Transmutation Capabilities of GEN-IV Reactors

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ABSTRACT

The Generation IV reactors all have the potential to play a significant role in future scenarios dealing with transmutation of spent fuel from LWR power reactors. The nature of the flux spectrum, thermal or fast, is the major factor in the effectiveness of transmuting various transuranic isotopes. We conclude that each Generation IV reactor concept could have a role, if properly coordinated and supported by significant development programs

The fast reactor concepts (liquid metal and gas-cooled) are the most effective in net consumption of unwanted actinides (plutonium, neptunium, americium and possibly curium. Thermal spectrum concepts (water-cooled reactors with and without inert-matrix cores, high-temperature gas-cooled reactors with and without inert-matrix cores, and liquid-salt-cooled thermal reactors) all can potentially reduce some of the minor actinides - even if only used in a single pass. Teamed up with subsequent fast reactor irradiations to reduce higher minor actinides (specifically americium and curium), their use could result in reducing the number of fast burner reactors required, per spent-fuel-producing LWR, compared to a system of only LWR and fast burner reactors.

Further evaluations of national and worldwide scenarios involving candidate Generation IV reactors appears worthwhile to explore and optimize potential spent LWR fuel transmutation scenarios.

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Next Generation Nuclear Plant (NGNP)

Attributes

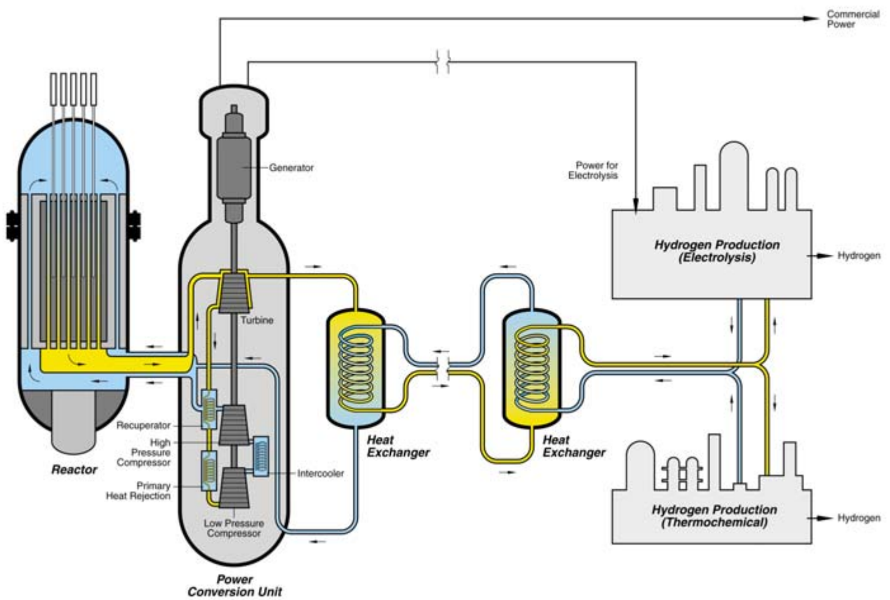
- Helium coolant up to 1000ºC outlet temp
- Modular 300-600 MW_{Th}
- Prismatic block or pebble bed core
- TRISO particle fuel
- Demonstration plant possible by 2017

Benefits

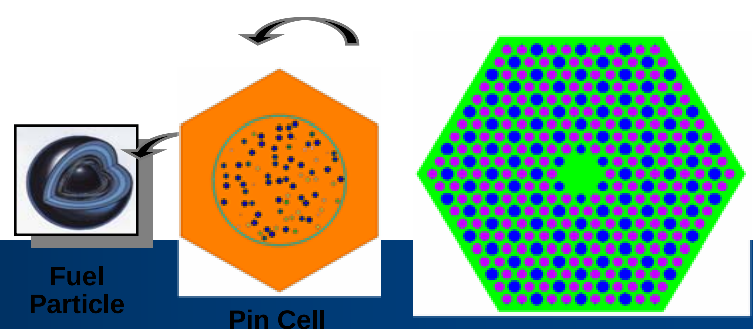
- Attractive safety aspects
- Helium Brayton cycle conversion with high efficiency
- Clean and efficient hydrogen production

Viability Issues

- High temperature materials
- Fuel performance and reliability
- Hydrogen production technologies
- Intermediate heat exchanger
- Waste generation



NGNP
Next Generation Nuclear Plant



Supercritical-Water-Cooled Reactor (SCWR)

Attributes

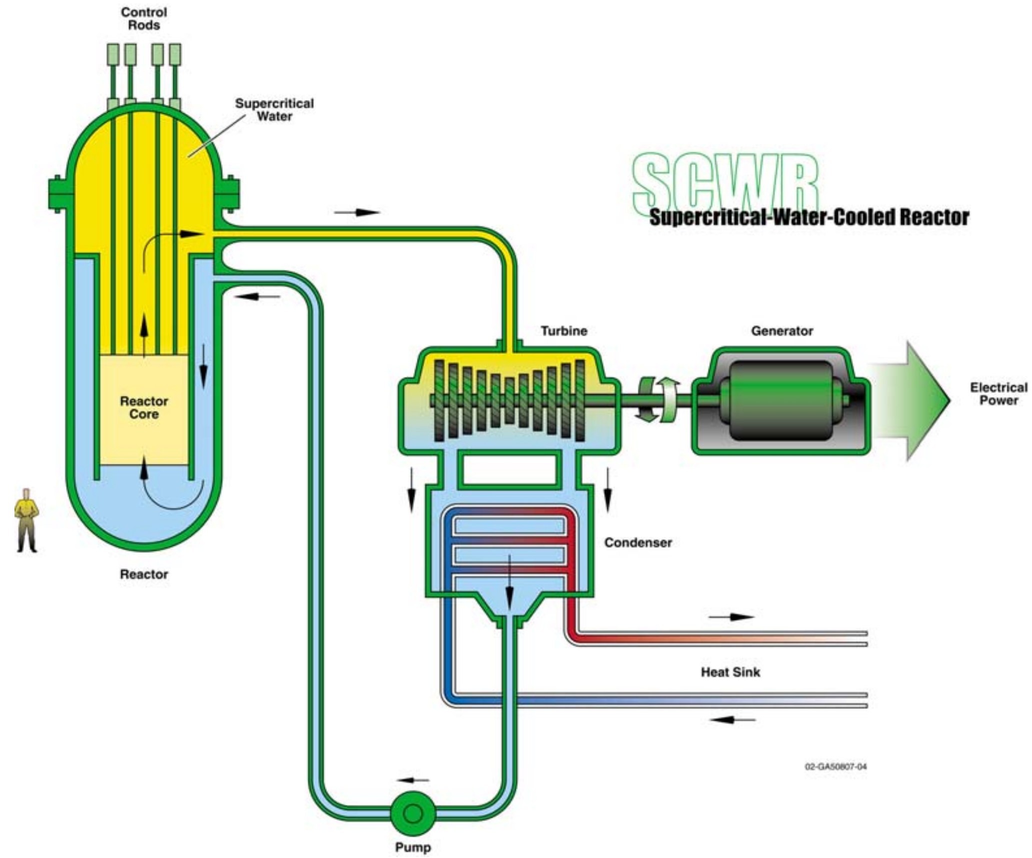
- Advanced reactor cooled by water above critical point (374 °C, 22.1 MPa)
- Direct-cycle cooling

Benefits

- Simplified system; fewer components; compact
- Thermal efficiency approaches 44%
- Economic
- Builds on existing technology

Viability Issues

- Coolant flow stability against oscillations
- Thermal and heat-transfer properties
- Safety concept and fuel design criteria
- Materials



Gas-Cooled Fast Reactor (GFR)

Attributes

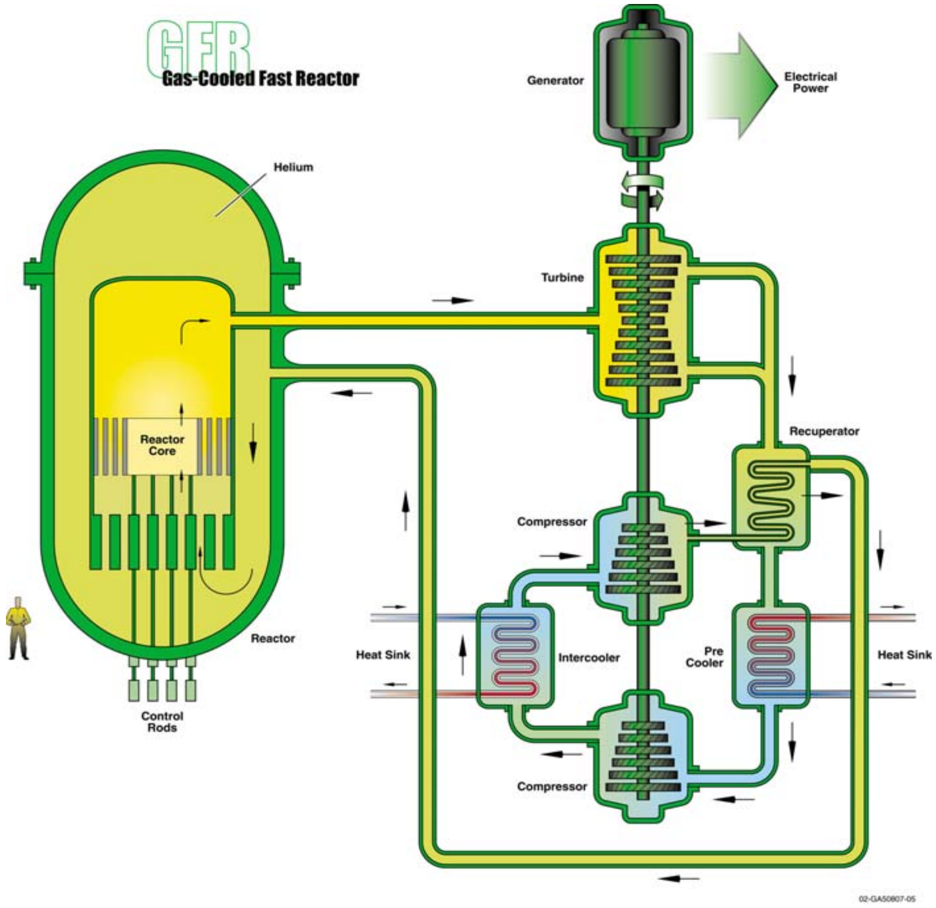
- He coolant, 850°C outlet temperature
- 600 MW_{th}/ 288 MW_e
- Direct-cycle gas-turbine

Benefits

- Efficient electricity generation
- High U-resource utilization
- Waste minimization
- Possible hydrogen production

Viability Issues

- Fuel and materials development challenges
- Active safety systems needed at targeted power density due to relatively low thermal inertia and poor heat transfer characteristics of coolant at low pressure
- Economics



Lead-Cooled Fast Reactor (LFR)

<u>Attributes</u>

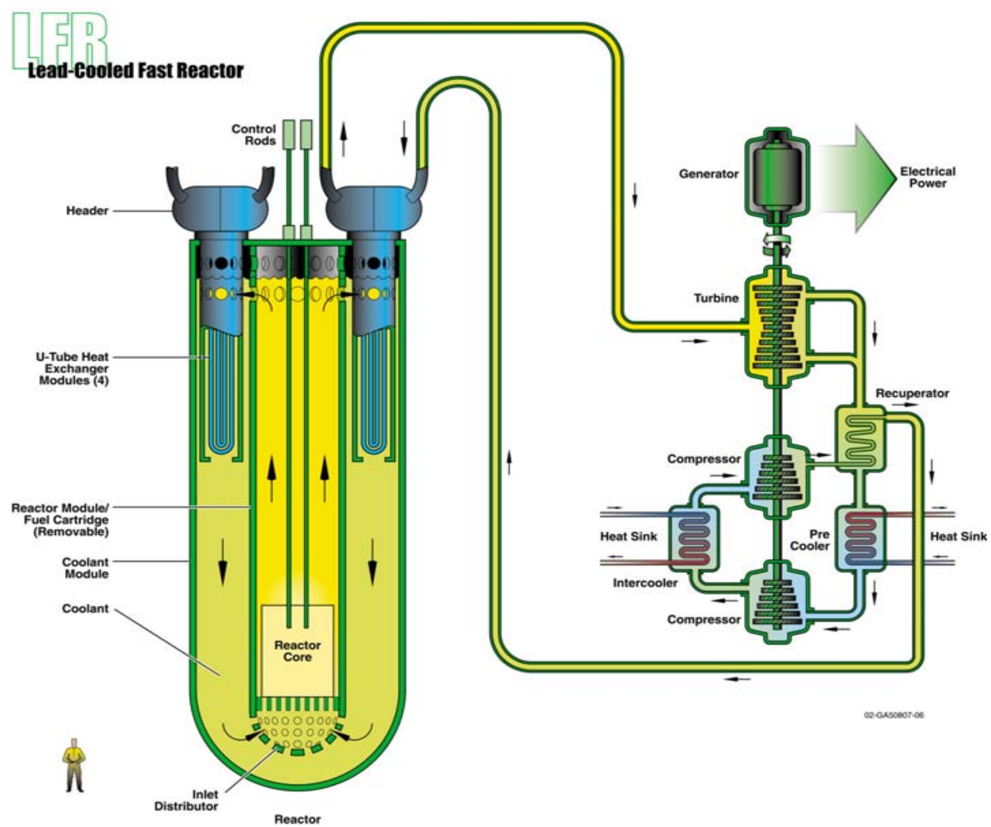
- Pb or Pb/Bi coolant
- 500°C to 800°C outlet temperature
- U-TRU nitride fuel
- 25–200 MW_e
- 15–30 year core refueled as a cartridge

<u>Benefits</u>

- Small size tailored to needs for remote or distributed generation
- No need for on-site fuel storage or local fuel cycle infrastructure
- Design simplification

<u>Viability Issues</u>

- Control of corrosion
- Coolant activation
- Seismic safety
- Qualification of Russian data



Sodium-Cooled Fast Reactor (SFR)

Attributes

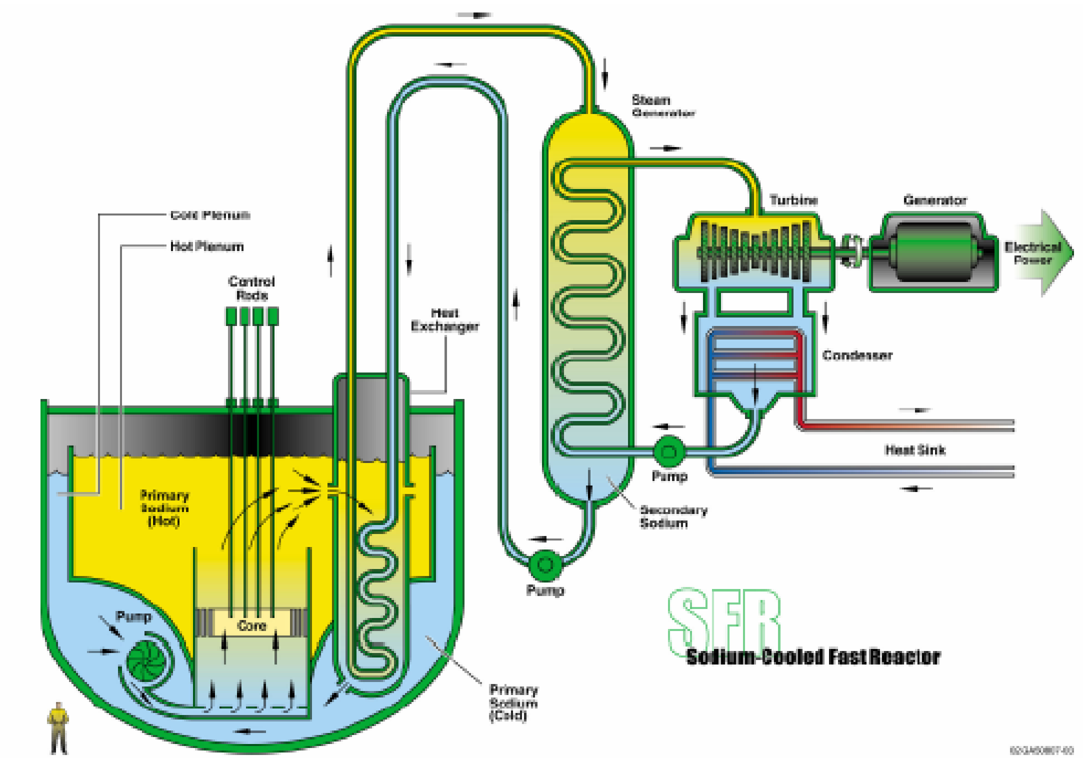
- Sodium coolant, outlet temperature 550°C
- Primary system at atmospheric pressure
- Efficient electricity generation
- 1000-5000 MW_{th}

Benefits

- Advantageous actinide management
- Efficient conversion of fertile uranium
- Metal or MOX fuel with advanced recycling

Viability Issues

- Development of oxide fuel fabrication technology
- Sodium leak prevention
- Economics



Molten Salt Reactor (MSR)

Attributes

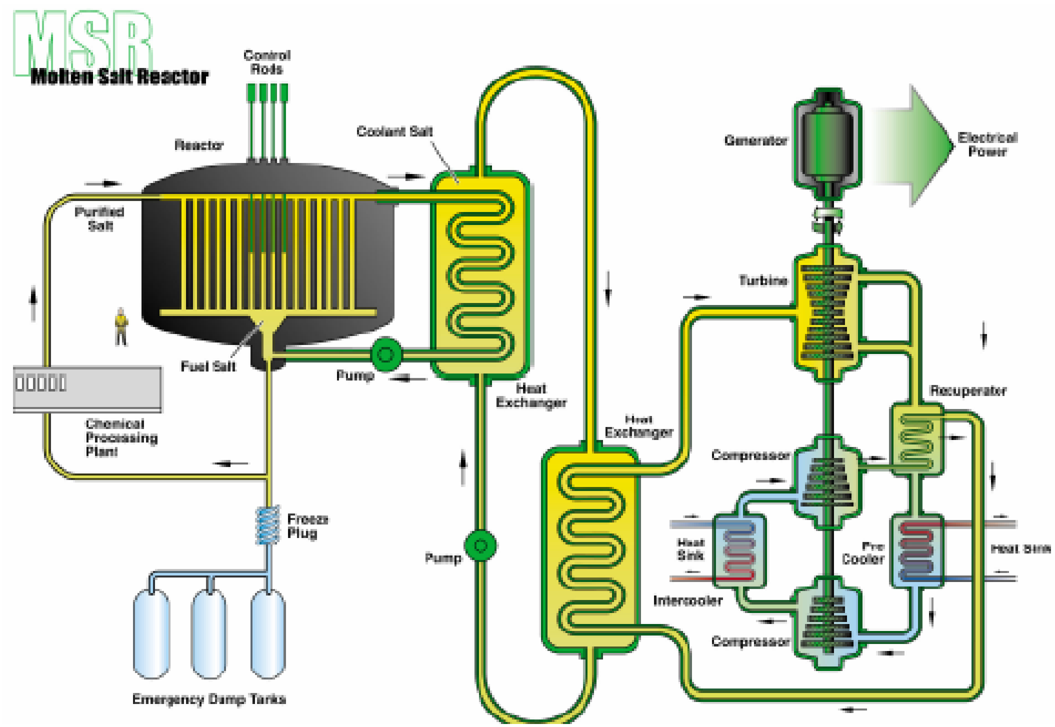
- Molten salt fuel mixture
- 1000 MW_e net power
- Efficient electricity generation

Benefits

- Inherently safe
- Potential for hydrogen production
- Actinide burning
- Efficient fuel utilization
- Low pressure reduce stress on vessel and piping

Viability Issues

- Molten salt chemistry and control
- Compatibility of fuel with structural materials, graphite, and heat exchangers
- Reliability of materials and corrosive effects

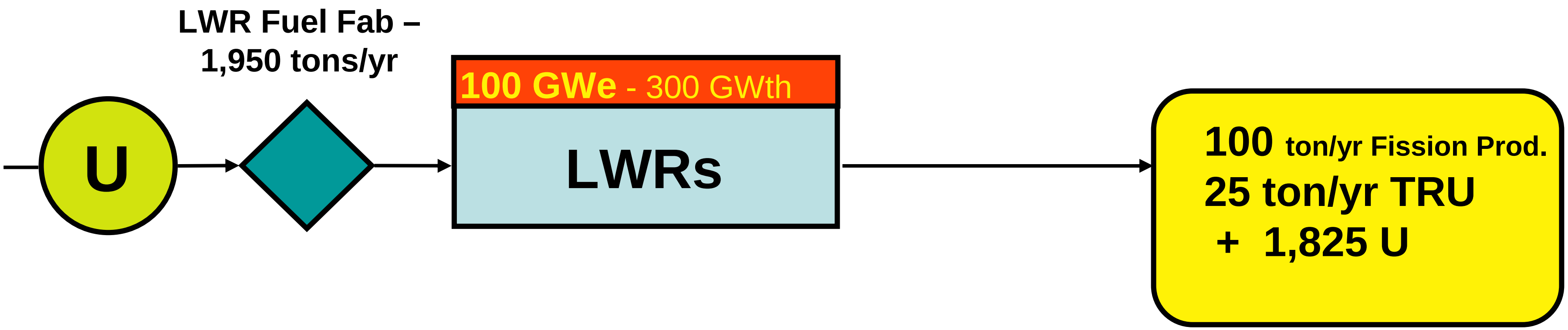


Concepts Detailed in Presentation to Illustrate Potential for Significant Actinide Consumption

- For Fast Spectrum Reactors: two sodium cooled liquid metal fast reactor cases
  - conversion ratio, CR = 0.5
  - conversion ratio, CR = 0.25

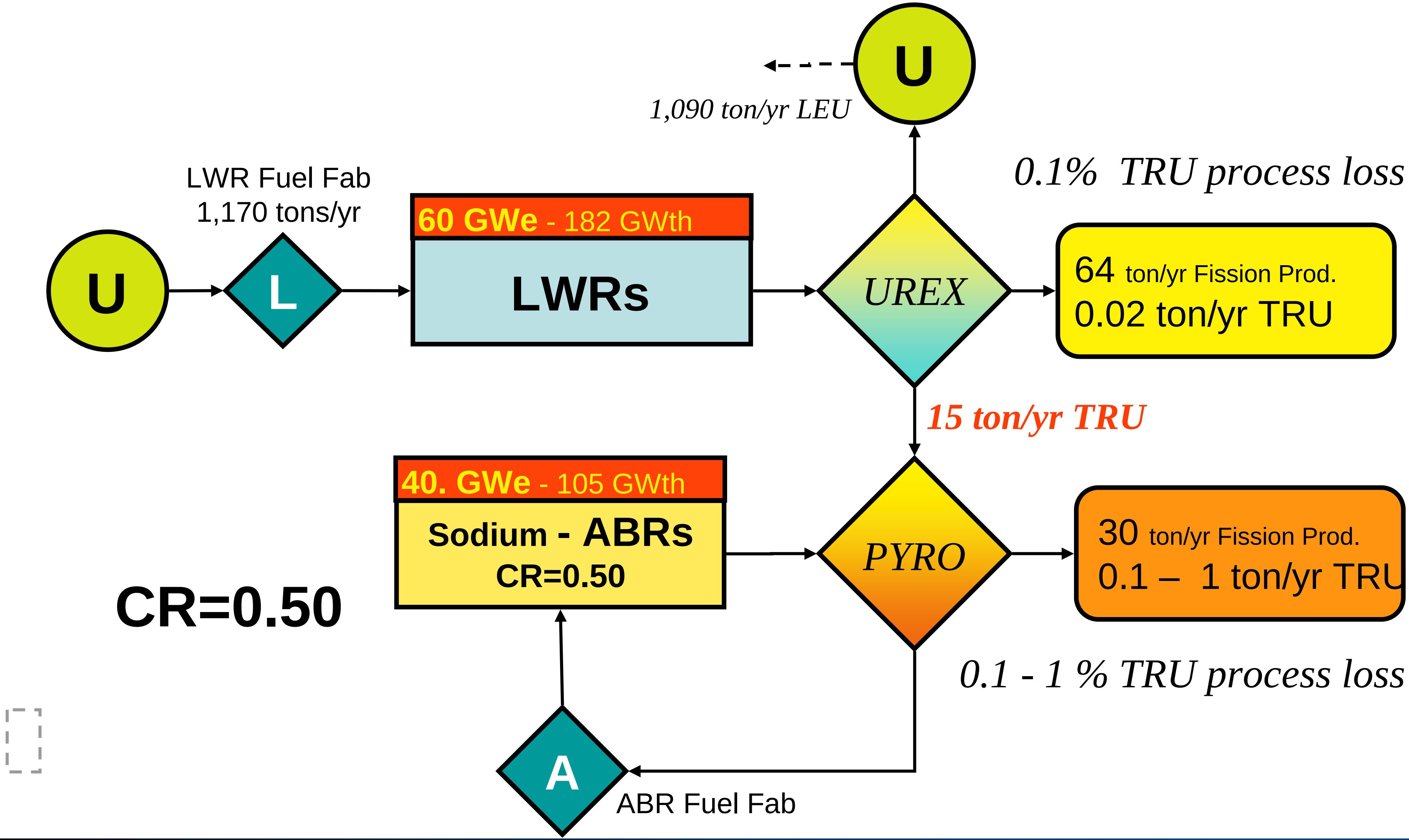
  For Thermal Spectrum Reactors:
  - a “Deep Burning” High Temperate Gas Reactor
  - a Molten Salt Reactor operating in a continuous recycle mode

100 GW(e) LWR once-through option – U.S. Reference

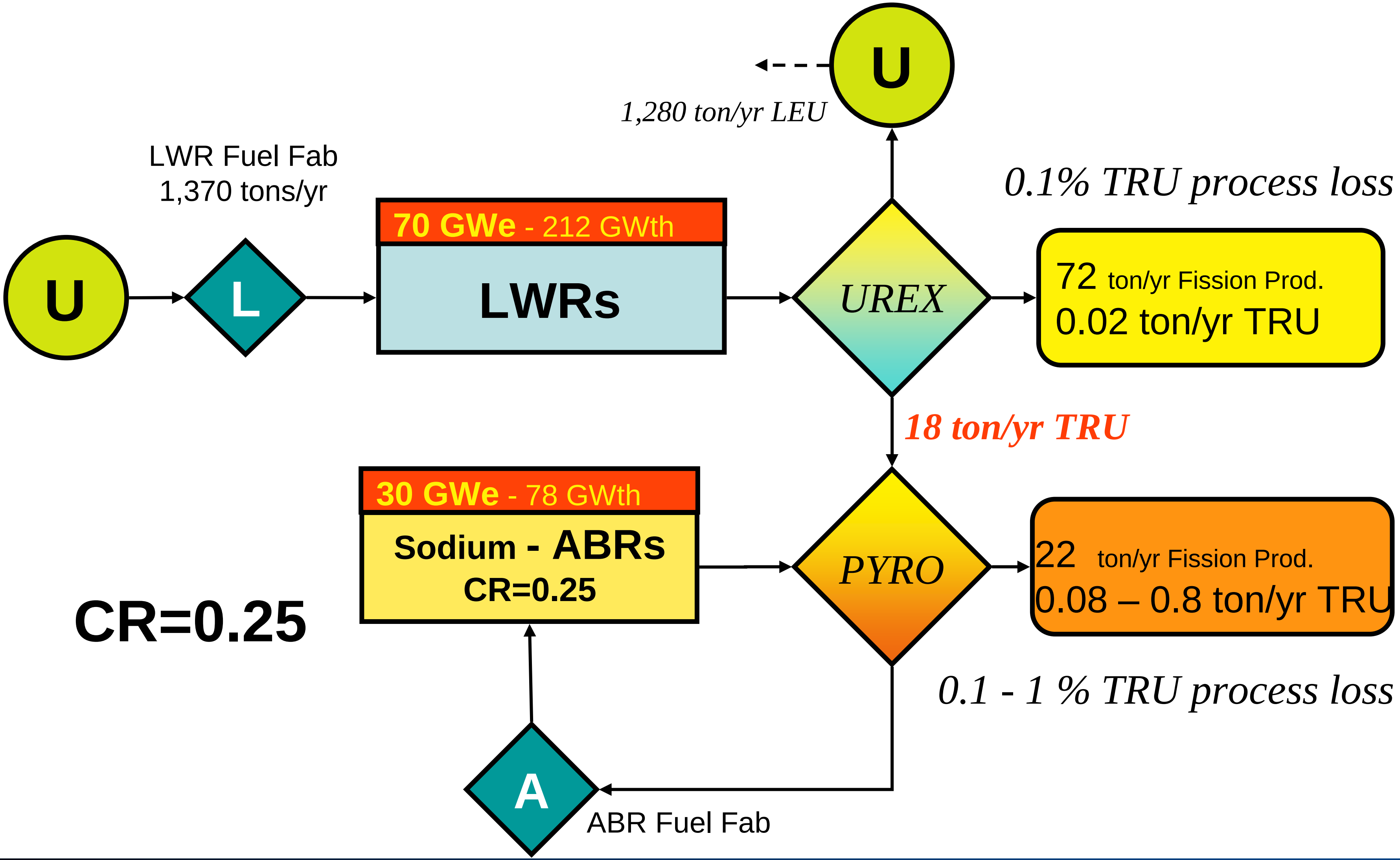


33% efficient power conversion
50,000 MWD/MT

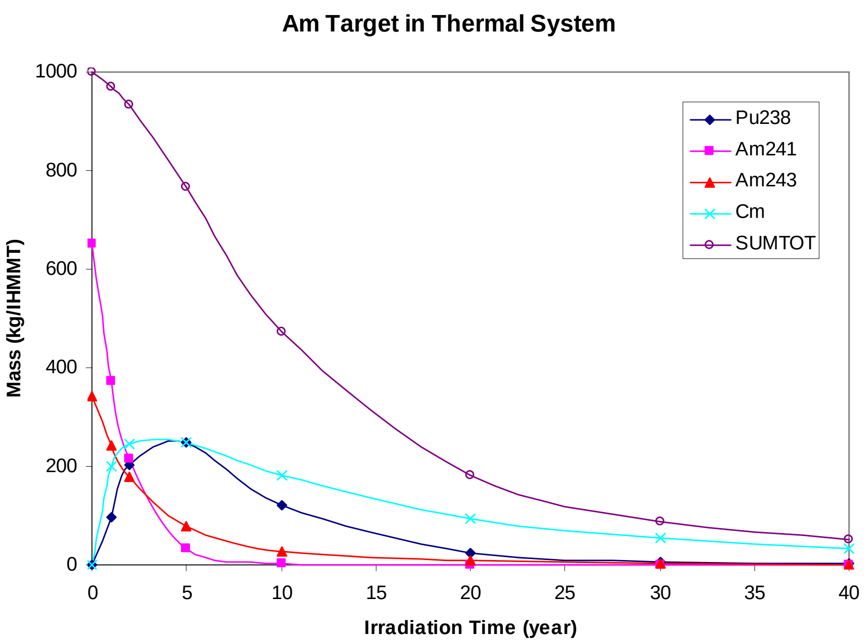
Equilibrium Example #1 - Advanced Burner Reactor at equilibrium feed rate – Much Less TRU to Repository

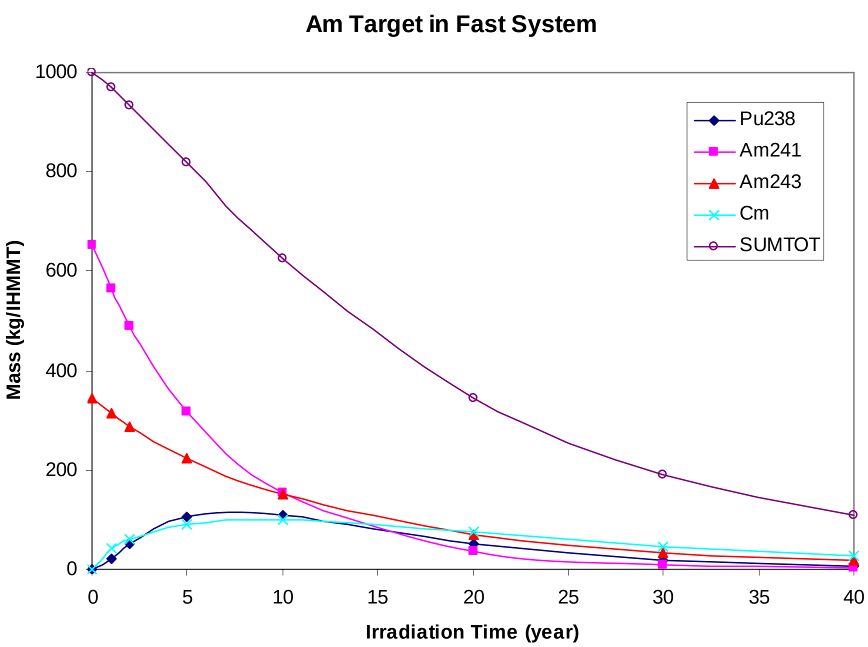


Equilibriun Example #2 – Low CR Advanced Burner Reactor at equilibrium feed rate



Am Target Behavior in Fast and Thermal Systems





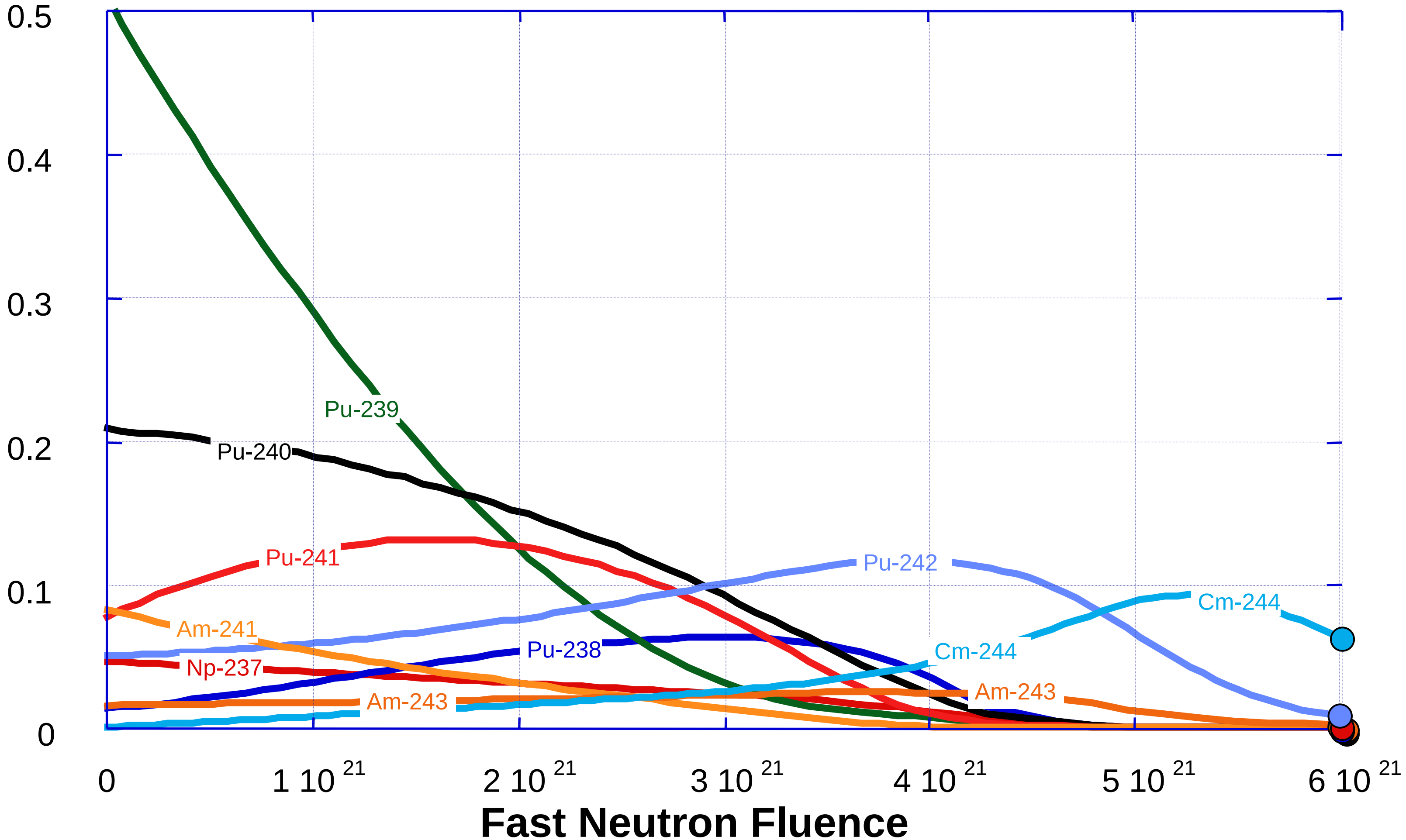
- **Am transmuted more quickly in a thermal spectrum**
- **For either system, multi-recycle will be required**
- **A thermal region in a fast reactor may combine benefits of both systems**

Representative Cases Showing the Potential of Thermal Spectrum Systems to Effect Actinide Consumption

- Three HTGR "Deep Burn" related cases
  - once through HTGR reference case
  - LWR feeding a Deep Burn HTGR
  - LWR, followed by HTGR deep burn feeding a liquid metal fast reactor

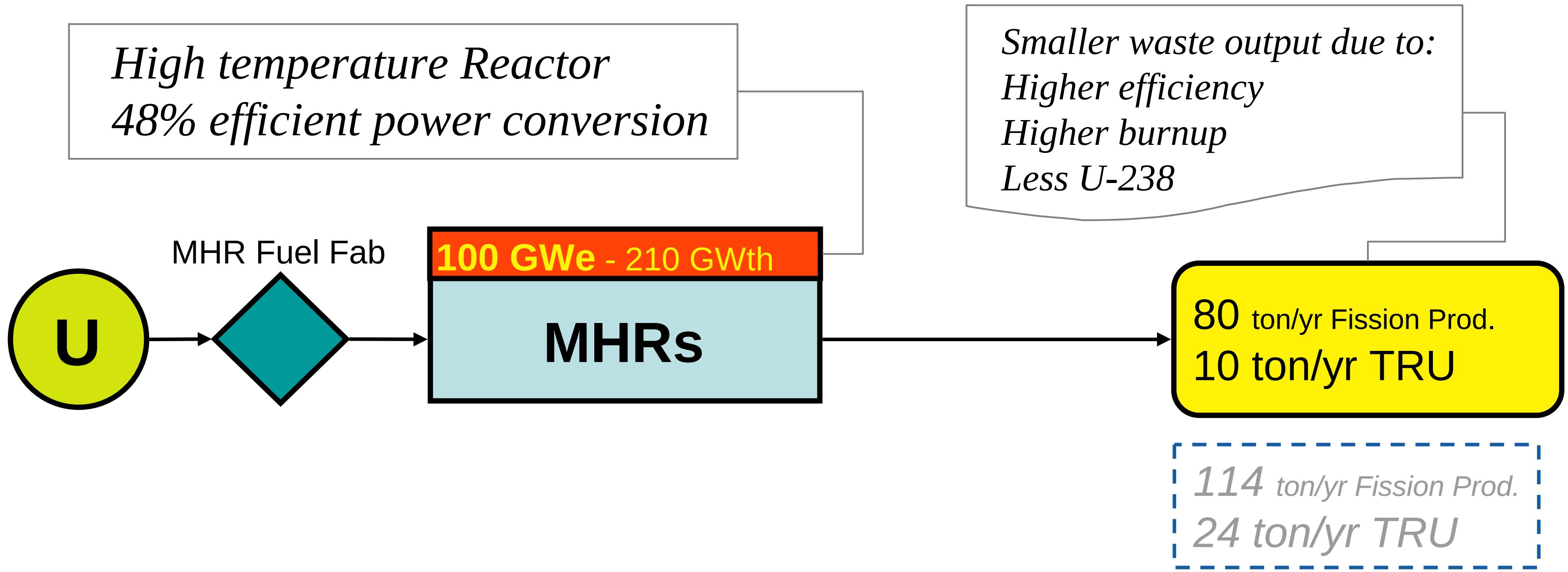
- A Molten Salt Reactor continuous recycle case

Irradiation of TRU-loaded TRISO in MHRs - General Atomics Inert Matrix Case – utilizing "Deep Burning" HTGR



Deep Burn Range is Defined as 600,000 MWD/MT ~ at mid-fluence range above

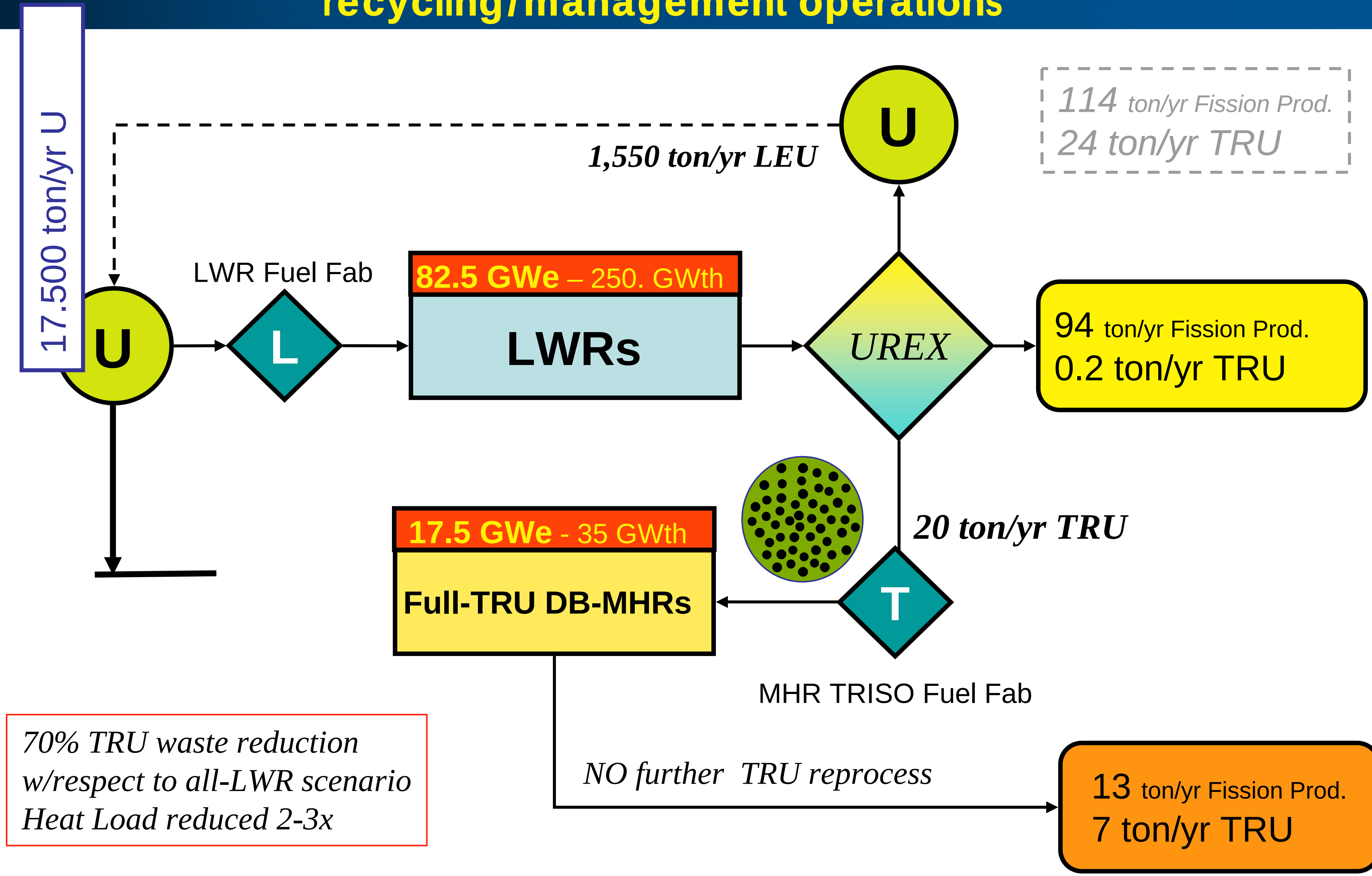
General Atomics: MHR once-through TRU Reduction option with 15% uranium enriched fuel



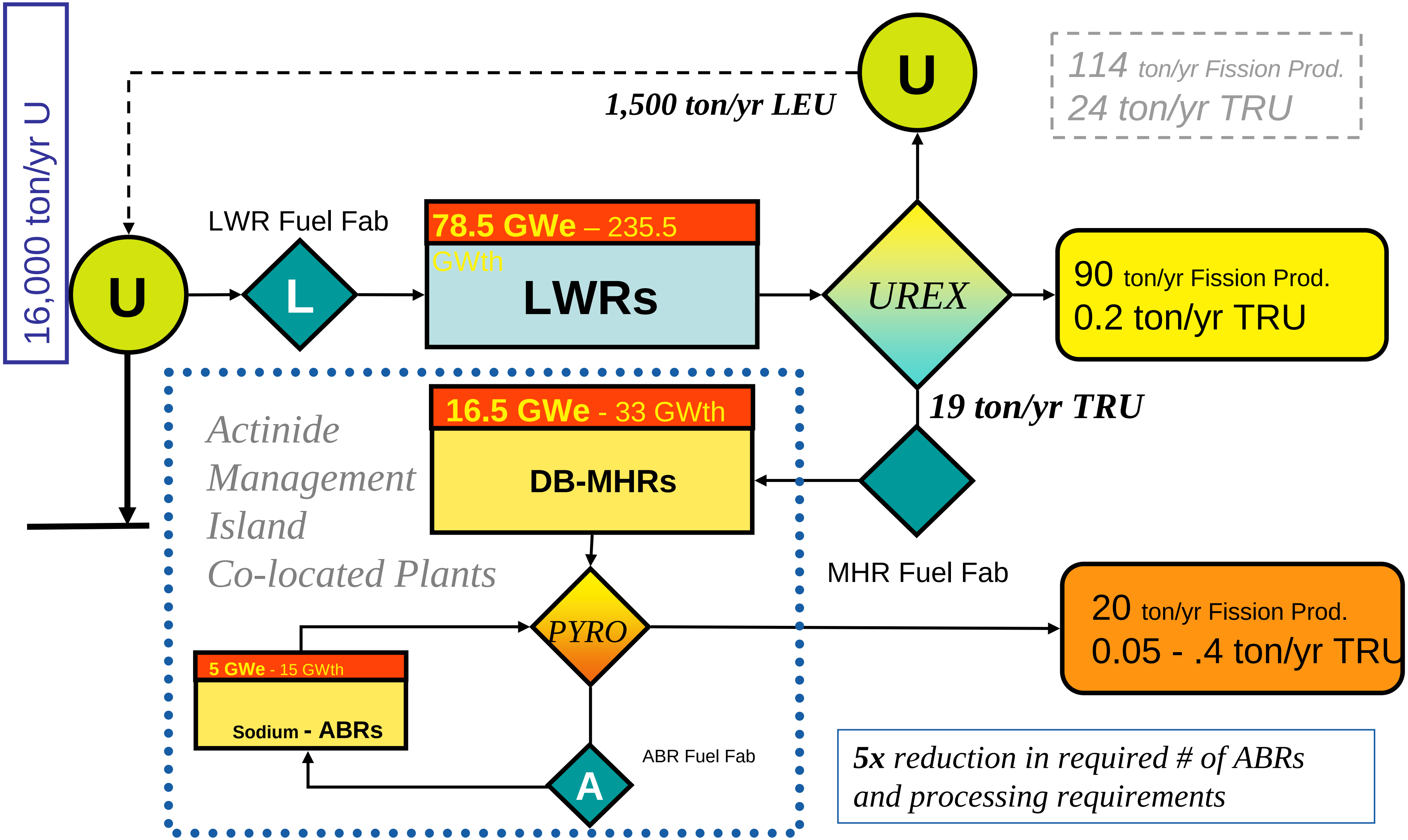
48% efficient MHRs are possible with today's technology (850 °C); 150,000 MWD/MT burnup

2.4 X reduction in TRU waste without reprocessing –compared to the LWR base case

General Atomics Message: Full TRU Deep Burn MHRs: to significantly reduce waste accumulation from LWRs without further TRU recycling/management operations"



General Atomics Message: "For the ultimate reduction in TRU waste accumulation: use 2-tier TRU management with Deep Burn MHRs and ABRs." "Actinide Management Island"



Molten Salt Reactor (MSR) – Significant Potential

Attributes

- Molten salt fuel mixture
- Large net power capability
- Efficient electricity generation

Benefits

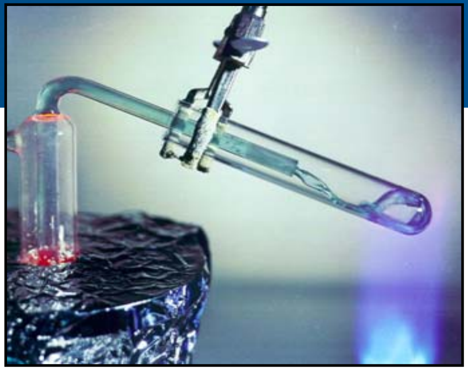
- No solid fuel fabrication (no Am and Cm handling problem)
- Homogeneous fuel salt that allows actinide burning without the need to blend before being fed to the reactor
- Large specific power with a small fissile inventory per GW(e)
- Inherently safe (low pressures, passive decay heat removal, etc.)
- Potential for hydrogen production
- Efficient fuel utilization

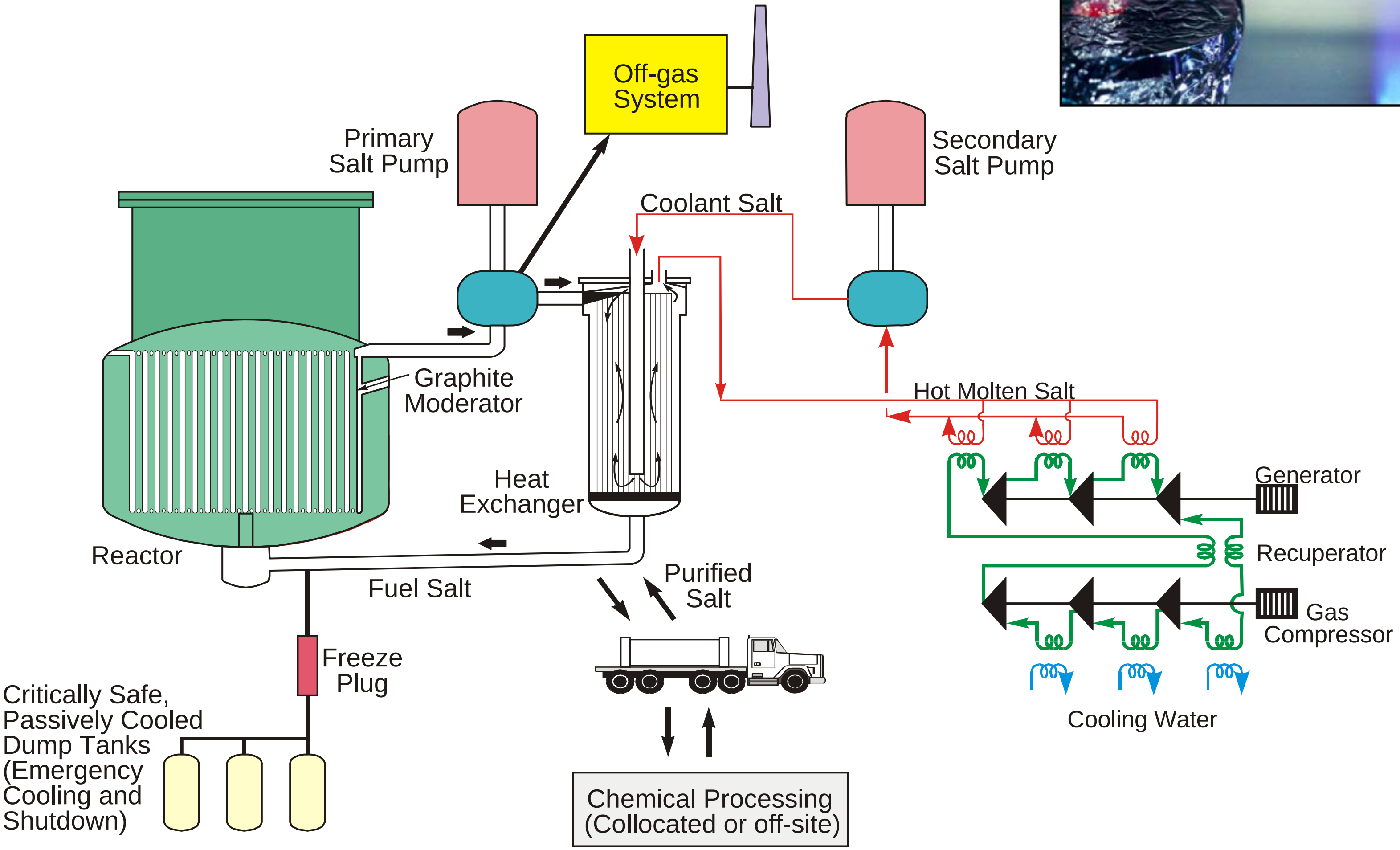
Viability Issues (Different mission than the original MSR breeder mission)

- Molten salt chemistry, process scale up, and control
- Reactor physics and safety analysis
- Optimum system design

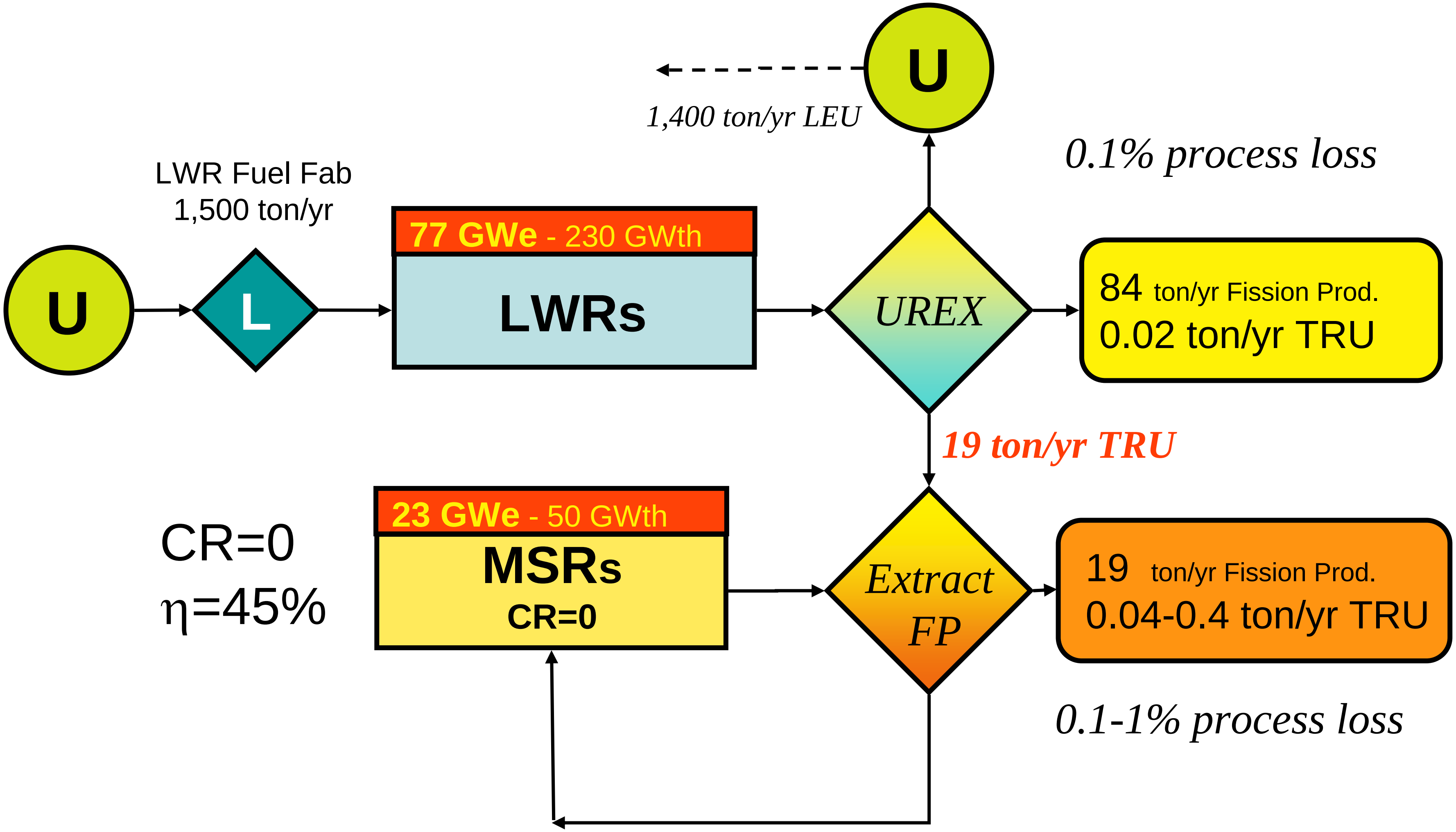
Molten Salt Reactors

(Liquid Fuel Reactors With Fuel Dissolved In Coolant)





LWR-MSR Burner Case -at equilibrium feed rate



Summary

The Generation IV reactors all have the potential to play a role in future scenarios dealing with transmutation of spent fuel from LWR power reactors – assuming successful research, development, and demonstration.

- Fast reactors can effectively consume all transuranics
- Thermal reactors appear suited for limited transmutation -- unless fertile-free ("inert matrix") fuel is used in which case once-through can be beneficial – potentially, with follow on multi-recycle in a fast reactor, or with a multi-recycle Molten Salt Reactor operating in a burner mode with significant TRU reduction potential
- Current U.S. policy of no separated Pu leads to development of recycling of LWR spent fuel transuranics, without separated Pu (UREX), and consumption of transuranics in a fast spectrum reactor