An Investigation on Irradiation-induced Growth in PLUS7 Fuel Assembly

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1. Introduction

To improve economy and safety aspects, an advanced nuclear fuel of PLUS7 for Optimized Power Reactor of 1000 MWe (OPR1000) and Advanced Power Reactor of 1400 MWe (APR1400) in Korea was developed, and four (4) lead test assemblies (LTAs) were irradiated successfully during three (3) cycles in Ulchin unit 3. Assembly-wise examination during refueling outage after each cycle and rod-wise examination after discharge has been performed in the poolside. In addition, the hotcell examinations on rods and skeleton are being performed currently.

In the meanwhile, PLUS7 started to be delivered to all eight (8) OPR1000s in Korea based on the irradiation performance results of LTAs. A surveillance program to reconfirm irradiation performance results using LTAs has been launched on the commercially supplied fuels. The four (4) fuel assemblies in Yonggwang unit 5 were selected for this surveillance program and were examined using the same examination procedures and measuring devices as those for LTAs. Considering that the above two (2) plants use the same operating parameters, the slight difference in assembly growths results from the design difference between two fuels.

2. Irradiation Growth Behavior

LTAs for irradiation test and fuels for surveillance adopted Zirlo guide tubes and Zirlo fuel cladding tubes to meet higher burnup. The different one thing is that fuels for surveillance adopted axial blanket of 6 inches at the top and bottom of fuel rods.

Irradiation growth is known as the change in shape of solid at constant volume that occurs during irradiation in the absence of stress. And this depends on the chemical composition, manufacturing processes and operating condition. Even though the previous researches to verify the mechanism had been tried [1, 2] and are being tried, most fuel vendors are using empirical models based on the measured data.

3. Poolside Examination

In this section the devices and methods to measure axial elevations of irradiated fuel assembly and rods in poolside are described.

3.1 Measurement of Assembly Elevations

Visual-Dimensional measurement device is installed on the elevator and the calibrated ruler of a 10 m tape is installed vertically as shown in Fig. 1. The encoder binded on the device is calibrated at intervals of 40 cm using the ruler by moving the device on the elevator up and down. For the next step, a fuel assembly hanged on the grapple shown in Fig. 2 is installed on the same distance apart as the ruler's position. The elevations of the assembly including top/bottom nozzles, grids and top positions of rod, etc. are measured using the encoder and then compensated for temperature. To get the assembly growth, the elevation measurements are compared with the as-built data measured during the fuel assembly fabrication.

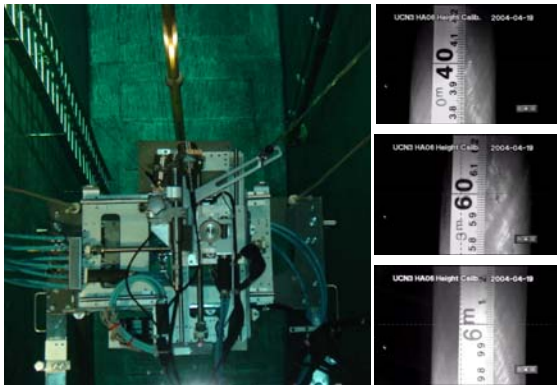

Fig. 1. Calibration of an encoder by the calibrated ruler

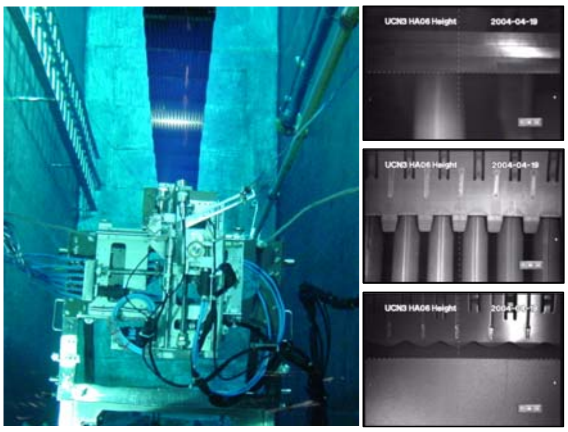

Fig. 2. Measurement of fuel assembly elevation

3.2 Rod growth measurement

Irradiated fuel rod lengths cannot be measured using the visual-dimensional measurement device directly because the bottom positions of fuel rods are invisible. At the first step, the configuration containing top nozzle and top of fuel rods is recorded as shown in Fig. 3. The shoulder gap on the rod at the center of the assembly face is measured in section 3.1. The shoulder gaps on the other rods are evaluated by analyzing the videotapes and by using the known value at the center rod. Rod growth which is obtained by subtracting as-built rod length from irradiated rod length is calculated by adding shoulder gap change to assembly growth in section 3.1.

Fig. 3. A Configuration Captured for Shoulder Gap

4. Evaluation Results

As per SRP 4.2 [3], excessive fuel assembly or rod growth is restricted to prevent their bows resulted in fuel failure. Assembly growth is dependent on stress-free axial growth, hydriding and compressive creep [4]. By considering the same stress-free axial growth and hydriding due to the same material and operating conditions, the different assembly growth results from the different compressive creep due to the design difference between two assemblies. The only one different thing between LTAs and assemblies for surveillance is that the surveillance fuel rods have axial blankets on both ends to improve neutron economy while LTA fuel rods do not.

The shoulder gap measured during PSE program using LTAs and surveillance program shows that LTAs showed decrease of about 2~3 mm after each cycle while those on assemblies for surveillance remained nearly unchanged. The shoulder gap decrease means that the continuous friction forces between grid springs and fuel rods occur as a function of burnup. These massive friction forces by rod growths is evaluated to contribute to reduce compressive guide thimble creep occurred due to the compressive force caused by holddown spring and uplift force caused by pressure drop. Fig. 4 compares assembly growths between LTAs and assemblies for surveillance. The fuel rod growth for surveillance is similar to assembly growth while LTA rod growth is greater than assembly growth.

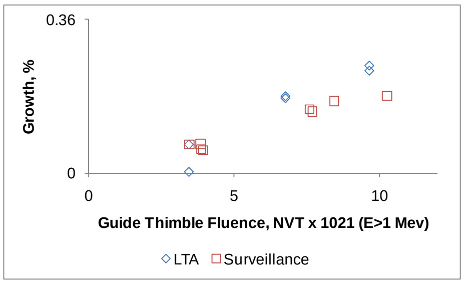

Fig. 4. A Comparison of Assembly Growths between PLUS7 LTAs and Assemblies for Surveillance

5. Conclusions

Through the irradiation test using LTAs and surveillance program, the irradiation performances of an advanced nuclear fuel of PLUS7 for OPR1000 and APR1400 in Korea were verified. In addition, PLUS7 rod growth difference contributes to the assembly growth quantitatively due to grid-to-rod friction force differences depending on assembly design feature. It is concluded that the assembly with greater rod growth reduce guide thimble compressive creep and result in assembly growth.

REFERENCES

[1] S.N. Buckley, Properties of Reactor Materials and the Effects of Irradiation Damage, Butterworths, London, 1979.
[2] R.B. Adamson, Zirconium in the Nuclear Industry, Third Conference, STP 633, ASTM, 1977.
[3] U.S. Nuclear Regulatory Commission, Standard Review Plan - 4.2 Fuel System Design, NUREG-0800
[4] P. Rudling, T. Ingemansson, Fuel Vendor – PWR Fuel Failure Management Handbook, ANT International, Sweden, 2004.