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Review of Verification and Validation for CINEMA Code

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1. Introduction

Korea Hydro & Nuclear Power Co. (KHNP), in collaboration with the Korea Atomic Energy Research Institute (KAERI), KEPCO E&C and FNC Technology, has developed an integrated severe accident analysis code, called CINEMA (Code for INtegrated severe accident Evaluation and MAnagement). CINEMA is a coupled code system designed to simulate severe accident sequences, from the onset of the initial accident to the release of fission products outside the containment. It consists of three sub-modules: CSPACE (in-vessel), SACAP (ex-vessel) and SIRIUS (FP transient). Since the release of version 2.0 in April 2023, CINEMA has continued to improve its model for applications in innovative small modular reactors (iSMR) and advanced nuclear power plant features.

In order to apply the code to nuclear power plant (NPP), the key task is to assess the code's capability to simulate the major phenomena and cope with uncertainty implementation and progression. There is normally a regulatory requirement that codes be assessed (validated) against relevant experimental data for the major phenomena expected to occur [1]. This paper reviews the current state of CINEMA verification and validation (V&V) and suggests way to improve code's accessibility and reliability.

2. Verification and Validation

Verification and Validation (V&V) are primary processes for ensuring that the code is designed for its intended use and adheres to Software Quality Assurance (SQA) standards. These processes help identify and rectify defects early, and improve the code's quality, reliability and overall success.

2.1 Verification

Verification is defined as checking the source code against its documentation. It ensures that the implemented code accurately represents the code specification and meets the requirements.

Currently, CINEMA has identified 33 verification problems, which are insufficient to cover all implemented models. Additional problems must be identified and addressed to enhance verification comprehensiveness.

2.2 Validation

Validation, or "code assessment", refers to the accuracy of code predictions. It demonstrates that the correct physics are being modelled, by mainly comparing the code results with the experimental programs.

The validation test for CINEMA includes Separate-Effect Tests (SETs), Coupled-Effect Tests (CETs), and Integral Tests. Additionally, a benchmark study with the MAAP5 was conducted for severe accidents in the OPR1000. A list of validation test performed is shown in Table I.

Despite considerable efforts in validation, the current measures are still inadequate. The current list does not provide enough information that the validated model is appropriate and covers the detailed phenomena (reflooding of a debris bed, IVR/ERVC, deposition and resuspension of aerosols, iodine chemistry. etc.) It also makes it difficult to distinguish which phenomena are insufficient for validation and to prioritize additional validation.

At this stage, it is necessary to develop a validation methodology that progressively extends the matrix and quantitatively evaluates the validation results to improve the accuracy and reliability of the code.

Table I: Validation Test List for CINEMA 2.0

Physical process	Module	Experiment/Plant
Plant Scale	CINEMA	OPR1000 LLOCA
Integral Test	CINEMA	TMI-2 accident
		Phebus FPT 0,1,3
Core degradation	CSPACE	QUENCH-06
		LIVE L3A
Vessel failure	CSPACE	OLHF-01
FP / Aerosol Transients	SIRIUS	ABCOVE AB5
		RSE
		TOSQAN Spray
		Marviken
TH in Containment / Hydrogen	SACAP	NUPEC (ISP-35)
		TOSQAN (ISP-47)
		ENACCEF (ISP-49)
		THAI (ISP-49)
HPME/DCH	SACAP	Zion type plant (scaled)
		Surry type plant (scaled)
		DCH-1,3,4
MCCI	SACAP	SURC-2
		OECD-CCI (2,3,5)
		ACE (L5)

3. Validation Strategy

The objective of the validation matrix is to specify a basic set of experiments for which the comparison of experimental and calculated parameters measures the accuracy of the code predictions. It shows an overall ranking that summarizes the values of each experiment for code validation based on the experimental characteristics. We propose several strategies to develop a validation matrix for this purpose.

3.1 Identification of phenomena for target application

Initially, it is crucial to determine the target applications (e.g. OPR1000, APR+, iSMR) and identify phenomena according to the severe accident sequence in those applications. Each identified phenomenon can be ranked for risk and importance according to its contribution to a severe accident sequence. At this point, the Phenomena Identification and Ranking Table (PIRT) for Korea NPP developed in 2022 [2] is useful as a starting point to identify detailed phenomena.

3.2 Validation Matrix based on experimental database

The validation matrix should be organized to include priorities and key information for performing code validation. This matrix is built by linking severe accident phenomena derived from the results in section 3.1 with all available experimental information. An example of the validation matrix is given in Table Ⅱ. Key features and selection criteria can be established by referencing other literature [3,4]. In addition, other necessary information in terms of experiments for code validation can be added.

Table II: Validation Matrix (for example)

CINEMA Code Validation Matrix				Integral Test			SET		
Phenomena versus test type ● : Phenomena well occurred ◐ : Phenomena occurred ○ : Phenomena not occurred or data not available ※ Rank (Importance/Risk) : H (High), M (Medium), L (Low)				XXXXX	XXXXX	⋮	XXXXX	XXXXX	⋮
(1) Key Test (1: ISP, Best qualified test, 2: well qualified test)				1	1	...	1	2	...
(2) Data/Documentation (●: Complete/Full, ◐: not sufficient, ○: Poor)				●	●	...	●	●	...
(3) Boundary Condition (●: well defined, ○: partially defined)				●	●	...	●	●	...
(4) Other Code Validation Data (●: more than 2, ◐: 1, ○: none)				●	●	...	●	◐	...
Phenomena			Rank						
RPV damage	Loss of Reactor core integrity	core heat-up	H / M	●	●	...	○	○	...
		core melt	H / M	●	●	...	○	○	...
		debris formation	H / H	●	●	...	○	○	...
		debris coolability	M / H	●	○	...	○	●	...
		melt relocation	M / M	●	●	...	○	○	...
	Loss of lower head integrity	debris coolability	H / H	●	○	...	○	○	...
		lower head heating/ablation	H / H	●	●	...	○	○	...
		lower head failure	H / H	○	○	...	●	○	...
		high pressure melt ejection	M / M	○	○	...	○	○	...
		upper structure failure	L / L	○	○	...	○	○	...
...	...	...	...	...	...	...	...	...	...

3.3 Quantifying the validation results

Merely performing more validation problems does not guarantee enhanced credibility. Efforts should be made to quantify the degree of agreement for code validation, taking into uncertainties in the code as well as experimental data. As there is currently no unified approach to uncertainty analysis for severe accident analysis code, we need to develop and adopt an appropriate uncertainty analysis methodology for CINEMA. It should be the top priority for all.

4. Conclusions

This paper reviews the current state of V&V for CINEMA and proposes validation strategies to improve the accessibility of the code. It emphasizes the importance of defining a methodology for code validation and the need for further research in this area. Much previous research has been undertaken on code validation methodologies, and a suitable methodology could be considered as a CINEMA model. Additionally, to facilitate the validation work of CINEMA, it is necessary to develop a program that allows many researchers to participate in code validation.

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REFERENCES

[1] OECD/NEA, CSNI Status Summary on Utilization of Best-Estimate Methodology in Safety Analysis and Licensing, NEA/CSNI/R (96)19, 1996.
[2] KNS, Roadmap for Resolving Issues in the Severe Accident in Nuclear Power Plants Operated in Korea, KNS(R)-001-2022, 2022.
[3] OECD/NEA, In-vessel Core Degradation in LWR Severe Accident: A State-of-the-Art Report to CSNI, NEA/CSNI/R (91)12, 1991.
[4] OECD/NEA, In-vessel Core Degradation Code Validation Matrix update 1996-1999, NEA/CSNI/R (2000)21, 2001.
[5] H.J. Allelin et al., Validation Strategies for Severe Accident Codes (with special emphasis given to integral codes), VASA, 1998.
[6] Robert Martin, An Evaluation Methodology Development and Application Process for Severe Accident Safety Issue Resolution, Science and Technology of Nuclear Installations, 2012.
[7] IAEA, Safety Report Series No.23: Accident Analysis for Nuclear Power Plant, Vienna, 2002.
[8] IAEA, Safety Report Series No.56: Approaches and Tools for Severe Accident Analysis for Nuclear Power Plants, Vienna, 2008.
[9] IAEA, Assessment of Equipment Capability to Perform Reliably under Severe Accident Conditions, IAEA-TECDOC-1818, Vienna, 2016.
[10] IAEA, Status and Evaluation of Severe Accident Simulation Codes for Water Cooled Reactor, IAEA-TECDOC-1872, Vienna, 2019.
[11] Joy Rempe, Test Data for USEPR Severe Accident Code Validation, Idaho National Laboratory, INL/EXT-06-11326 Rev.3, 2007.
[12] J. Song et al., A Comparative Simulation of Severe Accident Progressions by CINEMA and MAAP5, Nuclear Engineering and Design, Vol.404, 2023.
[13] N. I. Ryzhov et al., Evaluation of uncertainties associated with best estimates of parameters in the deterministic analysis of a severe accident, Nuclear Engineering and Design, Vol.415, 2023.