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# Evaluation of Fuel Performance for Fresh and Aged CANDU Reactor

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## 1. Introduction

Like all other industrial plants, nuclear power plants also undergo degradations, so called ageing, with their operation time. Accordingly, in the recent safety analysis for a refurbished Wolsong 1 NPP, various ageing effects were incorporated into the hydraulic models of a number of the components in the primary heat transport system for conservatism. The ageing data of thermal-hydraulic components for 11 EFPY of Wolsong 1 were derived by using NUCIRC [1] code based on the site operation data and they were modified to the appropriate input data for CATHENA [2] code which is a thermal-hydraulic code for a postulated accident analysis.

This paper deals with the ageing effect of the PHTS (primary heat transport system) of CANDU reactor on the fuel performance during the normal operation. Initial conditions for fuel performance analysis were derived from the thermal-hydraulic analysis for both fresh and aged core models. Here, fresh core means a core state just right after the refurbishment and the aged core is 11 EFPY state after the refurbishment of Wolsong 1. The fuel performance was analyzed by using ELESTRES [3] code for both fresh and aged core state and the results were compared in order to verify the ageing effect of CANDU HTS on the fuel performance.

## 2. Ageing Mechanisms in CANDU HTS

Fig. 1 shows a simplified presentation of the HTS components and coolant flow of a typical CANDU-6 reactor. Ageing of each HTS component may cause some changes to the primary HTS characteristics and these changes also affect operational and safety margins of CANDU reactor.

The ageing mechanisms which are relevant to modeling of the hydraulic characteristics of the Wolsong 1 main HTS include pressure tube diametral creep, magnetite deposition, and feeder orifice degradation [4]. Based on the primary ageing mechanisms, main hydraulic parameters were incorporated into the corresponding hydraulic model of 11 EFPY core after refurbishment.

- <u>Pressure Tube Diametral Creep</u>:

This phenomenon is due to the effects of irradiation by neutron flux, stress and reactor operating temperatures over the plant life. The increase in local pressure tube diameter reduces the effective local hydraulic resistance in the channel due to the increase in the local flow area, and the reduction in the frictional and form losses associated with sub-channel flow redistribution as more of the flow occurs in the larger space outside the fuel bundles. The corresponding reduction in flow in the sub-channel between adjacent fuel elements allows more sub-cooled boiling to occur and reduces the margin to fuel element dryout.

- <u>Magnetite Transport and Deposition</u>:

This arises from the varying solubility of magnetite with temperature and the variation of temperature around the heat transport circuit. The magnetite deposition on the various PHTS components has resulted in increased inside surface roughness and thus increased pressure drop across these components.

- <u>Degradation of Inlet Feeder Orifices</u>:

The reduced hydraulic resistance is due to rounding of the edge of the orifice plates associated with erosion and corrosion. With the other hydraulic characteristics of the orificed channels remaining constant, there would be an increase in flow in those channels.

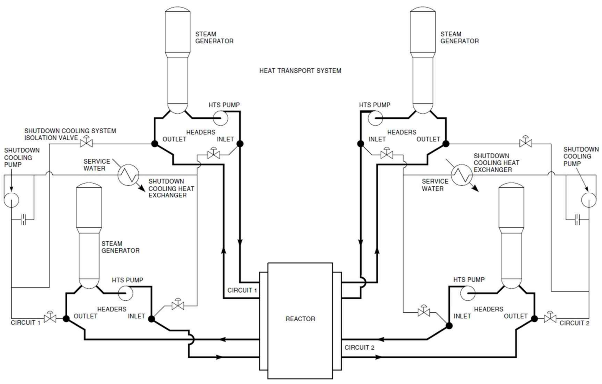

Fig. 1 Simplified CANDU-6 HTS

## 3. Evaluation of Fuel Performance

For the conservative evaluation, a limiting channel was assumed to have a channel power of 7.3 MW and the two central bundles at 935 kW.

### *3.1 Initial Conditions for Fuel Analysis*

The initial values of main thermal-hydraulic parameters for both fresh and 11 EFPY aged cores are summarized in Table 1. The RIH temperature and exit void fraction of aged core were conservatively assumed. From the CATHENA simulation, the steady-state thermal-hydraulic conditions of coolant pressure, temperature, and heat transfer coefficient were determined. The power-burnup histories for each ring were derived from the refueling simulation results and the ring power ratios. These coolant conditions and power-burnup histories were provided to ELESTRES code input to analyze the fuel performance for each fresh and aged core.

Table 1 Initial Condition of Single Channel Parameters

| Parameters | Fresh Core | Aged Core |
|---|---|---|
| Void Fraction at RIH (%) | 0.00 | 0.00 |
| Void Fraction at ROH (%) | 0.0 | 0.27 |
| RIH Temperature (°C) | 261.05 | 267.15 |
| ROH Temperature(°C) | 309.50 | 310.57 |
| Channel Flow Rate (kg/s) | 26.02 | 22.63 |
| RIH Pressure (MPa(a)) | 11.25 | 11.16 |
| ROH Pressure (MPa(a)) | 10.00 | 10.03 |
| Pressure Difference (MPa(a)) | 1.24 | 1.13 |
| Channel Power (MW) | 7.30 | 7.30 |

### *3.2 Fuel Performance Results*

Fig. 2 shows the results of fuel centerline temperature of outer element and center element of bundle 7 for the fresh and aged cores. Pellet centerline temperatures of the aged core fuel are higher than those of the fresh core fuel. This is because of the higher coolant temperature and lower heat transfer coefficient of the aged core. Fig. 3 shows the internal gas pressure results for two core states. The internal gas pressure for the aged core fuel is higher than for the fresh core state. This means that more fission product inventory between the fuel pellet and the sheath is produced for the aged core fuel. However, in the case of center element, there is a little difference of the internal gas pressure for two cases of core states. Fig. 4 shows the total hoop strain results at pellet end for two cases. The sheath strain of aged core is higher than that for fresh core. However, in the case of center element, the internal gas pressure is very low compared to the external coolant pressure so that the total strains of two cases have the minus value. That means the center element sheath compresses into the inner direction.

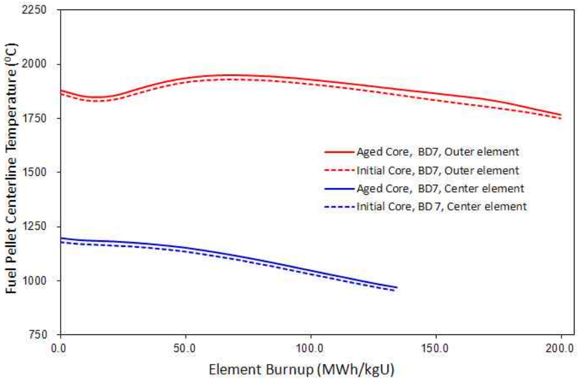


Fig. 2 Fuel Pellet Centerline Temperature

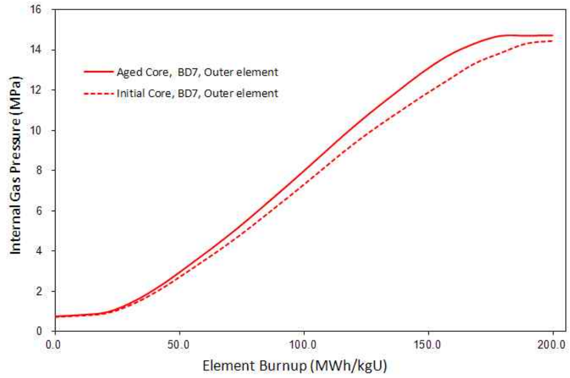


Fig. 3 Internal Gas Pressure

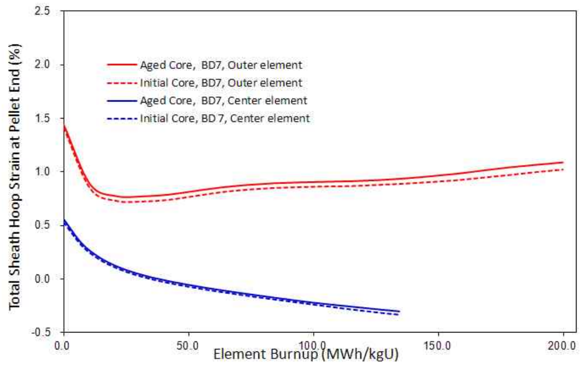


Fig. 4 Total Hoop Strain at Pellet End

## 4. Conclusions

The ageing effect of the CANDU PHTS on the fuel performance during the normal operation was investigated. From the thermal-hydraulic analysis, the coolant conditions of temperature, pressure, and heat transfer coefficient of 11 EFPY aged core were found to be worsen compared to those of fresh core. These thermal-hydraulic conditions directly affected fuel performance during the normal operation so that the thermal-mechanical parameters such as fuel temperature, gas pressure, sheath strain of aged core were found to be more conservative compared to those of initial core.

## REFERENCES

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[4] R. Chauhan, "Development of CATHENA Model of the Wolsong 1 Plant with Post-Refurbishment Aged Core at 11 Effective Full Power Years, AECL Report, 59REF-03500-AR-001, Rev. 1, January 2009.