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Post-irradiation inspections on TVSA-T fuel assemblies at Temelín NPP

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Introduction

Pool-side inspections on irradiated fuel assemblies are mostly provided in western countries, but the implementation of higher burnup and longer cycles bring other needs of fuel inspections during reactor operation worldwide. The post-irradiation pool-side inspections of fuel assemblies in the Czech Republic began in 2003 at NPP Temelín´s Unit 1 and in 2004 at Unit 2 after the first cycles with American fuel VVantage-6, made by Westinghouse LLC, and they are a part of a long-term monitoring of fuel behavior during the operation. This monitoring still continues on Russian fuel TVSA-T. This paper describes the experience with the fuel inspections and summarizes the results given by these inspections and measurements on selected fuel assemblies TVSA-T after three years of operation at Unit 1 and after two years at Unit 2 in comparison with previous cycles. The post-irradiation inspections are provided primarily by the vendor JSC TVEL, CV Řež is the independent fuel inspector that performs inspections in the cooperation with the fuel vendor.

PIIP at Temelín NPP

The Post-Irradiation Inspection Program on TVSA-T consists of visual inspection of whole fuel assembly, i.e. peripheral fuel rods, angles, spacer grids and top and bottom nozzle. The visuals can be performed as half-face or as a full-face visual inspection. In a frame of half-face there are four fuel rods and angle and in a frame of full-face there are both angles and seven fuel rods shown on screen, see Fig. 1.

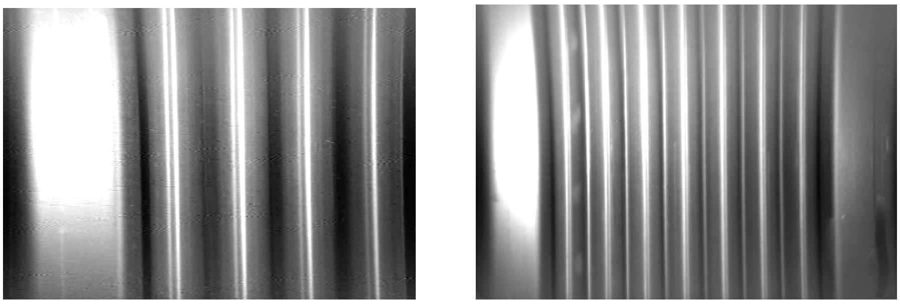

Fig. 1 Half-face (left) and full-face (right) visual inspection

Visuals are performed by means of the Fuel Repair and Inspection Equipment (FRIE). This equipment also allows some measurements of fuel assemblies, such as fuel assembly twist and bow, fuel assembly growth and fuel rod growth. If some leaking fuel assemblies are identified, the ultrasonic inspection is performed.

The PIIP program on TVSA-T started in 2011 at Unit 1. Twelve selected fuel assemblies were measured and inspected. Next cycle (C10) included 13 fuel assemblies and during the last outage at Unit 1, after Cycle 11, there were also 13 assemblies inspected. The PIIP at Unit 2 started in 2012 and included 7 selected assemblies, during the last outage there were 6 assemblies measured, after Cycle 10. The selection of fuel assemblies is made by TVEL in cooperation with CV Řež and Temelín´s physicists. Fig. 2 shows the positions of selected fuel assemblies after each cycle at Unit 1 and 2. In the layout there are also the positions of measured fuel assemblies in next cycles (U1C12 and U2C11).

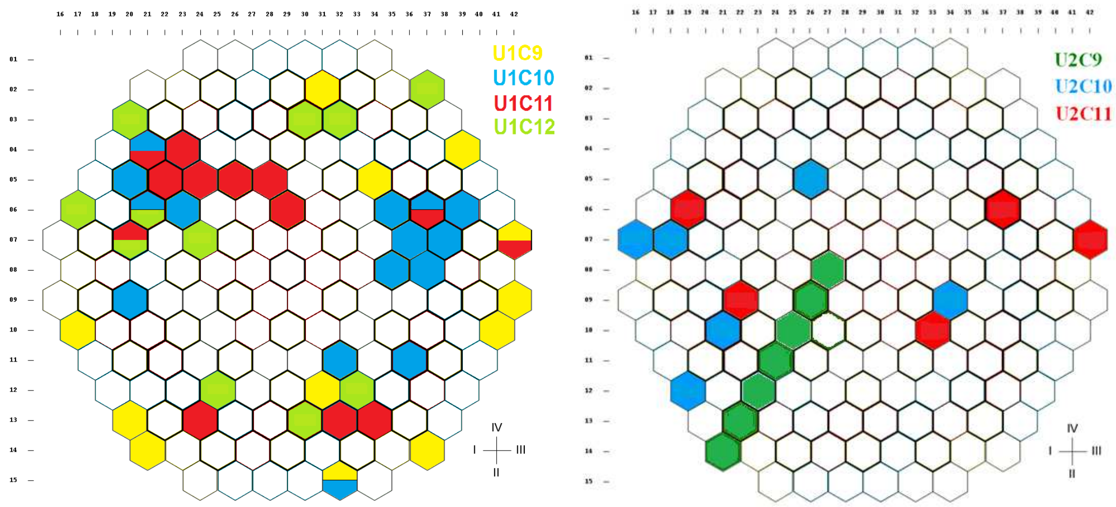

Fig. 2 Positions of selected fuel assemblies for PIIP at Unit 1 (left) and Unit 2 (right) during 2011 - 2014

PIIP in 2013

The first PIIP in 2013 started at Unit 2 in Spring. During this PIIP there were six selected fuel assemblies inspected and measured in the FRIE equipment. In the selection there were five two-year assemblies and one one-year assembly. Fuel assembly burnup was in a range of 15 - 25 MWd/kgU; the lowest value is for one-year assembly. There were no leakers identified during the operation and by means of the sipping test performed during fuel reload from the core to spent fuel pools. The twist of selected assemblies was zero or around 1° that means the twist is negligible. Fuel assembly bow was calculated as ≤ 5 mm, for one assembly in the centre of the core it was 8 mm. There was small difference of fuel assembly bow between results after Cycle 9 and 10. Measured fuel assembly growth was ≤ 2 mm and fuel rod growth was 3 – 8 mm, as shown in Table 1.

PIIP at Unit 1 in Summer included nine three-year fuel assemblies, two two-year and two one-year fuel assemblies. There were no leakers identified like at Unit 2. The assembly burnup was in range of 16 – 37 MWd/kgU. The twist was also negligible. Assembly bow was ≤ 4 mm, for one fuel assembly it was 8 mm). Small difference of assembly bow between Cycle 9, 10 and C11 was also identified. Measured assembly growth was ≤ 3.5 mm, and fuel rod growth was in range of 3 - 14 mm, as shown in Table 1.

Corrosion situation at both units shows good behavior of fuel assemblies during operation. There were no anomalies that would cause the limits on operation found. The corrosion of fuel assemblies meets the predictions.

Table 1 Results of PIIP in 2013

	U2C10	U1C11
FA age (years)	1 – 2	1 – 3
BU (MWd/kgU)	15 – 25	16 - 37
leakers	no	no
twist	≤ 1°	≤ 1°
bow	≤ 5 mm (1 FA: 8 mm)	≤ 8 mm
FA growth	≤ 2 mm	≤ 3.5 mm
FR growth	3 – 8 mm	3 – 14 mm

Evaluation of FA changes with irradiation

Figures 3 – 6 show the results from measurements in a frame of the PIIP after all cycles with TVSA-T at both units.

Fuel assembly twist after one, two and three cycles is negligible, as shown in Fig. 3. The assembly twist is independent on fuel burnup.

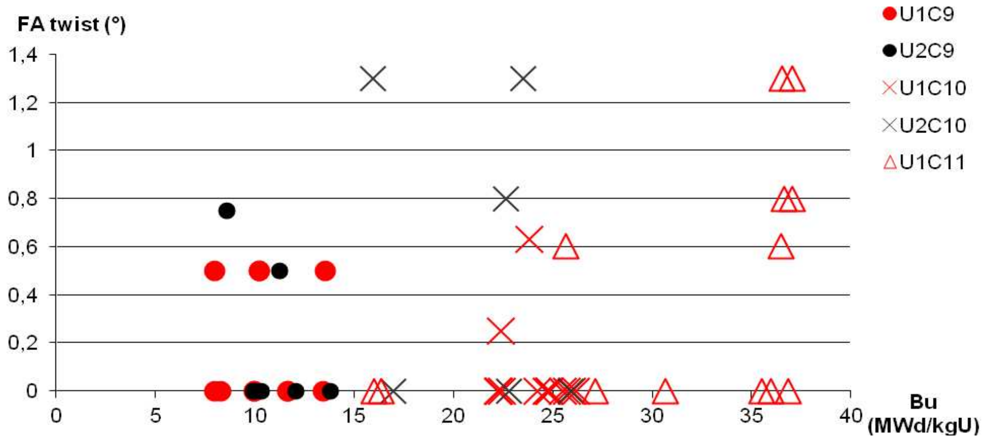

Fig. 3 Fuel assembly twist

Fuel assembly bow meets the expectations and does not develop with burnup, as shown in Fig. 4. The maximal value is for the assemblies located mostly between the centre and the periphery of the core (see a red cross and a red triangle around 8 mm).

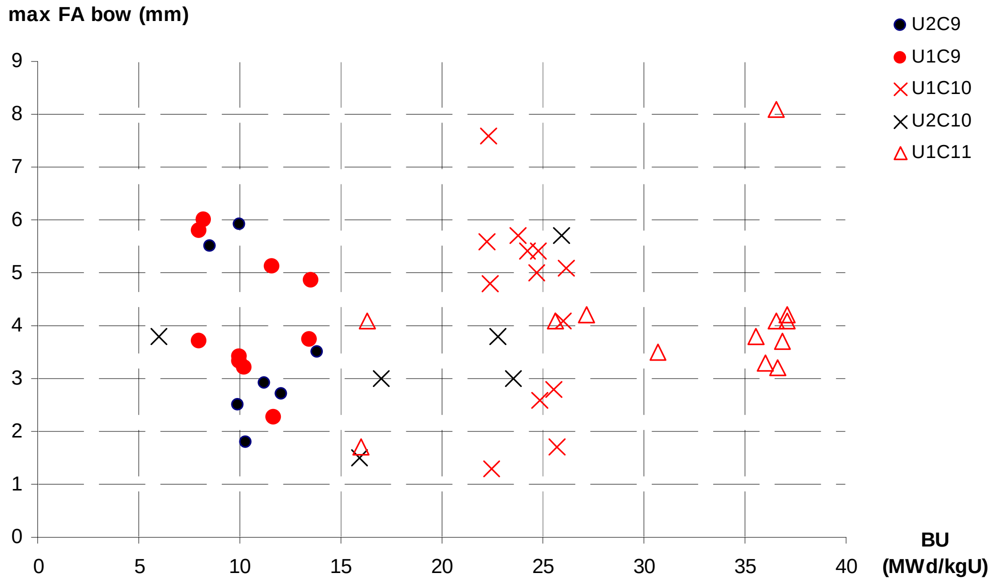

Fig. 4 Fuel assembly bow – maximal values

Fuel assembly growth seems to be affected by the position of upper core internals (BOT), see the negative values in Fig. 5.

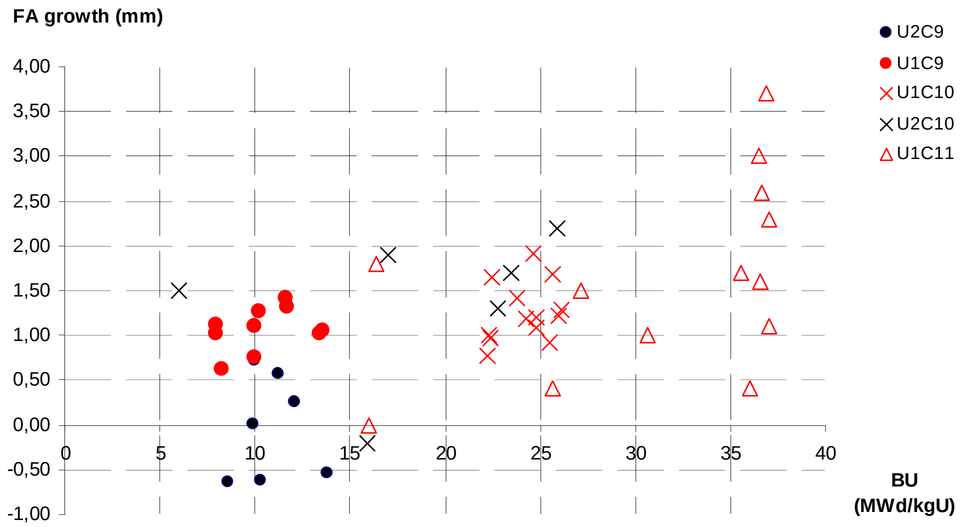

Fig. 5 Fuel assembly growth

Fuel rod growth is near the predicted value (0.1% / 10MWd/kg_U). There is a larger scatter after three cycles due to pellet-cladding contact, as shown in Fig. 5.

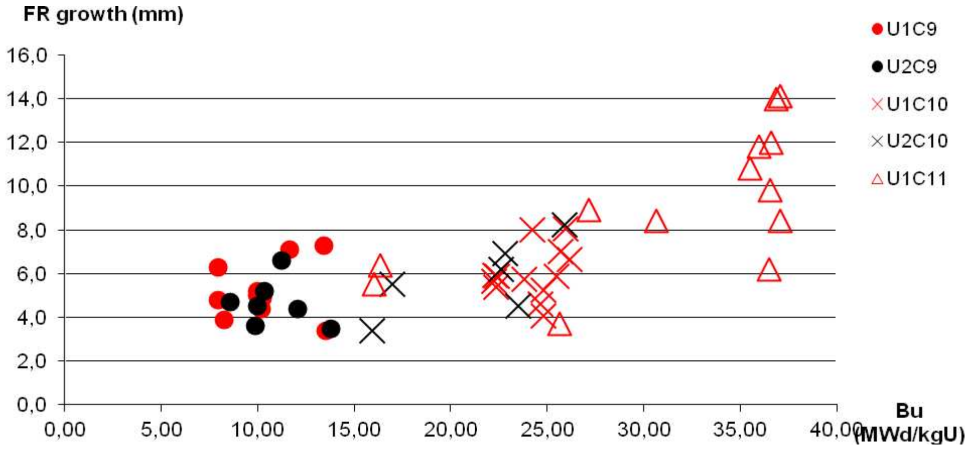

Fig. 6 Fuel rod growth

The growth of tvels (UO_2 fuel rod) develops with fuel burnup and is near the predicted value as mentioned above. The values of fuel rod growth are between 3 – 8 mm for one-year assemblies and up to 14 mm for three-year assemblies, see Fig. 6.

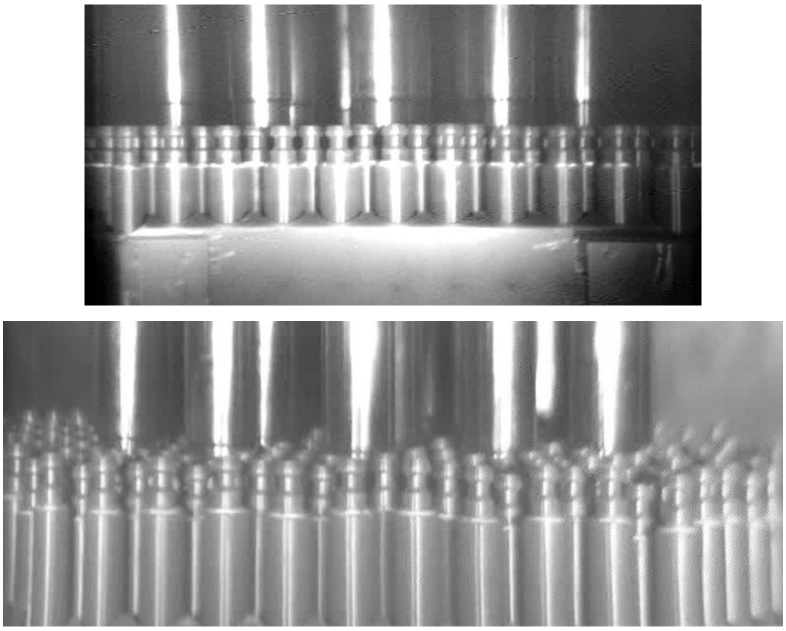

Fig. 7 Fuel rod growth after first cycle (up) and after third cycle (bottom)

Values of growth of fuel rods with Gadolinium absorber (tvegs: UO_2 + Gd_2O_3) give small but noticeable difference between tvel and tveg growth observed already after 1st cycle at both units. It does not pose any safety or operational problem, but contradicted predictions. Such growth was observed only for some assemblies and only for some tvegs. So it is not a common behavior of all tvegs. The difference between tveg and tvel growth is shown in Fig. 8.

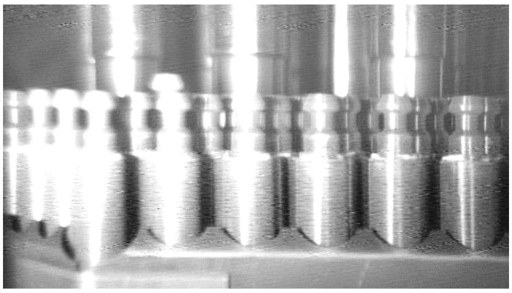

Fig. 8 Different growth of tveg and neighboring tvels

Such observed issue gave considered but dismissed possible causes: different tveg length from the manufacture, lower helium pressure under the cladding and faster cladding creep, different chemical composition or metallurgic properties of cladding tubes of certain batch, lower end-plug release from the fuel assembly support grid, pellet batch with higher content of hydrogen, or contamination of pellets or cladding tubes by organics leading to the hydriding of the cladding. The most probable reason is a difference in pellet-cladding contact moment between tvel and tveg. According to calculations the contact should occur slightly sooner in tveg, but not during the 1st cycle. After 1st cycle the growth could be caused if the fuel column is not fully centered.

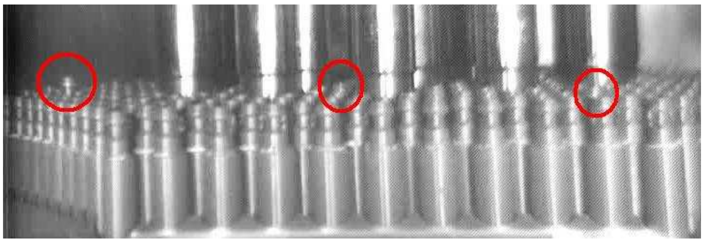

Fig. 9 Three tvegs of higher growth than tvels identified on one face of fuel assembly

Corrosion situation

Visual examinations revealed very small amount of corrosion on the cladding and assembly skeleton surface, which was taken as a confirmation of good corrosion performance. The corrosion of fuel assembly surface meets the prediction and does not show any anomalies in the behavior. The corrosion depends on position and height in the core. Bigger corrosion is in the middle of the assembly where the active part of assembly is located. This behavior also shows a good condition of the primary circuit chemistry at both units of Temelín NPP.

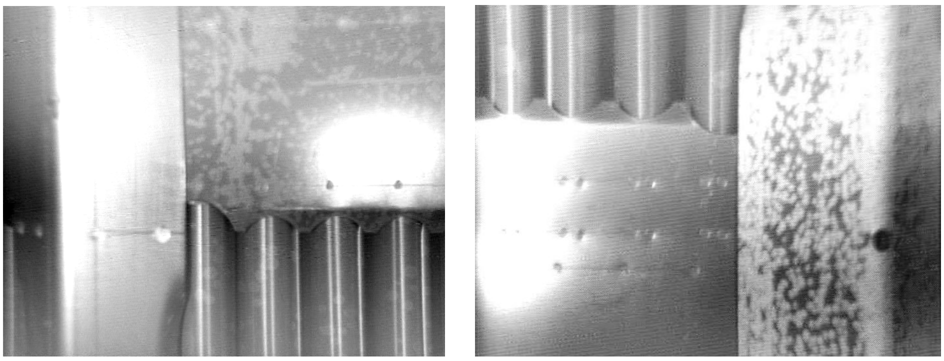

Fig. 10 Corrosion situation after first cycle (left) and third cycle (right)

Conclusion

After one, two and three cycles there are no anomalies that would limit safe reactor operation, no traces of handling damage, no defects of fuel assembly skeleton, no corrosion anomalies and no significant fuel rod growth. The mechanical stability of whole assembly is in a good condition. The results from PIIP program show that fuel assembly behavior meets the predictions.

Acknowledgements

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