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ON THE SIMILARITIES AND DIFFERENCES IN VAPOR EXPLOSION CRITERIA

An overview of recent ideas pertaining to vapor explosion criteria indicates that in general sense, a consensus of opinion is emerging on the conditions applicable to explosive vaporization. As indicated in Table I, experimental and theoretical work has lead a number of investigators to the formulation of such conditions which are quite similar in many respects, although the quantitative details of the model formulation of such conditions are somewhat different.

All model concepts are consistent in that an initial period of stable film boiling, separating molten fuel from coolant, is considered necessary (at least for large-scale interactions and efficient intermixing), with subsequent breakdown of film boiling due to pressure and/or thermal effects, followed by intimate fuel-coolant contact and a rapid vaporization process which is sufficient to cause shock pressurization. Although differences arise as to the conditions for and the energetics associated with film boiling destabilization and the mode and energetics of fragmentation and intermixing. However, the principal area of difference seems to be the question of what constitutes the requisite condition(s) for rapid vapor production to cause shock pressurization.

To account for such rapid vaporization Fauske[1] originally proposed that vapor formation occur at or near the maximum possible nucleation rate, as predicted from kinetic theory. Using Volmer's classical rate equation, a characteristic homogeneous nucleation temperature was assessed. However, simulant fluid experiments[2] indicated vapor explosions may occur below such a temperature threshold, which was accounted for in terms of wetting characteristics between fluids, which results in a lower threshold temperature commonly referred to as the spontaneous nucleation temperature. However, such wetting effect arguments may not account for all simulant fluid experiments where explosive vaporization was observed. In some experiments[3,4] a relatively gradual rise in pressure is noted with thermal conditions, rather than threshold events.

A somewhat different approach for rapid vaporization, dating back to early experience with metal-water interactions, is that resulting from fine-scale fragmentation and intermixing of fuel with coolant. The validity of explosive vaporization due to the generation of a large effective heat transfer area, sufficient to cause shock pressurization, has been demonstrated by calculational studies[5,6] and shown to accompany all known vapor explosion events[7]; thus, historically attempts at understanding the fragmentation process have been a principal area of investigation. Subject to the other conditions in Table I, the possibility therefore exists for explosive vaporization by either fine-scale fragmentation and intermixing or by spontaneous vapor nucleation or a combination of both. Since the UO_2-Na contact temperature is predicted to be well below the homogeneous nucleation temperature the problem becomes one of assessing the nature and efficiency of the fragmentation and intermixing processes.

As discussed in Ref. (8) research efforts with respect to fragmentation have primarily centered on a determination of the principal mechanisms involved. However, to assess the question of whether an MFCI induced vapor explosion can occur, an understanding of the kinetics of fragmentation, the resultant particle size distribution obtainable, intermixing energy considerations, and the heat transfer process between fuel and coolant must be known; which is not the case at the present time. However, the fact that fragmentation and intermixing leading to explosive vaporization occurred readily when vapor film collapse was initiated in a shock tube[9] or by acoustic means[10] and that such experiments have generated the highest known pressure increase associated with small-scale vapor explosion research. The results of such experiments provide a strong indication for a vapor film collapse/fragmentation mechanism for explosive vaporization. Thus, condition four as stated in Table I, for what is called a general model, is that fine-scale fragmentation and intermixing are necessary conditions for large-scale vapor explosions while attainment of the spontaneous nucleation temperature does not necessarily have to be achieved, although it may enhance either rapid vapor production or fragmentation and intermixing.

Although large-scale vapor explosions have been ruled out 'a priori' based upon the interface-spontaneous nucleation concept,[1] a definitive conclusion that fine-scale fragmentation and intermixing are highly improbable for a reactor environment has not, to date, been demonstrated. It therefore appears that explosive vaporization induced by fuel fragmentation and intermixing with coolant should be a principal area of future vapor explosion research. Some primary areas of concern with respect to such fragmentation are:

a) An understanding of the energetics of vapor collapse for prior film boiling and its effect on the fragmentation and intermixing energy requirements.

b) An understanding of the kinetics and energetics of fine-scale fragmentation, in the context of the propagating pressure-detonation concept of Board and Hall.

If it can be demonstrated that the fragmentation and intermixing energy requirements cannot be met, then it appears that the potential for large-scale vapor explosion occurrence in a reactor system can be considered negligible.

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TABLE I

COMPARISON OF VAPOR EXPLOSION CONDITIONS

Vapor Explosion Conditions	Fauske-Henry[1,2]	Board-Hall[12]	Anderson-Armstrong[4]	Cronenberg-Gunnerson[11]	General Model
1. Initially stable film boiling, so that vapor film separates the two liquids and permits coarse premixing without excessive energy transfer	Consistent	Consistent	Consistent	Consistent with all model concepts	Consistent with all model concepts
2. Breakdown of film boiling	Due to thermal or pressure effects	Due to pressure effects	Due to pressure effects	Due to thermal effects	Due to thermal or pressure effects
3. Fuel-coolant contact upon breakdown of film	Liquid-liquid contact	Liquid-liquid contact	Liquid-liquid contact	Liquid-liquid or solid crust-liquid contact	Liquid-liquid or solid crust-liquid contact
4. Rapid vapor production, causing shock-pressurization	Due to spontaneous vapor bubble nucleation (assessed from kinetic theory) and fine-scale fragmentation-intermixing	Due to a large effective heat transfer surface as a result of fine-scale fragmentation and intermixing	Due to a large effective heat transfer surface as a result of fine-scale fragmentation and intermixing	Due to a large effective heat transfer surface as a result of fine-scale fragmentation and intermixing	Large effective heat transfer surface due to fragmentation and intermixing; possible, but not necessary, spontaneous nucleation of vapor
5. Adequate physical and inertial constraints to sustain a shock wave	Consistent	Consistent	Consistent	Consistent	Consistent with all model concepts