# Application of new techniques (such as robots or drones) used at the Fukushima Daiichi Nuclear Power Station to ALARA

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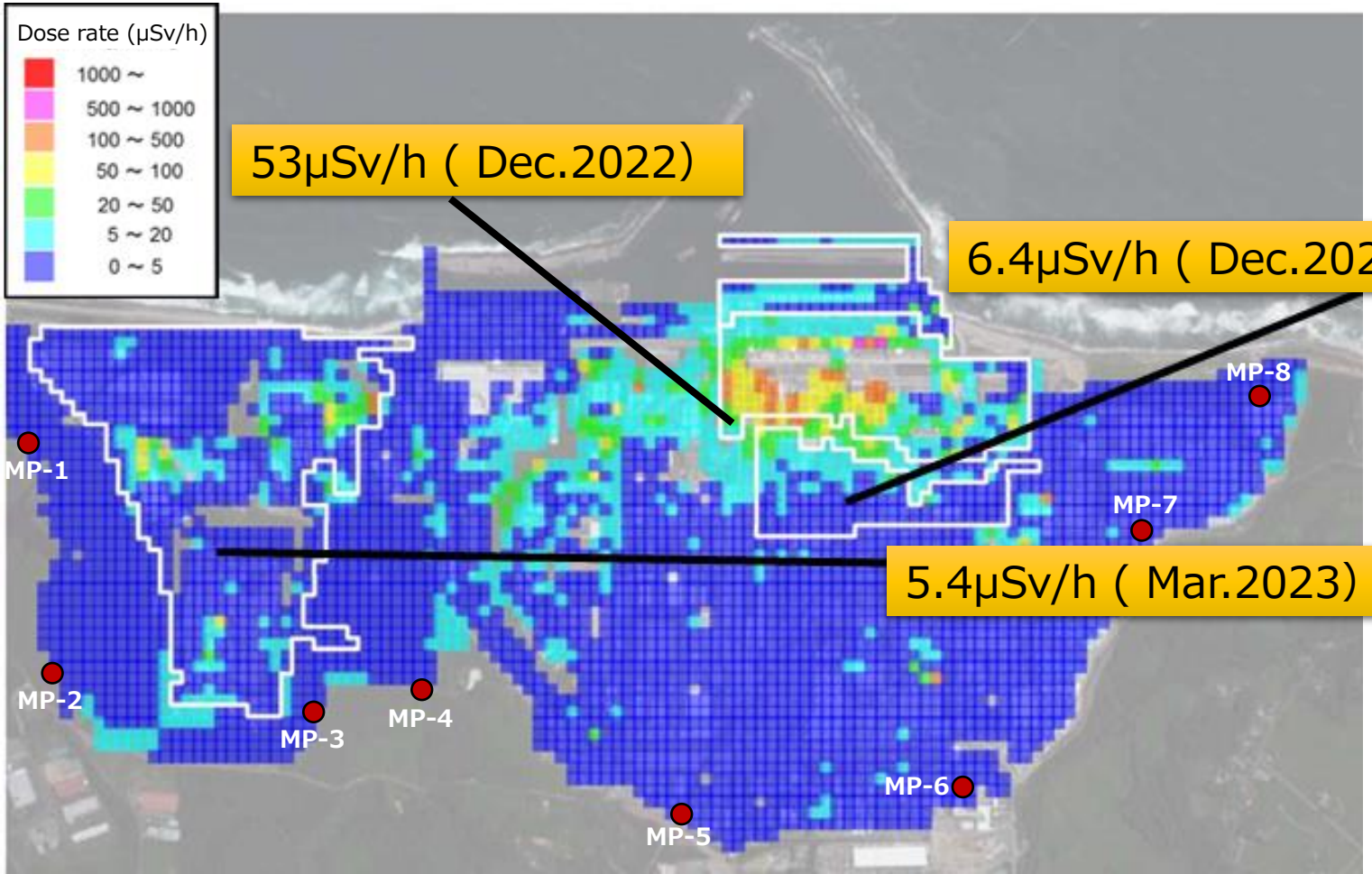
# Current status of air dose rates in the FDNPS

Unit: μSv/h (2024.06.02)

| MP-1 | MP-2 | MP-3 | MP-4 | MP-5 | MP-6 | MP-7 | MP-8 |
|---|---|---|---|---|---|---|---|
| 0.489 | 0.750 | 0.477 | 0.916 | 0.669 | 0.310 | 0.543 | 0.504 |




13 years after the accident,
97% of the areas in the FDNPS are now accessible in general working clothes, the values at the site boundary γ-ray monitoring posts are below 1 μSv/h and air dose rates do not exceed 10 μSv/h in many places except around R/B and T/B.

However, the situation within the R/B has not changed significantly,
for example, a dose rate of 1 Sv/h has been recorded in front of the X-6 penetration of Unit 2.

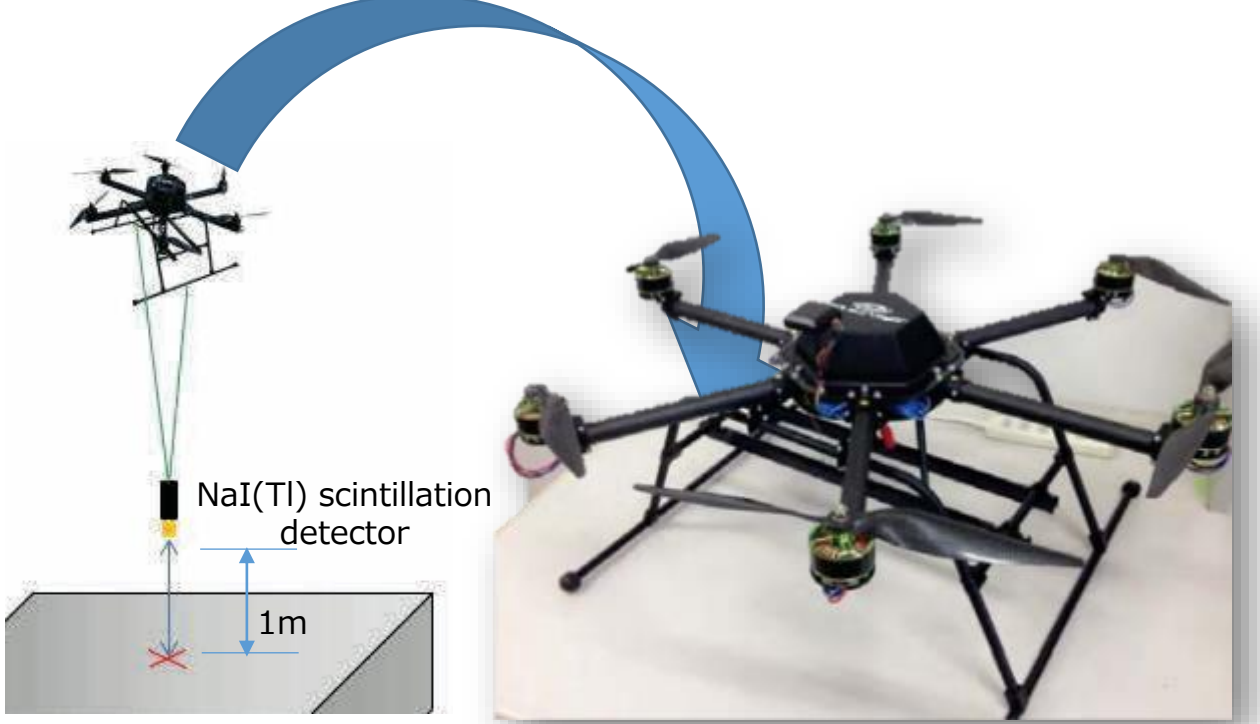
Therefore, remote monitoring equipment with robots or drones is essential for the investigation inside the R/B, where the dose rate is always in the mSv/h range

# Drones

# MS-06LA

Autonomous controlled flight of the drone near the ground surface was very difficult, so wire and the radiation measuring instrument was suspended from the drone at an altitude of around 1 m above the ground surface.Here the typical drone was used as follows.

Payload: 6 kg
Flight time: 20-30 min
Wind speed resistance: 14 m/s
Functions: automatic take-off and landing, automatic return
Autonomous navigation: GPS/INS ,3D-SLAM




Suspended dosimetry method

INS (Inertial Navigation System) is a computing system that houses an IMU consisting of a gyroscope and accelerometer, and a processing unit that uses a Kalman filter to calculate the best position estimate of the moving platform, combined with GPS to determine its exact position and orientation.

Outdoors

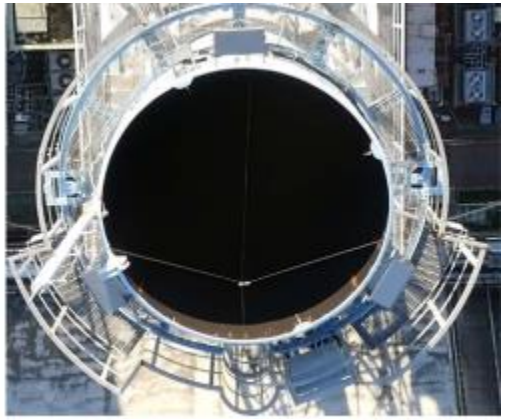
SLAM (Simultaneous Localisation and Mapping) is literally a technology that simultaneously estimates the self-location of a moving object and maps its environment.
SLAM is based on visible light cameras and LiDAR scanners and can be used indoors, outdoors and underground, as it does not use GPS.

Indoor

# MS-06LA

Air dose rates at the base of the exhaust stack range up to 1 Sv/h.

Inside the exhaust stack


External view of the top of the exhaust stack


Survey drone in flight photographed by monitoring drone

Two drones, one for survey and one for monitoring, were used to survey the inside of the cylinder body of the exhaust stack to be dismantled and to survey the external dose by visual flight.

The inside of the cylinder was photographed from the top of the exhaust tower using a camera with a zoom function mounted on the drone.

For the external dosimetry of the cylinder, the drone flew as close as possible to the surface of the cylinder and took measurements from three directions (north, west and south).

# Riser

Flight view

Final pre-flight inspection

Operator in the centre

In-building dose surveys using drones,the RISER, which uses CZT semiconductor detector and laser-based SLAM control, can fly stably even in indoor environments where GPS radio waves cannot reach.

A large amount of data can be obtained from dose surveys not only by autonomous flight but also by a combination of manual operations.

On the other hand, due to the specifications of the laser-based SLAM control, it was found that some environments could not be flown autonomously, and this was an issue for future development.



Cited from ATOX report

# Remote monitoring system

# Movable dose rate monitor


Weight approx. 160 kg

Movable dose rate monitor installed on site to enable workers on the power plant premises to see the real time dose rate at the actual site where they are working.
A total of 86 units installed on site.
Large displays have also been installed in the important seismic isolation building and the access control building so that workers can see the dose rate in the premises, including the area where they will be working, before they leave for the site.

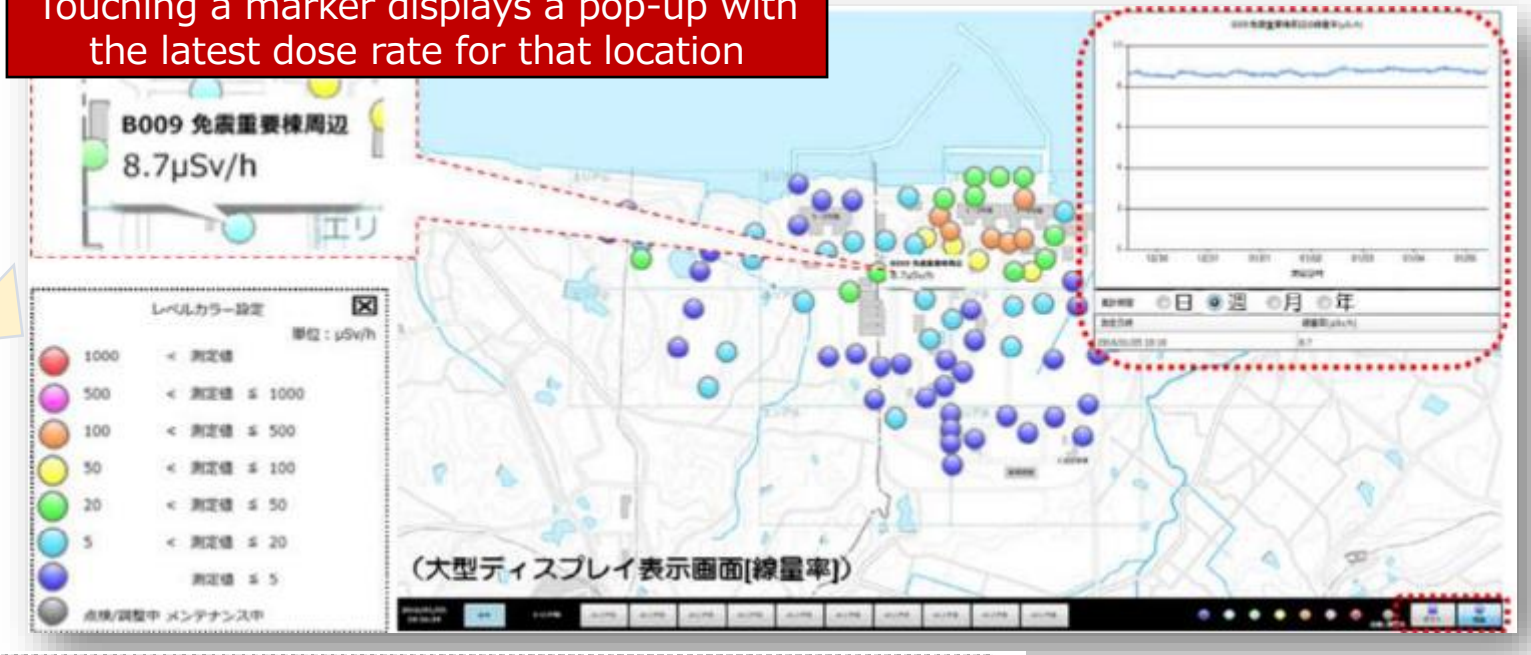
- Measured dose rate range 0.1 μSv/h-100 mSv/h
- Sampling at 10-minute intervals
- Solar-powered with GPS function
- Signal transmission distance approx. 200 m (Zigbee)

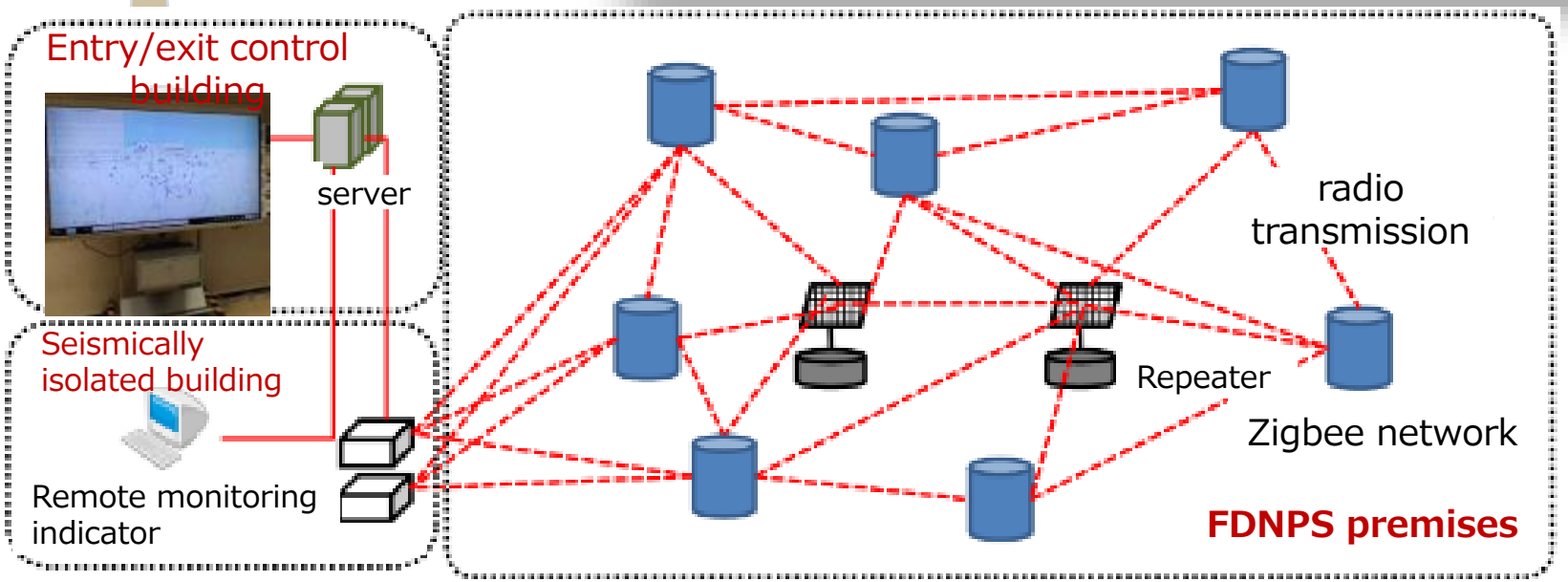
# Movable dose rate monitor

At the same time, trend data is also displayed in a pop-up window

Touching a marker displays a pop-up with the latest dose rate for that location

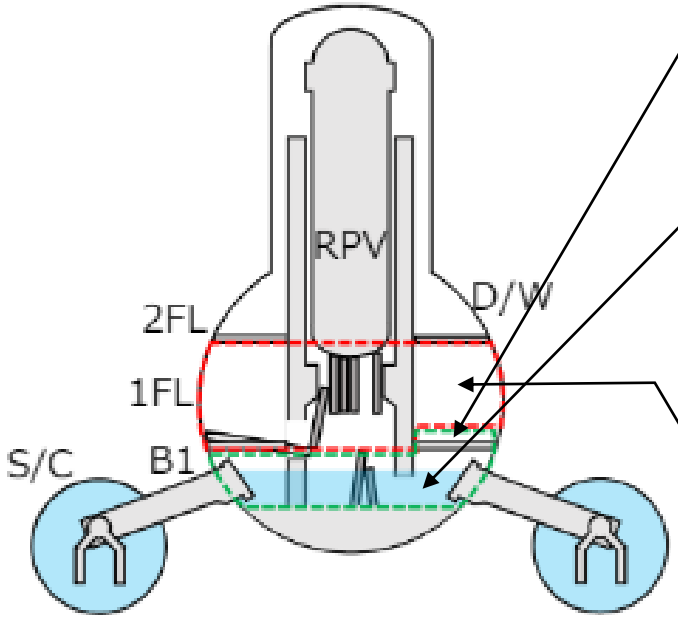
Dose rate data transmission network and display within FDNPS



# Robots

# Survey inside Unit 1



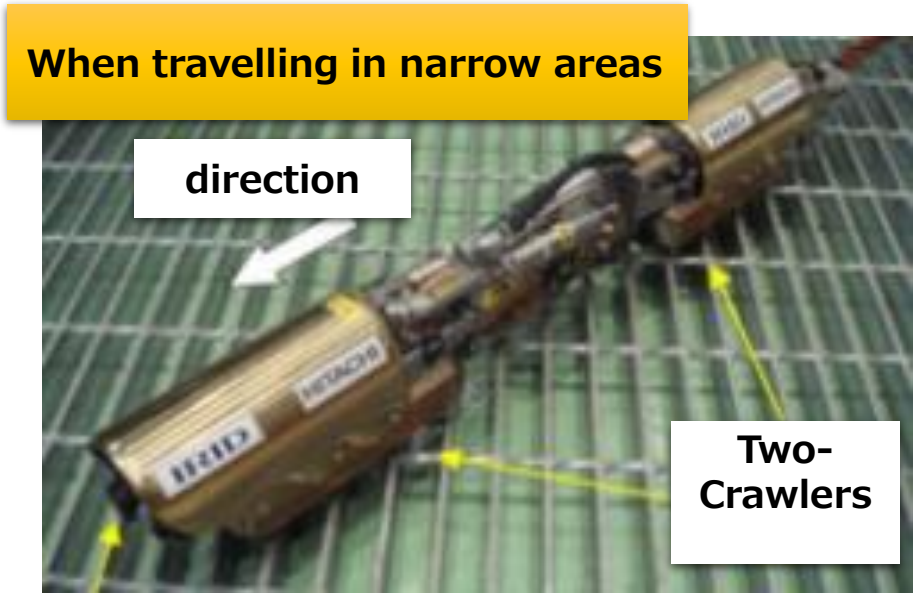

Schematic diagram of the survey area inside the PCV of Unit 1

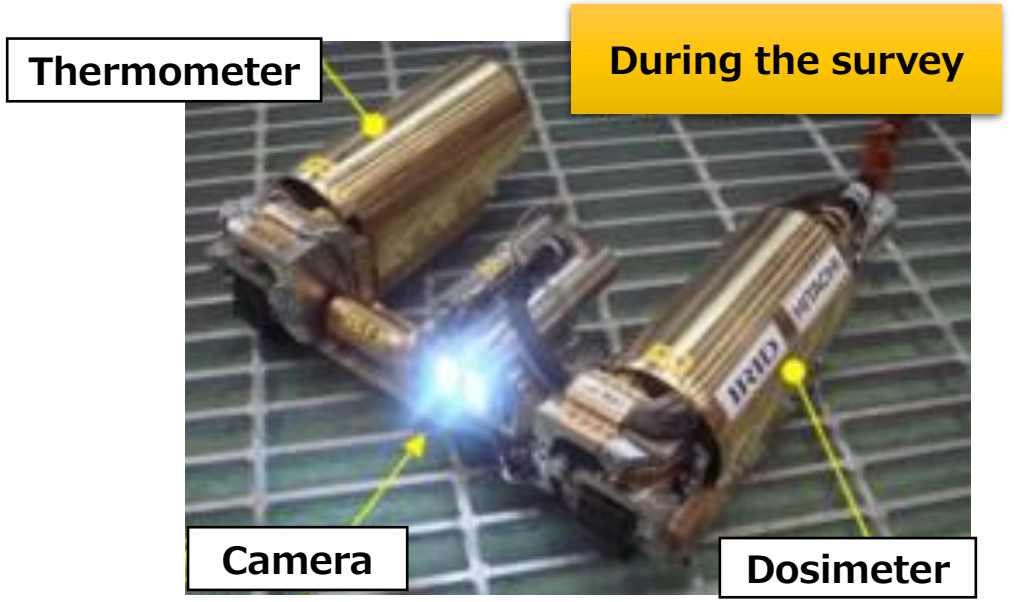
**1. Driving measurements:**
April 2015、the video, temperature and dose information inside the PCV (on the ground level outside the pedestal) was collected using the shape-changing robot PMORPH1.

**2. Underwater measurements:**
February 2022, the submersible robot boats ROV-A～E with a diving function were deployed into the PCV basement floor while the PCV remained isolated using a seal box, to conduct detailed visual inspection inside and outside the pedestal, three-dimensional mapping of the deposits in the outer pedestal basement floor, thickness measurement of deposits in the outer pedestal basement floor, fuel debris detection and deposit.

**3. Airborne measurements:**
February 2024, after connecting the seal box and opening the isolation valve, the narrow space inspection drone iBIS was launched from the X-2 penetration into the interior of the PCV. At the same time, a snake-shaped robot equipped with a radio repeater was deployed to cover the radio communication range of the small drone and acquire images of the 1FL area outside the pedestal and inside the pedestal.

# Robots for driving measurements




## Shape-shifting robot

The deformable robot was conceived as it was inserted through a narrow penetration

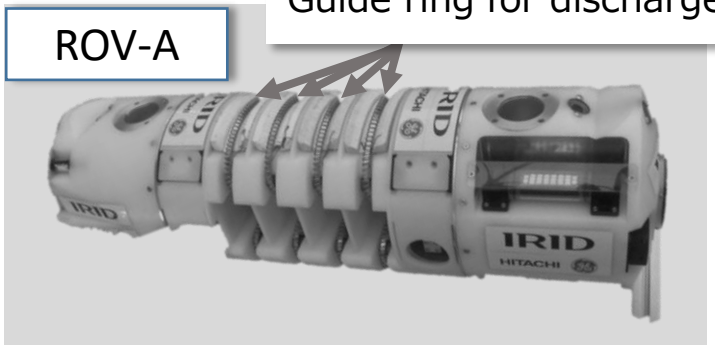
# Robot for underwater measurements

Swimming and diving in the survey moving range through the attached guide ring

- ROV-A: guide ring installation
- ROV-B: sediment 3D mapping
- ROV-C: Sediment thickness measurement
- ROV-D: Fuel debris detection
- ROV-E: Deposit sampling

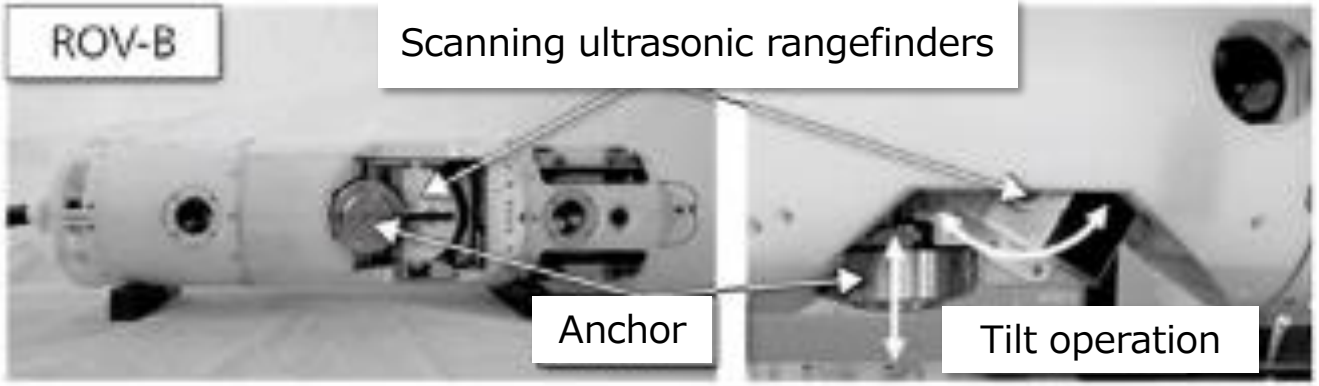
ROV-A

Guide ring for discharge




ROV-B

Scanning ultrasonic rangefinders

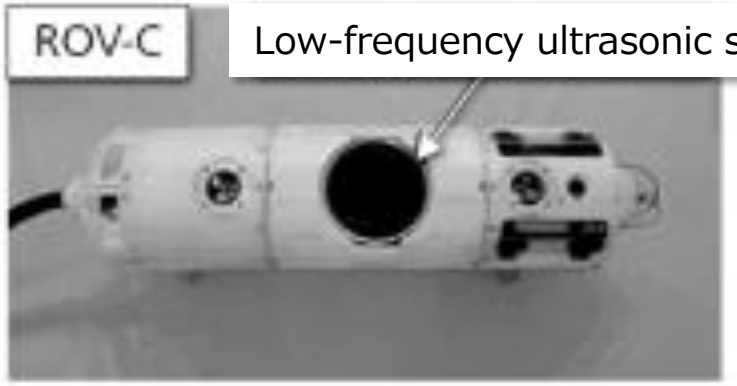


Anchor

Tilt operation

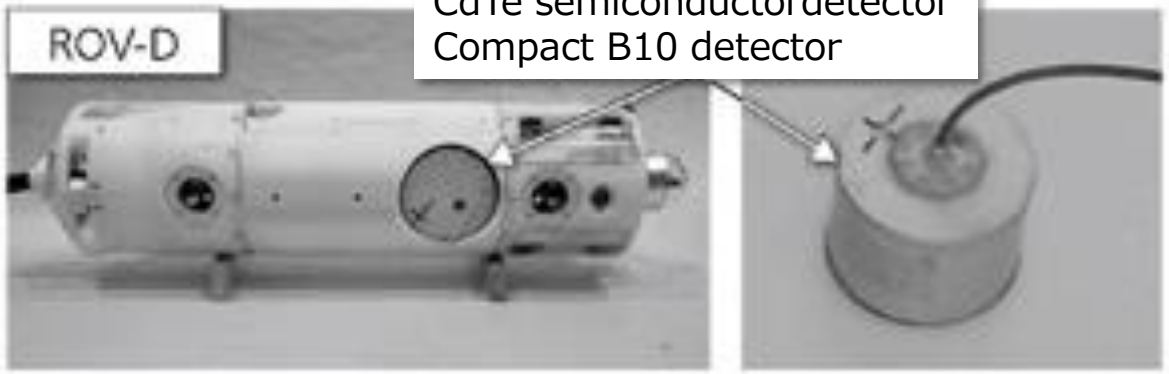
ROV-C

Low-frequency ultrasonic sensor



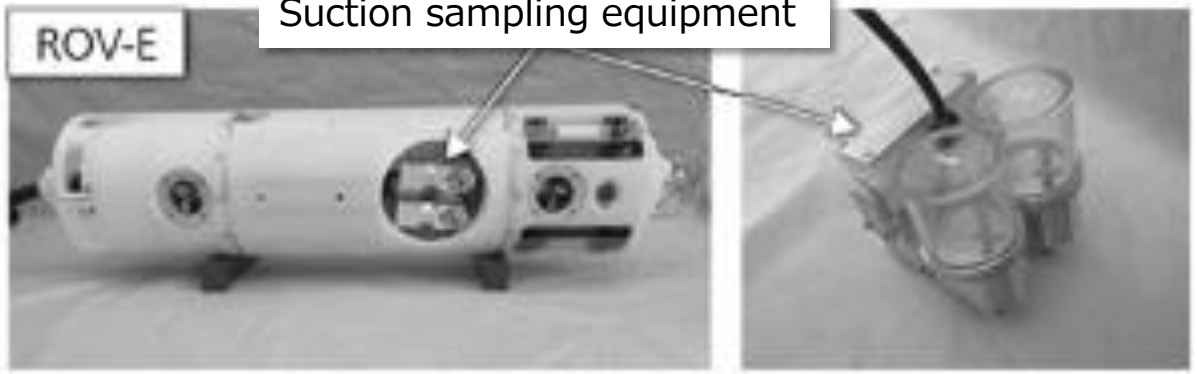
ROV-D

CdTe semiconductordetector
Compact B10 detector



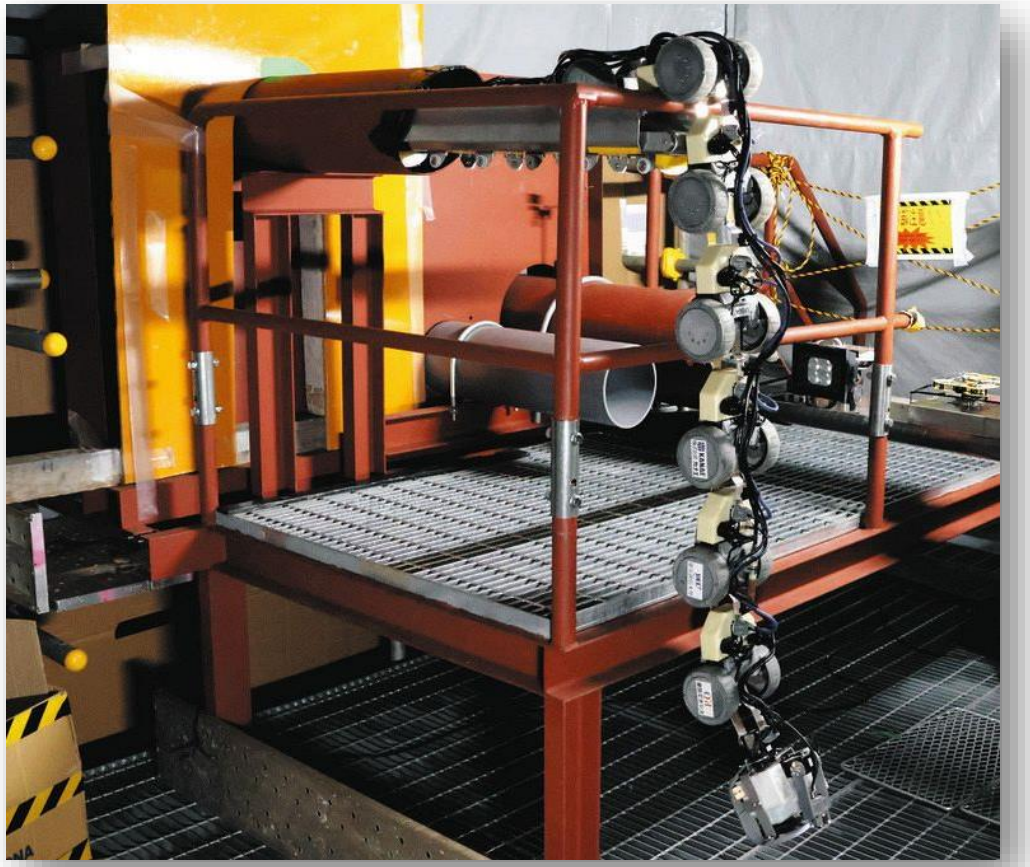
ROV-E

Suction sampling equipment



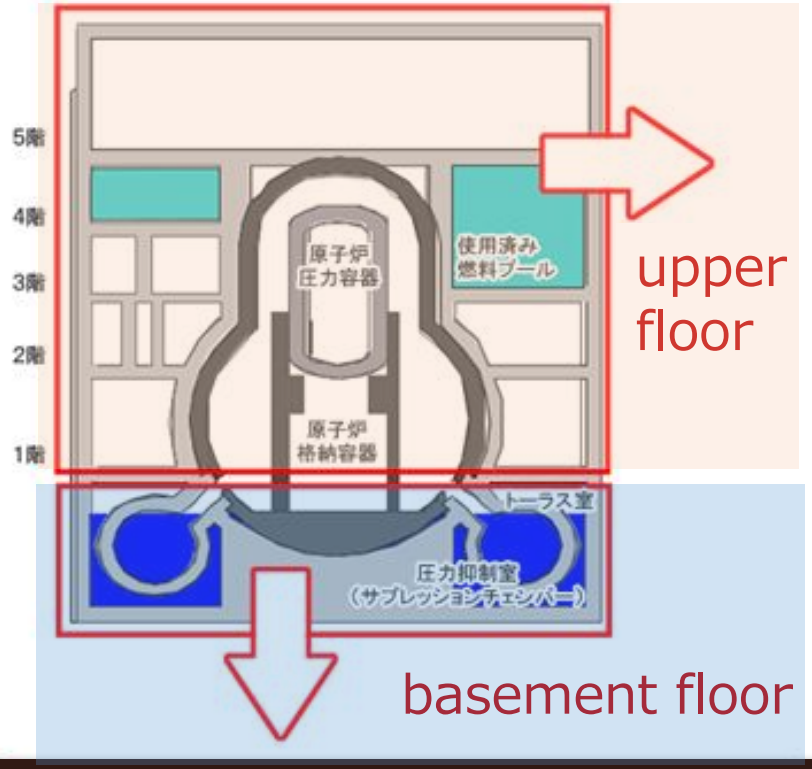
# Drone & robot for airborne measurements


**Liberaware iBIS narrow space inspection drone**
Weight: 185 g
Radiation resistance: 150 Gy
Control: wireless
Flight time: 8 minutes
Camera: full HD



**Snake-shaped robot**
Weight: 25 kg
Radiation resistance: 249 Gy
Control: wired
Wireless relay for drones
Camera: CMOS

# Robots used inside of Reactor buildings



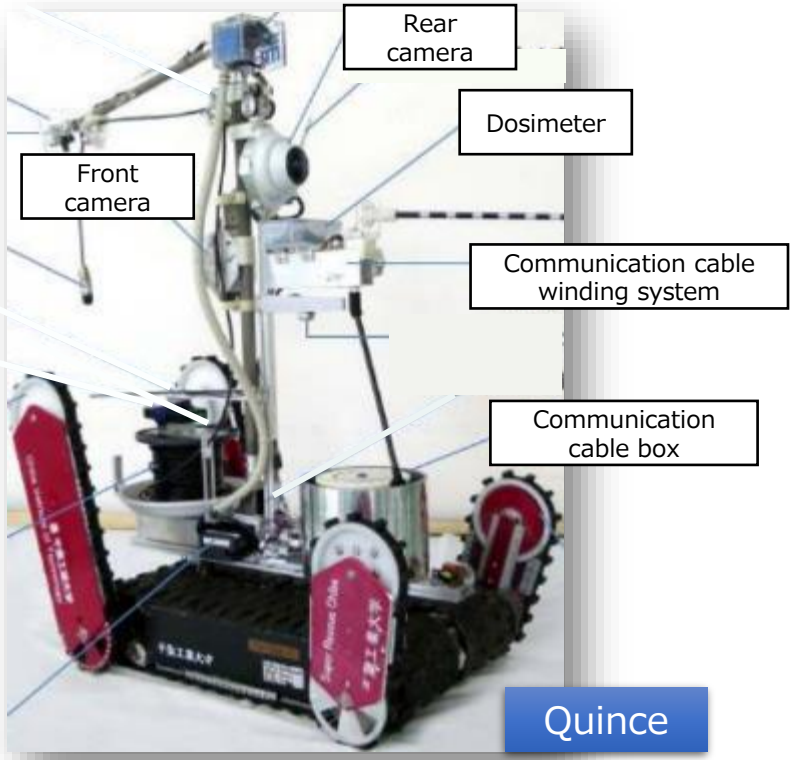

## Robots mainly used on floors above the ground floor

## Robots mainly used below basement floors

# Quince & Packbot

Quince was developed as a rescue robot on behalf of firefighters during a CBRNE.

On 24 June 2011, Quince was deployed to the FDNPS.
So far, dust sampling and dosimetry have been carried out on each floor.



Quince

Used in the US military

Packbot

On 4 July, it worked with iRobot's Packbot in the Unit 1 building.
The mission was for Packbot to open the door and conduct reconnaissance, but it was unable to open the door, although it was able to insert a key into the door keyhole.

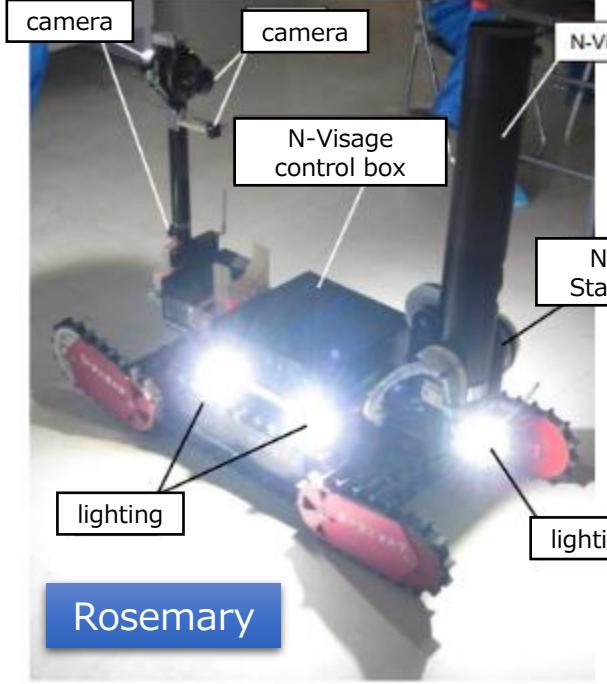
On 20 October, the communication cable was severed and the first unit was unable to return home, but later, the second and third unit equipped with a fully automatic communication cable winder and a rescue system in case of a cable cut, were deployed and continued to take measurements and check the situation.

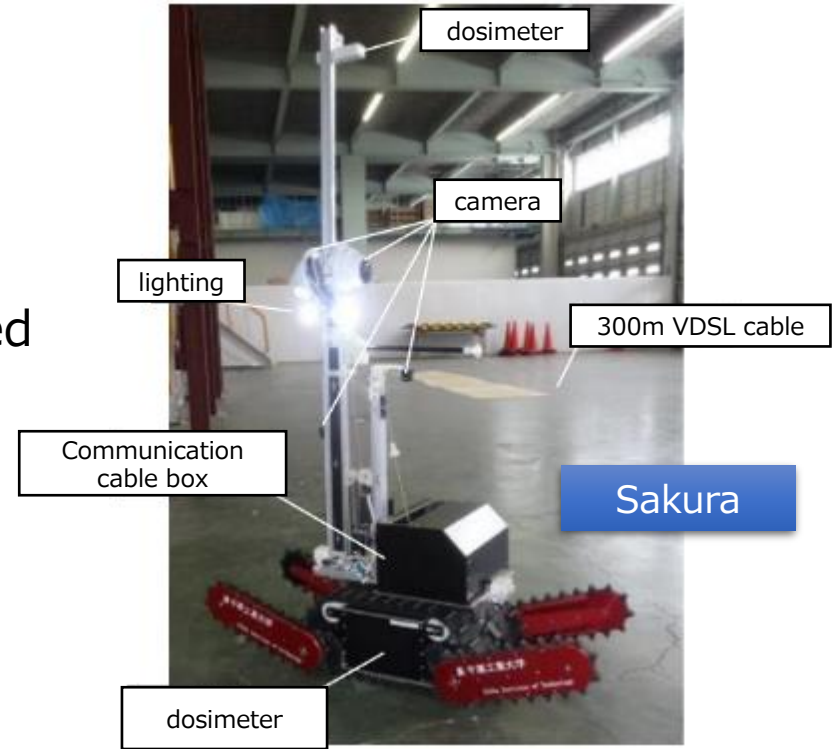
# Rosemary & Sakura

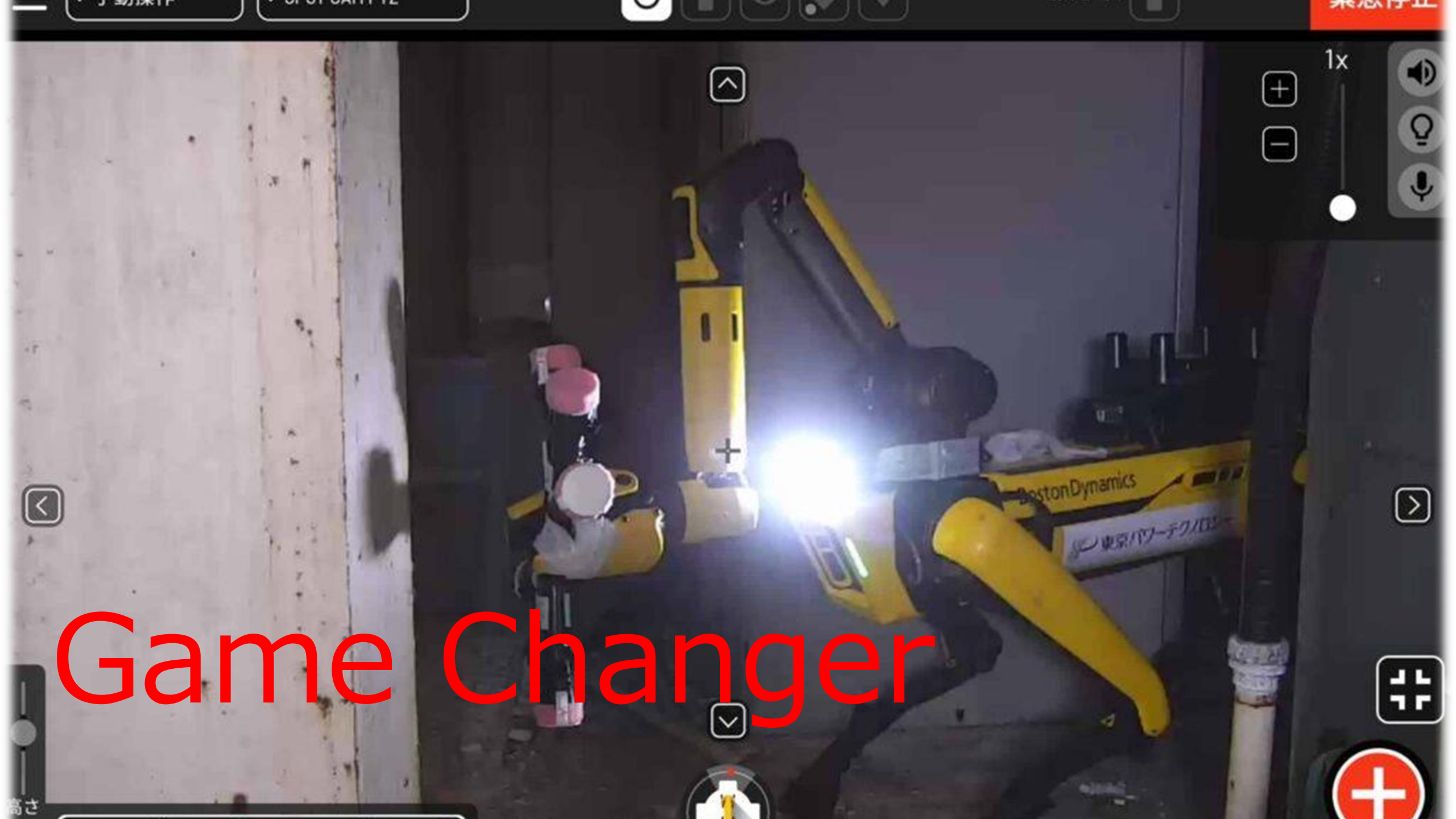
Robots such as Rosemary can ascend and descend the staircase stably by means of a flipper mechanism.

However, as these robots are mainly used for investigation purposes so the operation of the flippers is complex and depends on the competence of the operator.

In investigating the source of radiation in the reactor building, the N-Visage is mounted on the Rosemary to carry out investigations, but because the Rosemary does not have the space to install the communication cable winding/unwinding equipment required for wired operation, it had to be operated by radio communication. However, the radio communication infrastructure in the reactor building was not in place, and Sakura, a radio repeater, was deployed in parallel as a support robot.




1x
Boston Dynamics
Game Changer

# The game changer

More than a decade after the accident, many areas remain unexamined within the FDNPS.
Some of the doors to rooms in the facility have not been opened since the accident, and decontamination officials had little idea what was on the other side of those doors.
If laundry was thrown all over the floor, conventional wheeled and crawler robots would be practically completely immobilised.

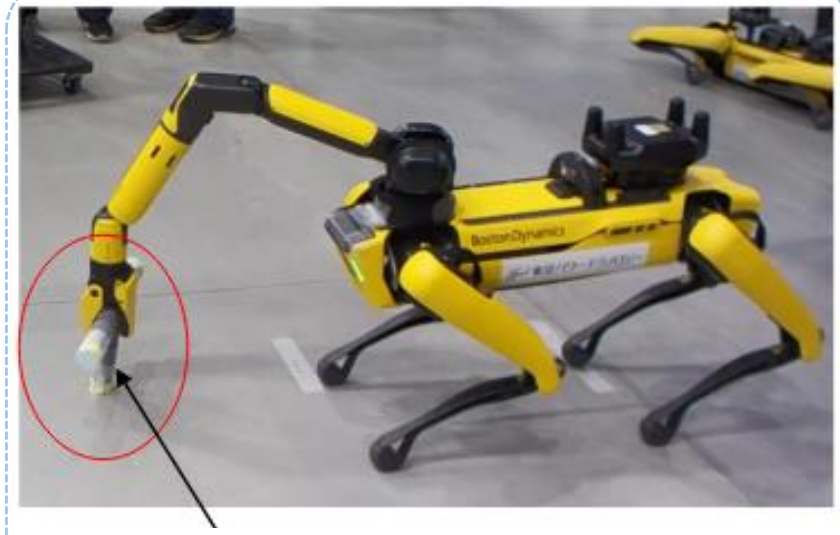
In 2022, however, decommissioning workers began using Boston Dynamics' Spot quadrupedal robots to open and close doors, collect data, take videos, measure doses and collect debris samples for radiation testing.

Prior to the introduction of FDNPS, Spot was brought to LANL and irradiated with gamma rays up to 33 Gy, but it was reported that no abnormalities were found.

Spot collected point cloud data with the LIDAR instrument, video with the onboard camera and smears with the Spot arm.
To facilitate communication, Spot installed mesh radios at suitable locations around the site.
Operators remotely controlled the robot from a safe distance, but the autonomous detection and movement capabilities of the Spot were demonstrated even while the operator was in control.
As a result, Spot was able to enter these environments and open doors that had not been opened in over a decade.

# Survey inside Unit 2

# A pair of SPOT has been introduced



Smear sampling jig

dosimeter


Second-floor operation room door open situation

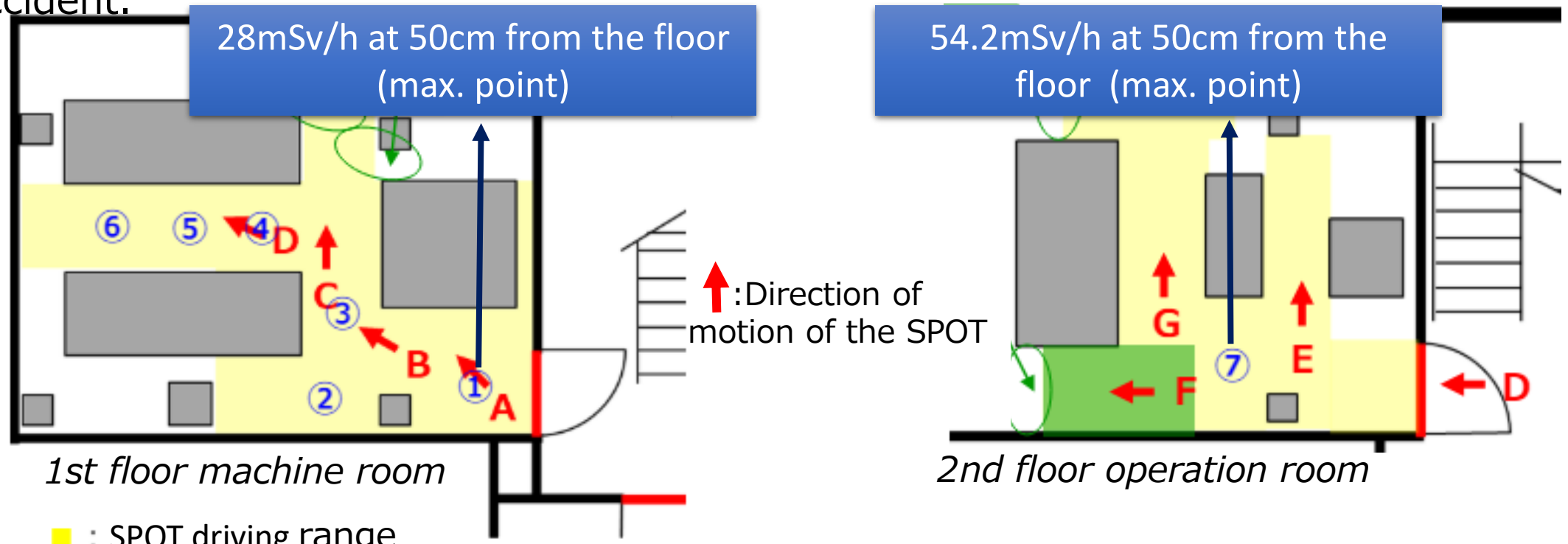
Smear sampling situation in the second-floor operation room

# Survey inside Unit 1

The Fuel Handling Machine Operation Room (FHM) on the Unit 2 operation floor has a broken window on the second floor and previous investigations have confirmed contamination in the room and on the roof.

The FHM operation room has been largely untouched since the accident and is estimated to be the main release route for radioactive materials from Unit 2.

As it is located in the vicinity of the shield plug, an investigation of this area will be carried out with the aim of obtaining information on the radioactive material released at the time of the accident.



Operating a robot within the FDNPS is all about how quickly it can complete its role with limited time, limited batteries and limited access

# Thank you for your attention!

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