International Standard Problem ISP-47 on Containment Thermal-hydraulics

H. J. Allelein, K. Fischer, J. Vendel, J. Malet, E. Studer, S. Schwarz, M. Houkema, H. Paillère, A. Bentaib*

The objective of the OECD/NEA International Standard Problem ISP-47 programme was to assess the capabilities of lumped parameter (LP) and computational fluid dynamics (CFD) analysis codes in the area of containment thermal-hydraulics. Following the recommendations made in the "State-of-the-art Report on Containment Thermal-hydraulics and Hydrogen Distribution", experimental data from different complementary experimental facilities were employed for the benchmark analyses applying a progressive modelling difficulty. The three experimental facilities – TOSQAN, MISTRA and ThAI – provided good quality experimental data suitable for CFD and LP code benchmarking both for steady-state and transient conditions.

The ISP-47 programme was successfully completed in 2007. Nineteen organisations from fourteen countries participated by contributing experimental results, analyses with twelve different codes and reviews. The programme's final report, which contains a full range of figures and details concerning the results, is available online at: www.nea.fr/html/nsd/docs/2007/csni-r2007-10.pdf.

** H. J. Allelein (Hans-Josef.Allelein@grs.de) and S. Schwarz (Siegfried.Schwarz@grs.de) work at the Gesellschaft für Anlagen- und Reaktorsicherheit in Germany; K. Fischer (fischer@becker-technologies.com) works at Becker Technologies GmbH in Germany; J. Vendel (jacques.vendel@irsn.fr), J. Malet (jeanne.malet@irsn.fr) and A. Bentaib (ahmed.bentaib@irsn.fr),work at the IRSN in France; E. Studer (etienne.studer@cea.fr) and H. Paillère (henri.paillere@cea.fr) work at the CEA in France; and M. Houkema (houkema@nrg-nl.com) works at NRG in the Netherlands.*

Experiments and benchmark exercises

The ISP-47 programme was carried out in two steps:

- Step 1 was dedicated to code validation using test data from the separate effects facility TOSQAN (7 m^3 volume) and the larger-scale MISTRA facility (100 m^3 volume). In the TOSQAN tests, wall condensation, steam injection in air or air/helium atmospheres, and buoyancy were addressed under well-controlled initial conditions in a simple geometry. The interactions of phenomena such as condensation/stratification and turbulence/buoyancy were addressed in the MISTRA tests. Both TOSQAN and MISTRA were specifically designed to produce data for CFD codes with state-of-the-art instrumentation. The TOSQAN benchmark was open, whereas the MISTRA benchmark was blind.
- Step 2 was devoted to code validation using an experiment in the multi-compartment ThAI facility (60 m^3 volume) with different steam and helium injection phases, transient stratification and mixing conditions in the atmosphere, development of natural convection, wall condensate distribution, fog formation, and transient thermal response of heat-conducting walls. From this experiment, detailed measurement data on velocity, temperature and gas concentration fields are provided for detailed code validation. The ThAI benchmark covered three sets of calculations: completely blind, partly blind and open.

Results

The three experimental facilities provided experimental data of high quality, using highly accurate measurement techniques suitable for CFD and LP code benchmarking in steady-state and transient conditions. In addition to pressure and atmospheric temperature measurements, detailed gas velocity and gas concentration (air, steam and helium) data were obtained for the first time.

For Step 1, the TOSQAN open benchmark results indicate that the model predictions generally fit the experimental results obtained during condensation steady-state conditions with good accuracy. However, some of the major transient phenomena are not always reproduced by the models. Some multi-dimensional models reproduce the kinetics of the transient stratification whereas most lumped-parameter models only reproduce the final level of concentration.

In the MISTRA blind benchmark, LP models, which usually incorporate fog modelling, give reasonable results if the nodalisation is sufficient to capture the main findings of the flow pattern. From the CFD contributions, open questions concerning simulation of a rising jet and the thermal behaviour of the steel vessel wall were identified. Mean values such as total pressure are predicted rather well by all the codes. Some computations reproduced the gas temperature profiles well; others showed large deviations that are mainly due to overpredicting the superheating. This overprediction has only a minor effect on the calculated helium concentrations, which are generally well-reproduced.

In the Step 2 ThAI benchmark, major improvements in the predictions have been achieved by several participants when moving from blind to half-blind calculations, mainly by refinement of the nodalisation and more systematic treatment of the injection jet entrainment. In particular, the atmospheric stratifications during the phases in which the injection jets are located inside the upper light gas cloud are reproduced well by several LP models. Generally, however, they are underestimated by most LP and CFD contributions. The very challenging conditions leading to maintain the stratification in the phase which has the steam injection at the lower nozzle are in most cases not met, neither by CFD nor LP contributions. The reason why two LP models have been able to predict this stratification blindly is related to nodalisation and entrainment simulation.

Conclusions and recommendations

In view of the high quality of the ISP-47 tests it is recommended that containment codes should be validated against ISP-47 tests before using the code for the assessment of hydrogen distribution in plant applications. This recommendation pertains to lumped parameter codes as well as to nuclear research and industrial CFD codes.

Evidently, LP models are currently the main tools for general containment thermal-hydraulic analysis. LP models require much less computing time than CFD models, and are thus suitable for parametric analysis and PSA level 2 studies. However, LP codes have some inherent limitations due to the simplified flow model applied. These limitations can apparently be overcome by an appropriate user modelling by taking into account the expected relevant phenomena: the best blind predictions for Step 2 have been achieved by two LP codes.

For assessing the hydrogen safety issue in a PWR containment, combined use of both LP and CFD codes is recommended. LP codes may serve as the basic tool for containment analyses, whereas CFD should be used to compute:

- accident scenarios which require more detailed analyses of the (local) phenomena that occur;
- critical accident scenarios which are difficult to analyse using LP codes due to their inherent limitations.

On the other hand, however, LP calculations show a large scattering due to the strong user influence: not only the best, but also the worst predictions are obtained. The user influence appears to be particularly dominant with respect to nodalisation.

Based on the experience gained with this programme, especially with respect to LP codes, it is recommended to initiate an international activity for elaborating general guidelines (especially regarding nodalisation) for LP codes including specific requirements for user manuals. For CFD codes, further improvements in the modelling of condensation and turbulence, including the wall treatment related to these two issues, are recommended.

The ISP-47 tests provide a good database for further code development. However, experimental data on some phenomena are still poor. The analysts should specify the data needed for designing further tests.

At present, there is no proposal for an additional containment thermal-hydraulics benchmark programme. This situation may change following further investigations of the ISP-47 tests and after performing the envisaged ISP on hydrogen combustion. Scaling from tests to real-plant applications remains a major issue: hence, a plant application benchmark should be envisaged in order to study, *inter alia*, nodalisation effects and the impact of steam and light gas injection based on a generic (and probably simplified) PWR containment. ■

References

1. NEA (1999), "State-of-the-art Report on Containment Thermal-hydraulics and Hydrogen Distribution", NEA/CSNI/R(99)16, OECD, Paris.
2. NEA (2007), "International Standard Problem ISP-47 on Containment Thermal-hydraulics", NEA/CSNI(2007)10, OECD, Paris.