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Film Boiling Behavior

in a

Nine Rod Cluster

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Film boiling in a cluster geometry was investigated during a recent test conducted in the Power Burst Facility. Cluster information is necessary to assess the applicability of single rod experimental data used in developing light water reactor fuel rod behavior models. The nine-rod test, part of the Power-Cooling-Mismatch (PCM) Test Series, was designed to investigate the film boiling behavior of a central fuel rod surrounded by fuel rods that were also in the film boiling heat transfer regime. Information obtained provides insight into film boiling fuel rod behavior, in an environment believed to be representative of a power reactor rod during a period of over-power or low-flow operation.

The nine test rods were arranged in a 3 x 3 lattice with spacing typical of a PWR cluster. Except for fuel enrichment and overall length, the rods were of PWR design. The relative positions and associated test rod instrumentation are shown in Figure 1.

DNB was attained at a peak test rod power of about 48 kW/m. Coolant conditions were 590 K inlet temperature, 15.3 MPa system pressure, and a mass flux of 1091 kg/s.m^2 through the cluster.

The test rod of primary importance, the center rod (Rod 205-5), entered film boiling about 4 minutes after the corner rod (Rod 205-1) and was subjected to stable film boiling for approximately 4 minutes. The center rod was surrounded by as many as seven rods also in film boiling. Cladding temperatures at the 0.68 and 0.78-m elevations (from the bottom of the fuel stack) on the center rod indicated peak stabilized film boiling temperatures of 1120 K. Experience with external cladding temperature measurements has shown that the devices generally indicate values on the order of 200 K lower than the actual surface temperature due to cooling fin effects. The cladding temperature measurement at the 0.68-m elevation (135° azimuthal orientation) and the corresponding fuel centerline temperature measurement for Rod 205-5 are shown in Figure 2 along with a plot of the relative change in cladding length. Time zero on the figure corresponds to initiation of DNB on the corner rod. The fuel thermocouple recorded a temperature of about 2900 K as film boiling was established, and subsequently became increasingly erratic. The transducer probably failed about 5 minutes into the transient. The time in film boiling for the center rod is also characterized by the rapid increase and subsequent decrease in cladding elongation shown on Figure 2.

The first indication of DNB was on a corner rod (Rod 205-1). The cladding temperature and the cladding elongation measurements on Rod 205-1 indicated the transition to the film boiling heat transfer mode. The corner rod, which was held in DNB for approximately 11 minutes, failed about 5.5 minutes after occurrence of the degraded heat transfer regime.

Four of the six other instrumented test rods experienced DNB at times subsequent to the occurrence of CHF on the corner rod. The rods entered DNB at various times and were subjected to stable film boiling for times apparently unrelated to their relative position within the cluster. Rods 205-7 and 205-9 did not show stabilized film boiling operation during the transient.

Film boiling behavior and fuel rod failure information was obtained from the cluster testing. Postirradiation examination of the cluster is intended to provide fuel and cladding temperature estimates for comparison with measured values, and quantification of rod-to-rod interaction in the bundle. Some rods within the cluster failed at various times during the transient, while others did not reach DNB. Position dependence of film boiling in the cluster was not apparent. Results obtained are intended to extend the present data base of single rod PCM events to include film boiling in an environment more typical of an operating light water reactor.

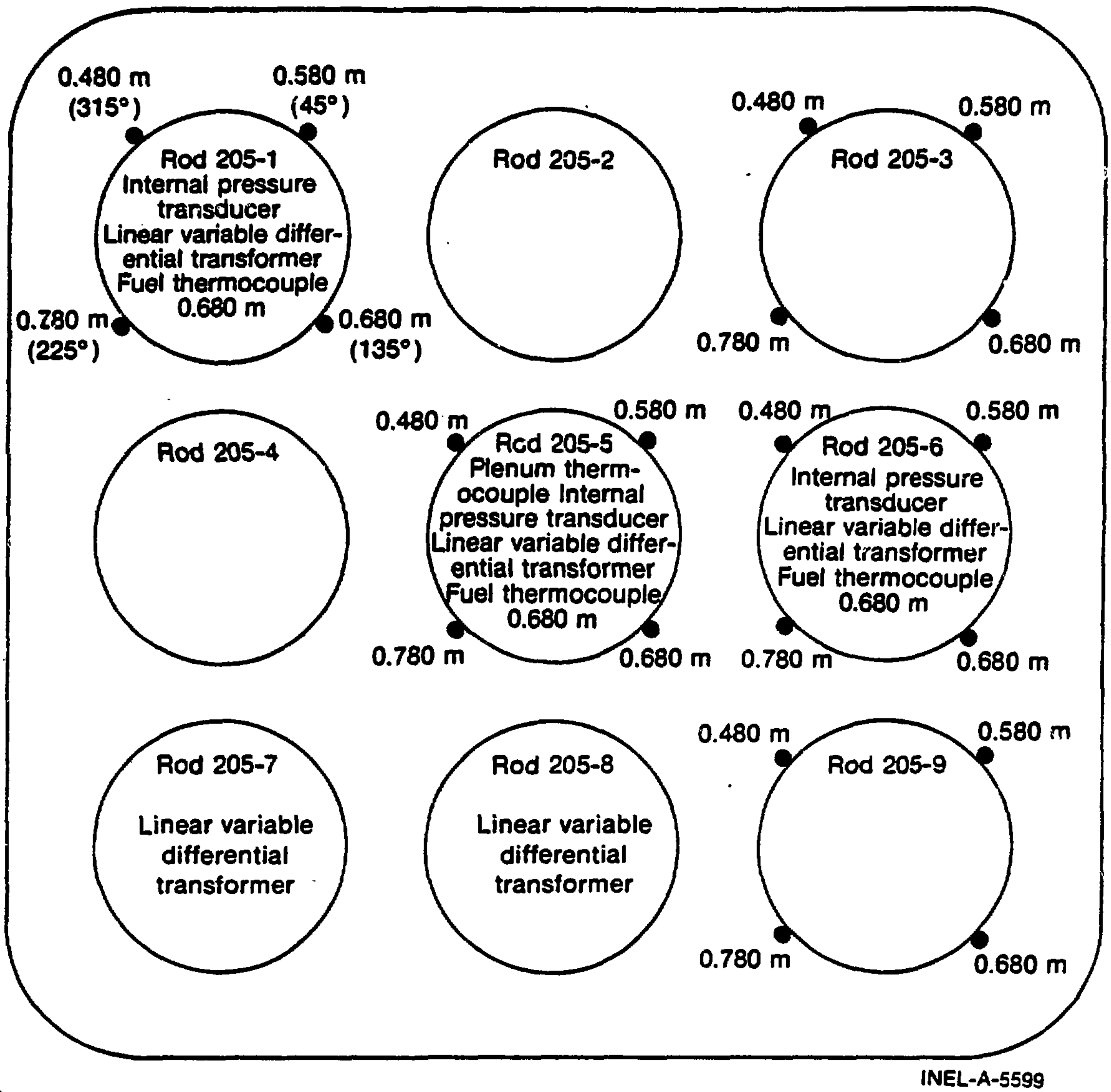

Figure 1 Relative positions of the nine fuel rods within the zircaloy-4 shroud and associated instrumentation for the cluster. (Elevations shown are relative to the bottom of the fuel stack.)

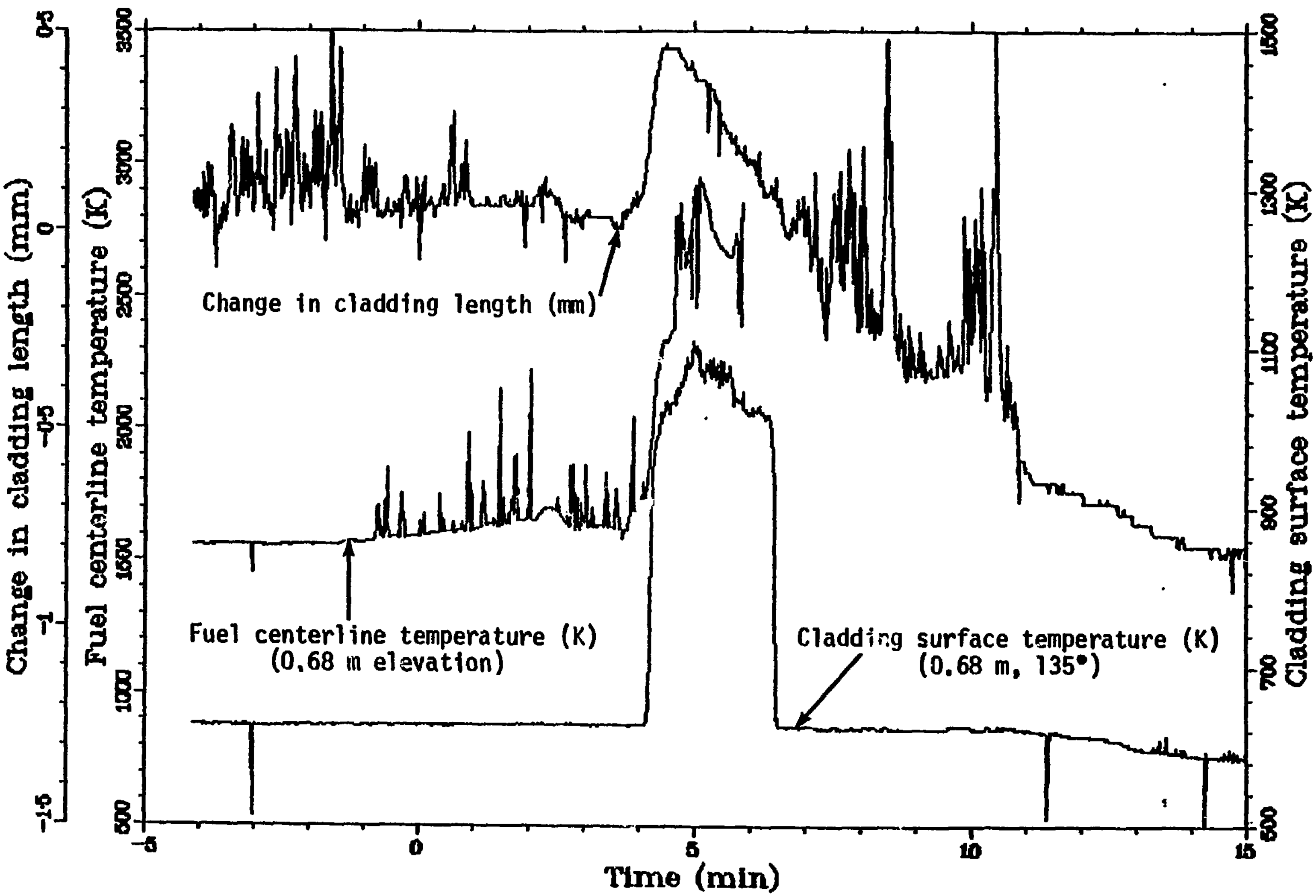

Figure 2 Comparison of fuel centerline and cladding temperatures at 0.68 m elevation and cladding elongation for the center rod (Rod 5).