INVESTIGATION OF SPENT FUEL INTEGRITY IN DRY STORAGE AT JAPANESE NUCLEAR POWER PLANTS

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ABSTRACT

In Japan, the first spent fuel interim storage facility away-from-reactor will start its operation in 2012.

This facility stores BWR / PWR spent fuel assemblies using dual purpose (storage / transport) metallic dry casks which will be transported to their destinations after the interim storage for decades. This facility is not equipped with a hot-cell for opening the primary lid of the cask because one of the basic concepts of the facility is a simple operation not to handle a radioactive material directly, that reduces radiation exposure of workers and a risk of contamination troubles.

On the other hand, a visual inspection of spent fuel assemblies is usually carried out before spent fuel transportation in Japan. Although a visual inspection of spent fuel assemblies is not carried out in the interim storage facility as has been discussed, we consider that it is necessary to confirm spent fuel integrity by the same level of confirmation as visual inspection before transportation after the interim storage. For this purpose, we will establish a quality control system of metallic dry casks from manufacturing to the end of storage, and for more conservatism, we are continuously investigating spent fuel integrity in dry storage at the nuclear power plants.

This paper introduces results and future plans of our investigation of spent fuel integrity in dry storage in Japan. (The investigation was also aimed at the integrity of metal gasket.)

INTRODUCTION

Japan's basic policy has been to effectively use plutonium and uranium obtained by reprocessing spent fuel. In Japan, 55 light water reactors (LWR) are in operation. The amount of spent fuel generated in Japan reaches as much as 1000ton-U every year. However, since Japanese reprocessing facility has a capacity of 800ton-U/year, for the time being, the surplus volume exceeding the capacity will be stored intermediately.

Japanese government amended Reactor Regulation Law in 2000 to be able to operate the spent fuel interim storage facilities away-from-reactor (SFISF-AFR). Subsequently, the Nuclear Safety Committee of Japan (NSC) established Regulatory Guide "Reviewing Safety of Spent-fuel Interim Storage Facilities Using Metallic Dry Casks" in 2002.

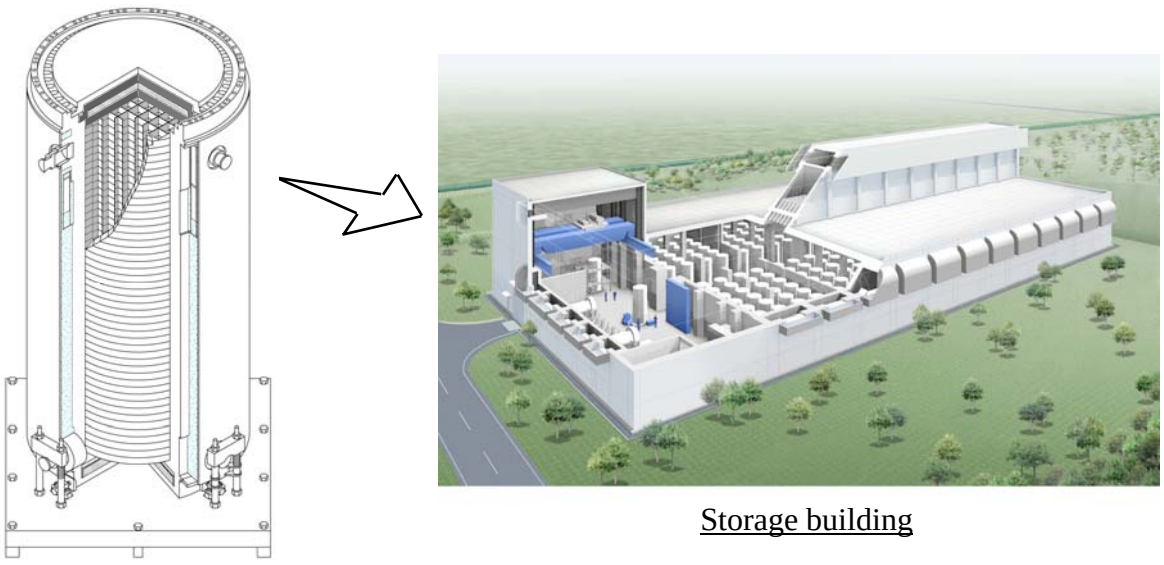
A Japanese first SFISF-AFR will start its operation in 2012 according to the legal framework.

OUTLINE OF A JAPANESE FIRST SFISF-AFR [1]

A Japanese first SFISF-AFR is currently under construction at Mutsu city, Aomori prefecture. The facility is owned by Recyclable-Fuel Storage Company (RFS), which was established as a joint company of Tokyo Electric Power Company (TEPCO) and the Japan Atomic Power Company (JAPC).

The outline of the facility is as follows.

- Facility Name: Recyclable-Fuel Storage Center (RFSC)
- Beginning of Operation: July, 2012
- Storage system: Dual purpose (storage / transport) metallic dry cask (Figure 1)
- Storage capacity: About 3,000 ton-U of LWR spent fuel (max. 288 casks)
- Storage period: Max. 50 years
- Storage building: L130m x W60m x H30m, Ferroconcrete, natural cooling (Figure 1)
- Stored fuel: Boiling water reactor (BWR) and pressurized water reactor (PWR) spent fuel assemblies owned by TEPCO and JAPC (Table 1)
- A hot-cell for opening the cask: None
- Cover gas in the cask cavity: Helium (negative pressure of approx. 0.8 atm)
- Containment structure of the cask: Double lids equipped with the metal gasket
- Cover gas between lids: Helium (positive pressure of approx. 4 atm)
- Cask handling process in the nuclear power plant: Spent fuel assemblies are loaded to the cask in the spent fuel pool. The cask is moved to the decontamination pit and cavity water is drained. After vacuum drying, helium is filled in the cask cavity. Leak tightness of each lid is checked and space between the lids is filled with helium. Tertiary lid and shock absorbers are attached on the cask for the transportation to RFSC.
- Cask handling process in RFSC: Shock absorbers and tertiary lid are detached from the cask. The cask is placed vertically on the floor in the storage building. Pressure between the lids and temperature of the cask surface are always monitored.



Metallic dry cask

Storage building

Figure 1. Metallic dry cask and storage building of RFSC

Table 1. The specification of spent fuel assemblies stored in RFSC

Fuel type		Cladding material of fuel rods	Burn-up (GWd/t)		Cooling period	
			Maximum for fuel assembly	Average for replacement fuel	TEPCO	JAPC
BWR	8 x 8	Zircaloy–2	40	27.5	18 years and over	
	New 8 x 8		40	28.5 / 29.5		
	New 8 x 8 Zr Liner	Zircaloy–2 (Zirconium liner)	40	33		8 years and over
	High Burn-up 8 x 8		50	39.5		
PWR	39GWd/t	Zircaloy–4	39	31		15 years and over
	48GWd/t		48	43		

PURPOSE OF THE INVESTIGATION

Metallic dry casks are just stored calmly in the SFISF-AFR for decades and spent fuel assemblies in the cask are kept in dry and inert-atmosphere. Moreover, in order to estimate a limit temperature on the spent fuel integrity in dry storage, thermal creep tests, hydride reorientation tests and irradiation hardening recovery tests were carried out at Japanese laboratories using LWR fuel cladding tubes irradiated in commercial power reactors in Japan. From these, it is predictable that spent fuel integrity will keep basically after the interim storage, if the fuel cladding temperature does not exceed the limit.

RFSC is not equipped with a hot-cell for opening the primary lid of the cask because one of the basic concepts of the facility is a simple operation not to handle a radioactive material directly, that reduces radiation exposure of workers and a risk of contamination troubles.

On the other hand, a visual inspection of spent fuel assemblies is usually carried out before spent fuel transportation in Japan. Although a visual inspection of spent fuel assemblies is not carried out in RFSC as has been discussed, we consider that it is necessary to confirm spent fuel integrity by the same level of confirmation as visual inspection before transportation after the interim storage. For this purpose, we will establish a quality control system of metallic dry casks from manufacturing to the end of storage, and for more conservatism, we are continuously investigating spent fuel integrity on the actual spent fuel dry storage at the nuclear power plants and the research facilities.

RESULT OF THE INVESTIGATION

Investigation of fuel cladding and metal gasket at the Japanese nuclear power plants

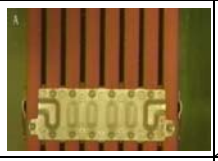
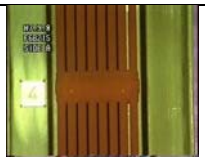
BWR spent fuel assemblies have been stored in metallic dry casks at Fukushima-Daiichi nuclear power station and Tokai No.2 power station in Japan. The casks at Fukushima-Daiichi and Tokai No.2 were opened for investigating the integrity of fuel cladding and metal gasket. The result is shown in Table 2, 3, 4. [2, 3]

Cover gas sampling of Castor V/21 cask at INL

PWR spent fuel assemblies have been stored in a Castor V/21 cask at Idaho National Laboratory (INL). The cover gas in the Castor V/21 cask is sampled at nominal 5-year intervals to fulfill Safety Analysis Report requirements. Japanese PWR utilities got the cover gas sampling data from INL for

the investigation of PWR spent fuel integrity in dry storage. The latest result of the cover gas sampling is shown in Table 2.

Table 2. The result of investigation for spent fuel integrity

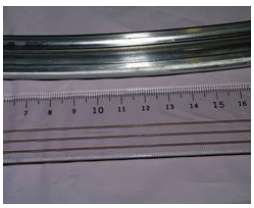
Site		Fukushima-Daiichi		Tokai No.2	INL
Cask type		Medium Type	Large Type	Hitachi Zosen	Castor V/21
Fuel type		BWR 8 x 8	BWR New 8 x 8	BWR New 8 x 8 Zr Liner	PWR 15 x 15 *1
Burn-up		28 GWd/t	32 GWd/t	33.5 GWd/t	35.7 GWd/t
Cooling period		7 years	5 years	8-9 years	2-4 years
Year of inspection		2005	2000	2009	2005
Dry storage period		10 years	5 years	7 years	20 years
Rod Temperature	At vacuum drying	Approx. 90 ℃	Approx. 145 ℃	Approx. 140 ℃	
	At the start of storage	Approx. 90 ℃	Approx. 140 ℃	Approx. 165 ℃	344℃
	At the inspection	Approx. 80 ℃	Approx. 115 ℃	Approx. 115 ℃	
Cover gas sampling		Kr-85 was not detected.			
Visual inspection	Result	The appearance of spent fuel remains the same as observed at the storage starting.			
	Before storage				
	At the inspection				

*1: equivalent to Japanese 39GWd/t type fuel.

Table 3. The result of sealing performance test of the primary lid

Site	Fukushima-Daiichi		Tokai No.2
Cask type	Medium Type	Large Type	Hitachi Zosen
Year of inspection	2005	2000	2009
Leak rate	5.3×10^{-8} Pa・m^3/s	1.6×10^{-7} Pa・m^3/s	9.0×10^{-11} Pa・m^3/s
The criterion of inspection before use	1×10^{-6} Pa・m^3/s		1.6×10^{-7} Pa・m^3/s

Table 4. The result of visual inspection of metal gasket for the primary lid

Site	Fukushima-Daiichi		Tokai No.2
Cask type	Medium Type	Large Type	Hitachi Zosen Type
Year	2005	2000	2009
Surface condition of metal gasket			
The result of visual inspection	Nothing abnormal occurred on confinement, but white coloring was observed on the gasket's surface due to residual water.	Nothing abnormal occurred on confinement, but white color change was observed on the surface of the gasket due to immersion to reactor pool water for several days before opening the primary lid.	No scratch, crack or oxidation was observed in the metal gasket. The integrity of metal gasket was confirmed.

FUTURE PLANS

There was no problem on the spent fuel integrity in actual dry storage for 10-20 years as shown in the above-mentioned. But in order to confirm that unexpected events will not appear on the spent fuel integrity for the storage period of about 50 years, it is hoped to continue the cover gas sampling (Kr-85 analysis) of the metallic dry casks periodically at the nuclear power plants and the research facilities in the future. If Kr-85 is detected on the cover gas sampling, a cause of the fuel failure will be investigated in detail.

Periodically continual investigations at Japanese nuclear power plants and INL

Japanese utilities are planning periodically continual investigations at Fukushima-Daiichi, Tokai No.2 and INL. The outline of the investigations is shown in Table 5.

Table 5. Periodically continual investigations at Japanese nuclear power stations and INL

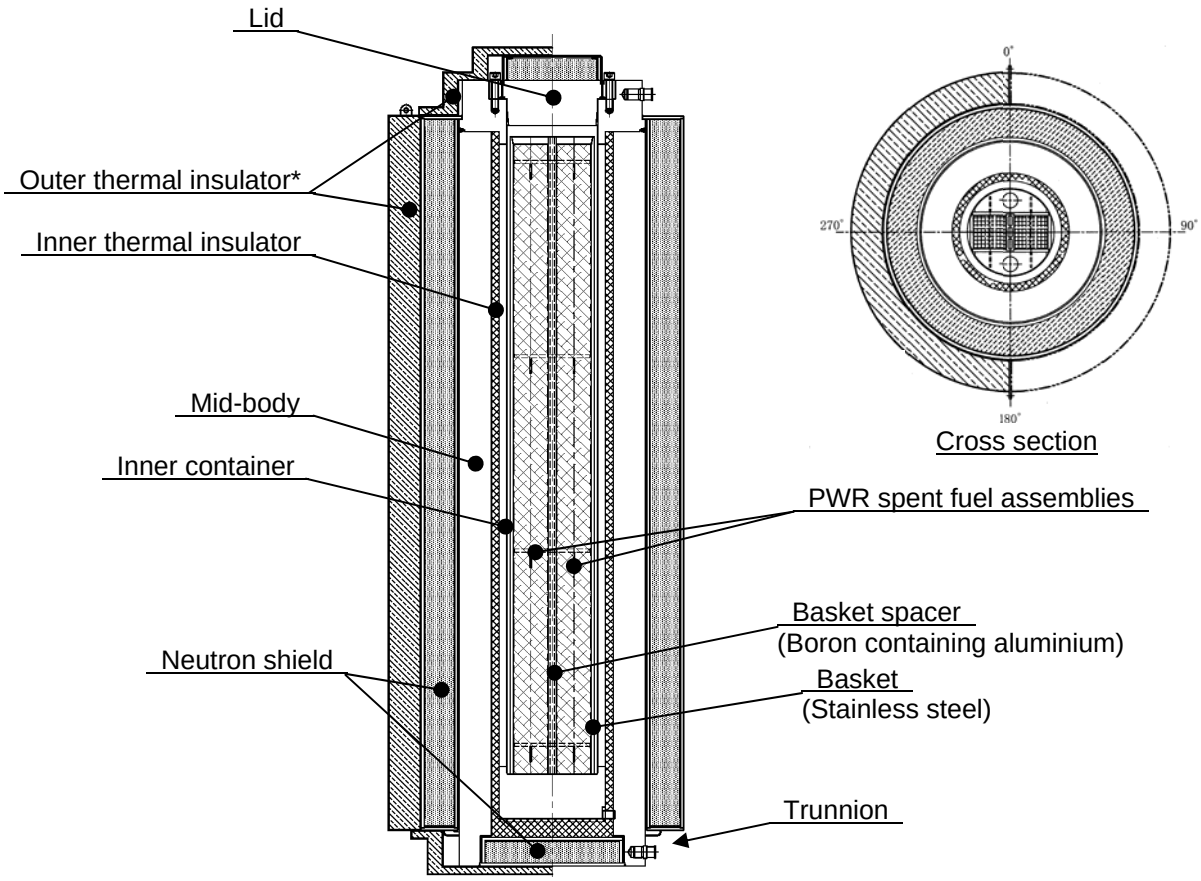
Site	Fukushima-Daiichi	Tokai No.2	INL
Cask type	Medium or Large	Hitachi Zosen	Castor V/21
Investigation interval	5-15 years	5-15 years	5 years
Fuel type	BWR New 8 x 8	BWR High Burn-up 8 x 8	PWR 15 x 15 *1
Burn-up	32 GWd/t	44 GWd/t	36 GWd/t
Rod temperature	Approx. 140 ℃	Approx. 200 ℃	344℃
Investigation method	Cover gas sampling (Kr-85 analysis)		

*1: equivalent to Japanese 39GWd/t type fuel.

PWR spent fuel dry storage test at NDC [4]

Because the dry storage of the PWR spent fuel is untried in Japan, Japanese utilities acquires the cover gas sampling data of the dry cask that stores the PWR spent fuel from INL. However, because the offer of the gas sampling data from INL has not been necessarily guaranteed for a long term, Japanese utilities are planning PWR spent fuel dry storage test at the domestic research facility (Nuclear Development Corporation (NDC)).

The test container is a small metallic dry cask. Two PWR spent fuel assemblies can be stored in it. The cover gas in the test container cavity is helium. The containment function is secured with the double metal gasket installed in the lid. The inner and outer thermal insulators are built into the test container to raise the temperature of the fuel cladding in the test container up to an actual temperature of the fuel cladding in RFSC casks. Fuel assemblies assumed for tests are PWR 48GWd/t type and 55GWd/t type. The test container will be manufactured in 2011 and storage test of 48GWd/t type fuel will start in fiscal 2012. For the first 10 years, only 48GWd/t type fuel will be loaded, and then 55GWd/t type fuel will be added. The test is planned to continue for up to 60 years. The spent fuel integrity is confirmed by conducting cover gas sampling and Kr-85 analyses periodically.



*Note: Outer thermal insulator installed at loading only 48GWd/t F/A is removed when 55GWd/t fuel assembly is added.

Figure 2. Test Container Profile

Table 6. Fuel assemblies Assumed for Tests

Fuel type	17×17 48GWd/t type	17×17 55GWd/t type
Beginning of storage	2012	2022
Burn-up	42.8 GWd/t	55 GWd/t or less
Cooling period	19 years	10 years or more
Rod temperature	Approx. 230 ℃	Approx. 230 ℃
Cladding material of fuel rods	Zircaloy–4	MDA or ZIRLO

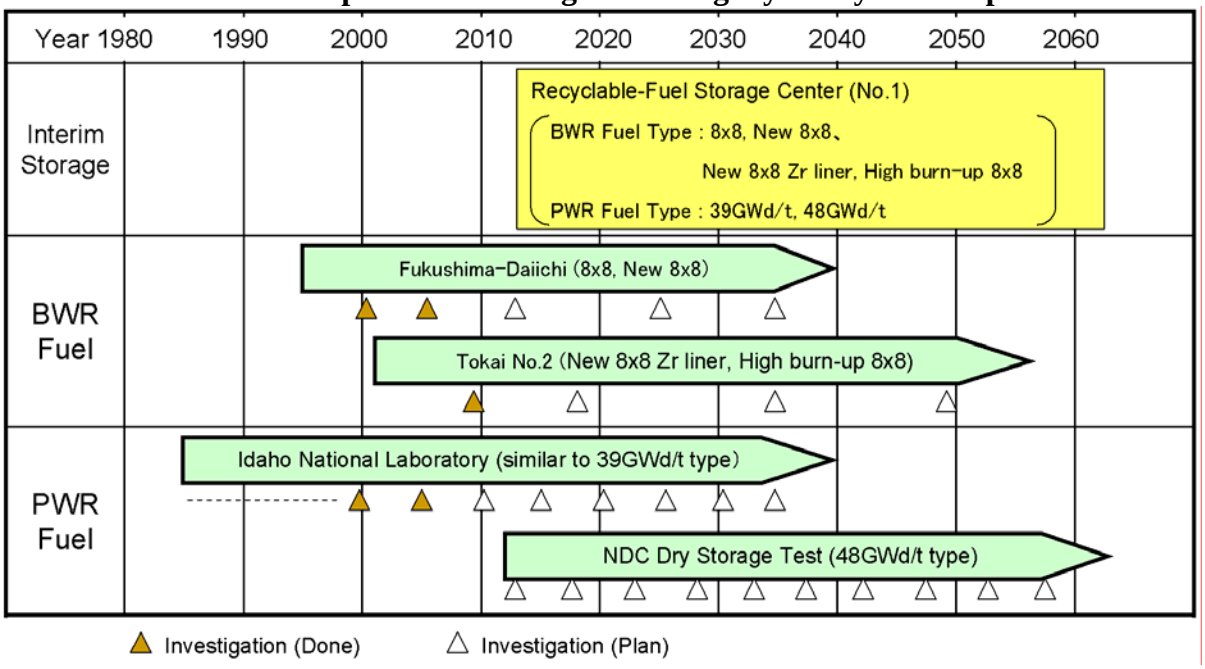
Table 7. Time Schedule of PWR Spent Fuel Dry Storage Test

Fiscal year	2009	2010	2011	2012	2013 –2022	2023 –2032	2033 –2042	2043 –2052	- - -
Planning & Designing		Planning Designing Safety analysis Licensing							
Manufacture & Preparation			Manufacturing of test container Thermal test (48GWd/t fuel)	(55GWd/t fuel)	Preparation & Fuel inspection Loading to container				
Storage test & Inspection			48GWd/t type fuel test 55GWd/t type fuel test Gas sampling						

A Road map for the investigation

Japanese utilities made a road map of the investigation in actual dry storage as shown in Table 6. The road map will be checked at the licensing examination of packaging design approval as transport casks and each renewal examination of it (5-year intervals).

Table 6. A road map to confirm long-term integrity of dry-stored spent fuel



CONCLUSIONS

The casks at Fukushima-Daiichi and Tokai No.2 were opened for investigating the integrity of fuel cladding and metal gasket in 2000, 2005 and 2009. Japanese PWR utilities got the cover gas sampling data from INL for the investigation of PWR spent fuel integrity in dry storage in 2005.

There was no problem on the spent fuel integrity in actual dry storage for 10-20 years from these data.
In order to confirm that unexpected events will not appear on the spent fuel integrity for the storage period of about 50 years, it is hoped to continue the cover gas sampling (Kr-85 analysis) of the metallic dry casks periodically at the nuclear power plants and the research facilities in the future. Japanese utilities are planning periodically continual investigations at Fukushima-Daiichi, Tokai No.2 and INL. Because the offer of the gas sampling data from INL has not been necessarily guaranteed for a long term, Japanese utilities are planning PWR spent fuel dry storage test at the domestic research facility (Nuclear Development Corporation (NDC)).

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[1] SHIMOOZAKI N. et al., Management of Casks in Japan's Interim Storage Facility, IAEA-CN-178/11p, (2010).
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