JAEA R&D Efforts for Decommissioning of the Fukushima Daiichi NPS

International Topical Workshop on
Fukushima Decommissioning Research 2022
&
The First 2022 Fukushima Research Conference
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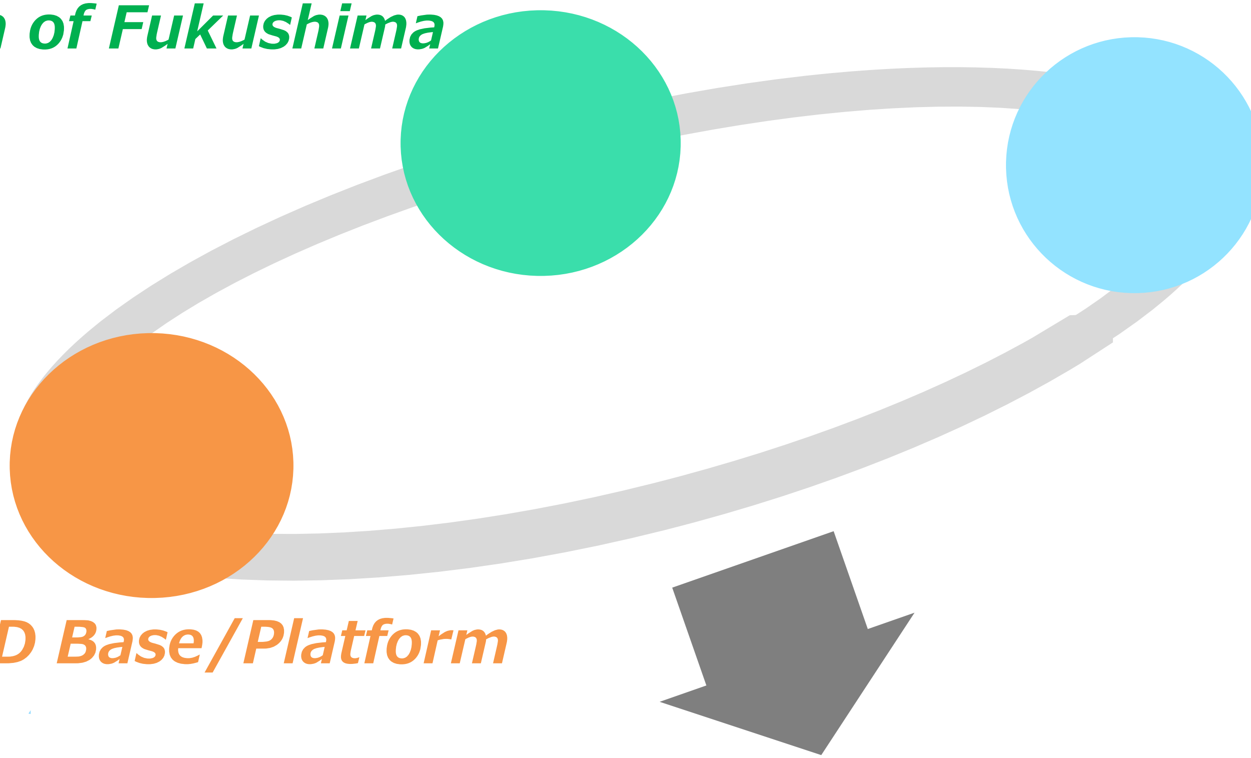
未来へげんき
To the Future / JAEA

1. Introduction

Mission: Three core pillars

R&D for Environmental Restoration of Fukushima

R&D for Decommissioning



Building R&D Base/Platform
- facilities
- human networks etc.

Contributing to Fukushima Revitalization

- Collaboration with local stakeholders
- Working with local industry
- Human resource development

Organization Chart

- Sector of Fukushima R&D
  - Planning and Co-ordination Office
  - Fukushima Research Institute
    - Safety Administration Department
    - Fukushima Administrative Department
    - Collaborative Laboratories for Advanced Decommissioning Science (CLADS)
    - Naraha Center for Remote Control Technology Development (NARREC)
    - Okuma Analysis and Research Center

History

Mar.2011

- Great East Japan Earthquake
- **Fukushima Daiichi NPS (1F) Accident**

2011

- JAEA started supports for environmental monitoring, decontamination activities and the national and local governments immediately after the 1F accident
- "Headquarters of Fukushima Partnership Operations" was established
- "Fukushima Office" opened


Environment monitoring


Decontamination


Internal exposure test


Information session for public

Dec.2011

- Mid-and-Long-Term Roadmap was established

2013

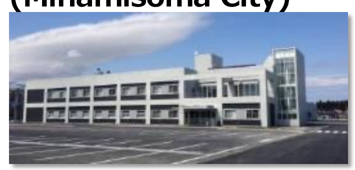
- "Nuclear Plant Decommissioning Safety Research Establishment" was established
- JAEA joins IRID

Apr.2014

- Reorganization as **"Fukushima R&D Sector"**

2015

- Iwaki Office opened
- **Fukushima CEC started research activities (Minamisoma City)**



2016

- **NARREC launched (Naraha town)**

- **Fukushima CEC started research activities (Miharu Town)**

2017

- **CLADS' "International Collaborative Research Building" launched**

2018

Okuma Analysis and Research Center launched (Okuma town)

- **"Administrative Building"**

2020

- Decommissioning research units and environmental restoration units were integrated as a new "CLADS"

2022

- **"Laboratory-1"**

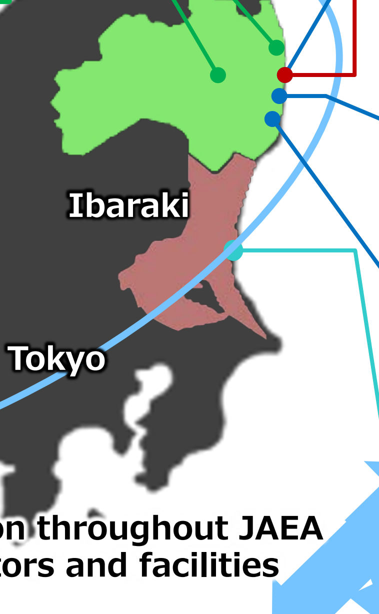
R&D sites/facilities for Fukushima R&D

R&D for environment restoration

CLADS at Fukushima CEC* (2 sites)

- Environmental dynamics research
- Environmental monitoring

*Fukushima CEC : Fukushima prefectural Centre for Environmental Creation



Fukushima Daiichi Nuclear Power Station

R&D for decommissioning

Okuma Analysis and Research Center

- Development of analytical methods
- Characterization of radioactive waste and fuel debris

CLADS

- Headquarter of JAEA's Fukushima R&D
- Severe accident analysis
- Waste management
- Remote visualization

NARREC

- Mock-up test and training
- Robot simulator
- Virtual reality system

Other JAEA sectors/centers

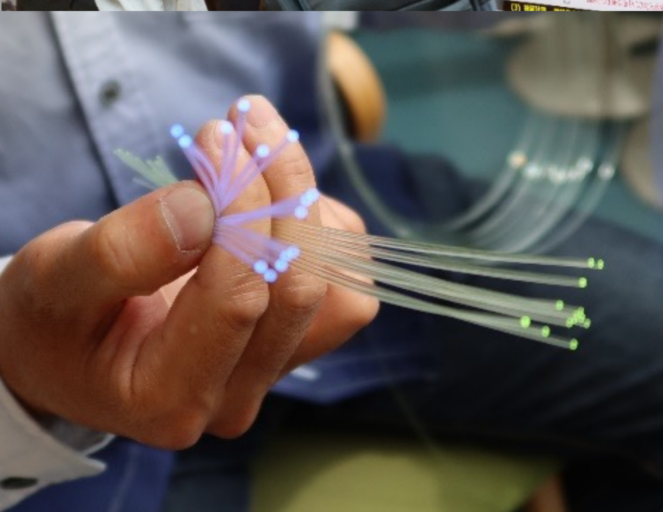
- Sector of Tsuruga Decommissioning Demonstration
- Aomori Research and Development Center
- Materials Sciences Research Center

Ibaraki area (Tokai and Oarai)

- Nuclear Science Research Institute
- Nuclear Fuel Cycle Engineering Laboratories
- Oarai Research and Development Institute

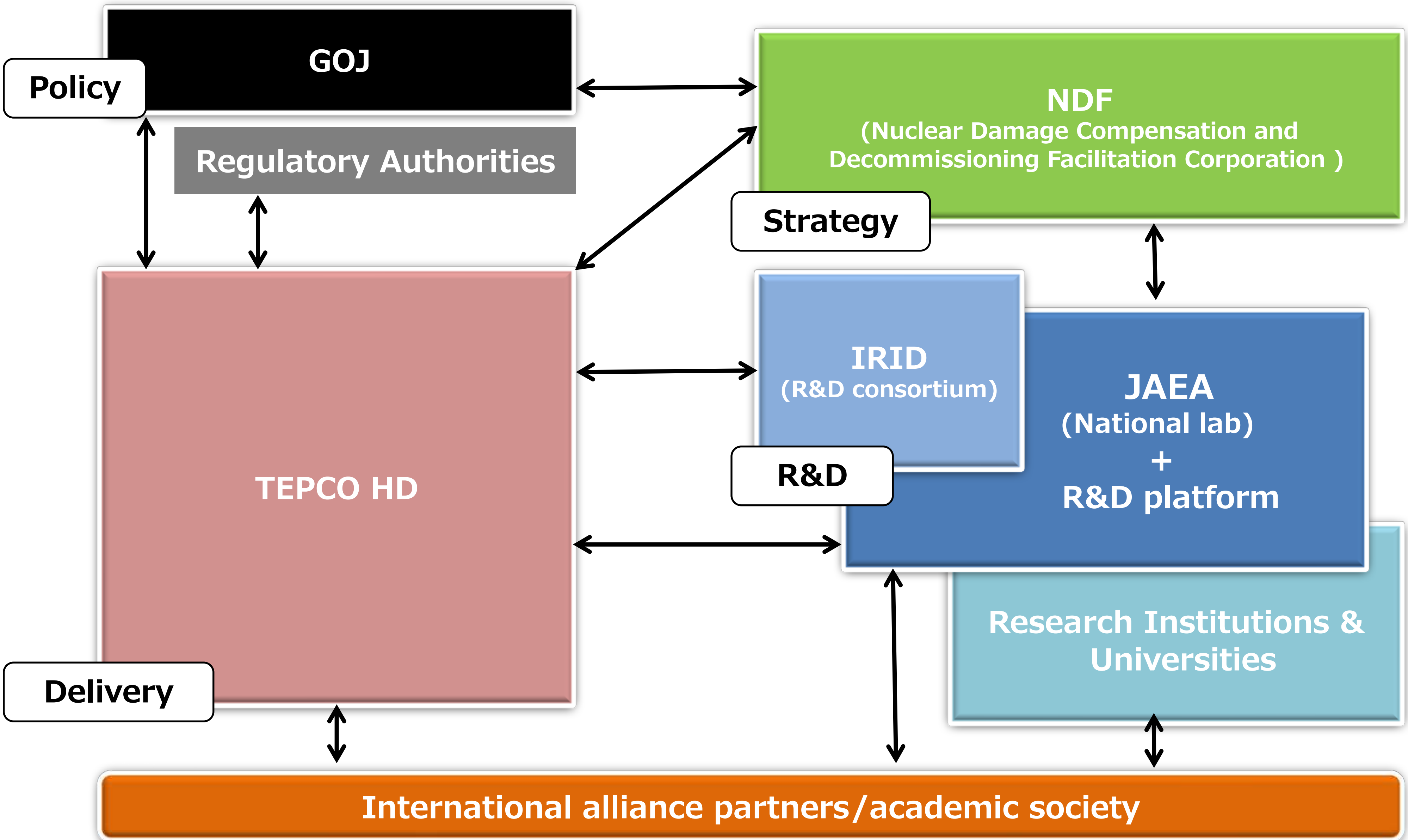
2. JAEA Roles for Decommissioning R&D



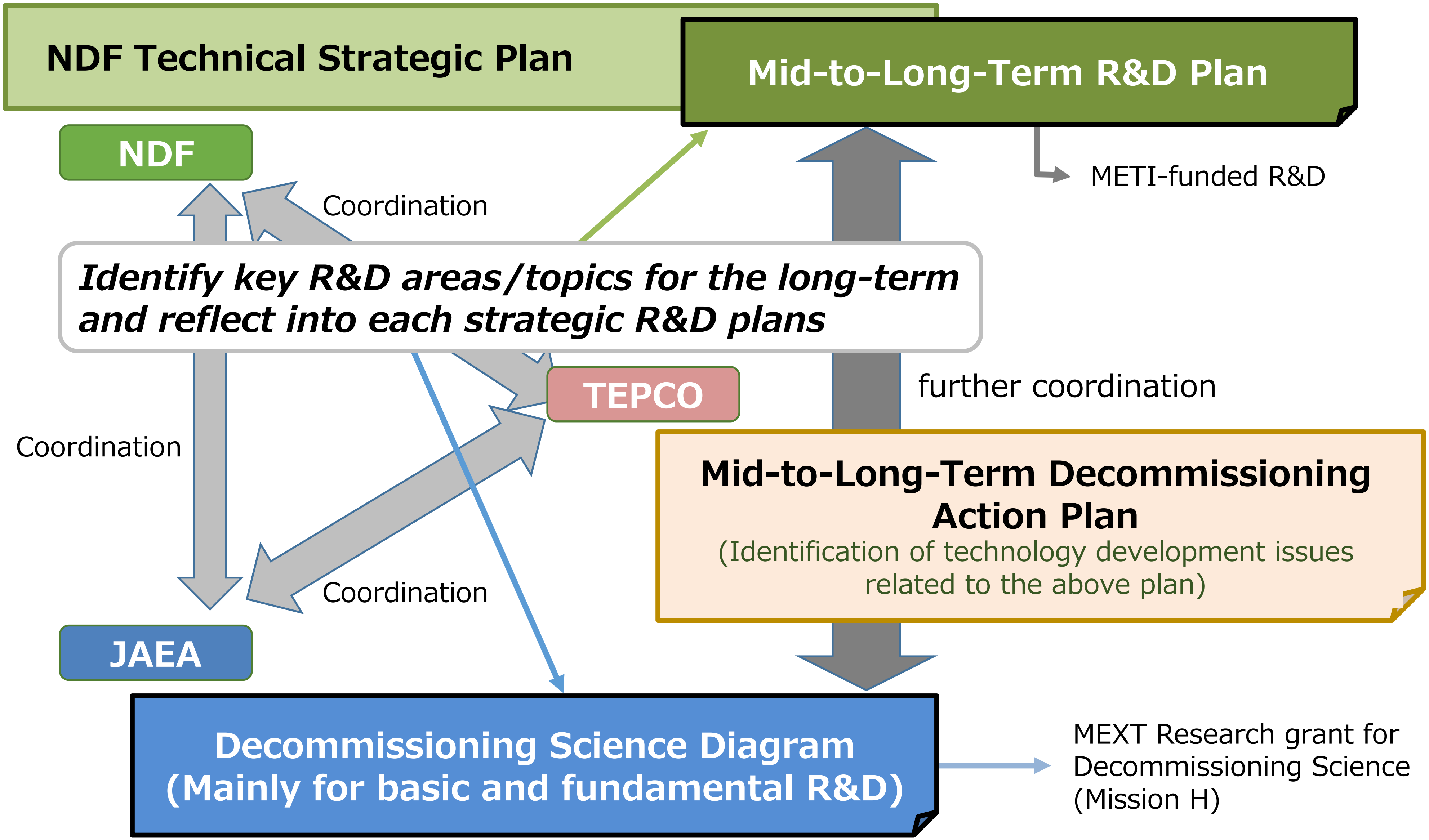




Y. Sato et. al., J. Nucl. Sci. Technol. 2019; 56: 801–808.

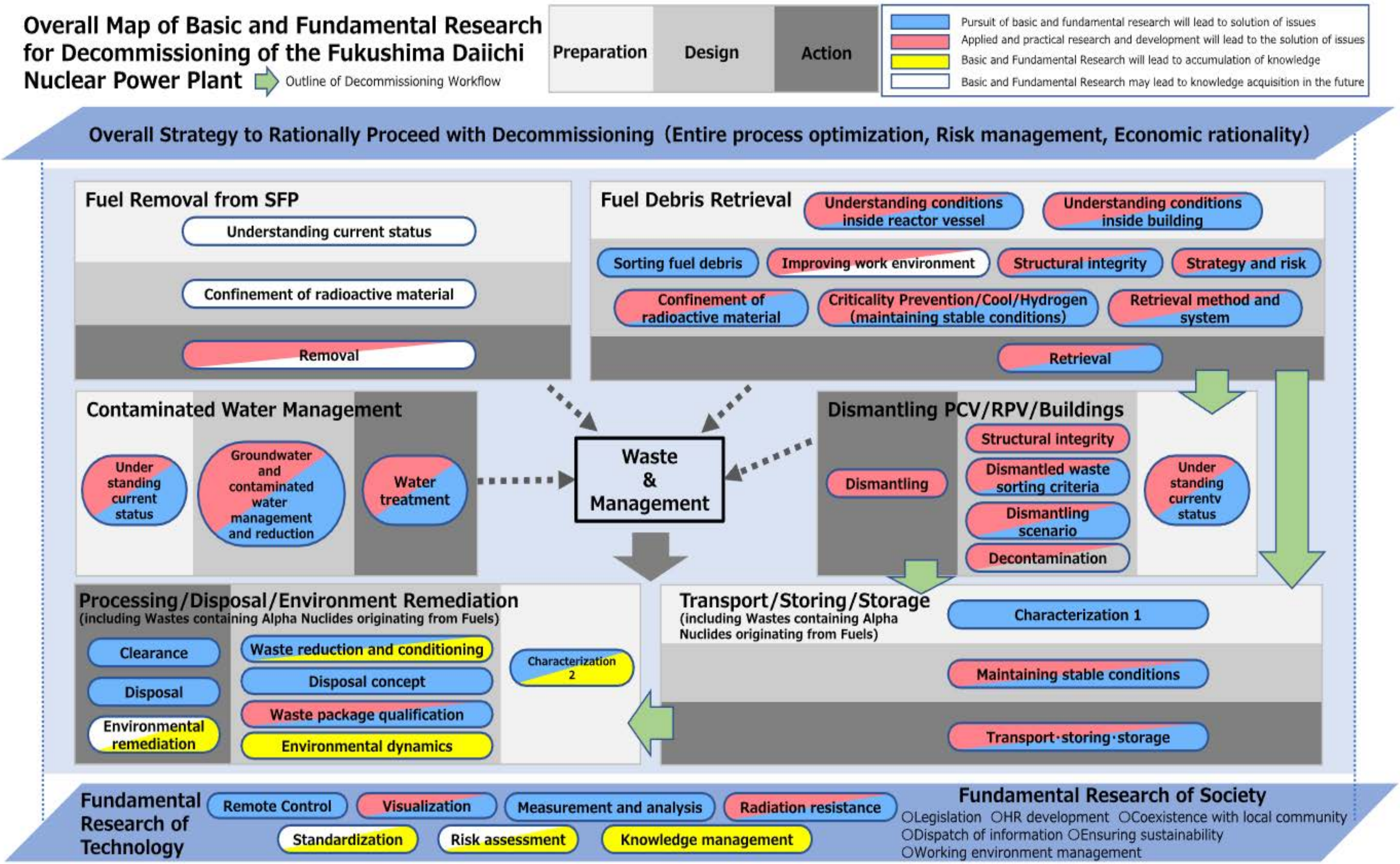

Organizations involved in decommissioning R&D



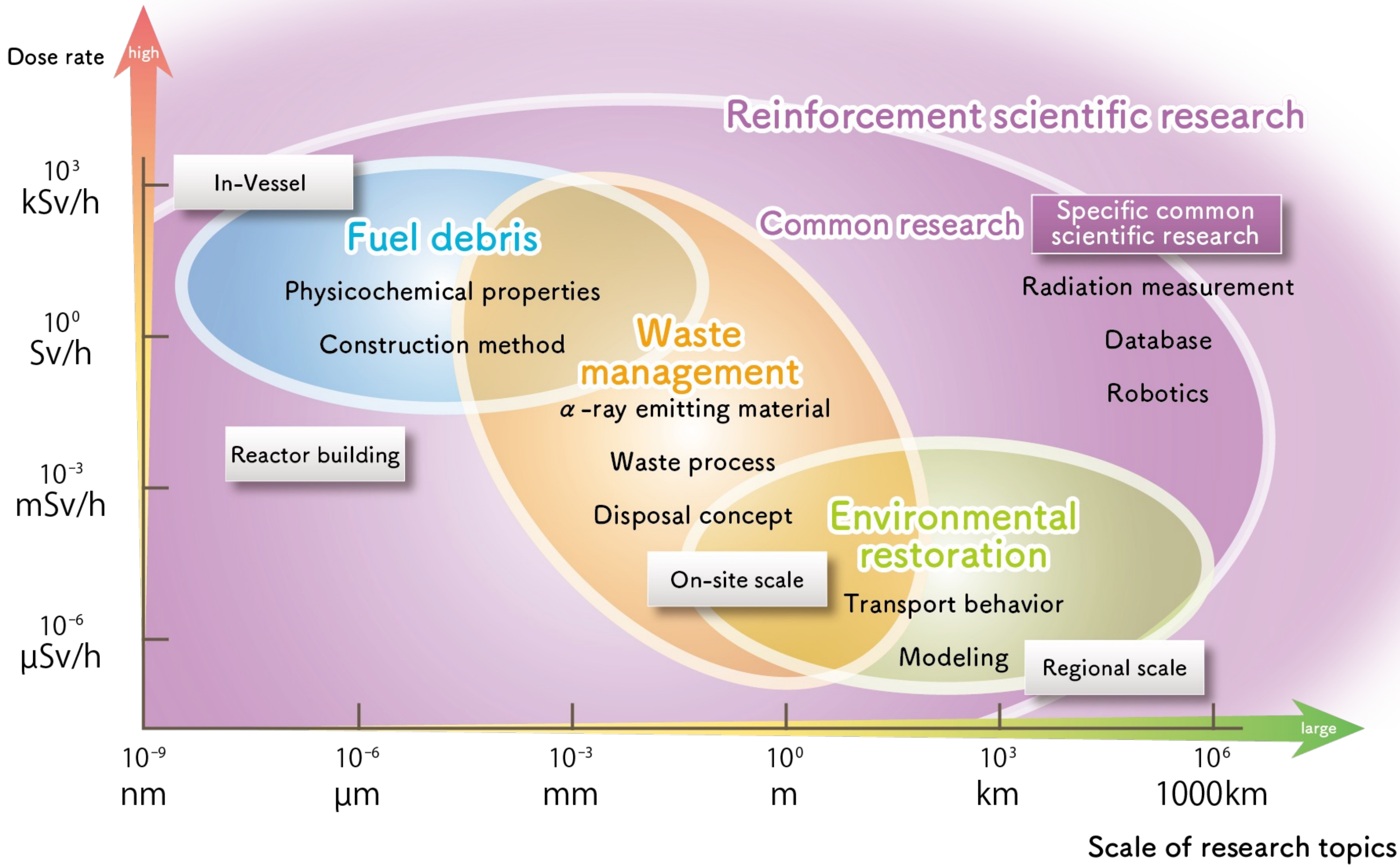
Mid-to-long-term R&D plans
Interrelation of strategic documents for decommissioning R&D



Decommissioning Science Diagram
mainly for basic and fundamental R&D



R&D scope of JAEA/CLADS



Remaining challenges and R&D needs

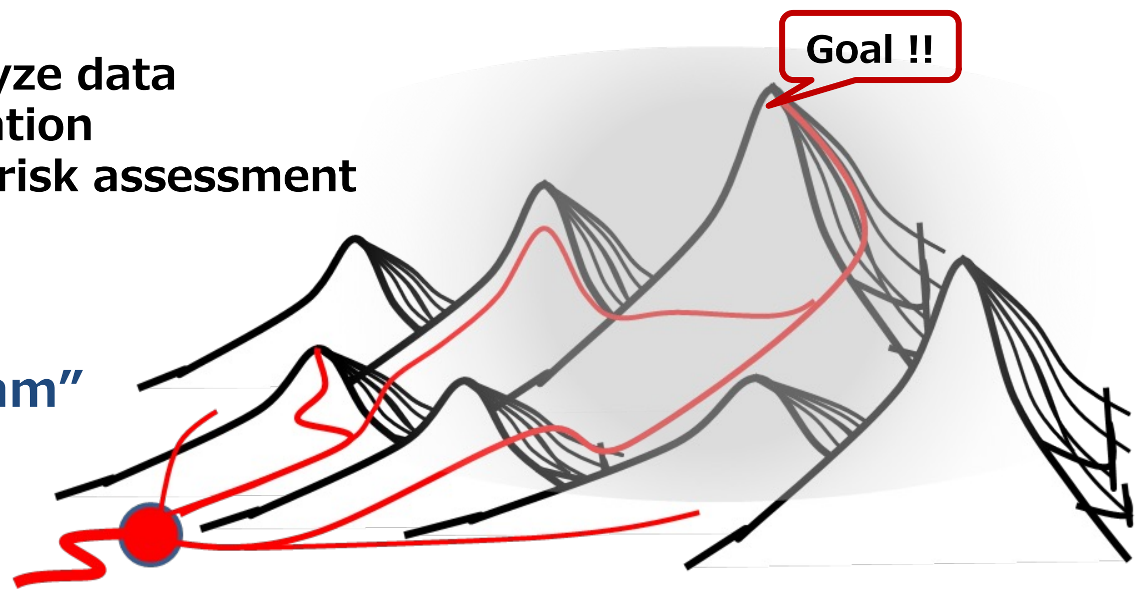
At the Fukushima Daiichi site, some progress has been made, ⋯⋯
But, there remain unpresedended challenges ahead for the long run.

- ✓ A large amount of radioactive materials, remaining unsealed and unknown
- ✓ Incomplete barriers for containment
- ✓ Uncertainties on the state of radioactive materials and containment barriers
- ✓ Difficulty in an access

(Source: NDF Technical Strategic Plan 2021)

R&D Needs

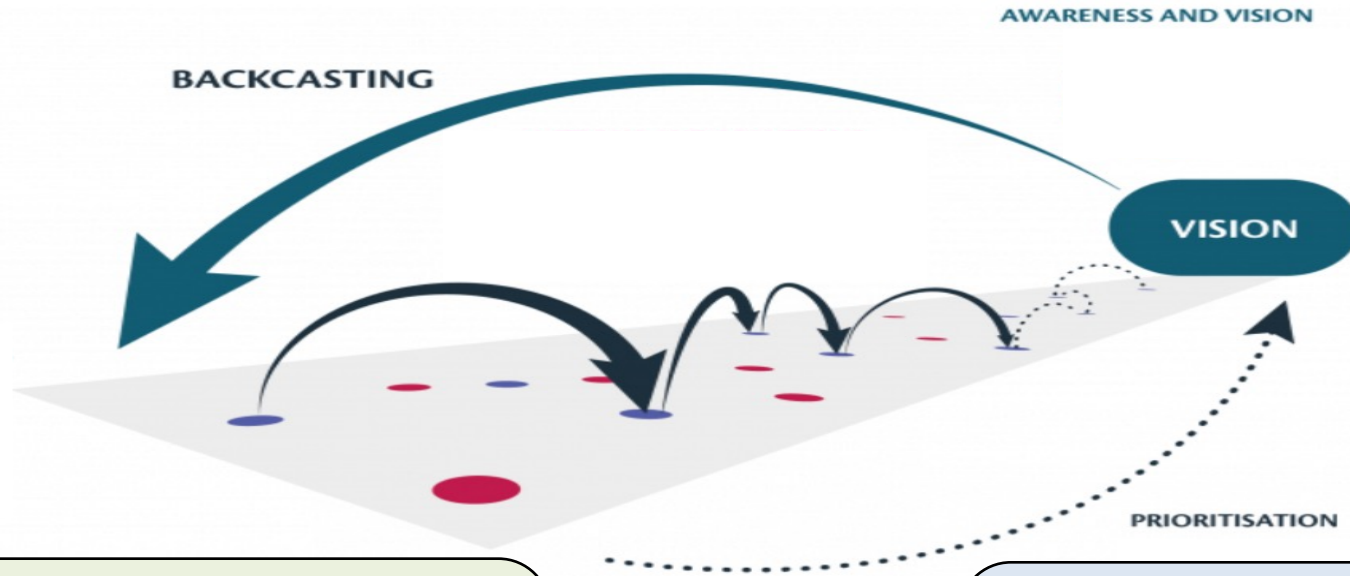
- ➢ **Collect, consolidate, and analyze data**
- ➢ **Characterization and visualization**
- ➢ **Methodologies for safety and risk assessment**



"Sherpa guide" for
"the mountain climbing team"

:

Backcasting approaches



Baseline analysis

What we have achieved during the past years ?
(e.g. R&D outputs/outcomes)

Future vision

What we need to achieve by around 2030 ?
(e.g. our mid-term goal)

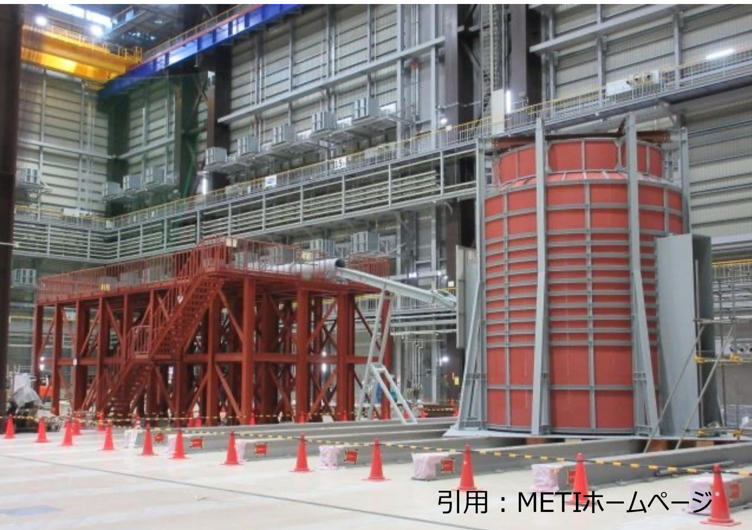
Forecasting

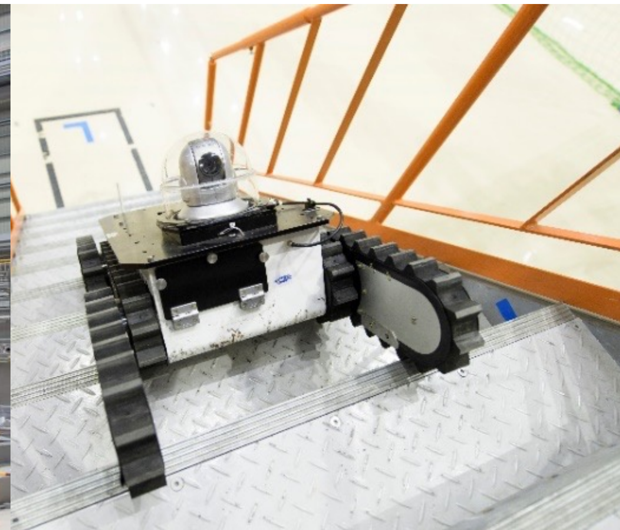
Backcasting

Prioritization of actions and solutions

Priority R&D issues/topics for the upcoming years
(e.g. "JAEA mid-to-term R&D plan for FY2022-2028")

3. Fuel Debris Retrieval R&D


引用：METIホームページ



Fuel Debris Retrieval R&D

■ Near-term goal: launch the first retrieval operations from Unit 2

Actions/solutions

Backcasting

■ 2030 vision: ideal state (to be discussed further)

1. Trial fuel debris retrieval from Unit 2 progressed, and larger-scale retrieval from Unit 3 nearly ready.
2. Fuel debris analysis (incl. non-destructive methods) becomes well ready
3. Methodologies for safety and risk management established

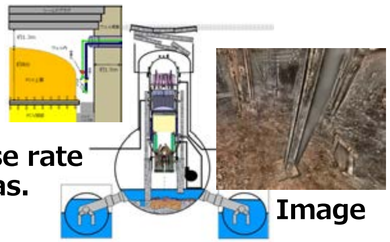
■ JAEA R&D focuses/priorities

- ☐ Estimation of PCV internal condition and fuel debris characterization
- ☐ Safety/risk assessment for fuel debris retrieval operation
- ☐ Analysis of fuel debris

Fuel Debris Retrieval R&D
Preparation for launching fuel debris retrieval and R&D needs

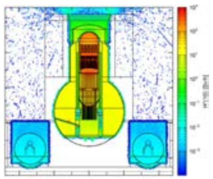
Year	~2022	2023~

Internal investigation, Estimation of core status, Development of analysis methods



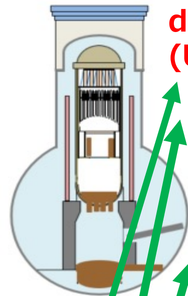
Dose rate Meas.

Image



Dose rate estimation

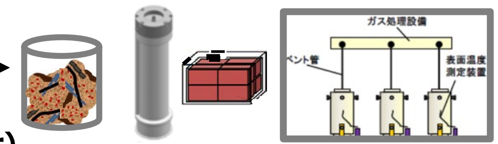
1F sample (Sediment etc.)



Start fuel debris retrieval (Unit 2)

Expand the scale of retrieval gradually (Unit 2)

(~g order)



(~kg order) (Total ~880t)

Temporary storage →Long-term stable storage

METI-funded R&D project (subsidy for research institutions) for decommissioning and contaminated water management

- Mainly for initiating trial retrieval of fuel debris -

① Development of analysis and estimation technologies for characterization of Fuel Debris
② Development of technologies for enhanced analysis accuracy

JAEA basic and fundamental research (MEXT-funded)

- Mainly for safety and risk management from fuel debris retrieval, transfer to storage, with longer-term perspectives

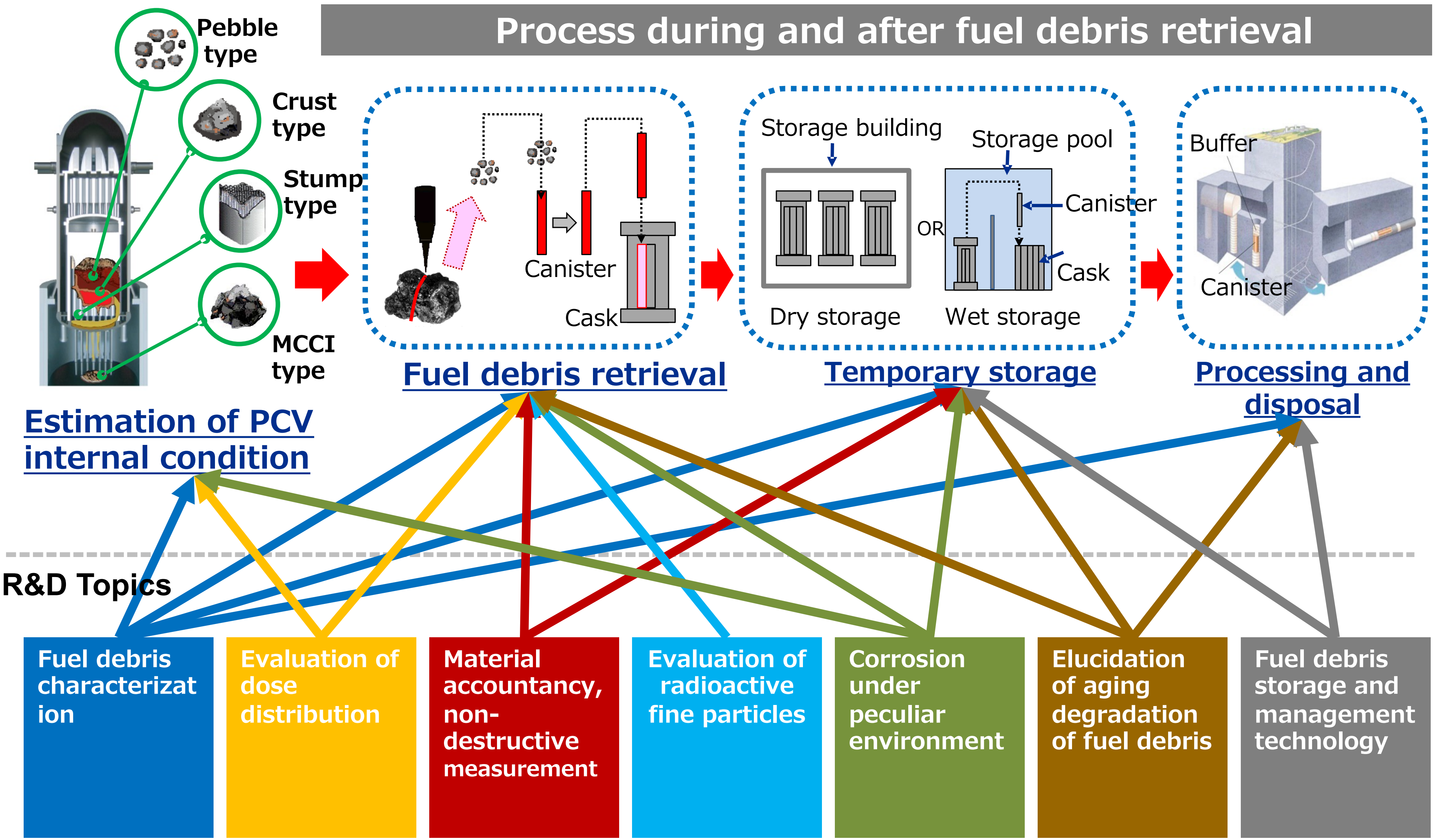
③ Evaluation of dose distribution
④ Material accountancy, non destructive measurement
⑤ Elucidation of aging degradation of fuel debris
⑥ Fuel debris storage and management technology
⑦ Corrosion under peculiar environment

R&D priorities for the mid-to-long-term

- Establishment of analysis and evaluation methods including non-detractive assay technology for fuel debris ranging from extremely small amounts to macroscopic amounts.
- Development of the sorting technology for fuel debris and radioactive materials
- Accumulation and organization of knowledge that contributes to understanding fuel debris characteristics (Generation mechanism, Aging degradation, Radioactive particle, etc.)
- Development of material accountancy measures
- Fuel debris storage and management technology (Evaluation of radiation effect, Radiolysis, H_2 production, Material corrosion, H_2 explosion , etc.)
- Safety assessment for disposal (H_2 production, Corrosion, Aging, Exothermic property, Long-term stability, etc.)

Fuel Debris Retrieval R&D

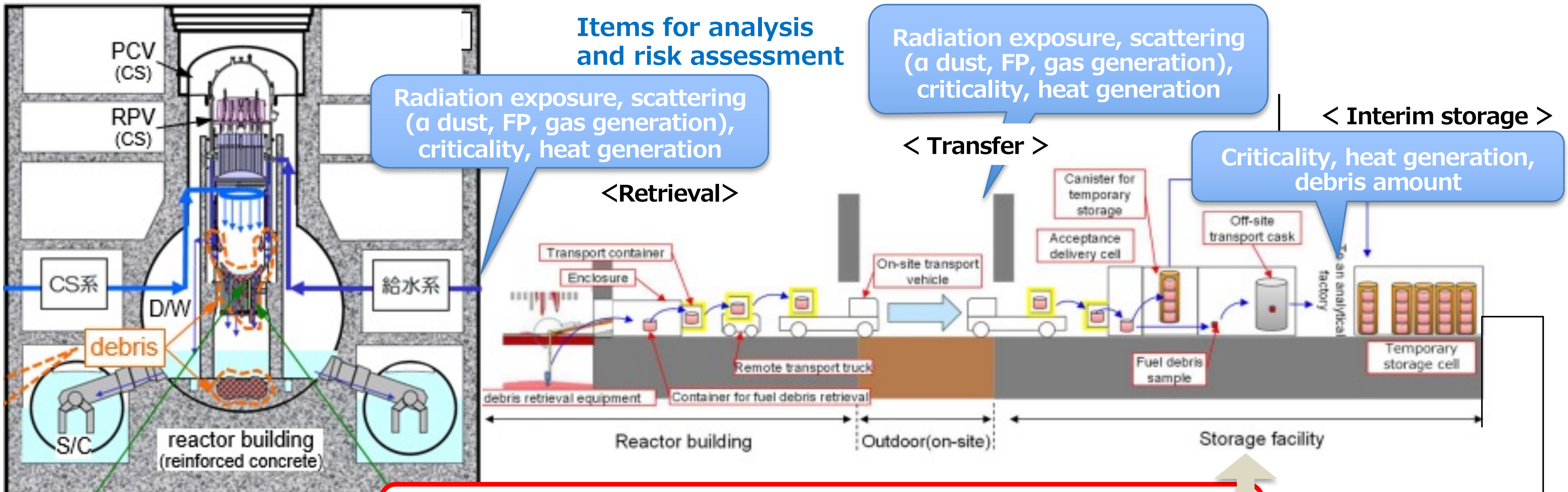
Preparation for launching fuel debris retrieval operations



Fuel Debris Retrieval R&D

Ensure safety during a series of fuel debris retrieval operation

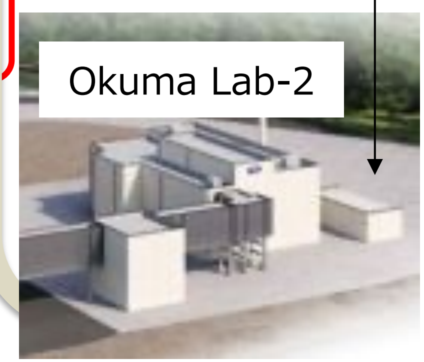
2030 vision ①a : the first/trial fuel debris retrieval from Unit 2 is progressed, so that safety / risk assessment methodologies of a series of fuel debris management operation are established



2030 vision ②: analysis/evaluation methods including non-detractive assay technologies are established

Key R&D priorities

- ☐ Estimate PCV internal condition and fuel debris characterization
- ☐ Examine safety/risk assessment for fuel debris retrieval operation
- ☐ Improve/update analysis capability and standardization
  - ✓ Build/upgrade sample analysis facilities
  - ✓ Develop non-distractive measurement technologies

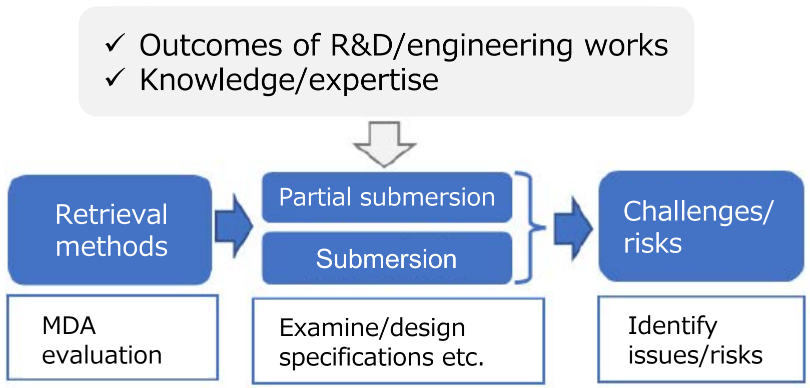


<Analysis>

Fuel Debris Retrieval R&D

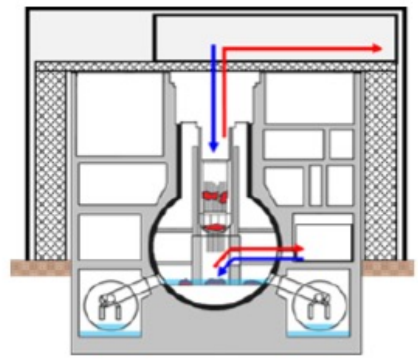
Ensure safety during a series of fuel debris retrieval operation

2030 vision ①b : larger-scale fuel debris retrieval from Unit 3 can become ready, as result of selecting and planning retrieval methods/approaches including access and containment

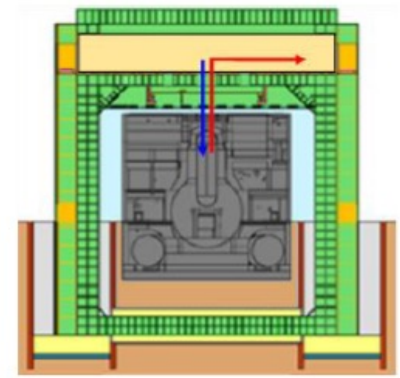


A flow of selecting retrieval methods

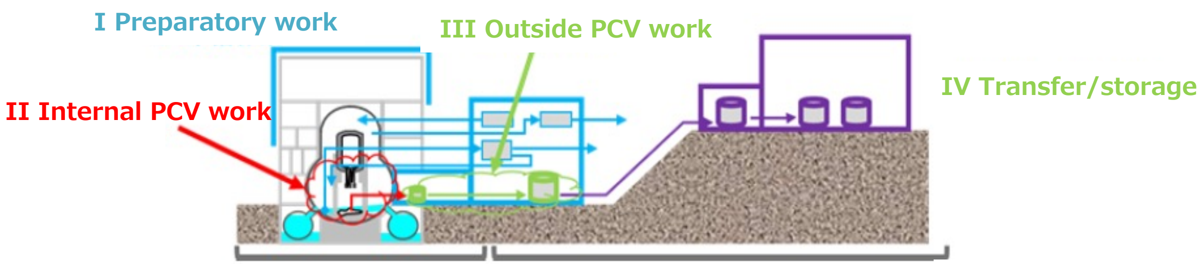
(Source: NDF Technical Strategic Plan 2022)



A partial submersion method
(Combination of top-entry and side entry accesses)



A submersion method
(Hull structure design)



Fuel debris retrieval work flow

2030 vision ③: safety/risk assessment methods of fuel debris during the retrieval, transfer and storage are established

Key R&D priorities

- **Estimate PCV internal condition and fuel debris characterization**
- **Establish methodologies for safety/risk assessment for fuel debris retrieval operation**
  - ✓ **Access to internal PCV**
  - ✓ **reducing radiation dose/ exposure**

Fuel Debris Retrieval R&D

Estimation of PCV Internal Condition and Fuel Debris Characterization

Fuel debris retrieval (First trial at Unit 2)

Fuel debris retrieval (Expansion of scale)

Estimate PCV internal condition and fuel debris

Improve work environment and reduce dose

Radiological and material analysis

Consolidate data to evaluate safety and risk

Actions/solutions

Backcasting

■ 2030 vision: ideal state (to be discussed further)

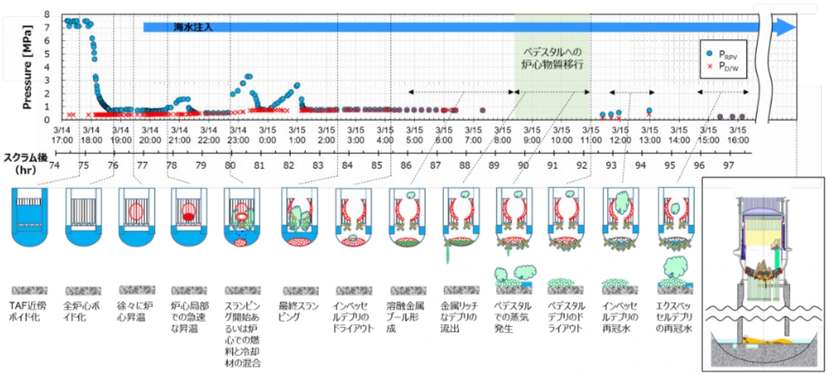
1. **The first/trial fuel debris retrieval from Unit 2 progressed, and larger-scale retrieval from Unit 3 nearly ready.**
2. **Fuel debris analysis (incl. non-destructive methods) becomes well ready**
3. **Methodologies for safety and risk management established**

JAEA R&D focuses/priorities

- **Estimation of PCV internal condition**
  - ➡ Unit 2
  - ➡ Unit 3
  - ➡ Unit 1
- **Fuel debris characterization**
  - ➡ Experimental approaches with simulated debris
  - ➡ Uranium-bearing particle analysis

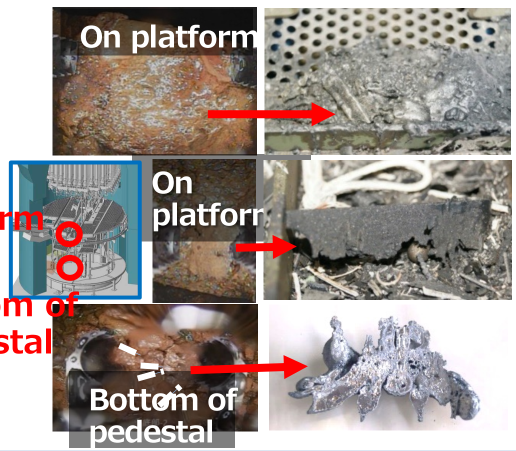
Estimation of PCV Internal Condition
Unit 2

・Most of the fuel debris is sedimented in the lower part of the pressure vessel.
・The fallen fuel debris is metallic and is deposited relatively thinly in the pedestal.
・Molten Core Concrete Interaction (MCCI) has rarely occurred.



【 Understanding the fuel collapse phenomenon 】
・Molten fuel collapses into the cooling water, and once cooled and solidified
・Many particulate debris (easily oxidized and dispersed, and easily air cooled)
・Re-melted (1000-1300°C) by decay heat, locally damaging RPV and falling

Relation between plant conditions resulting from the accident progression and subsequent condition changes.



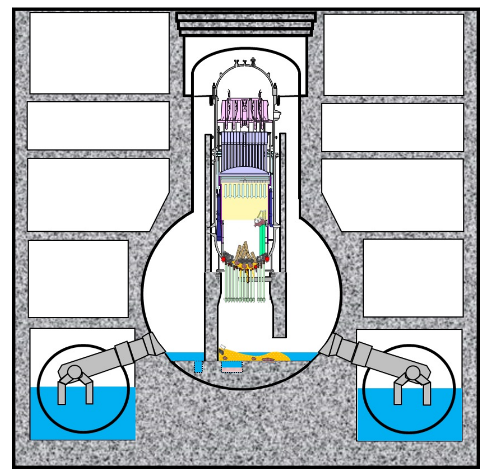
Molten and solidified metallic debris blockage (Stone-like accumulates)

Relocated pats of a control blade and the other assembly parts

Relocated and solidified metallic debris (Solidified molten material)

Understanding the formation process and characteristics of fuel debris through large scale simulation tests

Unit 2 containment vessel sediments and simulated products

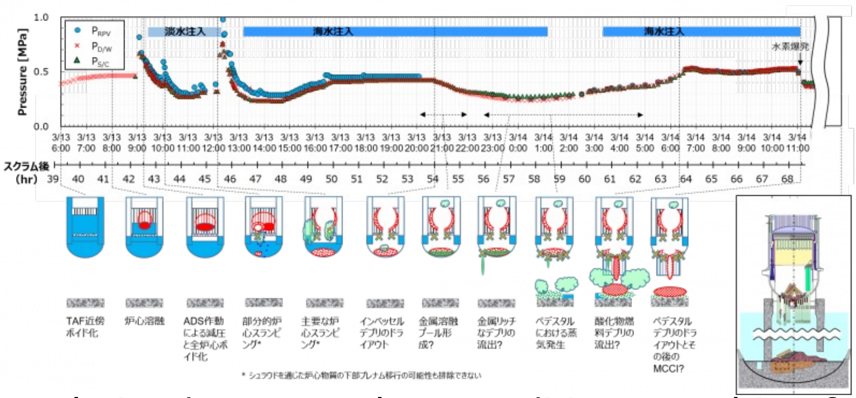


Estimated internal PCV condition

Estimation of PCV Internal Condition

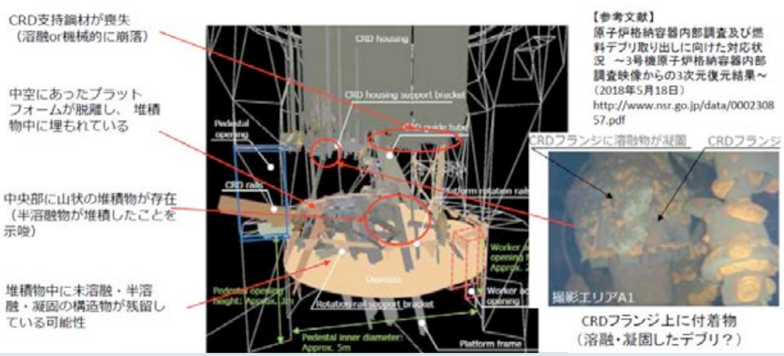
Unit 3

・Some fuel debris may remain in the lower part of the pressure vessel.
・Fallen fuel debris is sedimented on the pedestal in a complex state due to complicated solidification from the solid-liquid state and entrapment of structural materials.
・MCCI has rarely occurred.



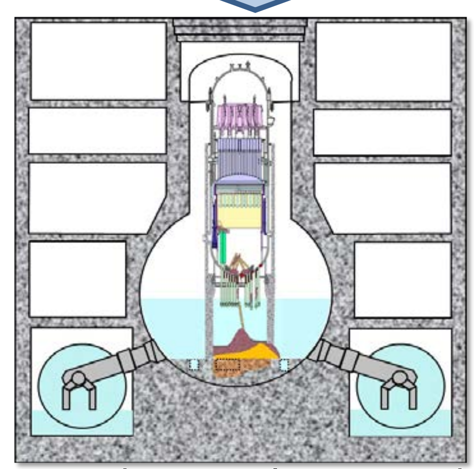
【 Understanding the fuel collapse phenomenon 】
・Molten fuel collapses into the cooling water, and once cooled and solidified
・Many lumpy debris (difficult to oxidize and disperse, difficult to air cool)
・Re-melted (2000-2300°C) by decay heat, and fell over several hours in a highly viscous state

Relation between plant conditions resulting from the accident progression and subsequent condition changes.



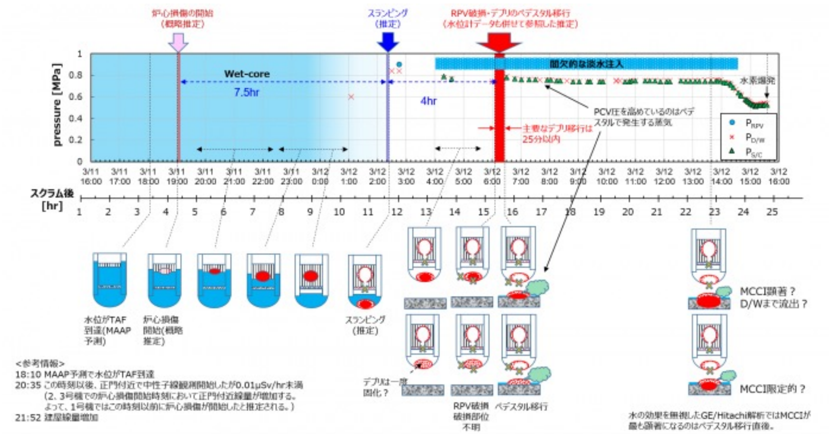
Estimated to be under sediment. Observe central heave and residual structural material.
⇒ Viscous collapses over several hours

Internal investigation result



Estimated internal PCV condition

・Almost no fuel debris estimated in pressure vessel
・Fallen fuel debris is spread inside and outside the pedestal and sedimented in a complex.



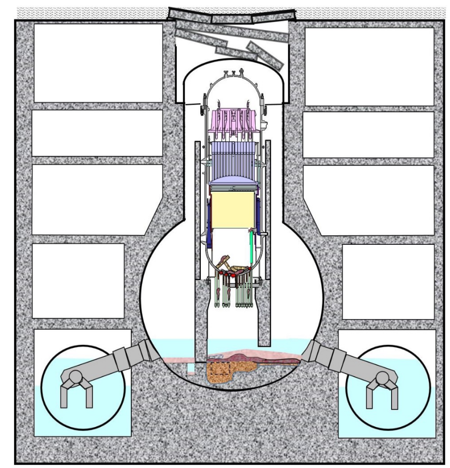
【 Understanding the fuel collapse phenomenon 】
・ Data at the time of the accident is scarce, and adequate evaluation has not progressed.

Relation between plant conditions resulting from the accident progression and subsequent condition changes.

Quite different from conventional expectations

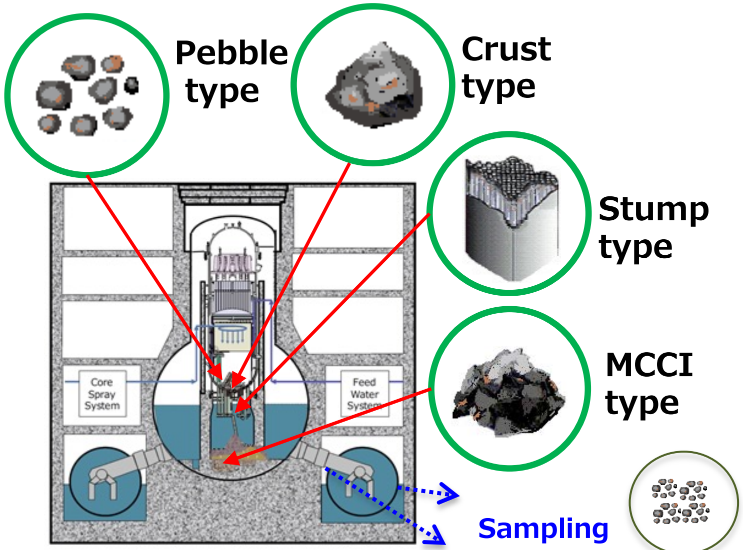
Internal investigation result

Future work



Estimated internal PCV condition

Fuel Debris Characterization
Debris characterization data and knowledge-base



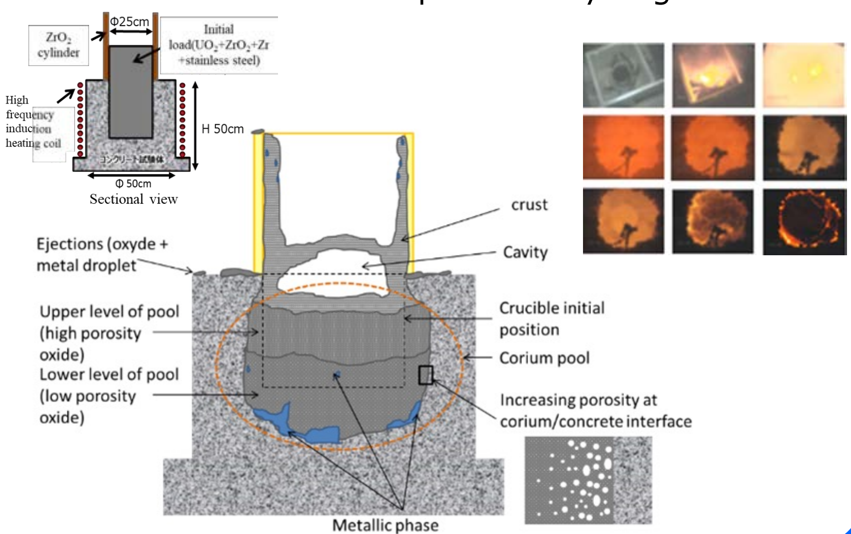
Estimation of core status
(Figure of debris' location)

Micro sample
(Sediments, smear, etc.)

Knowledge-base of fuel debris characterization (samples obtained from 1F internal investigation)

- Collaboration with analytical organization (hot laboratory) responsible for fuel debris analysis.
- Discussion by hot lab researchers and engineers with TEPCO HD experts.

Characterization of MCCI products by large-scale test



Characteristics list

The knowledge obtained through tests using simulated fuel debris and the development of analysis technology is summarized in a characteristic list with literature.

Category Materials/Phases	Density (g/cm3)	Vickers hardness (GPa)	Elastic modulus (GPa)	Fracture toughness (MPa・m1/2)	Thermal conductivity (W/mK)	Specific heat (J/g・K)	Melting point (oC)	Behaviour at high temperature	Stability
Oxide									
UO_2	11	6	190	2	10	0.3	2850		oxygen existing, and it causes volume change, makes powders
ZrO_2-T	6	11	200	10	1 – 3	0.6	(tr.)		
$(U,Zr)O_2$-C	6 – 11	6 – 18	140 – 220	3	1 – 10	0.3 – 0.6	2500 – 2850		
$(Zr,U)O_2$-T	6	6 – 18	150 – 200	8	1 – 3	0.5 – 0.6	(tr.)		
SiO_2	2 – 3	4 – 17	100	1	1	1.3	1710		
Al-Ca-Si-O	2 – 3	4 – 12	40 – 80	1	1	0.8	1600 – 1700		
Cr_2O_3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2400		
Fe_3O_4	5	7	[illegible]	2	20	0.8	1597		
$(Zr,U)SO_4$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
$UO_4 \cdot 4H_2O$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	(d.)		
Metal									
Zry-2	7	1 – 3	60 – 110	15	23	0.3	1850		There are explosion cases of Zr fine
α-Zr(O)	7	2 – 11	120 – 210	3 – 5	23	0.3	1580 – 2130		
SUS/Fe	8	1 – 10	190 – 200	200	80	0.4	1075 – 1535		
$Fe_2(Zr,U)$	7 – 8	7 – 9	160 – 200	3	80	0.4	1500		
Others									
B_4C	[illegible]	[illegible]	450	[illegible]	[illegible]	[illegible]	2450		
ZrB_2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Fe_2B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

1) Characteristic table for micro
-Characterisation of debris from microscopic point of view
(Mainly, properties of single-phase material)

2) Characteristic table for macro
-Characterization of debris from macroscopic point of view
(Mainly, features of multi-phases material/mixture)

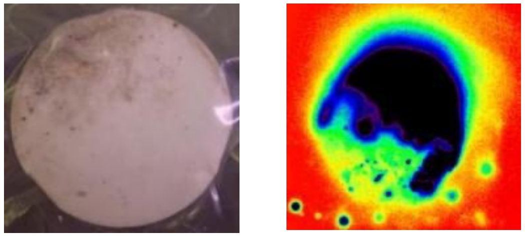
These were summarised & shared as basic information to discuss and evaluate fuel debris characterization and core status.

Analysis technology and characterization(samples obtained from 1F internal investigation)

Demonstrate a sequence of procedures for unknown particles containing uranium, including sample collection, transportation, selection of analytical methods, sample pretreatment, analysis, and evaluation. Preparations for the analysis of fuel debris for the trial retrieval of fuel debris and subsequent expansion of the scale have been reliably advanced. The results will be reflected in the analysis techniques for the Okuma Lab. 2.

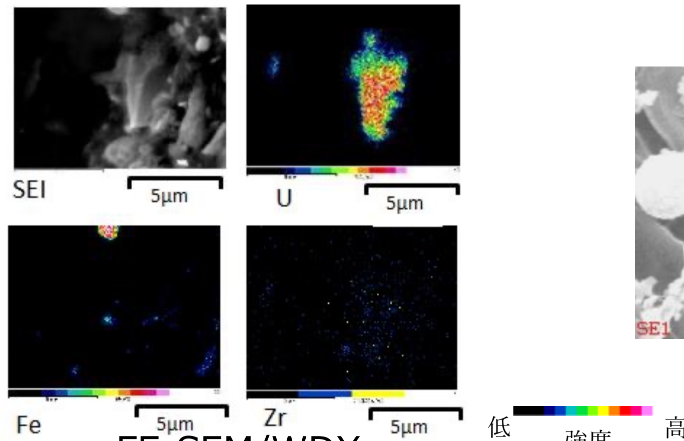
Well plug smear of Unit1

○Outer appearance and dose distribution

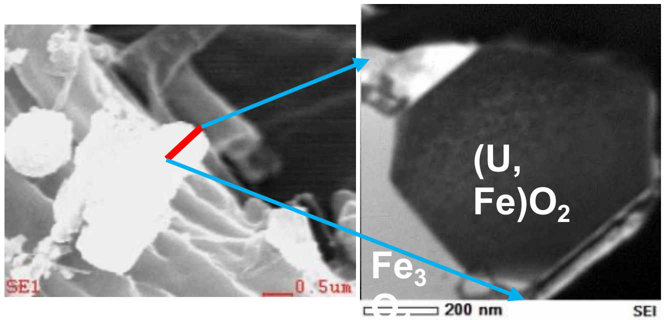


Outer appearance and IP

○Analysis result



FE-SEM/WDX



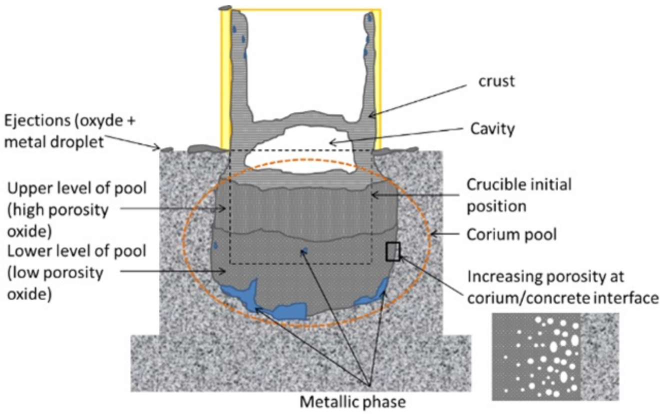
SEM/EDX

TEM

- Analysis results are integrated into debrisWiki and disclosed as a database.
- Utilized for estimation of knowledge such as chemical properties of fuel debris and estimation of accident progression scenarios.
- Provide the results to the international community through the OECD/NEA international project and utilize them for joint analysis by participating countries.

Integration of knowledge and data

Systematic and multilayered compilation of findings

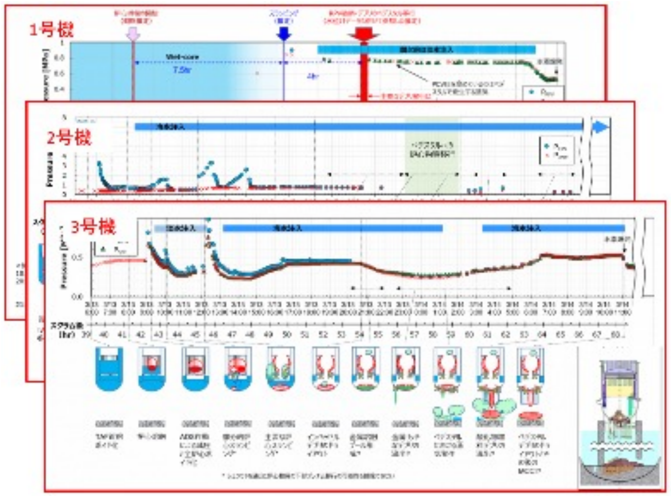


Characterization of MCCI products

Category Materials/Phases	Density (g/cm3)	Vickers hardness (GPa)	Elastic modulus (GPa)	Fracture toughness (MPa･m1/2)	Thermal conductivity (W/mK)	Specific heat (J/g･K)	Melting point (oC)	Behaviour at high temperature	Stability
Oxide									
UO_2	11	6	190	2	10	0.3	2850		oxygen existing, and it causes volume change, makes powders
ZrO_2-T	6	11	200	10	1 – 3	0.6	(tr.)		
$(U,Zr)O_2$-C	6 – 11	6 – 18	140 – 220	3	1 – 10	0.3 – 0.6	2500 – 2850		
$(Zr,U)O_2$-T	6	6 – 18	150 – 200	8	1 – 3	0.5 – 0.6	(tr.)		
SiO_2	2 – 3	4 – 17	100	1	1	1.3	1710		
Al-Ca-Si-O	2 – 3	4 – 12	40 – 80	1	1	0.8	1600 – 1700		
Cr_2O_3	5	22 – 29	100 – 240	1	10 – 33	0.8	2400		
Fe_3O_4	5	7	20 – 110	2	20	0.8	1597		
$(Zr,U)SO_4$	4 – 9	8 – 11	20 – 110	2	6	0.5 – 0.8	(d.)		
$UO_4 \cdot 4H_2O$	4	0 – 1	30 – 50	1	1 – 10	0.4	(d.)		
Metal									
Zry-2	7	1 – 3	60 – 110	15	23	0.3	1850		There are explosion cases of Zr fine
α-Zr(O)	7	2 – 11	120 – 210	3 – 5	23	0.3	1580 – 2130		
SUS/Fe	8	1 – 10	190 – 200	200	80	0.4	1075 – 1535		
$Fe_2(Zr,U)$	7 – 8	7 – 9	160 – 200	3	80	0.4	1500		
Others									
B_4C	3	24	450	5	29	2.3	2450		
ZrB_2	6	19 – 22	440	10	24	0.7	3040		
Fe_2B	7	16	200	10	24	0.6	1389		

Characteristics list

debrisWiki



Most probable accident scenario

Fuel Debris Retrieval R&D

Safety/risk assessment for fuel debris retrieval operation

Fuel debris retrieval (First trial at Unit 2)

Fuel debris retrieval (Expansion of scale)

- Demonstrate equipment and operator training
- **Improve work environment and reduce dose**
- Radiological and material analysis
- **Consolidate data to evaluate safety and risk**

Backcasting

Actions/solutions

■ 2030 vision: ideal state (to be discussed further)

1. **The first/trial fuel debris retrieval from Unit 2 progressed, and larger-scale retrieval from Unit 3 nearly ready.**
2. **Fuel debris analysis (incl. non-destructive methods) becomes well ready**
3. **Methodologies for safety and risk management established**

JAEA R&D focuses/priorities

- **Safety/risk assessment methodologies and knowledge**
  - ➡ Radioactive particles/radiation effect
  - ➡ Hydrogen generation
  - ➡ Aging management
- **Reducing radiation dose/exposure**
  - ➡ Radiation measurement/visualization
  - ➡ Advanced radiation source evaluation

Fuel Debris Retrieval R&D

Safety/risk assessment for fuel debris retrieval operation

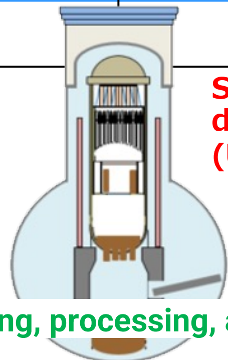
Year	～2022	2023～	2031～

Master plan

～2022:

PCV internal Investigation

Device design



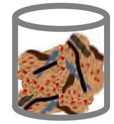
2023～:

Start fuel debris retrieval (Unit 2)

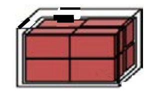
(~g order)

Analysis and Estimation →

(~kg order)
(Total ~880t)



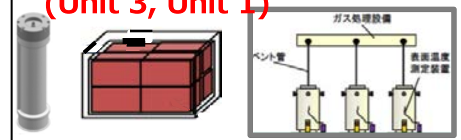
Expand the scale of retrieval gradually



α-contaminated waste by removal of obstacles, etc.

2031～:

Further expansion of fuel debris retrieval scale (Unit 3, Unit 1)



【Debris handling, processing, and disposal】

Review of investigation operations flexibly based on new findings

Equipment for safety system, storage maintenance, etc.

Conceptual design → Technology development → Installation of temporary storage Equipment (unit 2) → Installation of storage equipment (Unit 2, 3) - - → Long-term safe storage

Main task

～2022:

- R&D for fuel debris retrieval and storage
- Characterization

2023～:

- Elucidation of aging degradation of fuel debris
- Improvement of safe and efficient process and storage after retrieval, at conditioning and disposal

2031～:

- Sort of debris and waste
- Rationalization of equipment and facilities
- Long-term storage

R&D (Led by JAEA)

～2022:

- Characterization of fuel debris
- Radioactive effects (H_2 generation, etc.)
- H_2 diffusion / combustion explosion behavior analysis)
- Aging of fuel debris
- Risk control/reduction (H_2 recombination catalysts, etc.)

2023～:

Integration of knowledge on characterization of fuel debris
- Aging degradation, radioactive fine particles including α-dust

Storage and management
- H_2 generation, evaluation method (G value)
- H_2 combustion/explosion behavior analysis code system
- Suppression / reduction of radiation effect

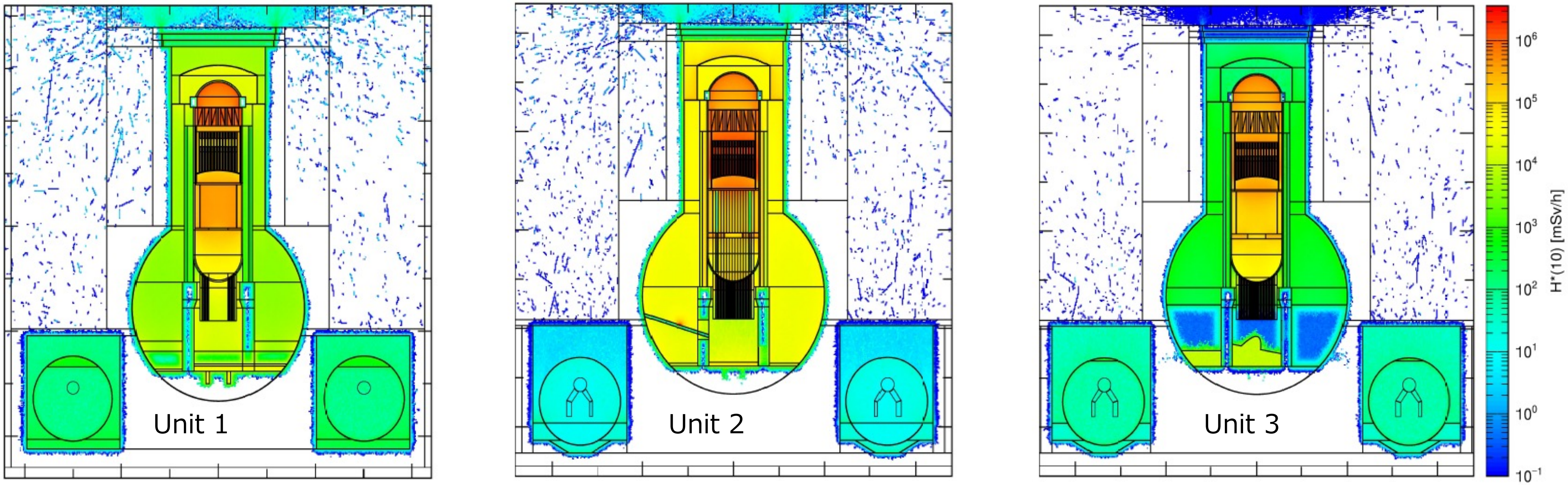
→ Establishment of effective evaluation methods for H_2 generation

Dissolution and microbial effects → Safety assessment during disposal
- Risk assessment methods for fire/explosion, corrosion/degradation, and leakage

2031～:

【JAEA'S mission】
Provide of knowledge such as the confinement of radioactive particles, radiation behavior, etc., information that contributes to discussions on fuel debris treatment and disposal, and knowledge on risk assessment methods.

Evaluation of spatially dose rate before the start of debris retrieval operation

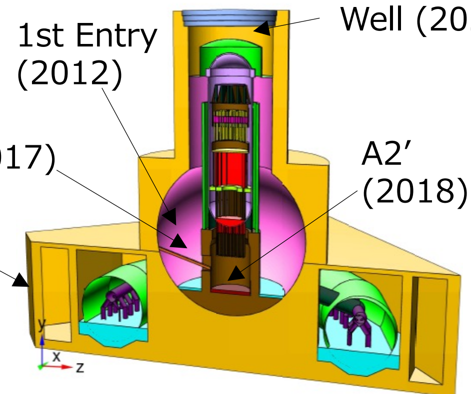


Feedback

- Accident progression analysis
- Combustion and radioactivation analysis
- Fuel debris characterization
- Muon imaging
- Camera imaging
- Radiation dose measurement

- Monte Carlo simulation
- Source sensitivity analysis
- Dose rate analysis

- Developing simulation model
- Enhancements/improvement

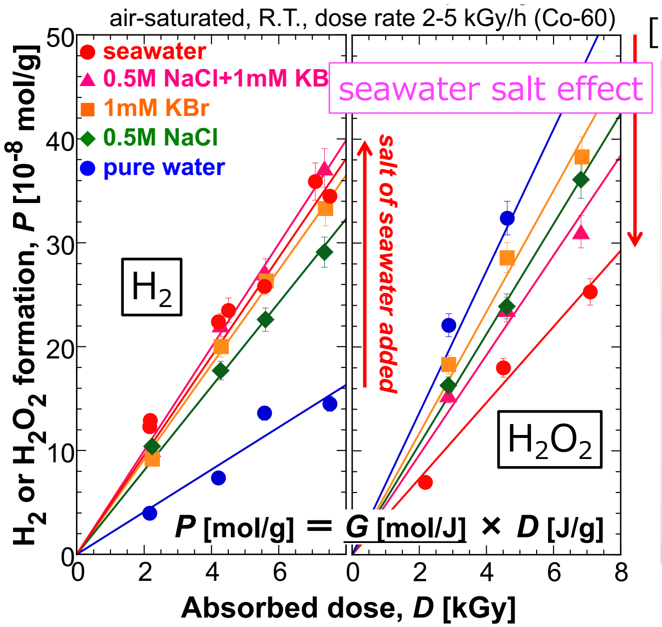


3D PCV model (Unit 2)

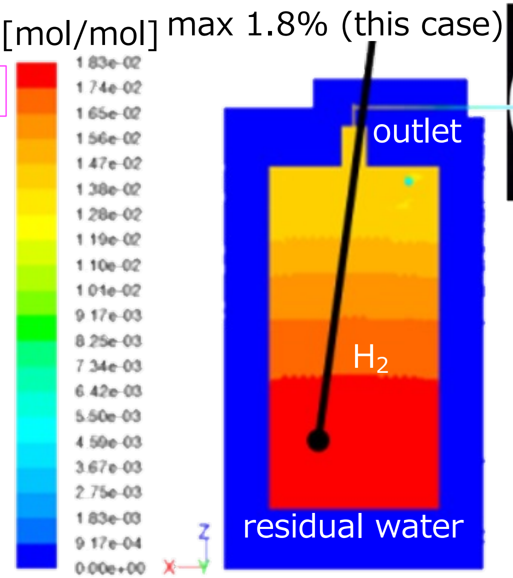
Safety/risk assessment: methodologies/knowledge

Hydrogen generation

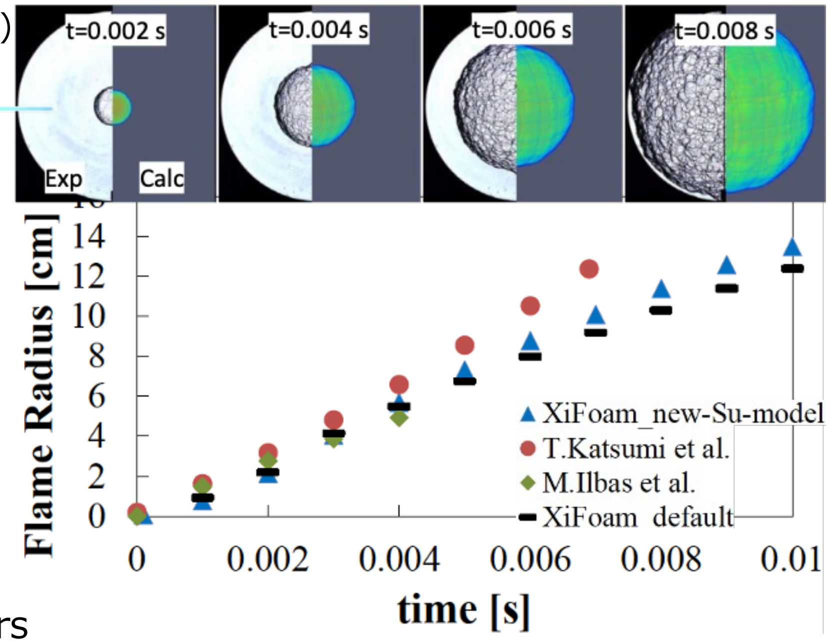
To assess the risk of H_2 explosion after storage of radioactive materials such as fuel debris, experimental and analytical researches from H_2 generation to explosion are conducted.



H_2 generation by water radiolysis (Exp)



H_2 distribution in containers (Calculation)



H_2-air premixed flame expansion (Exp+Calc)

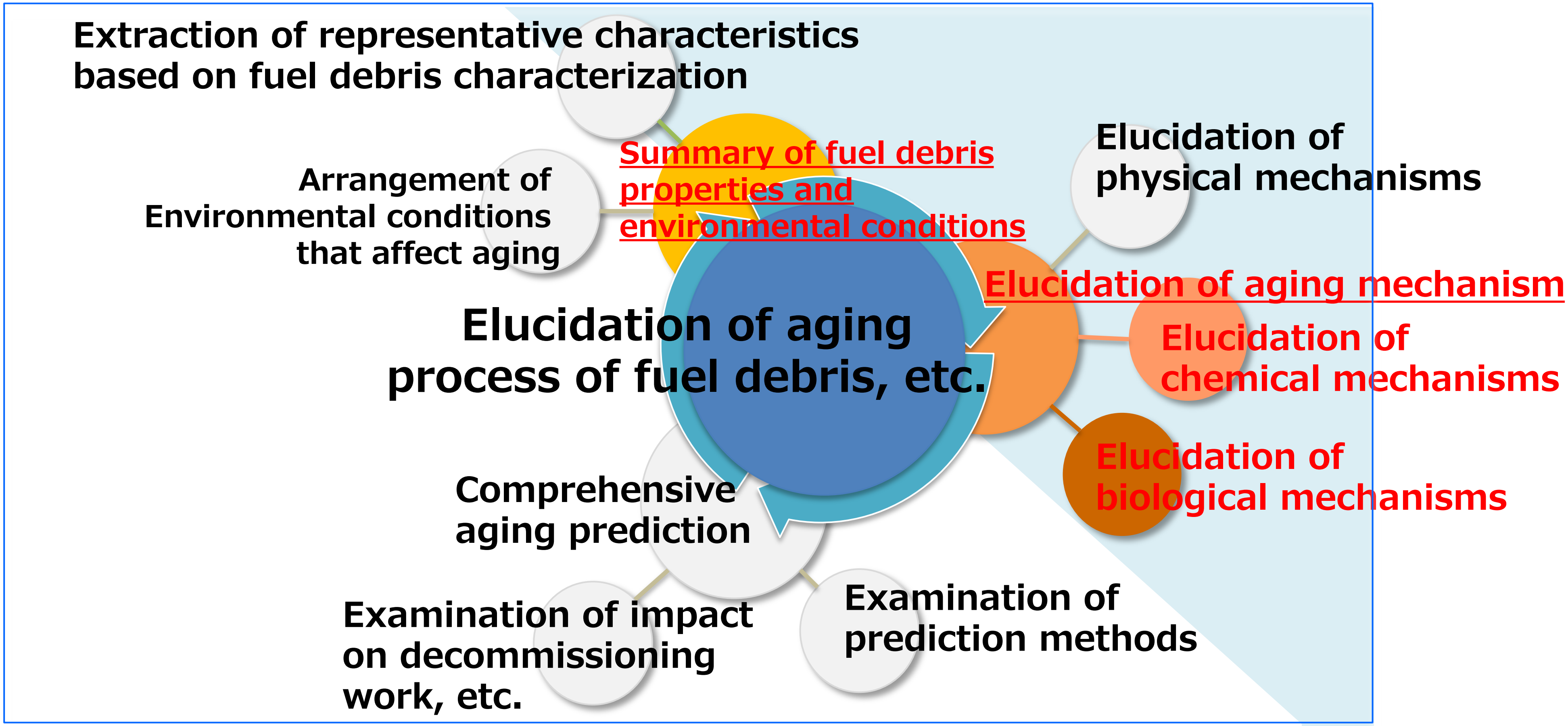
付与・吸収 **energy deposition** to complex system → 発生・損傷 **H_2 generation** by water radiolysis → 拡散・流動 **diffusion/convection** in/among facilities → 燃焼・爆発 **combustion/explosion** in facilities

(1) Radiation research part

(2) H_2 safety research part

H_2 flow diagram of generation to explosion

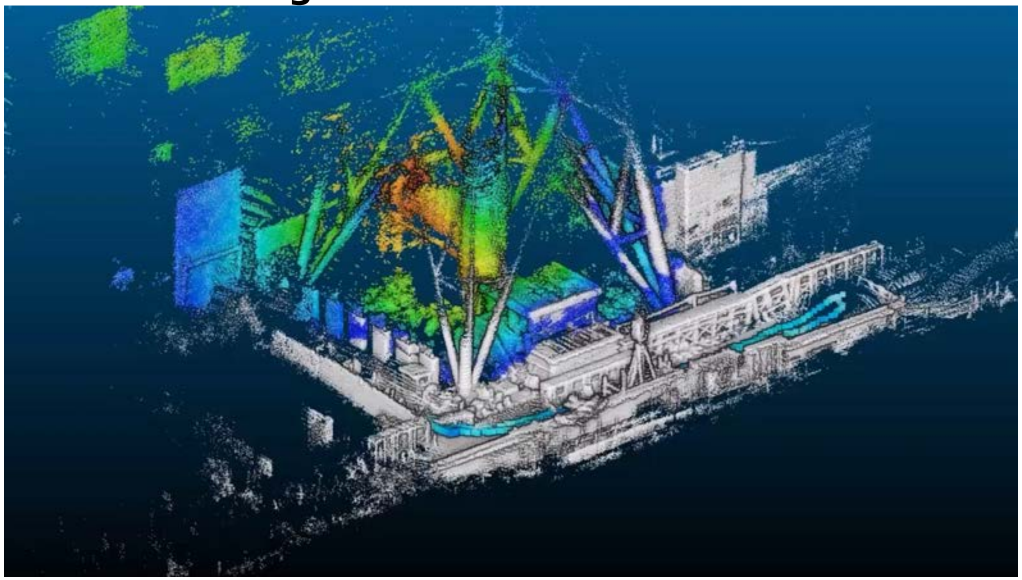
< Implemented in collaboration with universities>



< Implemented mainly by JAEA >

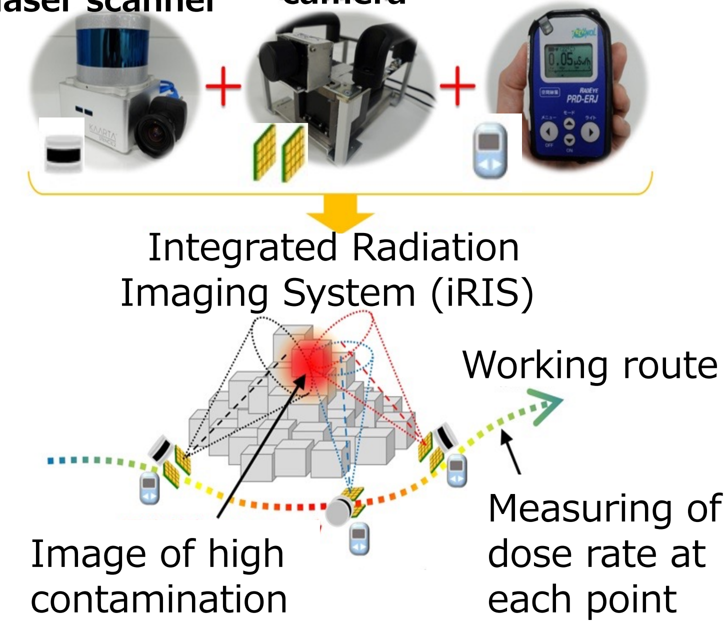
Reducing radiation dose/exposure
Radiation measurement/visualization

"Visualize" invisible radioactive hotspots in three dimensions —Understanding the distribution of radioactive substances.



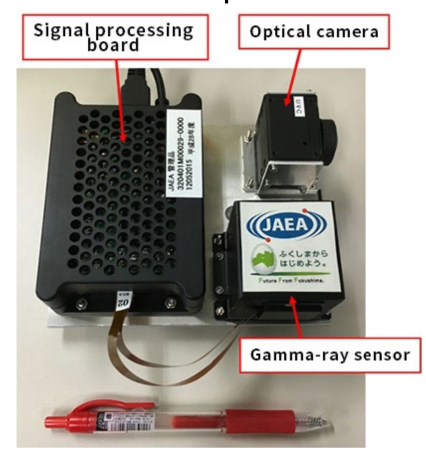
3D map visualizing radiation dose rate*1

Three-dimensional laser scanner + **Compton camera** + **Radiation survey meter**



◀The resultant image of the hot spots obtained from the Compton camera is overlaid on the three-dimensional model inside the Fukushima Daiichi NPS building constructed using the photogrammetry technique.*2

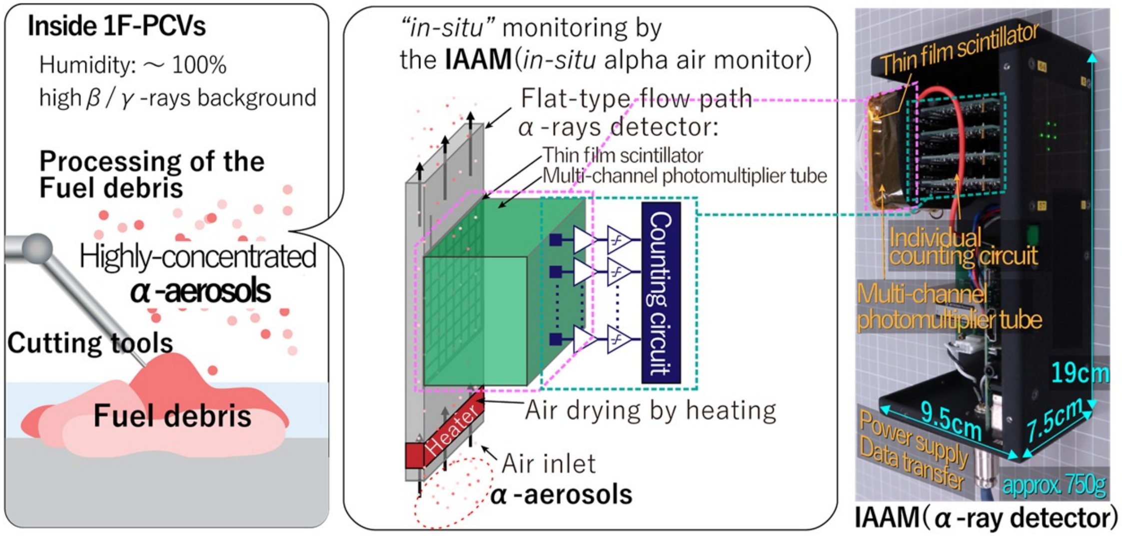
Compact Compton camera▶

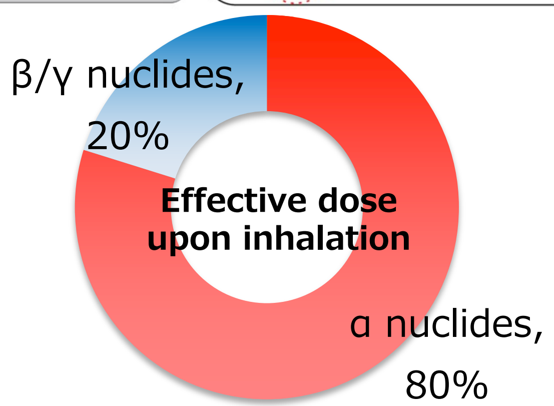


Reducing radiation dose/exposure
Radiation measurement/visualization

Monitoring and confinement management of alpha nuclides are critical during fuel debris retrieval works.

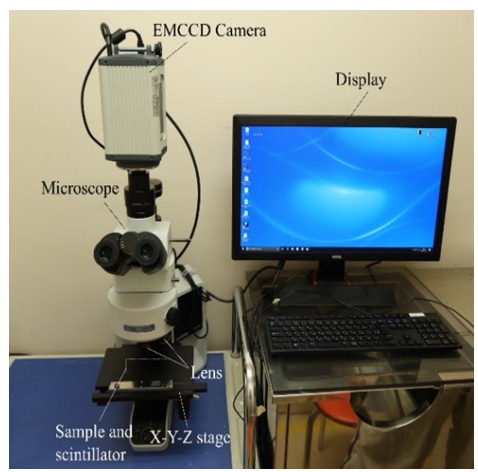
In-situ alpha aerosol monitor (IAAM)

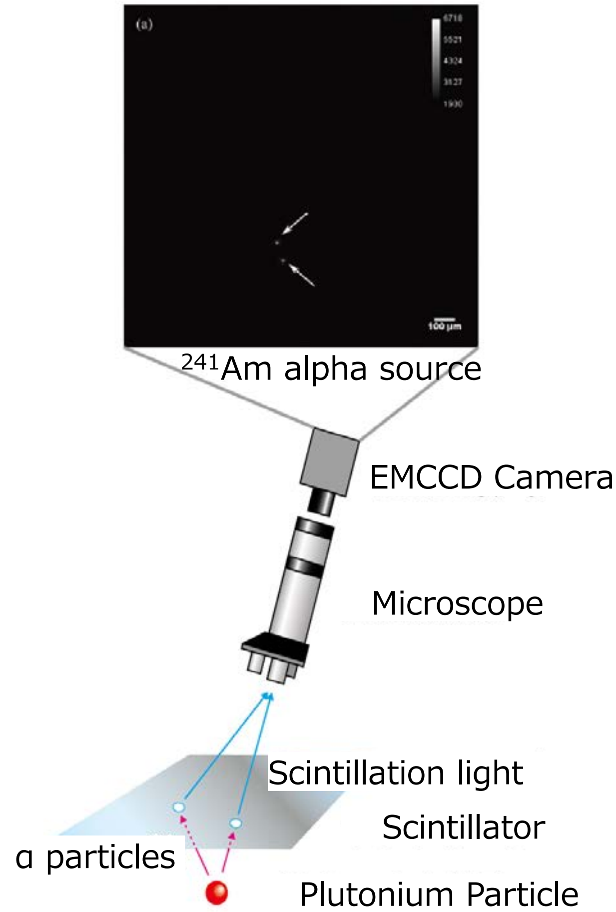




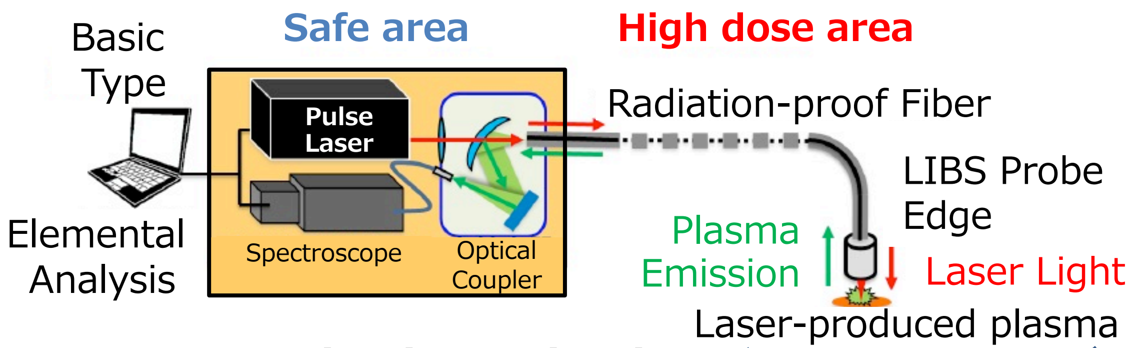
Percentage of effective dose upon inhalation, calculated based on the radioactive inventory of 1F-U2.

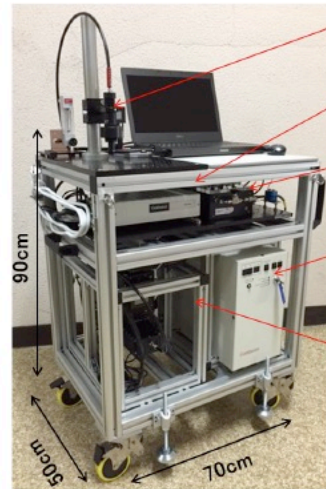
Real-time high-resolution visualization of individual alpha particle spots





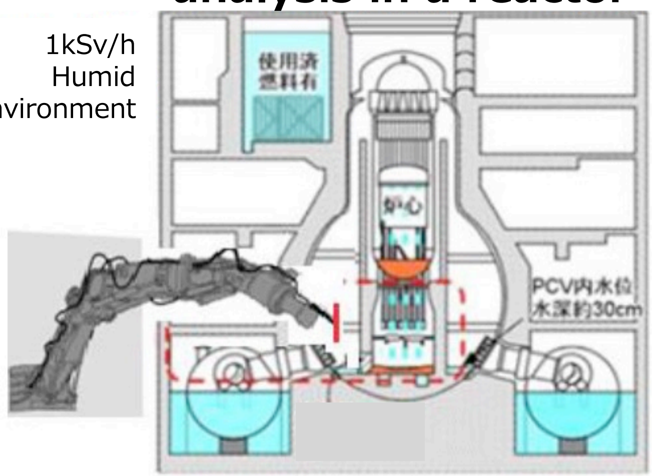
The Optical Fiber Laser-induced breakdown spectroscopy (LIBS) analysis method





Application to in-situ analysis in a reactor

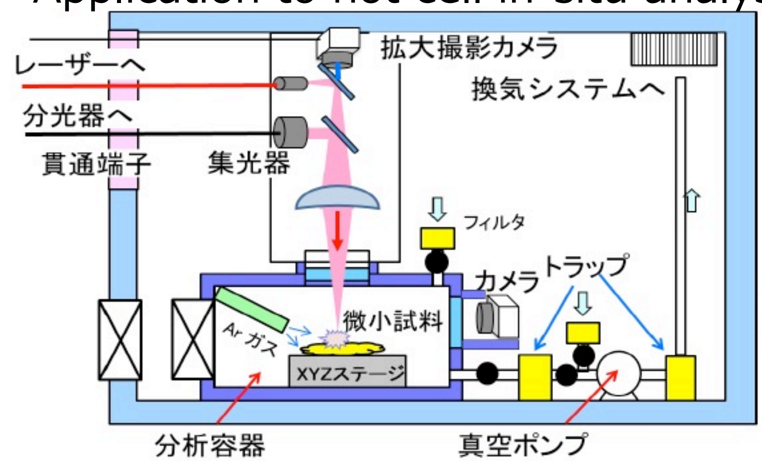
1kSv/h
Humid
Environment



ϕ 18 × L90

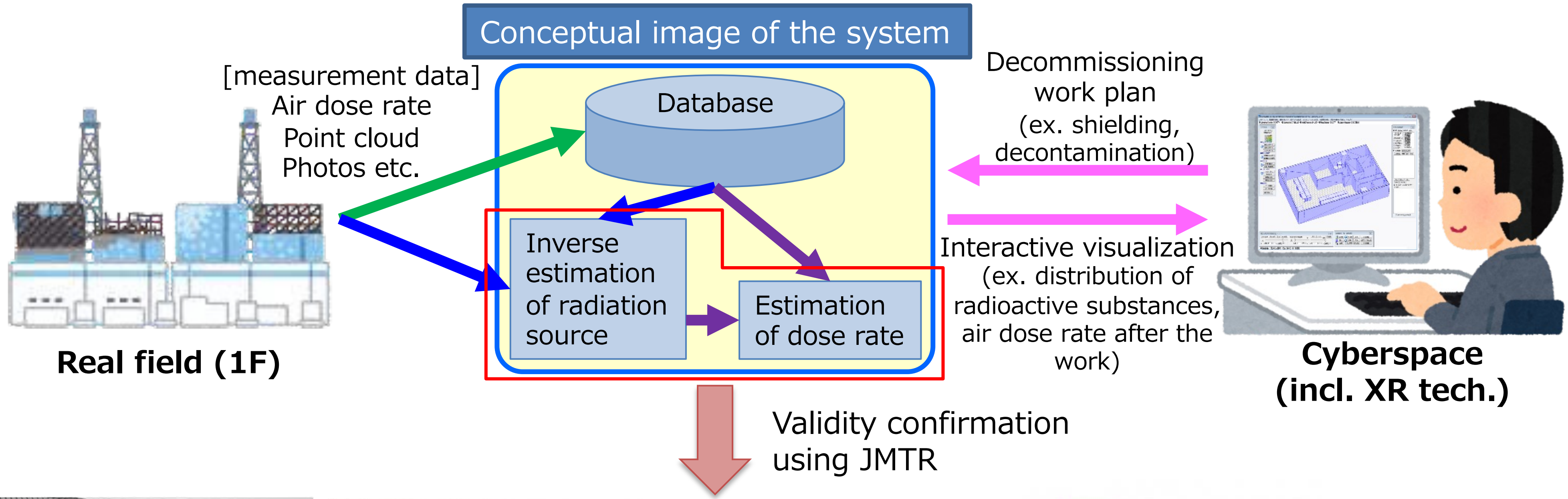
Using Basic Type

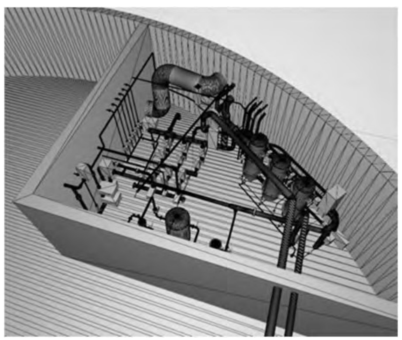
Application to hot cell in-situ analysis



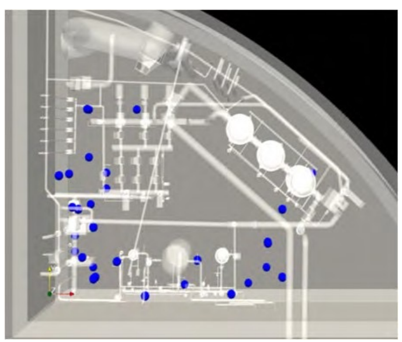
100Sv/h
Dry
Environment

Radiation source evaluation system by using digitalization technologies



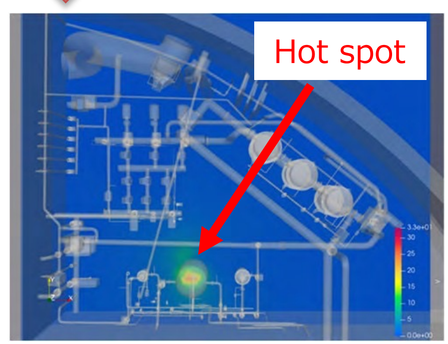


Structural model (Pool-canal room)

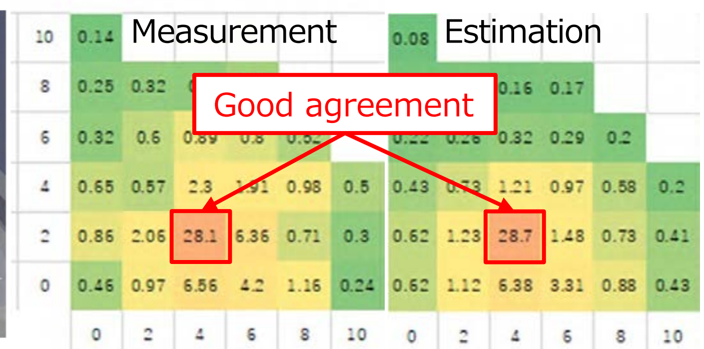


Optimized measurement points

Input measurement data



Estimated radioactive source

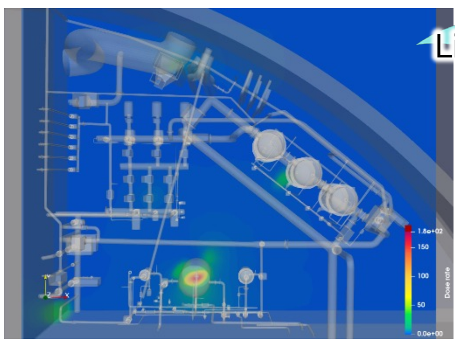


Measured and estimated dose rate distribution

NARAHA Center for Remote Control Technology Development (NARREC)

Efficient technology development and training via integration of physical and virtual mockups
- **Mockup : Highly reliable and replicable testing under specific condition**
- **Virtual : Inexpensive evaluation under a variety of conditions**

3D Virtual Reality System



Simulation of source location

Linkable

Full scale mock-up field

Unit 2 PCV mock-up for arm-like equipment demonstration test and operator training (IRID)

※ Source: METI official HP

Robot test areas

Mock-up stairs

Robot Test Pool

Motion capture system

Fuel Debris Retrieval R&D

Analysis of Fuel Debris

Fuel debris retrieval (First trial at Unit 2)

Fuel debris retrieval (Expansion of scale)

Demonstrate equipment and operator training

Improve work environment and reduce dose

Radiological and material analysis

Consolidate data to evaluate safety and risk

Actions/solutions

Backcasting

■ 2030 vision: ideal state (to be discussed further)

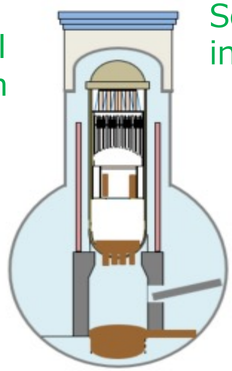
1. **The first/trial fuel debris retrieval from Unit 2 progressed, and larger-scale retrieval from Unit 3 nearly ready.**
2. **Fuel debris analysis (incl. non-destructive methods) becomes well ready**
3. **Methodologies for safety and risk management established**

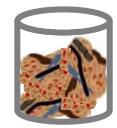
JAEA R&D focuses/priorities

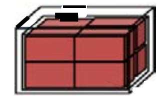
- **Radiological sample analysis at JAEA hot-lab in Ibaraki/Fukushima**
  - ➡ Enhancing capabilities and standardization
  - ➡ Okuma New analysis facility
- **Non-destructive assay technologies**

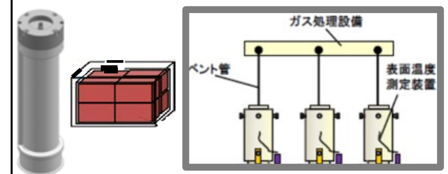
Fuel Debris Retrieval R&D
Analysis of Fuel Debris

Year	~2022	2023~	2031~
Master plan	PCV internal investigation	Scale up of PCV/RPV internal investigations; Design study of Preconditioning and storage facility; Start fuel debris retrieval (Unit 2) (~g order) → Expand the scale of retrieval gradually (~kg order) (Total ~880t); α-contaminated waste by removal of obstacles, etc.; Review of investigation operations flexibly based on new findings	Further expansion of fuel debris retrieval scale (Unit 1 or 3); Temporary storage →Long-term stable storage
Main task	・Analysis method ・Characterization ・Core status	・ Validation of method ・ Evaluation of fuel debris ・Analytical quality for regulatory ・Application to step-by-step approach of fuel debris retrieval	・Sort of debris and waste ・Material accountancy ・Long-term storage
R&D (Led by JAEA)	・Analysis method / Standardization ・1F sample analysis / Core status evaluation ・Preparation of the Ibaraki area analysis system ・Reflect to Okuma lab.-2	Outcome: Establishment of analysis method Standardization; Evaluation of dose distribution; TMI-2 debris analysis International round robin test; Sorting technology for fuel debris and radioactive materials; Non destructive assay technology; Accuracy of core status and retrieved fuel debris; Material accountancy (Criticality・SG・Waste management, security)	【JAEA'S mission】 Provide of knowledge such as analysis, peripheral technologies, and reliable analysis results necessary for implementation from fuel debris removal to long-term stable storage.









Utilization of JAEA's facilities and human resource development through OJT at these facilities

Information and analysis items necessary for safety and risk assessment

A Safety / risk assessment through fuel debris removal to storage / management

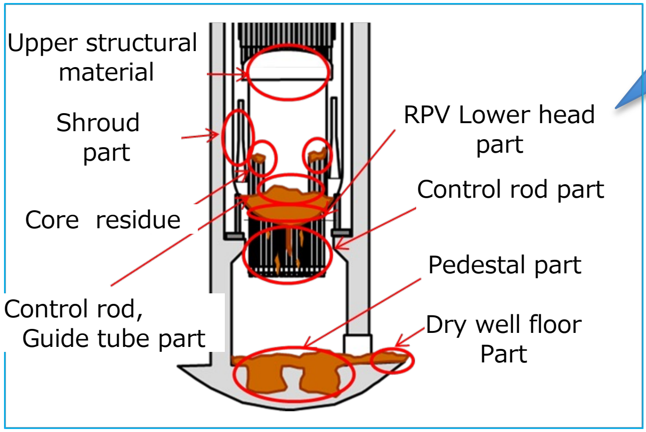
B Safety / risk assessment in fuel debris processing

・In addition to the items applicable to temporary storage, the same analysis items as radioactive waste are applied. (Inventory evaluation: 38 Nuclide analysis, etc.)

C Safety / risk assessment of fuel debris remaining in the container

Current status

Fig. Core status (Estimated debris distribution)



Safety / risk assessment items

Heat generation, criticality, scattering of fine particles, leakage of radioactive substances, (hydrogen generation)

Analytical needs

- Surface dose rate, dimensions (particle size), density, hardness
- Nuclide inventory, composition
- Chemical form, surface condition
- Moisture content, organic matter content, hydrogen
- FP emission behavior, thermal characteristics

Estimation

- Plant information
- Internal investigation results (Dosimetry, analysis of sediments, etc.)
- Analysis by calculation code such as thermal behavior
- Analysis of retrieved fuel debris

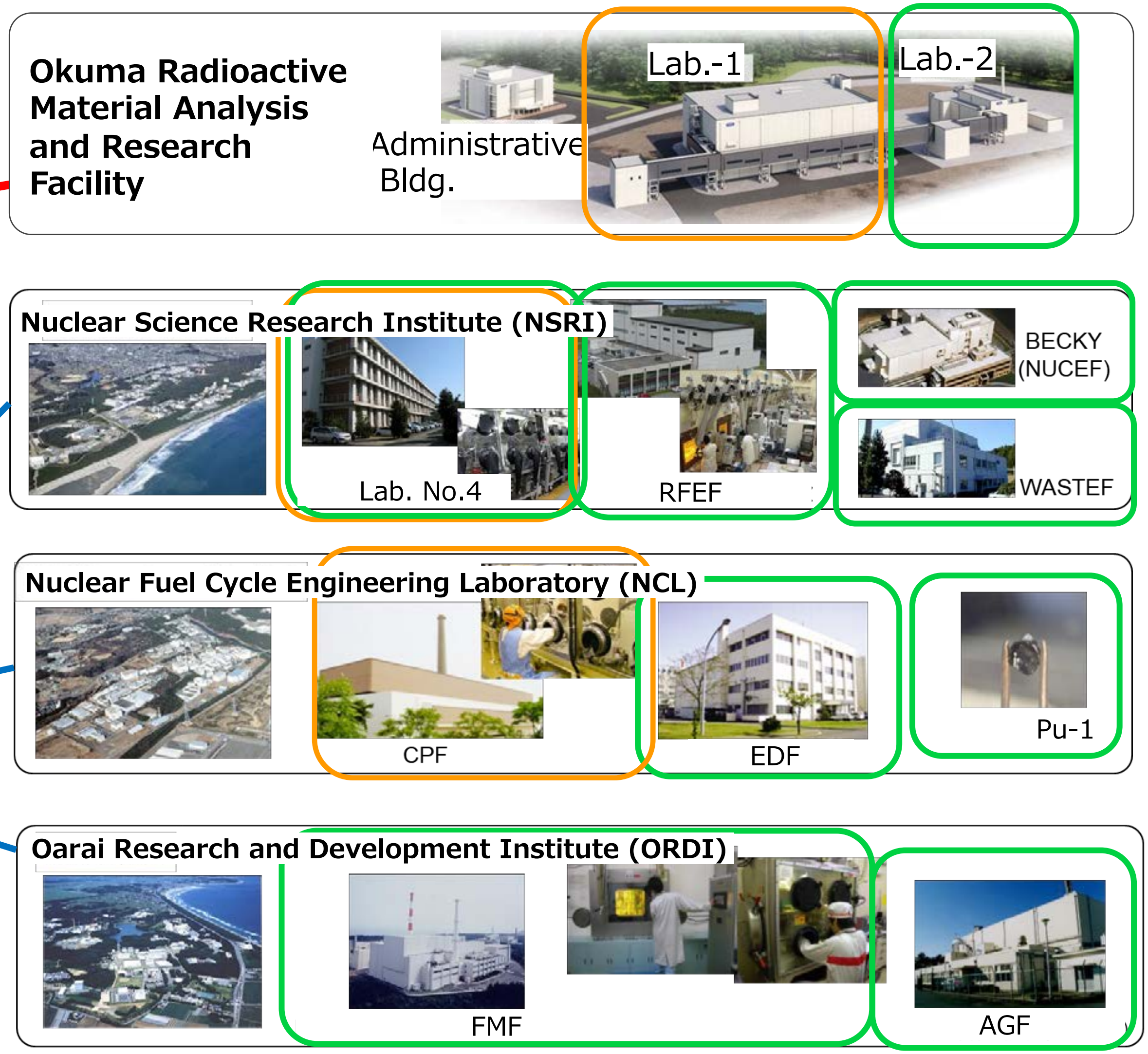
Analytical facility (Okuma, Ibaraki area)

Analysis / evaluation results

Feedback

JAEA's hot laboratories for radiochemical analysis and human resource development

Google mapより



For fuel debris analysis

For radioactive waste analysis

Fuel Debris Analysis
Enhancing capability and standardization

Technology and system for evaluating the characteristics of fuel debris will be established as an approach for samples with unknown composition.

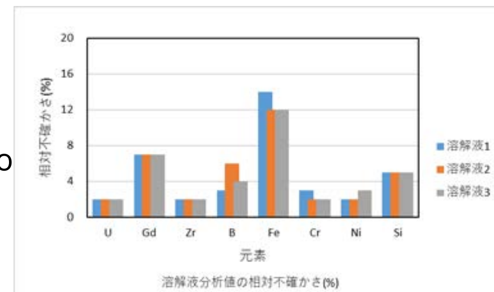
The simulated fuel debris prepared by an independent organization will be supplied to the hot laboratories in Japan.
The elemental composition will be analyzed using their own technology possessed by each laboratories.

Simulated fuel debris (uniform composition)
・Including U
・1F composition

Tohoku University

Hot laboratories	Dissolution method	Dissolution rate	Remarks
NDC	HNO_3	～60%	・Simple method ・Dissolves U and B compounds ・Complement the overall elemental composition by analyzing residue ・Improved dissolution rate by adding a small amount of HF
JAEA Oarai	HNO_3 + HF	～90%	
NFD	Aqua regia +HF	98%	・Almost complete dissolution ・High accuracy ・Possibility of fluoride precipitatio
JAEA NSRI	Alkali fusion	100%	・Complete dissolution ・High accuracy ・Contamination of alkaline reagent and crucible components

Conducted by remote control within the cell



Verification of accuracy and error for each analysis target element and operation

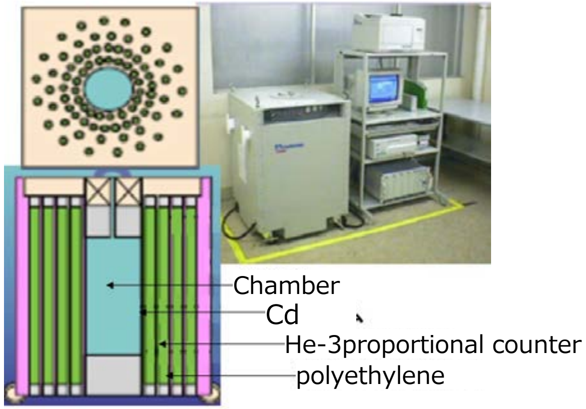
Analysis techniques for 4 basic evaluation items (morphology of analysis samples, nuclide/element content, phase state/distribution, density, etc.), which are important for fuel debris analysis items, are defined and shared among the parties concerned.

Non-destructive assay technology for sorting of fuel debris and radioactive waste

- ✓ Destructive analysis of recovered PCV materials up to the order of kilograms stored is difficult.
- ✓ In order to reflect the sorting of fuel debris and radioactive waste in the future, non-destructive assay technology will be developed to sort them according to the amount of nuclear fuel material.

Candidate methods currently under consideration in the IRID project:
(Participating organizations in the project: MHI, Toshiba ESS, Hitachi GE, JAEA collaboration)
(1) Active neutron method, (2) Passive neutron method, (3) Muon scattering method,
(4) X-ray CT method, (5) Passive gamma ray method

Active neutron method (JAWAS-T)
NSRI/NUCEF/BECKY



Passive neutron method (PSMC)
NCL/Pu-center

Considered for use in passive gamma-ray measurement, etc.
NSRI/RFEF

Overview of basic test equipment for non-destructive assay measurement methods
(JAEA facilities and equipment scheduled to be implemented from 2023)

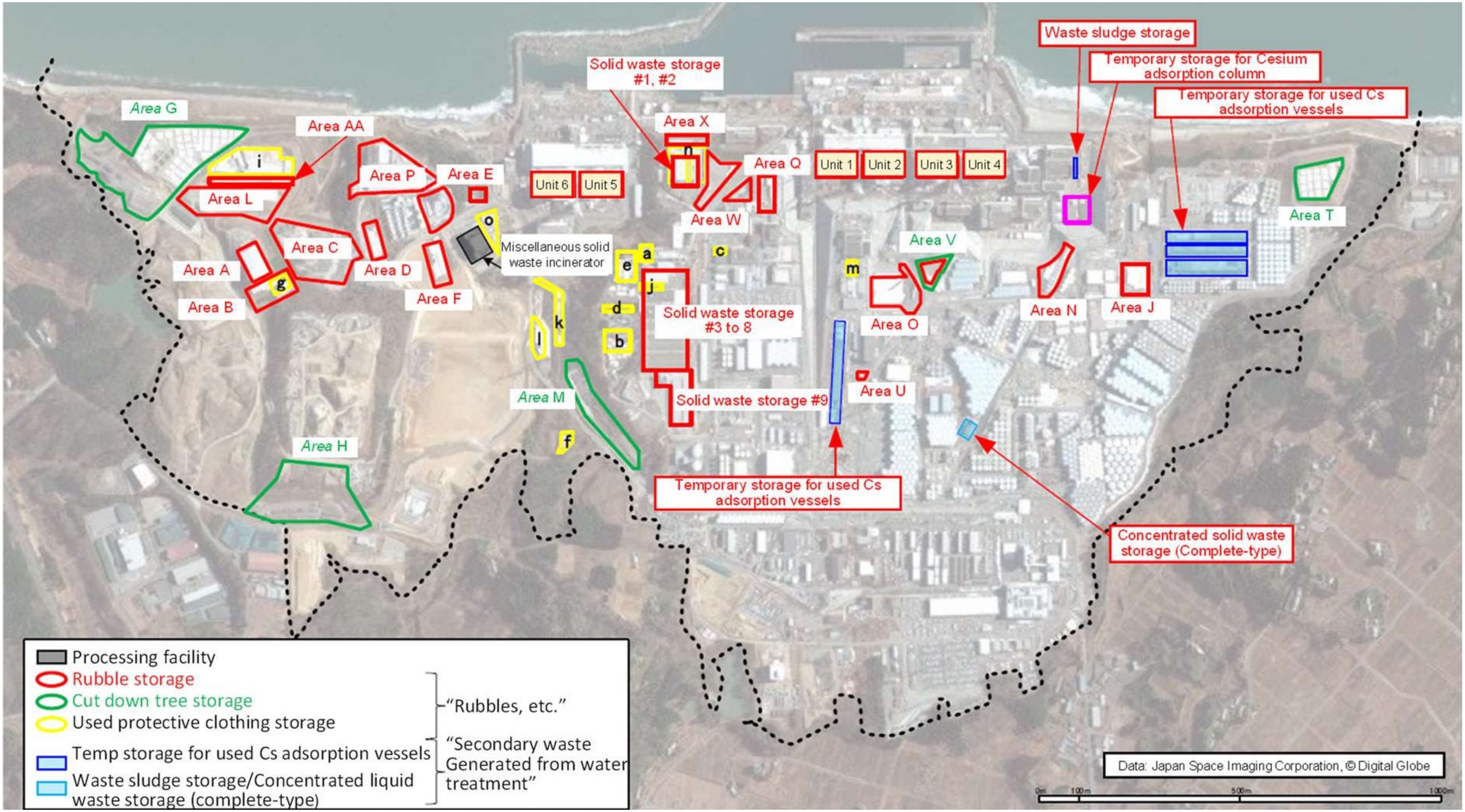
4. Radioactive waste management R&D






Current status of waste storage

■ Temporary storage of solid waste on site of Fukushima Daiichi



* NDF, "Technical Strategic Plan 2021," Fig. A10-1, October 29, 2021.

Radioactive waste management R&D

■ 2030 vision: ideal state (to be discussed further)

1. **A risk level of remaining high-risk radioactive waste considerably reduced**
2. **Rational characterization methodologies established (e.g. statistical methods)**
3. **Discussion on a variety of options for waste disposal can be started**

Backcasting

Actions/solutions

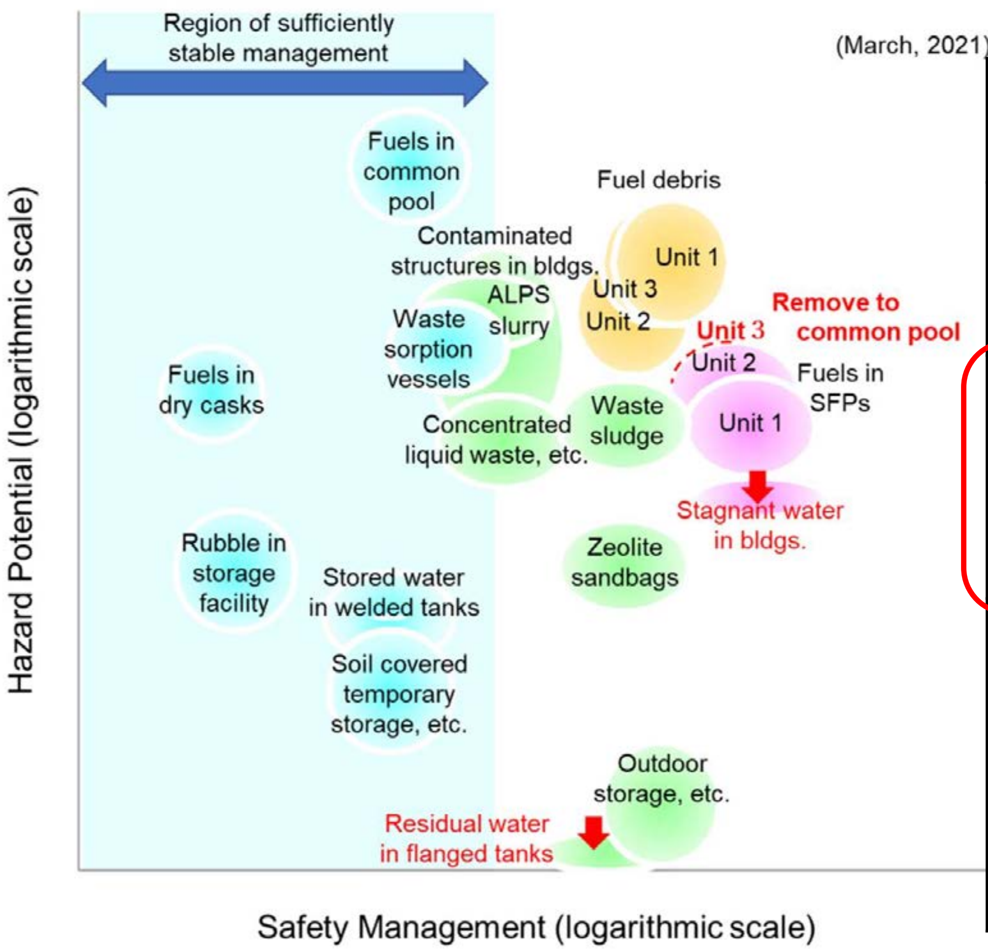
■ JAEA R&D focuses/priorities

□ Risk reduction of secondary waste from water decontamination
- ➡ Radiochemical and other analysis
- ➡ Investigating mechanism for storage

□ Waste characterization and development of statistical methods
- ➡ Continuing analysis
- ➡ Developing analysis method, planning, statistics, database

□ Safety of waste processing/disposal
- ➡ Basic data for processing and disposal

■ Safe storage of relatively high-risk waste: secondary waste from contaminated water processing



* NDF, "Technical Strategic Plan 2021," Fig. A10-1, October 29, 2021.

Table: Risk categories and sources

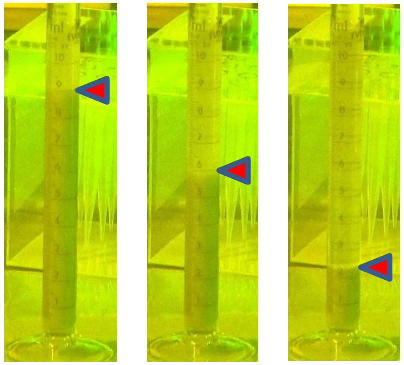
Relatively high risks given high priority	Fuels in SFPs
Immediate risk unlikely, but risk may grow when handling with haste	Fuel debris
Increased risk unlikely in the future, but appropriate decommissioning efforts are required	ALPS slurry, waste sludge, concentrated liquid waste, zeolite sandbags, outdoor storage
Sufficiently stable management	Fuels in common pool, Sorption vessels, Fuels in dry casks, Rubble in storage facility, Stored water in welded tanks, Soil covered temporary storage

(Note) Waste in red was already radiochemically analyzed.

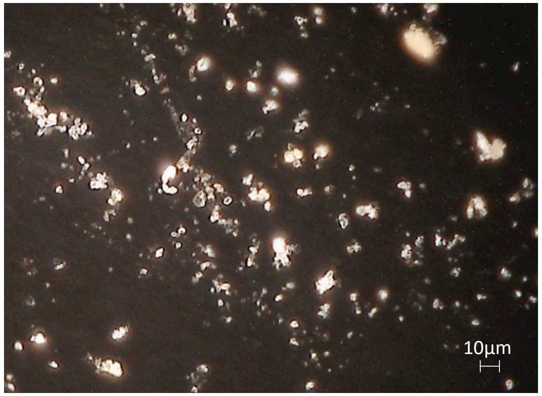
■ Extensive analysis of contaminated water treatment sludge

Sludge stored at "D pit"*

The only sample successfully collected

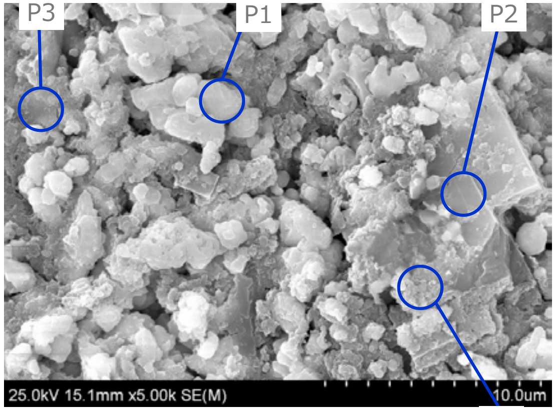


Sedimentation behavior of sludge observed in hot cell due to its high β activity

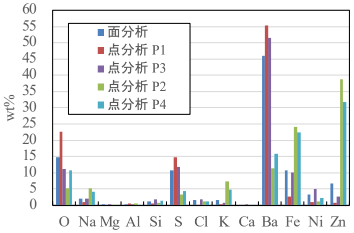


Visual observation of sludge particle

Distribution profile



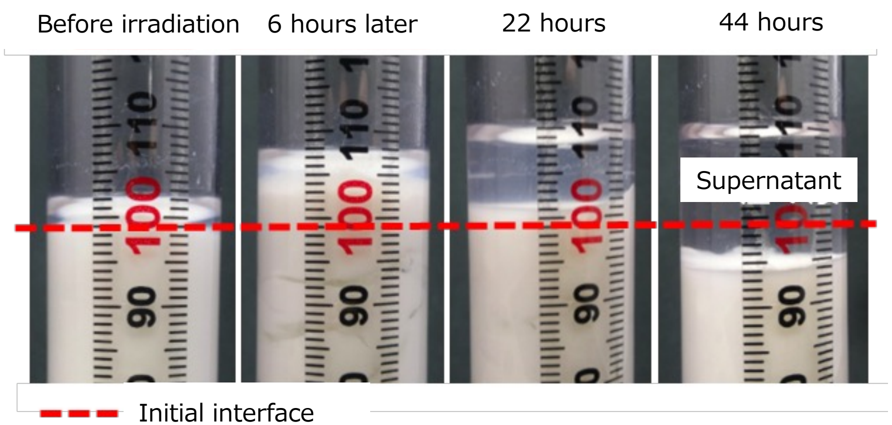
SEM image and points of elemental analysis



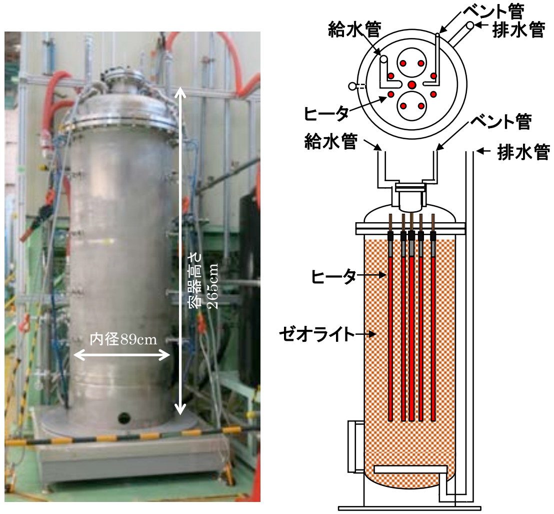
Elemental concentration

* TEPCO, "Report on stabilization of slurry and sludge," 25 July 2017.

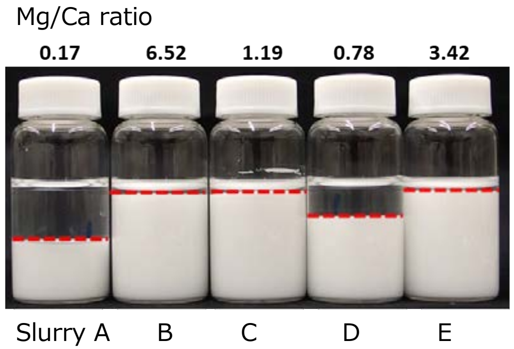
■ Study on storage methods: evaluate radiation effect during long-term storage

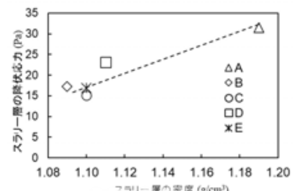


Expansion of solid phase due to generation of hydrogen, observed in simulating experiment using ^{60}Co source



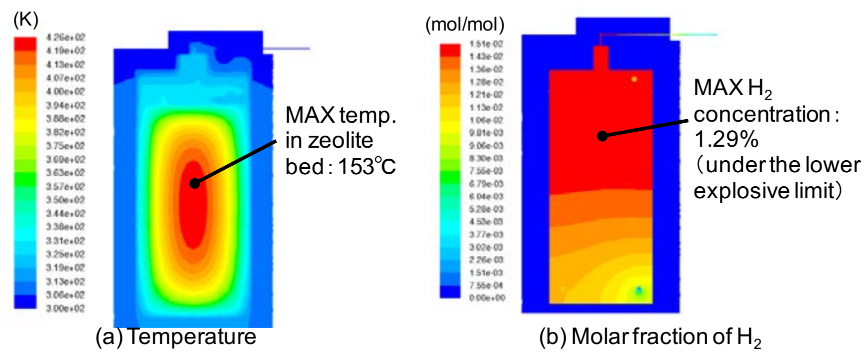
Experimental setup to investigate water evaporation behavior





Yield stress

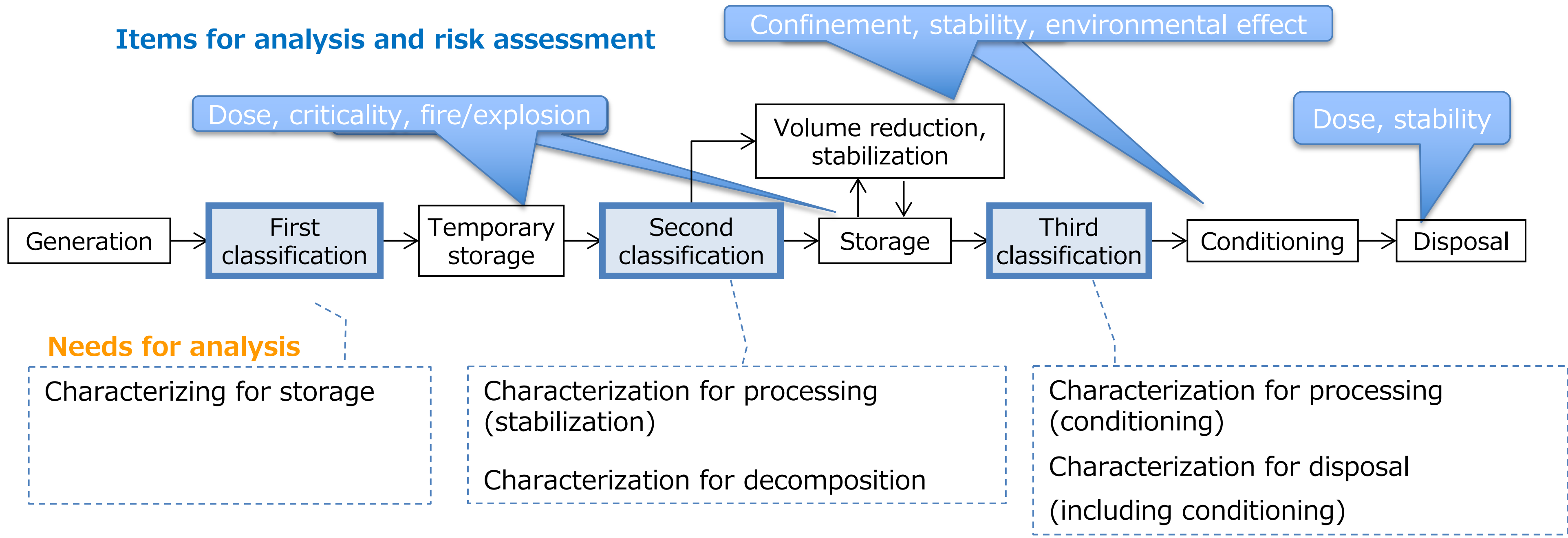
Synthesizing simulated sludge to investigate physical property of solid phase



Calculation of hydrogen concentration to confirm safety of explosion

Radioactive waste management R&D
Waste characterization and development of statistical methods

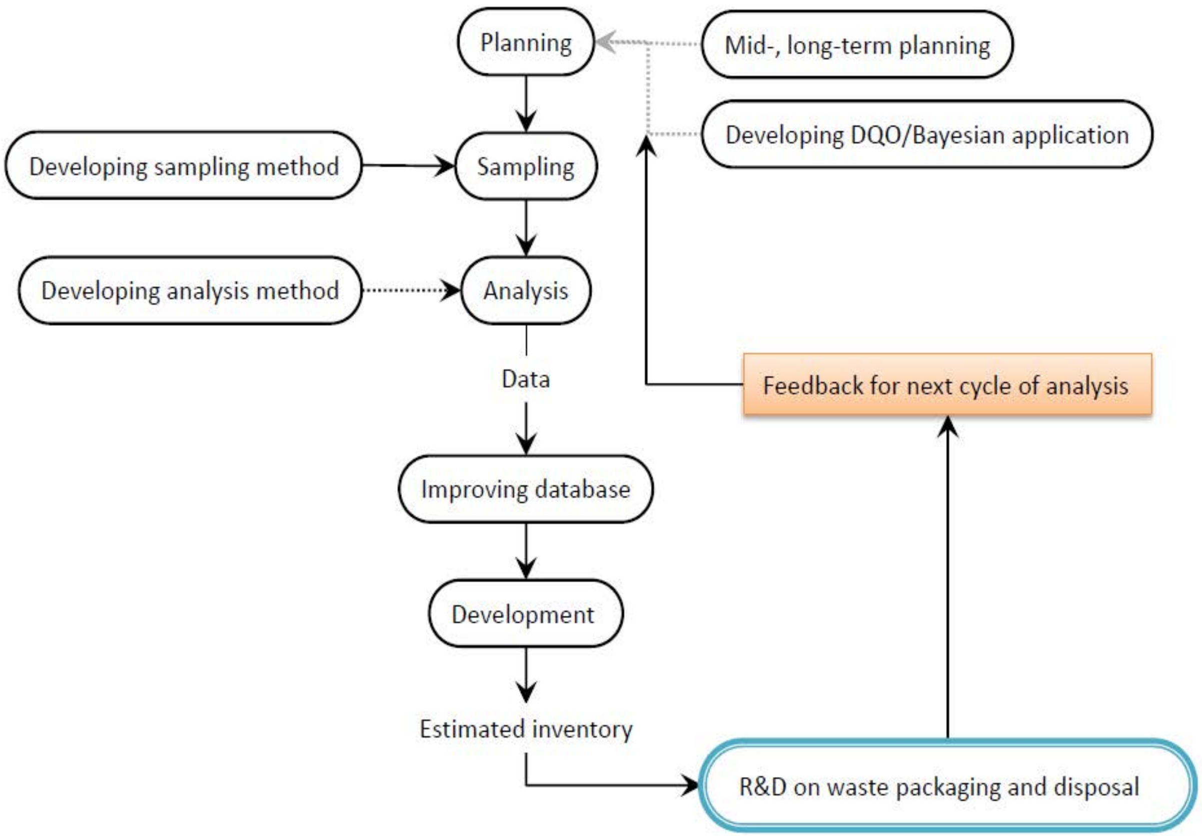
■ Analysis of radioactive waste: information/data required for risk assessment



✓ **Unique feature of waste originating from the Fukushima Daiichi accident**
- **Difficult to predict radioactivity composition including DTM "Difficult-To-Measure" nuclides**
- **Enormous amount**
- **High dose rate**

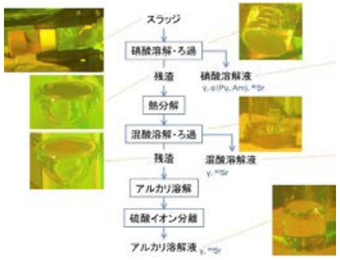
- **Inventory estimation method**
- **Analysis planning method**
- **Analysis method for DTMs**

■ Characterizing radioactive waste: analysis and related items for developing waste processing/disposal technologies



Flow of characterization, composite of various items

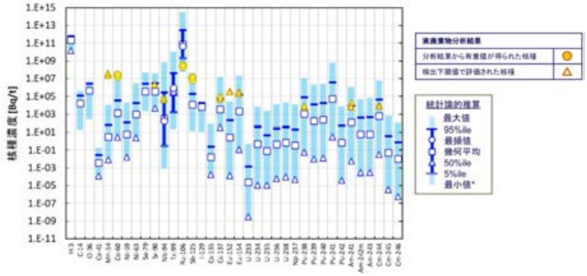
Sampling



Developing analysis procedure

Radiochemical analysis

Web-based database



Estimated radioactivity contained in waste

Important items of characterizing waste

Radioactive waste management R&D
Waste characterization and development of statistical methods

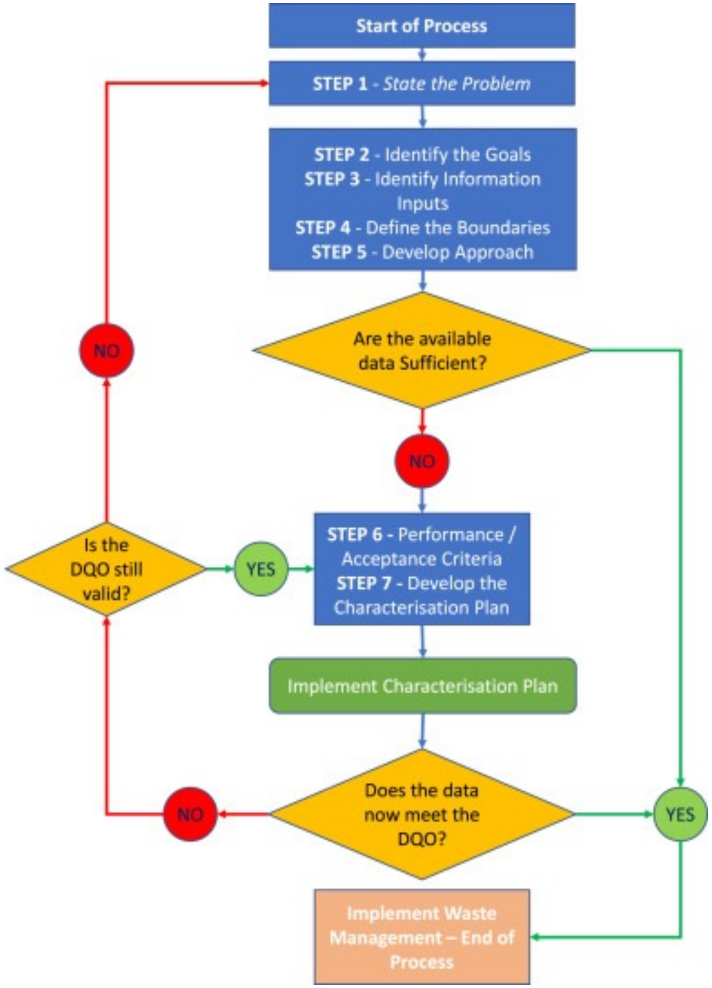
Class	Sample			Number
Rubble	Reactor building	Unit #1	Concrete, metal, precipitate inside PCV, others	49
		Unit #2	Concrete, plugging inside TIP, others	46
		Unit #3	Concrete, others	16
		Unit #4	Concrete, metal, others	14
	Turbine building	Unit #1	Sludge, others	9
		Unit #2	Sludge	3
		Unit #3	Sludge	2
		Unit #4	Sludge	1
	Waste building	Unit #1	Sludge	1
		Unit #2	Sludge	1
		Unit #3	Sludge	1
		Unit #4	Sludge	2
	Centralized waste treatment facility	Process main	Sludge	5
		Incineration	Sludge	3
	Rubble outside	Unit #1	Concrete	6
		Unit #3	Concrete	6
		Unit #4	Concrete	6
	Rubble stored	Vessel #1	Concrete	7
		Vessel #2	Concrete	7
		Vessel #3	Concrete	1
Combustible	Incinerated ash of protective clothes			5
Soil	On premise			13
Vegetation	Tree cut down	Branch, leaf		5
	Living tree	Branch, leaf, fallen leaf, leaf mold		123

Class	Sample			Number
Contaminated water	Reactor building	Unit #1	Accumulated	3
		Unit #1, PCV condensate	Accumulated	1
		Unit #2 including PCV, Torus	Accumulated	7
		Unit #3 including PCV	Accumulated	5
		Unit #4	Accumulated	1
	Turbine building	Unit #1	Accumulated	7
		Unit #2	Accumulated	4
		Unit #3	Accumulated	4
		Unit #4	Accumulated	1
	Waste building	Unit #1–4	Accumulated	4
	Centralized waste treatment facility	Process main	Accumulated	17
		Incineration	Accumulated	16
	Treatment system	Decontamination device	Processed	3
		Cs adsorption (KURION)	Processed	16
		Cs adsorption (SARRY)	Processed	26
		Cs adsorption (SARRY II)	Processed	6
		ALPS	Processed	51
		Evaporation	Processed	3
		Reverse osmosis	Processed	2
Secondary waste from water treatment	ALPS series	Iron precipitation	Slurry	2
		Carbonate precipitation	Slurry	10
		Adsorbent	Activ. carbon	3
			Titanate	2
	Decontamination device		Sludge	2
	Evaporation		Slurry	4
	Zeolite sandbag		Adsorbent	1

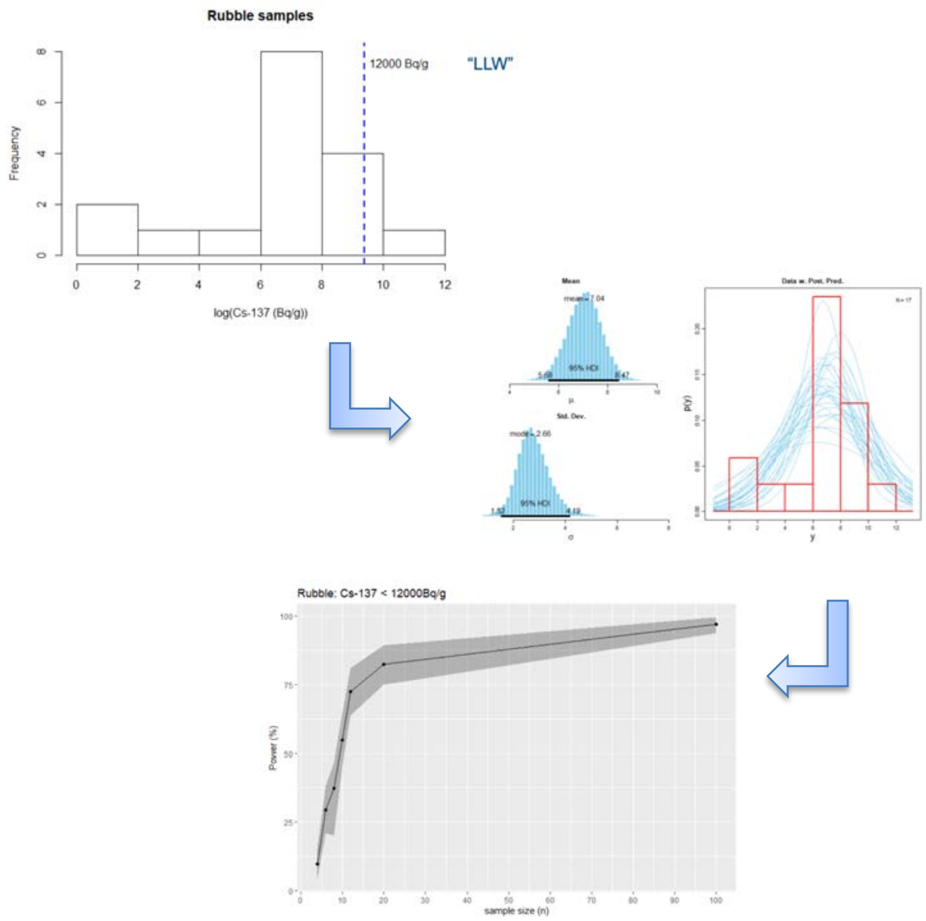
* As of May 2021.

2

■ **Analysis planning is enforced by integrating international expertise**



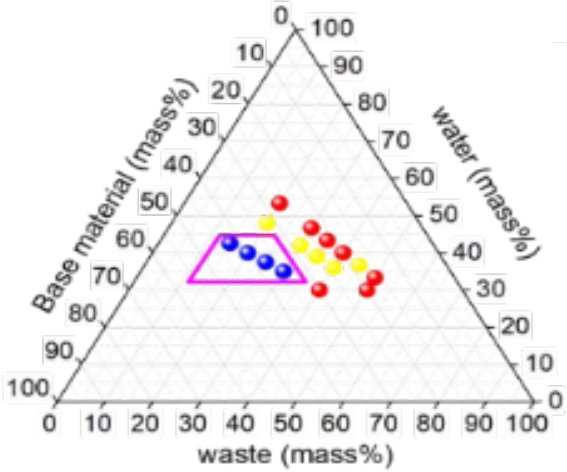
Data Quality Objectives (DQO) Process, originally developed by US EPA



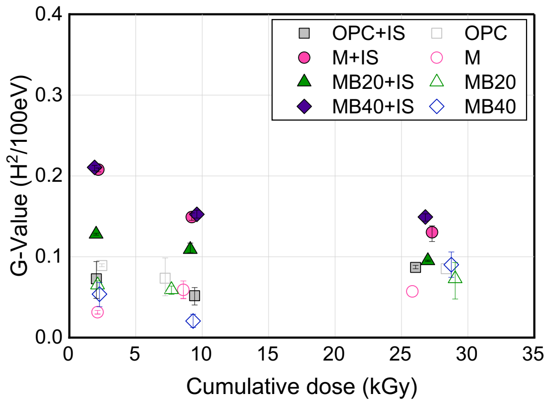
Calculating effective number of samples using Bayesian statistics as a result of UK collaboration

■ Preparing technology selection for solidification/disposal concept

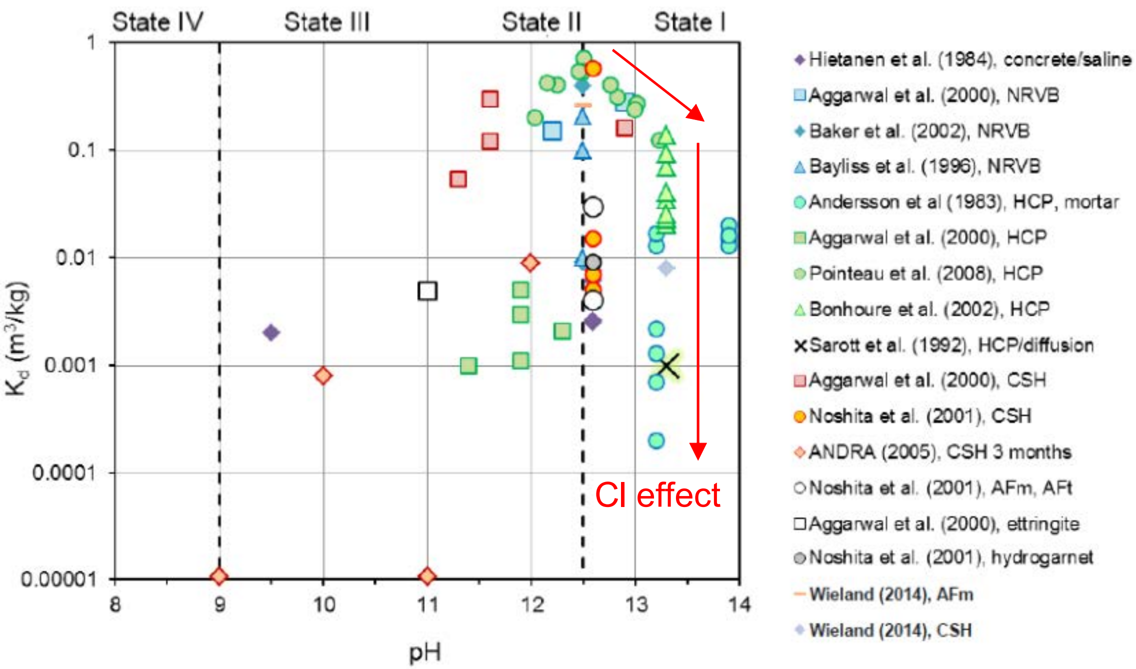
Examples of basic data related to waste processing



Cementitious solidification criteria for carbonate slurry

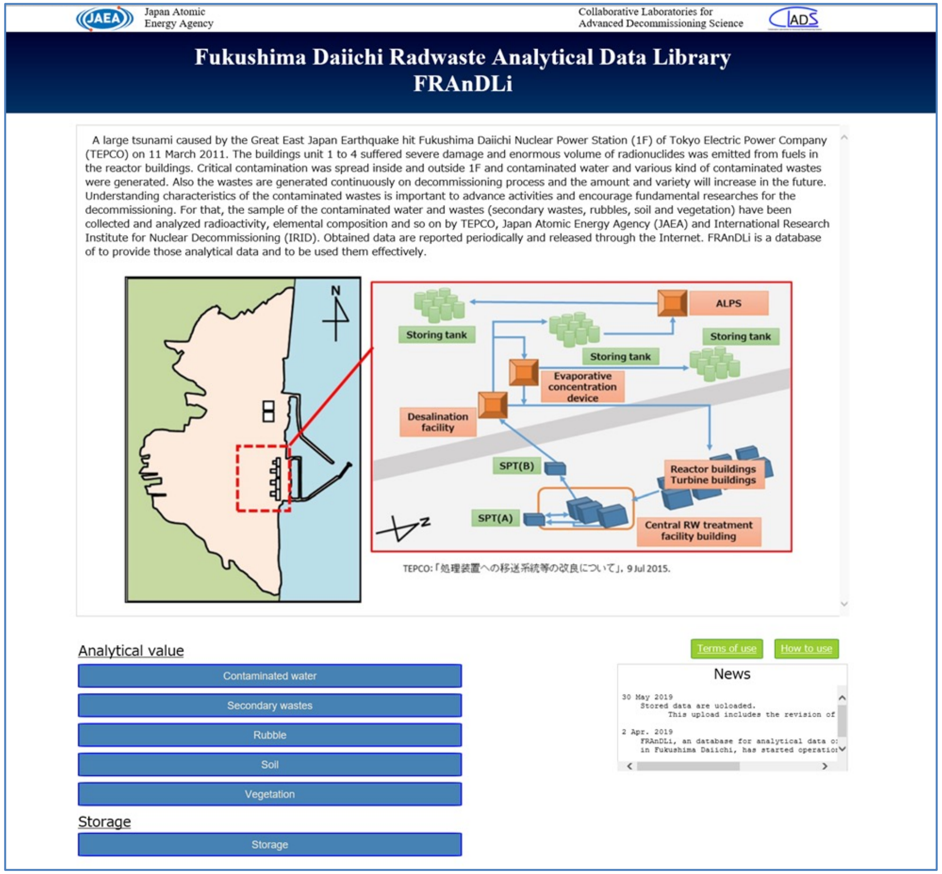


Hydrogen generation "G-value" from iron slurry

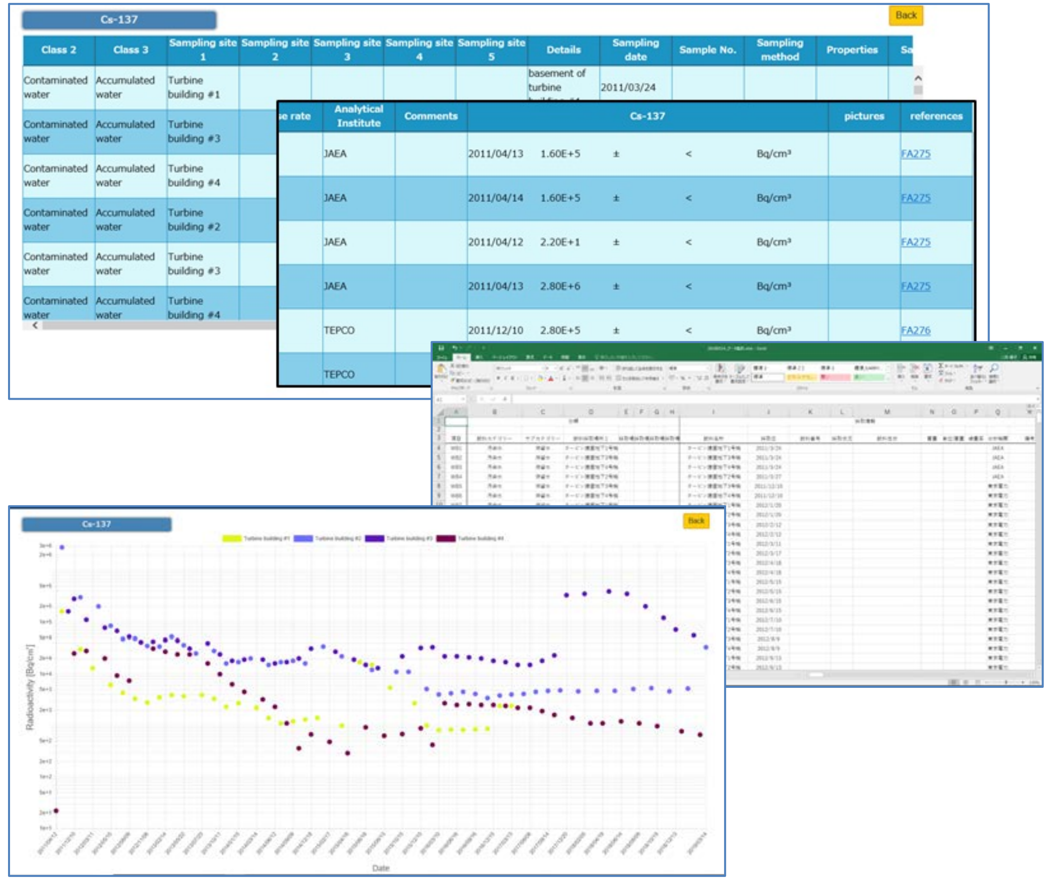


Example of basic data on disposal; Distribution coefficient of iodine for cementitious material

■ **A database, “FRAnDLi” is widely available for researchers involved in radioactive waste and decommissioning R&D**

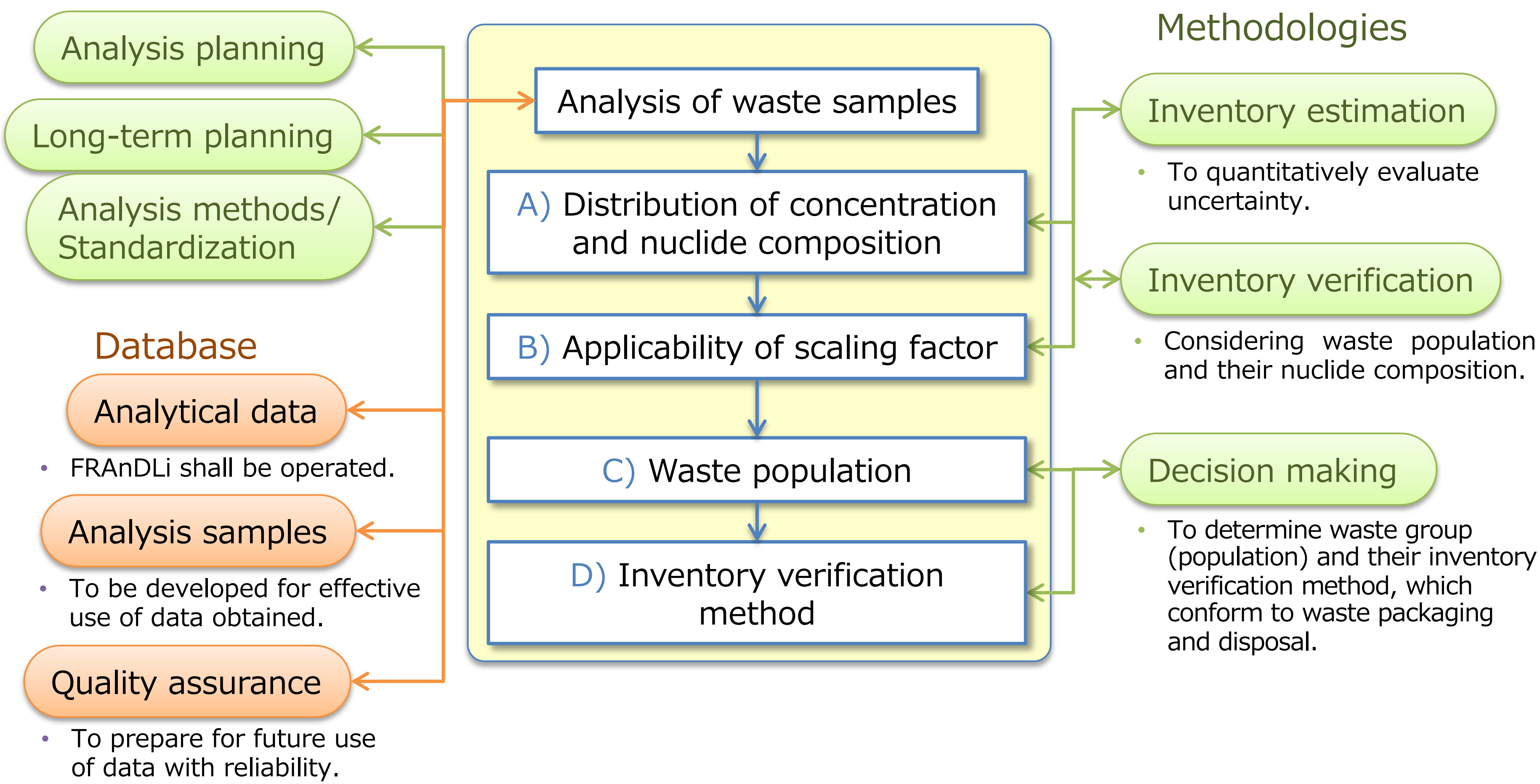


https://frandli-db.jaea.go.jp/FRAnDLi/



Example of contents; plot and tables (with CSV download)

- **Analysis data and related methodologies will be integrated to knowledge base for sustainable decommissioning activities**



Okuma Analysis and Research Center

Administrative building

Laboratory -1

- Hot-cell operation has started in October 2022.
- Analysis of low-and-medium-dose radioactive wastes.
- Analysis of ALPS-treated water as third-party institution.


Iron cells


Glove boxes


Fume hoods

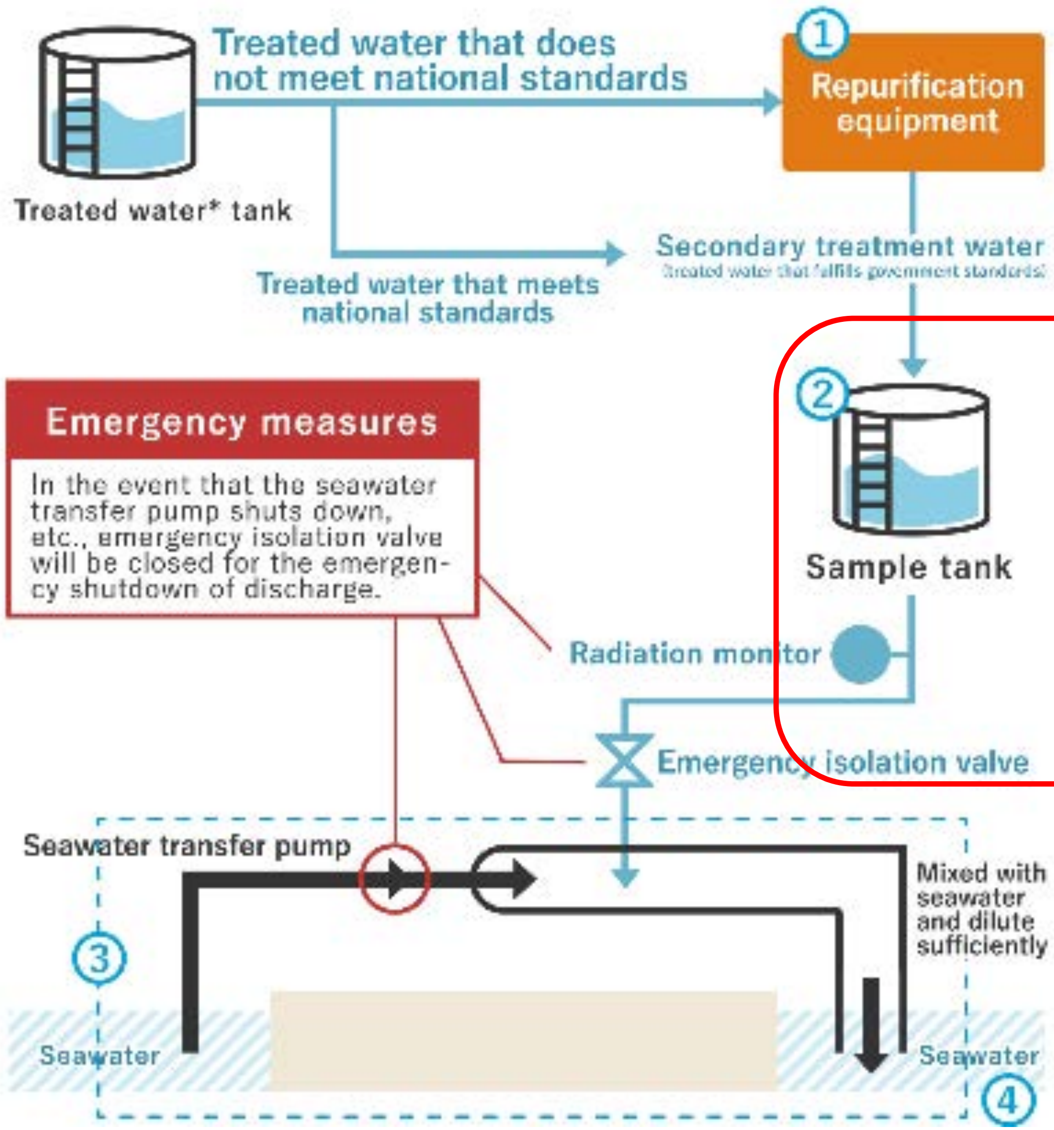
Lab-2 (Pre-construction phase)

- Construction will start soon after the licensing process to be cleared.
- Analysis of high dose samples such as fuel debris.


Concrete cells

※The image shows a concrete cells at another JAEA site.

Disposal of ALPS-treated water



❶ Repurification

❷ Treated Water Analysis

Third-party analysis will be used to confirm that the sum of the ratios to regulatory concentrations of radioactive substances, with the exception of tritium, is less than 1, and also to check tritium concentrations.

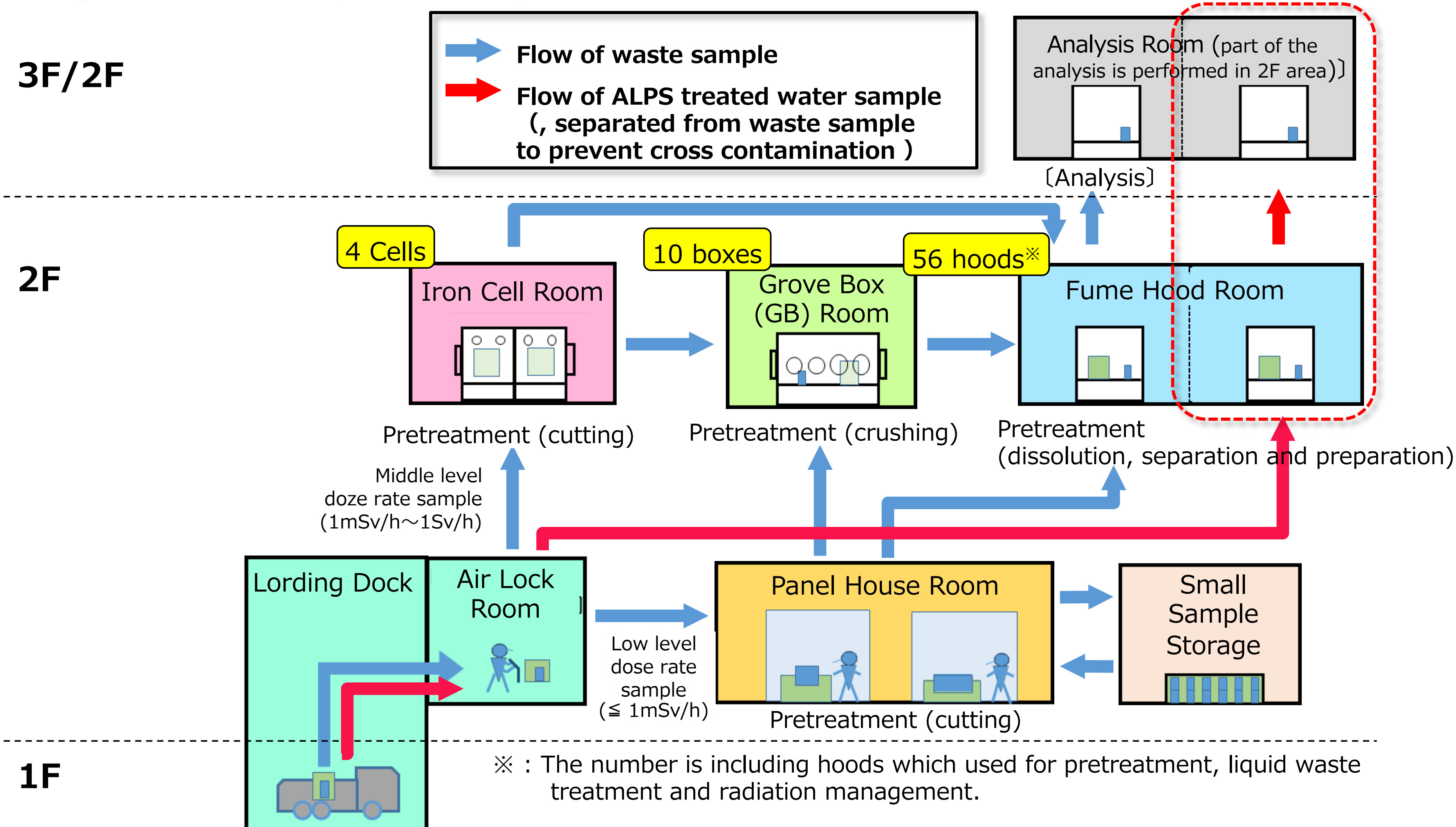
❸ Dilution with seawater

❹ Sea Area Monitoring

(Source) TEPCO website, https://www.tepco.co.jp/en/decommission/progress/watertreatment/oceanrelease/index-e.html

Disposal of ALPS-treated water
Third-party analysis at JAEA Okuma Research and Analysis Center

- Waste sample is pretreated in Iron Cell Room/GB Room/Fume Hood Rooms depending on surface dose rate. ALPS treated water sample is pretreated in Fume Hood Rooms.
- Sample flows are separated to prevent cross contamination.



※ : The number is including hoods which used for pretreatment, liquid waste treatment and radiation management.

Preparation is ongoing for reliable analysis with proper measurement methods for each nuclides

3 Steps for Analysis
①Pretreatment
②Measurement
③Evaluation

① Pretreatment

Sample is made finer, dissolved in a liquid, or separated according to properties, etc.

② Measurement

Pretreated sample is set into various measuring equipment. Acquired data is processed by calculation if needed.

③ Evaluation

Result is compared with standard value for judgement/check of data trends.

Measurement of tritium concentration in ALPS treated water

【Pretreatment】
Removing impurities that interfere with measurement by distillation

Fume Hood

【Measurement】
Measuring β radiation from tritium by liquid scintillation counter (LSC)

Example of LSC

Confirmation that the concentration of radioactive substances other than tritium is below the regulatory standard (Cs-137, Sr-90, Tc-99, etc)

【Pretreatment】
Adjusting the target nuclide to the state suitable for the measurement by operation such as separation

Ex. Separating target nuclides by operation such as solid-phase extraction that absorbs specific substance to resin

Fume Hood

【Measurement】
Measuring nuclides by equipment suitable for each nuclide
Ex.Cs-137:Ge semiconductor detector
Tc-99 :ICP-MS

Ge semiconductor detector

ICP-MS

5. Contribution to Fukushima reconstruction

Contribution to Fukushima reconstruction
Collaboration with the new Fukushima research institute (F-REI)

A pilot study of Fukushima Institute for Research, Education and Innovation (F-REI):
Long-term tracing research of Fukushima ecosystem (Long-term ecological research: LTER)

- Long-term ecological research with the use of **radioactive materials** released by the 1F accident and **stable isotopes** in the Fukushima ecosystem **as environmental tracers**
- **Field study** for a long-term ecological research in a watershed scale with a few 10 km square (installation of study field of long-term ecological research)
- Assessment of **impact of human activities** on the **biogeochemical cycle** and **biological community** in the study field of long-term ecological research

Fallout of radioactive materials

Nuclear power plant accident

<Evacuation>

<Decontamination>

✓ Return of residents
✓ Restart of human activities

1) Non-maintained semi-natural environment (plantation, Satoyama)

2) Maintained semi-natural environment (Satoyama)

Semi-natural environment (plantation, Satoyama)

Weather event
Human impact

Situation after event A

Situation after event B

Situation after event C

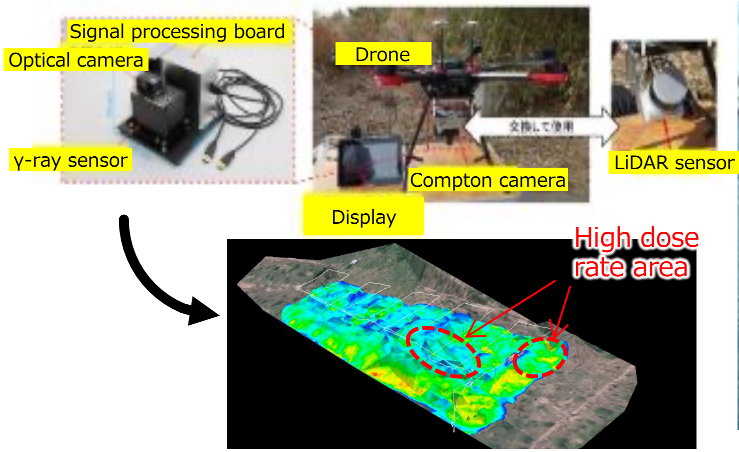
Situation after event N

"Analogue study on the impact of human activities on a semi-natural environment"

All research data is stored in the Data catalogue developed in this research

Contribution to Fukushima reconstruction
Collaboration with local stakeholders

Working with local industry partners

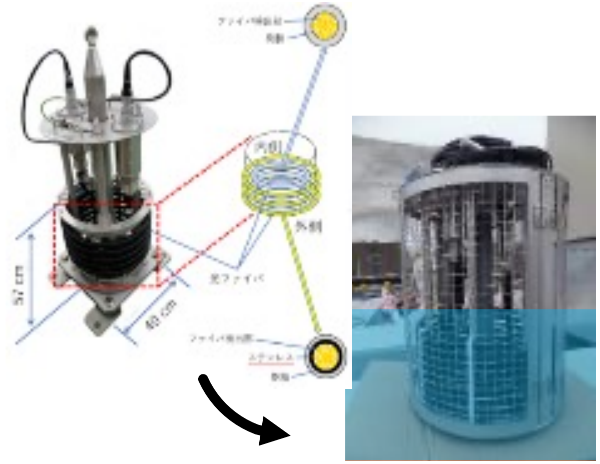


Radiation monitoring drone with visualization*1

Unmanned ship

Sensor

Unmanned ship for monitoring and sampling



Sensor for polluted water leakage

Education and training for young generation

Training courses for high-school

Creative Robot Contest for Decommissioning

*1 Y. Sato et. al., J Nucl. Sci. Technol. 2020; 57: 734–744. This system was developed jointly with Chiyoda Technol Corp..

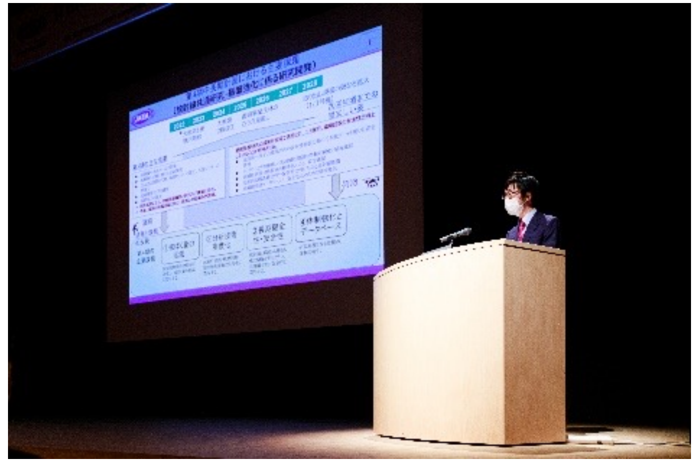
Contribution to Fukushima reconstruction
Collaboration with local stakeholders

Local events

▲ Nara-SUN-Fes 2021 exhibition ▲

▲ Open house ▲

Annual conference in Fukushima



▲ Presentation by JAEA staff

▲ Panel session

Poster session ▶

Fukushima Research Conference (FRC)

▲ FRC participants

▲ Workshop

Future conferences

Workshop on Mission H :

- Matching needs and solutions
- Promotion for Japan-UK joint research program
- FY2022 debriefing meeting

Working together for the future of Fukushima!

International Topical Workshop on Fukushima Decommissioning Research

×

JAEA's platform for fundamental research on decommissioning

Thank you very much for your attention.

未来へげんき
To the Future / JAEA