LETTERS TO THE EDITOR

COMMENTS ON THE DYNAMICS OF FUEL VAPOR PRESSURE BUILDUP IN LIQUID-METAL FAST BREEDER REACTOR CORE DISRUPTIVE ACCIDENTS

In a recent paper, Singh and Rao[1] studied the dynamics of vapor pressure buildup in voided liquid-metal fast breeder reactor cores during energetic power excursions in core disruptive accidents. This is an extension of earlier work by Ganesan and Srinivasan.[2] In both cases the authors investigate a very important problem, because any delay in fuel vapor pressure buildup necessarily leads to an increase in the predicted energy release. In the older accident analysis work, before the advent of the SIMMER code,[3] it was indeed tacitly assumed that the pressure in a mesh cell is equal to the equilibrium vapor pressure, as, for example, in the VENUS code.[4] A few comments on the modeling in Refs. 1 and 2 seem to be necessary.

The authors use a gas kinetics model of evaporation, which is certainly justified. They assume that evaporation takes place at the surface of a molten section (of length l_1) of the fuel pin, while the pin geometry is still retained. In their reference case, vapor from this surface area fills the channel section of length l_1, while in the parametric cases and in Ref. 2, vapor expands into larger sections of the channel in an extreme case over the entire channel length l_2.

In this author's opinion, this liquid fuel model is, in the reference case, simplified, but useful. The parametric cases and the cases treated in Ref. 2, however, must be considered as unrealistic for two reasons. The first one concerns the surface area available for evaporation. If the fuel pin is heated on a millisecond time scale, the fuel either fragments into small particles (or liquid droplets) before it reaches the vapor pressure threshold or it boils up, so that evaporation takes place into small vapor bubbles. The first case is more likely if the fast temperature transient starts while the fuel is still solid; the second case, if the fuel is initially at or near the melting point. In either case, the surface areea available for evaporation is larger than just the pin surface. Thus, the "effective length" of the space to be filled with vapor V/A, where V is the void volume and A the available surface area,[1] is smaller, or at most equal to the width of the coolant channel. The authors' reference case is therefore a reasonable upper limit, but the parametric cases are unrealistic.

The second point concerns the model assumption (used in the parametric cases and by Ganesan and Srinivasan[2] that the vapor originating in the molten section spreads over the entire channel without any momentum transfer to the liquid, so that the liquid fuel stays in place until the vapor fills the channel completely. Only then, the pressure is available to drive a "core disassembly" with its associated reactivity feedback. In reality, liquid fuel and vapor will expand as a two-phase mixture; this may consist of drops dispersed in the vapor, or (in the initial stage) of a boiling liquid, with increasing vapor fraction. In either case, the liquid moves with the expanding vapor, leading immediately to a negative reactivity effect. For these two reasons, the large delay times and the associated high-energy releases calculated with these assumptions must be considered unrealistic.

Note that evaporation of fragmented fuel was already modeled in 1977 by Refling et al.[5] The model was, however, only applied to the postdisassembly expansion phase, not to pressure buildup during the excursion. The case of fuel boiling was considered in a recent paper.[6] Experimental information is available from in-pile tests with high heating rates,[7] which show rapid expansion of finely dispersed fuel.

It is of interest to compare the results obtained with the reference model in Ref. 1 to the results of the boiling model published in Ref. 6. Singh and Rao obtained time delays $\tau \simeq 15$ to 20 μs for a reactor of the 300-MW(electric) class (Table I of Ref. 1). In Ref. 6, the superheat was estimated to be ~20 K for a heating rate of 400 K/ms. This corresponds to a time delay of 50 μs. It must be pointed out that the models differ in two respects: On one hand, a larger evaporation area is assumed in Ref. 6. On the other, it is known that the gas kinetics model gives an upper limit for the evaporation rate. In the boiling model,[6] the rate is limited by heat transfer and is, therefore, somewhat lower. In view of these differences, the results cannot be expected to agree. It is, however, gratifying that they are of comparable magnitude.

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May 2, 1986

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RESPONSE TO "COMMENTS ON THE DYNAMICS OF FUEL VAPOR PRESSURE BUILDUP IN LIQUID-METAL FAST BREEDER REACTOR CORE DISRUPTIVE ACCIDENTS"

In response to the remarks of Fischer,[1] we point out that the parametric study in our paper[2] was conducted because of the uncertainties in the values of α', the coefficient of evaporation, and V/A, the ratio of the volume available for the vapors to spread and the surface area available for evaporation. The value of α' is not known and could be orders of magnitude less than unity, particularly for oxide and carbide fuels. Similarly, the ratio of V/A is uncertain, and it is difficult to ascertain the correct value of V/A applicable to the accident situations of core melting in liquid-metal fast breeder reactors. To check the way in which the results are affected if α' is less than unity by orders of magnitude and/or V/A approaches its theoretical limiting highest value, we conducted the parametric study by arbitrarily taking l_2 several times larger than l_1 [see Eq. (10) of Ref. 2]. On the other hand, it could also mean that l_2 is effectively equal to l_1 but α' is reduced by orders of magnitude. To some extent, this point has been discussed in the last paragraph of Ref. 2.

We agree with Fischer's remarks that as far as the evaluation of V/A is concerned, the surface area available for evaporation is larger than just the molten pin surface area; therefore, the effective length of the space to be filled would be smaller. Thus the reference case of Ref. 2 appears to be a reasonable upper limit. As mentioned above, however, our parameteric study was intended to examine the uncertainties in α' also; hence, to this extent, parametric study is useful in providing the range of results due to this uncertainty.

We welcome the useful remarks of Fischer and appreciate his interest in our paper.

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June 12, 1986

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