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 2022

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1

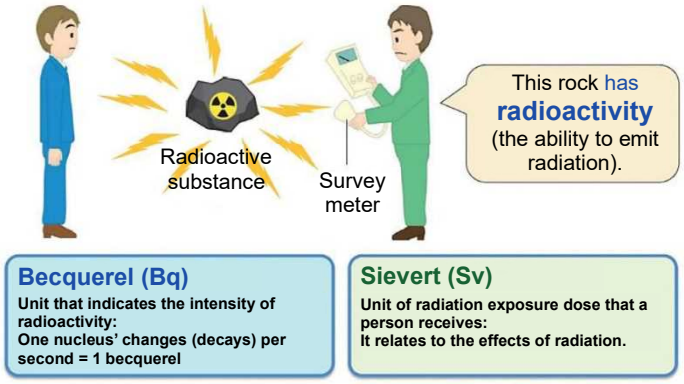
Fundamental knowledge on radiation and radioactivity

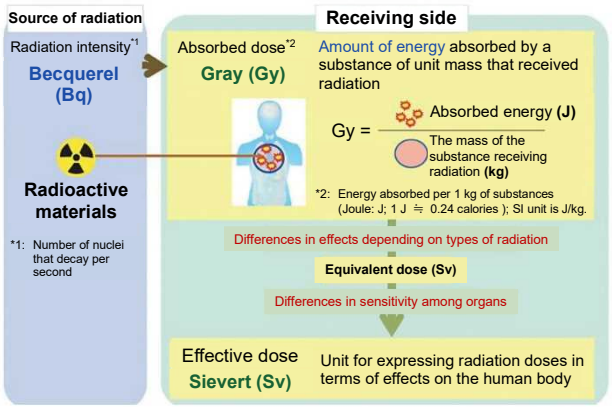
(1) Units of radiation and radioactivity

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. Alpha rays are known to be helium nuclei composed of two protons and two neutrons, which are ejected at high velocity. Beta rays are electrons emitted from atomic nuclei. Atomic nuclei in an unstable state, with high energy, emit γ-rays immediately after emitting α-rays or beta-rays in order to become stable.
The table below summarizes the units of radiation exposure. Roughly speaking, units of measurement of radiation are divided into two types: the absorbed dose, which represents the energy absorbed by a substance on receiving radiation; and the equivalent dose and effective dose, which represent the effects of radiation on human bodies. 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)

Radioactivity is the ability of a radionuclide to transform into another nucleus (called disintegration or decay). It is measured in the unit of Becquerel (Bq). Radioactive substances are materials with the power to emit radiation. Radioactivity is an ability. So we can say, “The concentration of radioactivity of substances with a weight of 2 kg and a radioactivity of 100 Becquerels is 50 Bq/kg.”
A statement such as, “It was contaminated with **radioactivity**” or “**Radioactivity** was released” does not make good sense. The correct representation is that “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 (2020)”.

(2) Principles for Radiation Exposure Protection

Reducing external exposure

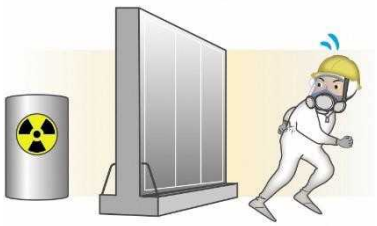
To reduce external exposure, it is important to understand the following four principles of radiation exposure protection.

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 prevent internal exposure, it is important to wear the required personal protective equipment so that radioactive materials are not taken into the human body. Measures must also be put in place to prevent radioactive materials from being blown around in the air, and to contain (and limit) any contamination and stop it spreading (dispersing).

Principle 1 Clearly outline contamination zones

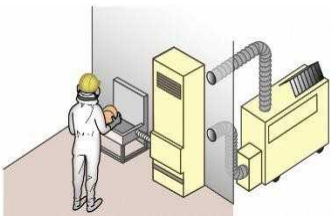
Clearly outline contamination zones and ensure full control and management of access to the zone. Cover any objects being removed from the contamination zone with a sheet or similar material to prevent spreading (dispersing) contamination.

Principle 2 Wear protective equipment

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

Principle 3 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.



Principle 4 Move to safety

When leaving the working area, check and remove any radioactive contamination on the body. Before removing protective equipment (masks, protective clothing, gloves, etc.), first wipe them off to prevent radioactive substances being taken into the body. Be sure to decontaminate them, and then remove them when undergoing the contamination checks. In the event of injury, move to an uncontaminated area immediately.

2

1F Site Operation Zone Control

(1) 1F site operation zone status

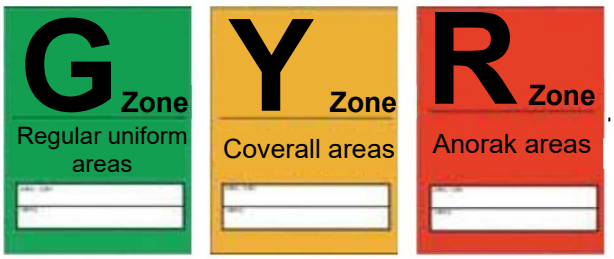
Controlled zones are classified into the following three classes, according to contamination level.

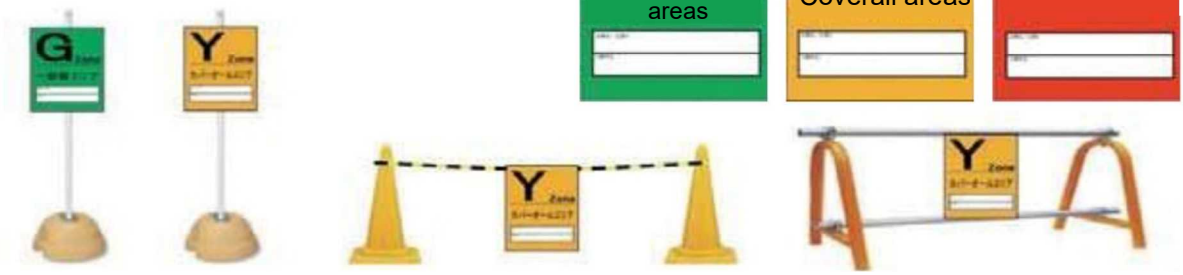
Zone		Protective Equipment
Red zone (Anorak areas) • Inside Units 1 to 3 reactor buildings • Peripheral areas with retained water of Units 1 to 4 buildings		• Full-face mask • Anorak • Work boots (for R zone) • Helmet (for R zone) • Cotton gloves + rubber gloves
Yellow zone (Coverall areas)	• Inside buildings that include water treatment facilities (such as desalination units, multi-nuclide removal facilities) • Work in areas around tanks that contain concentrated salt water or strontium-treated water*1, and work that involves the handling of transport lines to tanks.	• Full-face mask • Coverall • Work boots (for Y zone) • Helmet (for Y zone) • Cotton gloves + rubber gloves
	• Around Units 1 to 4 buildings • Specified as required to suit work environment (such as inside Units 5 and 6 buildings, parts of storage areas for high-radiation exposure dose rubble)	• Half-face mask • Coverall • Work boots (for Y zone) • Helmet (for Y zone) • Cotton gloves + rubber gloves
Green zone (Regular uniform areas) Areas except the above: changed from Y to G on and after March 30, 2017. Part of peripheral area of Units 1 to 4 buildings and slope faces of Units 1 to 4.		• DS2 mask • Site clothing, regular work clothing*2 • Work boots (for G zone) • Helmet (for G zone) • Cotton gloves + rubber gloves, or work gloves
• Inside important anti-seismic buildings and inside rest area		

*1: Excluding work that does not involve the handling of concentrated salt water, tank patrolling, field surveys during work planning, observation visits, etc.
*2: Certain light work (such as patrolling, monitoring, and transportation of items brought in from outside the premises)

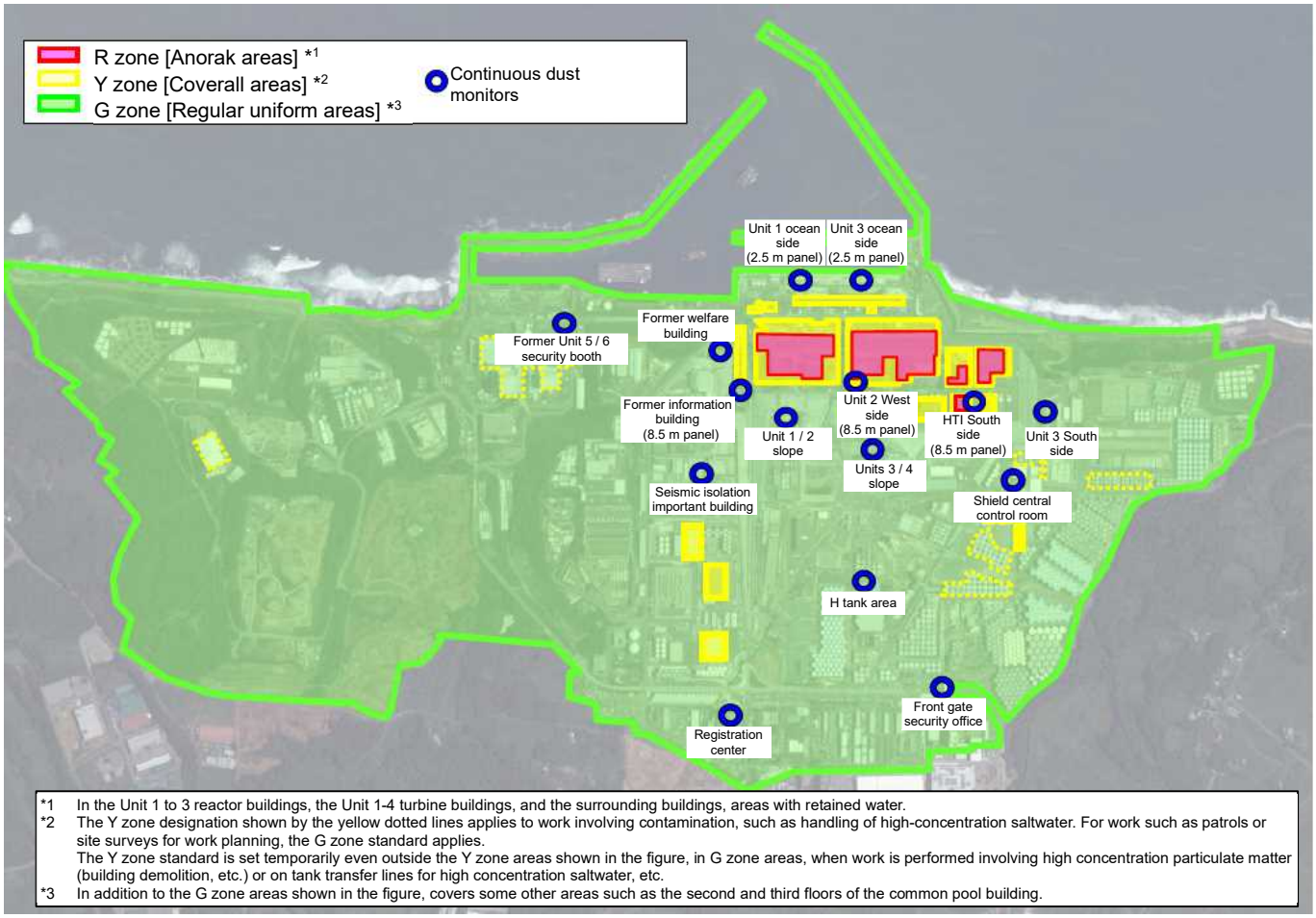
(Taken from the website of Tokyo Electric Power Company Holdings, Incorporated.)

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



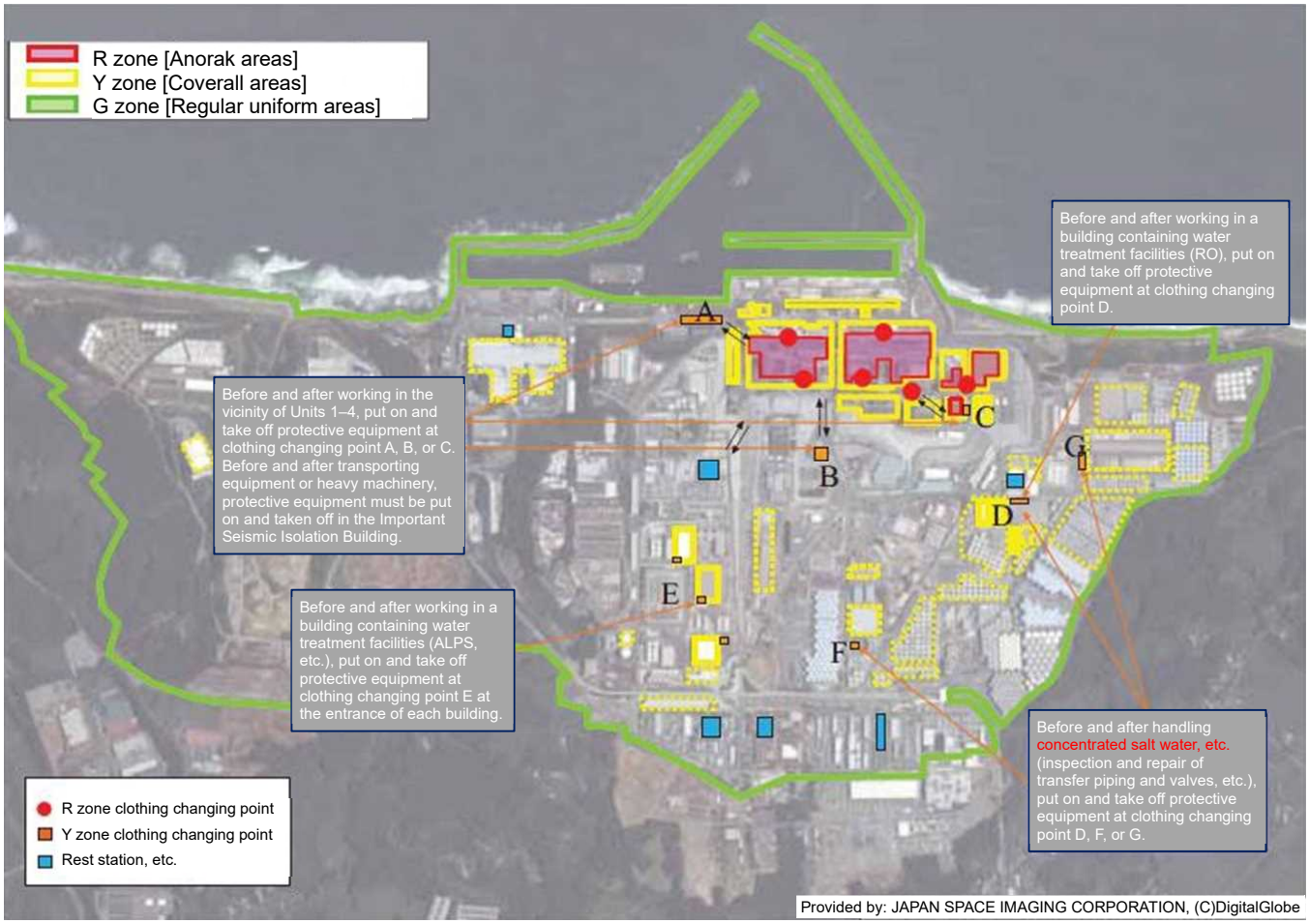


(Material provided by Tokyo Electric Power Company Holdings, Incorporated.)



*1 In the Unit 1 to 3 reactor buildings, the Unit 1-4 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 second and third floors of the common pool building.

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



(Material provided by Tokyo Electric Power Company Holdings, Inc., in April 2019.)

3

Good Practices

Location			Category		Good Practices in Radiation Exposure Dose Reduction Measures	
Inside reactor building	RB	Z	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 (Rα)	(Z)		6	Preventing spread of contamination	No.	03-01
			7	Other		

Title	Remote operation of rubble removal at the south of Unit 3 R/B, to reduce radiation exposure			
Work location	An area located at the south of Unit 3 R/B			
Overview	Since rubble removal is generally conducted in high-dose areas, we have planned measures to reduce exposure to radiation as much as possible, and have attempted to monitor the removal work with cameras, remove rubble with unmanned heavy equipment, and automate the rubble cutting process.			
Assessment (Qualitative / quantitative)	Effects		Before Implementation	After Implementation
		Radiation exposure dose (mSv)	6,490	1,930
		Person time (person-days)	17,472	16,794
Good Practice Description				

■ **Reducing radiation exposure by improving the removal operation**

To reduce the number of workers entering the work area and receiving high radiation dose rates, we introduced remote operation for the transfer of rubble to the rubble cutting equipment and the cutting work.

- Air dose rate
  Work area: approx. 1.3 mSv/h
  Remote control room: approx. 0.01 mSv/h
- Reduction effect
  Before implementation: approx. 6,490 person-mSv
  After implementation: approx. 1,930 person-mSv
  Reduced exposure dose: approx. 4,560 person-mSv

Remote control room (Monitor room)

Remote-controlled heavy equipment (PC450)

Remote-controlled cutting tool (wire saw)

Edited by Kajima Corporation

Location			Category		Good Practices in Radiation Exposure Dose Reduction Measures	
Inside reactor building	(RB)	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.	03-02
			7	Other		

Title	Development of a dosimeter for simultaneous discriminating measurement of β and γ radiation			
Work location	An area with presence of β rays, such as inside reactor building or multi-nuclide removal facilities			
Overview	We have developed a survey meter that can reduce radiation exposure by shortening the time required for β-ray measurement.			
Assessment (Qualitative / quantitative)	Effects		Before Implementation	After Implementation
		Radiation exposure dose (mSv)	—	—
		Person time (person-days)	—	—
Good Practice Description				

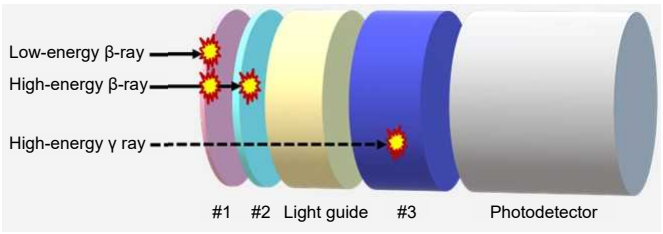
Before implementation: The β dose rate was evaluated by measuring the γ and (β + γ) dose rates, using the filter caps of the ionization chamber, and then calculating the difference between them.
In a highly contaminated environment such as 1F site, multiple units of ionization chambers must be prepared for measuring γ and (β + γ) dose rates because attaching and detaching filter caps on site poses the risk of cross-contamination. Ionization chambers are sensitive to shocks and must be handled with care. Carrying multiple chambers places a heavy burden on radiation control officers. Multiple measurements taken under high dose rates can lead to increased exposure.

Details of measures: After strong requests from on-site radiation control officers, our Group's radiation control and measurement technology development divisions worked together and developed a novel scintillator element with a (3+1) layer structure, a signal processing circuit designed for the element, and a real-time waveform identification algorithm. We now use this instrument as a new type of survey meter. It can measure dose equivalent rates in a real-time manner, while discriminating between γ and β rays (patent applied for). It will contribute greatly to on-site management at 1F, where the importance of β-ray control increases as decommissioning work progresses, considering the stricter regulations on equivalent dose limit for the crystalline lens.

Conventional β-ray measurement requires multiple measurements using multiple ionization chambers.

The new survey meter can measure β-rays with a single measurement, using a single unit.

Appearance and display of the new survey meter



Schematic of 3+1 layer scintillator configuration

Edited by Toshiba Energy Systems & Solutions Corporation

Location			Category		Good Practices in Radiation Exposure Dose Reduction Measures	
Inside reactor building	RB	R	6	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 (Rα)	Z			(6) Preventing spread of contamination	No.	03-03
				7 Other		

Title	Introduction of a full-face covering anorak			
Work location	R zone or Rα zone			
Overview	To prevent internal intake of radioactive materials when removing a full-face mask, we introduced an anorak (personal protective equipment) that covers a full-face mask.			
Assessment (Qualitative / quantitative)	Effects		Before Implementation	After Implementation
		Radiation exposure dose (mSv)	–	–
		Person time (person-days)	–	–
Good Practice Description				

■ **Purpose**

In operations in highly contaminated conditions, such as those performed in contaminated buildings, contaminants adhere to the surface of a worker's face when removing a mask after work. In response to this issue, we introduced radiation protection equipment (an anorak) that can cover the full-face mask, as one of the measures to prevent internal intake of radioactive materials.

■ **Items to be considered in producing an anorak covering a full-face mask**

(1) Examine the specifications of the desired anorak, taking into account the shape and size of the mask.

(2) Create a prototype of the anorak. Conduct trial fitting tests of the prototype (ease of wearing, effect on fogging of the mask, and other factors). Improve the prototype with feedback from the trial to determine the specifications.

(3) Order the necessary quantity of anoraks and deliver them to each site as appropriate.

<Full-face mask>

<Full-face mask with electric fan>

<Anorak>

<Characteristics>

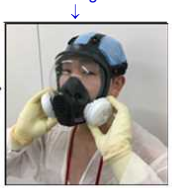
- The face part of the anorak has a shield to ensure visibility.
- The anorak has an opening hole with an elastic band that fits around the filter part and allows expiratory flow to pass through the opening, so as not to disturb breathing.
- The entire head and about 80% of the full-face mask part are covered by the anorak, preventing contaminants from adhering to the mask during work.
- The filter parts installed on the left and right sides of the full-face mask are not covered by the anorak. The filter parts must be covered by filter covers to prevent contaminants adhering to the filters.

[Before Implementation] Conventional anorak

The full-face mask is not covered by an anorak.
↓
Contaminants adhere to the surface of the full-face mask during work.
↓
After work, the contaminated full-face mask is removed.
↓
There is a risk of contaminants adhering to the face when removing the full-face mask.

[After Implementation] Full-face covering anorak

The full-face mask is covered by an anorak.
↓
Preventing contaminants from adhering to the surface of the full-face mask during work.
↓



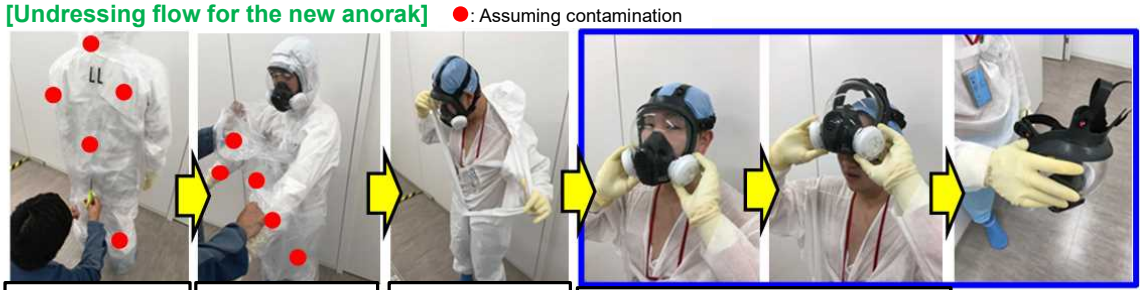
Risk of contaminant transmission is reduced when removing the full-face mask.

[Process of removing anorak and kaizen in the prevention of contaminant adhesion]

[Conventional undressing flow] ●: Assuming contamination

(1) The undressing assistant cuts an anorak.
(2) The undressing assistant removes the worker's anorak.
(3) The worker removes the coverall.
(4) The worker removes the full-face mask (contaminants propagate from the full-face mask to rubber gloves and worker's face).

[Undressing flow for the new anorak] ●: Assuming contamination



(1) The undressing assistant cuts an anorak.
(2) The undressing assistant removes the worker's anorak and filter covers.
(3) The worker removes the coverall.
(4) The worker removes the full-face mask (no more propagation of contaminants via the full-face mask).

[Deployment Schedule]

Mask type (manufacturer)		Progress
Full-face mask (made by Company A).		The examination of anorak specifications was completed in FY 2020, and 12,000 anoraks were made and put into operation in October 2021.
Full-face mask (made by Company B).		The anorak intended for use with masks made by Company A is being modified so that it can also be used for Company A's full-face masks introduced this fiscal year. The deployment is scheduled to begin in April 2022 or later.
Full-face mask with electric fan (made by Company A).		Test fittings, to check the countermeasures against anorak fogging. The date of deployment has not yet been set.
Full-face mask with electric fan (made by Company B).		

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