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Editorial: Novel nuclear reactors and research reactors

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Editorial on the Research Topic
Novel nuclear reactors and research reactors

The advancement of nuclear energy technology has brought significant attention to next-generation reactor systems, including Generation IV reactors, small modular reactors (SMRs), and fusion reactors. Generation IV designs—such as ultra-high temperature reactors, liquid metal-cooled fast reactors, and molten salt reactors—demonstrate marked improvements in sustainability, safety, cost efficiency, and proliferation resistance (Li et al., 2025; Mochizuki, 2025; Liu et al., 2018). Meanwhile, SMRs offer distinct advantages, including versatility in application, deployment flexibility, enhanced safety, and reduced environmental impact. Research reactors also play a pivotal role in nuclear innovation, serving critical functions such as material irradiation testing, isotope production, and theoretical/experimental studies in nuclear technology (Colvin and Palmer, 2025; Jin et al., 2025). Compared to conventional nuclear power plants, these advanced and research reactors exhibit unique design and operational characteristics, making their simulation and engineering processes notably more complex and multidisciplinary.

In recent years, with the continuous innovation of Generation IV nuclear systems, small modular reactors, and research reactors, nuclear reactor modeling and simulation have been evolving toward higher accuracy, multi-scale, and multi-physics coupling approaches (Weng et al., 2021; Fiorina et al., 2022). The design and application of novel reactors exhibit greater complexity and diversity, placing higher demands on thermal-hydraulic characteristics and safety, while also introducing new challenges in fuel behavior and material evolution. To address these needs, researchers are actively advancing the use of sophisticated numerical methods, coupled simulation tools, and high-performance computing, while also strengthening model validation and uncertainty analysis.

Meanwhile, neural network methods are increasingly being integrated into the analysis and optimization of reactor systems, providing strong support for the design and safe operation of next-generation nuclear technologies (Zou et al., 2023; Elhareef and Wu, 2023; Wang et al., 2025). Consequently, the nuclear engineering field continues to advance modeling and simulation technologies to address the complex and diverse challenges posed by novel reactor development, driving nuclear technology toward higher levels of performance and innovation.

We have collected four papers on reactor thermal-hydraulics and safety analysis for *novel nuclear reactors and research reactors* by Geng et al., Cui and Cai, Wu et al., and Lu et al. Geng et al. model transient behavior in the NHR-200-II passive residual heat removal system using RELAP5, identifying flow oscillations during valve failures and proposing design mitigations. Cui and Cai develop a novel degassing system for the HPR1000 pressurizer, improving shutdown performance via steady-state and transient simulations. Wu et al. couple ARSAC and ATHROC codes to simulate CPR1000 containment dynamics under TMLB' accidents, resolving pressure evolution and hydrogen distribution. Lu et al. employ Eulerian–Lagrangian CFD to analyze spray-induced depressurization in multicompartment containments, validating against OECD SETH-2 experiments.

We have collected three papers on nuclear fuel and materials, as well as the nuclear fuel cycle for *novel nuclear reactors and research reactors*, by Wan et al., Changbin et al., and Jiang et al. Wan et al. use cluster dynamics to model defect evolution in proton-irradiated RPV steels, linking solute clustering to embrittlement. Changbin et al. simulate blister formation in UMo/Zr monolithic fuel under annealing, revealing cladding creep's role in bubble growth. Jiang et al. investigate radioactive particle migration in liquid effluents, informing post-operation fuel treatment and environmental monitoring.

We have collected two papers on the conceptual design of *novel nuclear reactors and research reactors* by Qi et al. and Yang et al. Qi et al. propose a graphene-enhanced nanofluid heat exchanger for lead-bismuth reactors, optimized via genetic algorithms for thermal efficiency and compactness. Yang et al. analyze fuel rod vibration to enhance core integrity under dynamic loads.

We have collected two papers on uncertainty quantification, sensitivity analysis, and optimization by Cacuci. Cacuci introduces the nth-order adjoint sensitivity methodology (nth-FASAM-L) for exact high-order sensitivity computation in linear systems, later applying it to neutron slowing-down problems to demonstrate optimization efficacy.

This Research Topic focuses on the key aspects of design, simulation, and analysis for *novel nuclear reactors and research reactors*. The collected studies span thermal-hydraulic behavior, fuel and material evolution, conceptual innovations, and high-order sensitivity analyses. By employing multiphysics coupling, high-fidelity modeling, and advanced numerical techniques, these works demonstrate recent progress in enhancing the safety, efficiency, and engineering viability of next-generation nuclear energy systems.

Looking ahead, balancing computational accuracy with practical applicability remains a central challenge for advanced modeling and simulation technologies. Continued efforts in model validation, algorithm optimization, and integration with artificial intelligence will provide essential support for the industrial application of novel nuclear reactor systems.

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SL: Writing – original draft, Writing – review and editing. JL: Writing – review and editing. JY: Writing – review and editing. LW: Writing – review and editing. YZ: Writing – review and editing.

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