Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

The Performance of PLUS7 for Grid-To-Rod Fretting

Roh Kyung-Ho [1], Bae Seong-Man[2], Kim Yong-Hwan[3]
1. KHNP, 1312, Yuseong-daero, Yuseong-Gu, Daejeon, Korea, 305-343 (socoban@khnp.co.kr)
2. KHNP, 1312, Yuseong-daero, Yuseong-Gu, Daejeon, Korea, 305-343 (smbae@khnp.co.kr)
3. KEPCO NF, 1047, Daedeokdaero, Yuseong-gu, Daejeon, Korea, 305-353 (yhkim@knfc.co.kr)
[*]Corresponding author: socoban@khnp.co.kr

1. Introduction

Fuel and fuel assembly components, resulting in degradation and unexpected failures by a variety of mechanisms, have been challenged by power up-rates, longer cycles, and higher fuel duty and discharge burnup. GTRF [1] is the predominant fuel failure mechanism in the U.S. Therefore, U.S. is trying to mitigate GTRF failures. As such efforts, new fuel designs, poolside assembly repairs, fuel management, and coolant flow paths have been implemented or changed. Despite significant efforts, it is apparent that GTRF failures still occur and jeopardize the defect-free. With this experience, efforts are still needed to understand the fundamental and synergistic mechanisms and their relative sensitivities to GTRF failures to further develop mitigation and define margins. Figure1 illustrates the parameters currently affecting GTRF-induced fuel failures. Materials and designs of fuel cladding and assembly components, grid-to-rod clearance, and flow-induced vibration are all major variables to GTRF failures

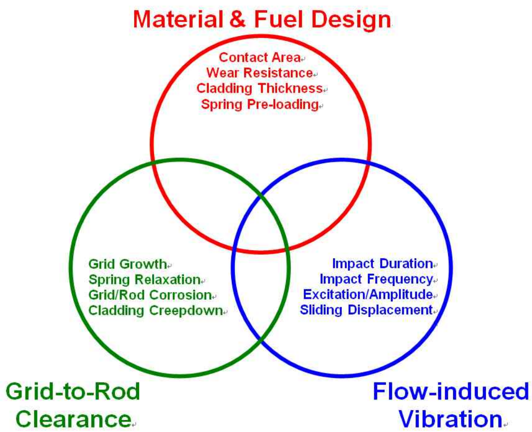

Figure1.Parameters affecting GTRF failures

This current understanding is rather qualitative and thus experimental and post-irradiation examinations and more-detailed modeling are needed to quantitatively assess various parameters that contribute to GTRF-induced failures. As such activities, EPRI contracted to KHNP. The contract name is "Margin assessment of PLUS7 Fuel for GTRF mitigation". This paper describes the results of the project. It is an initial effort to conduct a margin assessment of advanced fuel designs for mitigation of GTRF. A Lead Test Assembly (LTA) of the 16x16 PLUS7™ fuel design manufactured by Korea Nuclear Fuel (KNF) was discharged in 2007 after three cycles in Ulchin-3 (UCN-3) and was examined in the hot cell at the Korea Atomic Energy Research Institute (KAERI).

[1] Grid-To-Rod Fretting

2. Examinations and Results

In this section, in-reactor fuel rod performance of PLUS7 LTA and hot-cell examinations and testing of PLUS7 grids will be described.

2.1 In-reactor fuel rod performance of PLUS7 LTA

Four PLUS7™ lead test assemblies (LTAs) were loaded into the 5th cycle of Ulchin Unit 3 (UCN-3) on January 2, 2003 to verify in-reactor performance after three 16-month-long reactor cycles. The LTAs were discharged from UCN-3 on February 6, 2007. Table1 shows the effective full power days, the fuel assembly average burn-up and maximum fuel rod burn-up of the LTAs.

Parameter	1st Cycle	2nd Cycle	3rd Cycle
Effective Full Power Days (EFPDs)	463	475 (938)*	468 (1,406)*
LTA U3HA06 Burnup (MWD/MTU)	19,604	18,978 (38,582)*	14,632 (53,214)*
LTA U3HA06 Peak Fuel Rod Burnup (MWD/MTU)	D16: 23,414 P14: 23,396	D16: (42,647)* P14: (43,139)*	D16: (57,535)* P14: (58,139)*

Table1. LTA Irradiation Data and Information
* Values in ( ) are cumulative values

At the end of Cycles 5, 6 and 7 of UCN-3, pool-side examinations (PSE) of the LTAs were conducted. The LTA of U3HA06 was only selected for the full-scope PSE since the 4 LTAs were manufactured with the same specifications and were loaded symmetrically in the reactor core. In addition the U3HA03 LTA was also examined for additional information. Fuel assembly grid width and cladding outer diameter were measured during the PSE. PLUS7 LTAs 10 rods of the assembly were selectively transferred to PIEF (Post-Irradiation Examination Facility) of KAERI. Three rods: HA03A14, HA03B14 and HA03C03. The PIE focused on evaluating the fretting wear performance of PLUS7 fuel. Based on the results of the tests, in-reactor burn-up performance of the LTAs was evaluated.

2.1.1 Grid width

The grid width measured after three cycles of burn-up was 207.49 mm within designed criteria (207.77 mm)

2.1.2 Fuel rod outer diameter

The maximum value of the fuel rod outer diameters of the LTAs measured after three cycles of burn-up was 9.48mm at the maximum burn-up within design criteria.

2.1.3 Hot Cell Examination

Based on the PIE results, marks at grid spring and dimple locations were not identified. That is, any cladding defects were not found in three rods.

2.2 Hot Cell Examination on the PLUS7 LTA Grids

The skeleton of PLUS7 LTA was transferred to PIEF of KAERI and then the skeleton was dismantled by cutting the guide tube and the instrument tube in the 10m deep pool of PIEF to examine the irradiated grid at the point of fretting wear view. For reference, in PWR fuel assemblies, the grids support the fuel rods by the friction forces between the fuel rods and the springs/dimples. So it is important to understand grid dimension and grid spring force.

2.2.1 Dimensional measurement

Table2 shows average values of measurements for cell size, cell pitch and grid width.

Unit: mm

			Top	Mid #7	Mid #4	Bottom
Cell Size	OC[2]	HC_x[3]	9.363	9.528	9.507	9.334
		AB_x[4]	*	*	*	*
		HC_y	9.367	9.502	9.529	9.398
		AB_y				
	IC[5]	HC_x	9.337	9.540	9.486	9.332
		AB_x	*	*	*	*
		HC_y	9.378	9.515	9.508	9.409
		AB_y	*	*	*	*
Cell Pitch	OC	HC_x	12.849	12.903	12.883	12.821
		AB_x	12.724	12.721	12.725	12.591
		HC_y	12.812	12.909	12.848	12.865
		AB_y	12.757	12.760	12.775	12.660
	IC	HC_x	12.858	12.871	12.875	12.850
		AB_x	12.847	12.828	12.842	12.849
		HC_y	12.839	12.869	12.867	12.873
		AB_y	12.839	12.846	12.816	12.833
Grid Width		HC	206.281	207.411	207.120	206.105
		ND[6]	206.45	206.40		206.45

Table2. Average measurements for dimension

2.2.2 Cell Spring Stiffness Measurement

Table3 shows the stiffness changes of the grid spring due to irradiation.

Description			Inner cell (kN/mm)	Thimble cell (kN/mm)	Outer cell (kN/mm)
Top Grid (Inconel)	Before irradiation		*	*	*
	After irradiation		0.052	0.058	0.054
Mid grid (ZIRLO)	Before irradiation		*	*	*
	After irradiation	# 7	0.166	0.397	0.150
		# 4	0.204	0.355	0.117
Bottom Grid (Inconel)	Before irradiation		*	*	*
	After irradiation		0.096	0.110	0.126

Table3. The stiffness changes of the grid spring

3. Conclusions

At the end of Cycles 5, 6 and 7 of UCN-3, pool-side examinations (PSE) of the LTAs were conducted. The measured grid width and fuel rod outer diameter is within designed criteria. In order to evaluate the fretting wear performance of PLUS7 fuel assembly, PIEs for four grids; top and bottom grid, 4^{th} and 7^{th} mid grid of PLUS7 LTA, were carried out at PIEF of KAERI. Hot-cell examinations include visual inspection by dimensional measurement, and spring stiffness measurement. The cell sizes of top, bottom and mid grids are increased by thermal and irradiation relaxation. The cell pitch and width was increased except width of top and bottom grids. But, it is difficult to conclude that the width was decreased since the width was compared to the nominal dimension of drawing. The stiffness of top and bottom grid spring is decreased and the stiffness of the mid grid spring is increased except outer cell spring. These stiffness changes seem to be the change of fuel rod supporting condition from as built condition due to the increase of cell size and cell pitch.

REFERENCES

[1] The review report for In-Reactor Performance Evaluation Report on The PLUS7 LTAs by KHNP, Mar. 2011.

[2] The review report for The Hot-Cell Examination on The PLUS7 LTA Grids by KHNP, Oct. 2011

* Not written by the fuel vendor demand

[2] OC: Outer Cell

[3] $HC_{x,y}$: Measurement by Hot Cell test

[4] $AB_{x,y}$: As Built Measurement

[5] IC: Internal Cell

[6] ND: Nominal Dimension of drawing used because as built is not measured.