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Japanese perspectives and research on packaging, transport and storage of spent fuel

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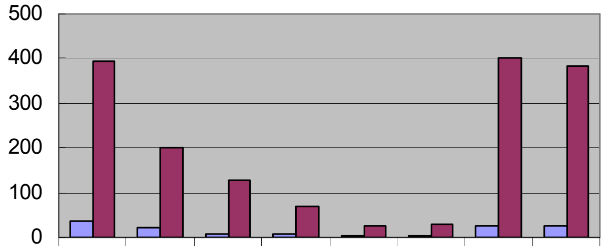
1. Introduction

The Japanese policy on spent fuel is reprocessing. Until, reprocessed, spent fuel shall be stored properly. This paper overviews current status of transport and storage of spent fuel with related research in Japan. The research was partly carried out under a contract of Ministry of Economy, Trade and Industry of the Japanese government.

2. Current status of transport and storage of spent nuclear fuel in Japan

2.1 Transport of spent fuel

Currently, spent fuel is generated from 52 reactors at 16 nuclear power stations and transported to two domestic reprocessing plants, located at Tokai and Rokkasho [1]. Fig. 2.1.1 shows a record of spent fuel shipment in Japan [2]. The number of shipment and amount of spent fuel will increase toward the operation of the reprocessing plant in Rokkasho that reprocesses spent fuel of 800 tU/year. Current status of regulatory and safety aspects in Japan is found in a paper titled “Japan’s Regulatory and Safety Issues Regarding Nuclear Fuel Material Transport” in this PATRAM 2004 [3].



year	1995	1996	1997	1998	1999	2000	2001	2002
▨ No. of Shipment	35	22	9	6	2	3	26	25
▨ Amount of SF (tU)	394	199	127	69	24	30	403	382

Fig. 2.1.1 Record of SF Shipment in Japan [2]

2.2 Storage of spent fuel

Spent fuel is accumulating and exceeding the capacity of reprocessing plant in Japan as shown in Fig. 2.2.1. Those spent fuel shall be stored properly. Currently, a dry cask storage facility at the TEPCO Fukushima Daiichi NPS with a capacity of 150 tU and a dry cask storage facility at Japan Atomic Power Co.’s Tokai Daini PS with a capacity of 260 tU are being operated. By the year of 2010, AFR storage facilities will be operated in Japan.

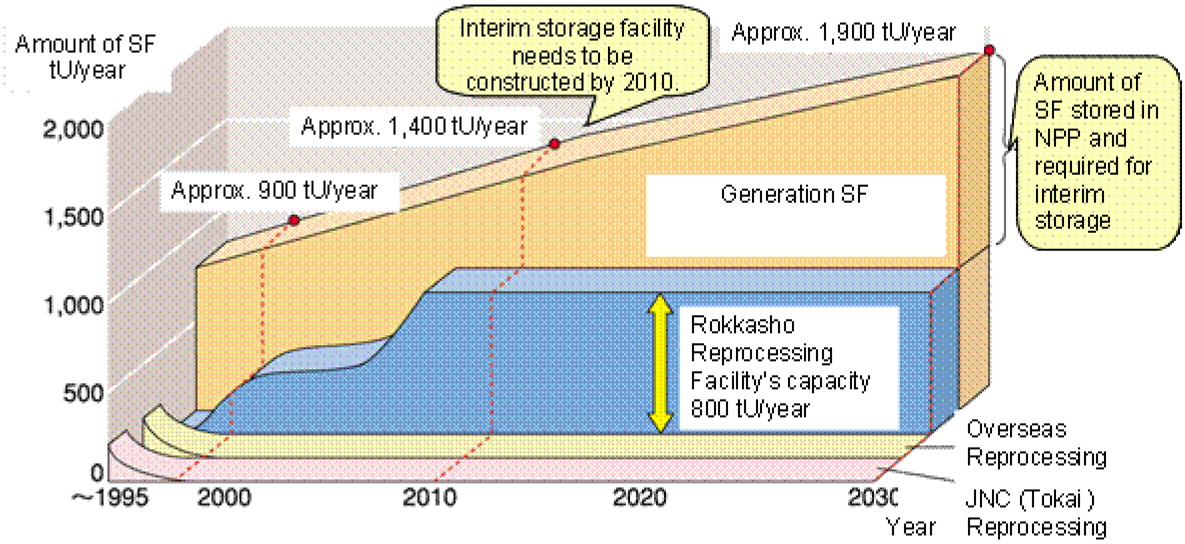
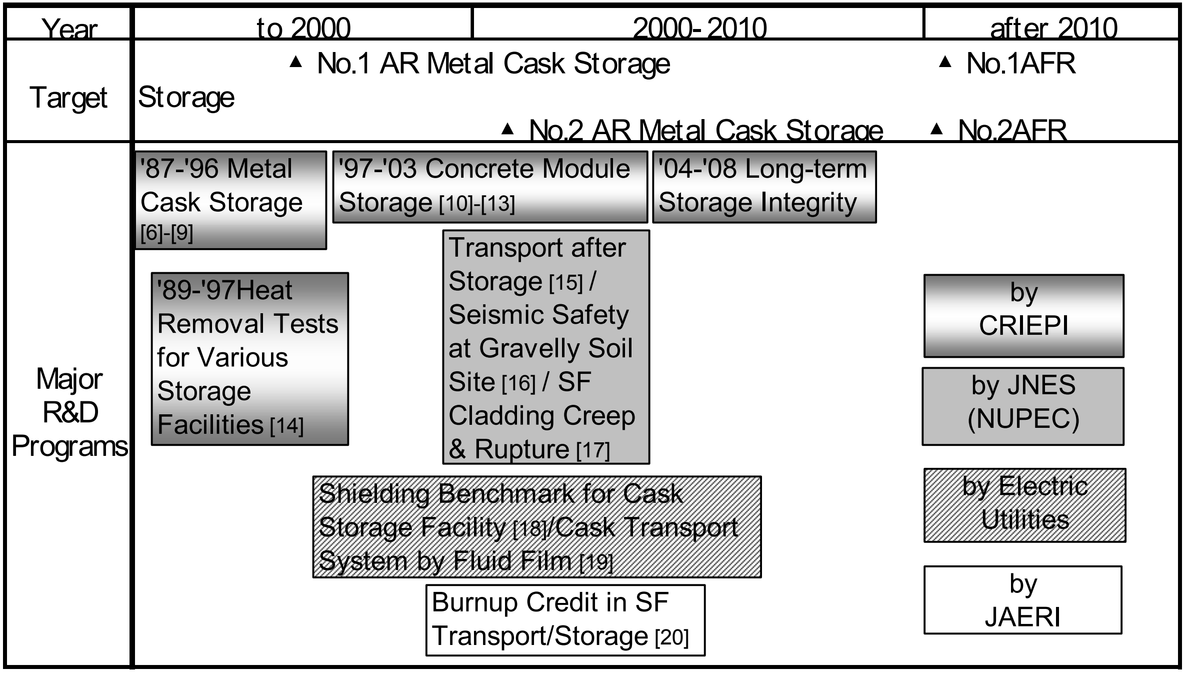


Fig. 2.2.1 Spent Fuel Storage Demand in Japan [4]

3. Research on storage of spent nuclear fuel in Japan

R&Ds on transport of spent fuel have been carried out and the results have been reported in the past PATRAM [5], etc. This paper overviews R&D on spent fuel storage in Japan. Fig. 3.0.1 shows R&D programs on storage that have been carried out by various organizations in Japan. In the following sections, highlights in those R&Ds on metal cask are introduced. The R&D on spent fuel storage by concrete casks is found in a paper titled “Demonstrative Drop Tests of Transport and Storage Full-Scale Canisters with High Corrosion-resistant material” in this PATRAM 2004 [21]. This paper overviews R&D on spent fuel storage, particularly by metal casks.

Fig. 3.0.1 Major R&D Programs of Dry Storage Technology in Japan



3.1 Cask Drop Tests without Impact Limiters

Full-scale casks without impact limiters were drop-tested onto a reinforced concrete target simulating hypothetical drop accidents during handling procedure in a storage facility by CRIEPI [6]. In this test, failure of the reinforced concrete will play an important role in absorbing impact energy. Three kinds of full-scale casks made of ductile cast iron were used for the tests as shown in Table 3.1.1. The casks had double lid structure with metallic gaskets. Table 3.1.2 shows measured maximum acceleration in the drop tests in three different orientations as partially shown in Fig. 3.1.1.

Table 3.1.1 Major Specifications of Specimen Casks for Drop Tests

Cask Type	X	Y	Z
Length x Diameter (m)	5.2 x 2.2	5.3 x 2.5	5.4 x 2.1
Wall thickness of Body (mm)	375	310	310
Weight with SF (ton)	114	107	106
SF Assemblies / cask	52 BWR	52 BWR	52 BWR

Table 3.1.2 Measured Acceleration in Cask Drop Tests

Drop height (m)	Cask orientation	Cask type	Maximum acceleration (G)
1.5	Vertical	X	160
	Horizontal	Z	37
5.0	Horizontal	Z	150
7.5	Vertical	X	330
	Tilted	Y	50
17.0	Vertical	X	380
	Tilted	Y	75

Table 3.1.3 shows results of leak tightness tests of the casks after drop tests. In any case of drop tests up to 17 m, the leakage was less than the design limit from the secondary lid although leakage was found from the primary lid at certain conditions.

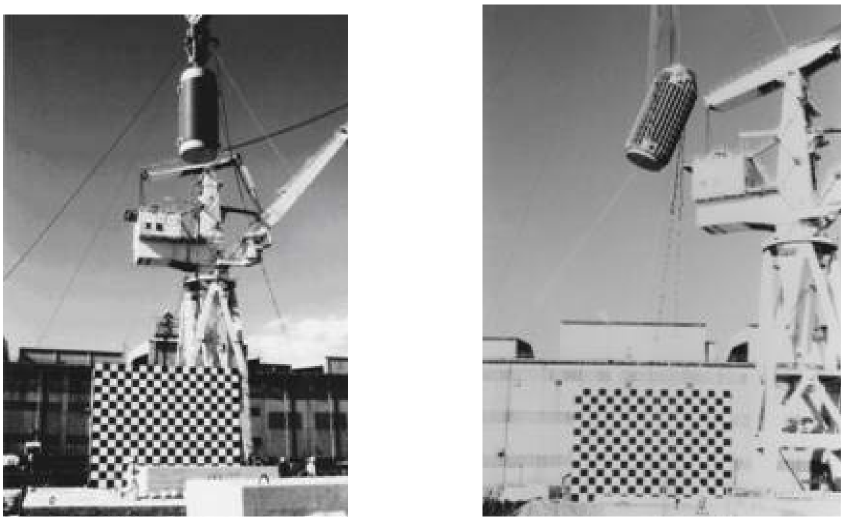

(a) Vertical drop test from 17 m high (b) Tilted drop test from 17 m high

Fig. 3.1.1 Casks about to be drop-tested in alternative orientations

Table 3.1.3 Leak tightness tests after drop tests

Drop test orientation	Drop height (m)	Leak rate (Pa-m^3/s)		
		Primary lid	Secondary lid	Design limit
Vertical	1.5	5 x 10^{-7}	3 x 10^{-9}	1 x 10^{-6}
	7.5	Beyond measurement	5 x 10^{-10}	
	17.0	Beyond measurement	3 x 10^{-10}	
Horizontal	1.5	5 x 10^{-10}	4 x 10^{-11}	
	5.0	Beyond measurement	2 x 10^{-7}	
Tilted	7.5	3 x 10^{-11}	2 x 10^{-11}	
	17.0	8 x 10^{-11}	6 x 10^{-11}	

3.2 Heavy Weight Drop Tests onto Cask by Building Collapse

A heavy weight drop test was carried out onto a full-scale cask simulating hypothetical collapse of a storage building due to earthquake, etc. by CRIEPI. Both mechanical and thermal integrity of the cask were tested and evaluated.

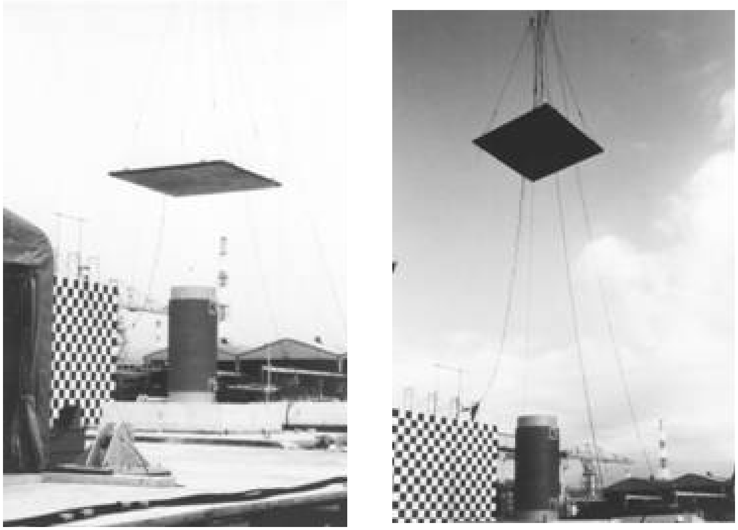

(a) Drop test from 5 m high (b) Drop test from 17.1 m high

Fig. 3.2.1 Concrete slabs about to be test dropped

3.2.1 Mechanical integrity of the cask

Fig. 3.2.1 shows concrete slabs drop tests onto the cask (the type X used for the previous test). A roof made of 160 mm thick reinforced concrete was dropped onto a cask from heights of 5 m and 17 m. No leakage from the cask lid and no stress larger than the yield stress in the cask body were measured by the test. The cask maintained its integrity by the building collapse [6].

3.2.2 Thermal integrity of the cask

Thermal integrity of the cask under thermally insulated condition covered with buried concrete debris was evaluated by experiments and analyses by CRIEPI [7]. A full-scale cask made of stainless steel and lead storing 21 PWR spent fuel assemblies was employed (Fig. 3.2.2). Table 3.2.1 shows test parameters and the results. Temperatures of cask components important to safety reached to steady state values in about 15 days, for the test cases I to III. The test case IV was maintained until 7 days and thereafter the result was estimated by analysis. The estimated temperature reached to a steady state value in two months.

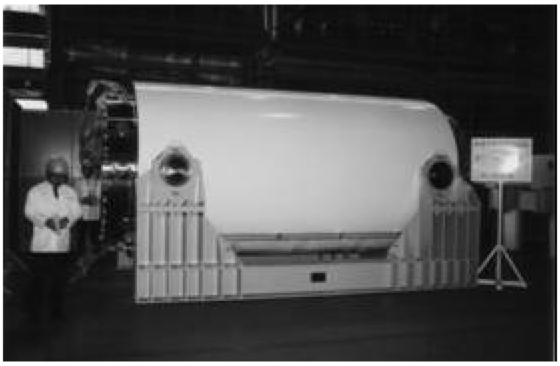


Fig. 3.2.1 A full-scale cask used for thermal performance test at building collapse

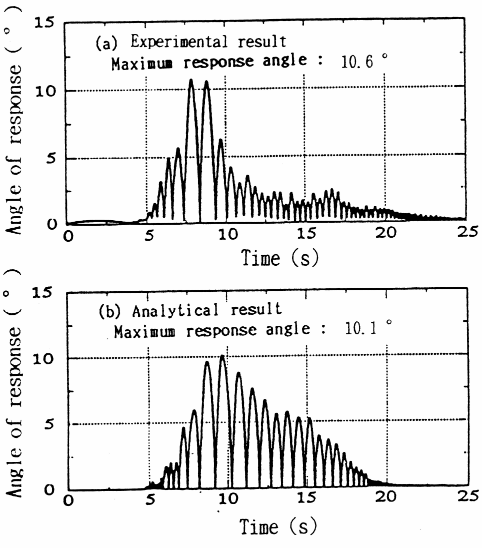
Leak tightness of the cask lids was measured by He leak method and vacuum method. For the cases I to III, the leak tightness was maintained after the burial tests. At the case IV, the leak tightness of the primary lid was maintained, but that of the secondary was not. Realistically, the cask will not be placed under the thermally insulated condition by the concrete debris. The cask will be partially cooled by the ambient air that comes in through gaps in the debris.

Table 3.2.1 Results of thermal performance tests and analyses at various test conditions of building collapse

	Temperature (°C) at various simulated test conditions				
Cask component important to safety	Case I : Lower part of a vertically standing cask is shut down from cooling air simulating burial with debris	Case II : Upper part of a vertically standing cask is covered with a hut simulating burial with debris	Case III : Upper part of a horizontally lying cask is covered with a case simulating burial with debris	Case IV : A horizontally lying cask is fully covered with rock wool simulating burial with debris.	Design Criteria on Max. allowable temperature
Spent fuel	335	349	320	423	500
Lead in body	208	226	201	239	327
Primary lid	171	207	156	242 in one month 248 in two month	250 for one month
Secondary lid	147	190	136	Not available	

3.3 Cask Toppling Tests by Earthquake

Analyses and experiments were performed by CRIEPI on a 1/3 scale-model of a cask (1.8 m in length, 1.0 m in diameter and 12 tons of weight) that is vertically standing and subjected to seismic motions on a shaking table simulating various types of earthquake [6]. Fig. 3.3.1 shows a result of response (rocking angle of the cask as a function of time for a long wave-length earthquake (Hachinohe-Wave experienced in Japan). The analysis and experimental results showed a good agreement. The maximum rocking angle will depend on the frequency of the earthquake wave length.



Critical angle of toppling : 19.9°

Fig. 3.3.1 Typical results of cask toppling for simulated Hachinohe earthquake

Table 3.3.1 shows the analytical results on response angle of the cask toppling by the simulated movement of the severest examples of the earthquake actually recorded and hypothetically magnified earthquakes for a study purpose. It is shown that the rocking (move-up) angle will not exceed the critical angle (19.9 degrees) for toppling, thereby the cask will not tip over by the earthquake.

Table 3.3.1 Analytical results on cask toppling response for seismic movement

Types of applied earthquake	Frequency (Hz)	Acceleration (gal)		Response angle (degree)
		Horizon.	Vertical	
S_2	2-6	354	213	0.4
		342	205	1.2
El Centro	2-5	342	206	0.2
		683*	413*	6.7
Hachinohe	0.5-18	203	150	0.0
		406*	299*	4.2

* : Hypothetically magnified values

3.4 Long-term Containment Tests

The function of sealing radioactive materials in a storage cask must be reliable for a long-term, e.g., 40-60 years. Long-term containment of metal gaskets in double lid structure of casks have been demonstrated with full-scale lid models at a constant temperature of 160 ℃ since 1990 (as shown in Fig. 3.4.1) by CRIEPI.

Fig. 3.4.1 Long- term containment tests using full-scale lids of metal cask

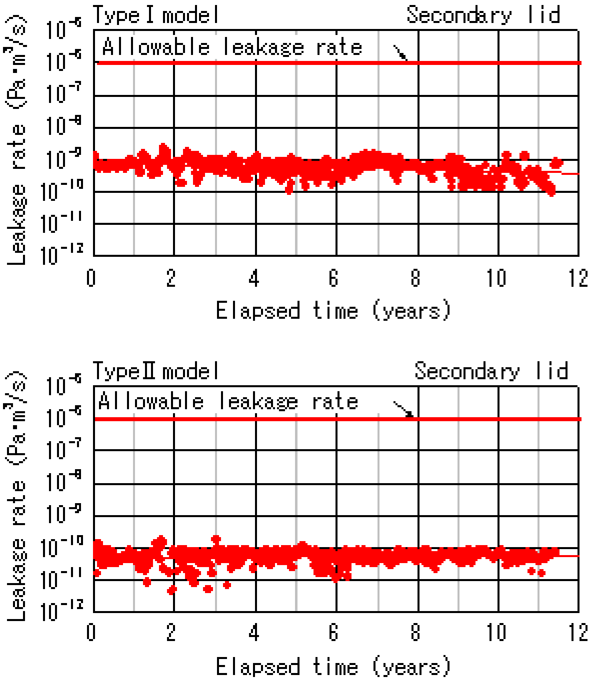


Fig. 3.4.2 Results of long- term containment tests

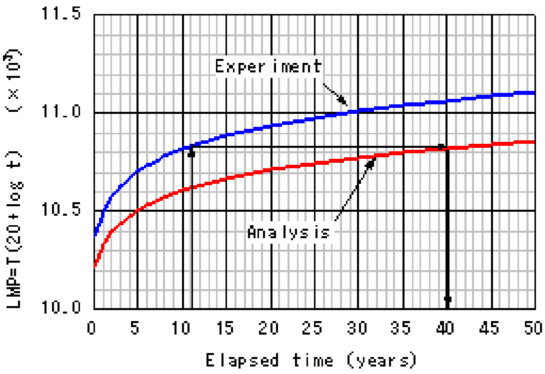


Fig.3.4.3 Estimation of long-term containment performance of the metal gaskets by tests & analysis

The results in Fig. 3.4.2 demonstrate the long-term containment for 13 years. In fact, the temperature of metal gasket as well as other components of the cask is decreasing with decay heat of spent fuel as a function of time. Thus, the results in Fig. 3.4.2 are those of accelerated tests. The realistic performance of the metal gaskets will be estimated through Larson-Miller parameter, as follows.

LMP = T(C + log *t*), where T is temperature (K) and *t* is time (h).

Plastic deformation ratio of the metal gaskets was found to be related to the Larson-Miller parameter as shown in Fig. 3.4.3 shows LMP value obtained by the long-term containment tests and that at conditions of real storage. The

LMP value at 11 years corresponds to that at approximately 40 years in real storage condition [8]. Currently, the long-term containment tests are still continuing and the containment is kept for 13 years corresponding to approximately 45 years in real storage condition.

3.5 Transportability Tests of Cask after Long-term Storage

On top of the above studies, studies on “Dual-Purpose Metal Cask Integrity after Long-term Interim Storage”, [15] have been carried out by Japan Nuclear Energy Safety Organization (JNES). R&D issues on degradation of materials in cask components and cask system due to long-term storage. as shown in Fig. 3.5.1 and Fig. 3.5.2 have been discussed. More recent results are presented in a paper entitled “Transportability of Cask after Long-term Storage” [22] in this PATRAM 2004.

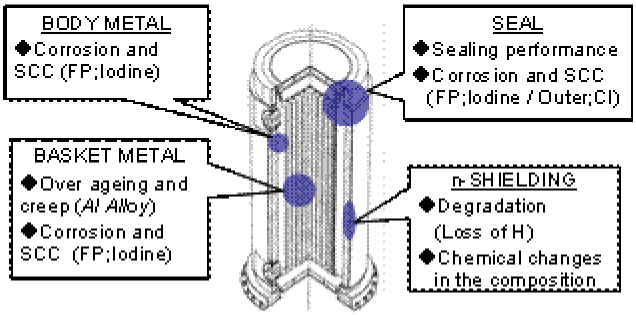


Fig. 3.5.1 R&D issues of materials in dual-purpose cask for transport after storage [15]

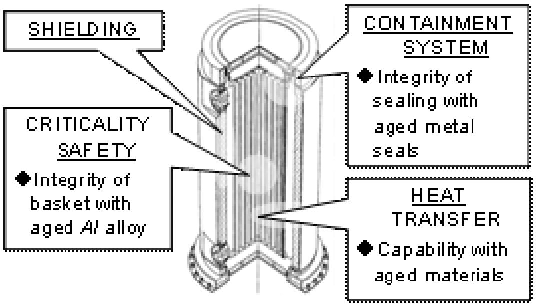


Fig.3.5.2 R&D issues of cask systems in dual-purpose cask for transport after storage [15]

3.6 Shielding Benchmark Experiment for Cask Storage Facility

Kosako and co-workers [18] carried out two kinds of benchmark experiments (huge duct streaming and cask shadow shielding) for three dimensional Monte Carlo calculation. Neutron distribution and dose were measured and also calculated by MCNP code. Good agreement between calculation and experiment was obtained. Applicability of MCNP to shielding calculation of spent fuel storage facility was confirmed.

3.7 Cask transportation System by Fluid Film Technology

Satoh and co-workers [19] performed verification tests of a Metal Cask Transportation System (MCTS) to transport a metal cask in vertical orientation in a storage facility. The MCTS showed good stability for transporting cask. It also showed seismic isolation behavior and no excessive acceleration of cask observed. Cask did not tip over and sliding distance was limited both for transportation and storage conditions against design basis earthquake.

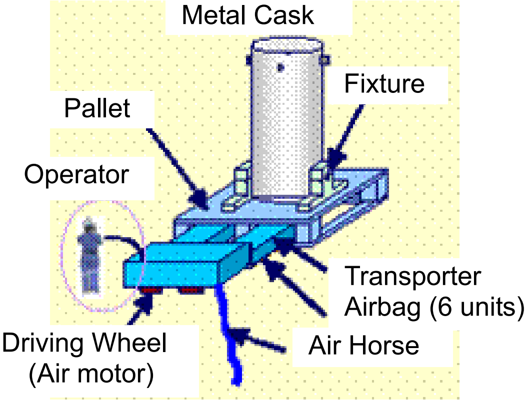


Fig. 3.8.1 Metal Cask Transport System

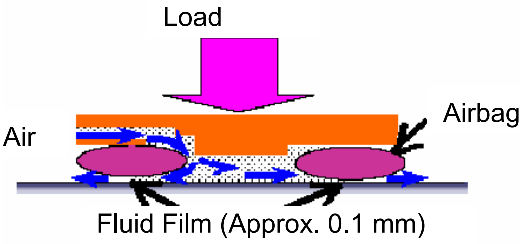


Fig. 3.8.2 Principle of Fluid Film Technology

3.8 Burnup Credit in Spent Fuel Transport and Storage

The JAERI recommended to develop more rational, systematic and simplified methods such as correction factors for depletion code or EUB which must be established for its reliability and generality. Checking burnup data by measurement might be replaced by referring to reactor management data, which must be verified for its reliability adequacy [20].

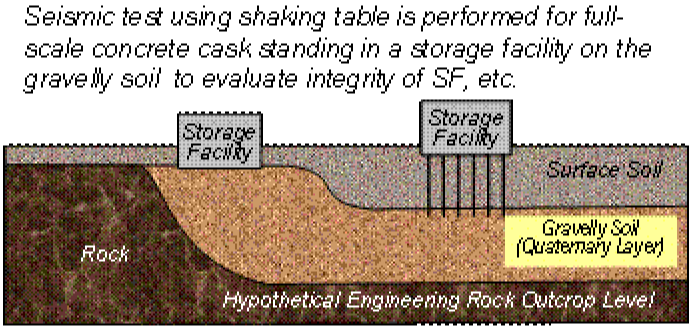
3.9 Ongoing R&D Program on Transport/storage Cask

For safety assessment of transport/storage metal cask, following tests using full-scale models are being performed in 2004-2005 by CRIEPI.

a. Drop test of metal cask without impact limiters in order to clarify inventory that may be released at the time of mechanical impact by drop accident.
b. Tipping-over test of a metal canister and simulated spent fuel assemblies by earthquake

Momentary leak from lid during impact

Fig. 3.6.1 Concept of drop test of metal cask without impact limiters



Seismic test using shaking table is performed for full-scale concrete cask standing in a storage facility on the gravelly soil to evaluate integrity of SF, etc.

Fig. 3.6.2 Concept of storage facility on gravelly soil

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