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DUAL-PURPOSE METAL CASK INTEGRITY AFTER LONG-TERM INTERIM STORAGE

(Activities for the verification test of a dual-purpose metal cask)

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ABSTRACT

The purpose of the verification test is to demonstrate structural integrity and functional safety of a dual-purpose metal cask for transport and storage of spent fuel. The test focuses on integrity under transport conditions after long-term interim storage and includes a survey study and testing which is subdivided into two tests, material property tests and system verification tests.

The Purpose of the material property tests is to evaluate the degradation of cask materials during long-term storage. The tests include (1) Corrosion and SCC tests of the metals of cask body and basket, (2) Thermal aging tests of the aluminum alloys of basket, (3) Neutron and gamma irradiation tests of neutron shielding materials (resin), (4) Thermal aging tests after irradiation of neutron shielding materials, (5) Thermal relaxation tests of metal seal and (6) Corrosion test of metal seal and its contact surfaces.

The cask system verification tests focus on the leak tightness of the cask containment system. The 9 meters free drop test and the thermal test based on the IAEA regulations might result in severe damage to the containment system. A full-scale lid section model composed of metal seals and double lids is appropriate for the tests.

This paper presents the general plan and the current technical topics concerning the verification test.

INTRODUCTION

Spent fuel interim storage provides an adjustable time period until the time of the fuel reprocessing and thus lends an element of flexibility to the nuclear fuel cycle as a whole. In Japan, the law concerning interim storage was enacted in 1999, and the private sector is now making preparations for commercial operation of storage facilities by 2010.

Nuclear Power Engineering Corporation (NUPEC) has been conducting verification tests on dual-purpose metal casks in accordance with the R&D government programs since 1999 for about five years. The results will contribute to the safety evaluations of spent fuel interim storage facilities.

These verification tests focus on dual-purpose metal casks used for both storage and transport, for some storage casks are now in service for storage at nuclear power station sites in Japan.

GENERAL PLAN FOR THE TESTS

The purpose of the verification test is to demonstrate the structural integrity and functional safety of dual-purpose metal casks. The test focuses on integrity under transport conditions after the long-term interim storage. Figure 1 shows the stage at which this test is curried out.

This verification test includes a survey study and testing. The survey study is intended to clarify the latest technical issues concerning spent fuel dry storage and to evaluate the necessity for testing. The testing is subdivided into material property tests and system verification tests. Material property tests are performed to evaluate the degradation of cask materials and components. System verification tests confirm the structural integrity and functional safety that a dual-purpose cask should have. The scheme of this verification test is shown in Figure 2 and the schedule is shown in Table 1.

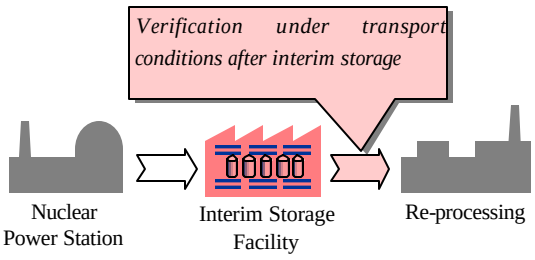


Figure 1, The stage of the verification test

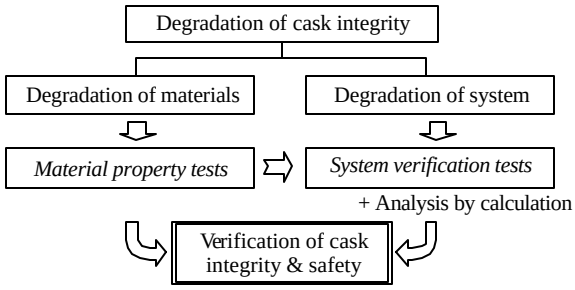


Figure 2, Scheme of the verification test

Table 1, Schedule of the verification test

Item		1999	2000	2001	2002	2003
1. Survey study	(1) Study of technical trend					
	(2) Study of long -term storage					
2. Testing	(1) System verification tests		Preparation			
	(2) Material property tests					
3. Evaluation						

SURVEY STUDY

Issues of long-term storage

During the storage period, casks are exposed to continuous heating, gamma and neutron radiations and corrosive ingredients in inner and outer atmospheres. Based on technical papers and research of actual spent fuel facilities, issues of long-term storage concerning the degradation of casks were clarified. Figure 3 shows these issues.

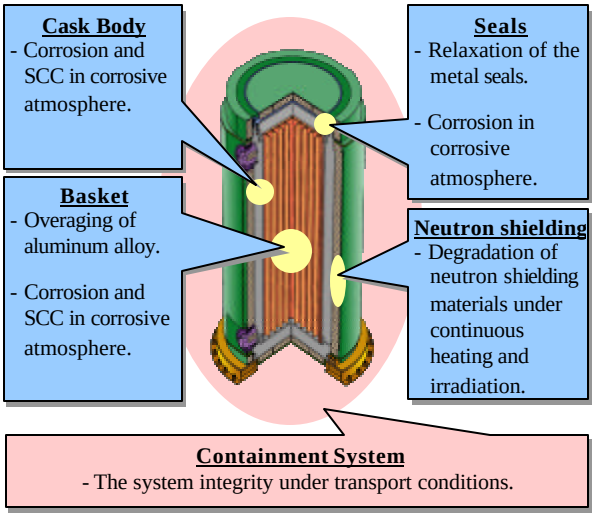


Figure 3, Issues of dual -purpose cask

Study of test conditions

To establish the testing conditions, the temperature and radiation exposure of a typical cask design were calculated. The results are shown in Table 2.

Table 2, Summary of testing condition

Section	Materials	Maximum temperature	Accumulated gamma ray exposure*)	Accumulated neutron exposure*)
Body	Carbon steel, Stainless steel	190 °C	2×10^8 Gy	4×10^{15} n/cm^2
Neutron shielding	Epoxy resin, Silicone resin	170 °C	2×10^3 Gy	8×10^{14} n/cm^2
Basket	Aluminum alloy, Boron added aluminum alloy	270 °C	5×10^8 Gy	7×10^{15}n/cm^2
Seal	Aluminum, Inconel	140 °C	2×10^8 Gy	4×10^{15} n/cm^2

*) During 100 years storage period.

TESTING

System verification tests

The purpose of the system verification tests is to confirm the integrity of cask safety functions at the end of the long-term storage period. Dual-purpose metal casks are used for both storage and transportation. The casks should be subjected to the tests for Type B packages after storage use. Based on the survey study, the maximum damage of cask is given by the 9 meters free drop test and the thermal test at 800°C for 30 minutes. Integrity under the free drop test can be evaluated by calculation in this verification test. The thermal test was selected as the system verification tests.

The thermal test is carried out using a cask lid section model that is modified for the degradation by long-term storage. The model was designed based on a typical specification for interim storage facilities. The model is now in the manufacturing stage.

The system verification tests focus on the sealing characteristic of the metal seal. Figure 4 shows the schematic drawing of the cask section model and the results of thermal analysis. The diameter of the lid section of the model is the same as that of an actual cask, and the body length is approximately 1/5 times that of an actual one. As a result of the thermal analysis, the model is equivalent to an actual cask in thermal profiles of the lid section under the thermal test condition, and the validity of the model was confirmed.

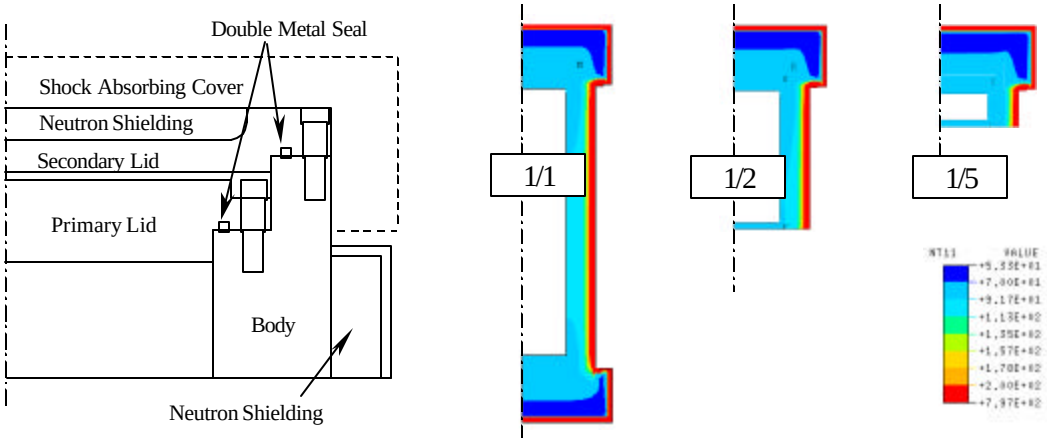


Figure 4, Schematic drawing of the cask section model and the results of thermal analysis

Material property tests

The purpose of material property tests is to correct degradation data of cask materials. Up to now, corrosion and SCC tests for cask body and basket metals, heating and irradiation tests for neutron shielding materials, and stress relaxation tests for metal seal have been realized.

Corrosion & SCC test for metals

Carbon steel is used for the cask body, and stainless steel and aluminum alloy are used for the basket. These metals were tested to evaluate their stability in a corrosive environment. The atmosphere is helium gas mixed with iodine, and temperature is 270°C. This condition assumes leakage of damaged fuel. Figure 5 shows a schematic drawing of the test equipment and the main parameters. Specimens were exposed for a month.

The result is that there was no significant corrosion and SCC as shown in Table 3.

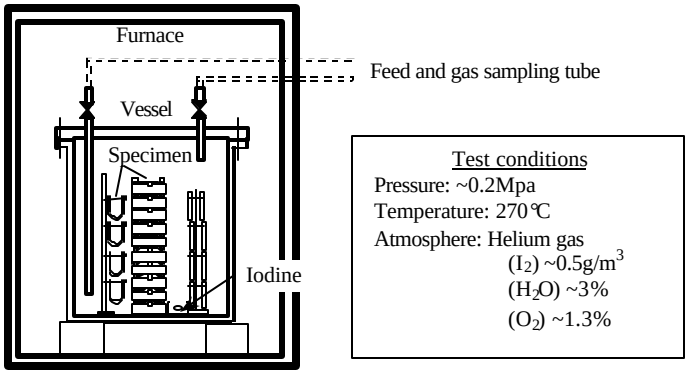


Figure 5, Corrosion & SCC test equipment and conditions

Table 3, Results of corrosion test for one month

Item	Standard	Materials	Corrosion Growth Rate (μm/y)	SCC
Cask body materials	ASTM A350 LF5	Carbon steel	0	none
	ASTM A350 LF5 Welding	Carbon steel	0	none
	JIS SUS F304	Stainless steel	0.12	none
	JIS SUS F304 Welding	Stainless steel	0.24	none
Basket materials	JIS A5052 H34	Aluminum alloy	0	none
	JIS A6N01 (5%B_4C)	5 wt% B_4C containing aluminum alloy	0	none
	ASTM A6351-T5 (1%B)	1 wt% boron containing aluminum alloy	0	none
	ASTM A887 SUS304B4 (1%B)	1 wt% boron containing stainless steel	0	none

Irradiation & thermal stability test of neutron shielding materials

Epoxy resin based material or silicon rubber based material is used for neutron shielding. The purpose of this test is to evaluate the synergistic effects of heating and irradiation. Also differences of effects between gamma ray and neutron irradiation are evaluated.

A neutron irradiation test was carried out on a fast neutron reactor "YAYOI". Figure 6 shows differences between gamma irradiation and neutron irradiation. Loss of weight could be used as a reference for shielding material degradation. There is no significant difference between these degradations.

Table 4 shows the results of heating and heating after gamma ray irradiation test. Both heating tests were carried out in the air, most of the degradation was due to heating.

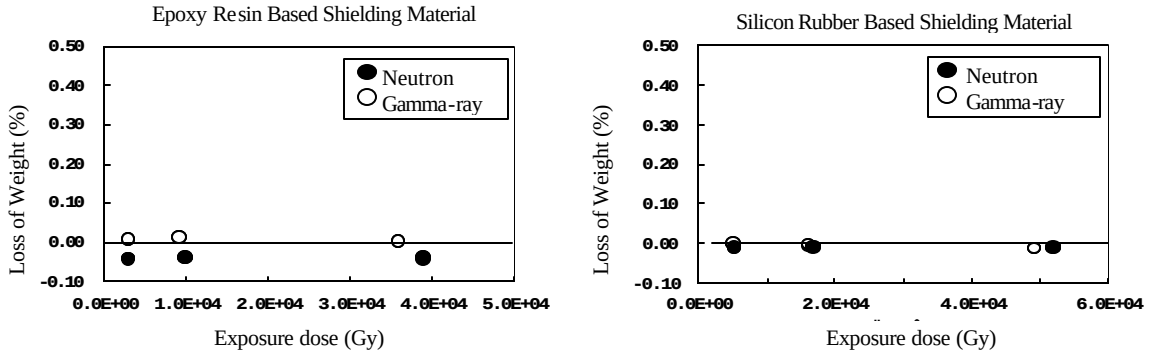


Figure 6, Stability of irradiated shielding materials

Table 4, Synergistic effect of irradiation and heating on shielding materials

Epoxy Resin Based Neutron Shielding

	Irradiation	Heating	Heating after Irradiation
Exposure dose	3.8×10^4Gy		3.9×10^4Gy
Heating condition		170℃ × 2000h	170℃ × 2000h
Loss of weight	0.001%	3.63%	3.70%
Loss of hydrogen	N/A	4.1%	5.2%

Silicon Rubber Based Neutron Shielding

	Irradiation	Heating	Heating after Irradiation
Exposure dose	5.0×10^4Gy		5.0×10^4Gy
Heating condition		170℃ × 2000h	170℃ × 2000h
Loss of weight	0.001%	3.63%	3.70%
Loss of hydrogen	N/A	2.7%	2.2%

Relaxation test of metal seals

This test was performed to evaluate the characteristic of thermal relaxation and plastic deformation of metal seals. It is assumed that the sealing capacity of a metal seal degrades during storage is due to heating. This degradation is caused by a relaxation of the seal. To evaluate the relaxation, an acceleration test method should be established. At the present, application of the Larson-Miller Parameter (LMP) method has been proposed. LMP is defined by the following formula:

$$LMP = T\,(C + \log t)$$

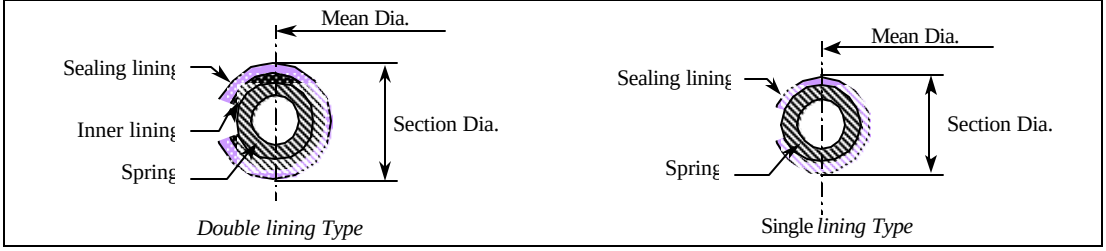
T: Temperature (°K)
t: Time (h)
C: Constant

Table 5 shows specifications and structures of the test specimens. Figure 7 shows the relationship between compression pressure and LMP of various seals. The seal compression pressure is inversely proportional to LMP. LMP is a function of testing temperature and heating time, the

relaxation could be accelerated by heating. Therefore The LMP method could be appropriate for evaluating the long-term performance of metal seals. And a larger section diameter of the seal is durable for the relaxation. Figure 8 shows the cross section of a seal after the relaxation test. These photos show that an aluminum sealing lining was plastically deformed.

Table 5, Specifications of the metal seal specimens

	A	B	C
Section Diameter (mm)	10.0	3.3	2.0
Mean Diameter (mm)	176	176	176
Type	Duble lining	Duble lining	Single lining
Sealing lining	Aluminum	Aluminum	Aluminum
Inner lining	Inconel 600	Inconel 600	-
Spring	Nimonic 90	Nimonic 90	Nimonic 90



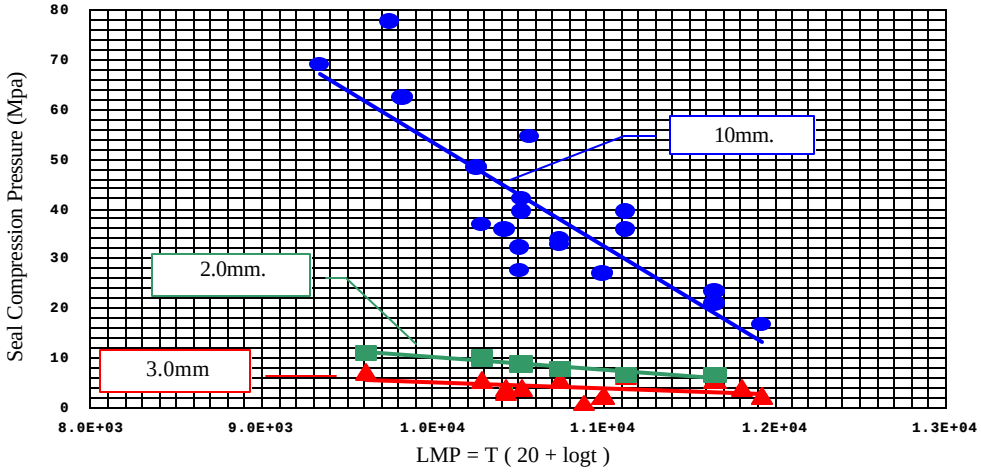


Figure 7, Relationship between compression pressure and LMP of various seals

10mm 3.3mm 2.0mm

Figure 8, Cross section of the seals after relaxation test

CONCLUSIONS

The purpose of the verification test is to demonstrate the structural integrity and functional safety of a dual-purpose metal cask. NUPEC has been conducting in accordance with the R&D government programs since 1999 for about five years.

Up to now, the results of the verification tests are as follows:

(1) The cask lid section model was designed for the thermal test. The model is in the manufacturing stage.

(2) Carbon steel, stainless steel and aluminum alloy were tested to evaluate their resistance against corrosion and SCC in an atmosphere of iodine. There was no significant corrosion and SCC.

(3) Epoxy resin based and silicon rubber based neutron shieldings were irradiated by neutron and gamma rays and heated after gamma ray irradiation. No differences in degradation between neutron and gamma ray irradiation were observed. Most of the degradation was due to heating.

(4) Metal seals were tested to record the property of stress relaxation. An acceleration test by LMP method is available for the metal seal degradation caused by stress relaxation. Larger section diameter of seal has durability for stress relaxation.

The above testing is being continued to verify the integrity of cask systems and materials up to 2003.

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