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Review Of FONESYS And SILENCE Nuclear Thermal-Hydraulic Networks Achievements

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ABSTRACT

The FONESYS and SILENCE networks are run by some of the leading organizations working in the nuclear sector, and work in a cooperative manner since about a decade having one or two meetings per year.

The FONESYS members are developers of some of the major system thermal-hydraulic 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 system thermal-hydraulic code development and their application especially for licensing purposes and safety analyses.

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; support to organizations and countries embarking in large experimental programs. SILENCE is also the promoter of SWINTH, an international workshop on instrumentation and measurement techniques.

In this paper selected key achievements from the networks are presented and some activities proposed to address the remaining issues in thermal-hydraulics are summarized.

1 INTRODUCTION

The development of 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 their 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 degree of accuracy. From a scientific, as well as from a 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; support to organizations and countries embarking in large experimental programs. 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). Two editions of the workshop have been held since 2016 [4].

FONESYS and SILENCE work in a cooperative manner for 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.

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 application of SYS-TH codes is important in safety analysis and licensing, even if new tools such as CFD or computational multi fluid dynamics (CMFD) codes appeared at the beginning of the 2000s. Another principal motivation was to form a network of experts and code developers that can challenge future problems during the development and use of the 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 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 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; 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 is GRNSPG/UNIPI and act as scientific secretariat.

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 The Key Items of FONESYS

The following 13 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;

• Coupling between SYS-TH and fuel performance codes;

• 3D core thermal-hydraulics;

• 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 was launched. Additional ideas for future FONESYS activities are presented in [8,9].

2.4 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 and 3D separate effect test facilities;
•Running and collecting results from 'specific additional' V&V: specific additional V&V activities involve basic, separate and integral test facilities as well as full scale NPP;
•Attending regular workshops, 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. Seventeen workshops, listed in Table 1, has been organized since 2010. Starting from 2012, the FONESYS meetings are organized in conjunction with the meeting of the SILENCE network. Starting from

2020 supporting topical meetings are also organized to facilitate the progression of joint activities. Furthermore, in-person (plenary) meetings were planned to be extended from 2 days to 3 days.

Table 1: FONESYS meetings

#	Data	Host Organization	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.-1 March 2018	Texas A&M University	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	-

2.5 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.

• Boiling channel benchmark [10]

• Technical paper on hyperbolicity and numerics in SYS-TH codes - FONESYS members expressed an agreed point of view on hyperbolicity ad numerics issues in SYS-TH codes [11].

• TPCF – benchmark (Super CANON, Edwards pipe, SUPER-MOBY-DICK, UCL, BNL & Sozzi-Sutherland) [12]

• Scalability of closure laws : comparison of code models for stratification [13]

• TPTF and Mantilla benchmark [14, 15]

• Inverse Uncertainty Quantification (IUQ): specifications of the activity and selection of the data base

• Validation and UQ : Identification of phenomena

• Compensating errors in modelling

• Passive systems and coarse 3D mixing problems (proposal of a new activity)

• Scaling tools : proposal of a new activity

• Counterpart tests : SB-LOCA CT : LOBI, SPES, BETHSY, LSTF + ATLAS simulation

• Reverse Natural Circulation : virtual benchmark (joint activity with SILENCE)

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 reactor, of both current and future generations.

3.1 Main Objectives

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 NPP, 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 ten 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, LUT University from Finland, State Power Investment Corporation Research Institute (SPICRI) from China, Paul Scherrer Institut (PSI) from Switzerland, Westinghouse Sweden, and Texas A&M University (TAMU, observing member) from the United States. GRSNPG/UNIPI from Italy, is the host organization of the network and provides the scientific secretariat, while administrative support is provided by the company Nuclear and Industrial Engineering (NINE), Italy.

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

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

Member	Facility
BT	THAI
CEA	POSEIDON platform, METERO
Framatome	PKL, INKA
HZRD	ROCOM, TOPFLOW
KAERI	ATLAS, PRIUS

LUT	PACTEL, MOTEL, PPOOLEX
PSI	PANDA, LINX
SPICRI	ACME, CERT
TAMU	RCCS
Westinghouse S	FIX-II, HWAT, FRIGG, ODEN

3.3 The SILENCE Working Modalities

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

The working modalities of the SILENCE network includes but is 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, thirteen meetings, listed in Table 3, were organized.

Table 3: SILENCE meetings

#	Date	Host Organization	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	-

3.4 Selected Key Achievements from SILENCE

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

- Report on counterpart tests
- Report on requirements for system code validation experiments
- Brainstorming on new measurements techniques for TPCF
- Uncertainty in Measurement
- Reverse Natural Circulation : virtual benchmark (with FONESYS)
- SWINTH 2019 follow up activity

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 [16] held in Santa-Barbara, California, United States, on March 17-20, 1997.A key feature of SWINTH is that no parallel sessions were organized, so as to give every participant the possibility to attend all the presentations. Two editions (SWINTH-2016 and -2019 [17, 18]) have been hosted so far in Livorno, Italy.

4 CONCLUSIONS

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

In FONESYS network, advanced modelling was discussed and compared, "old issues" as TPCF, CHF and horizontal stratification were revisited, benchmarking was done, documents were published or are still being elaborated, bilateral collaborations were initiated, and fruitful contacts were established also with the experimenters through the SILENCE network.

SILENCE members own and operate important thermal-hydraulic experimental facilities as a support to safety assessment and to 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.

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.

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