Development of Spent-Fuel Transport and Storage Dry Casks

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INTRODUCTION

Many nuclear power plants are running out of storage space in their reactor pools for storing spent fuel. On-site spent fuel storage in metal casks to store excess spent-fuel elements is now being in the stage of practical application in Japan. Mitsubishi Heavy Industries, Ltd. has developed a transportable dry storage cask "MSF-V" to carry high burnup spent-fuel. This paper describes an outline of the MSF-V-26P transport and storage cask to contain 26 PWR fuel elements, which is designed to meet practical requirements derived from the site handling operations.

Design characteristics of the cask are

- Increasing number of fuel elements accommodated in the cask taking into account the existing cask handling equipment capability and allowable extended cooling period for spent fuel.
- Designed in conformity with the domestic safety standards for spent-fuel storage in metal cask established by the Japanese Competent Authority.
- A multilayer structure (steel-lead-steel-resin) optimized shielding thickness for neutron and gamma attenuation.
- Original basket design and the multilayer shielding system provide minimum cask diameter with maximum fuel accommodations.

BASIS OF DESIGN

The MSF-V transport and storage cask is cylindrical in shape with a multilayer structure that consists of a stainless steel inner shell, an intermediate shell, chemical lead filled in the annulus between the two shells, which provides a gamma radiation shield, a stainless steel outer shell, and a layer of neutron shield enclosed between the intermediate and the outer shell. Stainless steel double lid closure system with metal O-rings provides containment boundary of the MSF-V. An internal basket consists of stainless steel supports, borated stainless steel square tubes, and copper heat conductors provides 26 accommodations for PWR spent-fuel elements. This basket design realizes higher capacity for the cask in a compact overall diameter. Weight and dimensional constraints imposed by the plant handling requirements have been accommodated within the design to ensure the cask is suitable for all operations.

General specifications of the MSF-V-26P are summarized as follows, compared with standard transport and storage casks MSF-V-21P and MSF-V-52B:

	Cask Type	MSF-V-26P	MSF-V-21P	MSF-V-52B
Fuel	No. of fuel elements	26 (PWR)	21 (PWR)	52 (BWR)
	Enrichment	4.1 wt%	4.1 wt%	3.0 wt%
	Maximum burnup	48 GWD/T	48 GWD/T	40 GWD/T
	Cooling time	10 years	5 years	5 years
Cask	Dimensions*	2.7 5.3 m	2.4 5.3 m	2.4 5.5 m
	Weight in storage*	116 t	116 t	121 t

* Without shock absorbers

PACKAGE DESCRIPTION

Cask Body

Inner shell, top and bottom flanges, bottom plate, intermediate shell, outer shell, and primary and secondary lids of the MSF-V-26P are all manufactured from 304 stainless steel. The 304 stainless steel possesses an adequate mechanical strength for the cask operation and is well-known as a corrosion-resistant material suitable for long-range use.

The inner shell is fabricated by rolling in two halves then welding these together, and the forged bottom plate and the ring shape forged top flange are welded to the inner shell section. The intermediate shell is concentric with the inner shell and is welded to the top flange. Lead is poured between the inner and intermediate shell and then the ring shape forged bottom flange is welded to the intermediated shell and also to the bottom plate in order to hold the poured lead.

The inner and intermediate shells, and the lead located between the two shells provide radial gamma shielding for the MSF-V-26P.

A layer of neutron shielding material GESC-NS-4-FR is enclosed between the intermediate shell and the outer shell and longitudinal copper fins bolted to the two shells through the NS-4-FR to keep good heat transfer. NS-4-FR is also installed outside on the bottom plate and on the secondary lid to provide axial neutron shielding. NS-4-FR with high hydrogen content provides a good ability to reduce neutron attenuation and is stable at a relatively high range of operation temperature.

The cask is equipped with two pairs of trunnions used for handling and for tie down during transport and storage. The trunnions fabricated from forged 630 stainless steel are located near the ends of the cask and each one is secured to the cask body by screws.
A smooth surface finish of the cylindrical outer shell facilitate the cask decontamination work.

Dimensions and weights of the MSF-V-26P components are given in Table 1.

Closure System

The primary lid forging is sealed against the body top flange by a dual-type metal O-ring incorporating a testable interspace. The primary lid bolts fabricated from 630 high-strength stainless steel are hexagon socket head screws. These are primary components of the MSF-V-26P containment. Three penetrations are retained into the primary lid: the drain port, the vent port, and the seal test port. The drain and vent port have cover plates with double metal O-rings which are the primary containment boundary. An inert helium gas is back-filled in the cask cavity during transport and storage.

The secondary lid forging with dual-type metal O-ring incorporating a testable interspace is bolted to the top flange and provides a secondary containment boundary for the cask. The secondary lid bolts fabricated from 630 stainless steel are hexagon socket head screws.

The pressure transducer port is located on the side of top flange for continuous monitoring of pressure changes interspace, between the primary and the secondary lids pressurized with helium gas during storage. The vent port for lid interspace is also located on the top flange. These two ports have cover plates with double metal O-rings.

Fuel Basket

The cask cavity is fitted with a basket designed as a structural support for the fuel elements. It consists of 304 stainless steel supports and 26 square tube shaped fuel cells fabricated from borated stainless steel to provide criticality control inside the basket assembly. Base material of the borated stainless steel is Type 304 and the boron content is 1 wt %.

Stainless steel supports and borated stainless steel cells are reliable structural members of the basket and allow high integrity against possible impact accidents and relatively high temperature during operation. Borated stainless steel is also a well established material for effectively absorbing neutrons to reduce the fuel arrangement pitch inside the basket.

Copper heat conductor plates, not as a structural member, are placed between the fuel cells to provide decay heat dissipation capability of the basket.

The basket design incorporated in the cask for carrying BWR fuel elements is a similar concept and uses elements of the same materials which are used for the PWR casks.

Table 1 summarizes the design features of the MSF-V-26P and Table 2 gives materials of construction.

Table 1. Design features of the MSF-V-26P

Dimensions (mm)	
Cask overall length	5,300
Cask overall diameter	2,700
Cavity length	4,200
Cavity diameter	1,800
Masses (ton)	
Body assembly	77.0
Primary lid	5.5
Secondary lid	3.5
Fuel basket	12.5
26 Fuel elements	17.5
Total in storage	116.0

Table 2. Materials of construction

Cask Feature	Material
1. Cask body	
Inner shell	Stainless Steel
Intermediate shell	Stainless Steel
Bottom plate	Stainless Steel
Primary lid	Stainless Steel
Secondary lid	Stainless Steel
Outer shell	Stainless Steel
Neutron shielding	GESC/NS-4-FR
Thermal fin	Copper
Trunnions	Stainless Steel
2. Basket	
Top & bottom plate	Stainless Steel
Support plate	Stainless Steel
Heat conductor plate	Copper
Outer shell	Copper
Fuel cell	Borated Stainless Steel
3. Shock absorbers	
Lid shock absorber	Stainless Steel
Bottom shock absorber	Stainless Steel
Wood infill	Oak

Figure 1 illustrates a schematic of the proposed MSF-V-26P in a vertical storage position. An artist's impression of the cask storage facility is shown in Figure 2.

SAFETY ASSESSMENT

Structural

Structural analyses of the cask were carried out in accordance with the criteria for Level A and Level D service limits given in "Design by Analysis" for Class 1 components specified in ASME Code Section Ⅲ. In the design of MSF-V-26P, impact analysis associated with site handling operation conditions were carried out to confirm that the cask has an adequate structural integrity for all operations.

Thermal

Heat transfer calculation for a normal storage condition indicates that the maximum fuel cladding temperature would not exceed maximum allowable temperature considering 1 % creep deformation.

Shielding

The design criteria for shielding assessment during storage are the same dose rates prescribed in the IAEA transport regulations; 2,000 μ Sv/hr at the cask surface and 100 μ Sv/hr at 1 m away from the cask surface (1-m is a strict value for the Japanese domestic transport regulation). Shielding calculations show that the cask shielding structure provides a good ability to reduce radiation attentions for both gamma and neutron.

Subcriticality

The design criteria for criticality safety are to satisfy that the effective neutron multiplication factor (keff), including statistical uncertainties 3 σ, shall be less than 0.95 under normal and accident conditions. Borated stainless steel containing minimum 1 wt% boron and an adequate water space to reduce the speed of neutrons provide keff + 3 σ = 0.930 for the MSF-V-26P under infinite arrays of damaged casks flooded with water inside the cavity.

Containment

Analysis of leaktightness of the metal O-rings was carried out in accordance with ANSI-N14.5 to confirm that the negative pressure inside the cask cavity could be maintained during 40 years of storage operation.

CONCLUSION

Mitsubishi has developed the MSF-V transport and storage cask both for PWR and BWR spent-fuel elements. The design of the MSF-V-26P transport and storage cask has achieved a large capacity to carry 26 PWR fuel elements with practical requirements for site operation of the cask. Detailed design of the cask has already been completed and is going to be in the licensing stage in the near future.

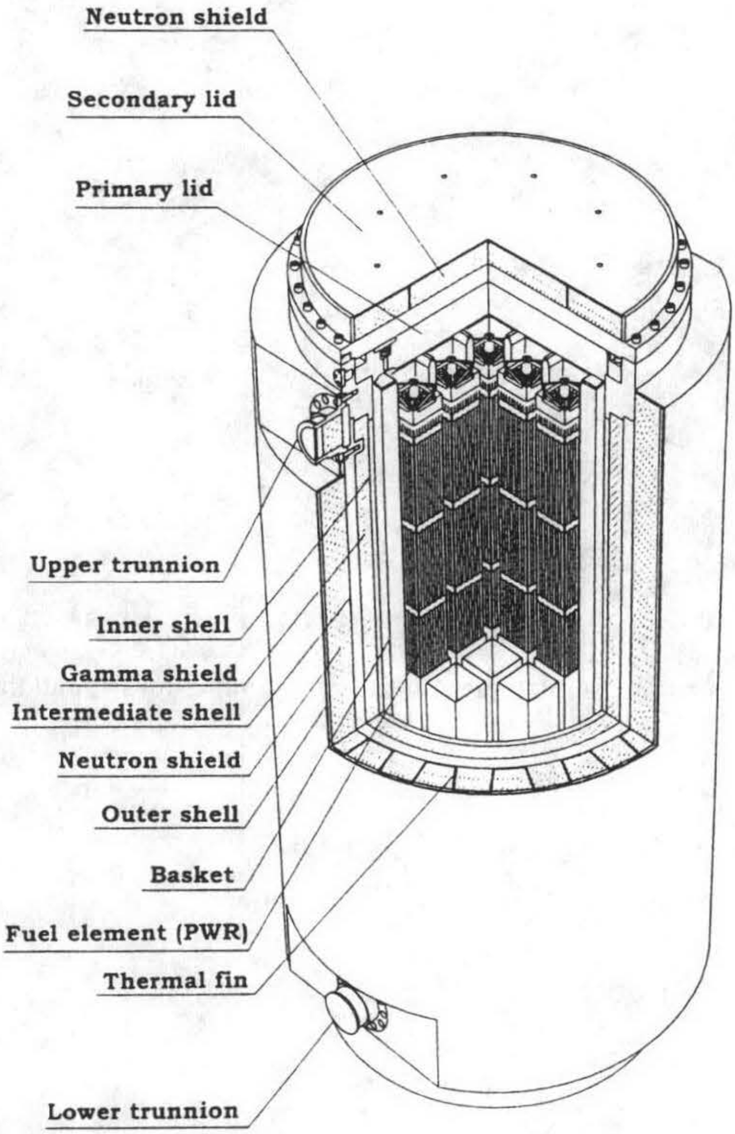

Figure 1. MSF-V-26P transport and storage cask.

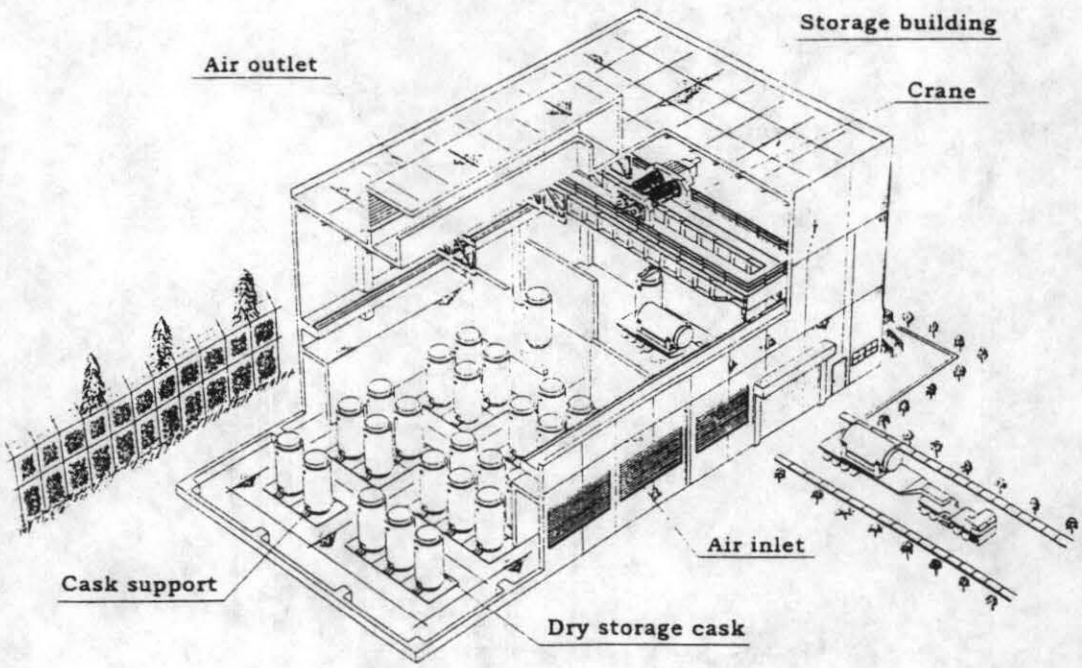

Figure 2. Emplacement of dry casks in the storage building.