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Non-proliferation aspects of gen-IV systems

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Generation IV goals

- Sustainability
  - Generate energy sustainably, and promote long-term availability of nuclear fuel
  - Minimize nuclear waste and reduce the long term stewardship burden
- Safety & Reliability
  - Excel in safety and reliability
  - Have a very low likelihood and degree of reactor core damage
  - Eliminate the need for offsite emergency response
- Economics
  - Have a life cycle cost advantage over other energy sources
  - Have a level of financial risk comparable to other energy projects
- Proliferation Resistance & Physical Protection
  - Be a very unattractive route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism

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Generation IV goals

- Sustainability
  - Favors reactors with CR $\geq$ 1.0
  - Either large monolithic reactors or use fertile blankets
- Safety & Reliability
  - Favors small reactors
  - Less positive void worth, reduced impact of severe accident etc…
- Economics
  - Favors small reactors in the short term
  - Reduced financial risks
- Proliferation Resistance & Physical Protection
  - Favors concepts without fertile blankets as these produce weapons grade Pu
  - However, several proposed designs include blankets (IFR, ASTRID…)

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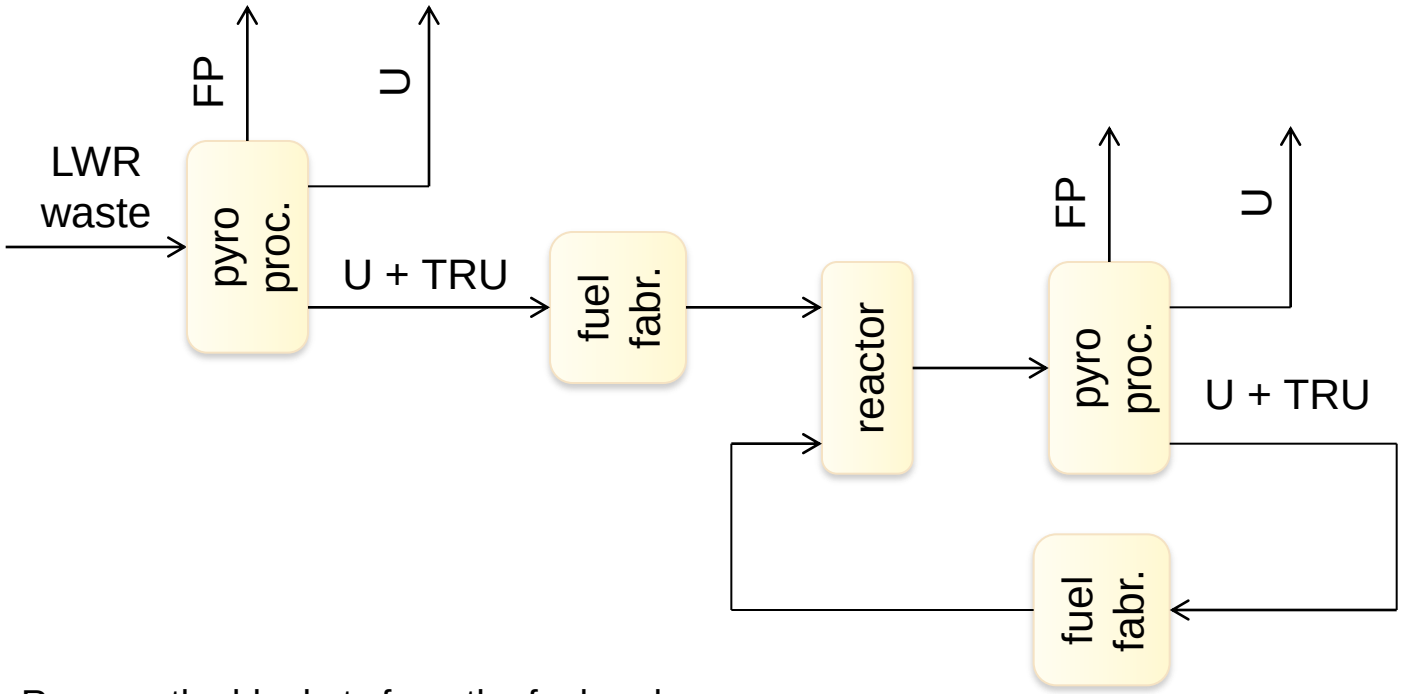
Blanket free burner reactor



- Remove the blankets from the fuel cycle
  - No WG-Pu at any place in the fuel cycle
  - Theft of weapons material impossible
- However, proliferation still possible at state level
  - Introduce hidden blankets
  - Conceal from safe guards or deny safe guards access (accept international sanctions)
- Only exporting the reactor technology would limit the possibility of illicit use
  - No DU supply, no fuel fabrication, no reprocessing tech
  - Non integral concept, but no weapons usable material at any place

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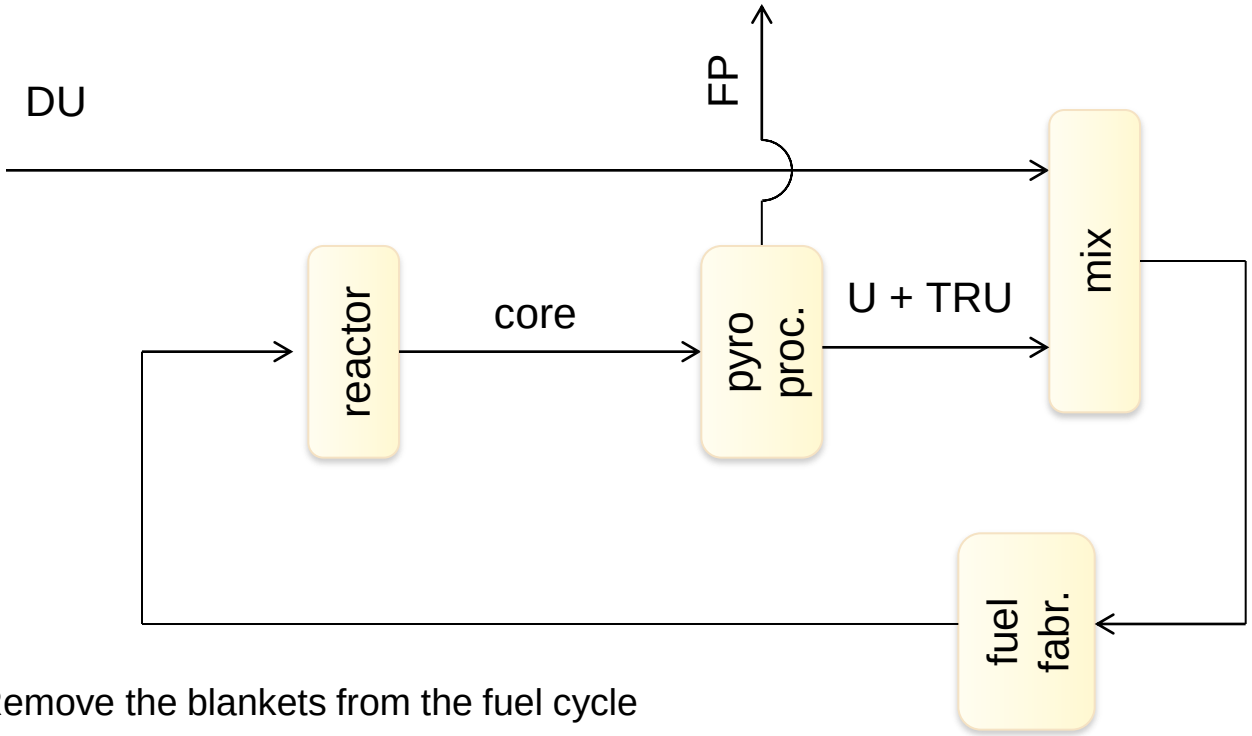
Blanket free breeder reactor



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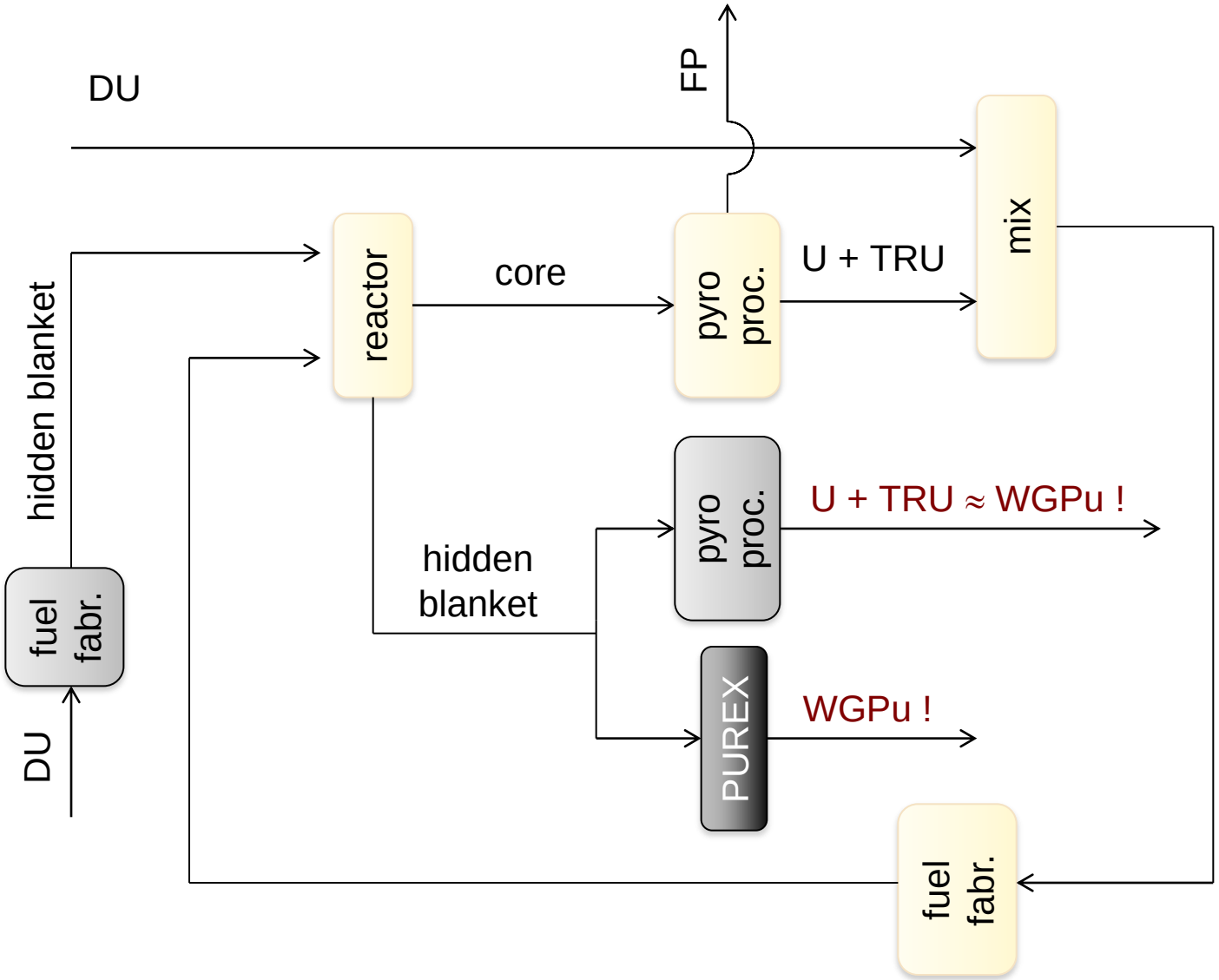

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Proliferation resistant Pu

- All isotopes of Pu could in theory be used in a nuclear explosive, but two factors complicate
- Spontaneous neutron production
  - Mainly from Pu_{240} and Pu_{242}
  - Initiates pre ignition of the device; leads to un-predictable yield or minimum fizzle yield
  - This is still at least a few 100 tons of TNT eq.
- Decay heat production
  - Mainly from Pu_{238} (568 W/kg) and Am_{241} (114 W/kg) alpha decay, with the latter originating from Pu_{241} beta decay
  - Kessler proposes that Pu is proliferation proof if the chemical explosives used to compress the core either melts or self detonates due to high temperatures
  - Identifies decay heat limits of 120, 240 370 W for the Pu core; these correspond to low, medium and high tech nuclear explosives
- If only the reactor technology is exported the lack of DU supply, fuel fabrication and reprocessing makes the system
  - Very proliferation resistant Pu is needed since fuel would be

G. Kesler Proliferation-Proof Uranium / Plutonium Fuel Cycles Safegurads and Non-Proliferation

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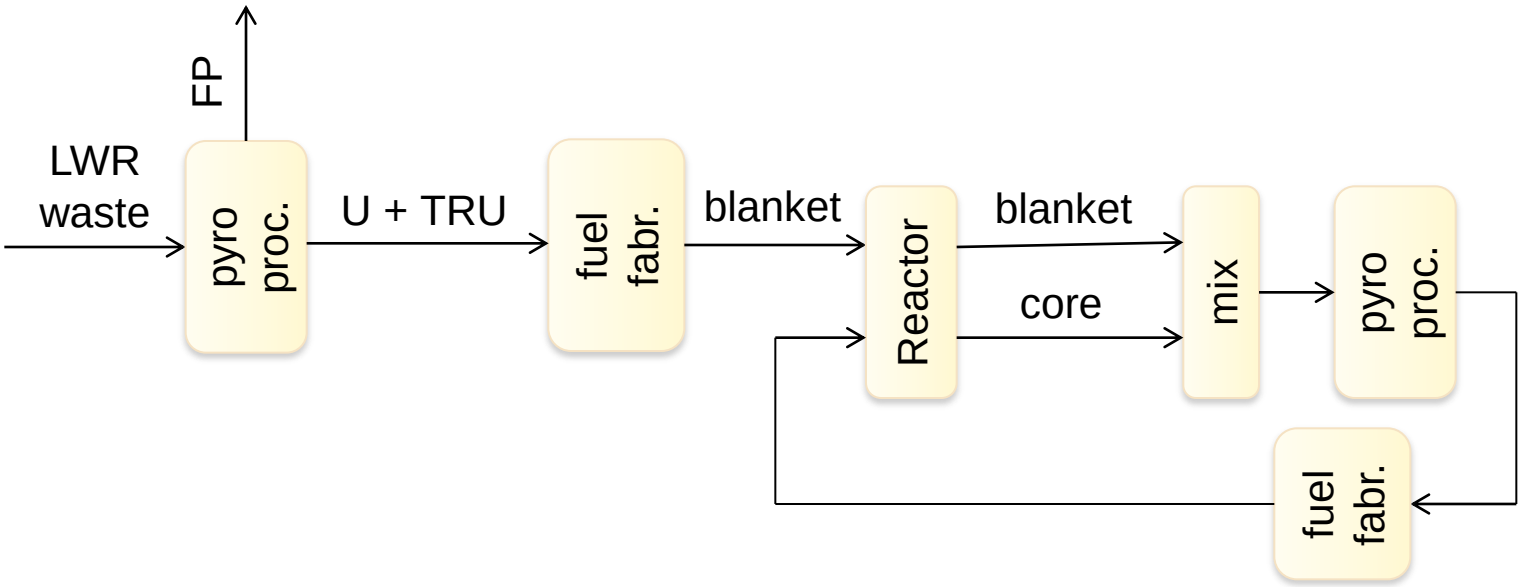
TRU blanket



- Don’t start with depleted uranium in the blanket to avoid production of WG Pu
  - Pu of low quality could be included in the blanket at start
  - Rineiski showed that proliferation proof Pu can be produced in FR blankets using a Th,U,Am – fuel cycle
- If we try to modify the IFR fuel cycle as little as possible, what could we achieve?
  - Start with LWR waste as blanket material
  - Use pyro processing to remove FP
  - Fabricate blanket with U+TRU feed

A. Rineiski Nuclear Engineering and Design **vol 240** (2010) 500

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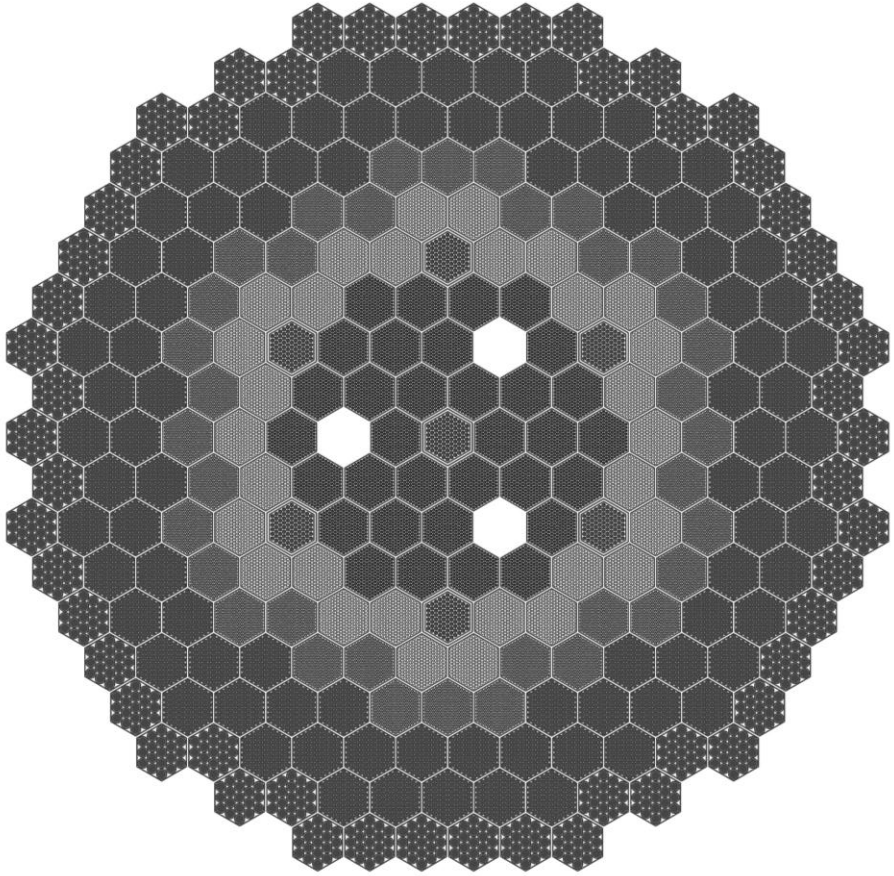
Blanket version of ABTR

- Advanced burner test reactor used as test case
  - Sodium coolant
  - Metal fuel
  - CR = 0.64 (without blanket)
- Inner row of reflector SA exchanged for blanket SA
  - 36 blanket SA
  - 30 outer driver SA
  - 33 inner driver SA
- Modeled in serpent
- 4 blankets tested
  - Depleted uranium
  - SNF 50 MWd/kg
  - SNF 70 MWd/kg
  - SNF 70 MWd/kg X 2



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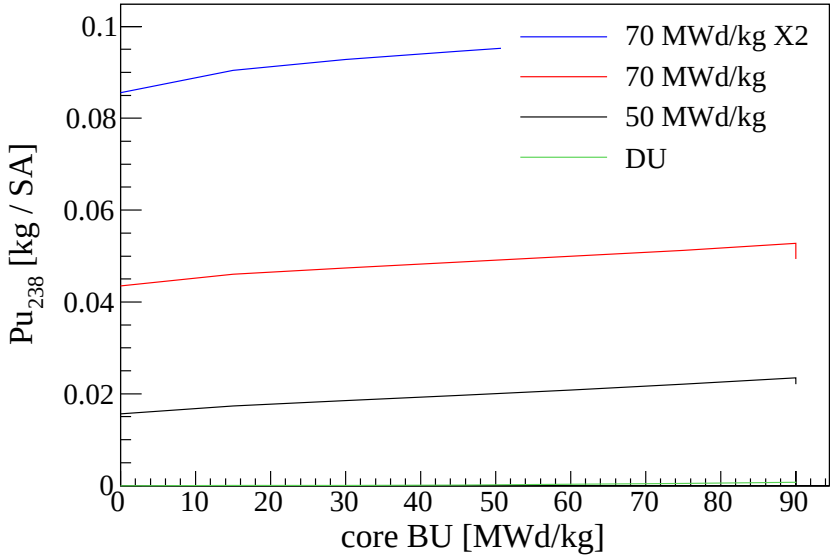
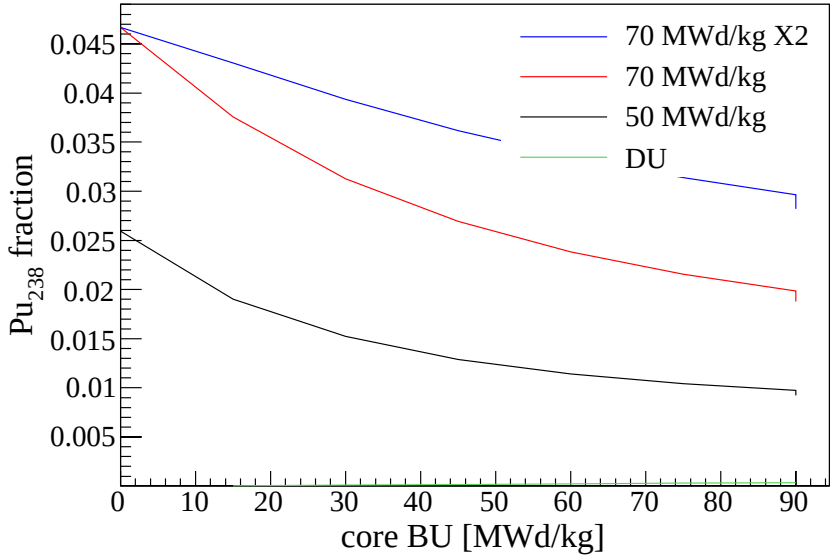
Pu_{238}

- Both Pu_{238} and Pu_{240} levels remain fairly constant
  - However, the relative fractions decrease
- Decay heat up to 20 W/kg
  - Would render low tech weapons impossible and medium tech very difficult
- Spontaneous neutron rate up to 400 kbq/kg
  - Guarantees fizzle yield
- Total amount of Pu239 in blanket about 10% to 20% higher compared to DU blanket
- If pyroprocessing is used to recover TRU from the blankets trace amounts of Cm would generate a strong radiation barrier
  - Limits hands on work to a few hours before lethal dose
  - PUREX and remote handling needed





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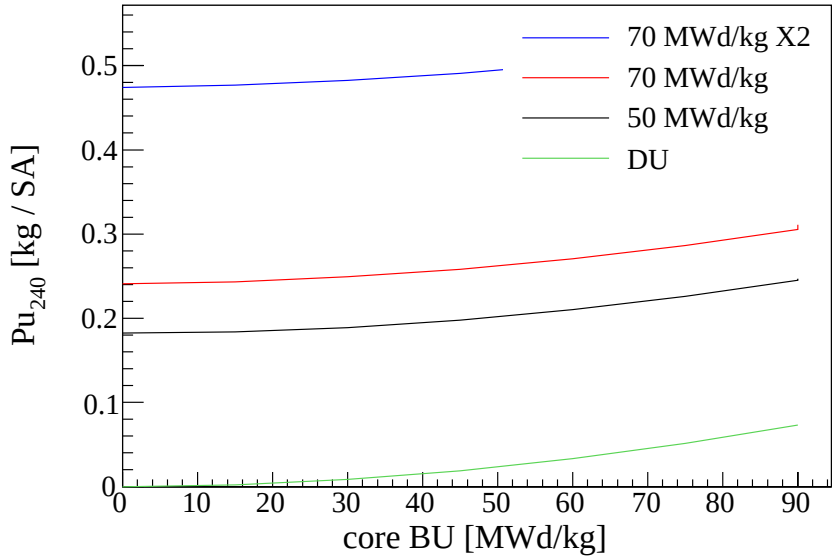

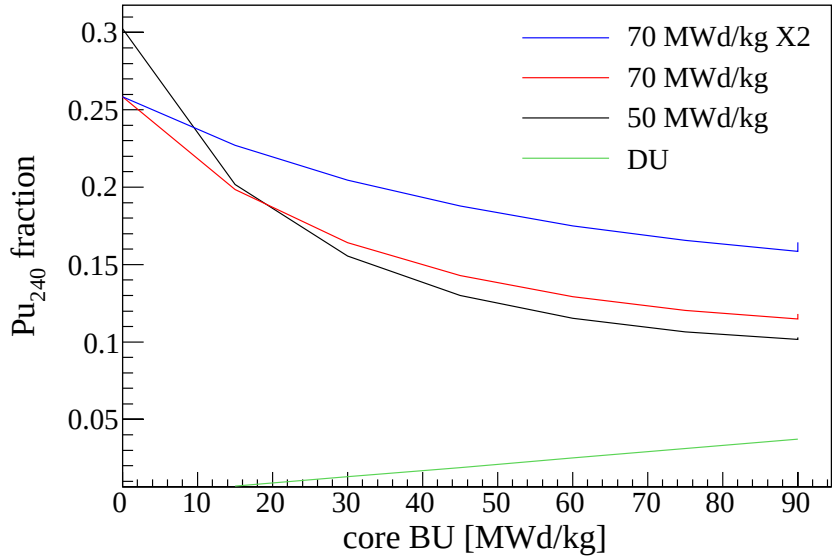

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Decay heat and spontaneous neutron emission

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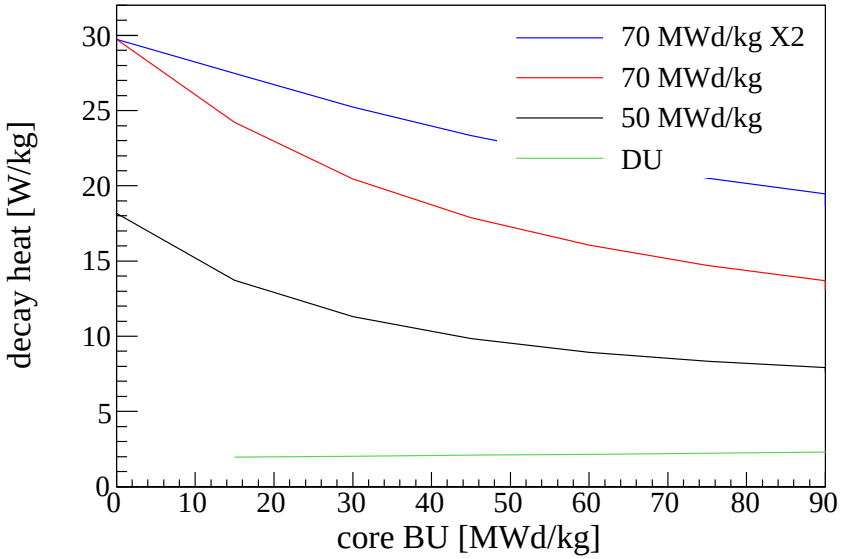

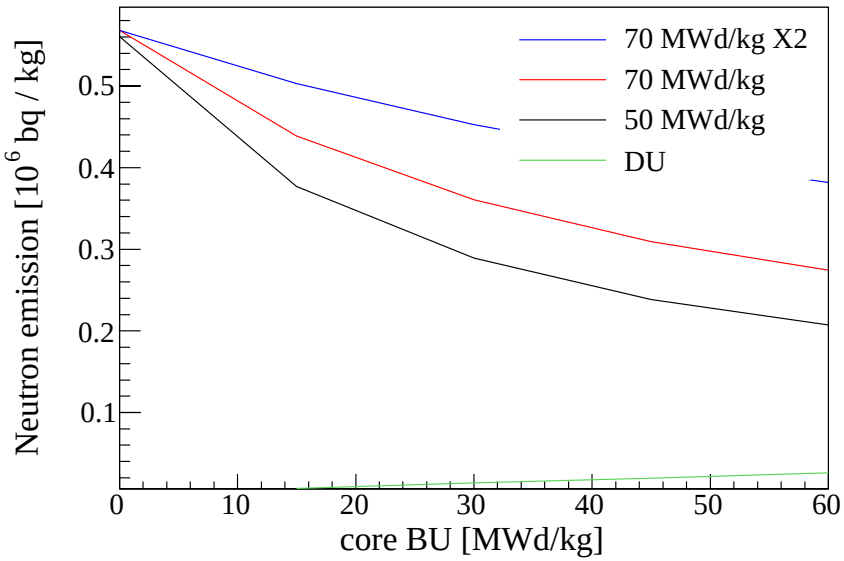

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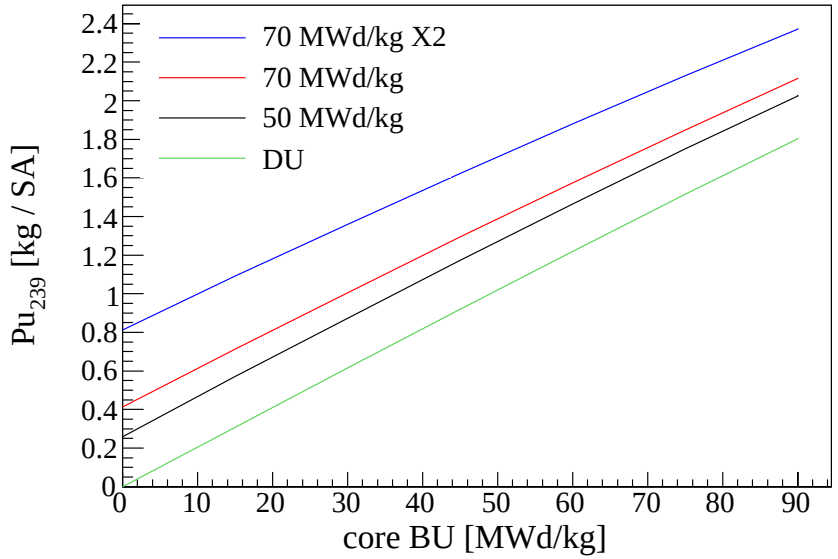

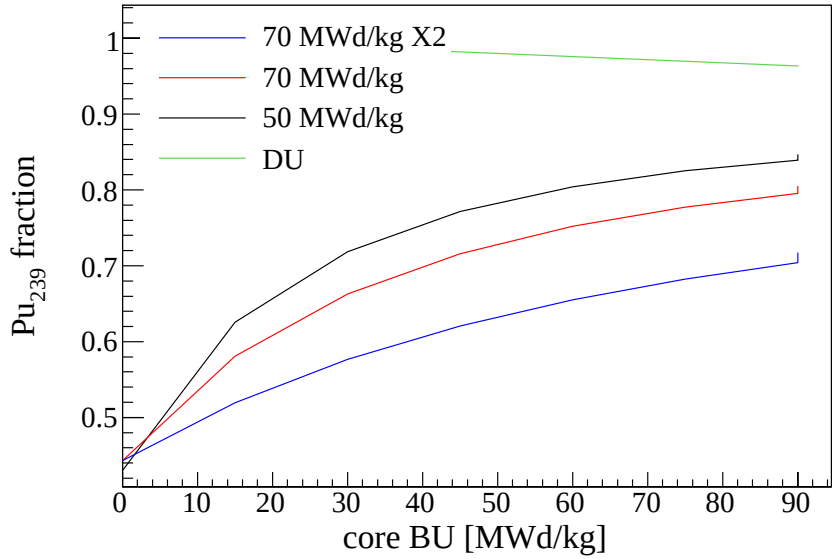

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Summary

- The goals of generation IV are to some extent contradicting
  - Easy to optimize one at the expense of at least one other
- Fully integral generation IV systems good to minimize theft risk of weapons material
  - But exporting DU supply, fuel fabrication, reactor and reprocessing could jump start a proliferant state; perhaps at the cost of international sanctions
- Focus on exporting reactor technology?
  - Would need international transports of fresh and used fuel
  - Excludes the use of DU blankets?
  - But no DU, fuel fabrication and reprocessing would likely render this a very unattractive route for a proliferant state
- Blankets composed of actinide mix from used LWR fuel
  - Eliminates low-tech weapons design; medium-tech design very difficult
  - Good enough?
  - In the end the regulatory bodies and public acceptance will decide