ENERGETICS

Advanced methods for the safety analysis and optimization of the operational performance of next generation Molten Salt Reactors under uncertainties

Funded By	Dipartimento DENERG

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Context of the research activity	The ENDURANCE project (EU kNowleDge hUb foR enAbling MolteN Salt ReaCtor safety development and dEployment) has the goal of supporting the safe operation and the technological deployment of the Molten Salt Reactor technology in Europe, by advancing the technical knowledge in different fields of the MSR research and by connecting the design developers and industry needs with the university and research centre capabilities and the regulator requirements. This PhD project aims at developing and applying: 1. state-of-the-art methods for non-intrusive, general-purpose sensitivity and uncertainty analyses for the multiphysics modelling of MSRs; 2. an integrated framework for the real time optimization of the reactor heat and electricity production strategies, based on intelligent techniques. Thanks to the mobility scheme of the ENDURANCE project, part of the PhD research could be carried out in a foreign institution or industry which is part of the consortium.

	The Molten Salt Reactor (MSR) concept belongs to the so-called Generation IV reactors, which are a set of promising design selected by the Generation IV International Forum as promising nuclear reactor technologies for the decarbonization targets in the energy sector. The main advantages of the MSRs are the adoption of a liquid fuel, which enables the adoption of closed fuel cycles, like the Th-232 – U-238 one, enhancing the plant sustainability, and their intrinsic safety features, like the low operational pressure and the strong feedback coefficients. The circulating fuel also eliminates by design the possibility of accidental core melting, increasing the safety standards of the reactor. Starting from the MSR Experiment at Oak Ridge National Laboratory (U.S.A.) in the ‘60s, the MSRs have been the objective of worldwide research efforts, including several private companies in North America and Europe. Due to its unique advantages and to the urgent needs for a deep decarbonization, the

Objectives	MSR technology is gaining momentum, as proved by the EU research projects and by the growing number of start-ups active in this specific field (Naarea, Thorizon, Seaborg Technologies, …). The NEMO group staff at the Energy Department at Politecnico di Torino is active in the field of MSRs technology since more than 20 years, having participated to many EU research projects in the field (EVOL, SAMOFAR and SAMOSAFER, just to name a few). The group members have developed a significant expertise in the physics of liquid fueled reactors, the adoption of high-fidelity Monte Carlo modelling tools, the development and application of uncertainty and sensitivity analysis methods, (physics-informed) machine learning techniques, reinforcement learning methods and reduced-order models (e.g., Artificial Neural Networks, Kriging) for the intelligent and computationally-cheap system simulation, and multi-parameter optimization of complex problems with nature-inspired meta-heuristics (e.g., genetic algorithms). The present PhD project will be part of the ENDURANCE project (involving many EU institutions such as Politecnico di Torino, Politecnico di Milano, TU Delft, CNRS, EPFL, KIT, consolidated industries like Framatome and private start-ups, e.g. Naarea and Thorizon). As such, the PhD candidate will develop their research activity in a stimulating and dynamic environment, by periodically presenting their work in the progress meetings of the project with the other partners, exchanging ideas and receiving feedback. The activity will be carried out specifically in the frame of two work packages, one related to the modelling and simulation to enable the safety assessment of the MSR, the other related to the aspects of the MSR (optimal) operational flexibility. In the first part of the thesis, the PhD will deal with the Best Estimate Plus Uncertainty (BEPU) methodology, which aims at combining high fidelity modelling with a proper uncertainty propagation. More specifically, the candidate will contribute with the development and application of a non-intrusive, general-purpose methods for the uncertainty and sensitivity analyses, aiming at their application to the different computational chains adopted and developed by the other partners (e.g., the OpenFOAM toolkit for the multiphysics modelling of the core and the Modelica language for the system level modelling). The methodology developed will be finally adopted in the frame of a numerical benchmark, related to the modelling of the radioactive source term (with the Serpent 2 Monte Carlo code) associated with the MSR. This activity will be complemented by performing a Target Accuracy Requirement (TAR) for the simulation of safety-relevant phenomena, i.e. the determination of the maximum uncertainty allowable for a reliable simulation of the plant. Then, exploiting the power plant simulator available from previous EU projects, the candidate will develop an integrated framework, possibly based on reinforcement learning and meta-heuristic techniques, for the real-time optimization of the system operational policies, taking into account the different poly-generation production strategies (e.g., electricity and hydrogen production) and the operational constraints of the system. In particular, the developed real-time optimization “engine” will take optimal decisions based on two inputs: (1) the health state of the (hybrid) energy production (cogeneration) system, continuously monitored on-line by (physics-informed) machine learning tools; and (2) the load requests coming from the users. Based on this information, the optimization module will find (and continuously update): i) the (cogeneration) system optimal operating condition; ii) the optimal policies and (control) actions to manage the shift between different types of energy production; and iii) the best maintenance strategies to be implemented in order to maximize the energy system productivity.

Skills and competencies for the development of the activity	The candidate should be familiar with the following topics: - Core physics of fission nuclear reactors - Monte Carlo particle transport codes - Methods for uncertainty quantification and sensitivity analysis - Basics of (nuclear) safety and risk analysis concepts and methods The candidate should be able to cooperate and interact collaboratively in an international research and industrial work environment.