Comments on the Fuel-Coolant Premixing Debate

Theofanous et al.'s[1] four-part work on the probability of containment failure due to steam explosions has generated a considerable amount of comment.[2] My particular concern is the degree to which the authors' conclusions appear to be based on large-scale "premixing" calculations with an unvalidated computer code, e.g., the modified version of K-FIX used in Part II. Although the limitations of using this particular two-field model have been stated previously,[2] it is worth noting again that the use of a fairly small melt diameter initially is going to produce a higher initial steaming rate than would occur if a larger diameter melt were used, that is then fragmented to smaller sizes, and that this high steaming rate tends to disperse the melt more than is likely to actually occur. This early dispersal will occur both if a homogeneous flow model for steam and water is used, as in the modified K-FIX code,[1] or if a code that includes slip is used, although the effect is likely to be aggravated in the former case. The initial high steam generation rate, combined with the homogeneous flow model, virtually guarantees that the water will be carried away from the melt by the steam, thus artificially producing less mixing of the melt and water than would otherwise occur.

Although Theofanous et al.[1] probably could not do anything about the homogeneous flow limitation, given the two-field model, a comparison to existing experimental data[3,4] would at least give some confidence that the computer model was working as intended, or a parametric study varying the initial fixed melt diameter could have been done to indicate the effect of the diameter on the calculation. Since neither of these steps was taken, it is impossible to conclude anything definite about "mixing limits" based on the large-scale mixing calculation in the paper.[1]

Theofanous rather offhandedly dismissed the simulant jet experiments conducted at Sandia National Laboratories[5] (SNL) as being poorly instrumented and producing no useful premixing information. Perhaps we should contrast this set of experiments, which are at least close to the correct length scales, jet Weber numbers, and density ratio for the reactor problem,[6] with a set reported in Theofanous et al.[1] In this experiment, water was poured onto the ground. A simple "back-of-the-envelope" calculation would have shown that the density ratio and jet Weber numbers for such a test are several orders of magnitude away from the reactor problem (850 versus 7, 5 versus 100) and that the tests, in fact, produced no data other than the informative comment, ". . . splashing associated with its impact with the ground."[1]

In connection with the comments made about improved computer models,[2] a great deal of work has been done at SNL to develop a computer code capable of modeling the full range of fuel/coolant interaction phenomena, including coarse mixing ("premixing") and propagating detonations. Work on the IFCI (Integrated Fuel/Coolant Interaction) code was started in 1985, and a report on a preliminary test problem was published[7] in September 1987. The IFCI features are intended to remove known limitations in previous approaches. The IFCI code would fit into Corradini's table of codes[2] as shown below:

Model	Advantages	Disadvantages
IFCI (Young)	Two-dimensional Dynamic breakup Subcooled boiling Compressible flow	No oxidation model No detonation model

The IFCI code uses two-dimensional, four-field (vapor, water, solid corium, and melt) compressible hydrodynamics; the code also includes physically based models for dynamic breakup of the melt and for subcooled boiling. The compressible flow formulation allows the treatment of shock waves, although the current dynamic breakup model does not include some aspects of propagating detonations that have been observed. This lack, along with the lack of an oxidation (hydrogen generation) model, is currently being remedied.

The models being developed for IFCI are validated or are being validated against experiment; only in this way can we put any credence in a calculation at large scale, for which there is no experimental data available. The dynamic breakup model has been validated against existing drop breakup data[8] and is currently being compared to available medium-scale breakup data.[4] For instance, a simulation of a nonexplosive FITS D test,[4] in which 20 kg of melt, with an ~10-cm diameter, was dropped into saturated water, resulted in calculated Sauter mean and mass median diameters of 7.5 mm and 1.27 cm, respectively, after mixing. The experimental range of Sauter mean and mass median diameters for the D tests are 3 to 6 mm and 0.5 to 1.6 cm, respectively. The subcooled boiling model, which allows both simulation of boiling in subcooled water and condensation of hot steam, was developed from film boiling data for single spheres[9,10] and is being compared to steam generation data for the ensembles of spheres in the Brookhaven National Laboratory experiments.[3] After validation of the boiling and mixing models against existing experimental data is completed, a simulation of large-scale mixing, as in Theofanous et al.[1] or Fletcher,[11] will be done.

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Response to "Comments on the Fuel-Coolant Premixing Debate"

Young's letter[1] contains no technical points, but the following series of formal ones:

1. In his *opinion* we have used a too small melt particle diameter in our calculations, and we were amiss not to have presented parametric calculations on this.

2. In his *opinion* we should have attempted to calculate and compare with Marshall's experiments.

3. He has a code, IFCI, that in his *opinion* is superior to ours because its models "are validated or *are being validated* [emphasis added] against experiment" and in particular "the dynamic breakup has been validated. . . . "

4. After validation "is completed a simulation of large-scale mixing . . . will be done."

Our response to these points is as follows:

1. Our choice of melt particle size and the conservative effect of ignoring additional breakup due to steaming and two-phase turbulence has been explained already (Young's Refs. 1 and 2; see also our response to Corradini in this issue of *Nuclear Science and Engineering*). In addition to particle size, there are several other parameters that need to be varied for a meaningful parametric/sensitivity study. This involves a very significant computational effort. We have only recently been able to complete it, and a paper (Part V of the series) is being prepared for publication. The results from this study, which in reference to this point covers melt particle sizes of 1 to 5 cm, support the premixing quantification given previously.[2]

2. We have stated previously (Young's Ref. 2) why Marshall's experiments cannot be used for testing premixing models. Interestingly enough, these experiments (already more than 3 years old) have not yet appeared in the archival literature, nor have they been used by Young (or anyone else) in the testing of

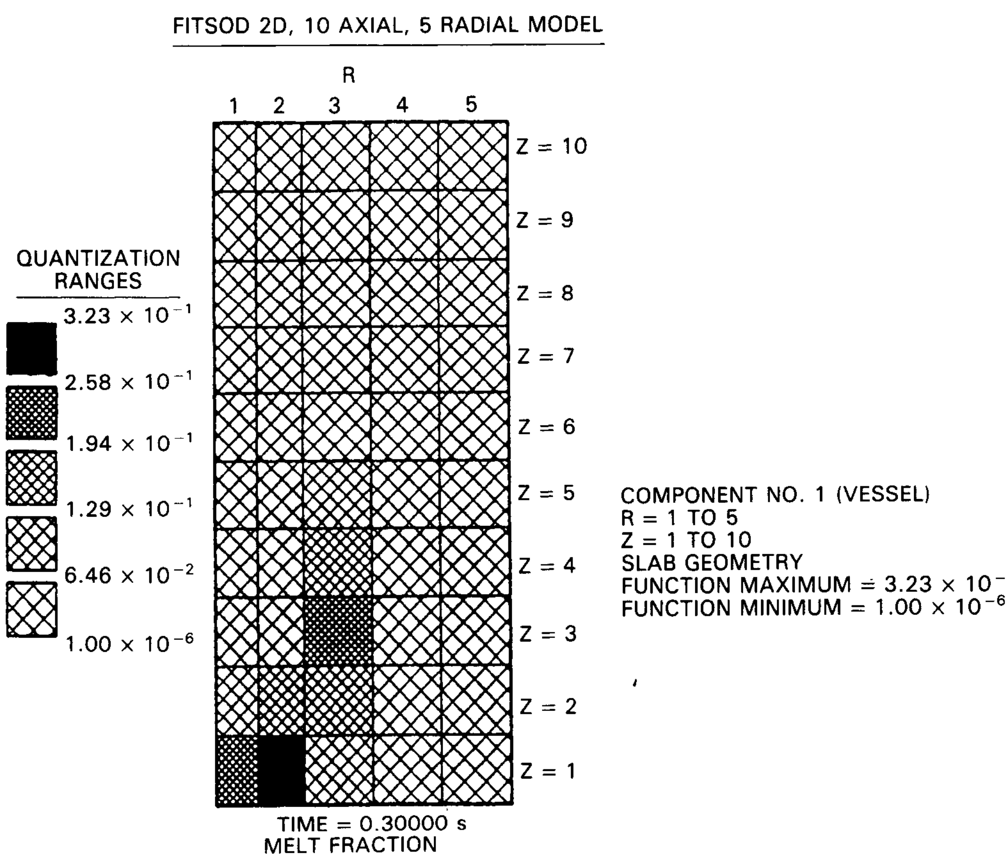

Fig. 1. Melt volume fraction at 0.3 s (reproduced from Young's Ref. 7). The radius is 34.5 cm and the height is 61 cm.