EXTENDED SUMMARY

COOLING MULTIPURPOSE SNF CASKS WITH REMOVABLE LIQUID–FILLED FINS

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Introduction

Spent nuclear fuel (SNF) produces decay heat. Because excessive temperatures will cause the SNF to degrade, methods for heat removal are required when storing SNF. Active cooling systems are used in SNF pools and have been used with shipping casks to transfer short-cooled SNF with high decay-heat loads. SNF stored in casks has traditionally been cooled by passive techniques: conduction of the heat through the cask with natural-circulation air cooling of the casks. Solid fins on the casks have been used to improve heat transfer. Passive cooling techniques are preferred because of their reliability, safety advantages, and the cost considerations associated with the long-term storage of SNF. Recently, however, a need has arisen for improved cooling methods during cask storage of SNF at reactors and off-site storage locations.

- *Terrorism.* SNF storage casks potentially provide a more secure method of storing SNF than traditional pool storage in the United States. The casks have thick walls and passive cooling, and the security requirements are less. Because of these considerations, there are increased incentives to store SNF in dry casks—including short-cooled SNF. However, the decay heat from short-cooled fuel is higher than that from long-cooled fuel. If shorter-cooled fuel is to be stored in casks, better cask cooling will be required.

- *Economics*. The cost of SNF storage decreases as the cask capacity increases. Better cask designs, new materials, and new technologies may enable the development of higher-capacity casks within the same gross weight and size constraints. For example, work is ongoing [1, 2] to develop depleted uranium dioxide (DUO_2)–steel cermet casks (DUO_2 embedded in steel). This cermet may be the highest-performance shielding material than meets all the requirements for a multipurpose cask—as part of a system in which the SNF is loaded into the cask at the reactor, the SNF is transported in the cask, and the cask is later used for disposal at the repository. Improved shielding materials implies more SNF and higher decay heat loads within an advanced cask with the same weight and size constraints as existing SNF casks. Better cask cooling is required to take full advantage of these new materials for cask construction.

The need for enhanced SNF cask cooling capabilities exists only for a limited period of storage time after the SNF is discharged from the reactor. SNF decay heat decreases with time; thus, the enhanced cooling capability may not be required by the time the SNF is transported and will not be required by the time the SNF is disposed of. The use of liquid-filled cooling fins is discussed as a mechanism to improve cask cooling.

Dry Storage Overpack

The typical maximum temperature for SNF in storage is 350EC. The heat transfer path is from the SNF to the cask body via the basket structure, through the cask, and from the cask surface to the atmosphere. The first and third components are the primary resistences to heat transfer. A series of studies were undertaken to find methods to reduce resistance to heat transfer from SNF to the atmosphere and thus allow for higher decay heat loads within the cask. This paper addresses improved methods for heat rejection from the cask body to the atmosphere. Parallel studies are underway to examine improved heat transfer in the basket structure and in the cask body.

The use of passive liquid-cooled fins (Fig. 1) is proposed to improve heat transfer. This is the same approach that is used in most utility electrical transformers. The primary resistance to heat transfer is from the metal surface to the air. Solid fins can improve this heat transfer by increasing the effective cask surface area; however, the effectiveness of the solid fins decreases with fin depth [3]. The total temperature drop can be drastically reduced by the use of liquid-filled fins that allow efficient transfer of heat from the cask wall to high-surface-area fins. The liquid absorbs the heat at the cask body wall and by natural circulation transfers the heat to the fin surface. The preferred coolant is water with antifreeze, appropriate corrosion inhibitors, and neutron absorbers. Each fin is separate from the others; thus, damage to any individual fin does not significantly degrade the total system performance. Liquid-cooled fins provide improved fire resistance because of the large quantities of heat required to boil off the liquids before the cask heats up. The liquid provides additional gamma and neutron radiation shielding.

Figure 2 shows the performance of vertical liquid-cooled fins, where each fin covers and cools 15 cm of the external circumference of the cask and is 2-cm thick. In this set of design calculations, the fin depth was progressively increased from 15 to 75 to 120 cm. With a 120-cm fin, about 1 kW per fin can be rejected with a delta T of 30EC between the cask body and the air. (This calculation is for 15 cm of the cask circumference.) For a cask with 21 pressurized-water-reactor SNF assemblies and a diameter of 1.8 m, the total heat rejection is 38 kW (1.8 kW per assembly).

For comparison, the heat rejection of solid fins with the same dimensions is also shown. The solid-fin performance is significantly lower because the temperature drop required to move heat through a solid fin by conduction is significantly greater than that required to circulate liquid in a liquid-filled fin. Almost no improvement in heat transfer is observed if the fin length exceeds 30 cm (details provided in full paper). In practice, a more complex fin design than the one shown in this model would be used to minimize space requirements (details in full paper). Such a fin design uses the water cooling to transfer heat from the cask to the liquid-cooled fin with smaller solid fins attached to the liquid-cooled fin. The optimum fin configuration (liquid filled or solid) changes with the required maximum heat rejection capability.

If coolant is lost, the fin operates as a solid fin, with higher temperatures required to reject the same heat load from the cask. In this context, the optimum design of the fin may be different than in other applications, such as use in electrical transformers. Additional metal in the fin structure can provide additional cooling capability in the event of a loss of coolant.

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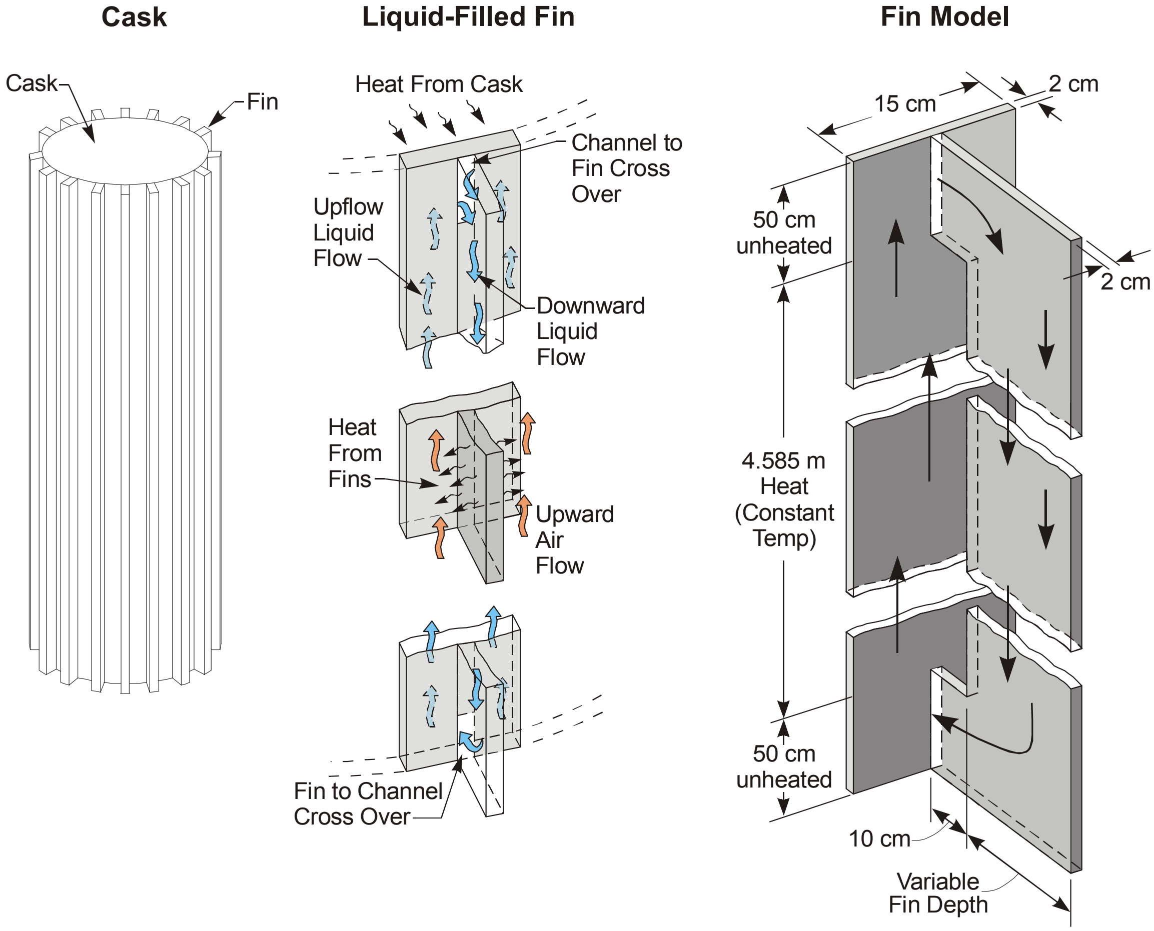

Fig. 1. Liquid-Filled Cooling Fins.

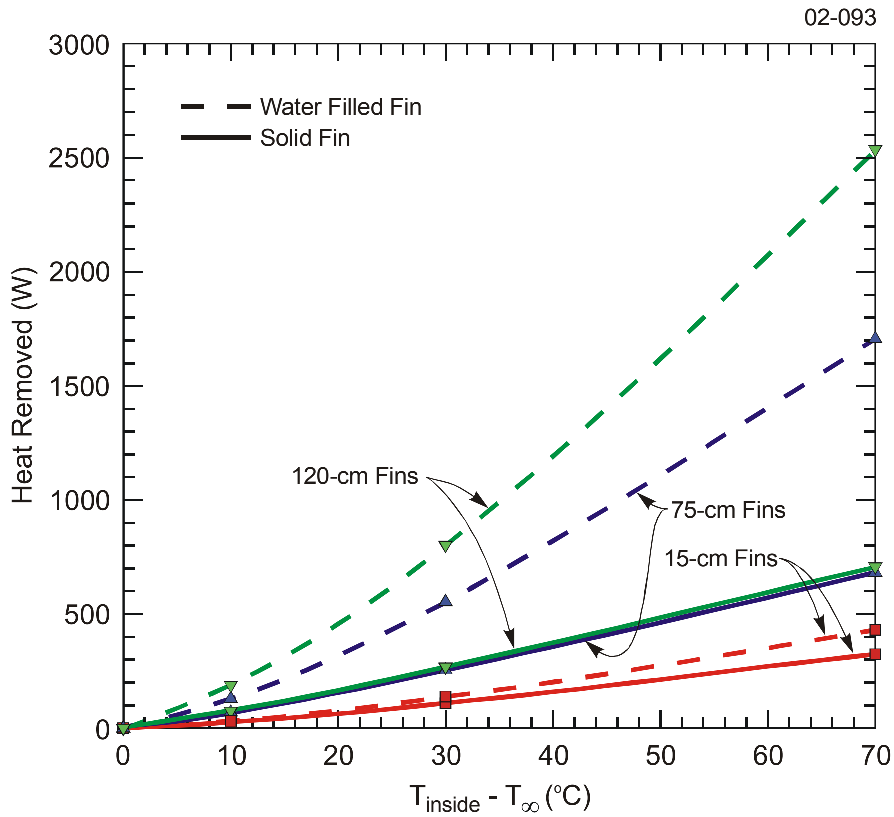

Fig. 2. Heat Rejection Per Fin Vs Temperature Drop For Different Fin Lengths.

The solid fins and natural convection loop in the water-filled fins were modeled with the commercial computational fluid dynamics code CFX [4]. The flow was modeled as laminar and the metal encasing the water volume (not a significant resistance to heat transfer) was not included in the model. The inner surface of the water jacket adjacent to the cask is assumed to be isothermal, and the surfaces of the fin exposed to air are assumed to dissipate heat to the environment by means of free convection. Nine cases were modeled with three surface–air temperature differences and three fin lengths. A simple fin configuration as shown in Fig. 1 was used in this analysis.

Performance and Regulations

As noted earlier, if coolant is lost, the fin operates as a solid fin with higher temperatures required to reject the same heat load from the cask. SNF integrity can be assured even if the there are higher SNF temperatures for limited periods of time (details in full paper). The traditional SNF storage temperature limit of 350EC is not absolute but is imposed to limit long-term SNF clad degradation. It is the combination of time and temperature that must be controlled to avoid SNF damage. If loss of coolant causes fin failure, the short-term SNF temperatures may be higher than desirable but would not be a major concern. This allows the use of light weight, low-cost cooling overpacks that meet all normal operating requirements but would not survive serious fires or accidents. Infrared cameras provide a low-cost method to verify the operation of each fin as a heat transfer system. There are also regulatory issues that must be addressed (details in full paper).

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