The 3rd International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station

Application of Remotely Operated Technology (ROT) under Fukushima Daiichi D&D strategy

2018. 08. 06

Toshihiko Fukuda

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF)

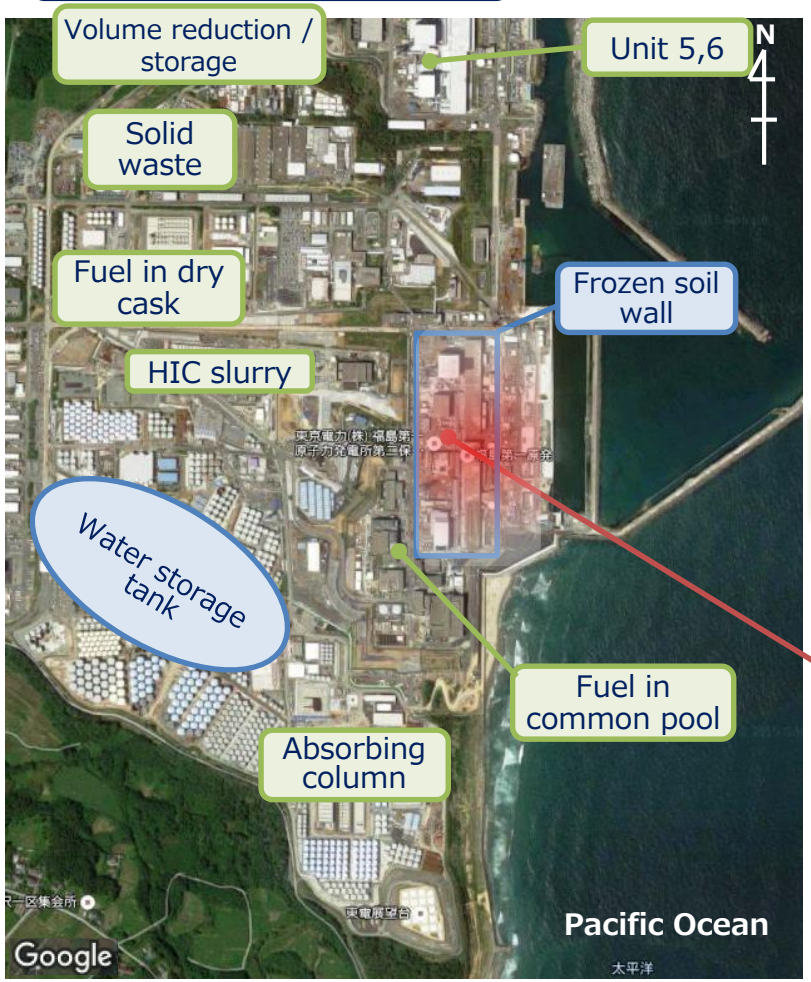
Contents for today

"Application of remotely operated technology under Fukushima Daiichi D&D strategy"

- ◆History of measures taken for 1F D&D strategy (Focused on remotely operated technology)
- ◆Risk reduction strategy for fuel debris retrieval and surveys using remotely operated technology
- ◆Policy for fuel debris retrieval and way forward
- ◆Remotely operated technology for fuel debris retrieval

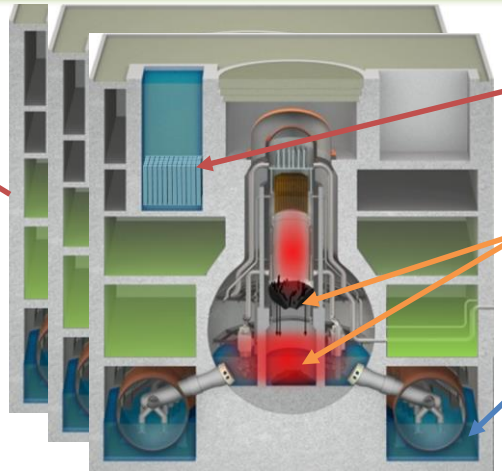
Overview of Fukushima Daiichi (1F) site

1F site



Site area ; approx. 4.4 Mm³

1F D&D is Siege of sturdy Japanese Castle?



- **Spent fuel pool**
- **Fuel debris**
- **Stagnant water**

Reactor Bld. 1-3 unit

History of measures for 1F and D&D strategy

Necessity of remotely operated technology for 1F D&D

Feature of 1F accident and its D&D

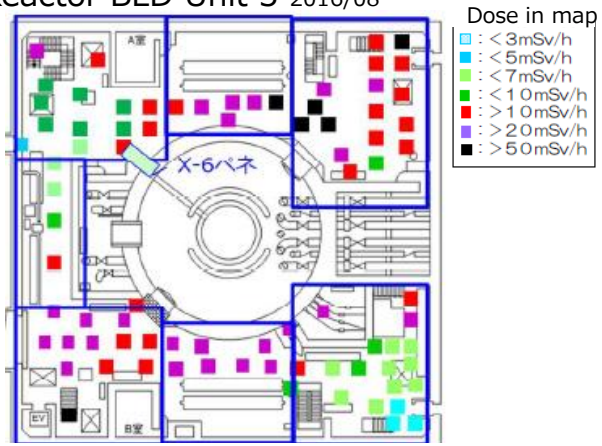
①Nearly no chance to use off-the-shelf machines and systems
②Extensive contamination and high dose
③Large damages to building/structures and scattered rubbles in-outside of Bld.
④Fuel debris scattered inside PCV, while SF left at high location
⑤Different situation at each Unit
⑥Large amount of Unknowns at site

Maximum challenge;
To secure access to the D&D site for survey and D&D work

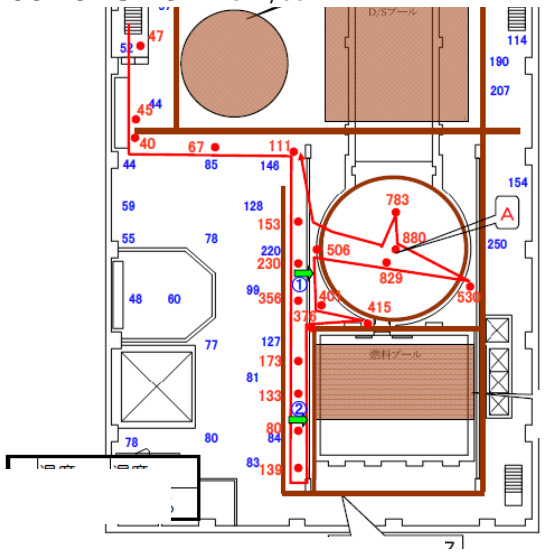
↓

Active and effective application of Remotely Operated Technology indispensable

Atmospheric Dose rate at 1st floor of Reactor BLD Unit 3 2016/08



Atmospheric Dose rate at operating floor of Unit 2 2012/06



Example of remotely operated technology at emergency response and stabilization

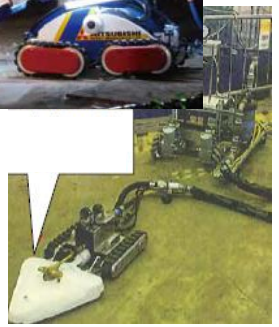
Water injection by fire truck

Remotely operated heavy machine

Water discharge to spent fuel by concrete pump car

Survey robot

Rubble removal robot



Floor decontamination robot

年	2011	2012	2013	2014	2015	2016	2017	2018
Survey (40units)	Inside RB						Inside PCV	
Decon (20units)			Unit 3 Pool Fuel/Inside RB of each unit					
Rubble Removal (24units)	Around RB		Unit 3 Pool Fuel				Unit 1 Pool	

Example of remotely operated technology for pool fuel removal

■Main demolition tool for rubble removal

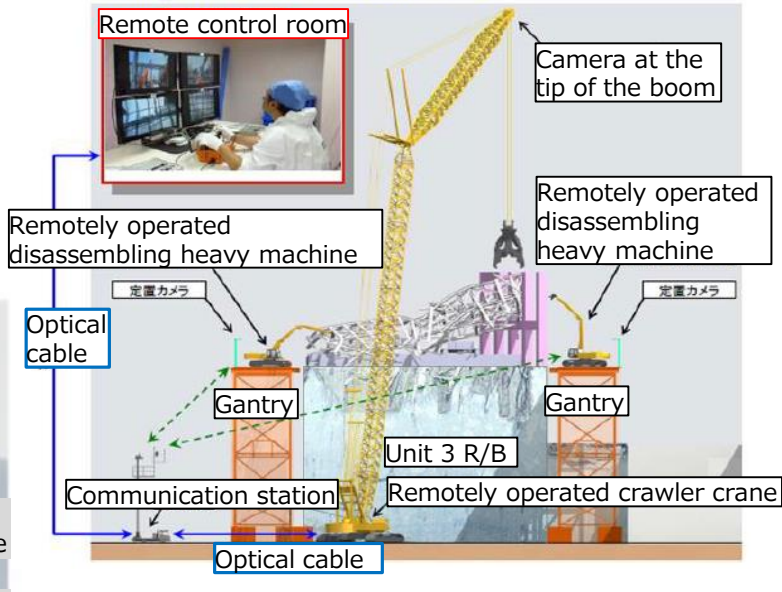

Hydraulic Fork


Hydraulic grab bucket

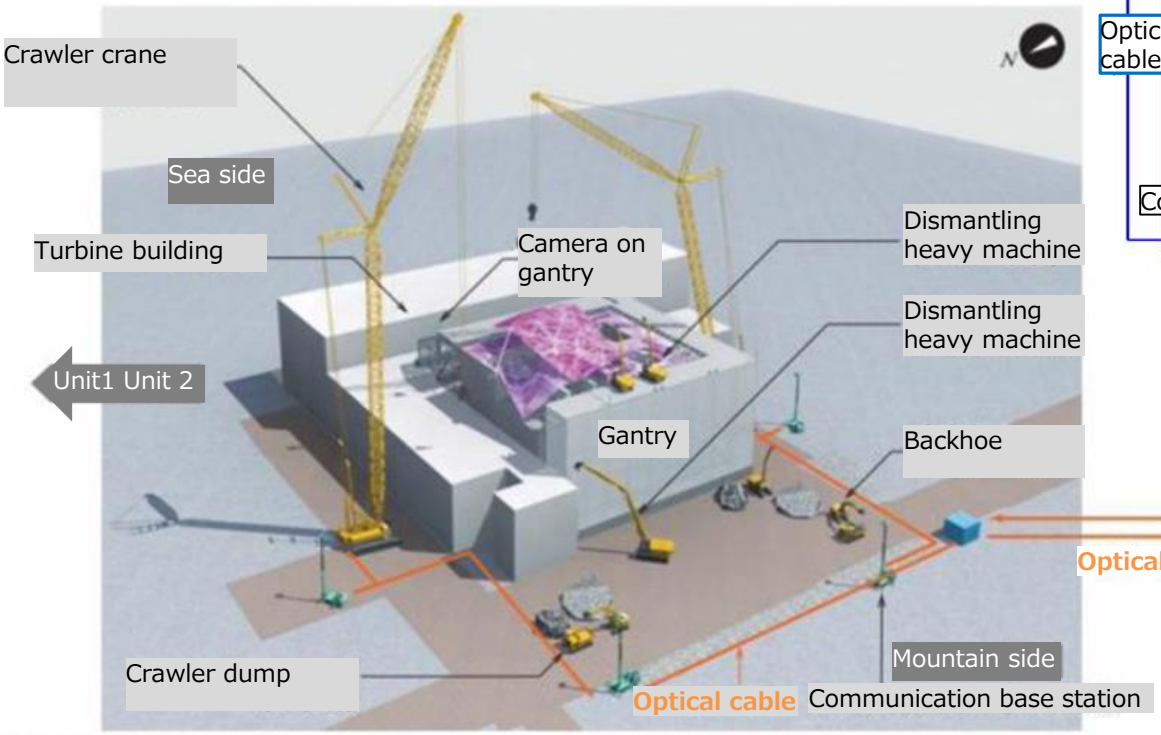

Hydraulic cutter


Hydraulic pliers

■Image of remote control system with disassembled heavy machine



■Images of rubble removal and attached building dismantling by 10 remote control heavy machines



Optical cable


Remote operation room 500 m away from the site

(資料・写真:鹿島)

Risk reduction strategy for fuel debris

Fuel debris NOW

- Certain stability
  - Cooling maintained
  - Sub criticality
  - Drastic lower release

⟷

- Risk identified
  - Uncertain
  - Unstable
  - Lack of enough control
- Threat of risk increase due to mid-and-long term aging

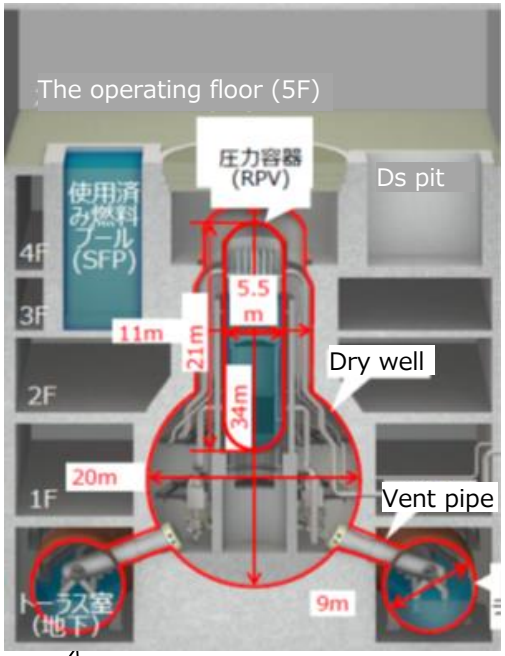
Risk reduction strategy on fuel debris

Timely and safe fuel debris retrieval → Safe and stable storage of fuel debris

Survey and understanding of the situation → Secure safety during retrieval / Removal system/method

①Identify damages at PCV (Survey of Torus room/inside R/B)	PCV repair method
②Understanding in-reactor situation (Fuel debris distribution, Inside of PCV) SA analysis codes, Muon measurement, PCV inside survey	Develop fuel debris retrieval method -Water level inside : flooding or in air -Access direction: top or side

① Identify damages at PCV (Survey of Torus room) Example of remotely operated technology



Torus room

Upper survey device of S/C for Unit 1

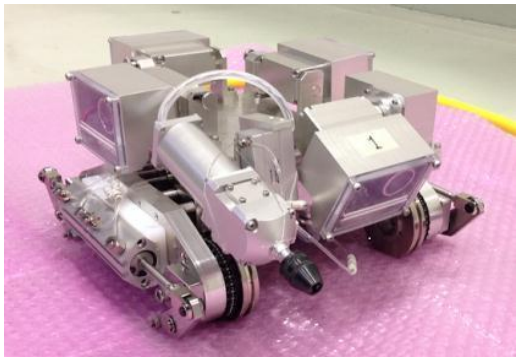
Survey device inside the torus room

Waling survey device at the lower vent pipe

S/C Inner side survey device

Wall surface survey device of torus room

Wall surface survey device of torus room

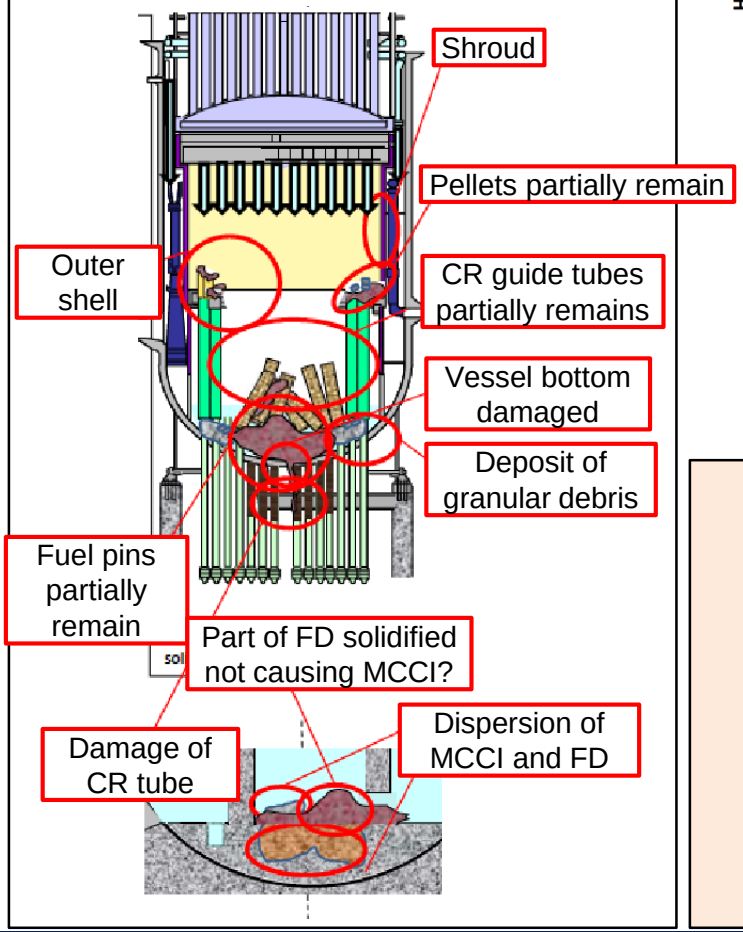


S/C Lower Outside survey device

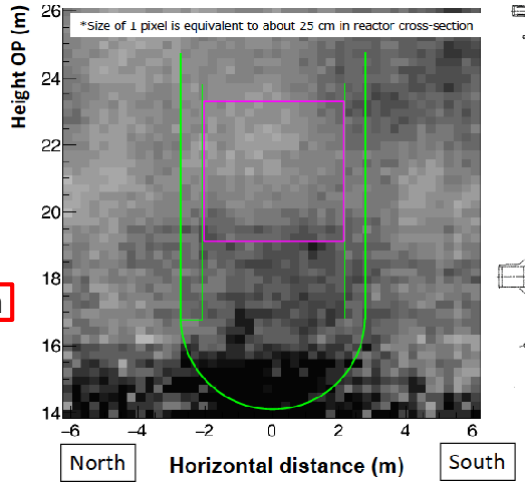
② Understanding in-reactor situation

SA Analysis

Estimation by MAAP/SAMPSON

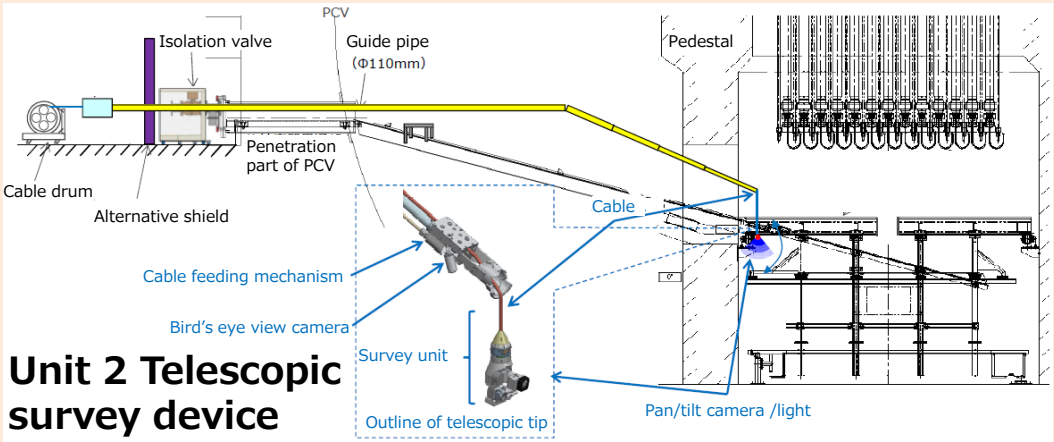


Muon measurement



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

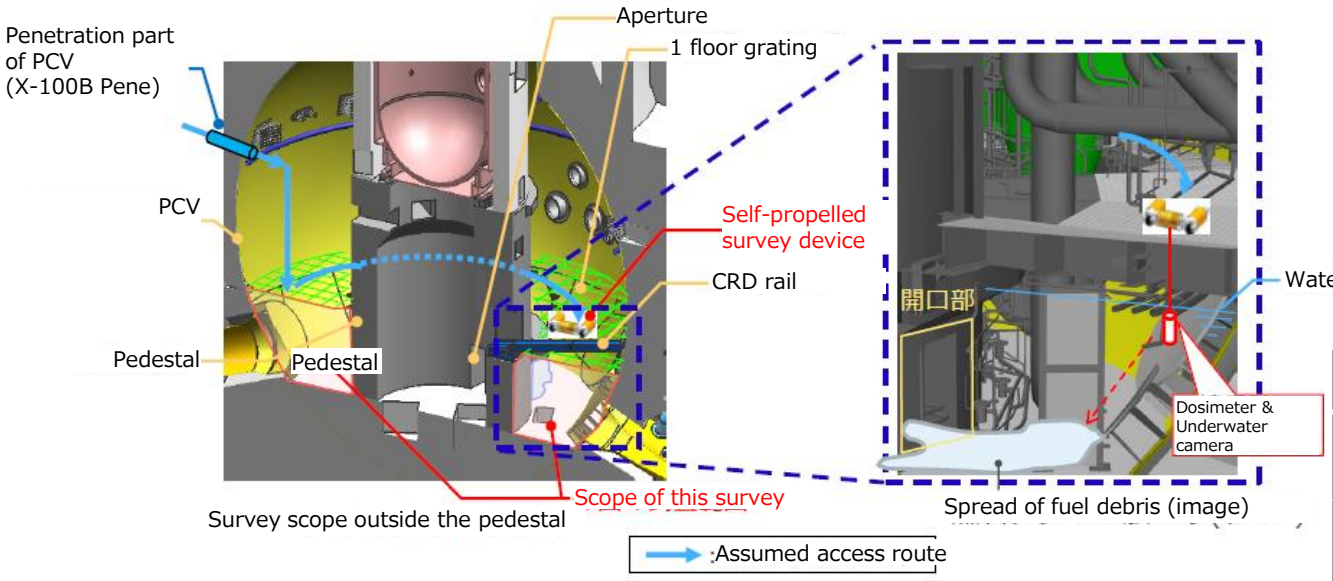
Remote survey

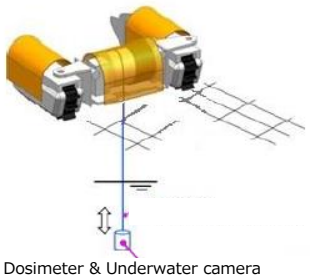


Unit 2 Telescopic survey device

Inside PCV survey Unit 1 (March 2017)

Outside of Pedestal with possible scatter of Fuel Debris

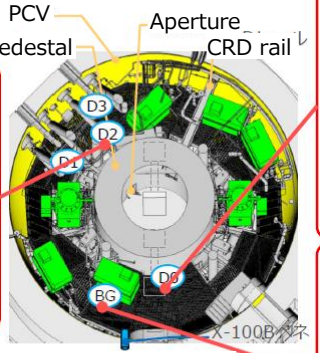




Measurement point	D0	BG	D2
On the grating Radiation dose(Sv/h)	7.8	3.8	12
Lowest point Radiation dose(Sv/h) (Height from the floor)	1.5 (約1m)	11 (約0.3m)	6.3 (約1m)

■ Representative images taken are as follows

3/20 D2 Shooting on lowest point



1 floor PCV section

3/18 D0 Shooting on lowest point

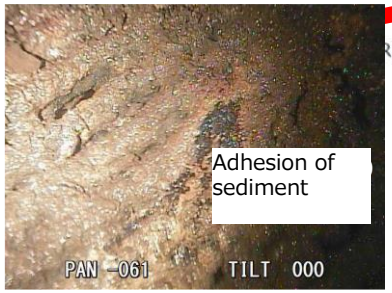
3/19 BG Shooting on lowest point

- First shoot of PCV bottom close pedestal opening
- Confirm deposits at PCV, Piping etc.
- Low dose underwater, while high dose closer to the floor
- No serious damages at existing structures
- ✓ **Next step to look into PCV floor conditions based on images and dose data obtained**

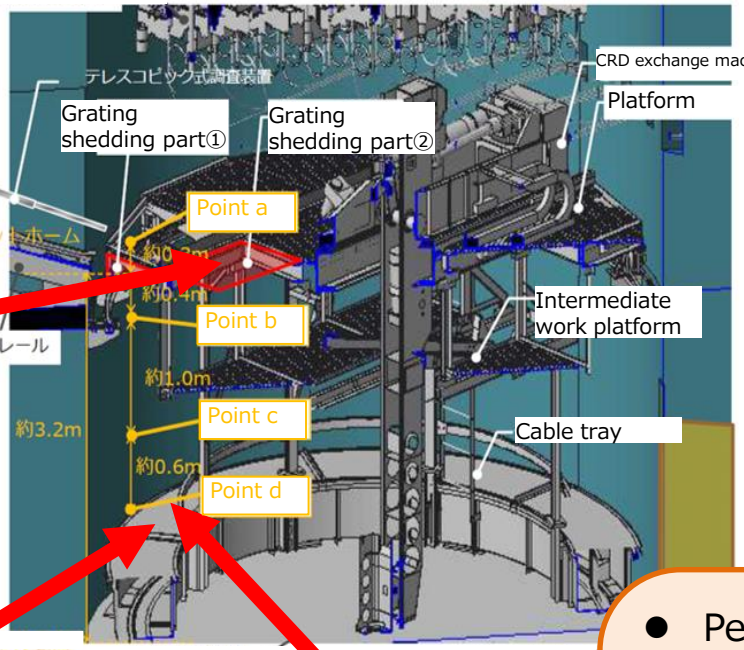
Inside PCV survey Unit 2 (Jan. 2018)

Bottom of Platform with possible scatter of Fuel Debris

PCV External
Work area in front of X6



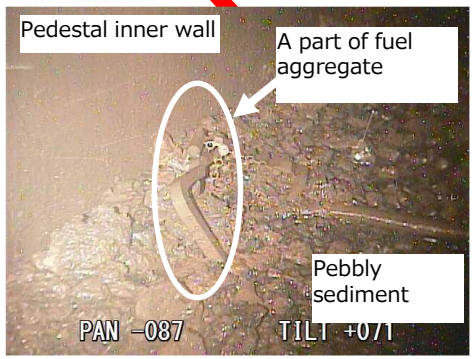
Grating shedding②



Measurement point	Dose rate [Gy/h]	Temperature [℃]
a	7	21.0
b	8	21.0
c	8	21.0
d	8	21.0

【Reference : Outside the pedestal】
Dose rate : Max 42[Gy/h]
Temperature : Min 21.1[℃]

Pedestal bottom



Pedestal bottom

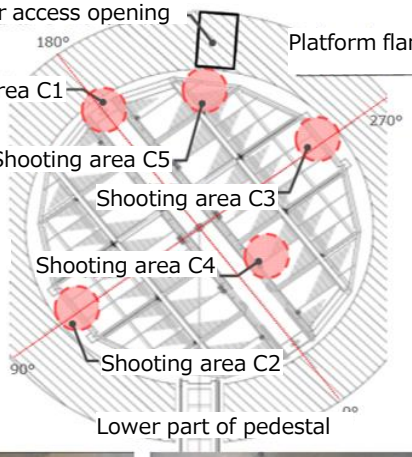
- Pebble like and Clay like Deposits at Pedestal bottom
- **Parts of FA fallen at Pedestal bottom. Deposits nearby could be Fuel Debris**
- **Higher dose rate at outside Pedestal than inside Pedestal**
- ✓ **Next step to look into PCV floor conditions based on images and dose data obtained**

Inside PCV survey Unit 3 (July 2017)

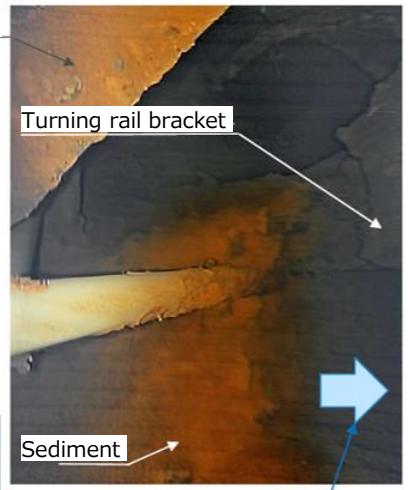
Survey of Inside Pedestal by Under water ROV

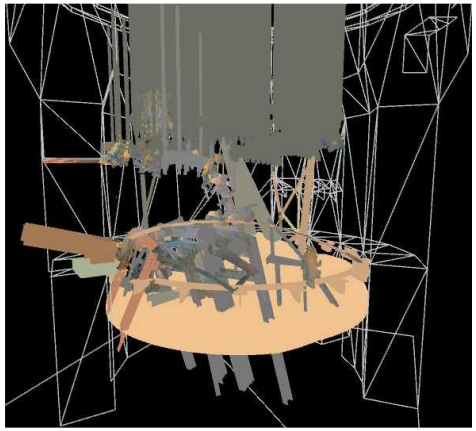
Shooting area C1
<Camera Orientation : Downward >

Sediment (Pebble shape)

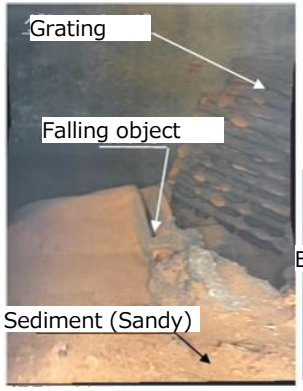


Shooting area C5
<Camera Orientation : Downward >



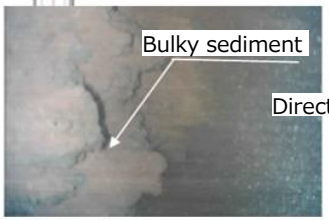


3D reconstruction from video



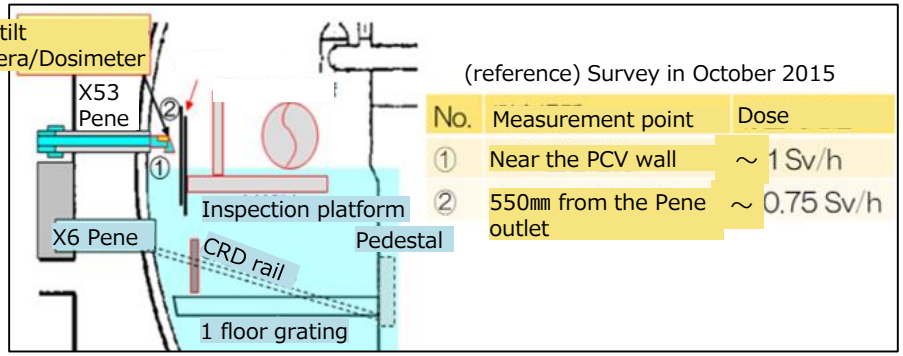
Shooting area C2
<Camera Orientation : Horizontal >

Shooting area C3
<Camera Orientation : Above >



Shooting area C4
<Camera Orientation : Downward >

Direction of worker access opening

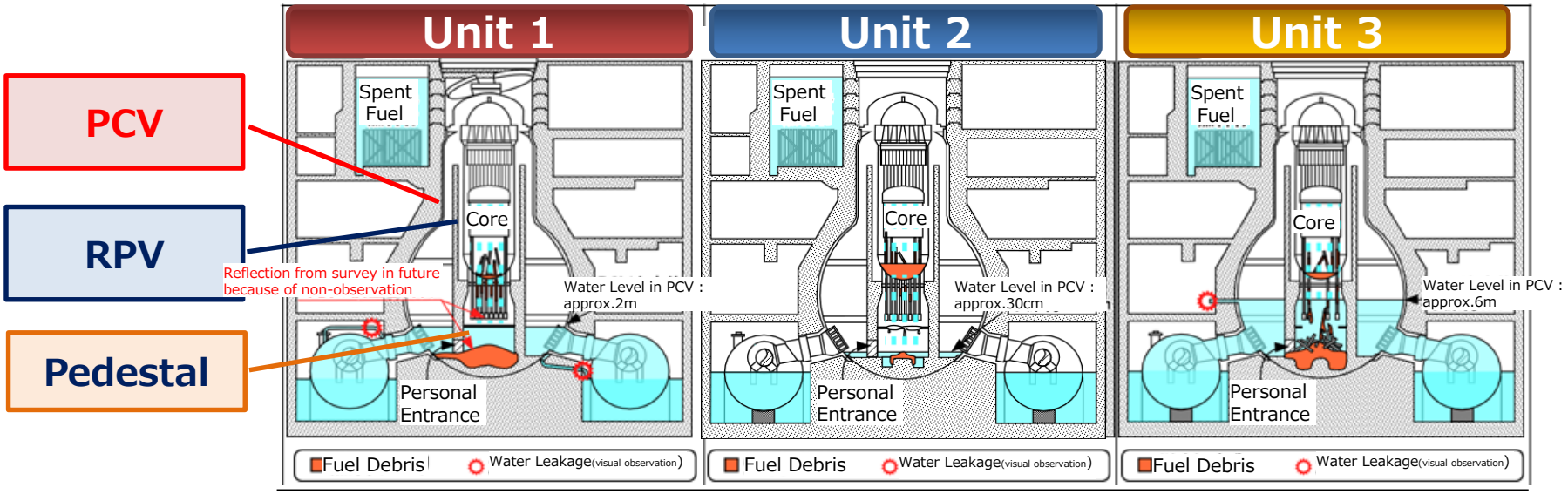


(reference) Survey in October 2015

No.	Measurement point	Dose
①	Near the PCV wall	～1 Sv/h
②	550㎜ from the Pene outlet	～0.75 Sv/h

- Sand like, Pebble like and Agglomerate like deposits bottom of Pedestal inside
- No direct observation at the opening for work access, while Deposits nearby confirmed
- ✓ Next step to study the design and procedures of retrieval system and pointed jigs using the information obtained on “conditions/positions of possible interfering structures” and “characterization/positions of FD”

Fuel debris in each Unit（Estimate）

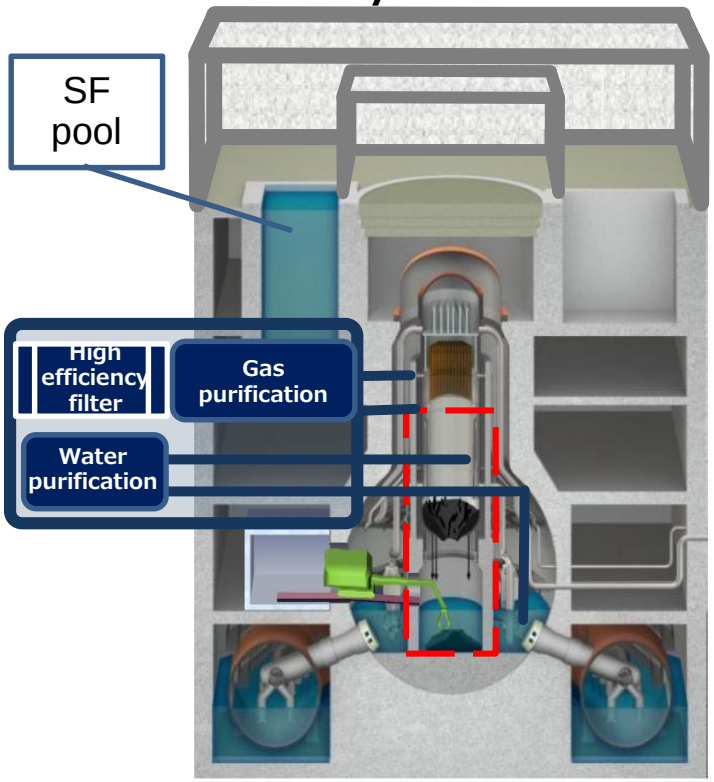


Situations of FD (Distribution estimated)	**●Small amount at bottom of RPV** **●Most of the amount at bottom of PCV**	**●Most of the amount at bottom of RPV** **●Small amount at bottom of Pedestal**	**●Part of the amount at bottom of RPV** **●More amount at bottom of PCV than Unit 2**

Fuel debris retrieval policy

【Most cautious care required for fuel debris retrieval with safety first】

1 : Leak prevention
2 : Lower exposure
3 : Safe recovery



Tech. Req.
Integrity of structure (seismicity)
Labor safety
Lower dose (Decontamination・Shield)
Confinement
Development of FD retrieval machine
Prevention of recriticality
Water level control

Retrieval Policy

① Step-by Step approach

② Optimization of whole D&D work

③ Combination of multiple methods

④ First priority to partial submersion method

⑤ Initial challenge to remove horizontally from the bottom of PCV

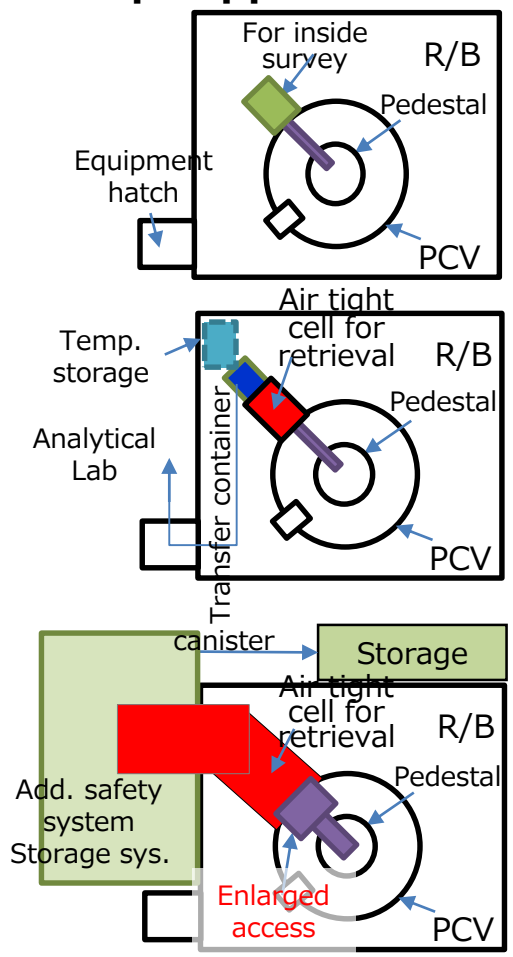
Way forward for fuel debris retrieval

Pre-Engineering → **Selected and focused R&D** → From R&D to actual D&D engineering phase

Image of “Step-by Step” approach for fuel debris retrieval

- Precede with horizontal retrieval at PCV bottom
- Stepwise enlargement based on new findings with flexible planning

Image of “Step-by Step” approach



① Inside survey

- ✓ Gather and reflect information and insights (on internal conditions, FD distribution etc.) for the help of FD retrieval by utilizing existing PCV opening
- ✓ Sampling and analysis of deposits for characterization

② Small scale retrieval

- ✓ Sampling of amount of deposits needed for FD characterization
- ✓ As a preparation for large scale FD, continuously pick up small amount of FD utilizing systems for survey and current safety system
- ✓ Store temporarily within buildings by fixing storage policy

③ Large scale retrieval

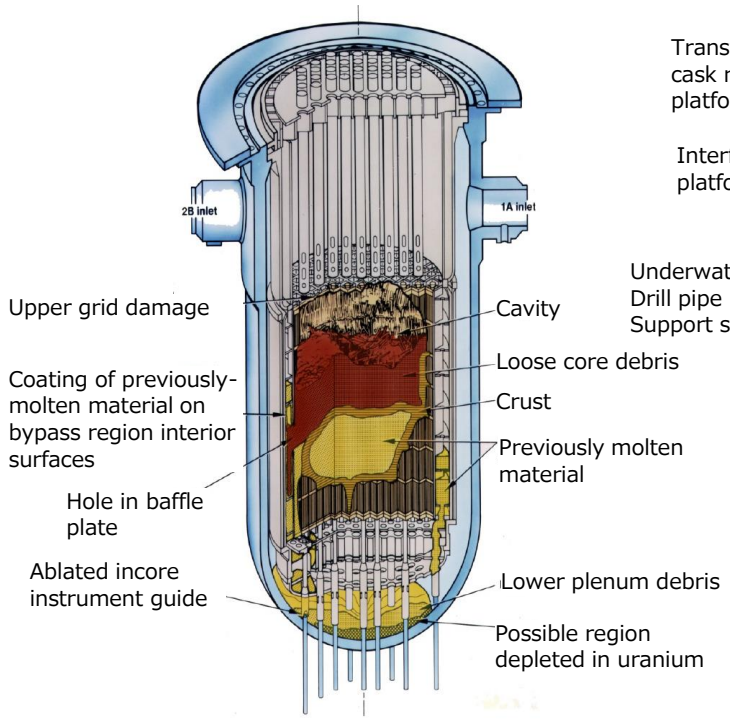
- ✓ As a continuous FD retrieval, PCV opening is enlarged and safety system and storage system is established. Then after large scale FD retrieval is to be started.

FD retrieval strategy of TMI-2 （Reference）

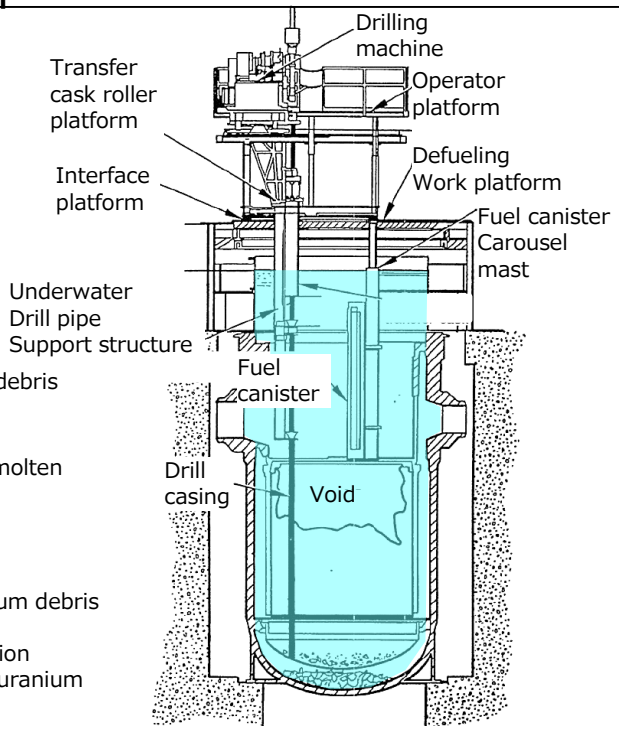
Features of TMI-2 Accident

- ✓ FD stayed inside RPV
- ✓ Workable with FD covered with water
- ✓ Relatively low dose upper RPC

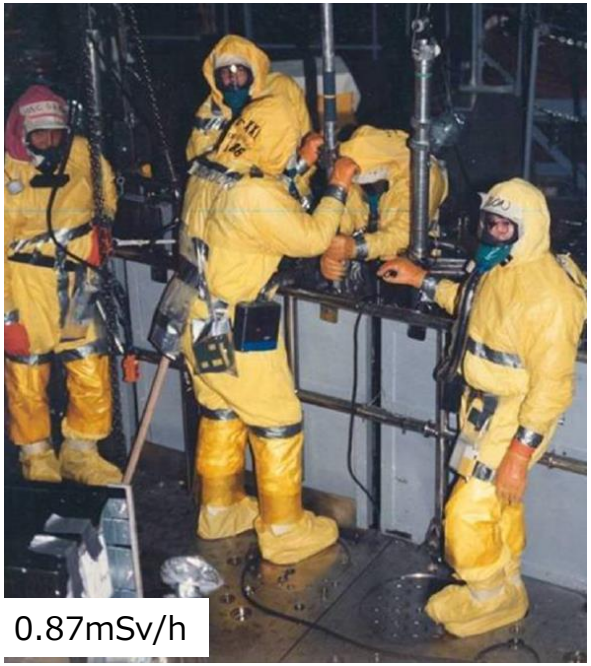
⇒Limited high contamination and working area
⇒Easier shielding and dust scattering prevention
⇒Easier access to upper RPV



Internal reactor



Fuel debris removal in flood



A state of removing fuel debris

Ref. : NUREG/KM-0001, Supplement1

Difficulties to apply remotely operated technology to FD retrieval

10 Challenges

1. Extremely severe radiation environment：High radiation resistance（Electronic parts，particularly camera）
2. Severe working conditions （dark, high-humidity, dust etc.) : Lighting, Weather proof
3. Damaged structures, obstacles (rubbles, water, depositions etc.) : Avoidance and removal of obstacles
4. No logistics（electricity, communication, measuring devices）：wired electricity supply and information transmission, judgment of orientation
5. Long distance for access and transportation of heavy load：trade-off between long distance for move and pay load
6. Unknown characterization of FD（hardness、fragility etc.）:preparation of versatile tools
7. Trade-off with safety function（confinement, cooling, sub criticality, inertization, structural integrity)：particularly entry/exit system with simultaneous confinement, min. necessary opening
8. Remote operation from the distance; man-machine interface
9. Long term operation：high-reliability equipment, maintainability
10. Likelihood of troubles and unplanned events ：rescue functions

To overcome by;
Solution of individual challenges
Development of elementary technologies
And overall system integration

Remotely operated technology at New Stage

Fuel Debris Retrieval

New stage Ⅳ to apply remotely operated technology to extremely high challenges

Stage – Ⅰ
Location : **Outdoor**
Objectives :
・Removal of rubble, transportation
Remote technology :
・Existing heavy machine
Feature :
・Emergency

Stage – Ⅱ
Location : **Inside R/B**
Objectives :
・Decontamination, survey
Remote technology :
・Small heavy machine, robot
Feature :
・Rubble, narrow
・Secure electricity, communication

Stage – Ⅲ
Location : **Inside PCV**
Objectives :
・Survey
Remote technology :
・Small robots etc.,
Feature :
・Small access
・Unknown Unknowns
・Secure confinement

Stage – Ⅳ
Location : **Inside PCV**
Objectives :
・Fuel debris retrieval
Remote technology :
・Large robots etc.
Features :
・Long distance access
・Keep debris shipment and confinement
・Long reach, heavy load
・Complex system
・Long working time and maintenance

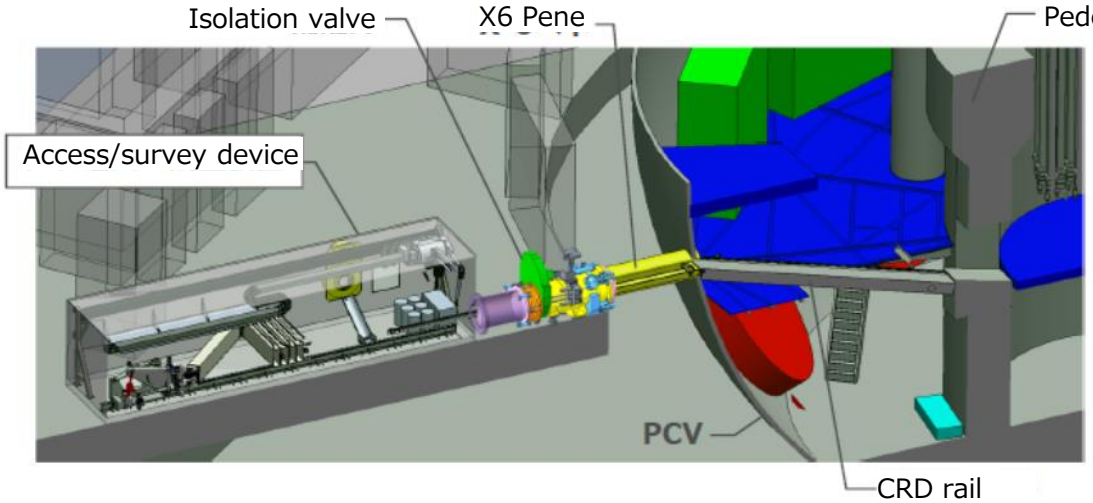
	Stage – Ⅰ	Stage – Ⅱ	Stage – Ⅲ	Stage – Ⅳ
Environ-ment	low dose rate	high dose rate	extreme high dose rate	extreme high dose rate
Scale	large	medium	small	large
Type	mobile	mobile	mobile	fixed
Usage	D&D work	survey/D&D work	survey	D&D work
Period	short~medium	short	short	long（permanent）
Develop-ment	nil	small	medium	large

ROT* for FD retrieval (1) In-PCV detail survey -1

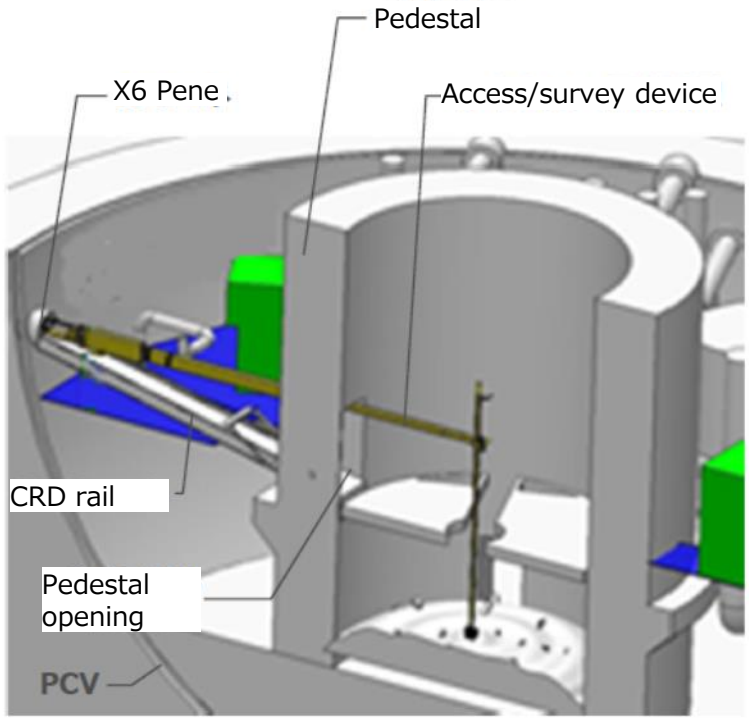
In PCV investigation next step

Use arm type manipulator enabling extensive survey through X-6 penetration again

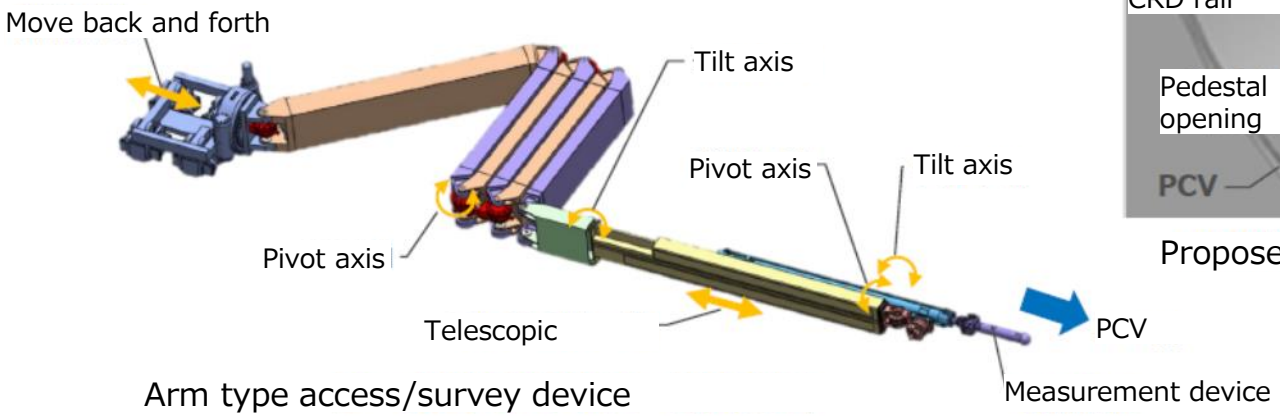
Try to understand scattering of structure inside of PCV and dose rate



Draft plan for access/survey device installation in front of X-6



Proposed deployment of access/survey device

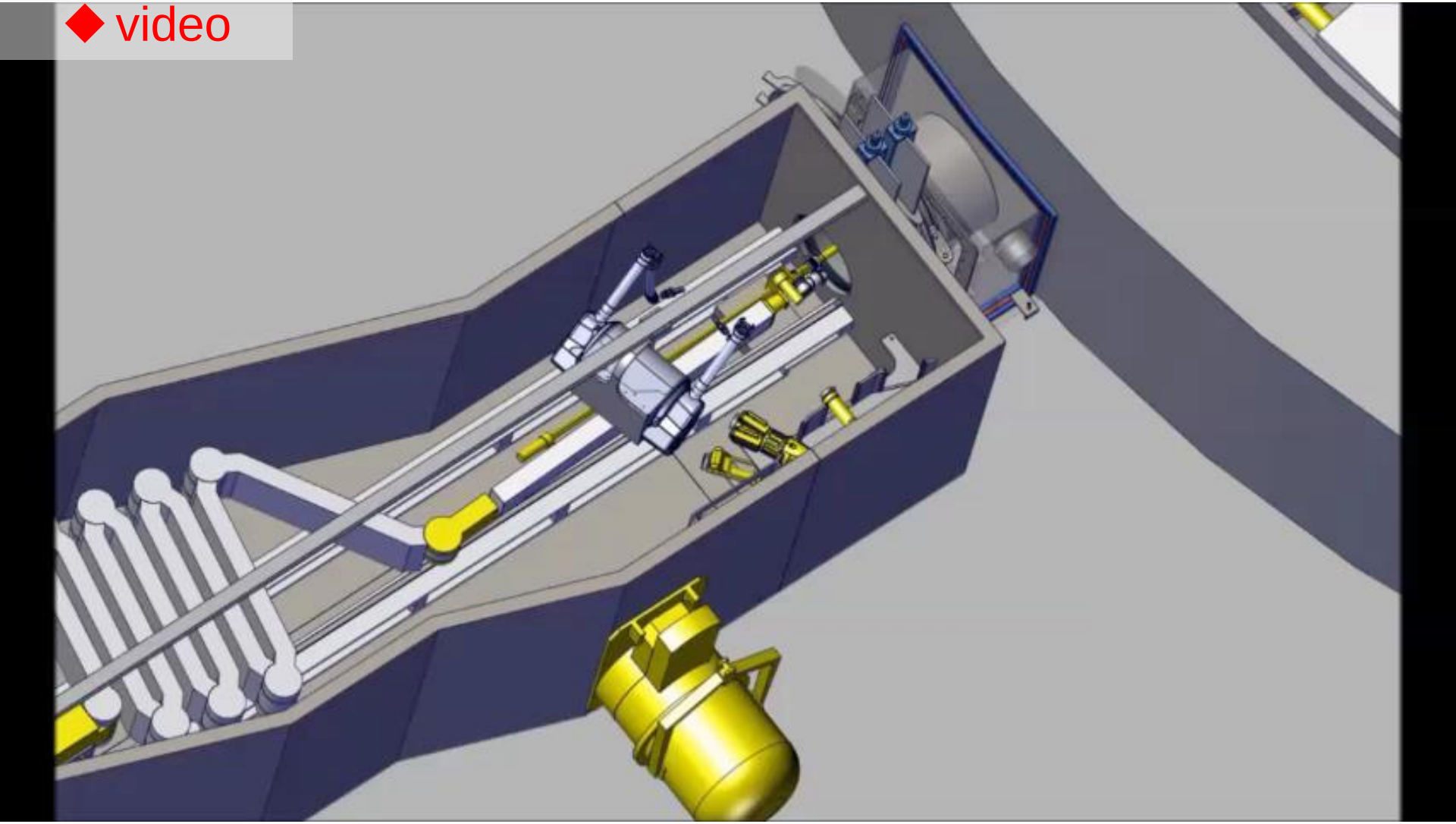


Arm type access/survey device

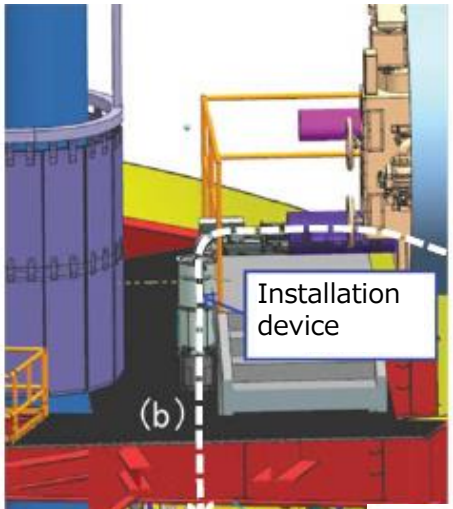
ROT*
Remotely Operated Technology

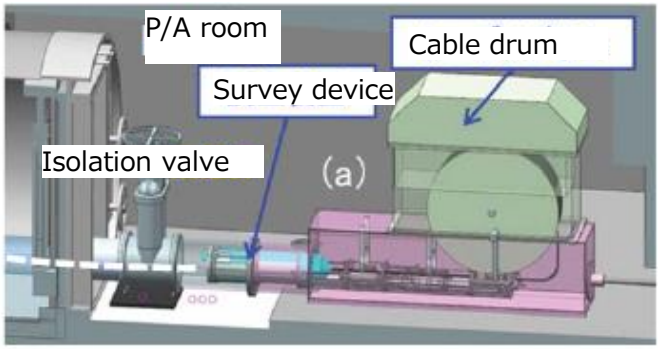
ROT for FD retrieval (1) In-PCV detail survey-2

◆ video

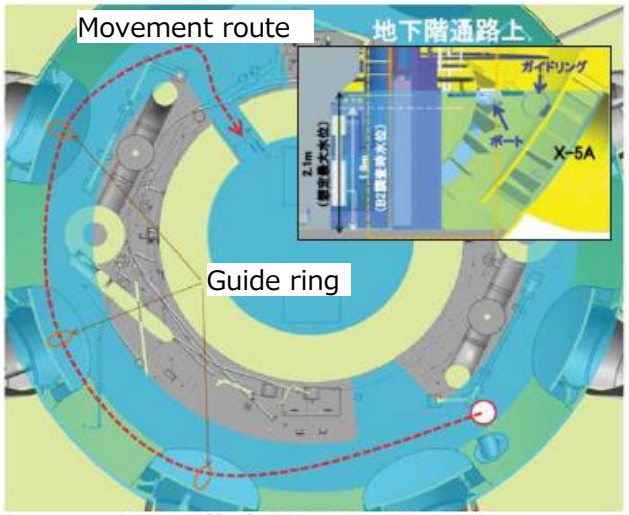


ROT for FD retrieval (1) Inside PCV Investigation-3

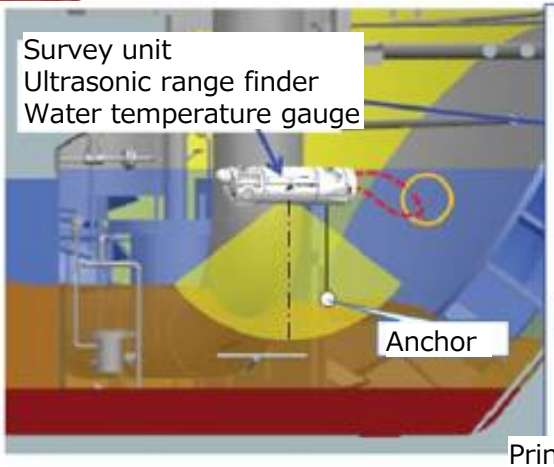




Unit 1 access/investigation machine



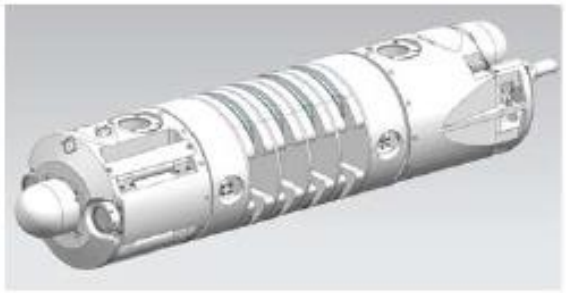
Underground transport



Appearance of sensor

Principle of measurement

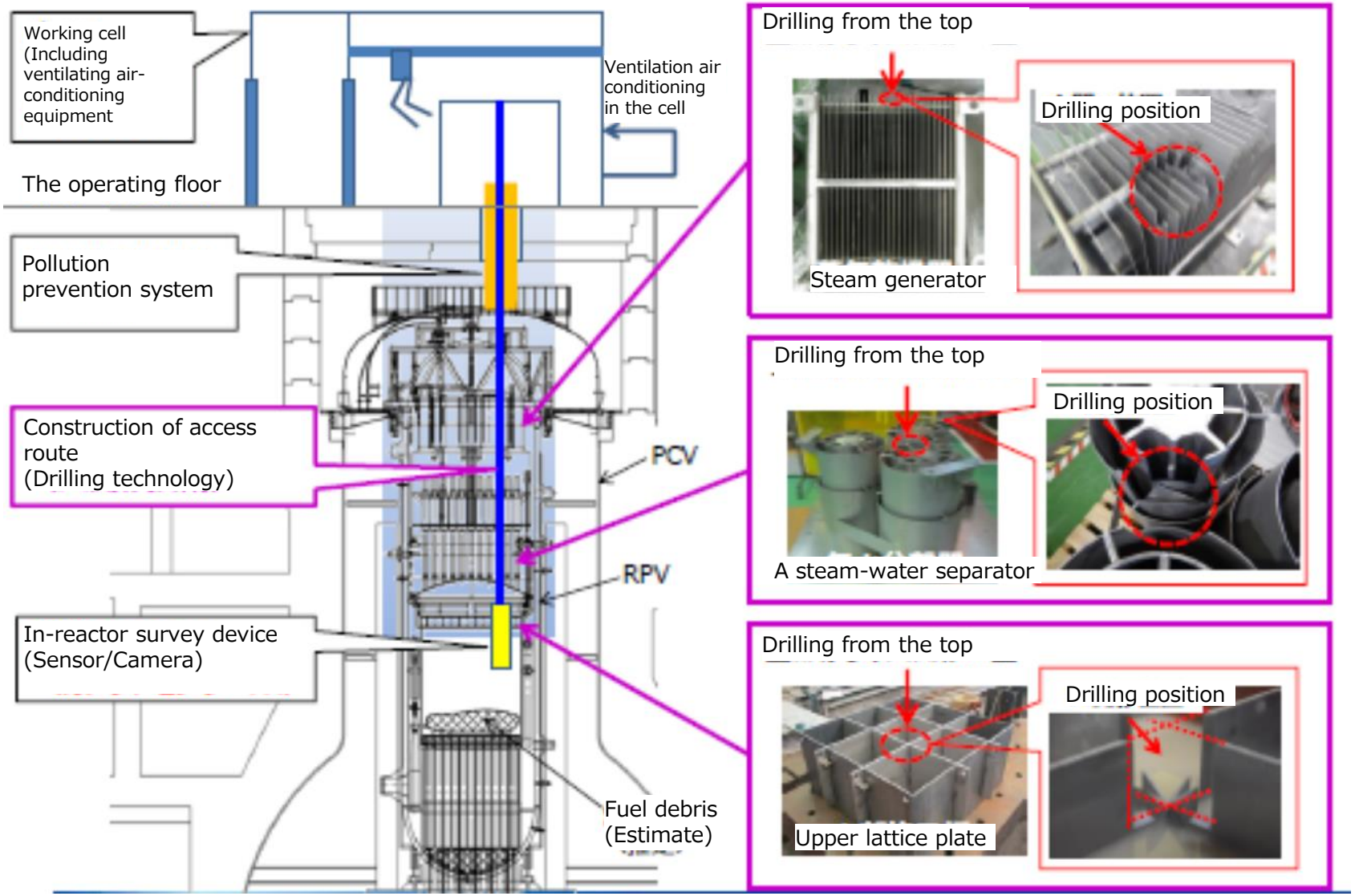
Scanning type UT distance measurement



ROV for guide ring installation
Diameter : φ25cm
Length : approx. 1.1m
Thrust : over 25N

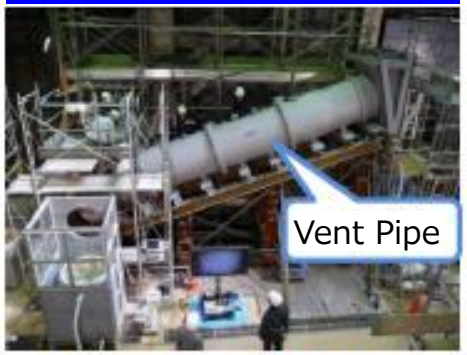
Underwater rover

ROT for FD retrieval (2) In-RPV Survey



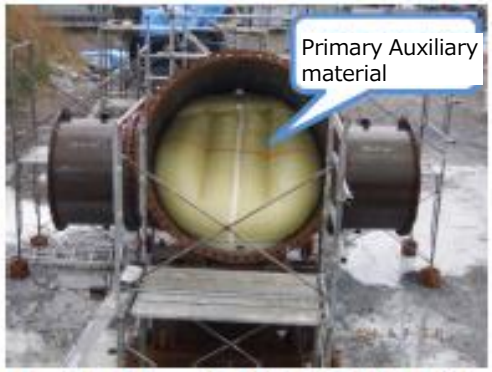
ROT for FD retrieval (3) Water stoppage at PCV bottom

Vent tube test

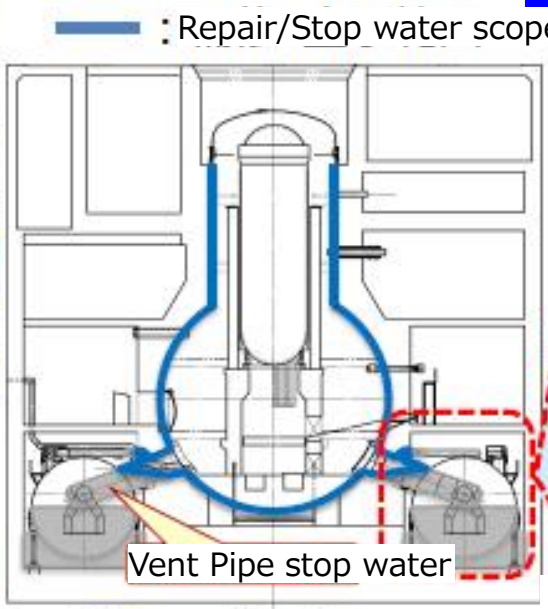


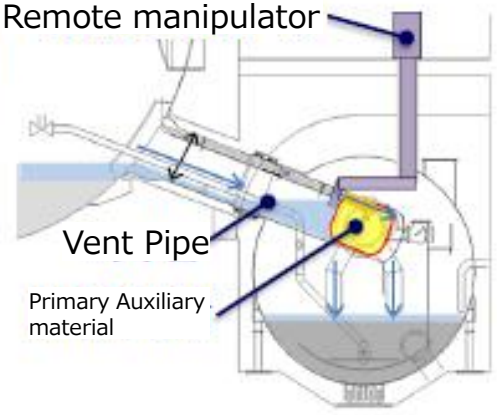
Confirm waterproof performance on 1/2 scale

Inflatable bag sealing test

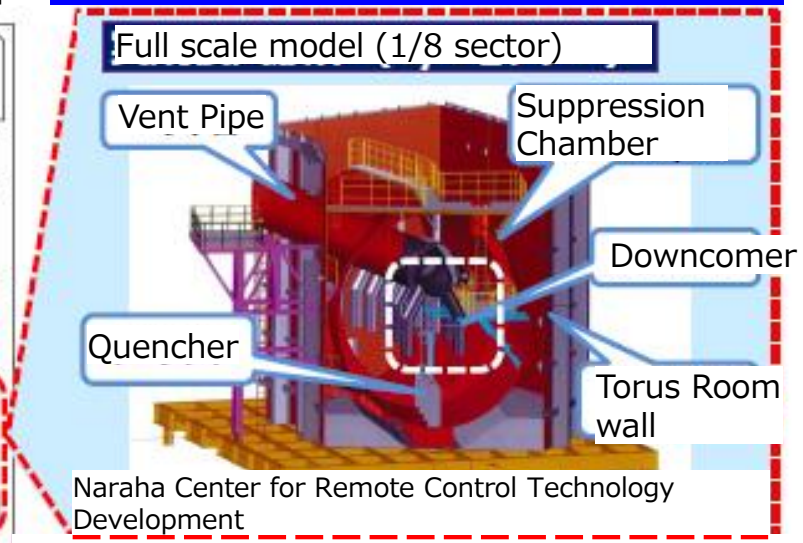


Confirm waterproof performance on 1/1 scale





Full scale test (1/8)



Naraha Center for Remote Control Technology Development

Remote manipulator

ROT for FD retrieval （4） Small scale retrieval

Insert access tool to

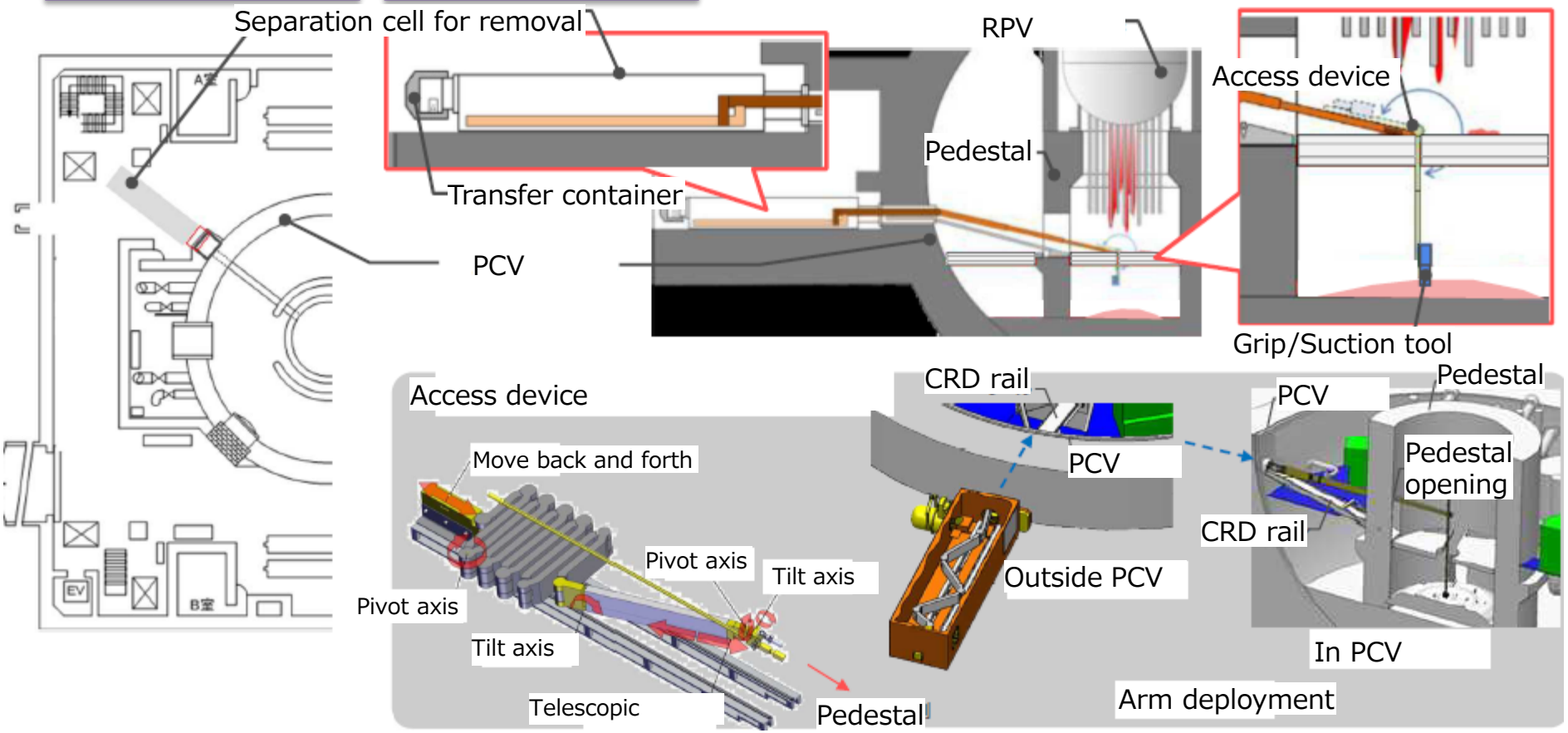
Penetration at PCV located 1st floor of Reactor Building

Retrieve FD located bottom of RPV horizontally

Small step

No new penetration made at PCV and building (no structural influence)

No influence to controlling of gas, water, criticality

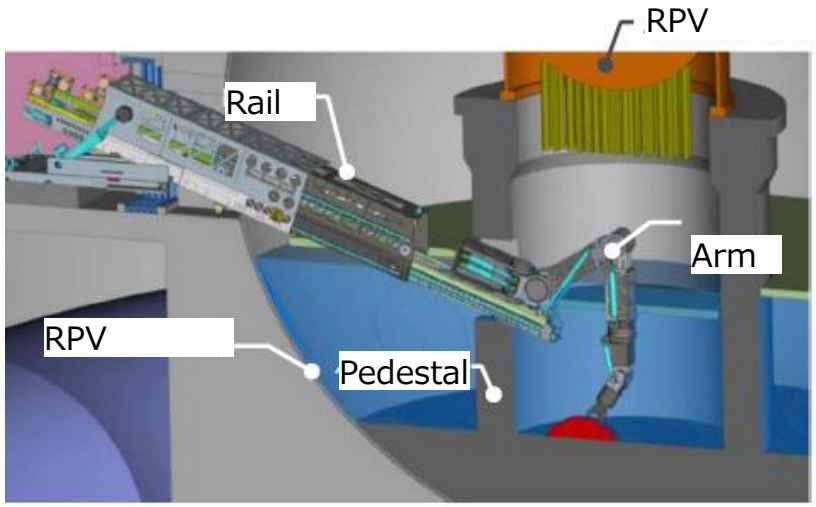


ROT for FD retrieval（5）Large scale retrieval-1

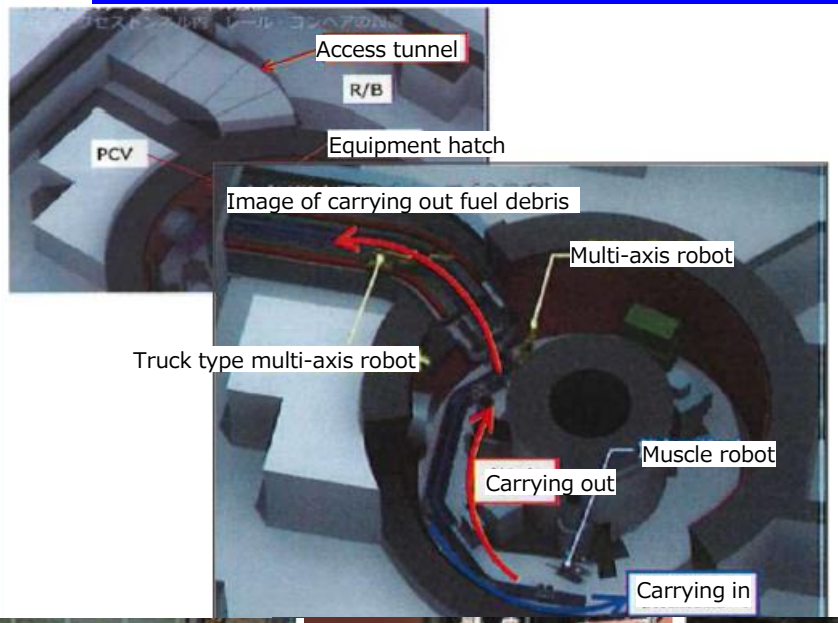
Summary

- Large scale retrieval like boring of cluster type debris
- Criticality control, confinement (gas/liquid)

Horizontal access (example 1)



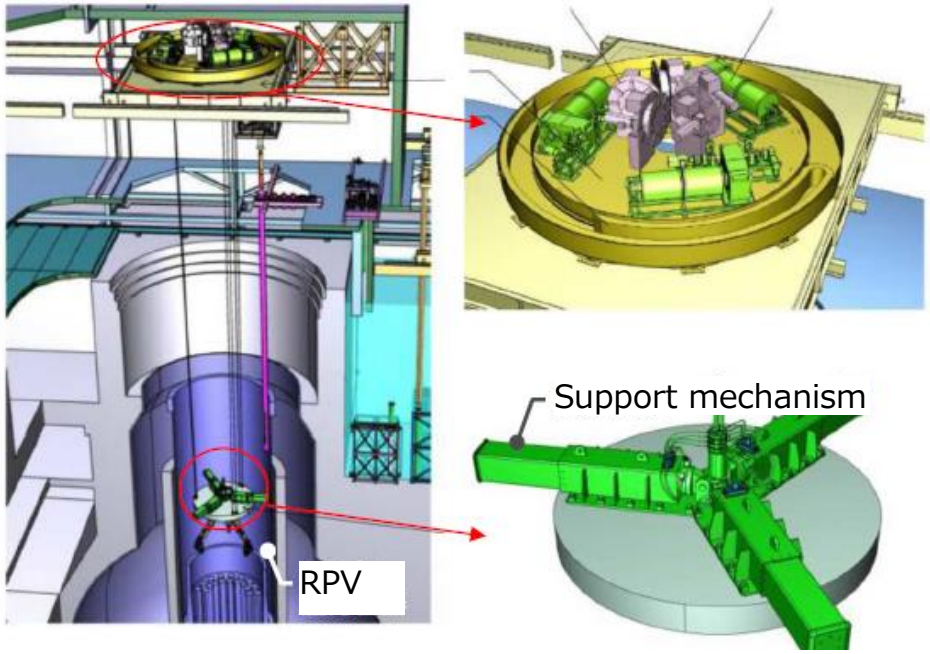
Horizontal access (example 2)



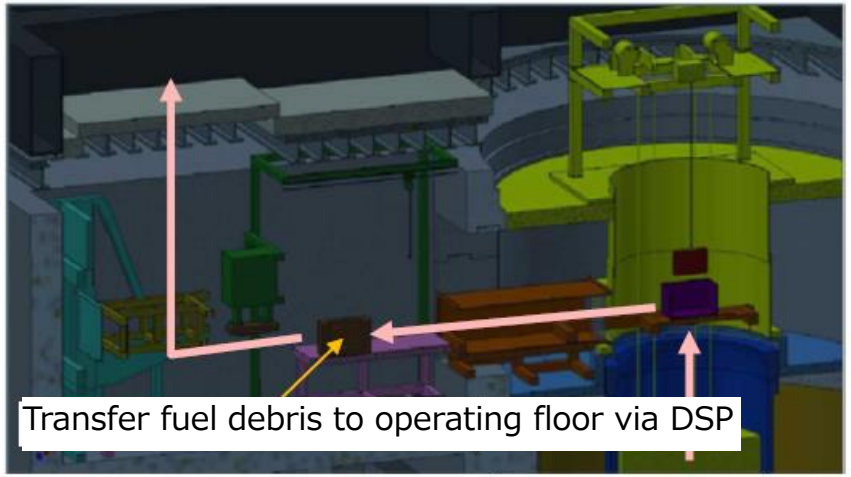
Working robot

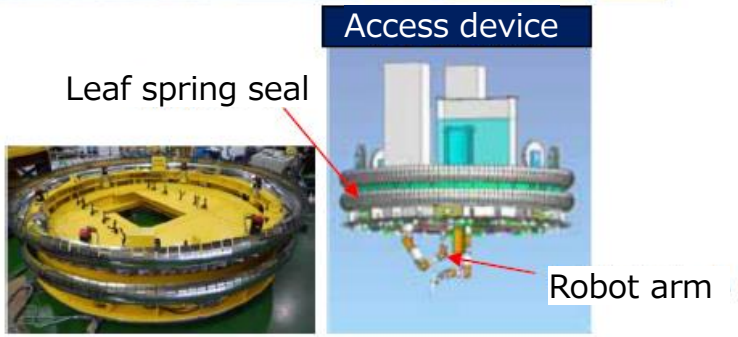
ROT for FD retrieval（5） Large scale retrieval-2

Vertical access (example 1)

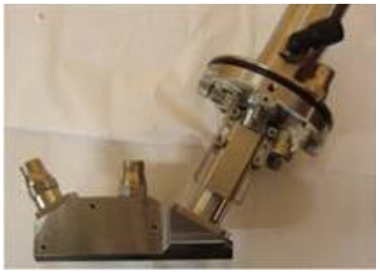


Vertical access (example 2)



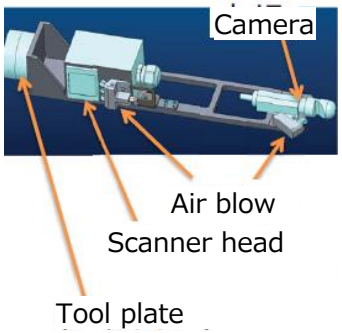


ROT for FD retrieval (6) Elementary and measuring technology



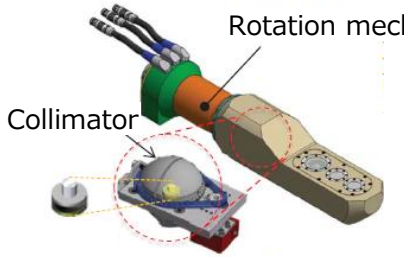
Development of underwater non-penetrating laser cutting head

Preliminary test of chisel processing



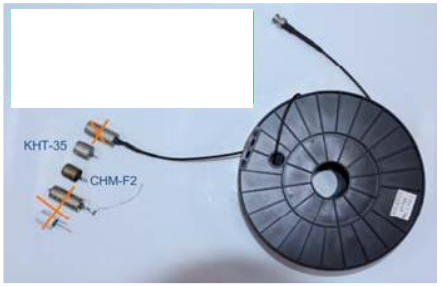
Development of geometry measurement device by light cutting method

Development of a radiation-resistant imaging tube camera

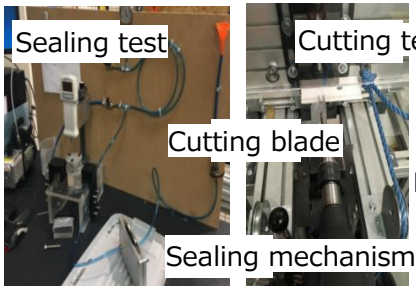


Gamma camera

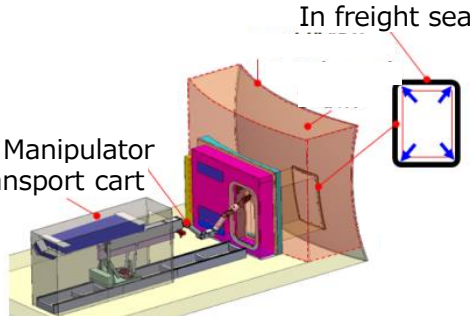
Development of radiation measurement device with gamma camera



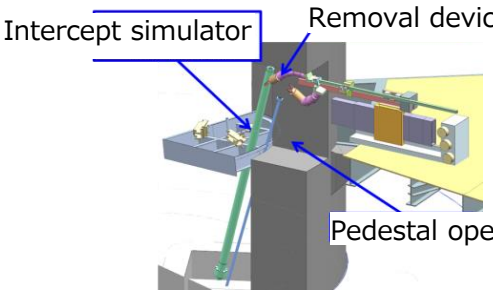
Development of small neutron detector



Element test of fuel debris cutting and collecting tool



Element test of inflate seal



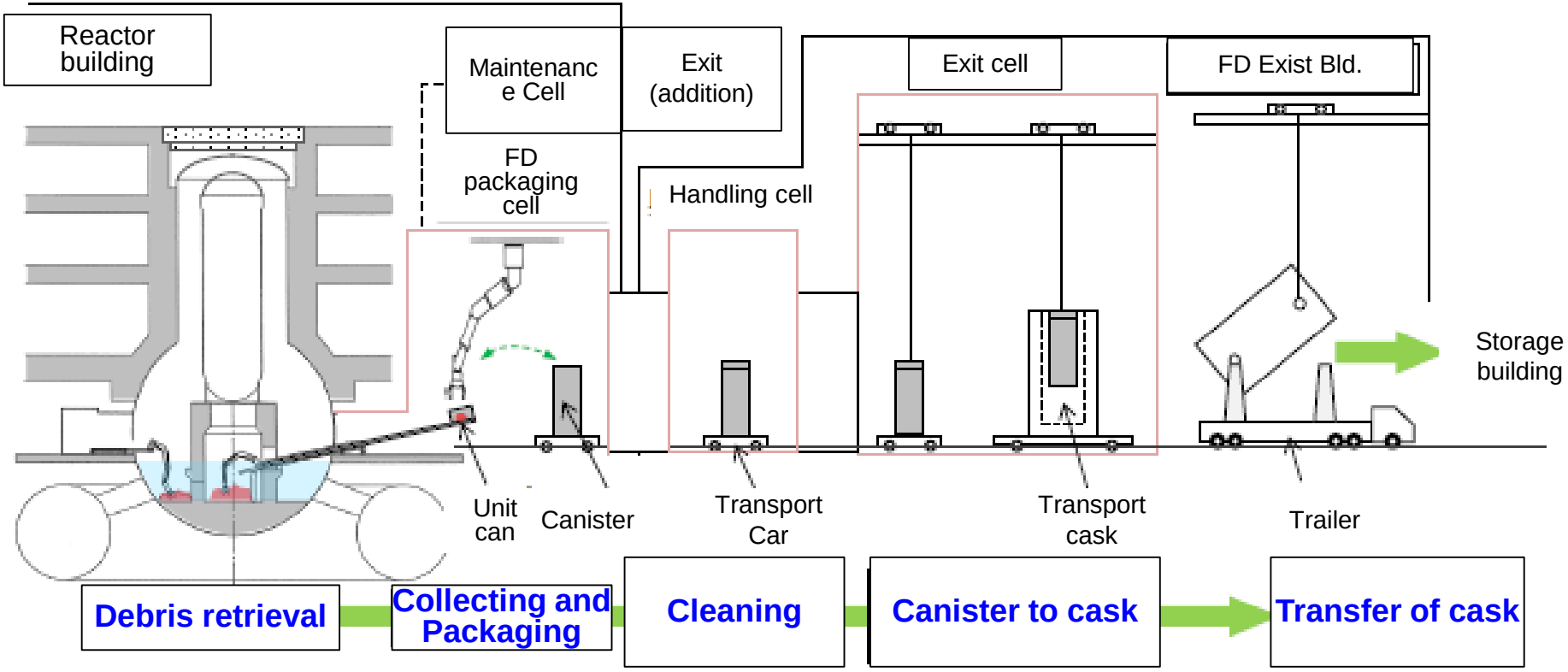
Element test of removal of interfering substance in the pedestal

ROT for FD retrieval (7) Packaging, transportation and storage

Design of Canister ⇒ **To meet 1F unique challenges**

- **High burnup and enrichment →High reactivity**
- **MCCI→H2 generation due to radiolysis of water in concrete**
- **Seawater injection and melt with I&C cables→ effect of salt, impurities**

Transfer (in case of dry and horizontal access)



Strategy for mockup

- **Mockup test as V&V**
  - **Clear definition of the mockup test through risk assessment for**
  - **Stakeholder engagement for assessment of feasibility at each step of requirement, design and fabrication**
- **Environmental mockup**
  - **For the verification of total remotely operated system for FD retrieval, applicability to be confirmed at environmental mockup simulating unclear 1f site conditions**
  - **To update environmental mockup according to new finding of in-PCV conditions and to reduce the risks by repeating mockup tests**
  - **To establish plans aiming at the rationalized cost and duration considering the unit-by-unit features and retrieval methods (horizontal, top entry etc.)**
- **Training mockup**
  - **Operators to join at the stage of environmental mockup and to conduct training mockup effectively and efficiently to flexibly cope with emergency conditions**
  - **Use of 3D simulator and VR is effective for reduced mockup test frequencies and training time.**
  - **To define the training for operation, maintenance and improvement from the long term viewpoint of FD retrieval**

Conclusion

- ➢ Remotely operated technology indispensable at 1F D&D due to its challenges like its high radiation dose
- ✓ Active operations of remotely operated technology in place so far for investigation, rubble removal decontamination etc.
- ✓ 1F D&D transitioned to new phase for actual fuel debris retrieval
- ✓ Fuel debris retrieval is “Castle Keep” and in a way department shop collecting wide range of challenges requiring remotely operated technologies
- ✓ No immediate application of world available experiences of remote technology to 1F situations
- ✓ Remotely operated technology as well transitioned to new stage = plunged into “Castle Keep”
- ✓ Clues to successfully apply to the actual sites
  - ◆ By gather world insights, solve individual challenges and develop elementary technology
  - ◆ Technical development to integrate individual elementary techniques
  - ◆ Mockup facilities to verify and improve site applicability and train operators
- ✓ Further enhancement of program/project management is important

Acknowledgement

We acknowledge lots of information and data as follows provided by TEPCO and IRID for this presentation.

（TEPCO HD）

- **Necessity of remotely operated technology for 1F D&D (images) P.4**
- **Examples of remotely operated technology for emergency response and stabilization stage etc. (images) P.5**
- **Examples of remotely operated technology for fuel pool removal (images) P.6**
- **Examples of remotely operated technology for investigation of torus room (image) P.8**
- **Information on in-reactor situation, investigation of inside of PCV of unit 3 (image) P.9,12**

（IRID）

- **Examples of remotely operated technology for investigation of torus room (image) P.8**
- **Information on in-reactor situation, investigation of inside of PCV of unit 1-3 (image) P.9,10,11,12**
- **investigation of inside of PCV -1,-2,-3（Image, video）P.19,20,21**
- **investigation of inside of RPV（image) P.22**
- **Water stoppage at PCV bottom (image) P.23**
- **Small scale retrieval, large scale retrieval 1,2 (image) P.24,25,26**
- **Elementary and measuring technology (image) P.27**
- **Packaging and transportation (image) P.28**

Thank you for your attention