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Performance Evaluation for New Design of 37-element Fuels

Sungmin Kim, Youngae Kim

Korea Hydro and Nuclear Power Co., Ltd., 1312Gil, 70, Yuseongdaero, Yuseong-gu, Deajeon, 34101, Korea
**Corresponding author: kimsungmin@khnp.co.kr*

1. Introduction

As a CANDU reactor ages, the thermal margin has reduced due to an aging phenomena such as pressure tube diametral creep, which increases bypass coolant flow to the fuel bundle in the channel. To mitigate this problem, Korea Hydro & Nuclear Power Co. Ltd. (KHNP) decided to load the new design of fuel bundle into the Wolsong NPP site in 2013. The new design of 37-element fuel bundle was developed by Canadian utilities, which is the same as the existing 37-element fuel bundle but for smaller center pin diameter. As the licensing process, KHNP performed the demonstration irradiation (DI). So, new design of fuel bundles were loaded in selected fuel channels of B10 and P17 at Wolsong NPP Unit 4 in October 2014. During the DI test period, KHNP had monitored various fuel performance parameters for the new design bundles. This paper shows performance results of P17. During the DI test of P17, fuel performance parameters had monitored. These are bundle power, bundle burnup, channel temperature and failed fuel detection. Also KHNP had performed visual inspection at the spent fuel bay. This is interim result of DI test. After finishing DI test, we will issue final result.

2. DI Test

Twenty-six new design of 37-element fuel bundles were fabricated by KEPCO Nuclear Fuel company, Korea, to the quality assurance levels normally applied to 37-element fuel supplied to Wolsong NPPs. For the DI test, the channel P17 and B10 were selected as Fig. 1. The P17 channel is at not very high power channel and flow-assist-fuelling region. It is to investigate performance evaluation at the full core refueling status. The B10 channel is at low power channel position and flow-assist ram-extension region. It is to investigate transition core with mixed fuel. The following objectives were monitored.

- To meet Limiting Condition for Operating (LCO) of channel and bundle power
- To experience wide power variation
- To experience normal dwell time
- To experience normal fuelling-induced power ramps
- To experience the highest burnup
- To experience the longest time
- To experience the longest time

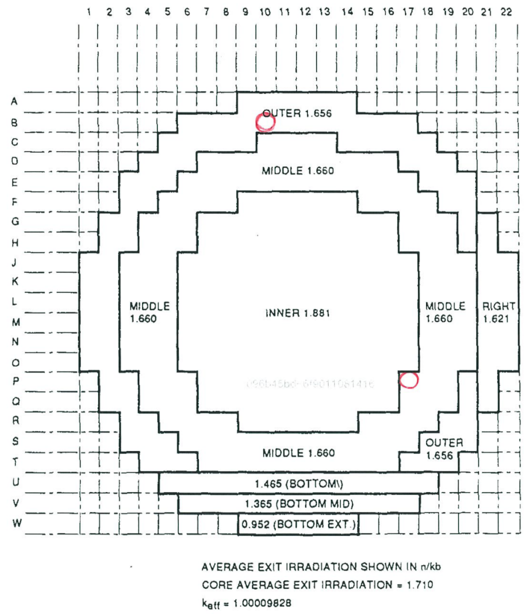

Fig. 1. Position of DI Test Channel and Exit Irradiation

3. Failed Fuel Detection Systems

CANDU Pressurized Heavy Water Reactors are refueled on-power with natural UO_2 fuel clad in collapsible Zircaloy-4 sheathing (Fig. 2)

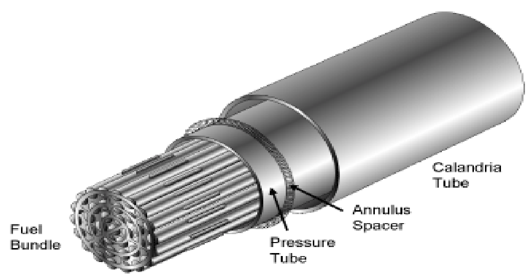

Fig. 2. Standard CANDU Fuel Bundle, Pressure and Calandria Tube.

CANDU-6 has two failed fuel detection systems, which operate independently, are provided as standard equipment on each reactor unit: the Gaseous Fission Product (GFP) monitor and the Delayed Neutron (DN) system.

3.1 Description of GFP Monitor

The GFP monitor is a computer controlled high resolution gamma ray spectrometer. It is designed to operate continuously, repeatedly measuring the gamma ray activity of certain gaseous fission products, Xe-133, Kr-88 and Xe-135, and of I-131, present in continuous sample flows from each of the two Heat Transport System (HTS) loops. The two sample lines, one from each HTS loop, carry the coolant from the HIS pump discharge to the sample holders. The sample transit time is designed to be about 15 minutes to ensure sufficient time to remove unwanted F-17 by radioactive decay.

A switch, located in the control room, is connected to air controlled valves that select the origin of the coolant in the sample tubes. Either loop1, loop2 or both loops mixed together can be monitored. This enables the operator to determine which loop contains a defective fuel bundle.

The noble gas Xe-133 (81 keV) is a long-lived fission product which has a high release rate from defective fuel. Its concentration when compared to that of short lived fission gas, such as Kr-88 (191 keV), provide some indication about the source, the extent of fuel sheath damage and the buildup of tramp uranium in the core.

The noble gas Xe-135 (250 keV), provides some information about the iodine release rates when high purification rates are removing fission products. This is due to the radioactive decay of I-135 to Xe-135 in the ion-exchange system. Since the noble gases are not retained by the ion-exchange system, it becomes a secondary source of Xe-135.

Radio-iodine I-131 (364 keV) is monitored for public safety reasons due to its biological hazard. Since its concentration is suppressed by the ion-exchange system, it is not a reliable indicator for assessing fuel damage. But, sometimes it makes spike during power transients.

3.2 Description of DN System

The DN system has to locate the fuel channel containing the defective fuel, and to be analyzed to determine when defective fuel deteriorates and release uranium to the coolant. Sampling lines from each of the 380 fuel channels carry coolant to the sample coil arrays in two water filled moderator tanks, one in each scanning room. Six BF_3 counter in each room are positioned by their carriage and lowered into the sample coil dry wells. The data are collected during the preset counting time and analyzed by an on line computer. The detectors are raised and repositioned in sequence until all channels have been scanned.

The design of the sampling lines incorporates a deliberate 50 second delay to eliminate interference from unwanted activation products. These are photo neutron producing N-16 and neutron emitting N-17. This leaves a high relative concentration of neutron emitting fission products: I-137 and Br-87 [1].

4. Fuel Performance Results

During the DI test of P17, fuel performance parameters had monitored. These are bundle power, bundle burnup, channel temperature and failed fuel detection. Also KHNP had performed visual inspection at the spent fuel bay [2].

The bundle power, bundle burnup, channel temperature and failed fuel detection were shown in Table 1 and Figure 3~8. The bundle powers are below of limiting condition of operation of bundle power (898kW) and average discharge burnup is 114% of target burnup. There is no remarkable trend of the channel temperature of P17. The GFP and DN data are not increased during monitoring period. It means that there is no sign of defected fuel.

Table 1. Bundle Burnup and Power of P17

Bundle Position	Fuel	Serial Number	Burnup (MWD/MTU)	Maximum Bundle Power(kW)
5	37M	C450022	7595.2	778.4
6		C450023	8016.5	847.9
7		C450025	8036.3	850.6
8		C450026	7617.5	786.7
9	37R	C303916	7940.4	687.1
10		C303915	8765.7	565.2
11		C303914	8429.6	389.8
12		C303913	6875.4	164.4
Average			7909.6	

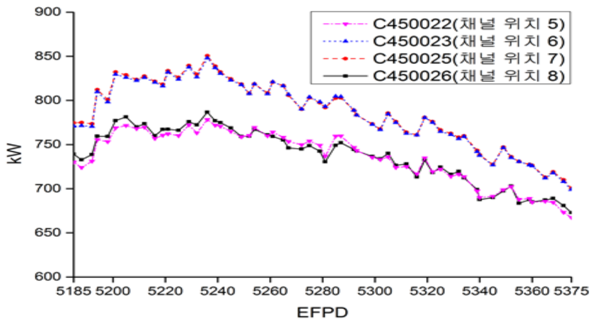

Fig. 3. Bundle Power Trend of P17

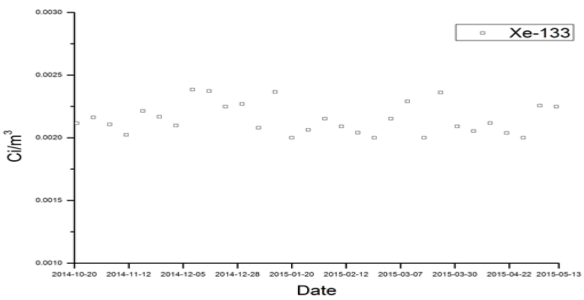

Fig. 4. Xe-133 Trend of HTS

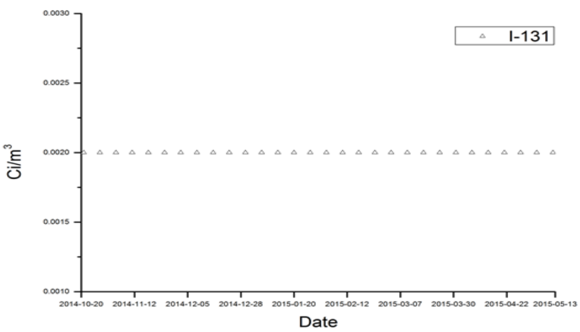

Fig. 5. I-131 Trend of HTS

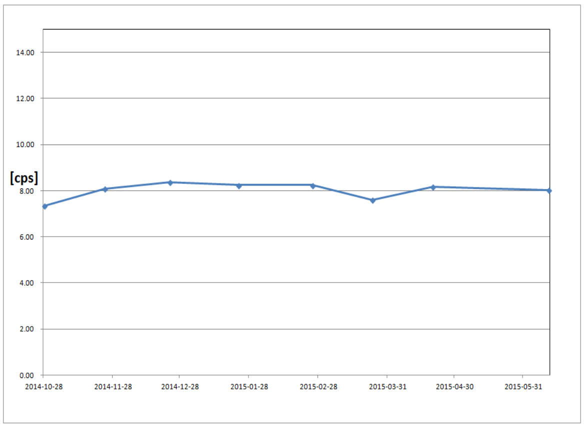

Fig. 6. DN CPS of P17

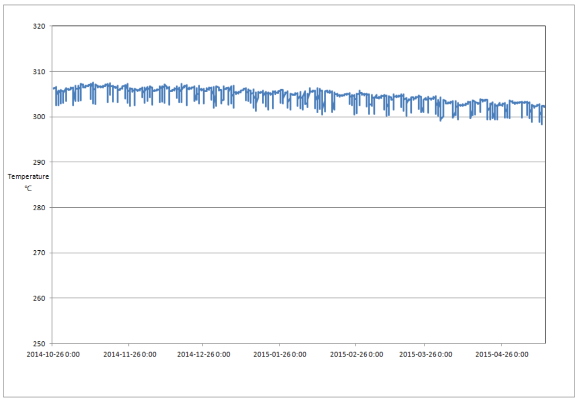

Fig. 7. Channel Temperature of P17

After discharge, P17 bundles were cooled at the spent fuel bay more than one month. After that we had inspected all of new design fuel bundles of P17. Fig.8 shows visual inspection results of of C450022. There is no sign of defected fuel.

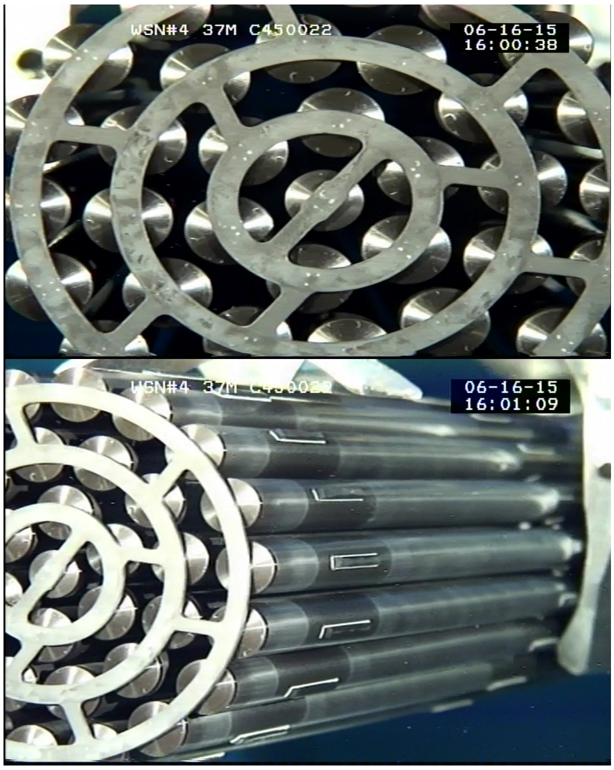

Fig. 8. Visual Inspection Results of C450022

5. Conclusion

The fuel performance parameters, which had been monitored about 6 months, showed that the new design fuel in P17 was being burnt with no significant or remarkable problems. The behavior of the new design fuel bundles was nearly the same as that of the existing fuel bundles.

After DI test, KHNP had performed visual inspection at the spent fuel bay. There are no sign of defect fuel. Therefore, based on the monitored parameters and visual inspection, the new design fuel can be loaded in the Wolsong reactors. The final fuel performance evaluation report will be issued.

REFERENCES

[1] A.M. Manzer, 'In-Core Assessment of Defective Fuel in CANDU-600 Reactors,' Aug 2015.

[2] Sungmin Kim et al., 'Performance Evaluation of Modified 37-element Fuels during Demonstration Irradiation,' Aug 2015.