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Development of Quality Assurance Automation Procedures for MULTID Component in MARS-KS Code

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1. Introduction

The MARS-KS (Multi-dimensional Analysis of Reactor Safety-KINS Standard) code was developed to analyze various multi-dimensional thermal hydraulic phenomena for LWR nuclear power plants [1]. Code is widely used in various fields including regulation and research, such as simulation of reactor transients and experimental facilities.

After development, the MARS-KS code has been continuously updated by correcting errors and reflecting improvements. When modifying the original code, it should be carefully reviewed to ensure that there are no unintended effects other than improvements. The improved code is evaluated for any unintended performance changes according to the code Quality Assurance (QA) procedure.

The QA of the thermal hydraulic analysis system code is a Software Quality Assurance (SQA) procedure [2, 3], and the code is comparatively Verified and Validated (V&V) through (1) phenomenological problems, (2) Separate Effect Tests (SET) and (3) Integrated Effect Tests (IET). Phenomenological problems are used to quantitatively and qualitatively judge whether the calculation results are valid for problems with analytic solutions. In addition, SETs are used to determine the prediction accuracy for specific physical effects of a group of models in the code. Finally, the IETs are used to evaluate the complex accuracy of the code through validation with the experimental results. IET experiments usually include transient scenarios in which various phenomenological effects that can occur in nuclear power plants.

However, this SQA procedure requires a lot of time and effort due to the large amount of computation and modeling with high difficulty. Therefore, it is necessary to automate the QA process to systematically and conveniently V&V of codes. In particular, it is necessary to facilitate the QA process for new version codes by automating not only calculation and evaluation but also visualization of results.

Accordingly, KINS has already established a methodology and procedure to automatically perform the QA procedure of the new version code [4, 5, 6]. This procedure consists of (1) Level-1 QA, which verifies validity by comparing the calculation results of the old version code with the new version code for the verification examples, and (2) Level-2 QA, which evaluates the predicted quality of the code including the thermal hydraulic model group by comparing the calculation results with the experimental data, and (3) Full QA, which comprehensively evaluates codes through a vast amount of all retained inputs and experimental data held by KINS.

However, the existing QA procedure only focused on the 1D component of MARS-KS code, and the MULTID component has a limitation in performing QA only for limited examples. Therefore, the need to perform QA on more diverse examples of MULTID components has been raised.

Therefore, in this study, the 1D component of various inputs used in the existing QA procedure was modified and developed as a MULTID component. In addition, the automated QA process was extended to the MULTID component. The developed QA procedure includes prediction error analysis between experiments and calculation results using MULTID components by selecting 89 major variables from 51 input data based on thermal hydraulic experiments. Based on the V&V procedure of computerized code quality assurance, the prediction performance of MARS-KS ver.1.6 was evaluated. In addition, the prediction quality of the calculation using the MULTID component was evaluated comprehensively.

2. Methods and Results

2.1 Test matrix

In this study, the QA procedure, which was previously developed mainly for MARS-KS 1D components, was extended to MULTID components. This is to evaluate how the prediction result of the MULTID component differs from that of the 1D component for a basic example problem. The comparative evaluation group (Test Matrix, Table 1) was selected from various conceptual problems, SETs, and IETs included in the Development Evaluation Report. Various detailed options of the MULTID component can be reviewed through examples included in the test matrix.

2.2 Modeling of MULTID component

The input modeling was changed from 1D to MD as shown in Figure 1. The difference in calculation results was compared by modifying the component that reflects the option to be reviewed with MULTID. Figure 1 is the modeling of the Bennett problem [7], and is an example of a SET selected to review the CHF model. The figure

Table 1 MULTID QA Test matrix

Type	Phenomena	V&V case
ETC.	Gravitational head	Nine-volume water over steam
	Non-condensable state	Nitrogen-water manometer problem
	Counter Current Flow Limitation	Horizontal stratified countercurrent flow
	Water packing	Pryor's pipe problem
SET	CHF	Bennett's heated tube experiments
		Christensen subcooled boiling test
	Interfacial heat transfer	MIT pressurizer test
	Entrainment and film tear off	GE level swell test
	Void fraction	FRIGG-2 test
		ORNL-THTF bundle test
		ECN tests
	Critical flow	Marviken test
		Edwards pipe problem
	Reflood	FLECHT-SEASET forced reflood tests
	Accumulator	LOFT accumulator blowdown test
IET	Natural circulation	Semiscale Natural Circulation
	LOCA	LOFT large break test

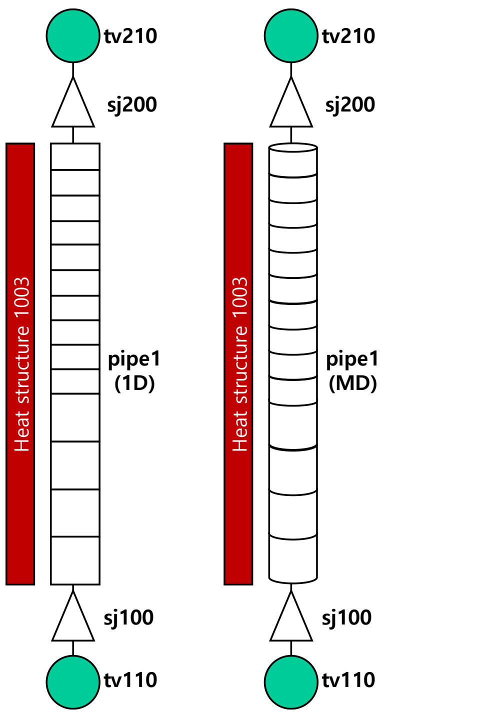

Figure 1. Schematic diagram of the modeling differences between 1D and MD

schematically showed that the pipe component located in the middle was changed from 1D to MULTID while maintaining the other geometries such as number of cells, volume, length and etc.. All other input models of QA have changed components in the same way.

2.3 V&V procedure automation with SNAP code

Using the SNAP program, the process of calculating MARS-KS and visualizing the results was automated. All cases in the QA test matrix are automatically calculated using SNAP Automatic Template (SAT). Error analysis is performed by comparing calculation results with the experimental data. Finally, the calculation results between the reference code (or reference component) and the new version of code are compared.

On the SNAP interface, as shown in Figure 2, the inputs to be calculated are connected with the MARS-KS code, and then the drawing figure of the result file is automated through the script function of the APTplot code. In addition, major statistical values such as mean error, standard deviation, maximum and minimum error representing the predictive performance of each calculation are included in the results. The prediction errors of individual variables are used to evaluate the accuracy and quality of the code.

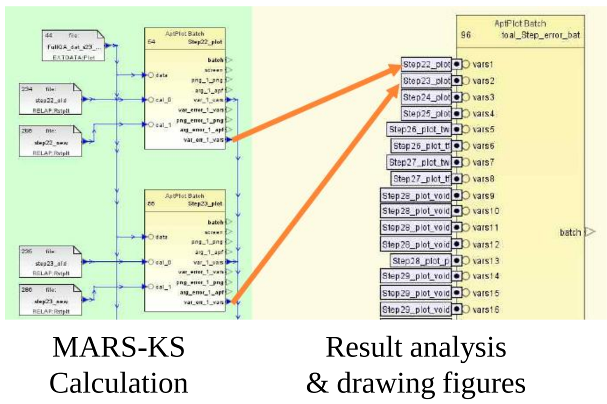

Figure 2 Schematic of SNAP automate template

2.4 V&V results

Quality Assurance of MARS-KS code was performed through the automated procedure of section 2.3. Figure 3 is an example of the visualization result of the automated calculation, the axial wall temperature in the Bennett test calculation. The comparison results of major variables are automatically output and saved, so the QA time can be shortened.

Figure 4 lists the errors in all calculation cases in the test matrix. Through this figure, the performance of the QA target code can be grasped at a glance, and it is easy to recognize how much error occurs in which case.

Finally, minor errors of MULTID component of MARS-KS 1.5 were found and corrected through the developed MULTID component QA procedure. In MARS-KS 1.6, errors were resolved and the code is released in August, 2021.

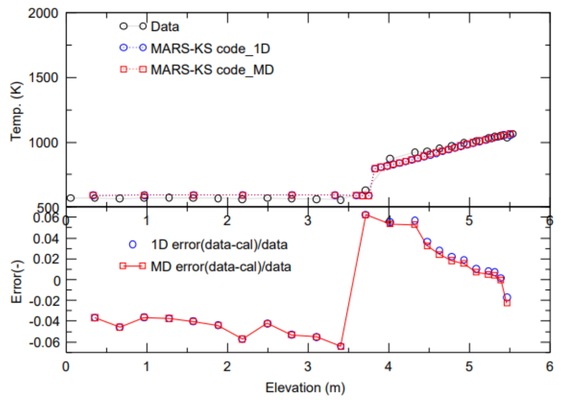

Figure 3 QA result of Bennett test 5358 (axial wall temperature)

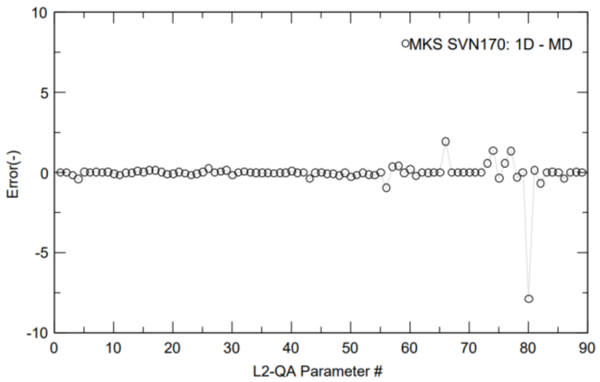

Figure 4 Errors of the calculation cases (example)

3. Conclusions

KINS established a methodology and procedure to automatically perform the QA procedure of the new version code. In this study, the QA procedure, which was previously developed mainly for MARS-KS 1D components, was extended to MULTID components. Finally, minor errors of MULTID component of MARS-KS 1.5 were found and corrected through the developed MULTID component QA procedure. In MARS-KS 1.6, errors were resolved and the code is released recently.

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