Nuclear Safety
NEA/CSNI/R(2020)13
November 2022
www.oecd-nea.org

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Universitat Politècnica de Catalunya
Barcelona, Spain
7–9 November 2018

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Nuclear Energy Agency

NEA/CSNI/R(2020)13

Unclassified **English text only**

21 November 2022

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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This document is available in PDF format only.

JT03508126

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- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
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COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) addresses NEA programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

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List of abbreviations and acronyms

APROS	Computer code developed by Technical Research Center of Finland Ltd (VTT)
ATHLET	Computer code developed by Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) (Germany)
ATLAS	Advanced Thermal-Hydraulic Test Loop for Accident Simulation
BDBA	Beyond design basis accident
BelV	Technical Safety Organisation of the Belgian Nuclear Safety Authority (Belgium)
BM	Benchmark (exercise)
CATHARE	Computer code developed by French organisations (France)
CCFL	Counter-current flow limiting
CHF	Critical heat flux
CSN	Consejo de Seguridad Nuclear (Spain)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
CT	Counterpart test
DEC	Design extension conditions
EDF	Électricité de France S.A. (France)
EK	Centre for Energy Research (Hungary)
FFTBM	Fast Fourier Transform Based Method
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit - Global Research for Safety (Germany)
HPSI	High-pressure safety injection
HSIT	Hybrid safety injection tank
ITF	Integral test facility
KAERI	Korea Atomic Energy Research Institute
LOCA	Loss-of-coolant accident
LPSI	Low-pressure safety injection
LSTF	Large-scale test facility (operated by Japan Atomic Energy Agency)
LUT	Lappeenranta-Lahti University of Technology (Finland)
MB	Management Board
MST	Measurement point
NEA	Nuclear Energy Agency
NPIC	Nuclear Power Institute of China (People’s Republic of China)

NRC	Nuclear Regulatory Commission (United States)
OKBM	Joint Stock Company “Afrikantov OKB Mechanical Engineering” (Russian Federation)
PACTEL	Parallel Channel Test Loop
PAFS	Passive auxiliary feedwater system
PCT	Peak cladding temperatures
PKL	Primary Coolant Loop Test Facility (Germany)
PMK	Paks model experiment (EK-CER, Hungary)
PRG	Project review group
PWR	Pressurised water reactor
RHRS	Residual heat removal system
SBO	Station black-out
SETH	Safety Research Thermal-hydraulics
SG	Steam generator
SGTR	Steam generator tube rupture
SIT	Safety injection tank
SLB	Steam Line Break
SPACE	Safety and Performance Analysis Code for Nuclear Power Plant
STUK	Finnish Radiation and Nuclear Safety Authority (Finland)
SUA	Sensitivity and uncertainty analyses
TH	Thermal-hydraulics
UPC	Technical University of Catalonia (Spain)
UPV	Polytechnic University of Valencia (Spain)
VTT	Technical Research Centre of Finland Ltd (Finland)
WGAMA	NEA CSNI Working Group on the Analysis and Management of Accidents (NEA/CSNI)

Executive summary

Since 2001, the Nuclear Energy Agency (NEA) has supported the Senior Expert Group on Safety Research Thermal-hydraulics (SETH), the Primärkreislauf-Versuchsanlage - Primary Coolant Loop Test Facility (PKL), PKL-2 and PKL-3 collaborative projects to investigate thermal-hydraulic safety issues for current pressurised water reactor (PWR) and new PWR design concepts through experiments at the integral test facility PKL. Similarly, since 2014 the NEA has supported the Advanced Thermal-Hydraulic Test Loop for Accident Simulation (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 (MBs) of both projects decided in 2018 to organise a joint workshop of related analytical activities.

The workshop of the PKL-4 and ATLAS-2 projects took place in Barcelona, Spain, at the premises of the Technical University of Catalonia, from 7 to 9 November 2018. This workshop aimed to bring together code users that performed calculations reproducing the PKL-4 (PKL, Parallel Channel Test Loop [PACTEL], and PMK) and ATLAS-2 experiments to present their simulation code results and to discuss modelling issues and problems. The workshop attracted 55 participants from 11 countries. It included 24 presentations covering the general overview of both programmes, the analyses of the benchmark exercise organised within the PKL-4 project, and some analyses related to other PKL-4 and ATLAS-2 tests, including application to reactor case. The workshop provided an efficient way to evaluate the current code capabilities for the scenarios conducted in the projects.

The participants appreciated the value of the code results benchmark exercises as a way of continuously testing the current thermal-hydraulics (TH) simulation codes in their predictive capabilities. The results of the blind phase of the PKL-4 benchmark exercises have shown a certain maturity of the predictive capability of current TH codes. Recommendations for future benchmark exercises have been identified based on the experience gained in the definition of PKL-4 benchmark specifications.

Emphasis was placed on the execution of blind calculations as a way of testing the predictive capability of codes. A general recommendation was to perform combined sensitivity and uncertainty analyses (SUA) to qualify the code performance. The Fast Fourier Transform Based Method (FFTBM) was used as well for a quantitative evaluation of measurement-prediction discrepancies, with a demand for further clarification of the interpretation of the obtained indicators and input parameters.

Further nuclear power plant applications, particularly in the direction of improvement of scaling techniques, were also encouraged.

As highlighted in similar analytical workshops previously (Barcelona 2003, Pisa 2005, Budapest 2006, Pisa 2010, Paris 2012 and Lucca 2016), it has been fruitful to have experimental and analytical specialists together at a common conference. These workshops are good examples of the effective and necessary interaction between codes and experiments for the solution of topical safety issues.

1. Workshop overview

The NEA PKL-4 collaborative project aims to investigate thermal-hydraulic safety issues for current and new PWR design concepts through experiments at the integral test facility PKL. The project started at the end of 2016 and covers tests carried out at the PKL facility of Framatome in Erlangen (Germany) with additional tests performed at the PMK facility (EK-CER, Hungary) and the PWR PACTEL facility (LUT University, Finland). The set of PKL-4 experiments is aimed at understanding the complex heat transfer mechanisms in the steam generators, the course of events following beyond design basis accidents, medium break size loss-of-coolant accidents (MB-LOCA), and accident situations occurring during cold shutdown conditions.

Similarly, the NEA ATLAS-2 collaborative project addresses thermal-hydraulic safety and accident management issues relevant for water reactors, by means of experiments at the ATLAS test facility. The ATLAS-2 project started in the second half of 2017 and covers tests carried out at the ATLAS facility of KAERI in Daejeon (Korea). The set of ATLAS-2 experiments seeks to investigate, among others, the performance of passive safety systems in different scenarios of small break loss-of-coolant accident (SB-LOCA), as well as the so-called Design Extension Conditions (DEC) that either are more severe than design basis accidents or involve additional failures, such as the steam generator tube rupture (SGTR) as a consequence of secondary breaks. The project additionally aims to further clarify the issue of intermediate break loss-of-coolant accident (IB-LOCA) and the analysis of counterpart tests.

A comprehensive experimental database for model development and code validation was then established in the PKL and in the ATLAS facilities that complements those previously available at those facilities.

Of particular relevance is the fact that both experimental projects include counterpart tests (CTs), i.e. tests with similar configuration and corresponding initial and boundary conditions to other previous tests performed in another integral test facility. These CTs are considered especially valuable to address the effects of geometrical design differences and the issue of scaling, which are always present between different test facilities and between facilities and actual plants.

Although the projects are essentially seeking to obtain experimental data, the project review group (PRG) and the management board (MB)s of both projects have encouraged requiring analytical activities that help the regular development of the experimental project. These efforts aim at either helping in the definition of the experiments (with pre-tests calculations) or the in-depth analyses of the experimental results (with post-test analyses) by providing further insights, information and variables, available with the TH simulation codes but not by the regular instrumentation of the experimental facilities.

Additionally, some benchmark activities of TH simulation code results have been established in both projects in order to check the predictability capabilities of current TH analytical tools available in the nuclear safety community.

These analytical support activities performed in the frame of similar previous NEA projects (SETH, PKL, PKL-2, PKL-3, ROSA, ROSA-2 and ATLAS), as well as the organisation of technical seminars to describe the analytical activities performed by the project participants, proved to be very useful in the past. This is why, during the fourth meeting of the PRG/MB of the PKL-4 project (Lappeenranta, Finland, on 23-24 May 2018) and the second meeting of the PRG/MB of the ATLAS-2 project (Abu Dhabi, United Arab Emirates, on 17-18 April 2018), the organisation of a joint workshop was approved[1]. The main purpose of this workshop was then to fulfil these actions.

This workshop, sponsored by the Committee on the Safety of Nuclear Installations (CSNI) of the NEA and the Nuclear Safety Council (CSN) of Spain, took place in Barcelona, Spain, at the premises of the Technical University of Catalonia, from 7 to 9 November 2018, as scheduled in the proposed agenda (Annex A).

In summary, the main objectives of the workshop were to:

- present and discuss in-depth analyses performed in the PKL-4 benchmark exercise on the i2.2 (run 3) test (MB-LOCA scenario);
- present and discuss in-depth the test analyses of other PKL-4 tests (including PACTEL and PMK);
- present and discuss in-depth the test analyses of ATLAS-2 and ATLAS-1;
- present and discuss plant application analyses related either to equivalent scenarios or to scenarios helpful to clarifying 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 five technical sessions, with the following specific objectives:

- Session 1 provided an overview of the main experimental series of both projects.
- Session 2 was aimed at presenting the main conclusions of the benchmark exercise related to the i2.2 test conducted in the PKL facility, the main conclusions of the benchmark exercise related to this test, and the details of the different blind and post-test analyses carried by the different participants in the exercise.
- Sessions 3 and 4 presented analyses related to, namely, other PKL-4 and ATLAS-2 tests.
- Session 5 opened the possibility to discussing plant application analyses.
- A final session was devoted to discussing and summarising the main conclusions of the sessions.

The list of participants is included in Annex B.

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

1. A second workshop was approved by the PRG and MB of both projects as well by the end of the projects.

2. Session 1: General overview of the NEA PKL-4 and NEA ATLAS-2 projects

The session aimed to provide an overview of the main experimental series of both projects, PKL-4 and ATLAS-2, putting a particular emphasis on those experiments that were covered during the rest of the presentations of the workshop, and so avoiding repetition of general descriptions of each analysed experiment.

The PKL-4 project includes tests carried out at the PKL facility, with additional tests performed at the PMK and PWR PACTEL facilities. The workshop was organised when about half of the planned experiments of the project had been performed. The studied topics cover phenomena during different size LOCAs (small, intermediate, and large), boron dilution transients occurring under shutdown conditions, and verification of cool-down procedures under different incident and accident conditions.

The ATLAS-2 project was carried out at the ATLAS facility. It covers an experimental test matrix, experimental conditions, and parameters to investigate safety issues regarding:

- passive core makeup during station black-out (SBO) and small break loss-of-coolant accident (SB-LOCA);
- intermediate break loss-of-coolant accident (IB-LOCA);
- DEC scenarios (such as Steam Line Break [SLB] followed by SGTR, and Shutdown Coolability without residual heat removal system [RHRS]);
- some open tests.

Both experimental projects are developed to allow for open tests, which are defined in consultation with project members, and they can cover some safety relevant issues for the partners or open issues from past tests. This adds flexibility to the management of the projects, and allows for the resolution of partners' particular problems. In PKL-4, the open series covered the analysis of cool-down strategies after multiple steam generator tube ruptures (M-SGTR). In the case of ATLAS-2, the open test has finally been devised to address scaling issues by performing the counterpart test of a previous LSTF Upper Head SB-LOCA.

Participants appreciated the use of test results from both projects as database for code validation and, during the workshop, the analyses of different experiments by project participants became essential parts of the projects.

The large involvement of project partners in the definition of experiments through pre-test analyses (assisting the operating agents in the definition of experiments) and through post-test analyses was also described as highly valuable. In this way, the capabilities of tools that are used in deterministic safety analysis of nuclear power plants are assessed and items for improvement are recognised.

Both projects include experiments tackling scenarios that have already been investigated on other facilities: so-called CTs. This type of test makes it possible to study the differences between facilities and the eventual influence of these differences on the experimental results. These exercises can also give hints as to the important aspects that should be taken into account when modelling full size nuclear power plants for transients and accidents.

In addition to that, in the PKL-4 project there are experiments in which an integral test facility (ITF) is used for separate effect type experiments. If the instrumentation of a facility is extensive, this type of tests can actually give more valuable data than when performed on a separate effect facility, because the initial and boundary conditions are closer to the ones that are encountered in nuclear power plants.

3. Session 2: Analyses of the benchmark exercise in the PKL facility

The objective of this session was to present the main conclusions of the benchmark exercise (BM) related to the i2.2 run3 test in the PKL facility, conducted in the PKL-4 project and co-ordinated by UPC (Technical University of Catalonia).

This experiment reproduces a cold leg intermediate break LOCA (IB-LOCA) for beyond design basis accident (BDBA) conditions. Such a scenario was selected to resemble as accurately as possible the NEA ROSA-2 test 2 and test 7 carried out at the LSTF facility (Japan). Those experiments represented a double guillotine break of nozzles (13% and 17% of cold leg size) connected to the primary system. While the 13% break case did not show significant core heat-up, the 17% break case showed an extensive increase of the cladding temperatures, a sequence that required core power reduction. Some codes or code users seemed not to be able to capture this behaviour and, accordingly, it was considered crucial to evaluate the capabilities of system codes to simulate the phenomenology involved in such scenarios making use of experimental data. For all these reasons, the main objective of the PKL i2.2 experiment is to help answer the questions on discrepancies with respect to peak cladding temperatures (PCTs) between experimental data and post-test calculations in conditions similar to those experienced at the LSTF facility. The i2.2 experiment is composed of three runs simulating events with a different break size (run1 and run2) and different injections (run3). The data of run3 are used for the BM calculations.

In this session, eight presentations were delivered, as scheduled in the agenda (Annex A).

The first presentation (2.1) was given by Simon Schollenberger (Framatome, Germany) and described the experimental results and the related phenomenology. The presentation addressed the low PCT excursion in the experiment and justified it by means of the pressure losses along the primary system, which are different compared to the ones in the LSTF facility.

The second presentation (2.2) was delivered by Jordi Freixa (UPC, Spain) and reported the results of all the BM participants in comparison to the experiment. In total, 12 participants from 8 countries took part in the BM activity. Some indicative explanations for the deviations were provided and the basis for the discussion on the writing of the BM report was set.

In the subsequent presentations, individual organisations presented their results and conclusions from their post-test calculations and, partly, from sensitivity studies, and shared their experiences from the blind pre- and post-test calculation phases. Six organisations presented analyses on test i2.2 (run3). Table 1 lists the organisations and codes presented during the session.

Table 1. Post-test calculations presented during Session 2

Presentation	Organisation	Code
2.3	KAERI (Korea)	SPACE
2.4	OKBM (Russia)	RELAP/SCDAPSIM/MOD3.4
		KORSAR
2.5	EDF (France)	CATHARE
2.6	GRS (Germany)	ATHLET
2.7	UPC (Spain)	RELAP5
2.8	NPIC (P. R. China)	RELAPSCDAPSIM/MOD3.5

During the general discussion of this session, the contents of the BM report as well as the next steps to follow were addressed. The following is a list of recommendations on the benchmark activity, specially focused on the writing and configuration of the final report:

- The operating agent should provide a list of physical phenomena significant for the i2.2 IB-LOCA course of events.
- The report should include individual phenomenon-related sections. The BM participants should feel encouraged to provide input/text passages.
- The BM participants are to identify key sources for uncertainties in their calculations (ranking of influence parameters).
- Benchmark participants will provide short descriptions (~2 pages) of their code and input file (e.g. picture of nodalisation or counter-current flow limiting (CCFL) models/correlations).
- The BM participants were invited to provide their expertise in the form of a more "in-depth" analysis of their code's performance and/post-test calculations to be included in the Appendixes of the report (critical analysis eligible).
- It was decided that a post-test phase would not provide added value to the benchmark report and thus it was not retained for the body of the report. However, this type of analysis can be included in the Appendixes.

Another topic tackled during the general discussion covered the problems encountered during the BM activity and how BM activities could be improved. The following is a list of recommendations for future BM exercises:

- During the preparation of the next BM exercise, there should be a list of key parameters and identification of potentially significant influence parameters. In the present BM exercise, some participants had difficulties understanding certain specifications, which led to mistakes that could have been avoided.
- The operating agent should provide a list of appropriate measurements (including position, physical property, uncertainty) to:
    - help the BM participants separate the important measurement position tags (i.e. MST) from the not-so-important ones;
    - create a consistency check in the comparison between test and calculation by defining how/where these key parameters are measured in the facility;
    - create a common designation of key parameter measurements for easier comparison;
    - compare the calculated values with raw experimental data rather than treated signals (e.g. use delta-P instead of evaluated collapsed water level);
    - combine uncertainty and sensitivity analyses for evaluation of code performance (one without the other has a limited significance for evaluation).

4. Session 3: NEA PKL-4 experimental results, code calculations and validation

Session 3 was devoted to system code simulations of different experiments of the PKL-4 project. In this session, three presentations were delivered, as listed in the agenda (Annex A).

The first presentation introduced the Technical Research Centre of Finland Ltd (VTT) post-test calculations of the benchmark exercise. The experiment is a 17% cold leg IB-LOCA. Calculations were performed with APROS 6.07 and 6.08. The main difference between the code versions is that the 6.08 version includes a CHF Groeneveld table for replacing the common empirical correlations when specified restrictions are violated. Several improvements were carried out to the PKL supplied input deck (heater rod models, ACCs, break piping and pumps butterfly valves). Results of both simulations showed a good agreement in the overall behaviour of the experiment. In addition, it was also detected that for both simulations APROS was under-predicting the height of the quench front before low-pressure safety injection (LPSI), and was introducing a non-reported core heat-up. In this sense, the Groeneveld table added to 6.08 version improved the simulation of the quench front but did not avoid reproducing the second core heat-up.

The second presentation (3.2) showed different post-test simulations of the I2.1 experiments (run1 and 2). I2.1 series are SB-LOCA tests in which the distribution of the N_2 along the primary system has a significant effect in the heat removal of the decay power. The post-test calculations were performed with KORSAR/BR and RELAP/SCDAPSIM/MOD3.4 codes; they showed very good agreement with experimental data, especially for run 1. For run 2, the pressure of the primary system was overestimated for both codes as a result of a higher accumulation of nitrogen in the U-tubes and lower primary to secondary heat transfer. The recommendations for assessing/explaining the differences were:

- compare the distribution of N_2 in the Reactor Coolant System (U-tubes, SG outlet chamber and cold legs) and assess the differences between the SGs of each loop and the accumulation of nitrogen in the individual tubes of each one;
- assess the heat transfer in the U-tubes and determine which are the active and passive zones.

The third presentation (3.3) introduced CATHARE simulations of the PKL Natural Circulation Test with different nodalisation approaches for the steam generators. The results of the simulations demonstrated the capability of the CATHARE code to reproduce the flow reversal in the U-tubes for both the one-phase (liquid) and the two-phase flow conditions. The comparison of the different nodalisation approaches showed better results in the 1D multi-tube model, especially in the redistribution of the flow. In addition, encouraging results were obtained by modelling the inlet chamber with a 3D model. In that sense, the following further aspects to consider were introduced:

- 3D model for the SG outlet chamber;
- transition from hot leg to the inlet chamber;
- void distribution below the tube sheet.

Finally, it was suggested to the operating agents that they provide the uncertainty of the mass flow measurements for two-phase flow conditions.

5. Session 4: NEA ATLAS experimental results, code calculations and validation

In this session, seven presentations were delivered. They considered, on the one hand, selected ATLAS experimental tests performed within the current NEA ATLAS-2 and former ATLAS projects and, on the other hand, thermal-hydraulic system code assessments in predicting the selected tests' results.

Several thermal-hydraulic system codes like ATHLET, SPACE, TRACE, and MARS-KS were used to simulate scenarios related to:

- SBO with asymmetric and delayed feedwater supply (ATLAS A1.1 test);
- prolonged SBO with SGTR (ATLAS A2.2 test); and
- SBO with hybrid safety injection tanks (ATLAS-2 B2.1 test) and IB-LOCA with surge line break (ATLAS-2 B3.1 test).

The ATLAS-2 tests related to the natural circulation characterisation experiments (NCR03, and NCR04) were also considered.

The simulation results highlighted, on the one hand, good overall code prediction capabilities, and, on the other hand, issues related to code difficulties in simulating the passive system behaviour that rely on safety injection logics connected with the hybrid safety injection tank (HSIT) temperature at a given elevation. It was observed that phenomena such as the temperature stratification and mixing in the HSIT were not correctly predicted by the used 1D models. Another issue that was identified related to the impact of heat loss modelling under prolonged natural circulation flow on the course of the transients. A practical methodology for correct heat losses assessment was proposed.

Concerning the IB-LOCA, the impact of the CCFL and the off-take models on the code predictions of the course of the transient was emphasised. Also discussed was the need to carry out sensitivity and uncertainty assessments and the way to decouple the effects of scaling and configuration of the facility.

Overall, the capability of the current thermal-hydraulic system codes in predicting reasonably well the overall course of the transients was judged satisfactory. However, limitations in codes predictions and the need for deeper modelling investigations were highlighted. This concerns mainly issues such as:

- the heat loss evaluation under prolonged transients governed by natural circulation flow regimes;
- the 3D modelling of phenomena that occur in the safety passive system components, such as the passive auxiliary feedwater system (PAFS) and HSITs during the course of the transients;
- the use of uncertainty assessment methodologies, based on propagation from inputs or accuracy extrapolation (FFTBM) to qualify and assess the code predictions;
- the off-take model under different geometry configurations and break orientations, and the impact on the code predictions of IB-LOCA scenarios.

6. Session 5: Plant applications and other topics

Plant applications are where the data and analyses produced in the PKL-4 and ATLAS-2 projects will ultimately be used. The efforts carried out in the different steps of ongoing research, such as designing ITFs and tests, performing experiments and giving analytical support by means of pre and post-test calculations, all contribute to generate knowledge for applications for nuclear power plants. The session had four presentations that can be summarised as follows.

Presentation 5.1 summarised the use by GRS of the NEA PKL-3 and ATLAS project results in the assessment of the system code ATHLET. The code application to counterpart experiments performed in different facilities was emphasised, as it provides a sound indication of the scalability of code results and allows investigation of scaling effects.

The next presentation (5.2) focused on the scaling of uncertainties in thermal-hydraulic system codes, showing how uncertainties in system code calculations can be scaled using codes, though it requires the use of proper methodologies.

Presentation 5.3 was about a study by KAERI on the issue of scaling the ATLAS facility by plant analysis of A5.1 Test. The presentation showed that results obtained in the ATLAS facility provide insight into what can be expected at reactor scale, providing that a proper scaling methodology is used.

Presentation 5.4, given by UPV, showcased their experience from SETH and different editions of PKL projects, in the analysis of accident management measures for a loss of RHRS at a PWR. The presentation laid out the latest results of the PKL-3 H3.1 test. A general conclusion was given regarding the need for specific tests to physically understand the scenario of loss of RHRS at different operating modes. It was stressed that the conclusions from a four-loop configuration test on PKL could be applied to three-loop configurations.

During the general discussion, the following comments and questions were raised:

- Experience and information gained from experiments can be used in different ways. They can be used simply to physically understand the scenario, or scaling considerations can be added. In the first case, the analysis will concentrate on similarities between the nuclear power plant and the ITF, while, in the second case, scaling distortions between the nuclear power plant and the ITF (or between different ITFs) will be studied.
- Distortions between calculation results can appear due to differences in scale, but also due to differences in configuration. Both items need to be addressed, and analysts are currently doing so.
- Discussing the connection between plant applications and designing new experiments, the group concluded that both scientific and practical concerns need to be considered when planning new tests. Different examples were cited. Both PKL and ATLAS groups accepted that such feedback is part of their role.
- Answering comments around the need to produce a document on good practices, the group concluded that the first step could be to encourage participants to introduce their scaling considerations in their presentations and reports. This will give an opportunity to consolidate the contents of a future report on good practices.

- Another technique for using the information gained from experiments was mentioned. The so-called inverse methods were developed to solve the inverse problem in modelling and simulation, which consists of estimating unknown model inputs from the knowledge (typically through measurement) of model outputs. Inverse methods allow a backwards propagation of uncertainty (i.e. from outputs to inputs).
- One major use of inverse methods is in the estimation, from the comparison of experimental data and model predictions, of the uncertainty introduced by the imperfection of physical models.
- In the field of thermal-hydraulic system codes, inverse methods are starting to be developed and applied intensely. A clear sign of this is the existence of two NEA projects (established by the NEA CSNI Working Group on the Analysis and Management of Accidents [WGAMA]) devoted to inverse methods: PREMIUM ("Post-BEMUSE Reflood Models Input Uncertainty Methodologies") and SAPIUM ("Systematic Approach for Input Uncertainty Methodology").

7. General conclusions of the workshop

This joint workshop on analytical activities of ATLAS-2 and PKL-4 projects aimed to bring together code users who performed calculations reproducing the PKL-4 (PKL, PACTEL and PMK) and ATLAS-2 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 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:

- The participants appreciated the code results benchmark exercises as a way of continuously testing the current TH simulation codes in their predictive capabilities. The PKL-4 project partners and the operating agent recognised the large number of participants in the action.
- In general, the obtained code results showed good performance and satisfactory agreement with experimental results, which increases the confidence in current TH code technologies.
- A general recommendation from several participants was the need to perform combined SUA to qualify the code performance. The use of FFTBM was considered valuable for a quantitative evaluation of measurement-prediction discrepancies, but further clarification of the interpretation of the obtained indicators (in the frequency domain) and required parameters (weights) was proposed.
- Participation by project partners was high in the definition of experiments through pre-test analyses and in the execution of post-test analyses. This strong involvement was remarked as highly valuable, as well.
- In general, most of the contributions to the workshop included indications and justifications of modelling strategies, as well as the improvements tested to solve code deficiencies and bad results. Many participants presented and discussed details on the rationale and capabilities behind the simulation models, which allows the cross-fertilisation among different code practitioners.

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

- Results of the blind phase for the PKL-4 benchmark exercises have shown a certain maturity of the predictive capability of current TH codes. Participants unanimously agreed that there is no need to continue this code benchmark exercise with the post-test (open) phase.
- Experience gained in the definition of PKL-4 benchmark specifications has identified some troubles due to an insufficient preparatory period. It was highly recommended to spend in future benchmarks more effort in the preparation of the specification 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, etc.). Any mistake at such an early stage may affect all subsequent calculations.

- An emphasis was put on the execution of blind calculations as a way of testing the predictive capability of codes. It was recommended to include SUA as a part of these blind exercises.

Some recommendations for future benchmark exercises were discussed:

- Prepare in advance a list of key parameters and identify potentially significant influence parameters.
- Detail and provide a list of appropriate measurements (position, physical property, uncertainty) to:
  - help the benchmark participants separate the important measurement position tag (i.e. MST) from the not-so-important ones;
  - create a consistency check in the comparison between test and calculation;
  - harmonise through a common designation of key parameter measurements for easier comparison;
  - compare the calculated values with raw experimental data rather than treated signals (e.g. collapsed water levels).
- Further nuclear power plant applications, particularly in the improvement of scaling techniques, were also encouraged.
- The role of ambient heat loss in transients at nuclear power plants was discussed. It is widely accepted that ambient heat loss plays a smaller role in nuclear power plants 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 received increased attention in recent years. It was proposed that the reduced impact that ambient heat loss has on nuclear power plant transients may become significant for long duration transients and warrants consideration in thermal-hydraulic analysis.
- It was a common understanding that the workshop was a step in the right direction and that efforts of this kind on analytical activities should be continued. A second joint workshop has been approved by the PRG and MB of both projects by mid-2020.

Other more general comments that were raised during the sessions are:

- 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 24 presentations that allowed detailed technical discussions on the current code capabilities and interpretation of test results. All the participants appreciated the meeting as a good occasion to exchange ideas and methods, to pose problems and suggest solutions.
- As highlighted in previous analytical workshops (Barcelona 2003, Pisa 2005, Budapest 2006, Pisa 2010, Paris 2012 and Lucca 2016), having analytical and experimental specialists together in a conference is fruitful for both groups of experts. Such workshops are good examples of the effective and necessary interaction between modellers and experimentalists for solving topical safety issues.

Annex A: Final agenda of the Joint PKL-ATLAS Workshop on Analytical Activities related to NEA PKL-4 and NEA ATLAS-2 Projects

Joint PKL-ATLAS Workshop on Analytical Activities related to NEA PKL-4 and NEA ATLAS-2 Projects

Final agenda

<u>Wednesday 7 November 2018</u>

8.30-9.00 **Registration**

(On the first day ID cards or passports shall be presented at the entrance of the conference room to get access badges)

9.00-9.30 **Welcome, opening remarks and introduction**

Chair: M. Sanchez (CSN, Spain)

- N. Sandberg, NEA Secretariat

- K. Umminger, PKL-4 Operating Agent (Framatome, Germany)

- Kyoung-Ho Kang, ATLAS-2 Operating Agent (KAERI, Korea)

- Javier Ramón, Consejo de Seguridad Nuclear (CSN, Spain)

- Neus Cónsul, Director of Tech. School of Industrial Engineering of Barcelona (UPC, Spain)

9.30 **Session 1: General overview of PKL and ATLAS Programmes**

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

9.30-9.55 (1.1) Overview on Test Results from the OECD/NEA PKL-4 Project *<u>S. Schollenberger</u>, Klaus Umminger, L. Dennhardt, B. Schoen, (Framatome, Germany)*

9.55-10.25 (1.2) Overview on OECD/NEA ATLAS-2 Project, *<u>Kyoung-Ho Kang</u> (KAERI, Korea)*

10.25-11.00 **Coffee break**

11.00 **Session 2: Analyses of the benchmark exercise in the PKL facility**

Chairs: J. Freixa (UPC, Spain) and S. Schollenberger (Framatome, Germany)

11.00-11.25 (2.1) Framatome presentation on the results of the benchmark experiment OECD-PKL i2.2 Run 3 *S. Schollenberger, Klaus Umminger, L. Dennhardt, B. Schoen, (Framatome, Germany)*

11.25-11.50 (2.2) Benchmark activity on the PKL IB-LOCA experiment i2.2 *J. Freixa, V. Martínez-Quiroga, M. Casamor, F. Reventós, C. Pretel (UPC, Spain)*

11.50-12.15 (2.3) Assessment of SPACE code on benchmark activity of OECD/NEA PKL-4 i2.2 test in PKL facility, *J. H. Lee (KAERI, Korea)*

12.15-13.45 **Lunch break**

13.45-14.10 (2.4) PKL-4 benchmark pre/post-test calculation by codes KORSAR/BR and RELAP/SCDAPSIM/MOD3.4, *Iurii Shvetsov, A. Falkov (OKBM, Russia)*

14.10-14.35 (2.5) EDF contribution to the i2.2 test benchmark exercise in the frame of the OECD/NEA PKL-4 Project, *Jean-Luc Vacher (EDF, France)*

14.35-15.00 (2.6) Simulation of the PKL Benchmark Test i2.2 Run 3 with the code ATHLET, *H. Austregesilo, T. Hollands (GRS, Germany)*

15.00-15.30 **Coffee break**

15.30-15.55 (2.7) Simulation of the PKL Benchmark Test i2.2 including uncertainty analysis, *V. Martínez-Quiroga, J. Freixa,, M. Casamor, F. Reventós, C. Pretel (UPC, Spain)*

15.55-16.20 (2.8) Simulation of the IB-LOCA experiment of PKL-4 by NPIC, *Huang Tao, Ding Shuhua, Li Zhongchun, Jiang Xiaowei, Deng Jian (NPIC, P. R. China)*

16.20-16.50 Session 2 General discussion

16.50 **First day adjourn**

Thursday 8 November 2018

9.00 **Session 3: OECD/NEA PKL-4 experimental results, code calculations and validation**

Chairs Klaus Umminger (Framatome, Germany) and Víctor Martínez-Quiroga(UPC, Spain)

9.00-9.25 (3.1) APROS calculations for PKL i2.2 run3 17 % IB-LOCA, *Marton Szogradi (VTT, Finland)*

9.25-9.50 (3.2) i2.1 run 1 and i2.1 run 2 PKL-4 post-test calculation by codes KORSAR/BR and RELAP/SCDAPSIM/MOD3.4, *Iurii Shvetsov, A. Falkov (OKBM, Russia)*

9.50-10.15 (3.3) CATHARE Simulation Results of the PKL-III-i Natural Circulation Characterisation Test using 3 Steam Generator Nodalization Approaches, *A. Bousbia Salah (BelV, Belgium)*

10.15-10.30 Session 3 General discussion

10.30-11.00 **Coffee break**

11.00 **Session 4: OECD/ATLAS experimental results, code calculations and validation**

Chairs: Kyoung-Ho Kang (KAERI, Korea) and Anis Bousbia (BelV, Belgium)

11.00-11.25 (4.1) Analytical work performed at GRS in the frame of the OECD/NEA ATLAS-2 Project, *H. Austregesilo, T. Hollands (GRS, Germany)*

11.25-11.50 (4.2) Post Calculation against OECD/NEA ATLAS A2.2 using SPACE, *Seung Wook Lee, Byoung-Uhn Bae, Kwi-Seok Ha (KAERI, Korea)*

11.50-12.15 (4.3) Analysis of natural circulation phenomena in the atlas facility, *María Lorduy, Sergio Gallardo, Gumersindo Verdú (UPV, Spain)*

12.15-13.45 **Lunch break**

13.45-14.10 (4.4) SPACE Calculation of Pressurizer Surge Line Break Accident B3.1, *Sung Won Bae (KAERI, Korea)*

14.10-14.35 (4.5) Effect of Hybrid SIT on System Behaviour During SBO, *Seok Cho (KAERI, Korea)*

14.35-15.00 (4.6) Test Result and MARS-KS Calculation for OECD/NEA ATLAS-2 B3.1 Test (Pressurizer Surgeline IB-LOCA), *Byoung-Uhn BAE (KAERI, Korea)*

15.00-15.30 **Coffee break**

15.30-15.55 (4.7) 1% SB-LOCA with Total Failure of HPSI and Varied PAFS Actuation Time, *R. Harrington and Shawn O. Marshall (NRC, United States)*

15.55-16.30 Session 4 General discussion

16.30 **Second day adjourn**

Friday 9 November 2018

9.00 **Session 5: Plant applications and other topics**

Chairs: Francesc Reventós (UPC, Spain), Rafael Mendizábal (CSN, Spain) and Philippe Freydier (EDF, France)

9.00-9.25 (5.1) Contribution of the OECD/NEA Projects PKL-3 and ATLAS to the Assessment of the System Code ATHLET, *H. Austregesilo and T. Hollands (GRS, Germany)*

9.25-9.50 (5.2) On the Scaling of Uncertainties in Thermal-Hydraulic System Codes, *M. Casamor, V. Martínez, F. Reventós, R. Mendizábal, J. Freixa (UPC and CSN, Spain)*

9.50-10.15 (5.3) Study on the Scaling Issue of the ATLAS facility by Plant Analysis of A5.1 Test, *Yusun Park (KAERI, Korea)*

10.15-10.40 (5.4) Analysis of PKL H3.1 Accident Management Measures for a PWR Loss of RHRS at a PWR, S. Martorell, S. Carlos, J. F. Villanueva, F. Sánchez *(UPV, Spain)*

10.40-10.50 Session 5 General discussion

10.50-11.45 **Coffee break**

11.45-13.15 **Session 6 Wrap-up and concluding remarks session (20 mn + 50 mn final discussion),** *Panel by chairpersons of all the sessions*

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

13.30 **Closure of the workshop**

Annex B: List of participants

Joint PKL-4-ATLAS-2 workshop – 7-9 November 2019

#	NAME	SURNAME	ORGANISATION	COUNTRY
1	Anis	BOUSBIA SALAH	BelV	BELGIUM
2	Xiaowei	JIANG	NPIC	CHINA
3	Guijun	LENG	NPIC	CHINA
4	Zhongchun	LI	NPIC	CHINA
5	Tao	HUANG	NPIC	CHINA
6	Zhongyu	JU	CGNPC	CHINA
7	Yanhua	YANG	SPICRI	CHINA
8	Hao	ZHANG	SPICRI	CHINA
9	Radim	MECA	UJZ	CZECH REPUBLIC
10	Jean-Luc	VACHER	EDF	FRANCE
11	Philippe	FREYDIER	EDF	FRANCE
12	Sofia	CARNEVALI	CEA	FRANCE
13	Tony	GLANTZ	IRSN	FRANCE
14	Marton	SZOGRADI	VTT	FINLAND
15	Eero	VIRTANEN	STUK	FINLAND
16	Henrique	AUSTREGESILO	GRS	GERMANY
17	Andreas	WOLF	GRS	GERMANY
18	Klaus	UMMINGER	FRAMATOME GmBH	GERMANY
19	Simon	SCHOLLENBERGER	FRAMATOME GmBH	GERMANY
20	Thomas	MULL	FRAMATOME GmBH	GERMANY
21	Lars	DENNHARDT	FRAMATOME GmBH	GERMANY
22	Byoung-Uhn	BAE	KAERI	KOREA
23	Sung Won	BAE	KAERI	KOREA
24	Kyoung-Ho	KANG	KAERI	KOREA
25	Seok	CHO	KAERI	KOREA
26	Seung Wook	LEE	KAERI	KOREA
27	Jong Hyuk	LEE	KAERI	KOREA
28	Yusun	PARK	KAERI	KOREA
29	Emil	AKHMEDOV	JSC ATOMPROEKT	RUSSIA
30	Maksim	GAVRILOV	JSC ATOMPROEKT	RUSSIA
31	Ivan	PETKEVICH	OKD GIDROPRESS	RUSSIA
32	Mikhail	SUSLOV	OKD GIDROPRESS	RUSSIA
33	Iurii	SHVETSOV	OKBM	RUSSIA
34	Jose María	POSADA	CNAT	SPAIN
35	Jordi	FREIXA	UPC	SPAIN
36	Francesc	REVENTOS	UPC	SPAIN
37	Victor	MARTINEZ	UPC	SPAIN
38	Carme	PRETEL	UPC	SPAIN
39	Kevin	MARTÍN	UPC	SPAIN
40	Max	CASAMOR	UPC	SPAIN
41	Sergio	GALLARDO	UPV	SPAIN
42	Gumersindo	VERDÚ	UPV	SPAIN
43	María	LORDUY	UPV	SPAIN
44	Sebastian	MARTORELL	UPV	SPAIN
45	Sofía	CARLOS	UPV	SPAIN
46	Julio	PÉREZ	CSN	SPAIN
47	Rafael	MENDIZÁBAL	CSN	SPAIN
48	Javier	RAMÓN	CSN	SPAIN
49	Miguel	SÁNCHEZ	CSN	SPAIN
50	Joakim	HOLMSTRÖM	RINGHALS AB	SWEDEN
51	Pascal	VEBER	RINGHALS AB	SWEDEN
52	Peter	HEDBERG	SSM	SWEDEN
53	Sergey	KALINICHENKO	SSM	SWEDEN
54	Shawn	MARSHALL	US NRC	UNITED STATES
55	Nils	SANDBERG	NEA	International Organisation