RADIATION SHIELD DESIGN FOR LMFBR SPENT-FUEL SHIPPING CASKS†

S. A. Dupree

Previous analyses[1] have examined a limited number of the alternatives available for designing an LMFBR spent-fuel shipping cask (SFSC) using a non-volatile neutron shield; i.e., a neutron shield which will not be lost in an accident involving a fire.* The present study extends the scope of these hypothetical designs to include combinations of volatile and non-volatile neutron shield materials.

The motivation behind the use of a non-volatile neutron shield in a SFSC is readily apparent and includes considerations of safety, maintenance, and postaccident recommissioning of the cask. On the other hand, the argument against use of such a shield is primarily economic. For example, one can quickly see the effect on the cost of a cask radiation shield resulting from the substitution of water for any of the neutron shields discussed in ref. 1. Thus, although a variety of non-volatile shields have been considered for use in casks in the past, the SFSC's which reach the licensing stage generally use a volatile neutron shield.**

† This work supported by the U.S. Energy Research and Development Administration.

* At the temperatures of concern--1475°F fire for 30 min.[2]

** The Transnuclear TN-8 and TN-9 casks[3] use a resin neutron shield which may not be totally lost except in extreme circumstances or over limited areas of the cask surface.

Postaccident radiation limits[4] permit casks to incorporate volatile neutron shields. In extant LWR SFSC designs, which assume shipment of non-recycled U-fueled reactor spent fuel, the loss of the neutron shield can be tolerated within the regulatory limits without requiring the gamma rays to be over-shielded in normal operation. However, this does not appear to be the case for mixed-oxide LMFBR spent fuel. The neutron source strength after 180 days cooling for an LMFBR spent-fuel assembly, as represented by fuel proposed for the Clinch River Breeder Reactor (CRBR), is roughly the same as that for a U-fueled PWR spent-fuel assembly after 150 days cooling. On the other hand, the gamma-ray source strength in the CRBR spent-fuel assembly is about one-third that of the LWR spent-fuel assembly. The fact that the active core height of the LMFBR assembly is roughly one-third that of the LWR assembly means that at the worst-case position--radially outward from the center of the core--the LMFBR spent-fuel neutron source is about three times larger compared with its concomitant gamma-ray source, than the LWR spent fuel neutron source compared with its gamma source. Thus, if a shield is roughly in balance--neutron and gamma dose rates approximately equal on the outside of the shield--there must be more neutron-shield material compared with gamma-shield material for an LMFBR SFSC than for an LWR SFSC. This, in turn, means that if an LMFBR SFSC incorporating a balanced shield design loses its neutron shield, the postaccident external neutron dose rate may exceed the regulatory limit.

This result is indicated in Table I. Hypothetical LMFBR SFSC's using water as a neutron shield and Pb (Column 2) or depleted U (Column 3) as a gamma shield, are compared with the NLI 10/24 LWR SFSC, which uses water and Pb as shielding materials.[5] The exterior dose rates of all three designs are reasonably balanced in their respective preaccident conditions.* In the postaccident state, the NLI cask meets the dose rate restrictions; however, both the LMFBR casks have postaccident neutron dose rates in excess of the regulatory standard. The U-shielded design provides considerably better postaccident shielding than the Pb-shielded design. All results include the effect of finite source geometry.

* Ground scatter effects, which increase the neutron contribution more than the gamma contribution, are neglected in the table.

To meet the postaccident criterion without grossly overshielding the primary gamma rays, while keeping the total cask cost as low as possible, and while using current technology for construction, a hybrid design incorporating both volatile (water) and non-volatile (B_4C) neutron shield layers and a depleted U gamma shield, has been considered. The cost of a design of this type should fall between those of the all-B_4C[1] and all-water designs. It offers the advantage of meeting the dose-rate limits with a balanced shield while making maximum use of inexpensive shielding material. The results of analysis of a conceptual design of this type is indicated in column 4 of Table I. In this case, the 5-cm layer of B_4C remaining after loss of the water, in conjunction with the U gamma shield, reduces the postaccident neutron dose rate to an acceptable limit. Furthermore, the added weight and cost of the B_4C layer is partially offset by a reduction in the thickness of the gamma shield, although the overall shield thickness and cost have been increased to achieve this advantage. Additional cask shielding concepts which will meet the regulatory requirements are also under consideration.

References

1. S. A. Dupree and H. J. Rack, Trans. Am. Nuc. Soc. 24, 242 (1976). Also "Status of Radiation Shield Design for Liquid Metal Fast Breeder Reactor Spent Fuel Shipping Cask Application," SAND-76-0595, Sandia Laboratories, Albuquerque, New Mexico, September 1976.

2. 10 CFR 71, United States Atomic Energy Commission, Rules and Regulations, Title 10, Part 71, December 31, 1968.

3. Safety Analysis Report, TN-8, TN-9, Transnuclear, Inc., White Plains, NY.

4. 49 CFR 173, Federal Register, Dept. of Transportation, Hazardous Materials Regulations Board, Vol. 33, No. 194, Part II, Title 49, Oct. 4, 1968.

5. Safety Analysis Report, NLI 10/24, NL Industries, Inc., Wilmington, Delaware.

Table I. Calculated Pre- and Post-Accident Dose Rates External to Reactor Spent-Fuel Shipping Casks

Source	150-Day Cooled LWR Spent Fuel	180-Day Cooled CRBR Spent Fuel		
Cask	NLI 10/24[a]	Single-Layer Neutron Shield[b]		Two-Layer Neutron Shield[b]
Gamma Ray Shield Material Thickness (cm)[c]	 Lead 15.24	 Lead 15.0	 Depleted U 9.0	 Depleted U 7.0
Neutron Shield Material Thickness (cm)[c]	 Water 22.86	 Water 21.0	 Water 19.0	 B_4C[d] + Water 5.0 19.0
Preaccident External Dose Rates (mrem/hr)[e] Neutron Gamma Ray[f] Total	 0.44 4.75 5.19	 1.3 2.9 4.2	 3.8 2.6 6.4	 1.3 3.8 5.1
Postaccident External Dose Rates (mrem/hr)[g] Neutron Gamma Ray[f] Total	 529 25 554	 2200 15 2215	 1390 9 1399	 629 18 647

[a] Values are taken from ref. 4. Cask payload is 10 PWR or 24 BWR spent fuel subassemblies. Ground scatter effects have been neglected.

[b] These are hypothetical casks designed to carry a payload of 9 worst-case CRBR spent fuel subassemblies. The designs are not optimized for minimum cost or weight.

[c] Values represent radial thicknesses at mid-point of active core material.

[d] B_4C is treated as commercial-grade powder hot-pressed in a Cu matrix. The B_4C is assumed to be loaded in the matrix to 75% of theoretical density.

[e] Values are at a point 6 ft from accessible surface of cask in mid-plane of active core material. The maximum permissible value is 10 mrem/hr.[2]

[f] Values include secondary gamma rays.

[g] Values are at a point 3 ft from accessible surface of cask in mid-plane of active core material. It is assumed that a fire has voided the volatile neutron shield layer. Regulatory [illegible] mrem/hr

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Gamma Ray Shield				
Material	Lead	Lead	Depleted U	Depleted U
Thickness (cm)[c]	15.24	15.0	9.0	7.0
Neutron Shield				
Material	Water	Water	Water	B_4C[d] + Water
Thickness (cm)[c]	22.86	21.0	19.0	5.0 19.0
Preaccident External Dose Rates (mrem/hr)[e]				
Neutron	0.44	1.3	3.8	1.3
Gamma Ray[f]	4.75	2.9	2.6	3.8
Total	5.19	4.2	6.4	5.1
Postaccident External Dose Rates (mrem/hr)[g]				
Neutron	529	2200	1390	629
Gamma Ray[f]	25	15	9	18
Total	554	2215	1399	647

[a] Values are taken from ref. 4. Cask payload is 10 PWR or 24 BWR spent fuel subassemblies. Ground scatter effects have been neglected.

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