Calculations of Fission Gas Release Based on Uncertainty Analysis for CANDU Fuel

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1. Introduction

The in-house fuel performance code developed in KNF models the performance of CANDU 6 fuel elements during normal operating conditions. The code performs the temperature, fission-gas release and internal pressure. The in-house code models the behavior of fission gas within the fuel pellet and fuel element because these fission gases play a significant role in determining fuel element performance during normal operation or under off-normal conditions. The release of significant quantities of fission gas can result in high internal gas pressures within the fuel element. To find the effects of fission gas release on rod internal pressure, the in-house code calculations are performed using the uncertainty analysis [1].

2. Methods and Results

In this section some of the techniques used to model the fission gas release are described. The fission gas release model includes fuel pellet grain growth model and fission gas diffusion model. Results from 124 simulation runs using uncertainty analysis are also shown in this section.

2.1 Fuel Pellet Grain Growth Model

The fission gas release calculations are for a generalized fission gas behavior. There are two types of processes that lead to fission gas migration. The first process involves changes to the grain structure in the UO_2 (Grain Growth), and the second process involves fission gas transport within the existing grain structure (Fission Gas Diffusion). High fuel temperatures promote the diffusion of the UO_2 molecules and fission gas within the pellet. This causes changes in the grain structure within the pellet. As a result grain boundaries move with irradiation, resulting in equiaxed or columnar grain growth. For equiaxed grain growth, the in-house code uses an empirical model that gives the rate of growth as a function of local temperature, enrichment and the grain size. Columnar grain growth has been observed in some experimental fuel elements irradiated at high powers and temperatures. The in-house code uses a columnar grain growth model [2] that is based on the logarithmic average between the rates for surface diffusion and for vapor transport.

2.2 Fission Gas Diffusion Model

The diffusion coefficient reflects the out-reactor measurement of Findlay [3], as well as normalization factors to reflect in-reactor gas release determined by Notley and Hastings [2]. The diffusion coefficient predictions by Notley/Hasting's model constitute an upper bound at higher temperatures, but provides a lower bound at lower temperature. Therefore, from a fission product release standpoint, Notley/Hasting's model over-predicts or under-predicts fission product release depending on the operating on the operating fuel temperature range, compared with the other model predictions.

2.3 Methodology of Uncertainty Analysis

The uncertainty evaluation methodology uses the Wilk's formula [4], performing 124 runs to obtain 95% probability and 95% confidence statements. The uncertainty evaluation methodology includes manufacturing parameters, fuel performance model parameters and operational parameters. Fuel performance model parameter includes fission gas release. After 124 in-house code simulations, each of key fuel performance output parameters is sorted in descending order to find the 3rd largest value of the 124 output parameters. The 3rd largest output value is compared with the relevant acceptance criterion for meeting regulatory design requirements.

2.4 Results

CANDU 6 fuel is selected for 124 in-house code runs for uncertainty quantification of fuel internal pressure parameter. Figure 1 shows the histogram of fuel internal gas pressure through 124 in-house code runs based on non-parametric order statistics. A histogram is a plot of the frequency distribution of a discrete set of a continuous parameter and provides an estimate of the probability distribution function. As shown in this figure, internal gas pressure is below the acceptance criteria of internal gas pressure (10.593 MPa).

Important parameters related to fission gas release are shown in Figure 2, Figure 3 and Figure 4. Figure 2 shows the internal gas pressure behavior for 3 largest-value cases. Fuel internal gas pressure increases as burnup increases. However all of 3 largest-value cases satisfies the acceptance criteria of internal gas pressure. Figure 3 and Figure 4 show the fission gas volume and grain growth radius behavior, respectively, for 3 largest-value cases. As burnup increases, grain size and fission volume increase. These figures show the prediction trend for fuel pellet grain growth and fission gas diffusion models described in Sections 2.1 and 2.2.

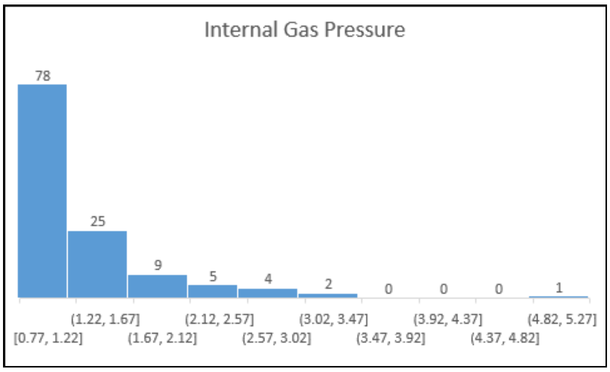

Fig. 1. Histogram of Fuel Internal Gas Pressure Through 124 In-house Code Runs Using Uncertainty Evaluation Method.

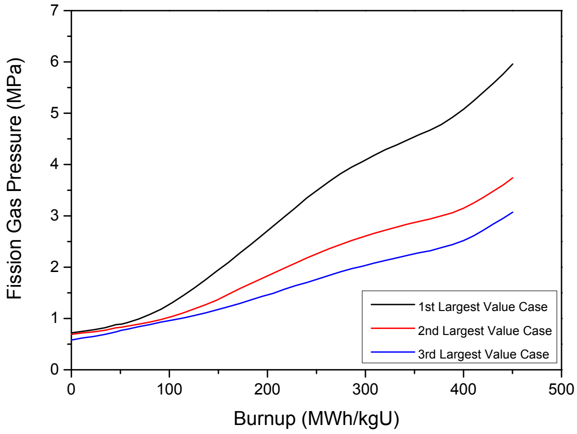

Fig. 2. Fuel Internal Gas Pressure (3 Largest-Value Cases)

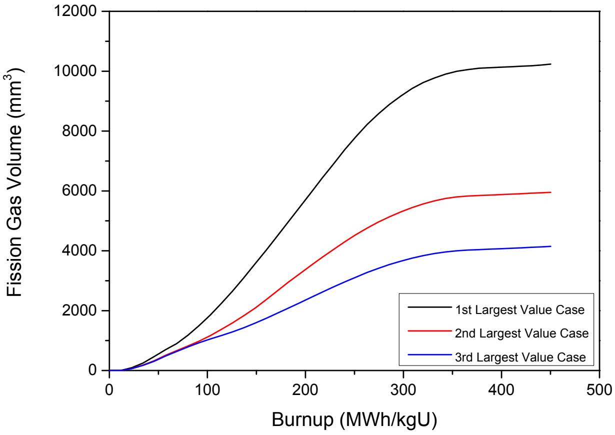

Fig. 3. Fission Gas Volume (3 Largest-Value Cases)

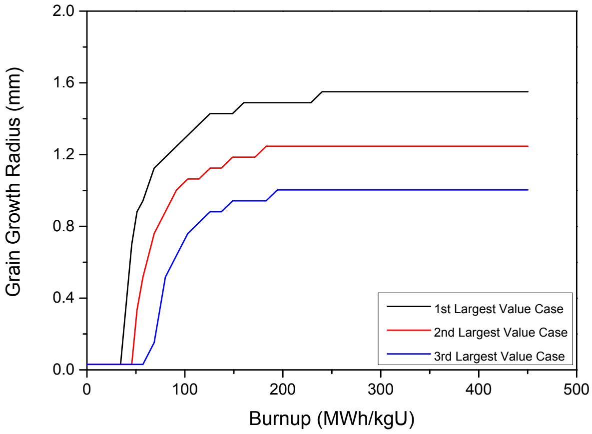

Fig. 4. Grain Growth Radius (3 Largest-Value Cases)

3. Conclusions

The in-house code uncertainty analyses for CANDU 6 fuel are performed to evaluate the effects of fission gas release. Results show that the 3rd largest output value from the 124 in-house code runs based on non-parametric order statistics satisfies the acceptance criteria of internal gas pressure.

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