Impacts of Using HALEU on the Nuclear Fuel Cycle
NC State University Building Future Faculty Program

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March 31, 2022

Outline

Background

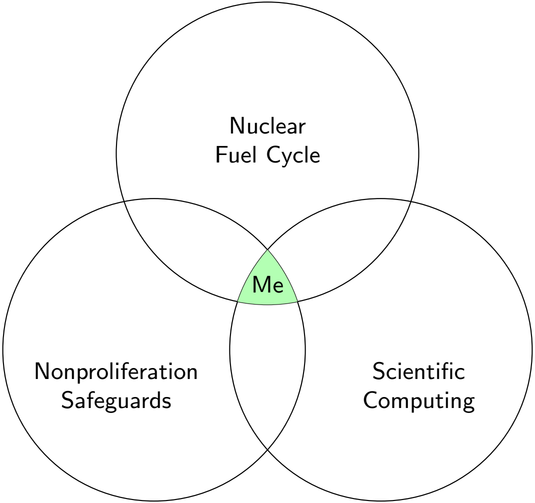
Education

- BS in Nuclear Engineering, University of Tennessee, Knoxville (2019)
- MS in Nuclear Engineering, University of Tennessee, Knoxville (2020)
- PhD in NPRE, University of Illinois Urbana-Champaign (In Progess)

Research Experience

- Multivariate modeling of radiation signatures for safeguards
- Modeling material flow through a pyroprocessing facility
- Comparing effects of Doppler broadening methods in SHIFT (ORNL)
- Investigating fuel cycle impacts of using High Assay Low Enriched Uranium (HALEU) in reactors

Research Interests



Outline

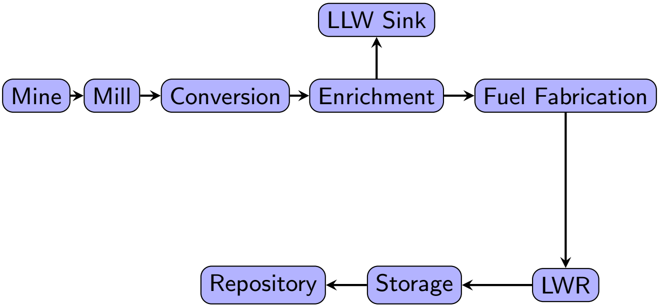
Introduction

- Multiple new reactor designs require HALEU fuel, which allows for:
  - Longer cycle times
  - Higher burnups
- To meet the HALEU demand, the U.S. Department of Energy (DOE) has proposed two methods [3]:
  - Recovery and downblending of High Enriched Uranium (HEU)
  - Enrichment of natural uranium

Table 1: Categories of uranium enrichment by weight fraction of uranium-235.

Category	Weight fraction (%)
Depleted	$<$0.711
Natural	0.711
LEU	0.711-20
HALEU	5-20
HEU	$\geq$20

Overview of the Nuclear Fuel Cycle



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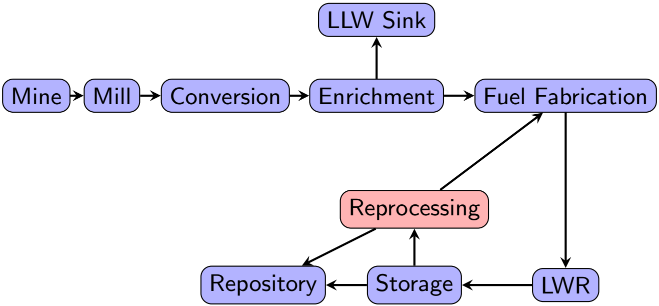

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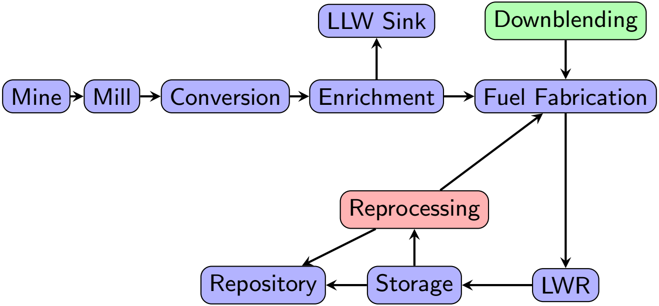

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- Quantify material requirements of the transition to reactors fueled by HALEU
- Perform sensitivity analysis to understand how each of these metrics are affected by model parameters
- Identify potential fuel cycles that are optimized for specific objectives
- Investigate how the impurities in HEU stockpiles affects reactor neutronics

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  - Energy demand
- We can use fuel cycle simulators to model these transitions

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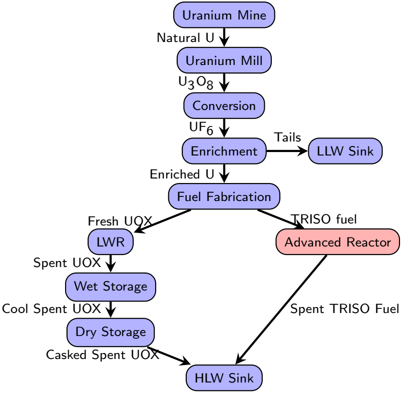

Figure 2: Fuel cycle facilities and material flow between facilities.

Model transitions using CYCLUS

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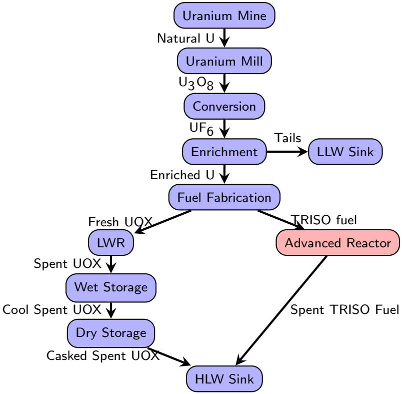

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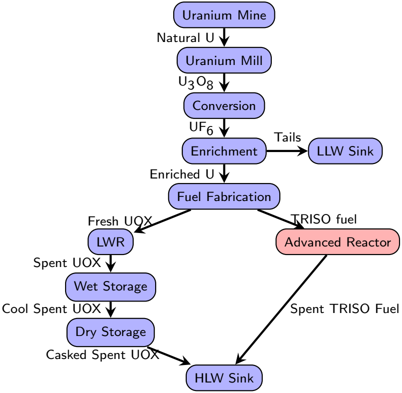

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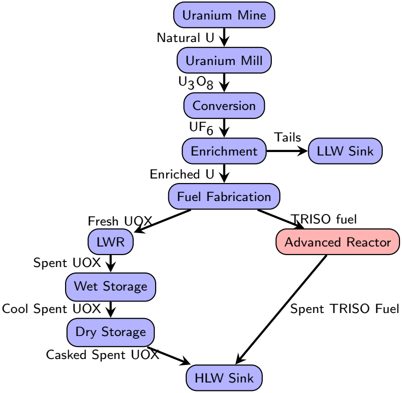

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- Transitions begin in 2025
- CYCLUS determines the number of reactors that need to be deployed

Multiple reactors and energy demands are considered

Table 2: Advanced reactor design specifications

Design Criteria	USNC MMR [6]	X-energy Xe-100 [4] [5]
Power Output (MWe)	10	75
Enrichment (% ^{235}U)	13	15.5
Cycle Length (yr)	20	Online
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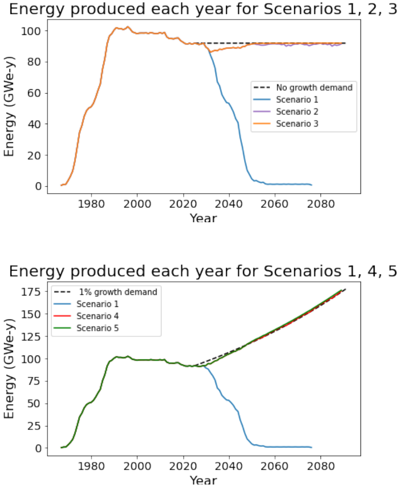
Table 3: Scenario Descriptions

Scenario	Advanced Reactor	Growth
1	N/A	N/A
2	USNC MMR	None
3	X-energy Xe-100	None
4	USNC MMR	1%
5	X-energy Xe-100	1%

Energy demand is not fully met during the transition

- Energy produced by LWRs in Scenario 1 in 2025 is 91.818 GWe-y
- Scenarios 2 and 3 do not meet demand between 2030-2050
- Scenarios 4 and 5 do not meet demand between 2026-2048



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- Scenarios 2 and 3 do not meet demand between 2030-2050
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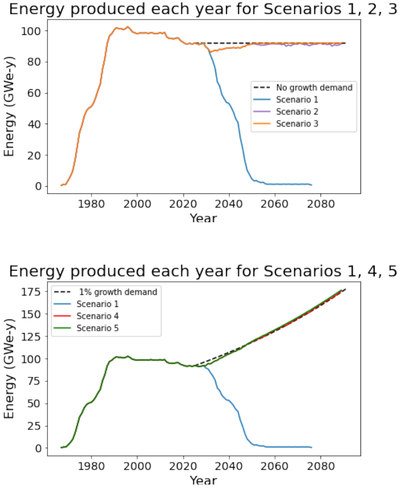
- Noticable deviations from demand in Scenarios 2, 4 when new reactors are deployed
- Initial gap between demand and energy produced is due to how Cyclus is deploying the reactors



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Reactor deployment scales with the power of the reactors

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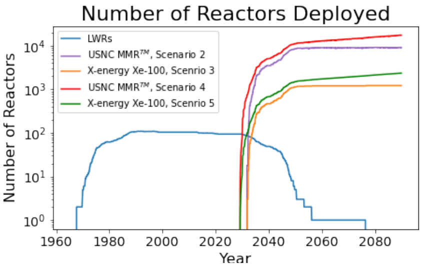

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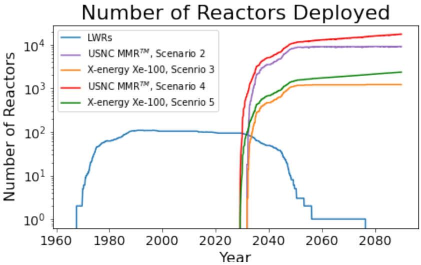

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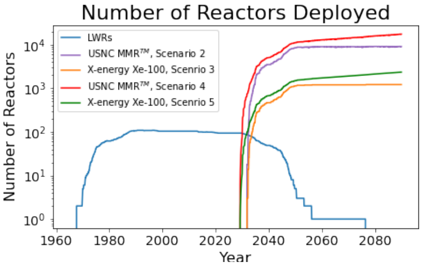
- In the 1% growth scenarios (Scenarios 4 and 5) the advanced reactors are deployed starting in March 2029
- The maximum number of advanced reactors deployed at one time in Scenarios 2-5 are 9182, 1225, 17656, and 2361 reactors, respectively



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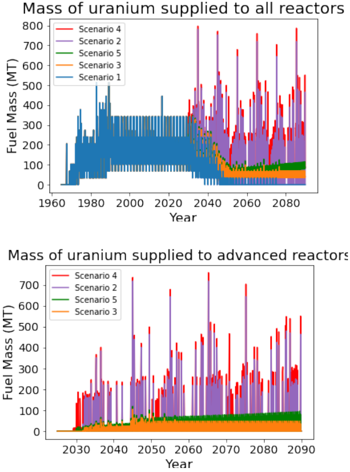

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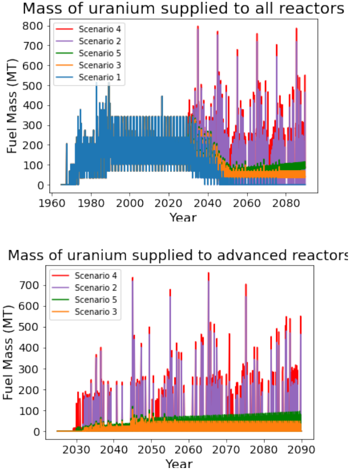
- Large peaks in Scenarios 2 and 4 correspond to the deployment of new reactors
- Less variation with time in the uranium supplied to reactors for Scenarios 3 and 5 than Scenarios 2 and 4



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- Online refuling of X-energy Xe-100 provides a more consistent demand for fuel
- Changing to a 1% growth demand model requires advanced reactors to be deployed 2.5 years earlier
- Understand the material demands of these transitions helps us design facilities for a future fuel cycle

Full results can be found in [2].

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Ongoing Work

- Once-through transitions
  - Incorporate LWR license expiration dates
  - Quantify natual uranium needs and waste production in these transitions
  - Simulate transitions to multiple types of advanced reactors

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  - Simulate transitions to multiple types of advanced reactors
- Model transitions with recycling
  - Impacts the resource utilization?
  - Impacts of limited vs continuous recycling?

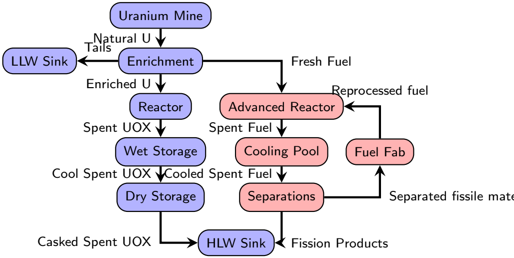

Figure 6: Fuel cycle facilities and material flow between facilities. Facilities in red are added in for the transition scenarios.

Ongoing Work (Cont.)

- Perform sensitivity analysis
  - Transition start time
  - Fleet share for each reactor
  - LWR lifetimes
- Optimize the transition

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  - Transition start time
  - Fleet share for each reactor
  - LWR lifetimes
- Optimize the transition
- Investigate neutronics effects of HEU impurities
  - Effects on neutron flux and k_{eff}
  - Effects on safety parameters?
  - More work to investigate this question?

Acknowledgements

This material is based upon work supported under an Integrated University Program Graduate Fellowship. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Department of Energy Office of Nuclear Energy.

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Summary

- Investigating the transition to HALEU-fueled reactors
- Results show larger uranium mass requirements to transition to MMR than Xe-100
- Working on investigation material needs when fuel is recycled.