Contract No:

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SRNL Activities Related to the Blanket and Fuel Cycle Program – FY22 Summary

The Office of Science's Blanket and Fuel Cycle Program is a multi-laboratory collaboration focused on providing technical knowledge and guidance on the Deuterium-Tritium (DT) fusion fuel cycle. Savannah River National Laboratory leveraged expertise in tritium handling and processing to develop and implement models of the DT fusion fuel cycle in both areas of real-time accountancy and inventory reduction investigation.

1. Real-Time Accountancy of Tritium in a Fusion Fuel Cycle

Tritium accountancy in a fusion fuel cycle is a significant concern for the operation of commercial devices. It is expected that a limit on the maximum amount of tritium inventory in the system will be implemented, meaning that accountancy of the tritium inventory in the fuel cycle will need to be as accurate as possible. This is difficult since not all locations along the fuel cycle can benefit from the implementation of a tritium accountancy sensor and measurements will inherently contain error. Commercial fusion plants will also operate continuously, challenging current accountancy techniques that rely on static processes in well-controlled environments. SRNL defined a simple fusion fuel cycle concept, and the time-dependent tritium inventory of each sub-system was calculated using a discrete time model developed in Python. The model takes a series of differential equations and returns the time-dependent inventory using the Euler Approximation. This discrete-time model will be referred to as the System Model. Once the System Model was developed the inventory output was then used to Simulate Sensor Measurements at specific points on the fuel cycle. The Simulated Sensory Measurements were a combination of the System Model output and a normal distribution error of about 60%. The Simulated Sensor Measurements and the System Model were then passed through a linear Kalman Filter (KF). The KF is a state prediction algorithm that take observations/measurements and information about the system to return the predicted 'true value' of the state. In the process, the KF reduces the error in the measurement for more accurate predictions of the state. In this work the state is the inventory of the subsystems. The Kalman Filter reduced the percent error in the measurement from 60% to 0.001%. This error percentage is lower than the accountancy standard of 1%. This study demonstrated that, with an accurate System Model and continued improvements, the Kalman Filter is a potential option for accounting the true inventory of tritium in a fusion fuel cycle.

Percent Error in the Kalman Filter Output (KF) to the System Model Output*

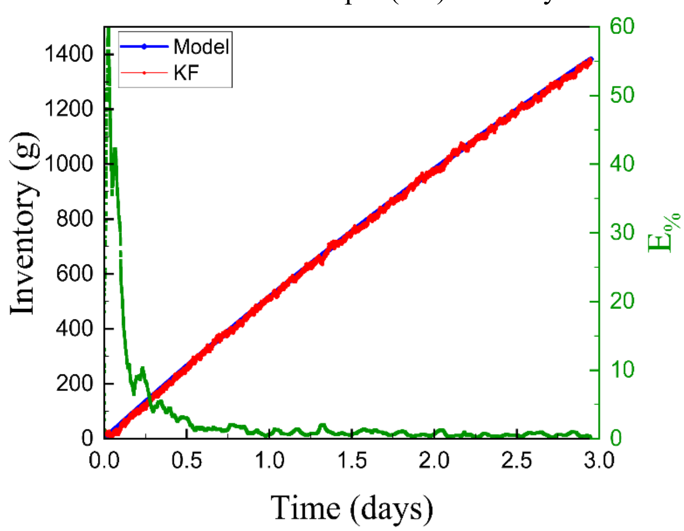
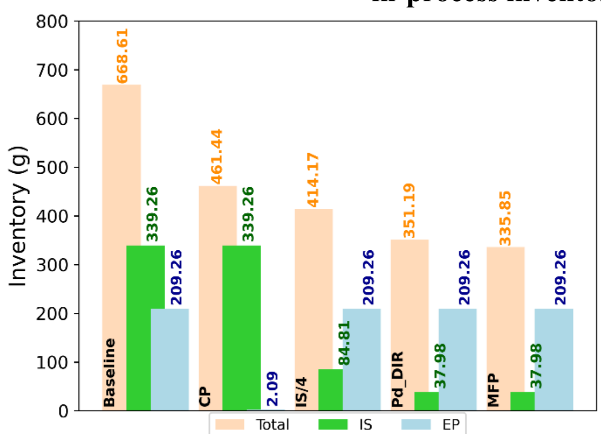


*Fig. 12 Flynn, H. B., & Larsen, G. (2022). Investigating the application of Kalman Filters for real-time accountancy in fusion fuel cycles. *Fusion Engineering and Design*, *176*, 113037.

2. Inventory Reduction of Tritium in a Fusion Fuel Cycle

Developing a Fusion Pilot Plant (FPP) design that minimizes risks due to tritium in-process inventory is an important concern for the operation of commercial devices. This becomes even more of concern since an FPP will be breeding more tritium than is burned in the reactor for sustainability. The in-process inventory (IPI) is the tritium moving through the system that is not in the storage and delivery sub-system. A process model that solves time-dependent differential equations based on processing times was used to investigate the reduction of IPI of a potential fuel cycle design. The impact of new and more efficient technologies such as Direct Internal Recycling (DIR), Metal Foil Pumps (MFP), Continuous Pumping (CP), improved Isotope Separation (IS), and hydrogen separating continuous pumps (HSCPs) on IPI was investigated by adjusting sub-system processing-times and material flow streams. It was shown that any of the insertions of DIR studied caused a reduction in the total IPI of the system and proved to be the optimal way to reduce IPI. The study also showed that fuel cycle modifications near the torus, such as a coupled DIR and improved pumping systems, produced the largest reductions in tritium inventory. The in-process inventory was reduced by > 50% when incorporating some form of DIR. A maximum reduction of > 71% was realized when implementing all modifications. It is important to note that any modification that included CP showed a reduction in in-process inventory.

Calculated IPI after 365 days for the Total IPI and the IS and EP sub-systems after implementing in-process inventory reduction methods



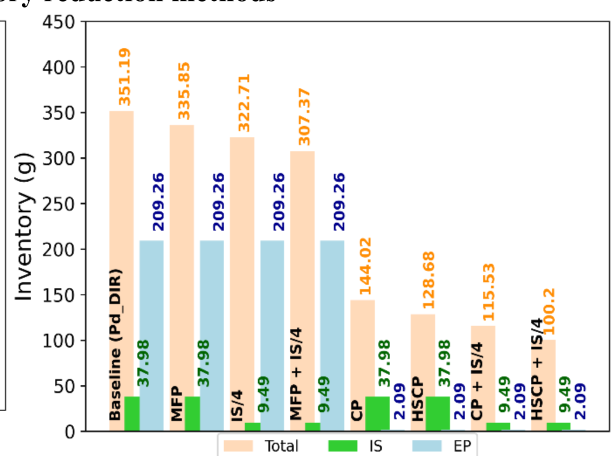


*Fig. 5 & 6 (Accepted) "Fusion Fuel Cycle Inventory Reduction Studies using a Processing Time based Discrete-Time Interval Model" in a Special Edition of Fusion Science and Technology, Young Investigators of Fusion

Citations

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