CONF-791102--25

MOLTEN FUEL CONTAINMENT ANALYSIS FOR SLSF EXPERIMENTS

M. S. El-Genk and R. L. Moore
(EG&G Idaho, Inc.)

The Sodium Loop Safety Facility (SLSF) experiments [1] are being conducted in the Engineering Test Reactor (ETR) at the Idaho National Engineering Laboratory to furnish information concerning the behavior of fast reactor fuel elements under a hypothesized loss-of-flow accident conditions. These experiments involve measurements and observations that will permit an assessment of the location and time of sodium void initiation, the nature of sodium expulsion and reentry, the time and nature of cladding failure and motion, the molten fuel motion, and the extent of flow plugging by molten fuel freezing at the axial extremities of the subassembly [2]. Because such high energy experiments are being conducted in-pile within the ETR facility, extensive pretest analysis was required to ensure loop integrity. One aspect of this analysis, which is the subject of this paper, was the assessment of molten fuel relocation and refreezing on the wall of the SLSF. Figure 1 shows a section of the lower in-pile tube in SLSF experiments.

The problem of a stagnant liquid freezing onto a semi-infinite cold wall which undergoes simultaneous melting was first introduced by Epstein [3]. Due to the conditions of semi-infinite geometry and no flow, the frozen crust and the wall-molten layer continue to grow with time. However, the freezing of a flowing liquid on a semi-infinite wall, with or without simultaneous melting of the wall [4,5], results in an unstable frozen crust which increases in thickness with time until it reaches a maximum size, whereupon it undergoes a reduction in thickness by remelting. Recently, an analytical study [6] was presented for the transient behavior of the frozen crust that forms in forced flow on a finite wall, with and without simultaneous melting of the wall. In that work [6], two problems of interest were studied analytically. The first problem considered a nonmelting wall subjected to an adiabatic boundary condition at its opposite surface. In the second problem, however, the wall was allowed to undergo simultaneous melting and was convectively cooled along its outer surface. It is this latter solution which is applied herein to assess the containment capability of the Sodium Loop Safety Facility, in which freezing of molten fuel and simultaneous melting of the inner containment boundary (usually an Inconel or stainless steel wall) are expected to occur [7].

The analysis considers the conditions of molten fuel flow, finite wall thickness, and convective cooling at the outer surface of the containment wall due to the sodium coolant flow, as illustrated in Figure 2a. A refined integral heat balance approach, introduced in Reference 8, was used to obtain the solution in which a set of four, coupled, nonlinear, first-order ordinary differential equations (two being second-order, second-degree) were obtained and integrated numerically for the instantaneous values of the time-dependent functions; namely, the frozen crust thickness, the wall-molten layer thickness, the temperature at the crust-molten wall interface, and the temperature at the outer surface of the wall. In the present calculations molten debris are assumed to have a volume fraction of 40% molten stainless steel and 60% $(U, Pu)O_2$.

The melting process through the Inconel wall was shown to be governed by the molten debris superheat and the sodium bypass flow conditions (that is, the coolant convective coefficient of heat transfer, h_c, and the coolant temperature, T_0). Figure 2b illustrates some of the results in which the simultaneous formation of a thermally stable solidified debris layer and an unstable molten layer in the wall is predicted. When the molten debris are 50 K superheated the wall-molten layer continues to grow with time until it reaches a maximum size of 14% of the initial thickness of the containment wall (0.001524 m in thickness) whereupon it undergoes a reduction in thickness by refreezing until it eventually disappears after a total lifetime of about 1.1 seconds. When the molten debris superheating is about 1000 K the maximum wall melting increases to 26% of the initial wall thickness with total lifetime of approximately 1.75 second. Increasing h_c or decreasing T_0 would reduce the maximum size and the total lifetime of the wall-molten layer [7], which is important because a short lifetime of the wall molten layer increases the probability of forming a thicker frozen debris crust. Noted that, although the formation of a thermally stable solidified debris crust presents an additional safety margin against further melting of the Inconel wall, increasing the sodium bypass flow seems to be important in the ensurance of a safe containment situation [7]. Thus, unless the fuel barrier (insulator) in the fuel bundle design is such that the possibility of molten debris reaching the outer duct wall (Inconel wall) is remote, consideration should be given to ways by which the coolant flow can be increased at any time during the transients.

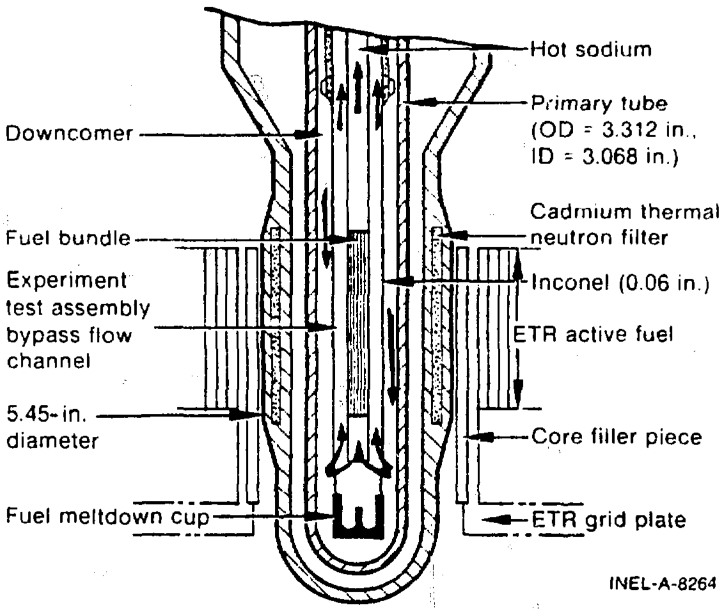

Fig. 1 Section of the lower in-pile tube in SLSF.

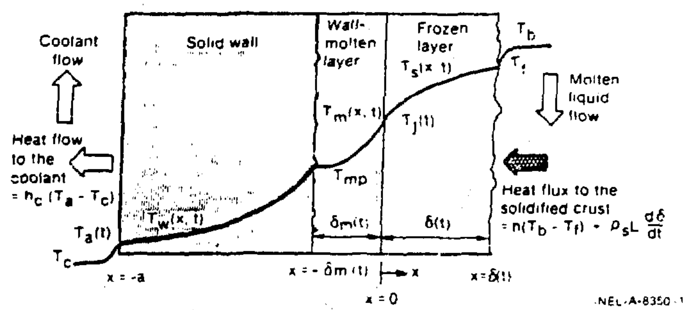

Fig. 2a Physical model.

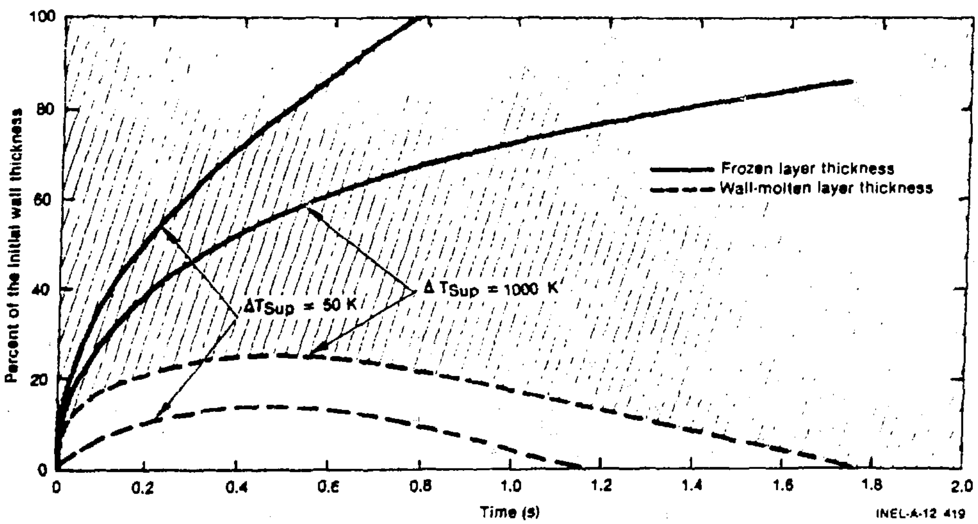

Fig. 2b Effect of molten debris superheating on the transient behavior of the frozen debris crust and the molten layer in the containment wall (Inconel).

REFERENCES

1. C. H. Gartside, et al., Nucl. Safety, 19, 339-355 (1978).

2. T. E. Kraft, Test Requirements for Sodium Loop Safety Facility In-Reactor Experiment P3, ANL/RAS 76-10 (April 1976).

3. M. Epstein, Nucl. Sci. and Eng. 51, 84-87 (1973).

4. M. S. El-Genk, Improvements to the Solution of Stefan-like Freezing and Melting Problems, with Application to LMFBR Safety Analysis, Ph.D Dissertation, University of New Mexico, (1978).

5. A. Yim, et al., Int. J. Heat Mass Trans. 21, 1185-1196 (1978).

6. M. S. El-Genk and A. W. Cronenberg, The 18th National Heat Transfer Conf., San Diego, California (August 5-8 1979).

7. M. S. El-Genk and R. L. Moore, International Meeting on Fast Reactor Safety Technology, Seattle, Washington (August 19-23, 1979).

8. M. S. El-Genk and A. W. Cronenberg, Int. J. Heat Mass Trans., 22, 167-170 (1979).