Commissioned by the Ministry of Health, Labour and Welfare
Project to Disseminate Correct Information and Raise Awareness
Concerning the Radiation Exposure Dose Reduction Measures
for Works Relating to the Decommissioning of
TEPCO's Fukushima Daiichi Nuclear Power Station

Good Practices in Radiation Exposure Dose Reduction Measures



Issued in February, 2026

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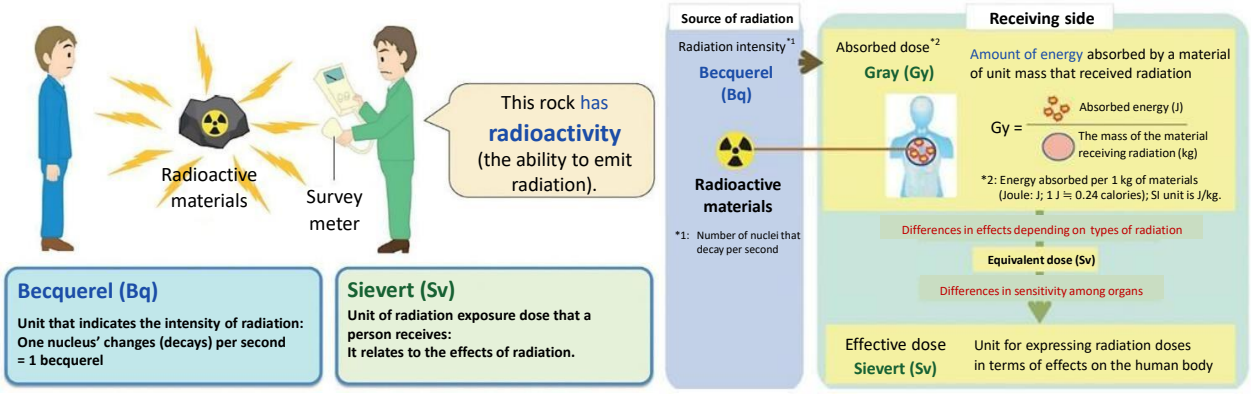
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1

Knowledge of measurement and assessment of the radiation environment in the workplace

(1) Units of radiation

The unit of radioactivity is the becquerel (Bq). As illustrated in the figure below, it represents the ability of a radionuclide to undergo nuclear transformation into other nuclei (referred to as decay or disintegration) per second. A comparable term is radioactive material. Radioactivity, a capacity, is used in the following manner: The radioactivity of 2 kg of radioactive material is 100 becquerels (Bq) and its concentration is 50 Bq/kg. Statements such as "It was contaminated with radioactivity" or "Radioactivity was released" are not scientifically accurate. A more appropriate phrasing would be: "Radioactive materials were released. The radioactivity of the released radioactive materials is 100 Bq."



Material provided by the Ministry of the Environment of Japan;
"BOOKLET to Provide Basic Information Regarding Health Effects of Radiation (2023)".

Radioactive materials emit radiation to the surroundings. Radiation includes alpha (α) rays, beta (β) rays, gamma (γ) rays, and others. Gamma rays have strong penetrating power and are the primary cause of external exposure.

The table below summarizes the units of radiation exposure. These units are broadly classified into absorbed dose, which represents the energy absorbed by a material when exposed to radiation, and equivalent dose and effective dose, which represent the effect of radiation on the human body. Absorbed dose is a physical quantity used for both humans and objects. Effective dose is a unit for expressing stochastic effects, such as human cancer and genetic effects.

		Unit	Definition
Unit of radioactivity		Becquerel Bq	The number of nuclei that decay per second (number/second)
Unit for measuring radiation exposure	Absorbed dose	Gray Gy	The amount of energy absorbed by a material when exposed to radiation A dose of 1 Gy corresponds to 1 joule (J) of energy absorbed by 1 kilogram (kg) of materials.
	Equivalent dose	Sievert Sv	The dose for each tissue or organ, measured in order to evaluate the effects of radiation exposure on the tissue or organ Equivalent dose = absorbed dose × radiation weighting factor
	Effective dose	Sievert Sv	Effective dose = Σ (equivalent dose × tissue weighting factor) The value obtained by multiplying the equivalent dose of an organ or tissue by the tissue weighting coefficient (due to differences between organs and tissues) Dose for evaluating the stochastic effect of cancer or other diseases on the entire human body

Note: The average annual exposure dose from natural background radiation is 2.4 mSv worldwide and 2.1 mSv in Japan per person.

(2) Principles for radiation exposure protection

Reducing external exposure

To reduce external exposure, it is important to understand the following four principles of radiation exposure protection.

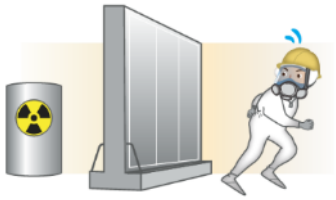
Principle 1 Remove radioactive materials

Move radioactive materials or wash them out (flush them) from the inside of piping.



Principle 2 Maintain sufficient distance from radiation

If possible, move away from the radiation source. Do not go any closer to it than required. (Also remember where the waiting areas are.)



Principle 3 Install shielding

Cover radioactive equipment, piping and other items, with shielding materials such as lead wool or lead plates.



Principle 4 Reduce working time

Make sufficient preparations before conducting work, such as discussing the procedures involved or inspecting tools, so that work proceeds smoothly.



Preventing internal exposure

To reduce internal exposure, it is important to understand the following three principles of radiation exposure protection.

Principle 1 Contain the source of contamination

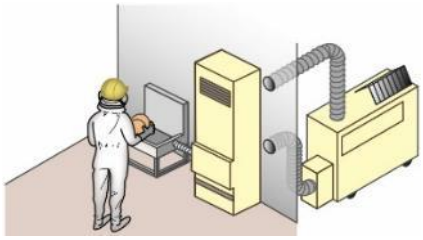
1. Install a pre-clean room, isolation doors, etc.
   Maintain the isolation functions (boundary) and manage the negative pressure.

2. Response to contaminants
   Pack contaminated materials and seal them in containers.

Principle 2 Do not allow contamination to spread

1. Identify contamination zones
   Clearly mark off contamination zones, and protective clothing, footwear, and other equipment for workers shall be periodically replaced.
   In addition, the entry and exit of materials shall be appropriately managed.

2. Use equipment and materials
   For work in areas where there is a risk of dust being blown around, use temporary shelters or exhaust fans with filters.
   Airborne radioactive dust levels, both inside and outside the controlled facilities, shall be measured and monitored to ensure prompt response in the event of any abnormalities.



Principle 3 Do not take contaminants into the body

1. Wear protective equipment
   Wear the required personal protective equipment.
   Fit the respiratory protective equipment properly, so that there are no leaks.



2. Prevention of physical contamination
   Ensure that protective equipment (masks, protective clothing, gloves, etc.) be removed or attached in such a way that it does not adhere to the body or underwear.

3. Move to safety
   In the event of injury, move to an uncontaminated area immediately.



Note: The exposure dose limit for workers is set at 100 mSv over five years and 50 mSv in one year.

2

Knowledge of setting up a travel flow line from the rest area to the work area

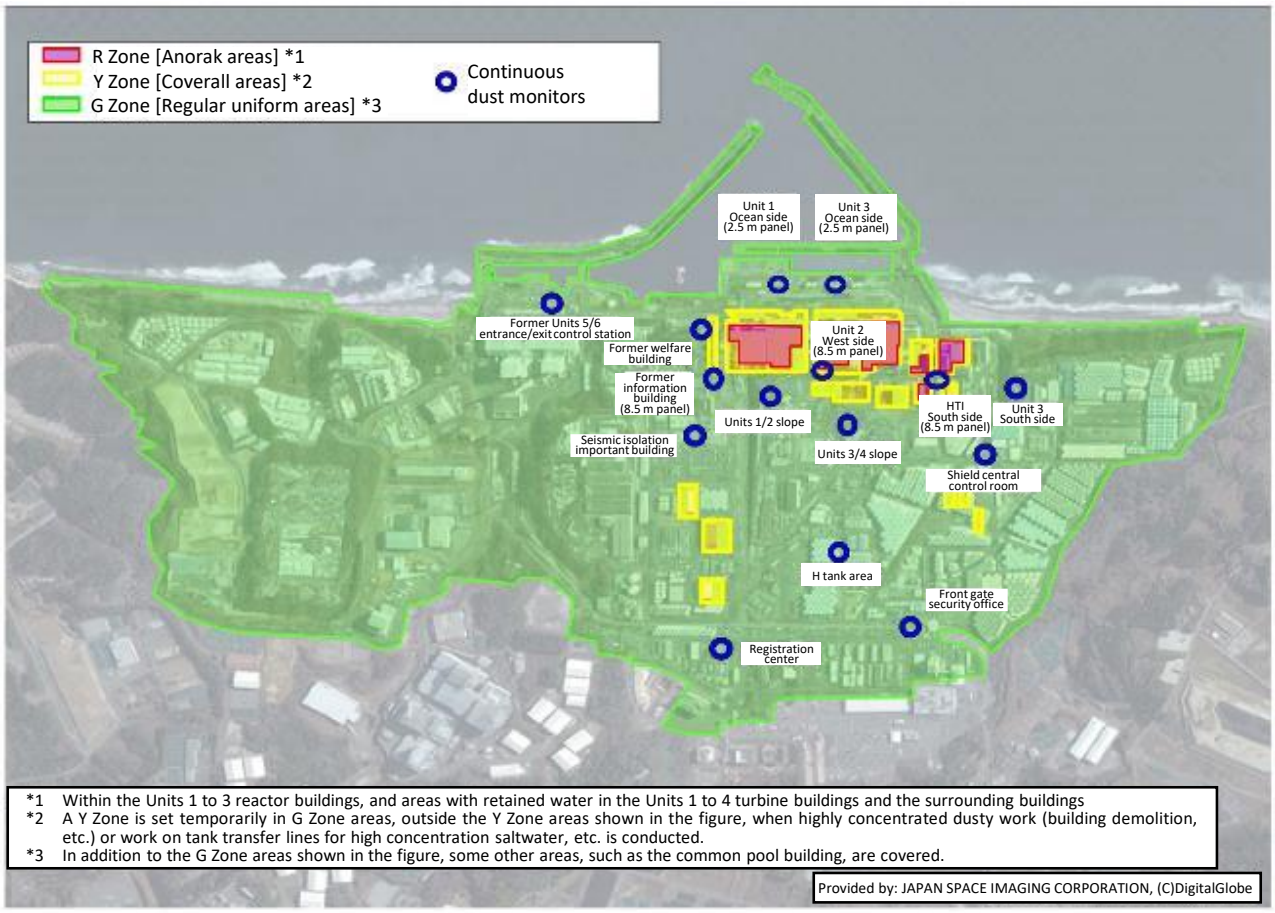
(1) 1F site operation zone status

Zone		Protective Equipment
Red α Zone (Anorak areas)	Work areas where the surface contamination density of alpha nuclides exceeds or is likely to exceed one-tenth of the surface concentration limit specified by law	・Full-face mask ・Coverall in one layer and Anorak ・Work boots (for R Zone) ・Helmet (for R Zone) ・Cotton gloves + rubber gloves ・Socks
Red Zone (Anorak areas)	・Inside the reactor buildings of Units 1 to 3 ・Refers to areas such as the basement of the reactor building and turbine building that hold retained water (retained water stored in the water level stabilization area and retained water stored in the buildings), areas for decontamination of retained water, and areas where contaminated water is handled directly.	
Yellow β Zone (Coverall areas)	・Inside the buildings, including water treatment facilities*1 ・Work in tanks containing concentrated saltwater/strontium-treated water and in tank transfer lines ・Areas where the 70 μm dose equivalent rate (γ+β)/ 1 cm dose equivalent rate (γ) exceeds 4 times	・Full-face mask ・Coverall single and Anorak ・Work boots (for Y Zone) ・Helmet (for Y Zone) ・Cotton gloves + rubber gloves ・Socks
Yellow Zone (Coverall areas)	・Part of the areas inside and around the buildings around Units 1 to 4 ・Areas where highly concentrated dusty work or work involving the handling of contaminated water is conducted ・Areas to be set up as needed depending on the work environment	・Half-face mask ・Coverall ・Work boots (for Y Zone) ・Helmet (for Y Zone) ・Cotton gloves + rubber gloves ・Socks
Green Zone (Regular uniform areas)	・Areas where the concentration of radioactive materials in the air is not likely to exceed the mask-wearing standards with the exception of the White Zone, Yellow Zone, Yellow β Zone, Red Zone, and Red α Zone	・DS2 mask ・Regular work clothing ・Work boots (for G Zone) ・Helmet (for G Zone) ・Cotton gloves + rubber gloves, or work gloves ・Socks
White Zone	・Permanent rest areas, seismically isolated important buildings, and the main office building (entrance/exit control stations of Units 1 to 4) ・Inside the filter unit of the temporary storage tank of the groundwater bypass ・Each temporary rest area	

*1: Excluding tank patrolling, field surveys during work planning, observation visits and work that does not involve the handling of concentrated salt water, etc.

Source: Taken from the website of Tokyo Electric Power Company Holdings, Incorporated

(2) Status of Zone areas in the NPS



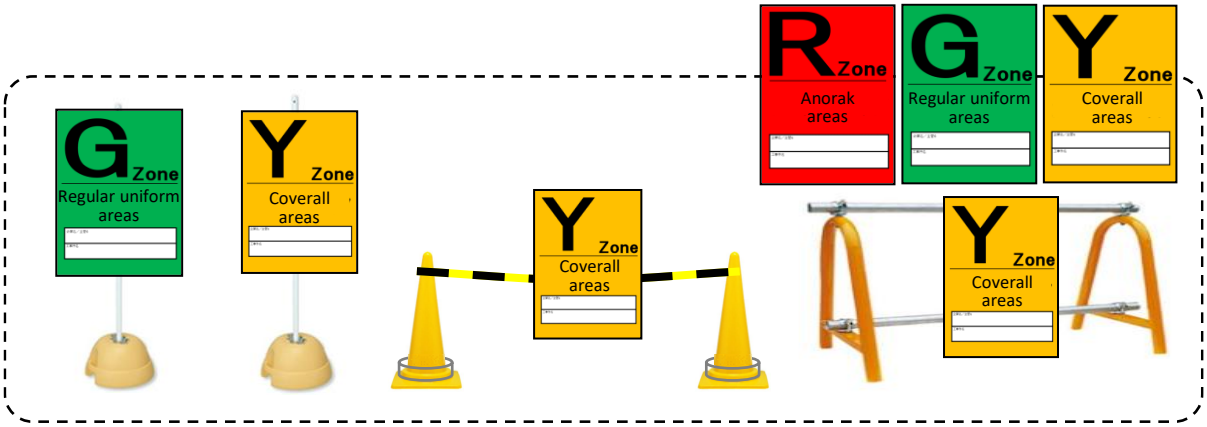
(Source: Material provided by Tokyo Electric Power Company Holdings, Incorporated)

(3) Basic items of operation zone management

R Zone (Anorak areas)	Work areas where the surface contamination density of alpha nuclides exceeds or is likely to exceed one-tenth of the surface concentration limit specified by law
	・Inside the reactor buildings of Units 1 to 3 ・Refers to areas such as the basement of the reactor building and turbine building that hold retained water (retained water stored in the water level stabilization area and retained water stored in the buildings), areas for decontamination of retained water, and areas where contaminated water is handled directly.
Y Zone (Coverall areas)	・Inside the buildings, including water treatment facilities ・Work in tanks containing concentrated saltwater/strontium-treated water and in tank transfer lines ・Areas where the 70 μm dose equivalent rate (γ+β)/1 cm dose equivalent rate (γ) exceeds 4 times
	・Part of the areas inside and around the buildings around Units 1 to 4 ・Areas where highly concentrated dusty work or work involving the handling of contaminated water is conducted ・Areas to be set up as needed depending on the work environment
G Zone (Regular uniform areas)	・Areas where the concentration of radioactive materials in the air is not likely to exceed the mask-wearing standards with the exception of the White Zone, Yellow Zone, Yellow β Zone, Red Zone, and Red α Zone.

Examples of signage

For easy identification of different zones, such as Yellow and Green Zones, any of the signs shown below are displayed.



(4) Protective equipment for each area

R Zone (Anorak areas)	Y Zone (Coverall areas)	G Zone (Regular uniform areas)
Full-face mask 	Full-face mask or half-face mask  	**DS2 mask** 
Coverall and Anorak 	**Coverall** 	**Regular work clothing** 

*1 For work at water treatment facilities including Advanced Liquid Processing System (ALPS), etc., a full-face mask is required. This does not apply to inspection work.

*2 A full-face mask must be worn during all work in tank areas where concentrated salt water or treated Sr water is stored (with the exception of work not handling concentrated salt water, patrols, and site surveys and inspections during work planning) and during work related to tank transfer lines.

Source: Material provided by Tokyo Electric Power Company Holdings, Inc.

3

Good Practices

(1) Efforts for radiation exposure dose reduction in radiation dose survey for the 1F-Units 1/2 SGTS Piping

Location		Category		Good practices in radiation exposure dose reduction measures	
Inside reactor building	RB	1	Time		
Inside turbine building	TB	2	Distance		
R ZONE	R	**3**	**Shielding**		
Y ZONE	Y	4	Removing radiation source		
G ZONE	**G**	**5**	**Remote control, robot operation**		
Other ( )	Z	6	Preventing spread of contamination	No.	
		7	Other		
Work location	Road on the west side of 1F-Unit 1				
Overview	When conducting a radiation dose survey for the Units 1/2 SGTS piping, where a radiation dose increase has been confirmed, remote operations using a large crane were adopted and the work area was shielded for the purpose of reducing the radiation exposure and burden of workers.				
Assessment (Qualitative / Quantitative)	Effects		Before Implementation	After Implementation	
		Population radiation exposure dose (person-mSv)	198.59	169.64	
		Person time (person-day)	1,521	1,614	

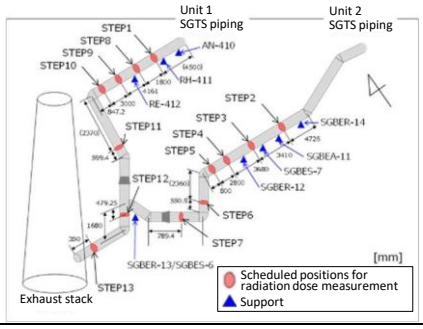
Good Practice Description

[Overview]

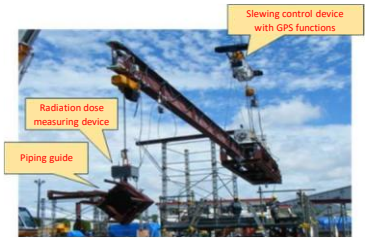
In the Units 1/2 Standby Gas Treatment System (SGTS) piping, a high concentration due to PCV ventilation has been confirmed, which will hinder future works, such as the installation of large covers around the Unit 1 reactor building and removal of the surrounding buildings, and therefore, the removal of the piping is scheduled also from the perspective of reducing the radiation exposure of site workers.

With regard to the SGTS piping around the exhaust stack, which has yet to be removed at present, it is necessary to ascertain the contamination density inside the piping at positions scheduled to be cut (13 positions in total) for assessing the influence on the site border to be caused by the scattering of radioactive dust at the time of cutting work. However, the environment does not allow direct assessment using the smear method, etc. Accordingly, we decided to prepare a radiation dose measuring device shielded with lead to avoid influences of external doses, measure surface dose rates of the piping with the device, and evaluate the contamination density inside the piping through analysis based on the measurement results. The measurement with the measuring device was conducted using a large crane, which was made to access each of the measuring positions (positions scheduled to be cut) through remote operation.

Additionally, during the work, position gaps of the measuring device were controlled by the application of a slewing control device with a GPS function to eliminate remeasurement or other backtrack works, thereby reducing the burden and radiation exposure of workers. Furthermore, we also took radiation exposure dose reduction measures in the device maintenance work.



Radiation dose measuring positions in SGTS piping



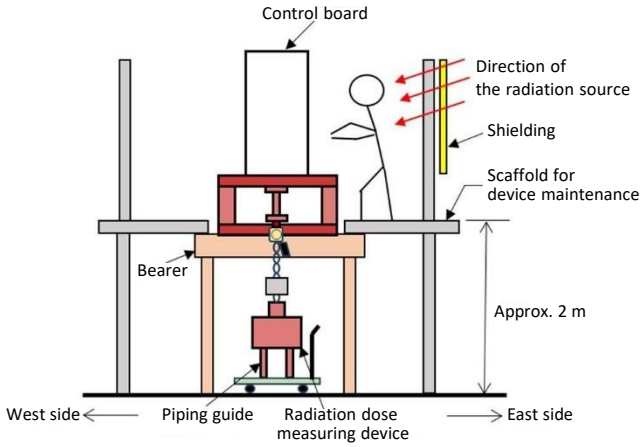
Radiation dose measuring device



Slewing control device with GPS functions

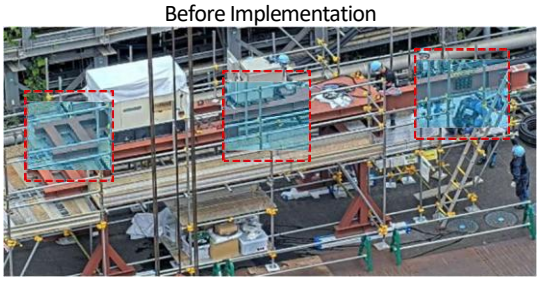
[Radiation exposure dose reduction measures in the device maintenance work]

In order to check the soundness of measuring devices before and after conducting measurement at measuring positions, it is necessary to do maintenance work on the dedicated scaffold (approx. 2.0 m above the ground) installed on the road on the west side of Units 1 and 2. Accordingly, we measured ambient dose rates on the scaffold and checked the direction of the radiation source. As a result, it was confirmed that ambient dose rates are apt to be higher in higher places on the scaffold and that dose contributions from the direction of the Units 1/2 exhaust stack and Unit 2 R/B are large. Therefore, we installed shielding in the direction toward the radiation source (east side) to reduce radiation exposure doses.



Outline drawing of the device maintenance area

Before Implementation



After Implementation



[Effects of the measures]

On the scaffold for device maintenance, one of the major work areas, we installed shielding on the east side (the side of the Units 1/2 exhaust stack). As a result, the atmospheric dose rate was reduced by 64% at the maximum.

The detailed effects of shielding on the scaffold were shown in the following table.

Effects of radiation exposure dose reduction by installing shielding on the scaffold for device maintenance (3 locations)

Measurement position	Before shielding	After shielding	Reduction rate	Shielding materials
	Geometric mean value (mSv/h)	Geometric mean value (mSv/h)	(%)	Lead (3mm) (number of sheets)
(i) Scaffold floor approx. 1.8 m above the ground + 1.2 m	0.095	0.0556	41.5	13
(ii) Scaffold floor approx. 2.3 m above the ground + 1.2 m	0.136	0.0486	64.3	32
(iii) Scaffold floor approx. 2.0 m above the ground + 1.2 m	0.141	0.0637	54.8	13

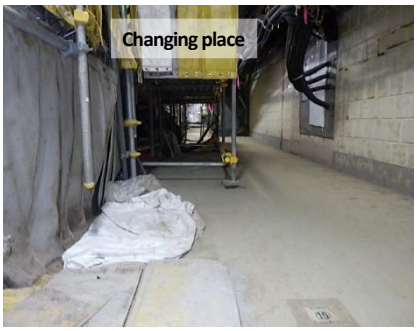
Edited by Hitachi GE Vernova Nuclear Energy, Ltd.

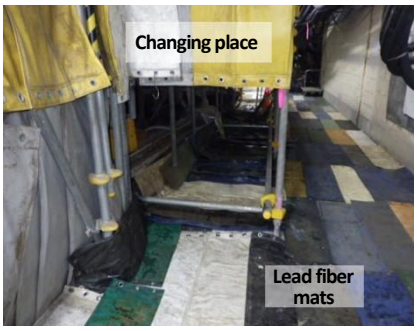
(2) Radiation exposure dose reduction in a gas-phase survey inside the 1F-Unit 3 PCV (micro-drone survey)

<table>
<tr><td colspan="2">Location</td><td colspan="2">Category</td><td colspan="3" rowspan="5">Good practices
in radiation exposure dose reduction measures</td></tr>
<tr><td>Inside reactor building</td><td>RB</td><td>1</td><td>Time</td></tr>
<tr><td>Inside turbine building</td><td>TB</td><td>2</td><td>Distance</td></tr>
<tr><td>R ZONE</td><td>R</td><td>3</td><td>Shielding</td></tr>
<tr><td>Y ZONE</td><td>Y</td><td>4</td><td>Removing radiation source</td></tr>
<tr><td>G ZONE</td><td>G</td><td>5</td><td>Remote control, robot operation</td><td colspan="3"></td></tr>
<tr><td rowspan="2">Other
(　　)</td><td rowspan="2">Z</td><td>6</td><td>Preventing spread of contamination</td><td rowspan="2">No.</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>7</td><td>Other</td></tr>
<tr><td>Work location</td><td colspan="6">Changing place for entering the heavily contaminated area in the Unit 3 turbine building</td></tr>
<tr><td>Overview</td><td colspan="6">Temporary shielding was installed at the changing place for entering the heavily contaminated area in the Unit 3 turbine building to reduce radiation exposure doses.</td></tr>
<tr><td rowspan="3">Assessment
(Qualitative / Quantitative)</td><td rowspan="3">Effects</td><td colspan="2"></td><td>Before Implementation</td><td colspan="2">After Implementation</td></tr>
<tr><td colspan="2">Population radiation exposure dose (person-mSv)</td><td>0.14</td><td colspan="2">0.09</td></tr>
<tr><td colspan="2">Person time (person-day)</td><td>—</td><td colspan="2">—</td></tr>
</table>

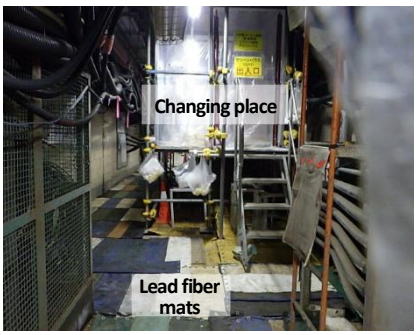
Good Practice Description

We laid 180 lead fiber mats on the floor surface, which is a radiation source in the changing place for entering the heavily contaminated area in the Unit 3 turbine building, with the aim of reducing the radiation exposure of people entering the reactor building and people assisting heavily equipped workers with undressing.









Before shielding

After shielding

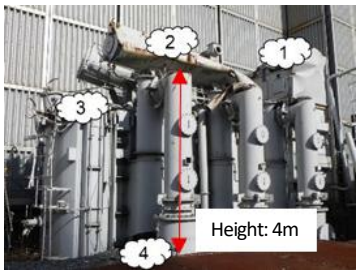
Edited by Hitachi GE Vernova Nuclear Energy, Ltd.

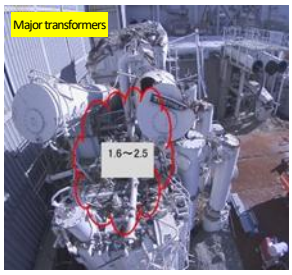
(3) Application of remote-operated heavy machinery in debris removal work

Location		Category		Good practices in radiation exposure dose reduction measures	
Inside reactor building	RB	1	Time		
Inside turbine building	TB	2	Distance		
R ZONE	R	3	Shielding		
Y ZONE	**Y**	4	Removing radiation source		
G ZONE	G	**5**	**Remote control, robot operation**		
Other ( )	Z	6	Preventing spread of contamination	No.	
		7	Other		
Work location	Major transformer and station transformer area in Unit 3				
Overview	Debris accumulated on transformers was removed using remote-operated heavy machinery.				

Assessment (Qualitative / Quantitative)	Effects		Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)	234.8	88.6(*)
		Person time (person-day)	340	232(*)

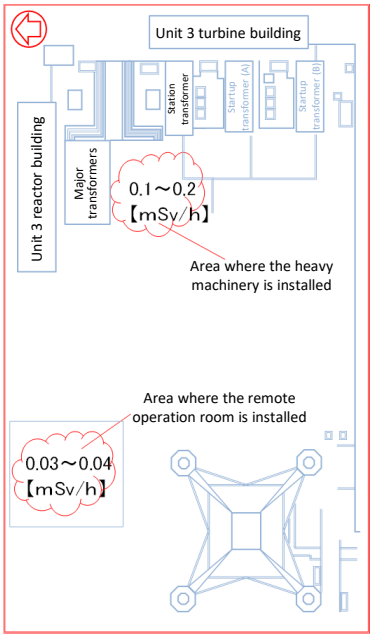
Good Practice Description

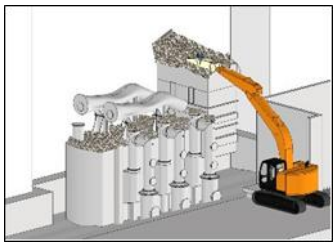




[Dose equivalent rates around transformers (mSv/h)]
1. Surface: 2.0 to 6.5 (at 1m: 1.6 to 2.5)
2. Surface: 2.0 to 6.5 (at 1m: 1.6 to 2.5)
3. Surface: 2.0 to 6.5 (at 1m: 1.6 to 2.5)
4. Surface: 0.3 to 1.5 (at 1m: 0.1 to 0.3)

How major transformers are installed





Debris removal work using remote-operated heavy machinery

[Dose equivalent rates after implementation (mSv/h)]
Area where the remote operation room is installed
0.03 to 0.04 mSv/h

Area where the heavy machinery is installed
0.1 to 0.2 mSv/h

Before implementation: Planned to remove debris by man power

After implementation: Removed debris accumulated on transformers by using remote-operated heavy machinery

(*) The work is underway at present, and the doses and man-hours in the above table are planned values.
In the plan, all procedures were to be carried out by remotely operating the heavy machinery from the remote operation room, but it was found that some parts cannot be confirmed on the screens in the remote operation room. Accordingly, the heavy machinery may be operated from a nearby area (area where the heavy machinery is installed) sometimes.

Dose equivalent rates in the case of including exposure to β-ray (β +γ) are almost the same as those in the case of exposure only to γ-ray.

Edited by Hitachi Plant Construction, Ltd.

(4) Radiation exposure dose reduction measures upon installing the 1F-Unit 2 FPC bypass line

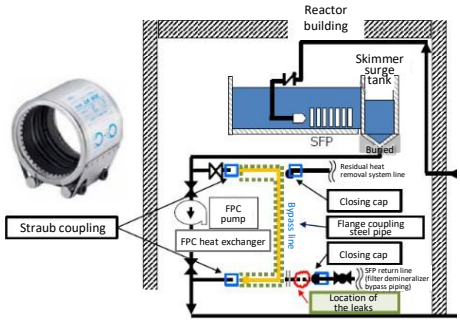
Location		Category		Good practices in radiation exposure dose reduction measures	
Inside reactor building	**RB**	**1**	**Time**		
Inside turbine building	TB	2	Distance		
R ZONE	R	**3**	**Shielding**		
Y ZONE	Y	4	Removing radiation source		
G ZONE	G	**5**	**Remote control, robot operation**		
Other ( )	Z	6	Preventing spread of contamination	No.	
		7	Other		
Work location	FPC heat exchange room on the 3rd floor of the Unit 2 reactor building				
Overview	As an emergency response to an incident of a drawdown in the Unit 2 SFP skimmer surge tank, an FPC bypass line was installed on the third floor of the Unit 2 reactor building.				
Assessment (Qualitative / Quantitative)	Effects		Before Implementation	After Implementation	
		Population radiation exposure dose (person-mSv)	1330.58	490.66	
		Person time (person-day)	—	—	

Good Practice Description

The following radiation exposure dose reduction measures were taken.

	Item	Outline
1	Adoption of automation and remote operation	Utilization of surveillance cameras and intercoms
2	Utilization of low-dose areas	We established the headquarters in a low-dose area on the first floor of the turbine building, and utilized the CRD repair room on the third floor of the reactor building as a temporary waiting room.
3	Shielding	We installed shielding around point radiation sources in the FPC heat exchange room.
4	Access route	We decided on an access route from the headquarters to the FPC heat exchange room and indicated the route with LED lighting.
5	Improvement of the construction method	We changed the construction method for piping from a conventional welding method to a method using Straub couplings. We used a crane for lifting scaffold members from the first floor to the second floor of the reactor building.
6	Mock-up	We conducted a mock-up for each work process while wearing protective equipment.
7	Other	We installed radiation dose indicators and illumination tubes, and adopted Hi-grip Boots.





Source: Tokyo Electric Power Company Holdings, Inc.

Edited by Toshiba Energy Systems & Solutions Corporation

(5) Utilization of Radiation Source Inverse Estimation System (3D-ADRES-Indoor) at 1F: Radiation Source and Dose Rate Mapping and Simulations of Measures against Radiation Sources

Location		Category		Good practices in radiation exposure dose reduction measures	
Inside reactor building	**RB**	1	Time		
Inside turbine building	TB	2	Distance		
R ZONE	R	3	Shielding		
Y ZONE	Y	4	Removing radiation source		
G ZONE	G	**5**	**Remote control, robot operation**		
Other ( )	Z	6	Preventing spread of contamination	No.	
		7	**Other**		
Work location	1st and 2nd floors of Unit 2, 1st floor of Unit 3, 1F				
Overview	Remote survey using SPOT (point clouds/dose rates), radiation source inverse estimation, and simulations of measures against radiation sources				
Assessment (Qualitative / Quantitative)	Effects			Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)		79 mSv	
		Person time (person-day)		32 × 36 days	

Good Practice Description

In order to develop digital technologies for reducing the radiation exposure of workers engaging in decommissioning work on 1F, the Japan Atomic Energy Agency (JAEA) was entrusted with the subsidized project under the "Subsidies for the Project of Decommissioning, Contaminated Water and Treated Water Management (Development of Technologies for Work Environmental Improvement in Reactor Building (Development of Exposure Reduction Technologies by Improved Functional Digitalization of Environment and Radioactive Source Distribution))" by the Ministry of Economy, Trade and Industry (national project) [1.1], and proceeded with R&D on digital technologies for improving the indoor radiation environment of 1F for two years from the beginning of April 2023 to the end of March 2025.

In this national project, a system was developed with the aim of measuring point clouds for creating indoor structure models and measuring radiation dose rate distribution by using a quadrupedal robot (SPOT by Boston Dynamics), and conducting inverse estimation of radiation sources and forward estimation of 3D distribution of radiation doses through simulations based on those measurement data obtained through remote operation to evaluate workers' radiation exposure doses, thereby enabling simulations of measures against radiation sources (decontamination, shielding, etc.) (see Figure 1).

A performance test of the developed system that was subsequently conducted successfully confirmed the achievement of the goal of making the difference between an estimated dose rate and the measured value at an arbitrary location remain within twice or half of each other, which is one of the most important requirements for this system. Accordingly, it is expected that this may lead to an evaluation of radiation exposure doses of workers engaging in decommissioning work by the use of avatars and ex-ante evaluation of improvements in the radiation environment to be brought about by measures against radiation sources in virtual space.

Through continued efforts for further advancing the aforementioned technologies, the JAEA would like to contribute to reducing the radiation exposure of workers in decommissioning work from now on.

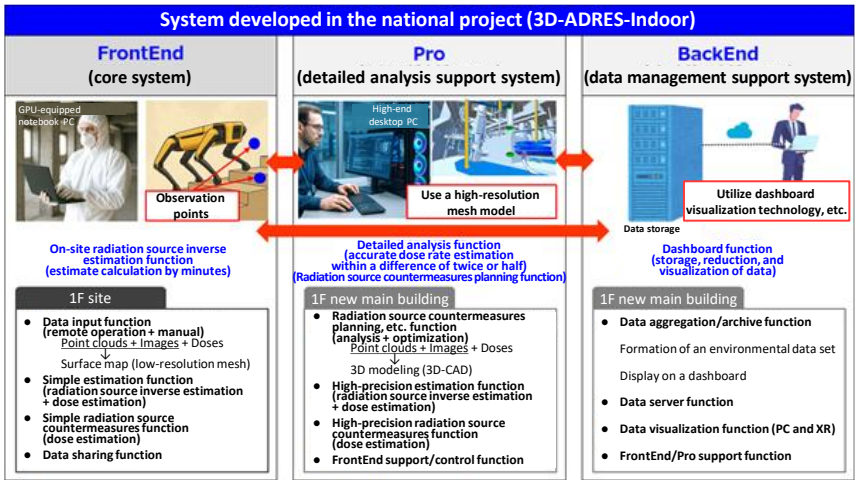


Figure 1: Developed system, 3D-ADRES-Indoor (consisting of three components)

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Good Practices

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Concerning the Radiation Exposure Dose Reduction Measures
for Works Relating to the Decommissioning of
TEPCO's Fukushima Daiichi Nuclear Power Station

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