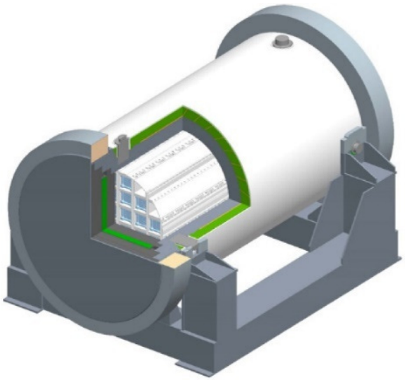
Higher Storage Capacity and Improved Safety of Spent Fuel Dry Storage Cask



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Development in restarting nuclear power plants with approved safety and decommissioning of nuclear reactors after years of operation generates a large amount of spent fuel, making its storage a critical challenge. With regard to dry storage systems using transport and storage casks with high safety (dry casks), their installation plans on the premises of power plants or interim storage facilities are being promoted. Mitsubishi Heavy Industries, Ltd. is working on the development of dry casks with the aim of making a contribution to spent fuel storage. This report summarizes MSF-24P and MSF-28P casks, whose type certificates have been obtained, and presents our initiatives to increase storage capacity and enhance safety.

1. Dry cask requirements and product line-up

The dry casks (MSF casks) have been developed by Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) to safely and economically transport or interim storage the spent fuel from nuclear power plants in Japan. Their design satisfies the transportation requirements (i.e., regulations on off-site transportation of nuclear materials from the factories or establishments) and the storage requirements (i.e., design conditions specific to each site). The former involves conducting tests such as the 9-m drop test and the fire test (at 800°C for 30 minutes), whereas the latter includes the criteria related to the events caused by natural disasters such as earthquakes and objects carried by tsunamis. The basic safety functions (subcriticality, heat removal, shielding and containment) are maintained according to these requirements.

Moreover, MHI offers a wide range of products to meet the demand for dry storage of the spent fuel kept in nuclear facilities (**Table 1**).

Table 1 MSF cask lineup (specifications)

Type(Note 1)	MSF-21P	MSF-24P	MSF-28P	MSF-32P	MSF-52B	MSF-76B
Fuel type	14×14 PWR 17×17 PWR	15×15 PWR 17×17 PWR	15×15 PWR 17×17 PWR	14×14 PWR	8×8 BWR	8×8 BWR
Payload	21	24	28	32	52	76
Cooling time (years)	≥15	≥15	≥20	≥15	≥12	≥22
U-235 Initial enrichment (%)	4.9 (14×14) 4.2 (17×17)	4.1 (15×15) 4.2 (17×17)	4.1 (15×15) 4.2 (17×17)	4.2 (14×14)	3.7 (8×8)	3.7 (8×8)
Maximum burnup (GWd/t)	55 (14×14) 48 (17×17)	48 (15×15) 48 (17×17)	48 (15×15) 48 (17×17)	48 (14×14)	50 (8×8)	50 (8×8)
Thermal power (kW)	13.9	15.8	15.7	14.8	13.7	14.2
Weight (tonnes)(Note 2)	117/131*	118/134*	117/135*	117/136*	116/132*	119/135*
Dimensions (m)(Note 2)	Φ3.6×6.8*	Φ3.6×6.8*	Φ3.6×6.8*	Φ3.6×6.8*	Φ3.6×6.9*	Φ3.6×6.8*
Type certificate/designation(Note 3) and storage orientation	◎ Vertical	◎ Horizontal/ vertical	○ Horizontal/ vertical	NA	◎ Vertical	○ Horizontal

Note 1: MSF stands for Mitsubishi Spent Fuel (In MSF-XXB/P, XX signifies the number of assemblies in a cask, while B/P represents the type of fuel).
Note 2: The numerical values given with * show the weight/dimensions including the shock absorbers for transportation.
Note 3: ◎: Type certificate/designation obtained; ○: Only type certificate obtained (preparing to apply for type designation)

With regard to MSF-52B and MSF-21P, their type certificates/designations have been obtained for use in the dry storage facilities located outside the power plants. On the other hand, MSF-24P's type certificate/designation is for use in the dry storage facilities inside the premises of power plants. As the types with the increased number of fuel assemblies in storage (i.e., higher storage capacity), MSF-28P and MSF-76B were developed; their type certificates were issued in 2023.

2. Introduction of horizontal storage systems

Dry casks are generally planned to be placed upright inside a dry storage building with earthquake resistance in Japan. In this type of storage, however, there are some issues to be dealt with, such as the necessity of having a robust foundation to prevent dry casks from falling over during an earthquake, the necessity of having a site area large enough to construct a storage building that contains the dry cask handling area, and the limitation on where to be installed on the premises of a power plant. Dry casks have been designed to satisfy the transport requirements (passing the 9-m drop test, fire test, etc.) and therefore withstand such impact. In 2019, "the assessment guidelines for spent fuel storage using transport and storage dry casks on the premises of nuclear power plants" were issued. The guidelines specify the storage method in which dry casks are horizontally oriented with the transportation packaging on (i.e., with the shock absorbers attached), thereby allowing dry cask horizontal storage. In this type of storage, there is no need to build the foundation of a storage facility or storage building, because the safety functions of dry casks can be maintained without fixing them to such foundations. Fewer restrictions are imposed on the conditions of site selection on the premises of a power plant, which makes it easier to introduce a highly safe dry storage system. The type certificates of MSF-24P and MSF-28P have been obtained for this horizontal storage (the type designation as well in the case of MSF-24P). We have also designed a dry storage facility made of concrete panels with a shielding function, and therein a single dry cask is placed horizontally (**Figure 1**), so can offer a wide range of storage systems.

When it comes to the shock absorbers used in horizontal storage, it is necessary to consider their temporal degradation due to causes such as heat and radiation over a long storage period. We have therefore developed a metal shock absorber with no less in performance in this regard. Attachment of this shock absorber to dry casks can maintain their safety against the events that may occur during a long storage period (such as earthquakes and falls). There are designed to have a porous structure made of a metal (aluminum alloy with no temporal degradation, and a high energy absorption efficiency or high ductility). The compression test was conducted to assess the energy absorption characteristics. The drop test using a 1:10 scale mock-up of a cask to which a metal shock absorber was attached confirmed the satisfactory buffer functions. The drop test results were also used to verify our analysis method. This verified analysis method was then used to analyze the drop of a full-scale cask. The results indicate the sufficient functions of the metal shock absorber (**Figure 2**).

With regard to this horizontal storage system, the application for the change of nuclear power plant on-site storage installations has been submitted by Kansai Electric Power for its Takahama Nuclear Power Station, and is currently under review.

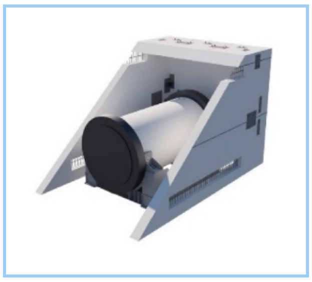

Figure 1 Dry cask horizontal storage system

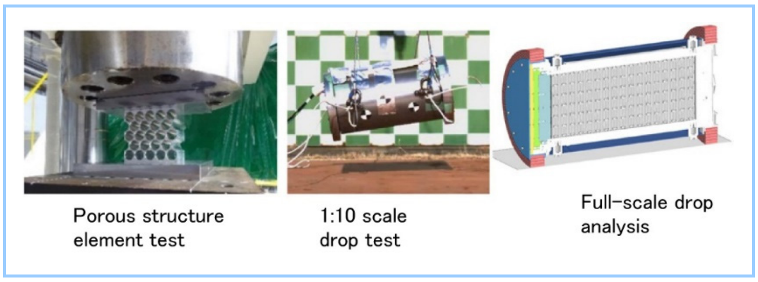

Figure 2 Development of shock absorber for storage

3. Increased capacity for spent fuel storage

With the aim of achieving a higher storage capacity for spent fuel, MHI has designed/developed MSF-28P and MSF-76B. Their type certificates were obtained in 2023. Of the two products, MSF-28P is described below.

3.1 Overview of MSF-28P

The specifications of MSF-28P are given in Table 1; a bird's-eye view is shown in **Figure 3**. Based on the basic structure of MSF-24P, the design of MSF-28P has been improved mainly from the following two points of view: fuel basket configuration and shielding design. In MSF-24P, fuel assemblies are arranged to be horizontally and vertically symmetrical. In contrast, the fuel basket configuration of MSF-28P is asymmetric minimizing the unused space (Figure 3). Moreover, the streamlined shielding design, which is described in Section 3.2, has increased the number of fuel assemblies in storage by four, while maintaining the weight, size and safety functions (subcriticality, heat removal, shielding and containment) that are comparable to MSF-24P.

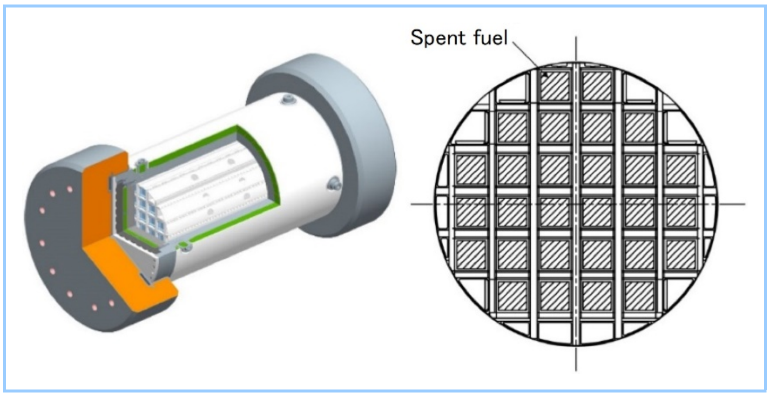

Figure 3 Bird's-eye view of MSF-28P and fuel arrangement

3.2 Shielding design

MSF casks has been designed to provide adequate shielding functions against radiation from spent fuel. Specifically, the shields made of carbon steel (for the body and lid) and resin are laid out in such a way that the maximum surface dose equivalent rate of an MSF cask is 2 mSv/h and the maximum dose equivalent rate at 1 m away from it is 100 µSv/h. Although the shields are heavy, it is desirable to minimize their weight from the viewpoint of easiness of cask handling. In MSF-28P, asymmetric fuel basket configuration has been adopted to increase the number of stored fuel assemblies. In shielding design, the three-dimensional (3D) Monte Carlo transport code was used for calculation, because it can handle complex 3D geometric shapes and provide accurate simulation results. The asymmetric fuel basket configuration was thus modeled/designed. **Figure 4** shows the calculation results using this code, which is the dose equivalent rate distribution around the MSF-28P cask with spent fuel assemblies stored therein. It has been confirmed that both dose equivalent rates on the cask surface and at 1 m away from it are below the specified levels, achieving a higher storage capacity despite its size and weight being almost the same as MSF-24P.

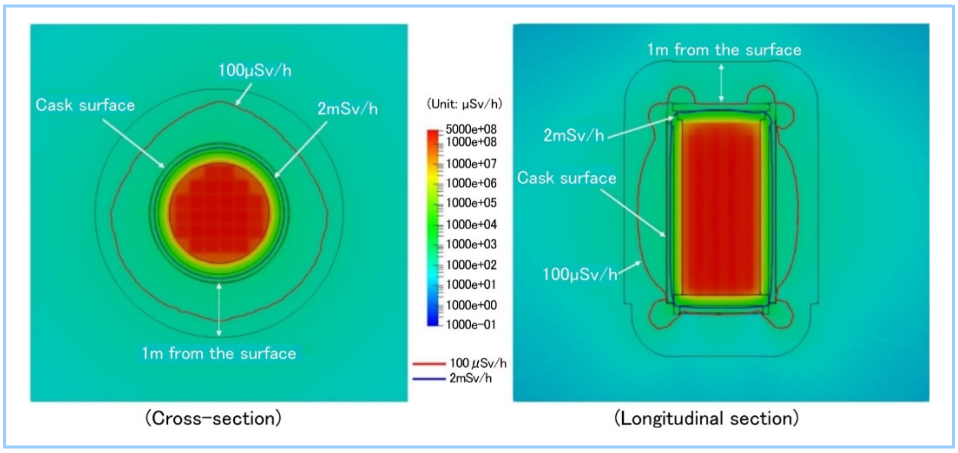

Figure 4 Dose equivalent rate distribution around MSF-28P

4. Future directions

As our MSF casks are an integration of the past achievements in material development, safety assessment technology and safety verification, we can design and manufacture dry casks that meet the requirements of safety, quality and high storage capacity. When it comes to dry cask storage systems, the horizontal storage units, which serve as a relatively quick option for introducing a dry storage system, are available in addition to the conventional vertical storage units. While the required safety performance is ensured, our system design and construction are efficient. As a nuclear power plant manufacturer, MHI will continue leveraging its comprehensive capabilities through the stages from design to procurement and construction, thereby promoting spent fuel dry storage systems.