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The Thorium Fuel Cycle: A Proliferation Resistance Focus Shift

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PONI Fall Conference, 2011

Thorium Fuel Cycle Basics

- Breeds fissile U-233 from Th-232
- Thorium Fuel Cycle (TFC) must be initiated with U-Th or Pu-Th mixed cycles
- No thorium enrichment, but reprocessing is a must
- Many beneficial characteristics:
  - Abundance
  - Neutronics
  - Stability

Thorium-Cycle Interest

- Fuel cycle option when uranium resources become scarce.
  - India has expressed the most interest thus far
- Most advanced nuclear states have some experience with thorium.
- Using thorium with U/Pu further degrades weapon's desirable characteristics in fuel.

TFC Proliferation Resistance Points

- Reduced plutonium quantity & quality
  - No Pu production with a pure TFC
- Much U-233 burned *in-situ*
- U-232 produced as a byproduct
  - Strong radiation from daughter products
  - Unique, easy to detect signature

But there are some major concerns

Proliferation Concern #1: U-233 Breeding

- Uranium separated from thorium fuel elements will have high concentration U-233
- U-233 is a superior fissile isotope
  - HEU at 12% U-233 compared to 20% U-235 enrichment
  - Better “weapon’s use” characteristics
- Plutonium vs. U-233

Thought: Why hasn’t anyone made a weapon from U-233?

U-232 “Doping”

One good reason is U-232 generation:

- Very strong radiation from Tl-208 decay (2.6 MeV)
- “Self-protecting” & unique radiation signature
- Difficult separation from U-233
- Production rate depends on reactor type, fuel

Select Reactor ^{232}U Creation Rates	
Reactor	**Approximate $^{232}U/^{233}U$**
LWR	1,000-3,500 ppm
PHWR	500 ppm
FBTR	100 ppm
SFR	10 ppm

Source: IAEA-TECDOC-1450

Proliferation Concern #2: U-232 Avoidance

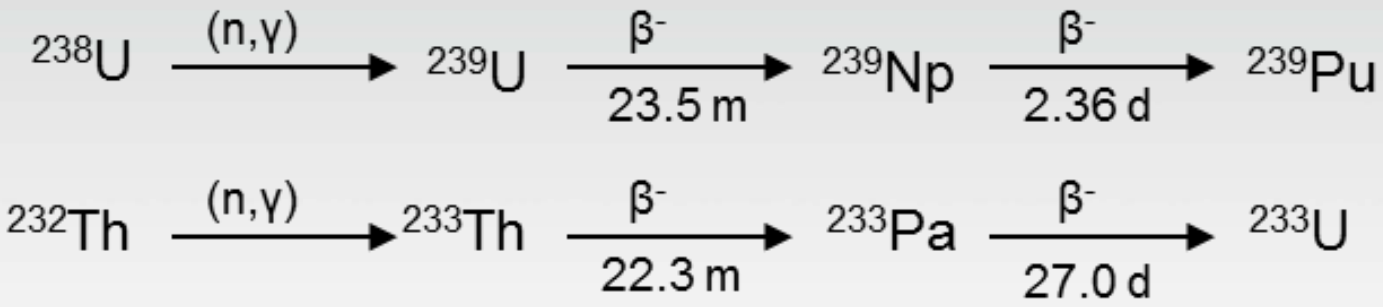
- Low breeding ratios
- Chemical separation removes U-232 daughter product buildup – temporarily.
- "Self-protecting" is difficult to achieve
  - Only true instance is immediate impairment/death

Thickness of lead needed to shield 1 kg U-233 (cm) - IAEA					
	Days after purification				
U232/U233	10	30	100	400	4000
100 ppm	6.75	10.4	13.3	16.4	18.4
1000 ppm	12.1	15.5	18.4	21.5	23.5
10000 ppm	17.2	20.8	23.5	26.0	28.1

Source: IAEA-TECDOC-1450

Proliferation Concern #3: Protactinium

- Pa-233 is the intermediate step to U-233 production
- But Pa-233 has a much longer half-life than Np-239
- Additional time for decay before separation



Protactinium Separation

Why worry about the protactinium?

Reprocessing to separate Pa before it completely decays leads to high quality U-233!

Photo complements of Argonne National Laboratory

Parting Thoughts

- TFC has lots of advantages – including many that I could not cover in this talk.
- Using thorium in existing fuel cycles makes the U/Pu less attractive.
- Nobody has created a weapon from U-233 (to my knowledge) mostly because of cost.
- TFC has unique proliferation vulnerabilities that require further assessment.

Acknowledgements & Sources

- Allen Bakel & Argonne National Laboratory
- PONI Conference organizers for their financial support

- *IAEA-TECDOC-1450 (May 2005)*
- *Argonne National Laboratory website graphics*
- *Ragheb, M. & Maynard, C.W. (1980)*