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CALCULATED GCFR FUEL-ROD BEHAVIOR FOR STEADY-STATE AND TRANSIENT OPERATION

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The Idaho National Engineering Laboratory (INEL) was contracted to review the Preliminary Safety Information Document (PSID) Amendment 10 for Gas-Cooled Fast Reactors (GCFR). As part of this effort the light water reactor codes, FRAPCON-1[1] and FRAP-T5[2] were converted to model GCFR fuel rod behavior. The conversion and application of these codes for GCFR analyses is the subject of this paper.

The LWR version of FRAPCON-1 computes the coupled thermo-mechanical behavior of the fuel and cladding during steady-state long-term irradiation. The coupled effects of fuel and cladding deformation, temperature, and internal gas pressure are considered. FRAP-T5 computes the coupled thermo-mechanical behavior of the fuel and cladding during hypothesized transient accidents such as a loss-of-coolant event or a power-cooling mismatch. The same three models of deformation, temperature, and pressure are used by FRAP-T5 with appropriate modifications to account for transient behavior. To establish initial conditions in FRAP-T5 prior to a transient, a software linking option has been provided between FRAP-T5 and FRAPCON-1. The material properties for the fuel, cladding, and gas are obtained from the modular subroutines program called MATPRO.[3]

The modifications to FRAPCON-1 and FRAP-T5 to make them applicable for analyzing GCFR rods include gas reactor design changes and fuel pellet and cladding behavior while exposed in a fast reactor environment. The design modifications were the replacement of zircaloy with SS 316, 20% CW material properties, replacement of water with helium cooling, replacement of a smooth with a roughened cladding exterior, and modifying the fuel rod internal pressure to equalize with the system pressure. The fuel pellet behavior included the fast-fuel effects of central void formation, columnar and equiaxed grain growth, and fuel cracking and relocation. The fuel behavior model also includes swelling and densification. The cladding behavior model includes primary and secondary creep and the GCFR effect of fast neutron swelling of SS 316, 20% CW.

The GCFR versions of FRAPCON-1 and FRAP-T5 were used to calculate the fuel rod behavior for the coastdown to natural circulation transient. First, FRAPCON-1 computed the changes in fuel rod geometry and fill gas composition resulting from prior steady-state power generation. Then, these initial conditions were passed to FRAP-T5 which computed the transient behavior of the fuel rod.

The steady-state fuel rod behavior was calculated by FRAPCON-1 to end-of-life for a typical GCFR fuel rod. The results of the FRAPCON-1 calculations show that during prior steady-state irradiation, neutron swelling of SS 316, 20% CW cladding is the dominant fuel rod behavior. As a result, no fuel-cladding mechanical interaction is predicted to occur in the model. The gap thickness between the fuel pellet surface and cladding inside radius are shown in Figure 1 for beginning-, middle-, and end-of-life (BOL, MOL, EOL).

The FRAP-T5 transient analysis assumed that a circulator trip would occur when the reactor had been operating for 750 full power days. The scram signal to the control rods was delayed 2.6 seconds after the circulator trip. The helium coolant then experienced coastdown to natural circulation velocities. Due to the uncertainty of the cracked fuel radius, a modification was made to the FRAP-T5 calculation. The modification closed the fuel-cladding gap at the initiation of the transient. Closing the gap reduces the uncertainty in the cracked fuel radius and allows a conservative prediction of radial and axial cladding stresses.

The results of the FRAP-T5 calculation predicts no fuel-cladding mechanical interaction. The fuel-cladding gap remains closed only during the first time-step of the transient. During this time the gap conduction is a maximum allowing the fuel pellet's stored energy to pass into the cladding very rapidly. This rapid energy transfer lowers the fuel pellet temperature and causes it to thermally contract away from the cladding. The gap never closes for the remainder of the transient because the fuel contraction is larger than the cladding contraction. These results are illustrated in Figure 2 which show the rod power, inlet mass flux, fuel-cladding gap thickness, and cladding temperature.

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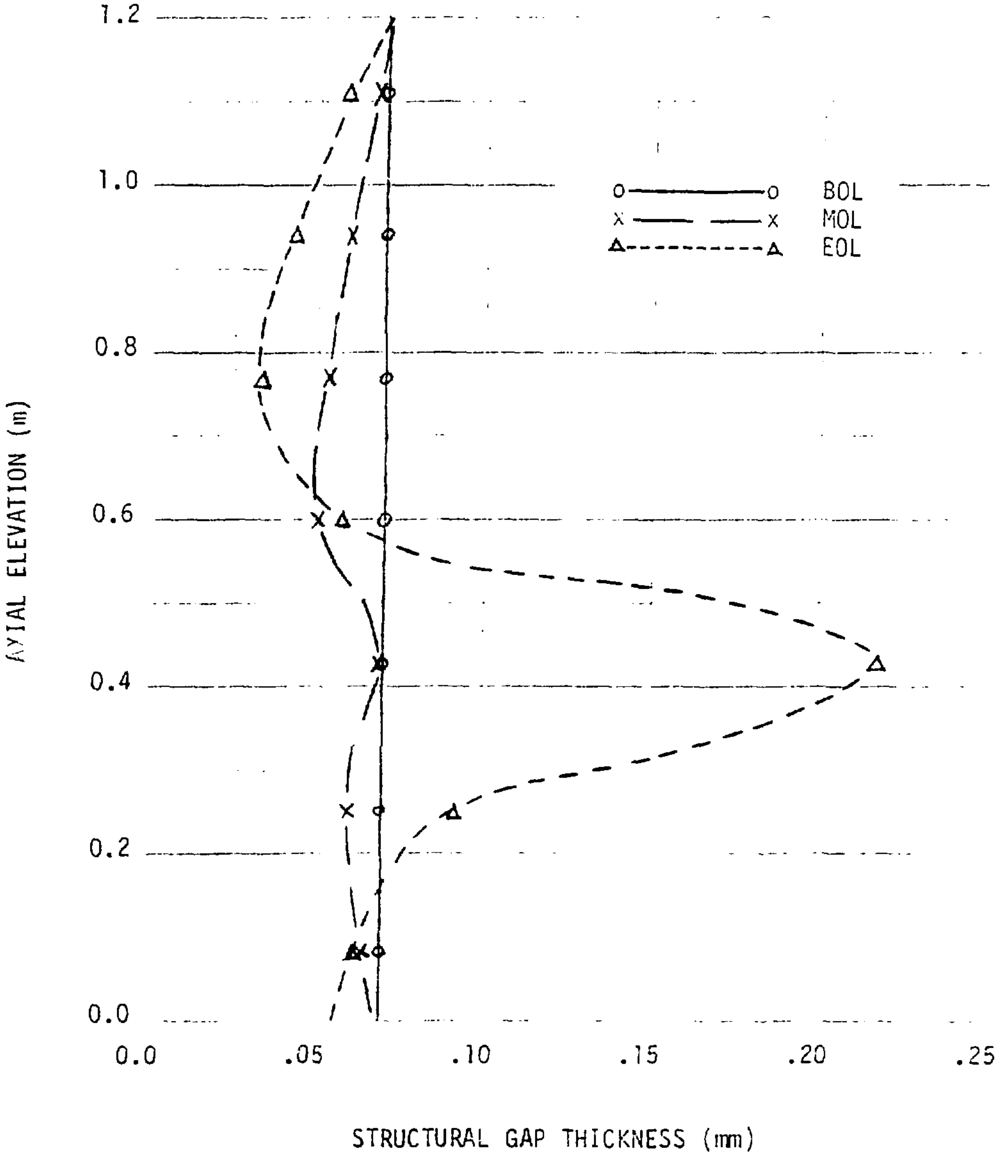

Figure 1. FRAPCON-1 STRUCTURAL GAP THICKNESS

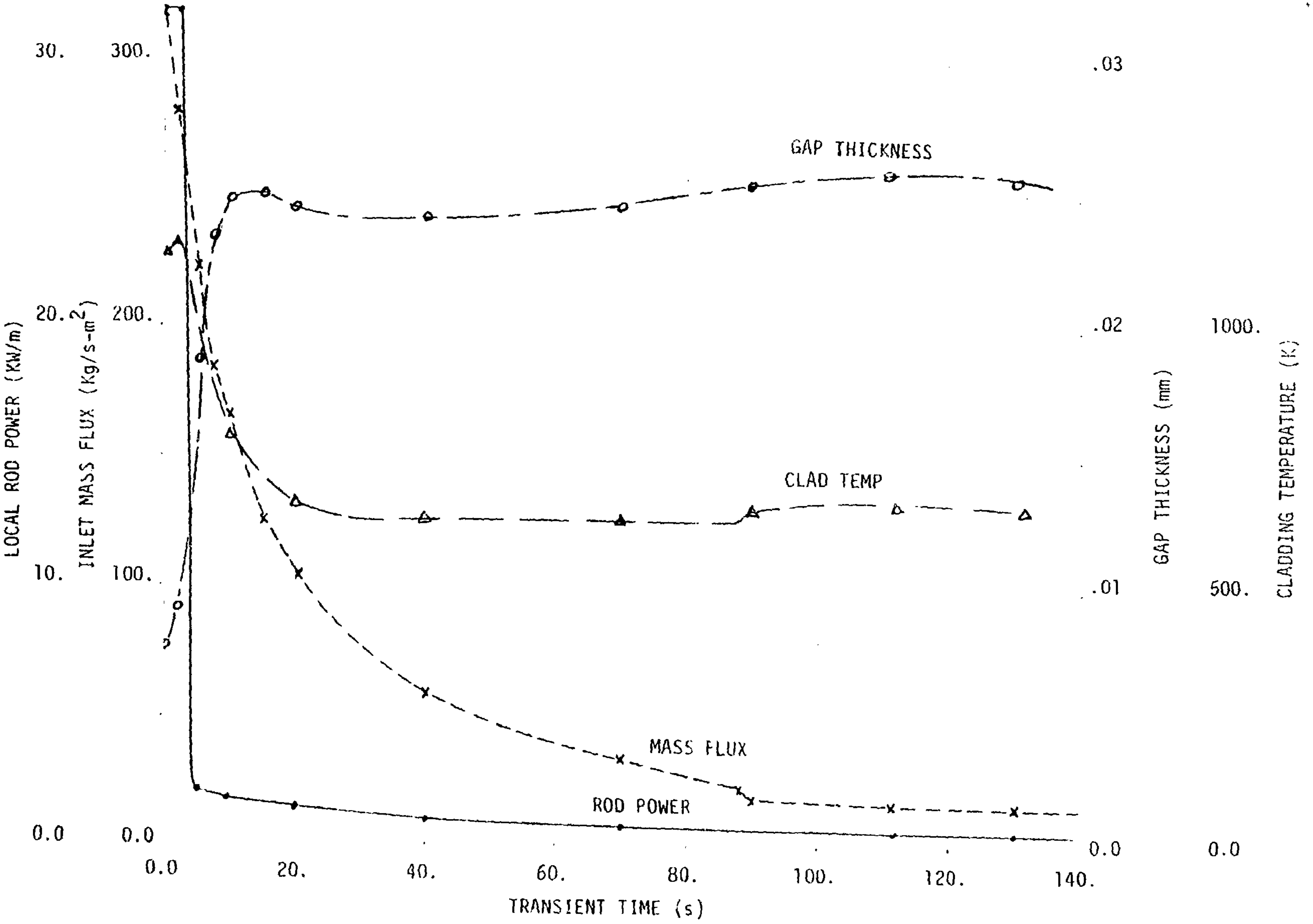

Figure 2. FRAP-T5 GCFR TRANSIENT