MSc thesis proposal (stay opportunity in CEA Paris)

Development and Uncertainty Quantification of Explainable AI/ML Models for Critical Heat Flux Prediction in Water-Cooled Nuclear Reactors

Context of the research

Critical Heat Flux (CHF) represents a key safety and operational limit in water-cooled nuclear reactors, marking the transition from efficient nucleate boiling to film boiling, which may lead to rapid and potentially hazardous temperature escalation. Accurate prediction of CHF is, therefore, critical for reactor thermal-hydraulic design, safety margin assessment and real-time operational decision-making. Conventional empirical correlations, mechanistic and LUT models, while widely used, are often limited in generalization capability and may not fully capture the complex multi-physics phenomena governing boiling heat transfer across diverse operating regimes. Advances in Artificial Intelligence and Machine Learning (AI/ML) offer new opportunities to improve CHF prediction accuracy. However, the adoption of these models in nuclear engineering applications requires rigorous interpretability, physical consistency and quantified uncertainty to ensure trustworthiness and regulatory acceptance.

Objective of the research

The primary objective of this thesis project is to develop and implement explainable AI/ML models for the prediction of Critical Heat Flux in water-cooled nuclear reactors, with emphasis on ensuring transparency, physical interpretability and uncertainty quantification (UQ). The methodology will be applied to a benchmark experimental CHF dataset provided by OECD/NEA projects. The research activities will include:

- familiarization with CHF, relevant datasets and case studies;
- literature review of the CHF prediction models, including AI/ML methods and UQ techniques;
- examination of explainable AI (XAI) approaches;
- development and evaluation of AI/ML learning architectures for CHF prediction;
- integration of XAI technique to support model interpretability and physical insight;
- implementation of UQ methods to assess prediction reliability and safety margins;
- validation of the proposed model against benchmark CHF dataset and compare performance with existing state-of-the-art modeling approaches;
- analysis and interpretation of the obtained results.

Collaborations

The work will be performed in the Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience (LASAR^3) in tight collaboration with CEA in Paris (France), where an internship is foreseen.

Required skills

- Good knowledge of statistics/applied mathematics and AI/ML technologies and techniques;
- Basic knowledge of the physics processes underlying the CHF phenomenon will be considered a plus;
- Interest in developing innovative algorithms to address real-world applications;
- Good knowledge of Python and/or R programming languages, with a focus on deep leaning (DL) and ML libraries.

For further information, please contact:

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