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DEVELOPMENT OF KATS – ECO-FRIENDLY SPENT FUEL TRANSPORT AND STORAGE CASK

H.TANIUCHI
Transnuclear, Ltd. 1-18-16, Shinbashi, Minato-ku, Tokyo, 105-0004, Japan

S. NAKASAKU
Transnuclear, Ltd. 1-18-16, Shinbashi, Minato-ku, Tokyo, 105-0004, Japan

H.AKAMATSU
Kobe Steel, Ltd. 2-3-1, Shinhama, Arai-cho, Takasago, Hyogo, 676-8670, Japan

J. SHIMOJO
Kobe Steel, Ltd. 2-3-1, Shinhama, Arai-cho, Takasago, Hyogo, 676-8670, Japan

ABSTRACT
A new type of Eco-friendly Spent Fuel Transport and Storage Cask named KATS has been developed, of which the main gamma shielding is provided by lead blocks. This structure enables to dismantle the cask body easily after the lifetime of the cask. The main body of KATS consists of the alloy steel plates, such as inner shell and outer shell. The copper fins connect inner shell and outer shell to remove thermal heat of spent fuels to outside of the cask, and the lead blocks are only inlaid with neutron shielding blocks into the lodgment between these shells and copper fins. Consequently, the amount of dismantle radioactive waste of KATS is minimized because only the inner shell, inner bottom and lid should be disposed and the other materials can be re-usable. The safety aspect of this structure such as the radiation streaming at the gap between fin and shielding blocks is investigated and solutions are discussed.

INTRODUCTION
Lead is very efficient as a gamma-shielding material because of its high density. However, it may not be appropriate to use lead as gamma shielding in spent fuel transport and storage casks from an environmental point of view. This is because the lead is usually bonded with the inner and the outer shells to get a good thermal transfer path between lead and shells. At time of disposal, the clean dismantling of lead is then not possible. Therefore, a new type of spent fuel transport and storage cask named KATS has been developed by Transnuclear, Ltd. and Kobe Steel, Ltd., in which the main gamma shielding is provided by lead blocks. The concept of KATS is therefore easy to dismantle and maximizes re-usable materials after a long term use.

KATS DESIGN
KATS uses lead and neutron shield blocks as main shielding materials. The structural soundness is secured by the main body consists of two layer of thick alloy steel plates, and the containment vessel is formed by an inner alloy steel plate, a primary lid and an inner bottom plate welded to the steel plate.

The cross sectional view of KATS is shown in Figure 1. The main body is divided into two parts: the inner shell and the outer shell. The lead blocks and neutron shielding blocks are sandwiched between these two shells. The copper fins connect the inner shell and the outer shell to remove thermal heat of spent fuels from inside to outside of the cask. Then no heat transfer ability is required for these lead and neutron shielding blocks.

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With respect to safety analysis aspect, the radiation streaming must be considered for this structure. One case is the radiation streaming trough gaps between shielding blocks due to fabrication tolerances. There might be some gap between shielding blocks and fins during manufacturing process and this may become a radiation streaming path. The other possibility of radiation streaming is linked to the stability of lead blocks under 9 m drop tests. As lead is easy to deform, there is a possibility of changing its shape and making large void to allow large radiation streaming when the lead blocks are submitted to high g-load. With respect to these two points, the methods of countermeasures have been discussed. The detailed discussion is described in the following sections.

AMOUNT OF RECYCLABLE MATERIAL IN KATS

Based on this principle, lead and neutron shielding blocks can be easily removed from the two shells by opening the top or bottom side of the body when the cask is to be dismantled. For example, the blocks shown in Figure 1 can be easily removed after having unbolted the bottom plate from the inner bottom and cut the welding part of the outer shell welded to the flange.

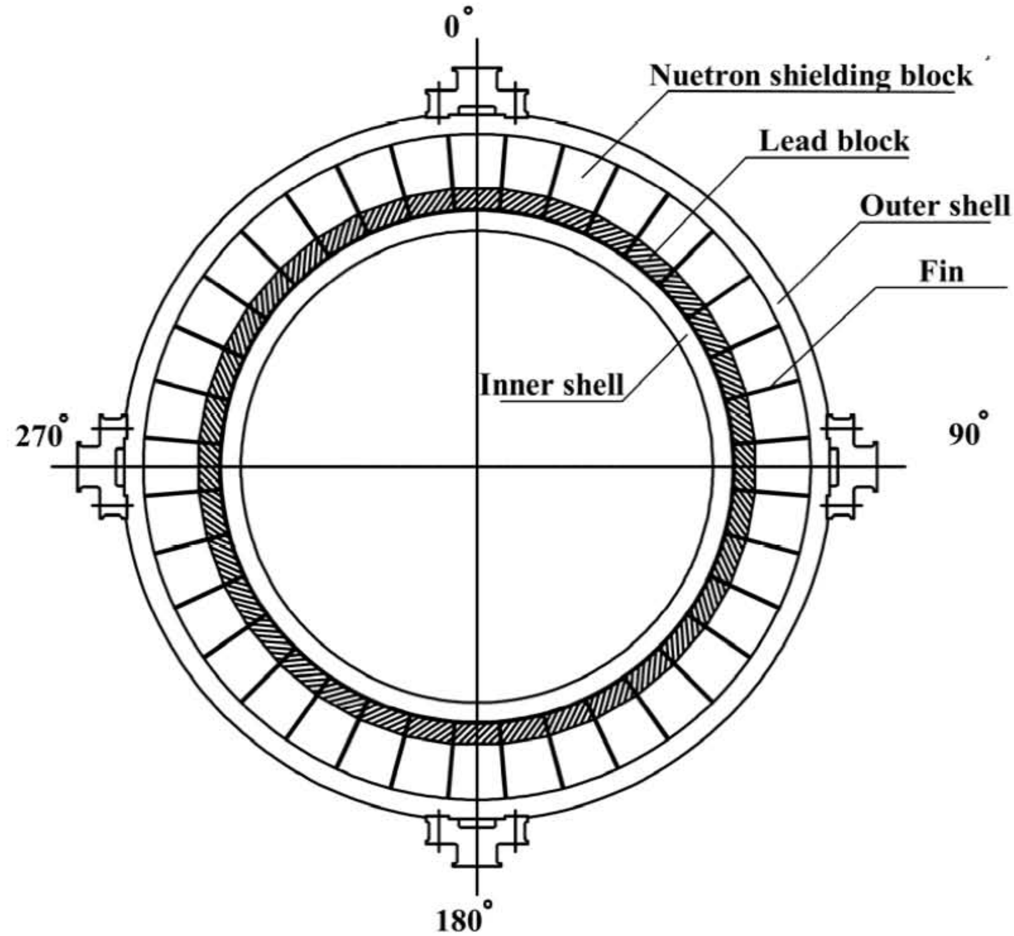
As the inner shell protects the blocks from the radioactive contamination, there is no chance for these blocks to be contaminated by radioactive materials. The activation of lead by neutrons from spent fuels is also negligible. Therefore, the lead can be re-used for another cask. The neutron shielding blocks are also not contaminated, but degradation is expected. This neutron shielding material may be considered as normal industrial waste, but not as radioactive waste. The amount of radioactive waste is minimized because the inner shell and lid only have to be disposed and other materials can be re-used. Figure 2 shows the re-usable materials of KATS with a weight ratio. Based on this estimation, the amount of radioactive waste of KATS is around 1/3 of the conventional cask such as forged carbon steel cask.

Consequently, the cost of the dismantling of casks will be remarkably reduced and lead-free waste to be disposed will be easily obtained. Namely, KATS is “Eco-friendly Spent Fuel Transport and Storage Cask”.

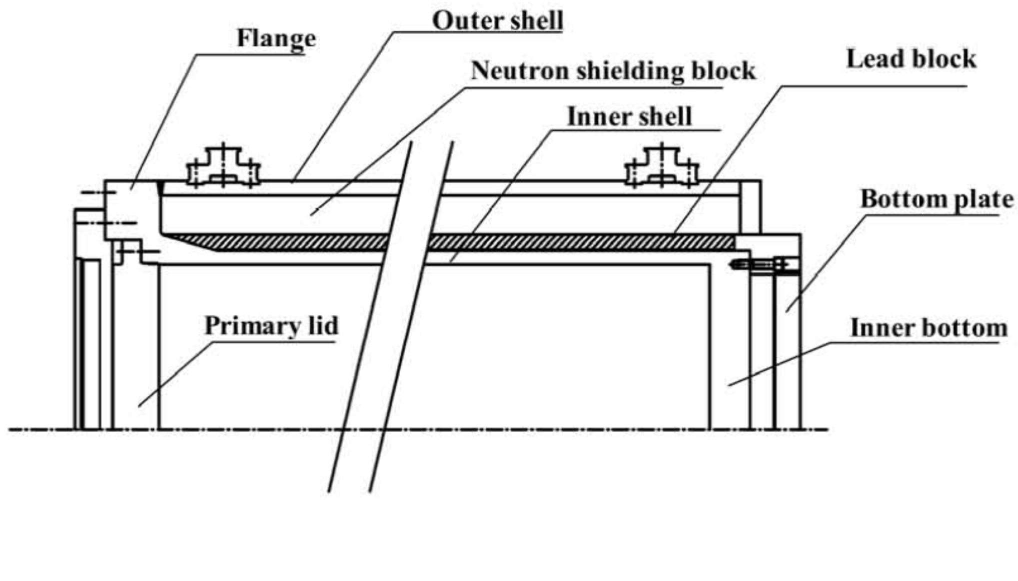
RADIATION STREAMING FROM GAP OF SHIELDING BLOCKS

The radiation streaming in the area of fins may be an issue. In the case of KATS, the streaming path is longer than one of a conventional design, and then the characteristics of the radiation streaming of KATS structure are thus to be investigated.

Figure 3 shows the streaming path of KATS. As KATS uses lead and neutron shielding blocks, some streaming path may exist between fin and lead and neutron shielding blocks. To investigate this effect, the amount of steaming dose rate is calculated by MCNP[1)] code. For these calculations, an axially infinite model is used and the dose rates at 1 m from the cask surface are evaluated.

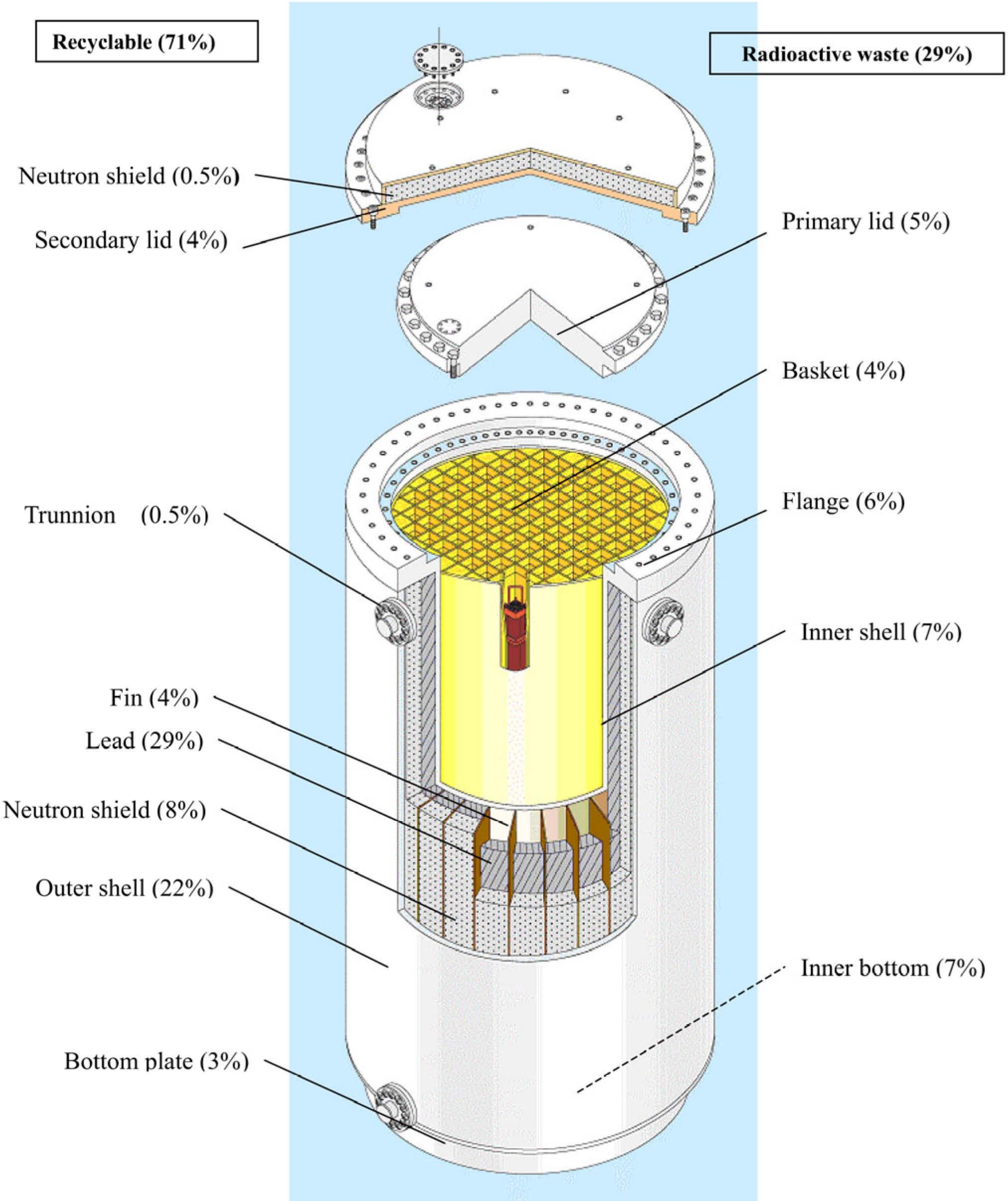


(1) Radial cross-section



(2) Axial cross-section

Figure 1 Cross-sectional view of KATS(Concept)



Note: Neutron shield is easy to dispose as normal industrial waste

Figure 2 Recyclable part of KATS

1) Effect of gaps between fin and shielding blocks

Actual structure of main body as shown in Figure 3 is considered for the calculation except that the gap between fin and blocks is used as a parameter. The shape of shielding blocks is trapezoidal. The total gap between fin and shielding blocks is assumed as 0.0, 1.0, and 2.0mm for gamma rays, and 0.0, 2.0, and 4.0mm for neutrons. The amount of streaming dose rates for each gap value is shown in figure 4. In this figure, the results of a simplified cylindrical model, which is the same with DOT[2)] calculation model for the safety analysis, are also shown as dotted lines.

The neutron is not sensitive at gap and the dose rate only increases of 10% for a 2.0mm gap. Furthermore, the dose rate with the simplified model structure used for the safety analysis is 10% higher than that of the actual design with no gap for neutron shielding calculation. This will compensate the increase of dose rate by the existence of gap up to 2 mm. This means that the gap between fin and shielding blocks is not an issue for neutron dose rate evaluation until it is lower than 2 mm.

On the other hand, the gamma rays are sensitive for these gaps and the dose rate increases around 20% with a 1.0 mm gap. Furthermore, the dose rate with the simplified model structure used for the safety analysis is only 5% higher than that of the actual design with no gap for gamma shielding calculation. This means that this dose rate increase must be considered in the safety analysis, or some countermeasures are necessary to reduce this gamma ray streaming.

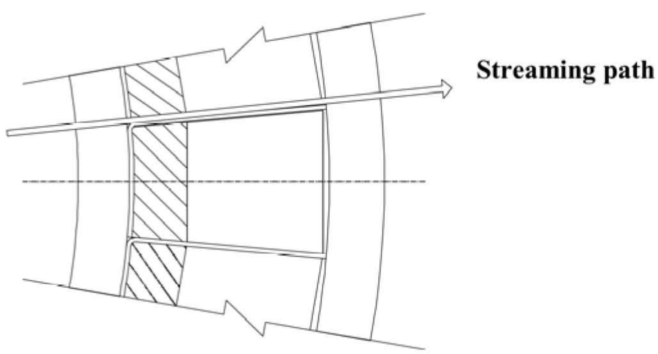


Figure 3 Radiation streaming path of KATS

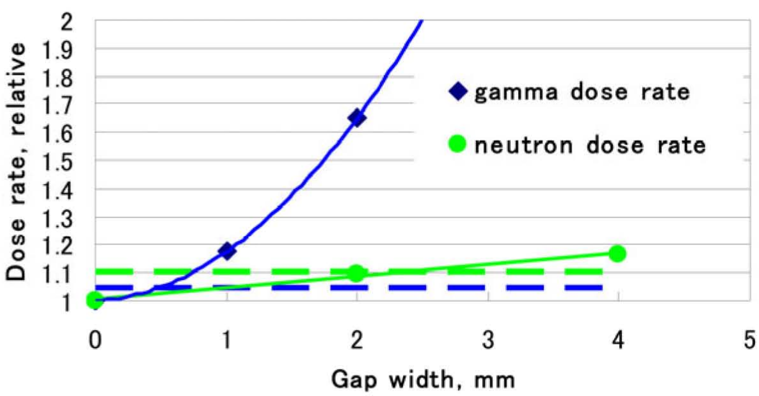


Figure 4 Radiation streaming against gap between fins and shielding blocks

2) Effect of slanting fin

To reduce the streaming dose rate due to the gaps, slanting the fins is usually considered in the cask design. To estimate the effect of these slanting fins, a parametric study is performed with changing the slanting angle. To make easy modeling of slanting angles, the simplified model shown in Figure 5 is used instead of the real design shown in Figure 3.

The effect of slanting fins against gamma rays is shown in Figure 6 with normalizing to the results of the real design. The effect is large enough to cancel the streaming dose rate with 1.0 mm gap when the fins are slanting with 30 degree. If the gap width is 2.0 mm, still around 20% dose rate increase must be considered in the safety analysis. On the other hand, calculated neutron dose rate is not sensitive with slanting angle of fins, as it is anticipated. The effect for neutron is less than 3% when the fins are slanting with 30 degree.

3) Countermeasures for radiation streaming

Based on the discussion above, following countermeasures are effective for the radiation streaming around fin and shielding blocks.

With respect to neutron, no countermeasure is necessary when the gap is less than 2.0mm. If the gap would become larger than 2.0 mm, the steaming dose rate which should be considered in the safety analysis is not so huge. On the other hand, gamma ray is very sensitive at gap and a dose rate increase of 20% should be considered when a gap of 1.0 mm exists. One countermeasure is adopting slanting fins with 30 degree to compensate this streaming effect. If the gap is 2.0 mm, a streaming increase of 20% should be considered even adopting 30 degrees slanting fins.

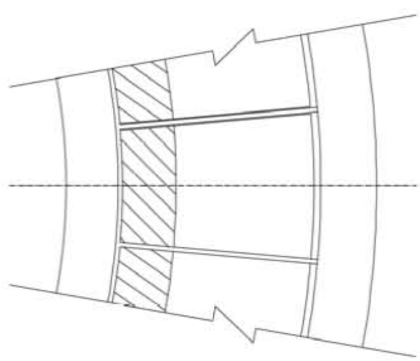
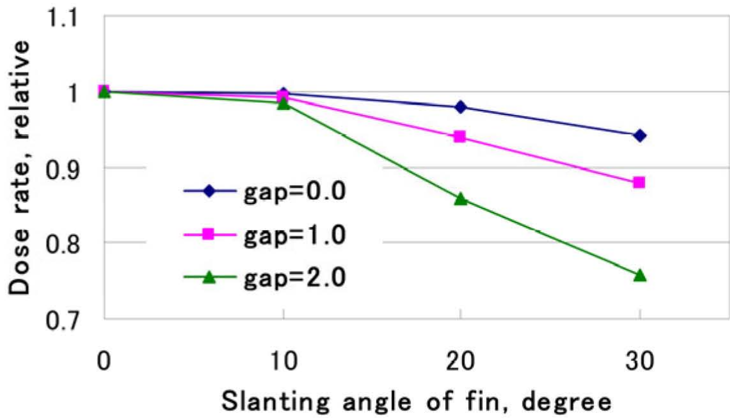
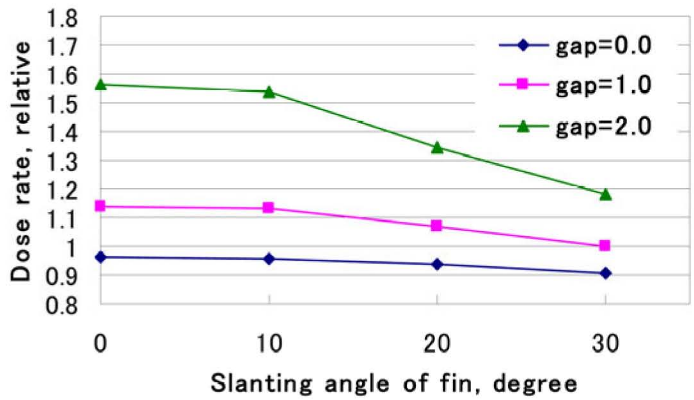


Figure 5 Calculation model for checking fin slanting effect



1) Normalized at 0 degree for each gap



2) Normalized to the dose rate obtained by simplified model used for safety analysis

Figure 6 Effect of angle of fins against radiation streaming (gamma-rays)

4) Behavior of lead blocks after a 9 m drop test

Based on Cask designer's guide[3)], the slumping effect must be considered when using lead for the gamma shield because lead is easy to deform when applying some g-values. This is true, but this is not considered in the KATS structure, because some countermeasures have been introduced in the design to avoid the deformation of lead blocks.

To check the efficiency of these countermeasures, several tests and dynamic structural analyses are under performing: for example, to put the lead blocks in box with punching holes penetrating this box. By applying these solutions to KATS, no additional radiation streaming should be considered.

OTHER SAFETY ANALYSIS OF KATS

The KATS safety analysis is performed considering typical BWR spent fuels. The structural analysis method is the same as for a conventional cask design except for the 9 m drop test. To confirm the g-value of KATS evaluated by dynamic structural analysis code, some 9-m drop tests using KATS 1/3 scale model are performed as shown in Figure 7. The thermal analysis is the same as with a conventional forged type cask because both use fins to penetrate shielding blocks. The shielding analysis is also the same as with a forged type cask except that the effect of gamma streaming is additionally considered. The criticality analysis is also the same as with a forged type cask.

CONCLUSIONS

The advantage of KATS design have been described and confirmed in this paper. KATS is "Eco-friendly Spent Fuel Transport and Storage Cask" using lead as the main gamma shielding material. Furthermore, the manufacturing cost of KATS is very reasonable considering the current market situation, where the materials especially forgings are very expensive. The delivery schedule of KATS is stable and shorter than that of forged type cask.

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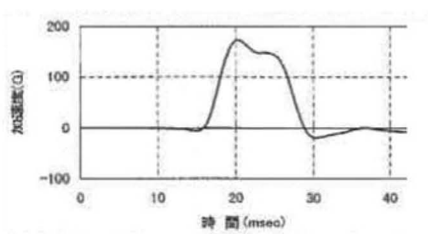
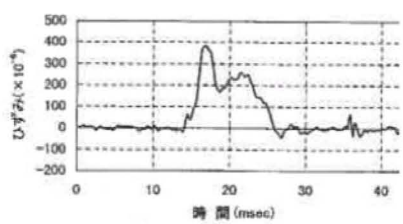
2) W. A. Rhoades and F.R. Mynatt, "The DOT III Two-Dimensional Discrete Ordinates Transport Code", ORNL-TM-4280(1973).
3) "Cask Designers Guide", ORNL-NSIC-68,(February 1970).



G-value under 9m drop test



Strain under 9m drop test

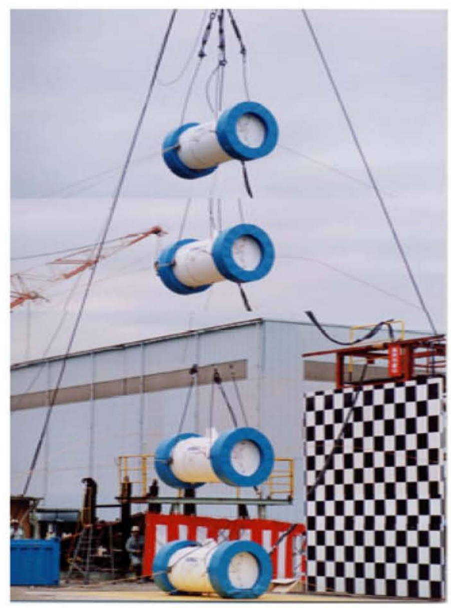


Figure 7 Horizontal 9m drop test using 1/3 scale model of KATS