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Estimated intake quantity of airborne dust and effective use of dust masks

1) Estimation of workers' respiration volume

Assuming that the respiration volume of an adult worker under average work intensity is 30 L/min, the respiration volume per hour would be 1.8 m^3/h.

The respiratory volume increases with higher labour intensity of the work.

2) Estimation of airborne dust concentration

According to the report on "Project for the Management of Working Environment Measurement Accuracy" conducted by the Japan Association for Working Environment Measurement in 1989, geometric means of airborne dust concentrations measured at 2,579 sites that generated mineral dust ranged from 0.2 to 0.5 mg/m^3 as highest occurrence rate, while the highest concentrations ranged from 5.0 to 10 mg/m^3. As these concentrations were measured at indoor workplaces that generate dust, where certain ventilation systems are available, they would be different from those measured at outdoor places without a function to control dust concentrations. At dust generating spots in the same workplace where the dust concentration becomes the highest, the collected dust concentrations (measurements B) ranged from 0.2 to 0.5 mg/m^3 as the highest occurrence rate, while the highest concentrations ranged from 50 to 100 mg/m^3. Figures 1 and 2 show the distributions of the measurements given in the report; B measurements had concentrations less affected by ventilation systems at workplaces. Therefore, these values can be considered as references for dust concentrations at areas near outdoor dust sources.

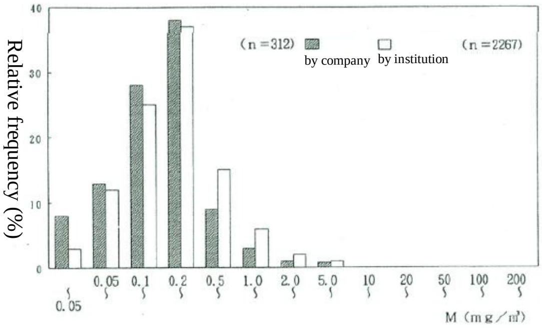
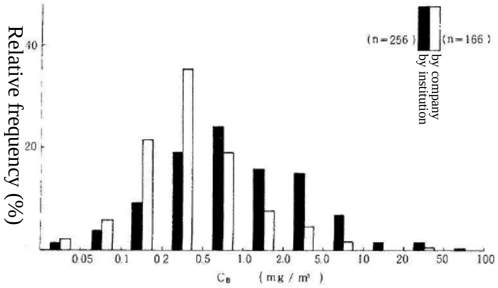


Figure 1 Work environment measurements at 2,579 work places that generated mineral dust (geometric mean concentrations)

Figure 2 Work environment measurements at 422 workplaces that generated mineral dust (B measurements)



The following table shows the actual measurements of the amount of dust as individual exposure concentrations and the amount of dust attached on dust masks, which were collected by Dr. Kikuji Kimura who used T-R samplers for measurement of the working environment at a stone cutting and grinding factory.

The T-R sampler, a device that collects airborne dust, simultaneously separates the total dust into coarse particles and respirable dust. The sampler determines the boundary between respirable dust and total dust at the 4.0 μm particle diameter where the filtration efficiency is 50% and the filtration efficiencies changes gradually around the boundary along with changes in particle size.

Table 1 Measured dust concentrations for individual workers doing dry grinding work

Worker #	Total (T) dust concentration (mg/m^3)	Respirable (R) dust concentration (mg/m^3)	(T/R) Ratio
1	12.0	1.7	7.2
2	2.9	1.3	2.2
3	34.6	10.6	3.3
4	1.7	0.2	7.6
5	32.3	9.1	3.5
6	30.3	8.7	5.3
7	28.0	5.2	5.4
8	3.9	0.9	4.4
9	2.1	1.2	1.8
10	9.1	2.7	3.4

2.4mg/day was the maximum dust quantity, which was filtered by the cartridge of a dust mask that a worker wore at the workplace and accumulated on its surface.

Based on these data, it is reasonable to assume for the airborne dust concentration (respirable particles) produced from soil contaminated by radioactive materials in a decontamination area that: the possible highest concentration is 100 mg/m^3, the typical occurrence range is 30 mg/m^3 or less, and the range of time-weighted average concentration is 10 mg/m^3 or less.

3) Estimates of the amount of dust that a decontamination worker inhales for 1 hour

Based on the conditions defined in 1) and 2) above, the highest possible concentration of dust that a decontamination worker may inhale for 1 hour can be calculated as described in Table 2.

Table 2 Highest possible concentration of dust that a decontamination worker may inhale

Condition	Formula	Inhalation per hour
Time-weighted average concentration	1.8 m^3/h (inhaled air volume) x 10 mg/m^3	18 mg/h
During work under high dust concentration	1.8 m^3/h (inhaled air volume) x 30 mg/m^3	54 mg/h
Highest possible concentration	1.8 m^3/h (inhaled air volume) x 100 mg/m^3	180 mg/h

As dust concentration varies over time and space, it is not likely that workers are working under the highest dust concentration for 6 hours or so. Thus, it can be concluded that it is almost inconceivable that workers would inhale 1 g dust /day.

4) Estimation of the radioactivity from inhaling radioactive dust

The radioactivity inhaled per hour was calculated as follows assuming that the radioactivity in objects to be decontaminated is 100,000 Bq/kg, 200,000 Bq/kg, and 300,000 Bq/kg because the highest content of radionuclides in such objects is currently unknown.

The radioactivity inhaled per hour (Bq/h)

= (Amount of dust inhaled per hour (mg/h)) x (Radioactivity in dust (Bq/kg)) x 10^{-6}

Table 3 Radioactivity that a decontamination worker may inhale per hour

Amount of inhaled dust	Radioactivity concentration in objects to be decontaminated (Bq/kg)					
	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000
18 mg/h	1.8 Bq/h	3.6 Bq/h	9.0 Bq/h	18 Bq/h	36 Bq/h	90 Bq/h
54 mg/h	5.4 Bq/h	10.8 Bq/h	27.0 Bq/h	54 Bq/h	108 Bq/h	270 Bq/h
180 mg/h	18 Bq/h	36.0 Bq/h	90.0 Bq/h	180 Bq/h	360 Bq/h	900 Bq/h

These amounts of radioactive materials taken by inhalation are comparable to the permissible level of radioactivity in 1 kg of agricultural and marine products (500 Bq/kg). Therefore they are not significant as the radioactivity that can be taken into the body, but are at the level that should be controlled below.

The radioactivity in Table 3 can be converted to the effective doses as follows.

Assuming that both Cs-134 and Cs-137 are contained at the ratio of 50%, their effective doses when they are taken into the body by inhalation are as follows.

Effective dose of Cs-134: 9.6×10^{-6} mSv/Bq

Effective dose of Cs-137: 6.7×10^{-6} mSv/Bq

Effective dose of a mixture of Cs (Cs-134 (50%)+Cs-137 (50%)): 8.15×10^{-6} mSv/Bq

Internal exposure dose due to inhalation of the dust during one hour of decontamination work

$= 8.15 \times 10^{-6}$ mSv x (Radioactivity in dust inhaled for 1 hour)

Table 4 Effective doses that a decontamination worker may inhale per hour (10^{-6} mSv/h)

Amount of inhaled dust	Radioactivity concentration in objects to be decontaminated (Bq/kg)					
	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000
18 mg/h	14.7×10^{-6}mSv/h	29.3×10^{-6}mSv/h	73.4×10^{-6}mSv/h	146.7×10^{-6}mSv/h	293.4×10^{-6}mSv/h	733.5×10^{-6}mSv/h
54 mg/h	44.0×10^{-6}mSv/h	88.0×10^{-6}mSv/h	220.1×10^{-6}mSv/h	440.1×10^{-6}mSv/h	880.2×10^{-6}mSv/h	2200.5×10^{-6}mSv/h
180 mg/h	146.7×10^{-6}mSv/h	293.4×10^{-6}mSv/h	733.5×10^{-6}mSv/h	1467×10^{-6}mSv/h	2934×10^{-6}mSv/h	7335×10^{-6}mSv/h

The effective dose per hour in Table 4 can be converted to the effective does per year as described in Table 5, assuming that workers work the standard working hours, or 40 hours per week, 52 weeks per year (or 2,080 hours per year), though working hours and days that workers actually spend for decontamination works are unknown.

Table 5 Effective doses that a decontamination worker may inhale per year (40 hours/week, 52 weeks)

Amount of inhaled dust	Radioactivity concentration in objects to be decontaminated (Bq/kg)					
	100,000	200,000	500,000	1,000,000	2,000,000	5,000,000
18 mg/h	0.031 mSv/y	0.061 mSv/y	0.153 mSv/y	0.305 mSv/y	0.610 mSv/y	1.526 mSv/y
54 mg/h	0.092 mSv/y	0.183 mSv/y	0.458 mSv/y	0.915 mSv/y	1.831 mSv/y	4.577 mSv/y
180 mg/h	0.305 mSv/y	0.610 mSv/y	1.526 mSv/y	3.051 mSv/y	6.103 mSv/y	15.257 mSv/y

5) Expected roles of respiratory protective equipment

Given that the values in Table 3 are the highest, the amount of radioactive dust inhaled during decontamination works is assumed to be the level that does not cause serious health effects, but the level that requires some reduction. In addition to radiation dose due to inhalation during the works, the decontamination workers are exposed to external radiation from their working environment as well as through their daily life by ingesting food and water. Considering that it is not easy to reduce radiation dose throughout their lives, dust masks could be used to reduce radiation exposure due to dust inhalation during decontamination works by an order of magnitude.

6) Performance of filter materials for dust masks

The type approval on dust masks for industrial use has been conducted in accordance with the "Dust mask standards" (30 March 1988, Notification of the Ministry of Labour No.19, latest revision on 19 December 2003) issued by the Ministry of Health, Labour and Welfare. In the standards, performance of dust mask filter materials (filters) is categorized as follows.

Table 6 Performance category of dust mask filter materials

For solid particles	For solid and liquid particles
In the particle collection efficiency test, particle concentrations in front of and behind a cartridge shall be measured by passing the test gas containing sodium chloride particles under the following conditions through the cartridge. Conditions of NaCl particles: The median diameter of the particle size distribution range is 0.06 - 0.1 μm, geometric standard deviation is 1.8 or below, and concentration in air is 50 mg/m^3 or below with variation within ± 15%.	In the particle collection efficiency test, particle concentrations in front of and behind a cartridge are measured by passing the test gas containing particles of dioctyl phthalate (DOP) under the following conditions through the cartridge. Conditions of DOP particles: The median diameter of the particle size distribution range is 0.15 - 0.25m, geometric standard deviation is 1.6 or below, and concentration in air is 100 mg/m^3 or below with variation within ± 15%.

Category symbol	Dust collection efficiency	Ventilation resistance	Category symbol	Dust collection efficiency	Ventilation resistance
DS1/RS1	Over 80%	60 Pa/70 Pa	DL1/RL1	Over 80%	60 Pa/70 Pa
DS2/RS2	Over 95%	70 Pa/80 Pa	DL2/RL2	Over 95%	70 Pa/80 Pa
DS3/RS3	Over 99.9%	150 Pa/160 Pa	DL3/RL3	Over 99.9%	150 Pa/160 Pa

D and R in the Category symbol in Table 6 represent disposable and replaceable types, respectively. S represents dust masks tested with sodium chloride particles while L represents those tested with DOP aerosol.

Filter material with the letter S in the Category symbol can be used only against solid dust particles, while that with the letter L can be used for both liquid aerosols, such as oil mist, and solid dust particles.

A filter has three mechanisms to collect particles: electrostatic suction, particle capture by mechanical collision, and adhesion to filter material due to particle diffusion. As the particles used for the collection efficiency tests described in Table 6, sodium chloride is selected to test filters with good electrostatic properties, while DOP is selected to test those that use capture by mechanical collision. This is because the diameters of these two kinds of particles give the lowest collection efficiencies for the tested filters. Therefore, it can be concluded that higher collection efficiencies of dust masks used in practical cases will be obtained when dust with bigger or smaller diameters than the test particles is collected, compared to the measured values under the standard test conditions.

If the purpose is to filter 90% or higher of the particles in air, it is necessary to select a filter with a dust collection efficiency of 95% or higher, or 99.9% or higher for the effective use of dust mask. Hence, DS1/RS1 and DL1/RL1 are not applicable. DS3/RS3 and DL3/RL3, which have the highest collection efficiency, show high ventilation resistance. This means that these dust masks would impose a severe respiratory burden on workers who work for long hours wearing them. Dust masks with a filter in the category of 95% are considered adequate for general decontamination works; however, it is safer to use DS3/RS3 and DL3/RL3 to decontaminate highly contaminated areas.

7) Dust mask geometry, leak rate, and protection factor

In addition to the filter dust collection efficiency, whether the face piece fits the wearer's face well without gaps is another important factor to determine the effectiveness of dust masks. The leak rate of dust mask with poor fit can be represented by the ratio of dust concentration in air inside the dust mask (Ci) to dust concentration in air outside the dust mask (C_0).

$$\text{Leak rate (\%)} = (Ci/C_0) \times 100$$

Protection factor (FP) may be used to indicate the fitting level as with the leak rate. The protection factor can be determined by the following formula.

$$\text{Protection Factor (PF)} = C_0/Ci$$

Dust masks include several types of masks such as full face piece, half face piece, and disposable half face piece dust masks. Figures 3, 4 and 5 show examples of these types of dust masks. As these are the types of mask body structure, a suitable filter should be selected from the types in the category shown in Table 2.

Figure 3 Full face piece dust mask

Figure 4 Half face piece dust mask

Figure 5 Disposable half face piece dust mask

In general, a full face piece dust mask provides better fit because it contacts with the peripheral part of the wearer's face. Still, any mask that does not match well with the size of the wearer's face can create gaps at the chin or forehead, which often causes leak because hair and/or beards got stuck between the mask and the face. Also it is known that one of the workers engaged in activities for stabilization at the TEPCO Fukushima Daiichi Nuclear Power Plant wore a full face piece dust mask over his eyeglasses, which resulted in air leaking at his temples were the eyeglasses were.

By contrast, fit of the half face piece dust masks is relatively less secure at the nasal root. Furthermore, it becomes worse if the wearer talks or makes facial movements. Disposable masks do not have elastic on the face-contacting part to give them a tight fit, and they lose their shape after long use to worsen the fit.

Leak rate of dust masks when they are being worn during work, the workplace protection factor

(WPF), is often measured in the United States, and many reports regarding its measurements have been made. OSHA determines the representative value of the WPF for each type of dust masks (assigned WPF) based on these reported values to provide a reference to select and use adequate dust masks to ensure safety. Figure 6 plots the WPF distribution created by OSHA for collected measurements of the rates of leakage into dust masks of workers in the United States when working while wearing half-face piece dust masks. The horizontal axis is the hazard ratio (C_0/PEL), the ratio of the concentration of an airborne toxic substance to the permissible exposure limit (PEL).

This figure illustrates that WPFs of half face piece dust masks can provide high respiratory protection, up to 100,000, while being below 10, depending on the fitting level. Points indicating the WPF of 10 or less account for 2.5% or less of the entire data points. OSHA determined an assigned WPF of 10 for filtering half face piece respiratory protective equipment (dust masks and gas masks including disposable types). Table 7 shows the assigned WPF by type for filter-type respiratory protective equipment that OSHA specified in 29CFR1910.134.

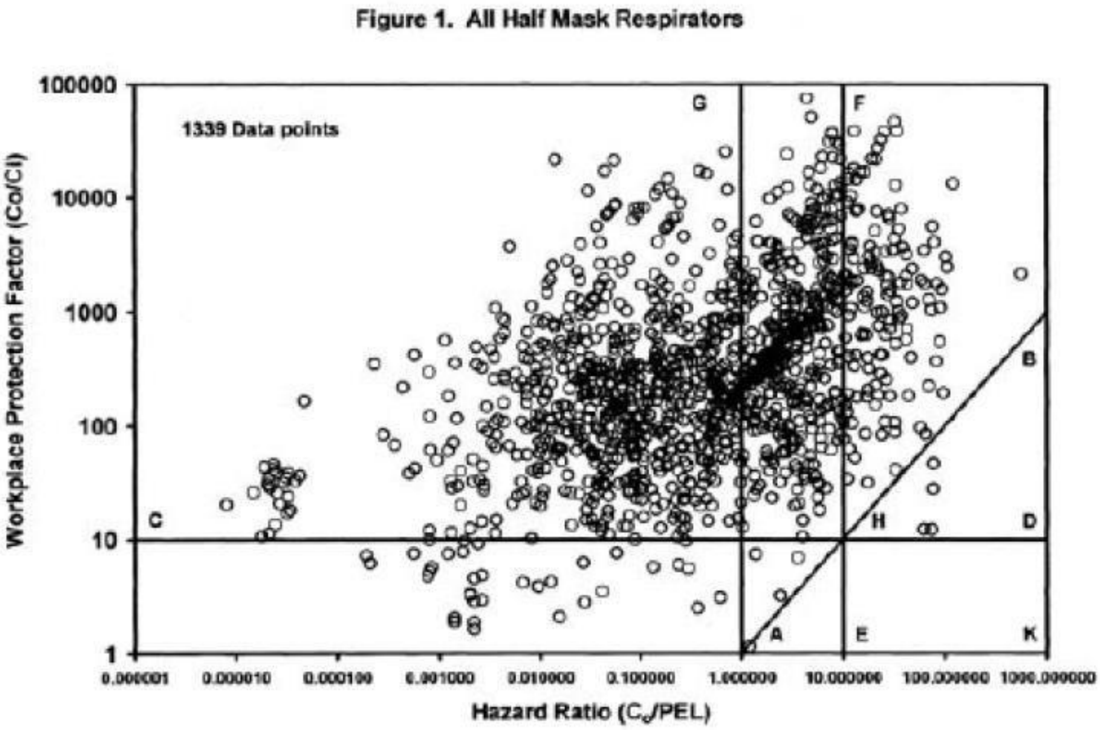


Figure 6 Plot of the relation between workplace protection factor and hazard ratio in the environment

Table 7 Assigned WPF by type for filter-type half- face piece respiratory protective equipment specified by OSHA

	Quarter-face piece	Half face piece	Full face piece	Helmet /Hood-type mask	Loose-fitting mask
Filter-type	5	10	50	……	……
Powered filter-type	……	50	1,000	25/1,000	25

Note 1) The assigned WPFs listed in this table are those that can be achieved by employers who provided their employees with legally required training for wearing dust masks and promoted them for planned use.

Note 2) Quarter-face piece is a small type of half-face piece dust mask that covers the mouth and nose, but does not cover the chin.

Note 3) Half face piece masks cover the mouth, nose, and chin and include disposable and replaceable types.

Note 4) The WPF of the helmet/hood type of powered air purifying respirator can be regarded as 1,000 only when its manufacturer has proved so with test results of leak rates.

OSHA's standard states that the WPFs in Table 7 can be achieved by providing workers with a dust mask best suited to the individual worker and training them in the wearing method specified by OSHA, and making them use dust masks in accordance with an established use plan.

8) Protection factor of dust masks in the combinations of face piece and filter

OSHA's WPFs in Table 7 do not take the particle penetration into the filter into account, and are only based on leaks from the gap between the face piece and face.

The following formula can provide practical protection factors that can be expected when a dust mask is used with a filter of dust collection efficiency with over 95% or 99.9% on the face piece.

- Protection factor that corresponds to the leak rate from gaps between the face piece and face: PF_1
- Protection factor that corresponds to the leak rate from the filter (assuming that the collection efficiency is E %)

  $PF_2 = 1/(1-E/100)$
- Total protection factor

$$PF_{TOTAL}=\frac{1}{(1/PF_1)+(1/PF_2)}$$

Table 8 shows the calculated results of comprehensive PF_{Total} values, assuming that a dust collection efficiency of 95% (PF_2 = 20) or 99.9% (PF_2 = 1,000) is used in combination with a choice of full-face piece (PF_1 = 50) and half-face piece ((PF_1 = 10)).

Table 8 indicates that the total protection factor PF_{Total} can be regarded as being approximately equivalent to 10 when a half-face piece is used with attached RS3 or RL3 with a dust collection efficiency of over 99.9% as a filter. The protection factor of 10 of half-face piece dust masks can be expected due to the fact that filters of actual products have higher dust collection efficiencies than the reference value of the standard, and if properly fitted dust masks improve the protection factor to better than the assigned value. To achieve that, it is necessary to provide hands-on training for workers who will need to wear dust masks when working.

Table 8 Calculated protection factors of full or half face piece dust masks

	Filter with a dust collection efficiency of 95% (PF_2 = 20)	Filter with a dust collection efficiency of 99.9% (PF_2 = 1,000)
Full face piece (PF_1 = 50)	PF_{Total} = 14.3	PF_{Total} = 47.6
Half face piece (PF_1 = 10)	PF_{Total} = 6.7	PF_{Total} = 9.9

9) Effectiveness of general use masks

Many decontamination workers are said currently to use masks that are used against flu. These general use masks do not provide good facial fit, and performance of some filters is not based on any standards or guaranteed. Although these masks can help protect from being splashed by body fluids when flu patients sneeze and cough, almost no effect can be expected in terms of protection against airborne dust. In 2009, the National Consumer Affairs Center of Japan released the results on leak rates of general use masks, which were determined by letting groups of 10 subjects wear 15 different kinds of commercially available general use masks for flu protection (with an emphasis on "virus protection") in a chamber where sodium chloride particles were supplied. The Center showed that the leak rates of the large masks – the so called pleated and three-dimensional types - ranged from 50% to 100%, implying that no effect could be expected to protect against inhaling particles in air.

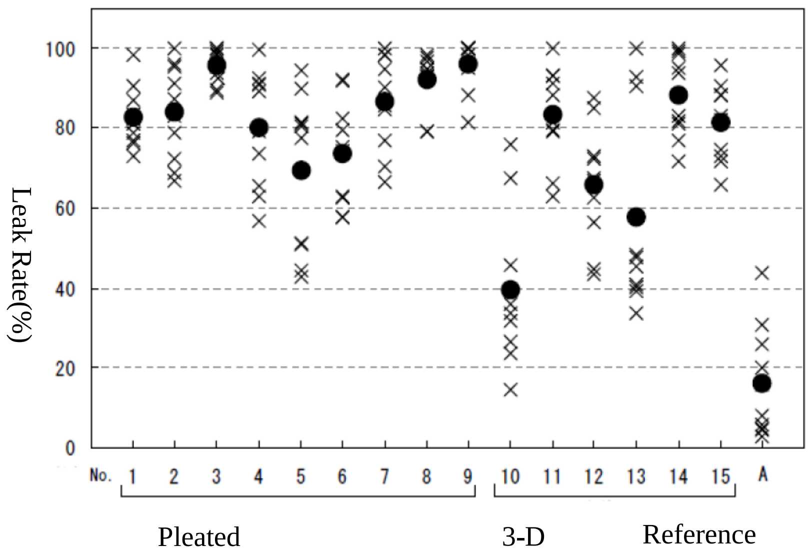


Figure 7 Test results on leak rates of 15 different general use masks and one type of N95 surgical mask

(Released by National Consumer Affairs Center of Japan, on 18 November 2009)

10) Guidelines for respiratory protection during decontamination works (Proposal by Matsumura)

Decontamination often requires outdoor works such as in fields and mountains, and areas with debris. Use of respiratory protective equipment should be avoided in such places because working with heavy equipment could pose another risk. Thus, it is important to select a type of dust mask after making sure of the necessity level.

It should be considered that full face piece dust masks have a smaller vision view and wearers cannot move their heads freely. Furthermore, proper fitting cannot be expected if a worker needs to wear glasses. This implies that there may be many cases that the half face piece replaceable dust masks or disposable dust masks are appropriate. The category of the cartridge mainly includes filters whose dust collection efficiencies were proved as over 95%. If work is required at a highly contaminated place, the use of powered half-face piece air purifying respirator should be considered, in addition to use of full-face piece dust masks.

So-called general use(surgical masks) are not effective and should not be used for respiratory protection. If the information on the level of radioactive contamination at the workplace is available beforehand, workers can select a proper category of the filters based on the level. Dust mask fit training should be provided to workers before they begin their work in order to ensure that they can obtain respiratory protection by wearing the dust masks.