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Technical Progress Report for 1989-1990

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Research on

CHARACTERIZATION OF JET BREAKUP MECHANISMS OBSERVED FROM
SIMULANT OF MOLTEN FUEL PENETRATING COOLANT

Submitted by

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Introduction

The objective of the proposed experiments is to replicate approximately, by injecting low melting point metal alloys into Freon-11 and liquid nitrogen, the dispersal of corium streams in water. To first gain a better understanding of the corium dispersal process to be simulated, experimental data from the CCM experiments, in which the injection of streams of molten corium into water was studied, was interpreted in cooperation with Argonne National Laboratory (ANL) staff.¹ The results of these experiments are discussed briefly below. This is followed by a description of the preparations made to date for the present simulant experiments.

CCM Experiment Results

In these experiments, direct observation of the interaction was not possible. Thus, a conceptual picture of the corium breakup process must be inferred from the responses of thermocouples placed beneath the water surface, from the pressure and temperature of the air/vapor in the interaction vessel, and from the changing water level (pool swell). The submerged thermocouples detected the expansion of the corium mixture, while vapor generation rates were estimated from the PVT data. The inferred breakup process was different from the immediate breakup observed by Marshall et. al. for iron-alumina in water².

The mass lengths (injected melt volume normalized by the orifice cross sectional area) of the corium streams (in the four single-stream tests where breakup lengths could be determined) varied from 14.3 to 33.7 stream diameters. In Figure 1, breakup length is plotted versus mass length for these four tests. Although the ranges of uncertainty for the breakup lengths are large, this plot suggests that breakup length increased with mass length. If a quasi-steady breakup length had been observed, it would have been independent of mass length (i.e., of the duration of the corium injection). A dependence of breakup length on mass length would indicate that corium dispersion occurred primarily at the leading edge of the penetrating stream, while its trailing column was perhaps protected from dispersion by a vapor blanket. This conceptual picture is supported by pool swell data from test CCM-5 (the only test for which both accurate pool swell measurements and unambiguous thermocouple data are available). Assuming that the corium mixture was roughly cylindrical at the time breakup was completed (i.e., at the time when the penetration velocity of the mixture rapidly decreases), the mixture would have had a void fraction of 0.3-1.0, and the velocity of the vapor flowing out of the mixture at the water surface would have been tens of meters per second. This suggests annular vapor flow occurred.

Figure 1. Measured breakup length ranges vs. mass lengths for the CCM tests

In summary, the CCM test results suggest that vapor generated by corium dispersion at the stream leading edge creates a large (compared to the stream diameter) vapor annulus surrounding a contiguous (or at least undispersed) trailing column. However, the central questions to be addressed by this project remain unanswered; namely, what is the determining mechanism for quasi-steady breakup length, and what is the mechanism of corium dispersion at the leading edge? Although breakup along the trailing column was not dominant for these short mass length tests, it is still not known if a quasi-steady breakup length exists within the 40-60 stream diameter coolant depth available in a PWR core melt accident. In addition, mean debris particle diameters varied considerably for comparable stream Weber numbers (possibly due to re-melting of partially quenched particles on the vessel bottom), and so could not be used as a test of the breakup model proposed by Chu and Corradini.³

Experiment Preparations

The major components of the experimental apparatus are two interaction vessels (i.e., the vessels into which melt is injected), a condenser, melt injectors, vapor duct connecting the interaction vessel and condenser, a catch tray to contain coolant spills, and a support frame onto which these components are mounted (see Figure 2). These components are being constructed in the Nuclear Engineering

Figure 2. Arrangement of major components

Department Machine Shop; the estimated completion date is 5/15/90

The experiment apparatus differs somewhat from that shown in the original proposal. Rather than using the same interaction vessel (the vessel into which the molten metal is injected and quenched) to observe both leading edge and trailing column breakup, separate vessels are being constructed. For the former, the horizontal vessel depth will be only two inches (for melt stream diameters of one-half to one inch). It is intended that a quasi-planar leading edge will be formed, for which the melt/coolant interface will be more easily observable from optical motion pictures. X-ray attenuation by the coolant will be about 60% for this depth; it is doubtful that useful x-ray photos could be obtained for greater depths. The vessel vertical depth will be 20 inches, large enough to encompass the field of view of the x-ray camera.

The second interaction vessel (shown in Figure 2) will have a horizontal depth of four inches, approximately the expected diameter of the vapor channel created by the penetrating melt stream. Thus, attenuation of x-rays by the coolant should be minimal in the region of interest near the melt stream. The vertical coolant depth will be about 45 inches, i.e., 60 diameters for a 3/4 inch melt stream. This corresponds roughly to the coolant depth available in a PWR.

In the original proposal, it was suggested that coolant level would be maintained constant by directing overflow

into a separate chamber. However, for long duration melt flows, coolant level should be fairly constant after the initial penetration. Therefore, overflow chambers have been omitted in favor of providing volume in the interaction vessel for level swell.

Liquid nitrogen (LN_2) was originally suggested for the coolant liquid. It is expected that the large diameter vapor channel characteristic of corium/water interactions could be replicated with either LN_2 or certain chlorofluorocarbon (CFC) refrigerants. However, operation at cryogenic temperatures would make vessel instrumentation (for obtaining PVT data) more expensive, and collection and condensation of generated vapor difficult. Although collection of these data is not a primary objective of these experiments, it would make them more useful as benchmarks for fuel/coolant mixing models. Therefore, it is planned to use Freon-11 coolant for the instrumented experiments. Generated vapor will be condensed to obtain heat transfer data and minimize release of CFCs into the environment.

References

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