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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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LIST OF ABBREVIATIONS AND ACRONYMS

ACC	Accumulator
AEKI	A research institute of the Hungarian Academy of Sciences (Hungary)
AM	Accident management
APROS	Computer code
ATHLET	Computer code developed by Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), (Germany)
ATLAS	Advanced Thermal-hydraulic Test Loop for Accident Simulation
BARC	Bhabha atomic research centre (India)
BelV	The Belgian technical support organisation
CATHARE	Computer code developed by French organisations (France)
CET	Core exit temperatures
CFD	Computational fluid dynamics
CPU	Central processing unit
CSN	El Consejo de Seguridad Nuclear (Spain)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
CT	Counterpart tests
DEC	Design extension conditions
ECC	Emergency core cooling
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Germany)
HZDR	Helmholtz Zentrum Dresden Rossendorf (Germany)
IBLOCA	Intermediate break loss-of-coolant accident
JAEA	Japan Atomic Energy Agency (Japan)
KAERI	Korea Atomic Energy Research Institute (Korea)
KORSAR	Computer code developed by the Alexanrdrov Research Institute of Technology (Russia)
LOCA	Loss-of-coolant accident
LSC	Loop seal clearing
LSTF	Large scale test facility (operated by Japan Atomic Energy Agency)
NCI	Natural circulation interruption
NEA	Nuclear Energy Agency

NINE	Nuclear and industrial engineering
SUA	Sensitivity and uncertainty analyses
TLOFW	Total loss of feed water
LUT	Lappeenranta University of Technology (Finland)
NPP	Nuclear power plant
PCT	Peak cladding temperature
PRZ	Pressuriser
PSI	Paul Scherrer Institute (Switzerland)
PWR	Pressurised water reactor
RPV	Reactor pressure vessel
SBO	Station black-out
STUK	Säteilyturvakeskus, Radiation and Nuclear Safety Authority (Finland)
TH	Thermal hydraulics
TSO	Technical Support Organisation
UNIPI	University of Pisa (Italy)
UPC	Universitat Politècnica de Catalunya (Spain)
VTT	Technical Research Centre of Finland Ltd (Finland)
WGAMA	Working group for the analysis and management of accidents (NEA/CSNI)

EXECUTIVE SUMMARY

The Nuclear Energy Agency (NEA) has, since 2001, sponsored the SETH, PKL, PKL2 and PKL3 collaborative projects to investigate thermal-hydraulic safety issues for current PWR and new PWR design concepts through experiments at the integral test facility PKL. Similarly the NEA has, since 2014, supported the ATLAS collaborative project to address thermal-hydraulic safety and accident management issues relevant to water reactors, by means of experiments at the ATLAS Test Facility. Due to the links between the two programmes, the management boards of PKL3 and ATLAS projects decided in 2015 to organise a joint workshop (WS) of related analytical activities.

The workshop took place in Lucca (Italy) at the Chamber of Commerce premise, from 13 to 15 April 2016. This WS aimed to bring together code users that performed calculations reproducing the PKL3 (PKL, ROCOM, PACTEL and PMK) and ATLAS experiments to present their simulation code results and to discuss modelling issues and problems. The WS attracted 60 participants from 16 countries. It included 34 presentations, covering the general overview of both programmes, the analyses of the benchmark exercises organised within the projects, and some analyses related to other PKL3 and ATLAS tests including application to reactor case. The activity provided an efficient way to evaluate the current code capabilities for the scenarios conducted in the projects.

In general, the code results have shown good performance and satisfactory agreement with experimental results, which increases the confidence in current TH code technologies. Emphasis had been made on execution of blind calculations within the benchmarks as a way of testing the predictive capability of codes. Participants unanimously agreed on the need of completing the benchmark exercises with the post-test (open) phases, in order to work around remaining shortcomings through further model improvements.

There were some presentations with applications of sensitivity and uncertainty analyses (SUA) as a part of these blind exercises. It was encouraged to further establish this type of SUA as a regular practice within code results benchmarks.

The experience gained from conducting counterpart tests (CT) was largely agreed on and recognised as being highly valuable in understanding the underlying phenomena and in enabling improvements in scaling techniques. Participants stressed the need of additional analytical effort devoted to applying current scaling techniques to these available CT results among the different facilities and up to the NPP scale.

The calculations supported earlier experience that system codes tend to underestimate the delay time between peak cladding temperatures (PCT) and core exit temperatures (CET) around temperature levels where accident management actions are usually taken in plants. Future analytical actions were recommended to keep focus on this point, in order to confirm previous conclusions on the issue (i.e. this underestimation does not create a safety concern in EOPs).

Different areas of interest for future tests on PKL4 and ATLAS2 projects (IBLOCA scenarios, CT, reflux-condensation operation, core blockages, among others) were highlighted.

WORKSHOP OVERVIEW

The PKL3 Project tests consisted of a programme of experiments intended to, inter alia, understand complex heat transfer mechanisms in the steam generators and the course of events following beyond-design-basis accidents as well as under accident situations occurring during cold shut down conditions, and boron precipitation processes under postulated accident situations. The tests, which were carried out at the PKL facility of Areva NP in Erlangen (Germany) with additional tests performed at the PMK facility (MTA-EK, Hungary), the PWR PACTEL facility (LUT, Finland) and at the ROCOM facility (HZDR, Germany), were completed in the beginning of 2016.

The tests of the ATLAS Project, which are being carried out at the ATLAS facility of KAERI in Daejeon (Korea), are to be completed in the first half of 2017. These ATLAS tests consist of a programme of experiments intended to investigate inter alia the so-called design extension conditions (DEC) that are either more severe than design basis accidents or that involve additional failures, such as station blackout (SBO) or total loss of feed water (TLOFW). The programme additionally aims to provide further clarification in the issue of intermediate break LOCA and in the analysis of some advanced passive safety features.

The experimental programmes in both facilities included counterpart tests (CTs), i.e. tests with similar configuration and corresponding initial and boundary conditions, to other previous tests performed in other facilities. These CTs are considered especially valuable for addressing the issue of the effect of geometry on scaling considerations.

A comprehensive experimental database for model development and code validation was then established in the PKL and in the ATLAS facilities. In addition to that, some benchmark activities of thermal-hydraulic simulation code results have been established in both projects, in order to check predictability capabilities of current TH analytical tools available within the nuclear safety community.

These analytical support activities performed in the frame of similar previous projects (SETH, PKL, PKL2, ROSA, ROSA2), as well as the organisation of technical seminars describing the analytical activities performed by the project participants, have proven to be very useful in the past.

For that reason during the 8th meeting of the PRG/MB of the PKL3 project (Madrid, Spain; 10-11 November 2015), and 4th of PRG/MB of ATLAS project (Daejeon, Korea; 21-23 October 2015) the organisation of a joint workshop was approved. The aim has been presenting and discussing in-depth analyses (pre and post-test) of different tests performed within the projects, as well as the discussion of the results and analyses of the benchmarks exercises. This workshop, sponsored by the Committee on the Safety of Nuclear Installations (CSNI) of the Nuclear Energy Agency (NEA), was held in Lucca (Italy) organised by the nuclear and industrial engineering (NINE) company at the Chamber of Commerce, premises, from 13 to 15 April 2016, as scheduled in the proposed Agenda (Appendix 1).

The main purpose of this workshop was to fulfil these actions by presenting and discussing the results of the ATLAS, PKL, PMK, PACTEL and ROCOM analytical studies performed by participants in the PKL3 and ATLAS Projects, as well as to present related plant applications. In summary, the main objectives of the workshop were:

- Present and discuss in-depth analyses performed in the PKL benchmark exercise on H2.2 test (SBO scenario).

- Present and discuss in-depth analyses performed in the ROCOM benchmark exercise on T2.3 test.
- Present and discuss in-depth analyses performed in the ATLAS benchmark exercise on Test A5.1 (LSTF counterpart SB-CL-32 test).
- Present and discuss in depth the test analyses of other PKL3 (including PACTEL, PMK, ROCOM) and ATLAS tests.
- Present and discuss plant applications analyses related either to equivalent scenarios or to scenarios helpful to clarify the involved safety issues.
- Discuss modelling issues and practices.
- Share experiences and practices among project participants.

The workshop was organised in three parts: Opening Session; Technical Sessions; and a Wrap-up Session. It was divided into seven technical sessions, with the following specific objectives:

- Session 1 provided an overview of main experimental series of both projects.
- Session 2 aimed at presenting the main conclusions of the benchmark exercise related to the A5.1 test in ATLAS facility (counterpart of LSTF SB-CL-32), as well as to cover details of the different post-test analyses carried out by the different participants in the exercise.
- Session 3 was devoted to describe the main results and conclusions of the blind phase of benchmark exercise related to the T2.3 test in ROCOM facility, and some details of the different post-test analyses performed with CFD and/or SYS-TH codes by the participants.
- Session 4 presented preliminary results of the H2.2 test conducted in the PKL facility, the main conclusions of the benchmark exercise related to this test, and the details of the different post-test analyses carried by the different participants in the exercise.
- Session 5 and 6 presented analyses related to, namely, other ATLAS and PKL3 tests, and opening the possibility to discuss plant application analyses.
- A final session was devoted to discuss and summarise main conclusions of the sessions.

The list of participants is included in Appendix 2.

In the sequel, a summary of the main conclusions of presentations, comments, recommendations and suggestions raised at each session general discussions are structured hereafter in six different sections. A final section summarises the general conclusions of the workshop.

SESSION 1: GENERAL OVERVIEW OF PKL3 AND ATLAS PROGRAMMES

The session aimed at providing an overview of main experimental series of both projects PKL3 and ATLAS, making particular emphasis on those experiments that were covered during the rest of presentations of the workshop, and so avoiding repetition of general descriptions of each analysed experiment in other presentations.

PKL3 project has included tests carried out at the PKL facility with additional tests performed at the PMK, PACTEL and ROCOM facilities. Tests consisted of a programme of experiments intended to understand complex heat transfer mechanisms in the steam generators and the course of events following beyond-design-basis accidents as well as under accident situations occurring during cold shut down conditions, and boron precipitation processes under postulated accident situations.

ATLAS project is being carried out at the ATLAS facility, and covers tests to investigate design extension conditions (DEC) (SBO, TLOFW), effectiveness of advanced passive safety systems and to provide further insights and clarification in the issue of intermediate break LOCA.

In addition to that, the experimental programmes in both facilities included counterpart tests (LSTF-PKL and LSTF-ATLAS CTs), with special value for the analyses of scaling issues and techniques. It was recognised the high value in conducting such type of CTs. An important output of this counterpart exercises has been to obtain consistent results among LSTF and PKL, and LSTF and ATLAS, although some pending discrepancies were reported. It was largely agreed the need for further clarification of these discrepancies with the help of codes and application of scaling methods, in order to determine the reason behind the difference.

PKL tests campaign included several cool-down scenarios in regard to natural circulation interruption (NCI). Main objective of this series has been to identify the maximum cool-down rate to avoid NCI, and possible configurations as well as the main parameters that affect or condition the NCI. It was pointed out that this type of scenarios is still very challenging to the current TH simulation codes.

It was also remarked as highly valuable, the large involvement of project partners into the definition of experiments through pre-test analyses, and post-test analyses with indication and justification of modelling strategies, modifications and/or deficiencies. The use of PKL and ATLAS tests results as database for code validation was highly appreciated by participants.

SESSION 2: ATLAS BENCHMARK EXERCISE

Session 2 was aimed at drawing conclusions from the benchmark exercise related to the A5.1 test in the ATLAS facility, counterpart of LSTF test SB-CL-32. To that end, 8 presentations were made followed by a general discussion. The presentations detailed both pre and post-test calculations for ATLAS Test A5.1.

The session began with a presentation given by NINE (Presentation 2.1). Experimental data was compared with blind-phase calculation results from 14 different participants coming from 9 different countries and using 7 different computer codes. It was stated that most participants were able to qualitatively well predict most parameters. A general discrepancy between code predictions and data were found in a few areas- loop seal clearing, surge in cold leg flow associated with accumulator/SIT injection, and integrated break flow was generally smaller than the data.

The next presentations (Presentations 2.2 to 2.8) were all given by the programme participants and focused on their individual pre and post-test calculations. Modelling issues, modelling practices and lessons learnt were discussed. Some presentations included sensitivity studies with their respective results and conclusions. There were many discussions following the presentations. Below is a summary of the Session 2 general discussion.

Scaling considerations for this counterpart test are complicated by differences in the plant designs which the test facilities were based on. These complications are not well understood as such scaling is not usually attempted. The main differences between the designs should be identified for consideration during scaling and benchmarking activities.

One such difference is in the loop seals. ATLAS has shallow loop seals. This allows them to clear earlier. What other impacts they might have been considered.

It was noted that identification of high quality relevant prototypical plant data could prove useful in addressing scaling issues. Lack of availability of such data to the entire working group, however, could preclude the practicality of such a strategy.

It was requested and agreed that NINE will include a chapter in the benchmark report concerning the scaling challenges stemming from design differences in the current benchmarking activities.

The next steps for the benchmarking activity primarily concerned post-test code predictions. The deadline for submission of test A5.1 post-test calculation data to NINE was identified as problematic for the relevant ATLAS project participants. Subsequent discussions at the ATLAS PRG meeting in the following days found resolution by extending the deadline to mid-May.

In the interim NINE was charged with explicitly identifying all of the information to be submitted – related to both participants' input models and calculation results. The purpose of this is to minimise false errors included in the benchmark report resulting from misunderstanding of data submission format.

SESSION 3: RESULTS AND ANALYSES RELATED TO THE PLK-3 ROCOM BENCHMARK TEST T2.3

This session contained 4 presentations (Presentations 3.1 to 3.4):

1. Overview on blind-phase benchmark results
2. Use of CFD code ANSYS CFX
3. Use of ATHLET system code
4. Use of CFD code STAR CCM+

Additional calculations by Bel V using CATHARE have been also presented in Session 6.

Overview on benchmark results

The objective of the ROCOM test 2.3 benchmark was to assess and compare the capabilities of CFD and SYS-TH codes in predicting the mixing in the RPV when cold borated water from the accumulator is injected in one of the 4 cold legs, while the RPV is under stagnant conditions.

Two solutions by CFD codes (HZDR-ANSYS CFX and PSI-STAR CCM+) were included as well as three solutions by system codes with 3D capability (GRS – ATHLET; Bel V – CATHARE2; UNIPI – CATHARE2).

Summary of CFD calculations

a) BPG (Best Practice Guidelines) application to the applied grid was not reported. It was assumed that we can rely on the experience from the former calculations.

b) Different turbulence models have been used by PSI (k-eps, shear stress transport, different types of Reynolds stress models -direct and algebraic-). Influence of using different models is seen on single effects in the backward flow in loop 1. The general behaviour in the down comer and core inlet plane is not much affected. Based on the results of the performed quantitative analyses, the prediction of the mixing phenomena cannot be improved by any of the aforementioned turbulence models.

c) The CPU time to perform the simulations took around one week.

Summary of system code results

a) Calculations have been performed with the ATHLET code using the newly developed 3D flow model for the down comer and lower plenum region. Some figures with TRACE results (PSI) have been also presented.

b) ATHLET results could reproduce satisfactorily mixing in the down comer.

c) In the discussion following the presentations it was generally agreed that coarse grids can capture the macroscopic effects of the coolant mixing in the RPV.

d) Two CATHARE nodalisation schemes based on 64 and 32 azimuthal node numbers show the same prediction accuracies of the mixing in the RPV and core lower plenum.

e) The CPU time to perform the simulations varied from tens of seconds (ATHLET) to 10 h (CATHARE nodalisation with 64 azimuthal node numbers).

Main outcomes of the discussion

The main outcome of the comparison is that the CFD and the system code solutions produce more or less the same results if comparing the average and maximum values in the different sensor planes. The results are qualitatively comparable to the experimental data. But all calculations show quantitative deviations in the order of 20-30%. All codes (system and CFD) generate excessive mixing of the injected cold water with the water present in the RPV.

Four main questions were discussed:

- Why CFD and 3D thermal-hydraulic system codes show comparable performance in this benchmark?

  System codes with coarse grids can capture the macroscopic effects of the coolant mixing in the given scenario. It seems (and is supported by sensitivity studies for CFD) that the turbulence models do not influence the behaviour in the calculations very much. The coolant mixing in this scenario is mainly affected by the macroscopic redistribution of the flow from different sources. Turbulence models have only a minor effect which can be observed for local effects (e.g. backward flow in loop 1 towards upstream sensor). Furthermore it seems that such results were expected since the phenomena under focus are taking place in large volumes (RPV down comer and core inlet plenum).

- Are the 3D system codes reliable enough to be used for safety calculations when coolant mixing phenomena are involved?

  The answer of this question depends highly on the scenario to be investigated. Based on the performance in one benchmark, conclusions cannot be drawn on classes of accident analyses. The results show that scenarios involving phenomena investigated in this benchmark can be calculated with good confidence by the involved system codes. For all other scenarios similar verification/validation activities as such a benchmark have to be conducted in the future to reinforce the current findings.

- What is the origin of the discrepancies between measurements and calculations?

  The question whether the measurement accuracy of the volume flow rate is responsible for deviations could be answered as follows: First of all the measurement system for flow rate was independently validated by ultra-sonic measurements before the instalment at the facility. Secondly during each test the exhausted integral of ECC-water volume was measured. These values were compared for all single runs with the integrated volume measured by the volume flow rate measurement system over the whole transient time. The comparison of these values shows a deviation between this fully independent determination of the injected volume of less than 0.5% for all single realisations of the test.

- Other origin may be connected with the impact of the mesh wire sensors on the measurements accuracy. However, the mesh wire sensors could generate only local turbulences. The latter could not create distortions or impact the global behaviour.

  Another explanation could be related to a non-correct prediction of the coolant redistribution due to trapped slugs in some parts of the RPV.

- Concerning the best practice of application of the thermal-hydraulic system codes with 3D capabilities, a question was raised about the minimal number of nodes that have to be used in the nodalisation scheme.

  According to the results of CATHARE, ATHLET and TRACE codes, it seems that for a reasonable prediction of the mixing phenomena (i.e. with typical accuracy of such 3D models), the minimal azimuthal node number under the considered scenario should be at least twice larger than the number of the loop nozzles connected to the RPV (i.e. 16). Higher azimuthal node number implies higher CPU costs and do not significantly improve the prediction accuracy.

SESSION 4: PKL BENCHMARK EXERCISE

The topic of this session was the PKL analytical benchmark exercise on test PKL3 H2.2 run2 (experiment on station blackout) co-ordinated by UNIPI

In a first introductory presentation AREVA gave a brief introduction into the scenario, the test specifications and on the main outcome and relevant phenomena observed in test H2.2. AREVA noted that the H2.2 test can be seen as a comprehensive approach, in which emphasis was put on the realisation of a test procedure that comprises all relevant scenario-specific phenomena in a serial way to avoid their overlapping and to facilitate the analysis of cause and effect initiated by inherent thermal-hydraulic processes or measures taken by the operating personnel.

The main phenomena and events observed in the PKL3 H2.2 test were:

- Heat transfer in NC condition at declining secondary-side fill levels (impact on primary-side temperatures and pressure).
- Loss of coolant inventory via PRZ during primary-side pressure control until occurrence of core heat-up.
- Primary-side depressurisation and subsequent ACC injection, temporary restoration of core cooling by ECC from ACC.
- Effectiveness of the activation of the secondary-side emergency feed-water supply on further pressure reduction, the continuation of the ACC injection and the contribution of the PRZ out surge to the anew restoration of the core cooling.
- Impact of the nitrogen released from the ACC into the primary side on long term heat removal to secondary side (primary-side pressure level).

Immediately following, UNIPI gave an overview on benchmark activity that, until now, only includes the results of the blind-phase calculations.

As reported by UNIPI, 10 organisations from 8 countries had participated in the benchmark activity and 7 different T/H codes/code versions had been employed.

Major observations from the comparison of pre-test calculation results with experimental results have been summed up as follows:

- In general the main events could be reproduced by the codes.
- The test duration and the number of events and actions (often in mutual dependence) created a course of events that proved to be challenging for the codes.
- Not all of the participants captured the relevant phenomena (e.g. second PCT excursion)
- Timing and magnitude of the PCT excursions display a large scatter of calculation results
- All codes calculated a faster rise of the PRZ level in the first phase following the boil-off of the SGs compared to the experiment
- The emptying of the SGs was captured well by the codes

- A general overestimation of the PRZ discharge flow (during pressure control and primary-side bleed) in the calculations
- An overestimation of the effectiveness of the ACC injection with respect to the pressure decrease in some calculations
- By trend, the course of events proceeds faster in the calculations

In the subsequent presentations, individual organisations presented their results and conclusions from their post-test calculations and –partly– from sensitivity studies, and also shared their experiences obtained during the blind pre- and post-test calculation phases.

Seven organisations presented analyses on test H2.2:

Presentation No.	**Organisation**	**Code**
4.3	EDF	CATHARE v.2.5_3 mod.3.1
4.4	AREVA	S-RELAP5
4.5	GRS	ATHLET Mod 3.0 A
4.6	KAERI	SPACE
4.7	Tractebel	RELAP5 mod.3.3
4.8.	UPC	RELAP5 mod.3.3
4.9	PSI	TRACE v.5.0p4

Based on the comparisons of the blind calculations with the experimental data elaborated and compiled by UNIPI and on the post-test and further calculations and benchmark-related work presented by the participants, the following discussion reached consensus on the following points:

- A correct modelling of the heat losses is necessary, in particular during the first phase following start of testing, as their impact on the sequence of events became evident.
- It was considered valuable to analyse the effect of heat losses in a more systematic way, i.e. a quantitative assessment of the impact of the heat losses on the sequence of events (in particular during the first phase with pressure decrease following the start of testing).
- It also became obvious that the correction of the heat losses according to the actual values in the test will not eliminate all discrepancies between the experiment and individual calculations.
- In general, even if the comparison of all blind calculations show a rather large scatter in timing of actions and magnitudes of relevant parameters, most of the phenomena and events of interest could be reproduced.
- Some points/phenomena have been identified which, if properly addressed, should improve the calculations:
    - Condensation efficiency factor in cold legs during ACC injections, to reproduce the stepwise ACC injection as observed in the experiment.
    - PRZ level before, during and after the PDE to correctly reproduce the instigation of actions based on the PRZ fill level as well as the phenomena strongly influenced by the PRZ coolant inventory (in particular the contribution of the PRZ inventory in the restoration of the core cooling after activation of emergency feed water during the second PCT excursion).
    - Modelling of the CET measurement in the nodalisations to obtain a proper criterion for the instigation of actions.

- Most blind calculations could have been improved if the following points had been better considered.
  - Correct replication of actual PKL primary and secondary-side volumes.
  - Correct replication of start-up conditions, e.g. ACC fill levels.

Common consensus was reached on the recommendation to include the current status of the PKL benchmark activity and the main outcomes in the final report of the PKL3 project.

Furthermore, it was common understanding that it would be valuable to continue the benchmark exercise with post-test calculations using the lessons learnt from the pre-test calculations. However, the soon termination of the PKL3 project requires the analytical activities to be continued in the following PKL4 project.

SESSION 5: RESULTS AND ANALYSES RELATED TO OTHER ATLAS TESTS

This session dealt with the simulation and analysis of tests conducted on the ATLAS facility other than that subject of the analytical benchmark. Eight presentations were included covering 7 different experiments, uncertainty evaluation on a specific case, counterpart test (CT), blind, post-test and sensitivity analyses. Different code results have been shown by the presenters both including 1D and 3D system thermal-hydraulic codes such as MARS-KS, RELAP5, TRACE, CATHARE and APROS.

On the overall it has been shown a general capabilities of codes in capturing reasonably well the measured quantities, however some lacks in predicting observed phenomena have been highlighted (e.g. asymmetric loop behaviour in Presentation 5.3) or unrealistic flow pattern in 3D fictitious nodalisation has been evidenced (Presentation 5.4). Another important consideration coming from Session 5 was that increasing the complexity of the developed facility numerical model (i.e. increasing the fidelity between the real hardware and the nodalisation) the results were remarkably improved (e.g. Presentation 5.7) especially under natural circulation conditions and with the consideration of passive system.

Sensitivity (Presentation 5.2) and uncertainty (Presentation 5.5) analyses have been presented showing their major role in deep understanding of the concerned experiment. Sensitivities have been carried out focusing on IBLOCA counterpart tests (CT) within the corresponding pre-test phase. Such sensitivities included variation of break area and ECC injection. Uncertainty evaluation was performed on A1.1 test adopting APROS code and applying the deterministic sampling method for the quantification of output uncertainties which have been compared with the prediction of a statistical sampling method.

SESSION 6: RESULTS AND ANALYSES RELATED TO OTHER PKL3 TESTS

In this section, additional analytical activities related to the PKL3 Project have been summarised in three presentations.

A comparison of the results of the PKL test as counterpart to a previous ROSA/LSTF test (1% cold leg break with steam generator secondary-side depressurisation) has shown that the applied scaling methodology was adequate. The overall transient evolution in the covered pressure range (less than 50 bar) was similar in both facilities, including the reproduction of the loop seal clearing (LSC). In both tests the core liquid level recovered after the LSC. The main scaling deviations observed in both tests are basically due to the different influences of steam condensation of the accumulator coolant by the differences in the accumulator injection configuration between the two facilities. A RELAP5/MOD3.3 simulation of the LSTF test was able to reproduce adequately the overall trends of the major thermal-hydraulic response, but failed to predict correctly the primary coolant distribution.

A summary of the analytical activities performed by the Belgian TSO Bel V in the frame of the PKL3 project has been presented. One main focus of the analytical activities was the investigation of natural circulation phenomena, mainly on the basis of the PKL3 Test H4.1 Runs 1.1.1, 1.2 and 2 (Cool-down under asymmetric natural circulation conditions). It was shown that during the cool-down procedure, under stable, single-phase natural circulation conditions, about 10% of the steam generator U-tubes experienced flow reversal. This observation was possible by comparing the inlet and outlet temperature measurements present in PKL. In order to improve the prediction of the natural circulation interruption (NCI) it is strongly recommended to increase the number of modelled U-tubes with different lengths (in this study, 7 different lengths were employed). On the other hand, the assessment of the 3D CATHARE model against the ROCOM coolant mixing T1 series experiments was presented. Two nodalisations with 32 and 64 azimuthal sectors were presented with no significant difference in the mixing predictions.

Finally, an overview of the test series on pressure wave propagation at the PMK-2 facility during large break LOCAs has been presented. Simulation of several test runs with the system code ATHLET has shown that this code can model sonic speed phenomena adequately. The same phenomenology was then used for the corresponding event taking place in a VVER-440 reactor. Sensitivity studies were performed and the results compared well with design curves provided by the vendor.

GENERAL CONCLUSIONS OF THE WORKSHOP

This joint workshop on analytical activities of ATLAS and PKL3 projects aimed to bring together code users that performed calculations reproducing the PKL3 (PKL, ROCOM, PACTEL and PMK) and ATLAS experiments to present their simulation code results and to discuss modelling issues and problems. The activity provided an efficient way to evaluate the current code capabilities for the scenarios conducted in the projects.

From the general discussion organised on the last day of the workshop and based on the session summary prepared by each session chair the participants identified a number of outcomes and suggestions or recommendations which are summarised hereafter.

Among the main outcomes from the presentation and discussion during the workshop, the following ones were identified:

- The great value of the code results benchmark exercises was appreciated by the participants, as a way of continuously testing the current thermal hydraulics (TH) simulation codes in their predictive capabilities. The large number of participants in the action has been recognised by the respective projects partners and operating agents.
- In general, the obtained code results have shown good performance and satisfactory agreement with experimental results, which increases the confidence in current TH code technologies.
- There has been a large participation of projects partners into the definition of experiments through pre-test analyses and into the execution of post-test analyses. This large involvement was remarked as highly valuable, as well.
- The objective of sharing indications and justifications of modelling strategies and improvements in order to solve code deficiencies and bad results has been largely accomplished in this workshop. Participants were open to present and discuss details on the rationale and capabilities behind the simulation models, what allows a cross-fertilisation among different code practitioners.

Some suggestions and/or recommendations were also raised during the workshop, which are summarised as follows:

- Results of the blind phase for the three benchmark exercises have shown certain maturity of the predictive capability of current TH codes. But, participants unanimously agreed on the need of continuing the code benchmarking exercises with the post-test (open) phases, in order to work around the results through further model improvements. Nevertheless current situation within the projects is different. ATLAS participants agreed to propose to the PRG/MB groups the continuation with the open phase within the last period of the current project. On the other hand, PKL3 participants suggested proposing to the future PKL4 PRG/MB groups to arrange a short analytical action at the beginning of the project aiming at finishing the open phase of the PKL3 benchmark.
- Experience gained in the definition of PKL3 and ATLAS benchmark specifications has identified some troubles due to the lack of sufficient preparatory period. It was highly recommended to spend in future benchmarks more efforts in the preparation of the specifications documents and

requirements, in order to avoid modelling errors and mistakes that in many cases happen prior to spending any computational effort (checks of volumes, heights, heat structures masses, initial conditions....). Any mistake at such an early stage may affect all subsequent calculations.

- Emphasis was made on execution of blind calculations as a way of testing the predictive capability of codes. There were some presentations with applications of sensitivity and uncertainty analyses (SUA) as a part of these blind exercises. Nevertheless it was also encouraged the further need of establishing this type of SUA as a regular practice within code results benchmarks.

- In previous similar workshop, the experience gained from conducting counterpart tests (CT) was largely agreed and recognised as being highly valuable in understanding the underlying phenomena and in triggering improvements in scaling techniques. As a reaction of this previous recommendation, three different counterpart tests have been conducted within these current PKL3·and ATLAS projects (two LSTF-PKL CT and one LSTF-ATLAS CT). Consistent experimental results between LSTF and PKL, and LSTF and ATLAS facilities namely, have been obtained for the respective tests. Nevertheless, some still pending issues and differences have been identified and reported that require further clarification. Participants stressed the need of additional analytical effort, particularly through application of scaling methods and techniques, in order to clarify the root cause of these differences. The group recommended arranging some joint and volunteer analytical group, specifically devoted to apply current scaling techniques to these available CT results among the different facilities and up to the NPP scale. It was proposed to explore this possibility within subsequent NEA projects (PKL4 or ATLAS2), in order to avoid eventual confidentiality problems.

- Further NPP applications, particularly in the direction of improvement of scaling techniques, were also encouraged.

- One of the objectives of the previous joint ROSA2-PKL2 WS was to describe analytical activities in support of the reliability of the core exit thermocouples (CETs) utilised worldwide as an important indicator to start some AM operator actions. The issue was deeply studied by the WGAMA Task Group on CET (2008-2009), who recommended a proposal for a follow-up activity within PKL and ROSA projects with pertinent experiments and/or analytical activities. An essential part of the answer from PKL2 and ROSA2 groups to this recommendation has been the arrangement of the counterpart test performed in the two facilities, mainly focused on addressing this CET issue. CET/PCT behaviour was discussed in most of the analyses presented in the WS. The calculations supported earlier experience that systems codes tend to underestimate the delay time between PCT and CET around temperature levels, where accident management actions are usually taken in plants. It was proposed to recommend to future analytical actions to keep focusing in this point, as a way of confirming previous conclusions on the issue (i.e. this underestimation does not create a safety concern in EOPs).

- The role of ambient heat losses in transients at nuclear power plants was discussed. It is widely accepted that ambient heat losses play a smaller role in NPPs as compared to experimental facilities because of the difference in surface area to volume ratio. It was noted that ambient heat losses play an enormous role at experimental facilities, especially for the long duration transients which have gotten increased attention in recent years. It was proposed that the reduced impact that ambient heat losses have on NPP transients may become significant for long duration transients and warrant consideration in thermal-hydraulic analysis.

- Different areas of interest for future tests on PKL4 and ATLAS were considered, particularly:
    - IBLOCA scenarios, particularly in the PRZ surge-line and 10% cold leg break (PKL, ATLAS);

- counterpart tests (PKL, ATLAS);
- hot leg SBLOCA (ATLAS);
- boron precipitation, particularly with a switchover to hot leg injection (PKL, ATLAS);
- reflux-condensation operation (ATLAS);
- core blockage (ATLAS and PKL);
- NPP EOPs scenarios, such as cool-down procedures.

· The fact of being at the end of the PKL3 Project has made some difficult to synchronise continuation activities of some of the analytical activities. It was recommended to anticipate as much as possible the discussion and organisation of this type of analytical activities (benchmarks, CT analyses, WS...) within the projects, in order to avoid some difficulties appearing at the end of the project schedule.

· It was a common understanding that this workshop was a successful step in the right direction and that this kind of efforts on analytical activities should be continued. It was then suggested trying to organise one future WS at the half part of the projects, and a second one at the end.

More general comments raised during the sessions were:

· These workshops on analytical activities within NEA experimental projects are good opportunities to go further (in length and in depth) in the analysis of scenarios, as well as a way of sharing code experiences and practices among project participants. In this case there were 34 presentations that allowed detailed technical discussions on the current code capabilities and interpretation of tests results. The meeting was appreciated by all the participants as a good occasion to exchange ideas and methods, to pose problems and suggest solutions.

· As it appeared to be also in previous analytical workshops (Barcelona 2003, Pisa 2005, Budapest 2006, Pisa 2010, Paris 2012), the experience of having analytical and experimental specialists together in a common conference has been fruitful for both groups of experts, being therefore a good example of the effective and necessary interaction between codes and experiments for the solution of topical safety issues.

APPENDIX 1: FINAL AGENDA

Wednesday 13th April 2016

9.00-9.20 **Welcome, Opening remarks and Introduction (20 mn)**

Chair: M. Sanchez (CSN, Spain)

- F. Michel-Sendis, NEA
- F. D'Auria, UNIPI
- M. Cherubini, NINE
- K. Umminger, Areva NP, PKL3 Operating Agent
- K. Y. Choi, KAERI, ATLAS Operating Agent

9.20 **Session 1: Overview of PKL3 and ATLAS Programmes (2 x 30 mn)**

Chairs: E. Virtanen (STUK, Finland) and M. Sánchez (CSN, Spain)

9.20-9.50	(1.1)	Overview on Test Results from the NEA PKL 3 Project *Klaus Umminger, (AREVA NP, Germany)*
9.50-10.20	(1.2)	Overview on Test Results from the NEA ATLAS Project, *Ki-Yong Choi, (KAERI, Korea, Republic of)*

10.20-10.45 **Coffee break**

10.45 **Session 2: ATLAS benchmark (1 x 30 mn, 4 x 20+5 mn)**

Chairs: R. Harrington (USNRC, USA) and K.Y. Choi (KAERI, Korea, Republic of)

10.45-11.15	(2.1)	ATLAS A5.1 benchmark blind-phase calculation results, *Marco Cherubini, Valeria Parrinello (NINE, Italy)*
11.15-11.40	(2.2)	A5.1 pre-test and post-test calculations, *Parimal Kulkarni (BARC, India)*
11.40-12.05	(2.3)	A5.1 test calculations with use of KORSAR and SOCRAT codes, *Anna Nikolaeva (OKB GIDROPRESS, Russia)*
12.05-12.30	(2.4)	Simulation of the ATLAS Benchmark Test A5.1 with the code ATHLET, *Livia Tiborcz, H. Austregesilo (GRS, Germany)*
12.30-12.55	(2.5)	Post-test calculation of ATLAS A5.1 test using SPACE code, *Jong Hyuk Lee, (KAERI, Korea, Republic of)*

12.55-14.15 **Lunch break**

14.15 **Session 2 (cont'd): ATLAS benchmark (2 x 20+5 mn, 1 x 30 mn)**
Chairs: R. Harrington (USNRC, USA) and K.Y. Choi (KAERI, Korea, Republic of)

14.15-14.40 (2.6) Sensitivity analysis of A5.1 test scenario using MARS code,
Yusun PARK, (KAERI, Korea, Republic of)

14.40-15.05 (2.7) Post-test analysis for ATLAS test A5.1 using MARS-KS code,
Kyung Won Lee, Aeju CHEONG (KINS, Korea, Republic of)

15.05-15.35 (2.8) Pre-test Calculation of the ATLAS Benchmark Test A5.1 with RELAP5 Code,
Zhongyi Wang, Nan Yu, Xiaoliang Fu, Yanhua Yang (SNPTC, China)

15.35-16.05 Session 2 General Discussion

16.05-16.30 **Coffee break**

16.30 **Session 3: ROCOM benchmark (1 x 30 mn, 3 x 20+5 mn, 1 x 30 mn)**
Chairs: A. Bousbia (BelV, Belgium) and S. Kliem (HZDR, Germany)

16.30-16.55 (3.1) Overview of the results of NEA/CSNI ROCOM T2.3 Blind Benchmark,
Sergii Lutsanych, Francesco D'Auria (UNIPI, Italy)

16.55-17.20 (3.2) CFD analysis of in-vessel flow mixing during cold leg accumulator injection based on the ROCOM Test T2.3,
Alexander Grahn, Sören Kliem (HZDR, Germany)

17.20-17.45 (3.3) ATHLET 3.1A Simulation results of the ROCOM T2.3 benchmark exercise – blind calculation phase,
S. C. Ceuca, P. J. Schoeffel, H. Austregesilo, T. Hollands, (GRS, Germany)

17.45-18.15 (3.4) Pre- and Post-Analysis of ROCOM T2.3 Benchmark using CFD: Influence of turbulence models,
Riccardo Puragliesi, (PSI, Switzerland)

18.15-18.45 Session 3 General Discussion

18.45 **First day adjourn**

Thursday 14th April 2016

9.00 **Session 4: PKL benchmark (1 x 30 mn, 2 x 20+5 mn)**
Chairs: F. D'Auria (UNIPI, Italy) and K. Umminger (AREVA, Germany)

9.00-9.25 (4.1) Results of the PKL 2.2 SBO-Experiment,
Simon Schollenberger, (AREVA, Germany)

9.25-9.55 (4.2) PKL3 H2.2Run2 benchmark blind-phase calculation results, *M. Lanfredini, F. D'Auria, V. Parrinello, Marco Cherubini, (UNIPI and NINE, Italy)*

9.55-10.20 (4.3) Simulation with the CATHARE code of PKL station blackout test H2.2 run 2 for the PKL3 project benchmark, *Philippe Freydier, (EDF, France)*

10.20-10.50 **Coffee break**

10.50 **Session 4 (cont'd): PKL benchmark (5 x 20+5 mn)**
Chairs: F. D'Auria (UNIPI, Italy) and K. Umminger (AREVA, Germany)

10.50-11.15 (4.4) Analysis of PKL Test H2.2 with S-RELAP 5, *Bernhard Karrasch, (AREVA, Germany)*

11.15-11.40 (4.5) Simulation of the PKL Benchmark Test H2.2 Run 2 with the code ATHLET, *Henrique Austregesilo, (GRS, Germany)*

11.40-12.05 (4.6) Simulation of PKL test H2.2 Run 2 using SPACE code, *Jong Hyuk LEE (KAERI, Korea, Republic of)*

12.05-12.30 (4.7) Simulation of PKL test H2.2 run 2 "station blackout" with RELAP5 Mod3.3 code, *Christophe Diakodimitris, Maxime Havet, (Tractebel-Eng, Belgium)*

12.30-12.55 (4.8) Thermal-Hydraulic Analysis of Station Blackout Experiments at the PKL Test Facility, *Jordi Freixa (UPC, Spain)*

12.55-14.15 **Lunch break**

14.15 **Session 4 (cont'd): PKL benchmark (1 x 20+5 mn, 1 x 30 mn)**
Chairs: F. D'Auria (UNIPI, Italy) and K. Umminger (AREVA, Germany)

14.15-14.40 (4.9) Pre- and post-test TRACE analysis of PKL H2.2 run1 and run2, *Roman Mukin, (PSI, Switzerland)*

14.40-15.10 Session 4 General Discussion

15.25 **Session 5: Other ATLAS analyses (2 x 20+5 mn)**
Chairs: M. Cherubini (NINE, Italy) and A. Guba (MTA-EK, Hungary

15.10-15.35 (5.1) Post-Test analysis on A2.2, *Byoung Uhn BAE (KAERI, Korea)*

15.35-16.00 (5.2) Effect of break size for IBLOCA, *Byoung Uhn BAE (KAERI, Korea)*

16.00-16.25 **Coffee break**

16.25 **Session 5 (cont'd): Other ATLAS analyses (3 x 20+5 mn)**
Chairs: M. Cherubini (NINE, Italy) and A. Guba (MTA-EK, Hungary)

16.25-16.50	(5.3)	Post-Test Analysis on A1.1, *Kyoung-Ho KANG (KAERI, Korea)*
16.50-17.15	(5.4)	Simulation of prolonged station blackout transient at ATLAS facility with RELAP5 Mod3.3 code, *Andriy Kovtonyuk, Simon Verdebout, (Tractebel-Eng, Belgium)*
17.15-17.40	(5.5)	Uncertainty analysis of the ATLAS A1.1 experiment, *Torsti Alku, Peter Hedberg (VTT, Finland & SSM, Sweeden)*

17.40 **Second day adjourn**

Friday 15th April 2016

9.00 **Session 5 (cont'd): Other ATLAS analyses (3 x 20+5 mn)**
Chairs: M. Cherubini (NINE, Italy) and A. Guba (MTA-EK, Hungary

9.00-9.25	(5.6)	ATLAS DVI Line Break: Benchmarking & 3D Modelling with TRACE, *Ron Harrington, (USNRC, USA)*
9.25-9.50	(5.7)	Summary and conclusions of the analyses related to the ATLAS experiments, *Attila Guba, M. Szogradi, A. Takács, I. Trosztel, I. Tóth, (MTA-EK, Hungary)*
9.50-10.15	(5.8)	Blind Calculation Predictions with TRACE for ATLAS Total Loss of Feed Water with Primary Feed and Bleed, *Ron Harrington, (USNRC, USA)*

10.15 **Session 6: Other PKL analyses (1 x 20+5 mn)**
Chairs: H. Austregesilo (GRS, Germany) and J. Freixa (UPC, Spain)

10.15-10.40	(6.1)	Comparison of LSTF and PKL Tests on Cold Leg Small-Break LOCA with SG Depressurisation, *Takeshi Takeda (JAEA, Japan)*

10.40-11.10 **Coffee break**

11.10 **Session 6 (cont'd): Other PKL analyses (2 x 20+5 mn)**
Chairs: H. Austregesilo (GRS, Germany) and J. Freixa (UPC, Spain)

11.10-11.35	(6.2)	BelV analytical activities within the PKL-3 project, *Anis Bousbia Salah (BelV, Belgium)*
11.35-12.00	(6.3)	Simulation of the PMK-2 pressure wave propagation experiments caused by fast LB-LOCA opening, *Attila Guba, G. Baranyai, V. Gottlasz, I. Trosztel, I. Tóth, (MTA-EK, Hungary)*

12.00-13.00 **Session 7: Wrap up and Concluding Remarks Session**
(5 x 5 mn + 35 mn final discussion), *Panel by chairs of Sessions #2 to #6*

- Summary of the seminar with the contribution of session chairs
- Final discussion: panel with all chairs

13.00 **CLOSURE OF THE WORKSHOP**

APPENDIX 2: LIST OF PARTICIPANTS

Joint PKL3-ATLAS Workshop – 13-15 April 2016 – List of participants

#	NAME	SURNAME	ORGANISATION	COUNTRY
1	Torsti	ALKU	VTT	FINLAND
2	Henrique	AUSTREGESILO	GRS	GERMANY
3	Byoung Uhn	BAE	KAERI	KOREA
4	Giorgio	BAIOCCO	NINE	ITALY
5	Anis	BOUSBIA SALAH	BelV	BELGIUM
6	Sabin Cristian	CEUCA	GRS	GERMANY
7	Marco	CHERUBINI	NINE	ITALY
8	Seok	CHO	KAERI	KOREA
9	Ki-Yong	CHOI	KAERI	KOREA
10	Francesco	D'AURIA	UNIPI	ITALY
11	Ronald	FRANZ	HZDR	GERMANY
12	Jordi	FREIXA	UNI CATALONIA	SPAIN
13	Philippe	FREYDIER	EDF	FRANCE
14	Tony	GLANTZ	IRSN	FRANCE
15	Alexander	GRAHN	HZDR	GERMANY
16	Attila	GUBA	MTA EK	HUNGARY
17	Aleksei	GUSEV	OKBM	RUSSIA
18	Ronald	HARRINGTON	US NRC	USA
19	Maxime	HAVET	Tractebel	BELGIUM
20	Caroline	HEIB	IRSN	FRANCE
21	Hiroaki	UEHARA	Nuclear Regulation Authority	JAPAN
22	Kyoung-Ho	KANG	KAERI	KOREA
23	Bernhard	KARRASCH	AREVA	GERMANY
24	Soeren	KLIEM	HZDR	GERMANY
25	JaeHwa	KOH	KHNP	KOREA
26	Virpi	KOUHIA	LUT	FINLAND
27	Parimal	KULKARNI	Bhabha Atomic Research Centre	INDIA
28	Kyung Won	LEE	KINS	KOREA
29	Jong Hyuk	LEE	KAERI	KOREA
30	Sergii	LUTSANYCH	UNIPI	ITALY
31	Franco	MICHEL – SENDIS	NEA	FRANCE
32	Roman	MUKIN	PSI	SWITZERLAND
33	Anna	NIKOLAEVA	OKB Gidropress	RUSSIA
34	Emma	PALM	Swedish Radiation Safety Authority	SWEDEN
35	Yusun	PARK	KAERI	KOREA
36	Valeria	PARRINELLO	NINE	ITALY
37	Alessandro	PETRUZZI	NINE	ITALY
38	Riccardo	PURAGLIESI	PSI	ITALY
39	Heikki	PURHONEN	LUT	FINLAND
40	ZhiHao	REN	China Nuclear Power Tech research	CHINA
41	Vesa	RIIKONEN	LUT	FINLAND
42	Miguel	SANCHEZ PEREA	Consejo de Seguirdad Nuclear	SPAIN
43	Andrea	SCHIAVETTI	NINE	ITALY
44	Simon	SCHOLLENBERGER	AREVA	GERMANY
45	Iurii	SHVETSOV	OKBM	RUSSIA
46	Takeshi	TAKEDA	Japan Atomic Energy Agency	JAPAN
47	Fulvio	TERZUOLI	NINE	ITALY
48	Livia	TIBORCZ	GRS	GERMANY

49	Chiung-Wen	TSAI	China Nuclear Power Tech Research	CHINA
50	Klaus	UMMINGER	AREVA	GERMANY
51	Valeria	VENTURINI	NINE	ITALY
52	Simon	VERDEBOUT	Tractebel	BELGIUM
53	Jose F.	VILLANUEVA	UNI VALENCIA	SPAIN
54	Eero	VIRTANEN	STUK	FINLAND
55	Zhongyi	WANG	SNPTC	CHINA
56	Markus	WEINRIEFER	GRS	GERMANY
57	Andrew	WHITE	NEA	CANADA
58	Yanhua	YANG	SNPTC	CHINA
59	Omar	ZERKAK	PSI	SWITZERLAND
60	Hao	ZHANG	SNPTC	CHINA