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from: M. Berman and R. K. Cole, Jr., 6441

subject: Status of Core Melt Programs -- May-June, 1983

I. Core Melt -- Coolant Interactions (CMCI)

1. Intermediate Scale Experiments
(M. Berman, N. A. Evans, M. S. Krein)

Five more experiments were performed in the EXO-FITS CM series using molten iron-alumina dropped into water; the conditions and results for the nine experiments conducted so far are summarized in Table 1. This particular series of tests has yielded some rather unusual results. The original intent of the series was to investigate coarse mixing (CM) processes. Nearly saturated water was used to inhibit the steam explosion. Earlier tests at intermediate-scale (FITSG) had resulted in no explosions with saturated water.[1,2] Furthermore, single-droplet tests by Nelson showed that low subcooling reduced the explosibility of molten iron oxide (i.e., the required trigger to initiate an explosion increased with decreasing subcooling).[3] Nevertheless, in earlier intermediate-scale tests by Buxton and Benedick, vigorous steam explosions were observed for saturated water.[4]

In the current CM tests, energetic interactions were observed at or near the surface for all tests, regardless of water depth, water vessel cross section, drop height, water subcooling or melt mass. In tests CM-8 and CM-9, these interactions seemed explosive in nature. In other cases, the interaction was violent enough to eject most of the incoming melt, but the interaction persisted for almost 100 ms or longer, a duration much longer than the few ms or less observed for "classical" steam explosions.

Table 1. CM SERIES (EXO-FITS) TEST CONDITIONS AND RESULTS

Test, Date	Mass Delivered kg	Water Volume side x depth, m x m	Water Subcooling and Temp. °C	Drop Height m	Final Melt in Vessel kg	Comments
CM-1 3/22/83	18.5	.31 x 1.21	9 85	.31	n.a.	Vigorous surface interaction at about 5 cm melt penetration. Intact chamber. Only low cam data.
CM-2 4/1/83	18.0	.31 x 1.21	4 90	.31	3.8	Late melt release. Top third of water chamber blown off.
CM-3 4/19/83	18.0	.61 x 1.21	3 91	.48	4.3	Surface interaction at penetration depth 5-8 cm. Top third of chamber blown off.
CM-4 4/27/83	18.9	.61 x 1.21	3 91	1.12	3.5	Prompt surface interaction. Subsurface events fractured water chamber.
CM-5 5/13/83	7.6	.61 x 1.21	4 90	1.12	3.4	Prompt surface interaction.
CM-6 5/24/83	4.0	.61 x .61	3 91	1.12	1.9	Prompt surface interaction.
CM-7 5/28/83	18.5	.61 x .46	73 21	1.12	*	Prompt surface interaction. Strong bottom explosion very late (555 ms after entry).
CM-8 6/3/83	18.6	.61 x .61	2 92	.44	*	Delayed surface interaction (about 20 cm penetration). Later "moderate" explosion (about 10 cm shards).
CM-9 6/8/83	18.6	.61 x .61	2 92	.44	*	Delayed surface interaction (15-20 cm). Later "moderate" explosion.

*Chamber completely destroyed.

The first four tests used 18-19 kg of melt, varying water mass, depth and cross-section, and melt drop height. The results were very similar. Approximately 30 - 36 ms after melt entry, corresponding to a depth of penetration of 5 - 8 cm, a violent ejection process began, resulting in the expulsion of most of the incoming melt. The ejection period lasted roughly 100 ms. Between 3.5 and 4.3 kg of frozen fuel simulant was recovered from the bottom of the chamber, essentially in a lump (very similar to the FITSG tests). The possibility of a mass (or volume) threshold of 4 kg for explosions in saturated water had been postulated prior to these tests.[5] To test this hypothesis, test CM-5 used 7.6 kg, and CM-6, 4 kg. CM-5 was very similar to previous tests. 3.4 kg remained on the bottom of the chamber, and the rest was expelled. CM-6, however, did show some differences. The expulsion period was of longer duration, about 200 ms, and only 1.9 kg remained on the bottom. These tests do indicate the possible existence of a mass threshold. However, the primary purpose of these tests was to investigate coarse mixing at larger scales than had been previously investigated. To accomplish this, it would be necessary to get larger masses into the water, not smaller.

Some new experimental procedures had been introduced in the most recent test series. The thermite powder is now baked longer to remove volatile impurities (6 hrs at 600°C vs 2 hrs at 200°C for earlier tests). In earlier tests, the bottom lid of the crucible was allowed to fall into the water; in current tests, the lid was hung on a chain, and it did not fall with the melt. To test the possible introduction of a systematic error, test CM-7 was conducted in cold water. This test also exhibited the surface interaction and melt expulsion, with approximately the same duration: the interaction, however, was strong enough to rupture the water chamber. In spite of the apparent loss of most of the chamber water, a violent steam explosion occurred at the base, 555 ms after melt entry, the longest delay to any explosion ever observed.

To investigate the possible effect of removing the crucible bottom lid, tests CM-8 and CM-9 were conducted with the lid allowed to fall into the water. The lid appeared to delay the onset of the surface interaction, which, for CM-9, began about 70 ms after melt entry, corresponding to a penetration depth of about 15-20 cm. In both tests, the interaction was vigorous enough to fracture the water chamber in pieces as small as 10 cm; no residual melt was recovered.* The lid appeared to mechanically delay melt-water contact; such contact appeared to occur first at the sides, rather than the bottom. These tests indicate the possibility that structure or frozen crusts in the

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* After a "normal" steam explosion, pieces of the lucite chamber are typically of the order of 1 cm or less; for the longer duration interactions (e.g., CM-1 ⟶ 6), the chamber wall is frequently "pushed out" intact.

reactor situation could influence the triggering and propagation of explosions; this would further complicate the in-vessel mixing and explosion probability and consequences.

Rather than illuminating the coarse mixing process at larger scales and in saturated water, this test series has highlighted some new and persistent phenomena. If surface interactions occur in saturated water at ambient pressure in the reactor case, as they have in the CM tests, then it may be very difficult to have a large-scale steam explosion, under those conditions. It is also possible that such interactions in a confined geometry could enhance mixing, which could subsequently lead to a large-scale explosion. In either case, a possible process might involve multiple or continuous vigorous interactions. The rates of steam and hydrogen generation could be very rapid. The characteristics of the debris are not known.

It is possible that the oxidation of the metal in the thermite fuel simulant may play an important role in the triggering and propagation of explosive and non-explosive interactions. To investigate this, we plan to conduct some tests using purely oxidic melts in the next few months.

2. Modelling of "Steam Spikes" and FITS Tests
(M. L. Corradini)

During these two months, we have been involved in three main activities: participating in the SARRP program, and analysis of small- and large-scale CMCI experiments. In the first area we are using a dynamic model of fuel-coolant mixing and interactions (WICSI) to perform sensitivity calculations on "steam spike" phenomena in the reactor cavity. The purpose of our work is to identify the physical phenomena that may actually contribute to the steam pressurization of containment. Currently, we consider four types of physical processes that cause the "steam spike": fuel-coolant mixing, steam explosions, gas discharge and entrainment, and possible molten core quenching as a pool by an overlying water layer (this final physical process has been suggested by Prof. T. G. Theofanous). Another contributor to containment pressure would be the direct heating of the atmosphere by hot aerosols that have been injected into the air. This mechanism may be considered at a future time.

We are currently trying to analyze the past experiments with single-droplets and the large scale FITS tests. We have a model for fuel fragmentation in the small-scale experiments and are now trying to apply it to the five standard single-droplet experiments used in the CSNI analysis in 1980. Also we have developed a lumped parameter model for the large-scale steam explosion. The model is our initial step in the development of a transient one-dimensional propagation model for the steam explosion which would supply the empirical input to a much more sophisticated two-dimensional calculation (e.g., CSQ). It is very similar to the Cho-Wright parametric model in concept and will be used in preliminary analysis of the FITS tests.

II. Molten Core/Concrete Interactions

(R. K. Cole, Jr., D. P. Kelly, M. A. Ellis)

1. CORCON Development

The crust-formation/freezing model is operational in Version 1.02.00 of CORCON, as described in our March-April letter. This model calculates heat transfer in solidified regions from conduction relations, and directly models the increase in thermal resistance as a layer freezes. This effect was simulated in MOD1 through the use of a two-phase (Kunitz) viscosity multiplier to reduce the heat-transfer coefficients calculated from convective correlations when temperatures were in or below the freezing range. The Kunitz multiplier is no longer needed and, as it has been implicated in some "peculiar" behavior in MOD1, we have eliminated it. Version 1.02.00 also has an improved (extended Shaw) model for viscosity of oxidic mixtures replacing the old Bottinga-Weill Correlation.

Dave Bradley, of the Advanced Reactor Safety Physics Division, used Version 1.02.00 in order to get boundary conditions for an aerosol generation calculation without the Bottinga-Weill-correlation/Kunitz-multiplier problems of MOD1. He found several problems, two of which have MOD1 implications. We have corrected these; the corrections will be included in a third correction set for MOD1 which will be issued at a later date.

One of his calculations demonstrated non-convergence of the single-layer heat-transfer routine, HTRLAY, which implements the crust-formation/freezing model. As in previous cases the non-convergence occurred as the last fractional-millimeter of a layer was freezing. While we have made significant progress in understanding the problem, it is not yet solved to our satisfaction.

2. Assessment

As reported in the last bimonthly report, the set of model sensitivity tests was completed, leaving only the input/initial conditions tests to finalize the assessment study. During this reporting period nine tests were performed and the necessary documentation completed. These tests included the following: (1) cavity geometry, (2) concrete composition, (3) decay heat, (4) surface temperature history of surroundings, (5) initial temperature of concrete, (6) ablation temperature, (7) emissivity of concrete surface, (8) initial oxidic melt temperature, and (9) initial metallic melt temperature.

One of the more interesting results from these tests was the effect of the initial concrete temperature on the calculation of the heat of ablation and, therefore, the amount of concrete ablated and gases generated during the interaction. The effect on the overall volume of concrete ablated during a six hour interaction is illustrated in the results below.

Initial Concrete Temperature (K)	Volume of Concrete Ablated
100	39.96
298 (base case)	41.31
500	45.87
800	55.17
1200	71.44

The high temperature case (1200 K) resulted in a reduction in the heat of ablation of 33% compared to the base case. This reduction in the heat of ablation resulted in increased generation similar in magnitude to that for concrete ablation shown above. It should be mentioned that at this elevated initial concrete temperature both evaporative and chemically bound water would be released. This phenomenon is not accounted for in CORCON-MOD1, explaining the large increase in gas generation during the interaction.

References

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