A COMPARISON BETWEEN MONO-WALL BODY AND MULTI-WALL BODY STRUCTURES FOR A LARGE SCALE METAL CASK

Ryoji Asano[1] **Yoshiaki Miyaji[1]** **Shintaro Miyazaki[1]**

[1]Hitachi Zosen Corporation, 26-3, Minami-Ohi 6-Chome, Shinagawa-ku Tokyo, 140-0013 Japan

Akio Nara[2] **Hirobumi Nunome[2]**

[2] Kansai Design Company Ltd., 6-33 Edobori 2-Chome, Nishi-ku Osaka, 550-0002 Japan

ABSTRACT

A large-scale transportation cask such as transporting spent fuels of a light water reactor has two kinds of body design alternatives; one being a mono-wall type using a large steel forging, and the other a multi-wall type using a combination of steel plates and lead as gamma shielding.

Historically, the multi-wall type was used at first for the body of transportation casks, and the mono wall type followed it. Currently, it can be said that there is a tendency that the mono-wall type is mainly used in European cask designs, and the multi-wall type is used in the United States cask designs. Both types of cask designs are used in Japan.

Assuming that the material of the mono-wall type body is a forged low alloy carbon steel, and that the multi-wall type body is a combination of carbon steel plate, lead and carbon steel plate, two types are compared for the instruction to the cask body type and materials for a new cask design.

The merits and demerits of each body type are discussed by not only their technical requirements, such as their: (1) Structural design strength, (2) Heat removal design and (3) Shielding design, but also their fabrication and economical standpoints.

In addition, the study considers the influence of transportable storage cask demand, which is much larger than that of transportation casks, to the design selection, and is expected to rise more in the near future. It also considers the influences of both nuclear renaissance and the increase of a high-pressure vessels demand in chemical industries, which have cropped up a few years ago.

The study concludes that the specifications of the content (spent fuels) are one of the key factors determining the cask body type required.

INTRODUCTION

The development of large spent fuel transportation casks; such as those used in transporting light-water nuclear reactor spent fuels from a nuclear power station to a reprocessing plant by rail or by sea-going vessels were started at the end of 1960’s and early 1970's These transportation casks have a robust cask body, which combines radiation shielding, and a bolted closure lid with elastomer seals that form the containment boundary of the cask. The spent fuels are contained in the cavity of the cask in a fuel basket to configure the fuels at their individual positions to keep them in a sub-critical condition. Trunnions and shock absorbers are equipped on the outside of cask for handling and reducing impact in the event of being dropped. Sometimes, fins are attached on the surface of the cask body for dissipating the decay heat of spent fuels. The cask is designed to conform to the regulatory requirements of each country, most of which are prepared based on the IAEA regulations for the safe transport of radioactive material. [1] The outline structure of typical transportation cask is shown in Figure 1. Figure 1 shows the two types of cask bodies, one is “Multi-wall type” consisting of an inner shell, lead (gamma shielding) and an intermediate shell, and the other type is “Mono-wall type” consisting of only an inner shell. The structure beyond the cask body is the same, which consists of resin (neutron shielding) and an outer shell.

The early stage of development, multi-wall type casks were designed that used steel for their structure material and heavy metals such as lead for gamma shielding material. The supposed reasons to select such a structure are as follows:

(1) Heavy metal was advantageous for the shielding material, because gamma shielding was dominant at that time.
(2) The availability of large forged materials used for cask bodies was not so easy at that time.
(3) Multi-wall type can be fabricated without any special equipment such as large machines and thick wall welding equipment.
(4) The initial design was a wet type cask, and the fuel cladding temperature was not a design factor to be considered.

Afterwards, the mono-wall type cask that combines structural material with the shielding material was proposed. A typical cask is TN12. The ideas behind such a mono-wall type cask being proposed are as follows.

(a) It became easier to obtain a large forged material.
(b) Both gamma and neutron shielding became design factors, because the cooling time of the spent fuels became longer, and its fuel burn-up increased.
(c) The welding technique for thick shells was improved.
(d) A dry type cask with high heat capacity was advocated to support dry handling at a reprocessing plant. The cask needed to improve heat transfer performance to keep the fuel cladding below the criteria.

The mono-wall type is the most common in Europe; on the other hand, the multi-wall type is the most common in the United States now. Both types are used in Japan. The transport casks for PWR fuels currently used for the transportation from NPS to Rokkasho reprocessing plant in Japan are the multi-wall type, and that for BWR fuels are the mono-wall type design. It is presumed that consideration of low-temperature brittle toughness of the material to the design is one of the reasons why the multi-wall type is dominant in the United States.

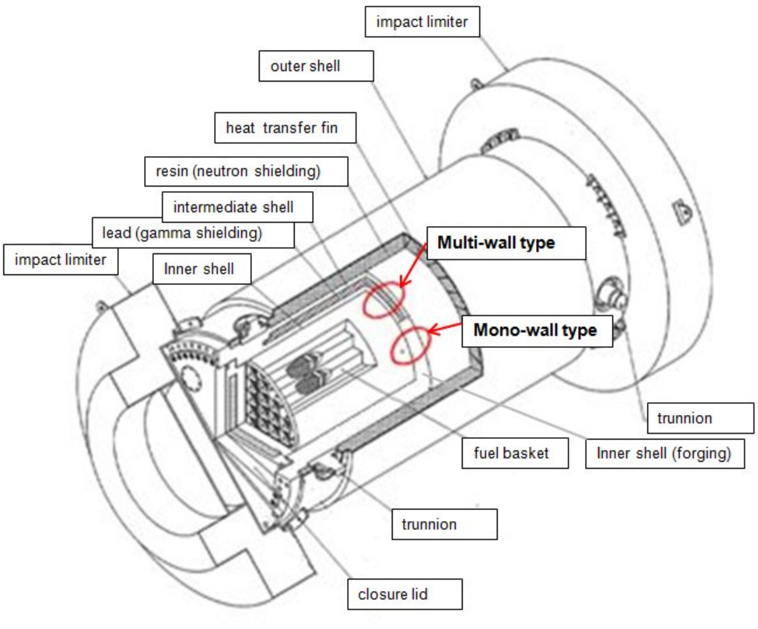

Figure 1 Large cask structure with multi-wall type and mono-wall type cask bodys

SAFETY REQUIREMENTS

Structural Performance

Though the cask body stiffness of the mono-wall type is higher than that of the multi-wall type, the multi-wall type still has enough stiffness to meet the design requirements, because its inner shell and the intermediate shell are made of thick steel plate of tens of millimetres. Moreover, the penetration strength of the multi-wall type is excellent compared to the mono-wall type, because the multi-wall type consists of two independent walls. As for the brittleness at low temperature, the multi-wall type is more advantageous, because steel plate, which has higher toughness at low temperature, can be selected for shell material.

A weak point of multi-wall type on structural strength is a lead slump, which may occur at a 9m drop in a vertical direction. The lead slump creates a gap at the opposite end of the lead, the width of which is varied by the design of impact limiters, but the gap usually becomes 20-40 mm. The gap should be considered to evaluate the radiation dose rate after the accident test conditions. On the other hand, the lead slump does not occur in a 9m drop test, if the shell is connected to the lead by the lead bonding process, which will be described in detail in 'Heat Removal Performance' below.

Heat Removal Performance

Figure2 shows temperature distribution in the multi-wall type body, the dimension of which is also shown in Figure2. The heat capacity of the spent fuels is 22.16 kW and the ambient temperature is 38 ºC. Because the structure of outside the intermediate shell is the same for both mono-wall type and multi-wall type, the temperature distribution of that part is omitted. The calculation model assumes a gap of 1 mm between the outer surface of lead and the inner surface of the intermediate shell, which would be induced by the shrinking of the lead after the lead pouring process if no surface treatment is done before this process. The temperature difference between the gap surfaces becomes about 20ºC. This is the weak point of multi-wall type on heat removal performance. Actually, the temperature difference is not so large when the contents is loaded into the cask, because the gap becomes smaller and finally makes contact with the inner surface of the intermediate shell by thermal expansion of lead. However, conservative consideration is necessary for the design and the gap should be considered.

On the other hand, the heat removal performance of the mono-wall type is excellent because of no discontinuity in layer and higher heat conductivity of the low alloy steel comparing to the lead. When there is the limit of content temperature, it is more advantageous to use the mono-wall type body to reduce the temperature.

There is a method called "lead bonding", which improves the heat removal performance of the multi-wall type. The lead bonding sticks the shell and lead together by making the lead alloy layer on the outer surface of the inner shell and the inner surface of the intermediate shell before pouring the lead to avoid generating a gap after lead pouring.

Figure 3 shows the comparison of the temperature distribution of the multi-wall type with lead bonding, and the mono-wall type. The heat capacity is 22.16 kW and the ambient temperature is 38 ºC. The heat transmission of the multi-wall type is improved. It is still a few degrees higher than the mono-wall type, but it becomes a similar temperature distribution to that of the mono-wall type. The dimension of the analysis models are shown in the figure below:

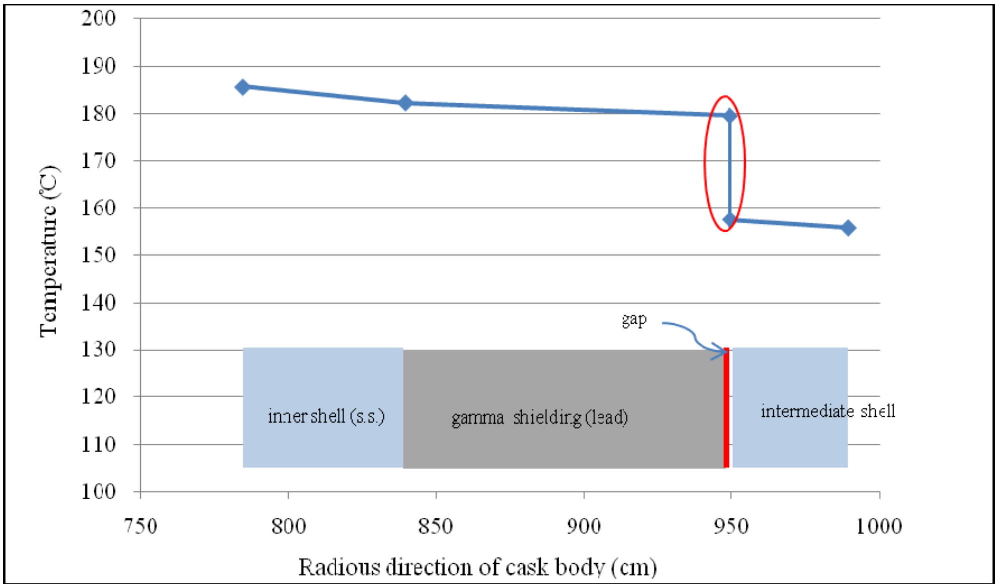

Figure 2 Temperature distributions in the multi-wall type body with a thermal gap

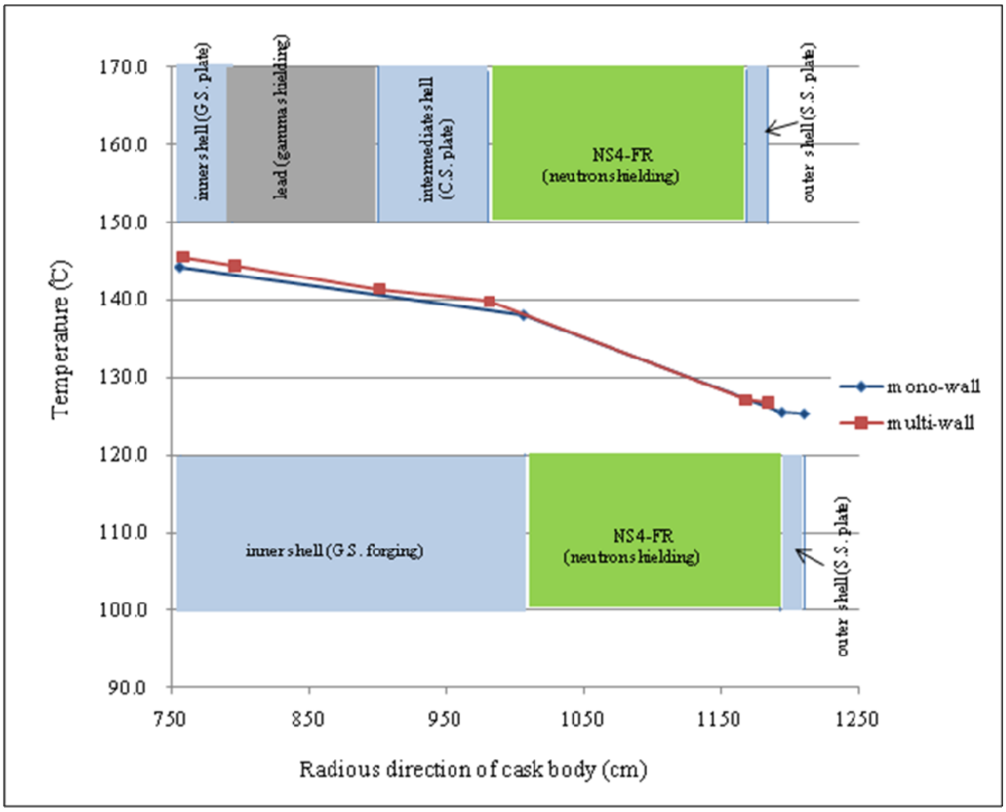

Figure 3 Comparison of temperature distributions between the mono-wall type and the multi-wall type with lead bonding

Shielding Performance

Figure 4 and Figure 5 shows the gamma and neutron dose rate attenuation curves in radial direction with the mono-wall type and the multi-wall type body casks. The dimensions of both types are shown in the figures below. For the multi-wall type body, lead is poured into the annulus consisting of an inner shell 5 cm in thickness and an intermediate shell 8 cm in thickness. The mono-wall, type has the same thickness of steel forging as the multi-wall type body.
Gamma ray energy spectrum obtained by ORIGEN-2 is used to calculate the attenuation curve. Comparison of the same thickness of both types shows that the gamma attenuation of the multi-wall type is 10 times (1,000%) higher than that of the mono-wall type at the outer surface of the intermediate shell for the multi-wall type, and that of inner shell for the mono-wall type. Figure 4 shows that the steel of the mono-wall type shall be thicker by 8 cm to obtain the same gamma attenuation as the multi-wall type.
The neutron energy spectrum used to calculate the attenuation curve in Figure 5 is fission neutron. Figure 5 shows that attenuation of the mono-wall type is 1.2 (120%) higher than that of the multi-wall type. The steel thickness of the multi-wall type shall be increased by 1.5 cm to obtain the same neutron attenuation as the mono-wall type.
Regarding specifications of spent fuels loaded into the cask, the fuel burn-up is increased, and cooling time is extended, which makes the neutron contribution to the total dose rate more than it was previously. However, radiation shielding performance of the multi-wall type is still superior to the mono-wall type. The calculation results mentioned above indicates that the total shielding thickness of the multi-wall type is 6.5 cm (8.0-1.5=6.5 cm) thinner than that of the mono-wall type.
Based on the result, the loading capacity is compared. Figure 6 shows two kinds of basket array. The cask cavity radius of 21 basket array is 72.9 cm, and that of the 24 basket array is 79.0 cm with a 25 cm cell width for PWR fuel. The load capacity of the multi-wall type can adopt one rank larger basket array than the mono-wall type with the same cask outer radius. Alternatively, the outer radius of the multi-wall type is smaller than that of the mono-wall type. In regards to the shielding performance, higher capacity is a benefit of the multi-wall type.

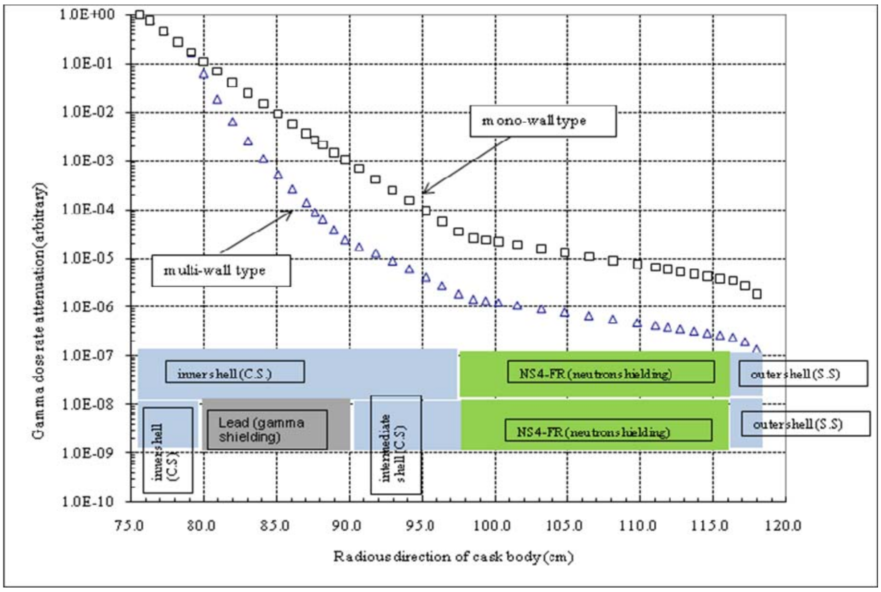

Figure 4 Comparison of gamma dose rate attenuation between the mono-wall type and the multi-wall type casks

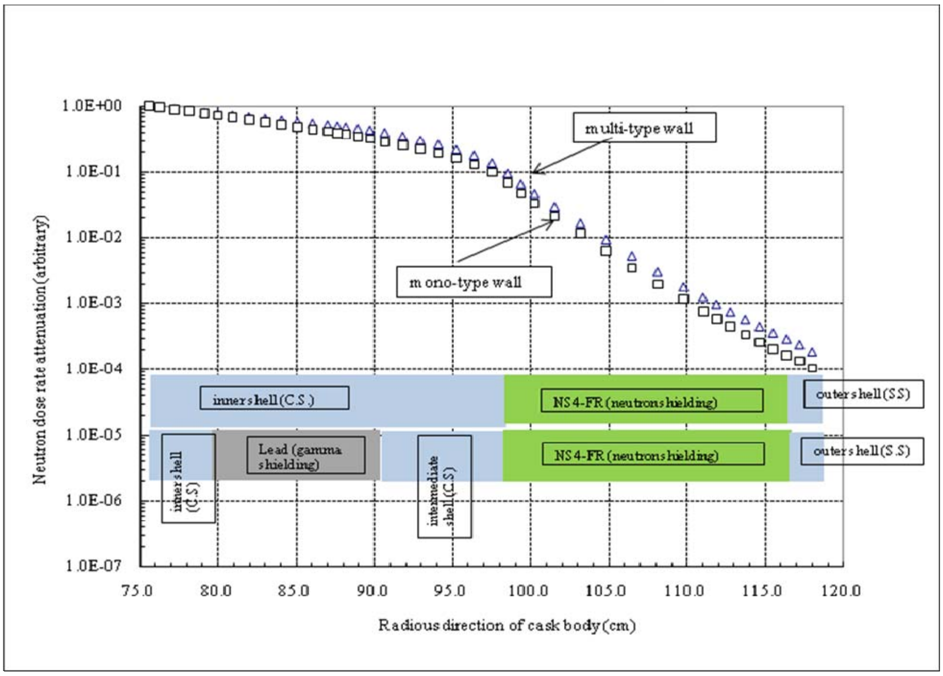

Figure 5 Comparison of neutron dose rate attenuation between
the **mono-wall type and** the **multi-wall type casks**

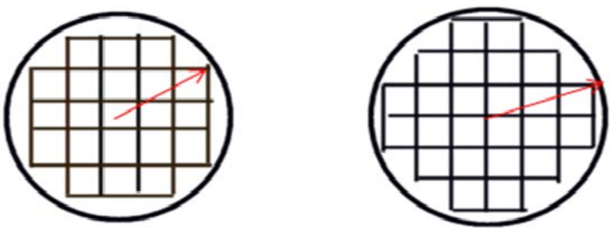

Figure 6 Comparison of cask cavity radius of two fuel basket array with 25 cm cell width

Fabrication

Large fabrication equipment, such as large machines and thick wall welding apparatus are necessary from an early stage in order to fabricate the mono-wall type of cask. On the other hand, no special fabrication equipment is necessary until the final stage of fabricating the multi-wall type of cask, because it is assembled from lighter parts and a large machine is necessary only in the final stage of fabrication. For this reason, suppliers of the mono-wall type casks are limited to comparing those of to the multi-wall type casks.

CONSIDERATION ON ECONOMY

Figure 7 shows the price index of forged materials [3], carbon steel plates [4], stainless steel plates [4] and lead [5], which are the main material of the mono-wall type and the multi-wall type. The index in 2005 is estimated at 100.

The sudden rise of the price of these materials started from 2005 mainly because of the big demand for pressure vessels for chemical plant construction, and strong the demand for rare metals worldwide. It stabilized afterwards, but it remains at a much higher level compared to the level in 2005 though carbon steel plates and forgings are still increasing. Restricting the discussion to special large forgings used for nuclear reactor vessels and the mono-wall type cask, its price index presented a more advanced level than the forgings in the figure, and actually, the price increased more than carbon steel plates and stainless steel plates, because of the Nuclear Renaissance and the limited supply capacity of large forgings.

Moreover, because the ratio of material costs in the mono-wall type to fabrication costs is larger than that of the multi-wall type, the increase of material prices had more influence on the mono-wall type than the multi-wall type.

It takes more than two years to develop a new cask. Although it is difficult to predict the economical environment in two years, the influence of the material cost should be considered when cask body type is determined. The worldwide demand for spent fuel storage casks is increasing, which will need larger units of cask than the transportation casks, so that the material selection becomes more important not only when ascertaining costs, but also the fabricator's ability to supply the correct capacity.

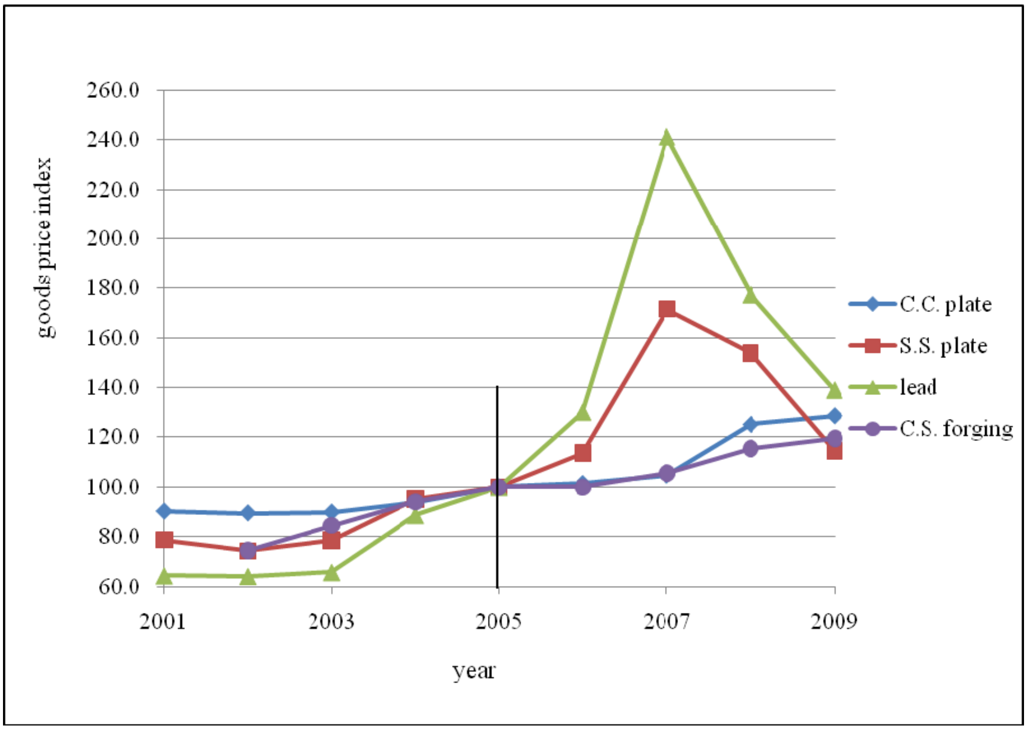

Figure 7 Goods price index of forged material, carbon steel plates, stainless steel plates and lead

CONCLUSIONS

The discussion above is summarized as follows:

(1) Absolute structural stiffness of the mono-wall type is higher than the multi-wall type. However, both types have enough stiffness to satisfy design requirements. Both types can be used as the cask main body structure.

(2) The thermal transfer performance of the mono-wall type is superior to the multi-wall type, because of higher thermal conductivity of the steel forging and the fact there is no thermal gap between the layers. When it is necessary to lower the cask cavity temperature, the mono-wall type is advantageous. Thermal resistance induced between layers of the multi-wall type can be decreased to the same level as the mono-wall type by lead bonding on both the outer surface of the inner shell and the inner surface of the intermediate shell.

(3) Integral radiation shielding performance of the multi-wall type is superior to the mono-wall type, though the neutron shielding performance of the mono-wall type is slightly higher than the multi-wall type. In particular, the performance of the multi-wall to gamma ray is excellent. Contribution of the neutron to the total dose rate is increased with the increase of fuel burn-up and the cooling time, however, the contribution of gamma rays are still dominant. If there is a limit in the outer diameter or weight when a new cask is designed, the multi-wall type is more advantageous than the mono-wall type in loading the same fuels. Generally, loading capacity for the multi-wall type is larger than that of the mono-wall type.

(4) Special equipment is necessary to fabricate the mono-wall cask. The supplying capacity of the mono-wall cask is limited compared to that of the multi-wall type.

(5) The price of raw material is influenced by the economic situation when procuring the item. When the cask is designed, price fluctuations and the contribution of material costs to cask fabrication cost ought to be considered. Moreover, when large volumes of casks are procured at one time, the material supplying capacity becomes more important.

REFERENCES

[1] Regulations for the Safe Transport of Radioactive Material, 2005 Edition Safety Requirements, IAEA Safety Standards Series No. TS-R-1

[2] Corporation Brochure, NUCLEAR FUEL TRANSPORT CO., LTD.

[3] Ferrous metal, Non-ferrous Metal and Metal Products, Statistics, Ministry of Economy, Trade and Industry

[4] Domestic Corporate Goods Price Index excluding Consumption Tax, Corporate Goods Price Index (2005 base), Bank of Japan Time-Series Data Search

[5] Japan Metaldaily.com/market/index/Lead Buttery Material