

Design of a Fast Reactor Using Depleted Uranium Fuel

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Introduction and Purpose

- Conventional thermal nuclear reactors are only capable of directly fissioning uranium-235, which constitutes approximately 0.7% of natural uranium resources.
- This project's objective is to design a fast-spectrum reactor with the function of optimizing fission in uranium-238. This isotope constitutes the highest proportion of depleted uranium, as well as the isotope of greatest abundance in natural, mined uranium.

Methodology

- Create and use MCNP models to find a critical configuration.
 - Done for both heterogenous and homogenous fuel types of the Revolver Cylinder style reactor
 - Done for a sphere geometry to simulate Thermometer style reactor
- Vary parameters to determine optimal geometry.
 - Size
 - Mass % Pu
 - Control Materials
- Find energy spectrum and use that to calculate breeding ratio and uranium 238 fission ratio
- State-space model developed for selected design based on advection-dominated heat transfer to assess dynamics behavior and ensure thermal limits are not exceeded
- Revolver Cylinder was initially chosen for its compatibility with heat pipes
- Thermometer Reactor was chosen for its controllability with thermal expansion

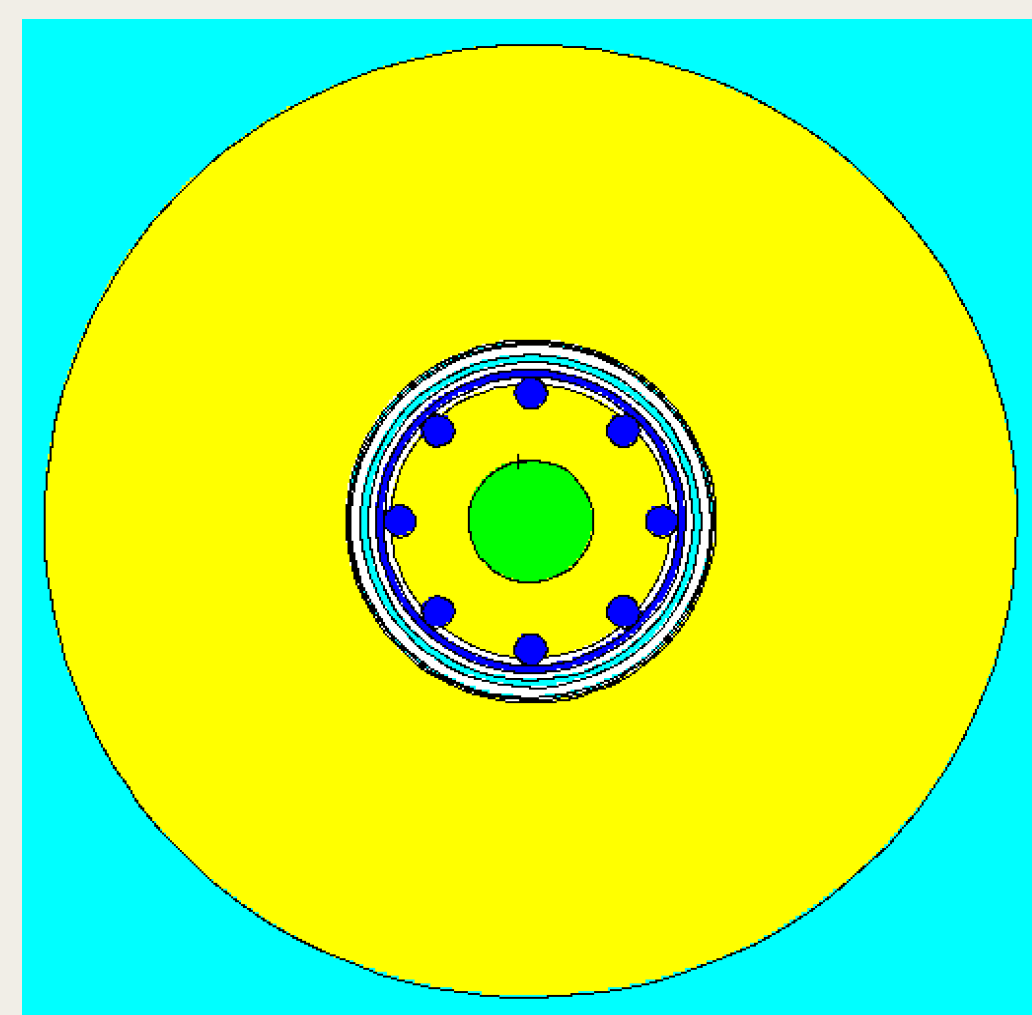


Figure 1. MCNP model of Revolver Cylinder reactor

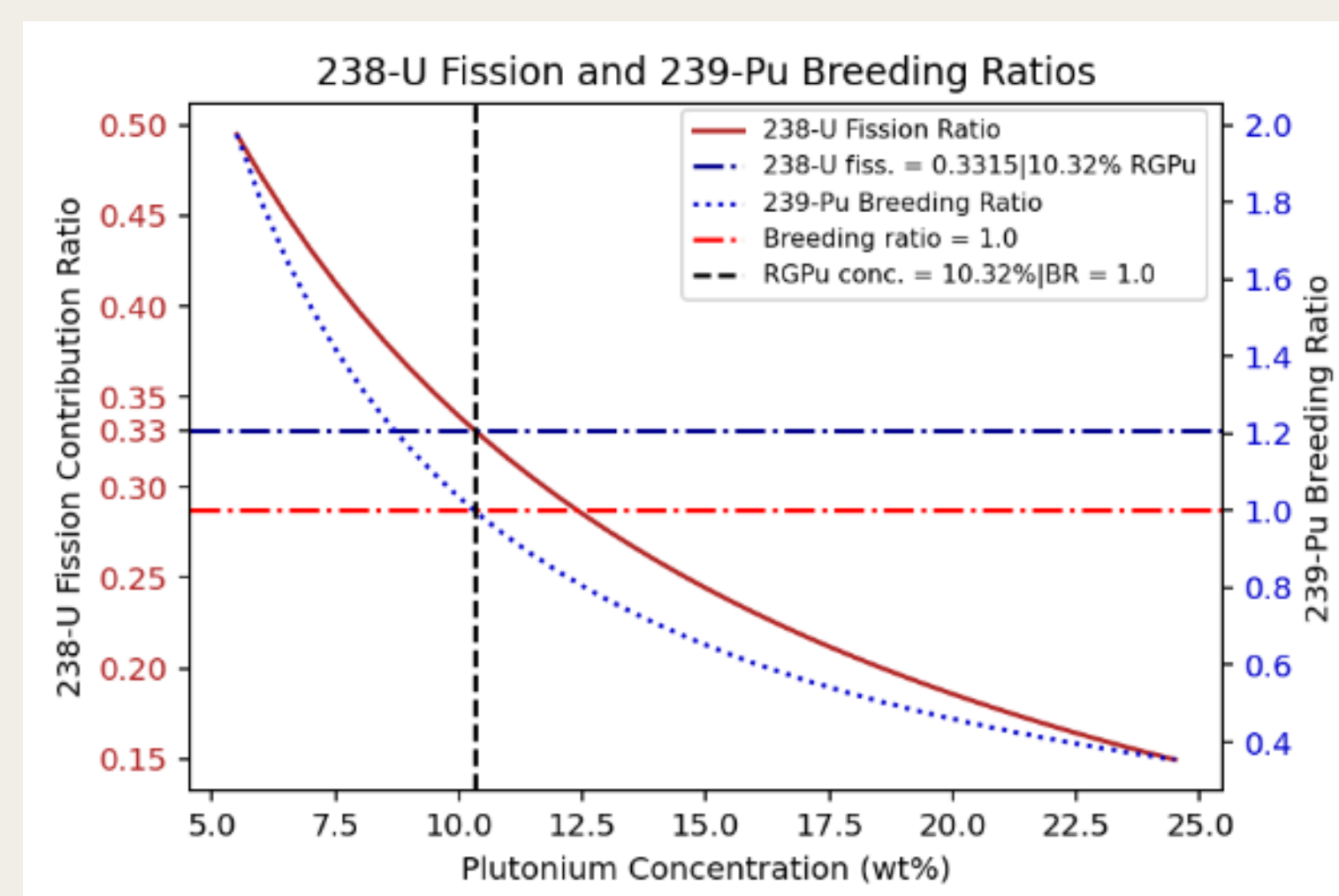


Figure 2. Fission and breeding ratios based on MCNP spectrum

Results

Revolver Cylinder Style

- Based on NASA's KRUSTY reactor [1].
- A temperature distribution in the fuel, seen in Figure 1, was generated in MATLAB using a convective boundary condition for the heat pipes and internal heat generation within the fuel bulk.
- The heat pipe convection coefficient was based on educated presuppositions and an analytical heat pipe model [2].
- The Revolver Cylinder style design produced low rates of uranium 238 fission from MCNP mesh tallies and was deemed ineffective.

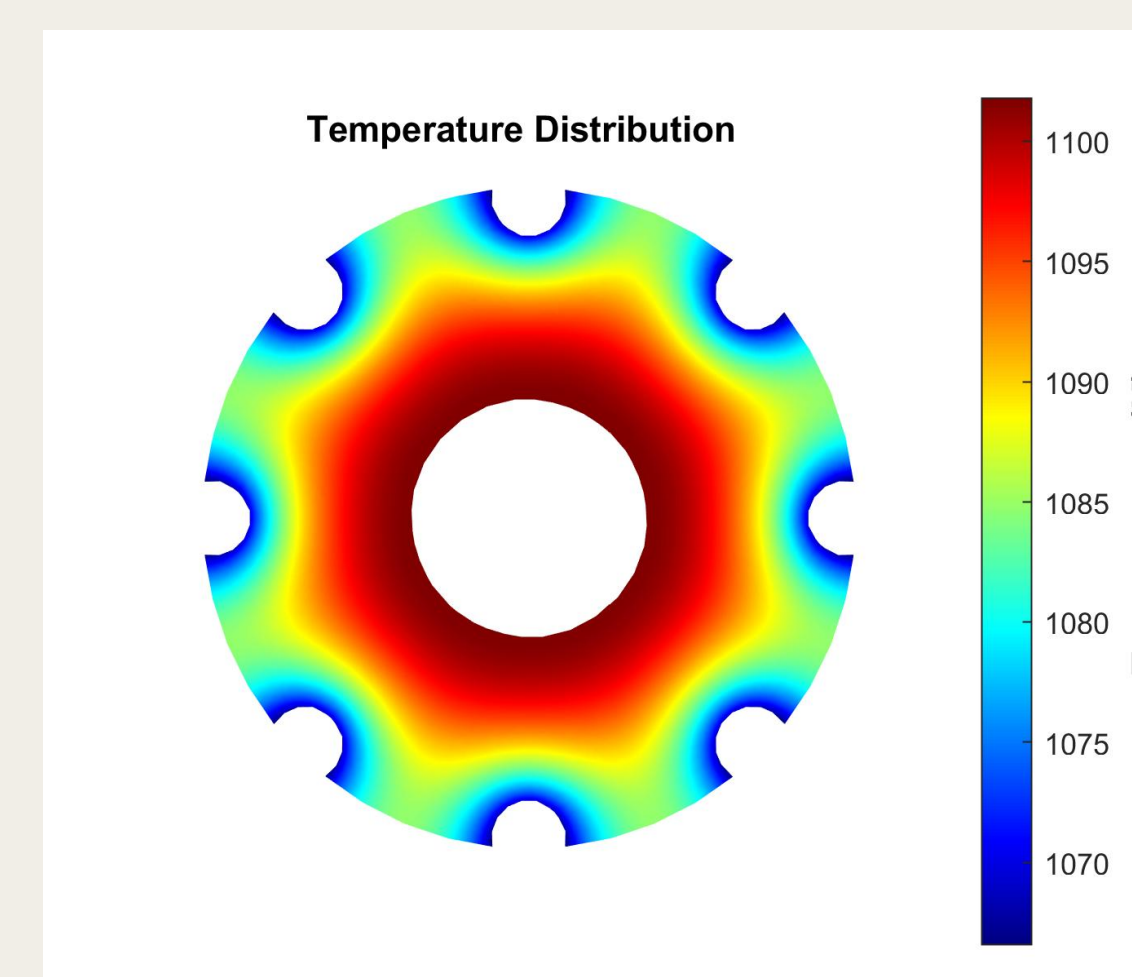


Figure 3. Temperature distribution of Revolver Cylinder style

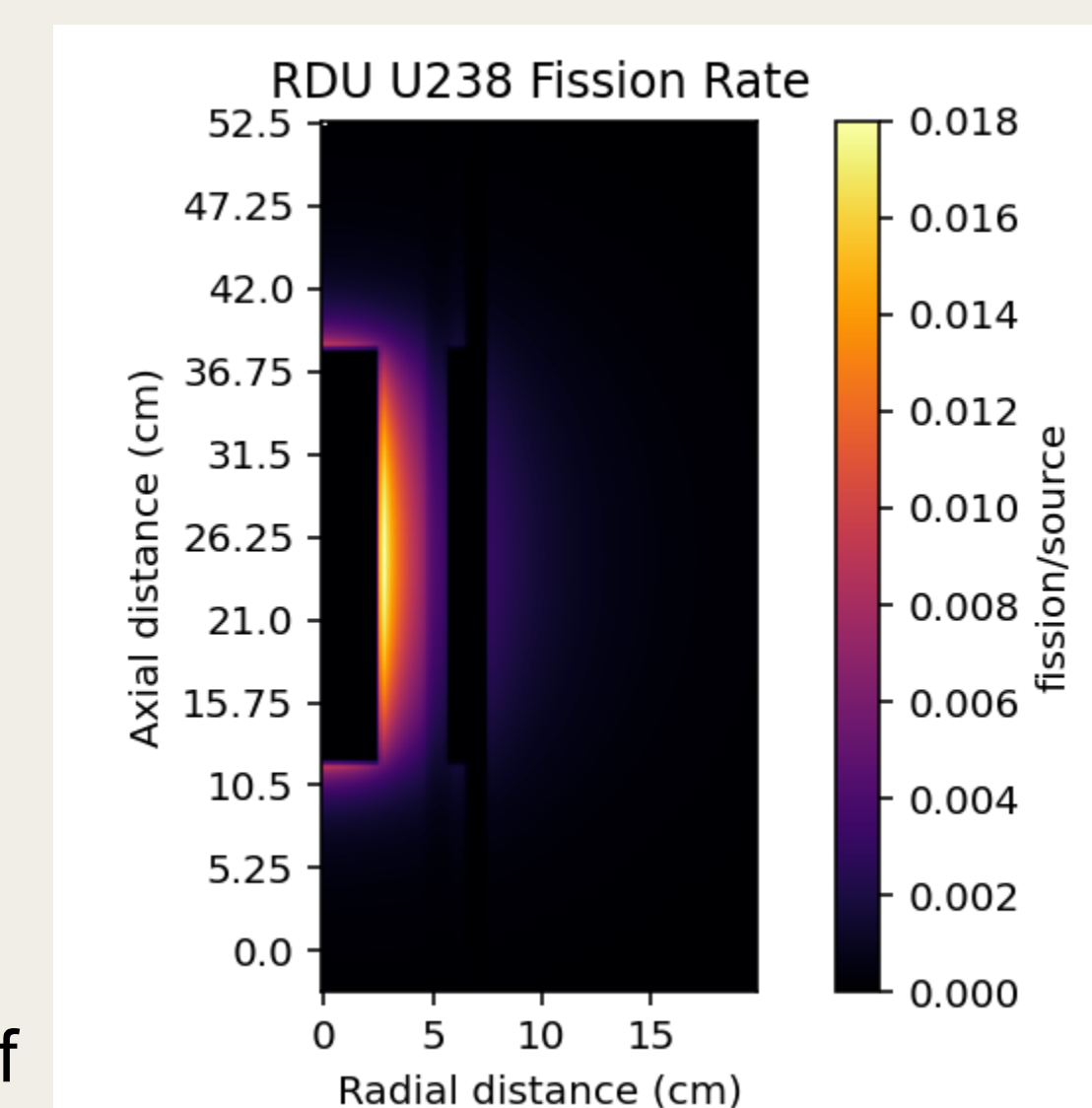


Figure 4. Fission Rate in U-238 for Revolver Cylinder style

Thermometer-Style

- Based on Homogeneous Reactor Test (HRT) [3]
- Fluid fuel allows reactivity insertion to be bounded by delayed neutron fraction using differential radiator pair [4]
- Thermal expansion of fuel into high-leakage "thermometer stem" plenum provides prompt + inherent feedback
- Large fission rate in DU, configured to breeding ratio 1.0
- Favorable dynamics determined by state-space model simulation

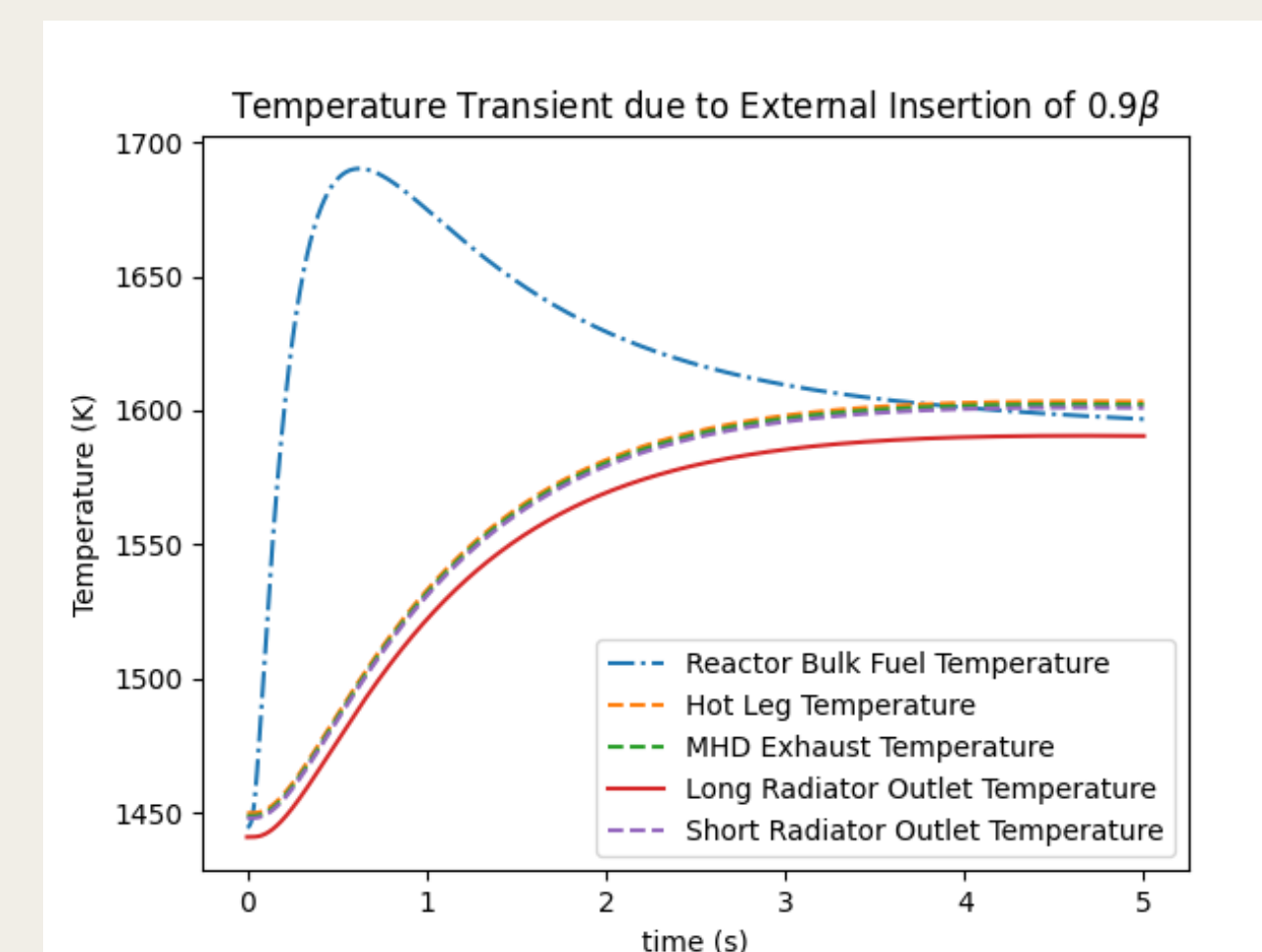


Figure 5. Temperature transient due to external reactivity insertion

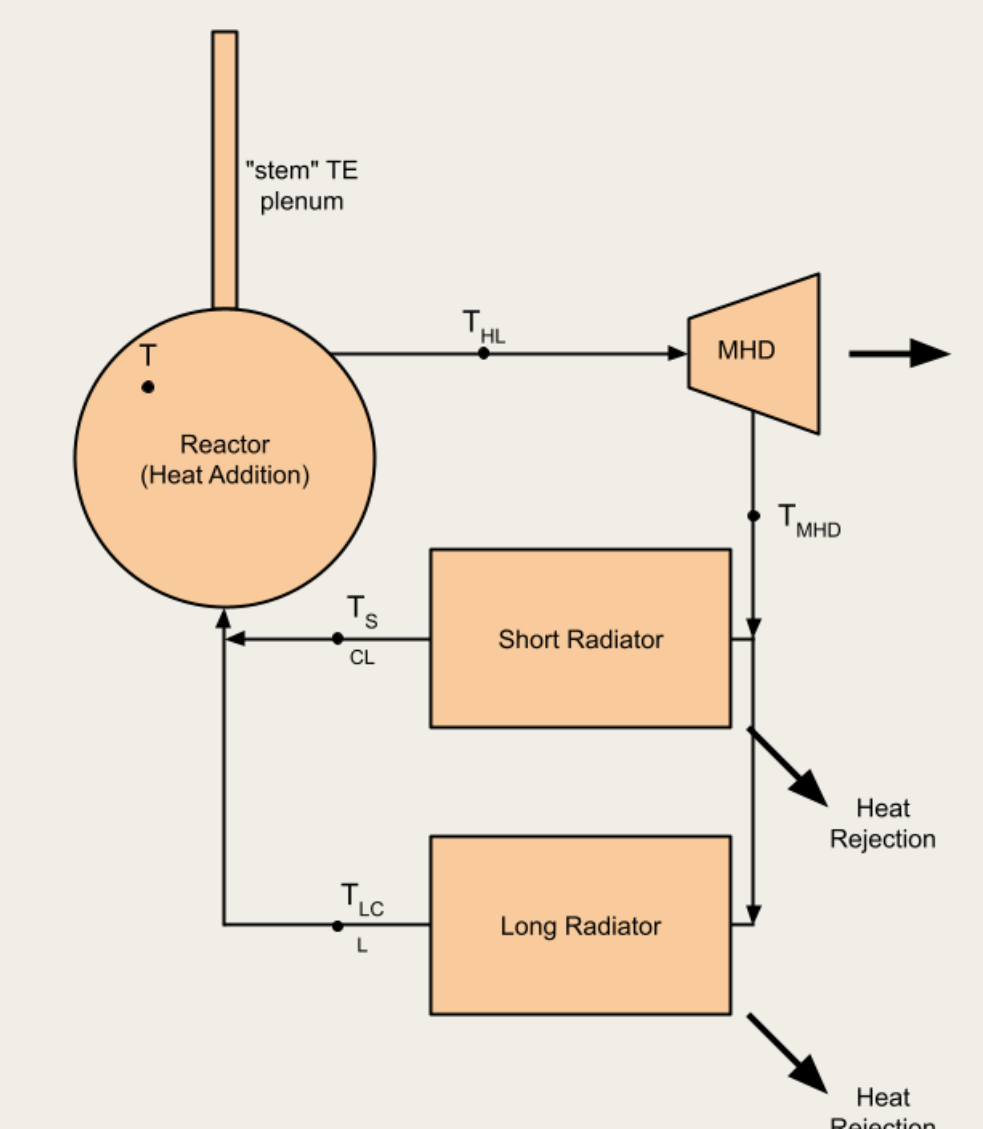
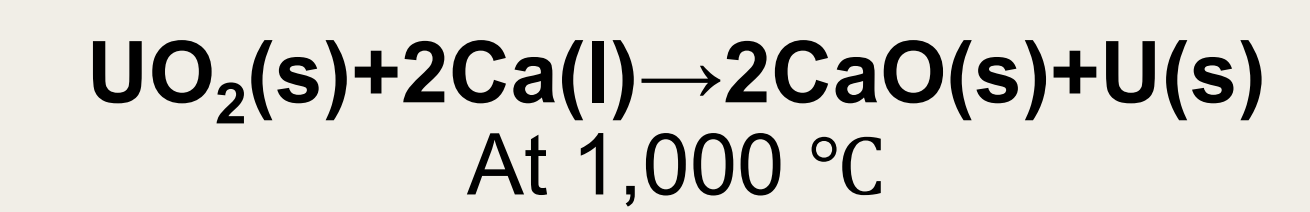


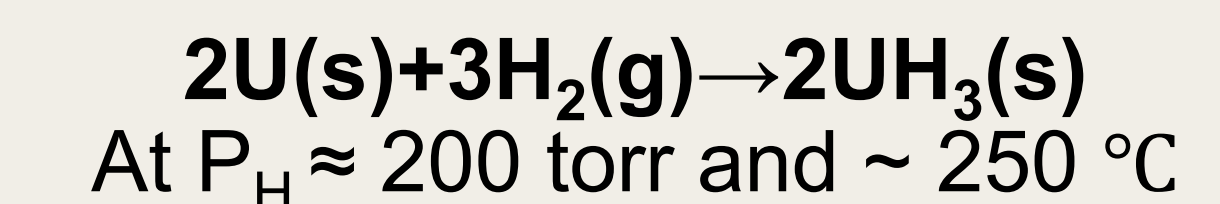
Figure 6. Process flow diagram of Thermometer Style plant

Experimental Design

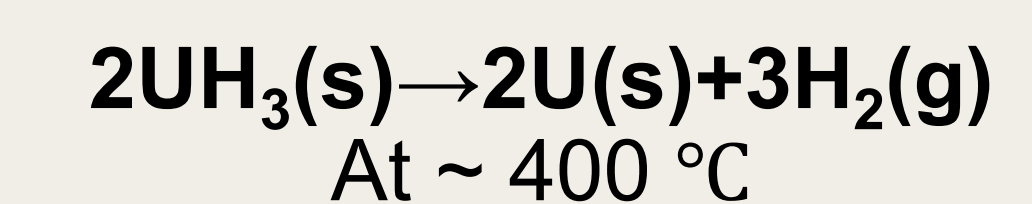
Calciothermic reaction



It should be noted that calcium is regularly used in industry to produce metallic uranium



Cool down with liquid nitrogen to physically separate out ferromagnetic $\text{UH}_3(\text{s})$ at ~ -196 °C



Sinter $\text{U}(\text{s})$ at $\sim 1,132$ °C

Future Work

- Improve MCNP models by including BOP piping
- Furnish data on materials' physical properties at expected operating temperatures
 - Experimental work is demanded on molten fuel alloy and structural materials
- Utilize data to refine state-space model
 - Implementation of a controller to test response time to transients using control configuration
- Implement continuous, 3D reaction rates
 - Obtain true breeding ratio and U-238 contribution
- Addition of spatially-resolved kinetics with multiple precursor groups
- Implement combined conduction and advection heat transfer
 - Provides more accurate description of reactor nominal power
 - Further specify thermal limits
- Determine accurate materials properties
 - Large experimental demand

Acknowledgements

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