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Review of the Computer Code Validation Methodology and Proposal for Its Improvement

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1. Introduction

Sodium-cooled fast reactor (SFR) was selected as one of Gen-IV reactors in Generation IV International Forum (Gen-IV Forum) in 2002, and has been under development world broadly. However, the operational experiences and experiments of the SFR specific phenomena and transients are believed not sufficient to understand the SFR features or to validate the computer codes which are used to analyze its safety. It is evident when compared to the situation of water reactors, which have a lot of experience and experiments but still have several safety issues and defects in their computer codes. For the reliable design and licensing of SFR the computer codes for safety analysis are important, together with various experiments. Of course, the computer code should be rigorously verified and validated (verification and validation, V&V). The rigorous code V&V should be more emphasized in case that there are only limited validation experiments.

Unite State Nuclear Regulatory Committee (US NRC) published Regulatory Guide 1.203 in 2005 to guide the process of the developing and assessing computer codes(i.e. evaluation models) that are used to analyze transient and accident behavior of nuclear power plant[1]. This guide stresses the importance of the assessment of the adequacy of the evaluation models. A core of the adequacy assessment is their performances to predict appropriately the key phenomena of experiments. Since the computer codes include so many empirical models and correlations, it is important to ascertain that they are used within the range of their assessment.

ASME V&V 20-2009[2] seems to be accepted as a useful code and standard for V&V of computer code. It provides detailed discussions from the concept of V&V to the example of validation evaluation.

In this study ASME V&V 20-2009 was reviewed in-depth and an improved methodology was suggested.

2. Review of ASME V&V 20-2009

2.1 Review of V&V Concept

This standard defines ‘validation comparison error (E)’ as the difference of simulation result(S) and experimental data(D). And E is equivalent to the difference of simulation error(δS) and experimental error(δD) as a result. δS is stated as the summation of model error(δ_{mod}), numerical error(δ_{num}), and input error(δ_{input}). Thus, the model error is

$$\delta_{model} = E - \left(\delta_{num} + \delta_{input} - \delta_D\right) \qquad (1)$$

Therefore, ‘validation standard uncertainty(u_{val})’ corresponds to the model error and is the estimate of the standard deviation in parent population for the combination of ($\delta_{num} + \delta_{input} - \delta_D$). In case that the three elements are independent with each other, the following formulation is setup.

$$u_{val} = \sqrt{u_{num}^2 + u_{input}^2 + u_D^2} \qquad (2)$$

And the simulation error of the code is expected to belong to ($E \pm u_{val}$).

2.2 Review of the Application Examples

For the practical application of the V&V concept, ASME V&V 20-2009 provides four cases of examples:

- Case 1: Estimating u_{val} when D is directly measured
- Case 2: Estimating u_{val} when D is determined from a data reduction equation (No measured variables share identical error sources)
- Case 3: Estimating u_{val} when D is determined from a data reduction equation (Measured variables share identical error sources)
- Case 4: Estimating u_{val} when D is determined from a data reduction equation that itself is a model

The experimental uncertainty and the numerical uncertainty are evaluated in experimental process and verification step, respectively. Input uncertainty is the main concern. Two methods are suggested: sensitivity coefficient method and Monte Carlo method. Input uncertainty is calculated using the computer code.

2.3 Findings from the Critical Review

Reviewing the ASME standard, we found the following findings:

- ASME V&V 20-2009 does not provide sufficient explanation on why the input error is considered in computer code error rather than in experimental error
- In case that not only the inputs but also the outputs are measured the propagation of input variables is difficult to analyze
- There are no comments on the experiment quality

3. Suggestion of Improved Explanation and Methodology

Fundamental idea of improvement starts from the improved concept of the statement form on the difference of simulation and experiment: the difference is to be quantified statistically as shown in Fig. 1.

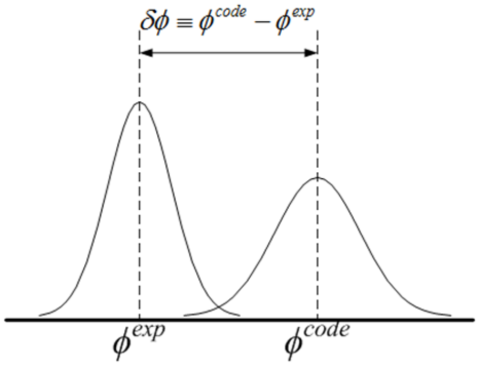

Fig. 1. Improved concept of the statement form on the difference of simulation and experiment

3.1 Approach 1: Comparison at Nominal Experimental Value

This approach is based on that the simulation result(S) at the nominal condition of experiment is unique. And the true experimental result(D^T) at just the nominal condition should be estimated using measurement uncertainty in experiment and the analysis of input uncertainty propagation through experiment. A final difference of simulation and experiment can be estimated referring to Fig. 2.

$$S - D_{X_i}^{U} - u_D^{meas} \le S - D^T \le S - D_{X_i}^{L} + u_D^{meas} \quad (3)$$

$D_{X_i}^{U}$ or $D_{X_i}^{L}$ is the experimental uncertainty caused by the experimental input uncertainties, which is difficult to obtain actually. The comparison point is just the nominal input value.

3.2 Approach 2: Comparison at Estimated experimental Value Based on Experimental Uncertainties

This approach first estimates the true input conditions, which will be given in the form of interval because of input measurement uncertainties. These inputs are propagated through the code simulation, and the simulation results are given in the form of interval, too. The true experimental condition is surely believed to lie somewhere within the interval of inputs. And the true experimental result is also surely located in the result measurement uncertainty. Thus, the final difference of simulation and experiment is as following (Fig. 3).

$$\left(S^L - D\right) - u_D^{meas} \le S^T - D^T \le \left(S^U - D\right) + u_D^{meas} \quad (4)$$

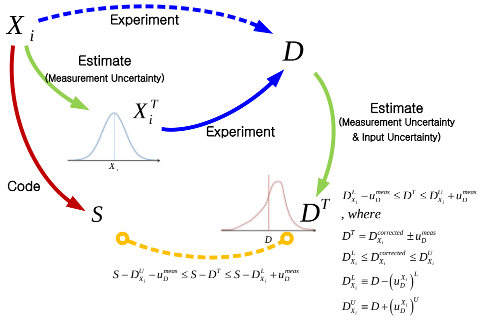

Fig. 2. Diagram of approach 1

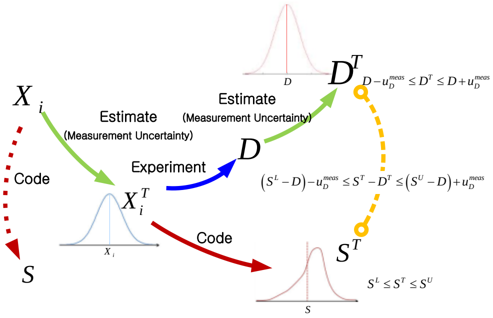

Fig. 3. Diagram of approach 2

3.3 Comparison of the Two Approaches and Applications

The final results given by Eqs. (3) and (4) should be equal or very similar at least. From this fact the experimental uncertainty caused by the experimental input uncertainty can be obtained.

$$\left(u_D^{X_i}\right)^U = S - S^L, \qquad \left(u_D^{X_i}\right)^L = S^U - S \qquad (5)$$

Comparing the measurement uncertainty of experimental result and input uncertainty propagation results, it is possible to comment on the quality level of experiment: these two values should be comparable for the good quality.

4. Conclusions

Intensive review on the ASME V&V 20-2009 was carried out and an improved explanation and method was suggested. For the completeness of the suggested method, substantial evaluation is needed, and this will be conducted in further studies.

REFERENCES

[1] Regulatory Guide 1.203, Transient and Accident Analysis Methods, U.S. Nuclear Regulatory Commission, December 2005.

[2] ASME V&V 20-2009, Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer, American Society of Mechanical Engineering, 2009.