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PELLET-CLAD MECHANICAL INTERACTION EVALUATION

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SUMMARY

Fuel rods irradiated in commercial Light-Water Reactors can experience fuel irradiation histories that impose significant mechanical interaction (PCMI) between the oxide fuel pellets and the zircaloy cladding. Two computer codes, RODEX and RAMPEX, have been written to model these irradiation dependent thermal-mechanical interactions. The RODEX code has been formulated to follow the axially dependent power histories generated by the core follow coarse mesh reactor simulation codes and the control rod location histories. The unique mechanical feature of both the RODEX and RAMPEX codes is their modeling of the redistribution of pellet crack volume. Crack volume is generated within the fuel to take into account the radial displacements and cracking macrostructures observed from photomicrographs. Once pellet-clad contact is predicted, then the pellets are represented as truncated wedges subdivided into radial regions within which crack closure occurs by a creep process dependent upon fissioning rate and temperature. The pellet to clad contact forces driving the crack volume redistribution and retarding cladding creep down are calculated with an elastic pellet-clad compliance model. The pellet compliance is adjusted to allow for additional compliance due to the crack volume. An explicit time incremental solution technique is used to calculate the inelastic deformational components due to fuel swelling, crack volume redistribution, densification and creep of the cladding. As the RODEX code tracks the irradiation history of a fuel rod, high pellet-clad contact pressures indicate those power change conditions which correspond to PCMI. For these PCMI's, the RAMPEX code is used to follow the thermal-mechanical interactions during the power ramp. The cladding deformational model in RAMPEX takes into account the biaxial deformational restraints due to the pellet-clad thermal expansions after contact and mechanically models the plastic and creep deformational processes in the cladding using the Prandtl-Reuss flow criteria. The plastic contribution of the cladding deformation and effective stress are used as the mechanical parameters to evaluate the severity of PCMI.

The two reactor operational maneuvers that can lead to severe PCMI are fuel shuffling from low to high power regions and the notched withdrawal of control rods. Using idealized power histories, parametric design evaluations and sensitivity studies have been run. These calculations have predicted reduced plastic clad deformations for a given irradiation history and ramp conditions when gap size is increased, pellet density is decreased, cladding thickness is increased, and cladding yield strength is increased. An operational history characteristic that leads to severe PCMI is a period of lower power operation followed by a shutdown and ramping to higher power. Under repetitive cyclic conditions the mechanical severity of a power ramp increases with exposure.

The RODEX-RAMPEX codes are design and history sensitive calculational models that can perform the deformational evaluations while tracking actual operational histories and can indicate propensity for failure under PCMI conditions.