

Use of Zone-Melt Refining to Enable a Uranium-Actinide Closed Fuel Cycle for Research Reactors

TRTR 2026

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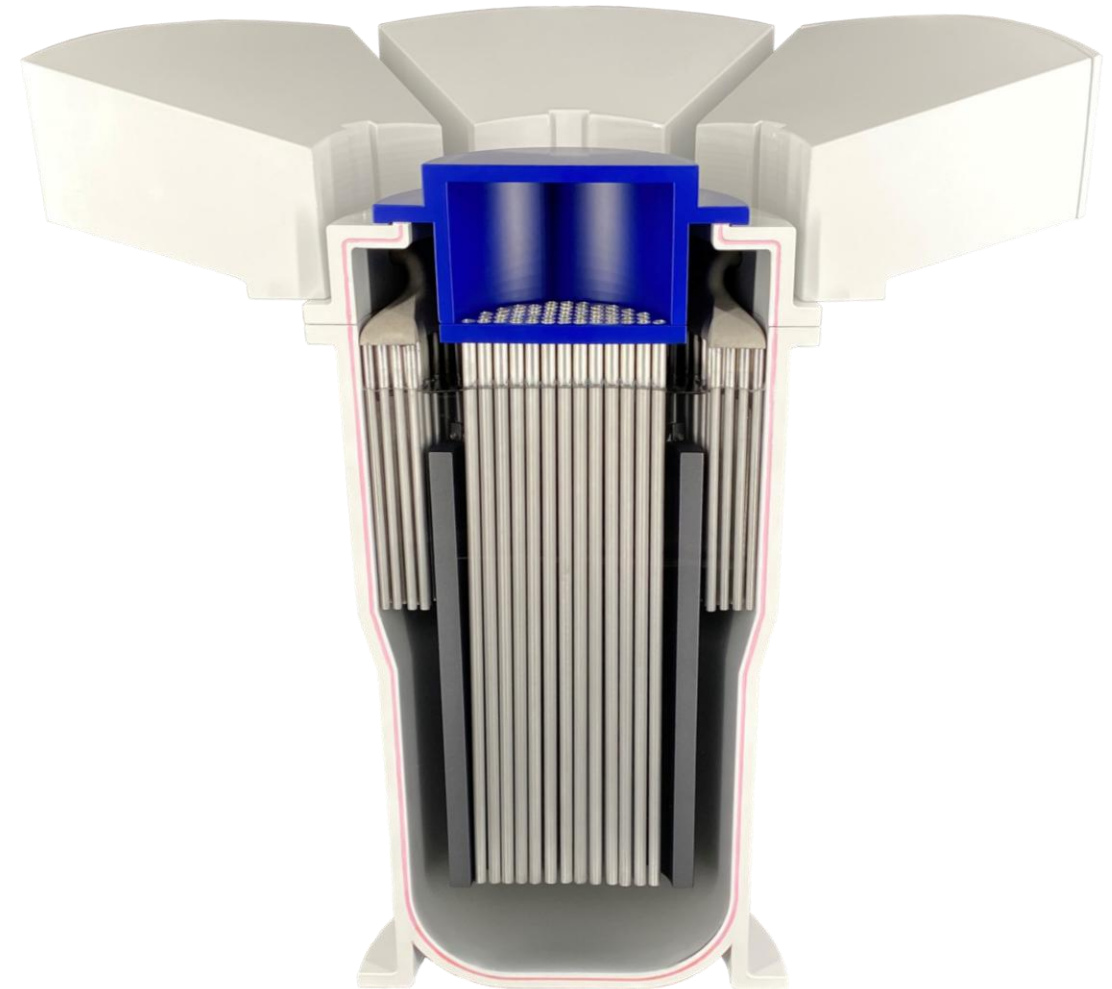
Jackson Keppen

Project Manager



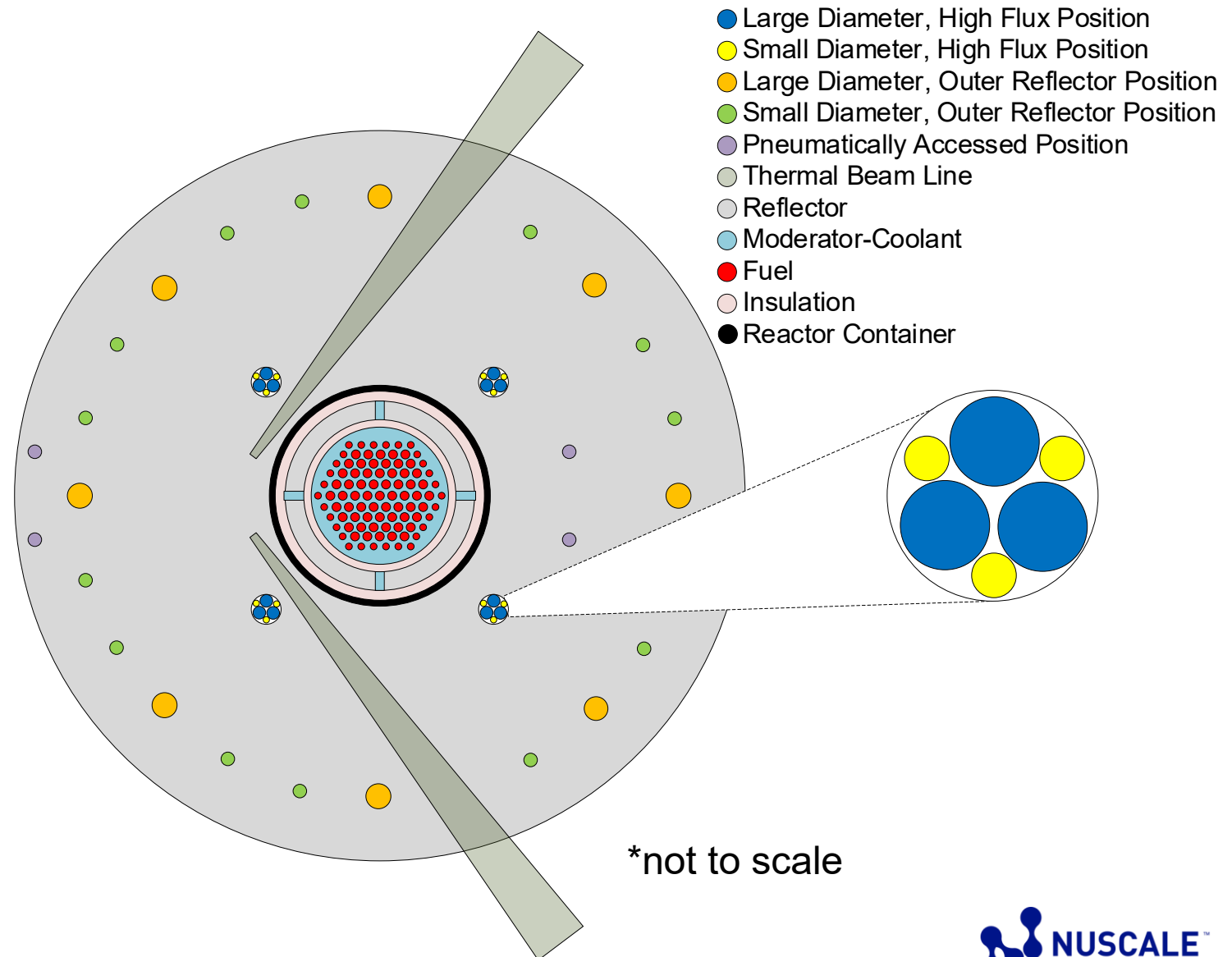
Overview of NuScale Microreactor Technology

- Liquid metal cooled thermal-spectrum nuclear reactor
- Targeting commercial and research reactor markets
- Research reactor needs include:
 - 2MWth for irradiation
 - 20 MWth for irradiation and power generation
- Up to 10 year core life
- Liquid uranium alloy fuel
- Passive fission product removal system (FPRS)
- Liquid metal moderator-coolant
 - Hydrogen-based power control system
- Fully passive primary cooling system
 - Pumped system potential for high power density systems
- Low pressure primary system
 - Eliminates the cost and licensing effort for pressure vessels



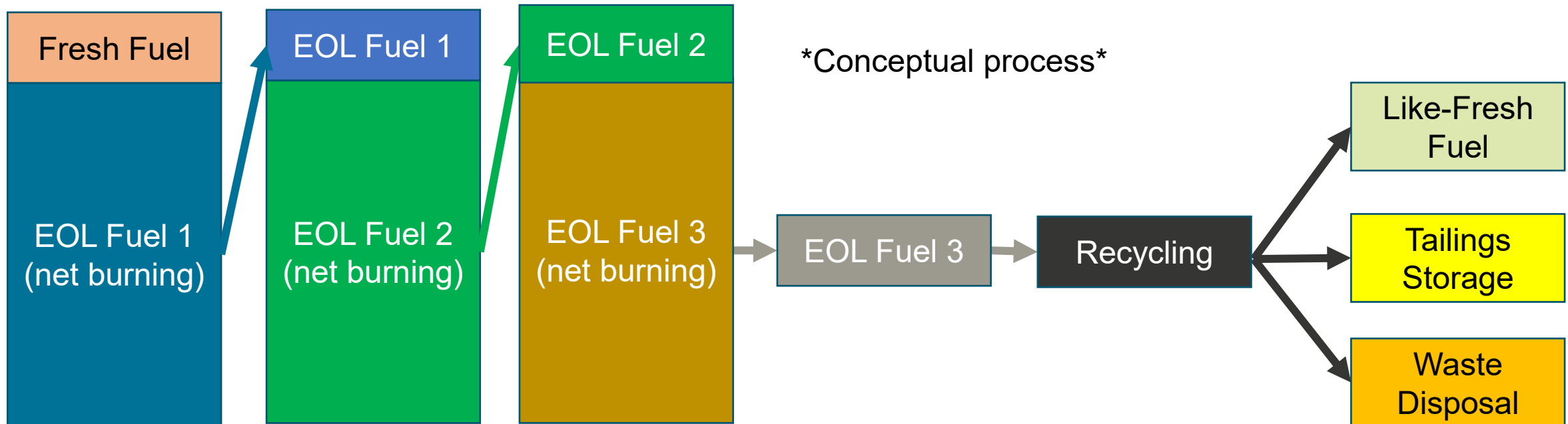
The NuScale Advanced Research Reactor

- Multiple reflector-based irradiation positions
- Online target movement
 - Core operation decoupled from target irradiation
- A range of fuel options yields thermal fluxes on the order of $1e14 \frac{n}{cm^2-s}$



Increasing fuel utilization prior to recycling - Cascading Fuel

- Fuel is cascaded from higher enriched portions of the core to lower enriched
- Precise quantities can be exchanged between regions
- No chemical processing prior to recycling
- Breeding is possible in the machine – depleted fuel would be used to dilute



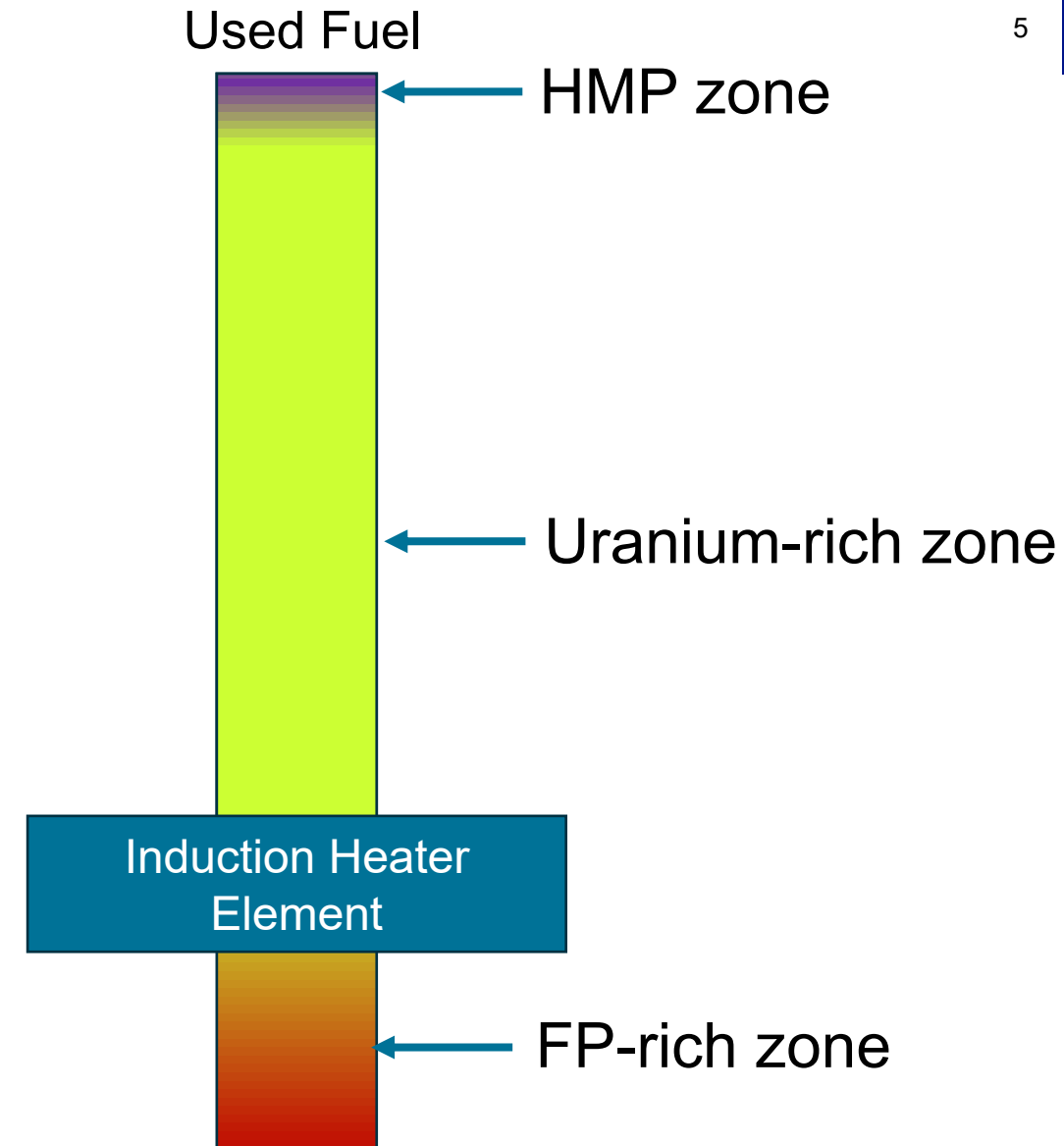
Enrichments: Fresh > EOL 1 > EOL 2 > EOL 3

Recycling: Zone Melt Refining

- Induction heating element yields localized fuel melting
- Heating element moves axially along fuel column
- Fission products are stratified from actinides within melt zone
- Three distinct zones are formed:
 - High melting point (HMP) transuranic-rich zone
 - Uranium-rich zone
 - FP-rich zone
- FPs can be physically removed from fuel column
- Actinides can be reused in next reactor cycle

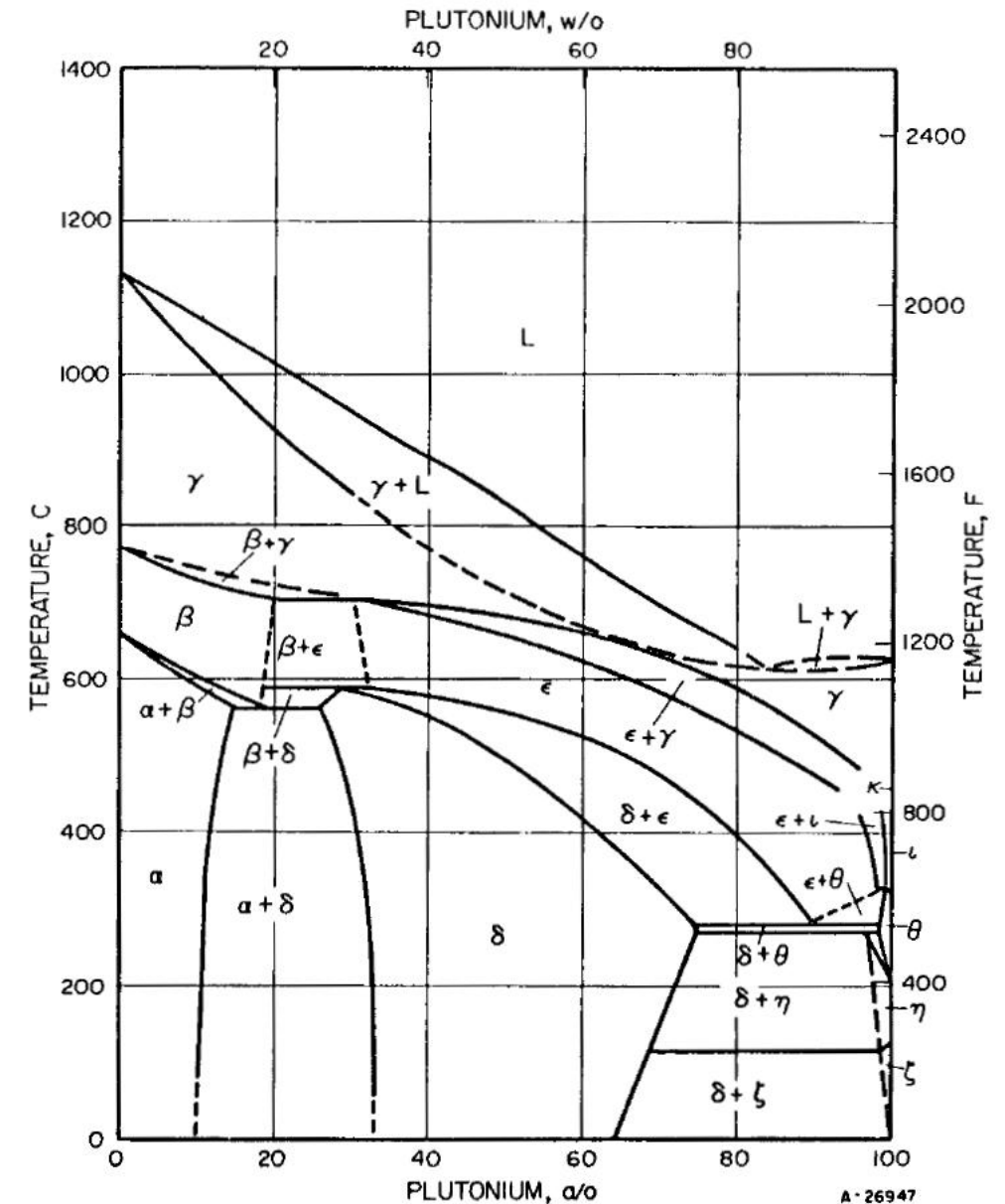
Fission product removal system

- Pre-removal of volatiles – simplifies process and reduces hazard.
- Some neutron poisons removed
 - Anyone who has insight on samarium volatilization, please come speak with me.



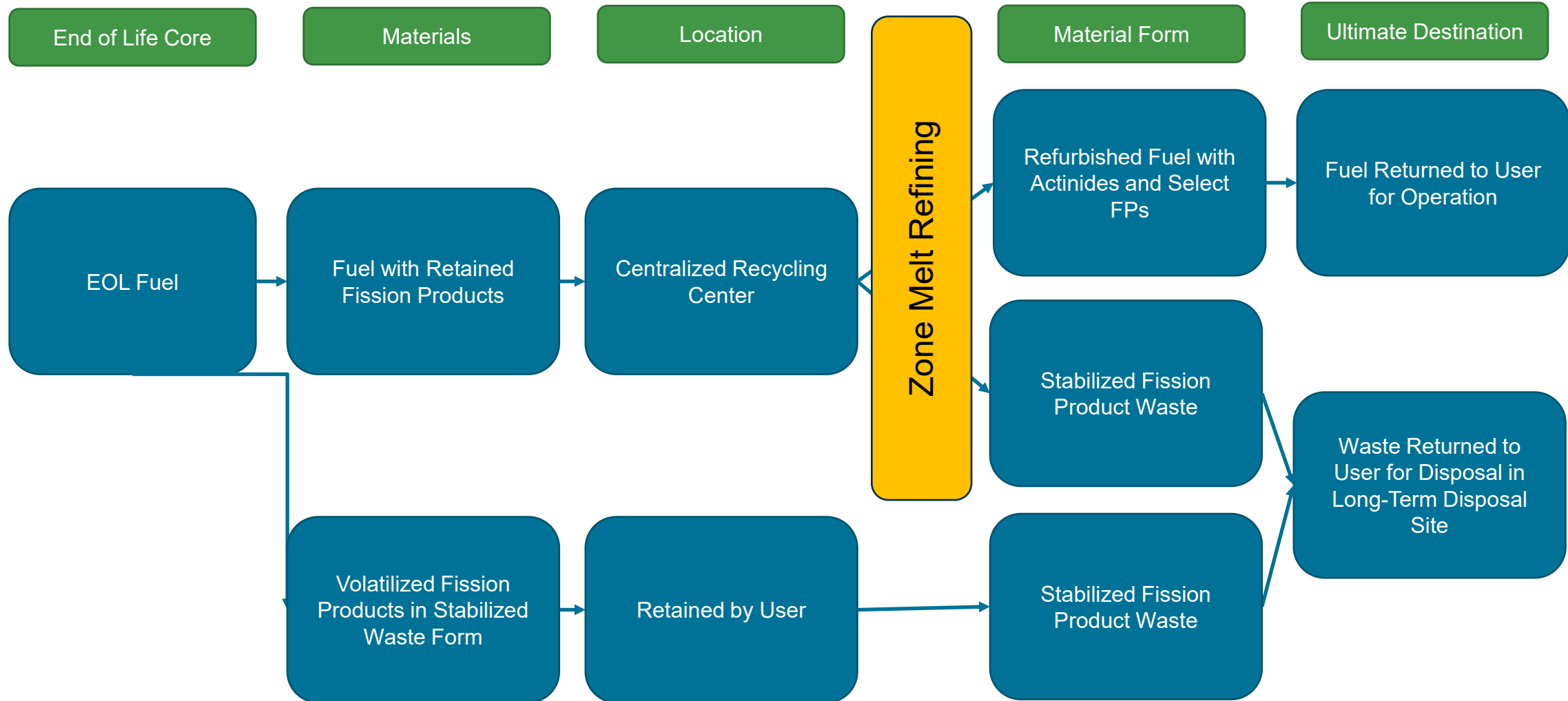
Pu-U Phase diagram

- Melt temperature can drive composition
- Composition can be controlled to produce a more useful fuel product
- Enhanced proliferation resistance by not producing pure plutonium
- The actual function of the system will be more complex – far more junk in the mix



CONSTITUTION OF URANIUM AND THORIUM ALLOYS, REPORT
NO. BMI-1300, Battelle Energy Institute

Proposed Recycling Overview



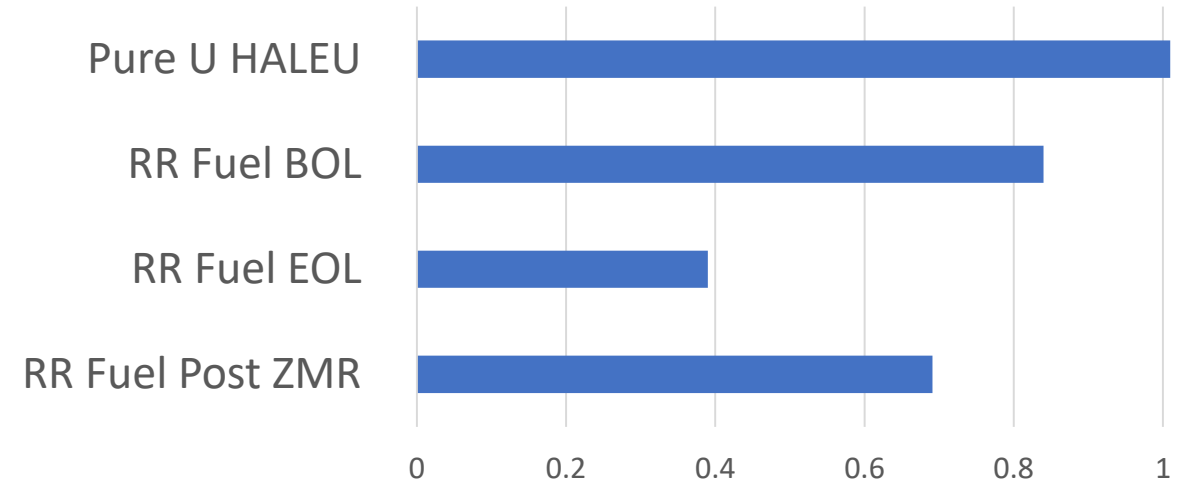
Quantitative Benefits from Recycling – Waste and Non-proliferation

Table 1. The Meaning of FOM When Applied to Metals or Alloys

FOM	Weapons Utility	Attractiveness	Attractiveness Level ³
> 2	Preferred	High	~B
1-2	Attractive	Medium	~C
0-1	Unattractive	Low	~D
< 0	Unattractive	Very Low	~E

An Assessment of the Attractiveness of Material Associated with a MOX Fuel Cycle from a Safeguards Perspective, Los Alamos National Laboratory

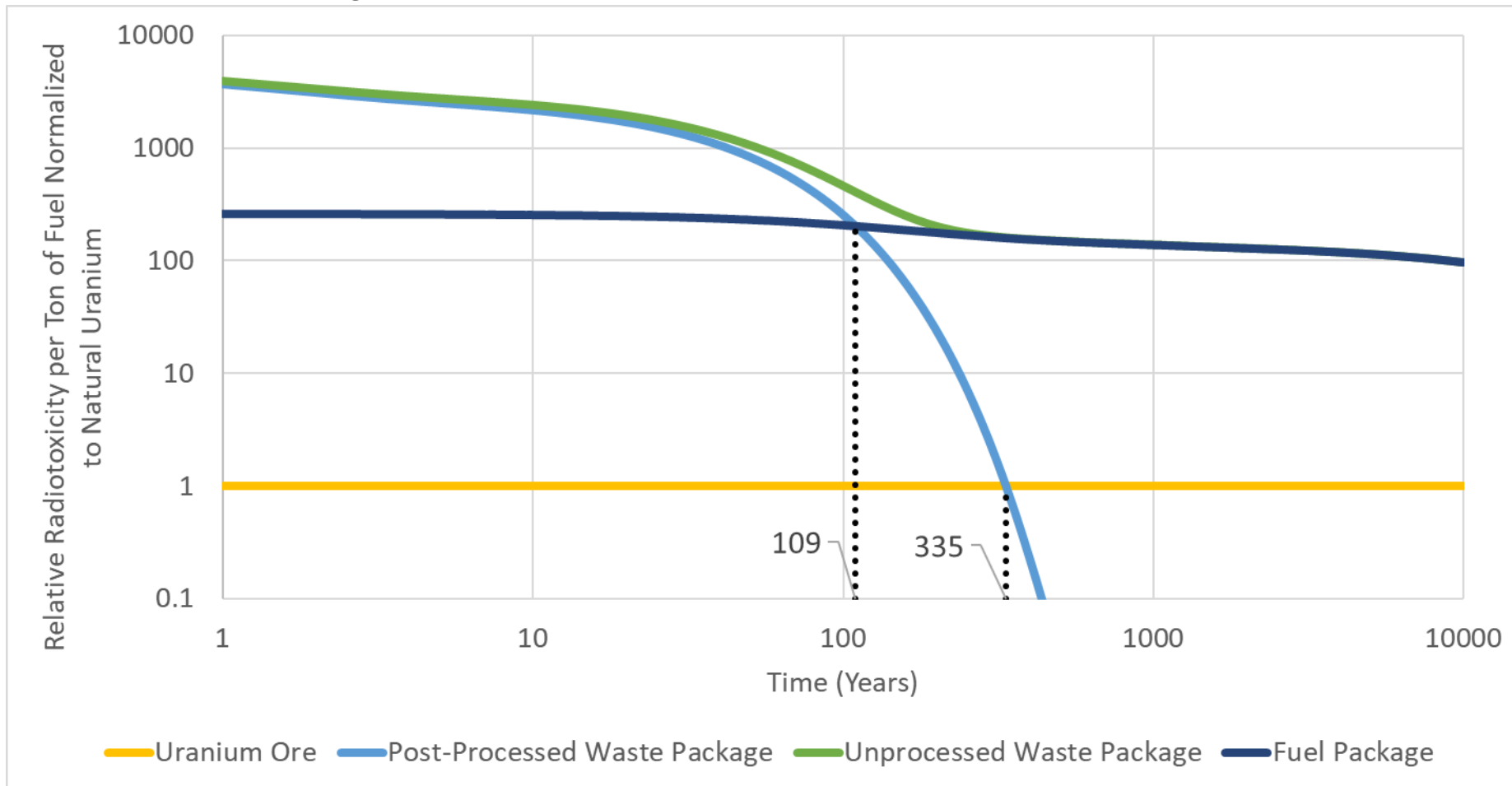
Bathke's FOM for Diversion Appeal



Reactor	Core Life (years)	Average Enrichment (wt%U235)	<u>Cost Reduction</u> from Recycling	Once-Through <u>Disposal</u> Mass (kgU)	Recycled Material for <u>Re-use</u> (kgU)	Recycled Material for <u>Disposal</u> (kg)	Recycled Material for <u>Storage</u> (kgU)
Research 20MWth	1	19.5	70%	260	230	10	20

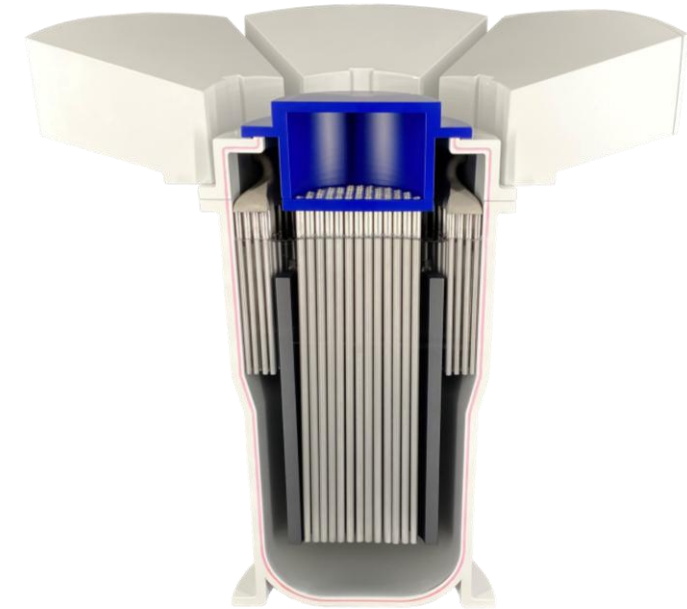
Quantitative Benefits from Zone-Melt Recycling – Waste Toxicity

- Fuel package includes all iron, actinides, actinide decay products, and technetium
- Post-processed waste package includes all other fission products



Final Fuel Cycle Considerations

- Unique benefits of utilizing zone melt refining with a NuScale microreactor
 - Few volatiles going into recycling stream due to fission product removal system
 - Design and operating scheme is uniquely suited to take advantage of zone melt refining recycling
- Safeguards
 - Fission products are removed, actinides retained
 - Actinides burned rather than stored
 - Relatively unappealing to divert post-irradiation fuel
- Disposal
 - Low actinide mass in disposed waste
 - Waste mass vastly reduced by zone melt refining





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Power for all humankind

Thank you!

Jackson Keppen
Project Manager
jkeppen@nuscleasepower.com