NENE 2015 September 14-17 PORTOROŽ SLOVENIA
24th International Conference Nuclear Energy for New Europe

FONESYS and SILENCE Networks: Looking to the Future of T-H Code Development and Experimentation

Sergii Lutsanych[1], **Fabio Moretti**[1,2], **Francesco D'Auria**[1], **Alessandro Petruzzi**[1,2], **Nusret Aksan**[1]
[1]San Piero a Grado Nuclear Research Group (GRNSPG), University of Pisa
1291 Via Livornese
56122, San Piero a Grado, Pisa, Italy

[2]N.IN.E. Nuclear and Industrial Engineering srl
19 Borgo Giannotti, 55100 Lucca, Italy
s.lutsanych@ing.unipi.it, f.moretti@nineeng.com, f.dauria@ing.unipi.it, a.petruzzi@nineeng.com, nusr.aksan@gmail.com

ABSTRACT

The purpose of this paper is to present briefly the projects called 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*), their participants, their motivations, their main targets and working modalities.

System Thermal-Hydraulics (SYS-TH) codes, also as part of the Best Estimate Plus Uncertainty (BEPU) approaches, are expected to achieve a more-and-more relevant role in nuclear reactor safety and design technology. Namely, the number of code-users is likely to increase in the countries where nuclear technology is exploited. Thus, the idea of establishing a forum and a network among the code developers and with possible extension to code users has started to have major importance and value. In this framework, the FONESYS initiative has been launched in 2010 aiming at creation of a common ground for discussing current limitations and envisaged improvements in various areas of SYS-TH and their application in the licensing process and safety analysis.

According to FONESYS statute, there are seven signatory Institutions and two observer Institutions currently participating in the project. Signatory Institutions are AREVA-NP, Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), San Piero a Grado Nuclear Research Group - University of Pisa (GRNSPG-UNIPI), Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Korea Atomic Energy Research Institute (KAERI), Korea Institute of Nuclear Safety (KINS), and VTT Technical Research Centre of Finland.

SILENCE is a network that intends to promote the cooperation among teams of experimentalists managing or involved in significant experimental projects in nuclear reactor thermal-hydraulics, with the aim to contrast the risk of losing expertise and vision in this important area of the nuclear technology. This network was launched in 2012, replicating for the TH experimental domain the role that FONESYS plays in the code-development domain.

Currently, the following Organizations are Members of SILENCE: AREVA GmbH, Helmholtz Zentrum Dresden-Rossendorf (HZDR), Korea Atomic Energy Research Institute (KAERI), Hungarian Academy of Sciences Centre for Energy Research (MTA EK),

Lappeenranta University of Technology (LUT), and Paul Scherrer Institute (PSI). SILENCE is currently organizing a “Specialists Workshop on Advanced Instrumentation and Measurement Techniques for Nuclear Reactor Thermal Hydraulics” (SWINTH-2016).

The San Piero a Grado Nuclear Research Group - University of Pisa (GRNSPG-UNIPI) is the Host Institution and plays as a Scientific Secretariat for both Networks.

1 INTRODUCTION

The development of the SYS-TH Codes began at the end of the 1960's as a response to the requirements, or knowledge targets, put by the Regulatory Body in the United States, US Atomic Energy Commission (US AEC), now US Nuclear Regulatory Commission (US NRC). The huge amount of investments in the nuclear reactor safety research and developments, including V&V, brought to the nuclear community the availability of the mature computational tools towards the end of 1990's, when those codes were classified as Best Estimate (BE) due to the use of number of mechanistic models in them.

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 required 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, specially 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. In view of these, two projects namely FONESYS [1][2] and SILENCE [3] were launched aiming respectively at establishing a forum and a network among the code developers and promoting cooperation among teams of experimentalists that are managing or are involved in significant experimental projects in nuclear reactor thermal-hydraulics.

2 THE ROLE OF FONESYS IN SYS-TH CODES DEVELOPMENT DOMAIN

2.1 Motivation and Main Objectives of the Project

The main motivation for starting the FONESYS project was to bring technical argumentation against disbelief in SYS-TH codes and to strengthen the current technology. SYS-TH codes development may stop and its application can become obsolete for ‘right’ or ‘wrong’ reasons (see for instance the disbelief in codes as from the Zuber or Wulff papers [4][5]). The motivation is to bring arguments against these ‘wrong’ reasons and at the same time to improve the codes simulation capability. While doing that, FONESYS should avoid what can be called the “Annapolis-1996 syndrome”, i.e. “deleting number of codes and starting the development of a ‘new-similar’ code on the basis of an ‘old’ one”. Also, motivation was to form a network of top level experts and code developers that can challenge future problems that can rise 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 decided by top-level experts within a framework consistent with standards of international Institutions. The main objectives are summarized and listed below:

- to create a common ground for discussing envisaged improvements in various areas of System Thermal-Hydraulics, promoting a cooperation aimed at the improvement of the SYS-TH Codes and their application in the licensing process and safety analysis;
- 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 identify the area of improvement and share experience on the graphical user interface (GUI), SYS-TH code coupling with other numerical tools, such as 3-D neutron kinetics, fuel pin mechanics, CFD, CMFD, etc.;
- to establish the acceptable and recognized procedures and thresholds for Verification and Validation processes;
- to maintain and improve the user expertise and the documented user guidelines for applying the code.

2.2 The FONESYS Members and Reference SYS-TH Codes

According to FONESYS statute there are seven signatory Institutions currently participating in the project. Host Institution is GRNSPG/UNIPI and as such acts as Secretariat. Signatory Institutions are AREVA NP SAS (AREVA-NP) and Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) from France, Gruppo di Ricerca Nucleare San Piero a Grado/ Universita di Pisa (GRSNPG/UNIPI) from Italy, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) from Germany, Korea Atomic Energy Research Institute (KAERI) and Korea Institute of Nuclear Safety (KINS) from Republic of Korea, and VTT Technical Research Centre of Finland.

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

2.3 Capabilities and Limitations of Current SYS-TH Codes

The system thermal-hydraulic codes are based upon the solution of balance equations for liquid and steam that are supplemented by a suitable set of constitutive equations. The balance equations are coupled with conduction heat transfer equations and with neutron kinetics equations, hence the need for coupling 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 is organized in a number of lumped volumes connected with junctions. Thermal-hydraulic components such as valves, pumps, separators, annulus, accumulators, etc. can be defined in order to represent the overall system configuration. The limitations and capabilities from the code users' point of view differ from those which concern the code developers [6].

The main aspects from the code users point of view:

- System nodalization – the user develops the detailed nodalization diagram of the whole system. This approach provides large flexibility but as a consequence a large responsibility lies on a user to develop an adequate nodalization scheme which makes the best use of the various modules and the prediction capabilities of the specific code;

- Physical model parameters – various possibilities of how the code can physically model specific phenomena. Due to the lack of the direct measured data, in many cases, the specification of those parameters are left to the engineering judgment of the user;
- Input parameter related to 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. An importance of the relatively small specific effects that occur in scaled facilities is often underestimated, what could lead to a wrong interpretation of the results based on an incomplete representation of a small-scale test facility;
- Input parameters needed for specific system components – although system behaviour 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 of components (e.g. pumps, separators, etc.) cannot be described without additional models. The data for those models are largely scaling dependent; therefore user has to extrapolate from the used data from different sources. Consequently, 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 QA procedures, possibility of error in specification of the initial and boundary conditions exists, and may introduce small imbalances in the initial data which may overwrite the simulated transient. Therefore, the specification needs to be done in a very detailed and precise manner;
- Specification of state and transport property data – calculation of state and transport properties is done implicitly by a code, but in some case the code user may influence on the accuracy with defining the range of reference tables;
- Selection of parameters determining time step sizes – automatic procedures are used by all existing codes for the selection of time step sizes. Because there are not always stable numerical results, the user sometimes needs to limit the maximum size of time step to solve this problem;
- Code input errors – probability for code input errors is high because of a huge number of data that has to be given manually.

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

- Simulated phenomena and range of transients/accidents;
- Physical origin – problem with not knowing the factions of physical reality that were not accounted for in the homogenization procedure, and what are properties of the continuum for it to adequately represent the physical interactions of discrete entities. Answer to this will impact the homogenization procedure and the formulation of constitutive laws;
- Mathematical modelling limitations of the code (e.g., does hyperbolicity provide the sufficient condition for obtaining convergent solutions?);

- Numerical limitations of the code – problem with defining and controlling the level of numerical diffusion and numerical oscillations that would allow sub-grid scale phenomena.

2.4 The Key Items of FONESYS

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

- Virtual mass and pi terms in the frame of hyperbolicity;
- Comparison “drift flux – 6 equations – multi-field”;
- Transport of interfacial area and turbulence models - experiments and development;
- 3-field equations: experimental basis and theory;
- Codes portability and “mesh convergence” issues.

Along with the main FONESYS topics, nine subtopics of interest were selected and are listed below. Their importance to the code developers is lower than of the main topics.

- use of best-estimate system thermal-hydraulic codes for licensing;
- acceptability of errors in code predictions;
- loop seal clearance;
- radiation heat transfer;
- droplet field impact on results of the code calculations;
- difference between the dispersion and diffusion in numeric;
- to clarify the meaning of convergence in time and in space;
- importance of 3-field equation models in system codes’ prediction;
- Jacobian.

For detailed information about each of the aforementioned key items and the FONESYS point of view please refer to [2].

2.5 The FONESYS Road Map

Following working modalities of FONESYS were proposed and accepted by all FONESYS 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 integral test facilities and 3D separate test facilities;

- Running and collecting results from 'specific additional' V&V: specific additional V&V activities performed will involve basic, separate and integral test facilities as well as full scale NPP;
- Attending regular workshops (e.g. 1/year), eventually creating 'ad-hoc' groups for special topics;
- Addressing the (possible) scepticism from international community & answering questions;
- Providing recommendations to prioritize code improvements.

FONESYS expert meetings are one of the most important parts of accepted working modalities of FONESYS project. They are organized as workshops where participants discuss one (or few) of the selected key items and subtopics, present and discuss benchmark results. These expert meetings have been precisely described in the FONESYS statute:

- FONESYS workshops will be attended by the Programme Committee representatives, the Signatories, and any other expert agreed between the Signatories;
- FONESYS workshops will be held at least once per year. It will be organized at GRNSPG/UNIPI headquarters or in any other place agreed by the Signatories;
- The Signatories will each designate one representative. These representatives may, at their discretion, delegate this responsibility to the appropriate individual with respect to a given issue.

From the start of the FONESYS project seven workshops were organized.

3 THE SILENCE NETWORK

SILENCE (**SI**gnificant **L**ight and Heavy Water Reactor Thermal Hydraulic **E**xperiments **N**etwork for the **C**onsistent **E**xploitation of the Data) is a Network [3] for cooperation among teams of experimentalists managing significant experimental projects in nuclear reactor thermal-hydraulics. Established in 2012 by GRNSPG and UNIPI, 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 Key Goals and Motivation of the Project

There is a risk to lose expertise and "vision" in the area of thermal-hydraulic experimental investigations, and a presidium should be maintained to avoid that. It is important that the experimentalists join together and constitute a "system", while large budgets available in the past cannot be replicated.

The main objectives of the project are summarized and listed below:

- To optimize the funding available worldwide for experiments, recognizing their vital role for the design and the safety of existing and coming NPP, including connecting with past and recent initiatives like CERTA-TN (former EC-Project) and STRESA-database;

- 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

According to SILENCE statute there are seven signatory Institutions currently participating in the Network: AREVA NP GmbH and Helmholtz Zentrum Dresden-Rossendorf (HZDR) from Germany, Korea Atomic Energy Research Institute (KAERI) from Republic of Korea, Gruppo di Ricerca Nucleare San Piero a Grado/ Universita di Pisa (GRSNPG/UNIPI) from Italy, Hungarian Academy of Sciences Centre for Energy Research (MTA EK) from Hungary, Lappeenranta University of Technology (LUT) from Finland and Paul Scherrer Institute (PSI) from Switzerland. SILENCE adopts the same administrative and management model as FONESYS.

3.3 The SILENCE Working Modalities

The working modalities of SILENCE include, but are not limited to developing of a common understanding (e.g. by collecting different opinions and achieving a consensus document) about the following key items:

- current relevance of experimental data;
- importance of supporting, maintaining and fostering data banks;
- importance of a systematic data base, with particular reference to complex experiments (integral test facilities).

From the start of the SILENCE project four meetings were organized.

3.4 A SILENCE Initiative: SWINTH-2016 International Workshop on Instrumentation and Measurement Techniques

The idea for organizing a "Specialists Workshop on Advanced Instrumentation and Measurement Techniques for Nuclear Reactor Thermal Hydraulics" (SWINTH-2016) has been emerged during the first SILENCE meetings. It was suggested by the observation that significant advances have been achieved in the instrumentation and investigation techniques for nuclear TH systems since the OECD/CSNI Specialists Meeting on Advanced Instrumentation and Measurement Techniques held in Santa-Barbara, California, US, on March 17-20, 1997 [7].

The motivation for starting SWINTH-2016 workshop 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-2016 workshop 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 system codes, component codes, and computational multi-fluid dynamics (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 workshop covers wide and complex subject and deserves "dedicated" discussion; therefore, specialized workshops such as the present one would be complementary to other events on code development and validation & verification (V&V), and initiatives in which the experimental area is not covered with sufficient detail and focus.

The SWINTH-2016 Workshop will be held on June 15-17, 2016, in Livorno, a nice Italian city very close to Pisa. For more information regarding the event please refer to the official website [8].

4 CONCLUSIONS

The present paper shortly presents the two projects namely FONESYS and SILENCE, their main targets, motivation and working modalities. The FONESYS initiative was started with the goal to promote the use of SYS-TH Codes and the application of the BEPU approaches, to establish acceptable and recognized procedures and thresholds for V&V and to create a common ground for discussing envisaged improvements in various areas, including user-interface, and the connection with other numerical tools, including CFD and CMFD Codes.

FONESYS Members and their codes were introduced. Brief overview of the current status of the SYS-TH codes, their capabilities and limitations were presented together with all the relevant topics like the scaling issue, the user effect, the quantification of uncertainty in best estimate codes, the qualification of code calculations, and the need for standardize consolidated experimental and calculated database. In the road map section the project working modalities, key items and subtopics, were presented.

Established in 2012, SILENCE network replicates for the TH experimental domain the role that FONESYS plays in the code-development domain. The 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. A brief description of the SWINTH-2016 International Workshop on Instrumentation and Measurement Techniques (Livorno, Italy, June 15-17, 2016), its motivation and purposes were provided.

REFERENCES

[1] Forum & Network of System Thermal-Hydraulics Codes in Nuclear Reactor Thermal-Hydraulics (FONESYS), http://www.grnspg.ing.unipi.it/fonesys/.

[2] Ahn S.H., Aksan N., Austregesilo H., Bestion D., Chung B.D., D'Auria F., Emonot P., Gandrille J.L., Hanninen M., Horvatovic I., Kim K.D., Kovtonyuk A., Petruzzi A., "FONESYS: The FOrum & NEtwork of SYStem Thermal-Hydraulic Codes in Nuclear Reactor Thermal-Hydraulics", J. Nuclear Engineering and Design, Vol. 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.grnspg.ing.unipi.it/silence/.

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

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

[6] Bucalossi A., "Current use of Best Estimate plus Uncertainty methods on operational procedures addressing normal and emergency conditions", EUR 23717 EN, 2008.

[7] OECD Nuclear Energy Agency, U.S. Nuclear Regulatory Commission, Proceedings of the OECD/CSNI Specialist Meeting on Advanced Instrumentation and Measurement Techniques, Santa Barbara, California, US, March 17-20, 1997.

[8] An initiative of SILENCE Network, Specialists Workshop on Advanced Instrumentation and Measurement Techniques for Nuclear Reactor Thermal Hydraulics (SWINTH-2016), http://www.grnspg.ing.unipi.it/swinth/, Livorno, Italy, June 15-17, 2016.