Views on Practical Approaches to Recycling Used Fuel

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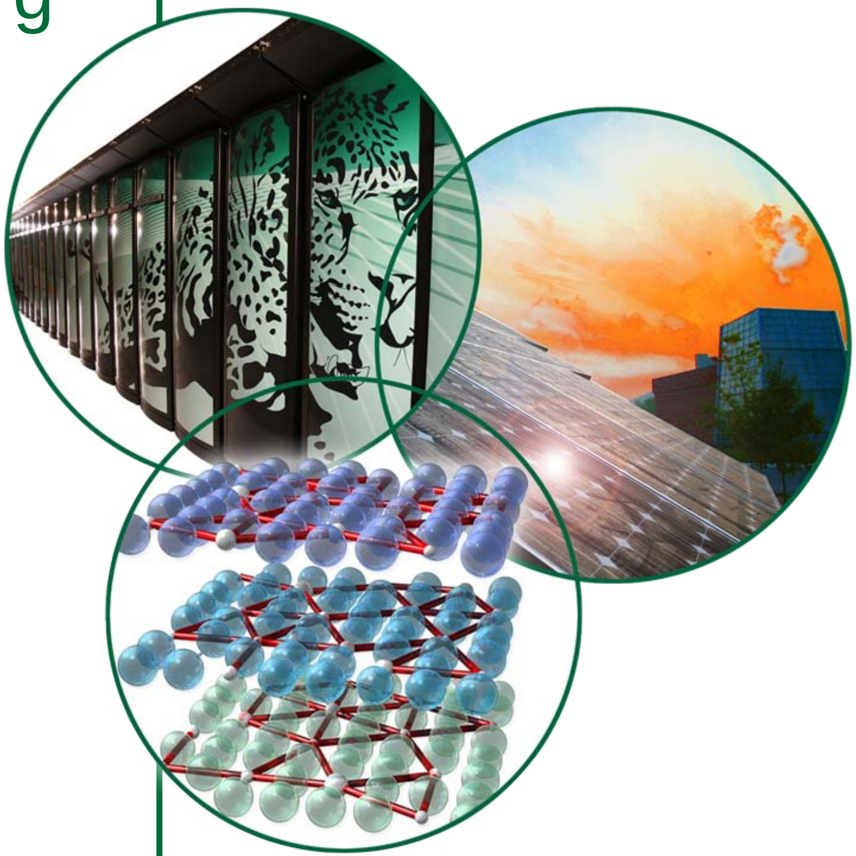

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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A Practical Solution to Used Nuclear Fuel Treatment to Enable Sustained Nuclear Energy and Recovery of Vital Materials

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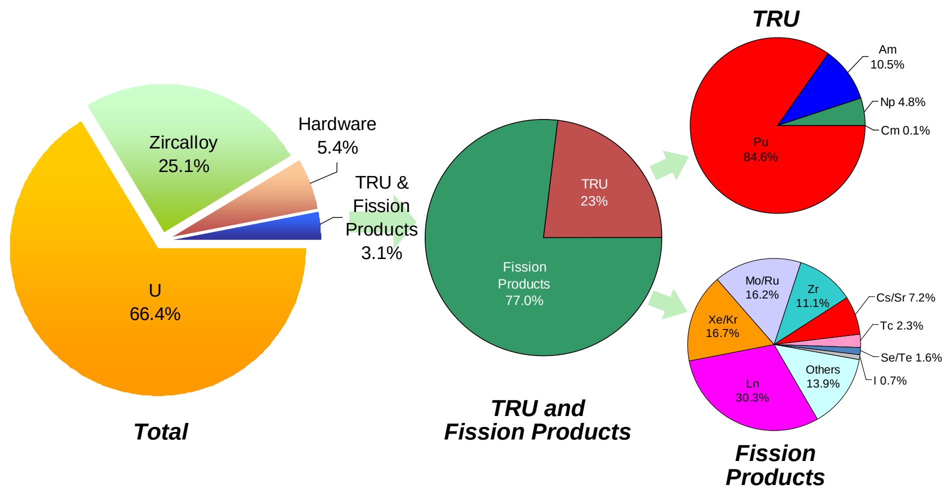
Public Perception for Nuclear Energy — Favorable or Not?

- Nuclear energy is a large, economical source of clean energy with very low carbon emission
- Public perception has become increasingly favorable
- The unresolved problem of nuclear waste disposal remains a major concern
- Safe disposal has been considered to be transportation to and emplacement in a geologic repository
- Finding an acceptable site for a geologic repository is a social and political problem
- Continued used fuel storage is not a permanent solution
- Situation may be a deterrent to public acceptance of nuclear energy

Advanced Fuel Recycle is a Practical Solution

- Base recycling technology deployment has occurred in other countries
- Advanced R&D studies have developed significant improvements
- Advanced fuel cycle approach would:
  - Deploy proliferation-resistant recycle facilities
  - Process oldest-fuels-first (~50-year-old fuels)
  - Incorporate more complete recycling of used fuel components by means of focused R&D to minimize eventual impact of geological disposal of radioactive waste

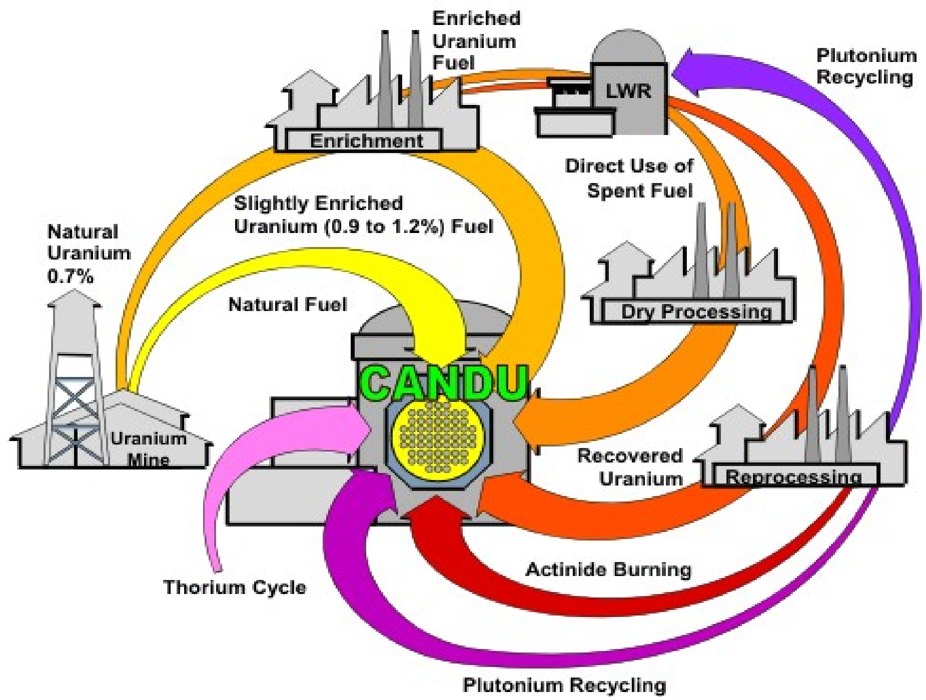
More complete recycling (>90% of mass components) can be done



- Current industrial treatment performed in other countries to recycle plutonium
- Uranium is separated and recovered—some is recycled
- Additional components can be recycled if R&D is focused
  - Other transuranium actinides
  - Zirconium from fuel cladding
  - Valuable gases, rare earth elements, and noble metals
- Need for a geologic repository will remain, but methods recommended can:
  - Delay the need
  - Minimize the capacity needed
  - Significantly reduce the hazard of the wastes disposed

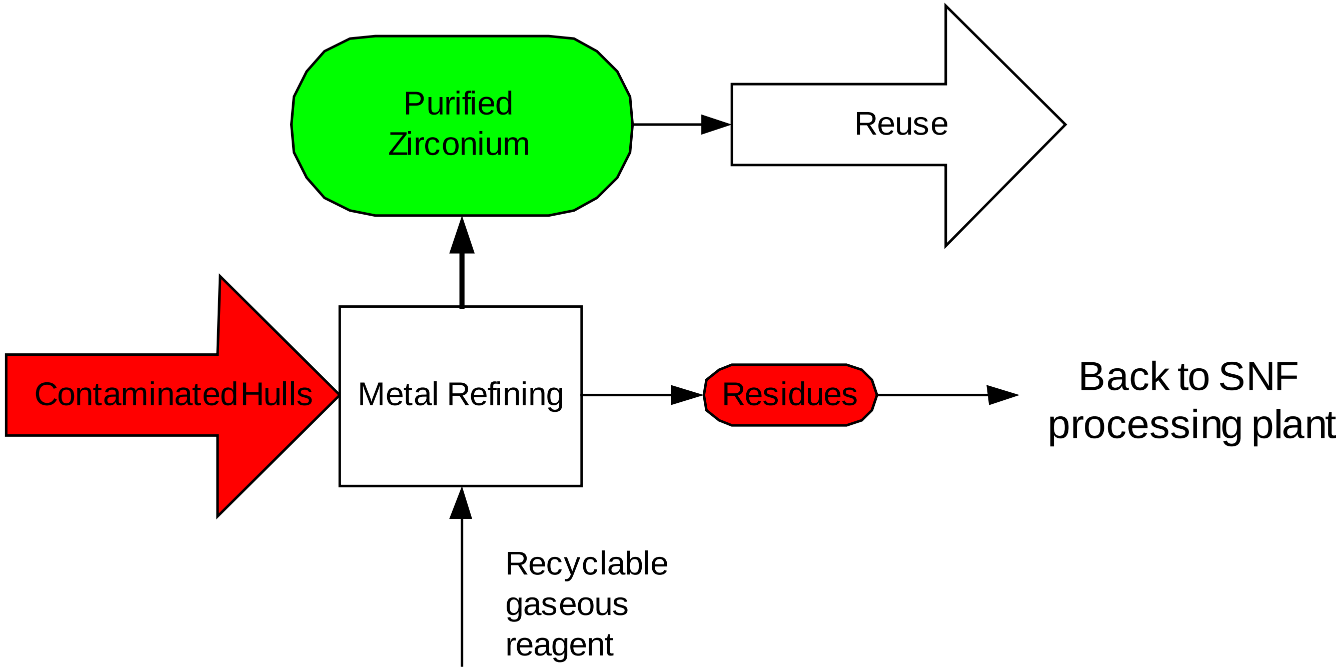
Uranium Recycle into CANDU Reactors

- The standard CANDU reactor uses natural uranium oxide fuel
- CANDU reactors are capable of operating with a full RU core
  - The Canadian CANDU fleet could use 2000 to 2800 MT/y RU
  - Average burnup will increase from 7.5 GWd/MT to about 10 GWd/MT
  - ^{236}U penalty is 1/5 of that for PWR reactors



Main Issue: RU will require extensive licensing and safety assessments with the Canadian Nuclear Safety Commission

Zirconium Recovery from Cladding



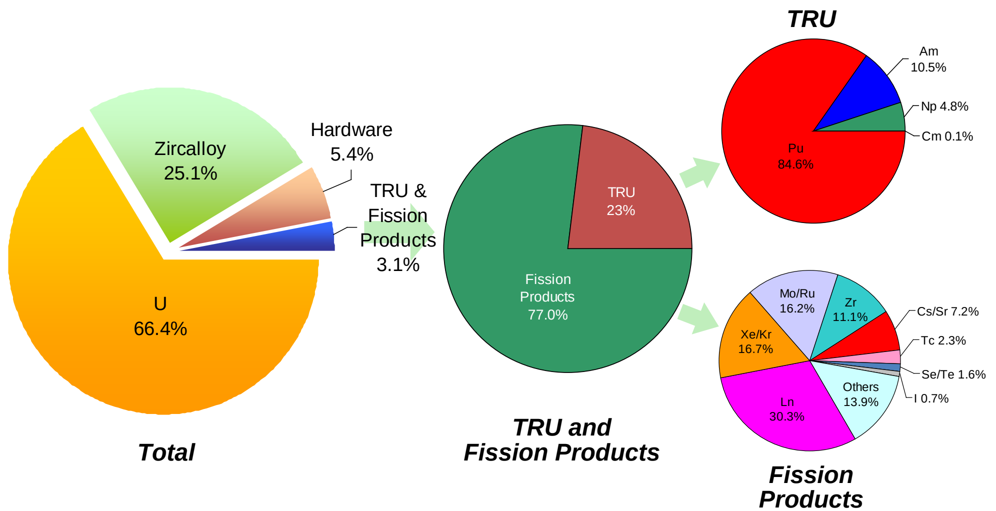
- Purified zirconium will remain radioactive
  - ^{93}Zr is not a significant radiological problem
    - Half-life is 1.53M years
    - Beta emission at only 90 keV (max.)

Cost of Recycle — Is it an impediment?

Fuel cycle type	UOX LWR direct disposal	UOX/MOX LWR current recycle (Pu only)	LWR advanced recycle (U, TRUs, Zr, and some fission products)	Advanced reactors breeder recycle (U, Pu) drivers DU blankets
Percent of used fuel assembly mass in waste	100	99	5	5–10
Comparable levelized costs, mills/kWh				
U ore/U enrichment/UOX fabrication/UOX credits	4.3	3.9	3.5	0.1
Reactors	49.5	49.5	49.5	59.0
Used fuel dry storage	0.3	0.0	0.0	0.0
Recycling	0.0	3.4	3.9	5.0
Waste disposal	1.6	1.0	0.3	1.5
Total	**55.7**	**57.8**	**57.2**	**65.6**
Fuel cycle component of above costs	**6.2**	**8.3**	**7.7**	**6.6**

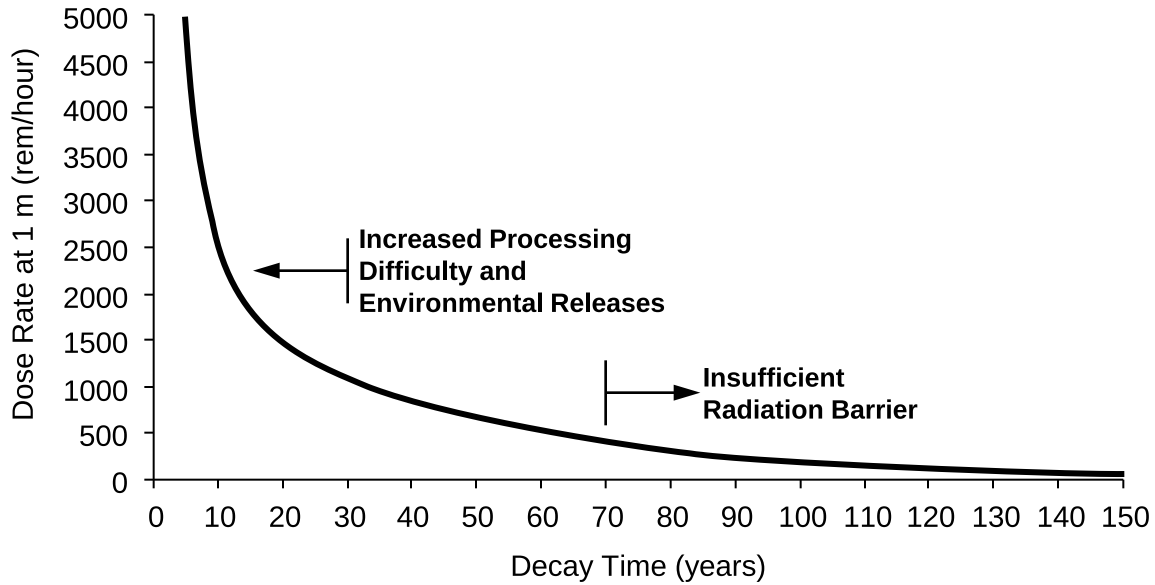
- Reactor costs dominate
- Fuel cycle costs are <15%
- Variation in fuel cycle costs differ by insignificant amounts
- Future need for breeding fissile materials from depleted uranium and thorium resources will require more expensive reactor and fuel designs

Identification of Proliferation-Resistance Factors — Used Fuel Components



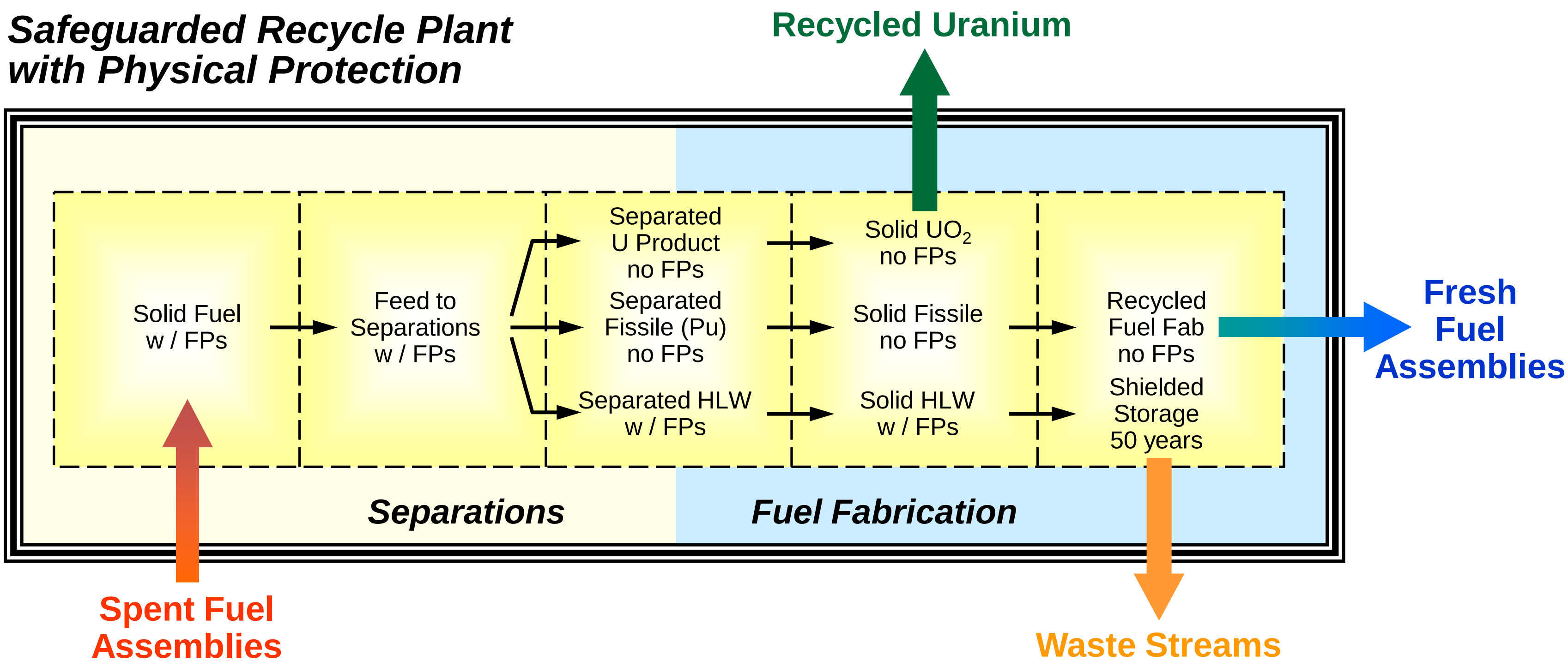
- Used fuel inherently contains the chemical element, plutonium, and its fissile isotopes
- Plutonium can be chemically separated and separation methods are well known
- Physical protection and other proliferation-resistance means are necessary to prevent diversion
- Used fuel and recycled fissile material must be protected for either:
  - Continued storage
  - Direct disposal
  - Treatment and recycle
- Engineered safeguards can provide adequate proliferation resistance

Engineered Safeguards — The Radiation Barrier



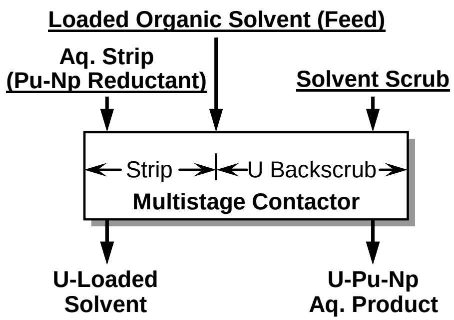
- Radiation barrier is provided by presence of short-lived and intermediate-lived radioactive fission products
- Barrier decays at exponential rate, making used fuel older than several decades more vulnerable to diversion and theft
- Vulnerability can be eliminated if fuel recycle is begun before radiation barrier has decreased to a susceptible level—re-irradiation will restore the effective radiation barrier

Engineered Safeguards — Co-location and Integration of Used Fuel Treatment Facilities

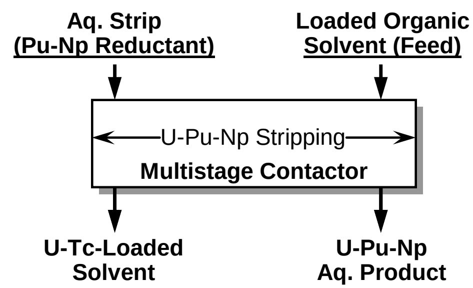


- Fissile material entry and removal in form of large, heavy, easily accountable fuel assemblies
- Effective monitoring/surveillance of wastes and personnel exiting recycle plant
- Minimized inventory of separated fissile material and recycle fuel
  - No separated plutonium
- Use of "near-real-time" monitoring and accounting of fissile material location and movement

Engineered Safeguards —
No Separated Plutonium

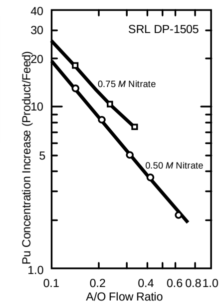


PUREX-Type
Partitioning Contactor Bank
(Complete or partial partitioning is possible)



UREX+ Codecon Flowsheet
Partial Partitioning Contactor Bank

- **Hydroxylamine nitrate (HAN) is used as combination Pu-Np reductant – aqueous salting agent**
- **Excess HAN in U-Pu-Np product readily decomposed by NO_x to gases and water**
- **No holding reductant (hydrazine) is required**



Source: M. S. Okamoto and M. C. Thompson, "Co-processing Solvent Extraction Studies," Nucl. Technol. 43, 126–131 (April 1979)

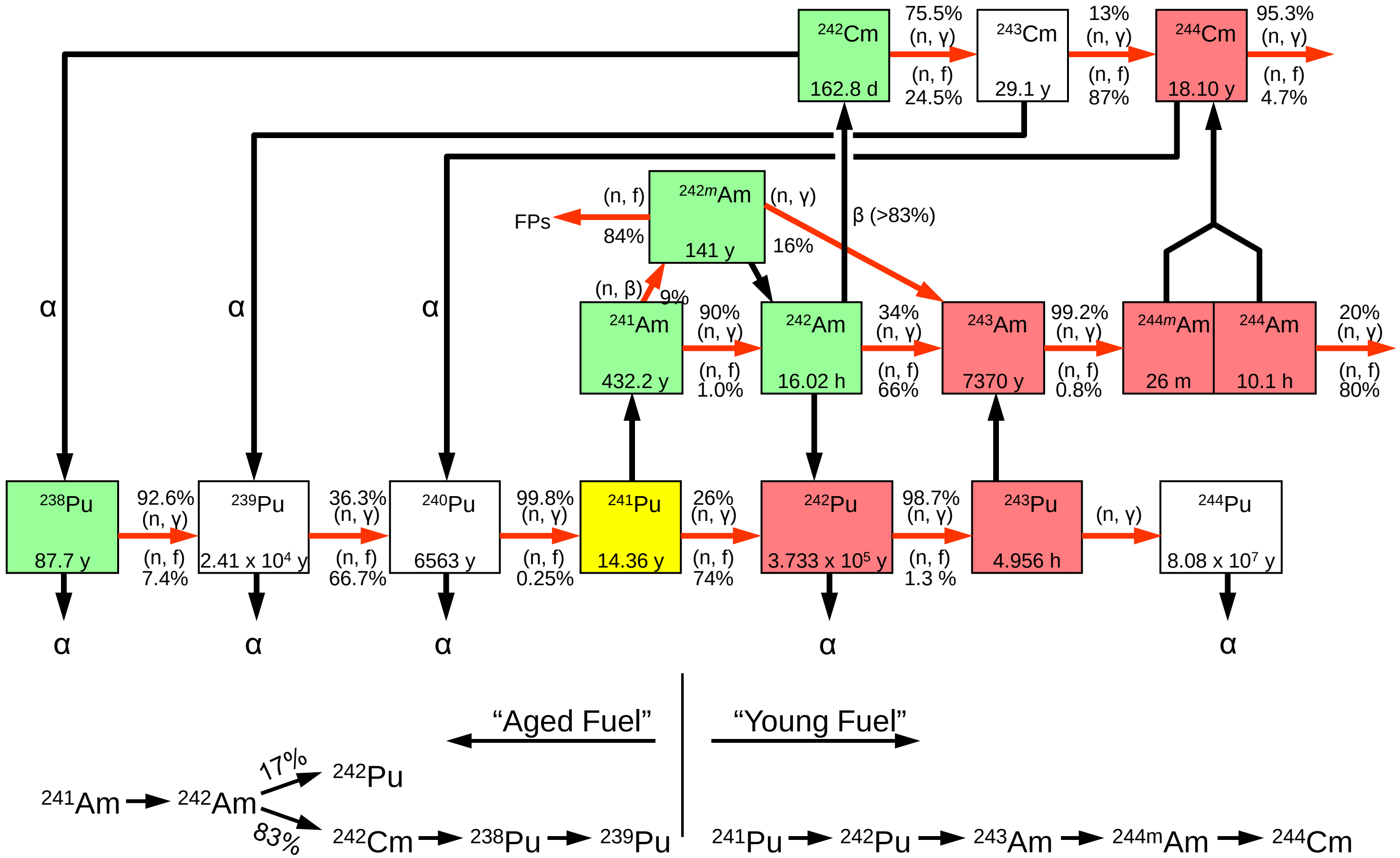
- Plutonium can be recycled without being separated from "non-neutron-poison" components
- Industrial plant can be designed to prevent plutonium separation
- Selected fission products (cesium) could be added to recycle fuel, but recycle fuel fabrication, transportation, and handling operations would be more difficult
- Physical protection requirements for treatment plant and recycle fuel transportation are not decreased

Time factors for implementing fuel recycle must be considered

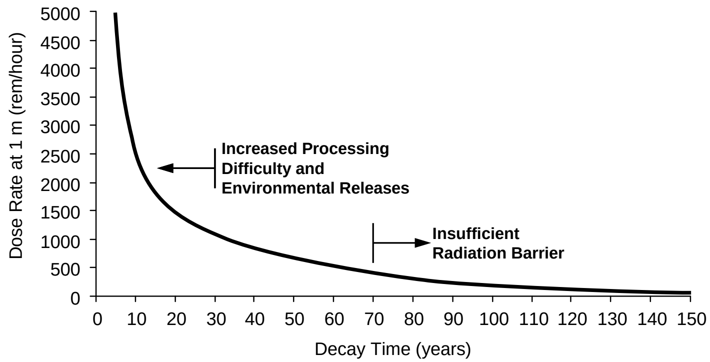
- The importance of spent fuel decay time on recycle processing and waste disposal — advantages are gained from processing older spent fuels
- In the U.S., a "50/50" concept could be considered (process 50-year-old spent fuel/store Cs-Sr-Eu within the separations facility)
- Less heat generation in stored wastes — ^{90}SrY, ^{137}CsBa — 10% of decay heat at 100 years
- Future impact of HLW emplacement into a geologic repository will be lessened
- Volatile radioactive emissions are lower — ^{3}H, ^{85}Kr capture/storage likely not required
- Separations processes required can be simplified and made less costly

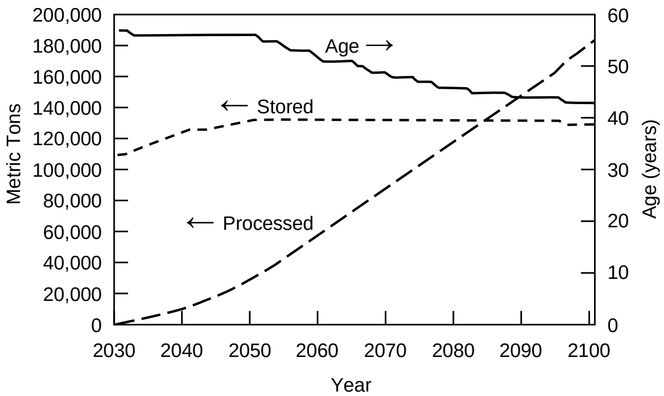
Transmutation Benefits of Older Fuel

- Alters transmutation pathway to produce lighter plutonium nuclides rather than heavy curium nuclides
- Allows use of existing LWRs and HWRs for transmutation of all long-lived TRU actinides



Optimum Processing Time





- Overall, an "optimum" age of 30–70 years for processing used fuels can:
  - Maximize safety
  - Reduce environmental effects
  - Lower costs
  - Maintain adequate proliferation resistance

- By processing the "oldest-fuels-first," the age of fuels processed can be kept in the range of 40–60 years

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Time required to implement industrial-scale recycling — not an overnight process!

	2010	2020	2030	2040	2050	2060
Number of reactors	104	108	116	124	132	136
Event	Decision to treat used fuel		1st treatment plant begins operation	2nd plant begins operation	3rd plant begins operation	
Treatment capacity (MT/year)	0	0	1,000	2,000	3,000	3,000
Used fuel generation rate (MT/year)	2,200	2,250	2,300	2,700	2,900	3,000
Storage capacity required (MT)	64,000	87,000	110,000	126,000	134,000	134,000

- Design and construction of each plant requires 15–20 years
- Multiple plants are needed to obtain capacity required to process amounts of used fuels currently generated and expected
- Based on world-wide experience, deployment of industrial-scale recycling is a multi-decade process

Time and sustainability are strong factors toward implementing fuel recycle

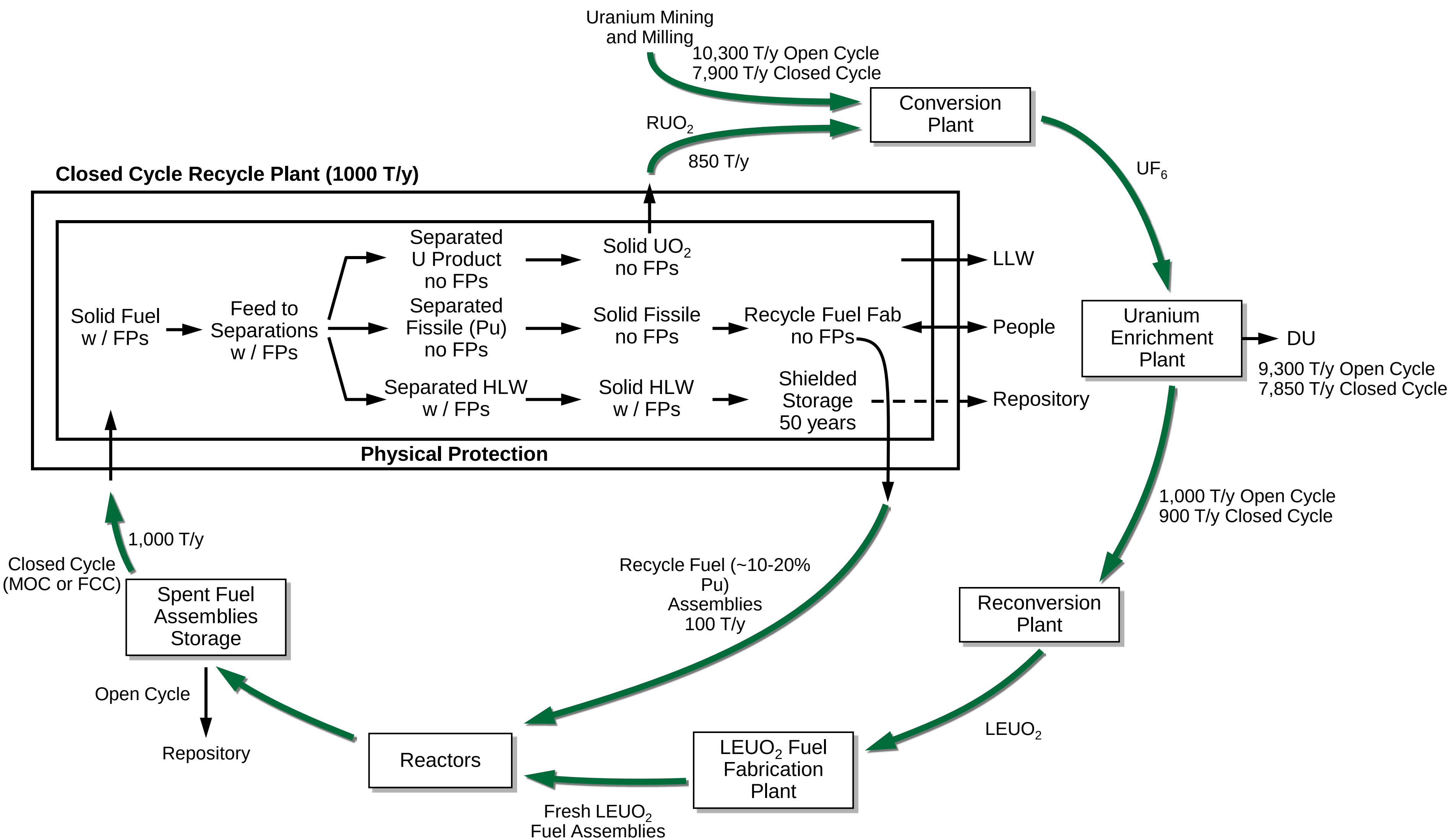
- Nuclear energy use is strong, with expected growth in the U.S., Europe, Japan, Russia, and others
- Rapid growth of nuclear energy is occurring in China and India, possibly in the U.K. and other countries
- At some time the availability of low-cost natural uranium (NU) will decline — but when?
- If nuclear energy is to be sustained beyond availability of NU, then there will be a future need for breeder reactors and industrial-scale fuel recycle capability
- Therefore, strong considerations for implementing fuel recycle are:
  - Future need for breeder reactors to use tremendous potential energy in fertile materials
  - The uncertainty of “when in the future” that NU will become unavailable
  - Multi-decade process required to implement industrial-scale recycle at capacity needed

Summary and Recommendations

- Our analysis concluded that:
  - The cost of implementing fuel recycle will be an insignificant change to the cost of nuclear electricity
  - Engineered safeguards can be used to provide adequate proliferation resistance
  - Continuing delay will likely occur in locating and operating a geologic repository
  - Continued storage of used fuels is not a permanent solution
- With no decision, the path forward for used fuel disposal will remain uncertain, with many diverse technologies being considered and no possible focus on a practical solution to the problem
- However, a decision to move forward with used fuel recycling and to take advantage of processing aged fuels and incorporation of near-complete recycling can provide the focus needed for a practical solution to the problem of nuclear waste disposal

Back Up Slides

Nuclear Fuel Cycles



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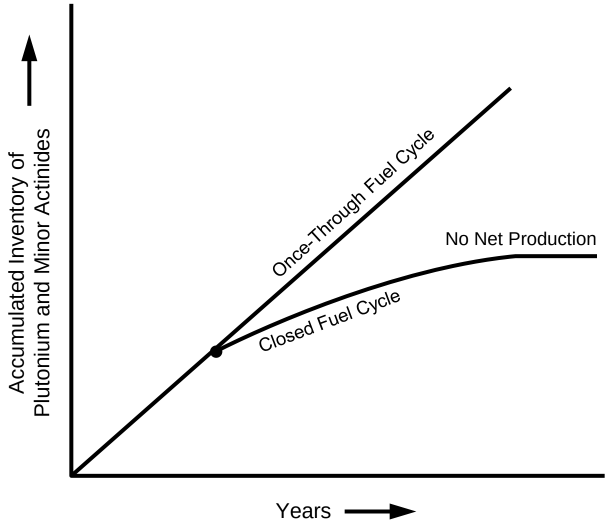
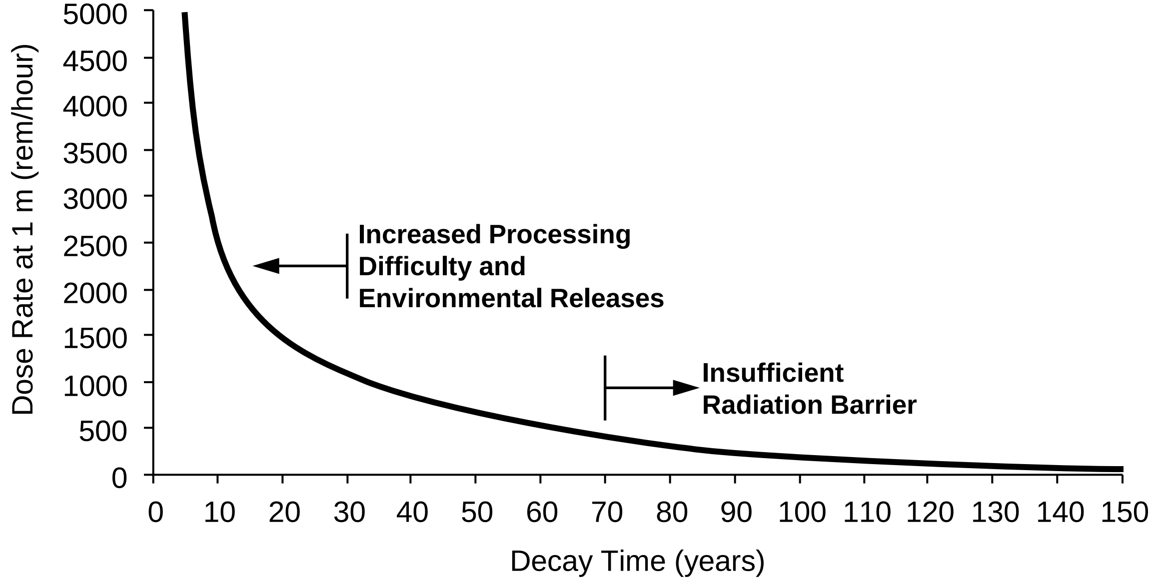
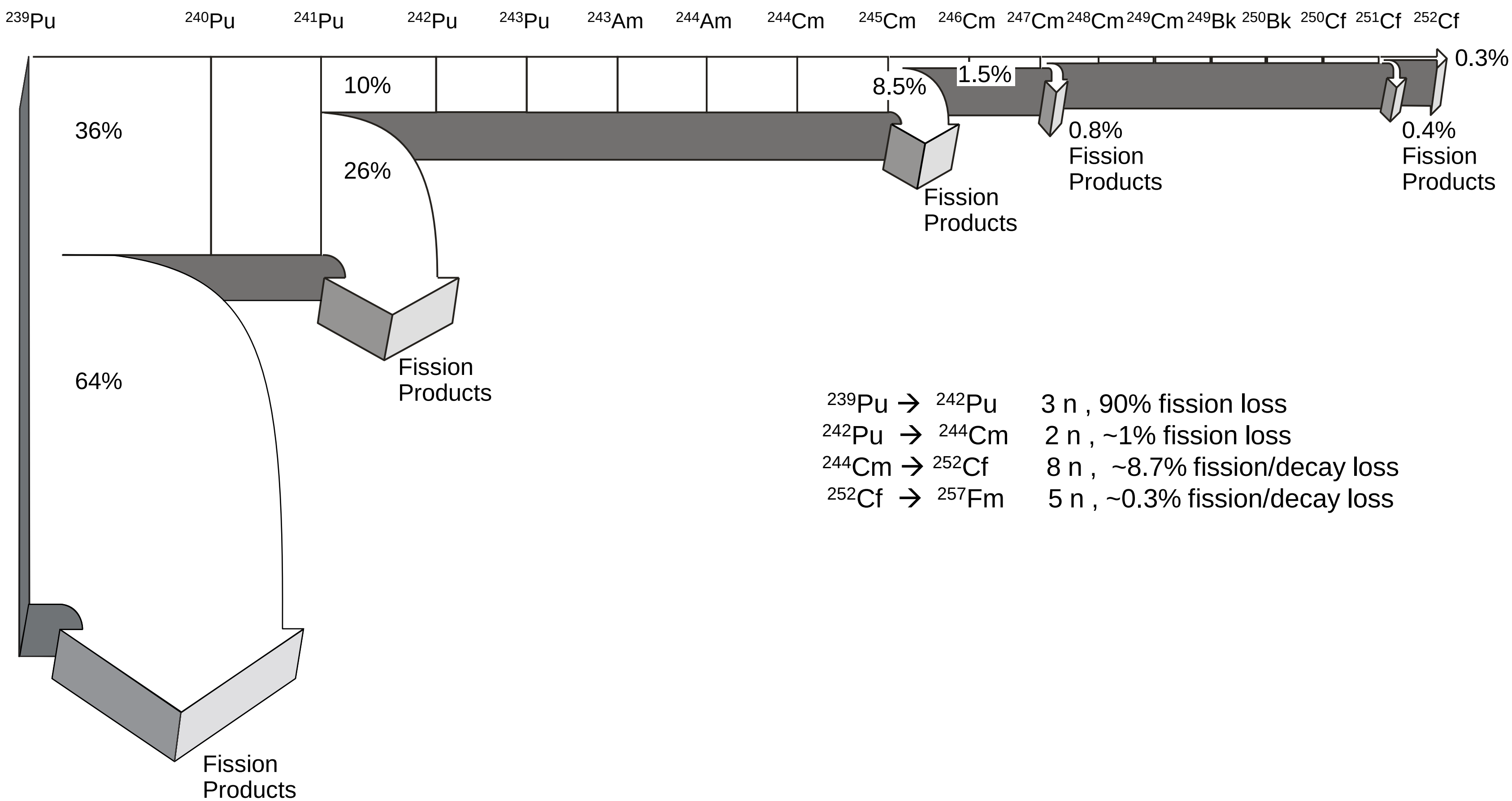
Continued Storage Concerns — increasing inventory and decreasing radiation barrier





- Current inventory contains ~500 MT and annual production is ~20 MT/year
- Radiation barrier decreasing exponentially with time
- At least 50 years required to build recycle capacity needed to match annual production
- With equal recycle capacity and production rates, inventory will continue to increase because of incomplete burnup in each partitioning-transmutation cycle
- Implementation of fuel recycle is needed

Transplutonium-Element Yield and Fission Loss During Thermal Neutron Irradiation of Plutonium



$^{239}Pu \rightarrow {}^{242}Pu$ 3 n , 90% fission loss

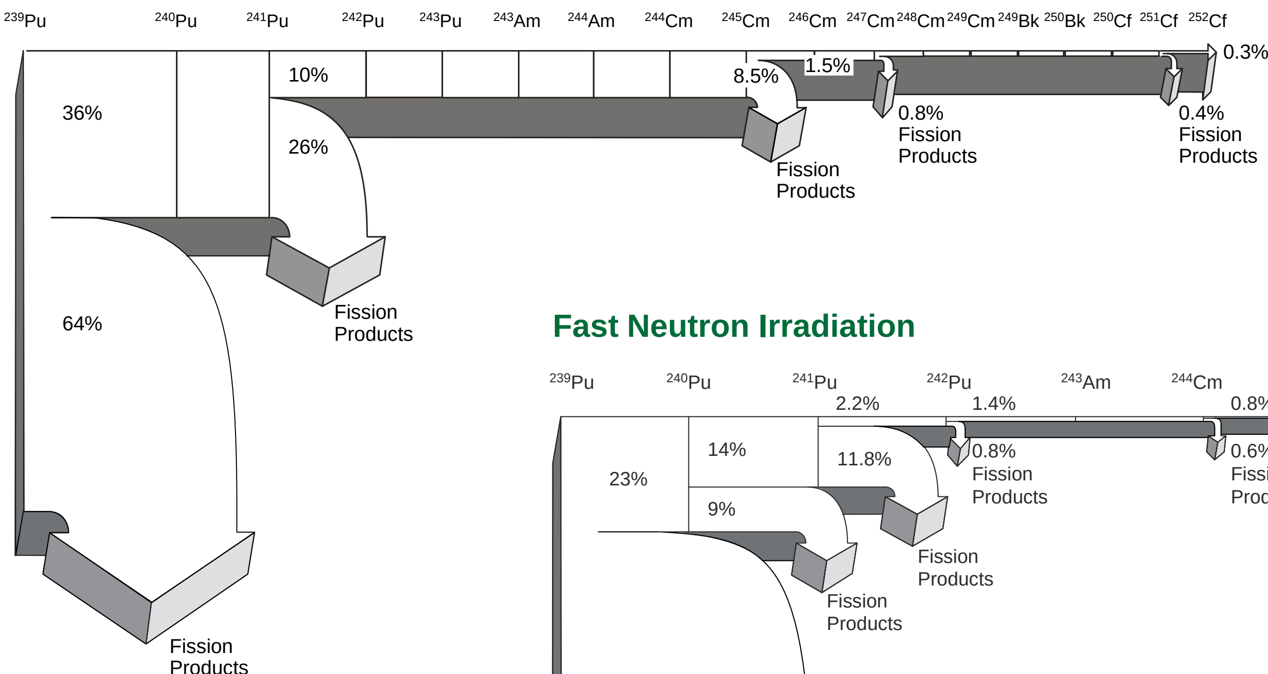
$^{242}Pu \rightarrow {}^{244}Cm$ 2 n , ~1% fission loss

$^{244}Cm \rightarrow {}^{252}Cf$ 8 n , ~8.7% fission/decay loss

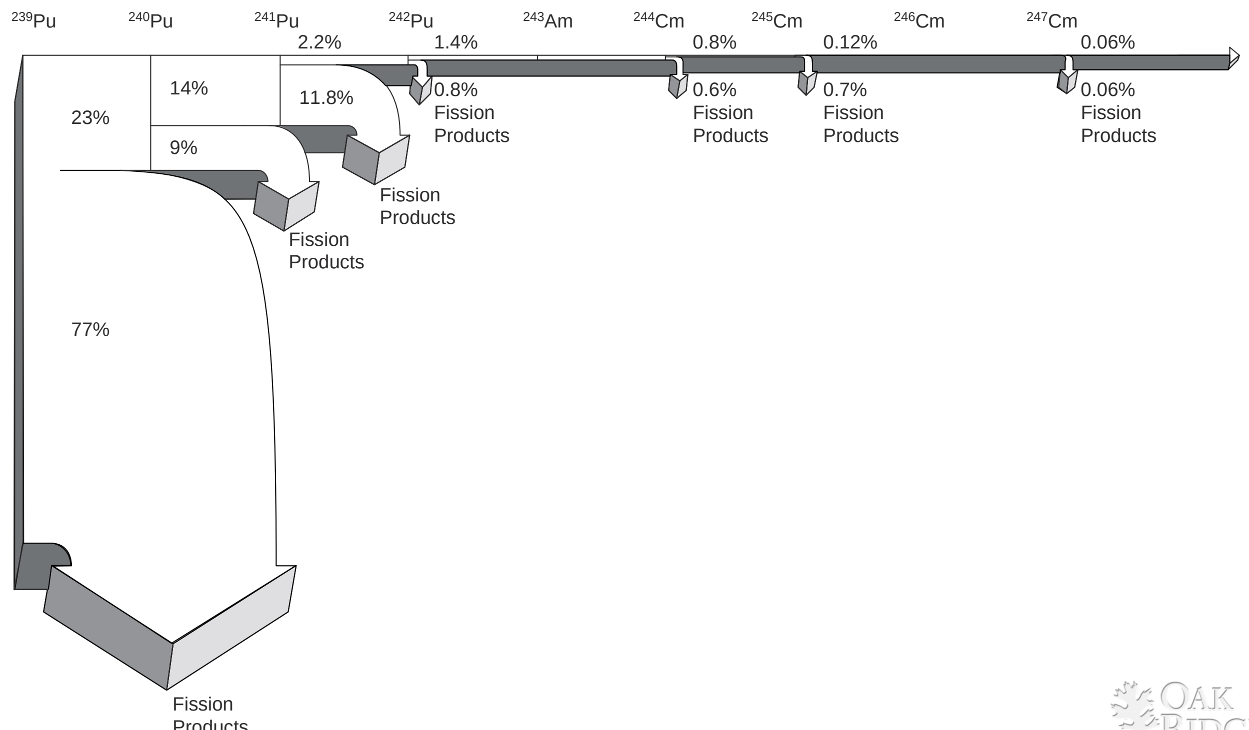
$^{252}Cf \rightarrow {}^{257}Fm$ 5 n , ~0.3% fission/decay loss

Transplutonium-Element Yield and Fission Loss During Irradiation of Plutonium

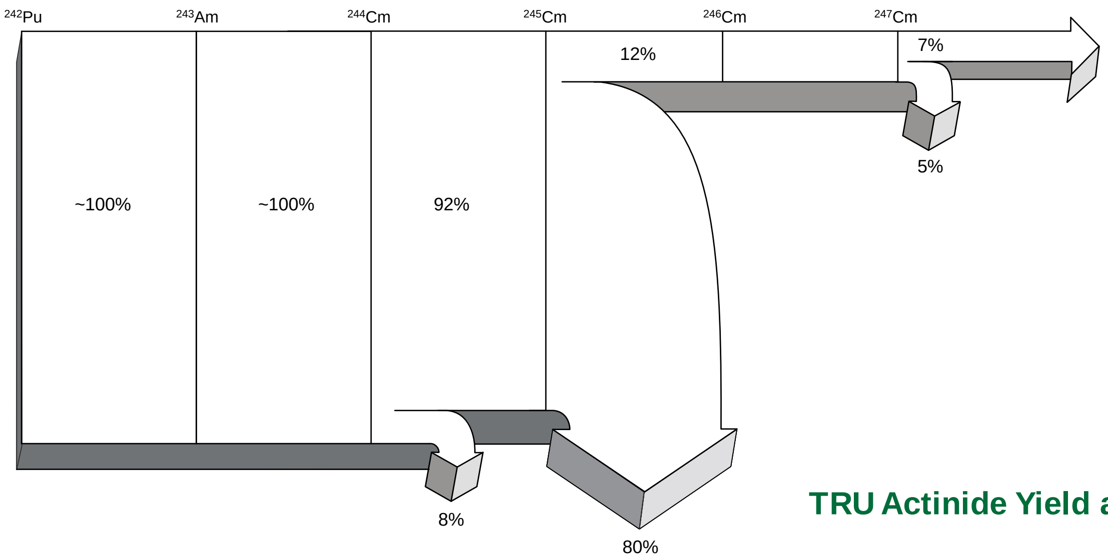
Thermal Neutron Irradiation



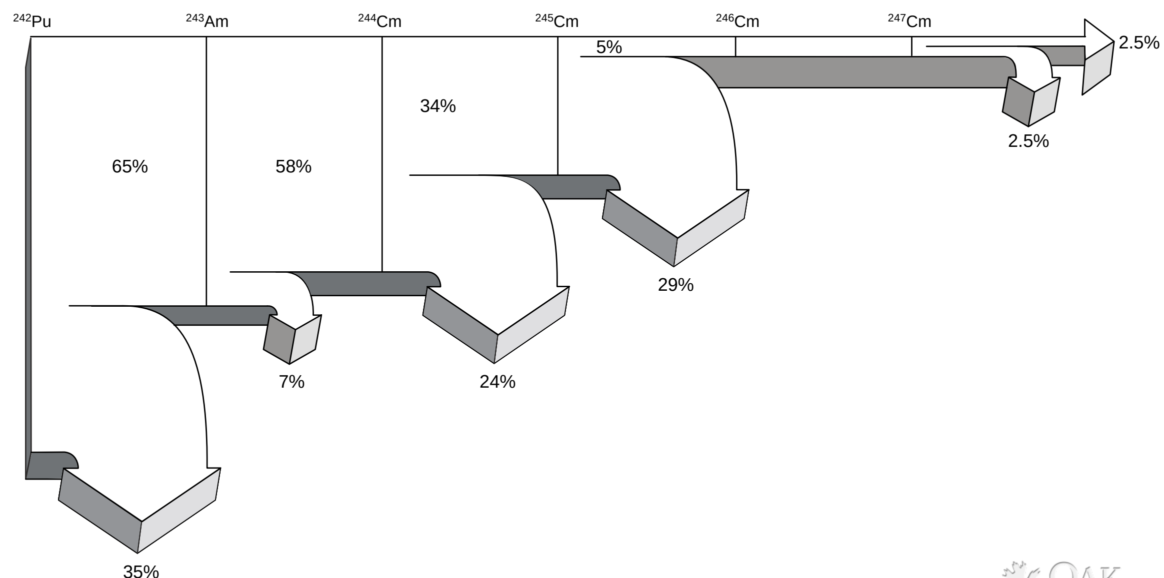
Fast Neutron Irradiation



TRU Actinide Yield and Fission Loss During Thermal Neutron Irradiation of ^{242}Pu



TRU Actinide Yield and Fission Loss During Fast Neutron Irradiation of ^{242}Pu



Co-location and Integration of SNF Separations and Recycle Fuel/Target Fabrication at Nuclear Fuel Park