Scoping Evaluation of CANDU Fuel Performance Using Non-Parametric Statistics

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1. Introduction

There is an increasing interest in computational fuel performance analysis to replace the conservative evaluation model calculations by a quantitative uncertainty analysis. Important parameters of fuel rod performance, such as rod internal gas pressure, peak fuel centerline temperature, and cladding hoop strain are affected by several uncertainties from scatter of measured values, approximations of modelling, variation and imprecise knowledge of initial and boundary conditions. Their propagation through code calculations provides probability distributions and ranges for the code results.

The non-parametric statistics method derives from the direct Monte Carlo method. The direct Monte Carlo uncertainty analysis(UA) method simply samples the input distributions N times, then uses the computer code directly to generate M key outputs which are used to estimate the actual probability distribution of the key output. The non-parametric statistics method, however, does not attempt to obtain information with regard to underneath probability distribution function(PDF) of the key output(say, fuel centerline temperature(FCT)), ignores the PDF, and uses non-parametric statistics to determine a bounding value of the population with a given confidence level.

This study is intended to presents CANDU fuel performance analysis using non-parametric statistics.

2. Applications of the UA Method

The UA method is the process developed to characterize the output variables affected by uncertainty(Figure 1)[1].

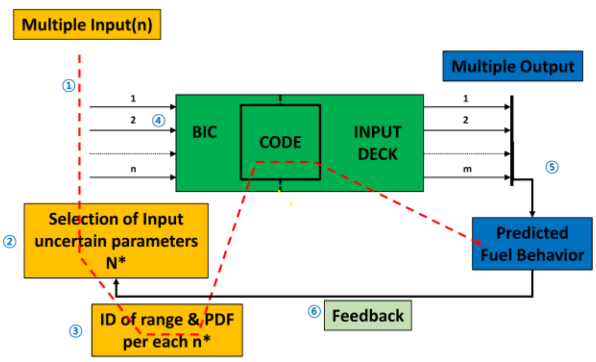


Figure 1. Uncertainty Propagation through the Code

The error propagation occurs through the code which is an 'imperfect' tool. In non-parametric statistics methods, the uncertainties must characterize the range of variation of each parameter and the number of performed code runs is a function of the target(selected) level of confidence. Sample size selection is usually based on Wilks' tolerance intervals (e.g., 124 runs for 3th order one-sided 95%/95% tolerance limit)[2, 3].

Using the in-house CANDU fuel performance code being developed in KNF, seven basic steps for performing an uncertainty analysis for Wolsong fuel performance under normal operating conditions are developed and applied as shown in Figure 2.

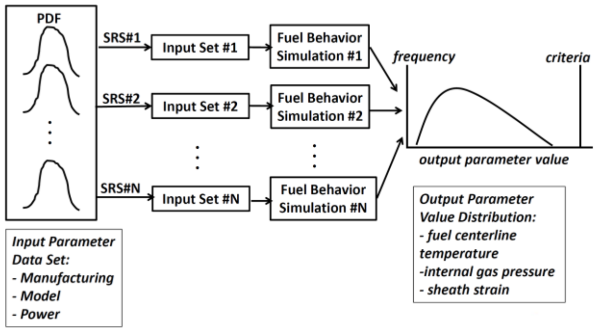


Figure 2. Fuel Performance Analysis Based on Non-parametric Order Statistics

Four cases are analyzed: UA Run Set #1 is the 1st order tolerance limit runs for 59 runs, UA Run Set #2 is the 3rd order tolerance limit runs for 124 runs, UA Run Set #3 is the 20th order tolerance limit runs for 554 runs, and UA Run Set #4 is the 950th order tolerance limit runs for 20,000 runs.

3. UA Analysis Results

This section describes UA analysis results to assess the combined effects of uncertainties preliminarily by using a non-parametric order statistics approach.

3.1 Input Uncertainty Characterization

All potentially important uncertain parameters are identified and quantified in the uncertainty analysis. The results from these phenomena are represented by three key output parameters of the code: FCT, internal gas pressure(IGP) and sheath strain(STS). Table 1 shows the importance rank for the primary phenomena linked to each key output parameter. The key parameters are selected, according to their ranks, as follows:

- Manufacturing parameters: UO_2 density, diametral clearance, grain size, dish depth, sheath wall thickness, pellet surface roughness,

- Model parameters: fission gas diffusion coefficient, pellet thermal conductivity, pellet thermal expansion, pellet to sheath conductivity, and

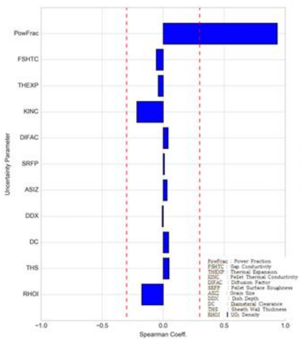
- Operational parameter: power-burnup history.

Table 1. Phenomena Identification and Ranking Table(PIRT) for Fuel Performance Analysis

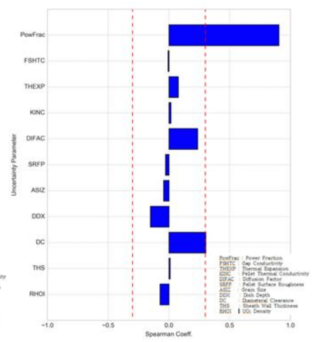
	Primary Phenomenon	Key Output Parameter	Rank
Fuel Fabrication Variables	UO_2 Density	Fuel Temperature	3
	Pellet Axial Clearance	Fuel Temperature	1
	Diametral Clearance	Fuel Deformation	5
	Helium Fraction	Internal Gas Pressure	1
	Grain Size	Internal Gas Pressure	3
	Pellet Outer Diameter	Fuel Temperature	2
	Dish Depth	Internal Gas Pressure	5
	Stack Length	Internal Gas Pressure	1
	Sheath Wall Thickness	Fuel Temperature	5
	Depth of Pellet Chamfer	Internal Gas Pressure	1
	Length of Pellet Chamfer	Fuel Temperature	1
	Pellet Surface Roughness	Fuel Temperature	4
	Pellet Land Width	Fuel Temperature	2
Fuel Design Model Variables	Fission Gas Diffusion Coefficient	Internal Gas Pressure	3
	Pellet Thermal Conductivity	Fuel Temperature	5
	Pellet Thermal Expansion	Fuel Deformation	5
	Pellet to Sheath Conductivity	Fuel Temperature	5
Power Variable	Power Fraction	Fuel Temperature	5

3.2 Output Uncertainty Characterization

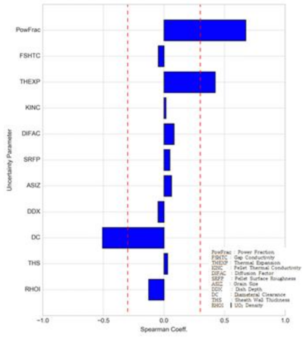
The results of the propagation of uncertainty are processed to get the most accurate possible picture about the uncertainty in the outputs. To determine the sensitivities of input parameter uncertainties on the uncertainties of key output parameter, results are shown in Figure 3 from statistical evaluations based on Spearman rank correlation coefficient[4].



(a) FCT



(b) IGP



(c) STS

Figure 3. Sensitivity Analysis Results Based on Spearman Rank Correlation

3.3 Comparison of Results with the Relevant Criteria

The uncertainty analysis results for four sets of runs are summarized in Table 2. The 95%/95% tolerance limits of key fuel performance output parameters meet the relevant acceptance criteria for all the four cases.

Table 2. Summary of Uncertainty Analysis Results

No. of Runs	Limiting Performance Parameter Value: 95% Uncertainty Limit			
	FCT (℃)	IGP (MPa)	STS(ridge) (%)	STS(mid) (%)
59	1,497	3.85	1.43	0.58
124	1,521	4.55	1.41	0.57
554	1,453	3.16	1.33	0.50
20,000	1,455	3.05	1.29	0.57
Acceptance Criteria	< 2,743.7	< 10.593	< 1.4	< 1.4

4. Result Summary

It is proposed that UA combines the various sources of uncertainty(manufacturing, model and power) in the key input parameters into an uncertainty in the key fuel performance output parameters(FCT, IGP and STS).

Four sets of simulation runs are performed, 20^{th} order UA case(554 runs) is chosen as a reference case. A statistical sensitivity analysis using Spearman rank correlation has been performed to provide the importance of the respective input parameter uncertainty on key fuel performance output parameters.

REFERENCES

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