REVIEW AND FUTURE ISSUES ON SPENT NUCLEAR FUEL STORAGE

T. SAEGUSA[1*], K. SHIRAI[1], T. ARAI[1], J. TANI[1], H. TAKEDA[1], M. WATARU[1], A. SASAHARA[1] and P. L. WINSTON [2]
[1] Central Research Institute of Electric Power Industry (CRIEPI)1646 Abiko, Abiko, Chiba, 270-1194, Japan
[2] Idaho National Laboratory (INL) P.O. Box 1625, Idaho Falls, ID, 83415,USA.
[*]Corresponding author. E-mail : saegusa@criepi.denken.or.jp

Received May 01, 2010

The safety of metal cask and concrete cask storage technology has been verified by CRIEPI through several research programs on demonstrative testing for the interim storage of spent fuel. The results have been reflected in the safety requirements for dry casks issued by NISA/METI (Nuclear and Industrial Safety Agency, Ministry of Economy, Trade and Industry) of the Japanese government. On top of that, spent fuel integrity has been studied by the Japan Nuclear Energy Safety Organization (JNES). This paper reviews these research programs. Future issues include the long-term integrity of cask components and high burn-up spent fuel.

KEYWORDS : Spent Fuel Storage, Metal Cask Storage, Concrete Cask Storage, Spent Fuel Integrity, Full-scale Cask Tests

1. INTRODCTION

As of the end of 2007, 55 commercial nuclear power units are operating in Japan, with a total electric generation capacity of 49,467 MWe. Nuclear power generation accounts for 30.5% of the total electric power generation, with 2 power plants currently under construction and 11 plants in preparation for construction. All 16 nuclear power plant sites have storage pools for spent fuel. The total amount of spent fuel stored at these sites was approximately 12,140 tHM as of September 2007, compared to a capacity of 19,000 tHM.

The *Framework for Nuclear Energy Policy*[1] was issued by the Atomic Energy Commission on October, 2005. According to this framework, spent fuel will be reprocessed, and the surplus amount exceeding the capacity will be stored intermediately. Construction of spent fuel interim storage facilities at NPP sites or outside of NPP sites is expected to be realized soon.

In addition, NISA issued the technical requirements on interim spent fuel storage facilities (ISFs) using dry metal casks and concrete casks on April 2006[2, 3]. In Japan, the first ISF outside of an NPP site in use of a dual-purpose metal cask, as shown in Fig. 1, is scheduled to start its commercial operation in 2012 in Mutsu city, Aomori prefecture.

In parallel with these regulatory and promoting activities of ISF, CRIEPI has performed supportive research studies for the regulation and early realization of ISF. Key issues of these studies include the safety requirements in the operation and maintenance during spent fuel storage and unloading/loading for transportation, long-term integrity of metal canisters and concrete materials, etc. In 1997, CRIEPI completed the research program of the demonstration test for the interim storage of spent fuel, mainly involving concrete cask storage technologies, to reflect the technical requirements issued by NISA. Moreover, a new research program for the verification testing of cask integrity under long-term dry storage conditions was undertaken. The schedule for these

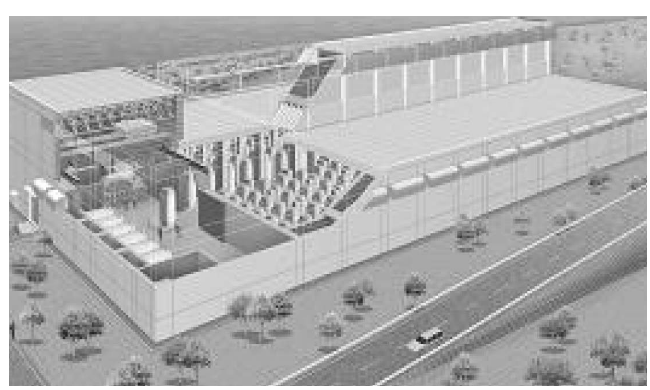


Fig. 1. First Interim Storage Facility Outside of NPP Site in Japan (3,000tU)

programs is shown in Table 1. On top of that, the JNES has conducted research on spent fuel integrity, as shown in Table 2. This paper summarizes these research programs.

2. CONCRETE CASK PERFORMANCE TEST WITH FULL-SCALE CASK

2.1 Demonstration Test

Concrete cask performance tests with a full-scale cask, including heat removal tests, drop tests, and seismic tests have been successfully completed during the phase 1 and phase 2 programs. To perform heat removal tests and drop tests with full-scale test bodies efficiently, a demonstration test facility, as shown in Fig. 2, was constructed in the Akagi Test Center of CRIEPI. In this facility, there are heat removal test areas and drop test areas. In the drop test area, a steel plate is fixed on the base concrete. The size of the steel plate is 7.5m long, 4.5m wide, and 50mm thick. The thickness and weight of the base concrete are 2m and 550tons, respectively. The preliminary design parameters are shown in Table 3. The concrete cask was assumed to be for indoor use.

2.2 Heat Removal Test

Two types of concrete casks, a reinforced-concrete cask (RC cask) and concrete-filled-steel cask (CFS cask)

Table 1. Test Programs for Storage Cask in CRIEPI

Program Item	2000	2001	2002	2003	2004	2005	2006	2007	2008
Concrete Cask Performance Test									
a. Basic Design									
b. Fabrication of full-scale concrete cask									
c .Demonstration tests - Heat removal			*Full-Scale*						
- MPC Drop					*Full-Scale*				
- Seismic	*1/3scale*					*Full-Scale*			
d. SCC evaluation test									
Containment Performance Test of Metal Cask									
a. Drop Test without Impact Limiter					*Full-Scale*				
b. Aircraft Crush Test							** Horizontal Test : 2/5Scale* ** Vertical Test : Full-Scale*		
c. Long-term Confinement Test of Lid Structure					*Full-Scale*				

Table 2. Test Programs on Spent Fuel Integrity in JNES

		2000	2001	2002	2003	2004	2005	2006
Survey and Planning								
Creep Test	Creep test	PWR48GWd/t, BWR50GWd/t					PWR55GWd/t, BWR55GWd/t	
	Creep rupture test	PWR48GWd/t, BWR50GWd/t						
Hydride Effects Evaluation Test	Hydride reorientation test Mechanical property test						PWR48GWd/t,55GWd/t BWR50GWd/t,55GWd/t	
Irradiation Hardening Recovery Test		PWR48GWd/t, BWR50GWd/t 330deg.C-420deg.C						<330deg.C

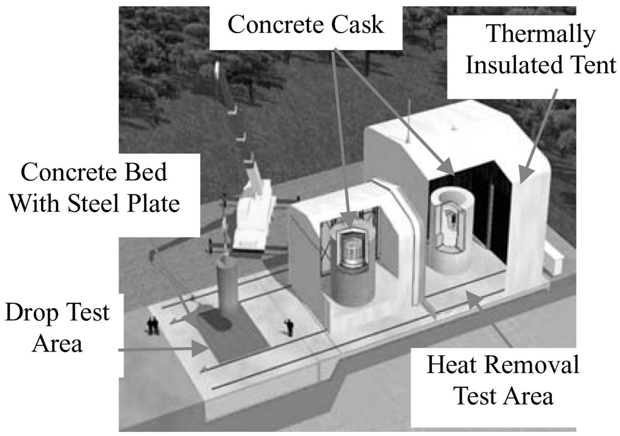


Fig. 2. Demonstrative Cask Test Facility

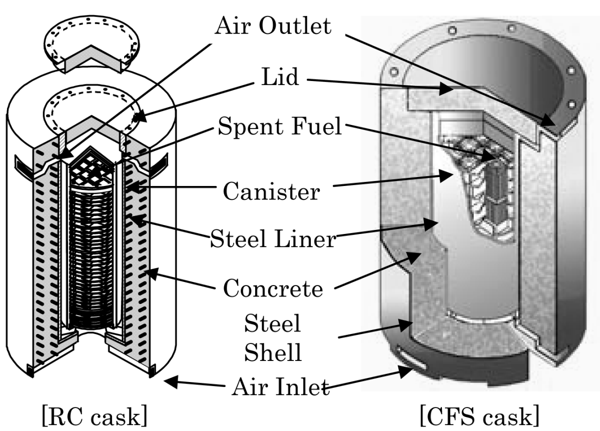


Fig. 3. Outline of the Two Types of Casks

Table 3. Design of Concrete Cask

Design storage period	40~60 years
Fuel type	17×17 array for PWR
Enrichment (wt % U^{235})	4.9%
Burn-up (Max)	55 MWd/kgHM
Cooling time	10 years
Environmental temperature	33°C
Storage cell	21
Total heat load (max)	22.6 kW

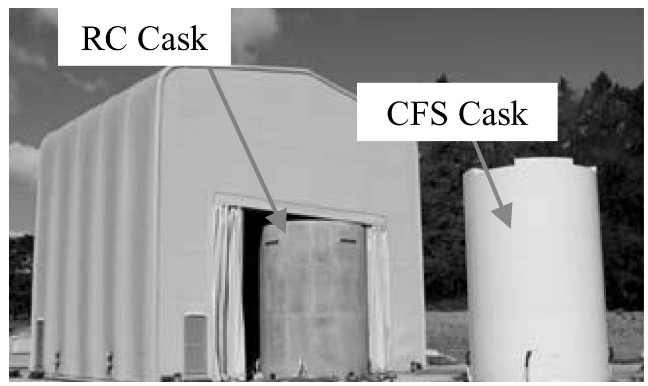


Fig. 4. Test Yard of Full-Scale Casks

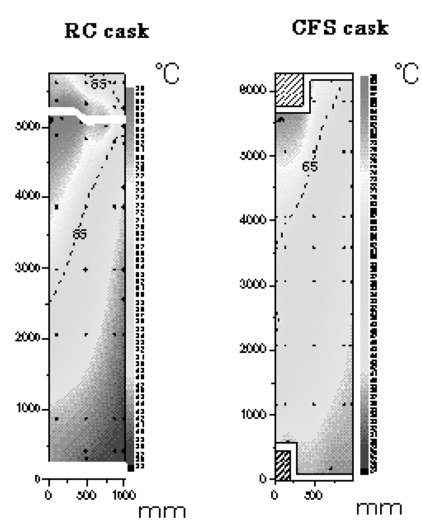


Fig. 5. Temperature Distributions of the Concrete Bodies in Normal Conditions

to store the high burn-up spent fuel, were designed. The preliminary designs for the two types of cask, the RC cask and CFS cask, were employed as the basic structure, as shown in Fig. 3. Two types of the concrete casks have been constructed in the test facility as shown in Fig. 4.[4, 5].

Fig. 5 shows the temperature distribution of the concrete inside for the test case of the initial storage stage with 22.6kW with an RC cask. The maximum value in the vicinity of the outlet duct was 91°C and exceeded the allowable temperature limit value for the long-term; i.e., 90°C[6]. In both casks, the canister surface temperature was below 100°C in the tests case of the final storage stage with 10.0kW, which may be susceptible to the atmospheric stress corrosion cracking of the stainless steel in a salty air environment.

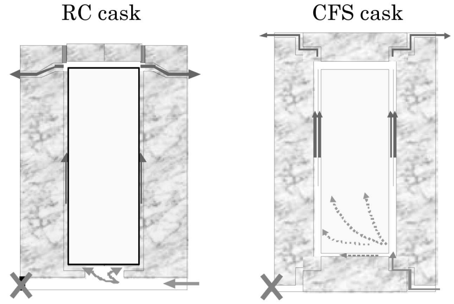
Considering the possibility of accidents, the tests were performed under the condition of blockages of two of the four inlets. In the RC cask, the air is uniformly distributed to the annulus gap from the bottom cavity. On the other hand, in the CFS cask, the air flows to the annulus gap directly, as shown in Fig. 6. In both casks, the maximum temperatures in the concrete container were under the allowable temperature limit value for the short-term, i.e., 175°C[6] within 24 hours.

2.3 Canister Drop Test

Table 4 shows the drop test conditions for the full-scale MPC[7]s. Two drop tests in the horizontal and vertical orientations were conducted considering non-mechanistic drop or impact events during handling, and the drop heights were 1m and 6m, respectively. Regarding contents of MPC, dummy steel structures equal to the total weights of the spent fuels (14.7ton) were used.

Fig. 7 shows photographs of the test MPC before and after the horizontal drop test. The test MPC was slightly deformed near the impacted area. He leak tests were performed before and after the drop tests to confirm the integrity of the leak-tightness of the test MPCs (especially welded lids) against impact loads. Measured leakage rates showed the integrity of the leak-tightness at the lids and MPC shell, as all values were under 1.0×10^{-9} Pa*m^3/s.

Fig. 8 shows a photograph of the test MPC in the vertical drop test. According to the He leak tests performed before and after the drop tests, the measured leakage rates



Symbol × means the position of inlet blockage.

Fig. 6. Flow Patterns under 50% Blockage of the Inlet Ducts

Fig. 7. Horizontal Drop Test of Canister

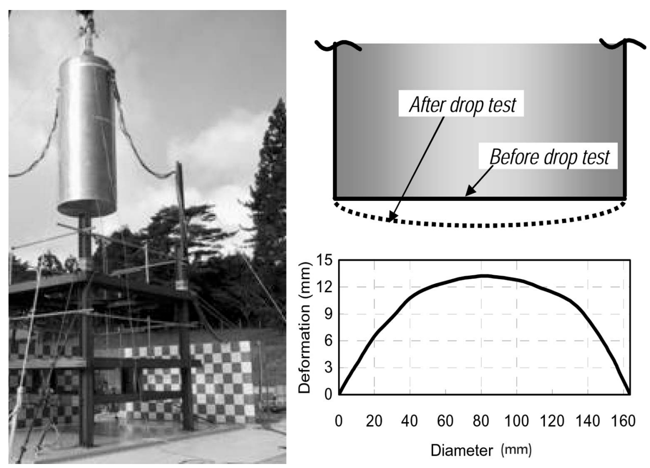
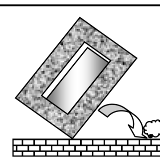
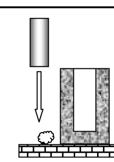


Fig. 8. Vertical Drop Test of Canister and its Deformation

Table 4. Drop Test Conditions of Canister

Non-mechanical drop or impact events during handling	Tipping-over Event : Equivalent drop height for rotational velocity caused by tipping-over from height of Gravity Center 	Drop Event : Drop height from cask height 
Orientation	Horizontal	Vertical
Height	1m*	6m**
MPC	Type I	Type II

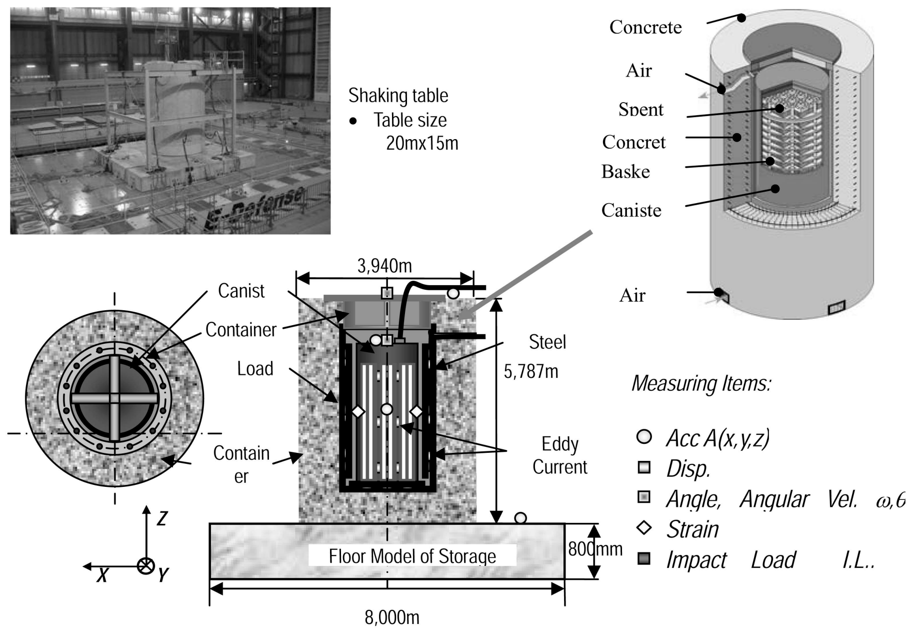


Fig. 9. 3-D Earthquake Testing with Full-Scale Concrete Cask and Concrete Floor

showed the integrity of leak-tightness at the lids and MPC shell, as all values were under 1.0×10^{-9} $Pa{\cdot}m^3/s$. From these results, it seems that the crack initiation may be avoided in the drop events with the vertical orientation, even if an impact load over 1000G was applied.

2.4 Seismic Test

For a vertically free-standing concrete cask on the floor pad in the cask storage facility, its tip-over and sliding behavior and the integrity of the spent fuel during strong seismic motions are still the technical key issues to guarantee its safe performance. Seismic tests with a full-scale cask (Fig.9) indicated that the cask would not tip over and the integrity of spent fuel would be maintained under typical Japanese design seismic loads[8].

2.5 SCC Evaluation Test

Interim storage facilities are likely installed at coastal sites in some countries. As the temperature decreases during the storage period, salt condensation increases on the metal canister surface. Key issue for the realization of the metal canister storage technology should be the long-term integrity of the canisters, considering the deterioration of the containment function of the metal canisters in a salt water environment.

2.5.1 SCC Test of Stainless Steels

Austenitic stainless steels are susceptible to stress corrosion cracking (SCC) in salty environments under tensile stress. The type of SCC induced by sea salt particles, chlorides, for example, is called external SCC (ESCC) or atmospheric SCC since the cracking starts from outside of the equipment in air, as shown in Fig. 10.

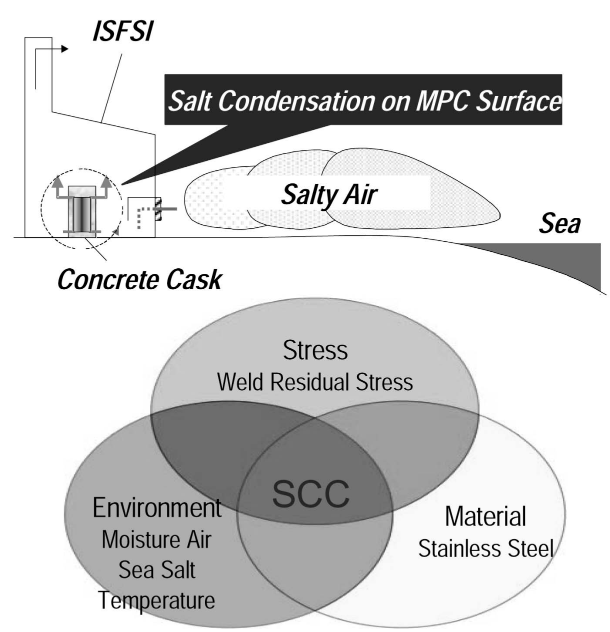


Fig. 10. Deterioration of Metal Canister in Salty Air Environment

The storage canister has several welding lines in the wall and lid which probably have high residual tensile stresses. Contamination by sea salt particles is also expected during the long service life of MPCs, as mentioned previously. Thus, to prevent penetration through the wall thickness, susceptibility to ESCC should be evaluated carefully for high corrosion resistance stainless steels (SUS 329J4L and YUS 270)[10]. Since 2004, CRIEPI has begun SCC evaluation tests to clarify basic deterioration mechanisms. Tensile specimens were attached to a loading apparatus that uses a spring to apply a constant stress, as shown in Fig. 11. After synthetic sea water deposition, the loading apparatuses with one specimen each, as shown in Fig. 12, were placed in constant temperature and humidity chambers considering the canister surface condition in the actual storage. The results are as follows:

a. The SCC is generated at a humidity of not less than 15% and a temperature of not less than 25°C.
b. Based on the actual weather survey value in a certain location near the seashore and the temperature decrease over the years of the canister surface used for the concrete cask storage, the time needed for SCC to generate (wetting time) was calculated as 58,400 hours.
c. In SCC testings with conditions (80°C, 35% of humidity) severer than a real environment under a constant load using 2 mm-thick specimens, SUS 304 materials were fractured in about 250 hours, whereas high corrosion resistance stainless steels did not fracture for at least 62,500 hours.
d. At the above-mentioned location, the loss of the containment function by the SCC of the canister could be prevented by selection of high corrosion resistance stainless steel.

2.5.2 Salt Particle Collection Test

From 2007, a salt particle collection performance test was undertaken to evaluate the effectiveness of such a device. The outline of the salt particle collection device designed by CRIEPI is shown in Fig. 13. The device might be attached to the inlet for natural cooling of the cask storage facility and consists of the multiple layered trays with a certain amount of water. When the air including sea salt particles goes through the trays, a part of the sea salt particles in the cooling air might be trapped by collision with the water of the trays. The top surface of each tray has projections to make the air collide with the water surface effectively. The salted water is discharged out of the facilities by overflowing these trays.

2.5.3 MPC Surface Inspection Test

Inspection of the canister surface was carried out using an optical camera inserted from the air outlet through the annulus of a concrete cask (VSC-17). The VSC-17 has been storing spent nuclear fuel for over 15 years as part of a dry cask storage demonstration project at Idaho National Laboratory (INL), as shown in Fig. 14

Fig. 15 shows photographs of the surface of the MPC. They were snapped by an optical camera inserted from the air outlet through the annulus of a concrete cask. According

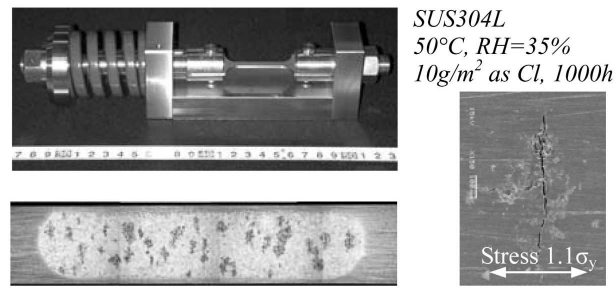


Fig. 11. SCC Test with UNS S30403 SS

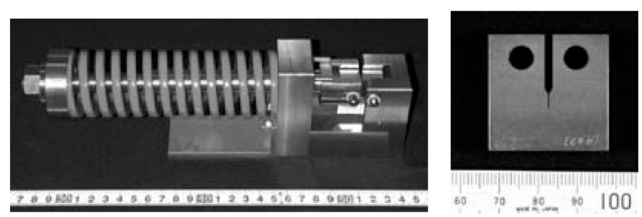


Fig. 12. SCC Crack Growth Test

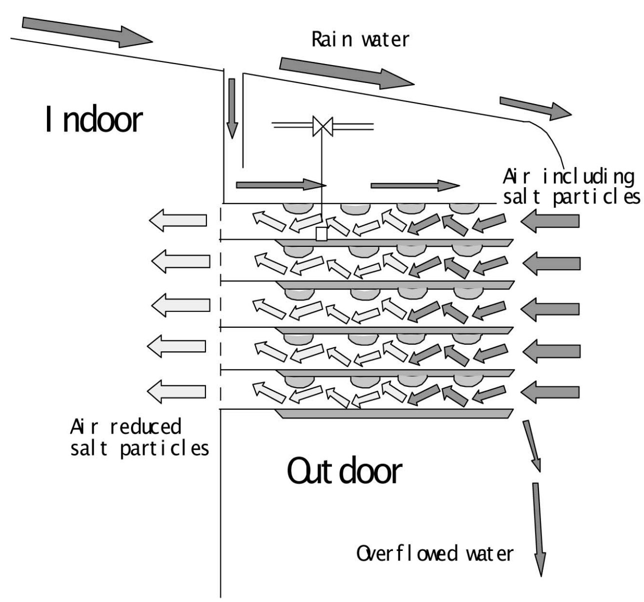


Fig. 13. Salt Particle Collection Device

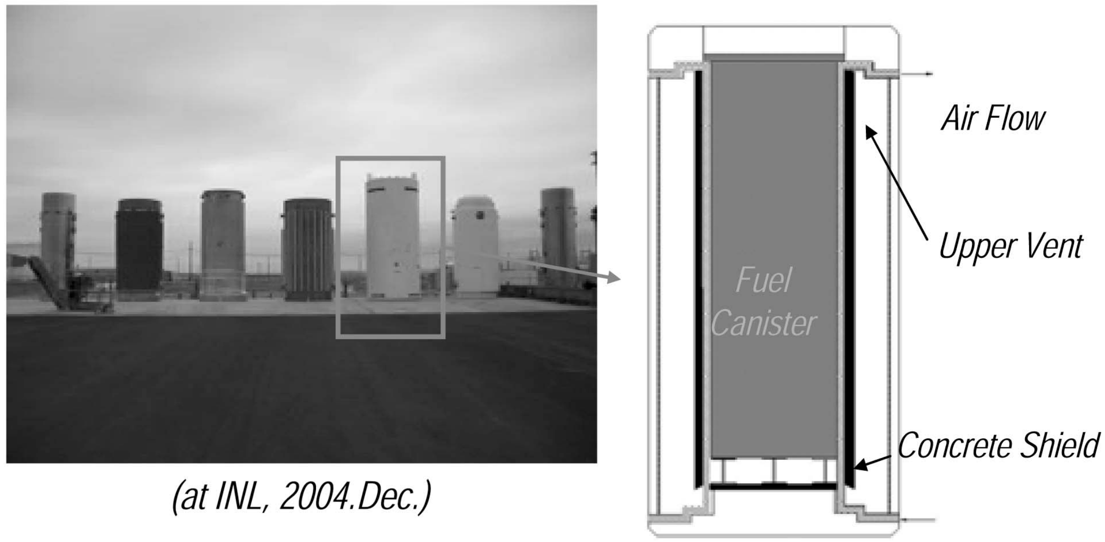


Fig. 14. Concrete Cask (VSC-17) at INL

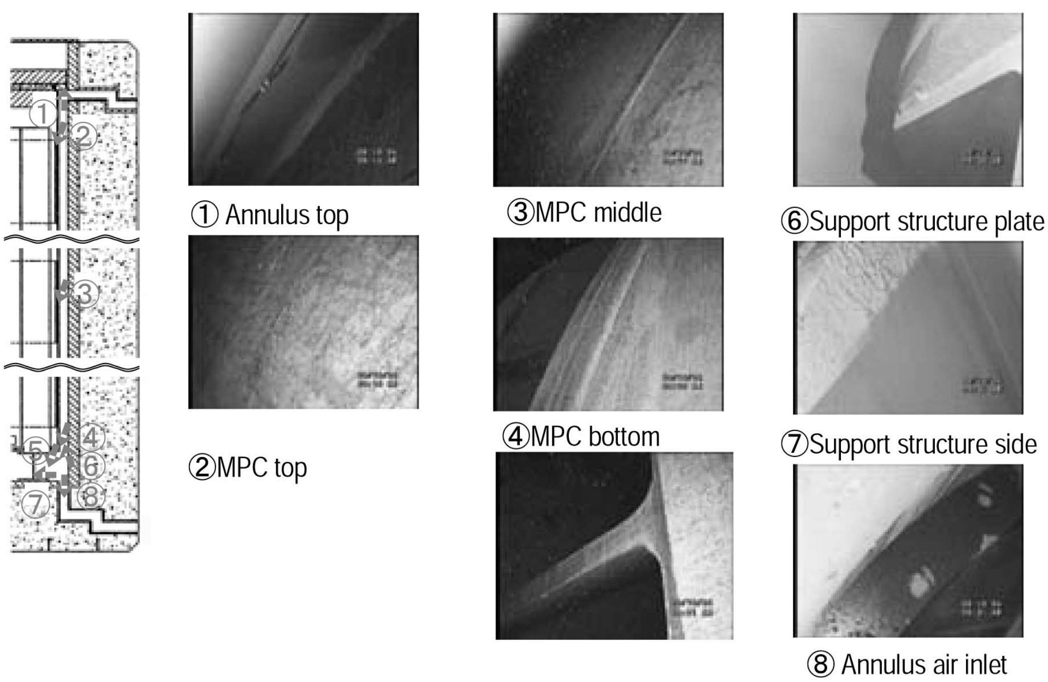


Fig. 15. Photographs of the MPC Surface

to the visual inspections, since there is some surface rust present but no large scale flaking, it seems that there is no gross corrosion, pitting, or general attack, and all coatings appear to be intact. Moreover, there is no considerable indication that the MPC support beams have undergone any structural degradation.

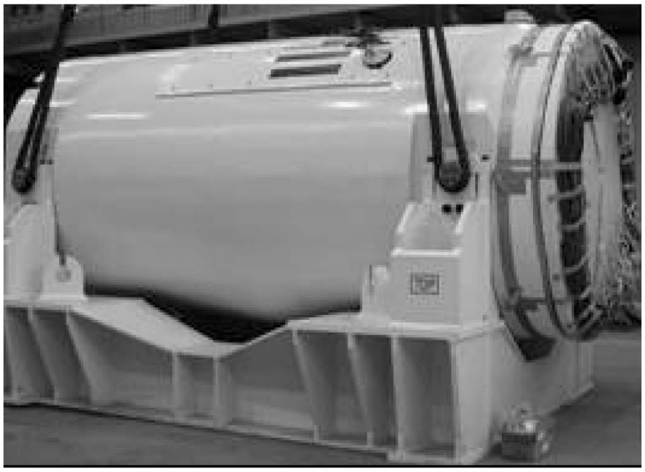


Fig. 16. Overview of Full-Scale Metal Cask Model

3. METAL CASK PERFORMANCE TEST WITH FULL-SCALE CASK

3.1 Drop Test Without Impact Limiters Under Accident Simulation Conditions

In an interim storage facility of spent fuel, metal casks will be handled without impact limiters. Therefore, leak tests were performed using a full-scale metal cask without impact limiters considering drop accidents during handling in a storage facility. The instantaneous leak rate was quantitatively measured at the drop tests[11].

Fig. 16 shows overview of a full-scale metal cask model for impact analysis. This model has been designed as metal cask for dry storage and transportation installing 21 PWR-type fuel assemblies.

A series of impact tests using the full-scale cask

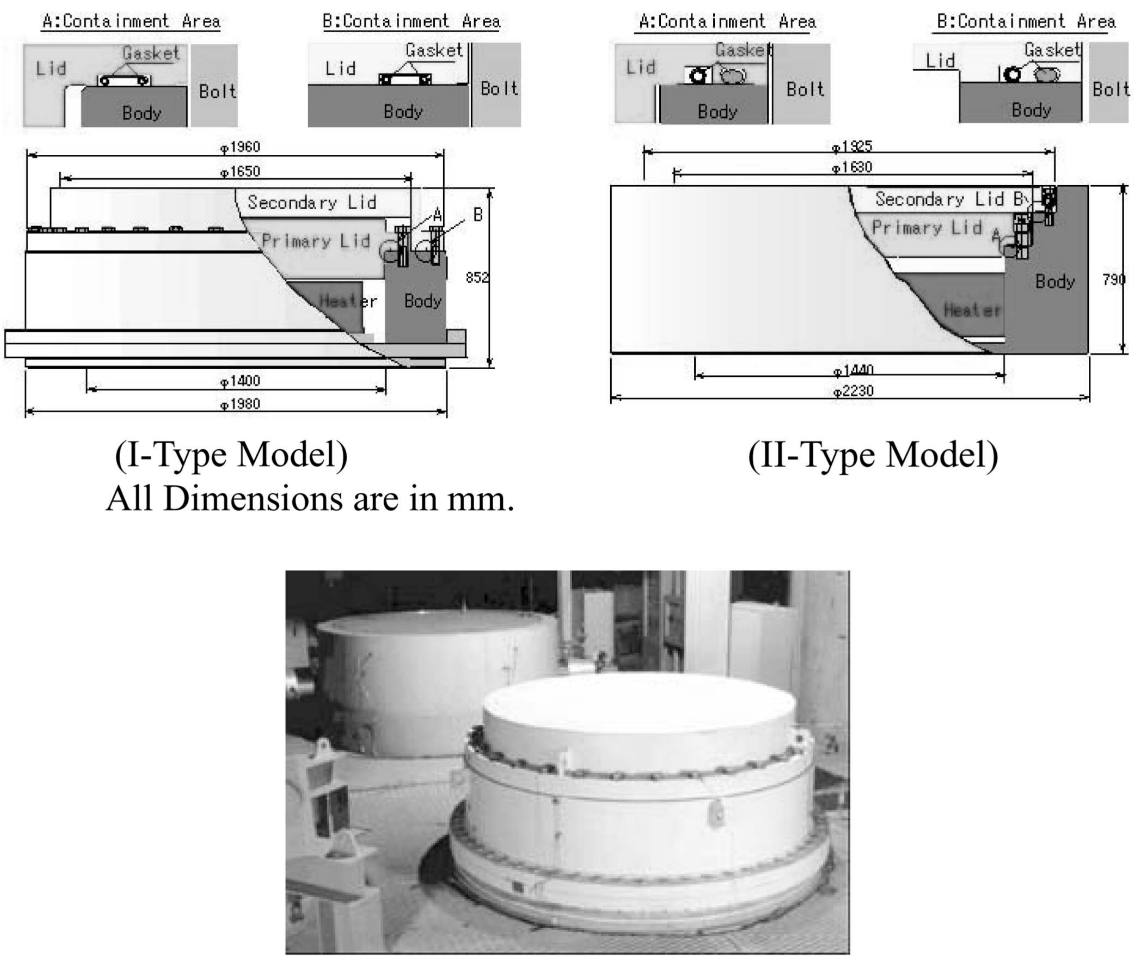


Fig. 17. Long-Term Containment Test Models

described above (a horizontal drop test from a 1m height and a rotational impact test around an axis of a lower trunnion of the cask from the horizontal orientation at a 1m height) were conducted on the reinforced concrete slab simulating the floor structure of the facility. The main measurement items are the sliding and opening displacements of the primary and secondary lids, leak rates, and inner pressure in the volume between the two lids. In the drop test, non-degraded (fresh) metal gaskets were used.

3.2 Long-Term Containment Performance Test of Metal Cask

The containment function is secured by inserting gaskets between the cask body and the lid and then bolting them together. Metal gaskets are used for long-term durability. Therefore, it is very important to clarify the influence of the stress relaxation of the gaskets on the containment performance of the metallic gaskets for a long-term usage.

Fig. 17 shows the two kinds of tested lids that are parts of full-scale model casks. In the I-type model, the cask body and lid are made of forged carbon steel. The sealing surface is overlaid with stainless steel welding (SUS304), and a double metal gasket (enveloped with aluminium) is installed. In the type-II model, the cask body is made of ductile cast iron, and the lid is made of stainless steel. In this model, an inner metal gasket (enveloped with silver), and an outer rubber gasket (silicone rubber) were installed. In both models, the test temperature (130~140°C at the secondary lid) was maintained with the electrical heaters installed in the cask cavities.

Containment of the secondary lid has been tested using a helium leak detector about twice a month for more than 19 years under a constant temperature. The containment performance has been demonstrated and confirmed to have as low of a leakage as 10^{-9}Pa·m^3/s. Moreover, by applying the Larson-Miller Parameter, the results indicate that the containment will be maintained for more than 100 years, taking account of the decay heat of the nuclear spent fuel[12].

3.3 Aircraft Crash Test

To investigate of the integrity of the lid structure of the metal cask during extreme impact loads due to aircraft crashes, two impact scenarios for an aircraft engine crash onto the metal cask without impact limiters are considered for both: a vertical impact onto the lid structure and a horizontal impact hitting the cask, as shown in Fig. 18[13]. The horizontal impact test using a scale model engine of an aircraft has been executed and the leak rate from the metallic gasket in the cask also measured at the impact in the test.

The scale cask was mounted on a supporting flame structure by the specific panel. The reaction forces were measured by six load cells installed between the panel and the supporting flame.

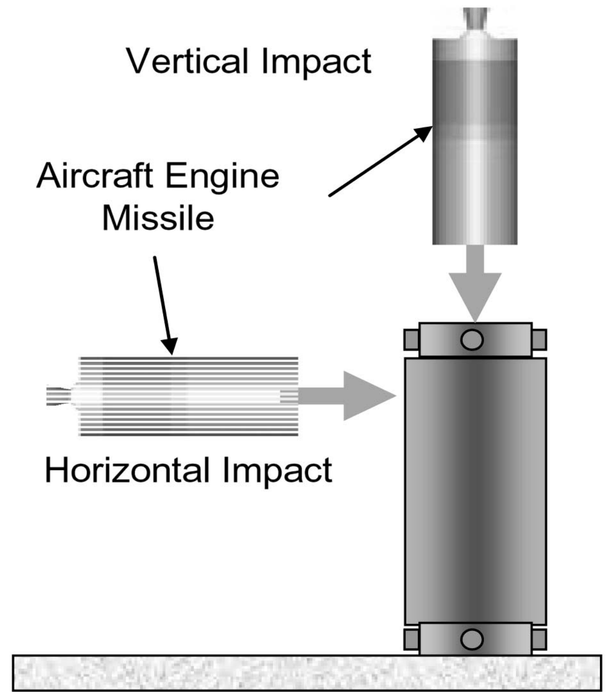


Fig. 18. Considered Scenarios for Aircraft Engine Crash onto the Metal Cask without Impact Limiters

The leak late from the lid was measured during the impact test. Although the leak rate value from the lid immediately increased by 5 orders of magnitude during the impact, the leak rate shows the high quality of the leak-tightness at the lid, as the value is under 1.0×10^{-5} Pa·m^3/s. From this test result, it seems that the loss of the inner pressure of the cask cavity may be avoided in an impact event with the horizontal orientation even if a severe impact load is applied onto the metal cask due to the aircraft engine crush.

4. SPENT FUEL INTEGRITY

CRIEPI has proposed a method to calculate the maximum allowable temperature of fuel cladding during storage assuming that the integrity of the fuel cladding is predominantly impaired by creep deformation[14]. Post irradiation examinations (PIEs) of spent BWR-MOX and PWR-UO_2 fuel rods irradiated in commercial LWRs and stored for 20 years were carried out to evaluate fuel integrity during storage[15]. The PIEs results showed no marked difference in the visual inspection of the cladding surfaces, fission gas release, oxide layer thickness on the cladding, pellet microstructure, and cladding mechanical properties or hydride orientation after storage.

The Japan Nuclear Energy Safety Organization (JNES) had investigated the technical subjects to be considered for maintaining the integrity of spent fuel during long term storage, and the test plans were established[16,17,18]. The factors which may affect the fuel integrity under dry storage condition are as follows:

(a) thermal creep,
(b) hydrogen effect in the cladding (hydrogen solution, hydride precipitate, hydride re-orientation, hydrogen migration according to the temperature gradient),
(c) irradiation damage recovery,
(d) stress corrosion cracking,
(e) cladding oxidation,
(f) He generation according to alpha-decay
(g) change of pellet characterization.

Factors (d) - (g) have not been adequately studied since the spent fuel was stored in an inert atmosphere environment and there may not be a significant change in the chemical condition in a fuel rod, so they were omitted from the scope of the project. On the other hand, the creep behavior of fuel cladding was regarded as the most important issue for spent fuel integrity based on the references. On subjects (a) and (b), it was judged that obtaining the creep data of spent fuel cladding is necessary as well as evaluating hydrogen effects (solution, precipitation, re-orientation). Moreover, preparation of the basic data for evaluating the cladding strength change during long-term dry storage due to the irradiation damage recovery is important for subject (c).

The JNES tests were composed of hydride effect evaluation testing, irradiation hardening recovery testing, and creep testing. In hydride effect evaluation testing, hydride reorientation testing has been performed in order to evaluate the correlation between hydride reorientation behavior and conditions, such as hoop stress, temperature, and cooling rate for BWR and PWR irradiated cladding tubes. As for creep behaviour, JNES had already established the creep equation based mainly on secondary creep rate evaluation for 50GWd/t type BWR and 48GWd/t type PWR fuel cladding tubes in 2003. The creep rupture behaviour had been evaluated for the same type of cladding tubes. The creep property of both BWR and PWR 55GWd/t type fuel cladding tubes was evaluated in 2006.

5. FUTURE ISSUES ON SPENT FUEL STORAGE

There are some issues relating to long-term storage and so on.

a. *SCC of canister in concrete cask storage*

Although the above-mentioned measure against SCC by the use of the high corrosion resistance stainless steel is one solution, it brings about a cost increase. The CTIEPI are now promoting research of measures against SCC that suppress this cost increase. That is, using the environmental data (actual measurement of salt concentration in the air) of a site near the sea coast and reducing the welding residual stress by Low Plasticity Burnishing, the measure against SCC of normal stainless steel (SUS 304) will be evaluated.

b. *Transport after Storage*

Dual purpose metal cask storing spent fuel shall be transported after interim storage. The transport license of the metal cask should be renewed every five years depending on the country. The license renewal may require inspection of the integrity of the spent fuel and cask components. The metal cask will not be open for inspection during storage; thus, alternative measures for the inspection should be provided. Transport/storage working groups of the NISA/METI of the Japanese government have issued a report[19]. The report describes alternative measures for the visual inspection of the fuel basket and spent fuel, and inner pressure measurement. The report concluded that records and documents before and during storage could be alternative measures for the necessary inspections. The report added that more data on the long-term integrity of the metal cask and spent fuel shall be continuously accumulated. The current data on spent fuel integrity are those of normal burn-up spent fuel. More data on high burn-up spent fuel will be required in the future.

Institutionally, the transport license shall meet the transport regulation at the time of transport. Some countries are having problems with relicensing the metal cask after storage. The IAEA Regulations for the Safe Transport of Radioactive Materials (TS-R-1) of 2009 edition stipulates Transitional Arrangements that allow the use of casks approved under the Regulations of 1973 and 1985 editions. It does not allow for the use of casks designed and manufactured under the Regulations of older editions. Spent fuel transport/storage casks designed and manufactured under current regulations may not be used in the future, unless the cask meets the future regulations.

c. *Large capacity for storage*

In the beginning of the history of spent fuel storage, interim storage might have played a role in emergency evacuation from reactors. A dual purpose cask (transport/storage) is a good measure to meet the initial storage needs. Metal cask storage and concrete cask storage methods have been chosen by most countries. However, after some time, more economical storage methods would be needed. Large capacity storage facilities are sought after now and will be desirable in the future.

Larger capacity casks or canisters are the early solution for such needs. This was made possible to design the canister with pressurized helium gas and/or an aluminum basket that enhances the effective heat removal from spent fuel.

Burn-up credit will allow designer to increase the capacity of the storage unit. Current fuel basket design is based on the nuclide composition of fresh fuel. In fact, the uranium enrichment of fresh fuel will be around 4% and that of spent fuel will be reduced to around 1%. Nevertheless, sub-criticality design is currently based on the fresh fuel. Some countries have begun to adapt burn-up credit for the storage of spent fuel.

The vault storage method is known to be economical for storage facilities with large capacity. If the interim storage of large capacity were planned from the beginning, the vault storage method would be chosen due to its economical advantage as compared to that of cask storage methods. Currently, the temperature limit of concrete structure is 65 degrees Celsius. An effort to increase the temperature limit, e.g. up to 80 degrees Celsius, is being made by CRIEPI, among others. The increase of the temperature limit will enable more efficient and economical storage of spent fuel in the future.

d. *Tunnel storage*

Some countries have more mountains than flat land. It is advantageous for such countries to dig a tunnel to store spent fuel in the mountains. The mountains could shield the radiation from spent fuel. Digging tunnels will not significantly damage the natural view. Seismic influence will be reduced in the tunnel so that the storage rooms will be more stable than that on flat land. In fact, a metal cask storage facility in a tunnel has started operation recently in Germany.

6. CONCLUSIONS

In Japan, utilities are planning to commence the operation of the first ISF in 2012. The regulatory authority correspondingly modified the reactor regulation law and has been settling the relevant safety rules to operate the interim storage facility. To prepare for the safety requirements and promote a rational reviewing procedure for the application of the ISF establishment license, CRIEPI is steadily performing key research studies, which include the degradation of cask component materials, leakage from the lid at accidents during the subsequent transportation after storage. The JNES showed a supportive study on spent fuel integrity. Future issues for spent fuel storage will include the long-term integrity of cask components and high burn-up spent fuel.

ACKNOWLEDGMENTS

Part of these works has been carried out under a contract from NISA/METI of the Japanese government.

REFERENCES

[1] Atomic Energy Commission of the Japanese Government, “Framework for Nuclear Energy Policy”, (2005).

[2] Nuclear and Industrial Safety Agency of the Japanese Government, “Technical Requirements on Interim Spent Fuel Storage Facility Using Dry Metal Cask”, NISA-314c-06-02, (in Japanese), (2006).

[3] Nuclear and Industrial Safety Agency of the Japanese Government, “Technical Requirements on Interim Spent Fuel Storage Facility Using Dry Concrete Cask” NISA-314c-06-01, (in Japanese), (2006).

[4] H. Takeda, et. al., "Heat Removal Verification Tests Using Concrete Casks under Normal Condition", NED 238, pp.1196-1205, (2008)

[5] M. Wataru, et. al., " Heat Removal Verification Tests of Full-Scale Concrete Casks under Accident Conditions ", NED 238, pp.1206-1212, (2008)

[6] Japan Society of Mechanical Engineers, “Code for Construction of Spent Nuclear Fuel Storage Facilities –Rule on Concrete Casks, Canister Transfer Machines and Canister Transport Casks for Spent Nuclear Fuel –“, JSME S FB1-2003, (2003).

[7] K. Shirai, et. al., "Demonstrative Drop Tests of Transport and Storage Full-Scale MPCs with High Corrosion-resistant material”, NED 238, pp.1241-1249, (2008)

[8] K. Shirai, et al., Experimental Studies of Free-Standing Spent Fuel Storage Cask subjected to Strong Earthquake, Proc. of the 15th Int. Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, Miami, Florida, USA (2007).

[9] Nuclear Safety Commission of the Japanese Government, “Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities”, Sep., (2006)

[10] J. Tani and M. Mayuzumi, “Stress corrosion cracking of canister materials for storage of spent nuclear fuel (Vol.2) – An evaluation of the possibility of SCC initiation-“, CRIEPI Report Q08007(2009)(in Japanese)

[11] H. Takeda, et.al., " Leakage Evaluation of Metal Cask during Drop Test ", Proc. of GLOBAL 2005, No.575, Tsukuba, Japan, (2005).

[12] C. Itoh, et al., Long Term Containment Performance Test for Spent Fuel Transport/Storage Casks, Trans. At. Energy Soc. Japan, Vol.2, No.2, pp.158-162, (in Japanese), (2003)

[13] K. Shirai, et al., Safety Analysis of Dual Purpose Metal Cask Subjected to Impulsive Loads due to Aircraft Engine Crash, Proc. of ICONE16, Int. Conference on Nuclear Engineering, Orland, Florida, USA, (2008)

[14] T. Saegusa, M. Mayuzumi, C. Ito, and K. Shirai, “Experimental Studies on Safety of Dry Cask Storage Technology of Spent Fuel- Allowable Temperature of Cladding and Integrity of Cask under Accident-“, J. Nucl. Sci. Tech., Vol.33, No.3, p.250-258 (1996).

[15] A. Sasahara and T. Matsumura, “Post-irradiation examination focused on fuel integrity of spent BWR-MOX and PWR-UO2 fuels stored for 20 years”, Nucl. Eng. Design, Vol. 238, p.1250-1259 (2008).

[16] S. Itooka, et al, “Supporting Study of Regulation for Interim Storage Facility for Spent Fuel in Japan”, Proc. ICONE 13-50617, Beijing, China, May 16-20, 2005.

[17] K. Ito, K. Kamimura, Y. Tsukuda, Y., “Evaluation of Irradiation Effect on Spent Fuel Cladding Creep Prpperties”, Proc. 2004 Int’l Mtg on LWR Fuel Performance, Orlando, Florida, Sept.19-22, 2004. Paper 1117.

[18] M. Aomi, et al, "Evaluation of Hydride Reorientation Behavior and Mechanical Properties for High Burnup Fuel Cladding Tubes in Interim Dry Storage ", Journal of ASTM international (2008).

[19] Transport and Storage WGs in NISA/METI of the Japanese Government, “Long-term Integrity of Dry Metal Cask and Contents for Interim Storage Facility of Spent Fuel using Dry Metal Cask”, June 25, 2010.