Effect of crossflow in prediction of oxide thickness by single channel fuel performance codes

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1. Introduction

Nuclear fuel performance is enhanced by introducing new cladding material, debris filter and intermediate flow mixer etc. New fuel design tends to increase pressure drop as well as thermal margin. In terms of cladding oxidation, it is one of major performance parameters regulated by design criteria, circumferential average oxide thickness 100μm. In general it is evaluated by single channel (SC) thermal-mechanical codes such as FRAPCON[1], FATES and PAD. Until now it is treated as natural that predicted oxide thickness is conservative and margin is enough.

Major parameters to cladding oxidation are power, temperature and time. Precise power history could give precise prediction. Coolant temperature at peak location is calculated by accumulation of axial node enthalpy rise from bottom to its elevation within single closed hydraulic channel. Higher power than core average power could give higher coolant temperature and oxidation but lower power case could result in reduction of temperature and oxidation in calculation. As discharge burn-up and LHGR is increased, oxide is closer to its limit.

The goal of this paper is to identify impact of crossflow induced by adjacent fuel assemblies to corrosion thickness predicted by single channel fuel performance code especially at lower power cycle. Sensitivity studies using irradiated fuel rod data shows that predicted oxide thickness using single channel fuel performance codes might be underestimated when high burnup low power rod is surrounded by fresh and relatively high power assemblies.

2. Methods and Results

Reference fuel rod is a Westinghouse 17x17 fuel rod, irradiated at Vandellos-2 reactor during 1994 and 1999. It was irradiated during 5 cycles, 2078 days. Core average power is 17.88kw/m and rod relative power above 1.0 except 4th cycle that the rod was irradiated with 0.254 power fractions. [2]

To simulate incoming coolant flow or crossflow from circumjacent assemblies at peak oxide node, 541mm height section above 2248mm from bottom of full height rod is taken which has identical geometry, incoming coolant temperature and power history except plenum length, this make it possible to adjust local coolant inlet temperature.

2.1 BOC initial oxide effect

Full height rod calculation is needed to set as a base for coolant temperature, oxide thickness and power level at specific axial elevation.

Crossflow temperature is influenced by adjacent assembly state and hard to predict. Therefore core radial average (CA) coolant temperature at certain elevation is taken and assumed as incoming coolant temperature by simple linear regression from core inlet and outlet temperature data.

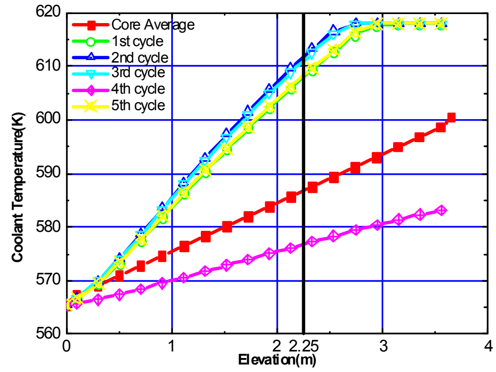

Fig. 1. Coolant temperature calculated with core radial avg. temperature and single channel calculation at each cycle

Coolant temperature effect during low power cycle can be influenced by initial oxide thickness at the beginning of the cycle. The base BOC initial oxide thickness predicted as 44.2μm was varied from 36.4 to 46.6μm to identify initial oxide thickness effect with both of SC and CA case calculation within 4th cycle.

As shown in figure 2, both of SC and CA case shows positive linearity with initial oxide thickness but SC case is more sensitive due to escalated coolant temperature. If low power cycle is not 4th but 5th, this oxide buildup difference is getting bigger as below.

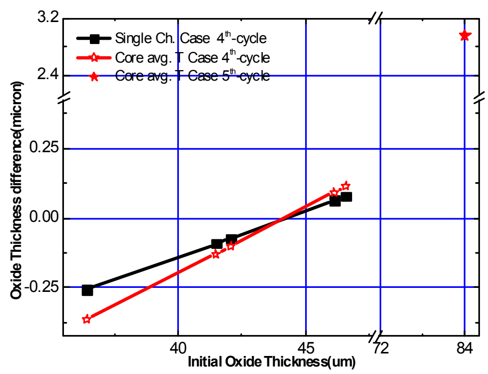

Fig. 2. Oxide buildup difference between SC and CA case vs initial oxide thickness

2.2 Core average coolant temperature effect

Cycle oxide buildup difference between CA and SC case calculation shows -3.7, -3.7, -6.2, 2.4, -16.3 μm at each cycles, at which negative means CA case result is lower than SC case. Except 4th cycle, cycle oxide buildup difference is increased since cycle initial oxide is getting thicker. CA case is calculated adjusting inlet temperature for test rod section 10°C in 4th cycle and -20°C in other cycles.

Single channel case predicted 4.76 μm oxide increases during 4th cycle at 2.54m elevation. When inlet temperature changed from 577K to 587K, core average temperature, oxide buildup increased to 7μm and EOL oxide at the end of 5th cycle also increased from 93.4 to 97.7μm as following table.

Table I: Cycle oxide buildup comparison between single channel calculation and core average temperature calculation

	1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle
SC	9.5	23	44.2	49.0	93.4
CA	9.5	23	44.2	51.2	97.7
Diff.	-	-	-	2.25	4.3

Even though oxide buildup difference between SC case and CA case within 4th cycle was small (2.25μm), it can be increased if cycle power increased up to 1.57 times of original with SC calculation.

2.3 Periphery rod consideration

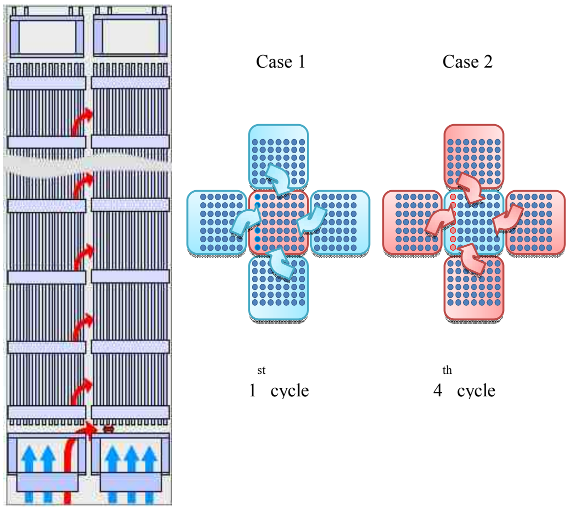

Fig. 3. Schematic diagram for crossflow to periphery rod

Outer most rods within single fuel assembly are more susceptible to the crossflow since they are encounter with incoming coolant not mixed at all.

Most of core loading pattern shows fresh fuel assembly is loaded near high burnup low power assembly taking into account core radial power distribution.

As shown figure 3, one case (case1) that the assembly containing test rod is surrounded by others burned with most weak 4th cycle power at first cycle is compared with other case (case2) that its assembly is surrounded with assemblies burned with 1st cycle power, so called "ring of fire".

Oxide buildup difference between case1 and SC case in 1st cycle reduced to 5.8 μm and EOL oxide thickness difference is also reduced to 17.3 um. Otherwise, oxide buildup difference between case2 and SC case in 4th cycle shows increased to 10.5 μm within 4th cycle and 21.5 μm at the end of life. Finally, EOL oxide thickness is calculated 76.1μm for case1 and 115μm for case2.

3. Conclusions

Effect of crossflow to the oxide thickness prediction using single channel fuel performance code was investigated. Focused on peak oxide fuel rod section, oxide buildup difference between single channel (SC) case and core radial average (CA) temperature was compared within one cycle that its power is relatively lower than average core power. Sensitivity study result shows that cycle oxide buildup difference between both cases is increased by cycle initial oxide thickness related with burnup and incoming coolant temperature compatible with adjacent fuel rod or assembly power and level of mixing into the peak oxide fuel section.

Predictions of fuel performance parameters of full length rod using single channel fuel performance codes have uncertainty in coolant temperature since codes have not considering crossflow.

Especially, one of important fuel performance parameters, oxide thickness is under predicted when the burnup is high and power is lower than core average without consideration of crossflow and its temperature effect.

Therefore, when rod cycle power is lower than core average LHGR, coolant temperature impact by crossflow should be considered not to under estimate fuel performance parameters.

REFERENCES

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[2] A. Shin, et al., "Pre-Calculation of CABRI Water Loop test CIP3-1 with FRAPTRAN code," Transactions of the Korean Nuclear Society Autumn meeting, Gyeongju, Korea, Oct. 27-28, 2011