Design of High-Capacity Transport/Storage Cask for High Burnup Fuels

H. Taniuchi, H. Yasuda
Kobe Steel Ltd.

INTRODUCTION

In Japan, the first interim storage of commercial spent fuels by cask was permitted by the Japanese Government in 1994. The casks, Japanese version TN24 (Kakunai et al. 1995), were fabricated and have been in use at the Fukushima site of the Tokyo Electric Power Company since mid-1995. Additional interim storage of spent fuels using casks is expected by other electric power companies. As the Japanese version TN24 cask was designed for conventional spent fuels, another cask for high burnup fuels will be necessary in the near future in Japan. The cost performance of the cask and storage efficiency at the storage facility are the most important considerations for interim fuel storage using casks. Considering the aspects above, brand-new, high-capacity transport/storage casks named KTC for high burnup fuels are being designed.

FEATURES OF THE KTC

Even though the TN24 was permitted only for use as a storage cask, and so far there is no permission for the transport/storage dual-purpose cask in Japan, the KTC is designed to satisfy both regulation of transport and storage. Therefore the concept of KTC is a low-cost transport/storage cask with high loading capacity of fuel assemblies. The specifications of the spent-fuel assembly considered in the current design of the KTC and the characteristics of the KTC are summarized in Table 1. The cross-sectional view of the KTC is shown in Fig. 1.

Table 1. Characteristics of the KTC

Specifications of the spent-fuel assembly :		
Fuel type	PWR	BWR
Enrichment	4.2 %	3.7 %
Burnup(average)	44,000 MWD/T	40,000 MWD/T
Cooling Time	10 years	7 years
Characteristics of the KTC :		
Design decay heat	25 kW	25 kW
Total No. of Fuel Assemblies	32	76
Weight (transport)	125 ton	125 ton
(storage)	120 ton	120 ton
Overall Size(transport)	ϕ 3.2x6.4 m	ϕ 3.2x6.6 m
(storage)	ϕ 2.5x5.2 m	ϕ 2.5x5.4 m

The feature of the KTC are as follows.

Basket

Usually the basket for PWR fuel has several wide water gaps between the basket holes to prevent the cask from becoming critical by spent fuels loaded into the basket holes. Because the enrichment of high burnup fuels is higher than that of the conventional spent fuels, the water gaps become much wider. This means the transport/storage efficiency becomes worse. On the other hand, there is no water gap in the conventional basket for BWR fuel because the reactivity of BWR fuel is less than that of PWR fuel, but some water gap is expected when high burnup fuels, which mean high enrichment fuel, are introduced.

To remove these water gaps, two measurements are introduced in the KTC design. One measurement is the usage of high performance neutron absorber such as borated aluminum alloy and borated stainless steel, both using over 90% ^{10}B enriched boron. In both materials, the content of boron is 1.0%. The other is the consideration of borated water in the PWR spent-fuel pool when the spent fuels are loading into a cask at the pool with respect to a criticality analysis. The effect of these measurements is investigated by the calculation using the infinite basket model. With the condition of 4.2% enriched PWR fuel and 10mm thick absorber plate, it is impossible to remove the water gap. When considering borated water in a basket, borated aluminum alloy with 90% ^{10}B enriched boron or borated stainless steel with normal boron can be used without any water gap. With respect to BWR fuel, when a 10mm thick absorber plate is used, enrichment of BWR fuel that can be loaded in the basket is up to 4.1% with borated aluminum alloy containing 90% ^{10}B enriched boron or up to 3.7% with borated stainless steel containing normal boron. Borated stainless steel is better for neutron-absorbing ability than borated aluminum alloy.

For the current design of the KTC, borated aluminum alloy is chosen for the basket material. This is because the neutron-absorbing ability of borated aluminum alloy is enough for this design, the thermal conductivity of borated aluminum alloy is much better than that of borated stainless steel, and the weight of borated aluminum alloy is about one-thirds that of borated stainless steel. Borated aluminum alloy is used in TN24, but in KTC design the boron content in aluminum alloy is increased from 0.6% to 1.0%. When the enrichment of fuel become much higher, the use of borated stainless steel becomes better for a basket design.

Body Structure

The inner, thinner containment vessel is made of carbon steel. The thickness of this vessel is determined by a structural analysis so as to have enough strength against a pressure in cavity and stress by the weight of body itself. The neutron shield is a type of resin, and the gamma shield is lead. Both shields are a block type, not a casting type which is poured directly between cask shells as the conventional cask. Some copper fins penetrate both the lead and resin regions from the inner vessel to the outer shell.

The TN24 uses forged carbon steel for gamma shielding because it has extremely good structural strength. It is not much disadvantaged for gamma shielding compared to other conventional casks even though some other casks use much better gamma shielding such as lead. The reason is the tolerance of shield thickness is very small when machined forged steel is used and very large when lead is poured between the inner shell and outer shell of a cask. For the KTC lead blocks are selected as gamma shield as described above. This is because the combination of neutron shield blocks and lead blocks used in the KTC makes the fabrication cost lower as these blocks can be produced by mass production methods. Furthermore, as the tolerance of shield thickness is expected to be much smaller, the shielding ability becomes better than the conventional type from the viewpoint of the safety analysis. As the heat pass is maintained by the fins that penetrate the lead and resin regions, there is no requirement for the lead and resin with respect to thermal conductivity. The conventional cask has separated heat passes for the lead and resin region. This difference affects the fabrication cost of a cask significantly. The thickness of outer shell is designed to maintain the integrity of the cask under accident conditions such as the 9-m drop test assigned by transport regulations. If it is a storage-only cask, its thickness can be much thinner.

SAFETY ANALYSIS

The summary of a safety analysis of the KTC is as follows. These results are for KTC with PWR fuels, and similar results are expected with BWR fuels.

Structural Analysis : The structural integrity of KTC is confirmed by structural analysis. With respect to the 9-m drop test, the KTC body can stand the deceleration up to 100 times of gravity.

Thermal Analysis : The temperature of each location of the KTC under transport conditions is calculated by ABAQUS code. The results are summarized in Table 2. As the allowable temperature of neutron shield, lead, borated aluminum alloy, and fuel is 150, 330, 300 and 380 ℃, respectively, there is no location which exceeds the allowable temperature.

Table 2. Temperature of KTC under Normal Transport Conditions

Location	Temperature (℃)	Location	Temperature(℃)
outer shell	110	basket plate	
neutron shield	125	outer side	160
lead	130	center	215
inner shell	140	fuel assembly	260

Shielding Analysis : The shielding analysis is performed by DOT 3.5 code(Mynatte et al. 1973). Axial burnup profile is considered such as the average burnup at both end with a length of one-twelfth of total fuel region and the peaking burnup at central region. Dose rate at 1m from a cask surface is

side	80(neutron) + 15(gamma) = 95 μ Sv/h (total)
top	25(neutron) + 50(gamma) = 75 μ Sv/h (total)
bottom	40(neutron) + 30(gamma) = 70 μ Sv/h (total)

Twice the quality factor is used in the neutron calculation. These results satisfy the allowable limit of dose rate at 1m, 100 μ Sv/h.

Criticality Analysis : The criticality analysis is performed using CSAS module of SCALE code system (Landers and Petrie 1990). The result is as follows;

$$\text{Keff} + 3\sigma < 0.92 \text{ (handling at pool)}$$
$$\text{Keff} + 3\sigma < 0.55 \text{ (transport/storage)}$$

CONCLUSION

The new design of the transport/storage cask KTC is described here. The KTC loads much more spent fuels compared with TN24, and its fabrication cost is expected to be lower than that of TN24, even though it is difficult to perform a direct comparison of the efficiency of the KTC with TN24. This means the brand new cask KTC makes it possible to greatly decrease the cost of interim storage by casks.

REFERENCES

Kakunai H. et. al., Experience of Fabrication of Transport/Storage Packaging "TN24", To be presented at PATRAM'95,1995.

Landers N. F. and Petrie L. M., CSAS4: An Enhanced Criticality Safety Analysis Module with an Optimum Pitch Search Option, Sect.C4 of SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR/0200, Rev.4 (ORNL/NUREG/CSD-2/R4), Vols.1-3, (draft February 1990).

Mynatte F. R. et al., The DOT III Two-Dimensional Discrete Ordinates Transport Code, ORNL-TM-4280, 1973.

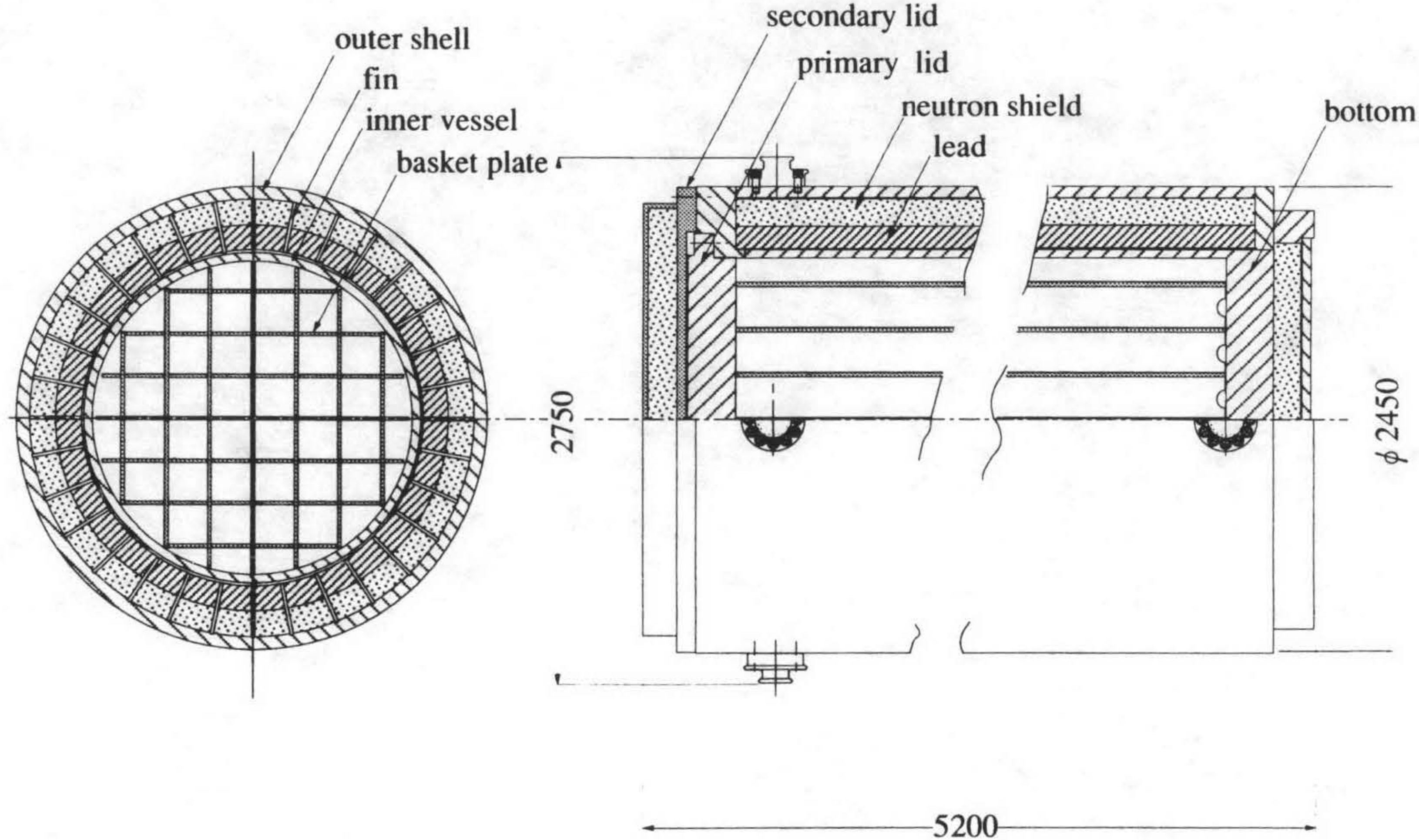

Fig. 1. Cross-sectional view of the KTC

Session VII-3.2: Basket and Shielding Materials