Closing the Fuel Cycle Can Extend the Lifetime of the High-Level-Waste Repository

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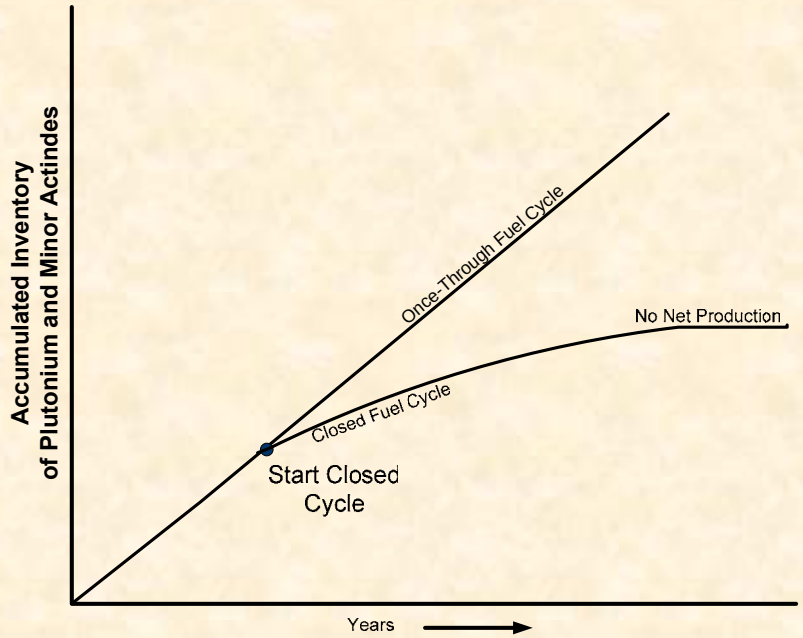
Spent Fuel Inventory in the United States (*Nuclear News*, December 2004)

Year	Metric Tons of Initial Uranium	
1968–2002	47,023	(16,708 from BWRs, 30,292 from PWRs)
2005	~53,470*	Now
2010	~64,200*	Exceeds YM licensed capacity
2015	~74,970*	
2020	~85,700*	
2025	~96,470*	

*Assumes ~2150 MT/year

Spent Fuel and Plutonium Inventory Growth with Once-Through Fuel Cycle



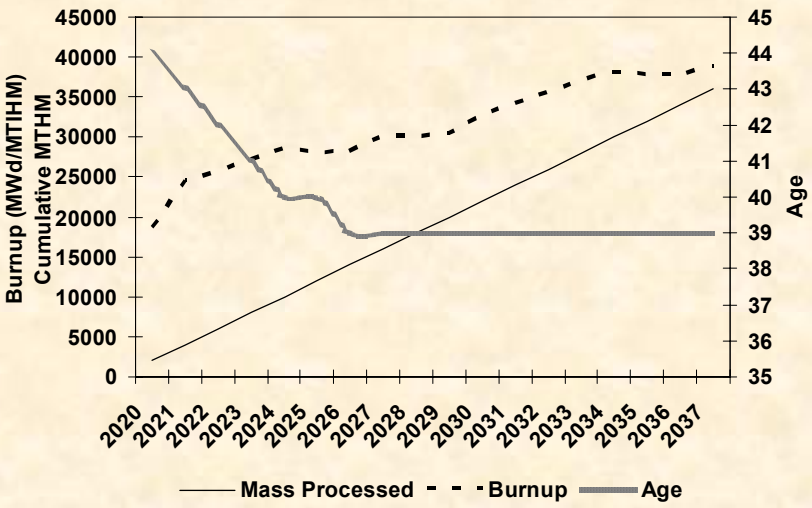
- **Additional spent fuel storage is required**
  - **Multiple repositories**
  - **Dry storage at reactor sites or special monitored retrievable storage (MRS) sites**
  - **Substantial costs**
- **Increased safeguards concerns over the unconstrained growth of fissile materials, together with decreasing radiation protection ("plutonium mines")**
- **Closing the fuel cycle sooner stabilizes the inventory growth and can stop the need for increased storage space**

Comparative Reprocessing Capacities

	Metric Tons per Year
France: LaHague UP-2	800
France: LaHague UP-3	800
U.K:. THORP	1200
Japan: Rokkasho	800

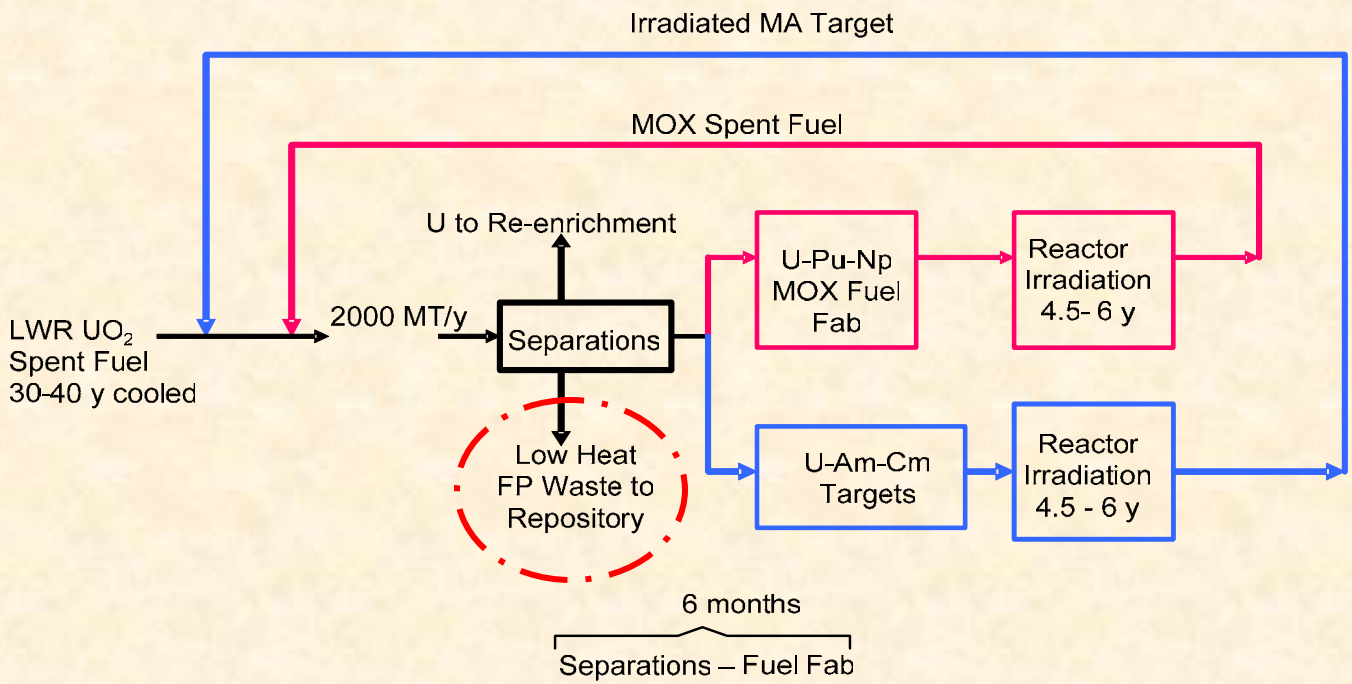
- Current generation rate in the United States is 2000+ MT/year
- Processing spent fuel at the rate of production is a reasonable goal
- Decreasing the inventory will be difficult

Spent Fuel Processing at the Rate of Production



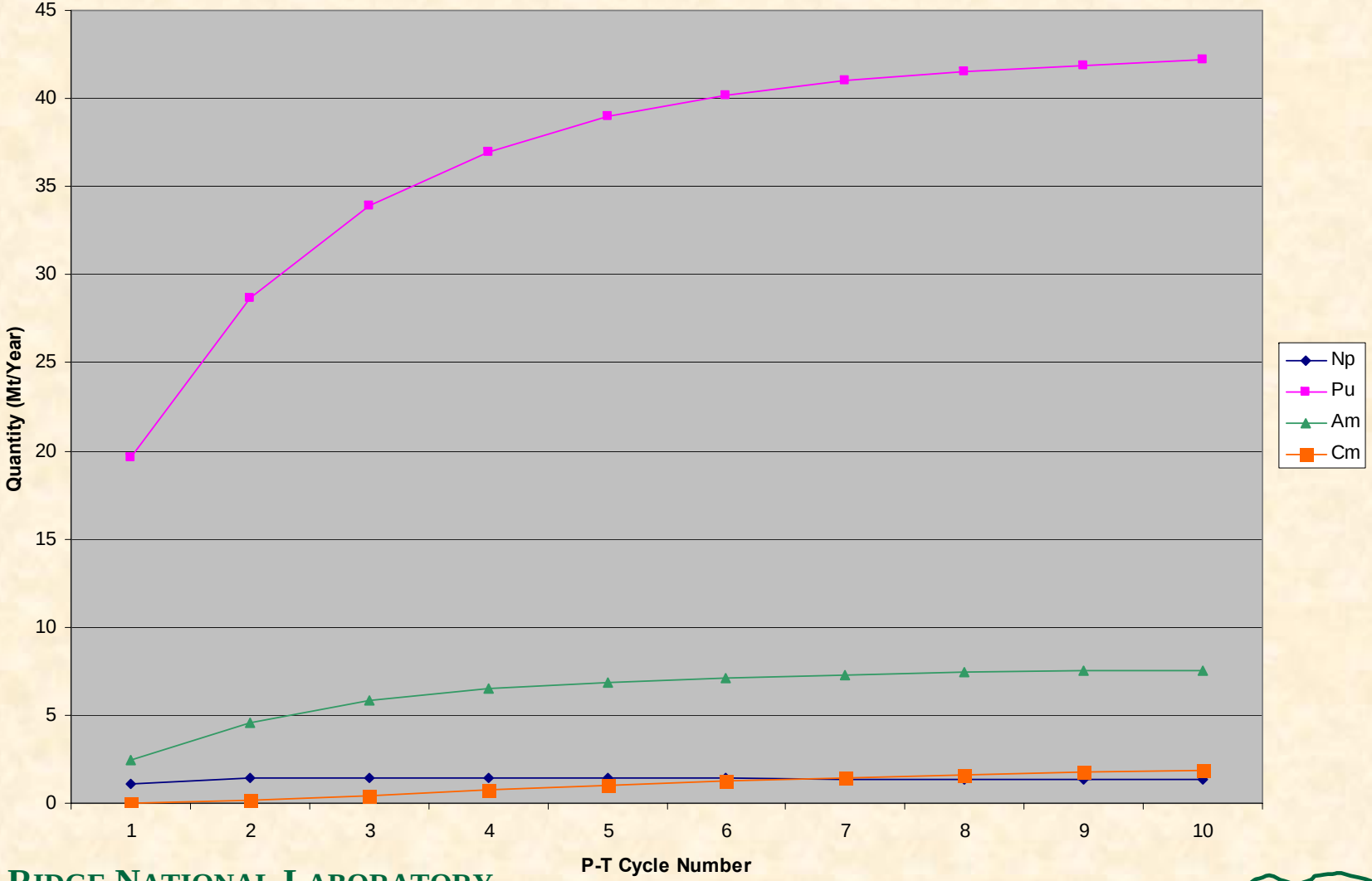
- **Design, construction, licensing, and startup operations require ~10 years or more**
- **Deployment studies show significant advantage of processing "oldest fuel first"**
  - **Less radioactivity and heat generation**
  - **Differences in actinide transmutations which enable "continuous actinide recycle" and maximum benefit (lifetime) for the repository**

Partitioning-Transmutation Scenario

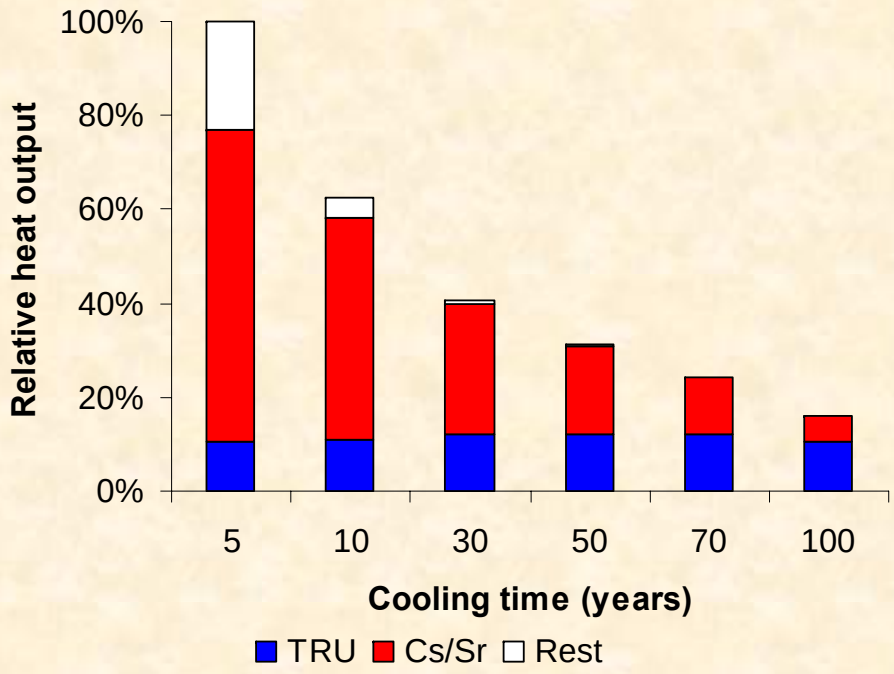


- **The P-T process maximizes lifetime of the HLW repository by minimizing input of heat-generating wastes**
- **The P-T process minimizes mass of wastes by recycling**

Production Rates of Transuranium Elements with 30-year Decay Cycles

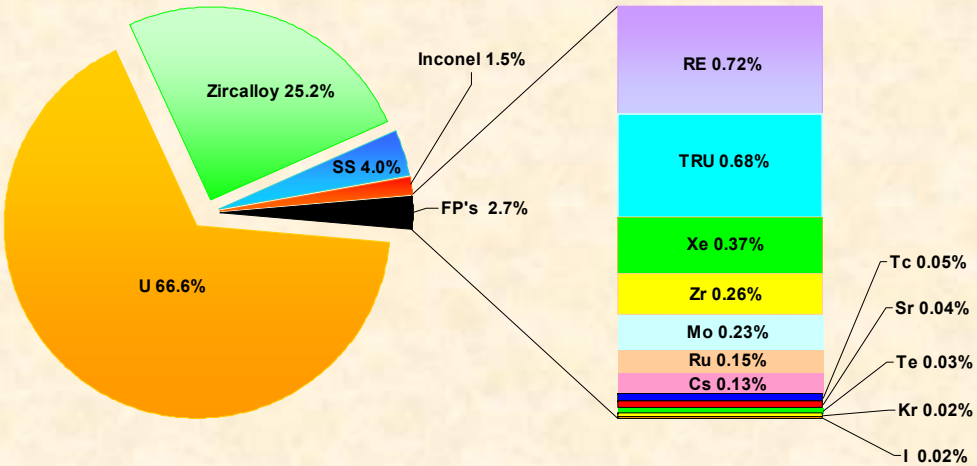


Removal of High-Heat Generators Is a Goal of the P-T Process



- **Primary heat generators in aged spent fuel**
  - **Intermediate lifetime (~30-y half-life) fission products, ^{137}Cs and ^{90}Sr**
  - **Long-lived transuranic activities (TRUs)**
- **Complete recycle of the TRUs is the goal of the P-T process**
- **Separation and managed storage of the Cs-Sr wastes is a goal of the UREX+ separations process**

Separation, Recycle, or LLW Disposal of Largest Mass Components



- **Another goal of the UREX+ separations process is to separate and purify the uranium and zircalloy components for recycle or disposal as low-level waste (LLW)**
- **Separation of the TRUs (plutonium and the minor actinides, neptunium, americium, and curium) from the fission products is necessary for TRU recycle**

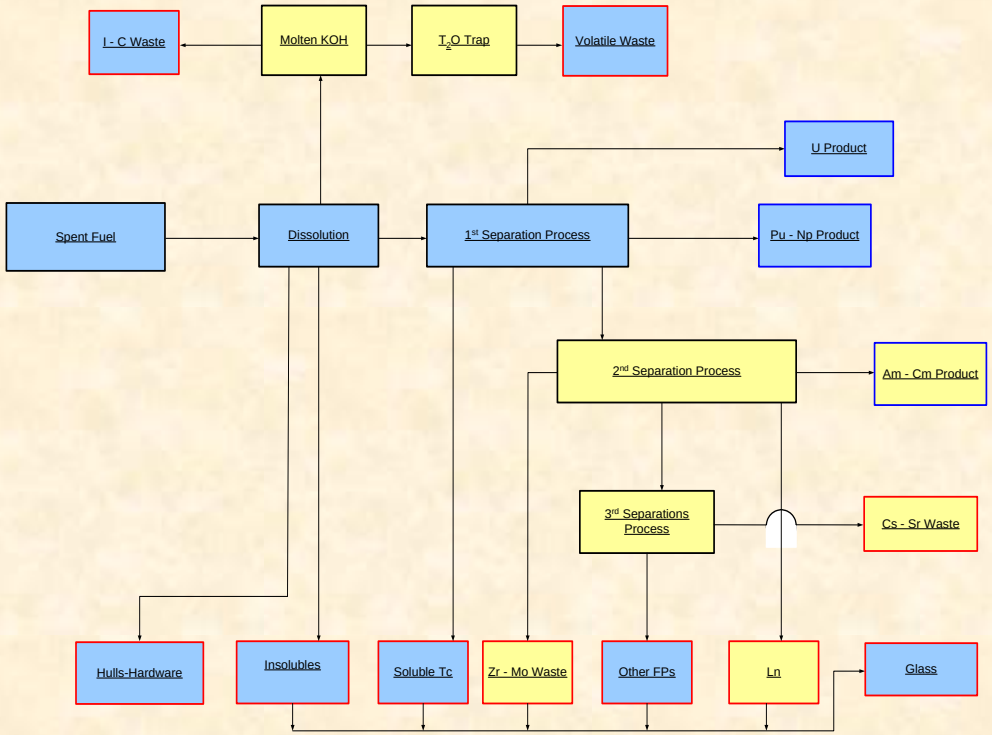
Suite of UREX+ Processes

Process	Prod #1	Prod #2	Prod #3	Prod #4	Prod #5	Prod #6	Prod #7
UREX+1	U	Tc	Cs/Sr	TRU+Ln	FP		
UREX+1a	U	Tc	Cs/Sr	TRU	All FP		
UREX+2	U	Tc	Cs/Sr	Pu+Np	Am+Cm+Ln	FP	
UREX+3	U	Tc	Cs/Sr	Pu+Np	Am+Cm	All FP	
UREX+4	U	Tc	Cs/Sr	Pu+Np	Am	Cm	All FP

Notes: (1) In all cases, iodine is removed as an off-gas from the dissolution process.
(2) Processes are designed for the generation of no liquid high-level wastes.

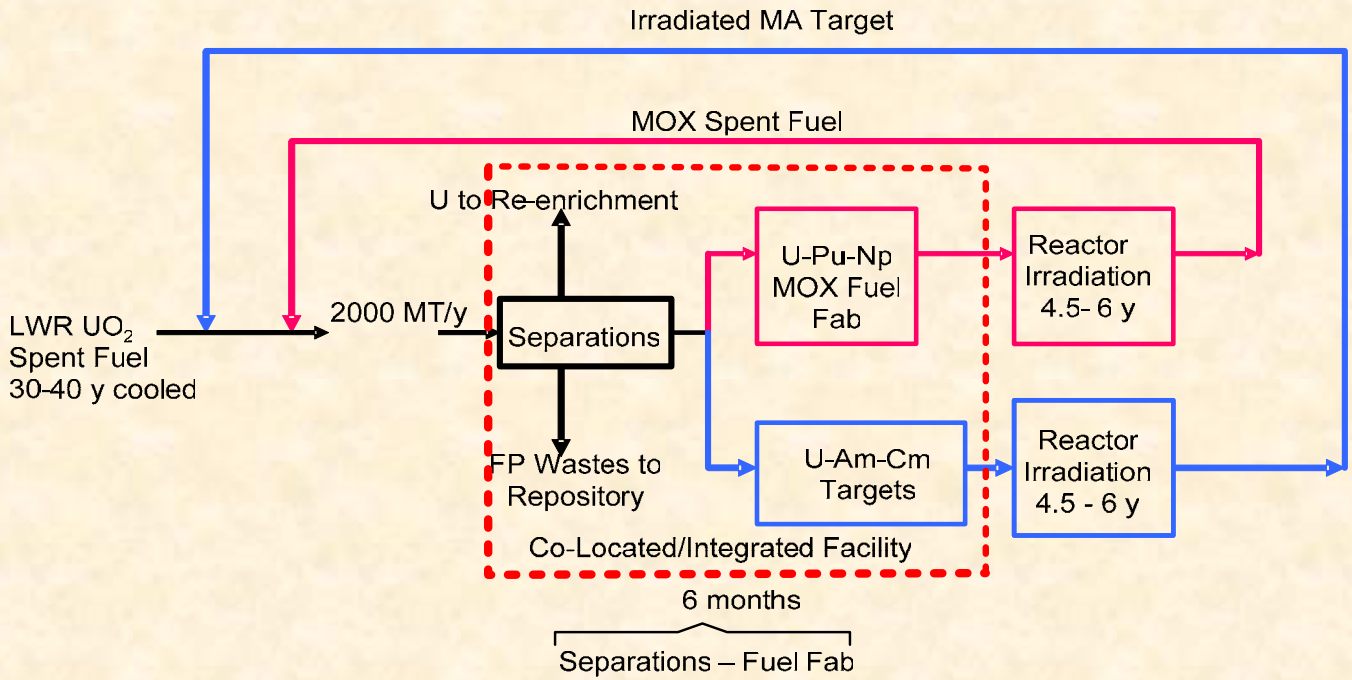
U: uranium (removed in order to reduce the mass and volume of high-level waste)
Tc: technetium (long-lived fission product, prime contributor to long-term dose at Yucca Mountain)
Cs/Sr: cesium and strontium (primary short-term heat generators; repository impact)
TRU: transuranic elements (Pu: plutonium, Np: neptunium, Am: americium, Cm: curium)
Ln: lanthanide (rare earth) fission products
FP: fission products other than cesium, strontium, technetium, iodine, and the lanthanides

UREX+3 Flowsheet is an Attractive Candidate for the P-T Separations Process



- **Head-end operations and 1st Separation Process are modifications of existing industrial-scale facilities**
  - **These could be used for an early start to spent fuel treatment**
- **AFCI projects are prioritized on the basis of these factors**
  - **Selection/optimization of Am-Cm recovery process**
  - **Fabrication of Am-Cm transmutation targets**
  - **Development of Cs-Sr waste form for managed storage**
  - **Development of advanced methods for process improvement, simplification, and cost reduction**

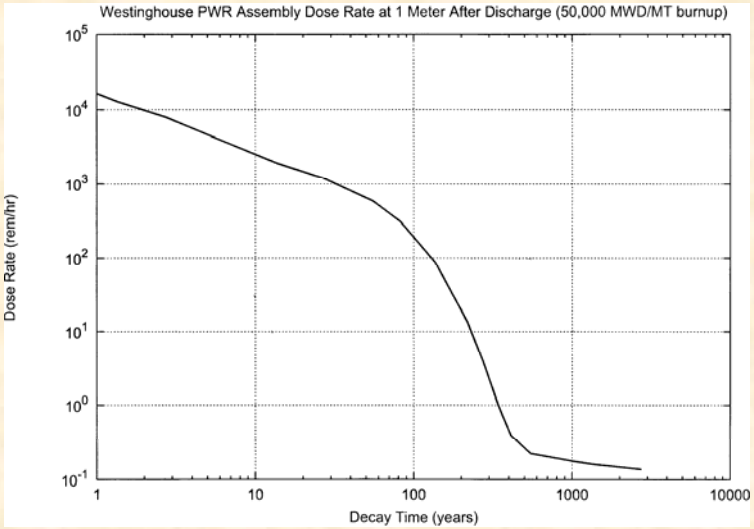
The Partitioning-Transmutation Process Must Be Proliferation Resistant



- **AFCI studies clearly show that the separations plant and the fuel/target fabrication plant must be co-located and integrated in a physically protected facility**
- **Most of the fissile inventory is in storage—protected by the high radiation barrier from the fission products**
- **Recycling (reirradiation) of aged fissile material restores the high radiation barrier**

Contribution of TRUs to High Radiation Barrier

Shield Material	Thickness (cm)	TRU	TRU, 0.6%Cs+Sr
None		**0.403 ± 9%**	**96.25 ± 10%**
SS-316	**2.5**	**0.428 ± 2%**	**36.28 ± 12%**
SS-316	**10.5**	**0.295 ± 2%**	**1.273 ± 55%**
SS-316	**24.5**	**0.120 ± 2%**	**0.128 ± 14%**
Poly-ethylene	**2.5**	**0.321 ± 2%**	**94.19 ± 10%**
Poly-ethylene	**10.5**	**0.069 ± 11%**	**55.14 ± 10%**
Poly-ethylene	**24.5**	**0.008 ± 39%**	**21.01 ± 4%**
Lead	**2.5**	**0.436 ± 1%**	**7.522 ± 25%**
Lead	**10.5**	**0.354 ± 2%**	**0.358 ± 2%**
Lead	**24.5**	**0.239 ± 2%**	**0.236 ± 2%**



- **Calculated radiation emissions**
  - **TRUs emit <1 rad/hour at 1-meter distance**
  - **Addition of fission products is necessary to achieve same radiation levels as spent fuel**
- **Addition of minor actinides or fission products to recycled plutonium will increase significantly the costs of fuel fabrication and transportation**
- **A cost/benefit (for proliferation resistance) trade study is needed**

Summary

- Concerns are arising over the increasing inventory of
  - U.S. spent fuel (and plutonium)
  - Increasing storage sites and costs
  - Safeguards problems
- The inventory can be stabilized by closing the fuel cycle as soon as possible
- Much of the partitioning-transmutation process has been implemented on an industrial scale in Europe and Japan
- AFCI projects are aimed at developing the necessary extended capabilities
- Repository lifetime can be maximized by processing spent fuels to remove the largest-mass components and heat generators