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Adequacy Results of 2nd Exercise in OECD/NEA ATRIUM Project for SPACE

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1. Introduction

SPACE development team in KAERI has participated in OECD/NEA ATRIUM (Application Tests for Realization of Inverse Uncertainty quantification and validation Methodologies in thermal-hydraulics), which is proposed in 2021 to demonstrate of the applicability of the best-practices, to resolve some identified open and new issues, and to summarize the lessons learned from the different participants [1]. In the ATRIUM, an intermediate break LOCA are selected as interesting scenario. In addition, two kinds of major phenomena of a critical flow and post-CHF heat transfer are defined as separated effect test (SET) and combined effect test (CET), respectively. Finally, the obtained input model uncertainties will be propagated on the OECD/NEA ROSA-2 Project LSTF IB-HL-01 test to validate their application in experiments at a larger scale. Currently, the 1st exercise of critical flow is finalized [2], and 2nd exercise of post-CHF is working. In this study, the experimental database for post-CHF will be evaluated using adequacy analysis method to select uncertainty quantification and validation databases.

2. SAPIUM Guideline

During the SAPIUM project [3], the logical guideline for IUQ (Inverse Uncertainty Quantification) is proposed with five elements. In addition, several sub steps in each element are guided. In the ATRIUM project, all process will follow the SAPIUM guideline for IBLOCA scenario. The element 1 is to identify and define the study case. Therefore, the IUQ purpose, system response quantities, and important phenomena should be identified in the element 1. For the post-CHF phenomena, wall temperatures with related variable ranges are defined as the major response quantity. In the element 2, the experimental database (ED) is developed and assessed. An appropriate dataset is selected by adequacy analysis. For the exercise 2, Becker, Stewart, and THTF tests are proposed. The input uncertainty quantification set and validation set are separately defined. In the element 3, simulation model is selected and assessed. Especially, code and simulation model (SM) will be selected according to capability and applicability on the phenomena. For post-CHF model in SPACE code version 3.2 will be used. The model input uncertainties quantification will be defined in the element 4. The Bayesian method using PAPIRUS of the uncertainty quantification tool will be applied to IUQ quantification. And Markov Chain Monte Carlo (MCMC) simulation will be applied. And model input uncertainties evaluated during the element 4 will be propagated to validate the IUQ model in the element 5. In this paper, the element 2 will be discussed.

3. Methods and Results

In the element 2 of SAPIUM, major goal is to develop and assess the experimental database used to perform IUQ. The first step (Step4 in SAPIUM) consists mainly in the setup of available experiments. The final database used for IUQ may vary by their adequacy (Step 5). ED will be selected for the input uncertainty quantification and validation (Step 6).

3.1 Experimental Database for 2nd Exercise

The proposed experimental databases for post-CHF are Becker [4], Stewart [5,6]. THTF [7]. Table I shows summary of experimental database with target test of LSTF. The various ranges of type, pressure, mass flux, heat flux, and inlet subcooling are considered for experimental database.

Table I: Summary of the experimental database

ED	**Type**	**No. tests**	**P [bar]**
Baker T/S 1	Tube	281	30-200
Baker T/S 2	Tube	102	30-200
Baker T/S 3	Tube	38	150-200
Stewart	Tube	312	20-90
THTF Film Boiling	Rod Bundle	22	40-130
THTF Uncovered Bundle	Rod Bundle	6	40-75
LSTF	**Rod Bundle**	**1**	**20-50**
	G [kg/m²s]	**q" [W/m²]**	**$T_{sub,in}$[K]**
Baker T/S 1	500-3000	100-1250	10
Baker T/S 2	500-3000	90-850	10
Baker T/S 3	780-2475	290-940	5-10
Stewart	115-2833	65-460	9-56
THTF Film Boiling	226-806	320-940	8-46
THTF uncovered bundle	3-30	74-480	46-103
LSTF	**0-600**	**500-2000**	**0**

3.2 Adequacy Analysis

Adequacy of the proposed ED can be defined with representativeness and completeness. Table II are several criteria for representativeness and completeness. Preliminary adequacy analysis based on the available documents describing the experiments and the previous knowledge of the expert about the phenomena may be performed to have a first rough selection of the adequate database. The check-list for C^r_2 contains facility documentation, instrumentation information, uncertainty data, repeatability, quality of measurement, etc.

The adequacy of ED can be considered as multi-criteria decision analysis problem. There are various methods for this problem. In this study, AHP (Analytic Hierarchy Process) method is applied to derive real valued score by exploiting pairwise comparisons [8].

Table II: List of representativeness and completeness

	Criteria	Sub-criteria
Representativeness	C^r_1: Fidelity with LSTF for the accidental transient of interest	$C^r_{1\text{-}1}$: Fidelity experimental facility geometry/LSTF geometry
		$C^r_{1\text{-}2}$: Fidelity of thermal-hydraulic conditions between experiment and LSTF
	C^r_2: Control of experimental data	Evaluation based on the check-list
	C^r_3: Modelling of the physical phenomena for their implementation in the system code	$C^r_{3\text{-}1}$: Capability to cover physical phenomena of interest required for the simulation
		$C^r_{3\text{-}2}$: separability
		$C^r_{3\text{-}3}$: Capability of the simulation tool to reproduce the experimental data
Completeness	C^c_1: Coverage of the application domain	
	C^c_2: Spatial distribution of the experiments in the experimental domain	

3.3 Adequacy results

The weights of criteria for the representativeness and completeness are evaluated with engineering judgment. It is also evaluated using AHP method as shown in Table III. The scores of each criterion is determined as 5, 3, 3, which means criteria 1 is the most important for the representativeness. And 2nd and third criteria are equally important.

Table III: weights of criteria in the representativeness

	C^r_1	C^r_2	C^r_3	Weight
C^r_1	1	1.6667	1.6667	0.45455
C^r_2	0.6	1		0.27273
C^r_3	0.8	1.3333	1	0.27273

With the same way, weights of criteria in the completeness are evaluated as 0.8 and 0.2 in order. Our judgement indicates the coverage of the application domain is 4 times important than the uniformity of database.

Each criterion is evaluated with considering sub-criteria. For example, the fidelity with LSFR (C^r_1) for each experimental database is evaluated. The test section type and hydraulic diameter are considered as geometrical fidelity. And experimental conditions of pressure, mass flux, heat flux are considered as thermal-hydraulic parameters. Table IV shows AHP results of each experiment database for C^r_1. Here, E1~E6 indicate Becker T/S 1, Becker T/S 2, Becker T/S 3, Stewart, THTF Film boiling, and THTF Uncovered bundle, in order.

Table IV: results of criteria1 in the representativeness

Score	**4**	**4**	**2**	**5**	**5**	**4**	Result
C^r_1	E1	E2	E3	E4	E5	E6	
E1	1	1	2	0.8	0.8	1	0.1667
E2	1	1	2	0.8	0.8	1	0.1667
E3	0.5	0.5	1	0.4	0.4	0.5	0.0833
E4	1.25	1.25	2.5	1	1	1.25	0.2083
E5	1.25	1.25	2.5	1	1	1.25	0.2083
E6	1	1	2	0.8	0.8	1	0.1667

With the same procedure, all criteria in representativeness for all experiment database is evaluated. The final representativeness is calculated with weighted summation (Table V). The criteria in the completeness are coverage and uniformity of experimental condition. Fig. 1 shows coverage of mass flux and pressure in the experiment database. The coverage criterion is simply evaluated for each parameter with LSTF conditions. In addition, the uniformity is evaluated with standard deviation of difference between near points. In this process, the data has its difference less then 1%, is neglected. Finally, the criteria in the completeness are summarized in Table V. The final adequacy result indicates that the good representativeness is obtained in the THTF film boiling and the Becker T/S 3 shows worst one. For the completeness the Stewart shows best coverage and the THTF uncovered bundle is worst one.

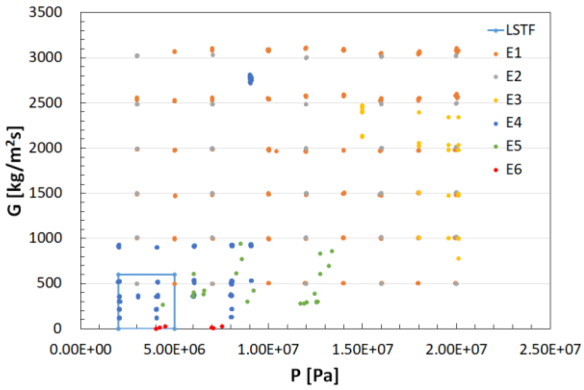

Fig. 1. Coverage with data points of experiment database

Table V: Results of adequacy analysis

ED	Representativeness	Completeness
E1	0.1733	0.2382
E2	0.1733	0.1912
E3	0.1354	0.0771
E4	0.1525	0.2553
E5	0.1922	0.1712
E6	0.1733	0.0671

3. Summary

Under the OECD/NEA ATRIUM Project, the IUQ application of IBLOCA test has been conducted. The IUQ process is based on the SAPIUM guideline. In the present, the 2nd exercise of post-CHF phenomena is working with SPACE code. Recently, thru the element 2 in the SAPIUM, the assessment of experiment database is conducted for 6 kinds of experiment database. The adequacy analysis is achieved using AHP method. Finally, the representativeness and completeness for each experiment database are obtained. In the next step, we will select experiment database for inverse uncertainty quantification and validation based on the adequacy analysis results.

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REFERENCES

[1] J. Baccou, et al. « A systematic approach for the adequacy analysis of a set of experimental databases: application in the framework of the ATRIUM project” submitted in NED.

[2] C. CHOI, J. Heo, and S. Lee, “Inverse Uncertainty Quantification using SPACE in ATRIUM (Application Tests for Realization of Inverse Uncertainty quantification and validation Methodologies in thermal-hydraulics)”, WORTH-10, Jeju, South Korea, 2023.

[3] OECD Nuclear Energy Agency, “SAPIUM: development of a systematic approach for input uncertainty quantification of the physical models in thermal-hydraulic codes,” Good Practices Guidance Report NEA/CSNI/R(2020)16 (2020).

[4] K. M. Becker, C. H. Ling, S. Hedberg and G. Strand, "An experimental investigation of post dry-out heat transfer," Departement of Nuclear Reactor Energy, Royal Institute of Technology, Stockholm, 1983.

[5] J. C. Stewart, "Low quality film boiling at intermediate and elevated pressures," PhD Thesis, University of Ottawa, Ottawa, 1981.

[6] J. C. Stewart and D. C. Groeneveld, "Low-quality and subcooled film boiling of water at elevated pressures," Nuclear Engineering and Design, no. 67, pp. 259-272, 1981.

[7] C. B. Mullins, D. K. Felde, A. G. Sutton, S. S. Gould, D. G. Morris and J. J. Robinson, "ORNL Rod Bundle Heat Transfer Test Data Volume 7. Thermal-Hydraulic Test Facility Experimental Data Report for Test Series 3.07.9—Steady-State Film Boiling in Upflow, NUREG/CR-2525, Vol. 7," Oak Ridge National Laboratory, Oak Ridge, 1982.

[8] T. L. Saaty, The Analytic Hierarchy Process: Planning Setting Priorities, Resource Allocation, McGraw-Hill, 1980.