Start Up of Naraha Remote Technology Development Center (NRTDC) and Consideration of Deployed Robot Operation for New Standard Testing Method

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- Mockup and instruments to be installed
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topic II: Examination of Operations by Deployed Robot in 1F for designing Standard Testing Method

- Approach to develop STM for nuclear emergency response robots
- Current examinations on the robot operations in 1F

Aim and status of NRTDC : background

- background

For research and development on the decommissioning of TEPCO's Fukushima Daiichi nuclear power stations (1F), 85 billion JPY was financed to Japan Atomic Energy Agency (JAEA) to construct the research institution in 2012 by Japanese Ministry of Economy, Trade and Industry(METI).

- challenge to create a test environment which can be performed only here to solve new problems concerning the decommissioning by using R&D results which have been accumulated in JAEA.
- integration of wisdom of researchers and engineers who have engaged in national and international related facilities, and nuclear human resource development through the R&D.

JAEA made decision to establish an essential research center with developmental facilities for contributable technology toward the decommissioning of 1F in Fukushima-prefecture, Japan

Aim and status of NRTDC : motivations

- aim & target

In the inside of the 1 F building, person cannot approach to the operation floor because of high radiation dose.

⇒ Remote operated technology are necessary for the decommissioning works.

Naraha Remote Technology Development Center (NRTDC)

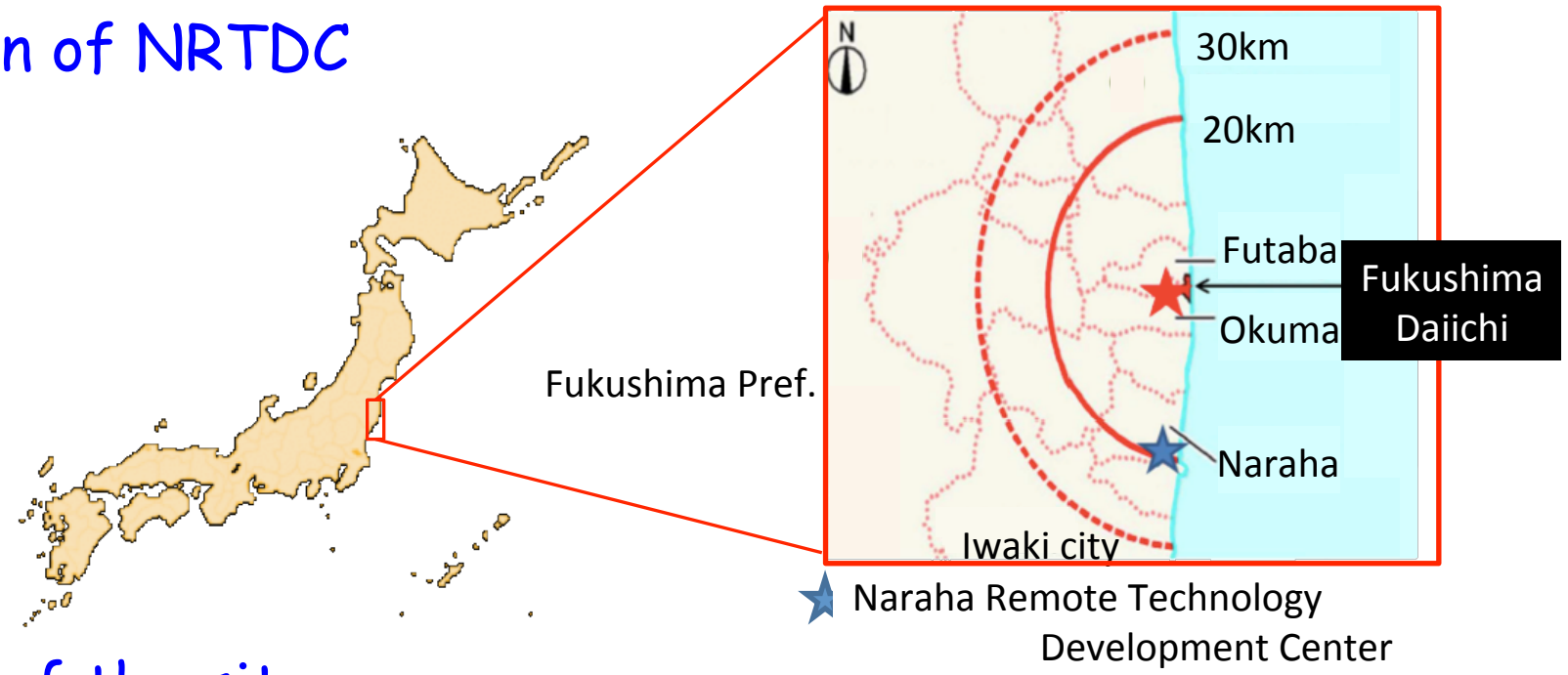
- contribution to decommissioning of 1F through the establishment of the technical base about remote controlled devices
- creation of the R&D base for the researchers of remote technology
- is being established and will be fully operational from April 2016. (currently , operated in partially)

NRTDC would be utilized for

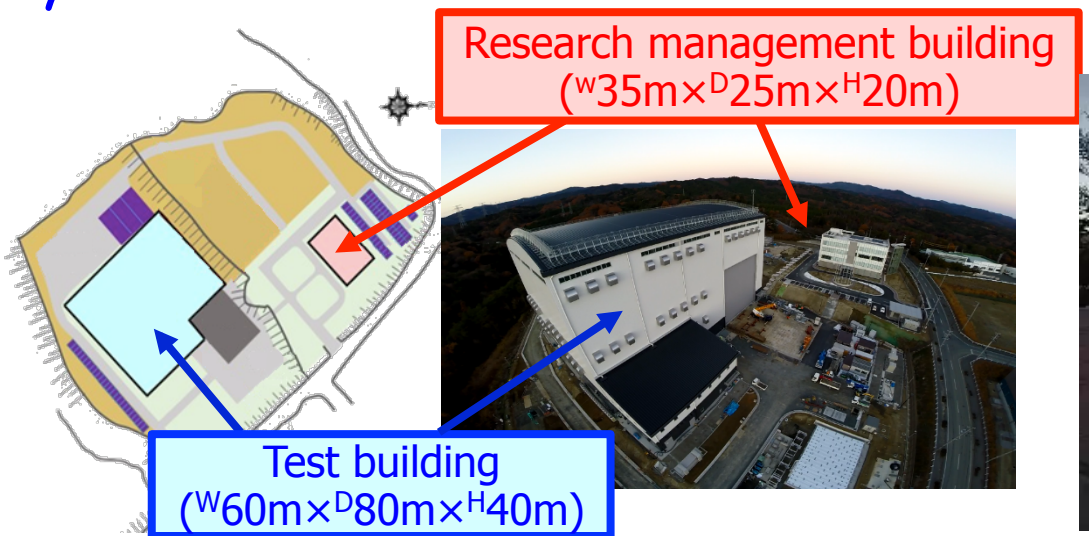
- development of remote operated technology and the worker's training by IRID and TEPCO.
- emergency response research and development by the researchers of the universities, the institutes and JAEA.

Aim and status of NRTDC : location & layout

- location of NRTDC



- layout of the site



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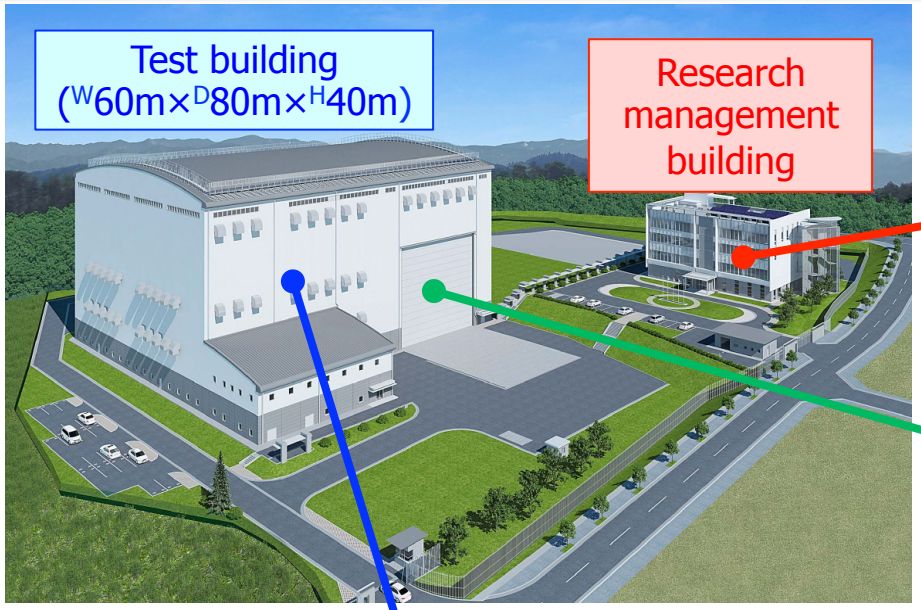
specific functions to be installed to NRTDC

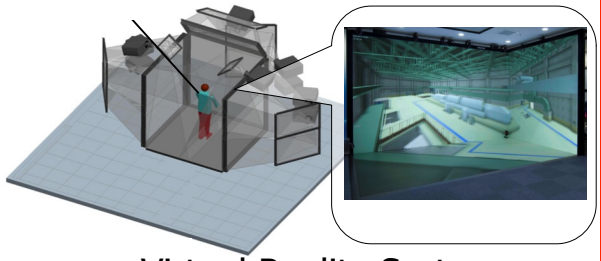
- Demonstration test for the techniques to repair a water leakage at the primary containment vessel (PCV) by utilizing the mock-up of PCV
- Test of the remote controlled devices to be used for the investigation & the decontamination in the 1F by utilizing the mock-up facilities
- Support development of the robot and the operators training by the simulator
- Confirmation and training of the work procedure for the workers in 1F by the virtual reality system

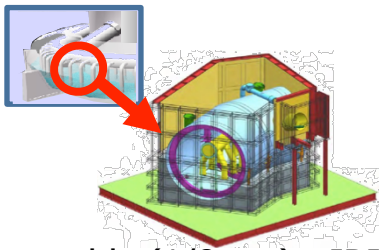
Mockup and instruments to be installed

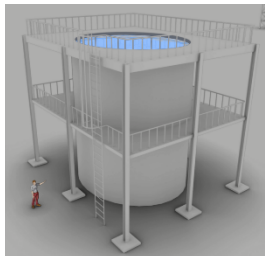
- facilities

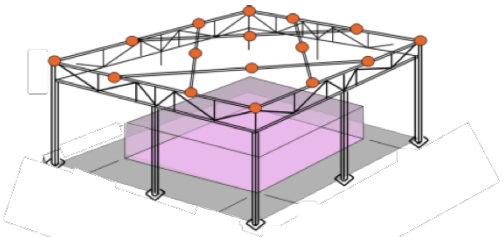
Demonstration test area for the technique to repair a water leakage at the PCV and development and demonstration test area for the remote controlled equipments are prepared in Test building

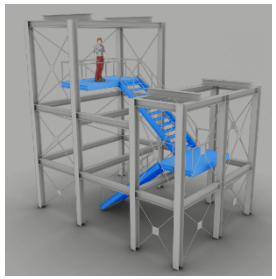



Virtual Reality System


Test assembly (1/8 cut) : IRID


Water pool


Motion capture camera


Mock-up staircase


Robot Simulator

Mockup and instruments to be installed

- outlooks of the facilities in Test building

approx. 8m

water pool

mock-up staircase

motion capture space
(with 16 tracking cameras)

【return】

Mockup and instruments to be installed

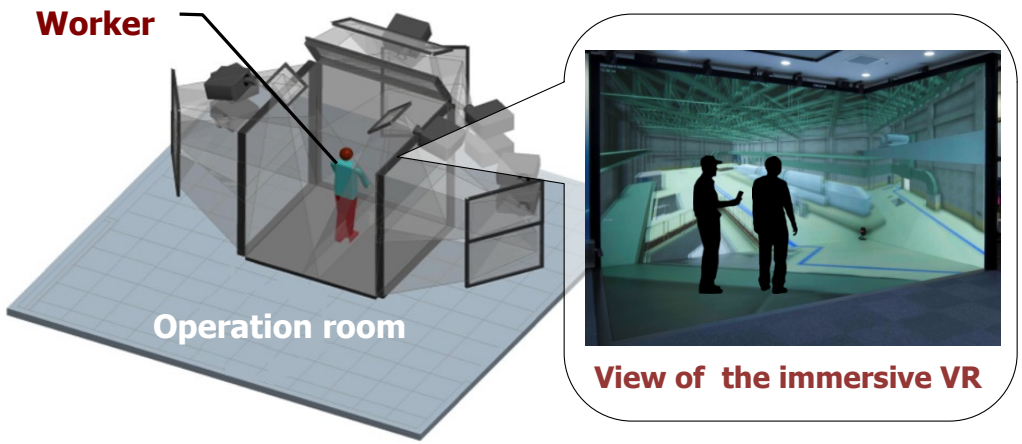
-Virtual Reality (VR) System

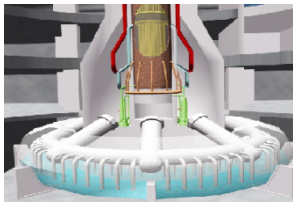
- Planning of the work procedure

  It will be used to validate the working method and procedure, by testing the plan in the virtual space.

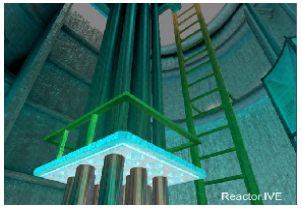
- Training and drill

  The workers can better understand the work environment, the work methods and procedures by going through the virtual scenarios as experience for real world scenarios.

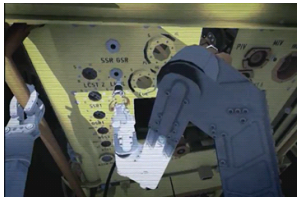




To make and verify the procedures for the decommissioning



Training and drills based on the procedures



Operation training and validation of remote handling equipment (ex. manipulator)

- outlooks of Virtual Reality System

* pictures with dummy env. data

- Tracking the head motion of an operator and feedback to projection of the view
- 3D-glasses and an input device
- Structural data of 2nd-unit of 1 F (cooperation with TEPCO)

【return】

Research subjects by JAEA at NRTDC (1)

- research theme for 7 years from FY 2015.

No.	Research theme	
1	Development of Robotic Technology	Standard test method
2		Robot simulator
3		Powered exoskeleton with radiation shielding
4		Nuclear emergency response robot
5	Development of Hot testing Technology	Laser machining technology
6		Laser diagnostics technology
7		Gamma-ray CT technology
8		Advanced instrumentation system
9		Water stoppage technology using photo-curing resin

Research subjects by JAEA at NRTDC (2)

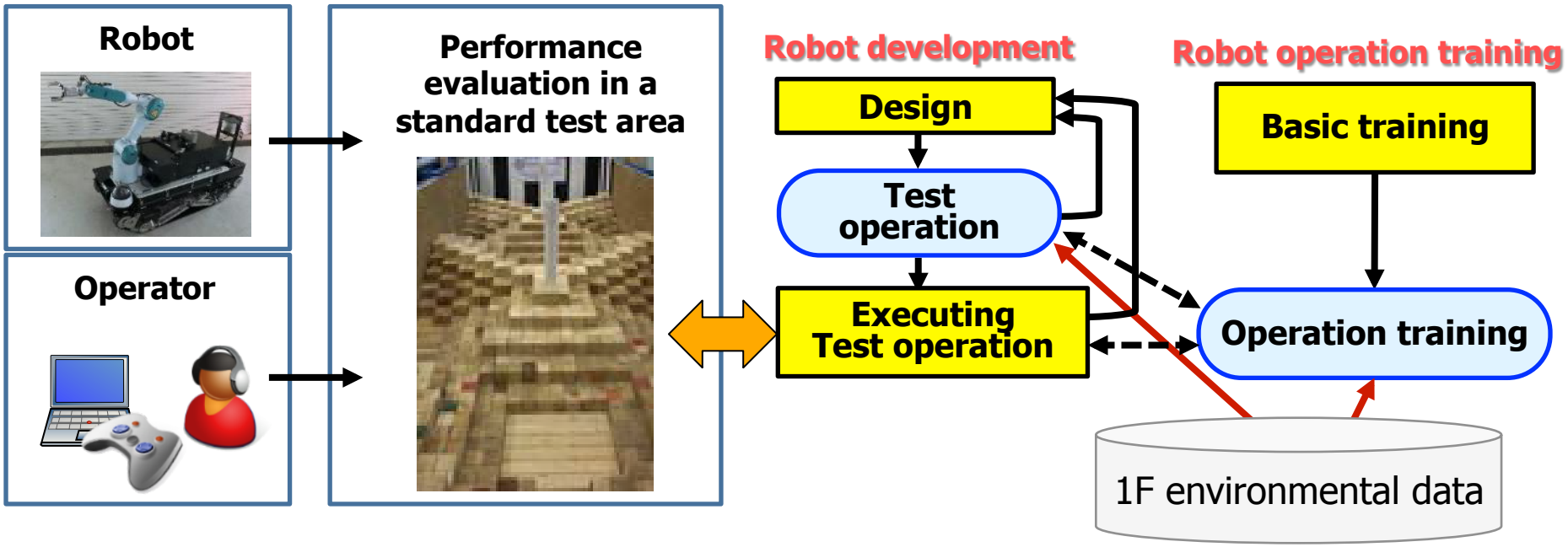
- subjects in robot technology for decommissioning

Standard performance test methods for nuclear emergency response robots

Developing test method for quantitatively evaluating common capacities of task performance for nuclear emergency response robot. Clarifying demanded level for robots and technical achievement level for operators

Robot simulator used for decommissioning of 1 F

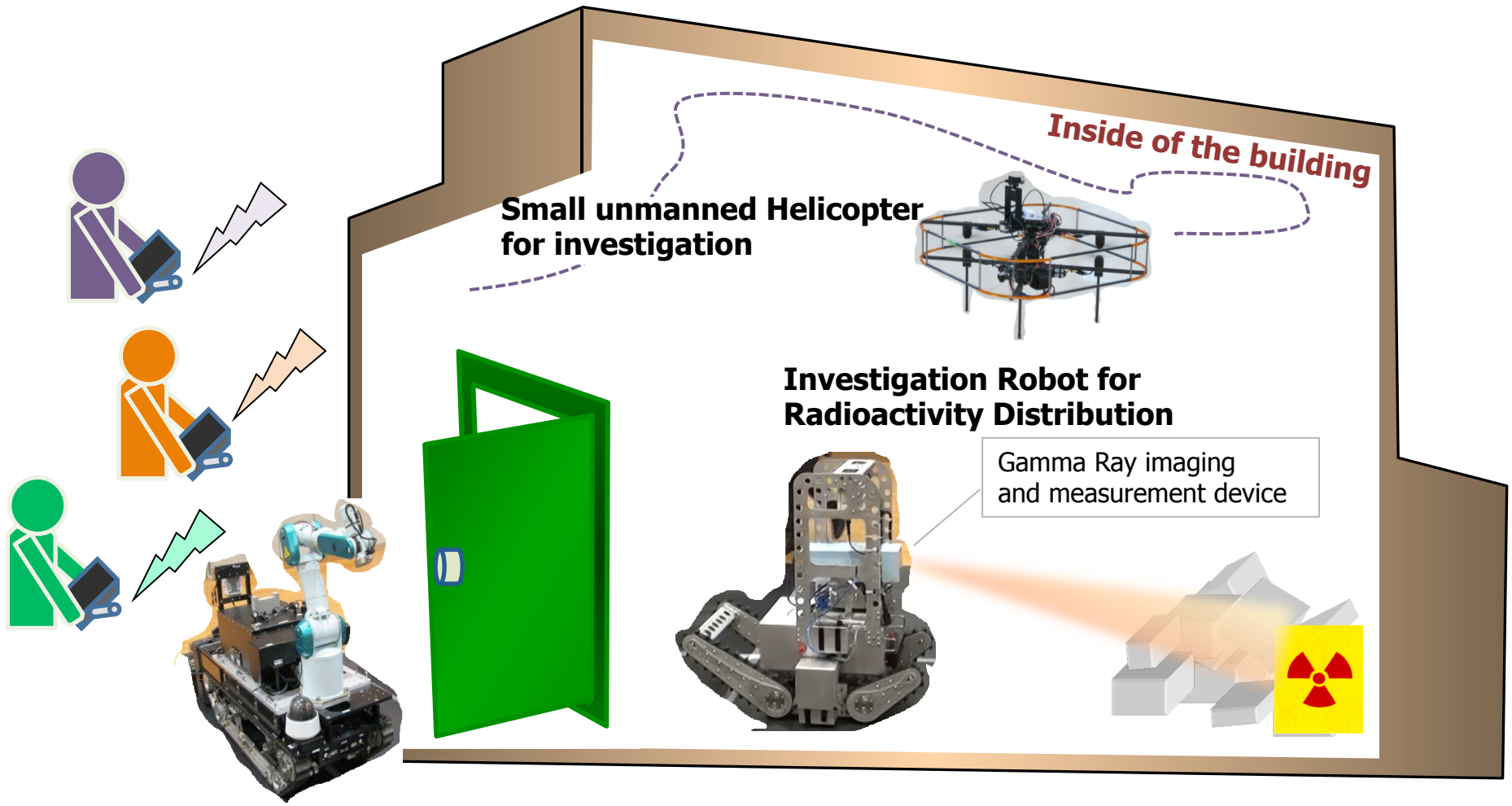
Inputting data into PC which include changeable work site environment for decommissioning and Developing simulator with the aim to plan and training of decommissioning work for robot, and its streamlined development



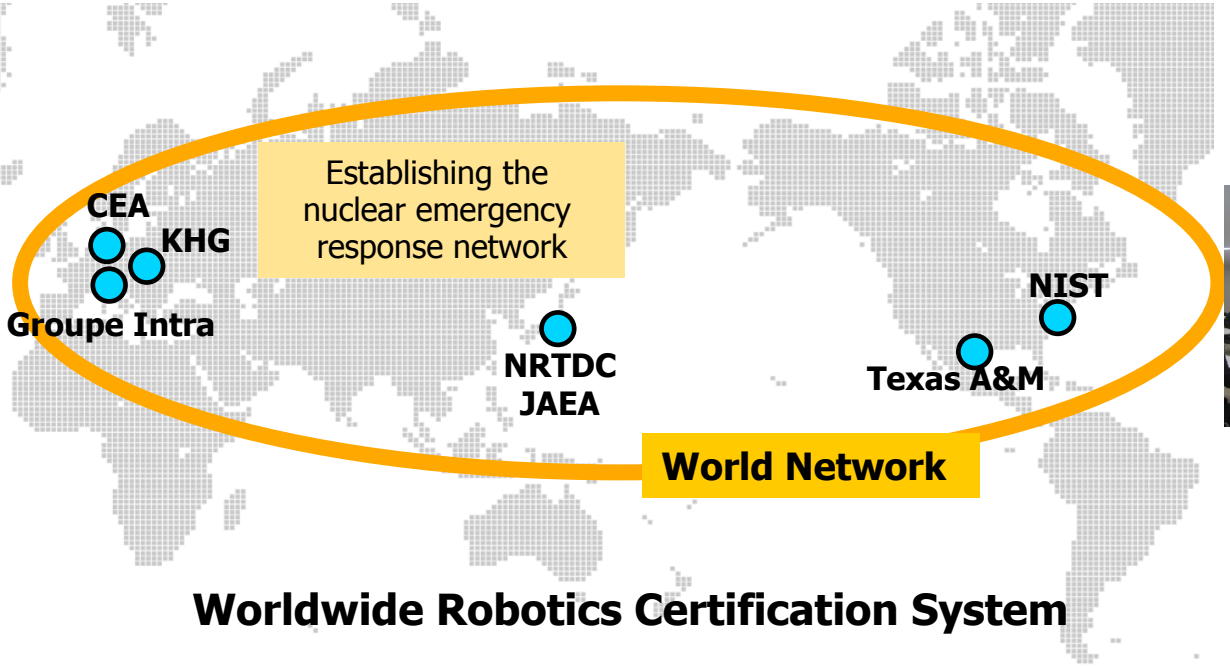
*Robotic simulation system is based on AIST's Choreonoid

Research subjects by JAEA at NRTDC (3)

- subjects in robot technology for emergency response



International cooperation



Worldwide Robotics Certification System

- International workshop on Standard Test MeMethod (Nov. 6th & 7th, 2015)

- International workshop on Emergency Response Robotics (Dec. 2nd & 3rd, 2015)

Establishment of strategic partnership

Successive development and operation

- **Establishment of the standard test method for nuclear emergency response robot**
- **Planning a robot competition**

Promotion of utilization

- **Survey of overseas facilities utilized for remote technology development and emergency response and establish a partnership.**
- **Open for foreign researchers and engineers to use**

Summary of topic I

- JAEA follows the medium-and-long term road map and pushes forward the establishment of the construction or design works of facilities.
- JAEA aims at the establishment of an attractive international base facility for R&D based on user's needs.
- NRTDC : the facilities for development of the remote controlled technology and device are available partially and will be in full operation from April 2016.

http://naraha.jaea.go.jp

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Background

- Utilization of the remote technology is indispensable for the long-term decommissioning missions in Fukushima Daiichi Nuclear power station.

- There were the cases that the troubles happened during the operations because of the working environment is complicated.

Advance preparations would contribute to reduce the risks

- measuring the performance of the remote equipment
- carrying out frequent training and rehearsal of the operators

realized by providing the simulated/expected working environment

Common evaluation is important to recognize/understand the robot's capability and the operator's proficiency.

- the quantitative evaluation methods are required

Aim

Standard Test Method(s) for response robots

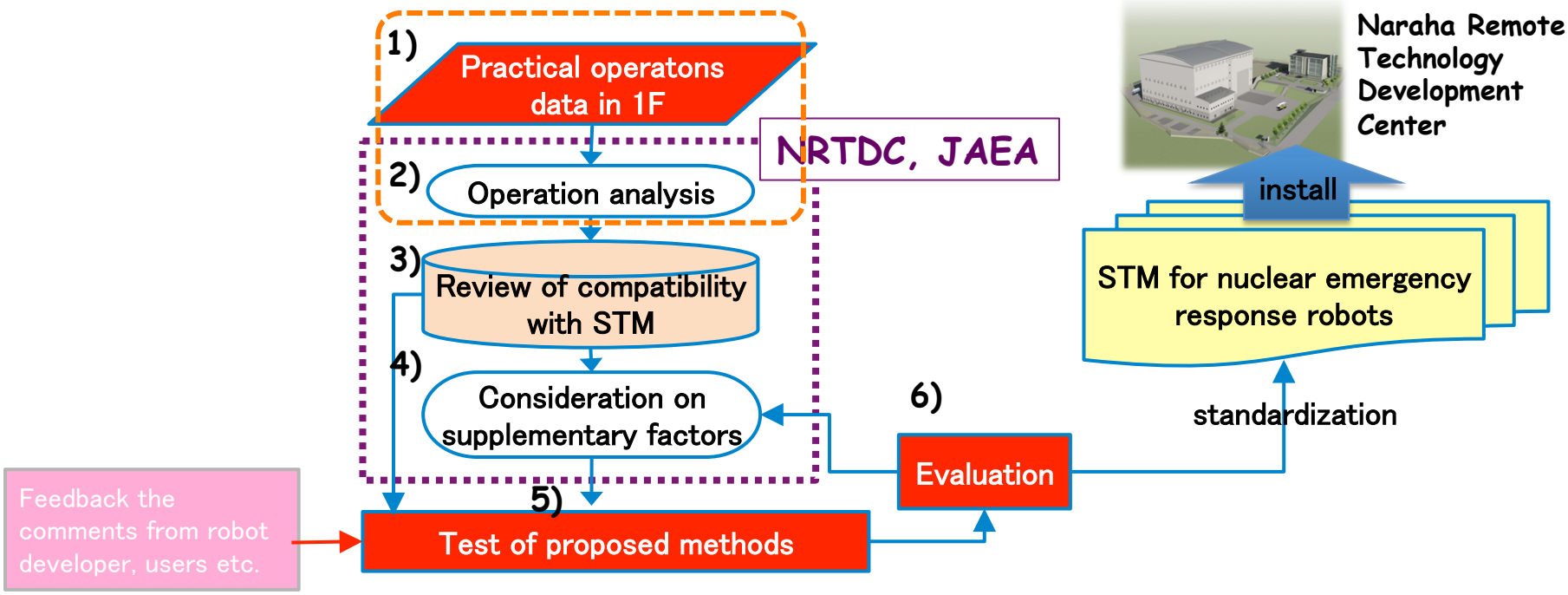
- a comprehensive set of standard test methods and associated performance metrics to quantify key capabilities of emergency response robots
- providing the standardized evaluation methods to evaluate the robots' and the operators' performance quantitatively.

concept/idea of STM coincides with the contributions to reliable decommissioning operations by using remote equipment

design of STM for nuclear emergency response robots

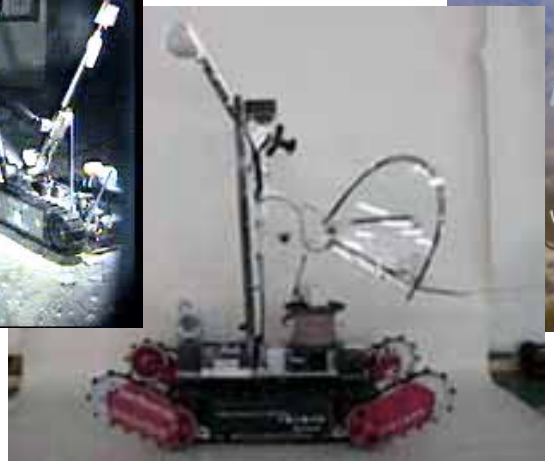
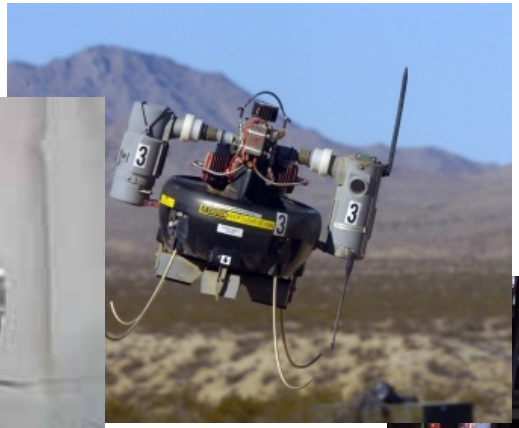
- analysis of the robot operations during the missions in 1F
- reviews on the accidents that were occurred to the robots.

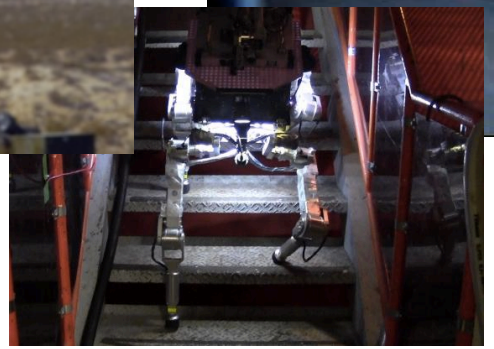
Developmental flow of STM for NERR



1) Practical operations in 1F
   - collect the robots types information and their activity data
2) Operation analysis
   - analysis of the robot tasks, the operation performance, etc.
3) Review of compatibility with STMs
   - examine the compatibility among the results of 2) and NIST-STM for extracting insufficiencies
   - fundamental test trials with prototypes if necessary
4) Consideration on the supplementary factors
5) Test of designed method
6) Evaluation towards standardization

Robots that work in 1 F






Videos & photos: http://www.tepco.co.jp/en/news/library/index-e.html

Video data opened by TEPCO

http:www.tepco.co.jp/tepconews/library/archive-j.html

type of the robot	number of information	number of video	data size	main works in the contents
510 PackBot	27	43	1411.1MB	removal of obstacles, dosimetry, decontamination
Quince	16	30	857.66MB	removal of obstacles, dosimetry, decontamination, sampling
RQ-16 T-Hawk	5	2	232.3MB	observation
Quadruped robot	5	4	249.3MB	investigation of vent pipe
710 Warrior	4	3	109.3MB	removal of obstacles, dosimetry, sampling
MEISTeR	2	0	-	dosimetry, sampling
Survey runner	2	2	798.5MB	dosimetry
FRIGO-MA	2	2	-	dosimetry
JAEA-3	1	1	11.2MB	dosimetry using gamma camera
ASTACO-SoRa	1	0	-	removal of obstacles

- most of the robots were utilized to survey missions.
- most of video data were the missions with Packbot and Quince.

analysis candidates: works with PackBot and Quince

Comparison of video data related to PackBot and Quince

PackBot

http://photo.tepco.co.jp/date/2011/201104-j/110420-01j.html

- the view from backside
- the view is not suitable to recognize the situation

Quince

http://photo.tepco.co.jp/date/2012/201202-j/120228-01j.html

- the operation screen view
- easier to recognize the situation of the robot and the operation

Quince video data is better candidate for work analysis.

Time analysis on the operation of the robot

Approach: time analysis on the operation

- definition of the sub-tasks on the operation/state
- classifying the operation of the robot into sub-tasks & counting accumulated use time.

extracted 9 categories from the video contents.

① traveling(flat surface, puddle, passing the obstacle)
② stop(capturing images, state confirmations)
③ traveling on gap(stairs, steps)
④ angular adjustment of sub crawler
⑤ camera adjustment
⑥ video signal lost※
⑦ turn
⑧ traveling in narrow space
⑨ turn at half landing of the stairs

※the building is comprised of concrete and an electric wave disorder happens.

Time analysis on Quince operation (1/2)

【mission on Feb.2. 2012, operation time 90min.】

	category		time(m:s)		ratio(%)		sum(%)	
①	traveling	flat	26:01	37:42	29	42	29	42
		puddle	06:27		7		36	
		obstacle	05:14		6		42	
②	stop		10:48		12		54	
③	traveling on gap	stairs	04:32	09:52	5	11	59	65
		step	05:20		6		65	
④	angular adjustment of sub crawler		09:48		10		75	
⑤	camera adjustment		06:39		7		82	
⑥	video signal lost		05:44		6		88	
⑦	turn		04:14		5		93	
⑧	traveling in narrow space		03:10		4		97	
⑨	turn at half landing of the stairs		02:26		3		100	

major sub-tasks to be thought in the operation

Time analysis on Quince operation (2/2)

【mission on June 13, 2012,operation time 167min. 12sec.】

	category		time(m:s)		ratio(%)		sum(%)	
①	traveling	flat	26:57	54:31	16.1	32.6	16.1	32.6
		puddle	06:05		3.6		19.7	
		obstacle	21:29		11.6		31.3	
③	traveling on gap	stairs	07:55	50:41	4.7	30.3	37.3	62.9
		step	42:46		25.6		62.9	
④	angular adjustment of sub crawler		22:58		13.7		76.6	
②	stop		17:31		10.5		87.1	
⑥	video signal lost		12:01		7.2		94.3	
⑦	turn		04:48		2.9		97.2	
⑨	turn at half landing of the stairs		02:11		1.3		98.5	
⑧	traveling in narrow space		01:24		0.8		99.3	
⑤	camera adjustment		06:39		0.7		100	

major sub-tasks to be thought in the operation

Results of time analysis

5 sub-tasks accounted for 80%+ of accumulated use time during the operations

① traveling
(flat surface, puddle, passing obstacle)
② stop
(capturing images, state monitoring)
③ traveling on gap
(stairs, steps)
④ angular adjustment of sub crawlers
⑤ camera adjustment

approx. 70%

--> approx. 10%+

If use time for "STOP" can be reduced, the efficiency of the operation would be improved.

It is estimated the state monitoring is to recognize the surroundings and the cable state etc.

Accident occurrence on the robots

Approach: occurred accident investigation

- approx. 35 robots and machines were applied to the missions during 3 years after the nuclear power station accident.
- for indoor use, investigation/inspection robots accounted for 40%+.
- 5 robots could not return / be recovered.

Missions		Type	Numbers	Missions
Rubble removal	outdoor use	Unmanned construction machine	(approx. 10)	?
	indoor use	BROKK	5	?
Reconnaissance	at surface	PackBOT QUINCE JAEA-3 QUINCE-2,3 Survey Runner	9	43 3 1 6 2
	at high place		1	2
De-contamination	for lower floor		3	3
	for higher floor		1	?
Others	core sampling	Meister	1 (common use: decont.)	2
	obstacle deconstruction	Warrior	1	6

Accidents that occurred during the operations

	Type of robot	Occurred accident
Un-repatriated robots	T-Hawk	Out of control？
	QUINCE	Communication cable was broken down？
	Survey Runner	Communication cable was broken down？
	Child robot of quadruped robot	Communication cable was jammed
	Warrior	Tumbled by mis-operation
Returned but troubled robots	QUINCE 2	Communication cable was broken down？ collected by wireless communication relay with QUINCE3
	Quadruped robot	Tumbled by mis-recognition of the material of the step collected by the operator
	JAEA-3	Communication / Power cable affected travelling performance (not smooth motion)

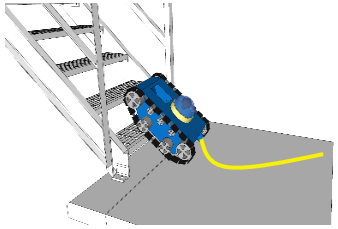
- accidents of ground robots accounted for approx. 50% of all cases
  - Un-repatriated robots left in 1F become the OBSTACLES and modify the env.
- accidents were caused by the troubles of the cable / tether
  - remodeling communication part into WIRED type for applying the works in nuclear power station

Possible subject for evaluating NERR

facts in the robot operation

- wireless signal is shielded by concrete structure a building → Wired signal transmission
- possibility of system or operation failure under complicated env.. → Recovered/removed by the other robot
- robot is contaminated by high dose of the radiation → Remote operated maintenance

Possible subjects

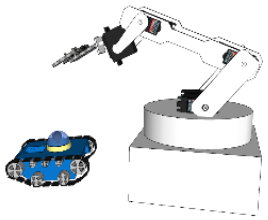


Influence of the cable

- influence of the cable tension should be evaluated quantitatively

Removability

- recoverability/ removability by the remote operation should be evaluated.



Remote maintenance ability

- Maintenance time, and the number of the tools to use should be evaluated quantitatively

Summary of topic II

- Towards design of Standard Test Method for nuclear emergency response robots…….

  - approach & current works
    - conduct time analysis of the operations with Quince based on the video open by TEPCO.
    - summarize occurred accidents on the robot that worked in 1F.
    - extract the issues to design standard test methods for nuclear emergency response robots.

  - future directions
    - attempt to design the prototypes of STM for NERR based on analysis results
    - interviews with the operators of the robots and the workers

Conclusions

- Presented topics

- Introduction of Naraha Remote Technology Development Center, JAEA

- Examinations on robot (Quince) operations in 1 F to contribute toward design of Standard Test Method for nuclear emergency response robots

Acknowledgements

We'd like to express our gratitude to Mr. Fumiaki Mori and Mr. Norihito Shirasaki of JAEA. They gave the efforts to discuss topics II.