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# Safe Below, Clean Above: Subsurface Engineering for Sustainable Nuclear Energy

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## Abstract:

As the world transitions toward a low-carbon energy future, nuclear energy stands as a critical component of the sustainable energy mix. However, its long-term viability hinges on the safe and permanent disposal of radioactive waste. This plenary lecture explores how geotechnical engineering plays a pivotal role in enabling the deep geological repositories (DGRs) that underpin the safety, resilience, and social acceptability of nuclear energy systems. Focusing on Canada's approach to nuclear waste management, this lecture presents recent advances in subsurface engineering for DGRs, including the characterization and modeling of complex thermo-hydro-mechanical-chemical (THMC) processes that govern the performance of both natural and engineered barriers. Through case studies and original research, the presentation will highlight how groundwater salinity, heat generation, gas migration, and glaciation cycles impact the integrity of host rock formations and barrier systems over geological timeframes. Advanced laboratory testing, physical modeling, and multiphysics simulations are used to assess long-term system behavior and guide the design of safe and sustainable nuclear waste repositories. The lecture will also discuss the implications of these findings for emerging nuclear technologies, such as small modular reactors (SMRs), and emphasize the need for continued geotechnical innovation in support of net-zero energy transitions. By bridging fundamental research with real-world applications, this lecture aims to showcase the indispensable contributions of subsurface engineering to the global pursuit of clean, secure, and sustainable energy.