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QUASI-STEADY STATE BOILING DOWNSTREAM OF A CENTRAL BLOCKAGE IN A 19-ROD SIMULATED LMFBR SUBASSEMBLY (FFM BUNDLE 3B)*

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SUMMARY

Results of sodium boiling tests in a centrally blocked 19-rod simulated LMFBR subassembly have been analyzed. The tests were part of the experimental series conducted with bundle 3B in the Fuel Failure Mockup (FFM) at ORNL.

The FFM is a recirculating sodium test loop in which 19-rod bundles, simulating LMFBR subassembly segments, have been subjected to thermal-hydraulic testing during normal and abnormal LMFBR conditions. Bundle 3B consists of 19 electrically-heated rods in a scalloped duct. The rods have a diameter of 5.84 mm (0.230 in.) and are spaced by 1.42 mm (0.056 in.)-diameter helical wire wraps on a 305 mm (12.0 in.) pitch. The circular scalloped duct encloses the 19 rods and partially simulates a hydrodynamic section of an infinite rod array by having unheated rod segments (with helical wire wrap) attached to the duct wall. Sodium, flowing vertically upward through the bundle, first encounters a 406 mm (16.0 in.)-long unheated rod section, then a 533 mm (21.0 in.)-long uniformly heated section, and finally a 76 mm (3.0 in.)-long unheated rod section before exiting vertically

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from the rod bundle. The 6.4 mm (0.25 in.)-thick stainless steel blockage plate is located 381 mm (15.0 in.) downstream from the start of the 533 mm (21.0 in.)-long heated section and blocks the 6 central flow channels (12.5% of the flow area). A complete description of the bundle and the test facility as well as single phase steady state results are given in Ref. 1. Previous tests on a different 19-rod bundle in the same test facility included controlled flow coastdown tests to boiling in an unblocked bundle.

The purpose of the tests herein reported was to investigate if and how local boiling downstream of a partial blockage expands into bulk boiling (encompassing the entire rod bundle cross section) during periods of constant flow and heater power. The tests were not intended to investigate upstream propagation of the boiling zone.

Sodium boiling downstream of the blockage was produced at rod surface temperatures of approximately 980°C (1800°F) as follows. Initially, steady-state non-boiling conditions were established in the test section (containing the rod bundle); this consisted of setting flow, heater power, and test section inlet temperature at 1.4 ℓ/s (22 gpm), approximately 8 kW/rod, and approximately 540°C (1000°F), respectively. The flow was gradually reduced by manually closing the test section inlet valve until boiling was detected. The onset of boiling was determined by monitoring (1) all bundle thermocouple temperatures on a continuous visual display, (2) acoustic energy detector signals on oscilloscopes, and (3) the amplified audio signal from an electromagnetic microphone attached to the rod bundle housing. The results of acoustic boiling detection during these tests are given in Ref. 3. Once boiling was detected, the test section flow was held constant for a specified time before re-establishing single-phase flow by reopening the test section inlet valve.

Two test runs, each containing several continuous boiling periods, were chosen for analysis; the longest boiling period (at constant flow and heater power) in each run was investigated in detail. The axial and radial extent of the boiling zone downstream of the blockage was determined from the responses of thermocouples located both on the inside surface of the heater cladding and in the wire wrap spacers. The thermocouples indicating sodium boiling in their vicinity were defined as (1) those whose temperature remains essentially constant while flow and/or heater power are varied either in steps or continuously, or (2) those whose temperature stabilizes near expected saturation temperatures prior to the time of temperature stabilization of the known "non-boiling" thermocouples. The first continuous boiling period selected for analysis lasted 9 seconds at quasi-steady state condition of test section flow of 0.51 ℓ/s (8.1 gpm), heater power of 8.8 kW/rod for 9 rods, and test section inlet temperature of 556°C (1034°F). The second quasi-steady state boiling period of 27 seconds in duration was preceeded by approximately 390 seconds of boiling (unsteady test conditions); however, this entire test run was conducted with only 18 of the 19 heaters powered since a heating element of one heater had failed in a previous test run. During the 27 second period, the test conditions were 0.35 ℓ/s (5.5 gpm), 7.9 kW/rod for 18 rods, and 486°C (907°F) for the inlet temperature.

The analysis showed that stable boiling (i.e., no propagation of the local boiling zone) occurred downstream of the 6-channel central blockage during both periods (9 sec and 27 sec) of constant flow and heater power. During these two periods, boiling was confined to the 6 blocked channels from 10 mm (0.4 in.) to 152 mm (6.0 in.) (end of heated zone) downstream of the blockage. Furthermore, several thermocouples in the 76 mm (3.0 in.)-long unheated section downstream of the boiling zone were found to show average sodium temperatures to be close to or exceed the estimated single-phase sodium saturation temperature during both periods analyzed, indicating that sodium flashing was possible in this region of the bundle. The thermocouple responses also showed that average sodium temperatures increased in the unblocked channels during the 9 sec period; the increase ranged from approximately 3°C (6°F) at 51 mm (2.0 in.) to 22°C (40° F) at 240 mm (9.2 in.) (position of bundle exit thermocouple rake) downstream of the blockage. However, during the more intense 27-sec boiling period, no average temperature increases in the unblocked channels were found.

It is concluded from this analysis that FFM bundle 3B, having 12.5% of its central flow area blocked in the heated section, did <u>not</u> experience a sudden "explosive" transition from local to bulk boiling during periods of constant flow and heater power. A gradual transition, however, may occur based on the results that average sodium temperatures in the unblocked channels during the 9 sec boiling period were increasing. On the other hand, the test results from the 27-sec boiling period, showing no average sodium temperature increases in the unblocked flow channels during this period, indicate that such a transition from local to bulk boiling may not occur at all in bundle 3B during certain quasi-steady state test conditions.

Two non-prototypicalities in the bundle 3B design do not permit straight-forward extrapolation of these conclusions to describe local boiling behavior in a full-sized, blocked LMFBR subassembly. In particular, the 76 mm (3.0 in.)-long unheated rod length downstream of the heated section is at least an order of magnitude shorter than that of a full-length LMFBR rod. Secondly, an attemperator tube, installed immediately downstream of the bundle exit to protect test section exit piping from excessive temperatures, injects sodium at test section inlet temperature into the hot sodium exiting from the bundle; this attemperator condenses all vapor bubbles downstream of the rod bundle. Because of these non-prototypicalities, the transition to bulk boiling, (i.e. boiling encompassing the entire rod bundle cross section) would occur sooner in bundle 3B than in a full size assembly since both non-prototypicalities tend to produce a lower sodium saturation temperature in the heated rod bundle cross section downstream of the bundle 3B blockage. The reasoning is that since both non-prototypicalities decrease the pressure drop downstream of bundle 3B and since the bundle 3B pump suction pressure (corresponding to the constant cover gas pressure in an LMFBR) is constant, bundle 3B produces a lower static pressure (lower saturation temperature) downstream of the blockage than would be found in a full-size LMFBR subassembly similarly blocked.

As mentioned previously, these tests were not intended to investigate upstream propagation of the boiling zone. However, some comments related to upstream void propagation can be made. The shorter length of bundle 3B downstream of the blockage compared with the full-length LMFBR rod bundle as well as the condensation of the vapor downstream of the bundle 3B resulted in a lower pressure drop from the upstream face of the void zone to the downstream end of the bundle; this decreased flow resistance tended to preclude upstream propagation of the vapor void. In addition, the resistance due to the partially-closed inlet flow valve upstream of the rod assembly also tended to prevent upstream void propagation. Future experiments will be performed in the revised FFM facility to investigate these effects specifically and will be reported at a later date.

References

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2. J. L. Wantland et al., "Flow-Controlled Coastdown Tests to Boiling in a Sodium-Cooled 19-Rod Bundle," ANS Trans. 22, pp. 300-301, (1975).

3. W. H. Leavell and W. H. Sides, "Effects of Entrained Gas on the Acoustic Detection of Sodium Boiling in a Simulated LMFBR Bundle," ANS Trans., 22, pp. 399-400, (1975).