Commissioned by the Ministry of Health, Labour and Welfare
Project to Enhance the Radiation Exposure Dose Reduction Measures for Works Relating to the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Plant

Good Practices in Radiation Exposure Dose Reduction Measures

Issued in February, 2025

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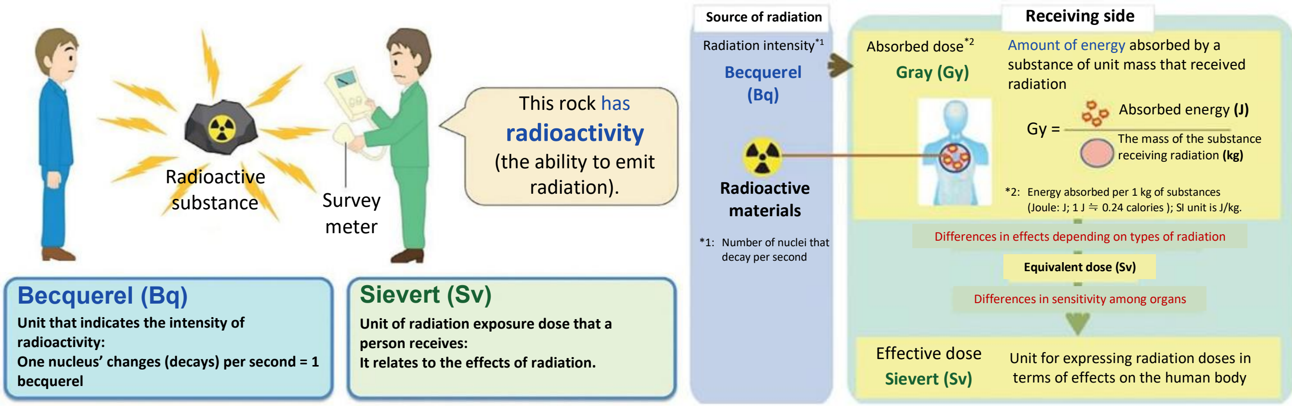
translator's note:
[1] '1F' means 'TEPCO's Fukushima Daiichi Nuclear Power Plant'.

1

Knowledge of measurement and assessment of the radiation environment of 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 substances were released. The radioactivity of the released substances 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 substances 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 radioactive decays per second (number/second)
Unit for measuring radiation exposure	Absorbed dose	Gray Gy	The amount of radiation energy absorbed in matter. A dose of 1 Gy corresponds to 1 joule (J) of energy absorbed by 1 kilogram (kg) of matter.
	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	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: Effective dose = Σ (equivalent dose × tissue weighting factor)

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

(2) Principles for radiation exposure protection

Reducing external exposure

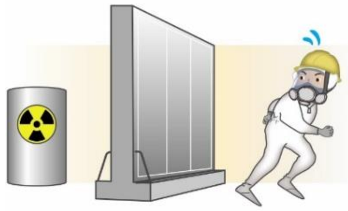
To reduce external exposure, it is important to understand the following four principles of radiation exposure protection.

Principle 1 Remove radioactive materials

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

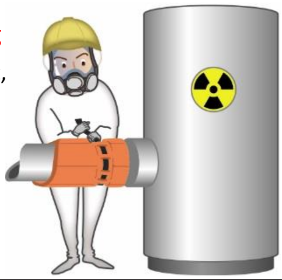
Principle 2 **Maintain sufficient distance from radiation**

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 leadwool 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.

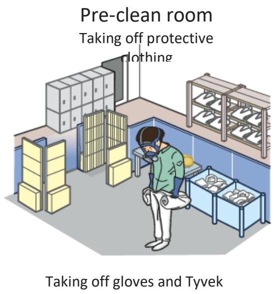
2. Response to contaminants

   Pack contaminated materials and seal them in containers.

Principle 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.

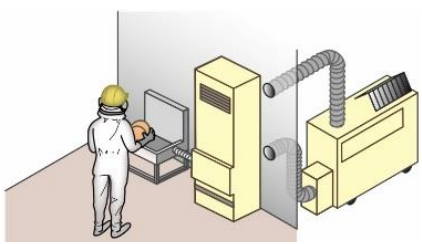
Principle 2 Do not allow contamination to spread

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. At the boundary of the contamination zone, inspect for contamination on the body or underwear using a body surface monitor, etc. 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.



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

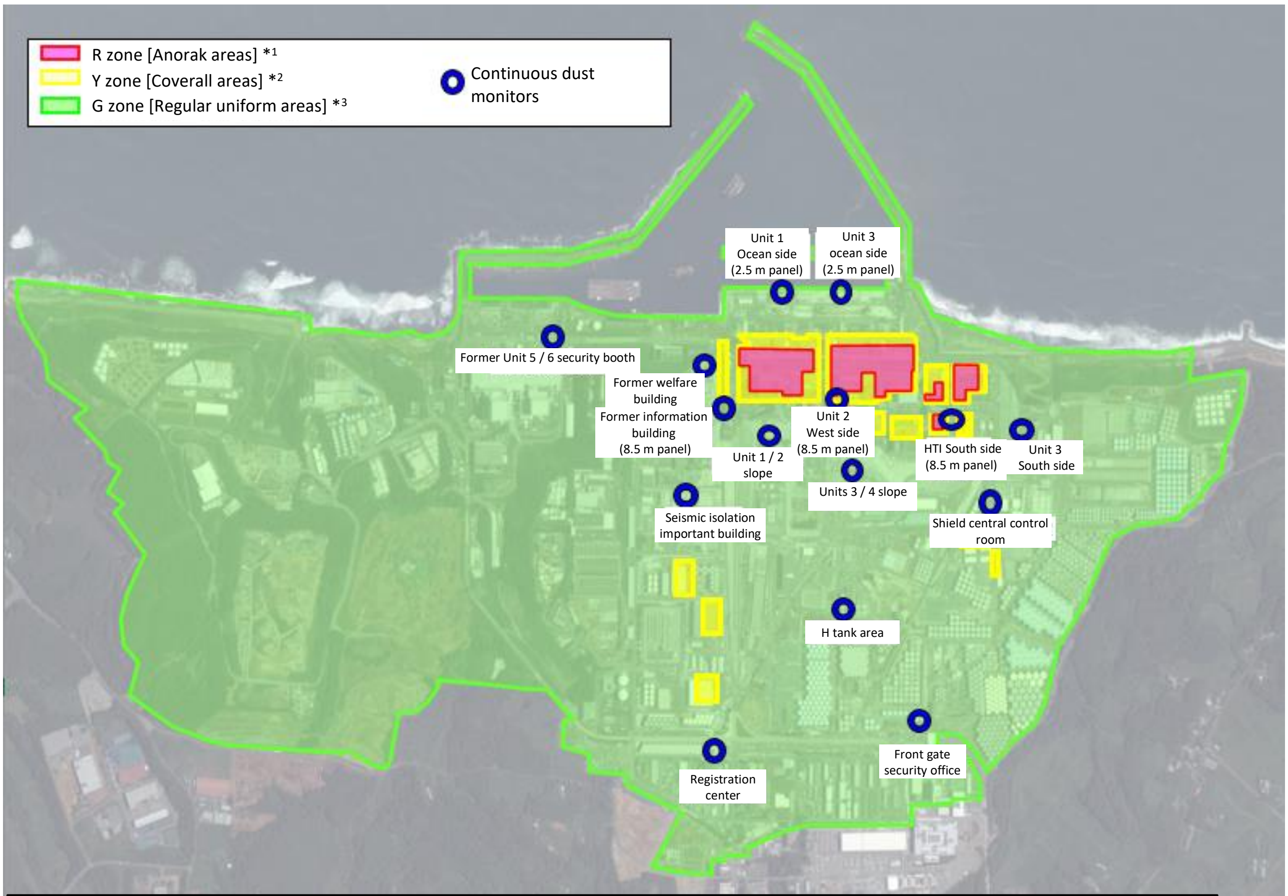
(1) 1F site operation zone status

Zone		Protective Equipment
Red αZone (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, the 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 βZone (Coverall areas)	・Inside the buildings including water treatment facilities*1 ・Work in tanks containing concentrated saltwater/strontium-treated water and in tank transfer lines*2 ・Areas where the 70 μm dose equivalent rate (γ+β)/1 cm dose equivalent rate (γ) is 4 times or more	・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)	・Inside and around the buildings around the 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 the 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.

*2: Certain light work (such as patrolling, monitoring, and transportation of items brought in from outside the premises)

(Taken from the website of Tokyo Electric Power Company Holdings, Incorporated.)



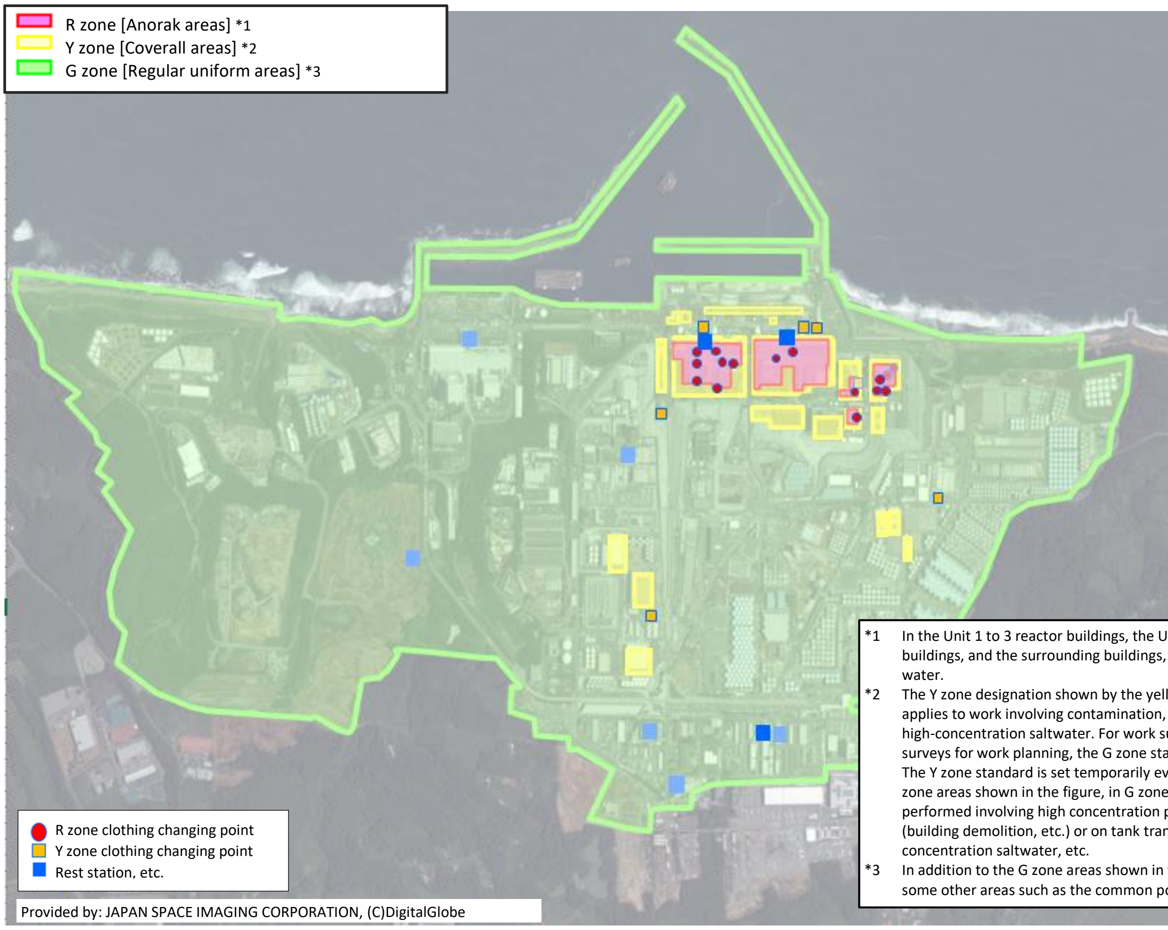
*1 In the Unit 1 to 3 reactor buildings, the Unit 1 to 4 turbine buildings, and the surrounding buildings, areas with retained water.

*2 The Y zone standard is set temporarily even outside the Y zone areas shown in the figure, in G zone areas, when work is performed involving high concentration particulate matter (building demolition, etc.) or on tank transfer lines for high concentration saltwater, etc.

*3 In addition to the G zone areas shown in the figure, covers some other areas such as the common pool building.

Provided by: JAPAN SPACE IMAGING CORPORATION, (C)DigitalGlobe

(2) Locations of each area, and of clothing changing points



*1 In the Unit 1 to 3 reactor buildings, the Unit 1 to 4 turbine buildings, and the surrounding buildings, areas with retained water.

*2 The Y zone designation shown by the yellow dotted lines applies to work involving contamination, such as handling of high-concentration saltwater. For work such as patrols or site surveys for work planning, the G zone standard applies. The Y zone standard is set temporarily even outside the Y zone areas shown in the figure, in G zone areas, when work is performed involving high concentration particulate matter (building demolition, etc.) or on tank transfer lines for high concentration saltwater, etc.

*3 In addition to the G zone areas shown in the figure, covers some other areas such as the common pool building.

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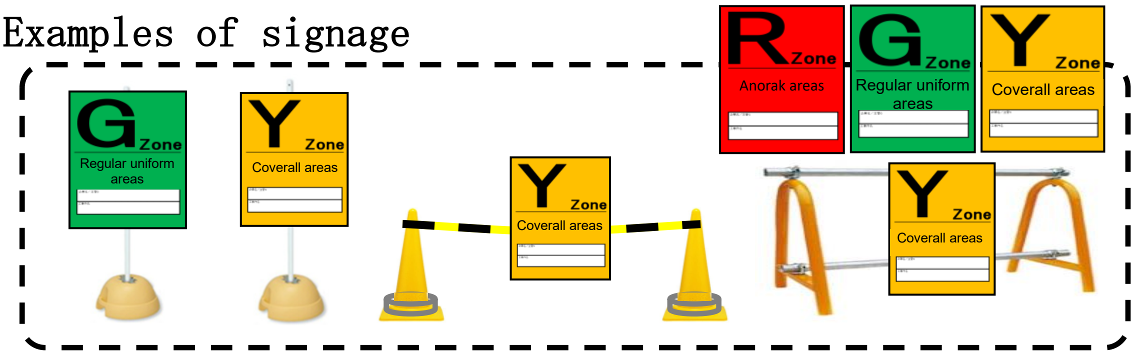
(Material provided by Tokyo Electric Power Company Holdings, Inc.)

(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, the 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*1 ・Work in tanks containing concentrated saltwater/strontium-treated water and in tank transfer lines*2 ・Areas where the 70 μm dose equivalent rate ($\gamma+\beta$)/1 cm dose equivalent rate (γ) is 4 times or more
	・Inside and around the buildings around the 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.

For easy identification of different zones, such as Yellow and Green zones, any of the signs shown on the below will be displayed.

Examples of signage



(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 *1 *2  	DS2 mask 	
Coverall and Anorak 	Coverall 	regular work clothing *3 	Dedicated on-site work 

*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 work during all work in tank areas containing concentrated salt water or treated Sr water (with the exception of work not involving concentrated salt water, patrols, site surveys, and inspections during work planning) and during work related to transfer lines.

*3 These management measures also apply to specific light-duty tasks such as patrols, monitoring activities, and the transportation of items brought in from outside the controlled area.

(Material provided by Tokyo Electric Power Company Holdings, Inc.)

3

Good Practices

Mapping tables

・Location

inside reactor building	RB
inside turbine building	TB
R ZONE	R
Y ZONE	Y
G ZONE	G
Other	Z

・Category

Time	1
Distance	2
Shielding	3
Removing radiation source	4
Remote control, robot operation	5
Preventing spread of contamination	6
Other	7

Location	TB, Y	Category	1
Title	Exposure Dose Reduction measures during the Installation Work of CST Reactor Injection Pump Room Walkway at Fukushima Daiichi Nuclear Power Plant		
Work location	CST Reactor Injection Pump Room, 1st Floor, Turbine Building, Units 1 to 3		
Overview	A walkway was installed to improve access to valves and measuring instruments inside the condensate storage tank (CST) reactor injection pump room.		

Assessment (Quantitative)	Effects		Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)	32.64	16.00
		Person time (person-day)	102	50

Good Practice Description	Reduction of on-site working hours to reduce radiation exposure

By conducting thorough prior consultation with the client (Tokyo Electric Power Company) regarding the specifications of the walkway to be installed, we were able to reduce the weight of the walkway, increase the ratio of prefabricated components, and minimize the amount of on-site (in-building) work required.

A comparison of manpower requirements before and after the implementation of walkway (10 m²) installation measures

Work item	Manpower before measures (person-days)	Manpower after measures (person-days)
Marking of walkway installation location	35	25
Installation and anchoring of walkway	15	25
Assembly of walkway	20	0
Welding of walkway	15	0
Painting of walkway	21	0
Total	102	50

Previously installed walkway

Walkway to be installed this time

Calculation of exposure reduction

(Working environment) (Working hours)

0.08 mSv/h × 52 person-days × 4 hours = 16.64 person-mSv

Location	Y, G		Category	1, 2, 3, 5
Title	Efforts to Reduce Radiation Exposure in Water Sealing Work at the Gap between Reactor Buildings			
Work location	Unit 4 Reactor building (outdoor)			
Overview	A work process analysis was conducted to establish a framework that enables tasks in high-dose areas to be performed by a minimum number of personnel.			
Assessment (Quantitative)	Effects		Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)	15.1 (Estimated dose)	12.5 (Actual dose)
		Person time (person-day)	684 (Actual dose)	684 (Actual dose)
Good Practice Description				

[Overview]

- Man-hour, working hours, and exposure dose were analyzed for each construction step involved in water sealing work at the gap between buildings. The analysis revealed that boring and drilling operations accounted for a significant portion of the total work process. Accordingly, priority was given to exposure dose reduction measures for these tasks, and their effectiveness was subsequently evaluated.

[Exposure dose reduction measures]

- The roles of workers engaged in boring and drilling operations were clarified. A minimum number of personnel required to remain in high-dose areas were selected. Work procedures and behavioral manuals were developed to ensure that workers remained in low-dose areas as much as possible.
- A monitoring system was implemented to enable remote monitoring of work conditions from low-dose areas, and a response system was established to address potential issues.

[Effectiveness of measures]

- By implementing both software and hardware measures, exposure dose was reduced by approximately 17%.
- Furthermore, composite exposure dose reduction measures were implemented, such as constructing a work platform to maintain distance from radiation sources and enclosing the platform with lead sheet mats.

Work status is monitored remotely from low-dose areas

Location	Y, G	Category	1,2,3,5
Title	Study on the Effect of Exposure Reduction through the Introduction of a Semi-Automatic Boring System		
Work location	Fukushima Daiichi Nuclear Power Plant premises (especially the areas surrounding Units 1 to 4 and the vicinity of the former contaminated tank group)		
Overview			

Assessment (Qualitative)	Effects		Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)	—	—
		Person time (person-day)	—	—

Good Practice Description	

Content

Requests for boring surveys in high-dose areas have been increasing.
However, it is becoming increasing difficult to secure boring teams capable of safely performing work at FDNPP due to the challenges of manual work under high-radiation conditions and the aging of boring machine operators. To address these challenges, the introduction of a semi-automatic boring system is under consideration. This system allows remote control of boring operations via a Wi-Fi-connected PC, replacing the traditional method where machine operators use manual levers.

Monitor and laptop for remote operation

It is assumed that PC-based boring operations will be conducted from within a vehicle parked at the work site.

Expected effects
(1) At a boring site with an air dose rate of 0.1 mSv/h and 5 hours of work per day, radiation exposure can be reduced by approximately 0.3 mSv per day (approximately 60%).
(2) Since PC operation can be performed from an air-conditioned vehicle, heatstroke risk is reduced, and stable working hours can be maintained even in summer.
(3) Even less experienced young operators can maintain work quality at the same level as that of skilled personnel, facilitating the securing of human resources necessary for long-term decommissioning work.

Location	Z		Category	7
Title	Measurement of Tritium Concentration in Air at ALPS Treatment Facilities, Fukushima Daiichi Nuclear Power Plant			
Work location	ALPS buildings, etc.			
Overview	To assess the impact of airborne tritium intake on radiation handlers operating in ALPS buildings and other related areas, the airborne tritium concentration was measured.			
Assessment (Qualitative / quantitative)	Effect		Before Implementation	After Implementation
		Population radiation exposure dose (person-mSv)	-	-
		Person time (person-day)	-	-
Good Practice Description				

- Objective

At the Fukushima Daiichi Nuclear Power Plant, water containing high concentrations of radioactive materials is treated using the Advanced Liquid Processing System (hereinafter referred to as ALPS) until the concentrations of radionuclides other than tritium are reliably reduced below regulatory safety limits. Tritium, however, cannot be removed by ALPS or similar treatment systems, and thus remains in the treated water at concentrations ranging from approximately 10^5 to 10^6 Bq/L. It is considered that tritium may be released into the air through evaporation from this system water.
To assess the impact of airborne tritium intake on radiation handlers operating in ALPS buildings and other related areas, the airborne tritium concentration was measured.

- Results

Figure 1 shows the airborne tritium concentrations measured in FY2023 at the existing ALPS, additional ALPS, and the desalination system (reverse osmosis membrane: RO-3) building. As shown in Figure 1, the maximum airborne tritium concentration was approximately 2×10^{-4} Bq/cm³. Based on this value, the committed effective dose was estimated under the following assumed working conditions: 3.5 hours of work per day, 20 workdays per month, over the course of one year. The evaluated dose was approximately 5×10^{-3} mSv, which is significantly below the dose recording threshold of 2 mSv.

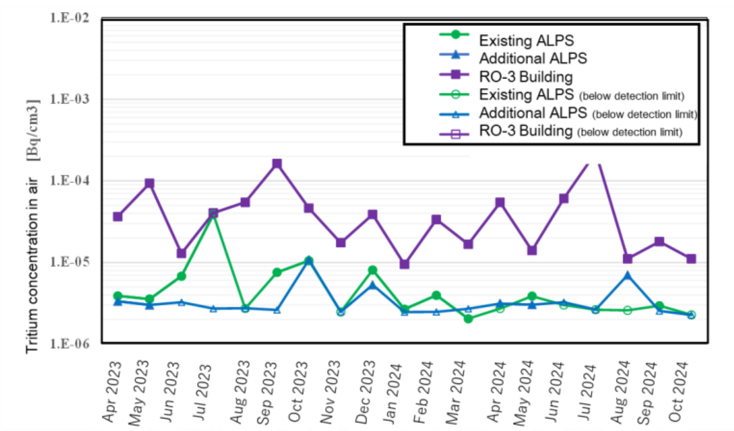
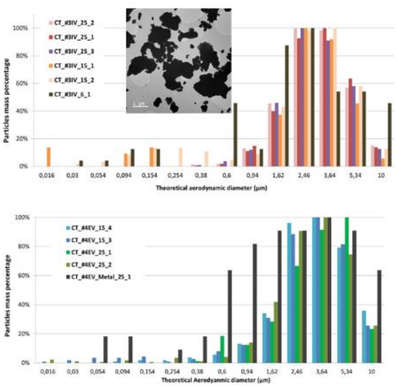
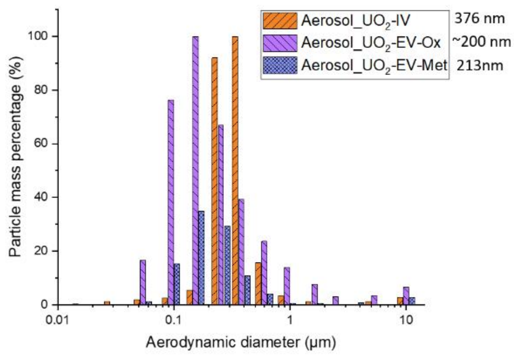


Figure 1: Airborne tritium concentration at existing ALPS, additional ALPS, and RO-3 building

<table>
<tr><td>Location</td><td colspan="2">R, Z (within PCV)</td><td>Category</td><td>7</td></tr>
<tr><td>Title</td><td colspan="4">Fuel Debris Retrieval and Radioactive Dust</td></tr>
<tr><td>Work location</td><td colspan="4">Inside the PCV of Units 1–3 (Dust study materials related to debris retrieval)</td></tr>
<tr><td>Overview</td><td colspan="4">In preparation for the upcoming full-scale retrieval of fuel debris, simulated fuel debris was fabricated to investigate the dispersion rates and radioactivity levels of radioactive dust during cutting and heating tests. The characteristics of dust generation are influenced by multiple factors including: debris formation pathway, material heterogeneity, variation in hardness, retrieval methods, retrieval environment, particle size distribution, elemental composition, and internal exposure effects (effective dose coefficients).</td></tr>
<tr><td rowspan="3">Assessment (Qualitative)</td><td rowspan="3">Effects</td><td></td><td>Before Implementation</td><td>After Implementation</td></tr>
<tr><td>Population radiation exposure dose (person-mSv)</td><td></td><td></td></tr>
<tr><td>Person time (person-day)</td><td></td><td></td></tr>
<tr><td>Good Practice Description</td><td colspan="4"></td></tr>
<tr><td colspan="5">During large-scale fuel debris retrieval inside the Primary Containment Vessel (PCV), the suppression and containment of radioactive dust generation are critical. In this study, among the five factors constituting the dust source term, the particle size distribution and radioactivity levels of dust generated during both mechanical and thermal processing of simulated fuel debris were experimentally evaluated. Shown below are actual measurement results of the particle size distribution of dust produced during mechanical processing (left figure) and thermal processing (right figure) of the simulated fuel debris. During mechanical processing, the generated particle size was relatively constant (MMAD to 4 μm), regardless of the debris formation pathway (in-vessel or ex-vessel). On the other hand, thermal processing resulted in the generation of submicron-sized dust particles. During thermal processing, it is also necessary to consider the temperature dependence of elemental volatility.


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