CONF-800403--4

IN-PILE POST-DNB BEHAVIOR OF A NINE-ROD PWR-TYPE FUEL BUNDLE*

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ABSTRACT

The results of an in-pile power-cooling-mismatch (PCM) test designed to investigate the behavior of a nine-rod, PWR-type fuel bundle under intermittent and sustained periods of high temperature film boiling operation are presented. Primary emphasis is placed on the DNB and post-DNB events including rod-to-rod interactions, return to nucleate boiling (RNB), and fuel rod failure. A comparison of the DNB behavior of the individual bundle rods with single-rod data obtained from previous PCM tests is also made.

Results indicate that corresponding power-coolant variations induce film boiling within the nine-rod test bundle in a random nature. Direct rod-to-rod film boiling and fuel rod failure propagation did not occur. The DNB behavior of a centrally located bundle rod appeared to be independent of the surrounding test fuel rods.

* Submitted to: ANS Topical Meeting on Thermal Reactor Safety, Knoxville, Tenn., April 8-11, 1980.

MASTER

SUMMARY OF IN-PILE POST-DNB BEHAVIOR OF A NINE-ROD PWR-TYPE FUEL BUNDLE

The result of many hypothesized nuclear reactor accidents is an imbalance between the heat generation rate of the nuclear core and heat removal capacity of the coolant. Two extreme cases have commonly been designated as the loss-of-coolant accident (LOCA) in which all or part of the coolant inventory is rapidly lost, and the reactivity initiated accident (RIA) in which a sudden power increase is initiated within the nuclear core. Between these two extremes lies a wide range of off-normal power-cooling conditions commonly referred to as power-cooling-mismatch (PCM) accidents. As demonstrated by the recent Three Mile Island incident, there are many credible single and coincident events that may initiate PCM accidents.

A PCM test series is being conducted by the Thermal Fuels Behavior Program of EG&G Idaho, Inc., as part of the U. S. Nuclear Regulatory Commission's Fuel Behavior Program.[1] Both single-rod and bundle tests are being performed in the Idaho National Engineering Laboratory (INEL) Power Burst Facility (PBF) and are designed to characterize the behavior of unirradiated PWR-type fuel rods during PCM conditions.[2]

The results of the most recent PCM test (Test PCM-5)[3], an in-pile nine-rod bundle test, are presented. Primary emphasis is placed on DNB, post-DNB, RNB, and fuel rod failure behavior. The primary objectives of Test PCM-5 were:

(1) to establish baseline data on the operation and response of bundle geometries under imposed PCM conditions,

(2) to assess the potential for rod-to-rod interactions during (or resulting from) periods of high temperature film boiling operation, and

(3) to assess the differences, if any, in the thermophysical behavior of an isolated (separately shrouded) rod versus a rod within a bundle geometry.

EXPERIMENT AND RESULTS

The nine PWR-type fuel rods were arranged in a square 3 x 3 lattice with a pitch indicative of a commercial 15 x 15 PWR fuel bundle. In this configuration, the central fuel rod environment is considered representive of a power reactor rod during a postulated PCM event. The zircaloy clad rods had an active fuel length of 0.914 m and provided a bundle average peak power of approximately 57 kW/m. To obtain a relatively flat rod-to-rod power profile, the nominal fuel enrichments were 93, 35 and 20% for the center, side, and corner rods, respectively. The coolant conditions were 592 K inlet temperature, 15.5 MPa system pressure, and 1050-1116 kg/s$\cdot$m^2 mass flux through the test bundle. Figure 1 is a schematic representation of the Test PCM-5 test train assembly showing the relative positions of the test fuel bundle and related instrumentation.

PCM conditions were initiated by slowly increasing the PBF driver core power in a stepwise manner while maintaining a constant pressure and coolant flow rate. During the power increase, a corner fuel rod in the test bundle commenced film boiling, followed by random film boiling on other rods. The test bundle was allowed to continue high-temperature operation for about 11 minutes, during which seven of the nine fuel rods experienced film boiling for various times. Figure 2 summarizes the film boiling history for the test.

During the film boiling period, a corner and a non-adjacent side fuel rod failed. The corner rod failed while operating at high temperature as a result of the severe cladding oxidation and embrittlement incurred during about 8.5 minutes of sustained film boiling. The side rod failed as a result of rewetting-induced thermal shock on an embrittled cladding following a film boiling period of approximately 300 seconds.

Side Rod 205-6 (Figure 2) commenced film boiling concurrently with the quench and rewet of adjacent Rod 205-5 during a period of PBF power decrease. A hydraulically coupled, rod-to-rod interaction was suspected and qualitatively assessed.

The power and coolant conditions at the onset of film boiling for Test PCM-5 are compared with previous PCM tests in Figure 3. As shown, the conditions leading to film boiling on the central fuel rod in Test PCM-5 compare favorably with those determined from previous PCM tests where the fuel rods were contained in individual coolant flow shrouds. Individual coolant flow shrouds eliminate the potential for direct rod-to-rod interactions.

CONCLUSIONS AND OBSERVATIONS

1. The order in which the test rods surpassed DNB and rewet appeared to be random and unpredictable on an overall bundle basis.

2. The DNB and rewet behavior of the individual rods could be directly related to corresponding power-coolant variations.

3. A single rod-to-rod interaction was suspected. Specifically, the quenching and rewet of one rod appears to have abetted the onset of DNB on an adjacent rod. Such an interaction was interpreted as a result of the inherent rod-to-rod hydraulic coupling.

4. Several modes of heat transfer were detectable during the return to nucleate boiling process (quench and rewet). Such an observation is consistent with recent post-DNB heat

transfer theories proposed by other investigators.[4] In addition, it is shown that rewetting occurs at cladding temperatures that are readily predictable from basic correlations previously developed.[5]

5. The central fuel rod of the test bundle behaved independently of the peripheral rods and similar to the behavior expected from a fuel rod within its own coolant flow shroud. The previously established DNB data base for individually shrouded fuel rods is considered applicable for assessing the DNB response of an interior bundle rod.

6. Rod-to-rod failure propagation did not occur.

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LIST OF FIGURES

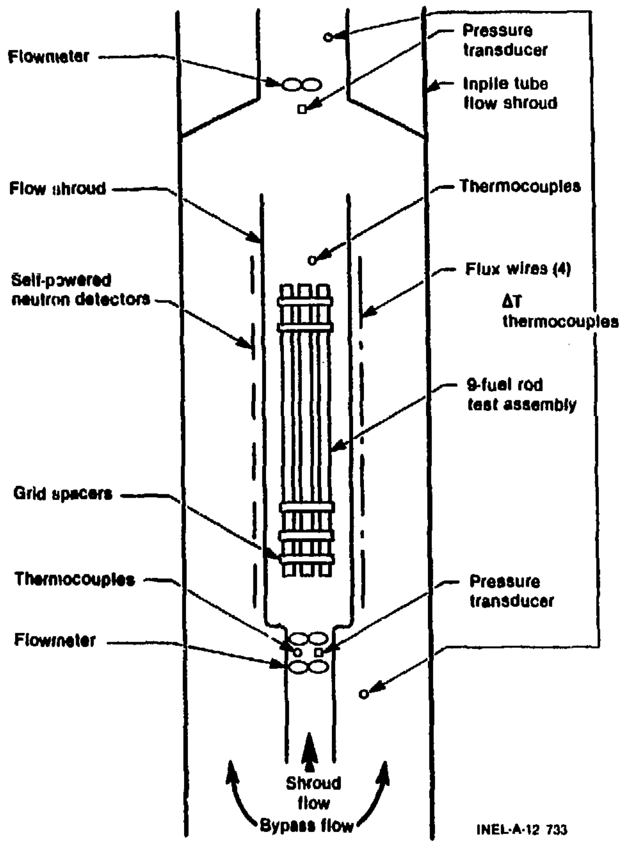

Fig. 1

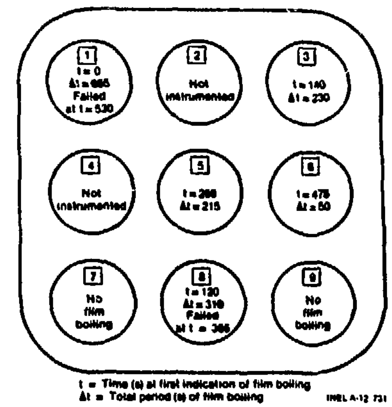

Fig. 2

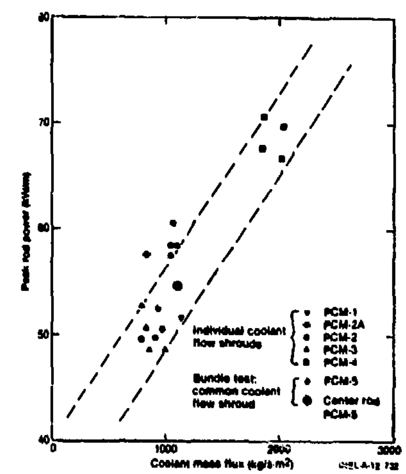

Fig. 3