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#5-252 Advancing Uranium Hexafluoride Conversion: Machine Intelligence in the Integrated Dry Route Process

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This research presents an enhancement to the Integrated Dry Route (IDR) process for uranium conversion in nuclear fuel fabrication, aiming to create a more adaptive system capable of dynamically responding to fluctuations in key variables. The approach involves applying advanced data conditioning and feature extraction methods to process historical industrial datasets, ensuring effective extraction of critical information for accurate analysis. Central to this modification is the development of Bidirectional Long Short-Term Memory (Bi-LSTM) sequence classification networks, specifically designed, trained, and rigorously tested to predict the quality of uranium dioxide (UO_2) output, with a focus on controlling fluorine content—a crucial factor in nuclear fuel applications. Fluorine content in uranium (F-in-U) is critical because it directly depends on the IDR process. Although other parameters may be influenced by subsequent processes, such as blending before palletisation, the F-in-U level remains essential despite fluorine's limited role in the fission reaction. High fluorine levels or other impurities can indirectly impact reactor performance by altering the fuel's thermal conductivity and expansion properties, potentially disrupting heat transfer within fuel rods and reducing reactor efficiency. Additionally, fluorine can react with reactor materials, causing corrosion or degradation of fuel cladding, which affects reactor integrity. While fluorine itself is not a strong neutron absorber, impurities like uranium fluorides can influence neutron moderation and absorption, altering reactor behaviour. High fluorine levels or other impurities can compromise the fuel's mechanical and chemical stability, leading to fuel degradation, increased retention of fission products, or reduced fuel assembly lifespan. From the available data, a set of features from the IDR process was selected, and additional features were generated using the kiln operator's datasheet and tacit knowledge gathered through conversations with the kiln's operators. Several training experiments using the Bi-LSTM were conducted: (1) using features from primary magnitudes (flow rate, temperature, and pressure) of the chemical elements involved (UO_2, H_2O, and H_2); (2) using the features described in (1) plus a set of variables (mostly temperatures and pressures) from other kiln sections; (3) using the features in (1) and (2) plus additional sequences created from operators' tacit knowledge and documented experiments; and (4) using only the features derived from tacit knowledge and previous experiments. The Bi-LSTM network demonstrated the highest level of effectiveness in test case (3), accurately predicting UO_2 quality outcomes (98% for rejected batches and 97% for acceptable batches), underscoring its potential as a foundational element in developing digital twins for the IDR process. Digital twins—virtual models that replicate real-world processes—would enable the IDR system to simulate and predict process variations in real time, facilitating immediate adjustments to kiln conditions. As the Bi-LSTM models are further refined, this technology could support a fully adaptive IDR process, allowing instantaneous responses to process conditions, optimizing efficiency and consistency in uranium conversion, and ensuring stringent quality control in nuclear fuel manufacturing.

Primary authors: PARKER, Andrew (Lancaster University); TAYLOR, C. James (School of Engineering, Lancaster University, United Kingdom); HUTCHINSON, Daniel (Westinghouse Springfields Fuels Ltd.); EAVES, David (Westinghouse Springfields Fuels Ltd.); ZABALZA, Jaime (University of Strathclyde); JOYCE, Malcolm

(Lancaster University); BANDALA, Manuel (Lancaster University); COCKBAIN, Neil (National Nuclear Laboratory); CHARD, Patrick (Mirion Technologies); MURRAY, Paul (University of Strathclyde); STIRZAKER, Paul (Westinghouse Springfields Fuels Ltd.); DUNPHY, R. David (University of Strathclyde); MA, Xiandong (University of Lancaster)

Presenter: BANDALA, Manuel (Lancaster University)

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