Foreword

Special issue on Heavy Liquid Metal–Cooled Fast Reactor Technology

Guest Editors

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We are delighted to present this special issue focusing on heavy liquid metal–cooled fast reactor technology and are privileged to have it featured in *Nuclear Technology*. As one of the leading candidates in the development of fourth-generation nuclear energy systems, lead-cooled fast reactors are garnering increasing global interest. This is evidenced by the growing number of activities and initiatives supporting their prospective deployment.

Lead-cooled fast reactors are considered one of the most promising solutions for sustaining decarbonized energy mix in Europe and beyond. As such, their development is supported by various stakeholders, including research centers, universities, established nuclear companies, as well as innovative start-ups.

This special issue of *Nuclear Technology* captures the latest developments in this expanding landscape, focusing on cutting-edge research, development, and design efforts done by organizations actively fostering lead-cooled fast reactor deployment. This issue aims to inform universities, research organizations, industries, nuclear safety authorities, and government entities about the latest advancements in heavy liquid metal technology. It also seeks to inspire students, researchers, developers, engineers, and architects to broaden their research horizons and explore new or collaborative projects in this field.

The scope of the issue includes materials science, thermal hydraulics, fluid–structure interaction, as well as component and system testing in nominal and off-nominal conditions, which are addressed either by modeling or through experimental activities.

The history of heavy liquid metal–cooled reactors dates back to the 1950s, when a large research and development program was launched in the former Soviet Union for the deployment of compact reactor units for the propulsion of nuclear submarines. Eight such submarines were built and operated between 1963 (the launch of the first prototype) and 1990 (the retirement of the last unit). Along with two land-based prototypes, the reactors accumulated about 80 years of operating experience. Activities on heavy liquid metal–cooled reactors have continued since, in the Russian Federation, with the design of the BREST-OD-300 lead-cooled fast reactor demonstrator.

Following the establishment of the Generation IV International Forum, the lead-cooled fast reactor has been recognized as one of the six candidate technologies under consideration. In parallel with the BREST-OD-300 project, other initiatives have been launched for research, development, and design of Generation IV lead-cooled fast reactors, in Europe, Japan, the Russian Federation, and the United States at first, and then also in the People's Republic of China and the Republic of Korea. All these countries (and Euratom, representing the EU member states) are also currently participating in the work of the Lead-Cooled Fast Reactor provisional System Steering Committee within the Generation IV International Forum.

Although each reactor design showcases different, and sometimes unique, solutions that significantly extend the range of innovation beyond the foundational technology, most underlying research and development programs converge on similar strategies to effectively tackle the challenges associated with heavy liquid metal coolants. The primary challenge lies in empirically demonstrating the reliability and performance of each specific design solution both under normal and off-normal conditions. This demonstration is crucial, in particular because the behavior of these designs significantly depends on the advantages and limitations inherent in using heavy liquid metals. As such, this demonstration includes the clear quantification of thresholds and performance limits, to be reflected in design codes and standards as well as regulatory requirements, thereby serving as the basis for further detailed design and safety licensing, respectively.

Accordingly, the primary emphasis of research and development programs in this field has been directed toward understanding environmental impacts, particularly the corrosion of structural materials in heavy liquid metals. Additionally, these programs have concentrated on the specific hydraulic characteristics of heavy liquid metal pools, including their behavior during seismic events. Another critical area of study (for the determination of accident source terms) is the retention of radioactive products in heavy liquid metals, especially the most hazardous fission products—i.e., iodine, cesium, and strontium. Furthermore, the overall chemistry of heavy liquid metals represents a significant aspect of these research endeavors.

As results and evidence continue to accumulate from preliminary investigations, confidence in the viability of the technology correspondingly grows. This increasing assurance stems not just from finding solutions to the main challenges, but also from identifying potential avenues to optimize designs and enhance the performance of the reactor concepts currently under development. Consequently, this research is instrumental in not only resolving critical issues but also in paving the way for future advancements in the technology.

The increased confidence in the viability of heavy liquid metal–cooled reactor technology has led to a significant expansion in investment for research and development programs. Over the years, this has allowed for a broadening of their scope. Particularly in pioneering countries, this has enabled a shift from basic research and technology development to the qualification of reactor designs. To support this transition, larger and more sophisticated facilities have been and are currently being developed. These facilities are equipped to house prototypical reactor components and equipment, enabling testing under conditions that are representative of both normal and off-normal operating scenarios. The primary aim of these facilities is to facilitate the characterization and qualification of reactor components and equipment, further advancing the field.

This special issue mirrors the recent advancements in research on lead-cooled fast reactor technology, featuring papers that were carefully selected to provide a comprehensive overview of the state-of-the-art work being undertaken in this field. The results presented in these papers shed light on the current level of advancement and the novel achievements in lead-cooled fast reactor technology, also in support of (pre-)licensing efforts. Moreover, the experimental facilities described in these papers demonstrate their capabilities, serving also as a source of inspiration for new opportunities in further advancing the research, development, and qualification of lead-cooled fast reactors, ultimately contributing to their eventual demonstration and deployment.

Finally, we sincerely thank all the contributors for their invaluable research and insights and the reviewers for their expertise and diligent efforts, which have greatly enhanced the quality and impact of this special issue.