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THE POTENTIAL FOR CLADDING THERMAL FAILURE IN LWRS DURING HIGH TEMPERATURE TRANSIENTS

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The primary safety consideration in nuclear reactor design is to ensure that no conceivable accident, whether initiated by a failure of the reactor system or by incorrect operation, will lead to a dangerous release of radiation to the environment. A number of hypothetical accidents must be considered in the design and licensing of light water reactors (LWRs). The extreme examples have been traditionally known as a loss-of-coolant accident (LOCA), where a part or all the coolant is lost from the active core, and a reactivity initiated accident (RIA), in which there is a rapid, inadvertent insertion of reactivity due to control rod ejection from the core. Between these two extremes, various off-normal power or cooling conditions may occur, generally termed as power-cooling-mismatch (PCM) accidents because of the coolant failure to successfully remove the heat generated within the core.

The temperature increase in the fuel and the cladding during a PCM accident produces film boiling at the cladding surface which may induce zircaloy cladding failure, due to embrittlement[1-3], and fuel melting at the centerline of the fuel pellets. Molten fuel may extrude through radial cracks in the fuel and relocate in the fuel-cladding gap. Contact of extruded molten fuel with the cladding, which is at high temperature during film boiling, may induce cladding thermal failure due to melting[4]. In the present work, an assessment of central fuel melting and molten fuel extrusion into the fuel-cladding gap during a PCM accident is presented. The potential for thermal failure of the zircaloy cladding upon being contacted by molten fuel during such an accident is also analyzed and compared with the applicable experimental evidence.

Irradiation effects (IE) and power-cooling-mismatch in-pile tests[5-7] have been performed in the Power Burst Facility (PBF) at the Idaho National Engineering Laboratory as part of the Thermal Fuels Behavior Program conducted by EG&G Idaho, Inc., for the Nuclear Regulatory Commission. These tests were performed to provide data on the behavior of irradiated and unirradiated pressurized water reactor fuel rods under various PCM conditions. In those tests, extensive central fuel melting of up to 80% of the pellet radius and extrusion of molten fuel into the fuel-cladding gap through radial cracks in the fuel pellets were observed.

The extrusion of molten fuel from the center of a fuel rod depends on the pressure difference between the central molten zone and the fuel-cladding gap, the length and width of existing radial cracks in the fuel pellet, and the temperature in both the melted and the unmelted portion of the fuel. Examples of molten fuel extrusion observed in the IE tests[5-7] are shown in Figure 1. The extrusion of molten fuel observed in one of those experiments[6] (see Figure 1a) was caused by a small pressure gradient (~0.008 MPa), in which the extruded fuel failed to reach the fuel-cladding gap because of an early blockage at the crack entrance caused by successive solidification of molten fuel. This pressure gradient could have been induced by the capillary forces (because of the small width of radial cracks in the unmelted portion of the fuel pellet). In other cases[5-7] where appreciable extrusion of molten fuel into the fuel-cladding gap was observed (see Figure 1b), the pressure difference between the central melting zone and the fuel gap is calculated to be much higher.

Melting of the zircaloy cladding upon being contacted by the extruded molten UO_2 depends on the initial rod temperatures, the thermophysical properties in both the initially molten UO_2 and the initially solid zircaloy cladding, and the metallurgical composition at the inner surface of the cladding (either α-zircaloy, or ZrO_2). The conditions for molten fuel freezing and simultaneous zircaloy cladding melting are predicted using the analytical solution introduced in reference[8]. As demonstrated in Figure 2, thermal failure of oxygen-stabilized α-zircaloy cladding upon being contacted by molten fuel at the fusion temperature would be expected if the initial cladding temperature is $\geq$1660 K. However, the existance of a ZrO_2 layer at the inner surface of the cladding would delay cladding melting up to an initial cladding temperature of $\approx$2640 K. Zircaloy cladding melting was not observed in the IE-tests[5-7] where the peak operating powers were approximately $\approx$65 kW/m. This was due to the fact that the molten fuel and the cladding temperatures during film boiling were below the level predicted for onset of fuel freezing and simultaneous melting at the inside surface of the cladding upon contact.

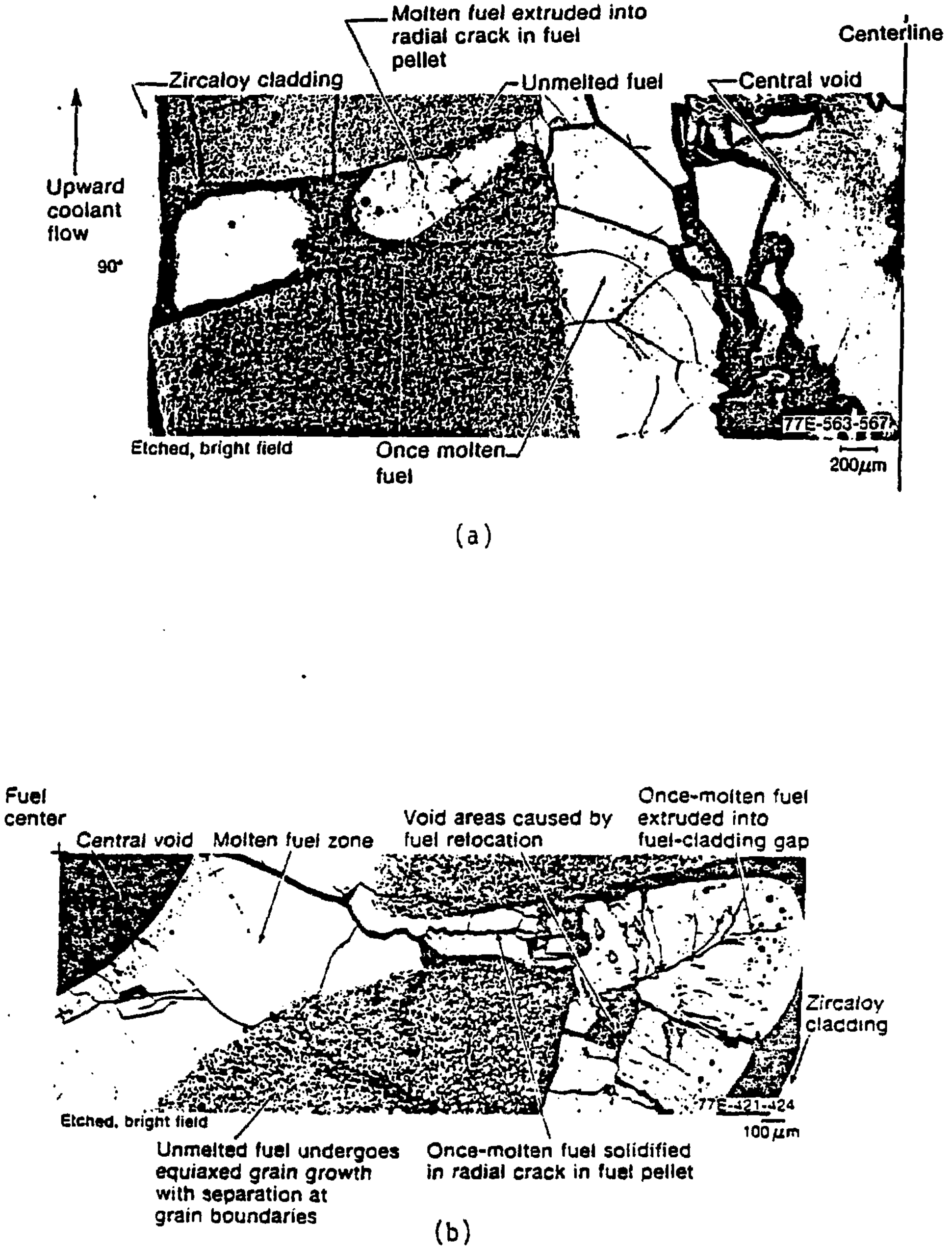

Fig. 1 Molten fuel radial extrusion from the central melting zone of fuel rods operating under film boiling conditions. An axial cross section is shown in (a) and a transverse cross section is shown in (b).

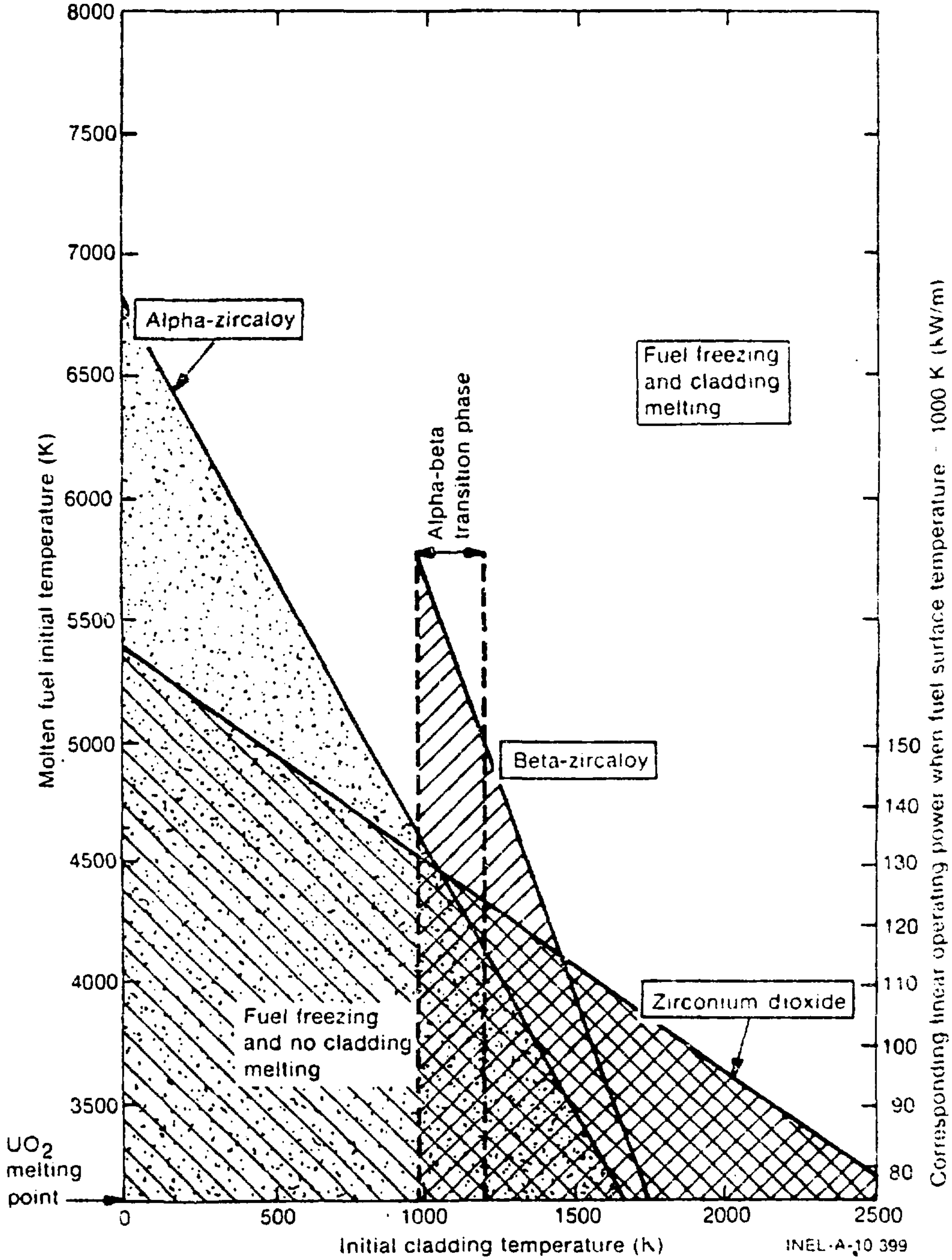

Fig. 2 Initial temperatures map for initially molten-UO_2 contacting an initially solid zircaloy-cladding.

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