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An Assessment of the Risk of Transporting Spent Nuclear Fuel by Truck

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Both of these cooling time periods after discharge were analyzed in the study. It was further assumed that shipments made in the mid-1980's would be on primary roads by licensed shippers. Table 4.2 shows the shipping characteristics assumed for analysis including the estimated shipping distances and number of truck shipments. Details of the calculations of spent fuel shipping requirements are presented in Appendix H.

TABLE 4.2 Shipping Characteristics for Spent Fuel by Truck

	Once Through Fuel Cycle	Spent Fuel Reprocessing
Shipment Origin/Destination	Reactor/ Interim Storage	Reactor/ Reprocessing Plant
Age of Fuel at Shipment (Time after Discharge from Reactor)	180 days and 4 years	180 days
Number of Shipments per Year by Truck	885	885
Average Shipment Distance (Km)	690 (430 mi.)	930 (580 mi.)

4.4 REFERENCE CASK DESCRIPTION

Shipments of spent fuel are assumed to be made in a reference truck cask designed to transport one PWR or two BWR fuel assemblies. The approximate loaded cask weight is 23 MT (50,000 lbs). The cask has an overall length of 544 cm (214 in.) and a diameter of 96 cm (38 in.). The cask cavity has a length of 452 cm (178 in.) and a diameter of 34 cm (13.5 in.). Interchangeable fuel baskets provide the cask with a capacity of one PWR or two BWR fuel assemblies.

The primary cask cavity consists of a nominal 0.8 cm (5/16 in.) stainless steel pressure shell surrounded by a lead gamma shield 16.8 cm (6-5/8 in.) thick and a stainless steel penetration barrier 3.2 cm (1-1/4 in.) thick. Neutron shielding is provided by a borated water-antifreeze solution contained in a 11.4 cm (4-1/2 in.) thick compartmentalized tank which surrounds the cask. An expansion chamber for the shield tank accommodates temperature sheathed balsa wood at each end of the cask given protection from impact damage.

The container has a single lid, attached with high-strength bolts and sealed with teflon O-rings. The closure requires a lifting spider, special tools and O-ring pressure test equipment. Two valve-type drain closures are provided.

Heat rejection is by convection through the water coolant in the cavity to the inner wall, conduction to the neutron shield, convection to the outer wall, and convection plus radiation to the atmosphere. Maximum heat rejection capacity is 11.5 kW. Maximum design conditions for the inner cavity during normal transport [i.e., 55°C (130°F)] direct sunlight, still air, maximum fuel burnup, minimum fuel cooling period) are 174°C (345°F) and 10 atm (150 psig). The primary cavity is designed to withstand temperature and pressure conditions of 278°C (532°F) and 67 atm (984 psig) under the fire accident condition [1/2 hr at a temperature of 800°C (1475°F)].

A detailed description of the reference spent fuel shipping cask is given in Appendix A.

6.2 RESULTS OF THE THERMAL ANALYSIS

The thermal analysis was performed with a special purpose computer code designed to analyze radiation and conduction heat transfer in detail and include an estimate of the effects of convection. Thermal failures of both the cask and fuel cladding were considered for several fire and loss of coolant situations. Thermal failure of the cask due to fire was assumed to occur when a cask component fails and radioactive material can be released to the atmosphere. The various basic events that lead to failure are identified in Section 8 through development of fault trees. The thermal analysis was conservatively based on the maximum decay heat load PWR fuel that can be carried in the reference cask. The analysis provides the information to determine the duration of a fire to cause various types of thermal failure and the time to failure for loss of coolant from other accident forces.

The cavity coolant was assumed to be lost from the cask when the mean cavity temperature reached 290°C. This is based on the rupture disk set to relieve the pressure at 76 atmospheres for saturated conditions. It was determined that the cask rupture disk would fail from overpressurization in about 2.5 hours after the cask was exposed to a 1010°C fire for 15 minutes. As the fuel temperature increases due to self-heating after the coolant is lost, the pressure in the fuel pins increases. This results in a hoop stress in the fuel pin cladding. Fuel pin failure occurs when the hoop stress exceeds the creep rupture strength of the Zircaloy 4 tubing. Smith[2] estimated that some PWR cladding will fail above 565°C and all fuel elements would fail above 675°C.

Data from seal manufacturers indicates that the teflon O-ring closure seal could withstand temperatures of 280°C (540°F) for a period of 48 hours. The seal can also withstand somewhat higher temperatures for shorter periods of time. For purposes of this analysis, the closure seal was conservatively assumed to fail if the temperature exceeds 320°C for longer than one hour. Considering the cask geometry, it was conservatively assumed that the seal would be at about the same temperature as the inner wall. It was then determined from the curves in Appendix G that a fire greater than 30 minutes duration at 1010°C would result in temperatures sufficient to fail the closure seal.

The drain valves and vent valve have teflon seals. Data on teflon valve seals indicate that failure would occur if the temperature exceeds 280°C (540°F). The valves are well protected from thermal stresses and it is difficult to predict what temperature they would be at during accident conditions. It was conservatively assumed that a fire duration of 30 minutes would fail the valve seals. Table 6.3 presents failure thresholds for the fire accident. It was conservatively assumed that loss of cavity coolant would occur in less than 2.5 hours for any seal failure due to fire.

TABLE 6.3. Thermal Failure Thresholds

Type of Failure	Minimum Duration of Fire[(a)] to Cause Failure
Loss of Coolant from Rupture Disk	15 min.
Closure Seal	30 min.
Drain Valve Seal	30 min.
Vent Valve Seal	30 min.

(a) All fires assumed to be 1010°C (1850°F).

Table 6.4 presents the length of time to failure of the reference cask and fuel elements for several cases analyzed in Appendix G. For cases with the coolant intact at the beginning of a 1010°C fire, the coolant is lost in less than 50 minutes. Case 3, an initial loss of coolant implies that the cask seals have failed allowing the coolant to drain from the cavity. Accident Case 6 shows that a fire which lasts longer than 15 minutes at 1010°C will result in release of the coolant. The column in Table 6.4 for time to fuel cladding failure is the length of time following a loss of coolant at which the first and last fuel elements fail by creep rupture. If an extreme mechanical impact precedes the fire, then all cladding may be initially failed.

The information in Table 6.4 is used in the analysis to determine the length of time over which the release occurs for the various fire accident cases, impact followed by fire, and the loss of coolant case. In all cases except the impact case, the significant release occurs over a period of time from 0.5 to 1.5 hours. For the impact case, an instantaneous release is conservatively assumed to occur.

All fire situations considered in this study exceed the cask licensing requirements.

TABLE 6.4. Time to Thermal Failure for Reference Spent Fuel Cask and Fuel

Accident Case	Time of Loss of Coolant (hr)	Time to Fuel Cladding Failures (hr)	
		Time to Initial Failure	Time to Failure of All Cladding
1. 1/2-Hour Fire[a] at 1010°C (1850°F)	~0.8	2.2	3.4
2. 2-Hour Fire[a] at 1010°C	~0.6	1.9	2.4
3. No Fire with[b] an Initial Loss of Cavity Coolant	~0	2.1	3.5
4. 1/2-Hour Fire[a] at 1010°C with an Initial Loss of Cavity Coolant	~0	2.0	3.1
5. 2-Hour Fire at[a] 1010°C with an Initial Loss of Cavity Coolant	~0	1.8	2.3
6. Minimum Duration Fire to Cause Loss of Cavity Coolant	~2.5 Hours for a 15-Minute 1010°C Fire	4.5	6.0

(a) Time zero at start of fire.
(b) Time zero when loss of coolant occurs.