CLM - P 517

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Preprint

INTERFACE TEMPERATURE CRITERIA AND THE SPONTANEOUS TRIGGERING OF SMALL-SCALE FUEL-COOLANT INTERACTIONS

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1978

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ABSTRACT

Several criteria have been suggested for the onset of fuel-coolant interactions the most important being based on the interface temperature, T_I, having to exceed some fixed value such as the fuel melting point. These are briefly discussed and it is shown that in three systems with low melting point fuels (i.e. low compared to the coolant homogeneous nucleation temperature, T_{hom}) the $T_I = T_{hom}$ criterion must be exceeded for spontaneous FCIs to occur in small drop experiments.

Paper to be presented to the Deutsches Atomforum e.V. 1978 Reactor Meeting Hanover, West Germany, 4 - 7 April 1978.

January 1978

INTRODUCTION

An important parameter in FCI experiments is the interface temperature and several criteria for the onset of FCIs have been based on it. The general validity of one, the superheat criterion, has been the subject of much debate. To extrapolate over the wide range of scale and simulant materials used in experiments to reactor materials and conditions it is necessary first to identify to which of several possible trigger mechanisms the superheat criterion is applicable and which mechanism is operative in a given circumstance. In this paper we present the results of experiments which demonstrate the validity of the superheat criterion for spontaneous triggering in small drop experiments with three pairs of simulant materials.

INTERFACE TEMPERATURE CRITERIA

On initial contact of fuel and coolant the instantaneous interface temperature, T_I, calculated below are based on conduction only across the interface and have been estimated from $T_I(1+\alpha) = T_f + \alpha T_c$ where α^2 is the ratio of $k\rho c$ for the coolant to that of the fuel. T_f and T_c are the fuel and coolant temperatures, k is thermal conductivity, ρ is density and c is specific heat. No account has been taken of the variation of physical properties with temperature.

Spontaneous triggering only occurs with molten fuel so that the first criterion to be observed is simply that T_I must exceed the fuel melting point, T_{mp}. This criterion will only hold so long as the solid layer at the interface is strong (thick) enough to withstand the stresses associated with vaporisation of the coolant.

The superheat criterion(1) states that T_I must exceed the spontaneous nucleation temperature, T_{spon}, of the coolant. T_{spon} lies between the coolant saturation temperature, T_{sat}, and its homogeneous nucleation temperature, T_{hom}, the precise value being determined by the nature and density of nucleation sites within the coolant or at the interface. An abundance of nucleation sites lowers T_{spon} to T_{sat}, while their complete absence raises T_{spon} to the homogeneous nucleation limit.

Finally, there is some evidence that, while the foregoing criteria are necessary for the production of fragmentation interactions, a third criterion is required for the onset of explosions. This could be of the form $T_f \gtrsim T_{min}$, the minimum film boiling point. In this paper we are concerned only with the applicability of the superheat criterion to systems with low melting point fuels ($T_{mp} < T_{hom}$).

TEMPERATURE INTERACTION ZONES AND THE SUPERHEAT CRITERION

In two of the systems described below 12g samples of molten metal or alloy were dropped into 2000 cm^3 of distilled, degassed, water 180 mm deep. The method is described elsewhere[2]. The third system described, 10 cm^3 of refrigerant R12 dropped into 500 cm^3 of water, differed from the others in that the coolant was changed and the fuel became the bulk phase.

The results of the drop tests are summarised in the fuel temperature-coolant temperature plots in figure 1. In all the systems a well defined zone was obtained, the Temperature Interaction Zone (shown shaded), inside which FCIs were possible, though not certain; violence depended on position within the zone[2]. Outside the TIZs spontaneously triggered FCIs did not occur. Each of the four systems is characterised by straight line boundaries with the left hand near vertical boundary giving, for each value of coolant temperature, the minimum fuel temperature for interactions to be possible.

Interface temperature lines corresponding to solidification of the fuel and to homogeneous nucleation of the coolant are plotted for each system in figure 1 and demonstrate that for low melting point fuels the left hand boundary is fixed by the superheat condition $T_I = T_{hom}$. (For water T_{hom} was taken as 573 K while for the refrigerant R12 the closest line to the boundary was drawn which corresponds to 312 K = 0.81 x critical temperature. 0.81 compares favourably with the Schins[3] approximation 27/32 or 0.84).

EXTENSION TO REACTOR MATERIALS

If TIZs exist for the UO_2/Na and steel/Na systems of interest to fast reactors they must be confined within a region in temperature space bounded by the material melting and boiling points. These regions are shown in figure 2 together with interface temperature lines corresponding to T_{sat}, T_{hom} and T_{mp}. In both cases the $T_I = T_{hom}$ line lies above the allowable areas in which TIZs could be located and the superheat criterion suggests that FCIs between reactor materials are unlikely to be spontaneously triggered in clean, idealised conditions. However, the superheat criterion[1] is that T_I must exceed T_{spon} and hence the critical interface temperature line could lie anywhere between those corresponding to T_{sat} and T_{hom}. The simulation experiments were performed under as clean a condition as possible so that it was not surprising that the homogeneous nucleation limit determined the positions of the left hand boundaries of the TIZs.

Under reactor conditions it is possible that the critical interface temperature line (that corresponding to T_{spon}) for the steel/Na system could intersect the shaded area of figure 2 between the lines $T_I = T_{hom}$ and T_{mp}. Spontaneously triggered FCIs might then be possible between stainless steel and sodium, but only if the steel is heated well above its melting point.

The critical line for the UO_2/Na system could also cut its shaded area but here the solidification line is far above even the $T_I = T_{hom}$ line and solidification should occur for all possible values of T_{spon}. Spontaneously triggered FCIs therefore appear unlikely to occur between UO_2 and sodium.

DISCUSSION AND CONCLUSIONS

Small-scale experiments in which tin, low melting point alloys and refrigerant R12 have been dropped into water show the existence of well defined temperature interaction zones for spontaneous triggering. Other trigger modes, such as base triggering and by external pressure pulse(4) are known to exist and interactions can be obtained outside the higher boundaries of the TIZ by these alternative triggers. However, there is no evidence that other trigger mechanisms can produce interactions below the lower fuel temperature boundary defined in the experiments above by the superheat criterion. On the contrary, this same criterion holds for both fuel dropped into coolant and vice versa and also in another contact mode of water injected into tin(5). From a safety viewpoint this boundary is therefore the most important and further experiments are needed to establish its generality for all possible contact and trigger modes. Extrapolation of results to reactor conditions might then be done with confidence.

ACKNOWLEDGEMENTS

This work was sponsored by the UK Safety and Reliability Directorate, Culcheth, whose support is gratefully acknowledged.

REFERENCES

1. Fauske H K, 1973, Reactor Technology, 15, pp.278-302.
2. Dullforce T A, Buchanan D J and Peckover R S, 1976, J.Phys.D:Appl.Phys. 9, pp.1295-1303.
3. Schins H E J, 1975, Atomkernenergie (ATKE), 26, pp.48-52.
4. Board S J, Farmer C L and Poole D H, 1972, CEGB Report RD/B/N2423.
5. Asher R G, Bullen D and Davies D, 1976, AERE-M2772.

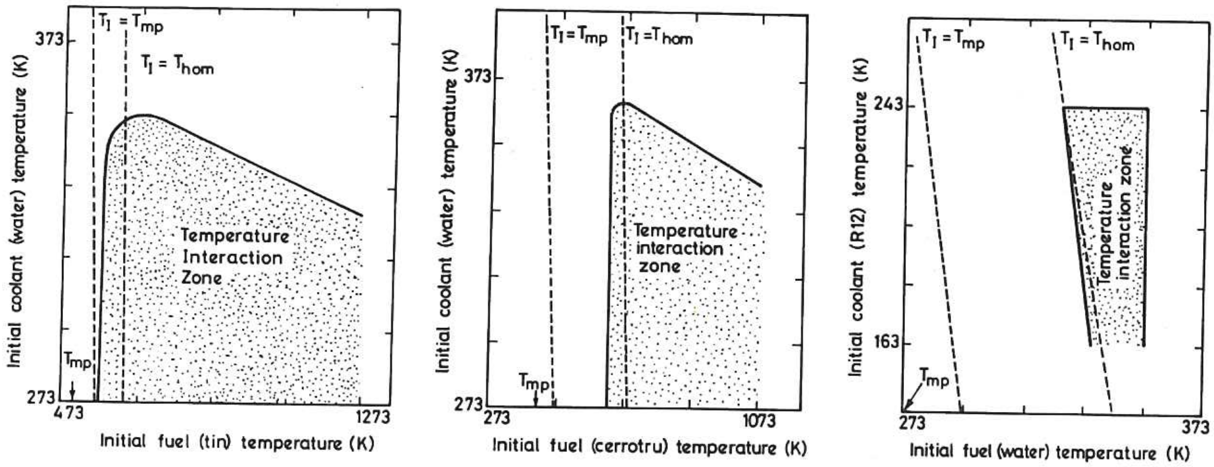

Fig. 1 Spontaneously triggered TIZs in three systems.

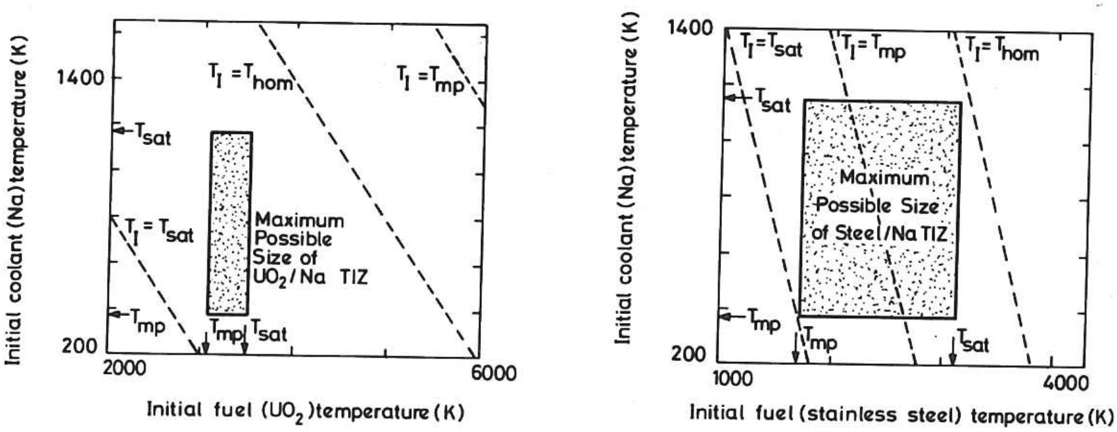

Fig. 2 Extrapolation to Reactor Materials