SCENARIO SELECTION AND SUMMARY RESULTS AND CONCLUSIONS FROM THE ORNL/TM-2007/24 REPORT AND FAST REACTOR STUDIES

GNEP/AFCI Systems Analysis Working Group Meeting

Washington, D.C.

March 15, 2007

Emory D. Collins
Oak Ridge National Laboratory

Closing the Fuel Cycle with Full Actinide Recycle—Is It realistically Feasible?—In the Near Term?

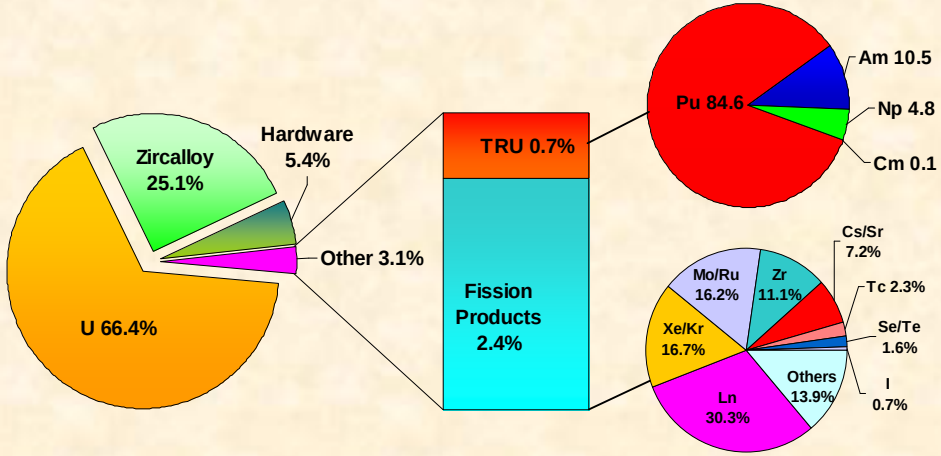
Open Cycle (Direct Disposal) → Multiple Repositories → Multiple $B Capital/Operating Costs

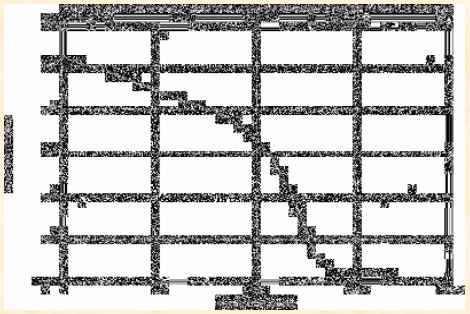
Closed Cycle → Recycle Facilities + 1 Repository → Multiple $B Capital/Operating Costs

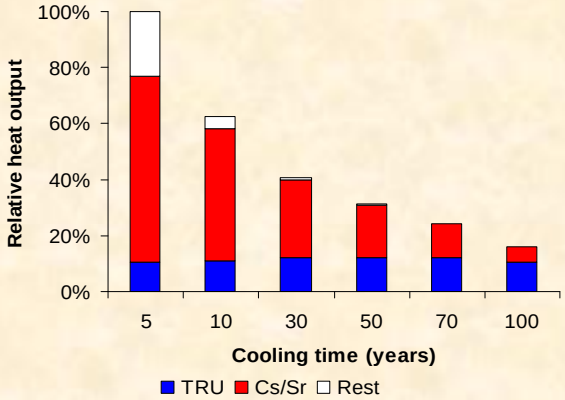
Major constraints:

- Minimizing capital/operating costs
- Providing "sufficient" proliferation resistance

The Starting Material—Characteristics of LWR Spent Fuel





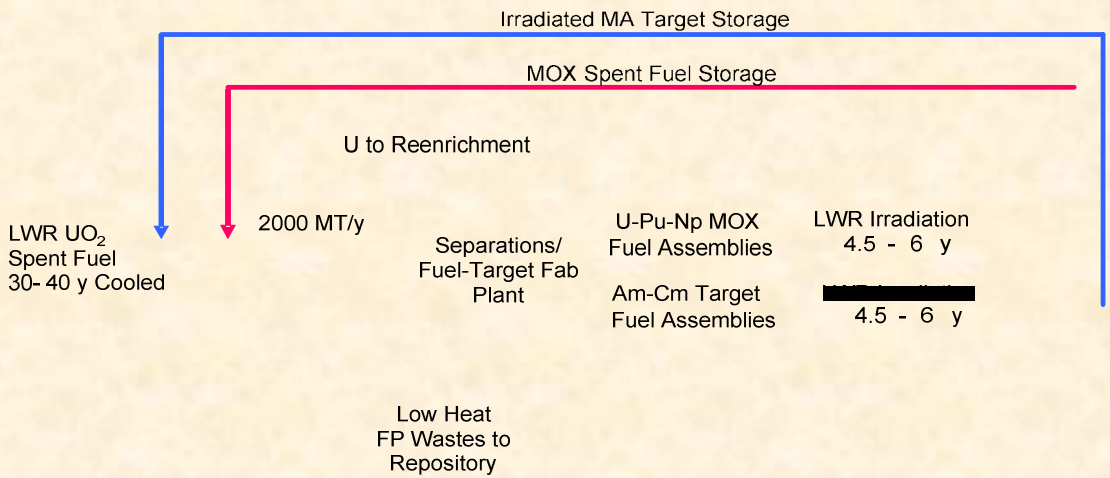


The United States has accumulated more than 55,000 MT of heavy metal in spent fuel and is generating ~2200 MT/year. The legacy fuel must be processed, and the actinides must be recycled to minimize the number of high-level waste repositories required in the future

Goal was to select a realistic scenario for multicycle full-actinide partitioning-transmutation (P-T) during the next ~100 years with emphasis on cost minimization and provision of sufficient proliferation resistance

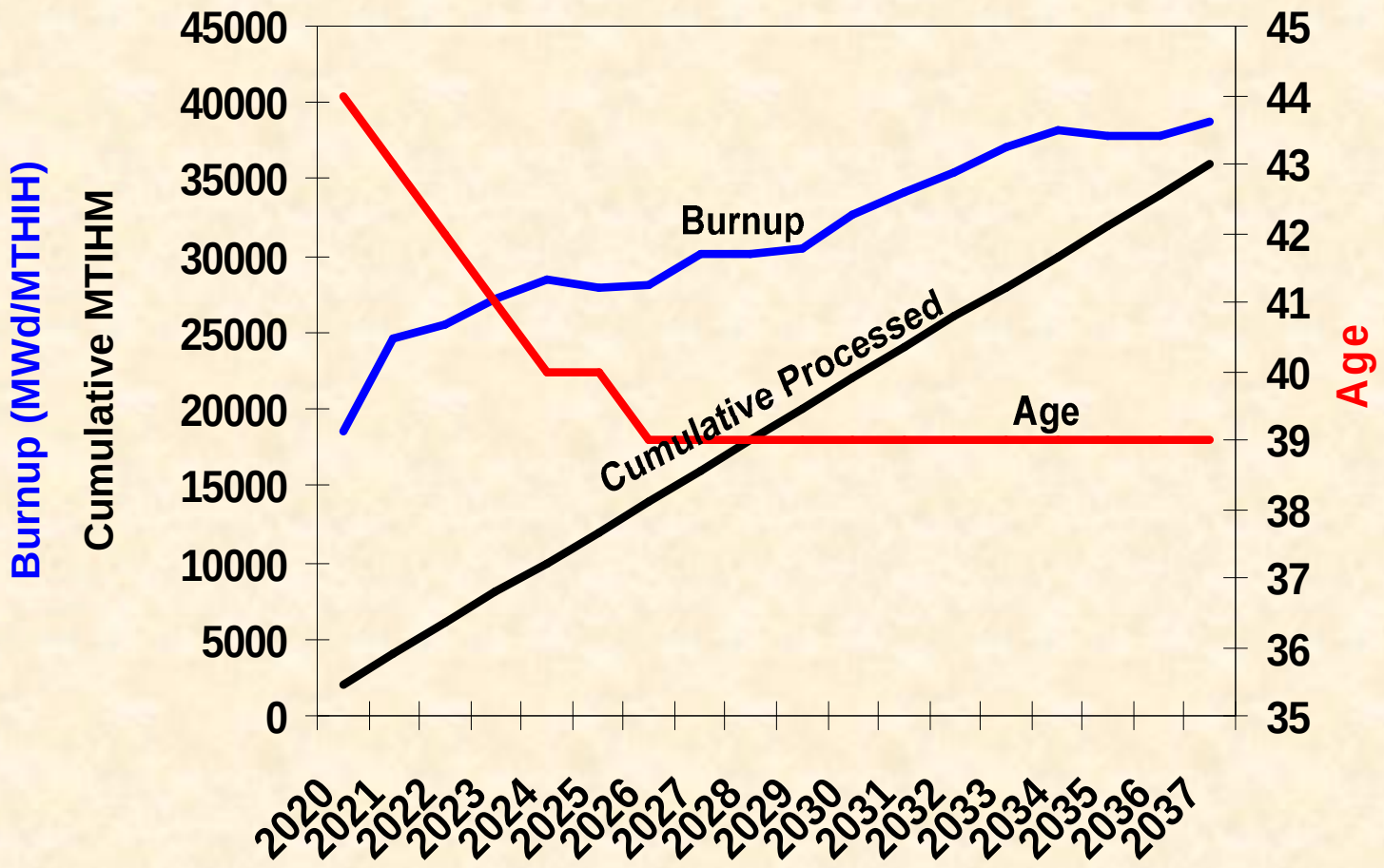
Options:

- **Spent fuel age**
- **Blending strategy**
- **Plant size**
- **Co-location/integration of separation and fuel/target fabrication**
- **Heterogeneous vs homogeneous actinide recycling**



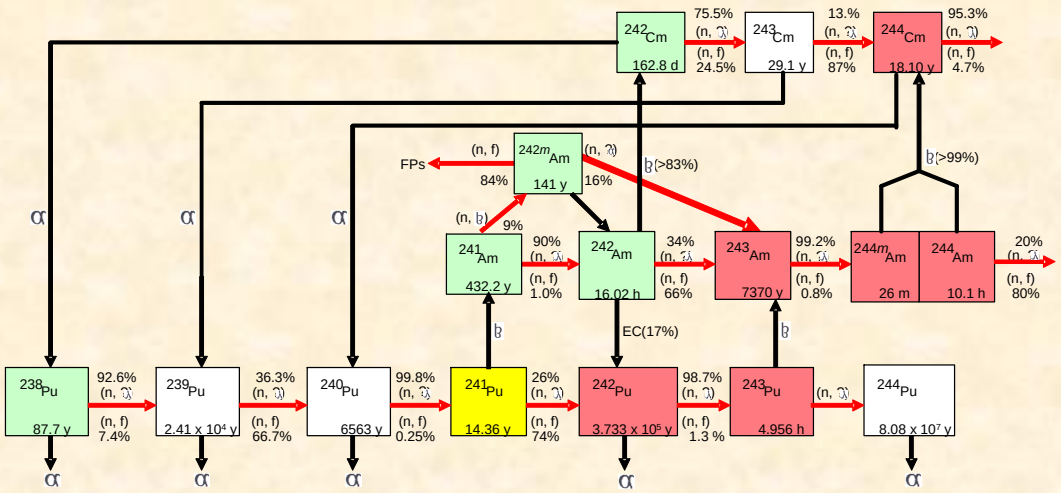
- **Irradiation configuration**
- **Cm separation/storage**
- **Use of IM for Am-Cm target**

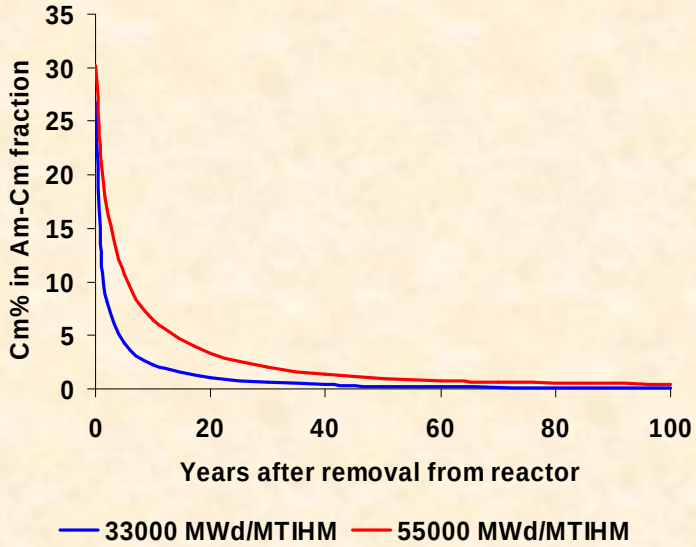
Processing of 2000 MT/Year of Older-Fuel-First



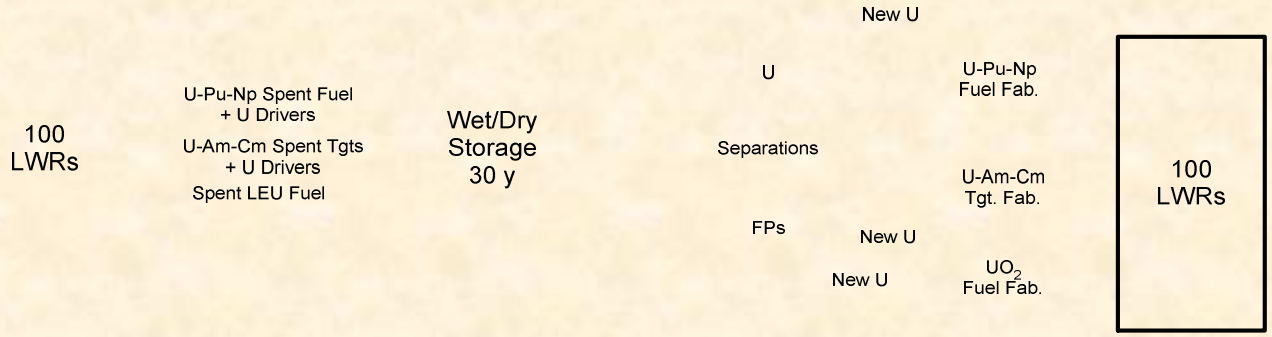
Benefits of Processing Oldest-Fuel-First

- Lower radioactive emissions
- Less radiation damage to equipment/instrumentation/process fluids
- Less heat emission from stored waste
- Alters transmutation pathway to produce lighter plutonium nuclides rather than heavy curium nuclides





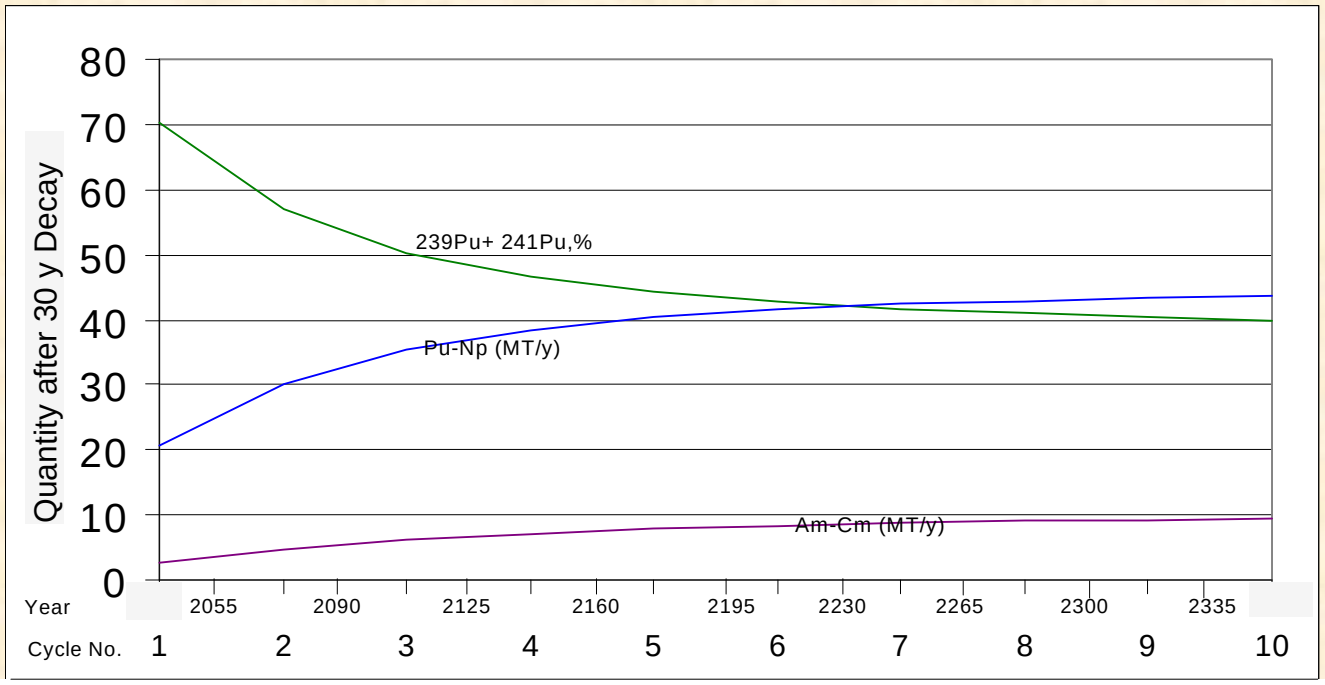
Blending Strategy



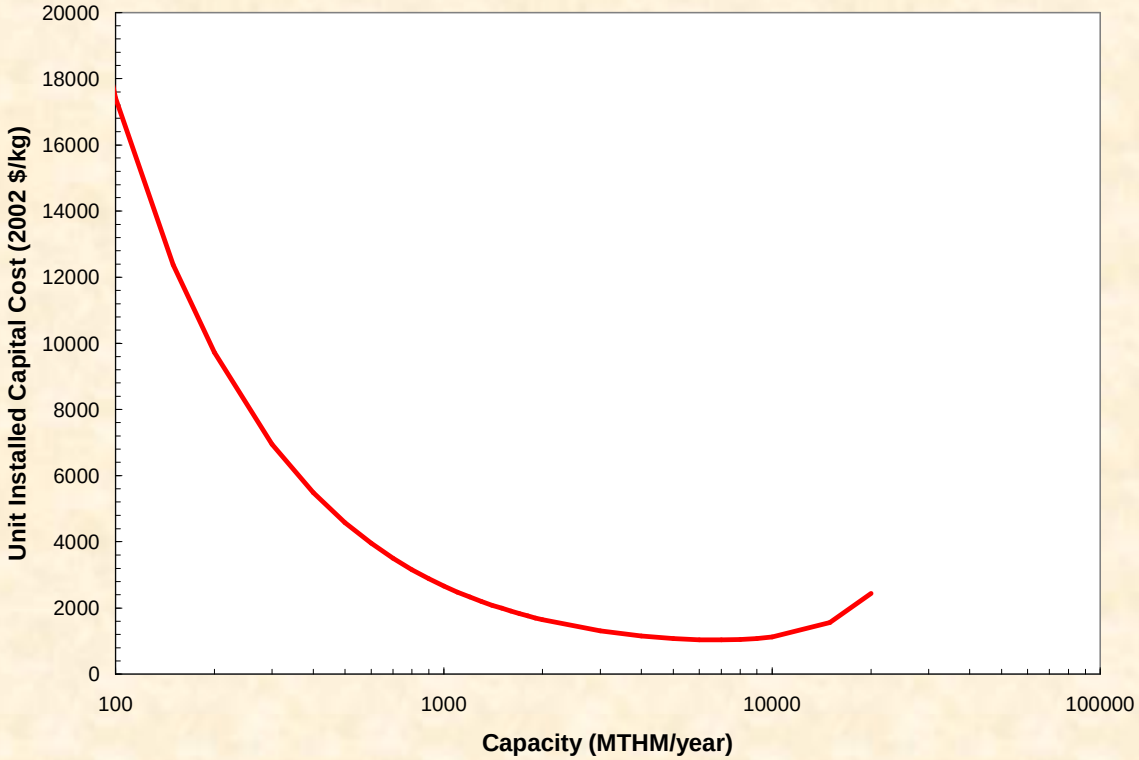
	Recycled MOX Spent Fuel	+	Recycled Irradiated Am-Cm Targets	+	"Fresh" LWR-UO_2 (LEU) Spent Fuel LWR-UO_2	=	2nd P-T Recycle Feed
Np, MT/year	0.38		0.06		0.96		1.40
Pu, MT/year	9.7		1.6		17.4		28.7
^{238}Pu, %	5.7		51.9		1.5		5.7
^{239}Pu, %	33.5		25.1		66.6		53.1
^{240}Pu, %	39.6		6.8		23.8		28.2
^{241}Pu, %	4.8		1.0		3.6		3.9
^{242}Pu, %	16.4		15.3		4.5		9.1
Am, MT/year	1.9		0.46		2.2		4.6
^{241}Am, %	84.6		74.4		92.8		87.5
^{243}Am, %	15.3		24.1		7.1		12.2
Cm, MT/year	0.095		0.068		0.018		0.18
^{243}Cm, %	0.7		5.8		1.3		2.7
^{244}Cm, %	70.5		61.1		83.7		68.3
^{245}Cm, %	25.4		27.6		13.7		25.1
^{246}Cm, %	3.3		5.5		1.0		3.9
Total HM/MT/yr	204		24		1772		2000
	10.2%		1.2%		88.6%		100%

Blending Strategy Conclusion

Utilization of a blending strategy in which recycled actinides are blended with low-enriched uranium spent fuel at the head-end of the separations plant will provide a sufficiently high fissile content for subsequent recycle of the actinide mix and will enable continuous, multicycle operation using LWRs, ABRs, or combinations of the two types of reactors



Plant Size



2000-T/year Plant

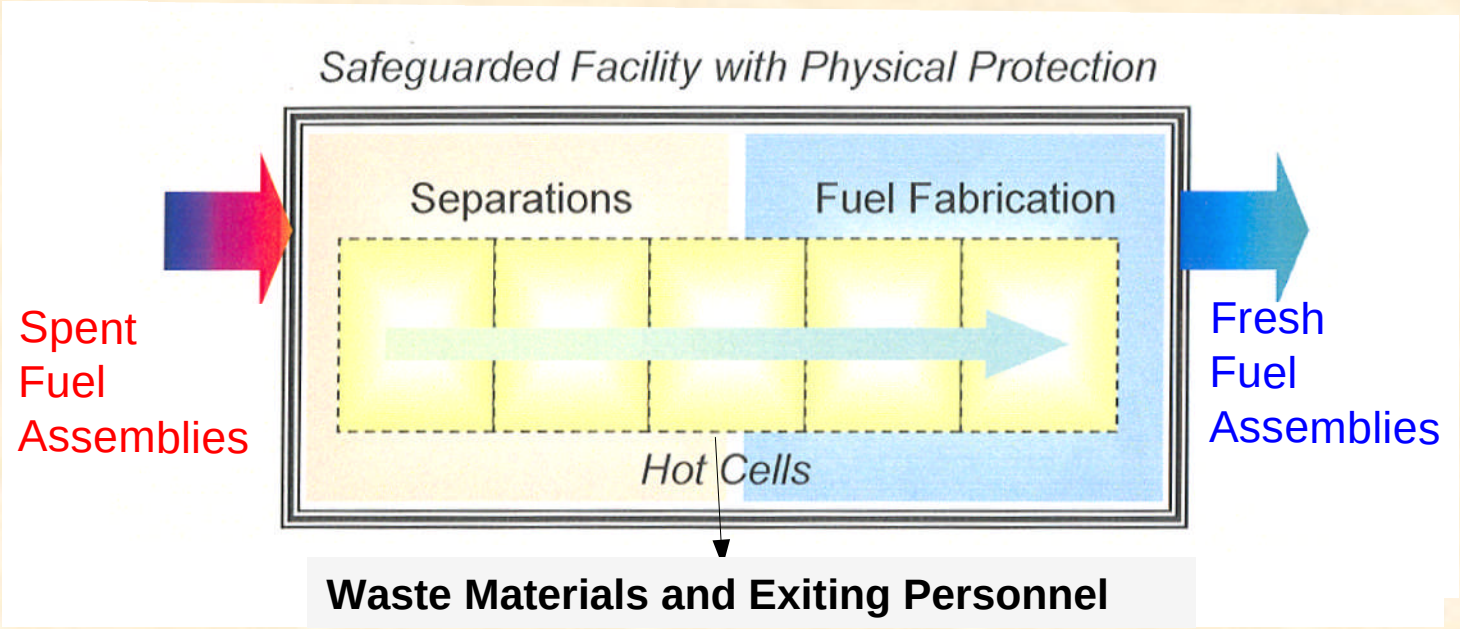
No. of Modules	Relative Cost
1	1.0
2	1.4
3	1.8

Estimations by Nexia Solutions (U.K.) based on experience with THORP Plant (1200 T/year)

Utilization of large spent fuel processing (separations and fuel/target fabrication) facilities with overall capabilities of 2000 to 3000 MT/year is practical and provides the lowest unit cost for processing

Co-location and Integration of Separations and Fuel/Target Fabrication

The Partitioning-Transmutation Process Must Be Economical and Proliferation Resistant



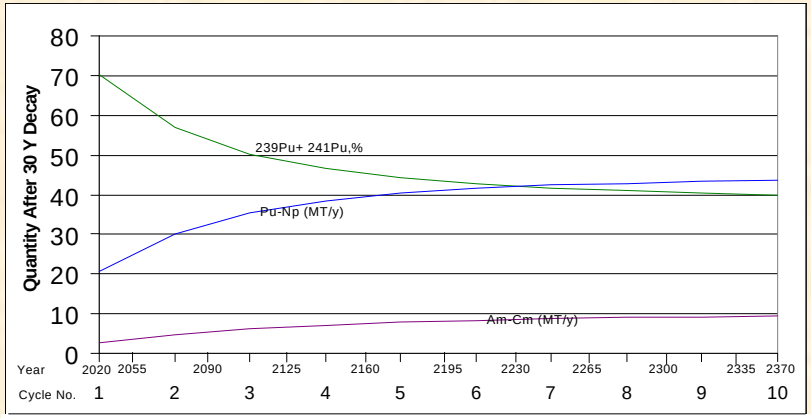
Utilization of large co-located and integrated separations and fuel/target fabrications operations located within a physically protected facility will provide significant cost reduction and maximized proliferation resistance

Heterogeneous Actinide Recycling

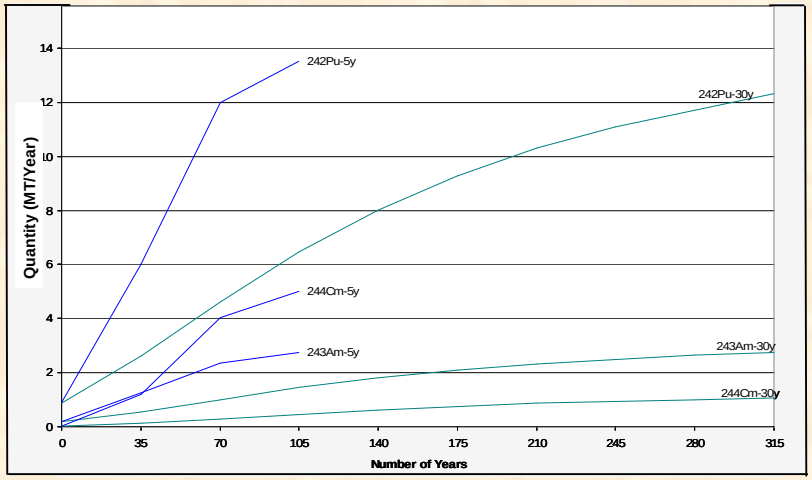
- Initial studies indicated no appreciable difference in actinide transmutation using either heterogeneous or homogeneous cores
- Major factor is less effort, time, and costs for fuel/target development and fabrication
  - U-Pu MOX is already developed and proven
  - Pu-Np is ~90% of TRUs; Am-Cm is ~10%
  - Fuel/targets containing Am-Cm are less developed, and fabrication of any fuel/targets containing Am-Cm require a shielded, remotely operated facility, which is more expensive to build, operate, and maintain
- Am-Cm provides no more proliferation resistance for Pu than dilution with uranium
- Separations process for Pu-Np is single step and industrially proven
  - Am-Cm separations process is less developed and not industrially proven
  - Group actinide separations is more complex and not industrially proven

Utilization of heterogeneous actinide recycling will provide (1) cost reduction in separations processes, fuel development, and fuel/target fabrication facilities and operation; (2) flexibility of P-T deployment; and (3) improved technical performance. Proliferation risk will not be increased

Thermal Transmutation in LWRs—Conclusions

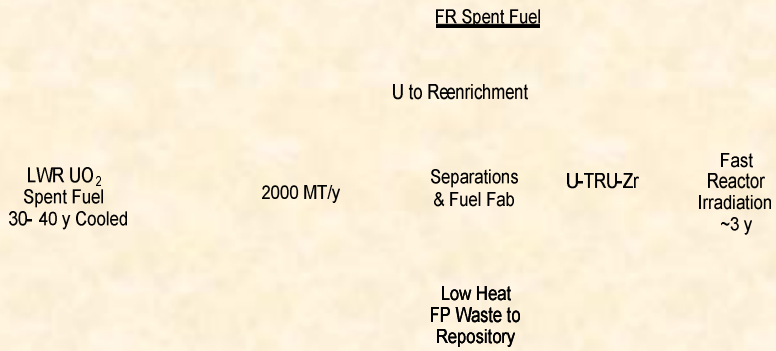


Use of multiple P-T cycles (continuous recycle) using only existing and new LWRs is feasible. Use of long decay periods (≥ 30 years) in the P-T cycles using LWRs will enable significant suppression of the production of curium and heavier actinides during the continued multiple P-T cycles

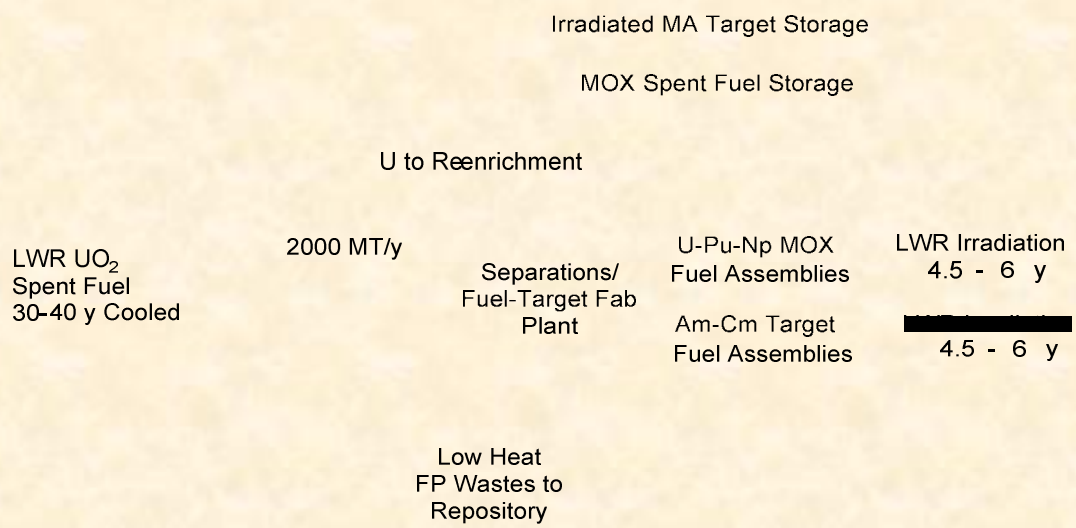


Alternatively, use of short decay periods (~5 years) for irradiation of plutonium in LWRs, as currently practiced in France and other countries, would significantly increase the production of heavier actinides (e.g., ^{242}Pu, ^{243}Am, ^{244}Cm)

Fast Reactor Studies



Fast burner reactor transmutation scenario



LWR transmutation scenario

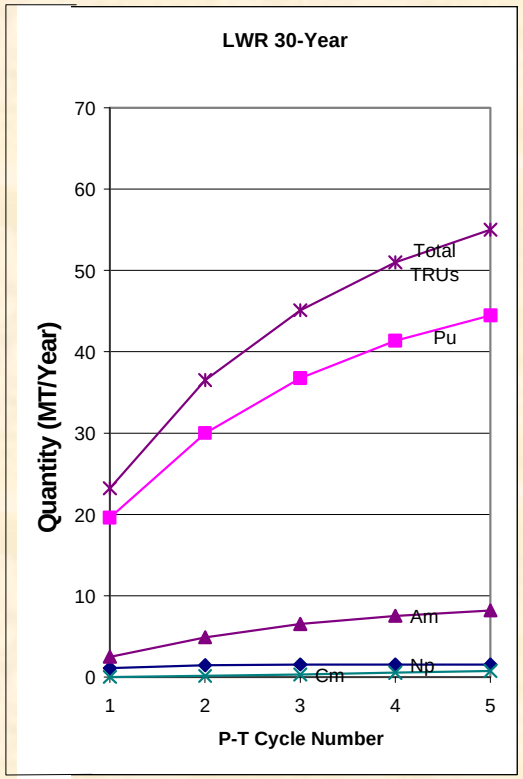
Fast Burner Reactor Studies—Conclusions

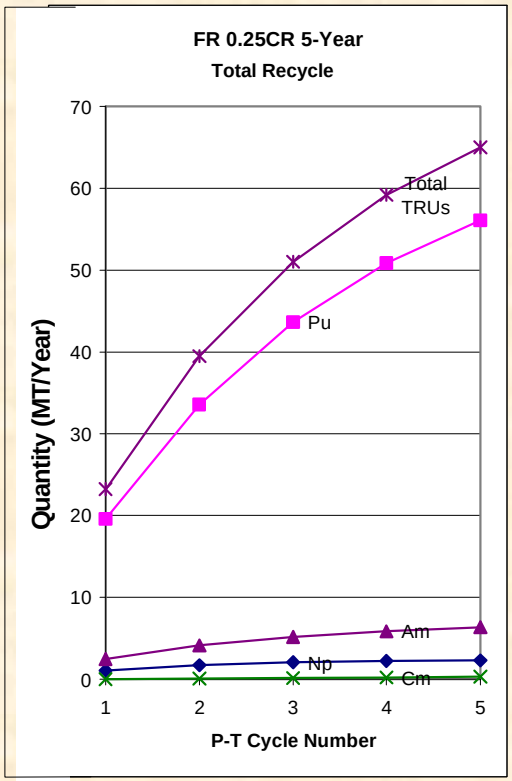
- Transmutation of Pu is optimum in a fast spectrum because production of ^{241}Pu and heavier isotopes (^{242}Pu, ^{243}Am, ^{244}Cm, ^{252}Cf) is suppressed
- When the MAs, ^{241}Am and ^{237}Np, are initially present (as they are in spent fuel produced by irradiation of LEU), the destruction rates are slower in ABRs than in LWRs
- Optimum performance can be obtained by irradiating Pu (or Pu-Np) in FRs and by irradiating Am-Cm in LWRs (the "hybrid" case)
  - Shorter decay periods (~5 years) can be utilized because production of ^{241}Pu and heavier actinides is suppressed

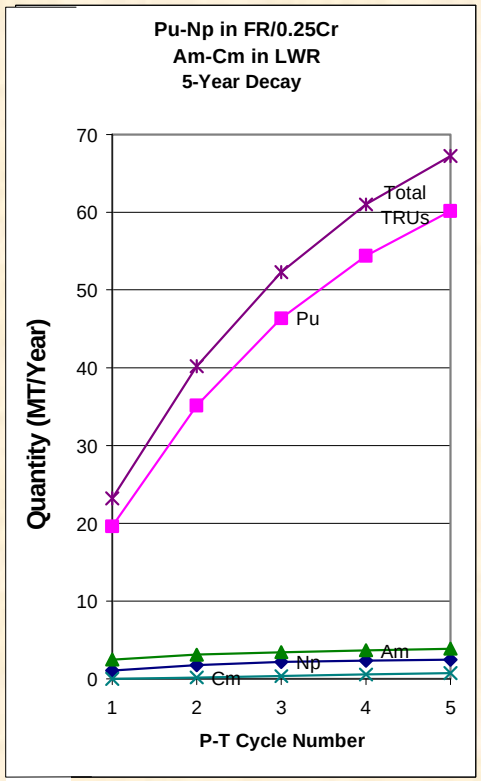
Cm Recycle Comparisons—Total Recycle from 5th P-T Cycle

	^{244}Cm (kg/year)	^{252}Cf (g/year)	Percent of Neutrons	
			Cm	Cf
All LWRs–30-year decay	871	0.058	96.8	3.1
All FR/–0.25 CR–5-year decay	381	0.0002	100	0
Hybrid–5-year decay	666	17.9	16	84

ABR/LWR Transmutation Comparisons

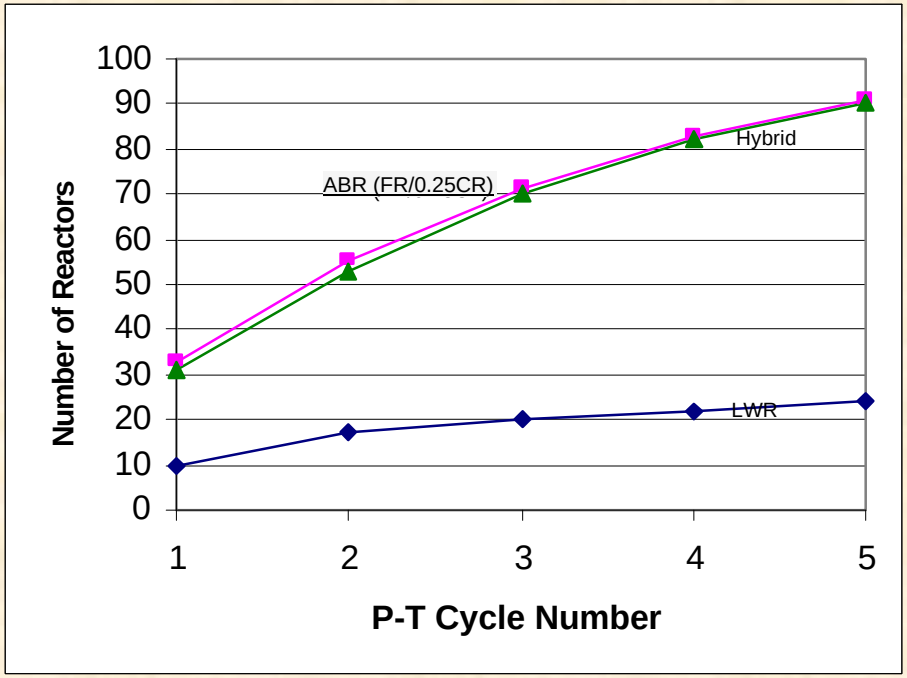






The approach to equilibrium of the actinides during multiple P-T cycles was not significantly different in cases evaluated for (1) all-thermal-spectrum (LWR) irradiations, (2) all-fast-spectrum (ABR) irradiations, or (3) hybrid irradiations (Pu-Np in fast reactors and Am-Cm in thermal reactors)

ABR/LWR Transmutation Comparisons (continued)



- **Because the ABR design size has been optimized at ~840 MW(t), a large number (33–90) of ABRs would be required to transmute the ~23 MT/year TRU actinides currently produced in ~2000 MT/year of low-enriched uranium spent fuel; in comparison, 10–24 existing (or new) 3400-MW(t) LWRs would be sufficient**
- **Based on these conclusions, full near-term implementation of P-T in the United States using only ABRs will be difficult, whereas near-term deployment using LWRs could be utilized. Similar results would be achieved if the oldest (legacy) spent fuel is processed first**

More-Realistic Scenarios for the Future

Current Studies

- **Early use of one P-T cycle (2020–2055) using all LWRs, followed by transmutation of Pu-Np in FRs and Am-Cm in LWRs**
  - **Evaluations using FRs with conversion ratios of 0.25 – 0.5 – 0.75 –1.0**

Proposed Studies

- **Same for CR = 1, but using larger-size FRs**
- **Optimization of irradiation configuration**