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Editorial: Numerical and experimental studies on small/micro nuclear reactors, volume II

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Editorial on the Research Topic
Numerical and experimental studies on small/micro nuclear reactors, volume II

As the demand of people for sustained energy supply in extreme environments grows exponentially, the technological bottlenecks of traditional energy systems are becoming increasingly apparent. For special application scenarios such as future space missions and deep-sea explorations, the long-term operational reliability and high-power density characteristics of energy systems have become important technological indicators. Against this background, small/micro nuclear reactors, with power output ranging from kilowatt-electric (kWe) to megawatt-electric (MWe), demonstrate significant technological potential and application prospects. These reactors offer numerous advantages over conventional energy systems, such as storage batteries and fossil fuels. They provide higher energy density, increased reliability, and longer operational lifetimes. Small/micro nuclear reactors can be classified into various categories based on the coolant they employ, including heat pipe cooled reactors, liquid metal cooled reactors, and gas-cooled reactors. Among these, heat pipe cooled reactors can achieve passive and efficient heat transfer, and their modular design significantly reduces system complexity. Liquid metal cooled reactors employ high thermal conductivity media such as sodium or lead-bismuth alloy as coolants, making them suitable for the design requirements of fast neutron spectrum cores. Gas-cooled reactors excel in modular integration and inherent safety. Currently, most of these reactors are still in the conceptual design stage, undergoing numerical studies and experimental research.

Compared with existing light water reactors, small/micro nuclear reactors have unique core structures and operating principles. In small/micro nuclear reactor systems, the strong coupling interactions among multiple physical fields render the traditional single-physics decoupling analysis methods used in light water reactors inadequate. During reactor operation, the thermal-hydraulic field, mechanical field, and neutron physics field exhibit highly nonlinear dynamic coupling relationships, which induce complex superposition effects that cause deviations between single-physics analytical results and actual operational characteristics. Therefore, it is necessary to develop and update existing research methods to accurately understand the operational characteristics and safety performance of these nuclear reactors. Researchers are actively working on improving simulation capabilities by developing novel modeling methods and multi-physics coupling analysis programs that consider various physical processes. These advancements provide researchers with a powerful tool to gain in-depth insights into the behavior and performance of small/micro nuclear reactors.

This Research Topic serves as a crucial platform for researchers to share and publish their latest findings and advancements in the field of small/micro nuclear reactors. The Research Topic covers various aspects, including thermal-hydraulic and safety analysis, multi-physics coupling, computational code development, and validation. Currently, this volume mainly focuses on simulation.

The current research on small/micro nuclear reactors primarily revolves around specific numerical simulation methods, which are of great help for understanding and analyzing the operation and performance of small/micro nuclear reactors. These simulations enable researchers to explore different operational scenarios and optimize various parameters for efficient and reliable reactor designs. In this research platform, Feng et al. focused on the megawatt heat pipe reactor with metal hydride moderators and burnable poisons under accident conditions, including reactivity insertion accidents, loss of power conversion unit heat sink accidents, and heat pipe failure accidents. They analyzed the influence of burnable poisons on core critical safety and hydrogen dissociation risk through an OpenMC/ABAQUS coupling model. They achieved neutronic-thermal coupling and revealed that the introduction of burnable poisons could be beneficial during the positive reactivity insertion accident. Yin et al. focused on the thermodynamic behavior of fully ceramic microencapsulated (FCM) fuel. An equivalent volume element model was established based on the DIGIMAT software, and the thermodynamic equivalent performance model of FCM fuel was obtained through analysis. The research showed that the thermal expansion coefficient and plastic performance were affected by temperature, fast neutron fluence, and the volume fraction of UO_2, while the specific heat capacity and thermal conductivity of the fuel pellet were mainly influenced by temperature and the volume fraction of UO_2. Shuoting et al. developed a flow and heat transfer network analysis method to rapidly calculate the core flow and temperature distribution of prismatic gas-cooled micro reactors, and compared the results with those of computational fluid dynamics, showing good consistency between the two. Liu et al. used the RELAP5 software to analyze the thermal-hydraulic safety characteristics of a 50 MWe lead-cooled fast reactor under inclined conditions, and the study pointed out that the core flow rate shows a negative correlation trend with the reactor inclination angle. In addition, the authors suggest that the angle between the heat exchanger and the central axis of the floating nuclear power plant should be arranged at 45°.

In summary, the design and development of small/micro nuclear reactors have emerged as a critical research frontier in nuclear technology, driven by the demands of extreme operational environments such as space missions and deep-sea explorations. Small/micro nuclear reactors, distinct from conventional reactors in core structure and operational mechanisms, make advanced numerical simulation methods incorporating multi-physics coupling become important for system optimization and performance enhancement. Although most technological implementations remain in the conceptual validation phase, numerical simulation frameworks integrating multi-physics analysis and adaptive algorithms have provided essential theoretical support for core thermal-hydraulic characterization, fuel element behavior, and system safety margin assessment. These advancements significantly facilitate their engineering deployment in harsh environments requiring long-duration high-energy-density power supply solutions. This Research Topic provides a valuable platform for researchers to share their latest findings, contributing to the broader understanding and continued progress in the field of small/micro nuclear reactors.

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