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FISSION GAS INDUCED FUEL SWELLING IN LOW AND MEDIUM BURNUP FUEL DURING HIGH TEMPERATURE TRANSIENTS

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SUMMARY

The behavior of light water reactor fuel elements under postulated accident conditions is being studied by the EG&G Idaho, Inc., Thermal Fuels Behavior Program for the Nuclear Regulatory Commission[1]. As a part of this program, unirradiated and previously irradiated, pressurized-water-reactor type fuel rods were tested under power-cooling-mismatch (PCM) conditions in the Power Burst Facility (PBF). During these integral in-reactor experiments, film boiling was produced on the fuel rods which created high fuel and cladding temperatures. Fuel rod diameters increased in the film boiling region to a greater extent for irradiated rods than for unirradiated rods. The purpose of the study described in this paper was to investigate and assess the fuel swelling which caused the fuel rod diameter increases and to evaluate the ability of an analytical code[2], the Gas Release and Swelling Subroutine - Steady-State and Transient (GRASS-SST), to predict the results.

The Tests IE-1 and IE-3[3,4] eight 1 m long, Zircaloy-4 clad fuel rods fabricated from previously irradiated (6·8 to 15·9 GWd/tU) PWR-type rods from the Saxton Reactor were tested. The rods (each contained in its own flow shroud) were tested four at a time in the PBF in-pile tube. The tests consisted of a series of preconditioning power cycles, a rapid power ramp, steady-state operation at a high power (70 kW/m peak power) for about one hour, and a 1 minute power-coolant-mismatch transient during which film

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boiling was produced. Rod diametral swelling up to 9 percent, fuel melting up to 75 percent of the fuel pellet diameter, and maximum cladding surface temperatures of about 1850 K were determined by posttest examination. Postirradiation examination suggests that the observed swelling was induced by fuel mechanically forcing the cladding outward rather than by gas pressure forcing the fuel and cladding apart.

Fuel rod swelling was analyzed and evaluated in terms of the contributing thermal and fission gas induced mechanisms. Thermally induced swelling mechanisms include both thermal expansion and the volume increase from fuel melting. The primary mechanisms contributing to fission gas induced swelling are fission gas bubble coalescence in molten fuel and fission gas accumulation at grain boundaries.

The overall fuel swelling, determined from postirradiation examination, represents the amount of fuel swelling during film boiling operation. The swelling values consist of the difference between the pre and posttest measured fuel rod diameters, the pellet cladding diametral gap width, cladding thermal contraction upon test termination, and cladding wall thinning.

The fission gas induced swelling values were determined by subtracting the calculated thermal and solid fission product swelling from the overall measured swelling values. The overall and fission gas induced swelling are summarized in Table 1. The contribution of fission gas induced swelling to the overall measured swelling in low burnup (6·8 to 11·1 $\frac{GWd}{tU}$) and medium burnup (14·8 to 15·9 $\frac{GWd}{tU}$) rods averaged 29 and 38 percent respectively.

Relative amounts of fission gas released during the high power one hour steady-state operation in PBF were determined from plenum pressure measurements. The fission gas release during the high power steady-state operation and fission gas induced swelling during the film boiling operation were also calculated using the GRASS-SST code.

From the analysis of the test data and GRASS-SST code calculations on the fission gas effects in irradiated fuel rods tested under PCM conditions, the following conclusions were reached:

1. Fission gas entrapped in the molten fuel and at equiaxed grain boundaries can coalesce into large bubbles and cause fuel swelling.

2. Fission gas induced swelling increases with burnup.

3. The fission gas induced swelling and fission gas release calculated by GRASS-SST compares favorably with the values estimated from measured total rod swelling and plenum pressure.

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[1] P. E. MacDonald, et al., Response to Unirradiated and Irradiate PWR Fuel Rods Tested Under Power Cooling Mismatch Conditions, Nuclear Safety, 19 (4) (1978)

[2] J. Rest, GRASS-SST: A Comprehensive Mechanistic Model for the Prediction of Fission Gas Behavior in UO_2-Base Fuels During Steady-State and Transient Conditions, NUREG/CR-0202, ANL-78-53 (June 1978)

[3] W. J. Quapp, et al., Irradiation Effects Test Series Test IE-1, Test Results Report, TREE-NUREG-1046 (March 1977)

[4] L. C. Farrar, et al., Irradiation Effects Test Series Test IE-3, Test Results Report, TREE-NUREG-1106 (October 1977)

TABLE 1.

OVERALL AND FISSION GAS INDUCED FUEL SWELLING

Rod	Sample	Rod Average Burnup (GWd/tU)	Elevation From Bottom of Rod (m)	Overall Measured Fuel Diametral Increase (mm)	Overall Fuel Swelling (%)	Thermal and Solid Fission Product Swelling (%)	Fission Gas Induced Swelling (%)	Contribution of Fission Gas Induced Swelling to Overall Measured Fuel Swelling (%)
IE-007	1	6.8	0.483	0.583	6.9	4.5	2.4	35
	2		0.635	0.545	6.4	4.5	1.9	30
IE-010	1	15.5	0.533	0.456	5.3	3.5	1.8	34
	2		0.559	0.586	6.9	4.3	2.6	38
	3		0.610	0.644	7.5	4.2	3.3	44
	4		0.635	0.518	6.1	3.7	2.4	39
	5		0.660	0.497	5.8	3.2	2.6	45
IE-015	1	11.1	0.597	0.532	6.3	4.6	1.7	27
IE-016	1	8.6	0.619	0.465	5.5	4.3	1.2	22
IE-017	1	14.8	0.552	0.476	5.6	4.0	1.6	29
	2		0.556	0.484	5.7	4.1	1.5	26
	3		0.572	0.580	6.8	4.2	1.6	24
	4		0.600	0.540	6.3	4.4	1.9	30
	5		0.608	0.538	6.3	4.5	1.8	29
IE-018	1	15.9	0.511	0.617	7.2	4.5	2.7	38
	2		0.556	0.767	9.0	4.8	4.2	47
	3		0.593	0.777	9.1	5.0	4.1	45
	4		0.607	0.718	8.4	4.1	4.3	51
	5		0.614	0.688	8.1	3.9	4.2	52