Effect of High Power Envelop for CANDU Fuel Safety Analysis

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1. Introduction

The main objective of the fuel analysis in safety assessment is to determine the quantity and timing of a fission product release from fuels when a postulated accident occurs in CANDU reactors. The amount of the produced fission product inventory during normal operation is evaluated by using the ELESTRES [1] code which is a design code for CANDU fuel. However, the validation report [2] of ELESTRES code reveals that the code has uncertainty range for some parameters such as fuel temperature, fission gas, sheath strain, and fuel internal pressure. Therefore, it has to be considered that the results from the ELESTRES code may cover the code's uncertainty range when the code is used for a safety evaluation.

Fission product inventories produced during the normal operation are closely related to the level of power and burnup of the irradiated fuel. Maximum inventory of isotopes with a long half-life occurs at the longer burnup such as the time of refueling. On the other hand, the maximum inventory of isotopes with a short half-life occurs when the power is highest.

Accordingly, in this study, the effect of power and burnup history of fuel bundle to the evaluated results from ELESTRES code was investigated. Two types of power envelops, one is a high power envelop and the other is a nominal power envelop, were derived and applied for fuel analysis. Results from two kinds of power envelop were compared and it was confirmed that the results using the high power envelop could cover the uncertainty range of the ELESTRES code.

2. Derivation of Power Envelop

Power and burnup of all the fuel bundles for a given CANDU-6 reactor core state were obtained from physics (refueling) simulations [3]. The nominal power envelop is a curve of bundle power versus bundle average burnup which encompasses most of the bundle powers predicted in a refueling simulation of reactor operation from startup until the time that the last remaining bundle from the initial core was discharged. High power envelop is obtained by modifying the nominal power envelop such as the maximum power is shifted up to the limiting condition for operation for bundle power (935 kW). Fig. 1 shows the nominal and high power envelopes for bundle which were derived from the refueling simulation results of the refurbished Wolsong-1 NPP.

Each fuel bundle in the reactor core experiences a unique irradiation history. The range of linear power and burnup of the fuel elements in the core is wide. However, it is not feasible to simulate each fuel element individually for the fuel initial conditions including the fission product inventory. Therefore, the nominal and high power envelops for each fuel element were used as references for each element power histories in the analysis. Single element power and burnup can be obtained from the bundle nominal and high power envelops using the relative power and burnup conversion ratios which are also known as radial power factor (RPF) and radial burnup factor (RBF). Fig. 2 shows the derived nominal and high power history for each element of the bundle.

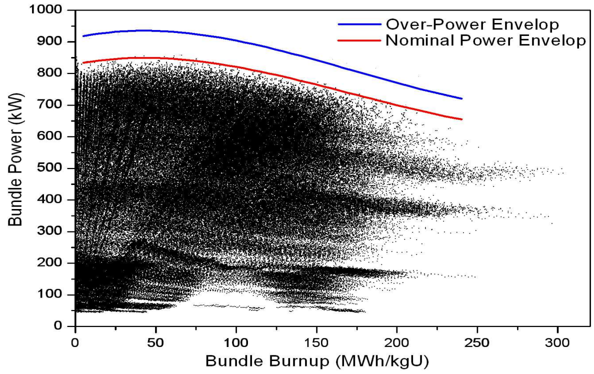

Fig. 1 Nominal and high power envelops of bundle for refurbished Wolsong-1 NPP

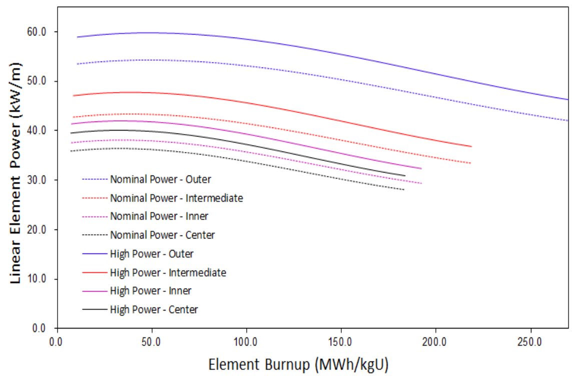

Fig. 2 Nominal and high power histories for each ring

3. Analysis Results

3.1 Fuel Behavior Results

Limiting channel was assumed and analyzed for two kinds of power envelops by using the ELESTRES code. Here, limiting channel is a hypothetical channel, of which channel power is a limiting condition for operation of 7.3 MW. Figs. 3, 4 and 5 show the analysis results of the sheath strain at pellet mid-plane, internal gas pressure and fuel temperature from the outer ring of 6^{th} bundle in the limiting channel for two kinds of power envelops. As expected, results from the high power envelop were higher than the results from nominal power envelop.

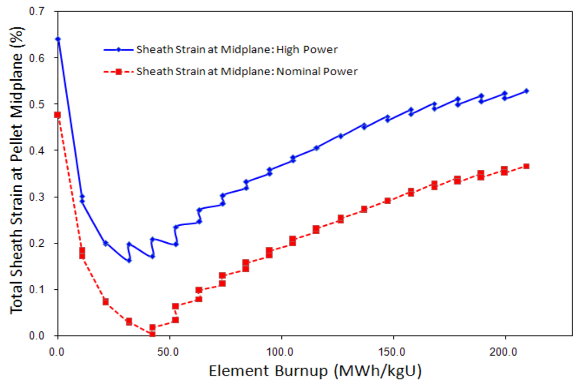

Fig. 3 Total sheath strain results

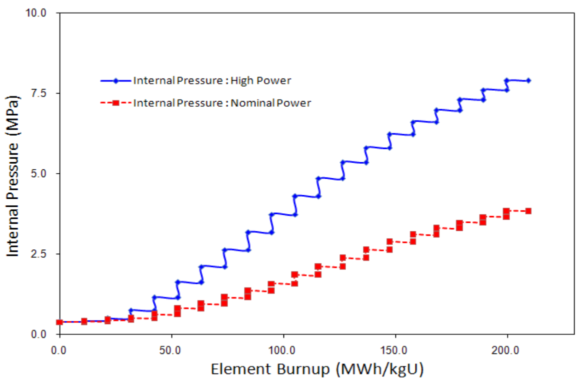

Fig. 4 Internal gas pressure results

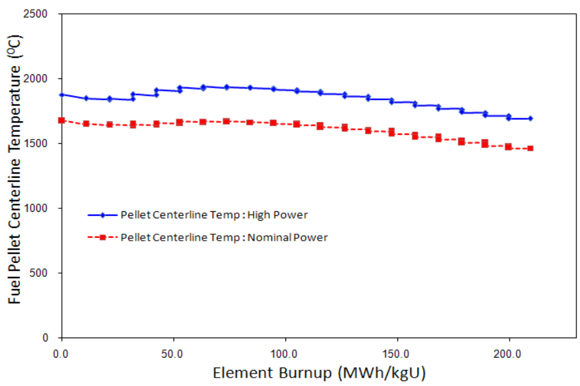

Fig. 5 Fuel pellet centerline temperature results

3.2 Uncertainty Consideration of High Power Envelop

Validation report [2] of ELESTRES code says that there is a bias of code prediction for key output parameters as shown in Table 1. These results were obtained by comparing the measured values from the experiment and calculated values from the code as the following equations.

$$\bar{\varepsilon} = \frac{1}{N}\sum_{i=1}^{N}(P_i - M_i),$$

Where, P: calculated value and M: measured value.

Table 1 Bias of ELESTRES code prediction [2]

Parameter	Code Bias
· Sheath mid-plane strain	· -0.075 %
· Sheath ridge strain	· 0.08 %
· Pellet centerline temperature	· -49 ^{0}C
· Internal gas pressure	· -0.21 MPa

Similarly, the mean relative error between the results from nominal power and high power envelops were evaluated by using the above equation. Here, the calculated and measured values were replaced by the results from the high power and nominal power, respectively. As shown in Table 2, using the high power envelops might be cover the prediction bias of ELESTRES code, especially for fuel temperature and internal gas pressure.

Table 2 Mean errors for the high and nominal powers

Bundle	Mean Error			
	Sheath strain at MP (%)	Sheath strain at ridge (%)	Pellet temp. (^{0}C)	Gas pressure (Mpa)
1	0.0001	0.0000	0.0	0.0001
2	0.0010	0.0010	2.7	-0.0004
3	0.0114	0.0158	12.0	0.0008
4	0.0054	0.0850	36.0	1.5600
5	0.0771	0.0510	72.0	8.2690
6	0.0114	0.0980	45.0	4.4260
7	0.0548	0.0520	59.0	8.4140
8	0.0792	0.0530	68.0	7.9900
9	0.0977	0.1560	161.0	5.4220
10	0.0294	0.0415	39.0	0.5820
11	0.0130	0.0451	31.0	-0.0117
12	0.0031	0.0051	17.6	0.0078
Average	**0.0320**	**0.0503**	**45.2750**	**3.0550**

4. Conclusions

The effect of applying the high power history in fuel safety analysis for CANDU reactor was investigated. The mean error results show that using the high power in fuel safety analysis might be cover the bias of code prediction for key output parameters.

REFERENCES

[1] G.G. Chassie, "ELESTRES-IST 1.2 User's Manual", AECL Report, 153-113370-UM-001, October 2006.
[2] G.G. Chassie, "ELESTRES-IST 1.2 Validation Manual", AECL Report, 153-113370-SVM-001, November 2006.
[3] B.G. Kim, "Reactor Physics Model", KHNP Report, 59RF-03500-AR-055, January 2008.