Decommissioning of the Fukushima-Daiichi NPP Progress and Issues

International Topical Workshop on Fukushima Decommissioning Research 2022 (FDR2022)

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Contents

Part-1 Reviewing the 11 years after the accident

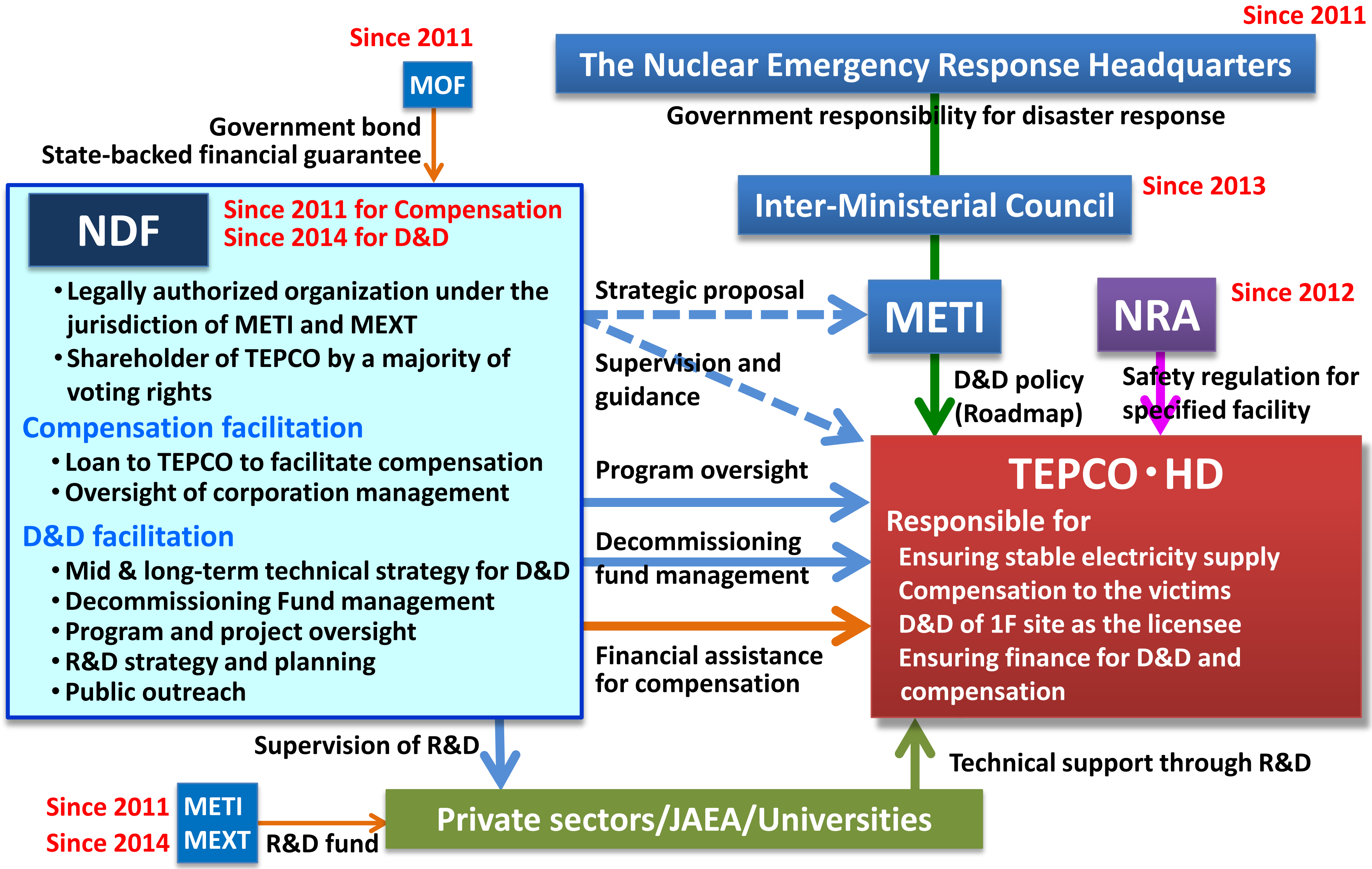
Part-2 Technical strategic plan, update (2022)

Photo：REUTER, May 19, 2022 (ttps://www.reuters.com/world/asia-pacific/japan-nuclear-regulator-grants-initial-nod-fukushima-water-release-plan-2022-05-18/) (Originally taken by Kyodo on Mar 17, 2022)

Part-1

Reviewing the 11 years after the accident

The Organizational Structure for 1F Decommissioning



Progress over the Past 11 Years and the Vision for the future

Up to the present

Origin: Mid. and Long-term Roadmap

2011 Mar.	2011 Nov.	2013 Nov.
8 months after the accident **Before achieving cold shutdown**	**Step-1** **Before start of spent fuel removal**	**Step-2** **Before start of fuel-debris retrieval**
Emergency response	**Stabilization and prepartion for long operation**	
Focused all the efforts on ending the crisis situation e.g. Cooling of damaged cores and spent fuel pools, and stoppage of radioactivity release	Gradual decrease of stagnant water in the buildings Contaminated water treatment and storage of ALPS-treated water Prevention of contaminated water leak-out with reduction of groundwater leak-in Spent Fuel removal from Unit-4 and 3 Prepartion of spent fule removal from Unit-1 and 2 PCV internal inspection Radioactive waste storage and reduction Study on fuel-debris retrieval methods Improvement of radiological environment	

Forthcoming plan

ca. 10 yrs after start of step-1	ca. 10 yrs after start of step-3
Step-3 **Expected to accomplish within 30 to 40 years after the start of Step-1 (2011 End)**	
Step-3 (1)	**Step-3 (2)**
Expanded internal inspection of PCV Scale up of trial fuel debri retrieval Preparation for full-scaled fuel debris retrieval Completion of spent fuel removal from SFP in all units Drastic minimization of contaminated water generation Enhanced waste management through characterization	Full-scaled fuel-debris retreaval for Unit-1 to 3 Safe storage of recovered fuel debris and spent fuels Resolving the contaminated water issue Waste management with storage, volume reduction, processing/disposal Preparation for the final disposal of raioactive wastes Other necessary operations to achieve the goal of D&D

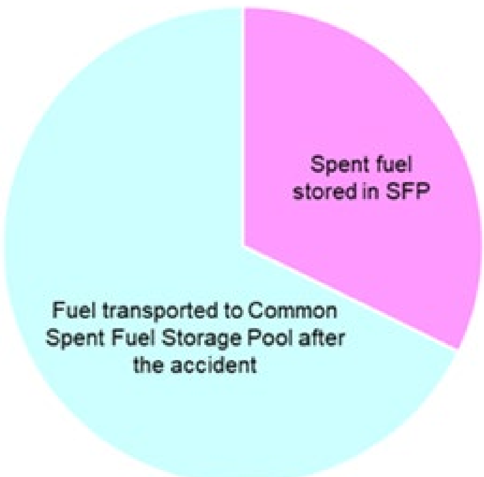
Overview of the Key Achievements

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Accident	●											
Contaminated Water Management	● Stopped leak from seawater trench											
	● KURION installed											
	● SARRY installed											
			● ALPS treatment started									
					● Highly contaminated water treatment completed							
								● Frozen wall installed				
												Implementation Plan for discharging ALPS-treated water approved ●
												Plan for discharge, approved by the municipalities ●
In-Reactor Inspection		● Camera inserted from penetration (Unit 2)										
		● Camera inserted from penetration (Unit 1)										
					● Observed with muon (Unit 1)							
					● Camera inserted from penetration (Unit 3)							
							● Observed with muon (Unit 2)					
							● Investigation with underwater ROV (Unit 3)					
								● Investigation with hanging camera (Unit 2)				
												Investigation with underwater ROV (Unit1) ●
Spent Fuel Removal				● Unit 4 Spent fuel removal completed								
											Unit 3 Spent fuel removal completed ●	
Waste Management						● Misc. solid waste incinerator installed						
								● Solid waste storage added				
Major Dicisions				● Decided decommissioning of Unit 5/6								
										Reorganized to project-based management ●		

How the Released Radioactivity was Relocated

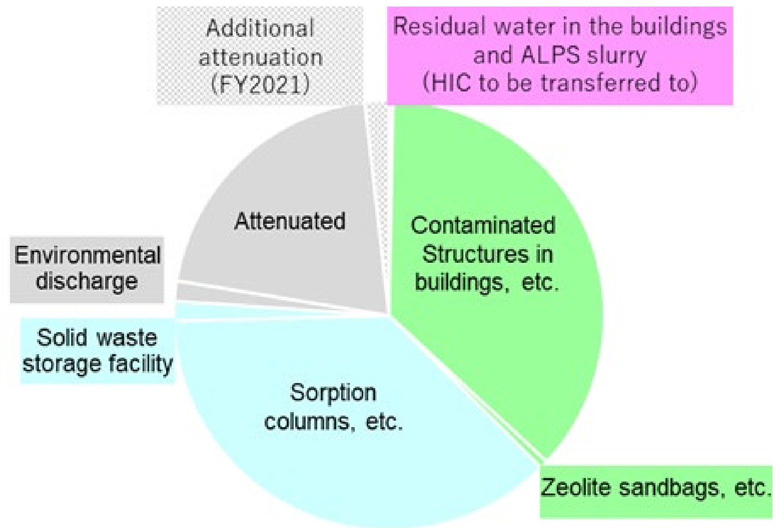
Origin: Technical Strategic Plan 2022

	Spent Fuels	Released Cs-137
2011	**2,774 assemblies** in total were stored in SFP of Units 1 to 4	**$7x10^{17}$ Bq of Cs-137** were released into the reactor buildings
2022	About 2/3 has been already transferred to the Common Spent Fuel Storage Pool	Most has been adhered to the sorbents and structures



*New fuel not included

Number of fuel assemblies of spent fuel (Units 1 to 4)



Radioactivity of Cs-137 released at the accident (Units 1 to 3)

Origin: Technical Strategic Plan 2022

SED, a simplified risk index

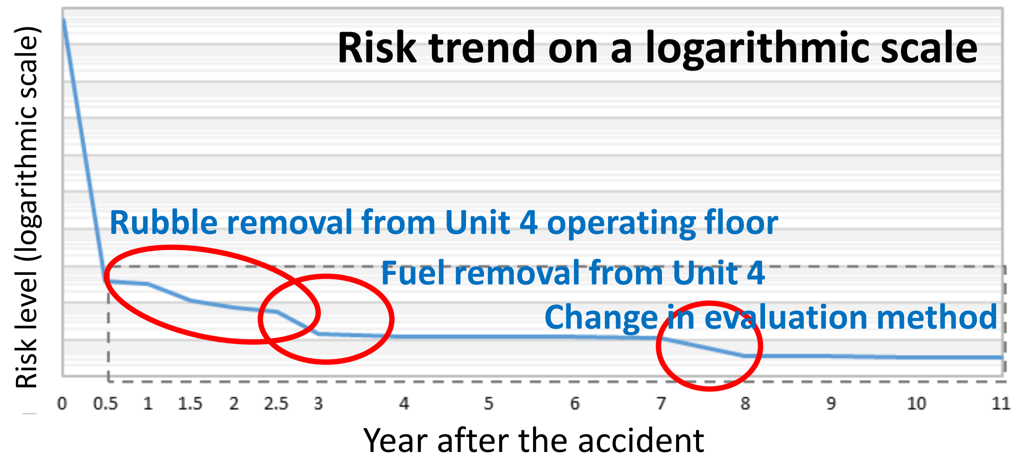
$$SED = (RHP + CHP) \times (FD \times WUD)^4$$

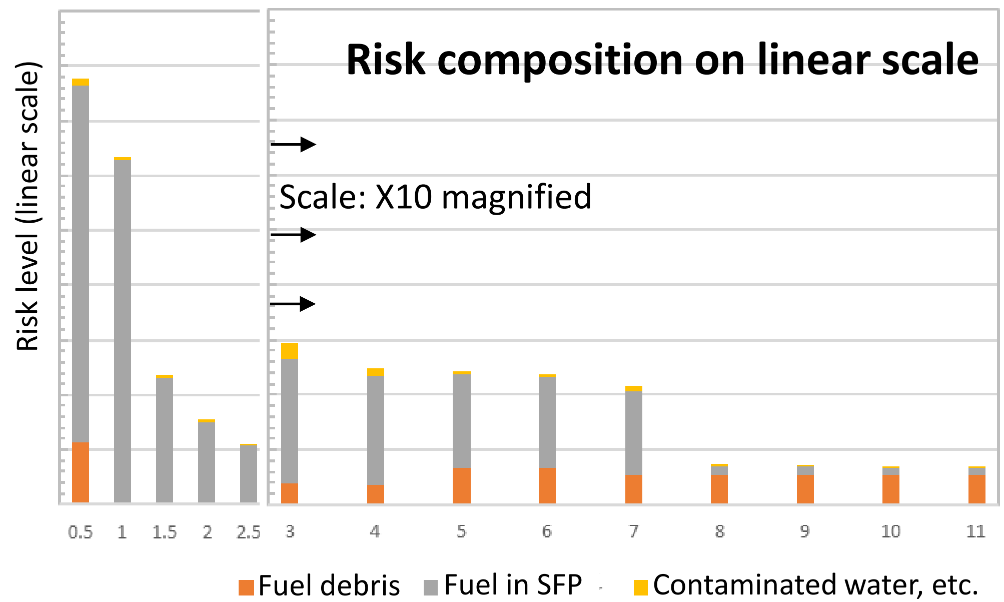
$$RHP = Inventory \times \frac{Form\ Factor}{Control\ Factor}$$

FD: Facility Descriptor

WUD: waste Uncertainty Descriptor

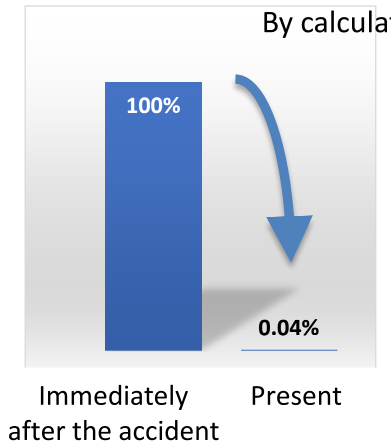
- Most of the risks on site originates from spent fuels and fuel-debris
- Total SED score has decreased 7 digits over 11 years
- Drastic decrease was achieved by radioactivity decay and SF removal from Units-3 and 4

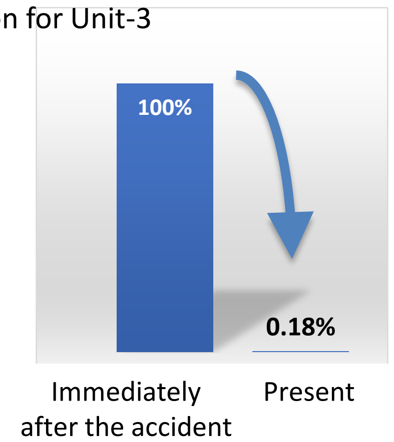




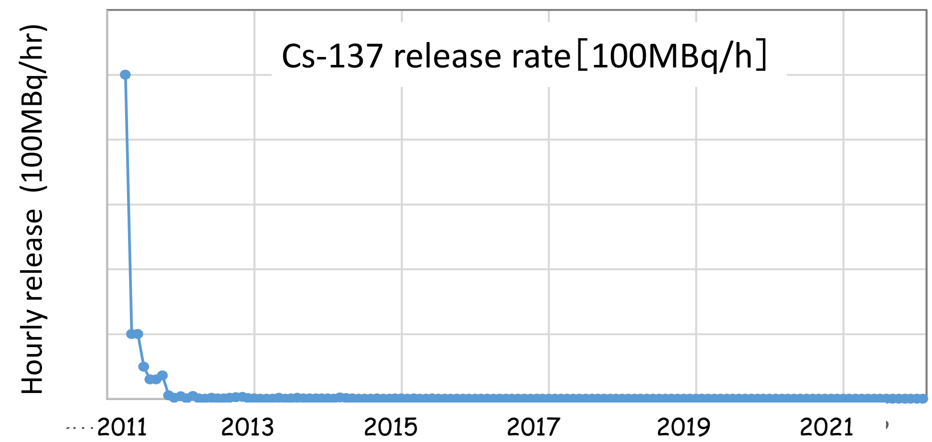
Radioactivity Release to the Environment

Residual heat of the reactor Radioactivity of the reactor

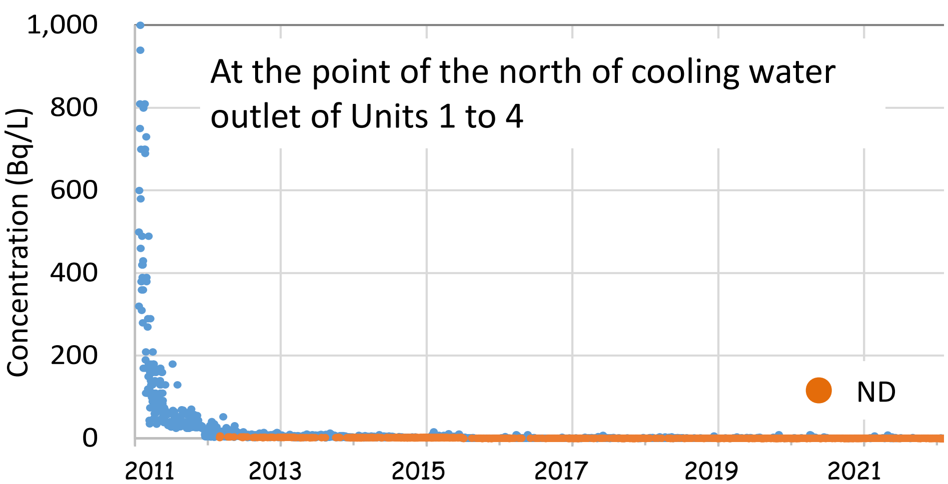




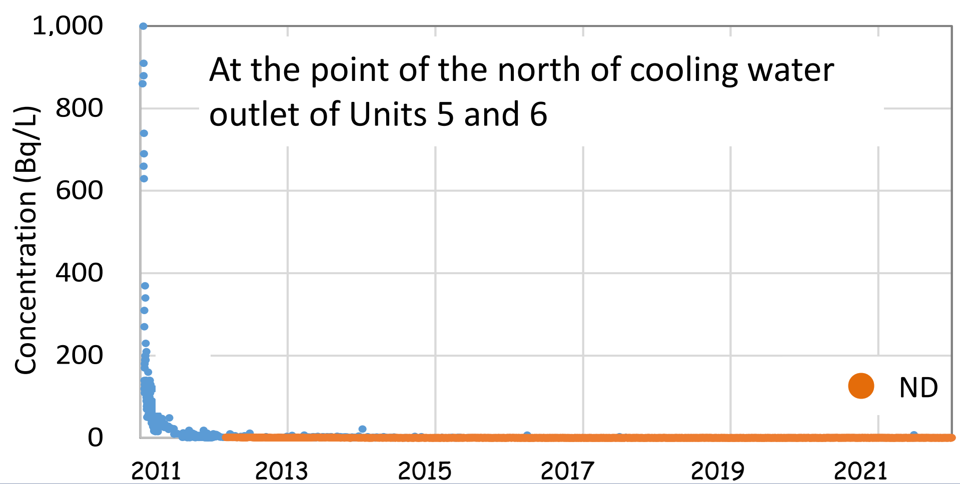
Environmental release of Cs-137 from reactor buildings



Cs-137 inside of the harbor



Cs-137 outside of the harbor



Techniques Adopted to Probe Inside of the Reactor

- Observation inside the reactor building with mobile robots

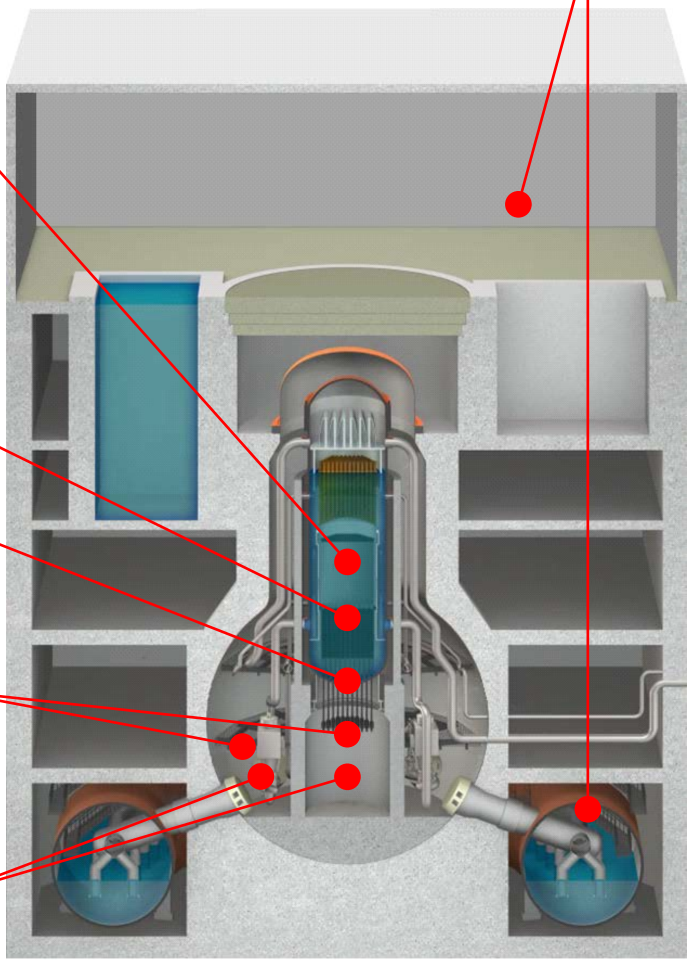
- Use of existing reactor instrumentation and reinforcement of condition observations
  PCV radioactivity concentration, hydrogen concentration
  bottom of PCV/RPV, temperature, PCV pressure, water level
- Estimation inside reactor by water injection stop testing

- Imaging with muon tomography

- Estimation inside reactor by core-disruption simulation

- Internal inspection by inserting a camera (U1: once, U2: 5 times, U3: once)
- Internal inspection with mobile robots (Once per Unit)

- Full mobile inspection (U1/ROV)
- Full remote arm inspection (Unit 2/trial)



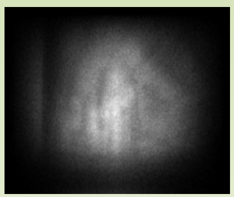
"The Long and Winding Road" to Reach a Convincing Understanding

Quantitative Information Acquisition

Qualitative Understanding

Situational Understanding

Estimation



Muon Tomography

Computer Simulation

Elucidation of Observed Instrumentation Signals with their Trends

In-Building Inspection with Robots or Human

PCV-Inspection with ROVs

PCV-Inspection through Penetration with Inserted Camera

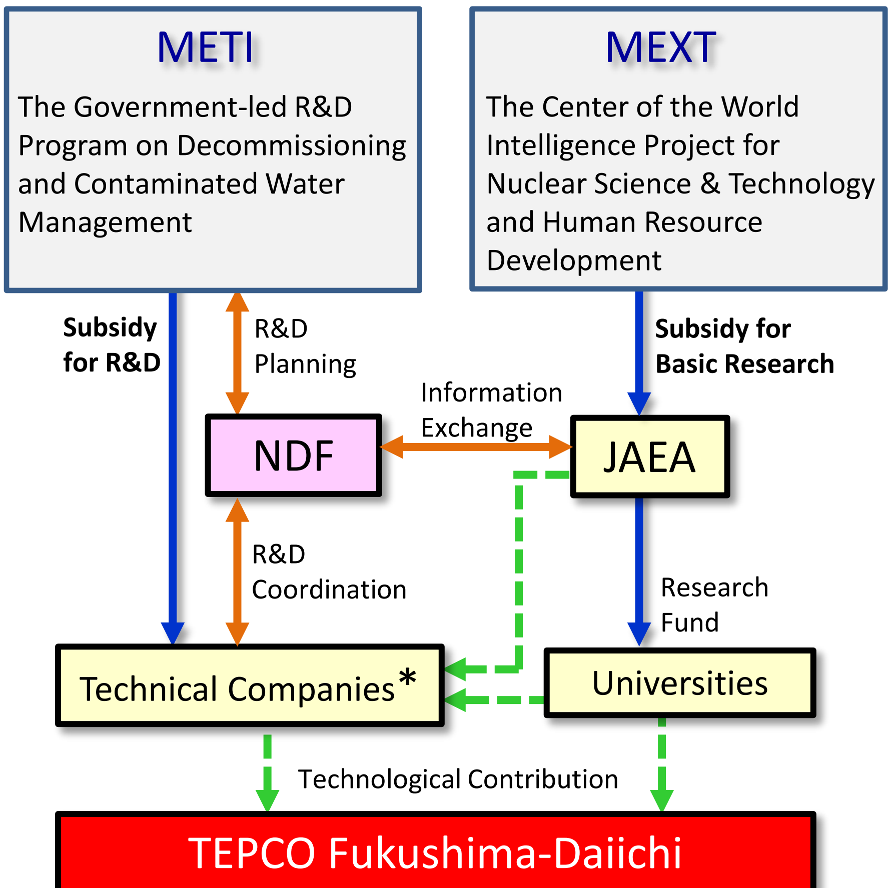
PCV-Inspection with ROV (U-1) 2022

PCV-Inspection with Long-Arm (U-2) 2023

Degree of Access to Core

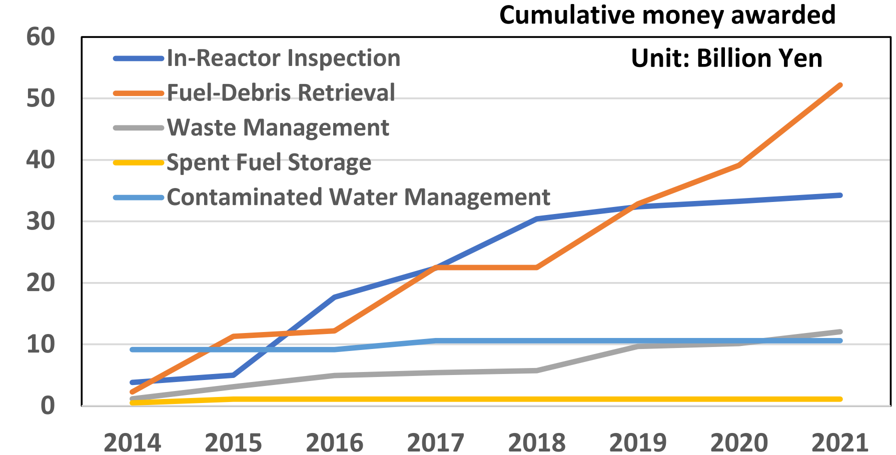
Government's Funds to Support 1F R&D

Structure of Government-led R&D



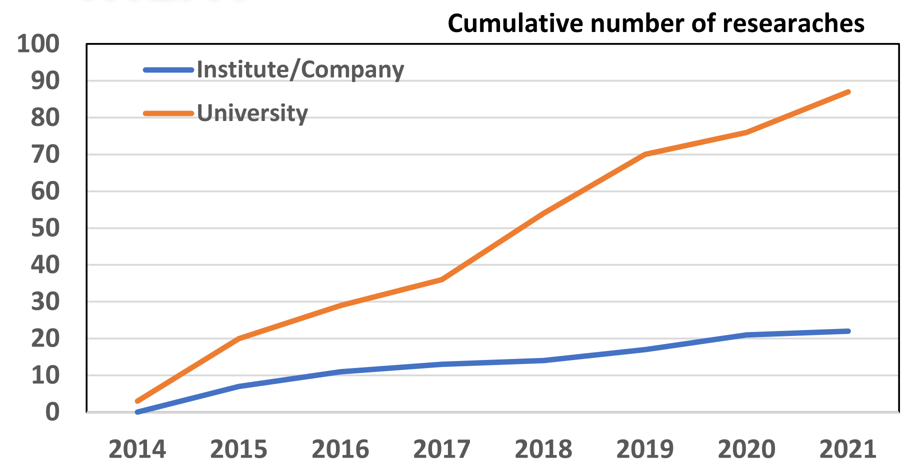
*: IRID (International Research Institute for Nuclear Decommissioning) ; A consortium is founded by some Japanese organizations

METI Amount of Awarded Money



About 100 B yen, invested for installing new facilities

MEXT Number of Awarded Researches



Part-2

Technical strategic plan, update (2022)

Released, Oct. 11, 2022

Acknowledged Documents Supporting 1F D&D

Government	Mid-and-Long-term Roadmap
NDF	Technical Strategic Plan
NDF&TEPCO	Withdrawal Plan for Reserve Fund
TEPCO	Mid-and-Long-term Decommissioning Action Plan

Variation of the Risk Profile of 1F Site

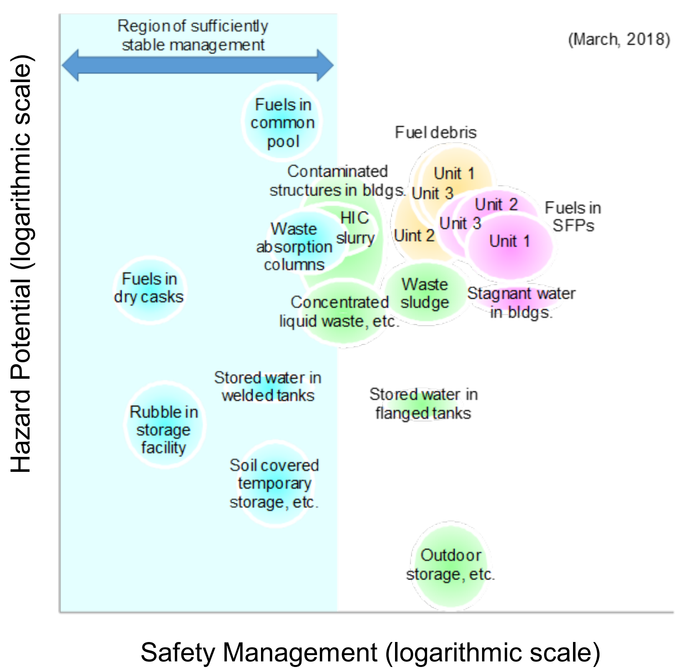
Origin: Technical Strategic Plan 2022

Change in the Risk map

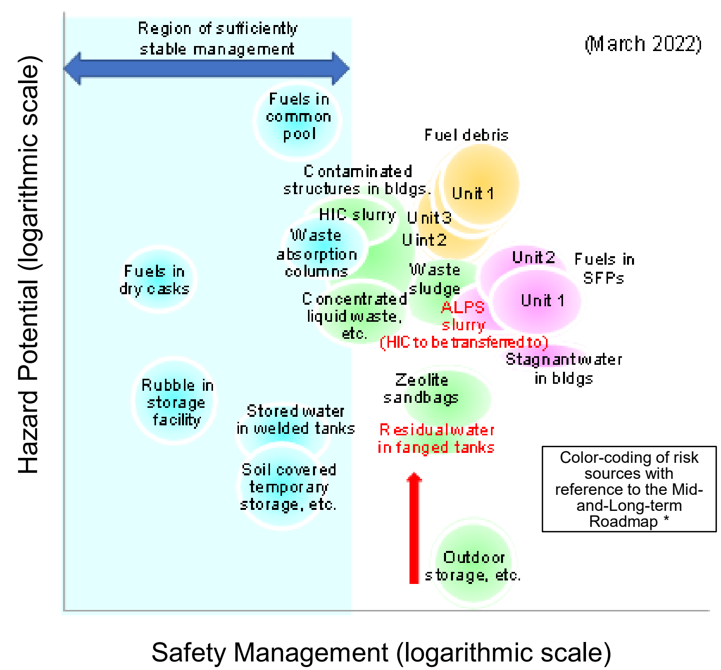
(Compared with the evaluation of 2018, the oldest evaluation using the same method)

- Risk reduction : Removal of Spent Fuel in Unit 3 SFP, treatment of stagnant water in buildings and residual water in tanks
- Separation of risk sources that require specific measures : zeolite sandbags and ALPS slurry (HIC to be transferred）

Technical Strategic Plan 2018



Technical Strategic Plan 2022



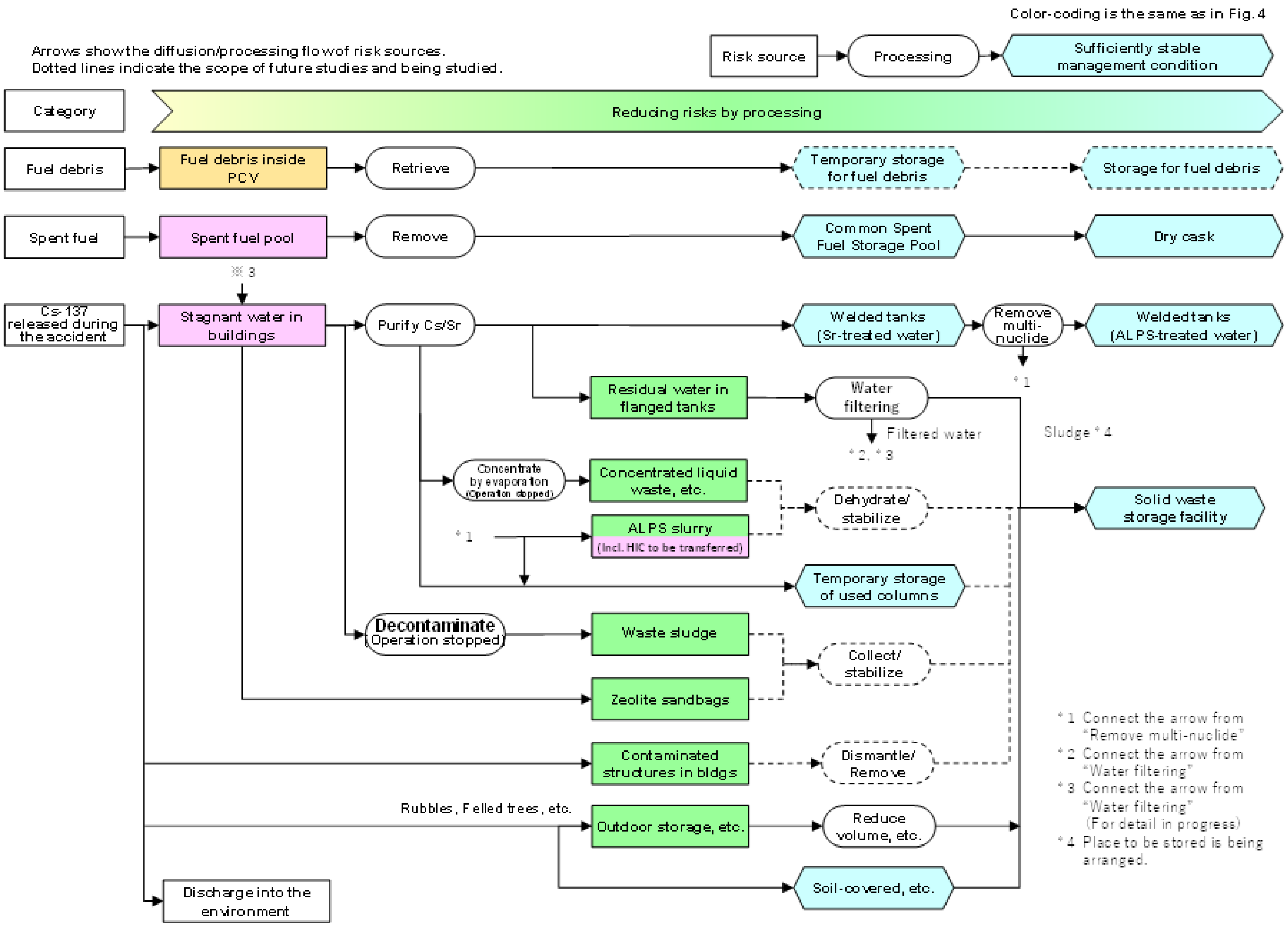
▪Hazard potential : an index of the impact of internal radiation exposure

▪Safety Management : an index of the likelihood that an event will occur

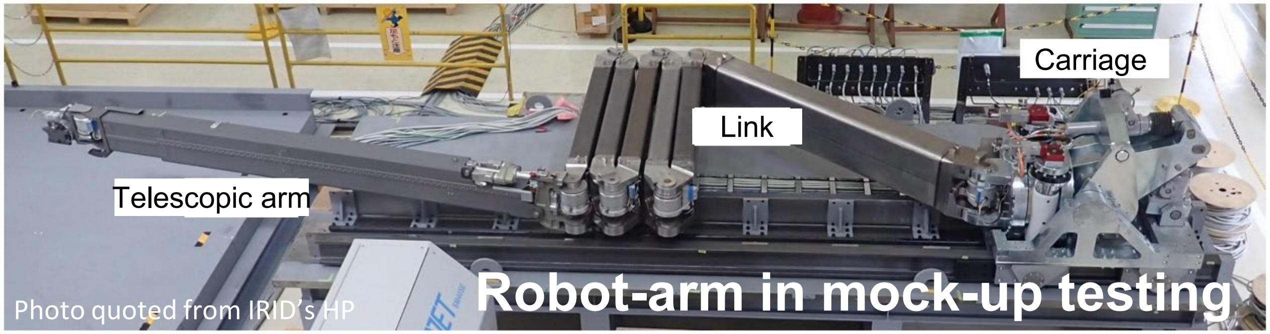
Risk Reduction Flow in the D&D Process

Origin: Technical Strategic Plan 2022

How the risk sources have changed (will change) to the “Sufficiently stable management” compared with the time of the accident



Operation of Trial Retrieval (internal investigation and fuel debris sampling) in Unit 2



- Trial retrieval (internal investigation and fuel debris sampling) is a series of operations, and fuel debris sampling is one part of 11 steps.
- After opening the hatch of the penetration X-6 and extending the containment barrier outside the PCV, it is important to ensure containment as the inside of the enclosure becomes progressively contaminated.
- For on-site applications with uncertainty, the challenges are to ensure functionality verification under various conditions and equipment can be rescued in case of emergency.

✓ It is necessary to ensure that the required conditions are satisfied by conducting mock-up tests.

✓ Due to the uncertainty of the PCV internal situation, work must be performed safely and carefully, keeping in mind that things may not go as planned.

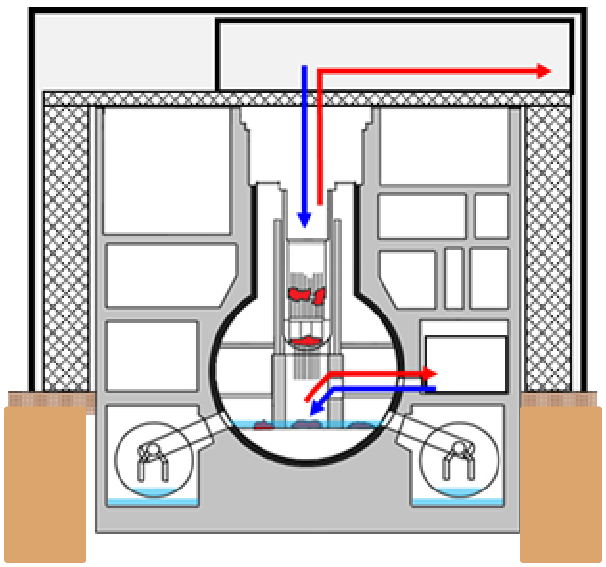
(1) Preparatory work (completed)
(2) Installation of isolation chamber (in progress)
(3) Opening of the hatch of penetration X-6 by hatch opener
(4) Removal of deposits in penetration X-6 by deposit remover
(5) Robot arm installation
(6) Robot arm entry
(7) Internal investigation by robot arm and fuel debris sampling
(8) Collect from fuel debris retrieval equipment to transport container, and dose measurement
(9) Acceptance and measurement of gloveboxes
(10) Removal of containers, storage in shipping containers, and carry-out
(11) Off-site transport and off-site analysis (analysis of fuel debris properties)

Study on the Concept with Good Potential for the Full-Scale Fuel Debris Retrieval

Origin: Technical Strategic Plan 2022

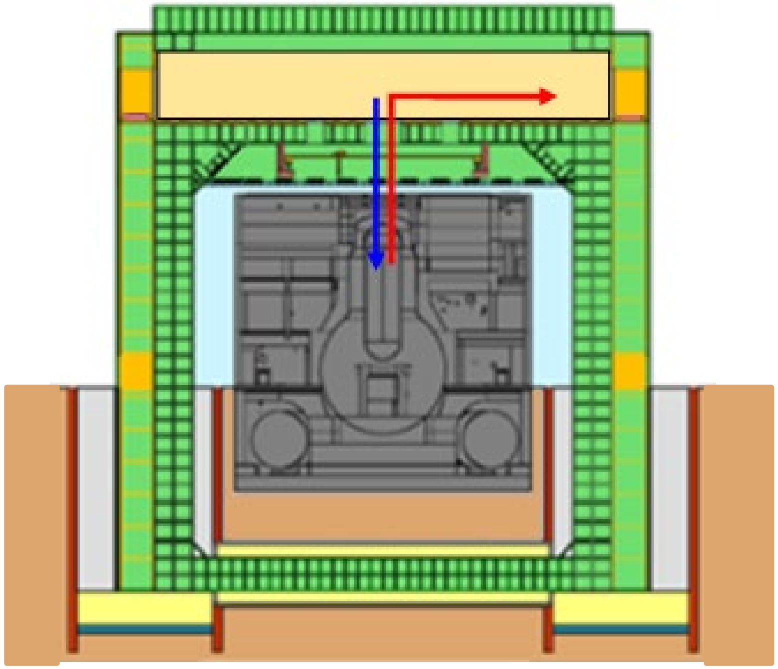
Conceptual drawing of the current partial submersion (dry) method

- This candidate partial submersion (dry) method does not use the upper or side access method alone but combines them, which has been examined previously.



Conceptual drawing of the submersion method (shell structure)

- This candidate submersion method uses a new idea to submerge the reactor building by enclosing the entire reactor building with a new structure called a shell structure as a boundary (shell method).



Basic Policy for the Waste Management Challenge

Challenges and technical strategies

Characterization

- For a variety of solid waste, it is needed to develop a medium-to-long-term analysis strategy that defines its priority, the objective of the analysis, and quantitative targets, etc., and to proceed with analysis/evaluation accordingly.

✓ Accumulate trial results and verify their validity in order to establish a development flow of the medium-to-long-term analysis plan with an analysis project approach using statistical methods.

Storage

- Storage of solid waste according to the progress of decommissioning work in the future should be advanced in a safe and reasonable manner, including temporary outdoor storage of the solid waste (except for secondary waste generated by water treatment and targets of reuse/recycling) will be eliminated (by FY 2028), that is stated in the Mid-and-Long-term Roadmap.

✓ Examine further possibilities by referring to advanced cases of overseas, while steadily continuing approach for volume reduction.

✓ Promote volume reduction through incineration, and cutting/crushing, and steadily consolidate storage inside buildings.

Processing/disposal

- The Mid-and-Long-term Roadmap stated that the specifications of waste form and their production methods will be determined in Phase 3, the study on appropriate overall measures should be initiated for specific management for solid waste.

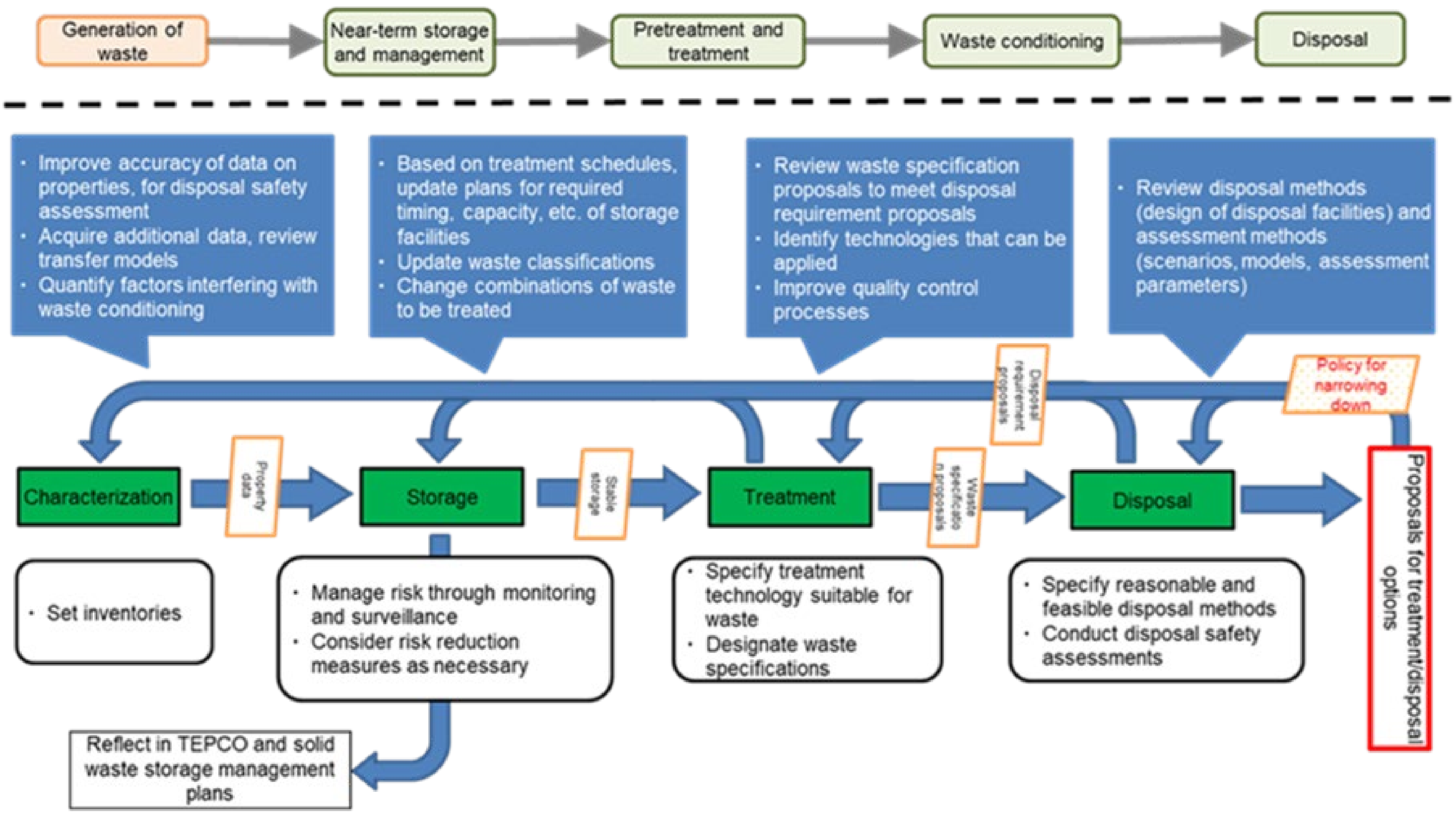
✓ Create processing/disposal options for solid waste by examining pending issues related to processing technology and disposal options.

✓ Compare and evaluate options using the property data that are becoming clear, and examine to establish a waste stream that is suitable for the characteristics of solid waste.

Holistic Approach for Radioactive Waste Management

Origin: Technical Strategic Plan 2022

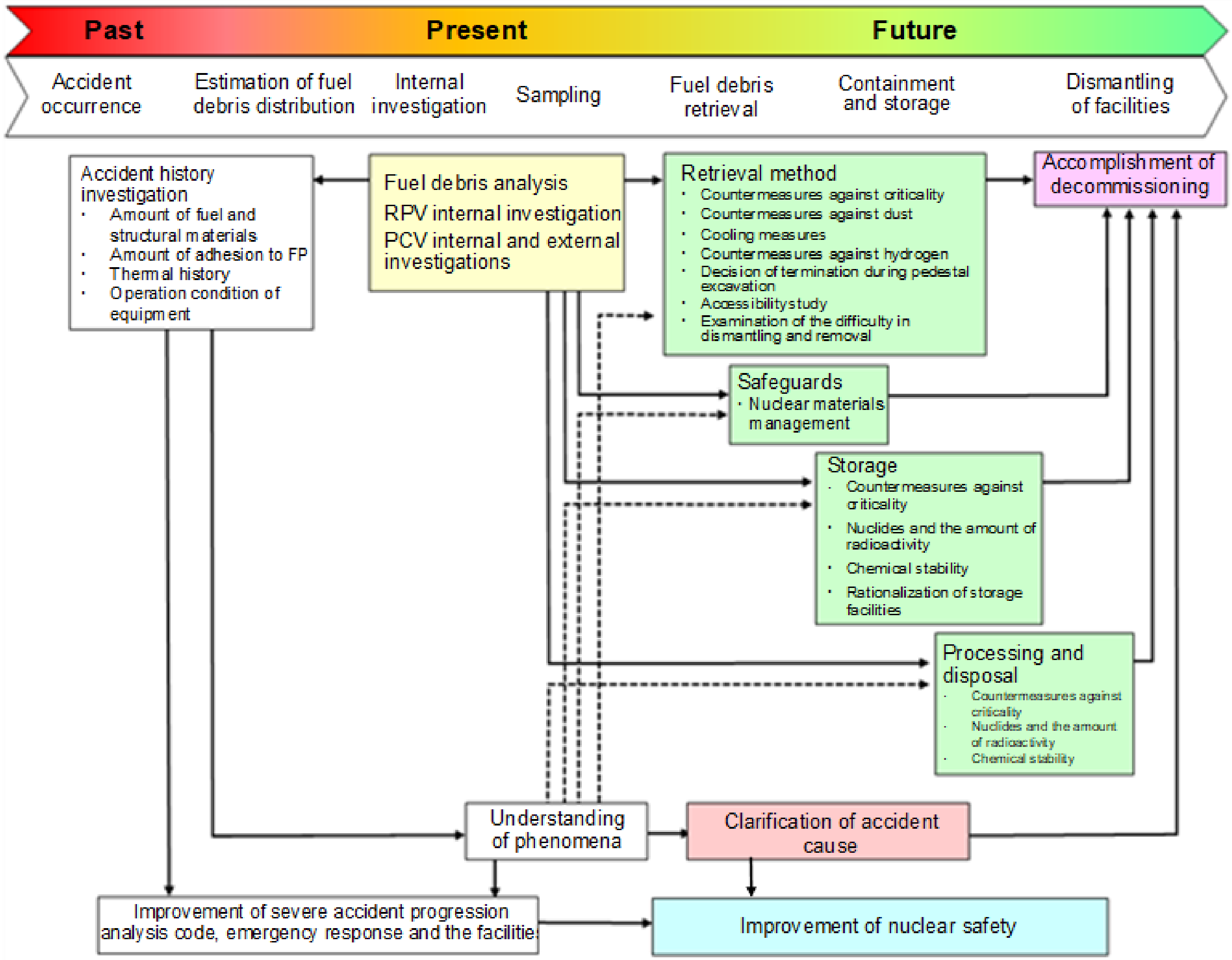
Given the prospects of processing/disposal methods and technology related to their safety presented in FY 2021, appropriate measures should be studied as management approaches for overall solid waste to establish a waste stream* according to the properties of solid waste.



Procedure to reasonably select safe processing/disposal methods of solid waste

Analysis and Characterization along the D&D Process

Origin: Technical Strategic Plan 2022



Enhancement of the Framework of Analysis

Origin: Technical Strategic Plan 2022

Significance and current state

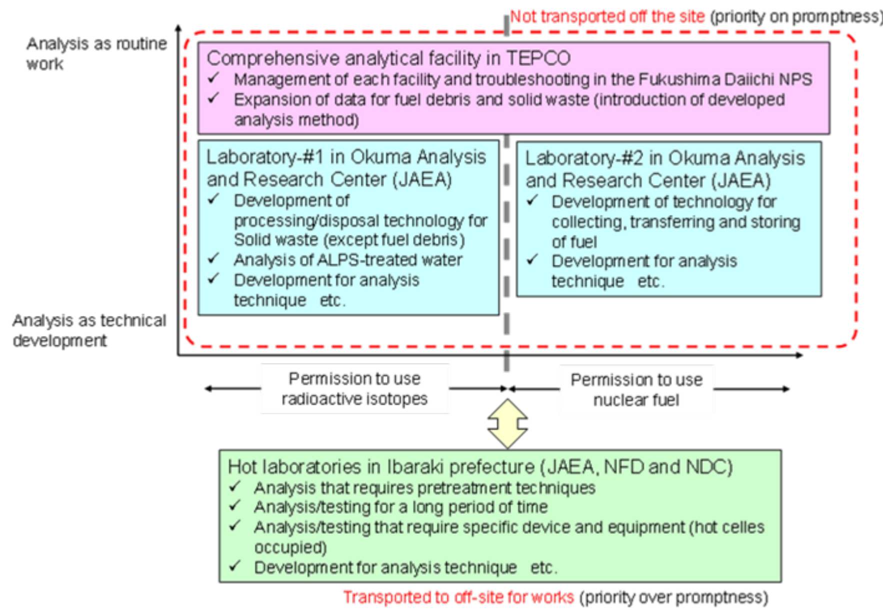
- At present, due to the large range of uncertainty regarding fuel debris properties, safety measures should be studied conservatively.
- If the range of such uncertainty can be reduced, there is no excessive margins needed, and thus, rational safety measures can be studied, it enables the promptness and rationality of decommissioning to improve.

Challenges and technical strategies

- Since the fine fuel debris generated as retrieval of fuel debris progresses are diverse with high radiation dose, it is a challenge to establish an efficient system for analysis.

✓ It is effective to expand the analysis data under the appropriate division of roles among the facilities in the Ibaraki area, where facilities and equipment are enhanced, and the new analytical facilities.

✓ It is important to efficiently promote human resource development with the cooperation of other institutions.

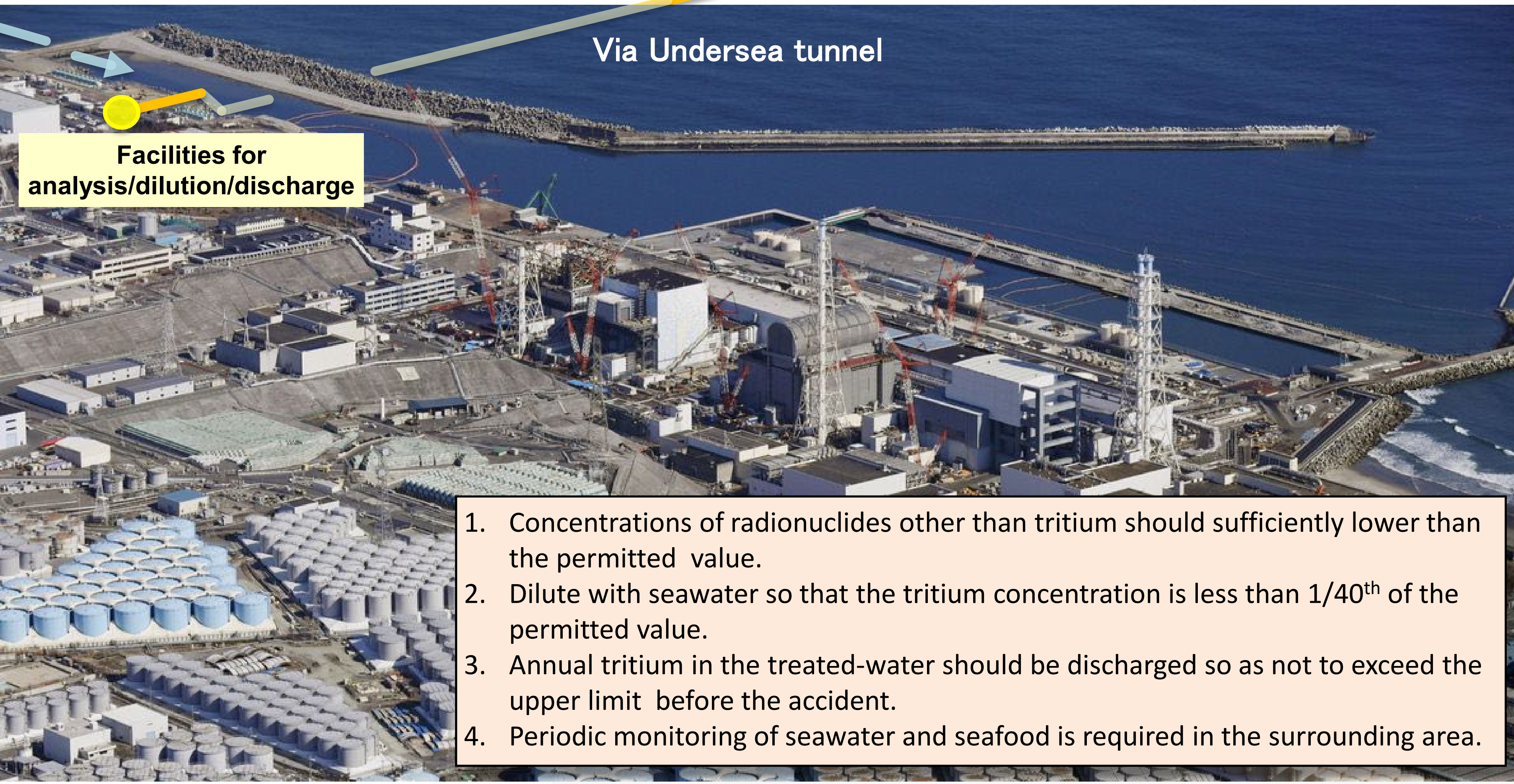


Characteristics and roles of each facility for analysis

The Plan of Discharging System for ALPS-Treated Water into the Ocean

Dilute by intaking seawater from outside the harbor

Discharge from the undersea outlet 1 km far from the shore



1. Concentrations of radionuclides other than tritium should sufficiently lower than the permitted value.
2. Dilute with seawater so that the tritium concentration is less than 1/40th of the permitted value.
3. Annual tritium in the treated-water should be discharged so as not to exceed the upper limit before the accident.
4. Periodic monitoring of seawater and seafood is required in the surrounding area.

Photo credit： REUTERS, Feb 14,2022 (https://www.reuters.com/world/asia-pacific/japan-welcomes-iaeas-inquiry-into-fukushima-water-release-2022-02-14/)

Key Issues for Implementing Discharge of Treated Water

Origin: Technical Strategic Plan 2022

Major target

- For the ALPS-treated water currently stored in tanks, measures will be taken for discharging the treated water about two years after the release of the Basic policy (April 2021)

Challenges and technical strategies

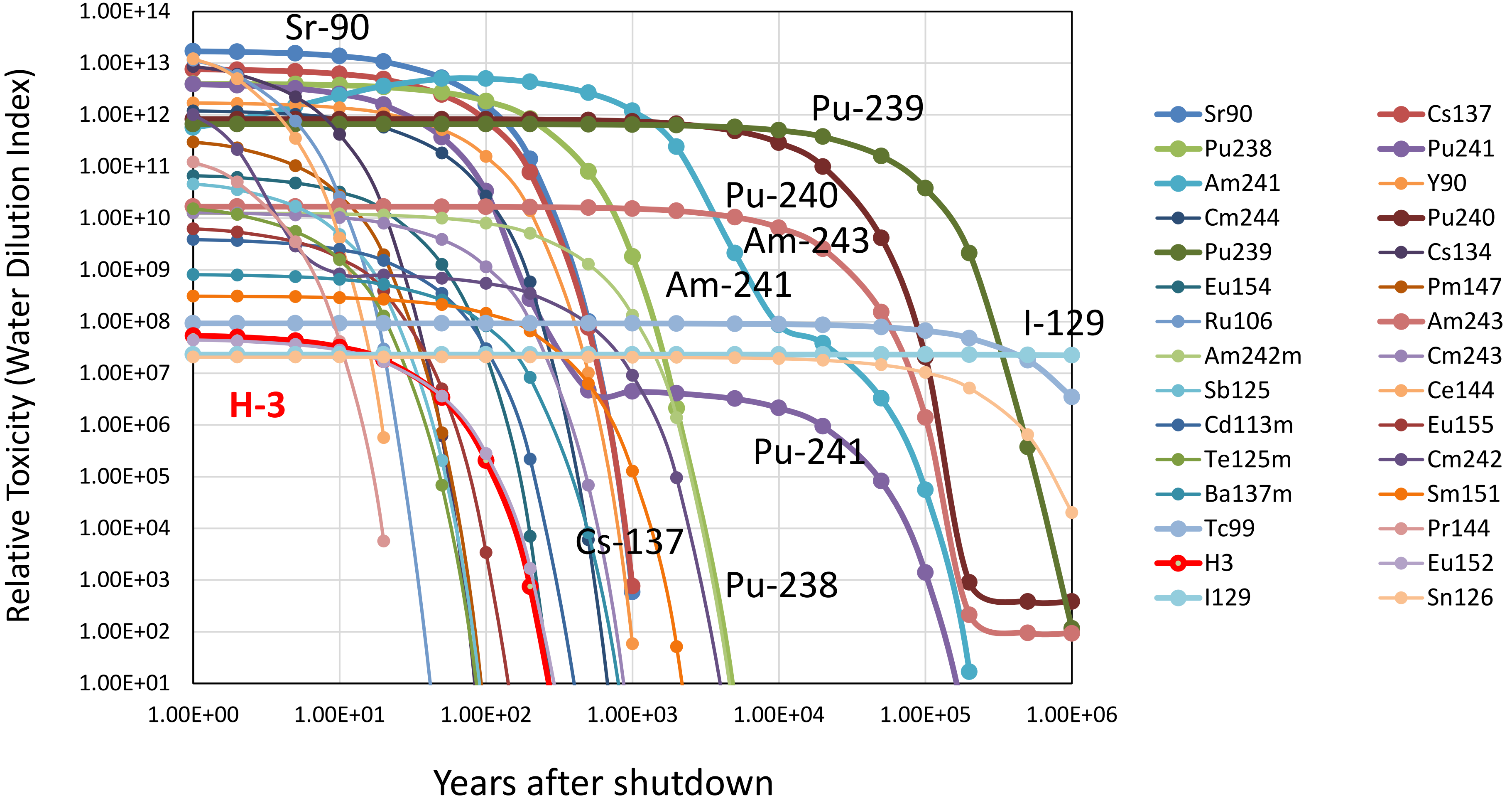
- In addition to "reliably" operate a series of plans including system operation, analysis of ALPS-treated water, maintenance and response measures in the event of trouble, TEPCO must review and expand the plans as needed and ensure its transparency.

✓ It is necessary to reassess radiation impacts on human and environment based on the nuclides to be analyzed, and disseminate the assessment results with high transparency.

✓ IAEA conducted a safety review on the handling of ALPS-treated water in February 2022.

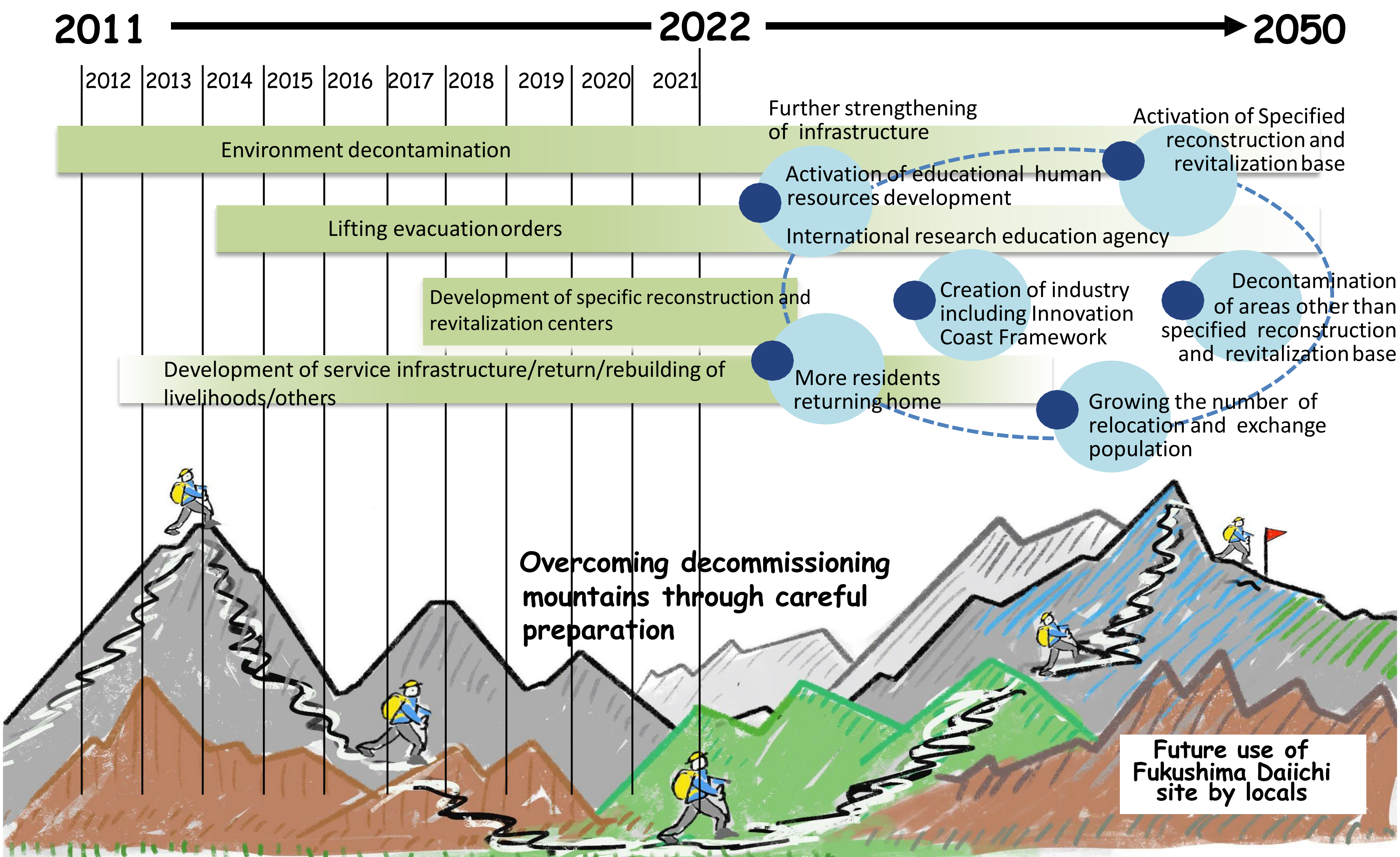
✓ The Japanese government plans to commission the JAEA to conduct third-party analyses before the discharge. The results of these analyses will be disseminated domestically and internationally with high transparency.

Position of H-3 in the Toxicity Management



Arranged from JAEA-Data/Code 2012-018 (K. Nishihara et al.)

Conclusion-1　The Way Forward



Conclusion-2　Trend of Technical Paper Publication

Analyzed with SCOPUS