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OECD/NEA Experts Activities on the Application of CFD Codes to Nuclear Reactor Safety Problems: Issues and Future Direction

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1. Introduction

The CSNI-WGAMA has been dealing with general issues on reactor and containment thermal-hydraulics (T-H) as well as new issues such as CFD Application to nuclear reactor safety (NRS) problems, etc. At the beginning of this century, the Writing Group on CFD application to NRS problems (WG-CFD) under WGAMA has been launched after the exploratory meeting of experts to define an action plan on the application of CFD codes to NRS problems [1]. According to the recommendations from the meeting in Aix-en-Provence (2002), the three experts groups (WG-1,2,3) have been setup in 2003 to produce the State-of-the-Art (SOAR) report on the use of CFD in addressing NRS issues. This paper presents a summary of the activities by the WG-CFD and identifies the issues and future direction for the CFD application to NRS problems mainly focusing on two-phase flow.

2. NEA Activities on CFD Application to NRS Problems

The WG-CFD has set up the three experts groups (WG-1,2,3). Major expectations were to review the NRS problems for which the use of CFD is needed for the analysis, or where its utilization is expected to bring major benefits, to review the existing assessment basis for CFD application to NRS, to identify the gaps in the technology and assessment bases, and finally to propose a methodology for establishing new assessment bases for CFD application to NRS problems in both single phase and two-phase flow area. In this chapter, major activities of each group will be briefly summarized.

2.1 WG-1 on Best Practice Guidelines (BPG)

The WG-1 aimed at providing a set of guidelines for the application of CFD to NRS problems, and published a report on the BPG for the use of CFD in NRS applications. For this, they reviewed existing single phase CFD guidelines, analyzed their completeness for single phase NRS applications, and made recommendations on the need to write a new guidance manual devoted to NRS. By reflecting a strong need for a set of guidelines for use of CFD to NRS analyses, the WG-1 published a SOAR on the BPG for the use of CFD in NRS [2].

2.2 WG-2 on Single Phase Flow Application

The WG-2 aimed at reviewing the NRS problems for which the use of CFD is needed for the analysis, or where its utilization is expected to result in major benefits, at reviewing the existing assessment basis for CFD application to single phase flow, and at proposing a methodology for establishing new assessment bases. This group published a SOAR on the assessment of CFD Codes for single phase flow problems [3], and also organized the CFD4NRS workshop (2006). The following recommendations have been drawn: To apply the BPG to analysis to minimize numerical error; to specify the measurement uncertainty and I.C./B.C's; to organize a workshop to promote the development of advanced measurement techniques and the CFD application to NRS.

As an following-up activity, a special CFD group has been setup for identifying generic and country-specific safety issues that need to be addressed using CFD and also for identifying needs and priorities for future CFD work. The list of items selected in terms of priority has been set up and also the web-based information center is being operated since 2008 [4].

2.3 WG-3 on Extension of CFD to Two-Phase Flow

The WG-3 aimed at the extensions needed to CFD codes for two-phase NRS problems. The main objectives of the activities are to classify NRS problems requiring two-phase CFD use, to select a limited number of NRS issues having a high priority and for which two-phase CFD has a reasonable chance to be successful in a reasonable period of time, to identify the remaining gaps in the existing approaches for the selected issues, to identify some test cases of special interests for each selected issue, and finally to propose benchmark exercises relevant to two-phase flow problems.

This group organized the XCFD4NRS workshop (2008) and is now preparing the SOAR on the extension of CFD codes application to two-phase NRS problems [5,6]. The following recommendations have been drawn: To apply the BPG to analysis more systematically; to improve physical modelling near the wall region; to develop advanced techniques to estimate experimental uncertainty; and to prefer the approach of benchmark analysis instead of ISP for facilitating communication among experts.

3. Six Subjects for CFD Application to Two-Phase Flow

The WG-3 has chosen six subjects for possible consideration of CFD code application to two-phase flow problems relevant to NRS based on the multi-step approach as shown in Fig. 1 using the following criteria: High priority issues (existence of on-going investigations), chance to be successful (maturity of present tools to handle the issue), availability of data (CFD grade), covering all water reactors, covering all flow regimes, and no overlapping with other GAMA activities. They are (1) Dry-out, (2) DNB, (3) Pressurised

Thermal Shock (PTS), (4) Pool Heat Exchanger, (5) Steam Discharge in a Pool, and (6) Fire Analysis.

Each subject has been carefully investigated, based on the results of reviewing the existing data base for validation, in terms of the eight items: (1) Identification of All Important Flow Processes, (2) Selecting a Basic Model, (3) Filtering Turbulent and Two-Phase Scales, (4) Identification of Local Interface Structure, (5) Modelling Interfacial Transfers, (6) Modelling Turbulent Transfers, (7) Modelling Wall Transfers, (8) Matrix of Validation Tests and Demonstration Tests.

Then a limited list of benchmarks related to each NRS has been selected and is proposed for a better evaluation of the present capabilities & limitations and to promote further progress of CFD tools. Each benchmark was selected by taking into account what has been learnt so far and to provide the best benefit for further progress. Depending on the case, the benchmark can be a basic validation test or a more global validation test, and can be a demonstration test to evaluate the capabilities of CFD to deal with a complex industrial application.

The proposed benchmarks are, for each subject, as follows: For DNB, ASU and DEBORA tests; For PTS, TOPFLOW and ROSA; For pool heat exchanger, LINX; For the steam injection in a pool, JICO(KAERI); and For the fire analysis, ICMFP benchmark exercise # 3.

4. Issues and Future Direction for CFD Application to NRS Problems

In order to analyze T-H phenomena relevant to NRS problems reasonably with quantifiable uncertainties, it is necessary to have capabilities of predicting multi-dimensional characteristics to appear in multi-scale flow system based on mechanistic modeling approach. This requires inevitably the use of CFD-based approach, and for doing so we have to answer the questions about the issues on verification & validation (V&V) as well as uncertainty quantification in both CFD analysis and experiments.

A systematic effort for the V&V issue is required to define more specific 3-D benchmarks instead of ISP-like efforts which require usually very heavy and concerted procedures. The following recommendations for V&V can be made: (1) The use of the method of manufactured solution should be promoted in two-phase CFD to produce tests with analytical solutions; (2) New experiments with simple prototypic flow configurations should be produced with very well defined I.C./ B.C.'s and well instrumented local measurements of possibly all principal variables; (3) New efforts should be made for evaluating the uncertainties associated with both the CFD analysis and high-precision benchmark experiments in a quantitative way for each conceptual problem to reveal usually multi-D, multi-field and multi-scale features.

Since the application of CFD analysis to NRS problems requires great efforts, it is recommended to stimulate safety analysis experts for their use of CFD approach in NRS issues by providing benchmarking data especially through either information exchange meetings or inter- national cooperation.

5. Conclusions

Following the initiatives of NEA/CSNI and IAEA, international experts group activities have been made focusing on the application of CFD to NRS problems rather recently. They have analyzed the status of CFD technologies developed in other technical fields than nuclear T-H field. Then they have setup and published the report on the BPG applicable to NRS problems, the assessment of CFD application to single phase flow, and the extension of CFD to two-phase flow relevant to NRS problems. From these activities, we could identify some important issues and future direction, which are associated with the use of CFD tools for NRS problems.

The work performed by these expert group confirms that the CFD application to NRS problems is becoming useful, complementarily to system analysis codes, for NRS investigations. Even though it did not provide yet an estimation of safety margins for any of the selected issues, it gives promising access to small-scale flow processes, and provides a better understanding of physical matters. CFD tools are already a useful tool for safety analysis and may become a tool for safety demonstration when all the steps of the methodology have been correctly addressed including a proper evaluation of uncertainties.

References

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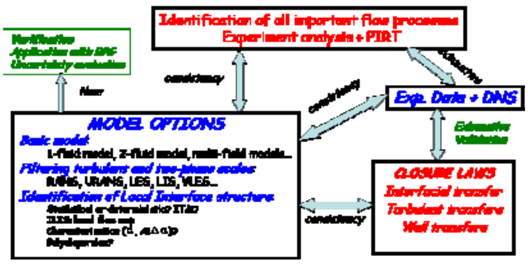

Fig. 1 General methodology for two-phase CFD application to nuclear reactor safety [6]