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Design Outline of MSF Transportable Storage Casks for Spent Fuels and The First “Type Approval” Experience in Japan

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Japanese “Type Approval” license system for a storage cask was institutionalized in 2012 in Japan, which can make a part of storage license certification for a storage cask in advance.
MHI applied two types of MSF (MITSUBISHI Spent Fuel) cask in 2015-2016, one of which is type MSF-52B for BWR spent fuel assemblies, the other of which is type MSF-21P for PWR spent fuel assemblies. The MSF cask is a transportable storage cask developed for interim storage of spent fuel assemblies in Japan. It has double lids with metallic gaskets which could have long term containment integrity during storage period. A tertiary lid with elastomer O-rings which could follow up a displacement between lid and body flange will be attached during transport for more safety. MSF-52B/MSF-21P can accommodate 52 BWR/21 PWR spent fuel assemblies with maximum burn-up of 50/48 GWd/t and with cooling period of 12/15 years or more, respectively.
Under the new licensing guideline relating to type approval, mainly sub-criticality, shielding, heat removal, containment, structure and long term integrity of materials had been examined and the first type certification was issued for MSF-52B by the Japanese competent authority, Nuclear Regulation Authority (hereinafter called “NRA”).

Introduction

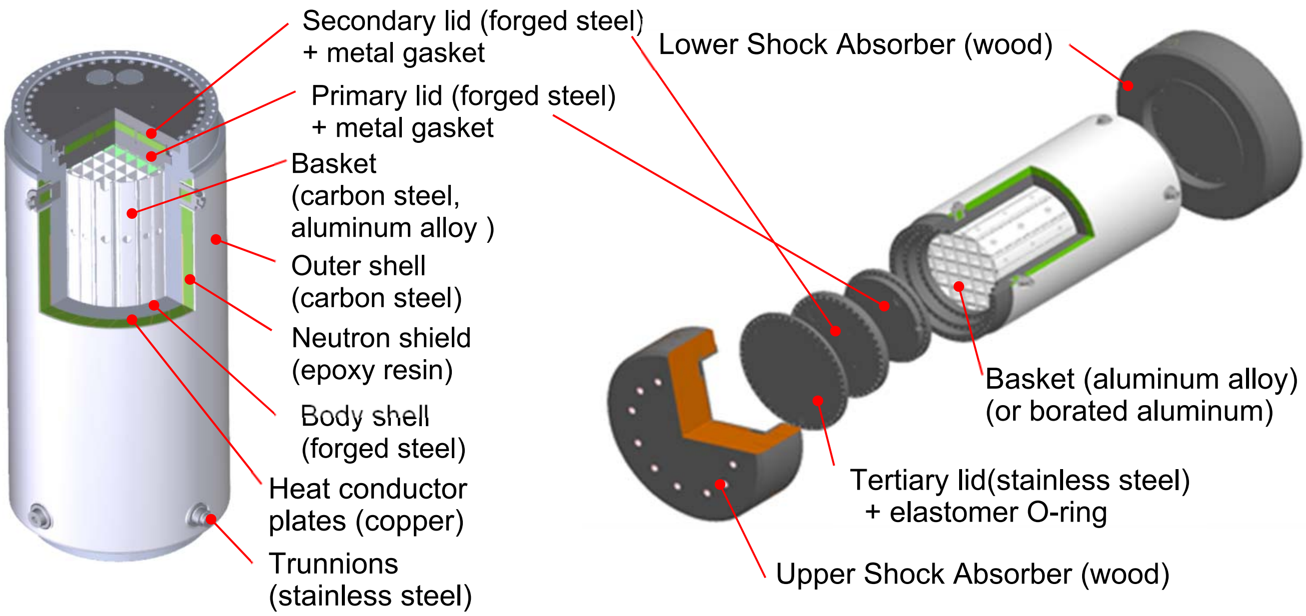
After the Great East Japan Earthquake, regulations and codes were tightened, and guidelines on natural disasters such as an earthquake, tsunami and on artificial disasters such as an airplane fall were revised as well. “Action rule of the regulation of nuclear source material, nuclear fuel material and reactors (Nuclear reactor regulation rule)” was revised in 2012 for the purpose of promotion of introduction of facilities which could improve a safety of a nuclear power station, and then the type approval license system was institutionalized. Metal dry casks used for an interim storage of spent fuel assemblies are one of the targets applied the type approval.
The re-operation schedule for the Rokkasho reprocessing plant in Japan is still in an unclear situation. On the other hand, it is clear that the fuel storage capacities of the spent fuel pools will be close to full within several years after nuclear power stations restart. Therefore spent fuel management plans including a start-up plan of the recyclable fuel storage center (dry interim storage facility) in Mutsu city, Aomori are essential for the nuclear energy policy in Japan. This type approval can shorten a period of approval for dry interim storage facility by examining beforehand metal casks used in the facility, so that this license is meaningful for spent fuel management in Japan.

1. Characteristics of MSF-52B and MSF-21P cask

MSF-52B type transportable storage cask which can store 52 BWR spent fuel assemblies, and MSF-21P type cask which can store 21 PWR spent fuel assemblies were developed by MHI for the interim storage of spent fuels in Japan. The basic specifications of both casks are shown in Table 1, and schematic diagrams are shown in Figure 1.

Table 1 Specification of MSF-52B Cask and MSF-21P Cask

Cask type	MSF-52B	MSF-21P
Payload	52 BWR spent fuels	21 PWR spent fuels
Burn-up (Max./Ave.)	50/43 GWd/MTU	48/44 GWd/MTU
Initial Enrichment	3.6 %	4.2 %
Cooling time	12 years or more	15 years or more
Thermal power	13.7 kW	13.9 kW
Weight(without/with S/As)	116/135 ton	117/131 ton
Dimensions	φ2.4×5.5 m (without S/As) φ3.6×6.9 m (with S/As)	φ2.5×5.2 m (without S/As) φ3.6×6.8 m (with S/As)



(a)MSF-52B (Storage configuration) (b)MSF-21P (Transport configuration),

Figure 1 MSF-52B & MSF-21P Transportable Storage Casks

1.1 Basket

(1) MSF-52B

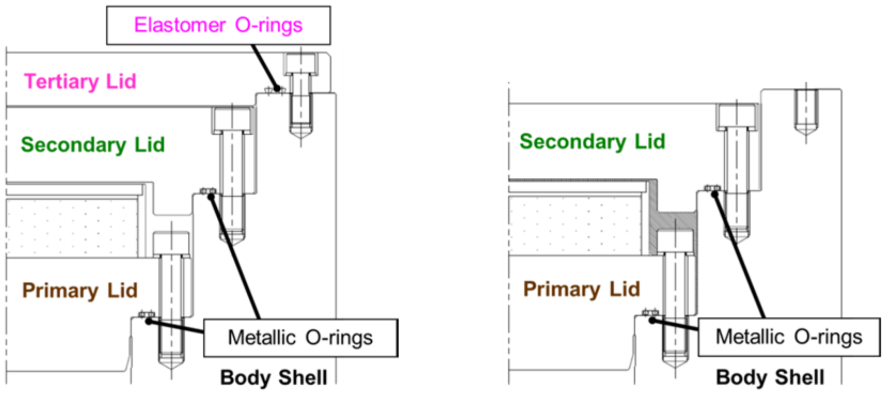
In order to have two functions of criticality prevention and decay heat dissipation during and after long term storage, basket consists of many carbon steel plates as structural members and boron contained aluminum alloy plates as neutron absorbers, which formed egg crate structure (box-of-cake

structure) in order to provide 52 compartments for BWR spent fuel assemblies.
Aluminum alloy forming materials are attached on the outer parts of basket structure for heat transfer, which are supported by steel structural materials.

(2) MSF-21P
In order to have two functions of criticality prevention and decay heat dissipation during and after long term storage, basket consists of many extruded aluminum alloy tubes as structural members and boron contained aluminum alloy plates as neutron absorbers, which formed egg crate structure (box-of-cake structure) in order to provide 21 compartments for PWR spent fuel assemblies.
Basket structure is designed to maintain its structural integrity during storage and transport after storage periods by defining the design strength of aluminum alloy taking into consideration of over-aging heat treatment and full annealing heat treatment.
Since its temperature could reach into an aluminum creep temperature range, the creep tests for about 10,000 to 20,000 hours were carried out to make sure creep rupture strength and steady state creep rate. Moreover, although an aluminum alloy is ductility with face-centered cubic structure, fracture toughness tests in low temperature or with high speed were carried out, and its ductility was confirmed.

1.2 Neutron shielding material
As a neutron shield material, an epoxy resin type material MREX® was developed by MHI. Long term integrity of its neutron shielding performance was confirmed by the test.

1.3 Triple lids system
Spent fuels whose integrity would be confirmed will be loaded into a cask and transported to an interim storage facility, and will be stored over the long term. In addition, to reduce risk of exposure to workers and to prevent waste materials dispersion, the interim storage facility in Japan has no hot cell. The spent fuels will be confirmed for their integrity indirectly by monitoring cask during storage, and be transported after storage without opening the lids. Therefore, the structure of lids seal part of MSF cask used in Japan is designed with triple lids system. (see Figure 2)
During storage, the primary lid and the secondary lid equipped with metallic O-rings are bolted to the body flange. The primary lid and the cask body form a containment boundary. Leakage of the lids can be detected by continuous monitoring of pressure variation in the space between the lids during storage. The sealing performance for long term services could be ensured by metallic O-rings attached to the lids.
During transport before and after storage, a tertiary lid equipped with elastomer O-rings will be bolted to the top of body flange. The tertiary lid and the secondary lid will play the role of a double containment boundary during transport. Even in case of a leakage of the primary lid during storage, the MSF cask can be transported safely.



a. Transport configuration **b. Storage configuration**

Figure 2 Closure system of MSF cask

1.4 Restriction of heat load for fuel cladding integrity

Since the interim storage facility in Japan has no hot cell, the primary lid cannot be opened for confirmation of integrity of spent fuel cladding. Therefore, temperature restriction of fuel cladding is required in order to avoid strength degradation of the fuel cladding caused by hydride re-orientation or creep degradation after long term storage.

Maximum temperature restriction of fuel cladding is 300^{o}C (in some cases, 200 ^{o}C) for BWR spent fuels and 275 ^{o}C for PWR spent fuels under vacuum drying process as well as during storage [3].

The burnup and cooling period of spent fuels are restricted and then the heat load per cask may be set to below 13.9 kW for MSF-21P and below 13.7 kW for MSF-52B.

2. Type approval experience

2.1 Outline of type approval

Utilities who intends to carry out an activity for interim storage of spent fuel shall obtain the permission of NRA by submitting the safety assessment for the basic design of the facilities in the stage of “Licensing for the Activity” (see STEP 1 in Figure 3) and also shall obtain the approval of NRA with respect to the design and construction method of the facilities in the stage of “Approval of Design and Construction Methods” (see STEP 2 in Figure 3).

By applying the newly institutionalized type approval process, not only utilities but also cask suppliers can file an application for type approval regarding the storage cask specific items prior to the original processes (see PRE-STEP in Figure 3). The type approval licensing process consists of two steps; “Type certification” corresponding to the Licensing for the Activity and “Designation of type” corresponding to the Approval of Design and Construction Methods.

Utilities can refer the approved cask design so that shortening of the examination period could be expected.

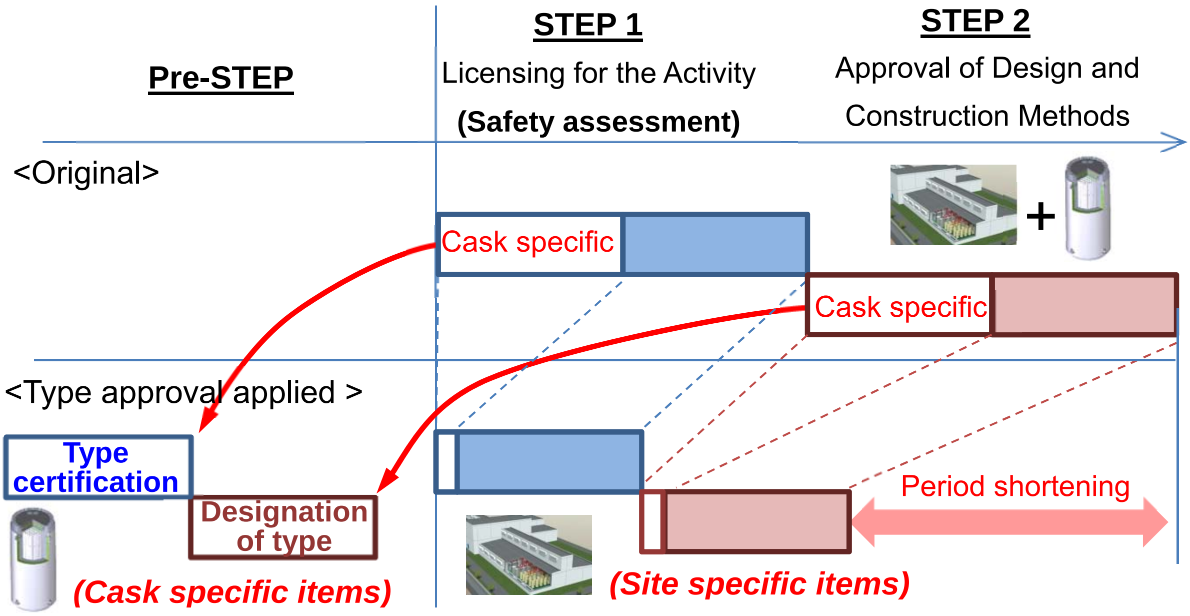


Figure 3 Shortening of examination period for transportable storage Cask

2.2 Outline of type approval activities

MHI filed an application for type certification of the MSF-52B cask on February 27, 2015, and acquired the certification (No.M-DPC15001) issued by NRA on August 19, 2015. Also as for the MSF-21P cask, it filed an application on November 20, 2015 and acquired the certification (No.M-DPC16001) issued by NRA on May 25, 2016. Currently, licensing activities for designation of type of MSF-52B is being examined by the Nuclear Regulation Department in NRA.

Chronology of these type approval activities are shown in Table 2. Only cask specific items such as prevention of criticality of spent fuel, shielding, containment, thermal dissipation, prevention of damage against earthquake (structural evaluation) and metal cask including long-term stability were examined by the Nuclear Regulation Department in NRA. Followings describe the requirements for storage cask and outlines of the examinations.

Table 3 Chronology of Type Approval Activities of MSF-52B and MSF-21P

Examination Items	2014FY	2015 FY				2016 FY	
	4Q	1Q	2Q	3Q	4Q	1Q	2Q
MSF-52B	Type certification					Designation of type	
Shielding, Criticality	**					+ +	
Containment, Thermal, Structural		**** *				+	
Long Term Integrity		*					+
Questions & Answers		****	****				++++
MSF-21P				Type certification			
Shielding, Criticality				*	*		
Containment, Thermal, Structural					** *		
Long Term Integrity				**	* * **		
Questions & Answers					***	***	

(1) Criticality evaluation

It is required that every individual cask package containing spent fuels shall maintain subcritical safety under any technically assumed conditions.

Since MSF casks have lids with high sealing performance, no water could permeate into their cavity so that it could be maintained to be dry during storage. However, during loading activity of spent fuels into a cask at a nuclear power station, the cask must be submerged in a pool, it shall be considered that subcriticality is maintained in both dry and wet conditions.

In subcriticality evaluation, close reflection and infinite array of casks were assumed, which conditions can cover the maximum storage capacity at interim storage facility. Dry, wet and intermediate conditions in the cavity and the most severe arrangement of fuels within basket cells were also assumed. Furthermore, tolerances of dimensions such as basket grid plate thickness and inner dimensions of basket cells were also taken into consideration.

As for the MSF-21P cask, NRA required influence evaluations on the subcriticality of variation of water level and existence of air bubbles during filling or draining of water since basket consists of hollow structures, and MHI explained that subcriticality can be maintained taking partial air layers in the basket hollow structures into account.

(2) Shielding evaluation

It is required that dose rates around an interim storage facility shall satisfy its criteria. However, because type certification is focused on an individual cask, evaluation conditions strongly relating to storage facility cannot be set up; such as a cask storage capacity, shielding thickness of building, a distance to the facility borderline, and so on.

On the other hand, the following shielding criteria for a transport cask shall be satisfied because both MSF-52B and MSF-21P casks are categorized as a transportable storage cask; "maximum dose rate equivalent at surface does not exceed 2 mSv/h", and "maximum dose rate equivalent at 1m from the surface does not exceed 100 μSv/h from the surface."

In shielding evaluation, NRA required a consideration of thermal degradation of materials, and MHI explained that the criteria for a transport cask could be maintained taking degradation (weight loss) of neutron shielding material resin by heat load in the long term storage period into account.

(3) Containment evaluation

Spent fuels are required to be contained within the limited space appropriately. Therefore, the cavity inside where spent fuels are contained is designed to maintain negative pressure through the designed storage period.

In containment evaluation, pressure increase of cavity space by gas release from spent fuels due to a cladding breakage was assumed. A breakage rate of spent fuel cladding was set to 0.1% conservatively in consideration of incidence rates of fuel leakage of about 0.01% under dry storage of spent fuels in U.S. [1] [2] and of about 0.01% or less under operation of light water reactor in Japan [1].

NRA examined especially long-term stability of containment system, monitoring system and recovery process after leakage. MHI explained the following specifications of double containment structure with primary and secondary lids adopted; pressure barrier by making positive pressure between the lids is formed beforehand, and metallic gaskets are used for seals of lids to maintain containment function through long term period. Moreover, a containment function is designed to be monitored by measuring pressure between the lids.

(4) Thermal evaluation

It is required that the decay heat from spent fuels can be appropriately removed without power. Especially NRA focused on temperature of spent fuels which shall be maintained below its criteria in order to prevent creep breakage and degradation of mechanical properties of fuel cladding.

In consideration of temperatures that the accumulation of creep strain of spent fuel cladding will be within 1%, and that possibility of recovery of irradiation hardening will be still low, and that the mechanical properties will not be degraded by re-orientation of hydrides of cladding material, MHI set the restrictive temperatures of the fuel cladding to 275^{o}C for PWR spent fuels and 300 ^{o}C for BWR spent fuels (200 ^{o}C for some BWR spent fuels) [3], and explained that the temperature of fuel cladding evaluated can be maintained below its criteria.

(5) Structural evaluation (prevention of damage against earthquake)

The spent fuel storage facility shall endure the seismic force sufficiently. During storage the MSF casks will be fixed onto the floor through a cask storage base which is a support structure in storage building. The cask and cask storage base are fixed with lower trunnions so that the stress during an earthquake at lower trunnions shall be below its allowable stress.

(6) Long-term integrity of metal cask

In order to assure the safety functions, it is required that strength and performance are maintained by selecting appropriate materials for main parts which has sufficient reliability to aging effect in design storage period, such as temperature, radiation, corrosion, creep, stress corrosion cracking, etc.

In evaluation of long-term integrity, it was confirmed that the safety functions can be maintained during storage of maximum 60 years under the temperatures estimated by the thermal analysis and under the amount of neutron irradiation estimated by the shielding analysis.

Spent fuel assemblies will be enclosed and stored in the cavity with inert gas atmosphere in order to prevent corrosion of cask body inside, basket, and spent fuel assemblies.

NRA especially focused on mechanical properties of aluminum alloy after long term storage, which is used as a structural material for basket of MSF-21P. MHI showed the mechanical properties of the aluminum alloy considering thermal aging on the basis of detail test data [4].

Conclusions

As transportable storage casks for interim storage in Japan, MHI developed MSF-52B and MSF-21P casks which can store 52 BWR and 21 PWR spent fuel assemblies, respectively.

The type approval licensing for storage casks newly enacted in Japan was applied to these casks, and type certification was acquired. Thereby, the safety performance of the MSF cask was certified as storage casks.

Towards the forthcoming dry storage demands, MHI continues our works to prove the safety of MSF cask series and to apply the following designation of type so that it can contribute to shortening of duration for approval and to an early start-up for dry storage facilities.

References

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