Replicating and Evaluating A Deep Larning Approach to Nuclear Fuel Transmutation in a Fuel Cycle Simulator

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INTRODUCTION

The nuclear fuel cycle is fundamental to nuclear energy production and reactor operations. Understanding the fuel cycle is essential for assessing how different enrichments and burnups affect the isotopic composition of spent nuclear fuel (SNF), including its concentration of various isotopes and decay heat. These factors play a crucial role in determining appropriate strategies for SNF management, including storage, reprocessing, or disposal. Optimizing these processes requires accurate depletion modeling to inform decision-making on waste handling and potential resource utilization[1].

This work replicates the study conducted by Bae et al. (2020)[2], where the authors trained a neural network model on the Unified Database (UDB)[3] for Pressurized Water Reactor (PWR) Mixed Oxide (MOX) fuel with varying enrichments and burnups. Their results demonstrated that the model provided a balance between fidelity and computational efficiency compared to other nuclear fuel cycle simulators. However, since the UDB has since been updated, there is an opportunity to validate their approach using new data. Bae et al. noted that, ideally, their model should be tested against a dataset it was not trained on, but this was not feasible at the time, leading them to validate the model using a subset of their training data. In this study, we implement their trained neural network model within the CYCLUS framework and evaluate its performance using the updated dataset. This allows us to assess whether the model still outperforms traditional recipe-based methods in fuel cycle simulations.

CYCLUS

CYCLUS [4] is an open-source, agent-based nuclear fuel cycle (NFC) simulation framework designed for flexibility and extensibility. Unlike traditional simulators that rely on fixed system models, CYCLUS treats each facility—such as reactors, enrichment plants, and storage sites—as independent agents that interact dynamically. These agents operate under predefined rules, exchanging materials through a market-based mechanism called the Dynamic Resource Exchange [5].

A key strength of CYCLUS is its modular architecture, which allows users to define and deploy custom facility models, known as archetypes, implemented in C++ or Python. Standard NFC processes, such as enrichment, reprocessing, and storage, are available in the Cycamore[6] repository, while additional community-developed archetypes extend its capabilities for specialized applications, including spent fuel transmutation and diversion modeling. This modularity enables CYCLUS to simulate a wide range of NFC scenarios, making it a powerful tool for analyzing the impact of policy decisions, technology changes, and resource availability on nuclear energy systems.

UNIFIED DATABASE

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