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System thermalhydraulics for design basis accident analysis and simulation: Status of tools and methods and direction for future R&D

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HIGHLIGHTS

- A state of the art on system code application is presented.
- Requirements for demonstration of code up-scaling capabilities are proposed.
- The role of multi-scale analysis in safety analysis is explained.
- Uncertainty quantifications methodologies for system codes and CFD codes are compared and discussed.

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ABSTRACT

System thermalhydraulic investigations of Design Basis Accident require several tools and methods including the Process Identification and Ranking Table, the scaling, experiment analysis, modelling, code development, code Validation and Verification, and Uncertainty Quantification. This paper intends to give an overview of these methods and tools showing what the state of the art is, and presenting some recent advances. Recommendations are made with future direction for R&D including the need of new advanced experiments and instrumentation, and the future role of CFD and multi-scale analyses. For many people it is not clear what current system codes are, and what they can be. Then the main characteristics of these codes are recalled and propositions are made to clarify the code capabilities and limitations and to improve the knowledge of the conditions for a correct application of the codes for safety in a Best Estimate Plus Uncertainty approach. Also, the on-going developments of 3-field models and Transport of Interfacial Area are summarized and associated experimental needs are identified. The growing role of 3D modelling of reactor core and Pressure Vessel requires additional experimental data for a proper validation. CFD in open medium also contributes to investigations when 3D geometrical aspects play an important role. Recent activities performed in the OECD-NEA Working Group for Analysis and Management of Accidents is summarized and recent applications of two-phase CFD to boiling flows and two-phase PTS scenarios are reported. The role of a multi-scale approach for safety issues is illustrated with the LOCA transients in LWRs. Attention is focused on the need of specific validation experiments and of consolidated uncertainty methods for both system codes and CFD codes.

1. Introduction

System thermalhydraulic investigations of Design Basis Accident (DBA) require several tools and methods including the Process Identification and Ranking Table (PIRT), the scaling, experiment analysis, modelling, code development and Validation and Verification (V&V), and Uncertainty Quantification (UQ).

This paper gives an overview of these methods and tools, presents the state of the art and some recent advances. Each step is considered and the role of the system codes is emphasized Attention is first drawn to the scale-up capability of system codes. Then, the status of the uncertainty methods is presented showing what should be further investigated on the determination and validation of the uncertainties of closure laws.

For many people it is not clear what current system codes are, what they should be, and what they can be. Then, the main characteristics of these codes are recalled and propositions are made to clarify the code capabilities and limitations and to improve the knowledge of the conditions for a correct application of the codes for safety in a Best Estimate Plus Uncertainty (BEPU) approach. Also the on-going developments of 3-field models and Transport

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of Interfacial Area (TIA) are summarized and associated experimental needs are identified. The growing role of 3D modelling of reactor core and Pressure Vessel (PV) requires additional experimental data for a proper validation.

CFD in open medium also contributes to investigations when 3D geometrical aspects play an important role. Recent activities performed in the OECD-NEA Working Group for Analysis and Management of Accidents is summarized and recent applications of two-phase CFD to boiling flows and two-phase PTS scenarios are reported. The role of a multi-scale approach of safety issues is illustrated for the LOCA transients in LWRs. Attention is focused on the need of specific validation experiments and of consolidated uncertainty methods for both system codes and CFD codes.

The two-phase CFD significantly progressed for a few applications and multiscale analyses are in progress. The status is summarized and the role in the solution of reactor issues is illustrated by some examples.

Recommendations are made with future direction for R&D including the need of new advanced experiments and instrumentation, and the future role of CFD and multi-scale analyses.

2. The methods and tools for DBA analysis

The reactor safety demonstration requires the analysis of complex problems related to accident scenarios. The equations of fluid motion and heat transfer are known but cannot be solved in a complex system due to the turbulence and the two-phase flows which have a wide spectrum of interacting scales from microscopic to macroscopic. No analytical solution exists and numerical solution of exact equations is still beyond the computer capabilities.

Experiments cannot reproduce at a reasonable cost the physical situation without any simplification or distortion and the numerical tools cannot simulate the problem by solving the exact equations. Only reduced scale experiments are feasible to investigate the phenomena and only approximate system of equations may be solved to predict time and/or space averaged parameters with errors due to imperfections of the closure laws and to numerical errors. Therefore, complex methodologies are necessary to solve a problem including a PIRT analysis, a scaling analysis, the selection of scaled Integral Effect Tests (IET) or Combined effect tests (CET) and Separate Effect Tests, the selection of a numerical simulation tool, the Verification and Validation of the tool, the code application to the safety issue of interest and the use of an uncertainty method to determine the uncertainty of code prediction. This global approach is illustrated in Fig. 1.

2.1. The PIRT

Phenomena identification is the process of analyzing and subdividing a complex system thermal-hydraulic scenario into several dominant processes or phenomena. Usually, there is a parameter of interest in the thermal-hydraulic scenario which may be a safety criterion (e.g. a peak clad temperature, a reactivity insertion, a thermal or mechanical load,. . .). Ranking means here the process of establishing a hierarchy between identified processes with regards to its influence on the parameter of interest.

PIRT is a formal method described in Wilson and Boyack (1998, NRC-RG 1.203). The main steps of the physical analysis based on PIRT are:

- Establish the purpose of the analysis and specify the reactor transient (or situation) of interest
- Define the dominant parameters or FoM (figures of Merit)
- Identify and rank key phenomena with respect to their influence on the FoM

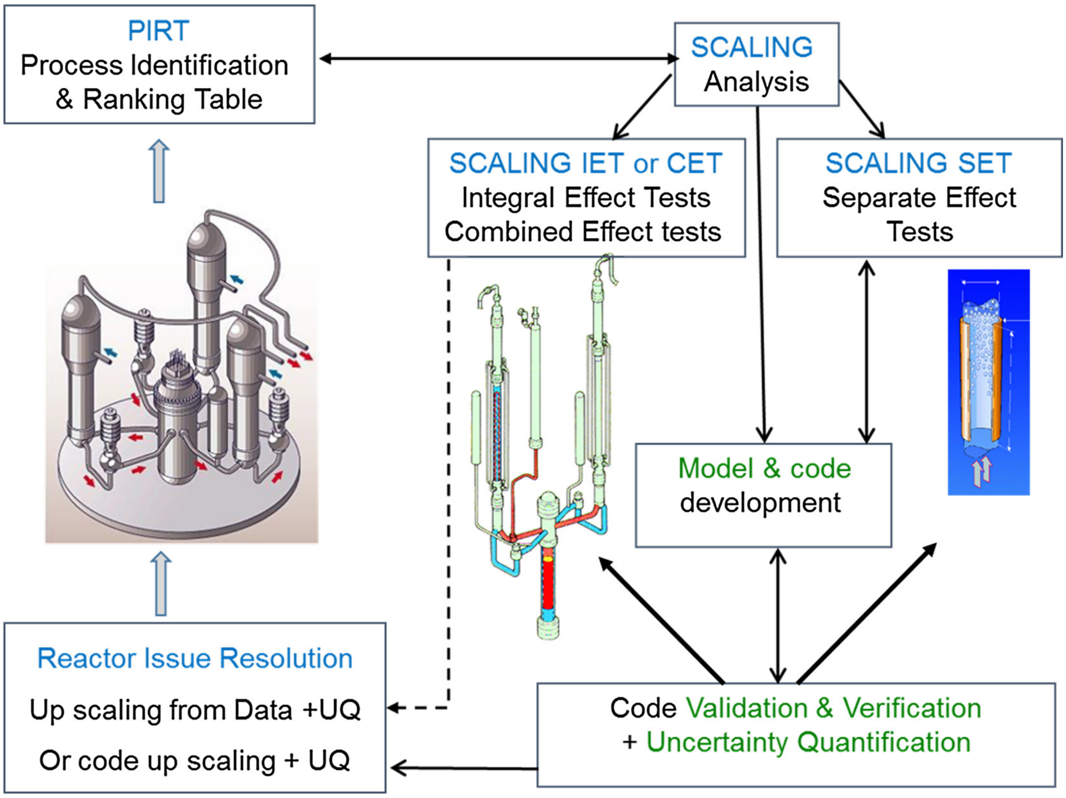

Fig. 1. Methodology to solve a complex reactor issue.

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