PhD in Energetics

Research Title:
Multiscale Approach for the Thermal-Hydraulics Analysis of Heavy Liquid Metal Pool System

Funded by	ENEA/DENERG

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Context of the research activity	Aging of nuclear power plants in Europe will require new capacity installed in a 10–15 year time-frame to meet the challenging objectives of the European Energy Policy and of the ambitious aim to become climate neutral by the 2050, objective heart of the European Green Deal. Advanced nuclear power plants as part of a balanced energy mix for a safe, sustainable and secure energy scenario are supported by EURATOM and by the European Sustainable Nucear Industrial Initiative (ESNII), which addresses the need for demonstration of Gen-IV Fast Neutron Reactor technologies. Lead-cooled Fast Reactors (LFR) are constantly gaining attention at international level as one of the most promising nuclear technologies, able to meet the goals set forth by the Gen-IV International Forum (GIF). The industrial interest for LFR technology increased worldwide thanks to the enhanced safety and sustainability performances, the potential for economic competitiveness and the unique flexibility in terms of plant size and potential applications. The technological experience gained in Europe

since the late 90s is paralleled only by Russia. Recently, China, USA, UK and other Countries are investing on LFR technology development plans and proposing commercial LFR options. Project examples in this context are the Russian BREST-OD-300, which is candidate to be one of the first to be constructed, or the Westinghouse LFR.

Europe has supported collaborative research and innovation actions on LFR technology at large with a total funding of more than 100 M€ from the European Commission in the period 2005–2014, complemented by a comparable amount from member states (in particular Italy and Belgium). Italy played a major role in the European collaborative research projects since the early actions, investing large funds on heavy liquid metal (HLM) technology research activities.

ENEA, Ansaldo Nucleare and CIRTEN have cumulated a significant expertise in the design of HLM-cooled reactor, through in-kind investments, demonstrating a leading role at international level. At the Brasimone Research Center, ENEA manages one of the most important HLM coolant technology parks, with several experimental facilities continuously improving the Technology Readiness Level (TRL) during the last 20 years.

From 2005, Romania initiated R&D activities on LFR technologies, extending its participation and role in European collaborative research projects, but also undertaking national initiatives. In 2011, Romania notified the European Commission about the availability to host the Advanced Lead-cooled Fast Reactor European Demonstrator (ALFRED) in the Mioveni nuclear platform.

At the successful conclusion of the LEADER project, the strong commitment of Ansaldo Nucleare, ENEA and ICN (Institute for Nuclear Research) was confirmed and formalized through the signature of the FALCON international Consortium, aimed at managing the R&D strategic needs and securing the necessary funding for siting, licensing and construction of ALFRED.

FALCON gathers European organizations who share the objective of making ALFRED the prototype of a viable competitive LFR commercial unit in the SMR segment, by 2035-2040.

ALFRED will bridge the gap between the research endeavour and the commercial application. Indeed, ALFRED was conceived with increased safety margins, and is now undergoing a substantial re-design oriented to simplicity, robustness and scalable size.

In support to the ALFRED Project, FALCON identified the minimum needs in terms of experimental facilities in

	support to the LFR demonstration programme. Two main facilities were conceived to address the pool thermal-hydraulic issues and progressively demonstrate the performances of the revised ALFRED configuration and of its main components: the Advanced Thermal-Hydraulic Experiment for Nuclear Application (ATHENA) facility and the European Lead Fast facility (ELF). Both are planned to be built in Romania, at the ICN premises, as part of the ALFRED Project. ATHENA is a large pool-type multi-purpose experimental infrastructure aimed at addressing thermal-hydraulic issues and component development. ATHENA features a large size vessel (3.2 m diameter, 10 m in height), which is capable of hosting and testing single and coupled full scale components, including an electrically heated fuel pin simulator currently able to deliver a total thermal power of 2.21 MW. ATHENA is representative of the LFR systems and is aimed at investigating a large variety of aspects that encompass: (i) R&D needs related to the lead technology (i.e. O2 control in a large pool); (ii) simulation of integral tests representative of normal operation (pool thermal-hydraulics, SG functionality and performances, PP functionality and performances); (iii) simulation of peculiar transient integral tests relevant to safety assessment and economic operation in representative scale (i.e. loss of electrical power, margin to freezing scenarios); (iv) test of full scale single components (i.e. SG, DHRs, PP); (v) experiences on peculiar separate effect tests relevant to safety (i.e. Steam Generator Tube Rupture, Fuel Assembly partial blockage); (vi) definition of a large experimental database suitable for model development and code V&V, with the goal to support the LFR design and its licensing phase; (vii) support to the design and licensing process of a LFR of representative power size.

Objectives	The interest in the field of computational fluid dynamics (CFD) is growing with the increasing performances of computer hardware, which makes this tool more efficient and suitable for a larger and larger range of applications. In order to become established design tools, CFD codes need to demonstrate their applicability in the decision-making process on the definitions of system parameters and conditions, proving lower costs with respect other tools. In the nuclear field, the TH behaviour in small systems is already predicted with good accuracy and the results validated against experimental data in many applications. However, limitations are still present in peculiar

	configurations, in systems involving two phase flow or in simulating domains of large size. The optimization of the ATHENA large scale HLM facility requires the full knowledge of the global system behaviour in normal and in transient conditions, to improve the safety and the economy of the infrastructure. The present tools for the simulation of the entire primary side of a pool facility, or also of the entire cooling system including the secondary side, is developed by the implementation of the so called System Thermal-Hydraulic (STH) codes, such as RELAP5. STH codes are generally based on one-dimensional (1D) mass, momentum and energy balance equations, for two-phase flow, including models based on empirical correlations (e.g. heat transfer, frictional pressure losses, etc.). STH codes are extensively validated for two-phase flow phenomena, while two-phase CFD codes are less mature and not yet ready for extended applications. On the other hand, single-phase CFD codes attained a satisfactory degree of maturity such as to justify and promote their use, especially for the study of complex three-dimensional (3D) phenomena where 1D codes are not suitable. Despite the increasing processing power of the new computers, the detailed CFD simulation of an entire system would require billions of cells. This aspect becomes even more serious if turbulence models with high resolution or with boundary layer constrains are adopted. The large number of cells makes the simulation time not reasonable for the application of this tool in the design process. The present work aims at developing coupling techniques where the STH code is coupled with CFD code, implementing a multiscale approach for the ATHENA design, in which some parts of the facility will be also simulated by the use of porous media (PM) coarse mesh CFD. The adoption of PM gives the possibility of a strong reduction in computational effort, preserving global quantities of the components and the possibility to run three-dimensional simulation of the phenomena.
Skills and competencies for the development of the activity	Knowledge and competencies on LFR and liquid metal TH. Skills on CFD, STH code, Matlab scripts.