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 2023

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1

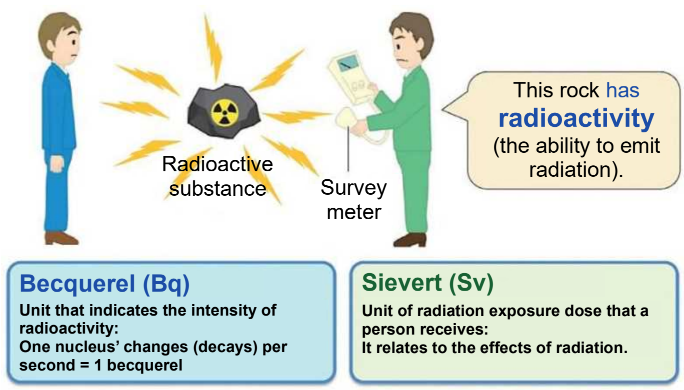
Fundamental knowledge on radiation and radioactivity

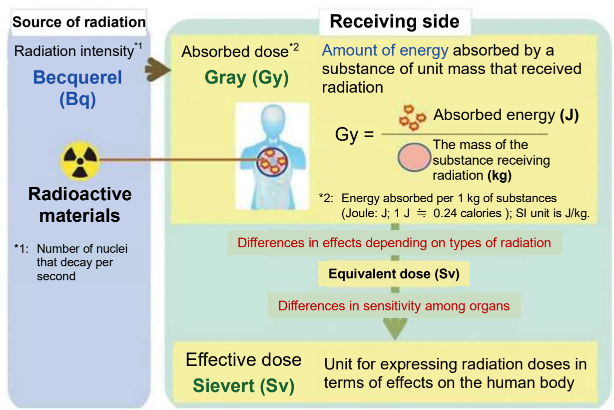
(1) Units of radiation and radioactivity

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

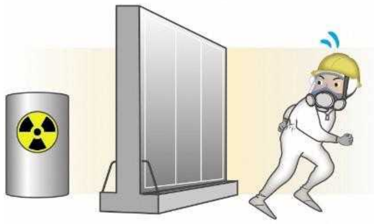
To reduce external exposure, it is important to understand the following four principles of radiation exposure protection.

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

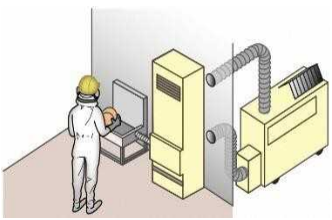
Clearly outline contamination zones and ensure full control and management of access to the zone. Cover any objects being removed from the contamination zone with a sheet or similar material to prevent spreading (dispersing) contamination.

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

1F site operation zone status

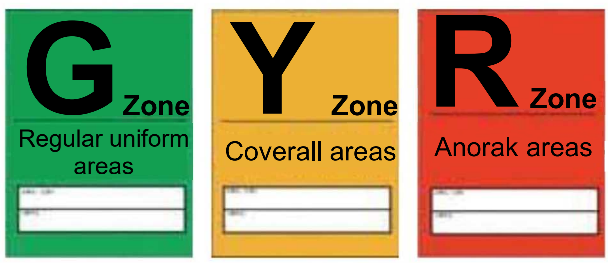
Controlled zones are classified into the following three classes, according to contamination level.

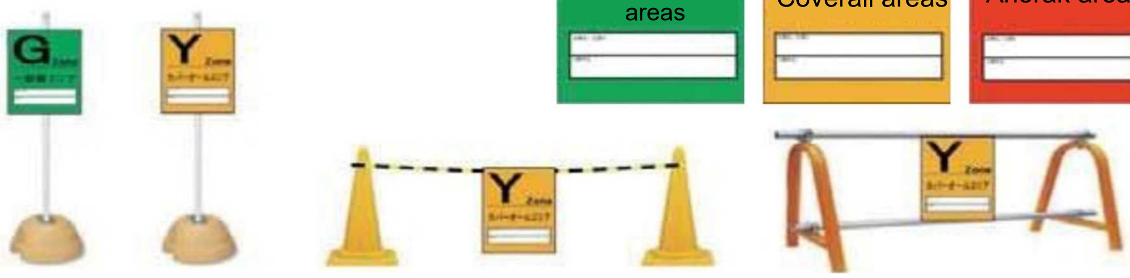
Zone		Protective Equipment
Red zone (Anorak areas) • Inside Units 1 to 3 reactor buildings • Peripheral areas with retained water of Units 1 to 4 buildings		• Full-face mask • Anorak • Work boots (for R zone) • Helmet (for R zone) • Cotton gloves + rubber gloves
Yellow zone (Coverall areas)	• Inside 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.)

[Ref.] Zone map (as of December 2022*4)

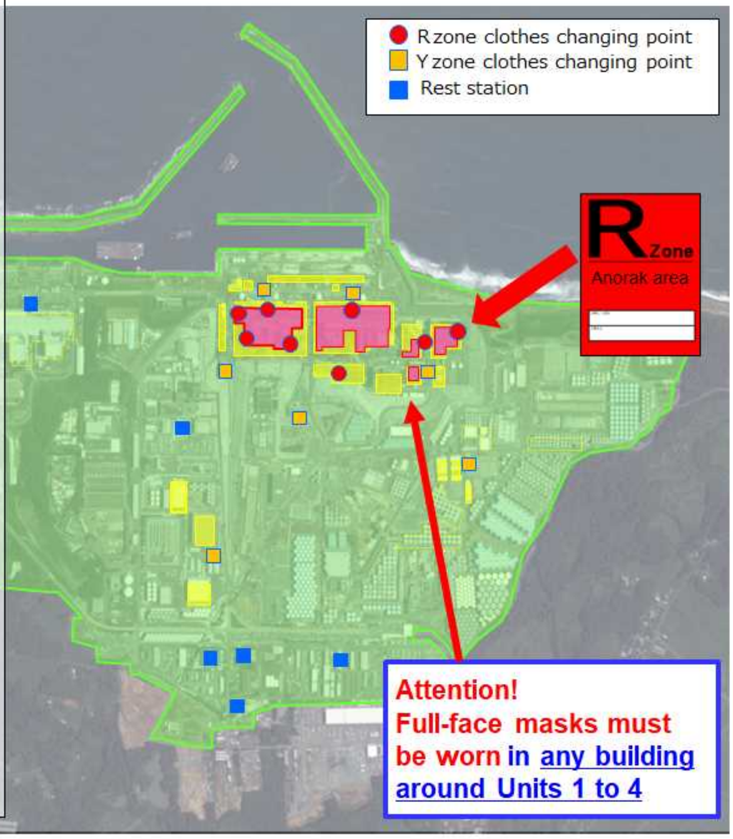
- R zone [Anorak area] *1
- Y zone [Coverall area] *2
- G zone [Regular work clothing area] *3

*1:**R Zone:** Inside Units 1 to 3 reactor buildings, and areas with stored water around Units 1 to 4 turbine buildings and surrounding buildings.

*2:**Y zone** shown in dotted yellow lines is for when working with concentrated salt water or **work related to contamination** and requires **G zone equipment** during patrols or when conducting site surveys for creating work plans. When performing work in high dust concentrations (such as demolishing buildings) in the G zone, or working with concentrated salt water or work related to tank transfer lines, those areas will be temporarily specified as the **Y zone**.

*3:In addition to the **G zone** on the map, also applies to some areas of the common pool building.

*4:Be sure to check the latest updates.



(Material provided by Tokyo Electric Power Company Holdings, Incorporated, in December 2022.)

3

Good Practices

Location			Category			Good Practices in Radiation Exposure Dose Reduction Measures
Inside reactor building	(RB)	RB	5	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. 4-（1）
				7	Other	

Title	Efforts to reduce radiation exposure related to the in-depth investigation inside the Unit 1 primary containment vessel			
Work location	Inside the Unit 1 reactor building (around the X-2 penetration of the primary containment vessel)			
Overview	Measures were taken to reduce worker radiation exposure during investigation of the inside of the primary containment vessel using a submersible ROV.			
Assessment (Qualitative / quantitative)	Effects		Before Implementation	After Implementation
		Population radiation exposure dose (man-Sv)	16.12	2.40
		Person time (person-days)	—	—
Good Practice Description				

- As the presence of deposits has been confirmed in the basement floor inside the Unit 1 primary containment vessel (PCV), we plan and conduct in-depth investigations of the basement floor inside the PCV* to confirm the situation in detail, including deposits, for the future removal of fuel debris.
- Because the basement floor of the Unit 1 PCV is a high-dose environment with retained water, we decided to conduct an in-depth investigation of the basement floor by deploying a remotely operated vehicle (hereinafter “submersible ROV”) that operates on the water surface or under water to survey a large area outside the pedestal and the interior of the pedestal.
- The submersible ROV is deployed for survey and collection using the access route established in the X-2 penetration (hereinafter “X-2 penetration”), and thus work is performed inside the reactor building (around the X-2 penetration). The following measures are being taken to reduce radiation exposure.

(1) Remotely operate the submersible ROV and provide on-site work instructions from low-dose areas (including the operation room in the seismic isolation building and the large item loading entrance on the 2nd floor).

(2) Perform decontamination and install shielding in area around X-2 penetration

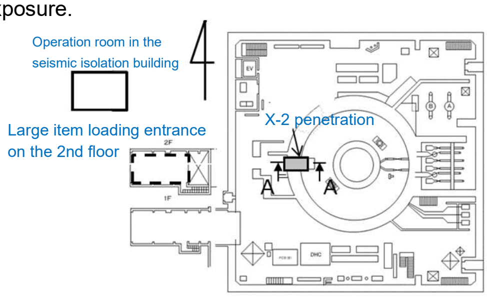


Figure 1: Location of X-2 penetration on the 1st floor of Unit 1 reactor building

(3) Wash submersible ROV with water during recovery.

(4) Improve work proficiency through full-scale mockups and operational training to optimize manpower and reduce work hours.

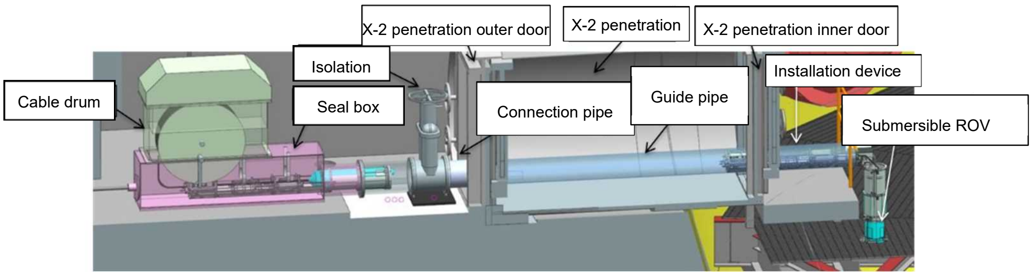


Figure 2: Image of equipment installation during detailed survey inside PCV (A-A arrow view)

*: This project is implemented by the International Research Institute for Nuclear Decommissioning (IRID), utilizing the findings from a decommissioning and contaminated water project subsidized by the Ministry of Economy, Trade and Industry (METI)
The figure is based on the data posted on the Tokyo Electric Power Company Holdings, Inc.'s website at the linked page below.
Linked page: https://www.tepco.co.jp/decommission/information/committee/roadmap_progress/pdf/2022/d221222_08-j.pdf

Edited by Hitachi-GE Nuclear Energy, Ltd.

Location			Category			Good Practices in Radiation Exposure Dose Reduction Measures
Inside reactor building	RB	R,Y	2, 5, 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	Z			6	Preventing spread of contamination	No. 4-（2）
				7	Other	

Title	Analysis of specimens collected during the investigation of the inside of the Unit 2 reactor well using a portable remote laser analyzer (portable LIBS system).
Work location	66-kV switchyard
Overview	The portable remote laser analyzer (portable LIBS system) that we developed was used to analyze test specimens (including deposits and duct components) collected during the investigation of the inside of the Unit 2 reactor well. In this analysis, the applicability of 1F was also evaluated by taking measures against contamination of the LIBS system, evaluating the radioactive contamination due to diffusion of dust generated by laser irradiation, and taking measures against worker radiation exposure, such as controlling analyzers by remote operation.

Assessment (Qualitative / quantitative)			Before Implementation	After Implementation
	Effects	Radiation exposure dose (mSv)	—	0.04
		Person time (person-days)	—	30

Good Practice Description	

●Purpose

Analysis of test specimens (including deposits and duct components) and other materials collected during the investigation of the inside of the Unit 2 reactor well using the “portable remote laser analyzer (portable LIBS* system)” that we developed.

*LIBS: Abbreviation for laser-induced breakdown spectroscopy. A technique for analyzing the wavelength of plasma emission light induced by laser irradiation.

●Measures to reduce radiation exposure

- The portable LIBS system consists of (1) an analysis vessel and (2) a laser oscillator/analyzer (Fig. 1). The analysis vessel, which handles samples with high dose rates, was installed in the Red zone (Photo 1), and the laser oscillator/analyzer in the Yellow zone (Photo 2). The sample stand in the analysis vessel was adjusted and laser oscillation/analysis was performed by remote control to reduce the radiation exposure of analysis workers.

- The sample chamber of the analysis vessel was simply sealed with acrylic boards and the air was exhausted through filters (HEPA/ULPA filters, and activated carbon) to prevent external contamination.
- As measures against contamination of the LIBS system, the laser oscillator/analyzer was housed in a simple acrylic hood and then cured.

●Effects of radiation exposure reduction measures, etc.

Analysis work was carried out by remote control and the minimum number of personnel engaged in work. We believe that these measures to reduce radiation exposure dose were effective. In addition, we found no contamination in the set of equipment that we brought in, achieving the original target.

For the first time, a portable LIBS system was applied to the 1F site to demonstrate remote analysis work. In the future, this analysis is expected to make a significant contribution to measures for reducing radiation exposure through remote analysis in no-entry areas with high dose rates and elevated contamination.

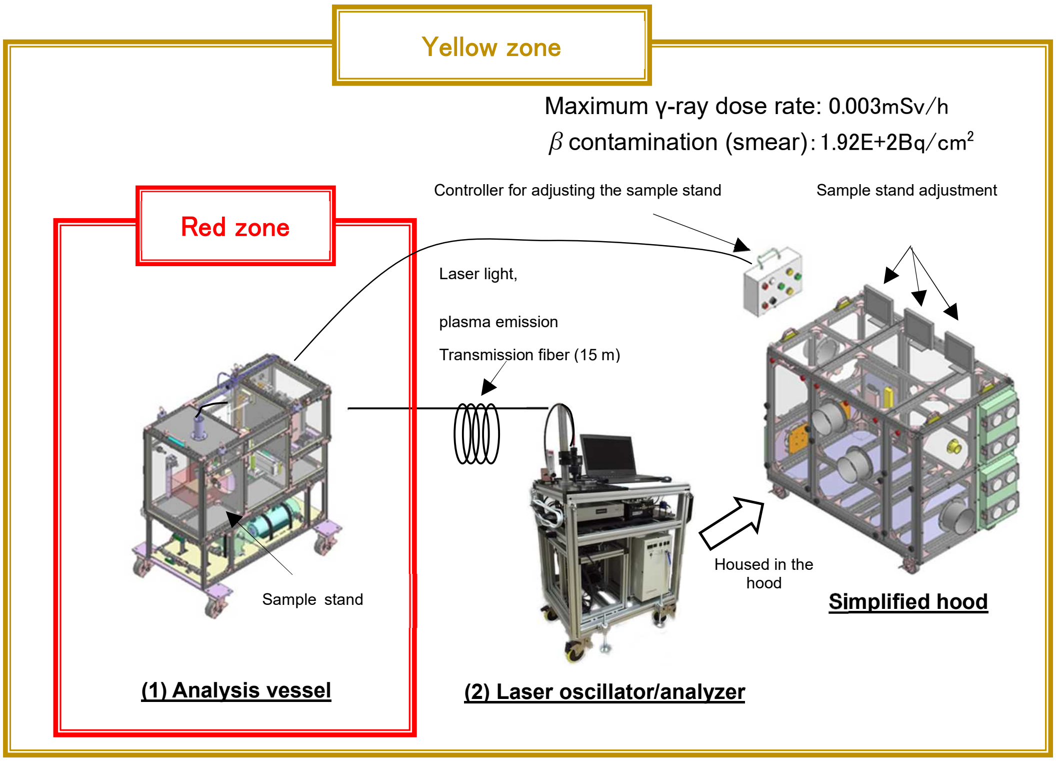


Figure 1: Overview of analysis using a portable LIBS system

Photo 1: Appearance of analysis vessel installation (Red zone)

Photo 2: Appearance of laser oscillator/analyzer

Edited by Japan Atomic Energy Agency

Location			Category			Good Practices in Radiation Exposure Dose Reduction Measures	
Inside reactor building	RB	R,Z	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.	4-（3）
				7	Other		

Title	Introduction of an improved anorak for full-face mask			
Work location	—			
Overview	We introduced an anorak (protective equipment) that can cover a full-face mask and a full-face mask with an electric fan to prevent internal intake of radioactive materials when removing the 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.

Mask type	FY2021	Initiatives for FY2022	
Full-face mask manufactured by **Company A** 	**Current model Anorak for full-face mask** In use since October 2021. (12,000 pieces purchased) 	Anorak for improved full-face mask  **- Reviewed the material of the anorak face section.** **- Can be worn with full-face masks made by both manufacturers.** ***5,000 pieces purchased**	Matters to be examined - Consider the specifications of an anorak according to the shape and size of the full-face mask. In addition, consider the specifications of an anorak for full-face mask designed for a full-face mask with an electric fan. - Consider the number of anoraks needed. - Study the materials for the anorak face section to prevent fogging when wearing an anorak for full-face mask. - Create an anorak prototype. Establish trial fitting test conditions and conduct trial fitting tests of the prototype. **Trial fitting test conditions** Checked for fogging in the face section in the large high- and low-temperature test chamber. - First test Testing was conducted at extreme room temperature settings. Environment assuming summer (at a room temperature of 31°C and at a humidity of 92%) Environment assuming winter (at a room temperature of -4°C and at a humidity of 68% to 78%) - Second test Environment assuming summer (at a room temperature of 21°C and at a humidity of 92%) Environment assuming winter (at a room temperature of -1°C and at a humidity of 68% to 78%)
Full-face mask manufactured by **Company B** 	Not yet started We have modified company A's anorak for full-face mask for common use and are conducting trial fit tests. Targeted start of operation is the second half of 2022.		
Full-face mask with an electric fan manufactured by **Company A** 	Not yet started We are conducting trial fitting tests and are considering measures against fogging of anorak. The target date for the start of operation is the second half of 2022.	Anorak for full-face mask with electric fan  **Can be worn over some manufacturers' full-face masks.** ***Purchased 500 pieces**	
Full-face mask with an electric fan manufactured by **Company B** 		To be considered in the future The structure is different from that of Company B's full-face mask with an electric fan; shared use is not allowed.	

【Characteristics】

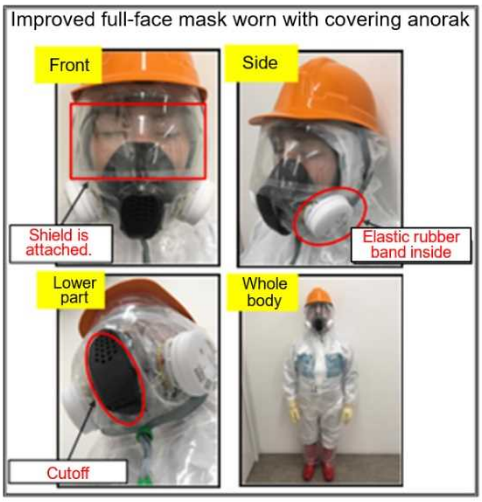
< Worn over a full-face mask >

- Can be worn over all the full-face masks that we use.
- The filter section (intake) is rubber-drawn and the exhaust section is cut out so as not to obstruct the breathing passage.

・The entire head and about 60~70%* of the full-face mask part are covered by the anorak, preventing contaminants from adhering to the mask during work.

- The shield section is processed so that it does not fog up due to heat from perspiration, etc. (antifogging film)

*Exposed area varies depending on the mask type.

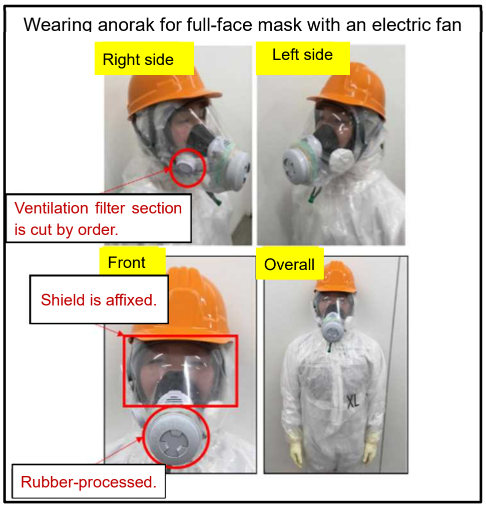


< Worn over a full-face mask with an electric fan >

- Can be worn over some full-face masks with an electric fan that we use.
- The filter unit section (intake) is rubber-drawn and the exhaust section is cut out so as not to obstruct the breathing passage.

・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 shield section is processed so that it does not fog up due to heat from perspiration, etc. (antifogging film)



Conventional anorak

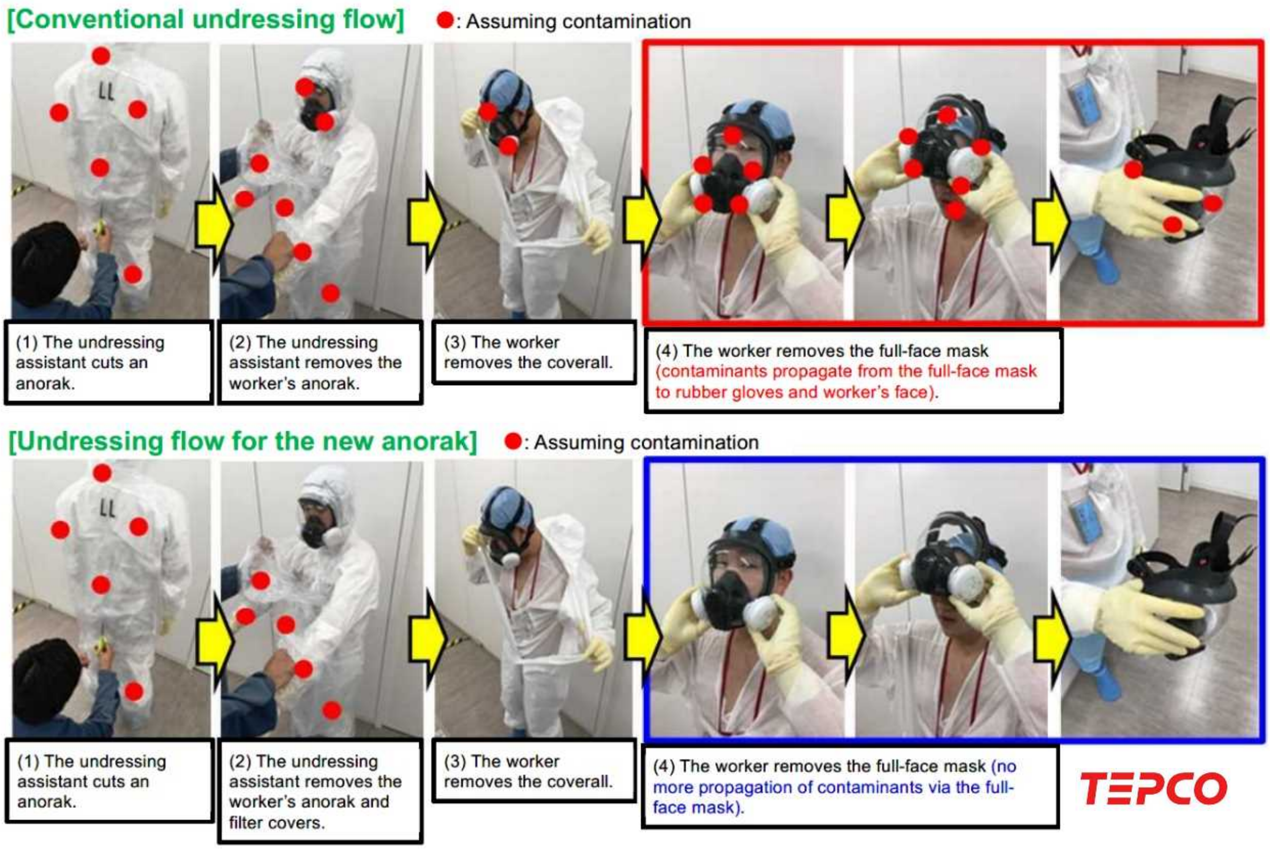
The full-face mask is not covered by an anorak.
↓
Contaminants adhere to the surface of the full-face mask during work.
↓
After work, the contaminated full-face mask is removed.
↓
There is a risk of contaminants adhering to the face when removing the full-face mask.

Improved 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.

[Wearing effect]



[Deployment schedule]

	2022				2023		
	April to September	October	November	December	January	February	March
Examination and trial fitting test							
Finalizing of specifications							
Anorak production							
Delivery scheduled							
Operation start scheduled							

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