Advancing Nuclear Reactor Thermal-Hydraulics:

Collaborative Initiatives FONESYS and SILENCE

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ABSTRACT

This paper introduces two collaborative network initiatives, FONESYS (Forum & Network of System Thermal-Hydraulics Codes in Nuclear Reactor Thermal-Hydraulics) and SILENCE (Significant Light and Heavy Water Reactor Thermal Hydraulic Experiments Network for the Consistent Exploitation of the Data), aimed at enhancing the field of nuclear reactor thermal-hydraulics. FONESYS, established in 2010 by Pr. D'Auria, brings together developers of leading system thermal-hydraulic codes worldwide to foster cooperation, share advancements, and discuss improvements crucial for safety analyses and licensing purposes. The initiative aims to promote the use of System Thermal-Hydraulics (SYS-TH) codes and Best Estimate Plus Uncertainty (BEPU) approaches, standardize Verification and Validation (V&V) procedures, and facilitate discussions on enhancements in various aspects, including user-interface and integration with Computational Fluid Dynamics (CFD) codes. Conversely, SILENCE, created in 2012 by Pr. D'Auria, comprises owners and operators of significant thermal-hydraulic experimental facilities. Its objectives include promoting collaboration, transferring knowledge, reviving interest in experimental campaigns, and supporting organizations embarking on large experimental programs. Together, FONESYS and SILENCE work synergistically, holding at least an annual joint meeting over the past decade, fostering a cooperative environment to advance nuclear reactor thermal-hydraulics research and development. Latest activities in SILENCE and FONESYS include respectively the reevaluation of the database for counterpart tests, and the investigations on the capability of two-phase models in predicting pressure drops. In the last framework, RNC (Reverse Natural Circulation) benchmark in PKL facility has been performed, comparing results from various system codes, and highlighting the influence of the uncertainty of singular pressure drops in natural circulation systems.

The recently proposed CONUSAF (Consortium of Users of Thermal-Hydraulics computational Tools for Nuclear Reactor Safety and Design) consortium aiming at involving code users in this framework is also introduced.

Keywords: *system thermal hydraulics codes, BEPU, V&V, experimental campaigns, network*

1 INTRODUCTION

The development of the system thermal-hydraulic (SYS-TH) codes began at the end of the 1960's. The huge amount of investments in the nuclear reactor safety research and developments, including verification and validation (V&V), brought to the nuclear community the availability of mature computational tools towards the end of 1990's, when those codes were classified as best estimate due to their advanced two-fluid modeling capabilities and their extensive validation. In the last twenty years the R&D efforts and the progress slowed down. However, some “old issues” are still valid and new ones may be raised by the users for new applications and needs. Also new advanced thermal-hydraulic simulation tools exist which may be used as a support in multi-scale analysis, and multi-physics simulation.

The design of reactor coolant systems and ability to predict their performance and assess their safety depends on the availability of experimental data and models, which can be used to describe various multiphase flow processes and phenomena with a sufficient accuracy. From a scientific as well as practical point of view, it is essential that the various mathematical models should be clearly formulated based on the physical understanding of multiphase flow processes and supported by experimental data. For this purpose, especially designed instrumentation and experiments are required which must be conducted together with, and in support of, model development efforts. Since the resources and capability for new experiments are limited, good planning and international cooperation between experimentalist, code developers, and code analysts are necessary and may represent a way to help finding solutions for some of the remaining issues in nuclear thermal-hydraulics (TH).

In view of this, two projects namely FONESYS [1,2] and SILENCE [3,4] were promoted by the San Piero a Grado Nuclear Research Group of the University of Pisa (GRNSPG/UNIPI).

The FONESYS members are developers of some of the major SYS-TH codes adopted worldwide. FONESYS has been created to strengthen the current technology, cooperate and share recent advances, identify and discuss further ways of improvements in SYS-TH code development. Organization of benchmark activities on selected topics, preparation of agreed technical publications and reports are also part of the working modalities.

On the other hand, SILENCE members own and operate important thermal-hydraulic experimental facilities. SILENCE aimed at promoting cooperation and knowledge transfer, discussion on state-of the art technological issues, revival of interest in significant experimental campaigns and support to organizations and countries embarking in large experimental programmes. A key SILENCE topic is the identification of current measurement needs and main gaps for further SYS-TH and computational fluid dynamic (CFD) codes development and validation. On this concern, SILENCE promoted the “Specialists Workshop on Advanced Instrumentation and Measurement Techniques for Nuclear Reactor Thermal-Hydraulics” (SWINTH).

FONESYS and SILENCE work in a cooperative manner since about a decade having at least one meeting per year. Starting from 2020, FONESYS-SILENCE joint meetings are also regularly organized in conjunction with the networks meetings to promote activities on topics of common interest as the scaling of TH phenomena.

Recently the CONUSAF consortium aiming at involving code users in this framework has been also proposed.

2 THE FONESYS NETWORK

2.1 Founding Motivation and Main Objectives of the Project

The main motivation for starting the FONESYS project was to bring technical evidence addressing possible disbelief in SYS-TH codes or criticism against them, e.g. [5,6], and to strengthen the current technology. The effort for SYS-TH codes development is decreasing and may even stop but its application cannot be avoided even if new tools such as CFD or computational multi fluid dynamics (CMFD) codes appeared at the beginning of the 2000s.

The motivation is to bring arguments against over-criticism and at the same time to improve the codes simulation capabilities, and to clearly identify the future roles of SYS-TH codes and CFD codes in reactor thermal-hydraulic studies. Another principal motivation was to form a network of experts and code developers able to solve future problems that may arise during the development and use of SYS-TH codes.. FONESYS objectives are to keep the code limitations ‘under control’, and to provide guidance for code improvements. Strategy and activities were planned and decided within a framework consistent with the standards of international institutions.

The main objectives of the project are summarized below:

- To create a common ground for discussing envisaged improvements in various areas of SYS-TH, promoting a cooperation aimed at the improvement of the SYS-TH codes and their application in the licensing process and safety analysis;
- To identify the area of improvement and share experience on the graphical user interface, SYS-TH code coupling with other numerical tools such as 3D neutron kinetics, fuel pin mechanics, CFD, CMFD.
- To share the experience on code inadequacies and cooperate in identifying experiments and/or code-to-code benchmarks for analysing and resolving the deficiencies;
- To share the user experience on code scalability, applicability, and uncertainty studies;
- To establish the acceptable and recognized procedures and thresholds for the V&V processes;
- To maintain and improve the user expertise and the user guidelines for applying the code;
- To share and resolve the safety issues and new licensing guide.

2.2 FONESYS Members and Reference SYS-TH Codes

Ten international organizations are currently involved in the FONESYS network, namely the Canadian Nuclear Laboratories (CNL) from Canada, State Power Investment Corporation Research Institute (SPICRI) and China Nuclear Power Technology Research Institute (CNPRI) from China, the VTT Technical Research Center of Finland, the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), Électricité de France (EDF) and Framatome from France, the Gesellschaft für Anlagen und Reaktorsicherheit (GRS) from Germany, the Gruppo di Ricerca Nucleare San Piero a Grado/Università di Pisa (GRSNPG/UNIPI) from Italy and the Korea Atomic Energy Research Institute (KAERI) from Korea. Moreover, the Korea Institute of Nuclear Safety

(KINS) is an observer. The host institution was GRNSPG/UNIPI and act as scientific secretariat, and NINE-Eng (Lucca, Italy) became co-host organization in 2023.

Institutions involved in the FONESYS project use or are developers of the following SYS-TH codes (in alphabetical order): APROS, ARIANT, ATHLET, CATHARE, CATHENA, COSINE, LOCUST, MARS-KS, RELAP5, RELAP5-3D, SPACE and TRACE.

2.3 Capabilities and Limitations of SYS-TH Codes

Current SYS-TH codes are based upon the 2-fluid 6-equation model (and in some cases the 3-field model separating droplets and liquid films) that are supplemented by a suitable set of constitutive equations. Thermal-hydraulic equations are coupled with conduction heat transfer equations and with point neutron-kinetics equations, or with multi-D core physics codes when necessary (typically, for asymmetric overcooling transients, and main steam line break for PWRs in particular). The two-phase flow field equations are discretized in a number of lumped volumes connected with junctions or in 1D models. Thermal-hydraulic components such as valves, pumps, separators, annulus, accumulators, etc… are used to represent the overall system configuration. The limitations and capabilities seen from the code user's point of view may differ from the one by the code developers [7].

The main aspects from the code user's' point of view are summarized below:

- System nodalization - The user develops a detailed nodalization diagram of the whole system. This approach provides large flexibility but also implies a full responsibility of the user in developing an adequate nodalization scheme, which makes the best use of the various modules and prediction capabilities of the selected code. The development of a nodalization is always a compromise between the desired accuracy and computational effort due to the code and economic limitations.
- Physical model parameters - Various possibilities of how a code can physically model specific phenomenon. Due to the lack of directly measured data, in many cases, the specification of those parameters is left to the engineering judgment of the user.
- Input parameters related to the specific system characteristics - Experimental data from the integral effect test (IET) or separate effect test (SET) facilities are the basis for assessment of SYS-TH codes. The impact of minor effects (e.g. sharp edge, heat losses, presence of dead ends with unknown fluid temperature and composition, bypass, small leakages…) is often underestimated, and this could lead to misinterpretation of the results related to small scale facilities.
- Input parameters needed for the specific system components - Although system behavior in SYS-TH codes is described by the basic discretization items (nodes and junctions) based on the formulation of the mass, momentum and energy equations, some components (e.g. pumps, separators) cannot be described without additional models.. The characteristics of these components depend on geometry and scale. Sometimes they are known, but sometimes not and the user must extrapolate from different sources (e.g. two-phase pump degradation functions). As a result, this introduces additional uncertainties to the SYS-TH codes prediction.
- Specification of initial and boundary conditions - The initial steady state condition has to be obtained using artificial control systems and the specified boundary conditions. Although user errors are handled by quality assurance procedures, possibility of errors in specification of the initial and boundary conditions exists and may introduce small imbalances in the initial data, which may distort the simulated transient. Therefore, the specification needs to be done in a very detailed and precise manner.
- Selection of parameters determining time step sizes - Automatic procedures are used by all existing codes for the selection of time step sizes. However, the code users sometimes need to limit a maximum size of the time step to achieve stable numerical results.
- Code input errors - Probability of code input errors is high because of a large number of data (e.g. boundary conditions, model selection) which need to be provided by the user.

From the point of view of the developers, important aspects of the current SYS-TH codes capabilities and limitations are the following:

- Problem with limited knowledge and understanding of physical processes - This leads to a certain degree of empiricism of the models and may affect the quality and scalability of the closure laws.
- Problem related to the macroscopic modelling - There is a possibility that the detailed physical nature of some important processes is not fully reflected (or even omitted) in a macroscopic description.
- Problem with insufficient V&V due to difficulty in obtaining enough experimental data for validation - Some phenomena and/or processes are not sufficiently covered in the validation process and new safety issues, which include new physical processes may occur, but it is often difficult to get adequate experimental data due to the high cost of experiments.

Well posedness of the system of equations: this problem is addressed in some codes by physical regularization or by numerical regularization in other codes (see [1]) .

- Numerical limitations of the code (e.g. stability, numerical diffusion and dissipation) and controlling of numerical errors.

2.4 The Key Items of FONESYS

The following twelve topics were identified by the FONESYS members as the ones of the highest importance to the code developers:

- Virtual mass and interfacial pressure difference terms in relation to the hyperbolicity, and the pressure and void wave propagation;
- System codes benchmarking on critical heat flux (CHF) prediction;
- Comparison of capabilities of various approaches as “drift flux”, “2-fluid 6-equation model”, and “multi-field”;
- The various approaches for break flow and choked flow prediction and system codes benchmarking on two-phase critical flow (TPCF);
- Transport of interfacial area (TIA) and turbulence modeling in system codes;
- Three-field equations separating liquid into droplets and liquid films: modeling and experimental validation;
- Extension of system codes capabilities for super critical water, gas, sodium and lead-bismuth reactors;
- Codes portability and “mesh convergence” issues;
- Coupling between CFD and SYS-TH codes;
- Scalability of codes closure laws supported also by benchmark activities;
- Uncertainty of code models
- Coupling between SYS-TH and fuel performance codes;
- Revisiting the modelling of two-phase pressure losses supported by benchmark activities
- 3D core thermal-hydraulics modelling and validation;
- Share and/or develop the experiments together.

Along with the above-mentioned FONESYS topics, subtopics of interest were defined and are listed below:

- Use of the best estimate SYS-TH codes for licensing;
- Scaling of thermal-hydraulic phenomena;
- Acceptability of errors in code predictions;
- Radiation heat transfer;
- Loop seal clearance: the physical process, the possible distortions in IETs, and the prediction capabilities of system codes;
- Dispersion and diffusion processes and the modelling in 1D and 3D approaches;
- The issue of convergence in time and in space;

- Jacobian and solution methods;
- Relevance of 3-field modeling in system codes and impact on code predictions;
- Reflood;
- 3D modeling capabilities of system codes;
- Natural convection heat transfers;
- Natural circulation;
- Dry-out;
- Critical flow, sonic velocity, effect of sharp edge cavitation;
- Counter current flow limitation (CCFL).

Detailed information on some of the aforementioned items and related point of view of the FONESYS members are reported in [2].

In 2021, a joint activity about the inverse uncertainty quantification of codes physical models has been launched. Additional ideas for future FONESYS activities are presented in [8,9].

2.5 The FONESYS Road Map and Working Modalities

The following working modalities of FONESYS network were proposed and accepted by all members:

- Developing a common understanding (e.g. by collecting different opinions and achieving a consensus document) about: SYS-TH codes (the definitions, the requirements, the capabilities, the current status), and limitations for SYS-TH codes (balance equations, numerical solution, user effect, from applications);
- Identification of specific code limitations not covered in the validation process in order to address the areas of investigations;
- Establishment of validation procedures for 3D SYS-TH codes for assigned phenomenon based complementary experiments performed in IET facilities and 3D separate effect test facilities;
- Running and collecting results from ‘specific additional’ V&V: specific additional V&V activities performed will involve basic tests, separate effect tests, integral effect tests as well as full scale NPP data;
- Attending regular workshops (e.g. 1/year), eventually creating ‘ad-hoc’ groups for special topics;
- Addressing the possible skepticism from international community and answering questions;
- Providing recommendations to prioritize code improvements and required experiments.

FONESYS expert meetings is one of the most important parts of the working modalities of the project. They are organized as workshops where participants discuss selected key topics and subtopics, but also show and discuss the results of the benchmark activities. From the beginning of the FONESYS project in 2010, 20 workshops, listed in Table 1, were organized. Starting from 2012, the FONESYS meetings are organized in conjunction with the meeting of the SILENCE network. Starting from June 2020 joint –FONESYS-SILENCE meetings are also organized to facilitate the exchanges between the networks.

The next FONESYS meeting is planned to be held in Paris-Saclay in the week November 4-8 ,2024.

Table 1. FONESYS meetings

#	Date	Host Organisation	Country
1	13-14 May 2010	GRNSPG/UNIPI	Italy
2	1-4 February 2011	CEA	France
3	12-14 December 2011	GRNSPG/UNIPI	Italy
4	12-14 September 2012	KAERI	Korea
5	25-26 June 2013	VTT	Finland

6	17-18 February 2014	GRNSPG/UNIPI	Italy
7	3-4 February 2015	AREVA-NP	France
8	3-4 December 2015	CEA	France
9	28-29 September 2016	Becker Technologies	Germany
10	28-29 June 2017	GRNSPG/UNIPI	Italy
11	28 Feb.-1March 2018	TAMU	USA
12	11-12 October 2018	KAERI & PNU	Korea
13	13-14 June 2019	LUT University	Finland
14	15-16 June 2020	Web-meeting	-
15	1-2 February 2021	Web-meeting	-
16	18-19 October 2021	Web-meeting	-
17	2-3 May 2022	Web-meeting	-
18	7-8 November, 2022	Aix en Provence	France
19	11-12 June, 2023	Stockholm	Sweden
20	26-27 February, 2024	Garching	Germany

2.6 Selected Key Achievements from FONESYS

In addition to the discussion held during the meetings, a number of joint activities have been performed according to the above-mentioned key items and the established roadmap for FONESYS operation. Selected examples are summarized hereafter. Noticeably, the FONESYS benchmarks, conducted by code developers themselves, are characterized by a reduced user effect.

2.6.1 The boiling channel benchmark

A benchmark activity was performed on a simplified 8x8 BWR fuel assembly. The exercise consisted in simulating a steady-state condition considering well-defined acceptability criteria [10] and an hypothetical transient assuming a slow power ramp.

Although a fairly good convergence of prediction for global parameters as total mass and average void fraction emerged, some rather surprising differences were observed.

The steady-state exercise showed some spread of calculated void fraction (±4% respect to the average value) and slip ratio (-15% to 30% respect to the average value) at top of active fuel. This is most probably related to the difficulties in performing void fraction measurements in experiments for model development and validation in heated rod bundles. Furthermore, a spread up to a couple dozen kelvin was observed for the rod surface temperature at middle active length, as shown in Figure 1. This reflects significant differences in the code models for the pre-CHF heat transfer coefficient.

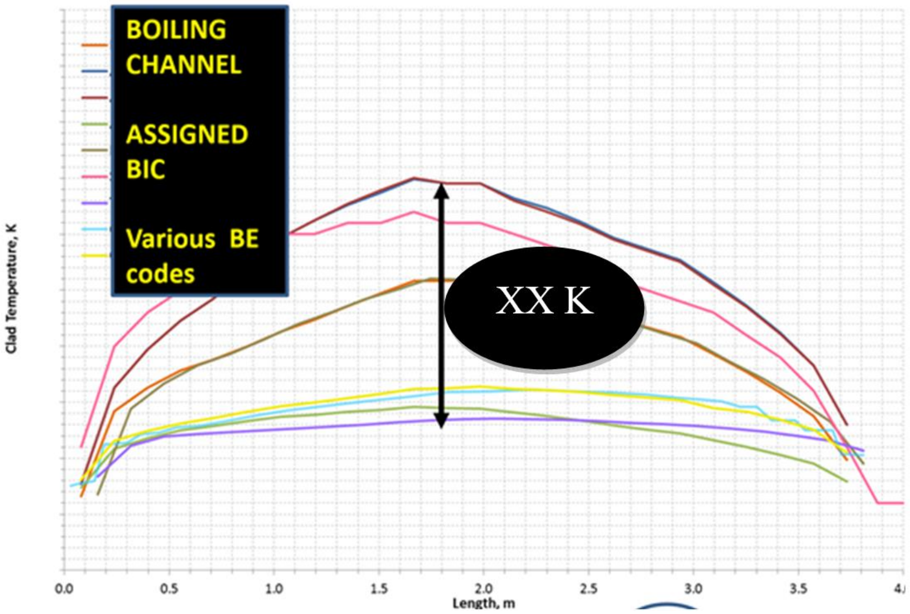

Figure 1. Cladding temperature in a pre-CHF boiling channel as predicted by various SYS-TH codes.

The transient exercise showed a significant impact of the different CHF correlations on the timing of the CHF occurrence and its location. This first benchmark lead a FONESYS member to update the Groeneveld lookup tables version implemented in his code.

2.6.2 Well-posedness and numerics in system codes

A technical paper –co-written by FONESYS members expressed an agreed point of view on hyperbolicity ad numerical issues in SYS-TH codes [11].

The publication summarizes the approach followed to develop the system of equation implemented in SYS-TH codes. The physical regularization and the numerical regularization strategies adopted to obtain hyperbolicity of the system of the 2-fluid, single pressure, 6-equation model or to bypass the problem were discussed concluding that both are acceptable in an engineering context. Issues affecting the two-pressure, 7-equations models developed so far were also identified.

Numerical schemes developed for modern SYS-TH codes were also reviewed with special focus put on the requirements for their application.

2.6.3 Two-phase critical flow (TPCF) benchmark

The first phase of the benchmark [12] launched in 2015, consisted in a simple code-to-code comparison for a discharge from a high pressure vessel into a low pressure volume in both a horizontal and vertical configuration as shown in Fig 2. A rather big scatter among the mass flow rate predicted by different codes appeared was found.

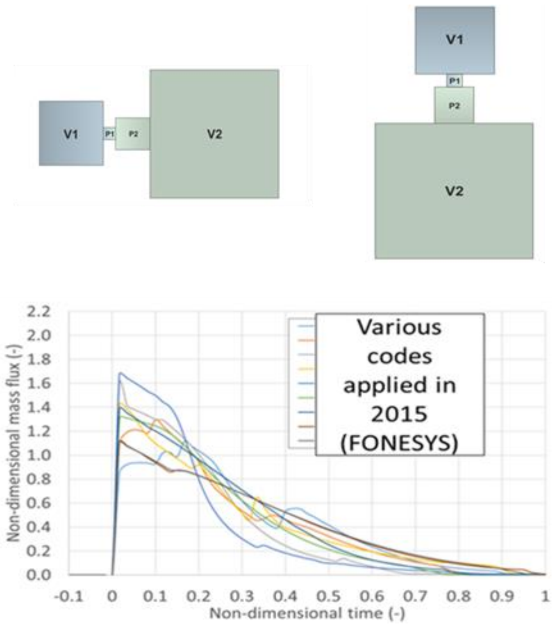

Figure 2. Mass flux time trend versus time during TPCF as predicted by various SYS-TH codes

To better investigate the TPCF modelling issue, FONESYS members decided to extend the benchmark by considering code to experimental data comparisons using two transient tests (i.e. Edwards pipe and SUPER CANON tests) and 90 steady state tests performed on UCL, Super Moby Dick, Sozzi-Sutherland and BNL facilities. Tests cover a rather wide range of geometrical configurations (two different L/D ratio and a Venturi nozzle), pressure (2-120 bar) and subcooling conditions (equilibrium quality ranging roughly between -0.15% and 0%). The UCL tests also allow assessing the capability of the codes to predict double choked flow experiments.

The benchmark highlighted that a maximum relative critical mass flow rate error of roughly ±40% can be expected in low subcooling conditions (Figure 3.). Even in high subcooling conditions, calculations can be affected by a relative error of about ± 20%. These errors affect current industrial SYS-TH codes versions adopting both 0D and 1D TPCF models.

Some additional information and a proposed roadmap for improvement are presented in [12].

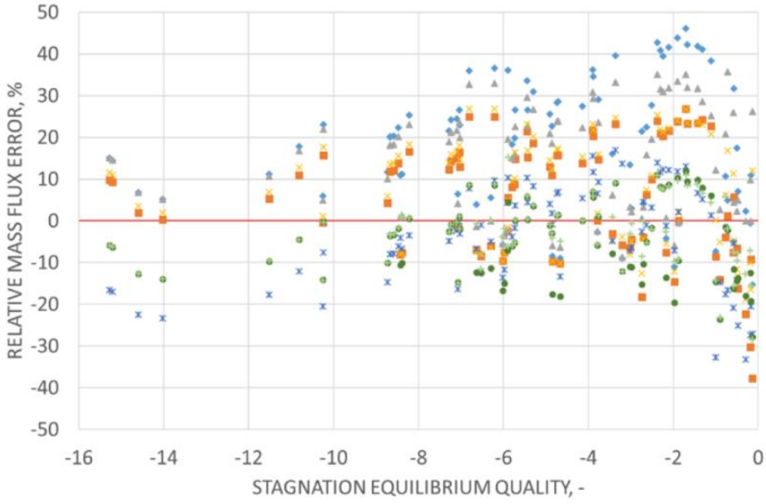

Figure 3. Relative mass flux error versus stagnation equilibrium quality as predicted by various SYS-TH codes

2.6.4 Scalability of stratification criterion and droplet entrainment in horizontal pipes

The prediction of horizontal flow stratification is characterized by significant differences among various SYS-TH codes. In some cases (e.g. for droplet entrainment or flow stratification by bubble sedimentation) there is even no consensus on the non-dimensional numbers used in the closure laws. This raises the question of the scalability of codes closure laws.

Considering the above, FONESYS members agreed to launch an activity on the comparison and scalability of selected code closure laws, which is now focusing on the criteria for horizontal stratification and droplet entrainment. The activity started in 2017. Key results from the comparison and the scalability study of the horizontal stratification criteria implemented into eight SYS-TH codes are presented in [13].

A benchmark on selected TPTF and Mantilla experiments was launched in 2019. The activity is also aiming to support and complement the activity on the comparison and scalability of the codes' closure laws. Key results are presented in [14,15].

2.6.5 Reverse natural circulation benchmark

This benchmark was performed to highlight the importance of two-phase pressure drops and their distribution on natural circulation. Therefore, the various participants, given a qualified nodalization of the PKL facility, have moved the heating power to the downcomer, in such a way to obtain reverse circulation. This has been performed at various primary mass inventories. A wide range of core flow predictions has been recorded, as depicted in Figure 4. Some insights are given in [16,17].

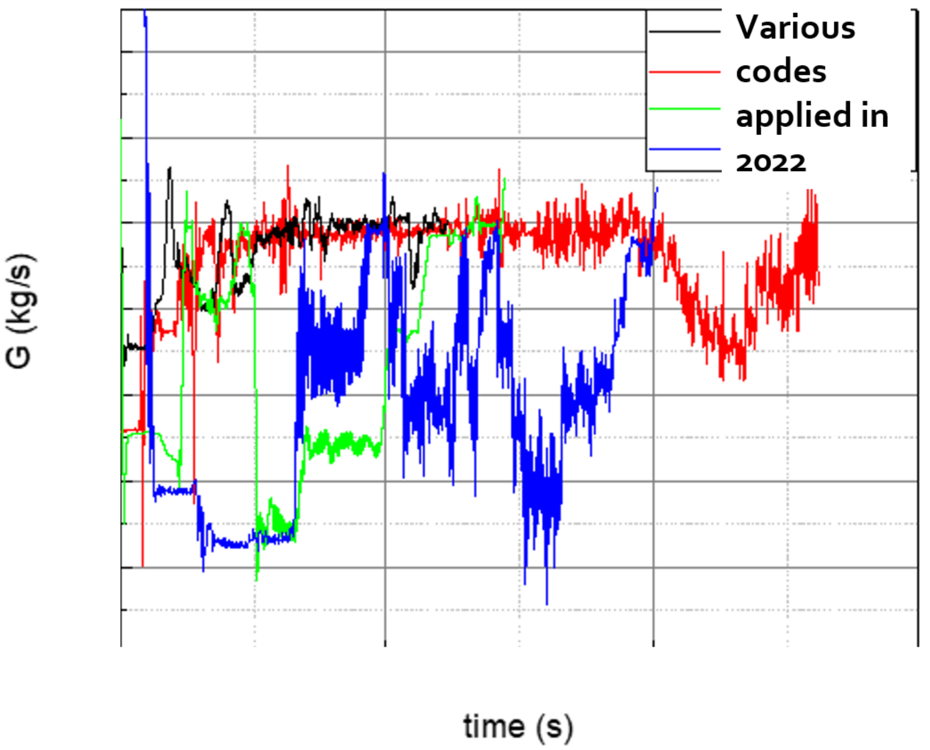

Figure 4. Core flow rate in RNC as predicted by different SYS-TH codes. The blue curve also includes core bypass.

2.6.6 Benchmark on 3D core crossflows

In this benchmark the predictions obtained by SYS-TH codes and sub-channel codes for steam cross flow between two fuel assemblies having different power in a dry zone above a swell level are being compared for two pressures. Figure 5 shows that a buoyancy driven crossflow from colder assembly to hotter assembly (chimney effect) is predicted at 7 MPa although a friction driven crossflow from hotter to colder assembly is predicted at 1 MPa. These crossflow have some impact on clad temperatures.

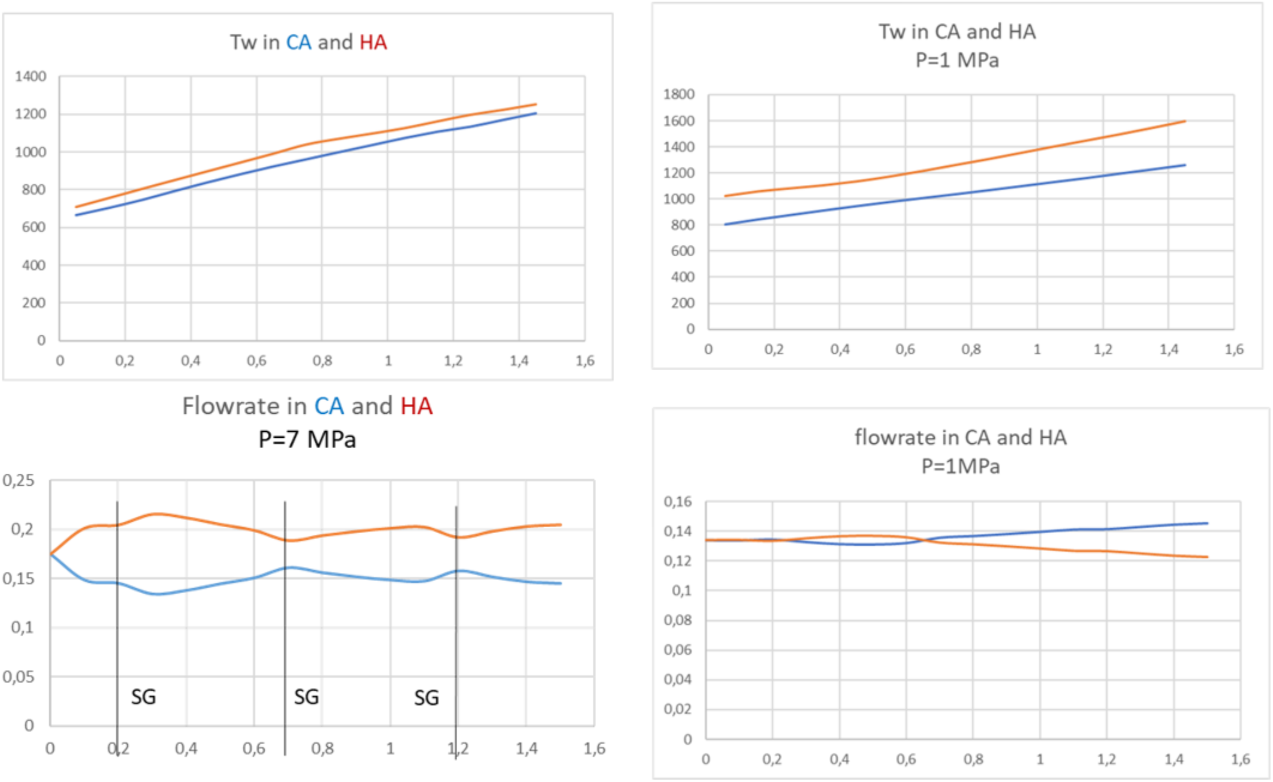

Figure 5. Wall temperature and mass flow rate as predicted by a SYS-TH code for steam crossflow at different pressures. CA cold assembly, HA hot assembly.

2.6.7 Benchmark on two-phase pressure losses in singular geometry

In this benchmark, singular pressure drops in vertical geometry for abrupt enlargement, restriction and diaphragm (Figure 6.) are being compared between different SYS-TH codes for different flow regimes. Also, sensitivities on the different modeling approaches are being performed.

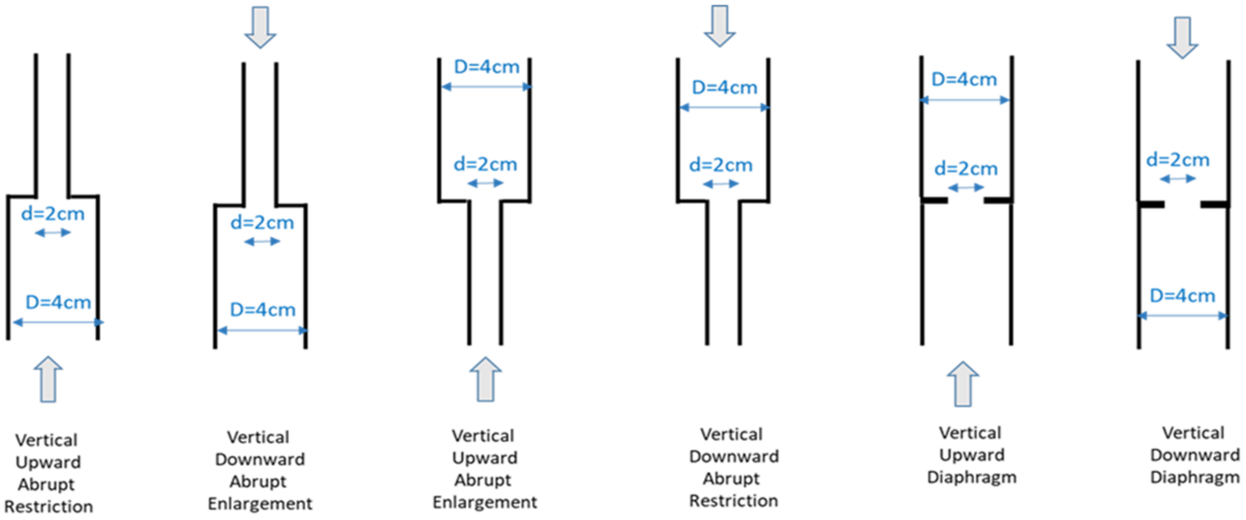

Figure 6. Geometrical configurations used in the two phase pressure drops benchmark

3 THE SILENCE NETWORK

SILENCE [3,4] is a network for cooperation among teams of experimentalists managing significant experimental projects in nuclear reactor TH. Established in 2012 by GRNSPG/UNIPI, the SILENCE network connects institutions and organizations that are involved in the development and exploitation of thermal-hydraulic experiments as a support to the safety assessment and the design of water-cooled nuclear reactors, of both current and future generations.

3.1 Founding Motivation and Main Objectives of the Project

There is a risk to lose expertise and “vision” in the area of thermal-hydraulic experimental investigations, therefore a presidium should be established and maintained in order to oppose this risk. It is important that the experimentalists join their efforts and constitute a “system”, as the large budgets that were available in the past for the experiments cannot be replicated nowadays. Thus, SILENCE network promotes and fosters the establishment of a common ground for cooperation and discussion, so as to drive the prioritization and decision-making processes related to the development of new experiments as well as to optimize the utilization of the existing data.

The main objectives of the project are summarized below:

- To help the optimization of the funding available worldwide for experiments, recognizing their vital role for the design and the safety of existing and coming NPPs, including possible connection with past and recent initiatives as the former EC-Project CERTA-TN, STRESA-database, etc.;
- To coordinate the efforts of teams of experimentalists in order to provide a support for international institutions, like OECD/NEA and IAEA, namely for launching and possibly organizing International Standard Problems;
- To address the scaling issue and providing an agreed view from the side of experimentalists, also including the design and the execution of counterpart tests;
- To set up a center of expertise for supporting experimental programs in “embarking countries” (i.e. new countries having nuclear programs) having interests in the area of large thermal-hydraulic experiments;
- To maintain, expand and use the database of experiments already available from various parts of the world, possibly in cooperation with the international institutions (particularly OECD/NEA, where NEA Data Bank is available);
- To identify margins for possible improvement of the existing measurement techniques.

3.2 The SILENCE Members and the Main Test Facilities Represented

There are eleven signatory institutions currently participating in the SILENCE network, namely the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) from France, Becker Technologies GmbH (BT), Framatome GmbH and Helmholtz Zentrum Dresden-Rossendorf (HZDR) from Germany, Korea Atomic Energy Research Institute (KAERI) from Korea, Lappeenranta University of Technology (LUT) from Finland, State Power Investment Corporation Research Institute (SPICRI) from China, Paul Scherrer Institute (PSI) from Switzerland, Westinghouse Sweden, GRSNPG/UNIPI and the company Nuclear Engineering (NINE) from Italy, whereas GRSNPG/UNIPI and NINE (since 2023) act as host organizations of the network providing the scientific secretariat and administrative support. Moreover, Texas A&M University (TAMU) participates as observer Table 2 summarizes some of the key test facilities operated by the SILENCE members, with indication of the corresponding type of tests (either integral or separate effect, IET or SET) and of the nuclear power plant system to which they are relevant (either containment or reactor coolant system, C or R).

3.3 The SILENCE Working Modalities

SILENCE network adopts a form of cooperation based the on exchange of information by means of technical reports, experimental data, correspondence, newsletters, visits, joint meetings, etc. and the execution of joint programs and projects.

Table 2. Some of the key test facilities operated by the SILENCE members

Member	Facility	Type, System
BT	THAI	IET&SET, C
CEA	POSEIDON platform, METERO	SET, R
Framatome	PKL, INKA	IET, R
HZRD	ROCOM, TOPFLOW	SET, R
KAERI	ATLAS, PRIUS	IET,R&C, SET, R
LUT	PACTEL, MOTEL, PPOOLEX	IET, R&C
PSI	PANDA, LINX	IET&SET, C
SPICRI	ACME, CERT	IET, R&C
TAMU	RCCS	SET, C
Westinghouse S	FRIGG, ODEN	SET, R

The working modalities of the SILENCE network includes but not limited to:

- Developing a common understanding (e.g. by collecting different opinions and achieving a consensus document) about selected topics;
- Attending regular workshops (e.g. one per year), possibly creating ad-hoc groups to address specific topics;
- Addressing remarks from international community in relation to the needs of new experiments;
- Providing recommendations, primarily to the SILENCE members but also to the other stakeholders of the international community, on how-to prioritize budget allocation when planning new experiments.

From the beginning of the SILENCE project in 2012, 16 meetings, listed in Table 3, were organized. The next meeting is planned to be held in Paris-Saclay in the week November 4-8 ,2024

Table 3. SILENCE meetings

#	**Date**	**Host Organisation**	**Country**
1	5-6 July 2012	GRNSPG/UNIPI	Italy
2	27-28 June 2013	VTT	Finland
3	19-20 February 2014	GRNSPG/UNIPI	Italy
4	11-12 September 2015	PSI	Switzerland
5	1-2 December 2015	CEA	France
6	26-27 September 2016	Becker Technologies	Germany
7	26-27 June 2017	GRNSPG/UNIPI	Italy
8	26-27 February 2018	TAMU	USA
9	15-16 June 2019	LUT University	Finland
10	17-18 June 2020	Web-meeting	-
11	4-5 February 2021	Web-meeting	-
12	21-22 October 2021	Web-meeting	-
13	5-6 May 2022	Web-meeting	-
14	10-11 November, 2022	Aix en Provence	France

15	14-15 June, 2023	Stockholm	Sweden
16	29 Feb -1 March, 2024	Garching	Germany

3.4 Selected Key Achievements from SILENCE

The main on-going joint activities carried out within the SILENCE network are listed below:

- Preparation of a technical report on the definition of requirements for validation experiments addressing SYS-TH, CFD, and containment codes;
- Preparation of technical reports on counterpart tests and similar tests focusing on test facilities operated by the SILENCE members (two separate reports on ITFs and containment test facilities);
- Mapping of information related to the existing test facilities operated by the SILENCE members;
- Addressing issues connected with the uncertainty in TH experimental measurement.

As already described in 2.6, there are also some ongoing Joint (FONESYS-SILENCE) activities, e.g. on two-phase critical flow and reverse natural circulation.

In addition to these activities, the SILENCE network promoted an international workshop on instrumentation and measurement techniques, SWINTH [3].

The idea for organizing SWINTH had emerged during the first SILENCE meetings. It was suggested by the observation that significant advancement has been achieved in the instrumentation and investigation techniques for nuclear TH systems since the OECD/NEA CSNI Specialists Meeting on Advanced Instrumentation and Measurement Techniques [18] held in Santa-Barbara, California, United States, on March 17-20, 1997.

The motivation for starting SWINTH workshops is consistent with both the “vision” and the “mission” of SILENCE network, which promotes and stimulates the establishment of a common ground for cooperation and discussion on thermal-hydraulic experiments, and wants to bolster new experiments, including improvements of the existing measurement techniques.

The purpose of SWINTH workshops is to bring together international experts on instrumentation, experiments and modelling in order to:

- Review the recent instrumentation and experiment techniques developments;
- Identify the specific experimental needs that arose from the development of modern simulation tools including SYS-TH codes, component codes, and CMFD codes provided with advanced models such as dynamic interfacial area modelling, poly-dispersion modelling of bubbly and droplet flow, multi-field models and two-phase turbulence models;
- Discuss future directions for instrumentation developments, modelling and experiments.

The subject is wide and complex and deserves dedicated discussion; therefore, specialized workshops such as the present one can be seen as complementary to other events on code development and V&V, and initiatives in which the experimental area is not covered with sufficient detail and focus.

SWINTH workshops also aim at addressing aspects such as:

- Code validation requirements;
- Test design requirements for code validation (e.g. “scaling issues”);
- Specific requirements for CMFD-grade experiments and related measurements for single- and multi-phase flows;
- Criteria for quality of data (e.g. measurement uncertainty assessment);
- Experimental data handling issues.

The Workshops should also help to identify the current gaps between the modelling and code qualification needs and the available technology as well as the margins for future advancements. The first and second SWINTH workshop was held in Livorno, Italy in 2016 and 2019,respectively. The next SWINTH will take place in June 2024 in Dresden, Germany, hosted by HZDR and co-organized by OECD/NEA-CSNI/WGAMA and the SILENCE Network.

4 CONUSAF: A NETWORK OF SYSTEM CODES USERS

CONUSAF is a consortium of users of thermal-hydraulics computational tools for nuclear reactor safety and design. Launched in 2018 by GRNSPG/UNIPI and Texas A&M University, the CONUSAF aims at connecting international institutions and companies performing R&D activities and/or frontier-type of application in the field of nuclear engineering like research centers, industries, universities, technical support organizations, consultancies, etc. The focus of the consortium is to bring solutions to the possible issues identified by the nuclear industry through research, training, and education. More information on the founding motivation and objectives of the consortium and the proposed working modalities are available in [7]. The ‘new’ founding meeting will be held in Pisa, Italy, on October 4-8, 2024, and it’s organized by KAERI.

5 CONCLUSIONS

The present paper provides an overview of the activities of two international networks named FONESYS and SILENCE, outlining their objectives, motivations and working modalities. Selected examples of the main achievements of the two projects are summarized.

The FONESYS network has already been working for over 14 years and experts in code development have found interest in the various activities. Advanced modeling was discussed and compared. Old issue as TPCF, CHF and horizontal stratification were revisited. Benchmarking of codes was done, documents were published or are still being elaborated. Bilateral collaborations were initiated, and fruitful contacts were established also with the experimentalists through the SILENCE network.

Established in 2012, SILENCE network replicates for the TH experimental domain the role that FONESYS plays in the code-development domain joining some of the institutions and organizations that are involved in the development and exploitation of thermal-hydraulic experiments as a support to safety assessment and design of water-cooled nuclear reactors, of both current and future generations. One noticeable achievement of the network is the organization of the SWINTH workshops.

To better exploit the potential of this environment, FONESYS-SILENCE joint meetings are regularly organized starting from 2020.

In addition to the two working networks, the CONUSAF consortium has been proposed to include code users among the actors involved in this framework.

International exchange under the framework of the presented networks may be a unique way to contribute solving some of the remaining or new issues in nuclear thermal-hydraulics.

REFERENCES

[1] “Forum & Network of System Thermal-Hydraulics Codes in Nuclear Reactor Thermal-Hydraulics (FONESYS),” http://www.nnees.sk/fonesys/ (2021).

[2] S.H. Ahn, N. Aksan, H. Austregesilo, D. Bestion, B.D. Chung, F. D’Auria, P. Emonot, J.L. Gandrille, M. Hanninen, I. Horvatovic, K.D. Kim, A. Kovtonyuk and A. Petruzzi,

"FONESYS: The FOrum & NEtwork of SYStem Thermal-Hydraulic Codes in Nuclear Reactor Thermal-Hydraulics," Nuclear Engineering and Design, 281, pp. 103-113 (2015).

[3] "Significant Light and Heavy Water Reactor Thermal Hydraulic Experiments Network for the Consistent Exploitation of the Data (SILENCE)," http://www.nineeng.org/silence/ (2021).

[4] F. Moretti, F. D'Auria, M. Lanfredini, N. Aksan, K. Umminger, U. Hampel, K.Y. Choi, H. Purhonen, D. Paladino, S. Gupta, D. Bestion, L. Liu and Y. Hassan, "Promoting Cooperation And Technical Exchange In The Area Of Thermal Hydraulic Experimentation: SILENCE Network & SWINTH Workshops," Proceedings of the ANS Best Estimate Plus Uncertainty International Conference (BEPU 2018), Lucca, Italy, May 13-19, 2018.

[5] N. Zuber, "The effects of complexity, of simplicity and of scaling in thermal-hydraulics," Nuclear Engineering and Design, 204, pp. 1-27 (2001).

[6] W. Wulff, "Critical review of conservation equations for two-phase flow in the U.S. NRC TRACE code," Nuclear Engineering and Design, 241, pp. 4237-4260 (2011).

[7] D. Bestion, F. D'Auria, Y. Hassan, N. Aksan, M. Lanfredini and K.D. Kim, "Remaining Issues in System Thermal-Hydraulics - How the FONESYS and CONUSAF Networks Can Help Find Solutions?", Proceedings of the 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-18), Portland, OR, USA, August 18-22, 2019.

[8] D. Bestion and F. D'Auria, "Identification of thermalhydraulic phenomena for PWR transient analysis and simulation," Proceedings of the 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

[9] D. Bestion, F. D'Auria and M. Lanfredini, "Tracking and minimizing compensation of errors in reactor experimental and numerical simulation," Proceedings of the 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

[10] M. Bonuccelli, F. D'Auria, N. Debrecin and G.M. Galassi, "A methodology for the qualification of thermalhydraulic codes nodalizations," Proceedings of the 6th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-6), Grenoble, France, October 5-8, 1993.

[11] S.H. Ahn, N. Aksan, H. Austregesilo, D. Bestion, B.D. Chung, E. Coscarelli, F. D'Auria, P. Emonot, J.L. Gandrille, J.I. Sauvage, M. Hanninen, I. Horvatovic, K.D. Kim, A. Kovtonyuk, S. Lutsanych and A. Petruzzi, "Hyperbolicity and numerics in SYS-TH codes: the FONESYS point of view," Nuclear Engineering and Design, 322, pp. 227-239 (2017).

[12] M. Lanfredini, D. Bestion, F. D'Auria, N. Aksan, P. Fillion, P. Gaillard, J. Heo, I. Karppinen, K.D. Kim, J. Kurki, L. Liu, A. Shen, J.L. Vacher and D. Wang, "Critical flow prediction by system codes - recent analyses made within the FONESYS Network," Nuclear Engineering and Design, 366 (2020).

[13] M. Lanfredini, D. Bestion, F. D'Auria, N. Aydemir, S. Carnevali, P. Fillion, P. Gaillard, I. Karppinen, K.D. Kim, J. Kurki, J.H. Lee, P. Schoeffel, H. Sha, T. Skorek, J.L. Vacher and G. Waddington, "Horizontal stratification criteria of 8 system codes and direct confrontation to TPTF and mantilla data," Proceedings of the 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

[14] M. Lanfredini, D. Bestion, F. D'Auria, N. Aydemir, S. Carnevali, P. Fillion, P. Gaillard, J.J. Jeong, M. Junk, I. Karppinen, K.D. Kim, J. Kurki, J.H. Lee, P. Schoeffel, H. Sha, T. Skorek, J.L. Vacher and G. Waddington, "TPTF horizontal flow prediction by SYS-TH codes - recent analyses made within the FONESYS network," Proceedings of the 19th International Topical

Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

[15] M. Lanfredini, D. Bestion, F. D’Auria, N. Aydemir, S. Carnevali, P. Fillion, P. Gaillard, J.J. Jeong, I. Karppinen, K.D. Kim, J. Kurki, J.H. Lee, J. Lee, P. Schoeffel, H. Sha, T. Skorek, J.L. Vacher and G. Waddington, “Droplet entrainment prediction in horizontal flow by SYS-TH codes – Mantilla experiments - Recent analyses made within the FONESYS network,” Proceedings of the 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

[16] Qingling Cai, Francesco D'Auria, Klaus Umminger, Dominique Bestion and Jianqiang Shan, 2022. Prioritizing pressure drop research in nuclear thermal hydraulics. Progress in Nuclear Energy. 153: p. 104358.

[17] Vincenzo Zingales, Qingling Cai, Francesco D’Auria, Dominique Bestion, Klaus Umminger,

Sensitivity Studies on Reverse Natural Circulation in the PKL Facility by Using RELAP5mod3.2mz, Proceedings of the 32nd International Conference Nuclear Energy for New Europe (NENE-2023), Portoroz, Slovenia, ID:407

[18] OECD/NEA/CSNI, Summary and Conclusions of the OECD/CSNI Specialist Meeting on Advanced Instrumentation and Measurement Techniques, Santa Barbara, CA, USA, March 17-20, 1997, NEA/CSNI/R(97)32.