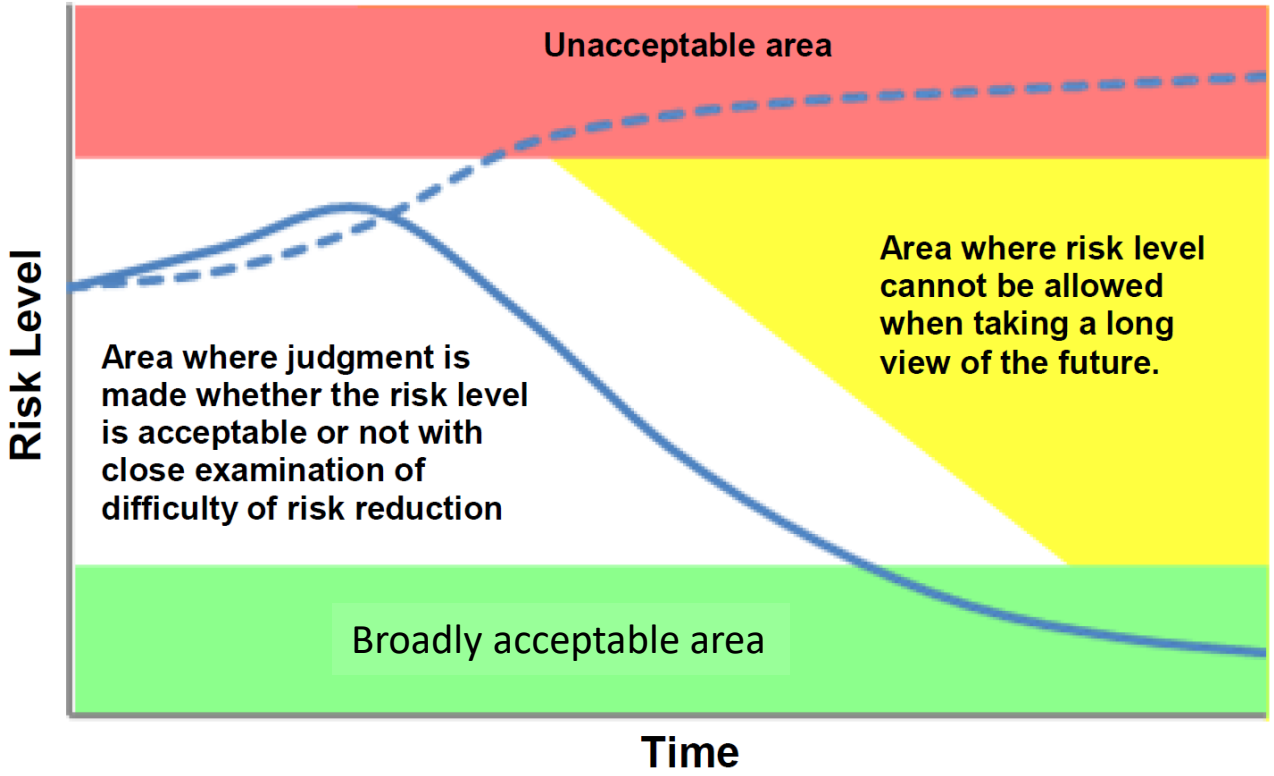


Responsibility sharing for the 1F Decommissioning

Organizations	Policy and Strategy	Finance	1F D&D Delivery	Related works
Multiple Responsible Ministries (Gov't)	Formulation of 1F D&D Policy (Roadmap: RM)			Individual administrative actions
METI (Gov't)	Supervision to TEPCO with RM	Subsidizing institutes for R&Ds	Administrative directive to TEPCO	Act as a secretariat in the government
MEXT (Gov't)		Subsidizing Universities		
NRA (Gov't)			Safety Regulation to TEPCO	
NDF (semi-Gov't)	Development of D&D Strategy by annual Technical Strategic Plan	Reserve Fund management	Project oversight Engineering oversight	Coordination of R&Ds and HRD Public Outreach International Affairs
Tokyo Electric Power Co. Ltd.	Development of implementation plan	Legally obliged to secure necessary fund	D&D Delivery as a license holder	Communication with the local community
JAEA and IRID			Sample analysis	Execution of R&Ds

METI: Ministry of Economy, Trade and Industry MEXT: Ministry of Education, Culture, Science and Sports NRA: Nuclear Regulatory Authority
NDF: Nuclear Damage Compensation and Decommissioning Facilitation Corporation IRID: International Research Institute for Decommissioning

Risk reduction strategy

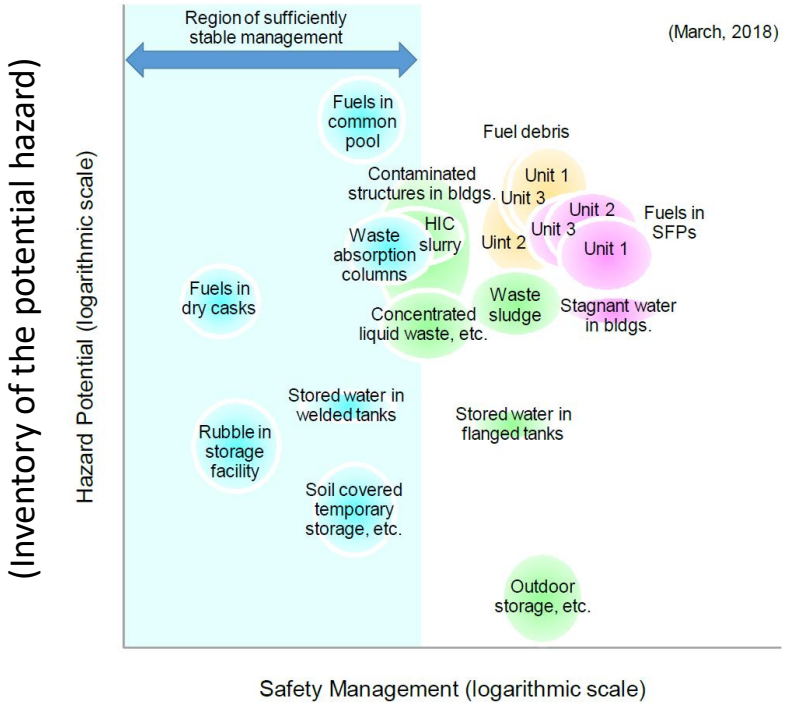


Reference: V. Roberts, G. Jonsson and P. Hallington, "Collaborative Working Is Driving Progress in Hazard and Risk Reduction Delivery at Sellafield" 16387, WM2016 Conference, March 6-10, 2016. M. Weightman, "The Regulation of Decommissioning and Associated Waste Management" 1st International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Plant (April 2016).

Data from Strategic Plan 2018 by NDF, 2017

Risk reduction as the basic strategy

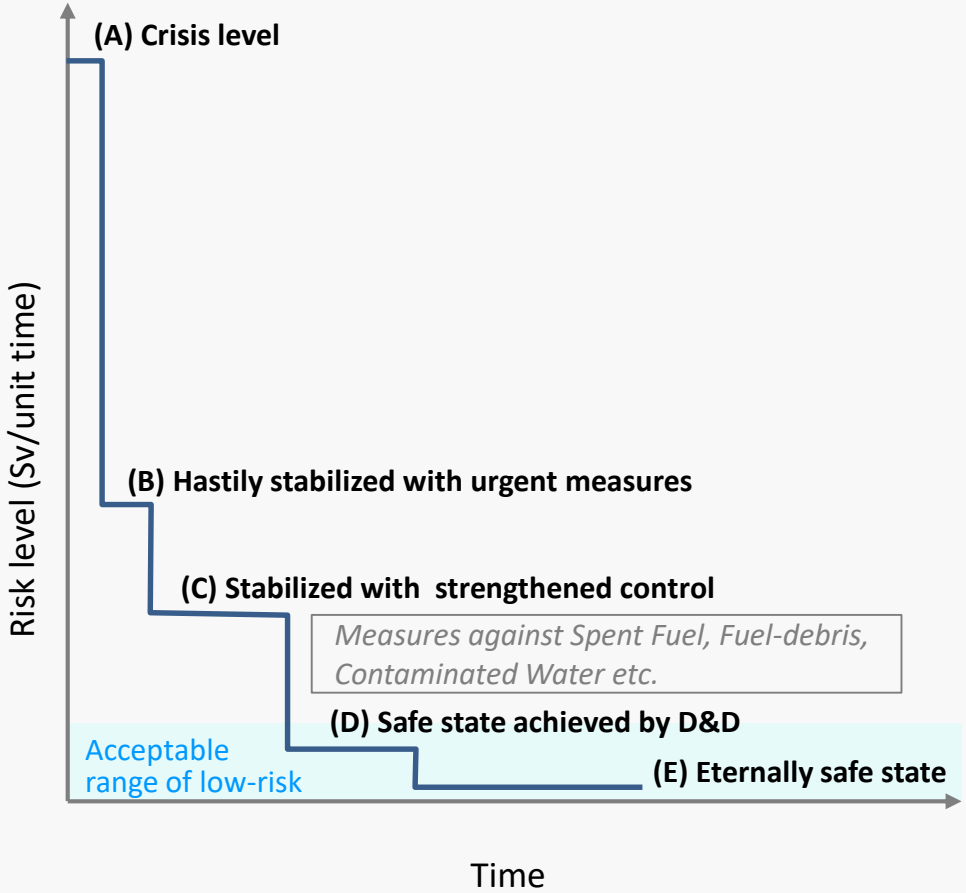
Snapshot of the existing risk sources



(Probability of exposure of the hazard)

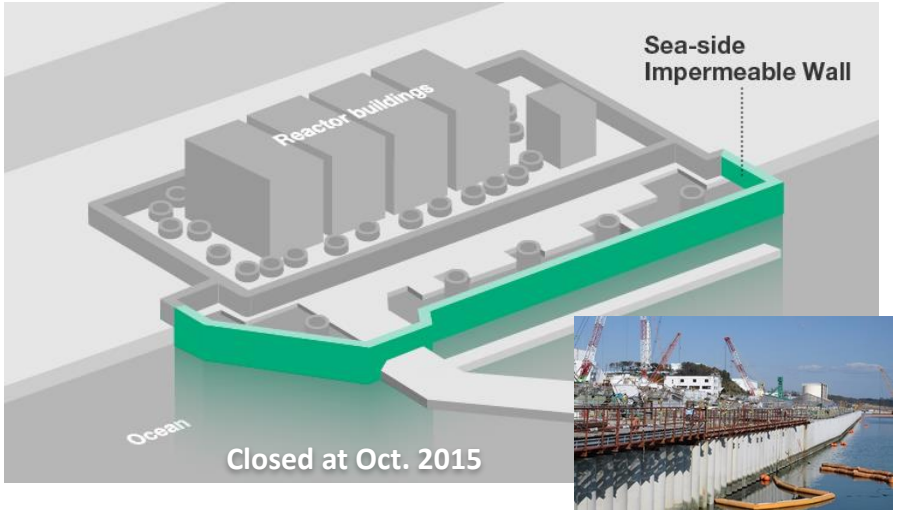
Data from Strategic Plan 2018 by NDF, 2018

Envisioned risk-reduction trend

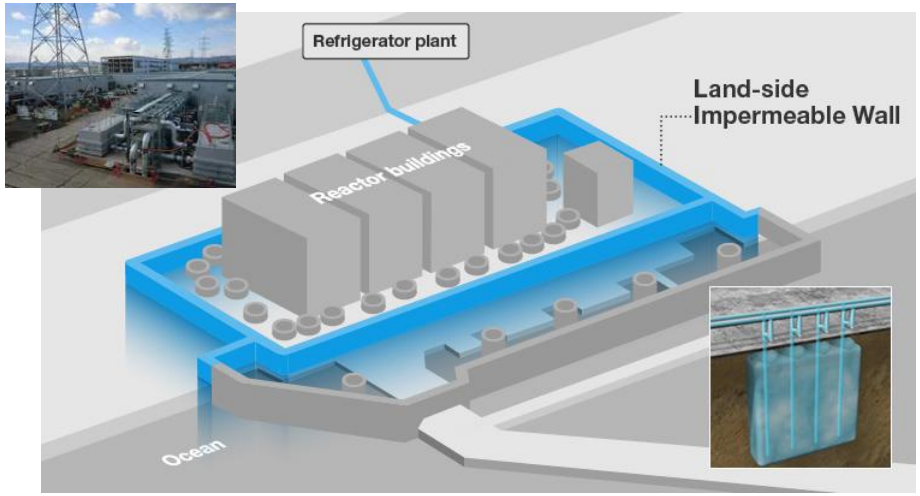


Contaminated water is successfully confined

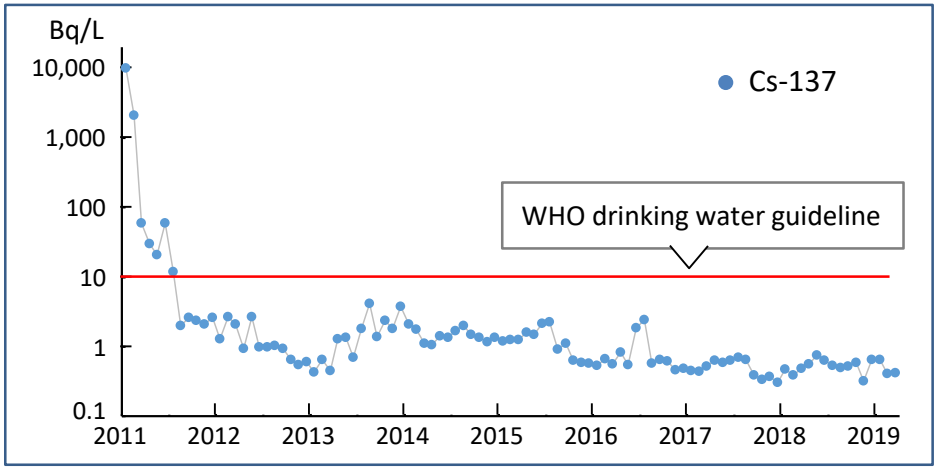
Sea-side impermeable wall



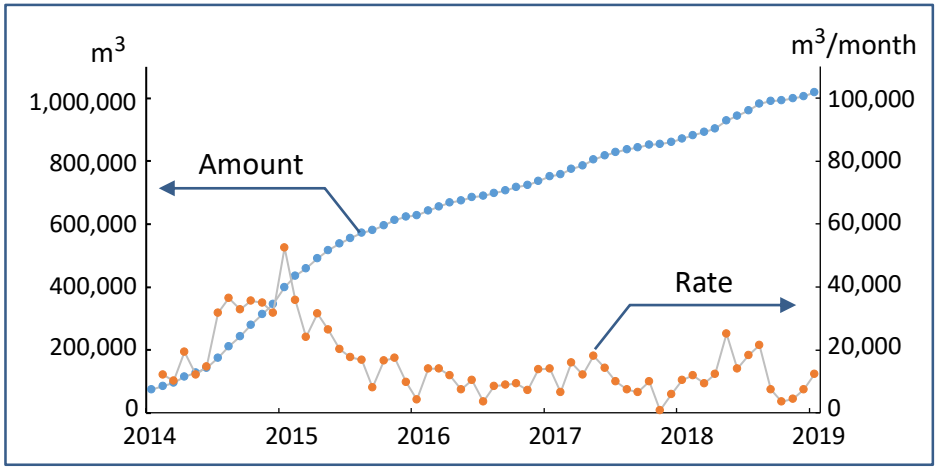
Land-side impermeable wall (Frozen soil)



Cs-137 concentration at the south part of the port



Generation of ALPS-treated water



Source: Modified from TEPCO website.

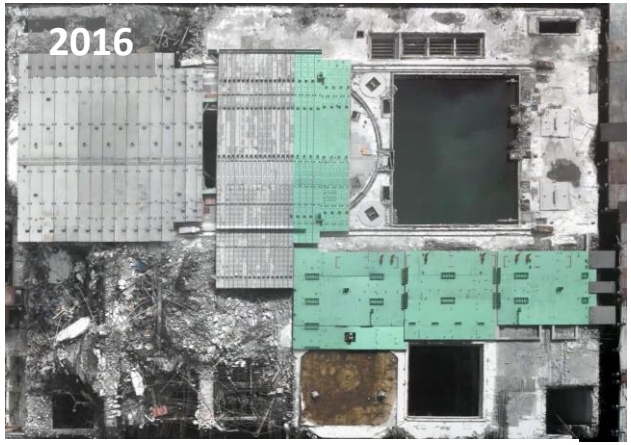
Large-scale remote operation enabled the SF recovery (Unit-3)

Operatiing floor damaged by hydrogen explosion (appearance)

Operating 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

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

Fuel-debris distributed inside the reactor

Distribution of fuel-debris :

Estimated by severe accident simulation codes, muon-tomography, and heat balance analysis, as well as by referring to the result of TMI-2 accident. Inside RPV has yet to be observed.

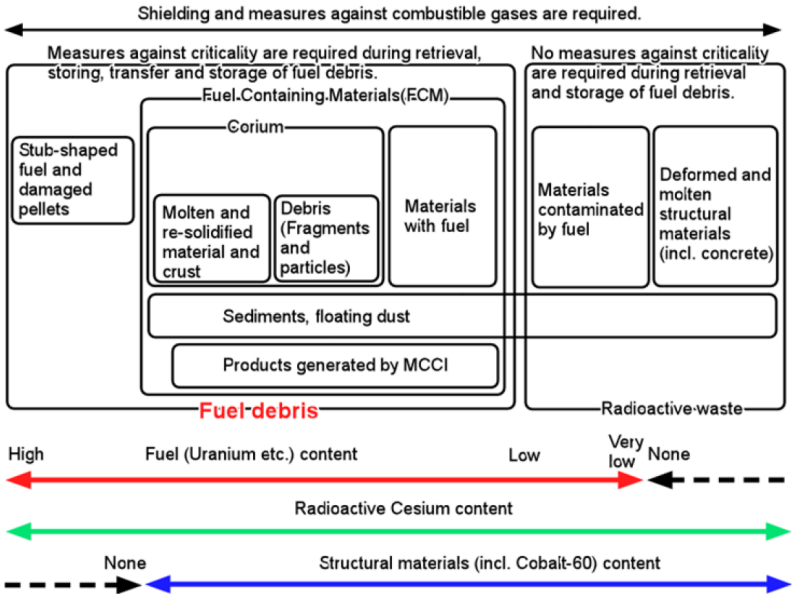


Fig. A5-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

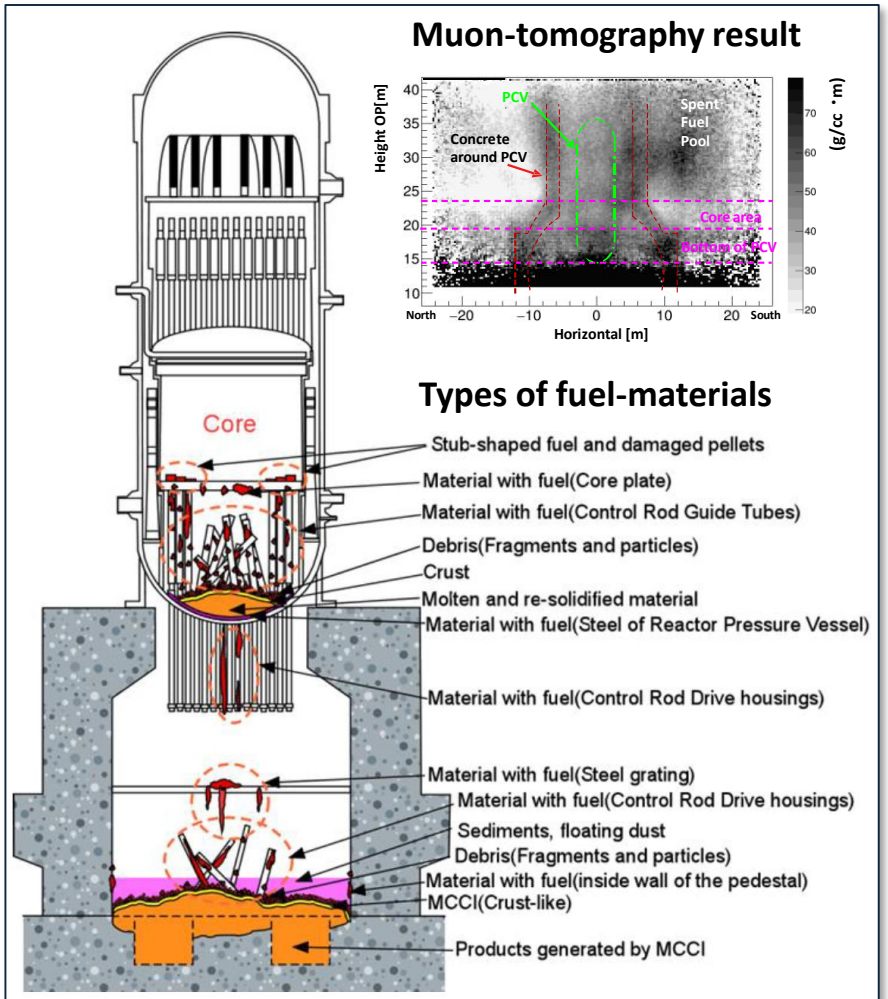
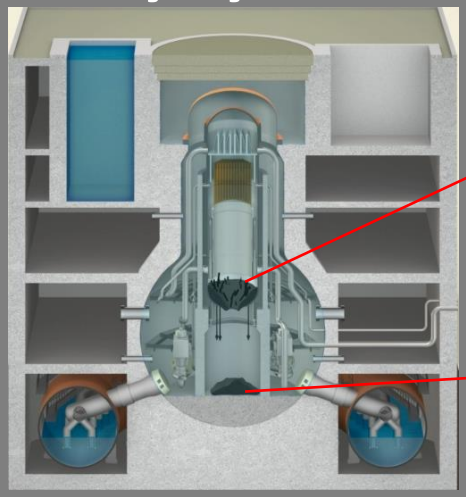


Fig. A5-1 Estimated inside of the PCV of the Fukushima Daiichi NPS

Data from Strategic Plan 2018 by NDF, 2018

Fuel-debris at Fukushima-Daiichi requires more investigation

1F-1,2,3



Fuel-debris

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

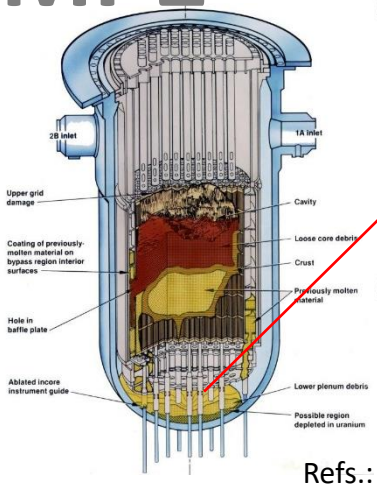
MCCI product

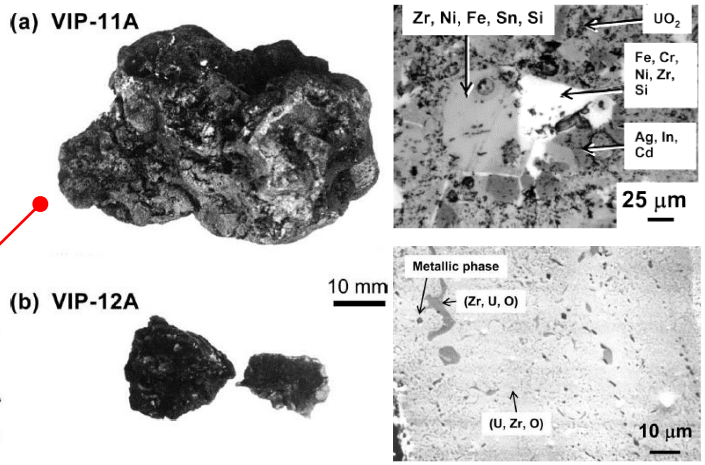
$(Zr, U, Ca)O_2$,
Al-Ca-O
Fe-Si-(Zr,U)-Al

Fuel-debris of 1F-1,2,3, as its 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

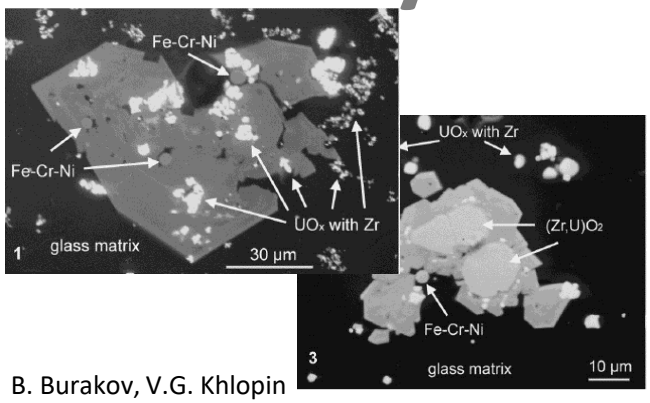
TMI-2





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

Chernobyl-4

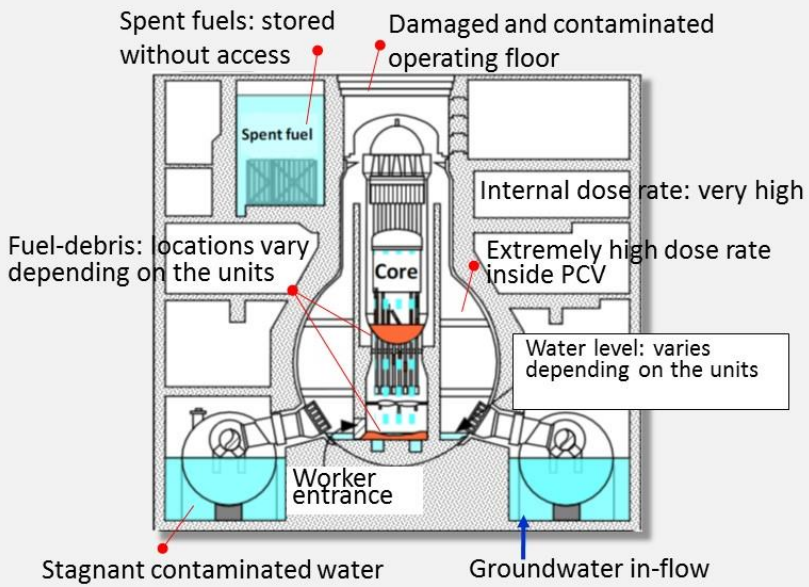


B. Burakov, V.G. Khlopin Radium Institute, Handout of the 2nd Int. Forum on the Decommissioning of Fukushima Dai-ichi NPS (2017).

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

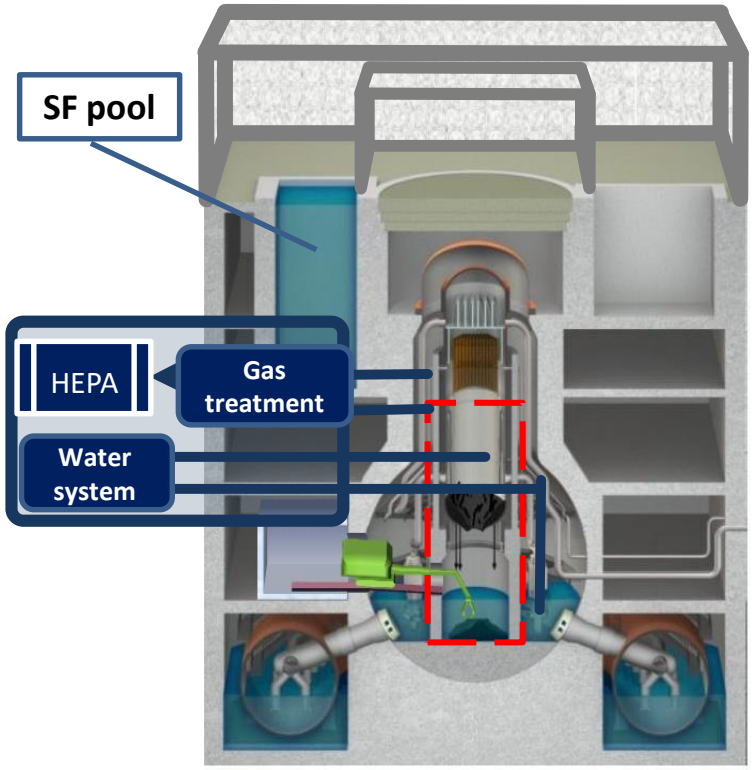
- **Internal inspection technique under extreme conditions inside PCV and RPV**
  Instrumentation, remote manipulators, robotics, radiation-resistant electronics, etc.
- **New techniques and devices for fuel-debris retrieval**
  Retrieval machinery for fuel-debris, canister for retrieved fuel-debris, 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.

Fuel-debris retrieval strategy

Careful preparation is necessary for the fuel debris retrieval

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

Partial-submersion plus side- entry 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 PCVs and buildings

Final selection of the fuel debris retrieval method

- Partial-submersion
- Side-entry

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

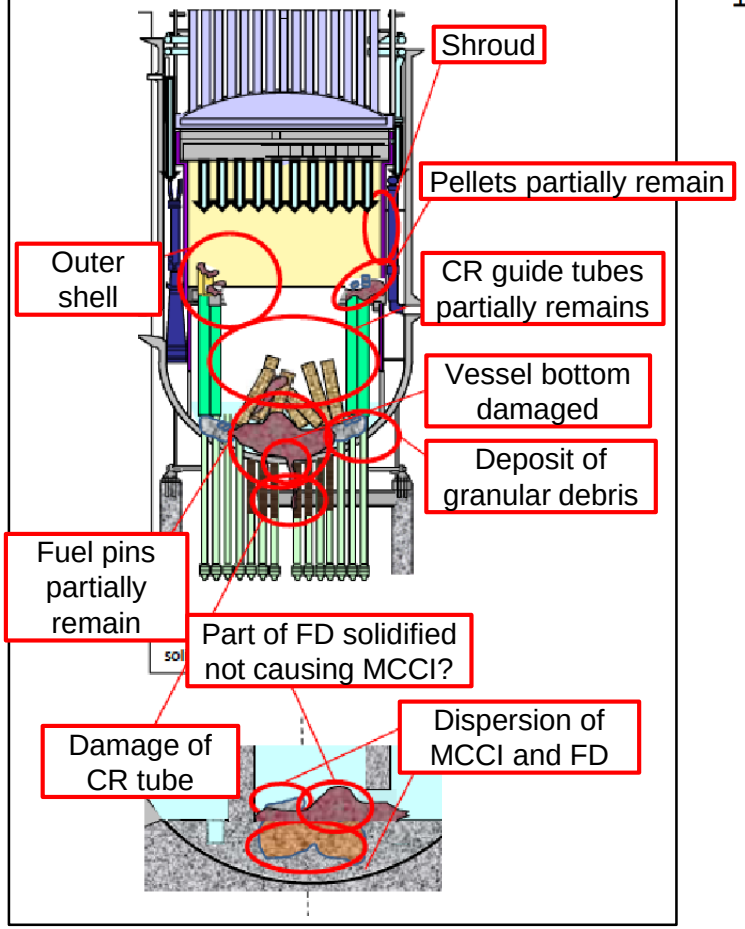
Possible to work with SF removal in parallel

Remote inspection techniques adopted

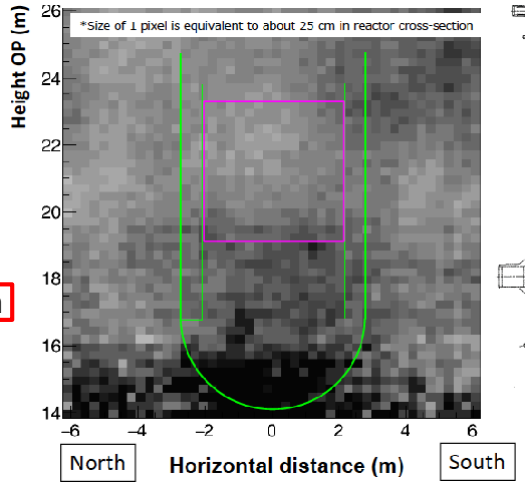
Pictures from IRID

SA Analysis

Estimation by MAAP/SAMPSON



Muon measurement



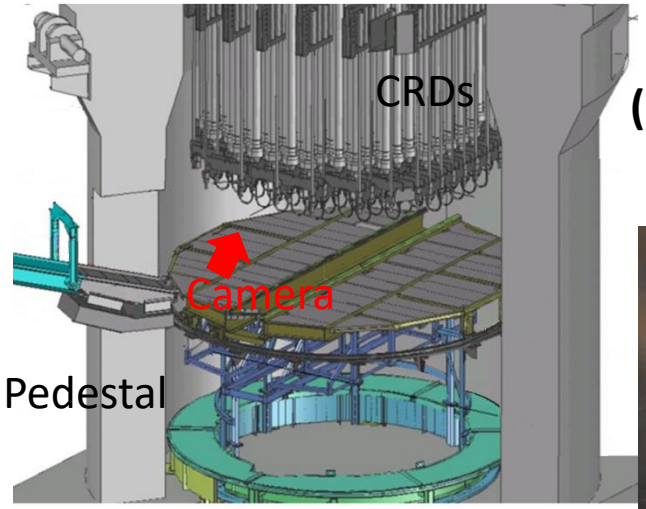
http://photo.tepco.co.jp/en/index-e.html

Remote survey

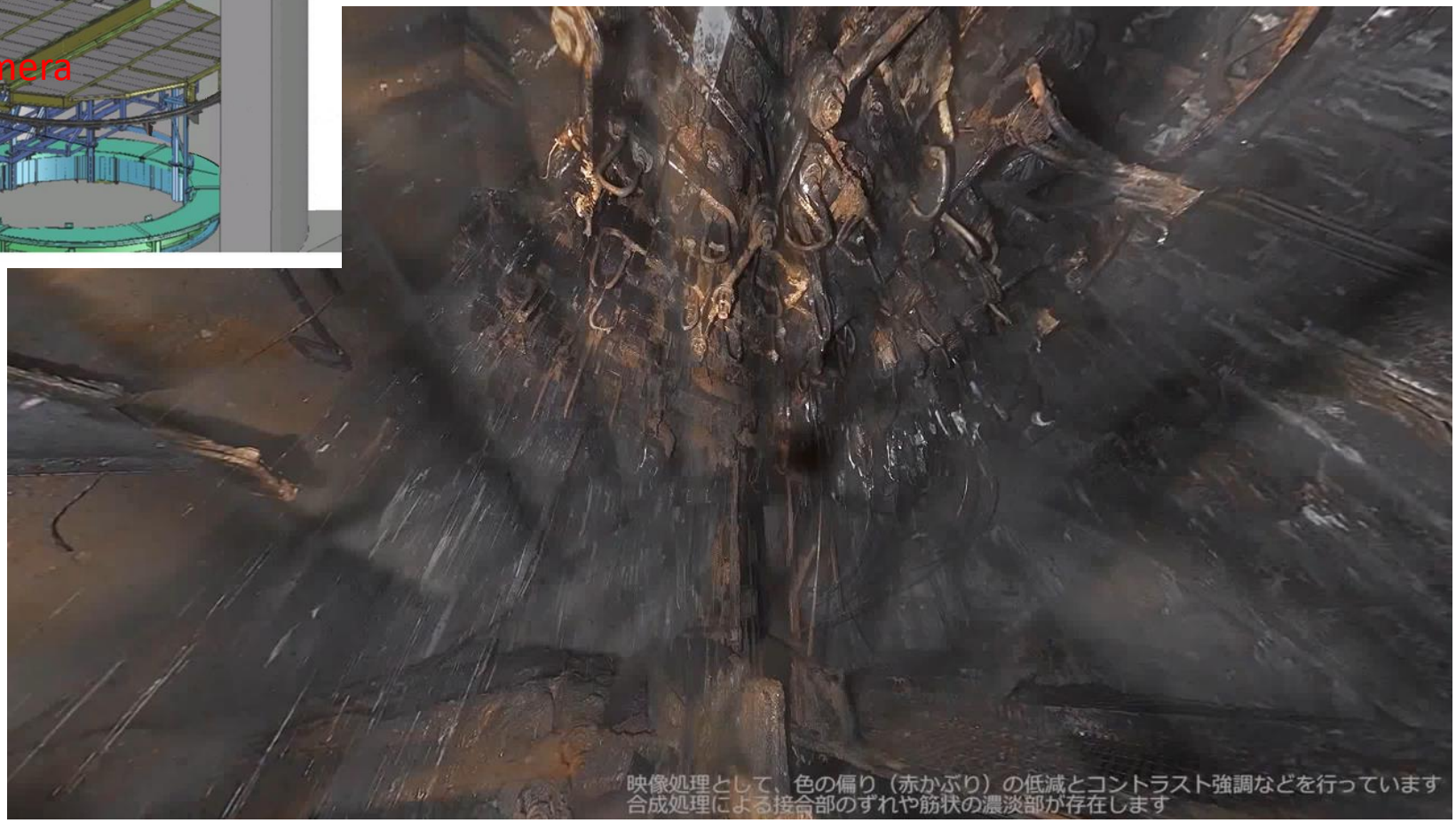
Photographic images inside the pedestal of Unit-2

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

Data from TEPCO

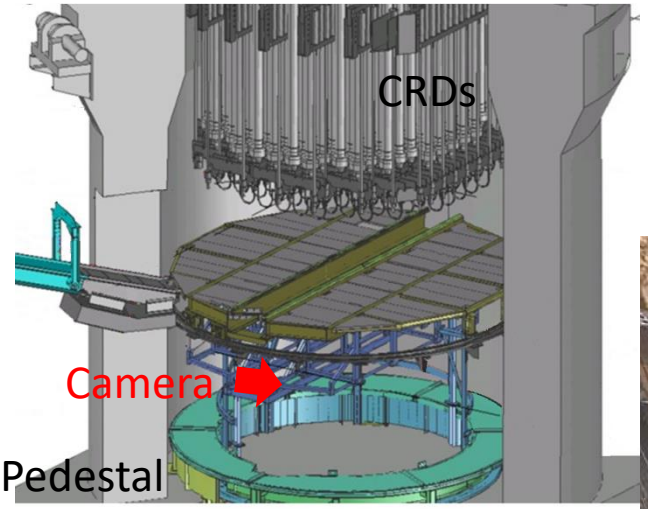


(1) At an upward angle to the lower part of RPV (CRD housings)



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

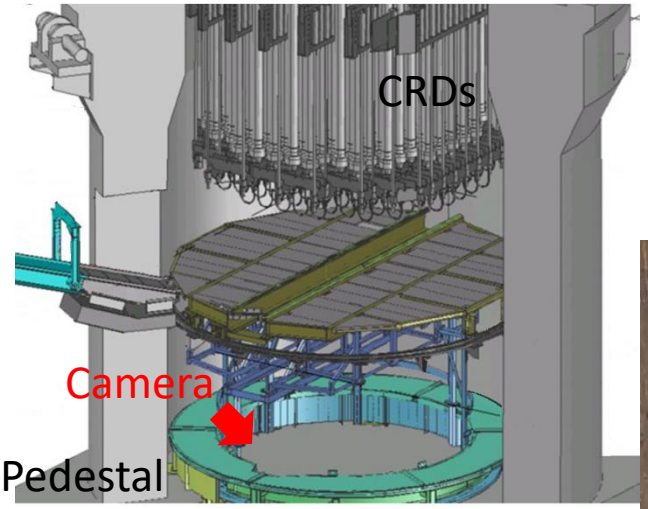
Data from TEPCO



(2) At a downward angle in PCV; inside Pedestal

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

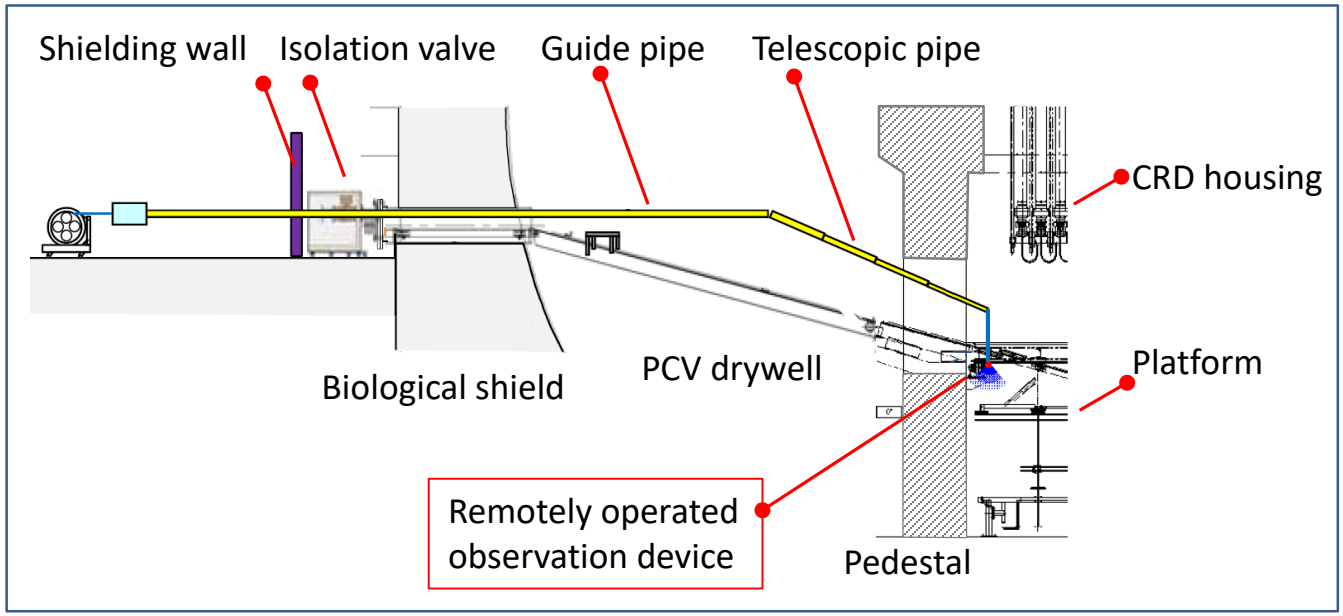
Data from TEPCO



(3) Bottom of PCV; inside Pedestal

Newest observation by remote inspection (Unit-2)

Data from TEPCO, Feb. 13/2019



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

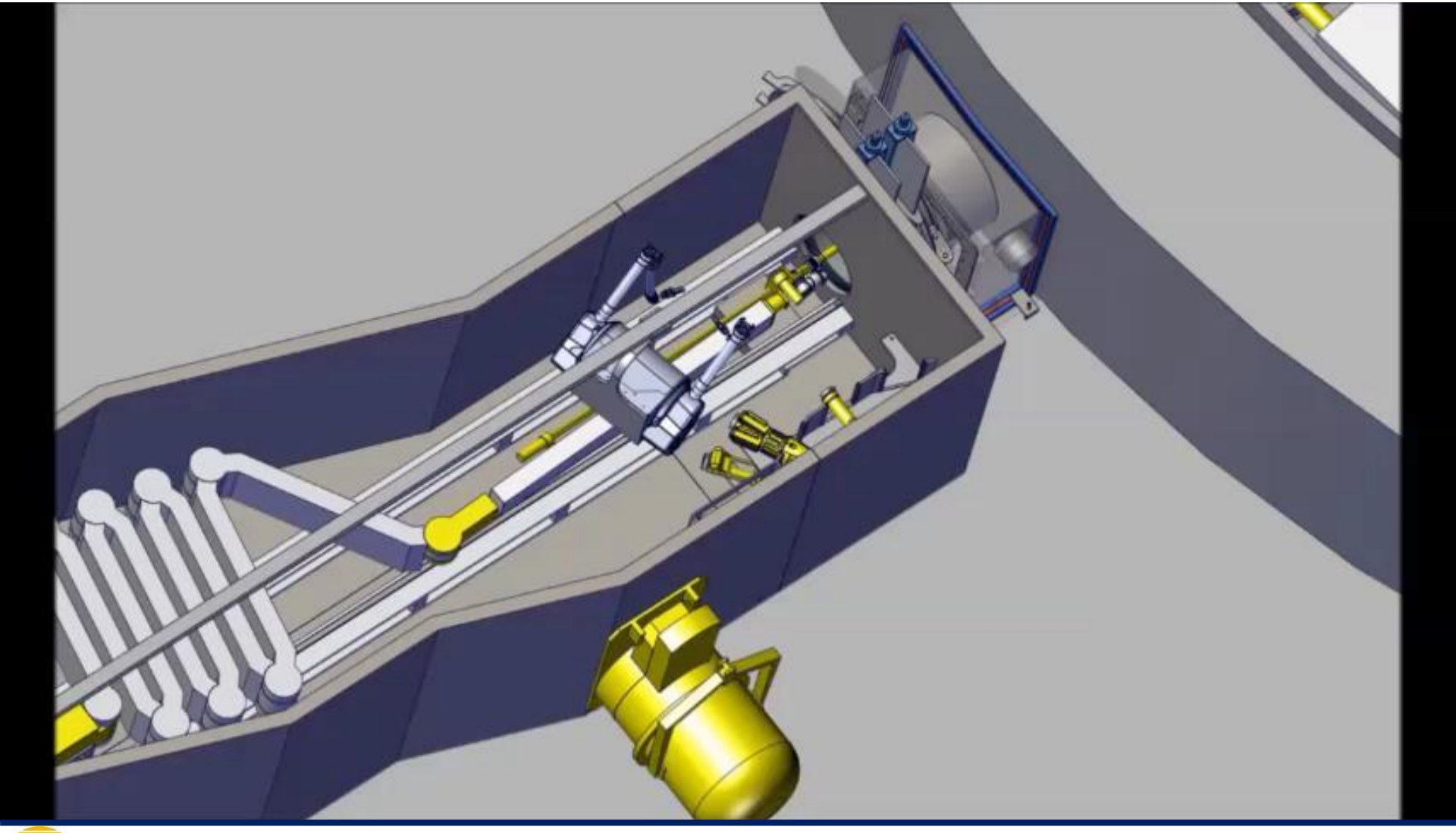
Newest observation by remote inspection (Unit-2)

Data from TEPCO, Feb. 13/2019

Planned internal inspection using an advanced remote arm

(1) Access to PCV through an existing penetration

Courtesy of IRID



Solid waste management approaches

Features of 1F Solid Waste

To date, ca. 400 kt accumulated

Rubbles (metal, concrete)/Woods & leaves/Soils/Incinerables/Adsorbers and sludge from water treatment /Waste from fuel-debris retrieval operation/ Waste from dismantling

- Huge volume
- High radiation
- A variety of nuclide compositions and concentration
- Lack of experience in managing and disposing of secondary waste generated from water treatment in Japan
- Characterisation needed along with progress of 1F D&D

Policy for Solid Waste Management

- Focus on characterisation, treatment, packaging and storage until determination of disposal approach

Today's Challenges and R&D

- To avoid generation of contaminated waste
- Volume reduction of solid Waste
- Quick waste characterization
- Determination future disposal method based on provisional waste form
- Pursuit of sustainable waste management scheme
- Reduction of workers dose

Increasing storage capacity for radioactive wastes


New incinerator


New waste storage facility


Storage for rubbles

R&D activities for solid waste management

Waste Generation

Characterization

Safe Storage

Treatment Solidification

Disposal

Ongoing studies along with the lifecycle of the waste

Characterization and analysis :

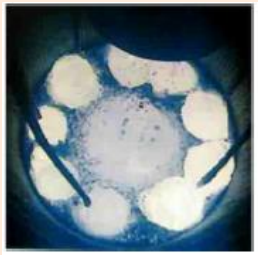
- Sampling from stored waste and reactors
- Analytical study to characterize wastes and contaminated materials
- Correlation study for nuclide composition
- Technique to streamline complicated analysis

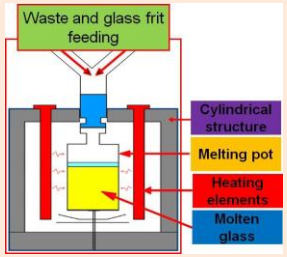
Improvement of the storage integrity and efficiency :

- Countermeasure for hydrogen generation
- Projection of the wastes pertaining to the fuel-debris retrieval operation
- Waste segregation by determination of the contamination

Comparative study of solidification technique :

- High temperature process
  CCIM, In Can Melting, GeoMelt
- Low temperature process
  Geopolymer, Improved Cement

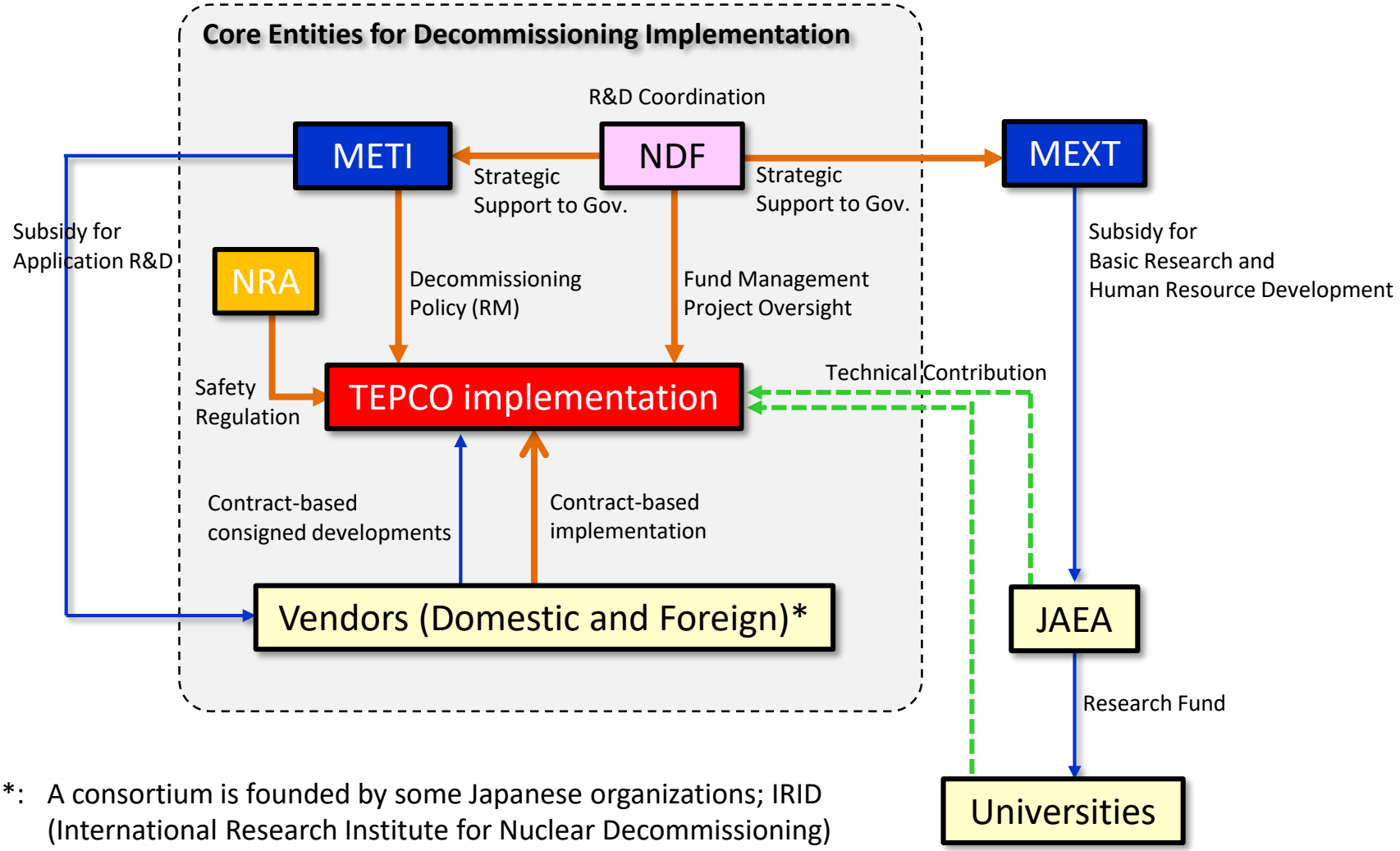




International survey on disposal :

- Disposal concept options
- Performance assessment
- Experienced regulatory requirements

Organizational structure for R&Ds



*: A consortium is founded by some Japanese organizations; IRID (International Research Institute for Nuclear Decommissioning)

Conclusions

In line with the holistic approach of Japan, the decommissioning of the Fukushima Daiichi NPP is progressing. The followings are the highlights.

- The situation of the site has been stabilized to date by adopting various best available techniques and knowledge.
- Institutional and organizational system to underpin the Fukushima Daiichi decommissioning has been solidified, and it is working.
- Risk reduction is recognized as the base of the long-term decommissioning challenge, and the result of the risk assessment shows the strategic direction.
- Difficult spent fuel recovery is progressing by using remote operations.
- Preliminary engineering and developments are ongoing for the fuel-debris retrieval which will start from sampling and small-scale operation using a remote arm.
- Inspection inside PCV is going forward, giving valuable information to unveil the unclear status of three units.
- Research and development for the waste management is continuing in line with the provisional approach.
- Research and development is underpinned by the cooperation of relevant organizations