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KNFC FUEL SERVICE TECHNOLOGY DEVELOPMENT

Jin-Young Park, Yong-Bock Kwon, Jae-Soon Choi, Jong Youl Park, Joong Cheol Shin
Fuel Service Department
Korea Nuclear Fuel Co., Ltd.
P.O. Box 14 Yuseong, Daejeon, 305-353, Korea
Tel: 081-42-868-1821, E-Mail: jypark@knfc.co.kr

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Korea Nuclear Fuel Co., Ltd. (KNFC) is supplying Westinghouse 14x14, 16x16 and 17x17 type fuels and W-CE 16x16 type fuels to 16 PWR power plants and also 37-bundle type PHWR fuel to 4 CANDU plant in Korea. KNFC is developing high burnup, high power and high integrity fuel in order to improve plants efficiency, safety and economics.
KNFC developed fuel repair technology to repair failed fuels such as Westinghouse 14x14, 16x16 and 17x17 type fuels and W-CE 16x16 type fuels. And also developed poolside fuel inspection technology to examine irradiation performance of existing as well as on-developing fuels. For the first step, single rod inspection technology to measure oxide layer thickness, fretting wear depth, diameter and defect measurements of single rod was developed and used for irradiation performance examination of Zirlo clad rods of one cycle burned Plus7 LTA (Lead Test Assembly, similar to WCE-type fuel assemblies) in October 2002 and second cycle burned Plus7 LTA in May 2004 at YGN#4.
For second step, fuel assembly inspection and function test technologies such as assembly bowing, twisting, and growing measurements, grid width and position measurement, peripheral rod growing and diameter and inside rod oxide layer thickness measurement have been developed and used for irradiation performance examination of two Plus-7 LTA, at UGN#3 in April 2004.
Now, KNFC is developing fuel ultrasonic cleaning technology to resolve axial offset anomaly that is occurred during operation of cycle in longer cycled core of PWR.

1. INTRODUCTION

1.1 Nuclear Power Plants and Fuels in Korea

Since Kori Nuclear Power Plant unit 1 started commercial operation in 1978, nuclear power plants have been constructed continuously in every one or two years in Korea. Now, 8 Westinghouse type nuclear power plants and eight (8) OPR1000 (Optimized Power Reactor; similar to W-CE type) and four (4) CANDU nuclear power plants are operating (Table 1). Additional nuclear power plants are scheduled to be constructed one by one in every one or two years.
KNFC is supplying 400 tonU/year of CANDU 37 rod cluster type fuel and 350 tonU/year of Westinghouse 14x14, 16x16 and 17x17 type fuel and W-CE 16x16 type fuel (Table 1, Figure 1) to these nuclear power plants, and increasing it’s capacity according to the increase of nuclear power plants and developing advanced fuels, as a result, become one of the leading world nuclear fuel suppliers.

Table 1. Nuclear Power Plants and Fuels in Korea

Nuclear Power Plant	Fuel Type	FA/Core	Capacity	Cycle Length	Comment
KRN#1	W 14x14	121	587 MWe	12 M	STD
KRN#2	W 16x16	121	650 MWe	12 M	Ace7 16x16

KRN#3,4, YGN#1,2 and UCN#1,2	RFA (Robust FA)	157	950 MWe	18 M	Ace7 17x17

Table 1. Nuclear Power Plants and Fuels in Korea (continued)

Nuclear Power Plant	Fuel Type	FA/Core	Capacity	Cycle Length	Comment
YGN#3,4,5,6 UCN#3,4,5,6	Guardian	177	1,000 MWe	18 M	Plus7 16x16
Shin Wolsung#1,2 Shin Kori #1,2	Guardian	177	1,000 MWe	18 M	Plus7 16x16, (Under Construction)
Shin Kori #3,4	Plus7	241	1,400 MWe	18 M	Plus7 16x16 (Under Construction)
WSN#1,2,3,4	37 rod Cluster	4,560	679 MWe	15 M	Natural U

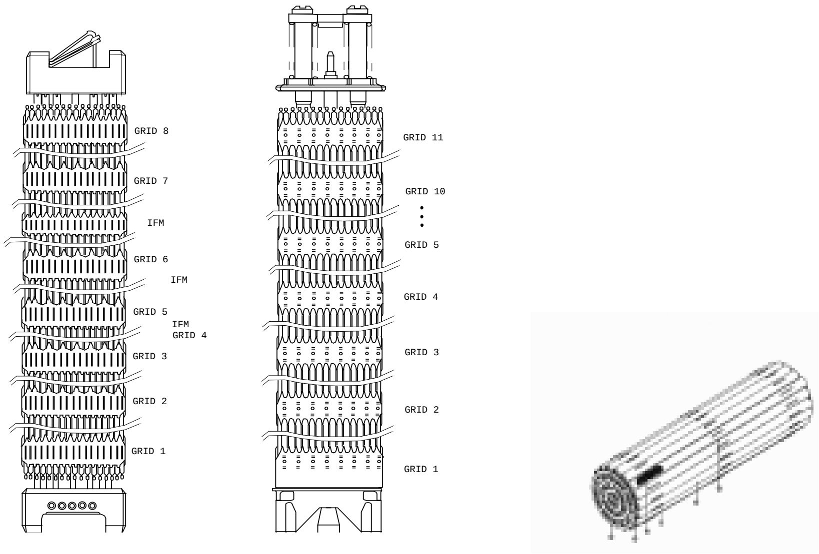

Figure 1. Westinghouse Fuels (left), W-CE Fuel (middle) and CANDU Fuel (right)

1.2 Fuel Service Technology Requirement

Most of utility eager to operate nuclear power plant more economically and efficiently as far as safety is maintained. As a matter of fact, so many nuclear fuels have been used; eventually some of fuels were damaged and/or failed during irradiation and/or handling mistakes. Several times, foreign engineers were invited to repair or inspect damaged fuels in Korea. Whenever Korean utility, KHNP (Korea Hydraulic Nuclear Power Cooperation), try to adopt new improved fuel, regulatory authority requests out-pile as well as in-pile test reports. Such aspects enforced KNFC to buildup fuel service technology.

1.3 Out-pile verification test required to backup Nuclear Fuel Development Plan

KNFC devotes all his effort to develop high burnup, high power and high integrity fuel to meet utility's wish to improve plant safety and efficiency. KNFC is developing advanced fuels such as Plus7 16x16 for OPR1000, Ace7 17x17 and Ace7 16x16 for Westinghouse type nuclear power plant. Change of cladding tube and design initiate in-pile verification tests as well as out-pile tests (Table 2).

Table 2. Advanced Nuclear Fuel In-Pile Test Schedule

	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11
Zirlo Cladding	Oct.		Apr.	Oct.						
PLUS7			Apr.	Oct.		Apr.	Oct.			
ACE7 17x17					Nov.		May	Nov.		May
ACE7 16x16					Apr.	July	Oct.		Jan.	

2. FUEL REPAIR TECHNOLOGY DEVELOPMENT

Before fuel repair technology developed, wheneVer one or two cycle burned fuel(s) which scheduled to be used at next cycle is (are) damaged, four fuel assemblies for each damaged fuel are substituted to keep symmetry of the core. The core loose 7 days for one damaged fuel and 10 days for two damaged fuels and so on. As a result of the fuel damage and loss of full power days, the nuclear power plant loose about one million dollars per each loss days of the cycle.

During startup test of YGN #4 of KHNP in 1995, coolant monitor shows radioactivity peaks. KHNP imports fuel reconstitution equipment and tools ((a) in Figure 2). KNFC build up fuel service group and re4paired the failed fuel by substituting two fuel rods with SUS rods with W-CE engineers.

In 1998, KNFC rents W-17x17 type fuel reconstitution equipment and repaired two failed fuels substituting damaged fuel rods with SUS rods jointly with Westinghouse at UCN#2.

In 2000, KNFC began to develop fuel repair technology jointly with W-Atom with a government R&D fund. Just after developed W-17x17 type fuel repair technology, KNFC repaired, jointly with W-Atom, 5 and 2 fuel assemblies of YGN #1 and #2 respectably, substituting damaged fuel rods with SUS rods. KNFC developed also fuel repair technology for W-14x14 fuels and W-16x16 fuels as well as fuel up-side-down rotation system ((b) in Figure 2). Up to now, KNFC repaired numerous damaged fuels and saved enormous amount of plant operation cost and increased plant safety.

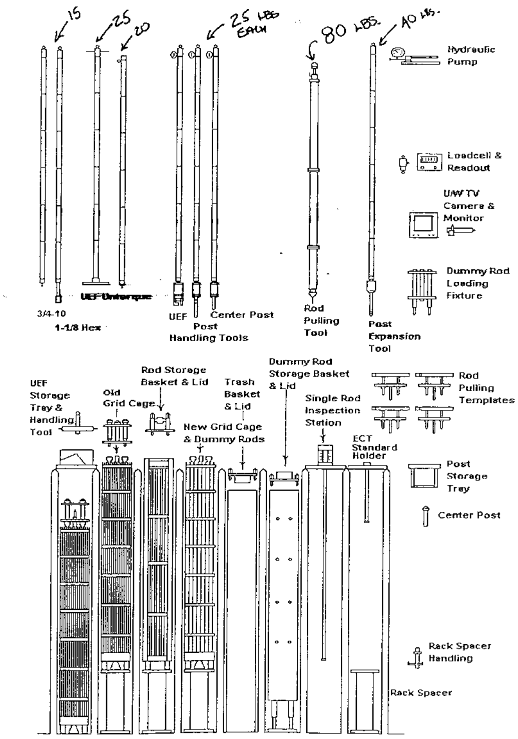

Figure 2. W-CE Type Fuel Repair System

3. FUEL INSPECTION TECHNOLOGY DEVELOPMENT

Whenever fuel is failed, utility, fuel supplier, nuclear regulatory authority, publics etc. are eager to know the root course of the fuel failure. Whenever new fuels are introduced, in-pile and out-pile tests are required. To develop advanced fuel and meet these requirements, KNFC has to build up poolside fuel assembly and single rod inspection technology.

3.1 Single Rod Inspection Technology Development

In 1999, KNFC tried to change fuel rod clad to improve irradiation performance and submit safety analysis report to nuclear regulatory authority to get approval to use. They approved to use under condition of verification test to prove oxide layer thickness to be less than 100μm and submit oxide layer thickness estimation model. In August 2001, KNFC rents a single rod inspection system from W-Atom (Sweden) and, jointly with W-Atom, measured oxide layer thickness of fuel rods irradiated up to 51.7 MWD/KgU ~ 57.1 MWD/KgU for 4cycles at

YGN#3.

After the single rod inspection campaign, KNFC began to develop poolside fuel inspection technology along with three years government R&D project; 'Development of fuel irradiation performance examination technology' from September 2002. For the first step, KNFC developed, jointly with Tecnatom (in Spain), single rod inspection technology for visual inspection, rod diameter, oxide layer thickness, wear depth and position of general defects measurements (Figure 3).

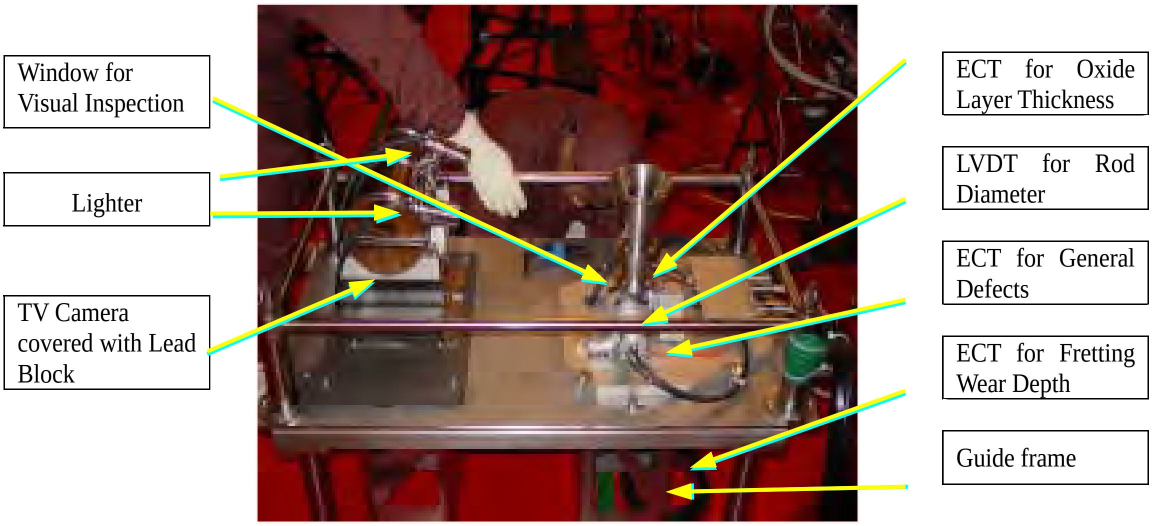

Figure 3. Single Rod Inspection Stand

By this time, KNFC tried to change cladding of the KSNP fuel to Zirlo tube to improve irradiation performance of the fuel. In 1999, KNFC submit safety analysis report for approval of change KSNP fuel clad to Zirlo tube to government nuclear regulatory authority. The nuclear regulatory authority requested to provide depth and mode of fretting wear.

After careful preparation including training, KNFC performed poolside inspection with eight rods from one cycle burned two fuel assemblies, jointly with Tecnatom, at YGN#4 in October 2002 (Figure 4). During the poolside inspection campaign, fretting wear depth, oxide layer thickness, rod diameter and positions of general defects measurements and visually inspection were performed for qualification of the fuel irradiation performance. Fuel repair technology was used to take out the single rods from fuel assemblies.

Next poolside inspection campaign was carried out with two cycles burned Zirlo tube fuel on April 2004.

Figure 4. Single Rod Inspection with W-CE Fuel Repair System at YGN#3

3.2 Fuel Assembly Inspection Technology Development

Along with development of PLUS7, KNFC was enforced to develop fuel assembly inspection technology. Along the 2nd step of the government R&D project, KNFC developed fuel assembly inspection technology jointly with AREVA Framatom. Peripheral rod bowing (gaps between rods) and growth (Figure 5), inner rod oxide layer thickness (Figure 6) and rod diameter (Figure 7), grid width (Figure 8) and positioning, assembly growing, bowing and twisting are major items to be inspected. Just after development of the assembly inspection technology, KNFC performed jointly with AREVA Framatom fuel inspection campaign (Figure 9) with one cycle (18month) burned two LTAs of Plus-7 at UCN#3 on May 2004. As all the poolside inspection results were acceptable to guide line of the regulatory board so as to allow Plus7 fuel loaded in the next reload region of the core.

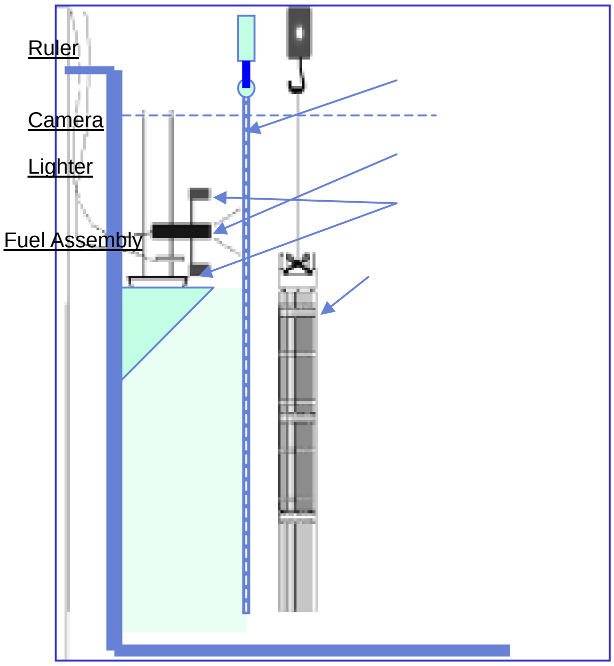

Figure 5. Fuel Assembly Visual Inspection System

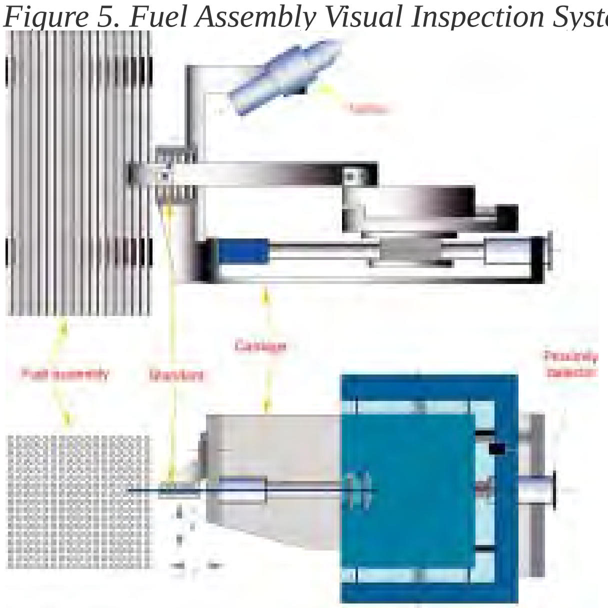

Figure 6. Rod Oxide Layer Measurement System

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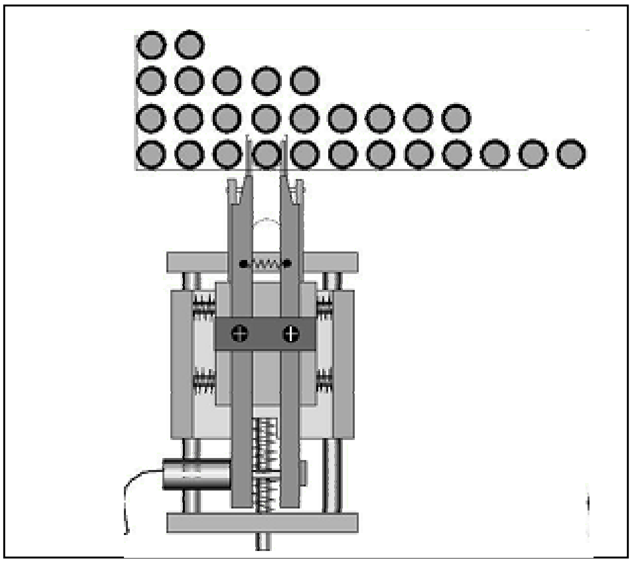

Figure 7. Peripheral Rod Diameter Measurement System

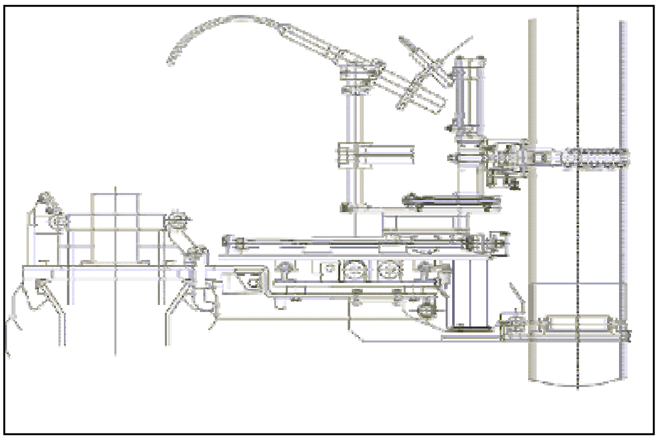

Figure 8. Grid Width Measurement System

Figure 9. Fuel Assembly Inspection Campaign at UCN#3

3.3 Fuel Component Function Test technology Development

When improvements of fuel to get longer cycle, higher burnup and higher power are applied, major technical interests are focused to oxidation of the cladding and grid design. Recently, fuel components mal-function appears to be important aspects to be resolved. According to the 3rd step of the R&D project, KNFC is developing fuel component inspection technologies; fuel rod dragging force and top nozzle dragging force measurement (Figure 10) and grid cell size inspection technologies. Near future, KNFC will develop grid cell visual inspection with endoscopes, spring force, top end piece drag/install force and top end hold-down spring force measurements and fuel assembly guide thimble inspection technologies.

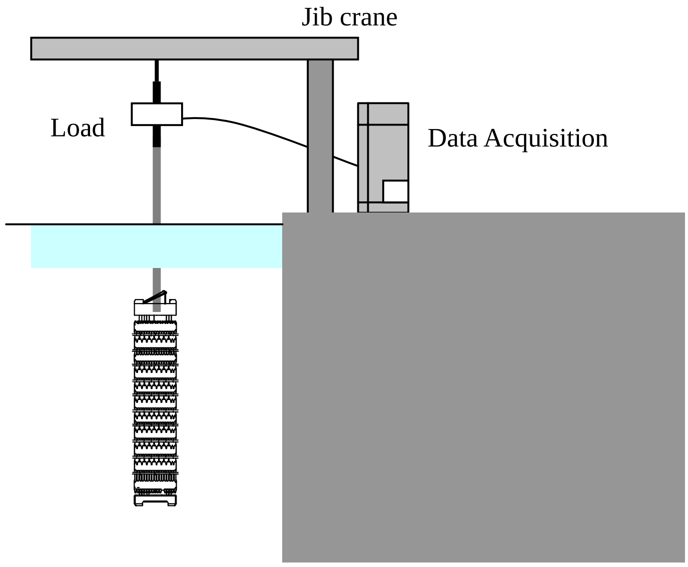

Figure 10. Fuel Rod Dragging Force Measurement System

4. AXIAL POWER OFFSET ANOMALY (AOA)

4.1 Definition of AOA

Nuclear power plant operation is restricted by safety factors such as safety limit to keep fuel integrity (SL), limiting safety system set points to maintain fuel integrity (LSSS; important factor: fuel melting point, 118% of full power, power/offset), limiting conditions for operations (LCO's; operational limit of initial condition for safety analysis) and axial offset or axial imbalance of upper power to lower power in core (AO; AO = (P_t-P_b)/(P_t+P_b) x 100, where P_t = total power of upper half of the core, P_b = total power of lower half of the core) as shown in Figure 11. Design factor for operation of AO or ΔI - 4.0, and limiting value for operation is between about –12 and +12, may slightly different depends on reactor type.

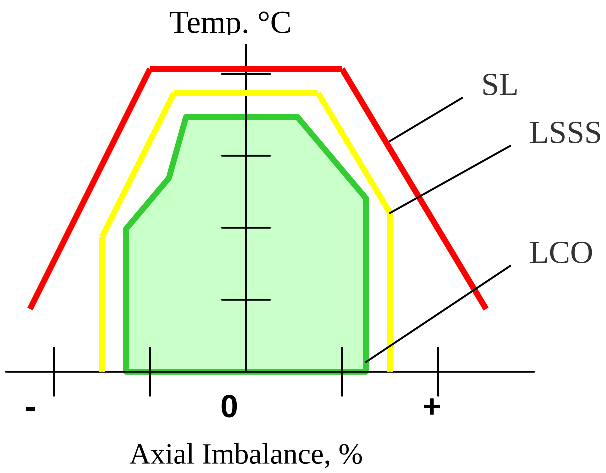

Figure 11. Major important factor for plant operation

As nuclear power plants are operating for long time (18 ~ 24 month) at high power, metallic oxide (① in Figure 12) are dissolved from inner surface of primary system and deposits on surface of fuel rods and becomes a thick ceramic structured layer which is called as crud. The crud composed with mainly oxide of iron and nickel oxide and minor boron and lithium oxide.

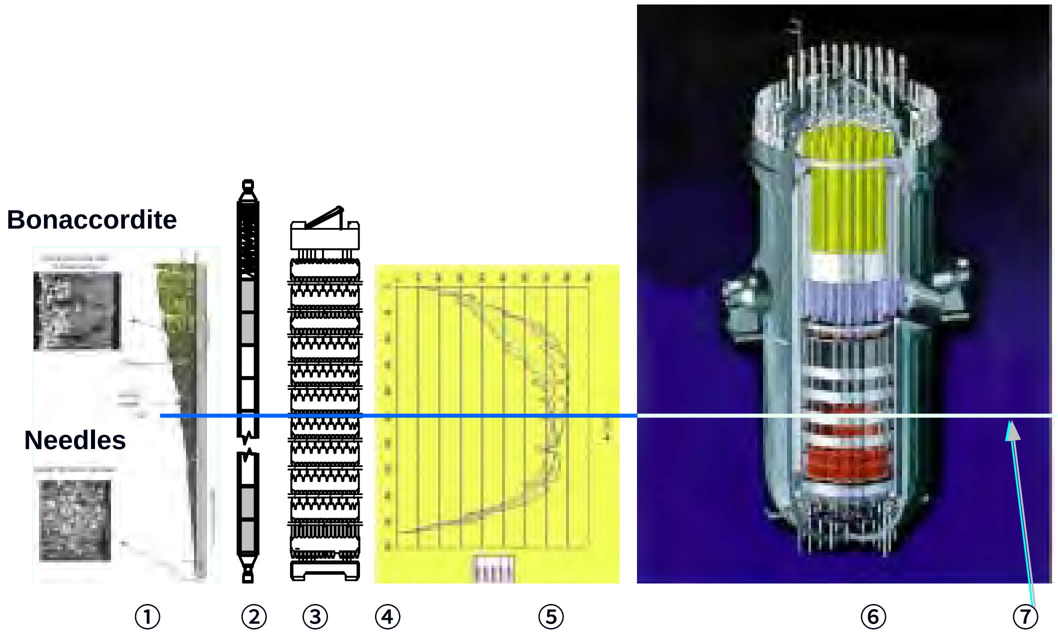

Figure 12. Axial Offset and Crud Deposition; ①: crud, ②: crud deposition profile, ③: nuclear fuel rod, ④: nuclear fuel assembly, ⑤: axial power profile, ⑥: nuclear reactor and ⑦: middle line of reactor belt line

As surface temperature of upper part of clad of fuel rods in fuel assembly is higher than that of lower part, the crud deposit on upper part of the core is much thicker than that of lower part as shown in ⑤ **of** Figure 12. Accordingly, boron deposits more on the upper part of the fuel rod than the lower part and so power of upper part becomes reduced than that of lower part. At the end of the core cycle, this unbalance of power distribution grow and grow and makes axial power offset anomaly (AOA). The loss of power due to the AOA during the cycle becomes equivalent to about five (5) effective full power days. These AOA occurred in mainly high enriched, low leakage and long cycle core.

4.2 Effect of the AOA

Once AOA occurs, peaking factor and shutdown margin reduces and enforces to reduce power [economic loss]. Crud concentration in the core does not reduced even during shutdown. Crud on the used fuel moves to nucleate boiling region of new fuel from beginning of the next cycle. And, the crud induces fuel failure and primary system contamination [plant safety and radiological problems]. The fuel with high amount of crud needs to be cleaned or substitute with new fuel [economic loss].

4.3 Case of AOA

Recently, Callaway, Catawba 1, Comanche Peak 2, Millstone 3, Seabrook, Vogtle 1&2 and Wolf Creak nuclear power plants reduced operation power during the time closer to EOC and shutdown reactor earlier than scheduled date due to the AOA. Even in Korea, AOA occurred in several Westinghouse type nuclear power plants. Recently, Callaway, Vogtle and Wolf Creak cleaned fuel using ultrasonic technology. AOA occurred and peaking factor was reduced also in long cycled core of Parlo Verde W-CE type nuclear power plant. Even in the core of Paks nuclear power plant (Russian VVER Reactor) in Hungary also experienced AOA.

4.4 Solutions for the AOA

4.4.1 ICEDECTM: W-Atom developed crud cleaning technology using water mixed with ice powder which is successful for BWR fuel but for PWR fuel.

4.4.2 CORD UV: Framatome-G developed crud cleaning technology with chemical method and demonstrate with VVER fuel at Paks in Hungary but not successful.

4.4.3 Ultrasonic Cleaning Technology: Dominion Engineering Co.(DEI) and EPRI developed ultrasonic fuel cleaning technology and used to clean fuel of Callaway nuclear power plant for the first time and performed cleaning more than 10 times by now.

4.4.4 KNFC starts to develop ultrasonic fuel cleaning technology jointly with DEI and EPRI from early of this year.

5. SUMMARY

KNFC developed fuel service technologies; fuel repair technology as well as fuel inspection technology. By using fuel service technology, KNFC helped KHNP (utility) to improve plant safety and reduce operation cost, refueling outages and radiation exposure of the operating personnel.

Recently, KNFC continues to develop and deploy fuel inspection, measurement and repair systems based on its many years of internal experience and international technical cooperation with Westinghouse, Framatome and Tecnatom. These fuel service works have also been provided increasingly for PWR plants in Korea.

Major fuel service works of KNFC are:

[1] Evaluation of the analysis data of coolant radioactivity and infer the burn-up of the damaged fuel assembly, if any.

[2] Repair failed fuel.

[3] Poolside single rod inspection; visual inspection, measurement of rod diameter, oxide thickness, swelling and general defects.

[4] Poolside fuel assembly inspection; fuel assembly growing, twisting and bending, peripheral rod diameter, oxide layer thickness and bowing and grid positioning and size changes.

[5] The objective fuels are 14x14, 16x16 and 17x17 Westinghouse type fuels and 16x16 W-CE type fuel.

[6] In near future, KNFC will develop ultrasonic fuel cleaning system and, as a result, fuel cleaning will be another big business.