LEU+ to HALEU transitions in advanced reactor fuel cycles

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Outline

What are our options if we cannot get HALEU fuel?

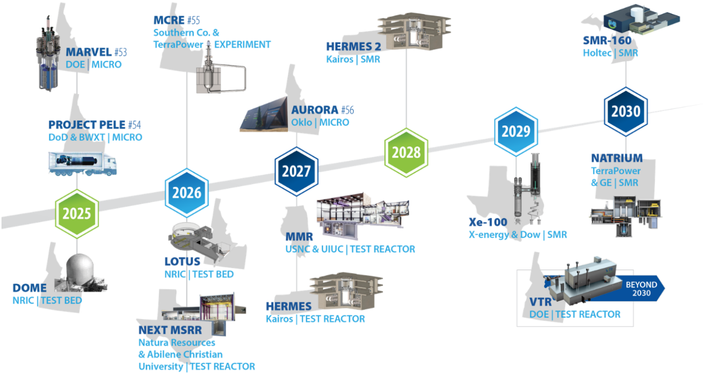


Figure 1: Advanced reactor demonstration and deployment projects [1].

Could we use low-enriched uranium plus (LEU+) while HALEU supply chains develop?

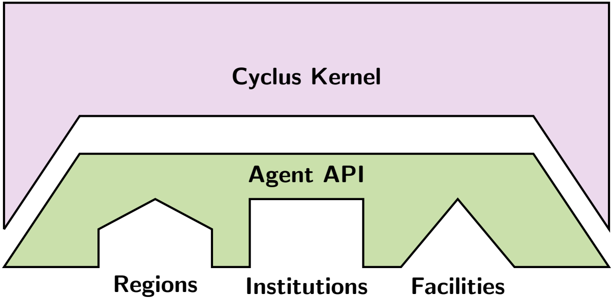
We simulate a 3-reactor-model transition for 2030-2100

Table 1: Advanced reactor design specifications.

Design Criterion	**MMR** [2]	**Xe-100** [3]	**AP1000**
Reactor Type	HTGR	HTGR	PWR
Power Output [MWe]	15	100	1000
Fuel Type	TRISO	TRISO	UO_2
Enrichment [% ^{235}U]	9.95, 19.75	9.95, 15.5	5
Cycle Length	20 [yrs]	Online Refuel	18 [mo]
Final Burnup [GWd/MTU]	82	168	65
Reactor Lifetime [yrs]	20	60	60

We use CYCLUS to model fuel cycles.

CYCLUS is an open-source agent-based fuel cycle code allowing for detailed facility and transaction modeling [4].



The CYCLUS ecosystem has many *archetypes*, or generic facility models, (like the CYCAMORE Reactor) that can be used to model different fuel cycle facilities.

Outline

Greedy reactor deployment algorithm

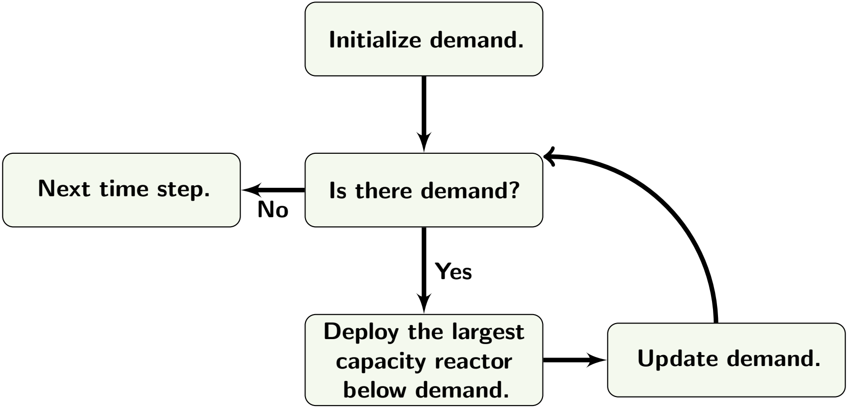


Figure 2: The greedy deployment diagram demonstrates a preference for the larger power capacity reactors, and shows how the scheme could under-deploy if the remaining capacity is less than the size of the smallest reactor.

Random reactor deployment algorithm

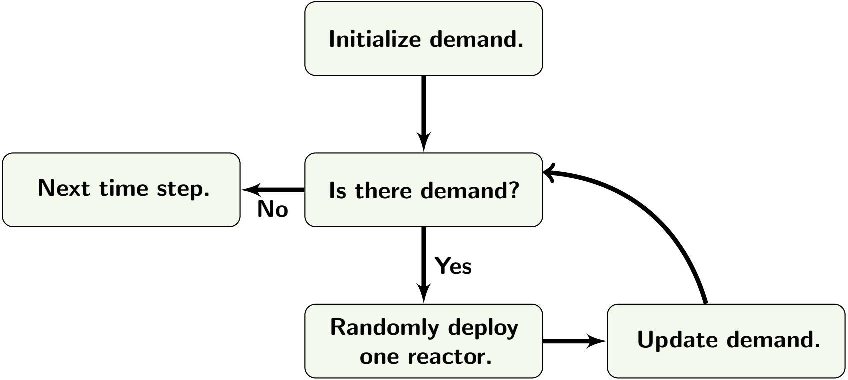


Figure 3: Random reactor deployment diagram. This algorithm randomly deploys reactors until the demand is met. If a reactor is deployed that exceeds the demand, it will simply be removed and the algorithm will try again.

Random + greedy reactor deployment algorithm

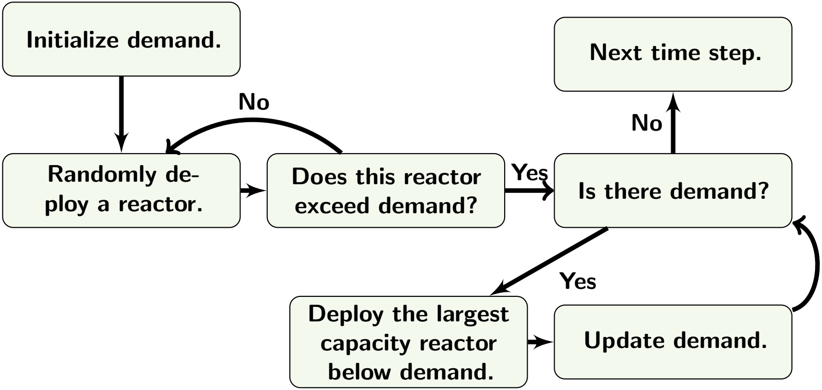


Figure 4: Random + Greedy deployment diagram. This algorithm first attempts to randomly deploy a reactor, and if that reactor exceeds demand, it will remove the last reactor and then use the greedy approach to fill in the remaining demand.

Outline

Our demand for energy is going up

We will compare each deployment algorithm with a demand growth scenario that:

- doubles nuclear capacity by 2050,

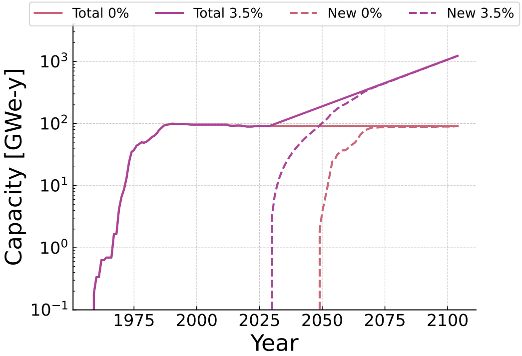
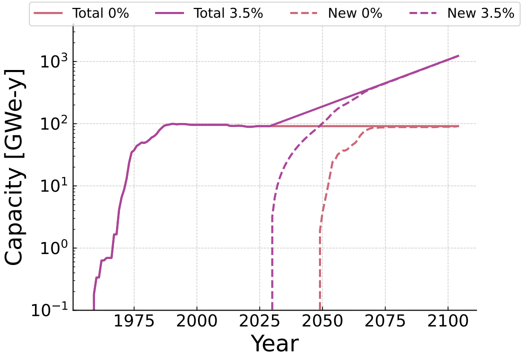


Figure 5: Nuclear electricity capacity to present day with projection of doubling nuclear by 2050 from DOE Liftoff Report [5].

Our demand for energy is going up

We will compare each deployment algorithm with a demand growth scenario that:

- doubles nuclear capacity by 2050,
- starts deploying the advanced reactors in 2030,



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Our demand for energy is going up

We will compare each deployment algorithm with a demand growth scenario that:

- doubles nuclear capacity by 2050,
- starts deploying the advanced reactors in 2030,
- and uses LEU+ from 2030-2040.

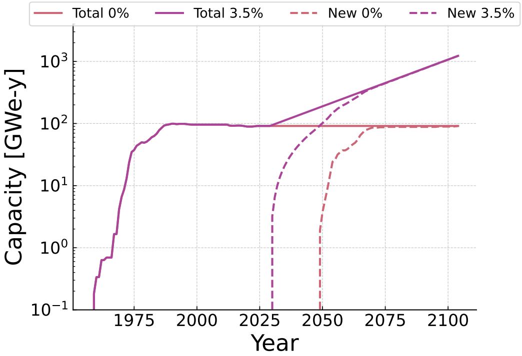


Figure 5: Nuclear electricity capacity to present day with projection of doubling nuclear by 2050 from DOE Liftoff Report [5].

The total mass for scenarios with and without LEU+

We have approximated that each reactor's capacity for LEU+ will be the same as their capacity for HALEU.

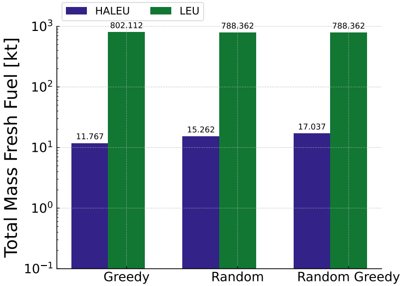


Figure 6: No-LEU+ scenario.

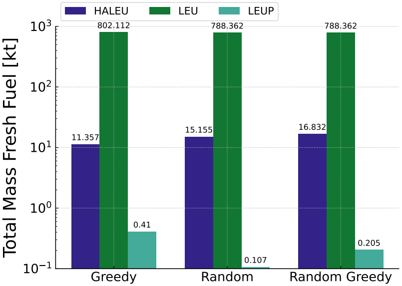
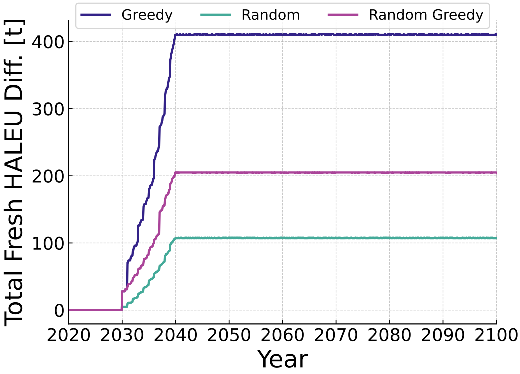


Figure 7: LEU+ to HALEU scenario.

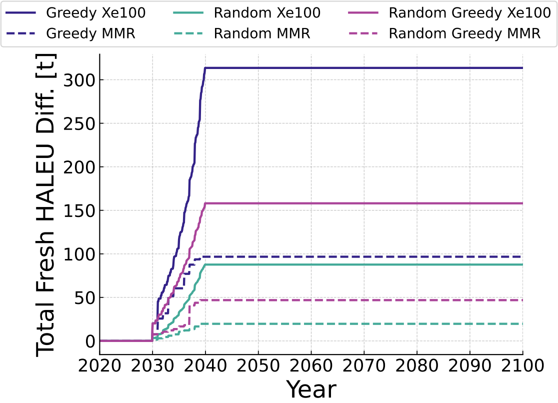
Comparing the mass of HALEU for each scenario

In our one-to-one scenario for LEU+- and HALEU-fueled reactors, the LEU+ scenarios require less HALEU on the order of hundreds of tonnes.



Breaking down the mass of HALEU by reactor

We can separate the differences in HALEU between the LEU+ and non-LEU+ scenarios by reactor for each deployment algorithm to show that the larger differences are for the Xe-100.



Outline

This is an upperbound on the amount of HALEU we could defer.

In our simple case, we transition from LEU+ to HALEU after 10 years of operation with no learning curve. We have discussed how:

1. The difference in the total mass of HALEU required for a LEU+ to HALEU transition is on the order of hundreds of tonnes.
2. The deployment algorithm impacts the total amount of HALEU required, with the Random and Random + Greedy algorithms requiring more HALEU than the greedy algorithm.

Future work

We are interested in:

- adapting neutronics models of the MMR and Xe-100 to be fueled with LEU+,
- investigating the impact of learning curves instead of a ready deployment on the results over time,
- and comparing these results with a triple-by-2050 scenario (also proposed in the Liftoff Report [5]).

Acknowledgement

Thanks to Luke Seifert for his help with running the neutronics models, and thanks to Amanda Bachmann and Zoe Richter for letting me adapt their reactor models for the MMR and Xe100.

Thanks to Madicken Munk and Katy Huff for their support throughout my studies.

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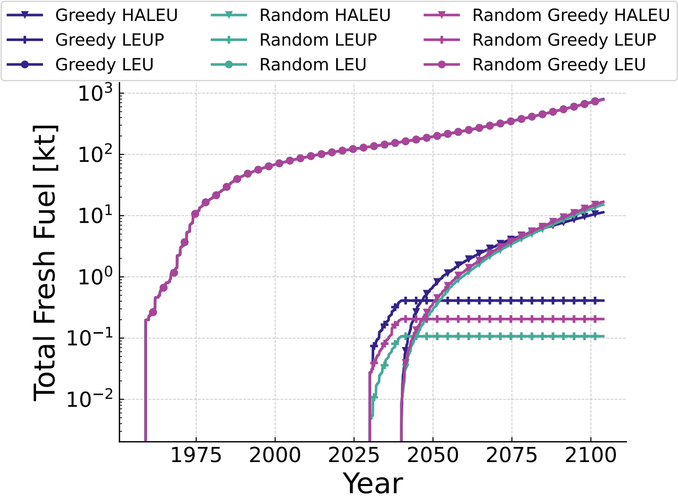
We define the enrichment levels as...

Table 2: Enrichment levels and their ranges.

Enrichment Level	Range [% ^{235}U]
Natural	< 0.711
LEU	0.711-5
LEU+	5-10
HALEU	10-20
HEU	≥ 20

These are a mash-up of economic and regulatory definitions.

Staggering enrichment could give the supply chain time to form



The differences between LEU demand are small in kt