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THE POTENTIAL FOR FUEL-TARGET MIXING DURING A FUEL MELTING ACCIDENT IN A SRS FUEL ASSEMBLY (U)

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SUMMARY

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Summary

The mechanical work potential during a whole core melting accident in the SRS production reactors is influenced by the amount of target material mixing with the fuel. As an example, if the fuel relocates without mixing with the target the potential for in-vessel recriticality is increased. If fuel and target relocate as a combined mass the potential for recriticality is reduced or eliminated. However, the amount of mechanical work that may be done could be larger for the case for which the fuel and target melt together than the case in which the fuel relocates without the target and is involved in a recriticality event. This is because there is more melt to mix with the water allowing for the possibility of a larger steam explosion. As can be seen the amount of fuel and target interaction then plays a major role in the progression of a core melting accident in a metal fueled heavy water production reactor.

A description of the heat-transfer characteristics between a molten fuel film and the underlying vertical target tube is then of major importance to safety assessments of postulated meltdown accidents. If the molten uranium aluminum alloy comes into contact with the inner and outer target, fuel solidification begins. The unsolidified outer portion of the fuel deposit will begin to drain under the influence of gravity. The latent heat released by the fuel solidification process as well as a portion of the internal heat generated within the fuel will be conducted into the target substrate, causing the target's temperature to rise toward's it's melting point. Once the target is at its melting point, melting and mixing of the target with the fuel residue begins. Thus the fraction of the fuel film deposited on the target that ultimately mixes with the target material depends on a race between molten fuel draining, fuel solidification, and target heating.

In the paper proposed for this meeting, an analysis of the temperature and draining history of the fuel film/target wall composite is made on the basis of conduction theory. The formulation includes the effects of turbulent fuel-film flow and finite target wall/fuel-film geometry. The computational procedure results in predictions of the fraction of the deposited fuel that is likely to mix with the substrate material as a function of target wall thickness and length of the fuel deposit.

In the absence of measurements of melting behavior of a SRS fuel assembly, our present emphasis is on the development of a simple mathematical model of the fuel solidification and draining process compatible with safety assessment requirements. While future experimental observations (especially those on the earliest stages of fuel-melt/target contacting process) may necessitate generalizations, our initial model is based on the following assumptions.

(A1) All physical properties (density, specific heat, thermal conductivity) are considered constant for the target and the molten and solidifies fuel regions. In addition, the physical properties of the target are assumed to be identical to those of the fuel.

(A2) The change in volume upon solidification of the fuel is neglected and perfect thermal contact between the target wall and the fuel film is assumed.

(A3) The solidification front is sharp and planar on the scale of the fuel melt thickness.

(A4) The fuel-melt film and the target wall are thin compared with their lengths in the vertical direction so that heat conduction in this direction is small compared to heat conduction through the thickness of the target/fuel composite.

(A5) The face of the target and molten fuel film behave as insulated boundaries.

(A6) The thermal conductivity of the fuel is sufficiently large that convective heat transfer across the draining fuel film is negligible compared to transient heat conduction.

(A7) The flow in the draining fuel film is considered to be turbulent.

(A8) The instantaneous thickness of the draining fuel film is assumed to be spatially uniform. That is, we only consider the time period over which the draining fuel film exhibits its initial behavior. During this time, the film is uniform and the internal term in the momentum equation is important.

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Assumption A8 implies that the initial draining velocity of the fuel upon contact with the target material is zero. At first glance this assumption may appear to be a nonconservative one, as globules of molten fuel may fall and accelerate some vertical distance in the fuel channel before striking the surface of the target's rings. Under these consideration the initial velocity would not be zero. However, if the fuel drop wets the underlying target surface, it will leave a tail of fuel in its wake as it flows over the targets's surface. The subsequent freezing and draining behavior of the fuel wake would begin with the zero velocity condition assumed here. If the target's surface in the path of the drop is not wetted by the drop then it is likely that the drop's motion will be terminated, since the diameter of the channel is less than the droplet capillary stopping mass[1].

A simple method for solving the combined heat conduction draining equations is described in the paper. The formulation presented is based on the integral profile method [2] and parallels that of reference [3] for the behavior of a frozen layer growing on a semi-infinite wall. In accord with this method, rather than demanding that the temperature satisfy the one-dimensinal heat conduction equation everywhere, we only impose a global energy conservation condition. The details of which are described in the proposed paper. Figure 1 is a description of the geomery of the combined model describing draining, heat conduction, and freezing.

Calculations have been performed using this technique. These calculations were made for the correct physical properties of the fuel and dimensions of the two target rings. While we will focus our attention on the amount of fuel material runoff during the target wall heat up period, it is instructive to first examine typical temperature profile histories within the fuel-film/target composite. In figure 2 are shown the temperature distributions with the target wall, the frozen fuel and the fuel melt region for an initial fuel deposit of 6.5 mm in thickness and 4.0 m in length and a target wall thickness of 4.5 mm. These geometric parameters were arrived at be assuming 75% of the fuel inventory is deposited on the inner target. The time is shown as a parameter in figure 2, which also displays the thickness of the frozen fuel region. At a time near 1.0 second, both the target material and the solidified fuel have been raised essentially to the melting point. Note that the fuel-melt temperature appears to remain at the melting point during the course of the transient. Actually it is predicted to rise about 2 degrees C above the melting point. The thermal conductivi-

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ty of the composite material is so large that the energy generated in the fuel melt cannot keep up with the heat conducted out of the melt into the cooler target and frozen fuel regions, thereby preventing the fuel melt temperature from increasing by more than a few degrees. The predicted behavior of the film surface position and velocity are shown in figure 3. This figure reveals that the fuel deposit has lost only 11.1% of its initial content vis draining. The rapid fuel solidification rate in this case renders most of the fuel stationary before gravity has a chance to exert its influence.

In the example presented above, the high thermal conductivity of the fuel/target composite leads to removal of preexisting temperature gradients, while rapid solidification interrupts the fuel draining process before a significant fraction of the fuel melt is removed. Once the temperature profile is nearly uniform and, for all practical purposes at the melting point, any further heat generated in the fuel will lead to simultaneous volumetric remelting of the frozen fuel region and the substrate target material.

References

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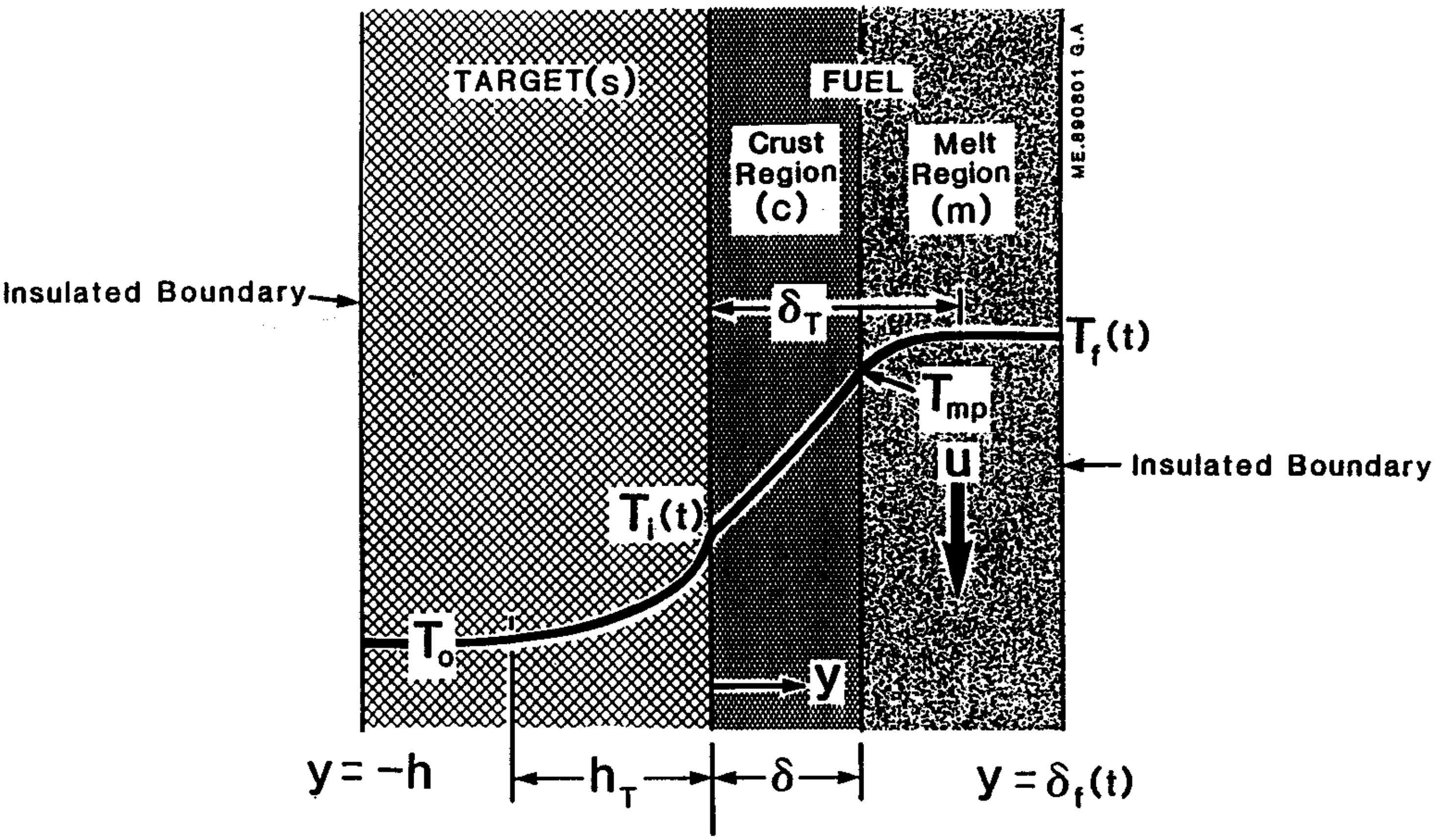

Figure 1. Schematic diagram of solidifying fuel layer on target wall, indicating early temperature profile and nomenclature.

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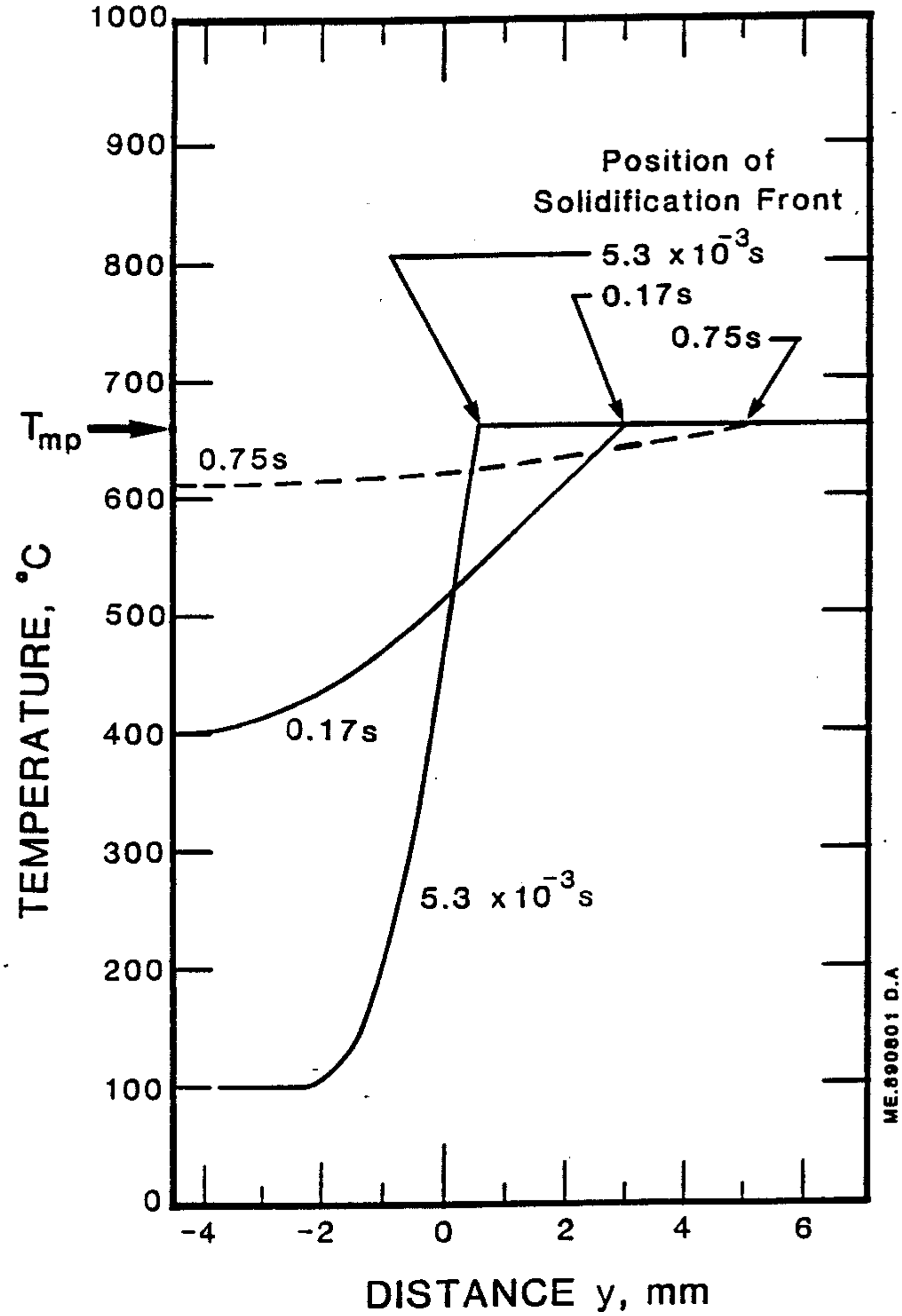

Figure 2. Effect of time on temperature profile in target wall (inner ring) and fuel layer: h = 4.5 mm, L = 4 m, $\delta_{f,o}$ = 6.5 mm. (Profile at 0.75 s dashed for clarity only.)

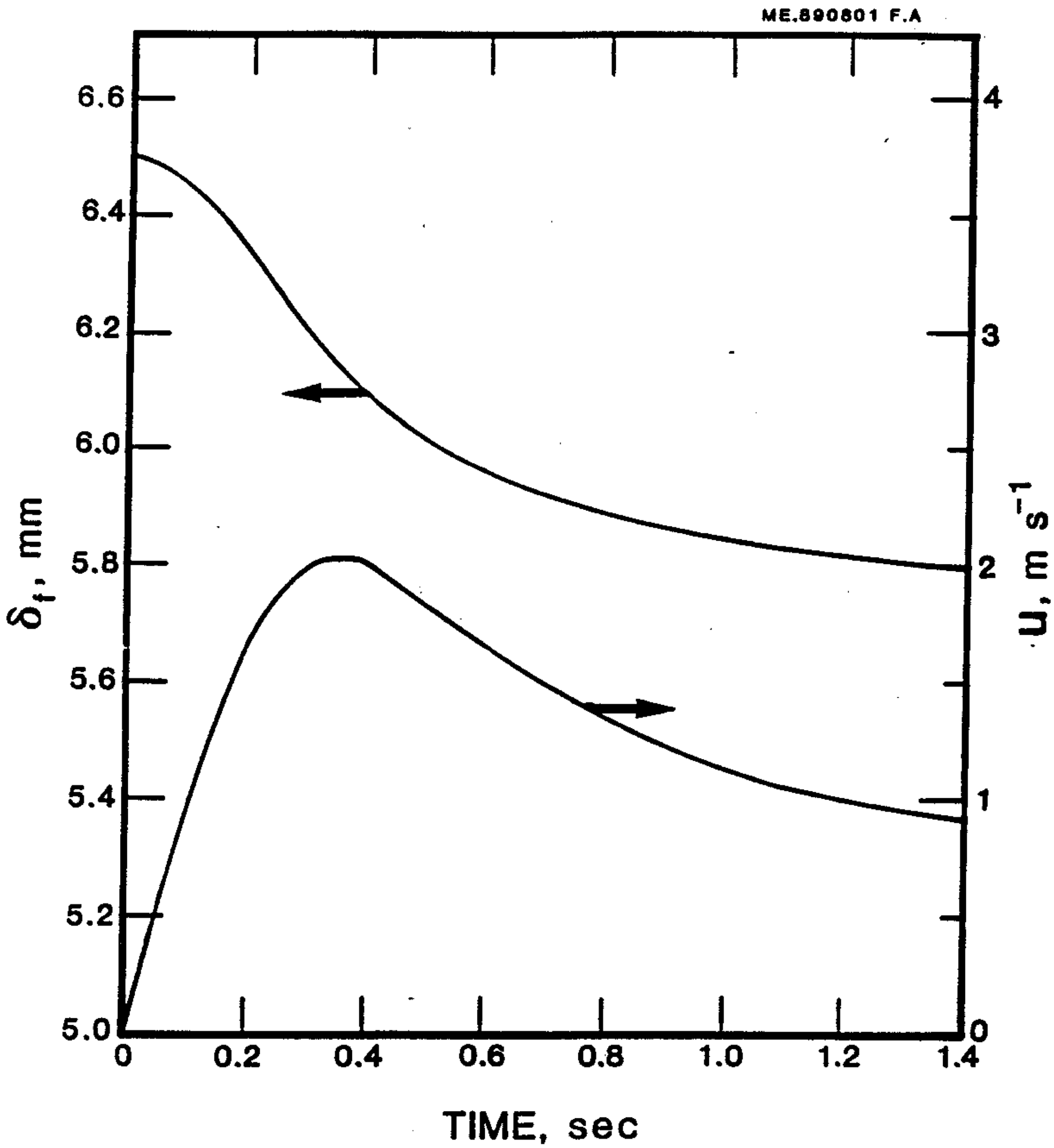

Figure 3. **Fuel-layer thickness and velocity versus time for the conditions of Figure 4-1 (h = 4.5 mm, L = 4 m, $\delta_{f,o}$ = 6.5 mm).**