For a sophisticated multi-billion-dollar venues like nuclear reactors or when dealing with ionizing radiation, it is not easy to build related education, research, and training projects to acquire the required skills of designing and operating safely and economically the desired nuclear systems. Computer simulations instead are used to design and visualize nuclear systems and to incorporate the ideas and knowledge of nuclear engineers. My research, as a nuclear engineering codes developer, aims to address the challenges associated with the safe and efficient operation of nuclear reactors by developing new computational methods for nuclear reactor multiphysics analysis.

Here then lies the first importance of my research where computational methods and simulation take the utmost importance in such cases, and one relies on mathematical equations implemented in computer codes to model and imitate real life designs and scenarios. Specifically, I focus on developing new tools for multiphysics analysis of nuclear reactors, such as adjoint-based perturbation analysis, computational fluid dynamics (CFD), finite element analysis (FEA), and which also include the time-dependent aspect of nuclear reactors operation. These methods help with sensitivity analysis, uncertainty quantification, and optimization in nuclear reactors analysis, and are used to improve the reliability and accuracy of nuclear reactors analysis of both traditional and advanced designs in the US.

As a researcher, I have been the lead developer of a nodal expansion method (NEM) computer code used in the design and analysis of nuclear reactors. NEM is a mathematical technique based on FEA for solving the neutron diffusion equation, which describes the behavior of neutrons in the reactor core. The method involves dividing the reactor core into many small regions, or "nodes," and solving the neutron diffusion equation for each node. In addition to developing and maintaining the computer code, which has been used in 30+ theses, I have added to it parallelization capability and the ability to couple thermal feedback parameters to the neutron diffusion equation by linking the code to another thermal hydraulics computer code. This allows for a multiphysics analysis framework for an accurate representation of the neutrons in a reactor core during normal and abnormal conditions. This method of my research is important for the US for designing and operating nuclear reactors because it is widely used in the US industry and research institutes for its computation speed and relatively high accuracy for simulating nuclear reactors cores. It is important for the safety analysis of nuclear reactors and allows for the prediction of the core behavior during transients and accidents, which can aid in the development of safety margins and accident management strategies in the US.

Another major part of my research work, which is funded by a leading industrial company in the field, focuses on utilizing adjoint perturbation analysis as a powerful tool for sensitivity analysis and optimization in nuclear reactors analysis. This mathematical technique allows for the efficient computation of the sensitivity of a given output variable with respect to many input variables. This method is based on the idea of constructing an adjoint model that is mathematically related to the original model, and then using this adjoint model to simplify complex computations. My research in adjoint perturbation analysis is particularly valuable in the field of nuclear engineering as it enables the identification of the most critical parameters that affect the behavior of a nuclear reactor and allows for the optimization of reactor design to achieve desired performance. I have developed and continue to research an adjoint methodology that results in a significant reduction in computational time when compared to the computer code provided by the leading industrial partner funding the research. Furthermore, it allows for the simulation of large perturbations in the targeted design inputs with high accuracy and speed. This research has led to a deeper understanding of the underlying physical phenomena in nuclear reactors, and the identification of key parameters that affect their behavior, ultimately contributing to the advancement of knowledge in the field of nuclear engineering and improving the safety and efficiency of nuclear reactors in the US by helping this leading US industrial company to upgrade its nuclear reactors designing computational codes to include such capabilities and methods.

Another aspect of my research focuses on the design and development of advanced nuclear reactors, with the goal of addressing the limitations and challenges of traditional nuclear reactors. These advanced designs include molten salt reactors (MSRs) and high-temperature gas-cooled reactors (HTGRs). My current and future research centers on developing computational codes to simulate and design these advanced nuclear reactors. For MSRs, they are a type of advanced nuclear reactors design that uses liquid fuel instead of solid fuel rods. My research is focused on adding the necessary linking methods to incorporate neutron physics and fluid dynamics due to the liquid nature of the fuel into a computer code for a leading US industrial company. For HTGRs, they use TRISO fuel, which is a "triple isotropically coated particle fuel," referring to the three layers of coating that surround the fuel kernel, which allow for high-temperature operation and safety. My research with HTGRs includes developing an uncertainty quantification tool for a US startup industrial company to help quantify the uncertainty of computational model predictions and experimental measurements in order to better understand and predict the behavior of the system. Those two advanced designs have been approved by the department of energy to be deployed in the US and our research is contributing to such pilot designs. These advanced reactor designs are important because they have the potential to significantly improve the safety, efficiency, and sustainability of nuclear energy in the US. They can provide higher temperatures that can be used for various industrial processes, and they are also more resistant to accidents, which reduces the risk of radiation releases. They could also be an important option for reducing the US nuclear waste as proven by my research.

A new research project that I just started, in collaboration with a US national laboratory partner, focuses on the NEAMS (Nuclear Energy Advanced Modeling and Simulation) framework and specifically, MOOSE (Multiphysics Object-Oriented Simulation Environment), which is a Department of Energy funded software for modeling and simulation of physical systems. My research involves adding an optimization framework to the MOOSE framework, which would allow for efficient computation of gradients of a model's output with respect to its inputs, which is critical for optimization and uncertainty quantification. The addition of an optimization framework to the MOOSE framework will enable the development of new tools and capabilities for reactors design and analysis. This research will contribute to the advancement of the field of nuclear engineering, and the optimization framework intended to be developed will help to improve the safety and performance of nuclear reactors and will be beneficial to the US as it will help to advance the US nuclear energy research and its associated workforce.

I am currently developing a research project that addresses the issue of education and training and aims to support the continued growth and advancement of the nuclear energy sector and its associated workforce in the US. This project is still in its early stages, but I am actively working on my "julia for enhancing nuclear engineering simulations" (JENES) project. Currently, I am exploring the development of new educational materials and training programs that are designed to meet the needs of the nuclear workforce for tomorrow by creating resources such as educational computational notebooks using the Julia computer language. These notebooks can combine computer code, text, multimedia, and mathematics and can be used to develop tools and codes for education and training as well as research. These resources can be designed to be accessible to a wide range of learners, from those new to the field to experienced professionals, in both pedagogical and industrial settings. I have had the opportunity to present and publish this type of nuclear engineering pedagogy-oriented research in several highly regarded conferences in the field of nuclear engineering. The feedback was positive, presenting an opportunity to continue this line of research which would help in providing a reliable and efficient way to train and update the skills of current and future nuclear engineers in the US.

As a nuclear engineering code developer with expertise in multiphysics analysis and code development, I have a proven track record of working on projects in collaboration with US national labs and industrial companies, which has helped me to develop new tools for traditional and advanced nuclear reactor design and analysis. My research will not only lead to a deeper understanding of the underlying physical phenomena in nuclear reactors and improve the safety and efficiency of nuclear reactors in the US, but it will also allow for the identification of key parameters that affect their behavior. Additionally, it will provide an important tool for the education and training of the nuclear workforce and help build the nuclear workforce of tomorrow in the US.