NUCLEAR SCIENCE COMMITTEE
and
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

OECD/DOE/CEA VVER-1000 Coolant Transient Benchmark (V1000-CT) –Workshop 3.5

Avignon, France
4 October, 2005

Hosted by
NURETH-11 conference

Summary of Meeting

OECD/DOE/CEA
VVER-1000 Coolant Transient Benchmark
NURETH-11 ad-hoc meeting (V1000-CT3.5)

(Avignon, France, 4 October 2005)

Sponsorship

An ad-hoc meeting for the VVER-CT benchmark was held on 4 October 2005 in Avignon, France, in connection with the NURETH-11 International Conference on Nuclear Reactors Thermal-Hydraulics. It is a follow-up to the third workshop held on 4-5 April 2005, in Garching, Germany, the second workshop, hosted by INRNE and KNPP, Bulgaria Sofia, Bulgaria, on 5-6 April 2004, the first workshop hosted by the CEA-Saclay (Paris), France, on 12-13 May, 2003, and to the starter meeting hosted by the Forschungszentrum Rossendorf (FZR), Germany, on 30 May, 2002. The V1000-CT Benchmark is sponsored by the US DOE, OECD, CEA, and the Nuclear Engineering Program (NEP) at the Pennsylvania State University (PSU). The NEP, PSU (USA), CEA-Saclay (France) and the Institute of Nuclear Research and Nuclear Energy (INRNE), Sofia (Bulgaria), perform these international benchmark activities in collaboration and with the assistance of the ANL (USA) and Kozloduy Nuclear Power Plant – KNPP (Bulgaria).

Background and Purpose of the Ad-hoc Benchmark Meeting

The Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD) has completed, under the sponsorship of the Nuclear Regulatory Commission (NRC), a PWR Main Steam Line Break (MSLB) Benchmark against thermal-hydraulic/neutron kinetics codes. Recently another OECD/NRC coupled code benchmark was completed for a BWR turbine trip (TT) transient. During the course of defining and coordinating the OECD/NRC PWR MSLB and BWR TT benchmarks a systematic approach was established to validate best estimate coupled codes. This approach employs a multi-level methodology that not only allows a consistent and comprehensive validation process but also contributes to determining additional requirements as well as to preparing a basis of licensing application of the coupled calculations for a specific reactor type and to developing a safety expertise in analyzing reactivity transients. Professional communities have been established during the course of these benchmark activities that allow in-depth discussions of different aspects of assessing neutron kinetics modeling for a given reactor and how to implement best-estimate methodologies for transient analysis using coupled codes. The above examples demonstrate the benefit of establishing such international coupled standard problems for each reactor type.

The continuation of the above activities foresees the development of a VVER-1000 coolant transient (V1000CT) benchmark, which defines coupled code standard problems for validation of thermal-hydraulics system codes for application to Russian-designed VVER-1000 reactors based on actual plant data. The overall objective is to assess computer codes used in the safety analysis of VVER power plants, specifically for their use in reactivity transients in a VVER-1000. In performing this work the PSU, USA and CEA-Saclay, France have collaborated with Bulgarian organizations, in particular with the KNPP and the INRNE. The V1000CT benchmark consist of two phases: V1000CT-1 is a simulation of the start-up of one main coolant pump (MCP) when the other three MCP are in operation, and V1000CT-2 concerns calculation of coolant mixing tests and main steam line break (MSLB) scenarios. Each of the two phases contains three exercises.

The reference problem chosen for simulation in Phase 1 is a MCP switching on when the other three main coolant pumps are in operation in a VVER-1000. It is an experiment that was conducted by Bulgarian and

Russian engineers during the plant-commissioning phase at the Kozloduy NPP Unit #6 as a part of the start-up tests. The test was done, as it is important for the safety of the NPP with VVER-1000, model 320. The reactor is at the beginning of cycle (BOC) with average core exposure of 30.7 EFPD. At the beginning of the experiment there are three pumps in operation – 1st, 2nd and 4th main coolant pumps and the reactor power is at 27.47% of the nominal power level (824 MWt). The control rod group #10 is inserted into the core. The group position in axial direction is at about 36% withdrawn from the bottom of the reactor core. Analysis of the initial three-dimensional (3-D) relative power distribution showed that this insertion introduced axial neutronics asymmetry in the core. At the beginning of the transient there is also a radial thermal-hydraulic asymmetry coming from the colder water introduced in ¼ of the core when MCP #3 is switched on. This causes a spatial asymmetry in the reactivity feedback, which is propagated through the transient and combined with insertion of positive reactivity. In summary, this event is characterized by rapid increase in the flow through the core resulting in a coolant temperature decrease, which is spatially dependent. This leads to insertion of spatially distributed positive reactivity due to the modeled feedback mechanisms and non-symmetric power distribution. Simulation of the transient requires evaluation of core response from a multi-dimensional perspective (coupled three dimensional neutronics/core thermal-hydraulics) supplemented by a one-dimensional simulation of the remainder of the reactor coolant system. Three exercises are defined in the framework of Phase 1:

a) Exercise 1 – Point kinetics plant simulation;
b) Exercise 2 – Coupled 3-D neutronics/core thermal-hydraulics response evaluation;
c) Exercise 3 – Best-estimate coupled 3-D core/plant system transient modeling.

In addition to the measured (experiment) scenario, extreme calculation scenarios were defined in the frame of Exercise 3 for better testing 3-D neutronics/thermal-hydraulics techniques. The proposals concerned: rod ejection simulations with scram set points at two different power levels.

Since the previous coupled code benchmarks indicated that further development of the mixing computation models in the integrated codes is necessary, a coolant mixing experiment and a MSLB scenario were selected for simulation in Phase 2 of the benchmark. Three exercises were defined for Phase 2:

a) Exercise 1 – Computation of a vessel mixing experiment;
b) Exercise 2 – Coupled 3-D neutronics/3-D vessel thermal hydraulics calculation with given MSLB vessel boundary conditions;
c) Exercise 3 – Best-estimate coupled 3-D core/3-D vessel/plant system simulation.

An additional option of CFD modeling of the vessel with specific boundary conditions rather than core boundary conditions and CFD modeling of the mixing is also included as Exercise 1 of Phase 2. For this specific case measured data from KNPP Unit #6 is made available. The selected mixing experiment was conducted at Kozloduy-6 as part of the plant commissioning phase. This asymmetric experiment includes steam generator isolation and heating-up at 9.4 % of nominal power with all MCP in operation. It will be used to test and validate vessel-mixing models (CFD, coarse-mesh and mixing matrix). Vessel boundary conditions and core power distribution are part of this exercise specification.

The transient to be analyzed in Exercises 2 and 3 of Phase 2 is initiated by a MSLB in the VVER-1000 NPP between the steam generator and the steam isolation valve, outside the containment. This event is characterized by a large asymmetric cooling of the core, stuck rods and a large primary coolant flow variation. Two scenarios are defined: the first scenario is taken from the current licensing practice and the second is derived from the original one using aggravating assumptions to enhance the code-to-code comparison. The main objective is to clarify the local 3-D feedback effects depending on the vessel mixing. Special emphasis is put on testing 3-D vessel thermal-hydraulics models and coupling of 3-D neutronics/vessel thermal-hydraulics. Use of vessel TH models validated against V1000CT-2 Exercise 1 (mixing test) and V1000CT-1 (mixing test with neutronics) for the same unit is assumed.

In June 2002 the Nuclear Science Committee (NSC) of NEA/OECD, at its annual meeting in Paris, approved and endorsed the developed V1000CT benchmark problem to become an international standard problem for validation of the best-estimate safety codes for VVER applications. Collaboration with the AER Working Group D involved in VVER safety research on the proposed VVER-1000 coolant transient benchmark has been established and the AER participates actively in the benchmark activities. The co-operation of this working group with the V1000CT benchmark group was endorsed by the OECD/NEA NSC, and is supported by the Safety Division.

<u>Scope and Technical Content of the Benchmark Workshop</u>

The ad-hoc meeting was aimed at:

- Discussion of final conclusions for Phase 1
- Presentation and discussion of cross-section modelling for Phase 2
- Presentation and discussion of results of Exercise 1, Phase 2
- Discussion of the Specifications for Exercises 2 and 3 of Phase 2
- Defining work plan and schedule, actions to progress in completing the 2 phases

<u>Organization of the Benchmark Workshop</u>

The meeting was organized during the NURETH-11 conference, and was considered as a special session of the conference.

<u>Participation in the Benchmark Workshop</u>

The represented participants of the benchmark were:

- Penn State University, USA, by B. Ivanov,
- Polytechnic University of Madrid, Spain, by D. Cuervo,
- Forschungszentrum Karslruhe, Germany, by V. Sanchez and M. Boettcher,
- Gesellschaft für Reaktor Sicherheit, Germany, by K. Velkov,
- Forschungszentrum Rossendorf, Germany, by S. Kliem and T. Höhne,
- VTT, Finland, by A. Hamalainen,
- Commissariat à l'Energie Atomique, France, by U. Bieder, S. Aniel and E. Royer.

Some experts in the field attended the meeting as invited persons:

- J. Banati, Chalmers University of Technology, Sweden,
- J. Zhang, Tractebel, Belgium,
- L. Sabotinov, IRSN, France.

Organization and Programme Committee of the Benchmark Workshop

Hervé Lemonnier (TPC of NURETH-11)
Centre d'Etudes de Grenoble
CEA/DEN/DER/SSTH/LIEX
38 054 Grenoble Cedex, France
Tel: +33 4 38 78 45 40; Fax: +33 4 38 78 50 45
E-mail: herve.lemonnier@cea.fr

Eric Royer
Centre d'Etudes de Saclay
CEA/DEN/DM2S/SFME
91191 Gif-sur-Yvette Cedex, France
Tel: +33 1 69 08 54 69; Fax: +33 1 69 08 85 68
E-mail: eric.royer@cea.fr

Francesco D'Auria
Professor
Universita degli Studi di Pisa
Dept. of mechanical, nuclear&production engineering
Via Diotisalvi, 2
I-56126 PISA, Italy
Tel: +39 (050) 836653; Fax: +39 (050) 836665
E-mail: dauria@ing.unipi.it
Member of CSNI, NEA, OECD

Secretariat: **Enrico Sartori**
OECD / Nuclear Energy Agency
12 boulevard des Iles
92130 Issy les Moulineaux, France
+33 1 45 24 10 72 (Phone), +33 (1) 4524 1110 (Fax)
E-mail: sartori@nea.fr

Summary

Discussion of final conclusions for Phase 1

B. Ivanov presented the final results submitted for Phase 1. There are 14 participants. One questionnaire is still missing in order to conclude the comparative analysis.

The remaining issue is the treatment of the experimental temperatures, since the thermocouples and thermoresistors have a long response time compared to the dynamic of the transients in the benchmark (pump start-up and steam generator isolation). A low pass filter is suggested, according to previous experience with similar VVER reactor. PSU will assess this technique. If it gives satisfactory results, the same process will be used for all the submitted results.

Presentation and discussion of cross-section modelling for Phase 2

During Phase 1 of the benchmark, unexpected discrepancies were observed for HZP calculations. After a deep analysis, it was found that the cross-section modelling is part of the reason, particularly at the core-reflector interface.

For Phase 2, several improvements are proposed:

- the kinetic parameters will be added for each composition,
- the cross-sections depend on three parameters (moderator temperature, moderator density, fuel temperature) instead of two, for the purpose of SLB application,
- the reflector model is improved (material composition, assessment of 2D effects),
- assembly discontinuity factors are incorporated as in Phase 1, but there is the possibility for the participants to derive their own discontinuity factors for the core-reflector interface.

The cross-sections will be verified on plant data near end of cycle conditions at 92% of power.

A question was raised for the temperature range: during the SLB, some computations may fall outside of the proposed range, in particular the moderator temperature. If this occurs, it was decided to extrapolate the cross-section values (as performed by the cross-section interpolation procedure).

Presentation and discussion of results of Exercise 1, Phase 2

E. Royer presented the analysis of the preliminary results submitted for Exercise 1. There are three solutions with system models, and three solutions with CFD models. The detailed comparison of the system solutions shows an overall agreement with the plant data. The main discrepancies can be explained by differences in initial conditions. Only limited analysis was possible for CFD computations, mainly because the computation domains were different (full vessel versus downcomer and lower plenum), and the result templates were not completed. It was decided to include several physical parameters in the comparison, in addition to the temperature: pressure line in the vessel (available measurements) and velocity field at core inlet.

Two other solutions are expected: one with the Fluent code by PSU/ORNL, and one with the Athlet code by GRS. They will be included in the final comparison. Tractebel indicates also a possible participation with the CFX code.

The following points were raised by the participants:

- the initial temperature in hot leg # 2 is not consistent with the time evolution,
- the energy balance of the plant is questionable (281/295 MW),
- the heat exchange in the isolated steam generator can be reversed during the transient,
- additional information on pressurizer regulation systems is necessary in the Specifications in order to correctly predict the primary pressure.

Discussion of the Specifications for Exercises 2 and 3 of Phase 2

E. Royer presented the Main Steam Line Break specifications, based on Cathare and Athlet calculations. Two scenarios are defined: realistic based on licensing conditions, and pessimistic for enhanced multi-dimensional effects in the core. The computation results obtained for the pessimistic scenario were discussed in detail.

The following points were raised by the participants:

- a six sector model for the core vessel is supposed to better predict the mixing effects,
- a detailed analysis of the break flow (liquid and vapor part) and of the water level in the steam generators will be necessary for Exercise 3,
- the vessel mixing models are validated in Exercise 1 for a perturbation in loop # 1, whereas the SLB is postulated in loop # 4.

Defining work plan and schedule, actions to progress in completing the 2 phases

The schedule defined for V1000CT-2 during workshop 3 in Garching, April 2005 (cf. NEA/NSC/DOC/2005(6)) was updated for some actions:

Nr.	Action	By whom	Deadline
16	Submit the final results of Exercise 1	Participants	15-12-2005
18	Prepare cross-section library	B. Ivanov	15-10-2005
20	Final specifications of Exercises 2&3	E. Royer, N. Kolev	30-11-2005
21	Submit results of Exercises 2&3	Participants	15-03-2006

A final meeting will be necessary after workshop 4 in Pisa, 24-25 April 2006. There is a proposal to organize an ad-hoc meeting during PHYSOR 2006 in Vancouver, Canada (10-14 September 2006). A survey will be made by e-mail to check if it is acceptable for enough participants.

It was requested to propose integral mixing coefficients in the Specifications for participants who do not have the opportunity to validate their vessel model in Exercise 1.

Appendix

Agenda of the meeting:

- Conclusions on V1000CT-1, B. Ivanov, K. Ivanov, S. Aniel, E. Royer, presented by B. Ivanov,
- Enhancement of the cross-section library for Exercises 2&3 of V1000CT-2 benchmark, B. Ivanov, K. Ivanov, S. Aniel, N. Kolev, presented by B. Ivanov,
- V1000CT-2 – Analysis of Exercise 1 coolant experiment, N. Kolev, E. Royer, presented by E. Royer,
- Status of the OECD V1000CT-2 MSLB benchmark Specifications, N. Kolev, E. Royer, presented by E. Royer,
- Comparison of preliminary CATHARE and ATHLET calculations of the OECD V1000CT-2 MSLB benchmark, N. Kolev, S. Nikonov, presented by E. Royer,
- Round table and conclusions.

The presentations are available on the cumulative CD-ROM prepared by OECD, and distributed to all benchmark participants.