Project Research — **Establishment of Optimal Risk Management**

Storage and Transport Technology for Spent Nuclear Fuel

Background and Objective

The Japan Atomic Energy Commission has identified three potential nuclear fuel cycle policy options according to the share of nuclear energy supply in future. Regardless of the chosen nuclear fuel cycle option (reprocessing or direct disposal), the needs for the interim storage of spent nuclear fuel (SNF) are increasing ever-further.

In this project, to realize the early utilization of economical and large-capacity storage methodology, we are executing study programs related to concrete cask storage technologies from the perspective of cask procurement risk management and economic benefit. Moreover, to confirm the safety of the confinement components during future transport after long-term storage, we are also executing study programs for the verification of the integrity of the metal gasket under long-term dry storage conditions, and we promoted codification activities on an alternative metal cask system using ductile cast iron material.

Main results

1 Applicability Evaluation of Ultrasonic Tests with Imaging Analysis for Type-304L Stainless Steel Canister Lid Welding

An image reading technique using ultrasonic images collected by phase-array ultrasonic examination equipment was applied to the full-scale canister lid welding model made of type-304L stainless steel with artificial defects, and the accuracy of the proposed technique was verified and a detectable flaw size-limit was proposed (Fig. 1) (N11057). These results will be reflected on JSME (Japanese Society of Mechanical Engineers) codification activities for the ultrasonic test inspection methodology of the lid welding to verify the confinement ability of the canister.

2 Prevention of Chloride-induced Stress Corrosion Cracking for Type-304L Stainless Steel Canisters

Based on the chloride deposition rate tests in a salty environment condition (atmospheric sea salt concentration about 2 $\mu g/m^3$), it was found that the amount of sea salt deposition on the hot metal surface in the vertical orientation was very low (about 0.03 g/m^2 per year), compared with the critical value of 0.8 g/m^2, corresponding to SCC initiation (N11028).

In addition, in order to measure the concentration of chloride attached to the canister, the laser-induced breakdown spectroscopy (LIBS) method was applied and the possibility of the quantitative measurement of chloride concentration from 0.05 to 1.0 g/m^2 on the canister by LIBS was confirmed (H11020).

Moreover, we developed a salt particle collection device with low-pressure loss that does not interfere with the air flow into the concrete cask (Fig. 3). Based on these research results, a preventive design (monitoring, inspection, and countermeasures) methodology for SCC occurrence on the canister surface was realized (N11044).

3 Evaluation of the Long-term Containment Performance of Metal Casks

We evaluated the ageing mechanism related to the relaxation of the gasket complex under the high temperature of the aluminum gasket for metal cask confinement and proposed the Finite Element Method to predict the recovery displacement of the gasket (Fig. 4). Moreover, the containment performance of the aluminum gasket for over 60 years was numerically verified using the temperature profile that appeared during the realistic long-term storage. (These tasks have been carried out under a contract from NISA/METI.)

4 ASME Codification of Ductile Cast-iron Casks for the Transport and Storage of Spent Nuclear Fuel

In order to diversify the options for the metal cask, we proposed material standards (Section II) and structural standards (Section III) for a ductile cast-iron cask to the authoritative and international ASME (American Society of Mechanical Engineers) codes based on the research results on ductile cast-iron casks for the transport and storage of spent nuclear fuel (N11027).

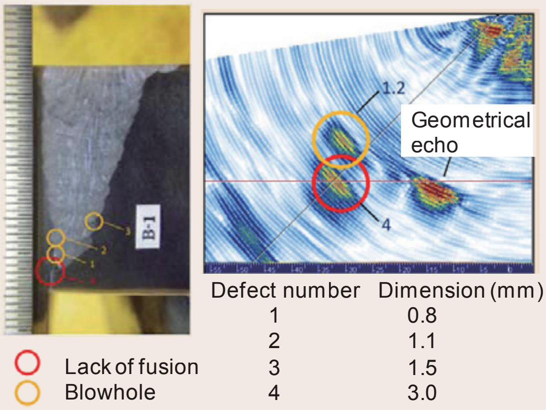


Fig. 1: Applicability of the ultrasonic test inspection methodology for faulty weld defects

The full-scale canister lid welding models (diameter: 1.83 m, shell thickness: 12.7 mm, lid welding: depth 32 mm) made of type-304L stainless steel with artificial defects by electro-discharge machining weld defects (depth of 20-60 mm) and faulty weld defects were fabricated. An image reading technique using ultrasonic images collected by automatic phase-array ultrasonic examination equipment was applied at room temperature, and the collected images were compared with the macroscopic test results. As a result, the accuracy of the ultrasonic test with imaging analysis was verified and the detectable flaw size-limit (2 mm) was proposed. Furthermore, the defects due to the lack of fusion (red open circle) in the initial layer were detected. On the other hand, defects such as blowholes (yellow open circle) of over 2 mm could be detected.

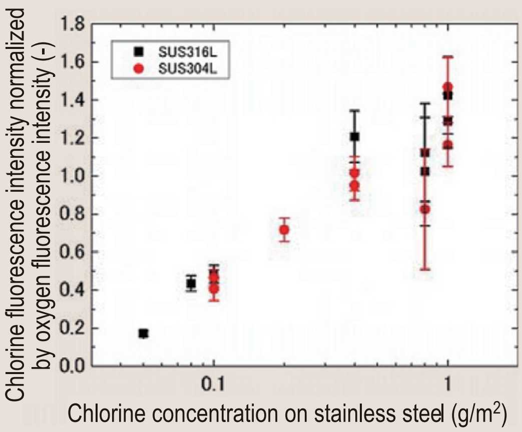
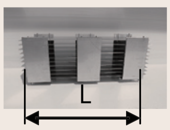


Fig. 2: Measurement of the concentration of chlorine on stainless steel by LIBS

The chlorine spectra were measured for the samples with a chlorine concentration from 0.05 to 4.0 g/m^2 by using double-pulse measurement. The double-pulse measurement was designed using collinear geometry. The chlorine fluorescence intensity normalized by oxygen fluorescence intensity increased monotonously versus the chlorine concentration, from 0.05 to 1.0 g/m^2 in the double-pulse measurements. These results show the possibility of the quantitative measurement of the chlorine content on the canister by LIBS.

Inlet air temp.: Tin (°C)	33
Outlet air temp.: Tout (°C)	98
Temp. difference: △T (°C)	65
Heat load: Q (kW)	22.6
Inlet air velocity: U_0 (m/s)	0.865
Air inlet height: H_0 (m)	0.28
Air inlet width: B (m)	0.3

Salt particle collection device



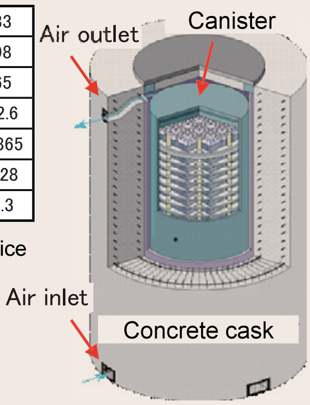


Fig. 3: Applicability of a salt particle collection device to a concrete cask

The effect of the device (L: 0.5 m, 15 plates) installed in a salty environmental condition near a seashore was evaluated. It was clarified that 40% of the salt particles in the air could be collected and that the device would not influence heat removal performance.

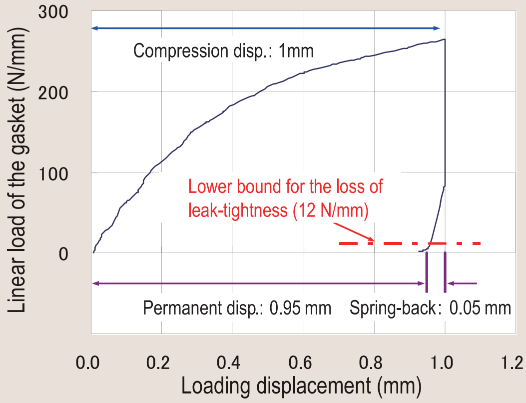


Fig. 4: Ageing effect on the load-deflection curve of the metal gasket after 60 years of usage

We evaluated the ageing mechanism related to the relaxation of the gasket complex under the high temperature of the aluminum gasket for metal cask confinement. The containment performance of the metal gasket after over 60 years was numerically verified using the temperature history (initial temperature: 139℃) during the realistic long-term storage. The ageing analysis showed that the spring-back displacement of the metal gasket was kept as 0.05 mm under the realistic condition (60 years of usage). The residual linear load was larger than the lower bound for loss of leak-tightness. Thus, the long-term reliability of the metal gasket was confirmed.