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Performance Evaluation Tests for the Newly Developed Transportation and Storage Casks in Korea

Woo-seok Choi
Korea Atomic Energy Research Institute

Sanghoon Lee
Keimyung Univ.

Kyoung-sik Bang
KAERI

Sang soon Cho
KAERI

Ju-chan Lee
KAERI

Seunghawn Yu
KAERI

Jongmin Lim
Korea aerospace Research Institute

Abstract

A spent-fuel storage and transport system are currently being developed in Korea. The spent fuels stored temporarily in wet storage at reactor sites are scheduled to be transported to interim storage in Korea in the near term. To prepare for spent-fuel transportation and storage, a dual-purpose cask and a concrete cask have been developed, and they are currently undergoing the license approval procedure. Spent-fuel transportation and storage systems should demonstrate their compliance to the safety requirements stipulated in regulations. Korean domestic regulation NSSC Notice No. 2014-50 for packaging and transportation of radioactive materials requires safety tests of transportation packages. The Korea Atomic Energy Research Institute (KAERI) has been performing safety tests of a dual-purpose metal cask to obtain test data to show its compliance to safety requirements. To demonstrate the compliance to the safety requirements for storage, several performance evaluation tests and analyses were performed.

Introduction

Korea is currently developing two transportation and storage casks for spent fuel. They are the dual-purpose metal cask, KORAD21, and the concrete storage cask, KORAD21C. Their specifications are given in Table 1, and Fig. 1 contains an illustration of the casks.

Table 1 Design specification of KORAD21 and KORAD21C

Items	Description
Capacity	- 21 PWR F/A(WH & CE)
Design Basis Spent fuel	- BU: 45,000 MWD/MTU - Enrichment: 4.5 wt.% U235 - Cooling time: 10 yrs - Decay heat: 16.8 kw/canister
Dimensions	- Canister: 1,686 mm O.D. × 4,880 mm L - Metal cask: 2,216 mm O.D. × 5,285 mm L - Concrete cask: 3,266 mm O.D. × 6,030 mm L
Weight	- Canister: 33.0 t (with loaded fuel) - Metal cask: 104.7 t (with loaded canister) - Concrete cask: 143.8 t (with loaded canister)

(a) KORAD21, DPC (b) Canister (c) KORAD21C, Concrete cask

Figure 1 New transportation and storage casks developed in Korea

Performance Evaluation Tests for Transport Conditions

Performance evaluation tests were performed at a test facility in the Korea Atomic Energy Research Institute (KAERI). The work in this section covers the performance evaluation tests of the dual-purpose metal cask. Pictures for each test at the facilities are shown in Fig. 2. The tests are as follows.

Drop and puncture test

Five cases of 9 m free drop tests (i.e., bottom vertical [No. 1], lid vertical [No. 2], horizontal [No. 3], oblique [No. 5], lid COG [No. 6]) and two cases of 1 m puncture tests (i.e., horizontal puncture [No. 4], lid vertical puncture [No. 7]) were performed. Schematics of the initial drop conditions are presented in Fig. 3. Accelerometers and strain gauges were attached on the test model and the internal structure of the cask such as fuel baskets and dummy fuel. After the drop and puncture tests, numerical simulations using the commercial software, ABAQUS, were performed. The results of the tests and simulations were compared to validate their compliance to the safety requirement.

Fire test

The fire test was performed on a sliced model with three sections. Thermocouples were installed on major components such as the basket, canister, cask body, neutron shieling layer, and outer surface. The thermocouple installation layouts are the same for each section. Three temperature data were acquired from the same location of each level, as shown in Fig. 4, for redundancy and consideration of insulation effects. Therefore, the temperature histories at the inside of the transport cask and at the flame were measured. The maximum temperature of each component was lower than the corresponding allowable temperature of each component material.

Water immersion test

The water immersion test was performed under enhanced conditions with a hydraulic pressure of 2 MPa for 1 hour. Before and after the drop test, puncture test, and water immersion test, the leakage rate was measured by a helium spectrometer. The leakage rate satisfied the allowable rate at each stage. All the performance tests for transport conditions were conducted under domestic and International Atomic Energy Agency (IAEA) regulations, and they satisfied the criteria prescribed in those regulations.

(a) Drop test (b) Fire test (c) Water immersion test

Figure 2 Facilities for performance evaluation tests at KAERI site

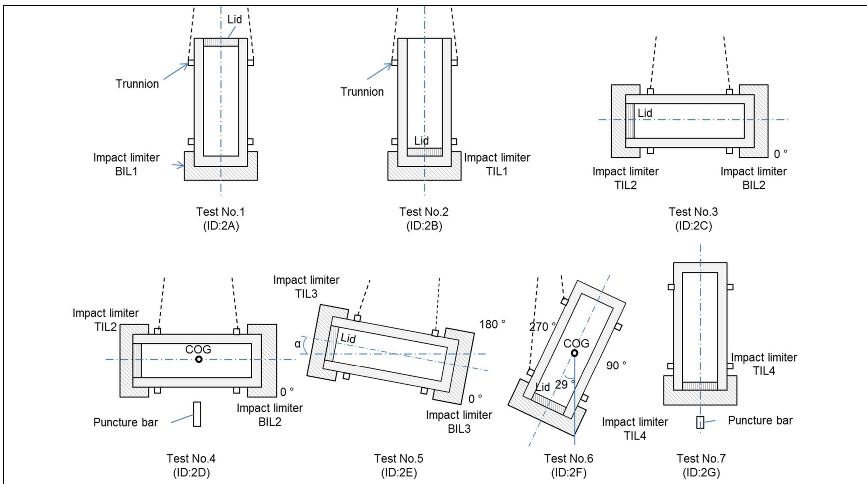


Figure 3 Initial drop orientations for each drop and puncture test

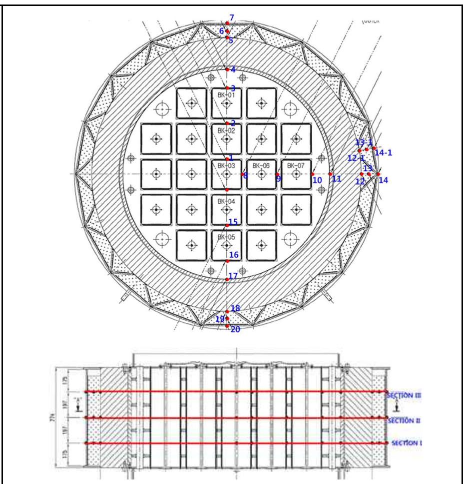


Figure 4 Thermocouple installation locations

Performance Evaluation Tests for Storage Conditions

The following tests and analyses were performed to demonstrate the integrity of the storage system.

<u>Seismic performance test and tip-over behavior evaluation test</u>

The seismic performance test was performed using a 1/3-scale model. However, the tip-over conditions of a full-scale model and a scaled-model are not the same. Therefore, an additional base plate was designed for attachment to the bottom of the cask. The dimension of the base plate was decided such that the tip-over condition of a full-scale model could be simulated with the scaled model. Two base pads (a concrete pad and a steel pad) were considered. Consequently, tests were performed using four models: (1) models with an additional plate on a concrete pad and (2) on a steel pad, and (3) models without an additional plate on a concrete pad and (4) on a steel pad. Two types of seismic loads were applied: Artificial Time History(ATH) and Site Response Time History(SRTH). The sensor arrangements are presented in Fig. 5. Tip-over occurred for 0.6gto 0.8g depending on the case. Numerical simulations under the same conditions as the tests were conducted for comparison and validation. The tip-over test of the scaled model test could not be guaranteed to be analogous to a full-scale model test. Therefore, an additional tip-over test was conducted as a side drop test with the equivalent energy of the full size model under tip-over behavior.

Metal seal accelerated test

The seals are the main components that constitute the confinement boundary in bolted casks that contain used fuel. Seals are categorized as elastomer seals and metal seals. In general, elastomer seals are used for spent-fuel transport casks, whereas metal seals are used for spent-fuel storage casks. Exposure to heat and radiation degrades the seal material. Thermal excursions, if sufficiently large, can induce creep of the metallic seal. This creep will result in stress relaxation of the sealing system, which could compromise the integrity of the seal. In addition to creep, fluctuations in temperature can result in thermomechanical fatigue, potentially leading to crack initiation and eventual failure.

Metal seals were adopted in KORAD21 and KORAD21C. Confinement performance tests in the form of accelerated tests are ongoing. The first accelerated test under 180°C has been finished, but the second test under 165°C is still being conducted. For the first test, the leak rate during the expected design life satisfied the allowable value. For the second test, the leak rate has so far satisfied the allowable value, as shown in Fig. 6.

Heat removal performance test

For the heat removal performance test, a full-scale concrete test model was built at the KAERI test facility site. Eighty thermocouples were installed at distributed positions such as the canister surface and the inner, middle, and outer surfaces of the concrete over-pack. Additional 18 thermocouples were installed to measure the ambient temperature.

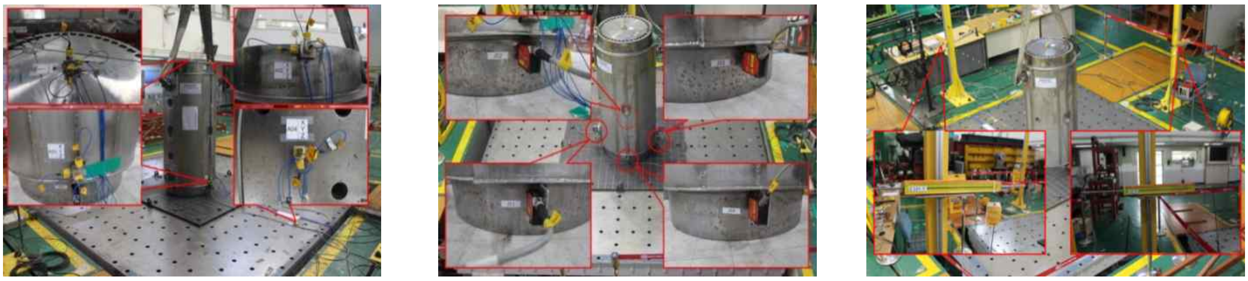
Thermal tests were performed to evaluate the heat removal performance of the concrete storage cask under normal and off-normal (i.e., half-blocked inlets) conditions. In addition, a thermal test was performed to evaluate the thermal integrity of the concrete under accident conditions. The main results of the study are as follows:

(1) The heat transfer rate to the ambient atmosphere by convective airflow through the passive heat removal system reached 93.5% under normal conditions. Accordingly, the passive heat removal system was well designed and worked adequately.

(2) The heat transfer rate to the ambient atmosphere by convective airflow through the passive heat removal system reached 87.4% under off-normal conditions. Therefore, halfway blocking the inlet openings has a relatively small effect on the maximum temperatures and temperature distributions.
(3) No significant temperature difference was found between the different cases of the location of the half-blockage of the inlet openings. Therefore, the influence of the direction of the half-blockage of the inlet openings on the heat removal performance was estimated to be minimal.
(4) The maximum temperature of the over-pack inner surface under accident conditions was measured as 103°C. Therefore, the thermal integrity of the concrete is maintained under accident conditions.

Aircraft Impact test (Impact resistance performance test)

A test was performed to evaluate the impact resistance performance for KORAD21, the dual-purpose cask, and for the over-pack of KORAD21C's concrete cask. This test was for the evaluation under aircraft crash conditions. For the test of KORAD21, the missile was designed to equivalently simulate the impact of an aircraft crash in a scale model test. The impact tests on the side and on the lid of the cask were conducted as shown in Fig. 8. For the test of KORAD21C, four different over-packs were evaluated under the severe impact condition, which were ones with and without a steel liner outside and ones with and without reinforced bars inside of concrete. For KORAD21C, the concrete cask, the aircraft impact test and simulation were performed as shown in Fig. 9.



(Accelerometer) (Laser displacement sensor) (LVDT displacement sensor)

Figure 5 Seismic performance evaluation test (model and sensor layout)

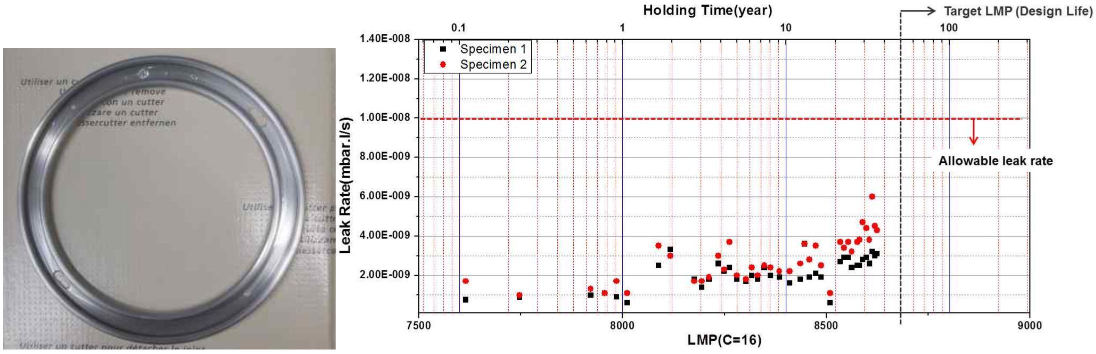
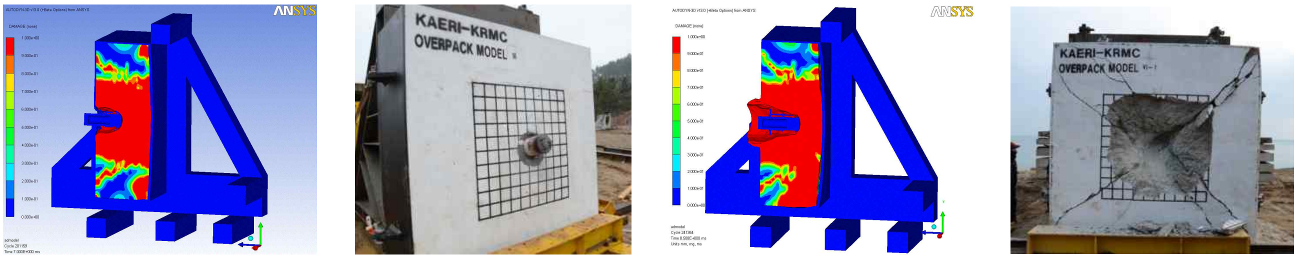


Figure 6 Metal seal and leak rate during ongoing accelerated test

Figure 7 Heat removal performance test

Figure 8 Impact resistance performance test



(a) KORAD21C over-pack with liner and reinforced bar

(b) Another over-pack without liner and reinforced bar

Figure 9 Test and analysis results for concrete over-pack

Conclusions

All the performance tests for evaluating the structural integrity under transport conditions were successfully conducted. It was verified experimentally that the structural integrity of the metal cask was maintained during drop accident conditions by the leak test performed before and after the drop test. The integrity of KORAD21 was demonstrated through the fire test and the water immersion test. All the above tests demonstrate that the storage system successfully complied with requirements. The acquired data and the analysis results will be utilized for the license approval of the developed storage system.

Acknowledgments

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