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TECHNIQUE FOR ESTIMATING RELOCATED GAP WIDTH
FOR
GAP CONDUCTANCE CALCULATIONS

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Thermally induced fuel fragmentation and relocation has been demonstrated to influence the thermal behavior of a fuel rod in two ways. The effective fuel pellet conductivity is decreased and pellet-to-cladding heat transfer is improved. This paper presents a correlation between as-built and relocated gap width which, used with the Ross and Stoute Gap Conductance Correlation[1] and an appropriate fuel thermal expansion model as discussed below, closely predicts the measured gap conductances.

As part of the Thermal Fuel Behavior Program being conducted at the Idaho National Engineering Laboratory by EG&G Idaho, Inc., the Gap Conductance Test Series is being performed to evaluate the effects of variations in fuel rod design on the thermal response and resulting gap conductance in low exposure light water reactor fuel rods. Table I lists the tested rod gap designs scheduled for examination in this test series. Data obtained from the gap conductance tests consists of sets of multiple fuel pellet and outer cladding surface temperature measurements taken at test rod power levels ranging from 10 to 60 kW/m. These measurements have permitted a determination of the azimuthally varying fuel pellet heat flux and gap conductances for known fuel pellet relocations obtained by postirradiation gap width measurements.[2,3,4]

The following correlation developed from comparisons of as-built and posttest measured gap widths obtained from rods tested in test series GC 2-1 through 2-3 is used to estimate the cold zero power relocated gap width.

Estimated Relocated Gap Width =

$$1.655 \times 10^{-2} + 0.868 \cdot G_{AB} - 13.436 \cdot G_{AB}^{2} + 71.682 \cdot G_{AB}^{3} \text{ (mm)}$$

G_{AB} = As-Built Gap Width (mm)

This relocated gap width in conjunction with a model for calculating cracked pellet thermal expansion is proposed for use in the Ross and Stoute Correlation.

The extrapolation from cold zero power to reactor operating conditions is accomplished by either of the following two expansion models, the choice of which is predicated by fuel rod design.

Experimentally derived gap conductances obtained from the PBF tests for narrow gap xenon and argon fill gas with diametral gaps < 0.14 mm and helium rods with gaps < 0.12 mm are closely predicted by the Ross and Stoute Correlation using the estimated relocated gap width and a uniform thermal expansion model. This uniform thermal expansion with power is indicative of a cracked pellet expanding with power as a solid pellet. Posttest examination of the fuel pellets from these narrow gap rods indicated the fuel pellets generally have smaller cracks than those observed in the pellets from the other rod designs tested. The smaller cracks allow more of the fuel fragment surfaces on opposing sides of cracks to be in closer proximity to each other than in a fuel pellet with large cracks. The resulting numerous interfragment contact points better communicate thermal expansion forces to all fuel fragments. Thus, pellet thermal expansion behavior is not significantly different from expansion of a solid pellet.

For rods having larger gaps, the fuel thermal expansion model is different. Once fuel relocation has occurred, forming relatively large gaps between fuel fragments, the thermal expansion forces are no longer uniformly communicated throughout the fuel pellet. The lack of this communication results in a smaller pellet-to-cladding gap closure rate than would be predicted by the solid pellet thermal expansion model. The gap conductance test results indicate that only 30% of the thermal expansion expected from a uniform thermal expansion contributes to closing these pellet-to-cladding gaps.

Comparisons between measured gap conductances and gap conductances calculated using the Ross and Stoute Correlations with and without the fuel relocation and fuel thermal expansion model modifications are shown in Figures 1 and 2 for sample cases of uniform and nonuniform thermal expansion. The modifications result in the calculated gap conductance for both uniform and nonuniform fuel expansion cases agreeing well with measured values.

These studies have provided a refinement to the Ross and Stoute Gap Conductance Correlation that accounts for the effect of thermally induced fuel fragment relocation. This refinement considerably increases the predicted gap conductance resulting in predicted lower fuel temperatures and stored energy. Lower stored energy predictions in turn promise to provide increased margins of safety with respect to current nuclear safety calculations.

References

1. Ross, A. M. and Stoute, R. L., "Heat Transfer Coefficient Between UO_2 and Zircaloy-2," Atomic Energy of Canada Limited, Report AECL-1552, June 1962.
2. Murdock, B. A., "Postirradiation Examination Data Report for Gap Conductance Test Series, Test GC 2-1," TREE-NUREG-1204, February 1978.
3. Kerwin, D. K., "Postirradiation Examination Data Report for Gap Conductance Test Series, Test GC 2-2," TREE-NUREG-1206, May 1978.
4. Cook, B. A., "Postirradiation Examination Data Report for Gap Conductance Test Series, Test GC 203," TREE-NUREG-1231, July 1978.

TABLE I

GAP CONDUCTANCE TEST SERIES-2 TEST FUEL ROD PARAMETER VARIATIONS

Test	Test Fuel Rod Designations and Designs			
	GC-501	GC-502	GC-503	GC-504
GC 2-1	0.239-mm gap 97% TD 2.6 MPa Xe	0.109-mm gap 97% TD 2.6 MPa He	0.248-mm gap 95% TD 2.6 MPa He	0.247-mm gap 95% TD 2.6 MPa Ar
	GC 522-1	GC 522-2	GC 522-3	GC 522-4
GC 2-2	0.245-mm gap 92% TD 2.6 MPa Xe	0.135-mm gap 95% TD 2.6 MPa Ar	0.133-mm gap 95% TD 2.6 MPa He	0.386-mm gap 95% TD 2.6 MPa He
	GC 523-1	GC 523-2	GC 523-3	GC 523-4
GC 2-3	0.121-mm gap 92% TD 2.6 MPa He	0.132-mm gap 95% TD 2.6 MPa Xe	0.381-mm gap 97% TD 2.6 MPa He	0.245-mm gap 92% TD 2.6 MPa Ar
	GC 524-1	GC 524-2	GC 524-3	GC 524-4
GC 2-4	0.220-mm gap 95% TD 2.6 MPa He	0.220-mm gap 92% TD 2.6 MPa HE	0.220-mm gap 97% TD 2.6 MPa He	0.220-mm gap 97% TD 2.6 MPa Ar
	GC 525-1	GC 525-2	GC 525-3	GC 525-4
GC 2-5	0.220-mm gap 92% TD 2.6 MPa He	0.100-mm gap 95% TD 2.6 MPa Ar	0.100-mm gap 95% TD 2.6 MPa He	0.360-mm gap 92% TD 2.6 MPa He

*Test Series GC 2-1, 2-2, and 2-3 completed at this date.

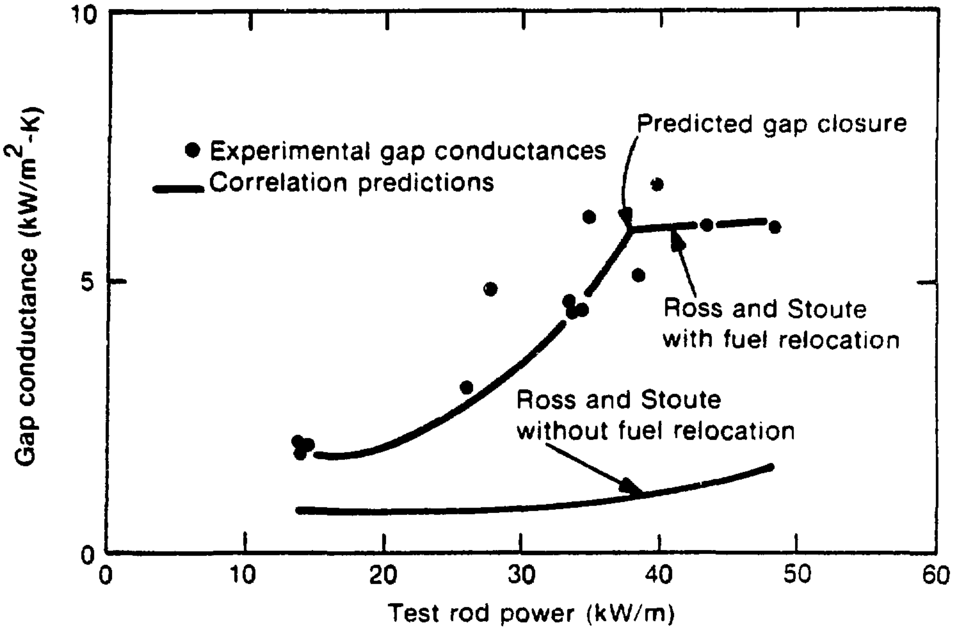

Figure 1 Gap conductance vs. power for a test rod predicted to undergo a uniform thermal expansion (Test Rod GC 522-2).

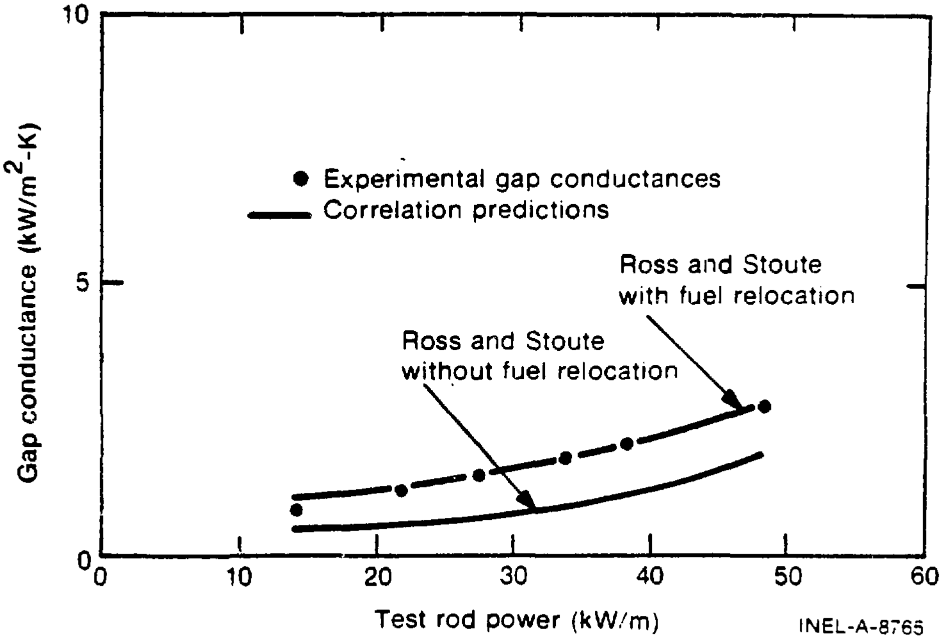

Figure 2 Gap conductance vs. power for a test rod predicted to undergo a non-uniform thermal expansion (Test Rod GC 523-4).