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Corroboration of the Calculation/Experiment Errors for the BFS-84-1 Physics Experiments

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing a 150 MWe small size Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) [1, 2] since 2012. To acquire license for the developing PGSFR, validation of the core neutronics code system is essential. For that purpose, KAERI performed a physical experiment, which is named as the BFS-84-1 experiment, by collaborating with Russian IPPE [3].

In this paper, the calculation/experiment (C/E) errors of the BFS-84-1 experiments are compared with the existing metal-uranium-fueled Sodium-cooled Fast Reactor (SFR) physics experiment database. In addition to the comparison, the 97.5/97.5 uncertainties for criticality, sodium void reactivity worth, and control rod worth are also reported.

2. Description of the Experiment Database

2.1 BFS-84-1

The detailed configurations for the BFS-84-1 physics experiments were in references [4] through [7]. The measured data of the BFS-84-1 critical experiments are as follows:

- Criticality
- Sodium void reactivity worth
- Control rod worth
- Axial fuel expansion reactivity worth
- Radial core expansion reactivity worth
- Fission reaction rate distributions
- Spectral indices
- Effective delayed neutron fraction (β_{eff})
- B-10 absorption reaction rate distributions
- Neutron generation time

In this paper, criticality, sodium void reactivity worth, and control rod worth are selected and list of selected data is shown in table I.

Table I: Number of selected data for the BFS-84-1 reactor physics experiment

	Number of data
Criticality	6
Sodium void reactivity worth	12
Control rod worth	9

2.2 Existing SFR Physics Database

Up to 2015, KAERI had been secured several metal-uranium-fueled SFR physics experiments, the BFS-73-1, BFS-75-1, and BFS-109-2A physics experiments [8-13]. In this paper, these experiments are named as "existing SFR physics data" to corroborate the BFS-84-1 physics experiment data. The list of existing SFR physics data for criticality, sodium void reactivity worth, and control rod worth is shown in table II.

Table II: Number of selected data for the existing reactor physics experiment

	Number of data
Criticality	3
Sodium void reactivity worth	5
Control rod worth	19

3. Procedure for Data Corroboration

According to the appendix 3.1 of the ASME NQA-1, the data corroboration is defined as comparisons of the data to both other sources of qualified data, as well as to sources of other existing data, as defined in data qualification plan [14]. Hence, in this paper, following procedure is considered for corroboration of the selected BFS-84-1 data:

1) Evaluate uncertainty band based on the existing SFR physics data
2) Confirm selected BFS-84-1 data is within evaluated uncertainty band

During the uncertainty evaluation process, the 97.5/97.5 probability/confidence factors were determined from the tables by reference [15].

3.1 Evaluation of Uncertainty Band Based on Existing SFR Physics Database

The Shapiro-Wilk normality tests were performed for existing SFR physics data and results are shown in table III. The W statistics and p significance probabilities in table III is used to determine the normality considering 5% significance level. The detailed definition of W and p can be founded in references [16] and [17]. All of considered data were passed the normality tests, and we can easily evaluate their 97.5/97.5 uncertainty as shown in table III.

Table III: Shapiro-Wilk normality test results for existing SFR physics data

	W value	P value	Normality	97.5/97.5 uncertainty
Criticality	0.93557	0.50984	yes	0.01457
Sodium void reactivity worth	0.95812	0.79678	yes	37.98%
Control rod worth	0.91219	0.08333	yes	11.16%

3.2 Compared results for the BFS-84-1 data

Distributions of the BFS-84-1 C/E data are shown in Fig. 1 through 3. Red dashed lines in figures represents 97.5/97.5 uncertainty band by existing SFR physics data. Blue dotted lines in figures represents 97.5/97.5 uncertainty band based on all physics data, in other words, physics data including BFS-84-1 experiments.

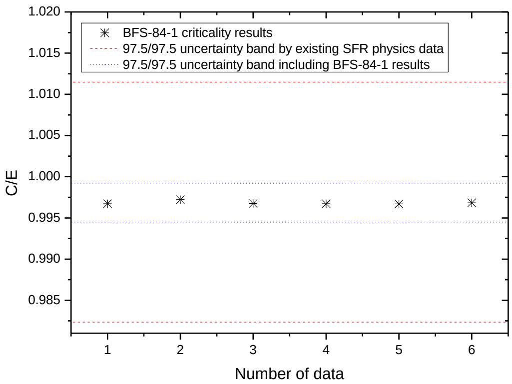

Fig. 1. Distribution of C/E results and 97.5/97.5 uncertainty bands for criticality

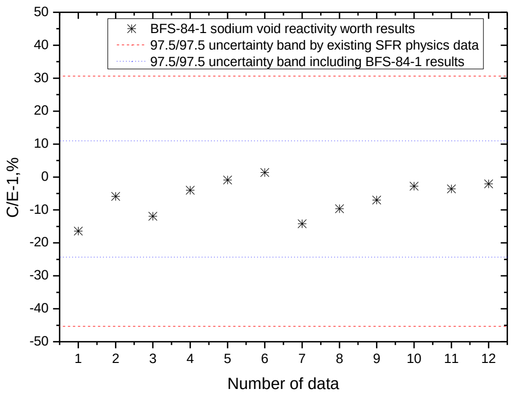

Fig. 2. Distribution of C/E results and 97.5/97.5 uncertainty bands for sodium void reactivity worth

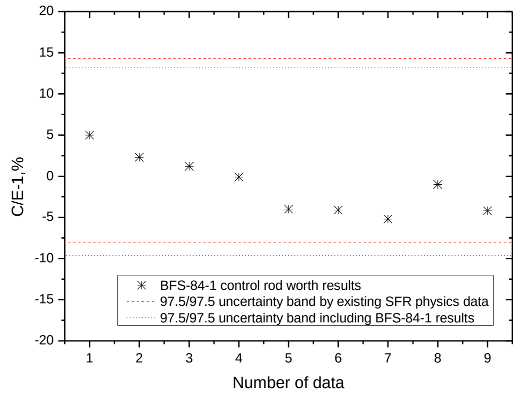

Fig. 3. Distribution of C/E results and 97.5/97.5 uncertainty bands for control rod worth

All of the BFS-84-1 results were placed within 97.5/97.5 uncertainty band by existing SFR physics data. In case of expansion of SFR physics database by including BFS-84-1 results, the 97.5/97.5 uncertainties were reduced by a factor of 6.15, 2.15, and 0.98 for criticality, sodium void reactivity worth, and control rod worth, respectively.

4. Conclusions

By comparison with newly updated BFS-84-1 results with existing SFR physics database, we can conclude that the BFS-84-1 results are corroborated based on the other metal-uranium-fueled SFR physics experiments for selected cases so far.

In addition, if the BFS-84-1 results were added to our existing SFR physics data, the uncertainties of criticality and sodium void reactivity worth are reduced significantly. However, uncertainty of control rod worth shows similar results in case with and without BFS-84-1 results due to relatively large number of data in existing SFR physics database.

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