



# Functional Reliability of Passive Safety Systems of Nuclear Power Plants (NPPs): Reduced Order Modeling and Advanced Sampling

## In collaboration with TRACTABEL (ENGIE) - Engie Tower-Bruxelles - Belgium

### **Context of the research**

Passive safety systems have emerged as a key feature in Gen IV Nuclear Power Plants (NPPs) and Small Modular Reactor (SMR) designs, aiming to reduce dependence on active interventions and foster greater public trust in nuclear energy. Unlike active components, these systems rely on inherent physical processes (e.g., natural circulation) for cooling and control, potentially offering advantages such as lower maintenance needs and reduced power supply requirements. However, their reliability remains difficult to quantify due to large uncertainties in the computational models and the complex interplay of physical phenomena, which can lead to unrecognized failure modes.

To address these challenges, traditional sampling-based techniques (e.g., Monte Carlo method) often demand significant computational resources, especially when simulating high-fidelity thermo-hydraulic codes. This constraint underscores the necessity of more efficient methods to ensure robust and realistic reliability estimations for passive systems.

Reduced Order Modeling (ROM) provides an efficient solution by approximating the full-order models with simpler surrogates that capture system dynamics. This can drastically reduce the computational burden related to the simulation of the system response. Furthermore, advanced sampling techniques—such as importance sampling and subset simulation—can help during the stochastic simulation to identify the critical failure regions. By integrating ROM with advanced sampling methods, it becomes feasible to handle complex physical behaviors, reduce uncertainties, and offer robust evaluations of passive systems reliability.

### **Objective of the research**

This research aims to develop a methodology that combines reduced order modeling with advanced sampling schemes for the reliability analysis of passive safety systems in NPPs. The activity will include:

- Collection, classification and study of the available literature on the subject.
- Analysis and comparison of the available techniques/methodology/tools.
- Development of a framework that integrates Reduced Order Modeling with advanced sampling methods.
- Application of the proposed framework on a representative SMR case study, evaluating accuracy, scalability and usefulness.
- The identification of methodological limitations and proposal of directions for future research.

### **Collaborations**

Tractebel, part of the Engie Group, is a leading engineering firm specializing in energy and nuclear safety. The work will be performed in the Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience (LASAR<sup>3</sup>) of Politecnico di Milano in tight collaboration with TRACTABEL in Bruxelles (Belgium), where an internship is foreseen.

#### For further information, please contact:

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