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NUCLEAR SCIENCE COMMITTEE
and
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

OECD/DOE/CEA VVER-1000 Coolant Transient Benchmark Summary of the Secong Workshop (V1000-CT2)

5-6 April 2004
Sofia, Bulgaria

English - Or. English

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NUCLEAR SCIENCE COMMITTEE
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OECD/DOE/CEA VVER-1000 Coolant Transient Benchmark - Second Workshop (V1000-CT2)

5-6 April 2004
Sofia, Bulgaria

Hosted by

Institute for Nuclear Research and Nuclear Energy (INRNE)
and the Kozloduy Nuclear Power Plant (KNPP), Bulgaria

SUMMARY

Background and Purpose of the Benchmark Workshop

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 allowed in-depth discussions of different aspects of assessing neutron kinetics modelling for a given reactor, and ways 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 type of reactor.

Further continuation of the above activities is 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 Soviet-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, 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 switching on of one main coolant pump (MCP) when the other three MCPs are in operation, and V1000CT-2 concerns the 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 undertaken, 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 one quarter 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. To summarise, 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 modelled 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 modelling.

In addition to the measured (experiment) scenario, a extreme calculation scenario was defined in the frame of Exercise 3 for better testing 3-D neutronics/thermal-hydraulics techniques. The proposals concerned: rod ejection simulations with a rod being ejected in the core sector coolded by MCP #3.

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 are selected for simulation in Phase 2 of the benchmark. The introduction as an additional option of CFD modelling of the vessel with specific boundary conditions rather than core boundary conditions, and CFD modelling of the mixing is also included as Exercise 1 of Phase 2. For this specific case additional data from KNPP Unit #6 are made available. The selected mixing experiment was conducted at KNPP #6 as part of the plant-commissioning phase. This asymmetric experiment includes single loop heating-up at 9 % 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. There is practically no coupling with neutronics because the boron concentration corresponds to the moderator temperature coefficient close to zero. In addition to this experiment, a second test with single loop cooling-down will be defined for code-to-code comparison (numerical experiment).

The transient to be analyzed in Phase 2 is initiated by a MSLB in the VVER-1000 NPP between the steam generator and the steam isolation valve, outside of 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 one is derived from the original one using aggravating assumptions to enhance the code-to-code comparisons. 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. The MSLB scenario simulation is divided into two exercises:

a) Exercise 2 consists of coupled 3-D neutronics/vessel thermal-hydraulics simulation using specified vessel thermal-hydraulic boundary conditions,

b) Exercise 3 consists of best-estimate coupled 3-D core/3-D vessel/plant system modelling.

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 VVER-1000 coolant transient benchmark is 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 Nuclear Safety Division. The AER Working Group meeting was held on 7 and8 April 2004 at the same premises in Sofia, Bulgaria.

Session 1 – Introduction: *Chair N. Kolev*

The meeting was opened by Prof. Jordan Stamenov, Director of INRNE that was hosting the meeting. He welcomed the participants on behalf of INRNE, Sofia, and wished them a successful work. Vasil Hadjiev welcomed the participants on behalf of the KNPP, Bulgaria, also hosting the Workshop in cooperation with INRNE. Dr. Nikola Kolev welcomed participants on behalf of the international benchmark team. Prof. Francesco D'Auria welcomed the participants on behalf of the CSNI-GAMA/NEA/OECD and underlined the importance of the benchmark for nuclear safety, design and operation. Prof. Jose-Maria Aragonés welcomed the participants on behalf of NSC/NEA/OECD acknowledging that this is the first NEA/OECD Workshop in Bulgaria and an important step in integrating the nuclear community in Bulgaria in NEA/OECD. Dr. Enrico Sartori welcomed the participants on behalf of the NEA Secretariat and thanked in particular the local organizers for their hospitality.

The meeting was attended by 44 participants from 11 countries representing 21 organisations (see Annex I). The agenda was approved with minor adjustments (see Annex II).

K. Ivanov reviewed the status of V1000CT-1 (Phase1) benchmark activities while E. Royer gave an overview of the status of V1000CT-2 benchmark activities.

Session 2: *Chair*: *G.Yoder*

B. Ivanov reviewed the participants' comments submitted and the modifications introduced in the V1000CT-1 benchmark specifications. M. Pavlova presented a discussion of Exercise 1 of V1000CT-1 including the input data and effect of some modelling issues such as the non-symmetrical mixing in the reactor vessel down-comer and the reactor vessel annular exit; impact of the heat structure temperature to the time delay for equipment measurement; and investigation of the pressurizer water level using the hot leg temperature correction.

Session 3: *Chair: P. Groudev*

B. Ivanov presented comparisons of the results submitted by the participants for Exercise 1 of the first phase of the benchmark. Nine participants from 7 countries submitted their solutions for this exercise. K. Ivanov discussed the modelling issues of Exercise 2 of Phase1 of the benchmark in his presentation. The overall conclusion is that the observed deviations in the power distribution results of participants' core neutronics models for the HZP comparisons (with "frozen" thermal-hydraulic feedback) are much larger than the deviations observed in similar comparisons for the previous benchmarks – OECD/NRC PWR MSLB and OECD/NRC BWR TT benchmarks. The presentation reviewed different possible sources of the observed deviations. The discussion on this issue continued further into the B. Ivanov's comparative analysis on Exercise 2, the participants' presentations and the discussions that followed. B. Ivanov presented comparisons of the results submitted by the participants for Exercise 2 of the first benchmark

phase. Eight participants from seven countries submitted their results for this exercise (please note that NRI, Czech Republic submitted two sets of results). These presentations were followed by a discussion, which identified the following issues to be clarified:

- The time delay of the plant measurements and how to incorporate it for comparison with calculated results
- Methods for calculating the reactivity and adding the time histories of reactivity components as required output for the 1st Exercise
- Decay heat power modelling in the 2nd Exercise and its impact on the participants' results
- The existing large deviations in predicted k_{eff} and radial power distributions for the HZP results submitted by the participants
- Utilization of mass flow rate core inlet boundary conditions and the provision of a method to reconstruct these boundary conditions on assembly basis

Session 4: *Chair: S.Kliem*

K. Ivanov presented a comparative analysis of the submitted results for Exercise 3 of the Phase 1 of the benchmark. Four participants from four countries submitted their results for this exercise. Further the participants presented their models, sensitivity studies and results for Phase 1 of the V1000CT benchmark. S. Aniel-Buchheit from CEA presented HZP comparisons of 3 codes and analysis of these results. The observed deviations in the radial power distributions at the interfaces – assembly interfaces and the core/reflector interface – may be caused by the introduction of ADFs implicitly into the cross-sections, which might be interpreted in different ways by the different methods for solving the diffusion equation in hexagonal geometry. The reason for this might be the fact that the cross-sections and ADFs are generated on the basis of single assembly homogenisation procedure and the different codes utilize different spatial meshing per hexagonal assembly. J. Vedovi from the University of Pisa presented the obtained results with PARCS/RELAP5 for the three exercises of the Phase 1 of the benchmark. He also demonstrated that the observed deviations between PARCS and NEM at HZP conditions are carried out in HP comparisons. A. Shkarupa from Kiev University presented the analysis of V1000CT-1 benchmark using RELAP-3D and results from the performed sensitivity studies on the impact of the detail of radial core thermal-hydraulic nodalization when using a three-dimensional core thermal-hydraulic model. His results for the extreme scenario demonstrated that there is a need for re-definition of the extreme scenario in the benchmark specification on Phase 1. V. Sanchez from FZK presented their investigations on the three exercises of V1000CT-1 using PARCS/RELAP5.

Session 5: *Chair: E. Royer*

In this session first the participants continued their presentations on Phase 1 of V1000CT benchmark. K Velkov from GRS presented their results for Exercise 1 using the system code ATHLET. He stressed the importance of correct modelling of mass flow distribution and especially the mixing (cross-flow) phenomena in the upper plenum and down comer during the initial conditions and modelled MCP switching on transient. Y. Kozmenkov from FRZ presented the obtained results for Exercise 3 of V1000CT-1 with the coupled code system DYN3D-ATHLET. He underlined that the extreme scenario should be redefined according to the latest results for the ejected rod worth. J. Hadek presented NRI results for Exercises 1 and 2 of V1000CT-1 using ATHLET and DYN3D codes. The interesting point was the comparisons between the results obtained with two DYN3D core models – one using 24 thermal-hydraulics channels (following the benchmark specifications) and the other using 211 thermal-hydraulic

channels, i.e. each neutronics assembly is coupled to a separate thermal-hydraulic channel. K. Ivanov summarized in his presentation the observed modelling issues for Phase 1 of the V1000CT benchmark based on the analysis of the comparisons of the submitted participants' results. The following issues were discussed and subsequent corrective actions were planned:

- Resolving the large deviations in k_{eff} and radial power distributions for the HZP comparisons of Exercise 2. The benchmark team will investigate the impact of the implicit treatment of ADFs, spatial mesh convergence, and group flux modelling in different methods especially in the reflector region.

- Providing the core inlet mass flow rate boundary conditions on the assembly basis for Exercise 2.

- Accounting for the time delays in plant measurement systems for the code-to-data comparisons.

- Updating the definition of the extreme scenario for Exercise 3.

- Definition of mixing phenomena problem for the MCP switching on transient.

At the end of this session E. Sartori initiated a discussion about the V1000CT-1 benchmark schedule, and next workshop. As a result the following V1000CT-1 schedule and list of actions were accepted by the participants in the workshop:

- End of August 2004 – the benchmark team to resolve the above described modelling issues and provide the participants with corresponding information.

- End of January 2005 – submission of final results on the three exercises of Phase 1 by the participants.

- Mid-March 2005– the benchmark team to prepare draft reports on the three exercises

- 4-5 April 2005 – 3rd V1000CT benchmark workshop in Garching near Munich, Germany, hosted by GRS. The workshop will be held in co-operation with the AER WGD and in conjunction with the AER WGD meeting, which will be held on 6-7 April 2005 also in Garching, Germany.

- October 2005 - special session on the V1000CT benchmark to be held at NURETH 11 conference in Avignon, France.

- End of 2005 – Final NEA/OECD reports on the Phase 1 of V1000CT benchmark.

Session 6: *Chair: P. Siltanen*

This session was devoted to a discussion of V1000CT-2 Exercise 1 Specifications. First, D. Popov from KNPP made an overview of the mixing tests performed at the KNPP. Second, N. Kolev discussed in detail the Specifications of Exercise 1 of V1000CT-2. One heat-up experiment (Test 1) is chosen for comparison with computations. Two sets of geometrical data are provided to allow a sensitivity study on the vessel modelling: one set is mainly based on design data, while the second set includes most of the Kozloduy-6 specific data. A numerical experiment (Test 2) is also planned to compare computations of

cooling-down conditions. Finally, U. Bieder from CEA described how the available plant data can be utilized to define the thermal-hydraulic benchmark for Exercise 1 and to generate reference solutions.

Session 7: *Chair J. Hadek*

N. Kolev presented the VVER-1000 MSLB scenarios, which are proposed for simulation in the 2nd and 3rd exercises of V1000CT-2. In the section on the participants' experience in VVER analysis and vessel CFD modelling P. Kodl from SKODA JS presented their model of PTS of VVER-1000 reactor vessel.

E. Sartori initiated a discussion about the schedule on Phase 2 of the V1000CT benchmark and next workshops. As a result the following list of actions for V1000CT-2, in addition to V1000CT-1, were accepted by the participants in the workshop:

- End of June 2004 – complete the specifications of Exercise 1 to include Test 2
- Mid-February 2005 – submit results on Exercise 1
- April 2005 – final Specification on Exercise 1
- June 2005 – draft Specifications on Exercises 2 and 3
- April 2006 – 4th Workshop hosted by the University of Pisa in conjunction with the AER WGD meeting
- December 2006 – finalization of the OECD/NEA reports on the three exercises of Phase 2

Prof. F. D'Auria discussed the impact of the benchmark activities involving coupled 3-D neutron kinetics and thermal-hydraulics on the nuclear reactor safety, design and operation. He also provided concluding remarks at the Workshop expressing appreciation for the benchmark activities of best estimate 3D core/plant coupling methods and their application to the VVER reactors.

The combined list of actions agreed at the Workshop concerning both phases of the benchmark are shown in Table 1.:

Proceedings of the Workshop

Participants will receive with this summary a CD-ROM containing all papers discussed at the meetings. The CD-ROM will also include all reports from previous workshops, which discuss this benchmark.

Co-operation with AER

The AER Working Group D Meeting was held during the following days, 7-8 April 2004 at the same premises. It was attended by 23 participants from 11 countries and 15 organisations. The co-operation of this working group with the VVER-1000 benchmark group was endorsed by the OECD/NEA NSC and is supported by the Safety Division. The members of the AER WGD are participating actively in the OECD/DOE/CEA V1000CT benchmark. One example of their contribution was the special presentation made by P. Siltanen at the AER meeting concerning the analysis of possible sources of the observed deviations in the benchmark participants' predictions of power distributions for the HZP state. The analysis was based on his experience with method developments in Finland for 3-D two-group

diffusion problem solution. The discrepancies in power distribution predictions might be caused by different methods for approximating the fundamental and transient components of the two group fluxes especially in non-diffusive regions such as reflector regions. P. Siltanen made several suggestions to the benchmark team to be investigated further and these suggestions were accepted with gratitude. The summary of this meeting has been prepared separately and is available to the AER participants.

Table 1. Schedule for V1000CT: Actions decided at the 2nd Workshop

#	Date	V1000CT-1	V1000CT-2	Who
1	29 April 2004	V1000CT Benchmark paper presented at PHYSOR2004		K. Ivanov
2	10-11 June 2004	Reporting at NSC&CSNI GAMA Meetings		J. M. Aragones F. D'Auria
3	End of June 2004		Complete Specification of Exercise 1 to include Test 2	N. Kolev E. Royer
4	End of August 2004	Updated Specifications to include clarifications on open issues		K. Ivanov B. Ivanov
5	End of January 2005	Deadline for submitting results on Exercises 1, 2, and 3		Participants
6	Mid-February 2005		Submit results for Exercise 1	Participants
7	March 2005	Drafts reports on Exercises 1, 2 and 3		K. Ivanov B. Ivanov
8	April 2005		Final Specification on Exercise 1	N. Kolev E. Royer
9	4-5 April 2005	3rd Workshop at GRS Garching in conjunction with AER-WGD Meeting (6-7 April 2005)		S. Langenbuch P. Siltanen E. Sartori
10	June 2005		Draft Specification for Exercises 2 and 3	N. Kolev E. Royer
11	June 2005	Reporting at NSC and CSNI GAMA Meetings		J. M. Aragones F. D'Auria
12	2-6 October 2005	Special Session at NURETH-11 Conference, Avignon, France		K. Ivanov E. Royer
13	December 2005	Finalization of reports 1,2 and 3		K. Ivanov
14	April 2006		4th Workshop hosted by U. Pisa in conjunction with AER-WGD meeting	F. D'Auria P. Siltanen E. Sartori
15	2006	Special session at PHYSOR 2006		K. Ivanov N. Kolev
16	December 2006		Finalization of reports 1,2 and 3	N. Kolev E. Royer

Annex 1

2nd Workshop on VVER-1000 Coolant Transient Benchmark, Sofia, 5-6 April 2004

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* regrets not to have been able to attend this time

Annex 2

OECD/DOE/CEA VVER-1000 Coolant Transient Benchmark - Second Workshop (V1000-CT2)

Sofia, Bulgaria
5-6 April 2004

Hosted by: INRNE/KNPP

PROGRAMME [01]

April 5th

Session 1 – Session Chair – Nikola Kolev

09:00-09:30 Introduction and Welcome
INRNE – *Jordan Stamenov, INRNE*
KNPP – *Vasil Hadjiev, KNPP*
OECD-NEA – *Francesco D'Auria, representing CSNI-GAMA*
José María Aragonés, representing NSC
Enrico Sartori, representing NEA Secretariat
Introduction of Participants *[02]*
09:30-10:00 Overview and status of V1000CT-1 (Phase 1) Benchmark - *Kostadin Ivanov [03]*
10:00-10:30 Overview and status of V1000CT-2 benchmark - *Eric Royer[04]*

10:30-10:45 Coffee Break

Session 2 – Session Chair – Grady Yoder

10:45-11:15 Comments and Modifications of V1000CT-1 Specifications – *Boyan Ivanov, Kostadin Ivanov [05]*
11:15-11:45 Discussion of Exercise 1 of V1000CT-1 – *Pavlin Groudev, Malinka Pavlova, Antoaneta Stefanova, Rositsa Gencheva [06]*

11:45-13:15 Lunch

Session 3 – Session Chair – Pavlin Groudev

13:15-13:45 Comparative Analysis of Exercise 1 of the V1000CT-1 Benchmark - *Boyan Ivanov, Kostadin Ivanov* [07]
13:45-14:15 Discussion of Exercise 2 of V1000CT-1 Benchmark - *Kostadin Ivanov, Boyan Ivanov [08]*
14:15-14:45 Comparative Analysis of Exercise 2 of V1000CT-1 Benchmark - *Boyan Ivanov, Kostadin Ivanov [09]*

14:45-15:00 Coffee Break

Session 4 – Session Chair – Soeren Kliem

15:00-15:30 Comparative Analysis of Exercise 3 of the V1000CT-1 Benchmark – *Boyan Ivanov, Kostadin Ivanov [10]*
15:30-17:00 Participants' presentations on Phase 1 – V1000CT-1
- V1000CT-1 Exercise 2, HZP Neutronic Comparisons: *S. Aniel-Buchheit, B. Ivanov, K. Ivanov, J. Hadek[11]*
- Joint Participation of University of Pisa and PSU to the VVER1000 CT Benchmark, *Juswald Vedovi, Giorgio M.Galassi, Francesco D'Auria, and Kostadin Ivanov [12]*
- VVER-1000 Kozloduy Benchmark Analysis Performed by KU with RELAP5-3D: *Alexander Shkarupa* [13]
- FZK Investigations for the V1000-CT Benchmark Phase1: V*ictor H. Sanchez Espinoza [14]*

April 6th
Session 5 – Session Chair – Eric Royer

9:00-10:00 Discussion of V1000CT-1 Modelling Issues and Obtained Results - *Kostadin Ivanov [15]*

10:00-10:30 Participants' presentations on Phase 1 – V1000CT-1
- Preliminary Results for Exercise 1 of V1000-CT Benchmark by GRS Applying ATHLET code: *S. Langenbuch, K.D. Schmidt, K. Velkov [16]*
- Simulation of Exercise 3 scenarios of V1000CT-1 using DYN3D-ATHLET coupled code system, *Y.Kozmenkov Soeren Kliem, [17]*
- Solution of V1000CT-1 Benchmark – Exercise 1 and 2 : *Jan Hádek, Radim Meca [18]*

10:30-11:00 Discussion of the schedule for Phase 1 activities – *Enrico Sartori*

11:00-11:15 Coffee Break

Session 6 – Session Chair – Pertti Siltanen

11:15-11:45 Overview of the Mixing Tests – *Dimitar Popov, Csvetan Tupalov KNPP [19]*
11:45-12:15 Discussion of the Specifications of Exercise 1 of the V1000CT-2 Benchmark – *Nikola Kolev, Dimitar Popov, Sylvie Aniel, Eric Royer [20]*
12:15-12:45 Preparation of the thermalhydraulic benchmark V1000CT –2 – *Ulrich Bieder, Sylvie Bétin, Gauthier Fauchet, Nikola Kolev. [21]*

12:45-14:00 Lunch

Session 7 – Session Chair – Jan Hadek

14:00-14:30 Description of VVER-1000 MSLB Scenario - *Nikola Kolev and Eric Royer [22]*
14:30-15:30 Participants experience on VVER analysis and vessel CFD modelling
- Thermohydraulic and Stress Model of Pressurized Thermal Shock of VVER 1000 Reactor Vessel: *Hana Hauerova, Petr Kodl, Eva Pechmannova*: [22]

15:30-15:45 Coffee Break.
15:45-16:15 Discussion of the schedule on Phase 2 and next workshops - *Enrico Sartori*
16:15-16:45 Discussion of the impact of the benchmark activities involving coupled 3-D neutron kinetics and thermal-hydraulics on the Nuclear Reactor Safety, Design and Operation - *Francesco D'Auria and K. Ivanov*
16:45-17:00 Conclusion and closing remarks – *Francesco D'Auria*