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AN INVESTIGATION ON IRRADIATION GROWTH BEHAVORS IN KOREAN PWR NUCLEAR FUELS

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ABSTRACT*: Dimensional stability in PWR nuclear fuels is an important consideration from the fuel integrity and compatibility points of view. Three types of irradiation-induced growths in nuclear fuel are considered: fuel assembly growth, fuel rod growth, and grid width growth. These growths are obtained by comparing the dimensions measured through the poolside examinations or hot cell examinations to their as-built data. The excessive growth in fuel assembly, rod and grid width may cause the interferences with the upper and lower core support plates in reactor resulted in fuel assembly bow, with fuel top and bottom nozzles resulted in fuel rod bow, and with core shroud in reactor resulted in being stuck within the reactor core shrouds. The fuel assembly growth depends on neutron irradiation, compressive creep by holddown force, and tensile creep occurring by drag force due to the growth difference between guide tube and fuel rod. And the fuel rod growth depends on neutron irradiation, and compressive creep occurring by drag force due to growth difference between guide tube and fuel rod while the spacer grid growth occurs by irradiation and hydrogen. During in-reactor verification test programs for the advanced fuels of PLUS7™, HIPER16 ™, and ACE7 ™, several verified materials were introduced and their growth behaviors were compared. In this paper, the effect of rod growth difference by cladding material on assembly growth is investigated. The assembly growth difference is due to the different compressive creep on guide tubes resulted from the drag force difference due to rod growth difference. The fuel assembly growth increases linearly as a function of burnup at cycle 1 but are saturated at cycle 2. It is due to the drag force decreased by cycle. The grid width growth is accelerated as a function of burnup due to acceleration of hydrogen absorption as a function of burnup. The grid width growth was quite different by grid design which are linearly increased or steeply accelerated smoothly as a function of burnup. The growth database by design or material should be widely accumulated through poolside examination and post-irradiation examination, and the effect of each parameter on these growths should be separated to develop the codes to predict their behaviors to develop the codes to predict their growth behaviors in reactor.*

KEYWORDS*: Fuel Assembly, Fuel Rod, Grid Width, Irradiation, Growth*

I. INTRODUCTION

Three(3) types of advanced nuclear fuels of PLUS7™, 16ACE7™ and 17ACE7™ had been developed with Westinghouse jointly and verified using lead test assemblies (LTAs) in Korean nuclear power plants. These fuels are being supplied commercially to the nuclear power plants. PLUS7™ is for currently operating twelve(12) 1000 MWe (OPR1000) plants and two(2) 1400 MWe (APR1400) plants, and for four(4) constructing 1400 MWe (APR1400) plants in the future. HIPER16 and HIPER17 which are patent-free higher performance nuclear fuels, have followed PLUS7™ and 17ACE7™, respectively, and has been or is being verified using LTAs in Korean PWRs. During these kinds of the development programs, several verified materials were introduced to these fuel designs for performance comparison or material diversification (Refs. 1, 2, 3, 4, 5, 6 and 7).

Dimensional stability in fuel assembly for PWR is an important parameter from the integrity and compatibility points of view. Three(3) types of growths for nuclear fuel in reactor are being considered: fuel assembly growth, fuel rod growth, and grid width growth. The fuel components consisted of zirconium alloy are grown by the intrusion of hydrogen occurred during corrosion process as well as the neutron irradiation. For the fuel assembly growth, more complicated mechanisms are added, which are the compressive creep by top nozzle holddown spring and the tensile creep by grid-to-rod drag force due to fuel rod growth. When the fuel assembly interferes with the reactor internals as a result of the excessive growth, it might be bowed. In addition, fuel assembly might be twisted by the non-uniform growth in the fuel assembly cross section. The bow and twist in fuel assembly may cause underload and/or overload problems during fuel handling in reactor and then resulted in the grid damage. Similar to fuel assembly growth mentioned above, fuel rod growth is a function of the growth due to neutron irradiation and hydrogen intrusion, and the compressive creep by grid-to-rod drag force due to growth difference between fuel assembly and fuel rod. In case that there is no gap between top and bottom nozzles due to the excessive fuel rod growth, fuel rod might be bowed and then resulted in Departure from Nuclear Boiling (DNB) penalty. In addition, the grid width growth is due to the neutron irradiation and hydrogen intrusion. Fuel assembly might interfere with core shroud in reactor in case of the excessive grid width growth, and then resulted in handling problems during loading and unloading fuels.

II. POOLSIDE EXAMINATIONS

Two(2) devices are used for measuring these three(3) types of growths during refueling outage: A visual-dimensional measurement device with the high density camera and an encoder for measuring assembly length and top nozzle-to-rod gap, a Linear Variable Differential Transformer (LVDT) device for grid width measurement. A visual-dimensional measurement device is installed on the elevator and the calibrated ruler is installed vertically. The encoder bound on the device is calibrated at some intervals using the ruler by moving the device on the elevator up and down. After calibration, a fuel assembly hanged on the grapple is installed on the same distance apart as the ruler's position are measured using the encoder and compensated for temperature. The elevations of the assembly including top/bottom nozzles, grids and top positions of rod, etc. are measured by using an encoder which is calibrated by using a pre-calibrated ruler (Ref. 8). Fuel assembly growth is obtained from the irradiated fuel assembly length in comparison to as-built fuel assembly length measured during the fuel assembly fabrication.

Fuel rod growths cannot be measured directly by using the visual-dimensional measurement device because the bottom positions of fuel rods are invisible. At the first step, the pictures containing top nozzle and top of fuel rods is recorded (Ref. 8). The top nozzle-to-rod gap at the center of the assembly face is obtained directly from encoder value at the stage of assembly growth measurement. The other gaps are obtained relatively from the videotapes and a known gap at the center of assembly obtained as a reference value. Rod growths are obtained by adding change between as-built gaps and measured gaps to assembly growth. As the fuel rods are nearly in contact with the bottom nozzle, these are restricted to grow only toward the top nozzle. The uncertainty related to the assembly and rod growth measurements using the visual-dimensional measurement device is within 2 mm.

Irradiated mid grid width is measured using LVDT device in poolside. And the grid width growths are obtained by comparing measured widths to as-built ones. Before and after measuring spacer grid widths, the calibration of LVDT system by using a standard is performed (Ref. 8). The minimum value is obtained by twisting the jaw of LVDT device forward and backward or up and down. The grid width measurements are performed three(3) times at four(4) faces on all six(6) mid grids for Westinghouse type plants and all nine(9) mid grids for OPR1000 and APR1400 plants. The grid widths measured three(3) times on each face are corrected by considering temperature and then averaged. The uncertainty related to the grid width growth measurement using LVDT device is within 50 μm.

III. EVALUATION RESULTS AND CONSIDERATION

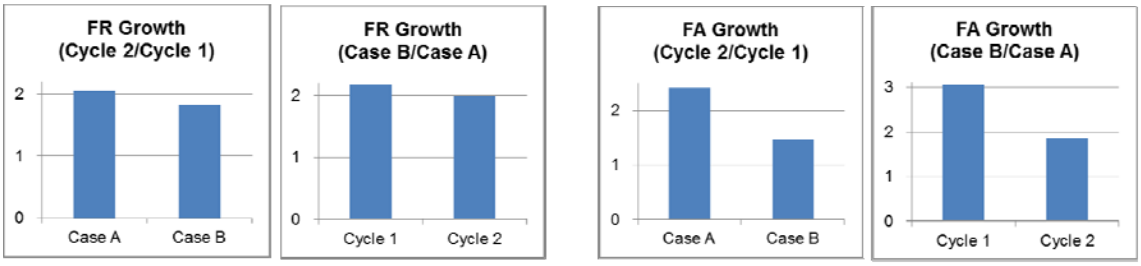
The irradiation growth is the change in shape of solid at constant volume that occurs during irradiation in the absence of stress and depends on the chemical composition, manufacturing processes and operating condition. It was known that assembly growth depends on the guide tube stress-free axial growth, hydriding and compressive creep, etc. Although a lot of researches had been tried and are being tried to investigate this mechanism, most fuel vendors are using empirical models based on the measured data (Refs. 9, 10). As per SRP 4.2 (Ref. 11), excessive fuel assembly or rod growth is restricted to prevent their bows resulted in fuel failure.

TABLE I. Growth Evaluation Cases Categorized by Plant Type, Fuel Assembly Type, and Zirconium Alloy Material

Case	Plant Type	Assembly Type	Material for Guide Tube & Grid	Cladding Material	Grid Stamping Direction
A (I-I-I-I)	I	I	I	I	Longitudinal
B (I-I-I-II)	I	I	I	III	Longitudinal
C (I-II-I-I)	I	II	I	I	Transverse
D (I-II-I-III)	I	II	II	II	Transverse
E (II-III-I-I)	II	III	I	I	Transverse
F (III-IV-I-I)	III	IV	I	I	Transverse

Six(6) cases categorized by plant type, fuel assembly type, and zirconium alloy material as shown in TABLE I are considered for comparing in-reactor growth performances on fuel assembly, rod and grid. On TABLE I, material types I, II and III are ZrSnNb type, ZrNbCu type and ZrNb type, respectively.

Cases A and B represent two cases which have the same conditions except cladding material. Fuel assembly burnups in these two cases are similar at each cycle. As shown in Fig. 1(a), fuel rod growth behaviors in these two cases are similar, which are linearly increased as a function of irradiation. More precisely speaking, Case A was accelerated a little bit while Case B was decelerated a little bit. The rod growth in Case B is over 2 times greater than that in Case A. Assembly growth is dependent on stress-free axial growth, hydriding and compressive creep (Ref. 12). Fig. 1(b) compares fuel assembly growth behaviors. Fuel assembly growth in Case A was accelerated while that in Case B was saturated. The stress-free axial growths due to irradiation and hydriding are similar because the material and operating conditions are the same. The different assembly growth is due to the different compressive creep on guide tubes resulted from the different drag force due to rod growth difference. The fuel assembly growth of Case B after cycle 1 was 3 times greater than Case A but Case B at cycle 2 saturates to 2 times greater than cycle 1. It is due to the drag force difference dependent on cycle.



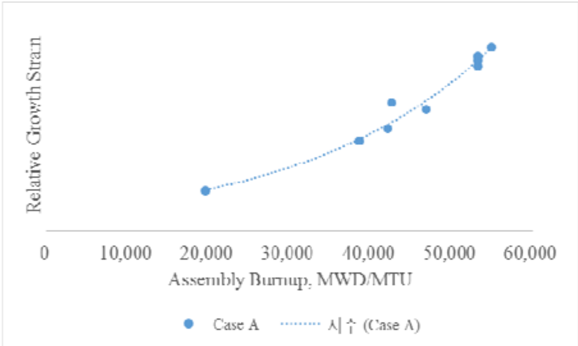
(a) Fuel rod growth (b) Fuel assembly growth

Fig. 1. Fuel assembly and rod growths by cladding material and cycle between Case A and Case B

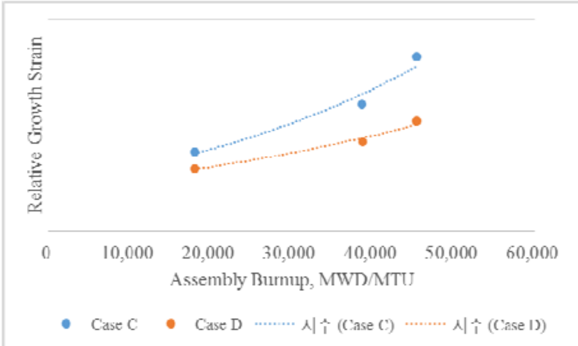
Fig. 2 compares the grid width growths on each type of fuel assembly. Fig. 2(a) shows that the grid width growth in Case A is accelerated as a function of burnup. It seems to be due to acceleration of hydrogen absorption as a function of burnup. Fig. 2(b) shows the grid width growth difference by grid material on Case C and Case D. The grid width growth in Case C with the different design and the same grid material is greater than that in Case A as shown in Fig. 2(a) and Fig. 2(b). In considering Case E and Case F use the same grid material and has the similar grid design, the grid width growth behaviors are quite different. The grid width growth in Case E is linearly increased or smoothly accelerated as a function of burnup while the grid width growth in Case F is steeply accelerated at higher burnup.

IV. CONCLUSIONS AND FUTURE WORKS

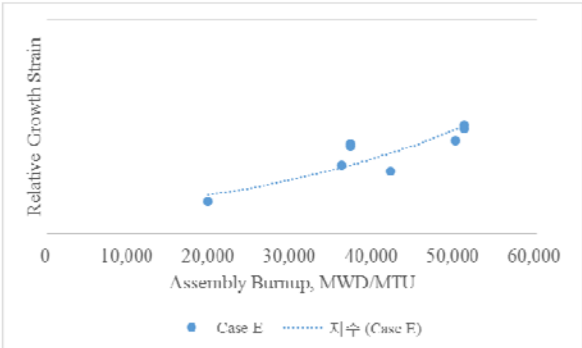
During in-reactor verification test programs for the advanced fuels of PLUS7^{TM}, HIPER16, and ACE7^{TM}, several verified materials were introduced. Three(3) types of growths were measured through poolside examination and compared to as-built data. The effect of rod growth difference by material on assembly growth were investigated. The different assembly growth was due to the compressive creep on guide tubes resulted from the different drag force due to rod growth difference. The fuel assembly growth increased linearly as a function of burnup at cycle 1 but were saturated at cycle 2. It was due to the drag force decreased by cycle. The grid width growth was accelerated as a function of burnup due to acceleration of hydrogen absorption as a function of burnup. The grid width growths were quite different by grid designs, which were smoothly or steeply accelerated smoothly as a function of burnup. To develop the codes to predict their growth behaviors in reactor, the growth database by design or material should be widely accumulated through poolside examination and post-irradiation examination, and the effect of each parameter on these growths should be separated.



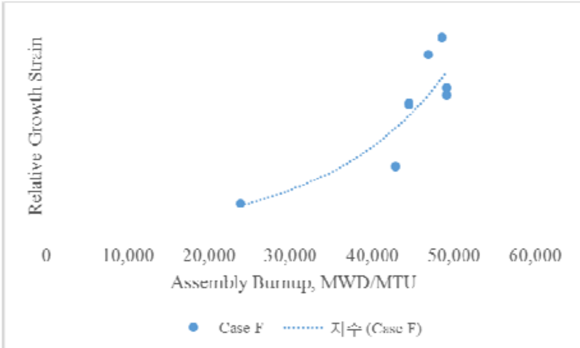
(a) Case A



(b) Case C and Case D



(c) Case E



(d) Case F

Fig. 2. Grid width growth as a function of assembly burnup

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