Performance Evaluation and Usage Guidelines for Iodine Adsorption Cartridges for Gas Respirators under Similar Environmental Conditions to those of the Accident at the Fukushima Daiichi Nuclear Power Station

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A quantitative assessment was carried out to evaluate the performance of iodine adsorption cartridges attached to gas and powered air-purifying respirators, under radioactive iodine concentrations, temperatures, and humidity conditions simulating the post-earthquake conditions at Fukushima Daiichi Nuclear Power Station. The test was conducted at the temperature of 30°C, the radioactive iodine concentration (radioactive methyl iodine concentration) and humidity conditions were varied, radioactive methyl iodine was directly aerated into the adsorption cartridges for a maximum of 10 hours, and the radioactive iodine removal performance of the adsorption cartridges was assessed. Some adsorption cartridges demonstrated a radioactive iodine removal performance of 10 hours or more, while the performance of others decreased with higher relative humidity. Based on the results of these performance assessments, respirator-wearing guidelines at Fukushima Daiichi Nuclear Power Station were established.

KEY WORDS: gas respirator, radioactive iodine, radioactive methyl iodine, high relative humidity, Fukushima Daiichi Nuclear Power Station accident.

I INTRODUCTION

Due to the tsunami accompanying the Great East Japan Earthquake on March 11, 2011, the reactors at the Fukushima Daiichi Nuclear Power Station (hereinafter referred to as 1F) lost their cooling function, and about $5.0 \times 10^{17}$ Bq of radioactive iodine (I-131) was released into the atmosphere. In the post-accident situation at 1F, the radioactive iodine concentration in the air was high (I-131 measurement value on May 6, two months after the accident, was $1.2 \times 10^{-2}$ Bq/cm$^3$) and workers were forced to carry out restoration work in a severe environment.

Initially, the workers wore gas respirators to prevent the inhalation of radioactive iodine. For restoration work in the reactor and turbine buildings during the initial stages after the accident, since the concentration of radioactive iodine was high, self-contained respirators were required. However, their number was limited and the period for which such respirators can be used (service time) is short.

The I-131 half-life of 8 days is not very long, and the concentration gradually reduced; however, it was necessary to determine the applicability of gas respirators equipped with iodine adsorption cartridges, which could be supplied in large quantities for the restoration work.

Previous performance tests of the iodine adsorption cartridges had been conducted by the manufacturers in Japan, in comparatively low temperature and humidity conditions (JIS T 81522)). These test conditions differed from the working environment at 1F after the accident. Hence, to help prevent the accidental intake of radioactive iodine, a performance assessment was conducted in test conditions that closely simulated the situation at the site. The relationship among the radioactive iodine concentration, humidity, and service time was determined, and was incorporated into the respirator-wearing guidelines.

II RADIOACTIVE IODINE CONCENTRATION AT THE 1F SITE AFTER THE ACCIDENT

After the accident, portable dust samplers were installed in the Unit 1 and Unit 2 buildings, and airborne radioactive materials were collected by means of dust filters and charcoal filters. These air samples were measured using germanium semiconductor detectors for measurement times of 300–1,000 seconds, and the radioactive iodine concentration was...
Figure 1 and Fig. 2 show the time-sequential tendency in the total radioactive iodine concentration of particulates and gasses over time. These results show that two or three months after the accident, the radioactive iodine concentration in the buildings sometimes exceeded $1.0\times 10^{-2}$ Bq/cm$^3$.

The upper iodine concentration limit for using iodine adsorption cartridges in 1F was $1.0\times 10^{-3}$ Bq/cm$^3$, and the test conditions for these cartridges were at 20°C and 50% RH humidity, but their use in high temperature and high humidity environments, as in the buildings during the accident, had not been assessed beforehand. Therefore, they could not be used in every building and emergency work had to be performed with self-contained respirators.

### III TEST METHOD

1. **Test specimens (samples)**
   
   Iodine adsorption cartridges (samples A, B, and C) attached to gas respirators, and iodine adsorption cartridges (samples D and E) attached to powered air-purifying respirators (hereinafter referred to as PAPR), provided by three respirator manufacturers, were tested.

   Table 1 describes the linear velocity (LV) and space velocity (SV) calculated from the adsorbent filling volume, filling form, ratio of flow rate and cross-sectional area, and ratio of flow rate and volume of samples A–E.

   **2. Test conditions**
   
   (1) **Pre-processing**: Oscillating processing (20 mm drop, about 100 times/min, for 20 min)
   
   Conforms with BS EN 14387 (2004) Standards

   (2) **Temperature & humidity conditions**: 30°C, relative humidity 70–95%
   

   (3) **Form of aeration gas (iodine gas)**: radioactive methyl iodine
   
   The reason for using methyl iodine as the aeration gaseous form was that most of the volatile constituent of iodine in the atmosphere was present as radioactive methyl iodine. Furthermore, compared to the atomic or molecular iodine and hydrogen iodide forms, the removal of radioactive methyl iodine is more difficult. In conditions of higher temperature and relative humidity, it is more difficult for the radioactive methyl iodine to be adsorbed by the triethylenediamine (TEDA)-impregnated activated carbon. Therefore, in this test, the performance of the cartridges was assessed with the safer form of radioactive methyl iodine.

<table>
<thead>
<tr>
<th>Cartridge</th>
<th>Flow rate (L/min)</th>
<th>LV (cm/min)</th>
<th>SV (min$^{-1}$)</th>
<th>Adsorbent fill weight (g)</th>
<th>Thickness (mm)</th>
<th>Diameter (mm)</th>
<th>Cross-sectional area (cm$^2$)</th>
<th>Filling Volume (cm$^3$)</th>
<th>Filling density $^*$ (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>426</td>
<td>294</td>
<td>35</td>
<td>14.7</td>
<td>77</td>
<td>47</td>
<td>68</td>
<td>0.51</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>435</td>
<td>364</td>
<td>28</td>
<td>12.0</td>
<td>76.5</td>
<td>46</td>
<td>55</td>
<td>0.51</td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>345</td>
<td>217</td>
<td>54</td>
<td>15.9</td>
<td>$39 \times 76 \times 98$ (trapezoid)</td>
<td>58</td>
<td>92</td>
<td>0.59</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
<td>758</td>
<td>431</td>
<td>58</td>
<td>17.5</td>
<td>92</td>
<td>66</td>
<td>116</td>
<td>0.50</td>
</tr>
<tr>
<td>E</td>
<td>47</td>
<td>573</td>
<td>405</td>
<td>77</td>
<td>14.2</td>
<td>102</td>
<td>82</td>
<td>116</td>
<td>0.66</td>
</tr>
</tbody>
</table>

*$^*$ Filling density was calculated with adsorbent weight / filling volume. Therefore, it differs from the bulk density of adsorbent.
(4) Radioactive methyl iodine concentration conditions and sampling intervals at test specimen inlet:
- 1.0E-01 Bq/cm³ ... 1, 2, 4, 7, 10 hours
- 1.0E-02 Bq/cm³ ... 1, 2, 4, 7, 10 hours
- 1.0E-03 Bq/cm³ ... 2, 4, 7, 10 hours
- 1.0E-04 Bq/cm³ ... 4, 10 hours
The aeration concentration of radioactive methyl iodine was set up based on the conditions at 1F after the earthquake.

(5) Flow rate of the aeration gas:
- Iodine adsorption cartridge attached to gas respirators ... 20 L/min
- Iodine adsorption cartridge attached to PAPR ... 38–50 L/min

(6) Aeration time: Maximum 10 hours

Table 2 describes the test conditions for the iodine adsorption cartridge attached to a gas respirator. Table 3 describes those for the cartridge attached to a PAPR.

<table>
<thead>
<tr>
<th>Type of cartridge</th>
<th>Sample</th>
<th>Temperature (°C)</th>
<th>Flow rate (L/min)</th>
<th>Oscillating processing</th>
<th>Relative humidity (%RH)</th>
<th>testing time (h)</th>
<th>CH$_{131}$I Inflow concentration (Bq/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>30</td>
<td>20</td>
<td>20 mm fall, 100 times/min, 20 min.</td>
<td>95</td>
<td>10</td>
<td>1.00E-02</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>95</td>
<td>80</td>
<td>1.00E-01</td>
<td>1.00E-02</td>
<td>1.00E-03</td>
<td>1.00E-04</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>80</td>
<td>70</td>
<td>1.00E-02</td>
<td>1.00E-03</td>
<td>1.00E-04</td>
<td>1.00E-04</td>
</tr>
<tr>
<td></td>
<td>A (improved)</td>
<td>95</td>
<td>80</td>
<td>1.00E-01</td>
<td>1.00E-02</td>
<td>1.00E-03</td>
<td>1.00E-04</td>
</tr>
<tr>
<td></td>
<td>B (improved)</td>
<td>95</td>
<td>80</td>
<td>1.00E-01</td>
<td>1.00E-02</td>
<td>1.00E-03</td>
<td>1.00E-04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of cartridge</th>
<th>Sample</th>
<th>Temperature (°C)</th>
<th>Flow rate (L/min)</th>
<th>Oscillating processing</th>
<th>Relative humidity (%RH)</th>
<th>testing time (h)</th>
<th>CH$_{131}$I Inflow concentration (Bq/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>E</td>
<td>30</td>
<td>47</td>
<td>20 mm fall, 100 times/min, 20 min.</td>
<td>80</td>
<td>10</td>
<td>1.00E-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90</td>
<td>7</td>
<td>1.00E-02</td>
<td>1.00E-04</td>
</tr>
<tr>
<td></td>
<td>D (improved)</td>
<td>30</td>
<td>47</td>
<td>20 mm fall, 100 times/min, 20 min.</td>
<td>80</td>
<td>10</td>
<td>1.00E-01</td>
</tr>
<tr>
<td></td>
<td>E (improved)</td>
<td>95</td>
<td>47</td>
<td>95</td>
<td>10</td>
<td>1.00E-01</td>
<td>1.00E-04</td>
</tr>
</tbody>
</table>
3. Test apparatus

Figure 3 shows a schematic view of the test apparatus.

A schematic view of the test chamber with test cartridge sample is shown in Fig. 4.

The flange for attaching the adsorption cartridge was manufactured for each cartridge. After attaching the cartridge to the flange, it was installed in the same test chamber.

The test chamber with the cartridge attached was installed in the thermostatic chamber (Thermostatic Chamber 2). Humidified air, generated by passing dry air into a moisture generator, was mixed with radioactive methyl iodine and directly aerated into the cartridge attached within the chamber.

The outflow gas from the chamber was passed through adsorbents for measuring non-adsorbed concentration. It then went through exhaust gas treatment before being emitted. The moisture generator was installed in the thermostatic chamber (Thermostatic Chamber 1), and was heated to control the humidity at the specified conditions. Heating was performed to prevent the decline in adsorption efficiency of the adsorbents for outlet concentration measurement due to humidity. Furthermore, some of the pipes were heated with line heaters to prevent condensation. In addition, the test apparatus, excluding the air pump, scrubber, and cylinder, was installed inside a simple exhaust hood to prevent accidental dispersion of I-131 into the test room. Moreover, when an outlet gas adsorbent sample was taken from the line, a gas respirator was worn to prevent the inhalation of I-131.

The humidity of the chamber inlet gas during the test (sensor: HM1) was measured at the position prior to the introduction of the radioactive methyl iodine gas in order to prevent corrosion of the sensors due to the gas, and the portion diluted due to the introduction of the gas was corrected and assumed as the humidity for the test.

To confirm the supply of radioactive methyl iodine to the test specimen in real time, a NaI detector was installed outside its chamber, and the test was implemented while verifying the accumulation of radioactivity in the test specimen.

4. Preparation of the radioactive methyl iodine gas

Radioactive methyl iodine was synthesized by the dimethyl sulfate method. Fig. 5 shows the synthesizing apparatus line.

When I-131 solution is put in the methylation container and dimethyl sulfate is added, radioactive methyl iodine (CH$_3^{131}$I) is generated by the following reaction (1):

$$\text{(CH}_3\text{O)}_2\text{SO}_2 + \text{Na}^{131}\text{I} \rightarrow \text{CH}_3\text{I} + \text{CH}_3\text{OSO}_2\text{ONa}$$

After the radioactive methyl iodine was generated, dry nitrogen gas was purged in the methylation container, and the generated radioactive methyl iodine was passed through a condenser and a magnesium perchlorate...
(Mg(ClO$_4$)$_2$)-filled dryer column for dehumidification. It was then transferred to an already depressurized cylinder. After the radioactive methyl iodine had been completely transferred from the methylation container to the cylinder, the cylinder was filled to a fixed pressure with nitrogen gas.

5. Test procedure

Prior to the gas test, the adsorption cartridges were tested for mechanical strength using a repeating drop test (20 mm drop, about 100 times/min, for 20 min) as per the BS EN 14387 (2004) standards. The adsorption cartridge was then attached to the flange, and the flange joint was checked for leakage to ensure that the leakage amount was below the aeration flow rate of 1/10,000. After the leakage check, the test chamber was assembled and installed in the thermostatic chamber.

By using a bypass line, the load gas with the specified flow rate was aerated and stability of temperature and humidity was confirmed. The variation ranges were assumed as ±2°C for temperature and ±5% for humidity (conforming to JIS T81522). Based on the TI-1 reading at the top of the test chamber for temperature, and the HM1 reading for humidity, the dilution by the mixed radioactive methyl iodine gas was calibrated.

After the temperature and humidity conditions had stabilized, radioactive methyl iodine gas was introduced, the bypass line was switched, and the load gas was aerated in the test chamber. Radioactive methyl iodine in the outlet gas passing through the adsorption cartridge was adsorbed using the potassium iodine (K1) + TEDA-impregnated activated carbon (Japan Enviro Chemicals, Ltd. granular Shirasagi WNS814). To prevent deterioration in the adsorption performance of the outlet gas adsorbents due to the humidity, the adsorbent folder was heated to 130°C during the sampling process.

The radioactive methyl iodine was aerated continuously for a maximum of 10 hours. To verify that the radioactive methyl iodine was being loaded in the test specimen, the radioactivity of the adsorption cartridges was measured by a NaI detector installed outside the cartridge chamber, and the accumulation of radioactivity was checked in real time. The quantitative

Fig. 4 Gas flow chamber for installation test cartridge.

Fig. 5 Synthesis apparatus system of CH$_3^{131}$I.
assessment of the supply of radioactive methyl iodine was performed by measuring the I-131 radioactivity adsorbed in the cartridges and the radioactivity of the outlet gas passing through them.

After the test, a germanium detector was used to measure I-131 radioactivity adsorbed in the cartridges and the radioactivity of the outlet gas adsorbent. The data was obtained by substituting the outlet gas adsorbent at intervals specified after beginning the test for each inlet radioactive methyl iodine concentration.

The collection efficiency (DF: decontamination factor) of the test specimen for each sampling time was assessed from the radioactive methyl iodine inlet concentration and outlet concentration of the aeration gas, thereby providing a quantitative understanding of the extent of performance deterioration due to the radioactive methyl iodine load. The DF value was calculated by the below equation;

\[ DF = \frac{\text{inlet I-131 concentration}}{\text{outlet I-131 concentration}} \]

Inlet concentration: (I-131 activity adsorbed in test cartridge + I-131 activity in outlet adsorbent) / (the volumetric flow of the aeration gas) [Bq/cm³]

Outlet concentration: (I-131 activity in outlet adsorbent) / (the volumetric flow of the aeration gas) [Bq/cm³]

The regulation value for radioactive methyl iodine in the notice defining the dose limit based on the provisions of the Ministerial Ordinance for Commercial Nuclear Power Reactors concerning Installation, Operation etc. is 1.0E-03 Bq/cm³, and when the radioactive methyl iodine concentration of aeration gas is 1.0E-01 – 1.0E-04 Bq/cm³, the DF must be 100 or more in order to satisfy this value. Therefore, DF100 was used as the evaluation standard.

Regardless of the humidity, gas-flow rate, or types of adsorbent, an error of DF value was 10–25% (within 200 minutes from introduction of the gas), 1–10% (after 200 minutes from introduction of the gas).

IV TEST RESULTS

1. Test results of iodine adsorption cartridges attached to gas respirator

(1) Results performed under 95% relative humidity

Figure 6 shows the test performed under 95% relative humidity. The test was performed while maintaining the concentration of radioactive methyl iodine at 1.0E-02 Bq/cm³ for samples A and B, and in the range of 1.0E-01–1.0E-04 Bq/cm³ for sample C. DF was equal to or greater than 100 up to 120 minutes for samples A and B. For sample C, it was equal to or greater than 1,000 under all concentration conditions and the test gas was absorbed into the adsorption cartridge without being influenced by the concentration of radioactive methyl iodine.

If the measured concentration of radioactive methyl iodine at the outlet was less than the lower detection limit value, it was plotted by calculating DF while assuming the lower detection limit value as the outlet concentration (the same is applicable below). The lower detection limit value varies depending on the measurement time etc. However, upon using the calculation formula for DF (DF = Inlet concentration/Outlet concentration), if the inlet concentration is higher where the lower detection limit value is the same, apparent DF will be higher.

(2) Results of the test performed under 80% relative humidity

The test was performed for samples A and B under 80% relative humidity to assess the effects of humidity. Figure 7 shows the results of this test.

The test was performed while maintaining the concentration of radioactive methyl iodine in the range of 1.0E-01–1.0E-04 Bq/cm³ for both samples A and B. DF was equal to or
greater than 100 until about 200 minutes for samples A and B. Furthermore, DF remained at the same value with no dependence on radioactive methyl iodine concentration.

(3) Results of the test performed under 70% relative humidity
Tests were performed using samples A and B by reducing the relative humidity to 70% to verify the effects. Figure 8 shows the results of these tests.

The tests were performed while maintaining the concentration of radioactive methyl iodine at 1.0E-02 Bq/cm³ in the case of both samples A and B. DF was 100 or more even after 480 minutes’ aeration for both samples A and B.

2. Test result of iodine adsorption cartridge attached to PAPR
(1) Results of the test performed under 90% relative humidity
Figure 9 shows the results of the test performed under 90% relative humidity. The test was performed while maintaining the concentration of radioactive methyl iodine
at 1.0E-02 Bq/cm³ for both samples D and E. DF was greater than 100 until 120 minutes for both samples D and E.

(2) Results of the test performed under 80% relative humidity

The test was performed under 80% relative humidity in the same way as the iodine adsorption cartridge attached to gas respirator test. The test was conducted while maintaining the concentration of radioactive methyl iodine within the range of 1.0E-01–1.0E-04 Bq/cm³ for samples D and E. Figure 10 shows the results of the test.

Results obtained for samples D and E were the same as those for the test performed under 90% relative humidity, but the DF of E was slightly higher. Furthermore, DF remained at the same value with no dependency on radioactive methyl iodine and showed a tendency similar to the results of the adsorption cartridge attached to the gas respirator test.

3. Test result of improved iodine adsorption cartridge

(1) Test result of improved iodine adsorption cartridge attached to gas respirator

Based on the test results for the iodine adsorption cartridge attached to gas respirator, improvements were made to the adsorption cartridge for samples A and B and the improved cartridge was evaluated. Figure 11 shows the test results for this.

The test was performed while maintaining the concentration
of radioactive methyl iodine at $1.0\text{E}-01$ and $1.0\text{E}-04 \text{ Bq/cm}^3$ for improved sample A, and $1.0\text{E}-01$–$1.0\text{E}-04 \text{ Bq/cm}^3$ for improved sample B. DF was greater than 1,000 after 600 minutes’ aeration for both improved samples A and B.

4. Test results of improved iodine adsorption cartridge attached to PAPR

Samples D and E were also improved in the same way as the iodine adsorption cartridge attached to the gas respirator, and these versions were evaluated. Figure 12 shows the test results.

The test was performed while maintaining the concentration of radioactive methyl iodine at $1.0\text{E}-01$ and $1.0\text{E}-04 \text{ Bq/cm}^3$ for improved sample D, and $1.0\text{E}-01$–$1.0\text{E}-04 \text{ Bq/cm}^3$ for improved sample E. After the improvement, the DF was 1,000 or more even after 600 minutes’ aeration for both improved samples D and E.

5. Results of comparison of relative humidity

For samples A and B of the iodine adsorption cartridge attached to the gas respirator, the DF was compared to when the test was performed under the radioactive methyl iodine concentration condition of $1.0\text{E}-02 \text{ Bq/cm}^3$, and in 3 conditions of relative humidity: 70%, 80%, and 95%. Figure 13 shows the results of the comparison of relative humidity.

At the time of 60 minutes’ aeration, partial reversal occurred. However, as an overall tendency in the case of both samples A and B, under the higher relative humidity conditions

Fig. 12  Test result of improved cartridge attached to PAPR (95%RH).

Fig. 13  Influence of relative humidity.
the DF was lower and the iodine removal performance of the cartridge was reduced.

6. Comparison of respective iodine adsorption cartridges
(1) Iodine adsorption cartridges before improvement

Iodine removal performance of the adsorption cartridges attached to the gas respirator, as shown in the results of the test performed under 95% relative humidity, was prominently higher for adsorption cartridge C, whereas for cartridges A and B it was equal. According to Table 1, the filling volume of the adsorbent for adsorption cartridge C was 1.5–2 times that for cartridges A and B. LV and SV of cartridge C were also lower as compared to the LV and SV of cartridges A and B. Moreover, since the filling density of the adsorbent was higher, the adsorption cartridges were filled in a consolidated state. These are believed to be factors contributing to the enhanced performance of cartridge C. However, since it is not clear whether or not any impregnated TEDA or other components were present in the adsorbent, these factors cannot be verified.

As shown in the test results with a relative humidity of 90% and 80% in Fig. 9 and Fig. 10, iodine removal performance of cartridges D and E attached to a PAPR were almost the same.

(2) Improved iodine adsorption cartridges

When the results of the test performed with improved iodine adsorption cartridges A and B attached to an improved gas respirator under 95% relative humidity (Fig. 11), and the results of the test performed with adsorption cartridges A and B before the improvement (left side of Fig. 6) were compared, it was found that both the improved cartridges A and B retained a DF of 1,000 or more for 600 minutes and the iodine removal performance significantly improved. Moreover, no significant difference was observed between the iodine removal performance of improved cartridge D and that of improved cartridge E. Adsorbent weights after the test were: D = 78 g, E = 92 g, improved D = 123 g and improved E = 97 g.

Since it is not clear whether or not any impregnated TEDA or other components were present in the adsorbent, these factors cannot be verified. However, it can be assumed that the increase in adsorbent quantity affects the performance improvement of the adsorption cartridge.

V Usage Guideline

A quantitative evaluation of iodine removal performance was carried out by testing the performance of iodine adsorption cartridges. Based on the results, respirator-wearing guideline under similar environmental condition at 1F after the accident were established as per Table 4. Respirators shall be used with a sufficient margin as the DF becomes 1,000 or more. It is important that humidity and radioactive iodine concentration in the working environment be checked before the use of a respirator.

VI Summary

A quantitative evaluation of performance was carried out by implementing a test in which radioactive methyl iodine

<table>
<thead>
<tr>
<th>Radioactive iodine concentration (Bq/cm³)</th>
<th>For gas respirator</th>
<th>For PAPR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of gas respirator</td>
<td>A (improved), B (improved), C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A,B</td>
</tr>
<tr>
<td>1.0E-04 or more</td>
<td>10 hours when humidity is 80% or less</td>
<td>10 hours when humidity is 80% or less</td>
</tr>
<tr>
<td>Less than 1.0E-03</td>
<td>10 hours when humidity is not limited</td>
<td>10 hours when humidity is not limited</td>
</tr>
<tr>
<td>1.0E-03 or more</td>
<td>4 hours when humidity is 80% or less</td>
<td>10 hours when humidity is not limited</td>
</tr>
<tr>
<td>Less than 1.0E-02</td>
<td>10 hours when humidity is not limited</td>
<td>10 hours when humidity is not limited</td>
</tr>
<tr>
<td>1.0E-02 or more</td>
<td>2 hours when humidity is 80% or less</td>
<td>10 hours when humidity is not limited</td>
</tr>
<tr>
<td>Less than 1.0E-01</td>
<td>10 hours when humidity is not limited</td>
<td>10 hours when humidity is not limited</td>
</tr>
</tbody>
</table>

Legend ○ : Can be used △ : Conditional use
was directly aerated in an actual adsorption cartridge, and the environment of a nuclear power station during an emergency was simulated in terms of radioactive iodine concentration, temperature and humidity.

- For iodine adsorption cartridges A and B attached to the gas respirator, DF remained at 100 or more for about 120 minutes under 95% relative humidity. Further, DF was retained at 100 or more for about 200 minutes under 80% relative humidity. DF exceeded 100 even after 480 minutes’ aeration under 70% relative humidity. Almost no difference was observed in DF depending on the difference in the concentrations of radioactive methyl iodine.

- For iodine adsorption cartridge C attached to the gas respirator, DF remained at 1,000 or more even after 600 minutes’ aeration under 95% relative humidity. Also, it was observed that DF increased with an increase in the concentration of radioactive methyl iodine.

- For iodine adsorption cartridges D and E attached to the PAPR, DF remained at 100 or more for up to 120 minutes under 90% relative humidity. Further, DF remained at 100 or more for about 200 minutes under 80% relative humidity.

- For all the improved adsorption cartridges A, B, D and E, DF remained at 1,000 or more for 600 minutes’ aeration under 95% relative humidity.

- From the test results it was observed that the iodine removal performance of the adsorption cartridge decreases under high humidity conditions. Regarding the effect of radioactive methyl iodine concentration in the aeration gas, there were some cases in which no concentration dependency was observed, and others in which DF decreased as the concentration decreased. Thus, the correlation between the difference in DF and difference in concentration was not clear.

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