# Report on the Government-requested Investigation on Respiratory Protective Equipment Fitting at the TEPCO Fukushima Daiichi Nuclear Plant Stabilization Center (J-Village)

**October 2011**

**National Institute of Occupational Safety and Health, Japan**

**Overview of the investigation**

An investigation was conducted on respiratory protective equipment used by workers engaged in the restoration work at the TEPCO Fukushima Daiichi Nuclear Power Plant with respect to how the equipment is selected and how it fits onto the faces of the workers to analyze the possibility of internal exposure for workers. The investigation was carried out at the Japan Football Association's National Training Center (J-Village) on 26 September 2011 by two experts each from the National Institute of Occupational Safety and Health, Japan and the Technology Institution of Industrial Safety.

Seven TEPCO employees, six radiation control engineers who have been engaged in the restoration work at the TEPCO Fukushima Daiichi Nuclear Power Plant and one engineer from the Head Office were subjects of the investigation. Under the assumption that respiratory protective equipment had been regularly used, air leak rates of the equipment were measured and the results were evaluated to identify causes of the leak. Then the air leak rates were re-measured and re-evaluated after taking measures against the identified leak causes to determine the effectiveness of the measures. Devices used for this investigation were a Mask Fitting Tester (model MT-03 manufactured by Shibata Science Technology Co.) and a real time counter (Portacount® Model 8020, manufactured by TSI).

In the fitting test, the leak rates of the six employees engaged in radiation control work were 1.1-56% (average 17.4 %), among which four employees had rates over 10%. Judging from observations on how individual subjects wore the full-face masks, it was found that their eyeglasses, work hats and frontal hair or mismatches in sizes and contours between their facial structures and their full-face masks caused a gap between their faces and the masks, resulting in the large leak rate. Therefore, countermeasures were implemented for the causes of the leak, and the fittings were tested again. To decrease the leakage due to eyeglasses, sealing pieces were used, which cut the leak rate to less than 5%. Not wearing cotton work hats and not tucking the frontal hair between the mask and face decreased the leak rate slightly, but the selection of masks more suitable in size for each subject resulted in a significant decrease in the leak rate. A significant decrease was also observed after tape sealing the space between the mask and protective clothing; however, this was tested only for one subject and further tests are required to judge its effectiveness. Lastly, leakage from the masks with an electric fan was measured. The leak rate was less than 5 % for every mask type with the electric fan. A high protection effect could be expected for the masks with the electric fan; however, there are several points to be reviewed for the practical use such as their heavy weight and restrictions on the visual range for workers.

Based on the above results, the following points were proposed as measures to be taken by TEPCO in order to prevent leakage from the full-face masks worn by workers engaged in the restoration works.

(1) Implementing measures for workers wearing eyeglasses

(2) Selecting masks with a good fit for each worker based on facial size and face contours (shape)

(3) Encouraging workers themselves to take measures to prevent air leakage when wearing masks

(4) Continuing the evaluation of masks that include an electric fan

(5) Improving the education for new workers on how to wear respiratory protective equipment

Hereafter, as the air leakage from the full-face masks used by workers engaged in the restoration work may result in internal exposure for workers, immediate implementation of measures by TEPCO is critical.

## I. Introduction

An investigation was conducted on the respiratory protective equipment (full-face masks, etc.)used by workers engaged in the restoration work at the TEPCO Fukushima Daiichi Nuclear Power Plant with respect to how the equipment is selected and how it is fitted onto the faces of the workers to analyze the possibility of internal exposure for workers. After measuring leak rates for the selected workers, they were given technical advice, including appropriate directions on the selection, fitting and daily maintenance of the respiratory protective equipment to ensure better usage.

## II. Methods

The review was conducted by the National Institute of Occupational Safety and Health, Japan (hereafter referred to as "Institute"), together with the Technology Institution of Industrial Safety (TIIS), MHLW and TEPCO on three items, conditions of the restoration work, type of respiratory protective equipment used now and their conditions of use, followed by on-site fitting tests on some workers engaged in the restoration work in various areas. Two experts each from the Institute and TIIS were present at the fitting tests. However, more experts from both organizations participated in the discussions preceding these tests in order to determine test details and methods and how to procure test devices and materials.

The test date was Monday, 26 September 2011, from 10 am to 3:30 pm (including some on-site preparation). The venue was a room at the Japan Foot Ball Association's National Training Center (J-Village, Photo 1) (located at 8 Utsukushimori, Yamadaoka, Naraha Town, Futaba county, Fukushima; currently used as the TEPCO Fukushima Daiichi Stabilization Center).

The subjects for the fitting test at the Center were six TEPCO employees belonging to the radiation control group engaged in the restoration work. Also, for reference, one employee from the TEPCO Head Office participated in the test.

First the seven workers wore respiratory protective equipment that is regularly used. The air leak rate[1)] for each subject was measured with the Mask Fitting Tester (model MT-03, manufactured by Shibata Scientific Technology Co.).

Next, a demonstration[2)] on how to wear a respirator was provided to the subjects using a real time counter (Portacount® Model 8020 manufactured by TSI)to help their understanding of the causes and the degrees of leakage and to provide instructions on methods for preventing the leak (Photo 2).

In particular, instructions on measures to prevent leakage were provided that included: utilizing sealing pieces for workers wearing spectacles; optimally selecting the masks according to the workers facial sizes and contours (shape); and proper steps for wearing the masks and checking their fit to the face.

After the demonstration, the subjects put on their respirators and the leak rate was measured using the Mask Fitting Tester to verify the effectiveness of the measures. Factors that could affect the leak rate (i.e. wearing eyeglasses, wearing work hats, tucking in of frontal hair, suitability for face sizes and contours, and effect of sealing the mask to the protective clothing) were also evaluated.

Lastly, the leak rates for masks with an electric fan, manufactured by three different companies and being considered for adoption by TEPCO, were measured and evaluated.

[1)] Leak rate is defined as the proportion of the in-mask dust concentration to the indoor dust concentration. It is measured by counting the number of particles with diameters of 0.3 μm or larger (the sizes of particles which are not filtered through the mask) in a certain volume of air using a light-scattering particle counter. If particles of this size are found inside the mask, it is considered that they entered there through gaps. Therefore, measurement focusing on particles with diameters of 0.3 μm or larger will allow the evaluation of mask leakage. Specifically, the number of dust particles in the indoor air (C1) is counted, and then the number of particles inside the masks when it was worn (C2) is counted. The contact level is quantified by calculating the ratio of the two (the leak rate: C2/C1).

[2)] Effectiveness of the demonstration using the real time counter: The contact level of a full-face mask easily changes in association with movements and actions, like speaking, of the workers who wear the mask. Workers get a better understanding of the causes of the leak by actually watching how the leak rate changes according to their body movements during the demonstration using the real time counter.


Photo 1 Room of J-Village where this investigation was conducted.

Photo 2 Demonstration by an expert from the Institute. He first explained the intention of the investigation, actually conducted a fitting test and showed the real time leak rate change that occurred according to movement of the body, etc. on the screen in back of him. The device circled in red is the Mask Fitter Tester – MT-03.

## III. Results

### 1. Leak rates before providing instructions

The leak rates for the seven subjects (A-G) before the instructions were provided are shown in Figure 1. Among them, one had a leak rate exceeding 50% and four had rates exceeding 10%. Subject F was from the TEPCO Head Office. Relevant information such as types of masks used and whether workers wore eyeglasses is shown in Table 1.

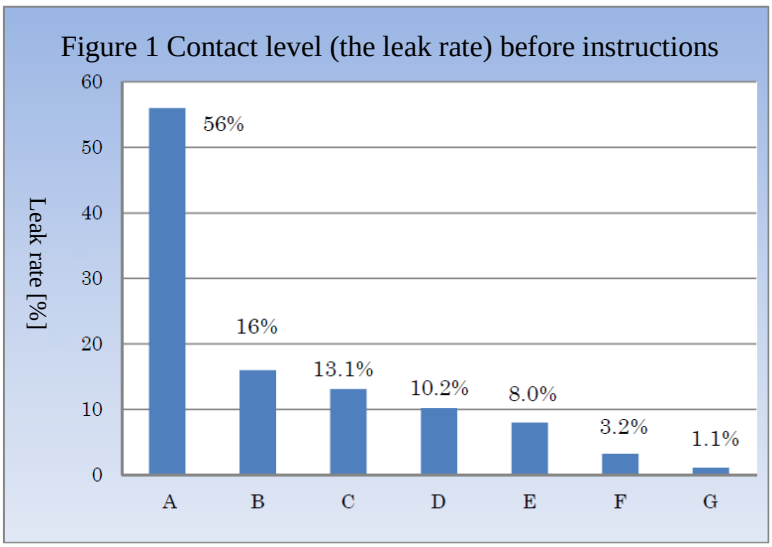


Table 1 Leak rates and masks used by seven subjects before providing instructions

| Subject | Leak rate | Mask types used | Remarks |
|---|---|---|---|
| A | 56% | Full face from Company X | Wore thick framed eyeglasses. Felt air leaking from the side of the mask during the time when wearing it. |
| B | 16% | Full face from Company Y | Wore eyeglasses. |
| C | 13.1% | Full face from Company Z | No eyeglasses. Had an impression that the mask was too large for his face size. Felt air leaking when he moved his mouth. |
| D | 10.2% | Full face from Company X | Wore eyeglasses. |
| E | 8.0% | Full face from Company X | Had an impression that the mask was slightly too small for his face size. |
| F | 3.2% | Full face from Company X | From TEPCO Head Office (reference subject) |
| G | 1.1% | Full face from Company X | No eyeglasses. Good contact level between the mask and the face. The leak rate was the lowest even before making improvements. |

## 2. Influence of wearing eyeglasses and decrease of leak rate by using sealing pieces

The leak rates changed when using the purpose-made sealing pieces (a rubber packing attached to the frame of the eyeglasses; Photo 3). This filled gaps between the mask and the temple for the five subjects wearing eyeglasses. The results are shown in Figure 2 and Table 2. All five workers demonstrated the effectiveness of the sealing pieces (the decrease of leak rates), and the rate decreased to less than 5 % (Photo 4).

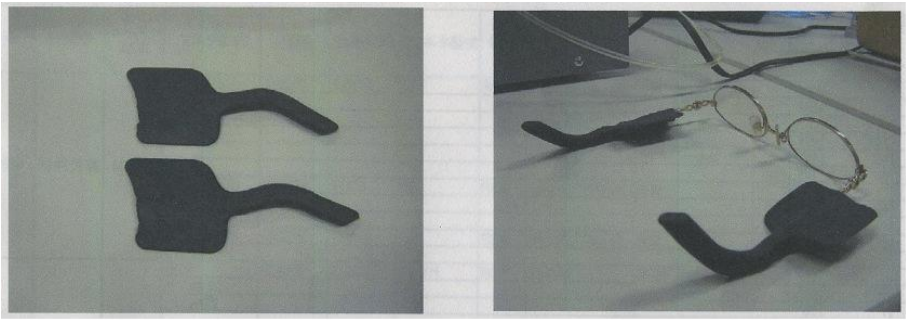

Photo 3 Sealing pieces for eyeglasses (Photos supplied by the Technology Institution of Industrial Safety)

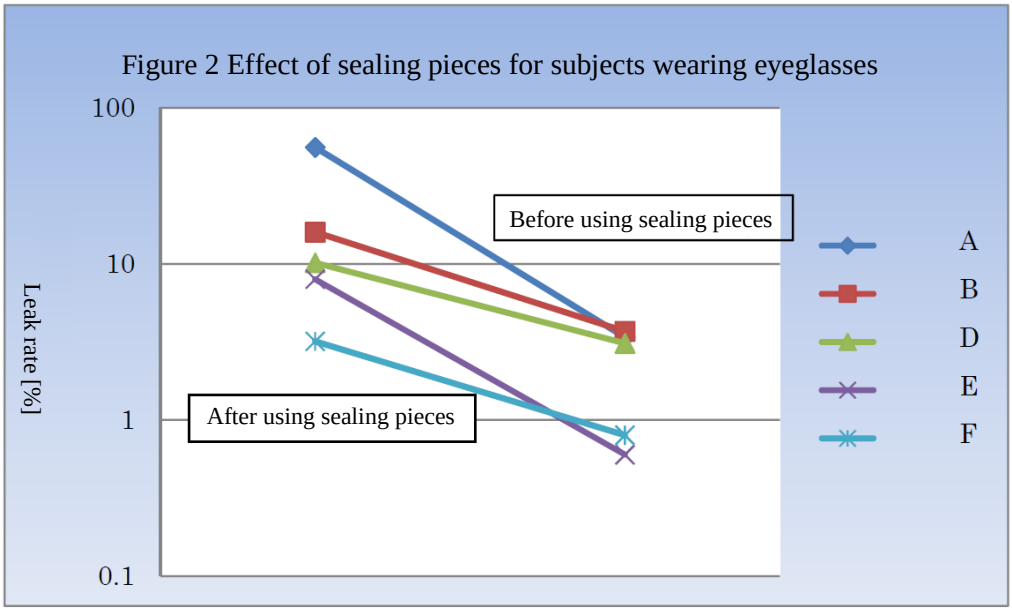


Table 2 Decrease of the leak rates after five subjects used the sealing pieces

| Subjects | Leak rates (before use) | Leak rates (after use) |
|---|---|---|
| A | 56.0 % | 3.4% |
| B | 16.0% | 3.7% |
| D | 10.2% | 3.1% |
| E | 8.0% | 0.6% |
| F | 3.2% | 0.8% |

Photo 4 Re-testing the fitting after a subject attached sealing pieces to his eyeglasses.

### 3. Effect from wearing work hat

Two subjects were selected to investigate whether the leak rate changed with or without wearing a cotton work hat. For the case in which a hat was worn, the effect of tucking in frontal hair between the face and the mask was evaluated. The results are shown in Figure 3 and Table 3.

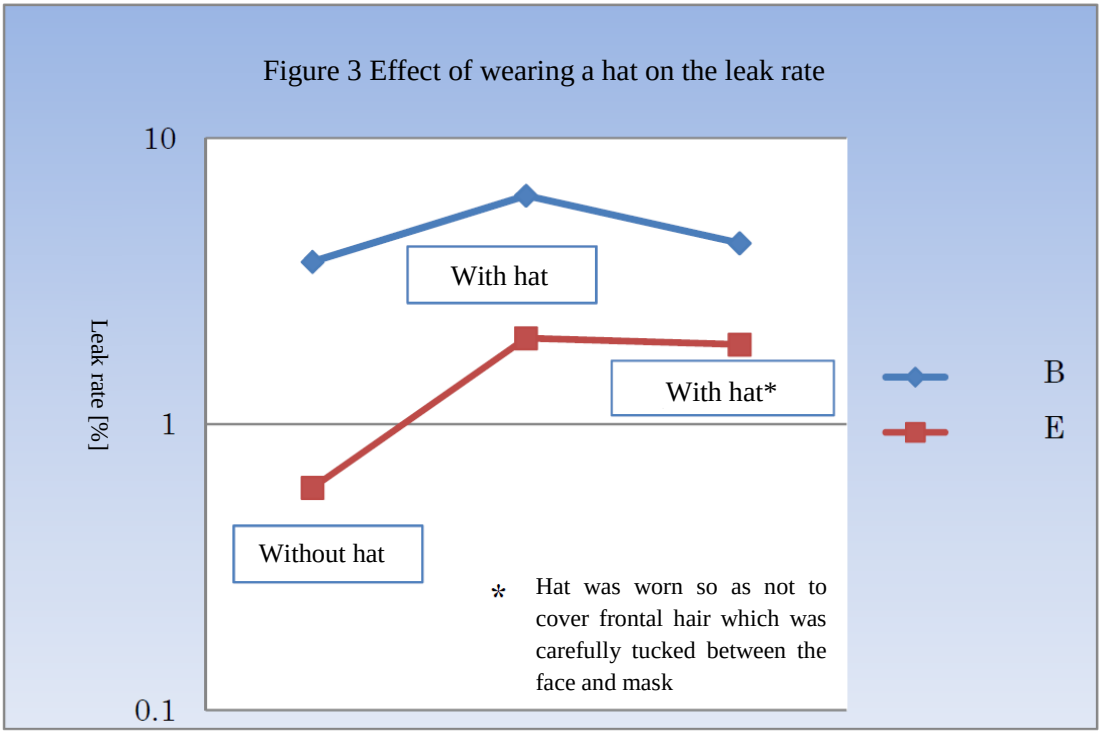


Figure 3 Effect of wearing a hat on the leak rate

Table 3 Leak rates with or without hats

| Subjects | Without a hat | With a hat | Carefully with a hat* | Remarks |
|---|---|---|---|---|
| B | 3.7% | 6.3% | 4.3% | Wearing eyeglasses |
| E | 0.6% | 2.0% | 1.9% | Wearing eyeglasses |

* The rate was re-measured after the hat was worn so as not to cover frontal hair which was carefully tucked between the face and mask.

**4. Effect of frontal hair**

One subject was selected to see the change in the leak rate when his frontal hair was tucked between his mask and face. In this case the subject removed his eyeglasses and hat. The result is shown in Figure 4 and Table 4.

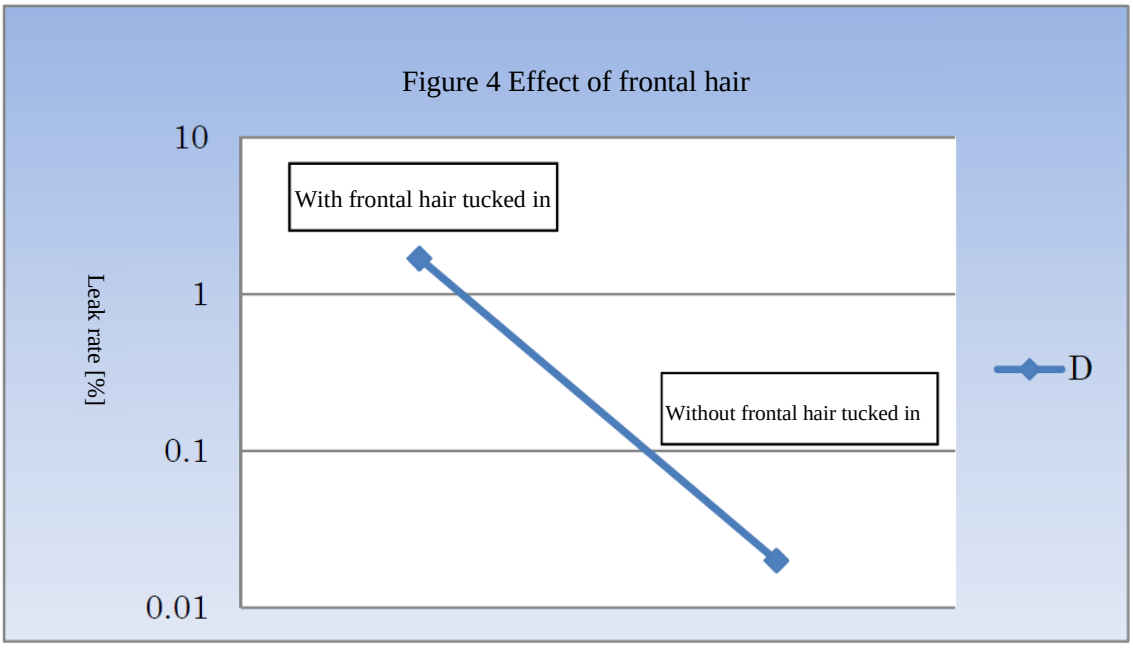


Table 4 Leak rate with or without frontal hair tucked in

| Subject | Leak rate with hair tucked in | Leak rate without hair tucked in | Remarks |
|---|---|---|---|
| D | 1.7 % | 0.02 % | Work hat and eyeglasses not worn. Mask with an electric fan worn. |

**5. Decrease of the leak rate by selecting a well-fitting mask**

For one subject who felt uncomfortable with respect to contact of the mask on his face, the change in leak rate was determined by having him wear a mask manufactured by a different company. The changes of the leak rates are shown in Figure 5 and Table 5. In the figure, manufacturer Z is for his previous mask, and manufacturer X is for the new mask.

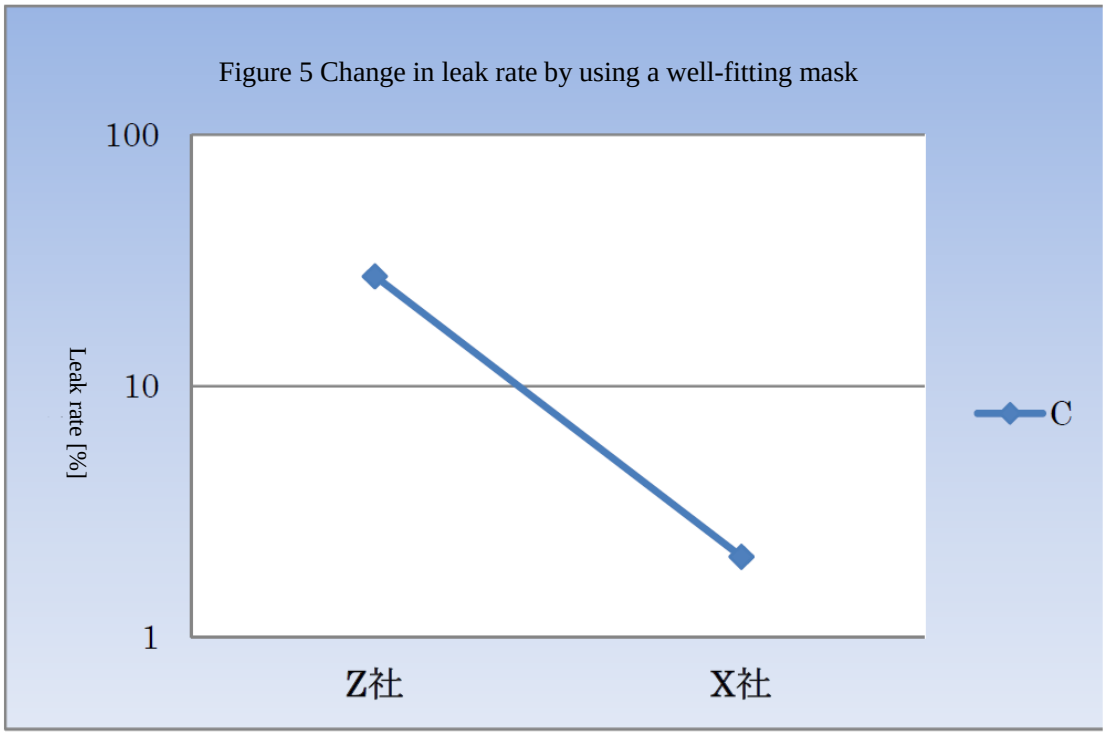


Figure 5 Change in leak rate by using a well-fitting mask

Table 5 Decrease in leak rate by using a better fitting a mask

| Subject | Leak rate: poor fit | Leak rate: good fit | Remarks |
|---|---|---|---|
| C | 27.4% | 2.1% | The leak rate change depended on the mask fit to the subject's face shape. This does not mean lesser performance of the previously used mask. |

## 6. Effect of tape sealing to protective clothing

One subject was selected to investigate the effect on the leak rate when using sticky tape to seal the mask to his protective clothing (Tyvek® SoftWear). The result is shown in Figure 6 and Table 6.

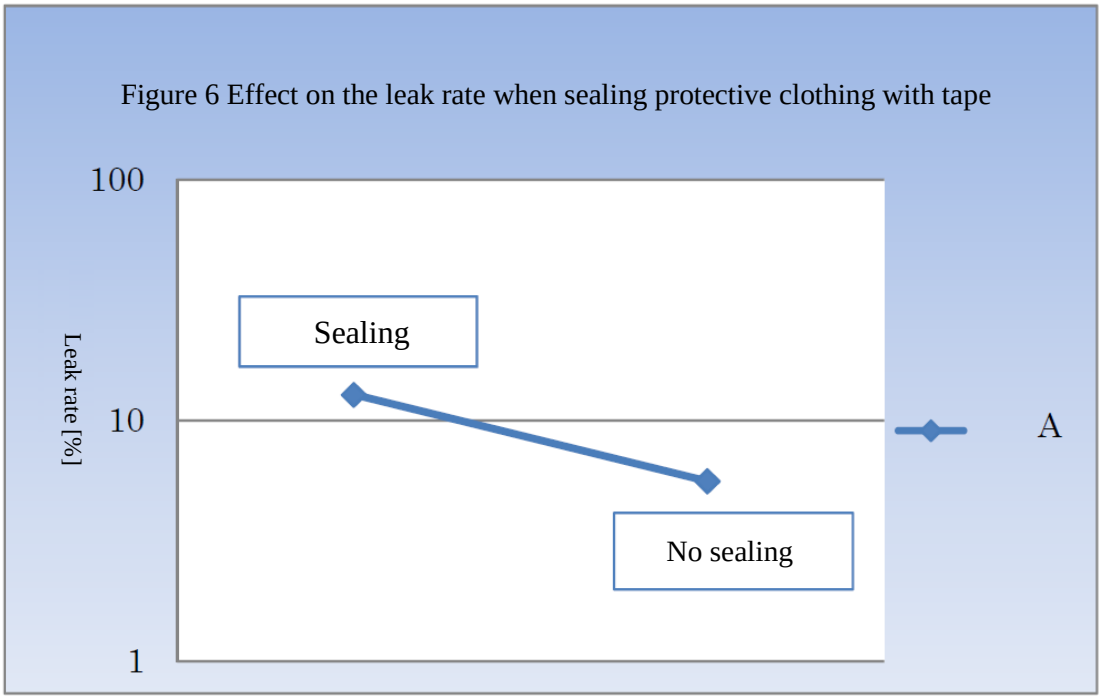


Table 6 Decrease in leak rate by sealing protective clothing with tape

| Subject | No Sealing | Sealing | Remarks |
|---|---|---|---|
| A | 12.8% | 5.6% | Protective clothing (Tyvek® SoftWear) worn. Eyeglasses without sealing pieces worn. Full-face mask (Company X) worn. |

## 7. Verification of the effectiveness of masks with an electric fan

Three subjects were selected to investigate change in the leak rate when they change their full-face mask to a mask with an electric fan. The result is shown in Figure 7 and Table 7.

Opinions from the subjects were sought regarding the weight of the mask and their visual range when they wore it. Subjects indicated that certain types of masks needed reduction of their weight and improvement of their visual range.

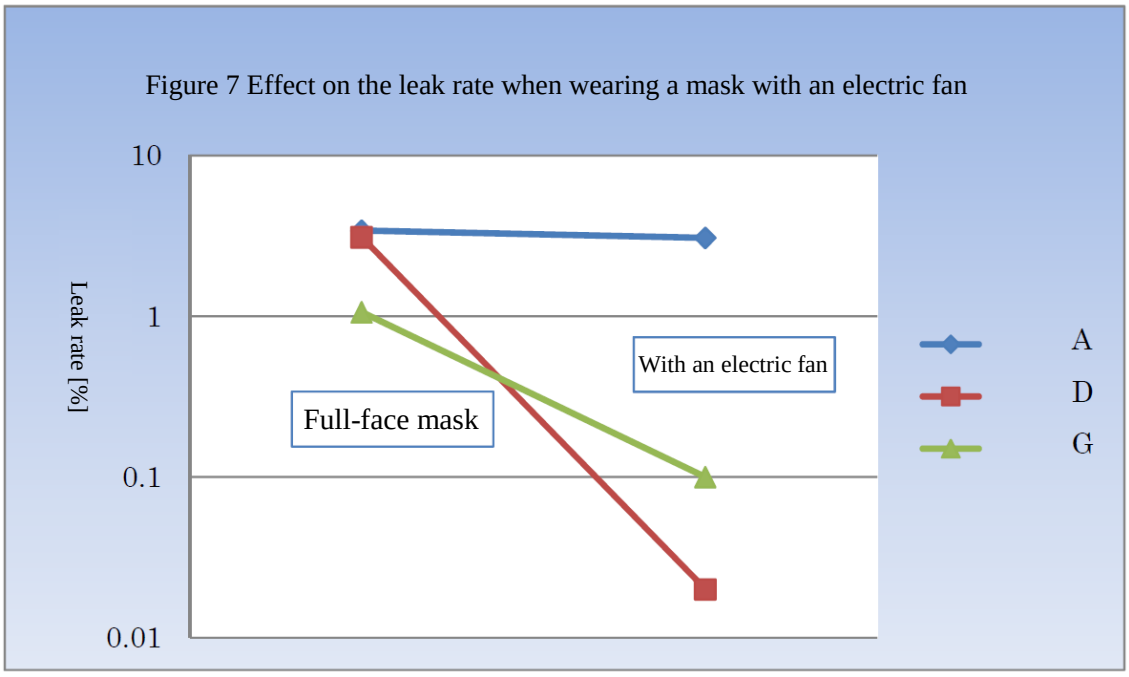


Table 7 Masks with an electric fan and the leak rates

| Subjects | Full-face mask | Mask with an electric fan | Remarks |
|---|---|---|---|
| A | 3.4% | 3.1% | Mask with an electric fan worn. Eyeglasses worn. |
| D | 3.1% | 0.02% | Mask with an electric fan worn. No eyeglasses. |
| G | 1.1% | 0.1% | No eyeglasses; subject did not regularly them. |

- List of the measurement data: All measured data on leak rates for the seven subjects are summarized and shown in Table 8 (Annex 1).

## IV. Summary

The following conclusions were obtained by measuring the leak rates in various situations.

i) Situation before improvements were made: The leak rate could exceed 50 % when the full-face mask was worn improperly (especially when the mask did not fit the face size or shape). After excluding the result for the employee from the TEPCO Head Office, The average leak rate of the six subjects who were radiation control engineers was 17.4% before the instructions for improvement were provided.

ii) Effect of eyeglasses and the change of the leak rate by using sealing pieces: Wearing eyeglasses tended to increase the leak rate when wearing a full-face mask. This trend depended on the shapes and sizes of the eyeglasses. However, when purpose-made sealing pieces were attached to the eyeglass frame, the leak rate decreased. Also, when the mask was well fitted to the face, it was possible to keep the rate at 5 % or less even wearing eyeglasses without sealing pieces.

v) Effects of work hats and frontal hair: Wearing a working hat tended to increase the leak rate. Frontal hair or the front rim of a hat also caused an increase in the leak rate when they were tucked between the mask and the face.

vii) Decrease of the leak rate by selecting a better fitting mask: Masks unsuitable to the facial shapes and sizes caused significant air leakage. The leak rate could be significantly decreased by using a mask that fit the face well.

ix) Effect of tape sealing to protective clothing: Tape sealing the mask to the protective clothing contributed to lowering the leak rate. However, only one subject was measured for this effect, and further tests are required before reaching the final conclusion.

viii) Effect of the mask with an electric fan: If worn and fitted properly, this type of mask could be expected to give a high protective effect (= low leak rate), regardless of whether or not the workers wear eyeglasses or a work hat. However, some types of electric fan masks and hood type electric fan masks require improvement including reducing their weight and widening the visual range. The use of this type of mask should be decided considering the purpose of the work.

## V. Recommendations given to TEPCO

Based on the results described above, the working group recommends five countermeasures to prevent air leakage of the full-face masks used during the restoration work.

(1) Implementing changes for workers wearing of eyeglasses
(2) Selecting well-fitting masks
(3) Encouraging measures be taken to prevent leakage when wearing a mask
(4) Considering introduction of electric fan masks
(5) Enhancing education of new workers on respiratory protective equipment.

For recommendation (1), it is a serious issue that the leak rates for the subjects wearing eyeglasses exceeded 10 % on average, as seen from the test results. This could lead to internal exposure to workers during the restoration work from the nuclear accident. It is necessary to take effective countermeasures immediately. The leak rate decreased to less than 5% by attaching the sealing pieces developed by the Technology Institution of Industrial Safety, indicating their effectiveness. Use of the sealing pieces on the eyeglass frame is an effective measure for those who wear eyeglasses to lower the leak rate.

For recommendation (2), the selection of well-fitting masks will prevent leakage caused by a mismatch between the facial size and shape (contours) and the mask size. In this fitting test, it was confirmed that the leak rate decreased by changing one full-face mask to a better fitting one. It is recommended that TEPCO prepare masks in various sizes so that workers are able to choose the one which well fits the shapes and sizes of their faces. At J-Village, large numbers of masks are provided. However, their sizes are not indicated. By grouping masks by size, workers can be expected to easily select one which fits them well.

For recommendation (3), workers are generally encouraged to take measures in order to prevent air leakage when wearing a mask, but workers should be reminded of the importance of these measures. From the fitting test, it was confirmed that the leak rate decreased by a few percent when preventing cotton work hats or frontal hair from being tucked between the mask and the face. Therefore, it is important to encourage workers take measures: to avoid leakage including not tucking in the cotton work hats (especially the brim), frontal hair, beards, and sideburns between the mask and face; to adjust mask strings and tighten the fit; and to perform a leakage test using a tester device.

For recommendation (4), all subjects who used the electric fan masks (three different manufacturers)

had leak rates of less than 5 %. The shapes and weights of these masks vary depending on manufacturers. The subjects gave various comments on these masks including that “work is interrupted because the mask or the battery is very heavy” and “work is disrupted by the position of the absorption canister”. It is necessary to review what type of work is being done and then select the type of mask based on the work. Also consideration is required about the environment that each type of mask is used in, and whether or not the breakthrough time will be shortened.

For recommendation (5), after being given an explanation on the current education that new workers receive, areas for improvement were identified (e.g., inappropriate photos were included in the educational materials). It was considered that TEPCO needs to improve education about the respiratory protective equipment for new workers at a work area. As seen from the present test results, recognizing the cause of the leak proved to be effective in decreasing the leak rate. Therefore, the education should include practical training using the Mask Fitting Tester. Also, the lecture on respiratory protective equipment should include not only the structure and characteristics of masks, but also present the causes of mask leakage (wearing eyeglasses, using a poor-fitting mask, tucking cotton hats and frontal hair between the face and a mask, failing to adjust attachment strings, and failing to check for leaks) and countermeasures for these causes.

(Annex1)
Table 8　Measurement results of leak rates

| Subjects | Face type | Mask used | Eyeglasses | Sealing pieces | Hat | Tape sealing to protective clothing | Leak rate (%) | Internal exposure* | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| A | Wide | Full-face X | ○ | – | ○ | – | 55.98 | 117.33 mSv | Wore relatively thick framed eyeglasses. Felt air leaking from the side of the mask |
| | | | ○ | ○ | – | – | 6.55 | | |
| | | | ○ | ○ | – | – | 3.41 | | Remeasured after tightening the mask. |
| | | Electric fan type Y | ○ | – | – | – | 3.08 | | |
| | | Full-face X | ○ | – | ○ | ○ | 12.77 | | Wore the mask with his forehead exposed. No tape sealing of protective clothing |
| | | | ○ | – | ○ | ○ | 5.6 | | Wore the mask with his forehead exposed. Used tape sealing of protective clothing. |
| B | Average | Full-face Y | ○ | – | ○ | – | 15.95 | 4.55 mSv | Measured while significantly moving his body. |
| | | | ○ | ○ | – | – | 3.68 | | |
| | | | ○ | ○ | ○ | – | 6.32 | | Measured when tucking his frontal hair between the mask and his face. |
| | | | ○ | ○ | ○ | – | 4.26 | | Wore the mask with his forehead exposed (frontal hair not tucked between the mask and face) |
| C | Narrow | Full-face Z | – | – | ○ | – | 13.06 | 40.16 mSv | Felt the mask was too wide compared to his face width. |
| | | Full-face X | – | – | – | – | 27.35 | | Felt air leakage when he moved his mouth. |
| | | | – | – | – | – | 2.08 | | Feeling of air leaking disappeared after changing the mask. |
| D | Average | Full-face X | ○ | – | ○ | – | 10.16 | 0.03 mSv | |
| | | | ○ | ○ | – | – | 3.11 | | |
| | | Electric fan type S | – | – | – | – | 1.4 | | Measured with the mask loose. |
| | | | – | – | – | – | 0.49 | | Measured with the mask tight. |
| | | Electric fan type Y | – | – | – | – | 1.69 | | Tucked his frontal hair between the mask and his face. |
| | | | – | – | – | – | 0.02 | | Measured when not tucking his frontal hair between the mask and face. |
| | | | – | – | – | – | 5.51 | | Measured with the electric fan stopped. |
| | | Hood type Y | ○ | – | – | – | 0.06 | | Judged as difficult to wear for normal work due to its weight. |
| E | Average | Full-face X | ○ | – | ○ | – | 7.95 | 13.40 mSv | Felt the mask was slightly small compared to his face size. |
| | | | ○ | ○ | – | – | 0.6 | | |
| | | | ○ | ○ | ○ | – | 1.95 | | |
| | | | ○ | ○ | ○ | – | 1.87 | | Adjusted the hat and remeasured with his forehead exposed. |
| F (TEPCO Head Office) | Average | Full-face X | ○ | – | – | | 3.19 | | |
| | | | ○ | ○ | – | | 0.84 | | |
| G | Average | Full-face X | – | – | ○ | – | 1.06 | 0.00 mSv | |
| | | Electric type Y | – | – | – | – | 0.09 | | |

(* It should be noted that, with regards to internal exposure, there is no direct correlation between the result of this test and the internal exposure levels since the test conditions differ from those in the working environment at the power plant.)