Solving the Bateman Equation using Physics Informed Neural Networks

Boiger Romana

Paul Scherrer Institute: Laboratory for Waste Management

In the context of nuclear energy production, waste management, and nuclear safeguards, the precise calculation and quantification of spent nuclear fuel characteristics are important for safety, efficiency, and sustainability. The abundances and activities of nuclear composites characterizing spent nuclear fuel can be mathematically modeled with the Bateman equation. This is a linear first-order ordinary differential equation that describes the time evolution of the nuclear assemblies based on decay rates. The complexity of solving this equation arises from the stiffness of the matrix and the potentially large number of considered nuclides. Moreover, inherent uncertainties of the input quantities from theory and measurements require reliable uncertainty quantification, especially for safety assessment.

This talk presents a novel approach to solving the Bateman equation using Physics Informed Neural Networks (PINN). Several different versions of PINN with various loss functions and network architectures, including classical PINN, Hard Boundary Method, Extreme Learning Machine Method, Exponential Method, and Domain Decomposition Method were implemented and validated. Their performance was tested on a simplified real use case considering the decay of Plutonium241. The performances of the PINNs were validated against the current state-of-the-art solution method, the Chebyshev Rational Approximation, and showed comparable accuracy.

Furthermore, the best PINN model was used to perform uncertainty quantification, demonstrating how the use of transfer learning can result in competitiveness with state-of-the-art solvers. The talk will present the advantages as well as the limits of the considered PINN methods for solving the Bateman Equation.