NDF International Forum in the Decommissioning of the Fukushima Daiichi Nuclear Power Station
Iwaki, Aug. 6, 2018

Remote Technology for Decommissioning of Fukushima Daiichi Nuclear Power Station

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Agency for Natural Resources and Energy (ANRE) and TEPCO:
Council for the Decommissioning of TEPCO's Fukushima Daiichi NPS, member
Nuclear Damage Compensation & Decommissioning Facilitation Corp. (NDF):
Fuel Debris Retrieval Expert Committee, member
Decommissioning R&D Partnership Council, member
International Research Institute for Nuclear Decommissioning (IRID), TC member
Japan Atomic Energy Agency(JAEA): Working Committee on Remote Control Equipment and Device Development Facility (Mock-up facility), Chair
Fukushima Innovation Coast Framework Promotion Committee, member

Accident of Fukushima Daiichi Nuclear Power Plant

- Earthquake (14:47)
- Loss of Power Supply
- Activation of Emergency Diesel Generator
- SCRAM

  Stop Reactors
- Tsunami
- Damage of Fuel Tanks and Generators
- SBO (Situation Black Out) (15:39)
- Failure of Cooling System of Reactors and Fuel Storage Pool
- Loss of Cooling Water
- Melt down
- Hydrogen Explosion (Mar. 12-15, Unit 1, 3, 4)

Fukushima Daiichi Nuclear Power Plant

Seismic Center

By Janet Loehrke, USA TODAY

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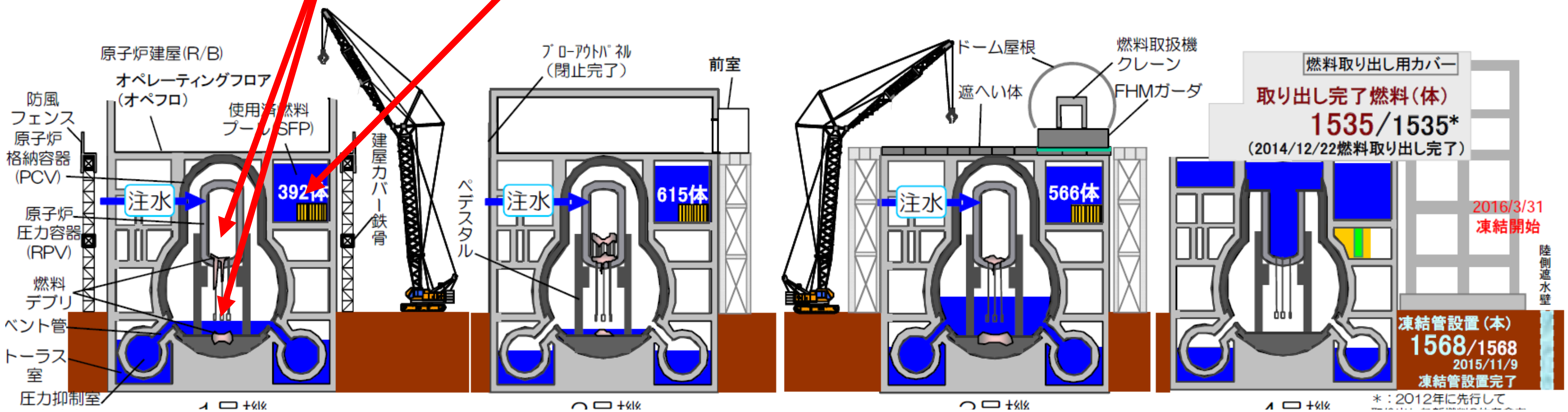
Current Situation of 4 Units

Fuel Debris (Melt-down Fuel)

Spent Fuel and New Fuel in Spent Fuel Pool



55th meeting of Japanese Government and TEPCO: Council for the Decommissioning of TEPCO's Fukushima Daiichi NPS

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Mid-and-long-Term Roadmap Summary
(TEPCO)

Present（Completion of Step 2)	*Within 2 Years*	*Within 10 Years*	*After 30-40 Years*
Step 1, 2	**Phase 1**	**Phase 2**	**Phase 3**
<Achieved Stable Conditions> -Condition equivalent to cold shutdown -Significant Suppression of Emissions	**Period to the start of fuel removal from the spent fuel pool (Within 2 years)**	**Period to the start of fuel debris removal (Within 10 years)**	**Period to the end of decommissioning (After 30-40 years)**
	-Commence the removal of fuels from the spent fuel pools (Unit 4 in 2 years) -Reduce the radiation impact due to additional emissions from the whole site and radioactive waste generated after the accident (secondary waste materials via water processing and debris etc.) Thus maintain an effective radiation dose of less than 1 mSv/yr at the site boundaries caused by the aforementioned. -Maintain stable reactor cooling and accumulated water processing and improve their credibility. -Commence R&D and decontamination towards the removal of fuel debris -Commence R&D of radioactive waste processing and disposal	-Complete the fuel removal from the spent fuel pools at all Units -Complete preparations for the removal of fuel debris such as decontaminating the insides of the buildings, restoring the PCVs and filling the PCVs with water Then commence the removal of fuel debris (Target: within 10 years) -Continue stable reactor cooling -Complete the processing of accumulated water -Continue R&D on radioactive waste processing and disposal, and commence R&D on the reactor facilities decommission	-Complete the fuel debris removal (in 20-25 years) -Complete the decommission (in 30-40 years) -Implement radioactive waste processing and disposal

Actions towards systematic staff training and allocation, improving motivation, and securing worker safety will be continuously implemented.

ring

Needs (Tasks) for Remote Technology

- Water injection
- Removal and transportation of rubbles, fuels (including fuel debris), and contaminated water, etc. (Cutting, suction, handling)
- Investigation, measurement, and mapping (images, radiation, etc.)
- Sampling (dust, contaminated water, concrete core, fuel debris, etc.)
- Decontamination and Shielding
- Fixing of contaminated water leakages
- Handling, transportation, removal, setup, and dismantling of devices, instruments, equipments, facilities, etc.
- Waste and contaminated water management
- Dismantling

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Missions depending on phases

- Phase 1: Emergent Situation
  - Cooling down of reactors
- Phase 2: Stabilization
  - Containment, systems reconstruction, for aftershocks
- Phase 3: Decommission
  - Fuel removal
- Reduction of radiation exposure of workers

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Phase 1
Procure off-the-shelf robots and equipment (for general purpose)


Putzmeister
Concrete Pump Truck


Remotely Controlled
Construction Machines


QinetiQ Talon


Brokk-90


Honeywell
T-HAWK


iRobot Packbot


iRobot Warrior


QinetiQ Bob Cat


Brokk-330

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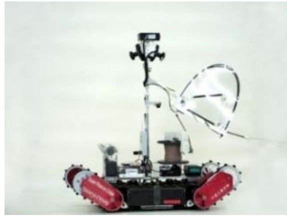
Phase 2
Remodel developed system and technology

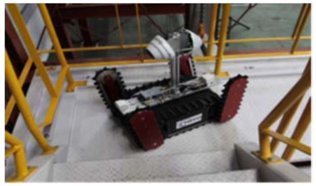

Quince


Quince 2


Quince 3


Gamma-ray
Measurement Robot

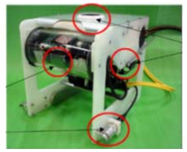

JAEA-3

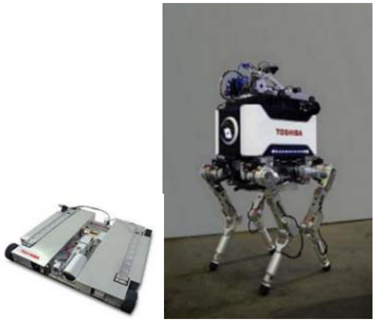

Sakura


Rosemary


FRIGO-MA

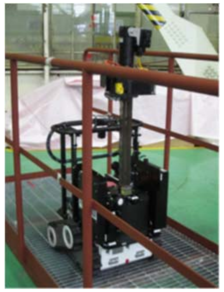

Survey Runner


ROV


Quadruped Robot
& Inspection Robot


ASTACO-SORA


MEISTeR


Inspection Robot
Of upper part of S/C


Manipulator
for Robot Set-up

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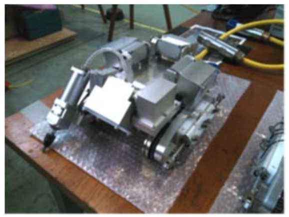
Phase 3
New development
(for specific use)

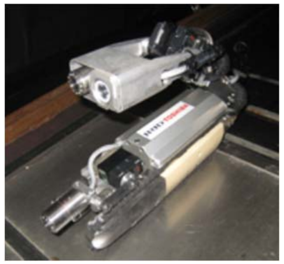

Robot for
Decontamination


Water Surface
Inspection Robot


Inspection robot
for high location


Inspection Robot for
Lower part of S/C


Robot for Measurement
of S/C Water Level


PCV Inspection Robot
Scorpion Robot

PCV Inspection Robot
PMORPH


PCV Inspection Robot
Mini Mola Mola

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Remotely controlled machines utilized for the response of accident of nuclear power plant (Foreign Machines)

Putzmeister
Concrete Pump Truck

iRobot Packbot

Brokk-90

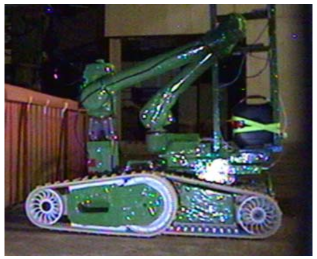
Brokk-330

iRobot Warrior

QinetiQ Talon

Pentek Moose

Honeywell
T-HAWK



iRobot Kobra

QinetiQ Bob Cat

Createc RISER

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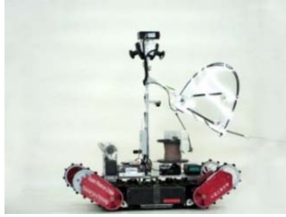
Remotely controlled machines utilized for the response of accident of nuclear power plant (Domestic Machines)


Remotely Controlled Construction Machines

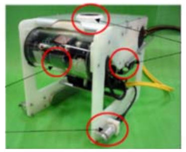

Quince


Quince 2


Quince 3

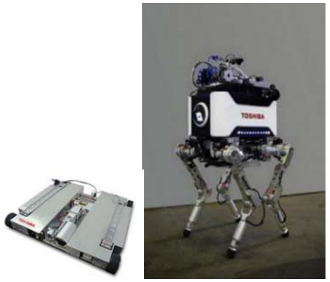

Survey Runner


JAEA-3


ROV


FRIGO-MA


ASTACO-SORA


Quadruped Robot & Inspection Robot


Inspection robot for high location


Inspection Robot for Lower part of S/C

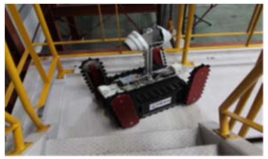

Transform

PCV Inspection Robot PMORPH


Robot for Decontamination


MEISTeR


Manipulator for Robot Set-up

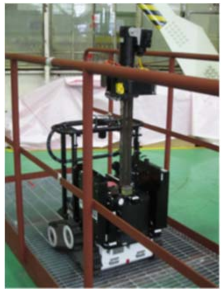

Sakura


Robot for Measurement of S/C Water Level


UUV


PCV Inspection Robot Scorpion Robot


PCV Inspection Robot Mini Mola Mola


Inspection Robot Of upper part of S/C


Water Surface Inspection Robot


Rosemary


Underwater Floor Mobile Robot

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What have achieved so far
(Successful)

- Exploration, investigation & measurement
  - States, Spatial Radiation Dose (Level & Distribution), 3D data, etc.
- Rubble removal
  - On Site Field (Outdoor), Inside R/B, Inside Spent Fuel Pool, on Operation Floor
- Sampling
  - Dust, Contaminated Water, Core Samples

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What have achieved so far
(Insufficient or on-going)

- Decontamination
- Water Leakage Fixing
- Sampling
  - Fuel Debris
- Fuel Debris Removal and Transportation

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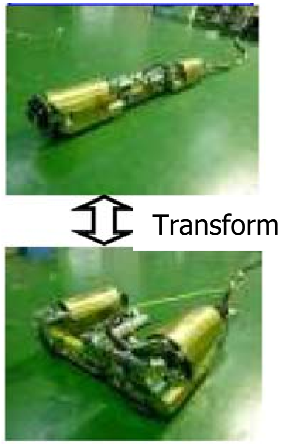
Unrecoverable Robots



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Factors of failures

- Direct factors
  - Communication failures
  - Misoperation
  - Malfunctions by radiation
- Indirect factors
  - Prototypes (not products)
  - Unknown environment

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Measures for Direct Factors

- Communication failures
  - Combination of wired & wireless communication
  - Implementation of wireless com. infrastructure
- Misoperation
  - Training
  - Improvements of Human Interface (situation awareness)

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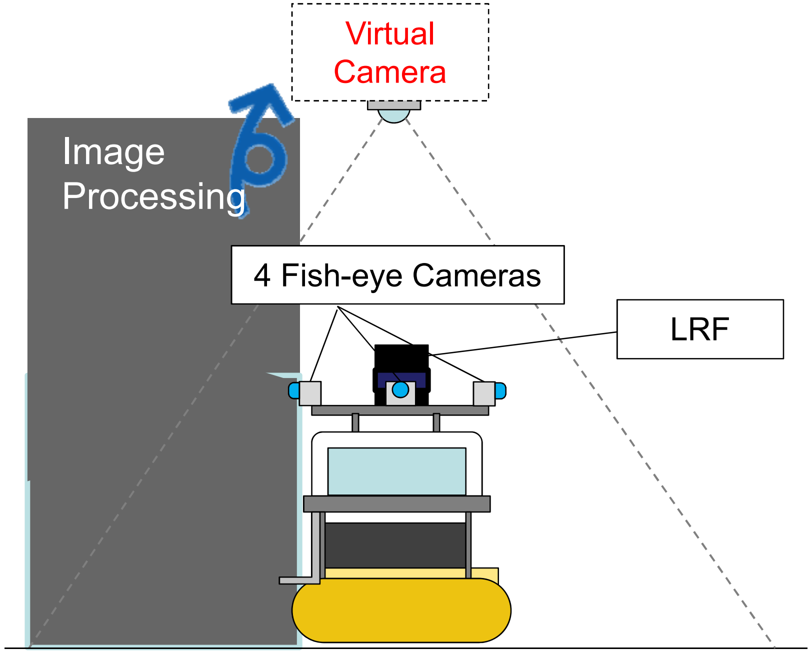
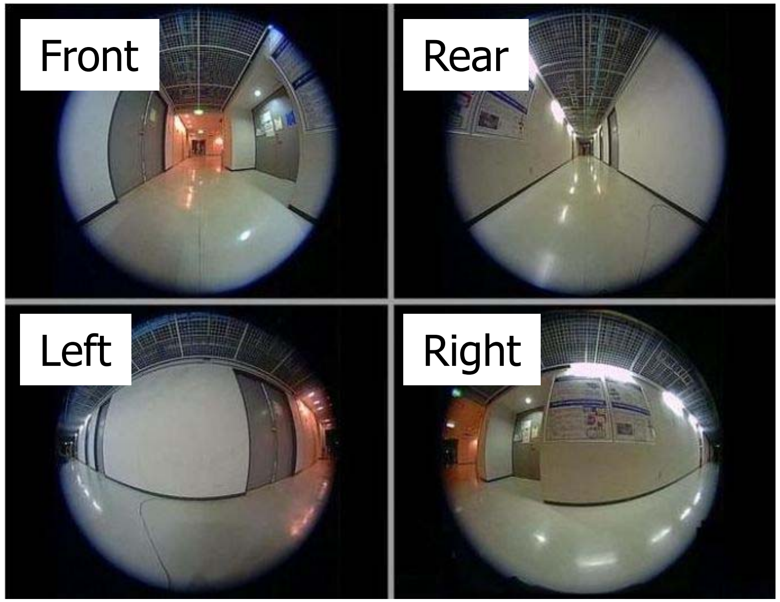
Concept of Bird-eye view Display

- Production of Virtual bird-eye camera image by integrating Multiple Fish-eye cameras
- Obstacle detection by LRF



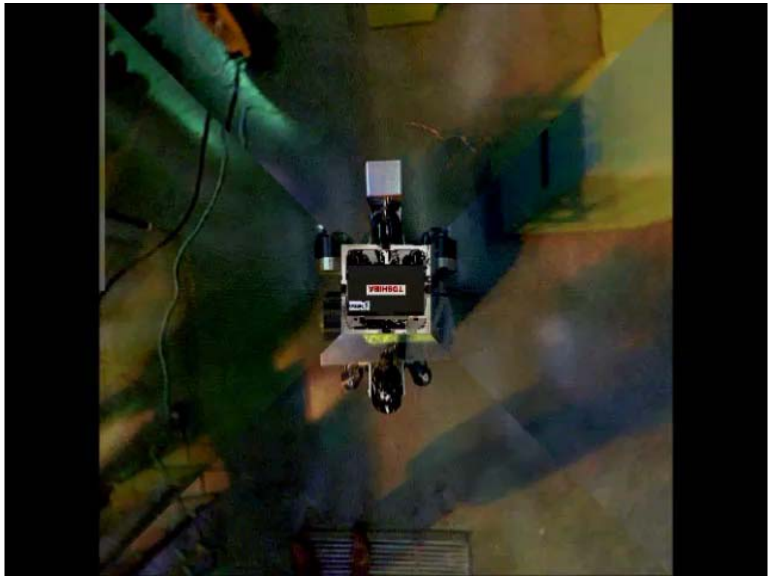
Concept of Bird-eye View



Multiple Fish-eye Camera Images

Outcome of the Project

Narrow Passage (Maze)



Bird-eye View Image

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Application to Robot for Decommissioning of NPS

MHI Super Giraffe

MHI MEISTeR

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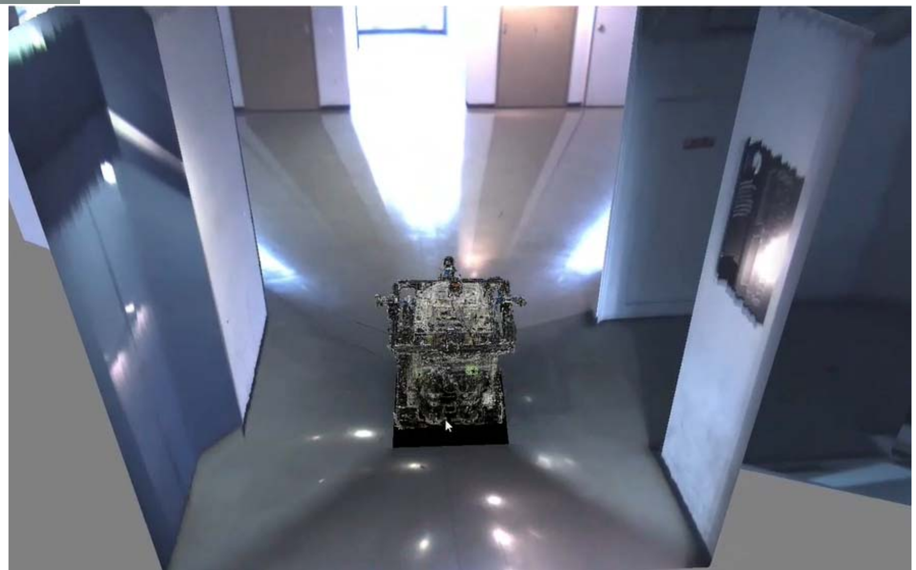
Generation of robot view from arbitrary viewpoints



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Measures for Direct Factors

- Communication failures
  - Combination of wired & wireless communication
  - Implementation of wireless com. infrastructure
- Misoperation
  - Training
  - Improvements of Human Interface (situation awareness)
- Malfunctions by radiation
  - Rad-hardened devices, mechanical systems (not use semi-conductor)
  - Design of robust systems
  - Redundant and functionally degradable

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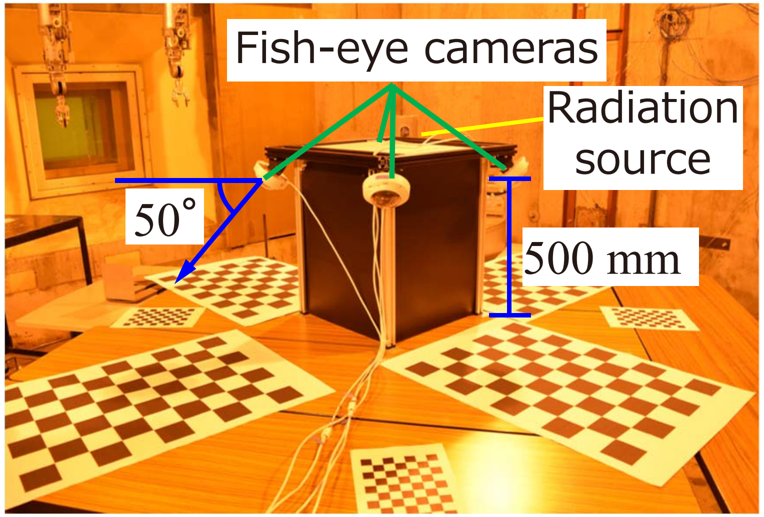
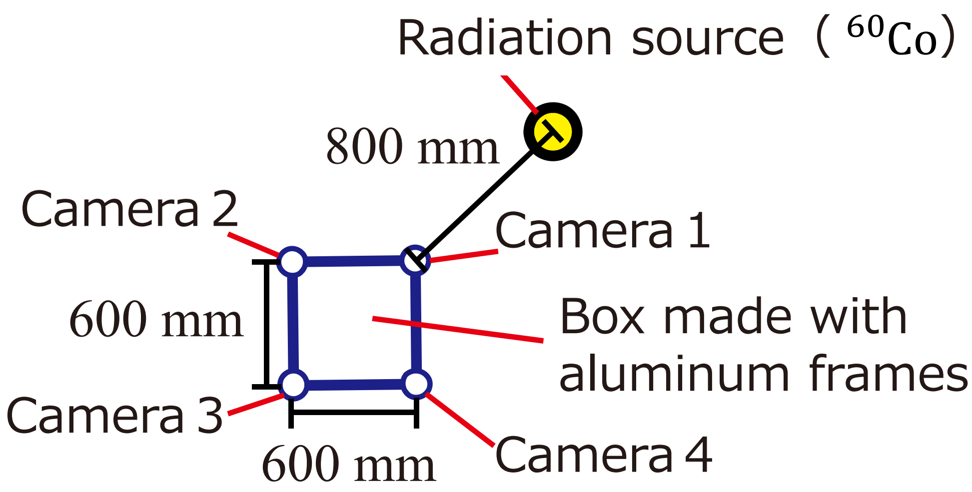
Gamma irradiation experiment

- The gamma irradiation was conducted in the Technology Development Center of ATOX Co., Ltd.

Camera model：AXIS M3007-PV



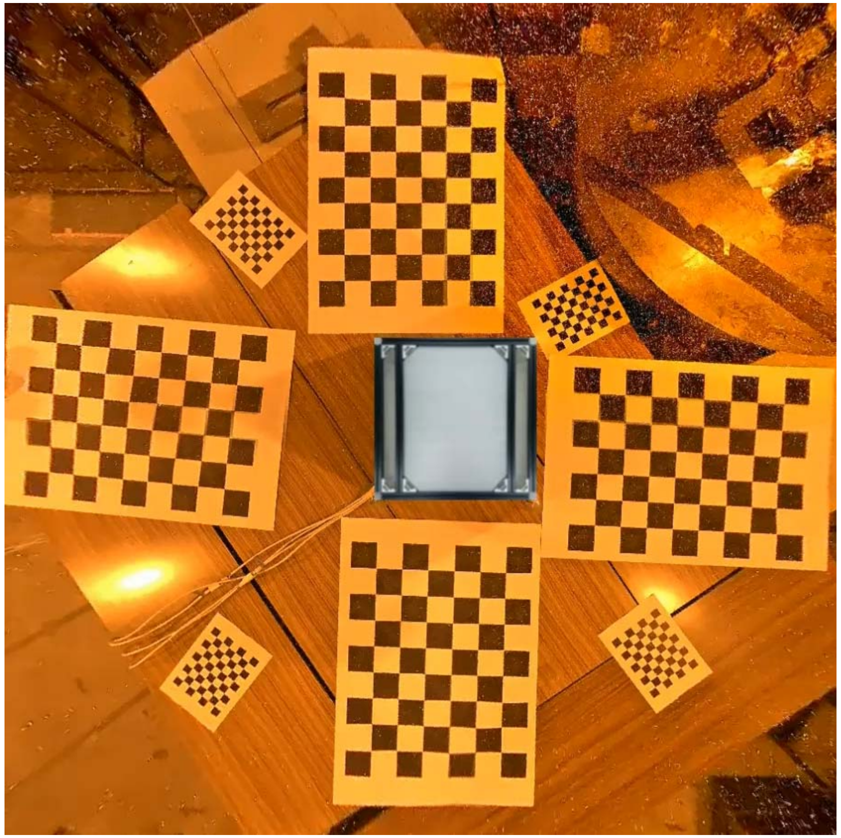
Experimental environment



Experimental layout seen from above

Gamma irradiation experiment : Movie

- After 23 min irradiation



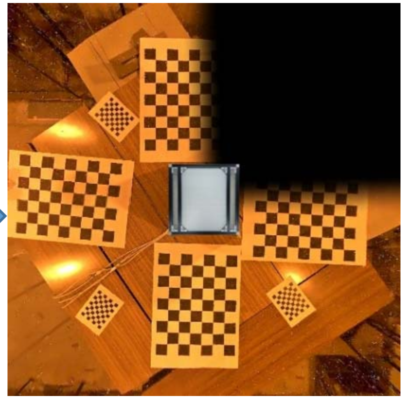
Bird's-eye view

Bird's-eye view generation corresponding to camera malfunction

Gamma irradiation experiment : Result(1)

- Camera 1 malfunctioned after 23 min irradiation (Integral dose: 192.1 Gy)

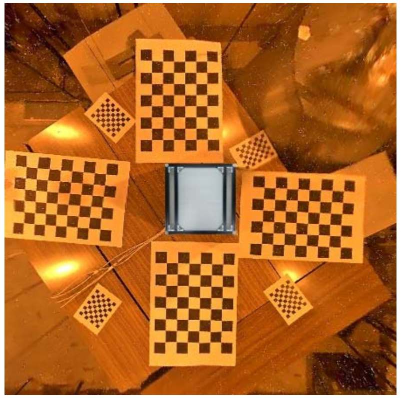
4 cameras



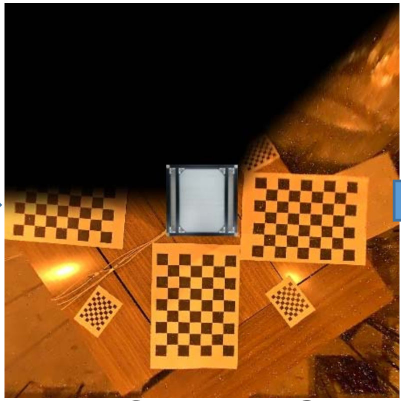
Camera 1 malfunctioned

Proposed method

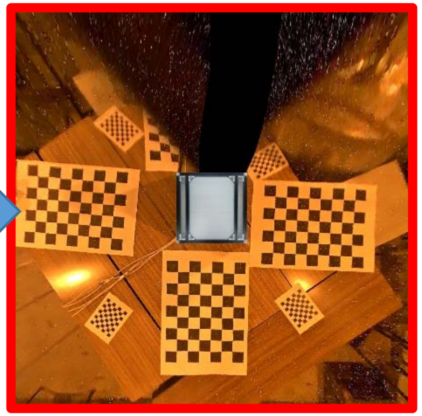
- Camera 2 malfunctioned after 54 min irradiation (Integral dose: 141.3 Gy)



3 cameras



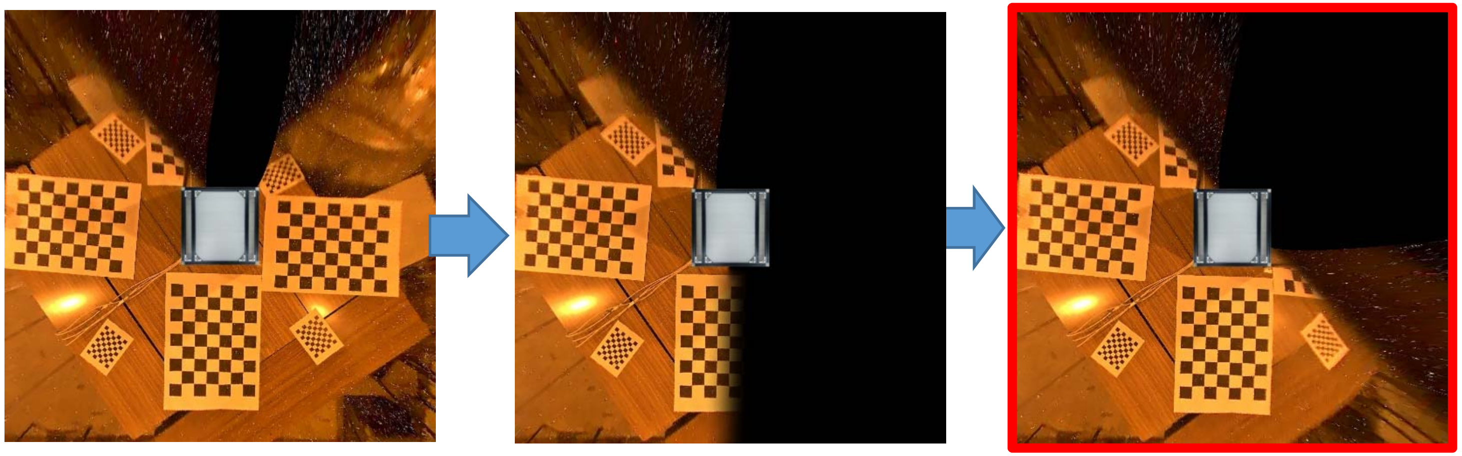
Camera 2 malfunctioned



Proposed method

Gamma irradiation experiment : Result(2)

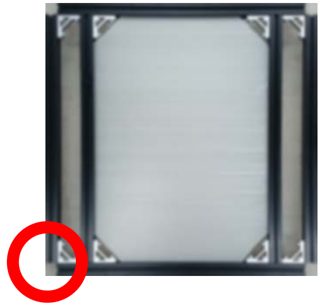
- Camera 4 malfunctioned after 82 min irradiation (Integral dose: 224.1 Gy)



2 cameras

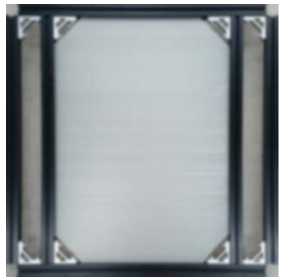
Camera 4 malfunctioned

Proposed method



Camera 3 Camera 4

- Camera 3 malfunctioned after 94 min irradiation (Integral dose: 162.9 Gy)



Camera 3

Measures for Other Factors

- Prototypes (not products)
  - Risk assessment for failures
  - Testing

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Fukushima Innovation Coast Framework

R&D bases, organization for ollaboration, human resource development in Fukushima prefecture

1

- メカトロニクス研究室
- 環境放射能研究所

- ロボット工学
- 先端情報科学研究センター
- 復興支援センター

【アカデミアコンソーシアムふくしま】
- 県内１９の高等教育機関の連携組織
- 独自の単位互換制度

機械工学科
（ロボット、浅部地中熱）
電気電子工学科
（ロボット、医療工学）

コース（ロボット工学等）

Human Resource Development ミー、工業高校等)

- **テクノアカデミー**
  ・再エネ、医療など本県復興を担う人材を育成
- **福島高専、県内工業高校**
  例)郡山北工高生徒が開発の探査ロボが世界2位
- **相双技塾**…機械金属加工技術、メカトロ産業技術分野

Collaboration with Industry プラザ等)

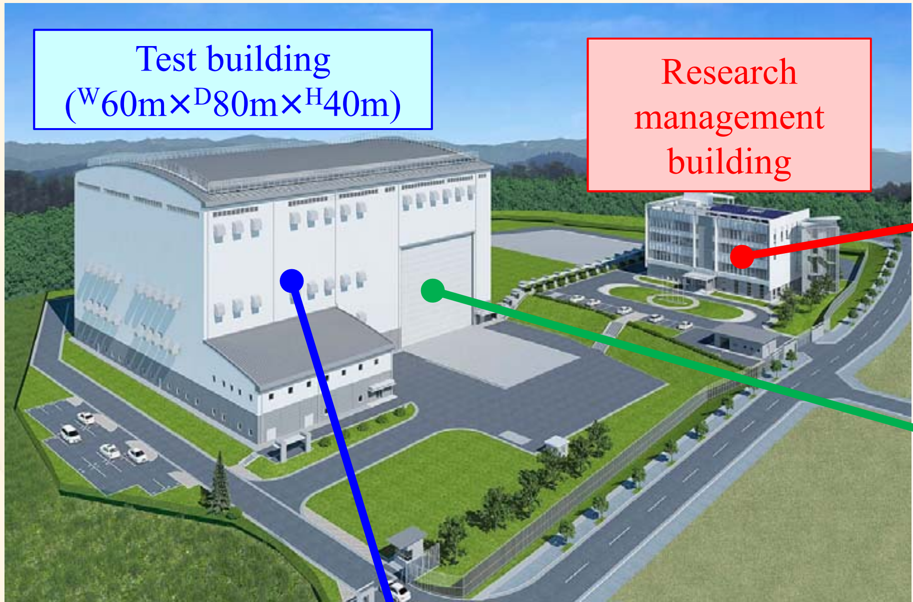
( )数字は構成機関・団体数

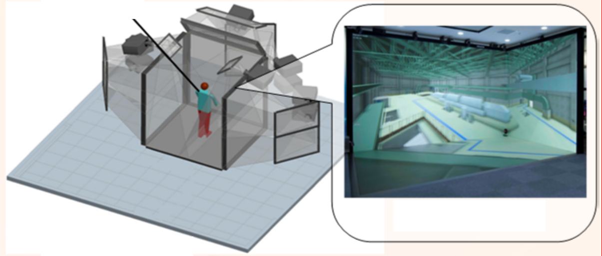
- **福島県廃炉・除染ロボット技術研究会(ハイテクプラザ)**
  ・各メーカーからの情報収集、情報共有化に関する産学ネットワークの構築(109)
- **関連産業協議会・研究会**
  ・医療機器(258)　・再エネ(501)　・輸送用機械(376)　・半導体(134)
- **ハイテクプラザの取組実績**
  ・技術相談…1,500社4,000件/年　・機器開放…30000時間/年
  ・依頼試験…3,500件/年
  ・放射能測定…工業製品1000検体/年、加工食品2500検体/年

Mockup and instrumentation tools to be installed

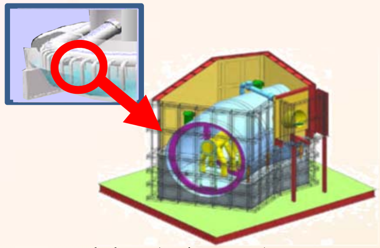
☐ Facilities

Demonstration test area for the technique to repair a water leakage at the PCV and development and demonstration test area for the remote controlled devices are prepared in Test building





Virtual Reality System



Test assembly (1/8 cut) : IRID

Water pool

Motion capture camera

Mock-up staircase

Robot Simulator

Measures for Other Factors

- Prototypes (not products)
  - Risk assessment for failures
  - Testing
- Unknown environment
  - Advance investigation
  - Assumption of various situation

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For Fuel Debris Retrieval and Decommissioning

- Development of diverse technology (Portfolio)
  - Devices and robots for specific and general use
  - Cutting devices, manipulators, handling devices (Sampling, leakage fixing, contaminated water processing, retrieval of fuel debris)
  - Endoscope-type Robot

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Summary of Technology Diversity (Portfolio)

Needs	Basic Function	Environment/Objects	Means
Access	Mobility	Basic Environment type	
		Ground	Move by crawlers, wheels(normal, magnet), endscope
		Aerial	Move by multi-copter, baloon, blimp, suspension-type, telescopic
		Water, Underwater	Move by boat(ROV, USV), submarine(ROV, UAV)
		Others	Combination, specialized
		Environment conditions	
		Obstacles	Avoiding, pushing, clearing, climbing
		Narrow space, Pipes	Passing through (active/passive)
		High radiation	Radiation-tollerant
Information acquisition	Sensing	Basic Environment type	
		Ground, aerial, underwater	Camera, gamma camera, dosimeter, laser range sensors, endoscope
		Environment conditions	
		Obstacles	Image processing (counter-occlusion)
		Turbidity	Soner
		Water drop	Image processing
		High radiation	Radiation-tollerant
Work		Objects	
(debris removal, decontamination, set-up)	Manipulation, handling, vacuuming	Material(Rubbles, debris, shielding blocks, walls/floors)	Arm, gripper, vacuumer, water injection
	Cutting, scabbling	Material(Rubbles, debris, shielding blocks, walls/floors)	Machining tools, laser cutting devices, waterjet
(samping)	Vacuuming, cutting, manipulation, handling	Material(fuel debris, concrete-core), air, dust, sand, water	Vacuumer, machining tools, waterjet, arm, gripper

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For Fuel Debris Retrieval and Decommissioning

- Development of diverse technology (Portfolio)
  - Devices and robots for specific and general use
  - Cutting devices, manipulators, handling devices (Sampling, leakage fixing, contaminated water processing, retrieval of fuel debris)
  - Endoscope-type Robot
- Water proof devices
- Radiation-tolerant devices
- Autonomy and intelligence of remotely controlled systems
- 3D reconstruction from movies
  - Structure from Motion

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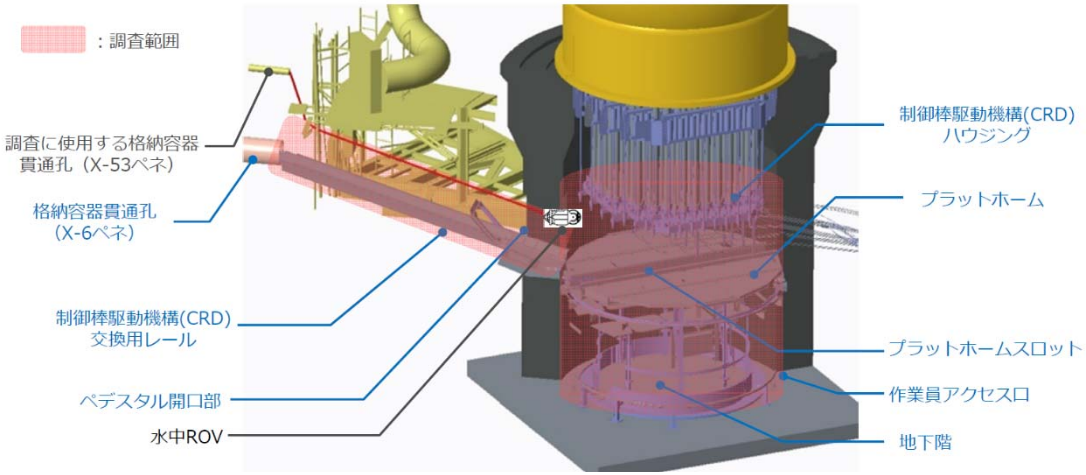
Inspection inside PCV in Unit 3

(operated by IRID/Toshiba and TEPCO)

July 19-22, 2017



Mini Mola Mola

Mola Mola
(Sunfish)

- Structures
- Melt
- Deposits

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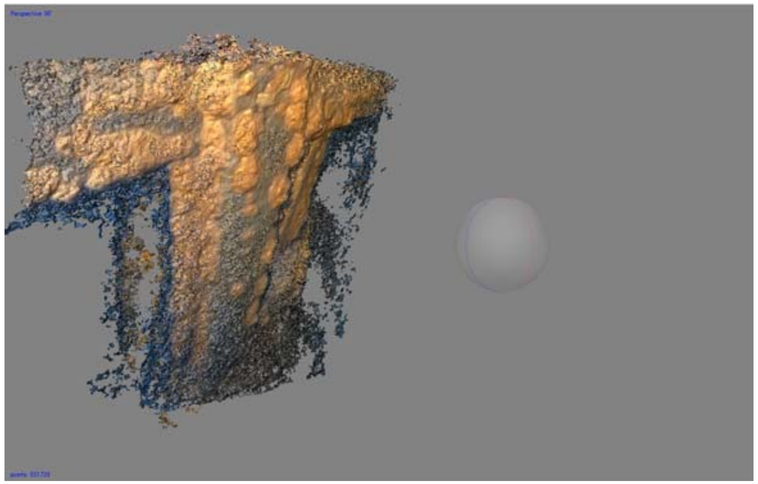
3D Reconstruction of Unit 3 Pedestal

- 3D Reconstruction by Structure from Motion

3D reconstruction using multiple images



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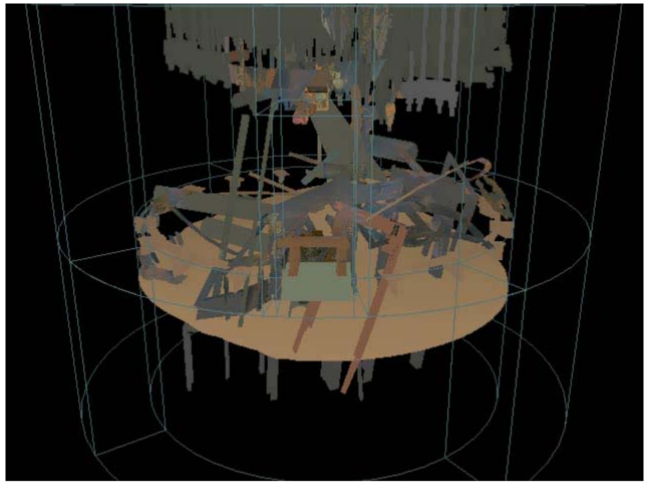

IRID, Toshiba

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Coming soon

- Removal of spent fuel of unit 3
- Dismantling of exhaust pipe of unit 1-2
- Investigation inside PCV of unit 1
- Retrieval of fuel debris of unit 2

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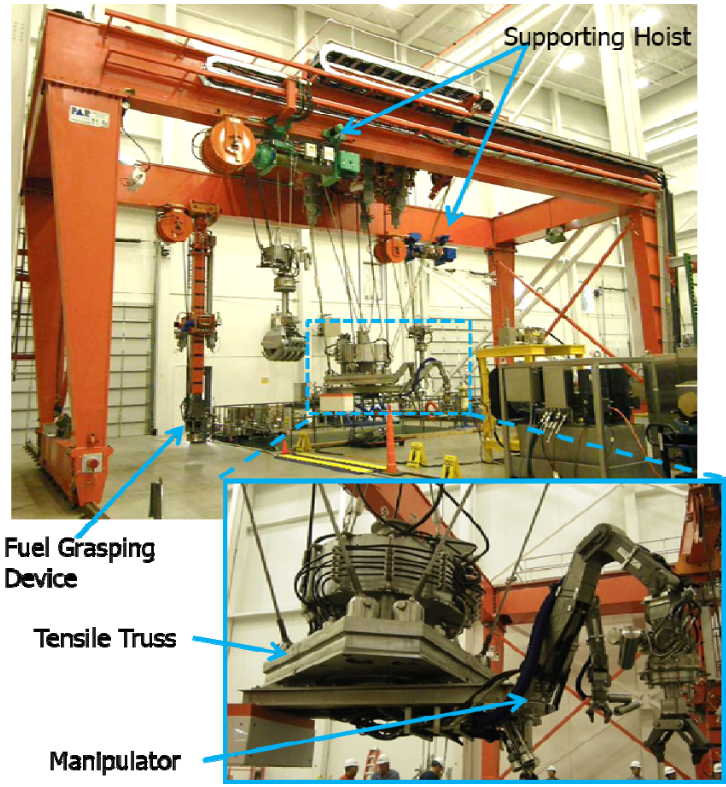
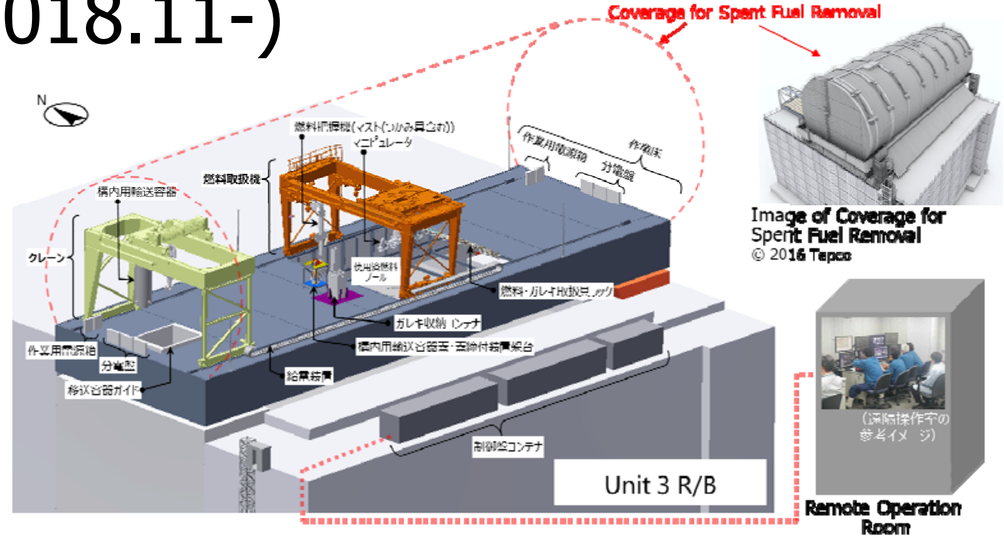
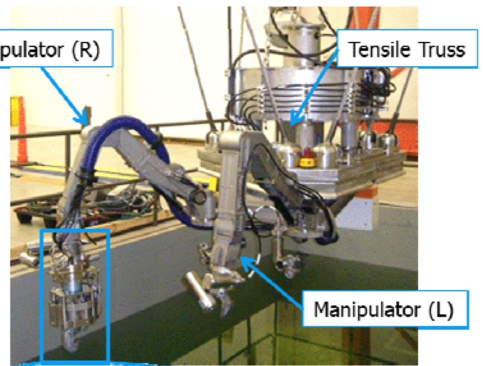
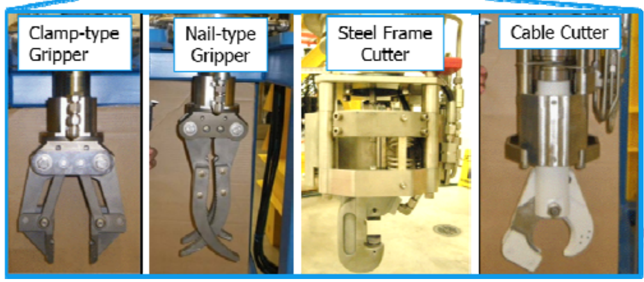
Removal of spent fuel of unit 3

(2018.11-)









(Toshiba, IRID)

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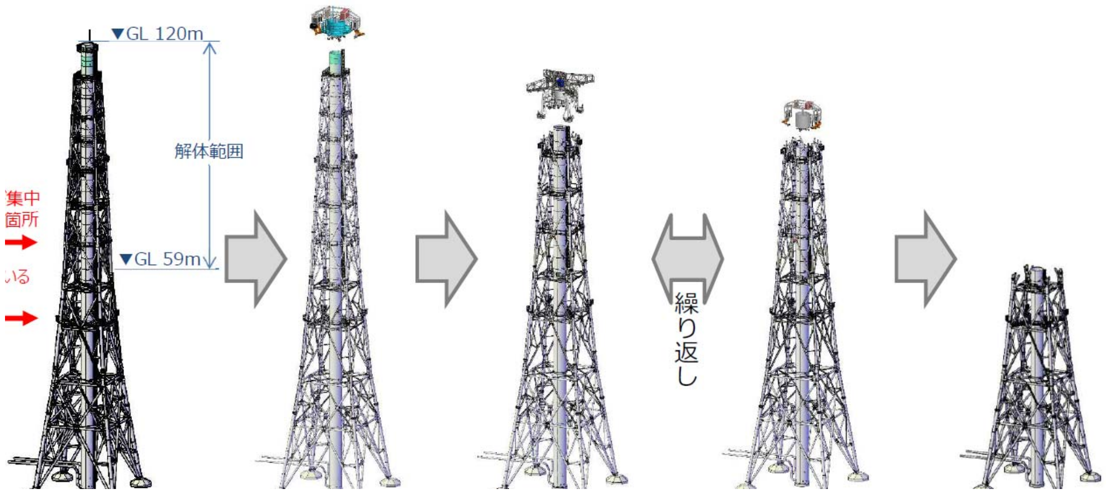
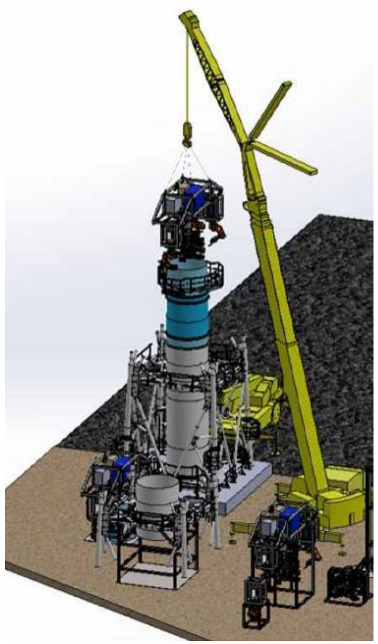
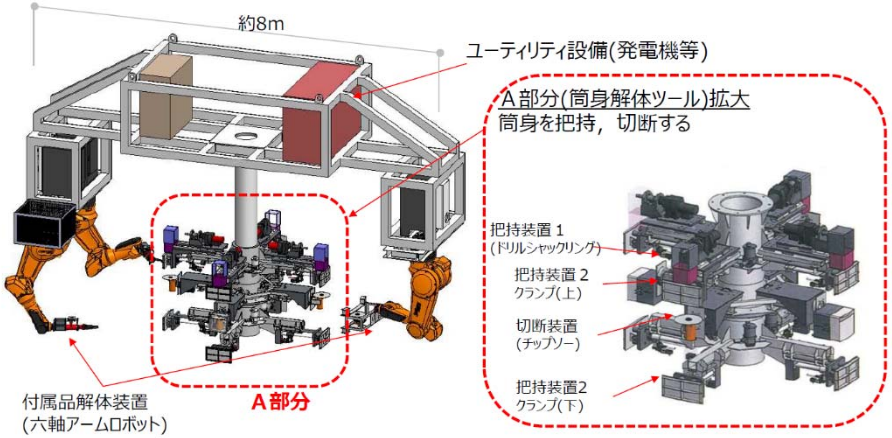
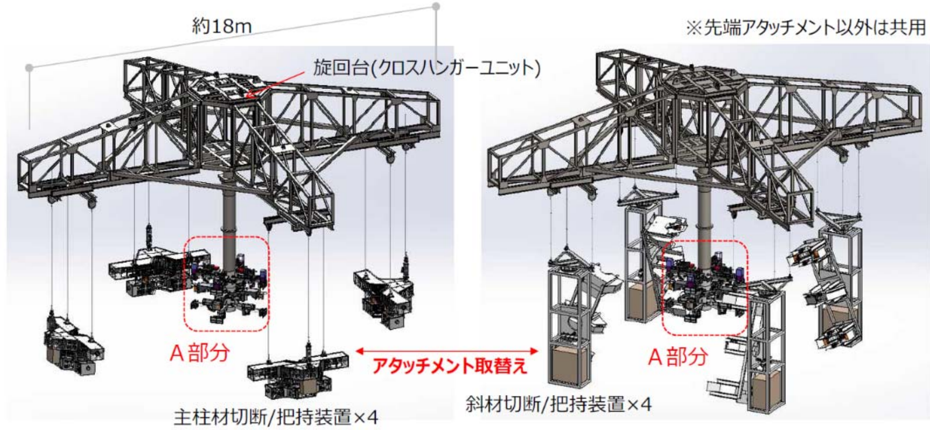
Dismantling of exhaust stack of unit 1-2 (2018.12-)

(TEPCO, ABLE)









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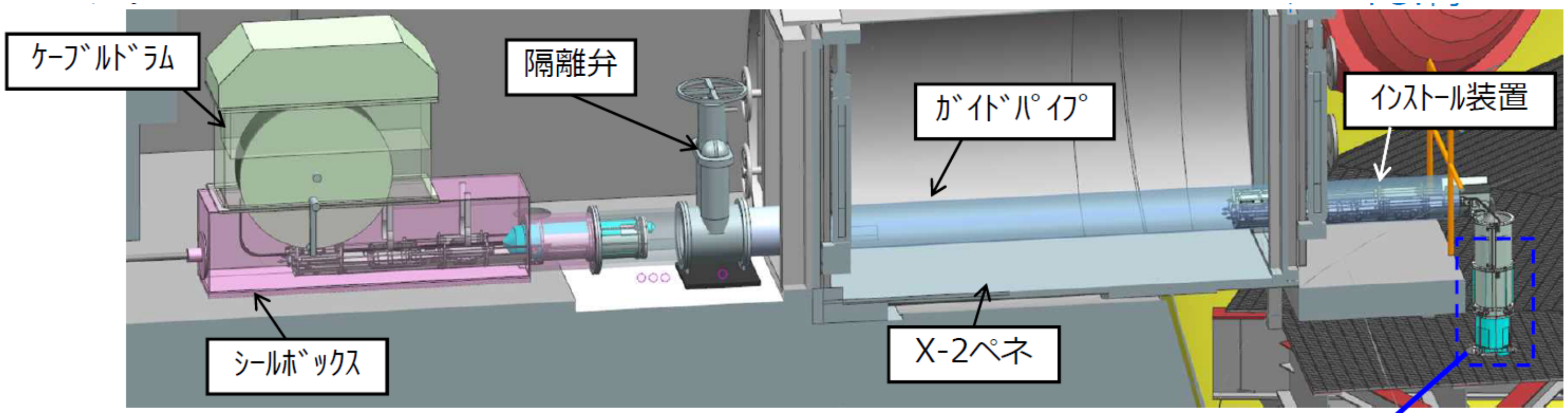
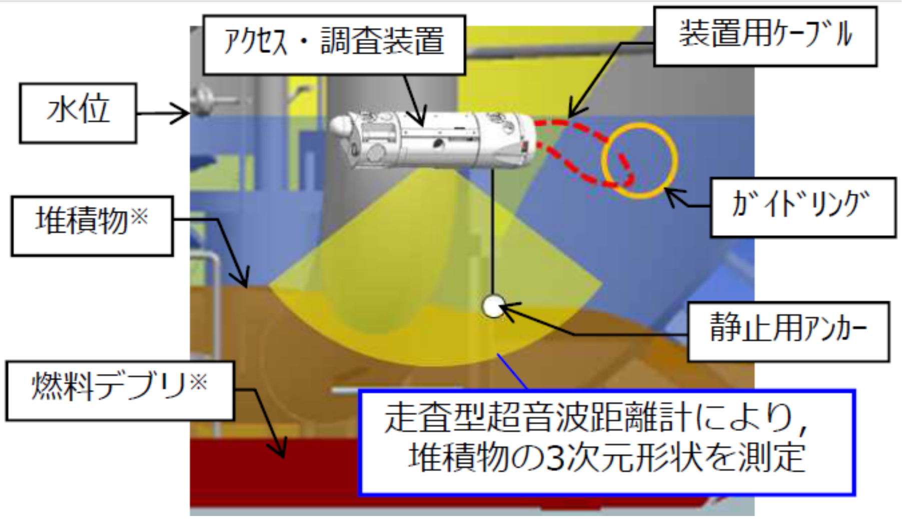
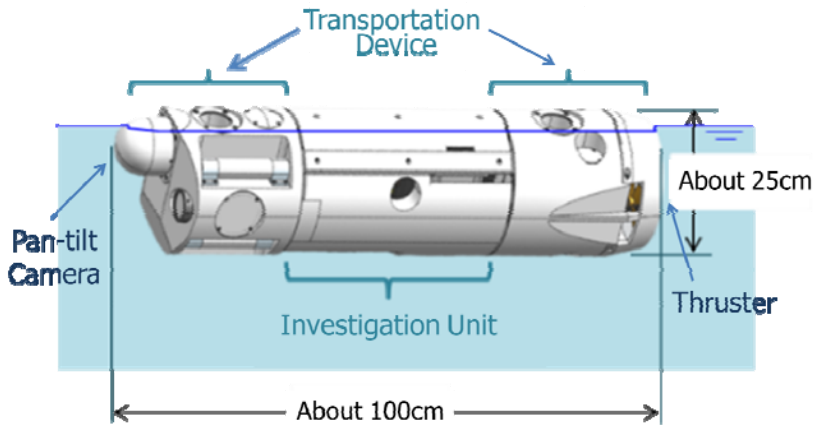
Investigation inside PCV of unit 1 (2019-)

(HGNE, IRID)







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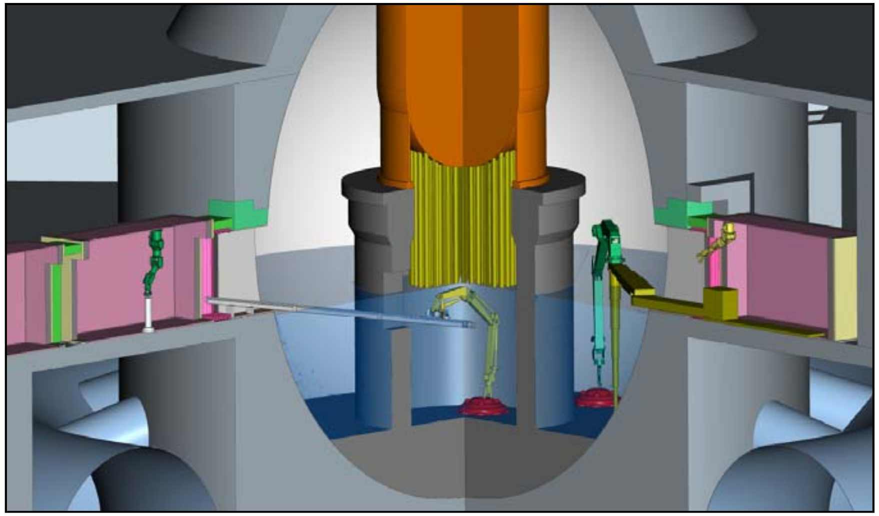
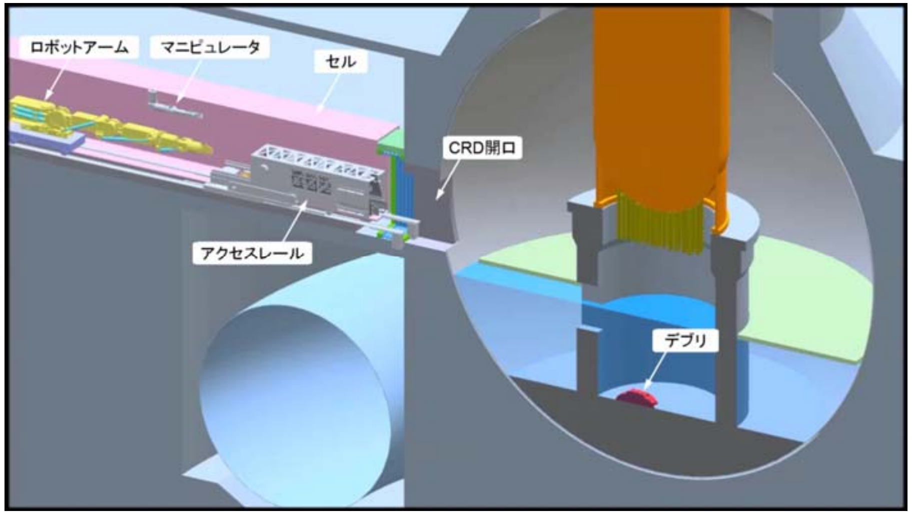
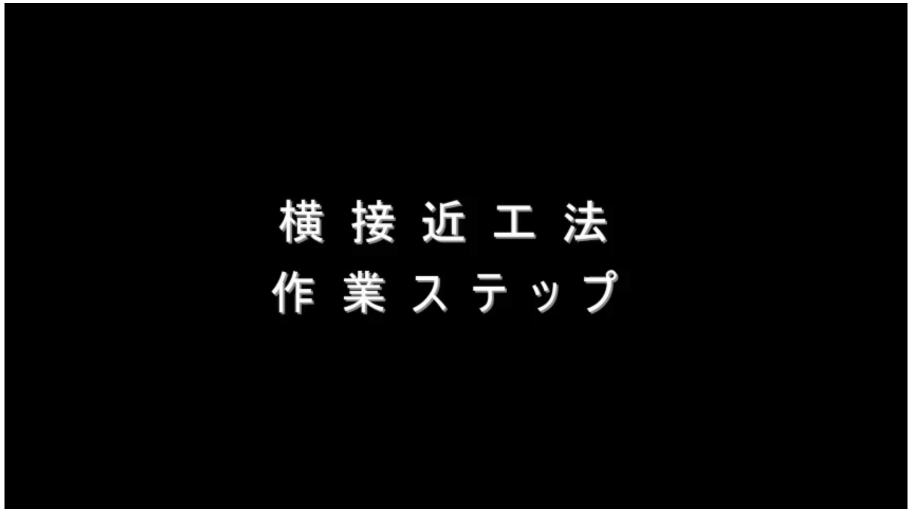
Retrieval of fuel debris of unit 2 (2019-)

(MHI, IRID)







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For Future Development

- Make use of the failure experience
- Utilization of available technology
  - SLAM, SfM, Drones, AI (Deep Learning), IoT, etc.
- Efficiency: Systematic and drastic design for repeating use
- Common platform
  - From specific system development to standardized components

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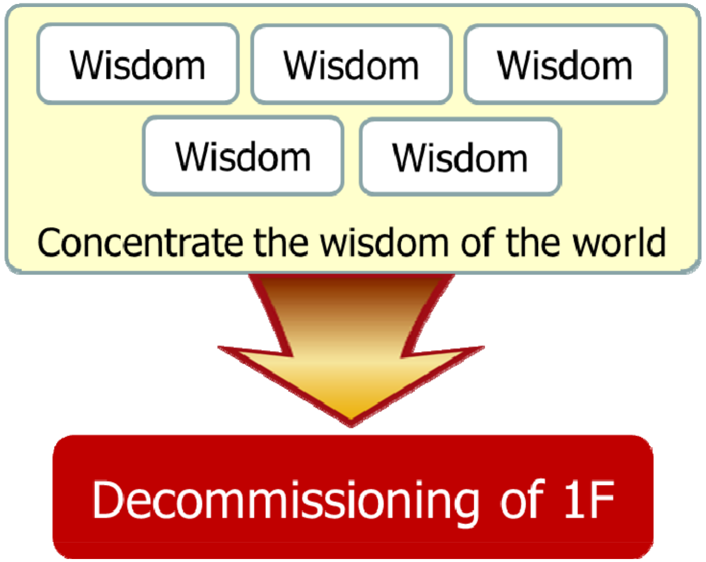
Summary

- Robot Tech.=Remote Tech.
  - System integration
  - Derivation of solutions
  - Intelligent (not just mounting AI)
- Needs to concentrate the wisdom of the world
  - Nuclear accidents do not happen often
  - International cooperation in knowledge sharing and technology transfer
- Dissemination of the developed technology to other sites and applications
- Develop young human resources



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IFAC World Congress 2023

(International Federation of Automatic Control)

Venue:

PACIFICO Yokohama (All-in-One Venue)

Dates (tentative):

July 9th (Sun) – 14th (Fri), 2023

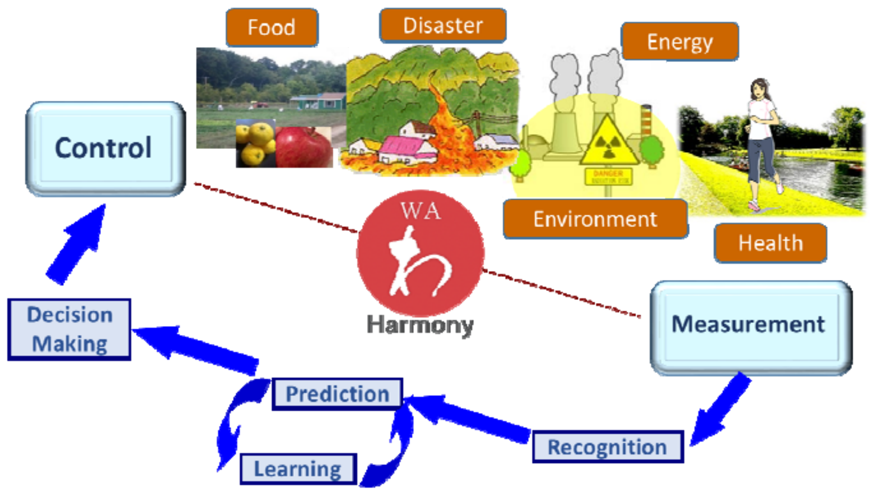
Vision:

Wa: Harmony of Traditional Culture and Innovative Technology

Traditional Culture

Innovative Technology

Control for Solving Societal Problems and Creating Social Values



Thank you for your attention!

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