SUMMARIES OF INVITED PAPERS

Michel Réocreux, "Safety Issues Concerning Nuclear Power Plants: The Role of CFD"

Dr Réocreux's presentation opened the technical part of the workshop, and provided the thematic backcloth for the papers that followed by identifying the need for CFD in nuclear reactor safety. He emphasised that several safety issues are known to be highly dependent on strong multi-dimensional flow behaviour, and that ordinary 1-D system codes are quite unable handle this situation. He noted the role played by the OECD Writing Groups in formulating NRS-specific Best Practice Guidelines for CFD, in assembling a database for single-phase applications, and in identifying those areas in multi-phase CFD requiring further development.

He picked up three examples for further elaboration: in-vessel mixing, Pressurized Thermal Shock (PTS) and containment hydrogen distribution. In each, simplified modelling has often been chosen as a first step for supplying answers to NRS issues. It appears also that simplified modelling was generally extensively assessed using experiments, but that several limitations make their prediction on plants questionable. The key word here is *Transposition*, or more specifically the uncertainties in extrapolating from the scale of the experiment to that of the plant. He saw a clear role for CFD in controlling transposition process as an alternative to absorbing all uncertainties into conservatism.

Use of such codes for NRS purposes requires that the applicability of the codes be demonstrated for the expected applications. The validation process is intended to provide this demonstration. He identified a specific strategy based on combined experimental and analytical approaches for handling the question of the transposition within the validation process. This strategy basically echoed that of other speakers: verification (of numerics), validation (of physical models) and demonstration (of code capabilities). Experimentation using separate-effect tests and global tests play a key role this process. His recognition of the part to be played by CFD was in controlling the simplifying assumptions during transposition to real plant scale by reducing such assumptions to a minimum.

As a final word, Dr Réocreux endorsed the role of CFD in NRS in supplying best-estimate predictions, but this needs to be combined with uncertainty evaluation, both in regard to experiments used for validating models and at the code level. These two points were emphasised repeatedly during the workshop, so the final message is clear: experimenters need to provide measurement uncertainties in their data and analysts should follow BPGs to qualify their code predictions.

Mirela Gavrilas, "Lessons Learned from International Standard Problem no. 43 on Boron Mixing"

Dr. Gavrilas presented an overview of the design and execution of ISP 43 (a boron dilution validation benchmark), from the viewpoint of someone who had organized the ISP and survived the process. In addition to the illustration of the general ISP process, she reached a conclusion that echoed a statement made by William Oberkampf in his paper:that it is very important to estimate experimental error through the scatter of results in a number of redundant experiments. Standard experimental error analysis leads to error bounds that are significantly smaller than those inferred from attempting to repeat the same experiment several times.

There was also the issue of the practicalities of organising an ISP, which are very time-consuming. The activity involved developing the experimental series and coordinating transfer of information to participants, as well as collating and evaluating the submissions. Nonetheless, ISP-43 represented the first International Standard Problem geared to CFD code validation.

One important lesson learned from the exercise was that it is absolutely necessary to have experimentalists and code analysts meet together and converse regularly in the selection of the figures of merit for the exercise prior to finalizing the experimental setup. This ensures that target phenomena are monitored, while sufficient data is obtained to analyze the code predictions. Thus, the facility has to be instrumented with due consideration to both the level of detail required for the assessment of a CFD code and also the fundamental, global phenomena under investigation.

Finally, one of the major lessons learned from actually coordinating an ISP were recognizing the importance of optimizing geometric similarity to the prototype against what can be realistically modeled by the code. An original contribution of the ISP-43 exercise was providing the facility geometric description in a standardized, electronic format that could be read by most commercial mesh generators. This minimized the time expended by individual analysts on preparing input models, and reducing the potential for user error. Because the input deck was prepared by the same staff that devised and conducted the experiments, it also minimized issues of completeness.

William L. Oberkampf, "Design of and Comparison with Verification and Validation Benchmarks"

In his paper Dr. Oberkampf laid out basic definitions and criteria for benchmarks supporting verification and validation (V&V), and provided a detailed outline of "strong-sense" V&V benchmarks. He noted that reactor safety has a long history and wide range of validation benchmarks, but very little has been done for verification benchmarks. In response to a question concerning the scale of validation data and when a given scale could be considered appropriate, Dr. Oberkampf emphasised the role of the program manager in determining adequacy of data for a given application. During the ensuing discussions, he also noted that experimental uncertainty is a major issue, and best determined through the use of redundant experiments. This point was also made by Dr Gavrilas in her talk. The comment was also made that it would be very useful to compare this paper's proposals for *strong-sense* validation benchmarks with the guidelines for design and operation of CSNI ISPs, as given in the current revision of CSNI Report 17 (NEA/CSNI/R(2004)5. Dr. Oberkampf noted that he saw a need for more precise definition of initial and boundary conditions for ISP 43, and reiterated the need for more verification benchmarks in addition to the validation activity. There was general consensus on the need for more verification benchmarks, but the point was made that requests for information possible for single-phase validation experiments ca not always be met for two-phase flows. The issue was taken up on whether verification is or is not the responsibility of the code developer rather than the code user. Dr. Oberkampf considered that the onus was indeed on the developer, but the verification process needed to be formalized, and that users must demand verification documentation from the developers.

H.-M. Prasser, "Novel Experimental Measuring Techniques Required to Provide Data for CFD Validation"

Professor Prasser's talk focussed upon his past experience in leading an experimental group at FZR, Germany, together with his visions regarding the further direction of work at ETHZ, Switzerland. He noted that CFD code validation requires experimental data that characterize distributions of parameters within large flow domains, and that the development of geometry-independent closure relations for CFD will have to rely on advanced instrumentation and experimental techniques. This point was illustrated by numerous examples. For boron dilution studies in single-phase (using salt solution as tracer), use of wire-mesh sensors enabled concentration levels to be measured simultaneously at 4096 positions in the ROCOM facility, and the downcomer below the nozzle plane was covered by a dense network of 32x64 measuring points. Two-phase flow model development for CFD was recognised as the most challenging area, but here again wire-mesh sensors were applied to characterize the dynamics of the gas-liquid interface in a vertical pipe flow to provide closure relations for CFD. This work contributed to the formulation of the *Inhomogeneous MUSIG Model* now implemented in the code ANSYS CFX.

Also presented was a novel technique to conduct fluid-dynamic experiments at pressures and temperatures typical for nuclear power plants. A pressure chamber is used as the containment for the test facility itself, which may then be operated in pressure equilibrium, allowing flow structures to be observed by optical means through large-scale windows even at pressures of up to 5 MPa. The so-called “Diving Chamber” technology will be used for Pressurized Thermal Shock (PTS) tests.

Finally, an outlook concerning the trends in instrumentation for multi-phase flows was given. This included a description of the state-of-art of ultra-fast X-ray and gamma tomography, and a discussion of the potential of other non-intrusive techniques, such as neutron radiography and Magnetic Resonance Imaging (MRI).

G. Yadigaroglu, “CFD4NRS with a Focus on Experimental and CMFD Investigations of Bubbly Flows”

This lecture focussed on Computational Multi-Fluid Dynamics (CMFD), and reinforced the message given in the talk of Prof. Prasser in that the validation of CMFD methods will require new kinds of experimental data: average flow parameters (heat flux, velocities, average temperatures or at most the profiles of their averages) will not be sufficient. Three-dimensional and much more sophisticated flow field data will be needed.

The point was illustrated in terms of a number of bubble-flow experiments conducted recently at PSI. The experiments used a range of state-of-the-art measurement techniques, such as double optical probes (bubble dimensions, void fraction and bubble velocity), hot-film anemometry (liquid velocity), photographic techniques, but a new feature was the use of Particle Image Velocimetry (PIV) for obtaining instantaneous, simultaneous measurements for the liquid and bubble velocity fields. Ensemble averaging of these data exposed non-steady characteristics of the flow which would be masked using time-averaged data. In particular, the data provide material for the development of mechanistic models for two-phase turbulence and bubble plume spreading, for example using Large Eddy Simulation (LES) techniques, rather than relying on artificial models involving tuneable coefficients. Such data provide not only unique and very interesting insights into the dynamic behaviour of bubble-induced flows, but the type of localised data essential for validating CMFD models.