DEFORMATION AND FAILURE ANALYSIS IN THE FRAP FUEL ROD CODES

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SUMMARY

The FRAP codes are a pair of computer codes being developed for the U.S. Nuclear Regulatory Commission, Division of Reactor Safety Research, to predict the behavior of nuclear fuel rods during both extended burnup and accident conditions. The FRAP-S (steady-state) code is used both as a normal operation analysis tool and as the generator of burnup dependent initial conditions required for the FRAP-T (transient) code. In each case a fully coupled mechanical-thermal-hydraulic analysis of a fuel rod is performed. The mechanical analysis is performed by three separate subcodes: FRACAS, BALLOON, and FRAIL.

The FRACAS subcode analyzes the small deformation behavior of the fuel rod. FRACAS solves for a complete elastic-plastic-creep solution in the fuel pellets and the cladding including the effects of pellet-cladding mechanical interaction, arbitrary temperature distributions, and temperature and strain-rate dependent material properties. Both radial and axial cracks in the fuel are considered. A new efficient matrix sweeping technique is used in FRACAS, which permits the analysis of cracking without artificially modifying the material properties. Axial mechanical coupling is automatically considered when appropriate.

In the transient code FRAP-T, provision is made for a large deformation analysis should local bulging occur as during a LOCA. This analysis is performed by the BALLOON subcode, which is automatically called when a strain rate sensitive plastic instability criteria is exceeded. This subcode considers the non-axisymmetric cladding deformation due to arbitrary pressure differentials and temperature fields. Strain rate effects due to the superplastic behavior of Zircaloy are included. Excellent agreement is shown in comparison with experimental tube burst tests.

A novel feature of the FRAP codes is the failure subcode FRAIL. At each timestep the stresses computed by FRACAS or BALLOON are passed to FRAIL, which then determines if the cladding has ruptured. FRAIL computes a probability of failure based on uncertainties in the failure data base, The probability of failure may be interpreted as a percentage of rods having failed. Failure due to a number of different mechanisms is considered: Overstress, Overstrain, Creep Rupture, and Crack Growth as enhanced by Stress Corrosion. Although based on data taken from various (out of pile) tube burst tests under different conditions, Frail is shown to successfully predict the failure probability computed from forty-four in-reactor power ramp tests.

The FRAP codes thus have the capability of efficiently analyzing the behavior of fuel rods. The small deformation solution permits the analysis of radial and axial cracking without artificially modifying the material properties. The BALLOON subcode predicts the shape of local bulging of fuel rods during a LOCA, and the FRAIL subcode continually monitors the damage occurring to the fuel rod and predicts the percentage of fuel rods failing at each step. Inasmuch as the failure predictions by FRAIL are dependent on the stresses and strains obtained from a coupled thermal-mechanical analysis, the successful prediction of the Halden power ramp failure frequencies demonstrates a unique capability in the prediction of overall fuel rod performance up to failure.