PURDUE UNIVERSITY | School of Nuclear Engineering

# Nuclear Engineering Seminar

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*Oak Ridge National Laboratory*

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Dr. Pradeep Ramuhalli is a Distinguished R&D Staff member, and Group Lead for the Modern Nuclear Instrumentation and Controls (I&C) group at Oak Ridge National Laboratory, where he has been working for about 6 years. Prior to ORNL, he worked at Pacific Northwest National Laboratory and at Michigan State University. His research interests are in systems resilience and reliability and lie at the intersection of measurement science, data science, and decision science. His current research is focused on developing sensors and algorithms for continuous online monitoring and diagnosis; physics-informed machine learning algorithms for virtual sensing and prognostic assessment of system and component health and in particular, passive components in nuclear power; and risk-informed methodologies to assure reliability of measurements and resilience of systems. His research is enabling development and application of digital twins and related digitalization technologies for energy systems, leading to life extension, operations and maintenance practice optimization, and economic operation of power plants, and increasing cyber-physical resilience of systems.

AI-enabled Digital Twins for Accelerating Nuclear Energy – Opportunities and Challenges

## Abstract

Advancements in artificial intelligence (AI), coupled with those in sensors, communication protocols, and visualization technologies, are expected to enable the deployment of true Digital Twins (DTs). The resulting capability is expected to have the potential for redefining and reshaping the economics of the nuclear power industry. Although interest in the use of DTs in nuclear energy is increasing rapidly, at present their implementation is limited and near-term applications are focused largely on achieving greater efficiencies in maintenance actions. Achieving real-time DTs will require the ability to rapidly analyze large volumes of streaming data and integrate information from multiple data streams. AI methods, particularly machine learning (ML), can operate on high volume data in real-time, and are being considered for applications such as the creation of a virtual reference for plant operations, for training, optimization of maintenance intervals, prioritization of maintenance activities, etc. Although nuclear power systems have a history of robust control and operations, advances in AI-enabled control have the potential to enable new operational paradigms. Recent research in this area has focused on developing the mathematical foundations and framework for controlling and optimizing complex systems through data-driven machine learning and artificial intelligence (AI). Advances in privacy preserving federated learning are beginning to highlight methods to leverage proprietary data sets, with continual learning methods helping keep DTs current with the plant state. However, several challenges will need to be overcome to achieve robust and reliable deployment of these AI-enabled DTs for nuclear energy. Quantifying confidence in the DT predictions is high on the list of challenges and will need to be addressed if the technologies are to achieve wider deployment. There also remain challenges with data adequacy, quality, and access, as well as verification and validation of the technologies as part of a robust qualification program. This presentation provides an overview of AI-enabled DTs and applications of subsets of these technologies for monitoring active and passive system health, along with opportunities and challenges in the context of safety critical applications.