Sealing Technology for Transport and Storage Casks

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Containers in which spent nuclear plant fuel are stored must remain sealed indefinitely without leakage despite accidents such as fires and shock during transport. We evaluated allowable gasket leakage by parameterizing cask leakage in long-term storage and transport. We confirmed that gasket leakage is lower than the reference by studying leakage in vertical and side deviation, finding that a metallic gasket suits both storage and transport. This report details cask sealing techniques and verification.

1. Introduction

To cope with the problem of insufficient storage capacity for spent nuclear fuel at nuclear power stations, transportable storage containers (referred to as "casks" in this paper) urgently need to be developed. The current plan is to use the casks as a means of interim storage for spent nuclear fuel at power plants for the period of time before it is sent to a reprocessing plant. Mitsubishi Heavy Industries, Ltd. (MHI) has recently developed the MSF-69B transportable storage cask which has a larger storage capacity than conventional casks.

A transportable storage cask needs to be capable of maintaining its sealing performance to prevent radioactive materials from leaking out during storage or in case of accidental overturn, fire or fall of the cask during transport. This paper describes the basic leakage rate determined to ensure the sealing performance of the MSF-69B transportable storage cask, and gives the results of the metal gasket displacement tests assuming the occurrence of accidents during transport.

2. Sealing mechanism inside cask

Fig. 1 shows the basic construction of the MSF-69B cask and details of its sealing mechanism. This cask is covered with a double lid, and metal gaskets are used on both primary and secondary lids to form a sealing system. The valve regulating the inside pressure of the cavity is installed on the primary lid, and the valve cover is also sealed with a metal gasket. The cavity in which spent nuclear fuel is loaded is so constructed that it always maintains a helium gas atmosphere at negative pressure to prevent the spent fuel cladding tubes from corroding and radioactive substances from leaking out during long-term storage. To prevent corrosion, the space between the lids is pressurized with helium gas so as not to allow outside air to enter the cavity.

In conventional transportable casks, rubber O-rings are generally used as seals on account of their flexibility to impact. Since helium gas permeates substantially through rubber O-rings, it was decided to use metal gasket instead. It thus became necessary to examine the sealing performance of the lids sealed with metal gaskets if they are subjected to accidental impact, fire, etc.

3. Determination of allowable leakage rate for gaskets

Fig. 2 shows the analytic model used to calculate the leakage rate. The interior of the cavity needs to be maintained below atmospheric pressure (negative pressure) including a margin for foreseeable variations in atmospheric pressure. The rise in pressure inside the cavity with days elapsed was calculated by using the rate of leakage from the gasket as parameter, on the assumption that the pressure in the space...
between lids remains unchanged from the initial value set on the safe side. The total of leakage from the two gaskets was used in this calculation.

**Fig. 3** shows the results of the leakage rate analysis. The inside pressure of the cavity rises above atmospheric pressure at the end of the storage period when the total leakage rate at the gaskets in two places is $2 \times 10^{-6}$ Pa·m³/sec, but it remains within the negative pressure range when the gasket leakage rate is $1 \times 10^{-6}$ Pa·m³/sec. Accordingly, the sealing performance can be maintained for a period of long-term storage by keeping the leakage rate per gasket at $1 \times 10^{-7}$ Pa·m³/sec or lower, including a surplus.

The allowable leakage rate for the period of transport is discussed on the same graph. Assuming that leakage at the rate of $1 \times 10^{-6}$ Pa·m³/sec had continued for a long time and that the pressure inside the cavity after such long-term storage is taken as the initial value (0.09 MPa), the leakage rate that can maintain negative pressure in the cavity during the transport period (about 100 days including some allowance) is $2 \times 10^{-4}$ Pa·m³/sec. This means that a period of time needed for emergency transport can be taken out when the leakage rate per gasket is $1 \times 10^{-4}$ Pa·m³/sec or lower. This value was thus determined as the allowable leakage rate for the period of transport.
Table 1  Set values for design in view of sealing performance

<table>
<thead>
<tr>
<th>Remarks</th>
<th>Primary lid</th>
<th>Secondary lid</th>
<th>Design temperature of gasket (°C)</th>
<th>150</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial clearance between lid and flange (mm)</td>
<td>1.0 max.</td>
<td>1.0 max.</td>
<td>Machined and installed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening in lid caused by impact when falling (mm)</td>
<td>0</td>
<td>0</td>
<td>Estimated by analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening in lid caused by deformation resulting from fire, etc. (mm)</td>
<td>0</td>
<td>0.02</td>
<td>Estimated by analysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Design requirements for sealing performance

Table 1 lists the set values for designing the cask in view of sealing performance. Of these items, the radial clearance between lid and flange influences the sealing performance of the cask during the period of transport.

The cask’s lids are designed to be tightly bolted with an adequate axial force to prevent the lid from being displaced even by an impact load. The examinations were made to study the changes in the leakage rate assuming that the metal gasket is laterally displaced to change the degree of opening.

5. Verification test

(1) Test gasket

Fig. 4 shows the shape of the test gasket. The test gasket is identical in type, structure, material composition and wire diameter to those of which the sealing performance has already been proved for use during long-term storage.

(2) Testing methods

The leakage rate of the test gasket was examined by a “vertical compression restoration and airtightness test” and a “horizontal displacement test” at room temperature and 150°C as the actual operating temperature of the gasket in the cask. In the latter test, a horizontal displacement of 1.5 mm was applied as a key displacement amount on the safety side in view of the size of the actual cask.

For the vertical compression restoration and airtightness test, the test gasket held between the flanges was pressed on the compression tester as shown in Fig.5, and the amount of displacement and changes in the leakage rate after restoration were measured. For the horizontal displacement test, the test gasket held in three pieces of grooved flanges is displaced by pushing down the center flange with the compression jig as shown in Fig.6, and the amount of displacement and changes in the leakage rate were measured.

3) Test results

Fig.7 shows the results of the vertical compression restoration and airtightness test. When the metal gasket was fastened with the flanges, the leakage rate was $1 \times 10^{-9}$ Pa·m$^3$/sec or lower. The amount of restoration needed to maintain this leakage rate was about 0.1 mm. There was no noticeable difference in the amount of restoration between the room temperature and the high-temperature tests.

The result of the horizontal displacement test is shown in Fig.8. The maximum leakage rate shown after the displacement was not more than $1 \times 10^{-7}$ Pa·m$^3$/sec. Generally, the high-temperature test revealed a lower leakage rate than the room-temperature test. This suggests that the aluminum material forming the surface of the gasket softens at high temperature to increase the airtightness.

6. Conclusion

The basic leakage rate required for the metal gaskets to be used in the casks was determined first
through analysis of the leakage which can occur during long-term storage and transport. Then, the metal gasket was tested for sealing performance under conditions in which the lid was displaced accidentally during transport. The examinations and tests have confirmed the applicability of the metal gaskets to the transportable storage casks.

MHI will carry out verification tests for deterioration of metal gaskets with lapse of time and will confirm the reliability of the transportable storage casks to which the sealing system described here is applied.

References
(1) Kato, O. et al., Study on Long-term Sealability of Gaskets for Spent Fuel Storage Cask, U92009 (CRIEPI)
(2) Kato, O. et al., Study on Long-term Sealability of Gaskets for Spent Fuel Storage Cask (No.2), U94029 (CRIEPI)