NUREG/CP-0139

Transactions of the Twenty-Second Water Reactor Safety Information Meeting

To Be Held at
Bethesda Marriott Hotel
Bethesda, Maryland
October 24–26, 1994

Date Published: October 1994

Compiled by: Susan Monteleone, Meeting Coordinator

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Metallic Core-Melt Behavior in Dry-Core BWR Accidents: The Ex-Reactor Experiments

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The XR1-1 and XR1-2 (Ex-Reactor) experiments, investigating metallic core melt relocation in boiling water reactor (BWR) geometry were performed in August and November of 1993. The XR1 tests represented the BWR control blade and channel box structures in the lower part of the BWR core as metallic core materials are beginning to melt and drain downwards. The purpose of this experiment program is to examine the behavior of downward-draining molten metallic core materials in a severe reactor accident in a dry BWR core, and to determine conditions under which the molten materials drain out of the core region or freeze to form blockages in the lower portion of the core.

The XR1-1 and XR1-2 tests both included a BWR-type stainless/B_4C control blade and zircaloy walls representative of the BWR fuel canisters. The XR1-2 test differed from the XR1-1 test in that a 0.5 m test section was used rather than the 1 m test section used in the XR1-1 experiment. As in test XR1-1, the top of the XR1-2 test section was heated to ~1550 K with the bottom of the test section held at ~500 K. This resulted in an axial temperature gradient in the XR1-2 test that was approximately twice that of the XR1-1 test due to the difference in test section lengths.

The tests simulated conditions in an unrecovered BWR core-melt accident after manual vessel depressurization has occurred (dry core conditions) and just as the metallic core components are beginning to melt and drain downwards. The melting of metallic core materials was represented by a controlled pour (dribble) of control blade material (~12 kg of stainless steel and B_4C) into the preheated lower channel box-control blade test section. The quantity and rate of the melt pour was scaled to the test section cross sectional area and the height of the control blade above the lower-most meter of the core. The pour was sustained over a prototypic period of about 10 minutes, and the test was performed in an argon-inerted environment.

The test sections, which included structures representative of the lower core plate and the fuel assembly nosepieces, were preheated so that the lower-most part was at ~500 K and the upper-most part was at the melting temperature of the control blade structure (~1550 K). Thermocouple instrumentation was used to measure the axial thermal gradient prior to and after the pour of molten control blade material into the test. These data provide information on initial conditions and on the lateral distribution of molten materials as they enter the test section geometry. In addition, a real-time x-ray examination of the central portion of the test section recorded an image of the control blade material flowing into the channel and the accumulation of melt into blockages, and an optical view of the draining materials was recorded from a bottom view of the test bundle.

Preliminary examinations of the XR1-2 test bundle show significant differences in the degree of downward melt penetration in the test channel and notable differences in the lateral spreading behavior of the melt. In XR1-2, apparently because of the shorter channel length and the resulting steeper axial temperature gradient, more molten material penetrated to the bottom of the channel than in XR1-1. In XR1-1, on the order of 20% of the melt drained to the lower core plate region, forming a blockage on the core plate. The remainder of the melt in XR1-1 formed blockages higher in the test channel. In XR1-2, however, there was less accumulation on the core plate, and more drainage into the lowermost bladed section of the channel. In a real BWR, this melt drainage would bypass the core plate and drain into the control blade guide tube region.

A follow-on set of experiments designated as the XR2 tests, will include fuel rods in the test bundles, along with more detailed representations of the lower core plate, fuel support pieces and control blade velocity limiter structures. Furthermore, the XR2 tests will include a second Zr-melt pour following the control blade melt pour. These additions are included in the XR2 experiments to fully represent the metallic melt relocation events considered typical for the BWR dry-core accident scenario, and will provide information needed to determine BWR core blockage or drainage behavior. A major effort in preparation for the XR2 experiments has been the development of a melt delivery system capable of melting both control blade materials and zircaloy metal, and delivering the melt at a controlled rate at the desired locations in the experiment. Details on the melter development effort and on the planned XR2 experiments will be provided.