Foreword

Special Issue on Advancements in Uncertainty and Sensitivity Analyses: Current Status and Perspectives

Guest Editors

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This special issue of *Nuclear Technology* is focused on the recent advancements in uncertainty quantification (UQ) and sensitivity analysis for nuclear reactor safety applications, within the framework of deterministic safety analyses (DSAs), including their more recent extension to severe accident (SA) analyses and source term (ST) evaluations. This collection reflects the growing international efforts to move beyond traditional conservative approaches and toward advanced methodologies for the characterization of safety margins.

Over recent decades, the best-estimate plus uncertainty (BEPU) methodology has become an internationally recognized approach for the assessment of safety margins in DSAs. Originally developed and widely applied in the context of design-basis accident analyses, BEPU has progressively demonstrated its key role in reducing conservatisms in nuclear safety assessments. More recently, the same philosophy has been extended to the analysis of SAs, in which the complexity of the accident progression, the coupling among physical phenomena, their consequent multiphysics nature, and the ST estimation introduce new methodological and computational challenges.

The papers collected in this special issue provide a meaningful view of the current state of the art in this evolving field. The manuscripts highlight both consolidated practices and emerging directions, covering a broad spectrum of topics including, e.g., uncertainty and sensitivity analyses for postulated SAs in pressurized water reactors (PWRs) and small modular reactors (SMRs), the identification of cliff-edge effects in SA analyses, the application of the Shapley effect for sensitivity analysis, uncertainty treatment in system thermal hydraulics and SA codes, the user effect in forward uncertainty propagation, and ST uncertainty. This special issue also includes contributions on, e.g., applications to passive safety systems, hydrogen generation, core degradation, accident management actions, power decay heat calculation uncertainties for spent fuel, the applicability of system reliability analysis methods to the identification of cliff-edge effects in SAs, and thermal radiation modeling. The special issue further benefits from contributions addressing several computational tools and methodologies including, e.g., adaptive sampling, Monte Carlo filtering, solver implementation, and a comparative assessment of sensitivity analysis techniques for SAs.

An important feature of this special issue is its breadth in terms of reactor concepts. The contributions span, e.g., reference PWRs, boiling water reactors, SMRs, CANDU systems, RBMK spent fuel applications, and molten salt reactors. In addition, the main achievements of current initiatives developed in different frameworks are also presented.

As such, this special issue does not only document technical developments; rather, it illustrates the progressive maturation of uncertainty and sensitivity analysis as a cross-cutting discipline in nuclear safety. This is particularly relevant in the present context, where advanced reactors, including SMRs, are attracting increasing attention, and where the best-estimate assessment of passive systems' performance using advanced methodologies is becoming increasingly central to licensing and safety demonstration.

Another key message emerging from this collection of papers is that the future of uncertainty and sensitivity analysis will integrate novel computational approaches. The challenges associated with the analysis of complex and long accident progression scenarios, such as SAs, have motivated the application of novel methods utilizing artificial intelligence, machine learning, surrogate modeling, and pattern recognition algorithms to provide an innovative gateway toward computationally affordable and accurate methodologies for UQ and sensitivity analysis.

Taken together, the contributions in this special issue show that the field is moving from the application of traditional uncertainty methods toward the adoption of novel approaches. At the same time, the papers make clear that important challenges remain open and require further effort. For these reasons, this special issue aims not only to disseminate recent scientific and technical achievements, but also to help identify the main research gaps and future needs and direction for the nuclear safety community. We hope that this special issue will serve both as a useful reference for specialists already active in the field and as a reference point for researchers and practitioners approaching uncertainty and sensitivity analysis in DSAs studies.

Finally, we would like to express our sincere gratitude to all the authors who contributed to this special issue for the quality of their work and for their commitment to advancing the field. We also warmly thank the reviewers for their valuable time, expertise, and constructive comments, which were essential in ensuring the scientific quality of the published papers. Our appreciation also goes to the editorial team for their support and professionalism throughout the preparation of this issue.

We trust that this collection will stimulate further discussion, promote methodological progress, and contribute to the continued development of approaches for nuclear safety analysis.

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