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QUENCH COOLING OF SUPERHEATED DEBRIS BEDS IN CONTAINMENT DURING LWR CORE MELTDOWN ACCIDENTS*

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ABSTRACT

Light water reactor core meltdown accident sequuence studies suggest that superheated debris beds may settle on the concrete floor beneath the reactor vessel. A model for the heat transfer processes during quench (removal of stored energy from initial temperature to saturation temperature) of superheated debris beds cooled by an overlying pool of water has been presented in a prior paper. This paper discusses the coolability of decay-heated debris beds from the standpoint of their transient quench characteristics. It is shown that even though a debris bed configuration may be coolable from the point of view of steady-state decay heat removal, the quench behavior from an initially elevated temperature may lead to bed melting prior to quench of the debris.

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*This work performed under the auspices of the U. S. Nuclear Regulatory Commission.

DISCLAIMER

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Core meltdown accident sequence studies in light-water reactors suggest that reactor vessel failure would occur as molten core material (corium) thermally attacks the lower vessel dome. In many important sequences water would be available in the region beneath the vessel. As indicated in Fig. 1, melt would be ejected from the reactor vessel upon failure and some degree of corium-water mixing would occur, accompanied by rapid steam generation, and possibly steam explosions. The melt would be partially quenched by the water and would eventually settle to the concrete floor beneath the reactor vessel ("quench" implies reduction of debris temperature to water saturation temperature). Much uncertainty exists as to the state and configuration of the melt at this point. The corium may be in the form of a partially quenched solid debris bed or in the form of a molten pool which is both attacking the concrete and transferring heat to the overlying liquid layer. The lack of convincing evidence from large scale tests regarding the nature of the debris following arrival to the concrete floor necessitates consideration of the impact of two scenarios on the accident progression: (i) the quench of solid debris beds by overlying pools of water and their coolability, and (ii) the

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cooling behavior of molten pools which attack the concrete and are cooled by overlying pools of water. This paper considers the quench cooling of superheated debris beds in containment during core melt accidents.

Debris bed quench heat transfer has in the past been computed using a single lumped-parameter energy equation for the debris bed, together with steady state debris bed heat removal formulations [1]. As a consequence of this assumption, the debris temperature would be predicted to decrease monotonically with time if the bed were coolable based upon steady state debris coolability considerations [2]. Experimental results suggest that steady state heat removal concepts [3] can be used to predict the debris bed heat removal rate under transient quench conditions. The data, however, indicate that the bed quench is a complex, multi-dimensional process that cannot be treated using a single-volume energy equation method of analysis. Models have been developed [4,5] to characterize the transient debris bed quench process. Early results [4] suggested that remelting of the debris is possible under some circumstances, dependent on bed parameters and initial conditions. More recent results, presented below, demonstrate that debris beds which are coolable based upon steady state debris bed heat transfer principles are not necessarily coolable during the transient bed quench process.

The analytical model [4] considers that a decay-heated, superheated debris bed is cooled in the two-stage quench front propagation process represented schematically in Fig. 2. Coolant is assumed to initially penetrate the bed, leaving dry regions of particles which continue to heat under decay heating. Upon arrival of the downward front to the base of the bed, a final upward-directed front propagates up the bed, removing the remaining stored energy.

Representative calculations were performed for conditions shown in Table 1. The Lipinski steady state debris coolability model [2] was used to represent the heat removal rate from the beds of 6 mm debris. Figures 3 and 4 present the downward- and upward-frontal positions as a function of time for beds of depth 0.5 m and 1.0 m, respectively. The effect of initial bed temperature is shown on each figure. The temperature rise of the unquenched debris is shown in Fig. 5 for each initial temperature condition. The bed heat loading for the 1-m deep bed is 1.5 MW/m^2. The heat removal rate based on the Lipinski model is 2.29 MW/m^2. Thus, the superheated debris beds considered here are coolable for the conditions of Table 1 based upon the Lipinski debris coolability model.

The model assumes that particles which are as yet unquenched continue to heat due to decay heating. On the basis of this model, a bed is judged to be uncoolable if the unquenched portion of the bed reaches the melting temperature of the oxide fuel, taken to be 3120K, prior to completion of the quench process. Quench completion is indicated in Figs. 3 and 4 by intersection of the upward frontal curve (positive slope) with the ordinate corresponding to the bed height. The bed is assumed coolable if the quench time so indicated occurs prior to the time of fuel melting, which would be obtained from Fig. 5. For example, observation of Fig. 5 indicates that if the initial bed temperature is 1700K, fuel melting would occur after an elapsed time of approximately 2700 s. Figures 3 and 4 indicate, therefore, that for this initial bed temperature the 0.5-m deep bed would be coolable, while the 1.0-m bed would not be coolable.

Table 2 summarizes the bed quench coolability conclusions which are derived from the calculational results. It is recalled that the beds considered here are coolable based upon the conditions of Table 1 and the Lipinski steady state bed coolability model. The results summarized in Table 2 clearly demonstrate that debris quenching imposes an additional constraint on establishment of conditions for bed coolability. Table 2 suggests that transient bed coolability is a strong function of debris bed initial conditions. The question of steady state, decay heat removal debris coolability is moot unless one can first demonstrate that conditions are favorable for debris quench to water saturation temperature. These results point to the need for more detailed examination of debris bed initial conditions and of the physical mechanisms which lead to bed formation.

TABLE 1. Debris Bed Characteristics

Debris Density	8000 kg/m^3
Debris Specific Heat	600 J/kg K
Bed Porosity	0.4
System Pressure	0.5 MPa
Debris Particle Diameter	6 mm
Initial Bed Temperature	1000K, 1700K, 2400K
Bed Height	0.5 m, 1.0 m
Decay Heat Generation (per volume bed)	1.5 MW/m^3

TABLE 2. Transient Bed Quench Coolability Limits*

Bed Height (M) Initial Temp (K)	0.5	1.0
1000	C	C
1700	C	N
2400	N	N

* C = coolable
N = non-coolable

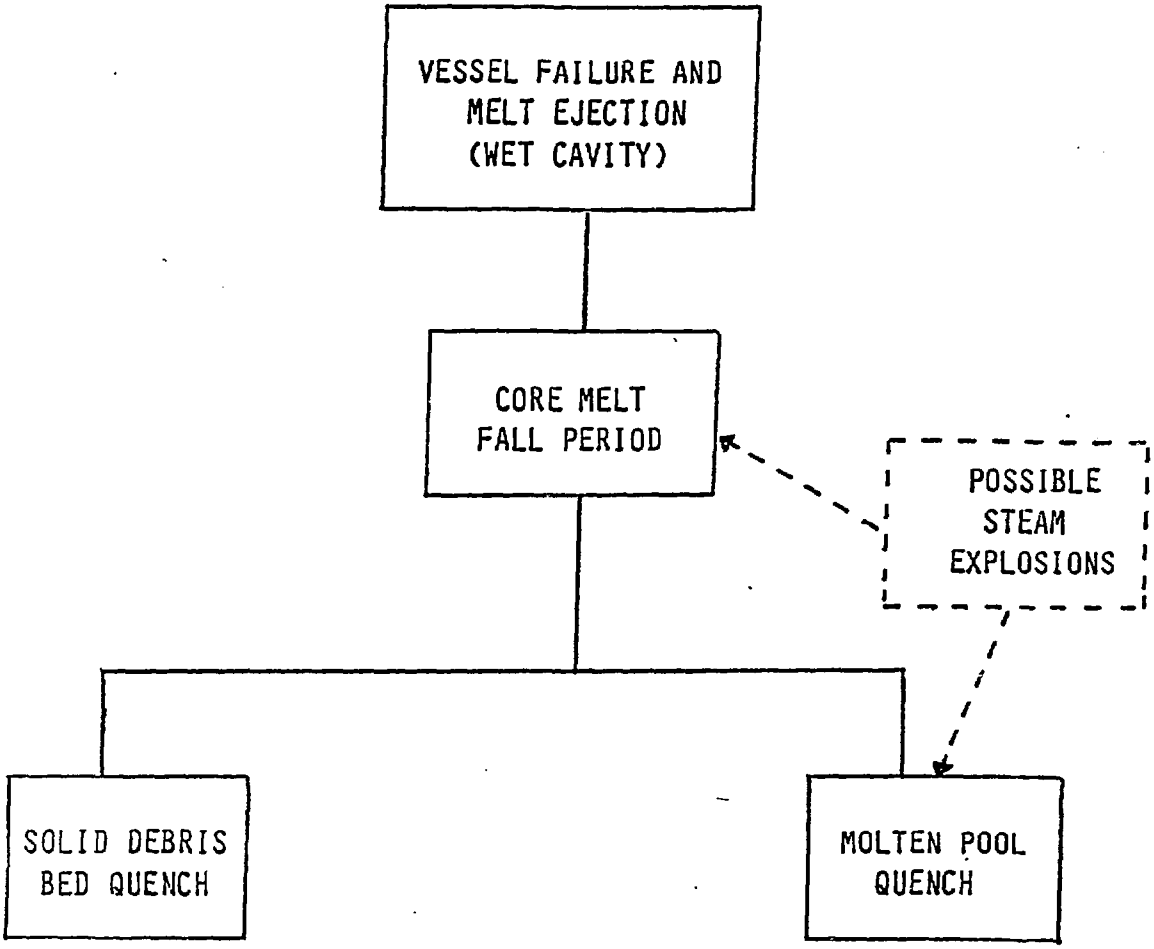

FIGURE 1. Accident Progression Following Vessel Failure

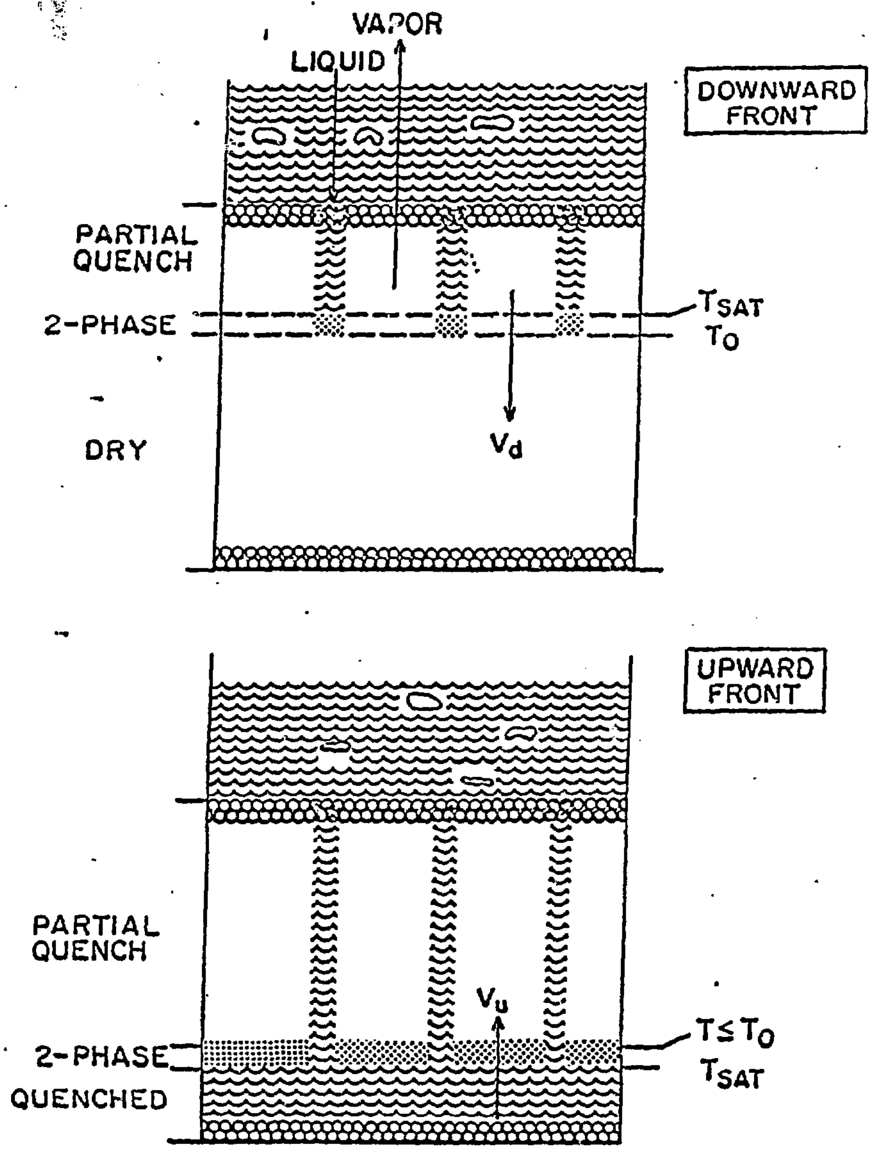

FIGURE 2. Schematic of Superheated Debris Bed Quench Front Propagation

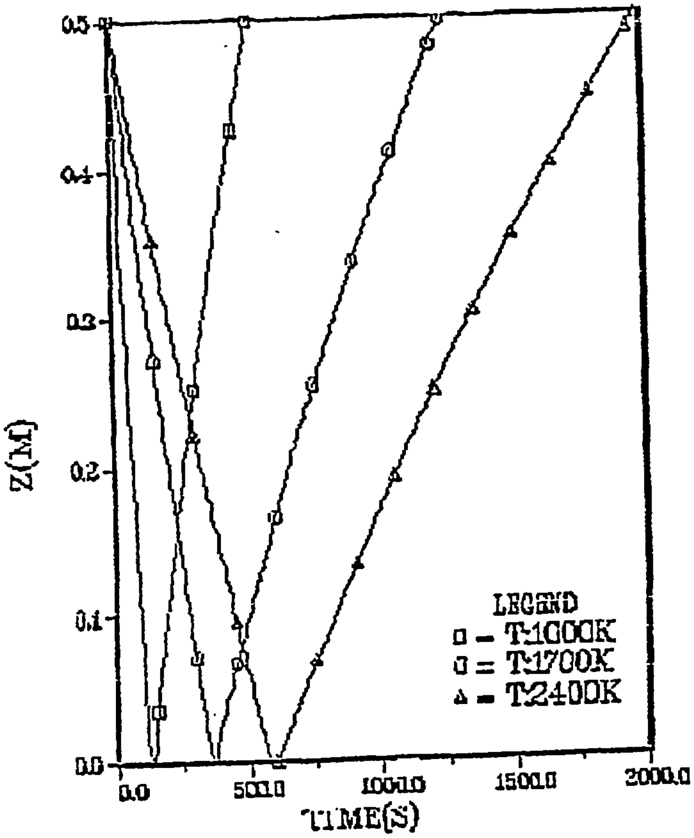

FIGURE 3. Bed Quench Frontal Propagation Curves
Bed Height - 0.5 meter

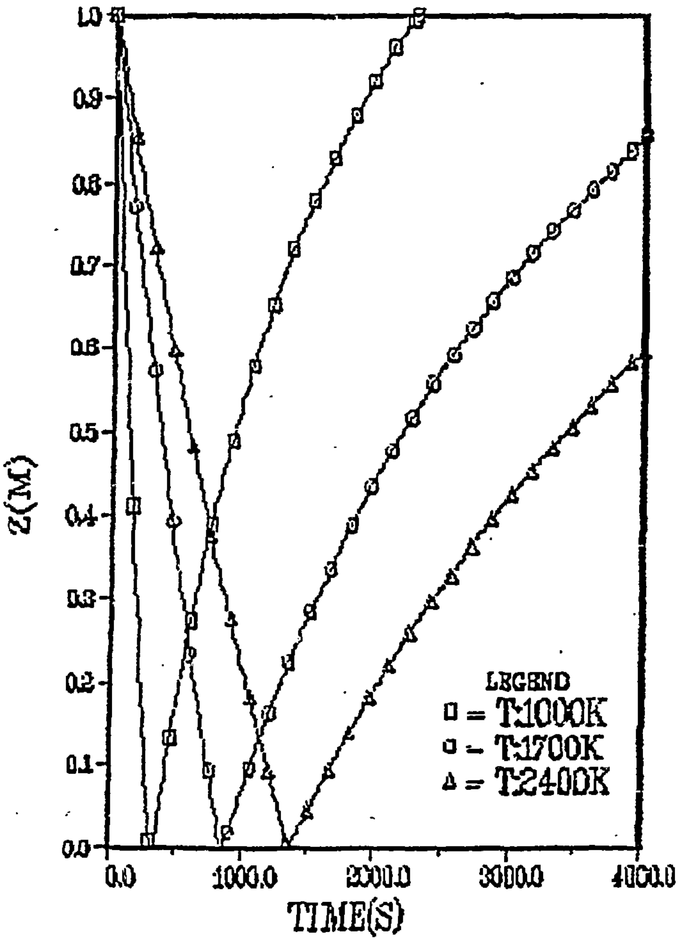

FIGURE 4. Bed Quench Frontal Propagation Curves
Bed Height - 1.0 meter

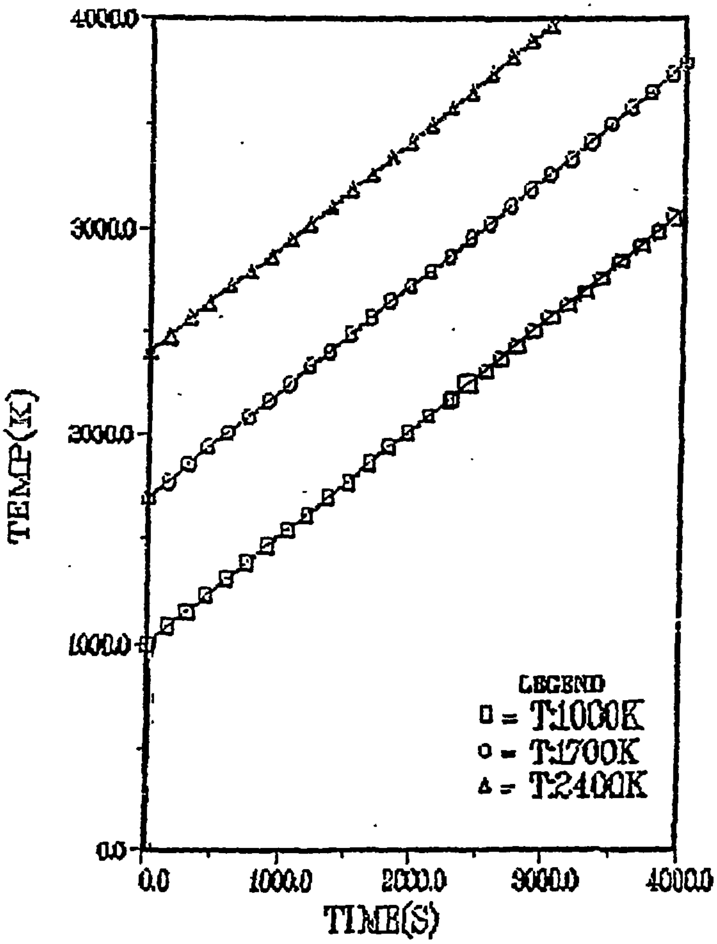

FIGURE 5. Temperature Rise of Unquenched Region of Bed: Applicable to 0.5 Meter and 1.0 Meter Bed Heights

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