Development of CANDU Void Reactivity Uncertainty Evaluation Methodology

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1. Introduction

One of inherent characteristics of CANDU reactor is positive void reactivity in contrast to other pressurized light water reactors. During the large break loss of coolant accident, power pulse will be occurred during short time of early phase of accident due to positive void reactivity. However the duration of this power pulse is short, energy due to power pulse would be accumulated in the cladding material and will affect the peak cladding temperature or number of failed fuel elements. Recently, Canadian Nuclear Safety Commission (CNSC) indicated that the amount of void reactivity might be larger than the assumed values in safety analysis and this indication was based on the experimental data from ZED-2 facility. Based on that, the estimation of uncertainties due to the void reactivity during LBLOCA is the most important issue for CANDU safety analysis. In this study, a framework of uncertainty evaluation methodology for CANDU void reactivity and its impact on safety analysis result were developed.

2. Void Reactivity Issue Identified

In Generic Action Items (GAI) 95G04 by CNSC in 1995, problems related to the coolant void reactivity (CVR) was specified as following;

"Positive reactivity feedback is a hazard that results in the creation of an unsafe system condition when a mismatch between the rates of heat generation in the core and heat removal by the coolant or a fall in coolant pressure occurs."

"The results of R&D programs carried out in the last 12 years have showed significant underestimation of the magnitude of CVR in original design and safety analysis. The original estimates of the magnitude of the CVR were shown to be non-conservative by nearly 50%."

To resolve this issue, CNSC suggested problem resolving methodology as following;

1. Hazard identification
2. Hazard Evaluation
3. Hazard Control
4. Integrated Resolution Strategies

Hazard identification step consisted of 1 technical area and this is about void reactivity and kinetics parameters. Hazard evaluation step consisted of 3 technical area and these are as following;

- Acceptance Criteria, Validation of Methods
- Realistic methodologies (BEAU)
- Frequency of DEQB in large diameter pipes

Hazard control step consisted of 1 technical area and this is about design changes. Integrated resolution strategies means all resolution methods derived from step 1~3.

The impact of underestimated CVR in safety analysis can be illustrated as Fig. 1.

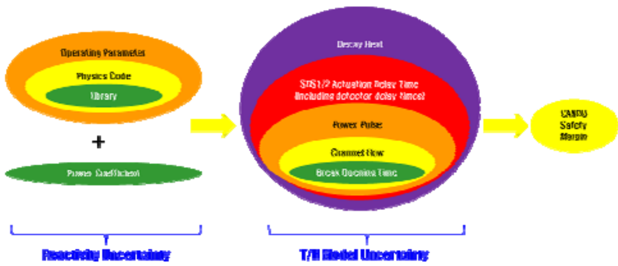

Fig. 1 The impact of underestimated CVR in safety analysis

3. Void Reactivity Uncertainty Evaluation

The purposes of this study were as following;

- To identify the sources of uncertainty related to coolant void reactivity
- To provide the preliminary information for the detailed analysis for the licensing process and regulatory activities
- To develop the guidelines to estimate LLOCA safety margin regarding uncertainties related to coolant void reactivity

Due to the various sources which can affect the void reactivity, 3-aspects related to the reactivity calculation was compared and 1-aspects will be reviewed.

- Nuclear Physics Code Uncertainty Factors
- Nuclear Data Uncertainty Factors
- Operational Parameters

3.1 MCNP vs. WIMS-IAEA

For the range of 0~50% void fraction, estimated values from MCNP and WIMS/IAEA showed almost same trend. As burnup increased, void reactivity increased as well with small gradient. WIMS/IAEA underestimated void reactivity compared with MCNP.

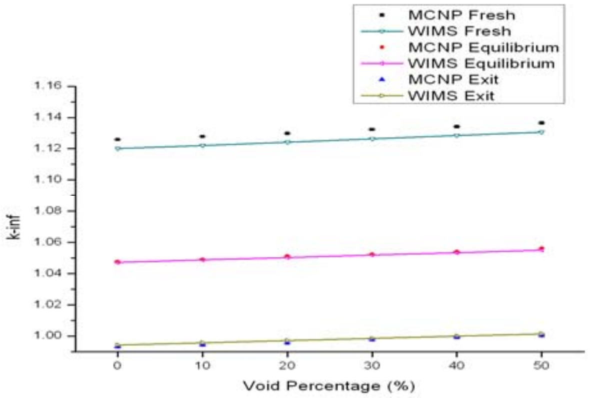

Fig. 2 Comparison result for MCNP vs. WIMS-IAEA

3.2 ENDF.B-VI vs. ENDF.B-VII

Use of ENDF/B-VII provided better results than ENDF/B-VI for criticality experiment data. Enhancement of accuracy for fuels including Pu was not enough for ENDF/B-VII compared with the results from CANDU criticality experiments. For equilibrium core which contains Pu isotopes, further research is required to enhance accuracy of results from the use of ENDF/B-VII.

3.3 Operational Parameters

Reactivity was calculated using MCNP by changing the values of ;

- Moderator purity
- Coolant purity
- Boron concentration
- Fuel temperature

Changes of reactivity per each property were compared with values in design document of Wolsung unit 1.

Table 1. Comparisons for operational parameters

		MCNP	WIMS/IAEA	WS1 Design Document
Moderator Purity (mk/ mol%)	Fresh	31.6803±0.4331	32.7702	34.0628
	Equilibrium	29.0272±0.5521	30.6558	32.1792
Coolant Purity (mk/ mol%)	Fresh	0.9123±0.1870	1.0778	0.9579
	Equilibrium	0.5558±0.2391	0.7829	0.5530
Boron Concent. (mk/ ppm)	Fresh	-7.5224±0.1008	-7.9008	-8.2560
	Equilibrium	-	-	-
Fuel Temp. (mk/K)	Fresh	-0.0110±0.0013	-0.0113	-0.0133
	Equilibrium	-0.0004±0.0016	-0.0007	-0.0039

4. Future Plans

By considering the results from past research projects in which uncertainty and probability concepts were considered, factors those might affect the uncertainties during thermal hydraulic analysis, will be identified. Factors which are directly related to void reactivity and/or void reactivity uncertainty will be considered. Factors which are related to the response and performance of safety systems such as shutdown systems and ECCS, will be considered.

5. Conclusion

Through this project, useful insights related to uncertainties exist within nuclear physics codes, libraries and models were provided. Feasibility of applying Best Estimate and Uncertainty (BEAU) to CANDU void reactivity issue will be explored. Unexplored area of uncertainties will be studies in next project in plan. Because of the limitation, further detailed analysis and basis development were not performed but this study will contribute to further verification work as a regulatory actions.

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