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CLADDING BREACHES IN MIXED OXIDE FUEL PINS

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Breaches of the cladding have occurred on eleven fuel pins from the HEDL mixed oxide (75 w/o UO_2 - 25 w/o PuO_2) irradiation tests in EBR-II. These pins were in 19 or 37 pin subassemblies being irradiated as part of the HEDL Steady State and Run-to-Cladding Breach activities for the FFTF Reference Fuel Program. The linear powers and temperatures[1,2] of these tests were within the FFTF Steady State design envelopes.[3] Cladding materials included solution-annealed type 304 and 20% or 30% cold-worked type 316 stainless steel. All pins were fabricated to the reference specifications current at the time for the FFTF driver fuel, except for those with the 30% cold-worked cladding.

The objectives of the studies and examinations of the breached pins are to: 1) establish the burnup capability for reference fuel, 2) identify cladding breach mechanisms, 3) determine the effects of cladding breach on neighboring fuel pins, 4) evaluate the effects of short term postbreach residence in reactor on fuel-coolant interaction, and 5) provide data for failure criteria.

Examination and characterization have been completed on nine of the eleven breached pins, with two pins currently being examined. In addition, 46 neighbors to the breached pins have been evaluated for possible effects as a consequence of the breach. Figure 1 is an arrangement of the breached pins by burnup range, cladding type and condition, and cause of breach. Descriptions of the breaches and postulated causes were presented in previous reports[3,4] for four pins, PNL 5-1, P-12A-63K, HEDL N/E-N122 and PNL 10-14. Briefly, the first three showed evidence of overheating in a very localized volume of the cladding with the breach formed by the interlinking of creep caused pores. The breach in PNL 10-14 was found in an arc of cladding reduced to approximately one third [0.13 mm (0.005 inch)] of its original thickness by wear. The problem of cladding wear from adjacent fuel pins in nonprototypically loose subassemblies is discussed in Reference 2. The breach was a pinhole formed by mechanical overloading of the drastically thinned cladding.

Subsequent examinations of the five additional breached pins have identified the cause of breach on four of them. The breach in PNL-11-39 was located in a wear mark with a cladding thickness approximately one half [0.18 mm (0.007 inch)] that of the original 0.38 mm (0.015 inch). High internal gas pressure combined with stresses arising from wear is believed to have caused the thinned cladding to breach. Detailed examination of PNL 5-17, P-12A-11B and P-23B-1A showed evidence of high cladding temperature in the immediate vicinity of the breach that exceeded the calculated nominal temperature by several hundred degrees. Each breach was characterized by porosity associated with grain boundary precipitates of second phases expected to appear at the higher than nominal temperatures. The breaches themselves are postulated to be a link up of these creep pores. A model describing the failure mechanism on these pins whose cause of breach is classified as localized high temperature, is presented in a companion paper of this session.(5)

Metallographic examinations failed to show a through-the-cladding breach on pin HEDL N/E-054 although postirradiation internal helium pressurization definitely located the position of a leak in the pin cladding. Although no cause of failure is postulated, evidence from the examination of this pin and others in the same subassembly suggest that a high level of nitrogen impurity in the fuel and the unusually long residence time in the EBR-II reactor basket, had an adverse affect on the mechanical properties of the cladding.

In the evaluation of 46 pins that were neighbors to the breached pins there was only one instance where a neighboring pin showed any evidence of having been directly affected by the cladding breach. This was a stain on the wire wrap of the pin directly adjacent to the breach on PNL 11-39.

Sodium ingress through the breach was confirmed in PNL 11-39 and P-12A-11B. The release of fission gas from both fuel pins was accompanied by the detection of delayed neutrons, suggesting rather large initial cladding breaches. Partial reactor startups were required, in both cases, to positively identify the breach-containing subassembly. The large initial breach size combined with the partial rises to power are believed to have been the cause of sodium entry. There is evidence that extension of the cladding cracks may have resulted from fuel-sodium chemical interaction.

In conclusion the HEDL breached fuel pin experience has not yet included what is considered to be an endurance failure, that is cladding with multiple sites of incipient failure. Two failure mechanisms suffice to explain the formation of eight of the breaches: mechanical instability of the wear-thinned cladding and creep failure of cladding altered by localized high temperature. All the cladding breaches are located above the axial midplane of the fuel. They have all been benign, that is no significant effect produced by the breach has been found on neighboring pins and there was no pin-to-pin failure propagation. Only two pins had sodium ingress; from which fuel-sodium chemical interaction may have caused some extension of the breach. Because the breaches all have been dependent upon very localized cladding condition such as high temperature or wear, it has not been possible to formulate a generalized failure criteria. Considerably more information will be forthcoming from the additional subassemblies in the HEDL Run-to-Cladding Breach activity.

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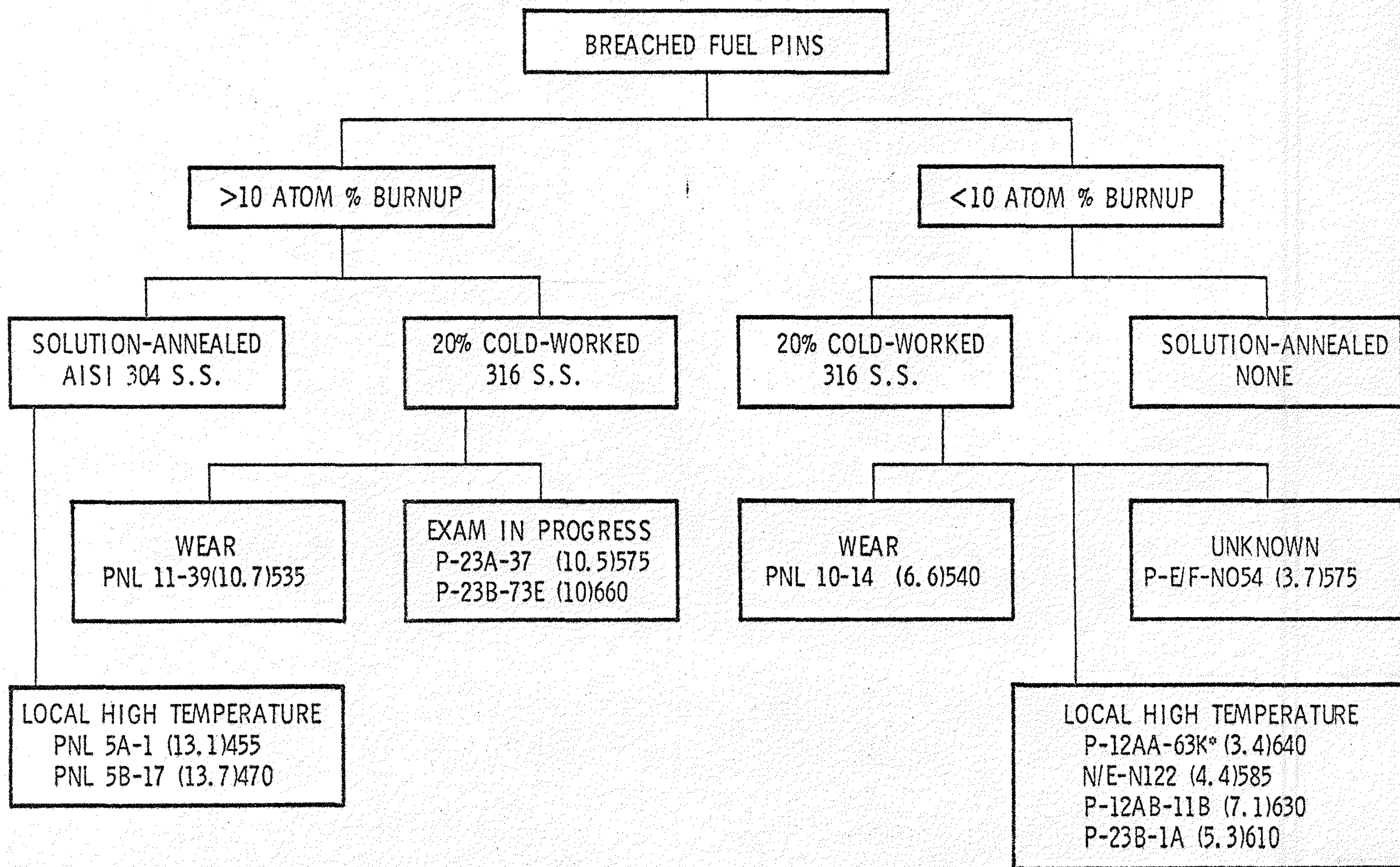

*30% COLD WORKED STAINLESS STEEL

KEY: (BURNUP, ATOM %) CLADDING MAXIMUM MIDWALL TEMPERATURE, °C

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