NEW DESIGN OF A SPENT NUCLEAR FUEL SHIPPING CASK USING A DEPLETED URANIUM SHIELDING*

S. SANO, T. ISHIKAWA, R. HOMMA, S. ONODERA
The Japan Steel Works Ltd,
Tokyo

H. YOSHIDA
Muroran Plant,
The Japan Steel Works Ltd,
Muroran

Japan

Abstract

NEW DESIGN OF A SPENT NUCLEAR FUEL SHIPPING CASK USING A DEPLETED URANIUM SHIELDING.

In anticipation of future demand for shipment of higher burnup spent nuclear fuel (SF), a higher performance shipping cask (JSU-1), with a depleted uranium (DU) gamma shield, has been designed. The cask can transport 12 PWR SF assemblies with a burnup of 45 000 MW·d/t U or 32 BWR SF assemblies with a burnup of 40 000 MW·d/t U under dry conditions, its total weight, including SF, being about 100 t. Various investigations, including trial manufacture of a DU casting and confirmation of its properties, the influence of assembly accuracy and the internal defects of the DU on shielding performance, dynamic compression tests of balsa blocks, used as shock absorbers, and the economic evaluation of shipment using the JSU-1 cask were made. It was confirmed that use of a DU shield in a JSU-1 cask would permit transport of a greater number of higher burnup SF assemblies safely and economically compared with existing types of casks.

1. INTRODUCTION

Development of higher performance fuel for light water reactors, for reasons of economy, is proceeding in several countries including in Japan. A higher performance cask suitable for shipping extended burnup spent nuclear fuel (SF) is thus thought to be necessary for the future. This study was carried out with these requirements in mind.

From the very beginning of design work, considerations of the characteristics of higher burnup SF, such as higher uranium enrichment, higher radioactivity, higher decay heat and so on, were made from the point of view of safe and economic transport. It was then decided that the use of depleted uranium (DU) metal as a gamma

* Work supported by the Science and Technology Agency, Tokyo, Japan.

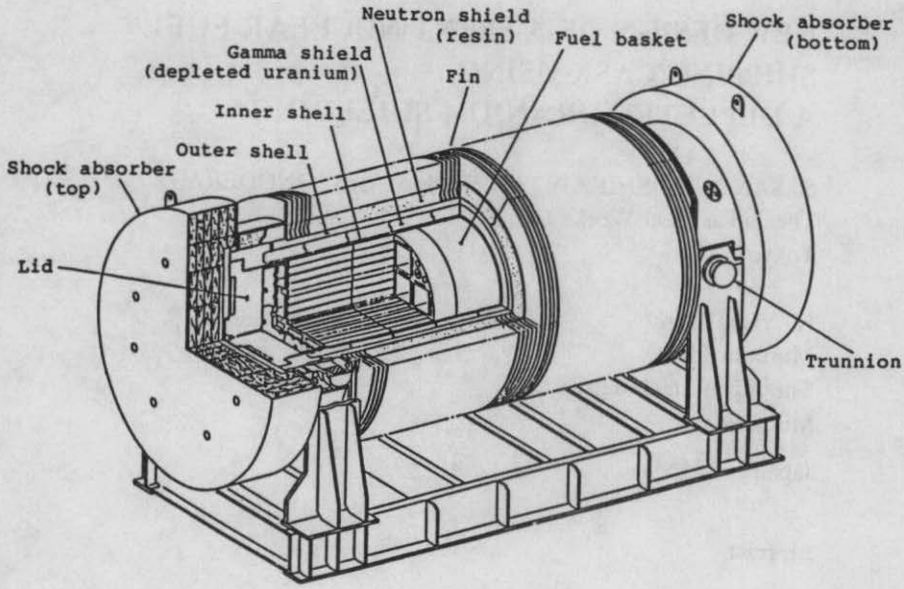

FIG. 1. General view of the JSU-1 cask.

shield would be the best method to keep the cavity capacity of the cask as large as possible, while still remaining under the limits of weight and the mandated external radiation levels. This paper outlines the features of the JSU-1 cask and also some results of the safety analysis.

2. FEATURES OF THE JSU-1 CASK

The JSU-1 cask was designed as a Type B(M) package for spent fuel. A general view of the cask is shown in Fig. 1. A feature of the cask is that depleted uranium (DU) is used as a gamma shield. It has been recommended that in the case of a cylindrical shield with an inner radius of 150 mm and a thickness of 300 mm, the ratio of the thickness and weight of the DU shield to the lead shield should be about 0.57 and 0.75, respectively [1]. Accordingly, it was considered to be effective to use DU as a gamma shield in the design of the cask, giving it enough shielding capability and the largest cavity possible under the weight limit. The JSU-1 cask is a dry-type cask of simple construction and is designed to be able to contain SF from either PWRs or BWRs.

The main specifications of the JSU-1 cask are shown in Table I. The main specifications of the IF-300 cask [2], which uses a DU shield, and the TN-12 cask [3], which is one of the largest existing casks, are also shown in Table I. The

TABLE I. SPECIFICATIONS OF THE JSU-1, IF-300 [2] AND TN-12 [3] CASKS

Type of cask	JSU-1		IF-300		TN-12	
Weight (t)	98[a]		63[b]		94[a]	
Length (m)	5.3[a]		5.3[b]		5.4[a]	
Diameter (m)	2.3[a]		1.6[b]		2.5	
Inner diameter of cavity (m)	1.2		1.0		1.2	
Specification of fuel						
Reactor type	PWR	BWR	PWR	BWR	PWR	BWR
Number of fuel assemblies	12	32	7	18	12	32
U enrichment (%)	4.0	3.5	—	—	3.5	3.5
Burnup (MW·d/t U)	45 000	40 000	35 000	35 000	32 000	33 000
Specific power (MW/t U)	40.0	24.0	—	—	38.4	24.8
Time of cooling (d)	360	270	120	120	360	—
Decay heat generation (kW)	87.8	86.0	61.5	61.5	75.2	63.4
Gamma shield	Depleted uranium		Depleted uranium		Steel	
Neutron shield	Resin		Water		Resin	
Cooling system	Natural convection of air		Forced circulation of water		Natural convection of air	
Transport	Ship, trailer or railroad		Railroad		Ship, trailer or railroad	

[a] Except shock absorbers.
[b] Except cooling system.

JSU-1 cask is capable of containing 12 PWR SF assemblies with a burnup of 45 000 MW·d/t U or 32 BWR SF assemblies with a burnup of 40 000 MW·d/t U and its total weight, including the SF, is about 100 t. It is considered by some to be superior in shipping capacity of SF to the IF-300 cask and in burnup of SF to the TN-12 cask.

3. GENERAL DESCRIPTION OF THE JSU-1 CASK

As shown in Fig. 1, the JSU-1 cask consists of the main body, the lid, the fuel basket and the shock absorbers. The main body consists of three layers: the inner shell (stainless steel), the gamma shield (DU-Mo alloy) and the outer shell (low alloy steel). Copper fins for heat dissipation are welded onto the outer shell. The spaces between the fins are filled with a neutron shield (resin), the lid is made from stainless

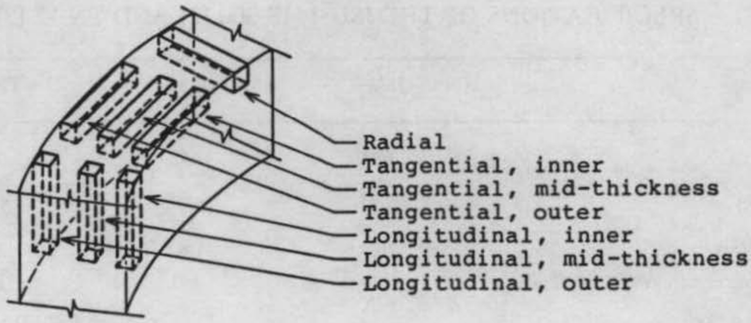

FIG. 2. Locations and directions of specimen cut off from the DU ring casting.

steel. The fuel basket is made from aluminium alloy and the shock absorbers are made from balsa blocks covered with stainless steel plates. The gamma shield consists of ring castings of DU, which are shrink-fitted on the outer surface of the inner shell. Finally, the gamma shield is contained in the inner shell, the outer shell and the top and bottom ends.

4. RESULTS OF INVESTIGATIONS

Various investigations concerning the safety, manufacture and economy, especially the use of the DU shield, were carried out. Some results of these investigations are described here.

4.1. Manufacture of a DU ring casting and confirmation of its properties

Manufacturing experience in producing a large DU ring casting shield, as used in the JSU-1 cask, is lacking both in Japan and anywhere else in the world. While there is information on the properties of metallic DU (or U), it is felt that this information cannot be directly applied to a large-size DU casting. Thus a DU ring casting with an outer diameter of 1200 mm, an inner diameter of 988 mm, thickness of 106 mm, height of 444 mm and weight of 3.06 t and with a mass approximately the same as a full-size casting for a JSU-1 cask, was manufactured to confirm its soundness, and to investigate its properties.

The internal soundness of the casting was confirmed by gamma scanning using ^{60}Co. Then, as shown in Fig. 2, certain specimens were cut out, with due regard to location and direction, to test the homogeneity and anisotropy of the casting. As a part of the investigations, tensile tests, Charpy impact tests and dynamic fracture toughness tests were carried out. The results are shown in Figs 3–5, respectively. No noticeable inhomogeneity and anisotropy were found. Physical properties, such as

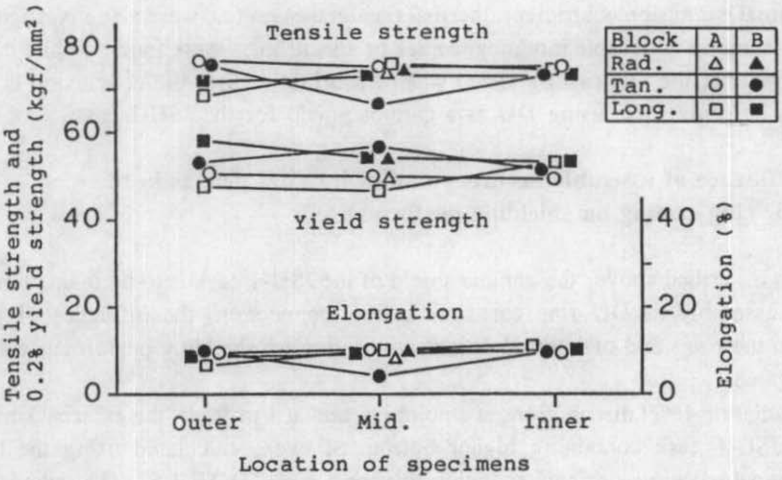

FIG. 3. Tensile properties of the DU ring casting.

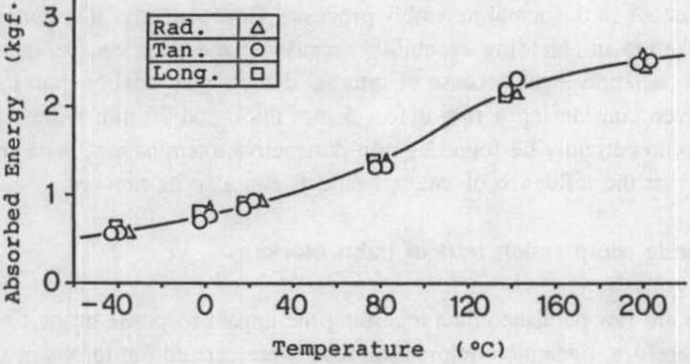

FIG. 4. Impact properties of the DU ring casting.

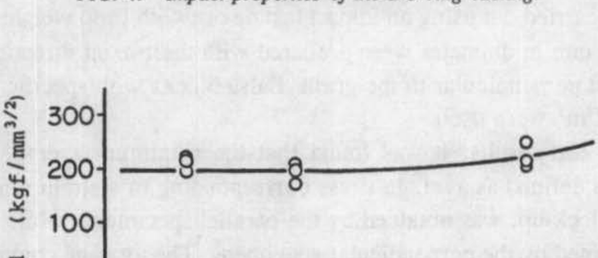

FIG. 5. Dynamic fracture toughness of the DU ring casting.

the thermal expansion coefficient, thermal conductivity, etc., were also investigated, though again no noticeable inhomogeneities or anisotropies were found. While it was confirmed that the DU casting tested was of a brittle nature, the conclusion is that there is no problem in using DU as a gamma shield for the JSU-1 cask.

4.2. Influence of assembly accuracy and of internal defects in the DU ring casting on shielding performance

As described above, the gamma shield of the JSU-1 cask is to be manufactured by the assembly of DU ring castings. In this connection, the influence of gaps between the rings and of internal defects in the ring on shielding performance were investigated.

Radiation-level distributions at a point on, and at 1 m from, the external surface of the JSU-1 cask containing higher burnup SF were calculated using the two-dimensional, discrete-ordinate radiation transport code 'DOT 3.5'. The calculation model was an infinite cylinder and the gaps between the DU rings and the internal defects were assumed in the model. Figure 6 shows the influence of these gaps on radiation-level distributions. The maximum radiation level at 1 m from the external surface is 9.8 mrem/h even in the case of a 5 mm gap ($t_2 = 5$) which, of course, will never occur in the actual assembly process.[1] Consequently, it is concluded that the deterioration in shielding capability because of the gaps can be ignored. The increase in radiation level because of internal defects was smaller than that caused by gaps, even considering a ring defect 5 mm thick and 20 mm wide which, if it existed, would certainly be found by non-destructive examination. As a result, it is concluded that the influence of internal defects can also be ignored.

4.3. Dynamic compression tests of balsa blocks

There are few published data regarding the impact response properties of balsa blocks. Therefore, dynamic compression tests were carried out to obtain the necessary data for balsa blocks for use in drop-impact response analysis of the JSU-1 cask. The tests were carried out using an impact test device with drop weights. Cylindrical specimens 102 mm in diameter were prepared with their axial direction parallel, at 45 degrees, and perpendicular to the grain. Balsa blocks with specific weights from 180 to 260 kgf/m^3 were used.

From the test results, it was found that the maximum average compression stress, which is defined as average stress corresponding to a strain range from 0.05 to the point of lock-up, was obtained by the parallel specimens, while the minimum stress was obtained by the perpendicular specimens. The average compression stress increased with an increase in the specific weight. Figure 7 shows the dynamic stress–

---

[1] 1 rem = 1.00×10^{-2} Sv.

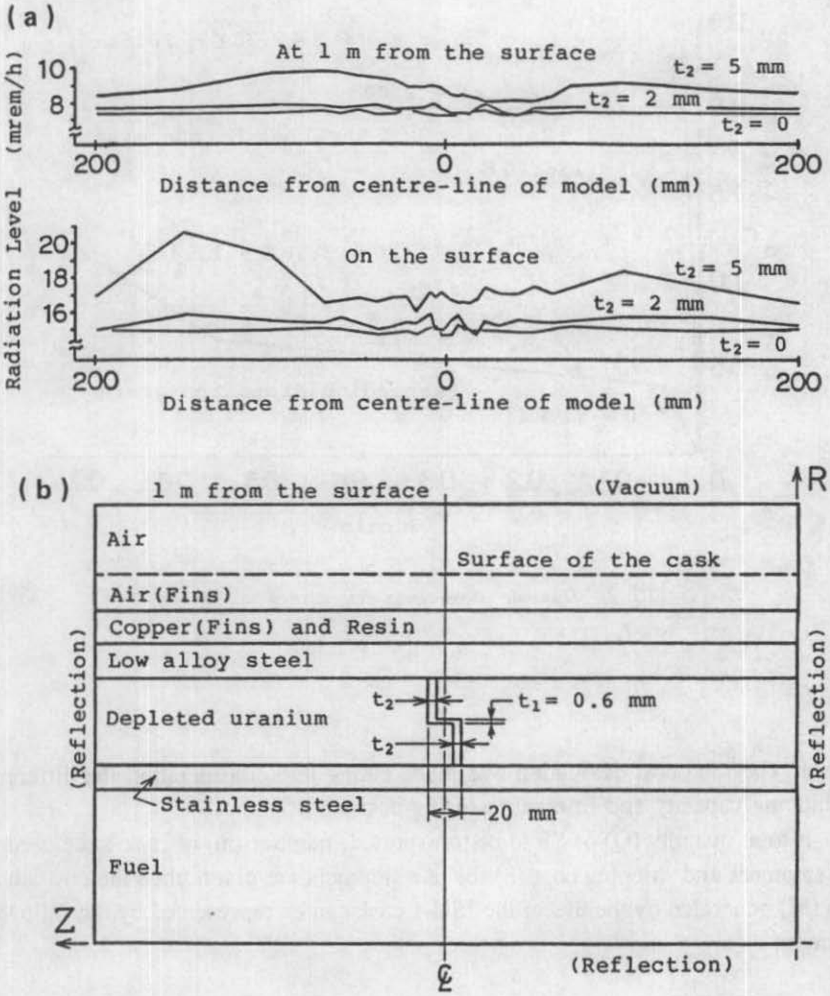

FIG. 6. Influence of gaps between DU rings on shielding performance. (a) Radiation-level distributions, (b) calculation model.

strain diagrams for balsa blocks (specific weight: 230 kgf/m^3) used in the safety analysis of the JSU-1 cask.

4.4. Economic evaluation of the JSU-1 cask

The manufacturing costs of the JSU-1 cask will be higher than for existing casks because of the high cost of the DU shield. However, the JSU-1 cask will be able to contain a larger number of higher burnup SF assemblies than any other type of cask, while still remaining under the permissible outer radiation level and the package

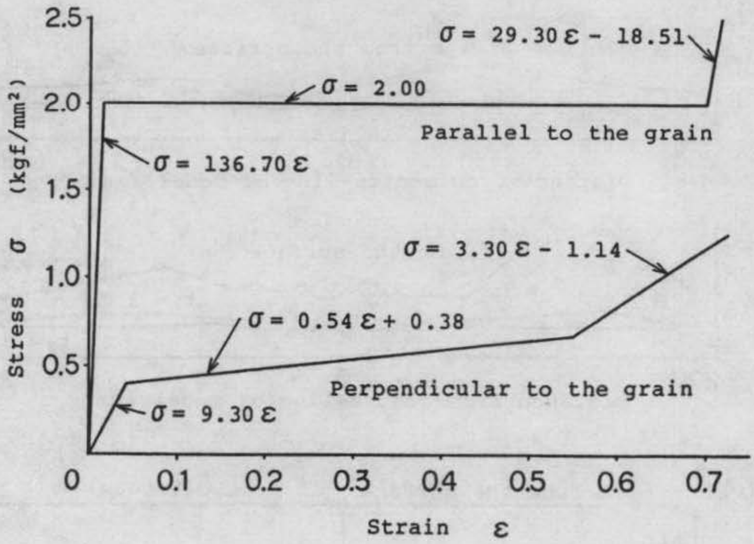

FIG. 7. Dynamic stress–strain diagrams of balsa blocks.

weight. The total cost evaluation was made taking into consideration the difference in shipping capacity and in manufacturing costs.

If total quantity (Q) of SF to be transported, number (m) of cask to be used for one shipment and shipping cost (S) for one shipment are given, then the cost advantage (M) generated by the use of the JSU-1 cask can be represented by the following equation:

$$M = \frac{S}{m} \cdot \left(\frac{1}{n_2} - \frac{1}{n_1} \right) \cdot Q - m(c_1 - c_2)$$

where n_1 and n_2 are, respectively, the numbers of SF assemblies per JSU-1 cask and an existing type of cask ($n_1 > n_2$) and c_1 and c_2 are, respectively, the manufacturing costs per JSU-1 cask and an existing type of cask ($c_1 > c_2$).

The first term in the equation represents the cost advantage generated by the use of the larger-capacity JSU-1 cask, and the consequent saving in shipping time. This term grows with an increase in Q. The second term in the equation is the cost disadvantage incurred as a result of the higher manufacturing costs of the JSU-1 cask and this term is constant. Figure 8 shows the relationship between M and Q based on this equation. It is obvious that M will become positive as the value of Q is increased.

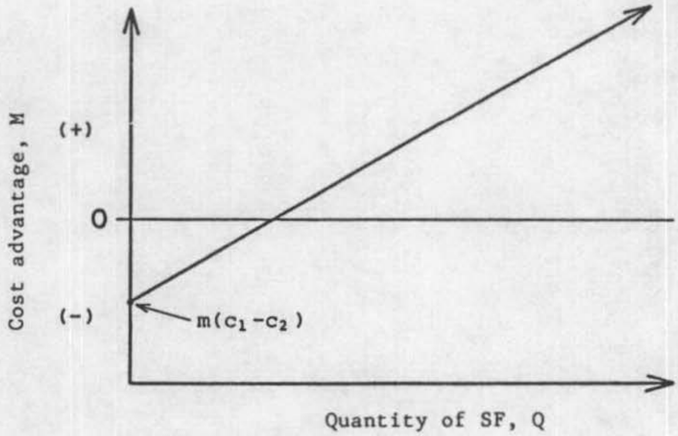

FIG. 8. Cost advantage as a result of using the JSU-1 cask.

5. CONCLUSION

The anticipated growth in the demand for shipment of higher burnup SF had led to a design proposal for a higher performance (JSU-1) cask with a DU gamma shield. Various investigations, including the properties of DU, performance of the DU shield, impact characteristics of balsa blocks for use as shock absorbers and the economics of shipping using the JSU-1 cask were carried out. An advantage to using a DU shield is that while still being under the limits for the package weight, the JSU-1 cask can transport a greater number of higher burnup SF assemblies safely and economically compared with existing types of casks. In the future, further investigations, such as model tests, should be conducted, in order to keep pace with the development of higher performance fuel and plans for reprocessing in Japan.

REFERENCES

[1] CLIFFORD, C.B., Design and Fabrication of a Prototype Laminated Uranium Metal Shipping Cask for Large Shipment of Cobalt-60, Rep. KY-521, Paducah Gaseous Diffusion Plant, Union Carbide Corporation, KY (1967).

[2] IF-300 Irradiated Fuel Shipping Cask, Rep. NEDO-10864-2, General Electric Company, San Jose, CA (1979).

[3] Storage and transport of spent fuel, Karyoku Genshiryoku Hatsuden (Thermal and Nuclear Power) **36** (1986) 87.