NUCL 402 Engineering of Nuclear Power Systems

Lecture 17: Fuel Reprocessing

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Spent Fuel Reprocessing

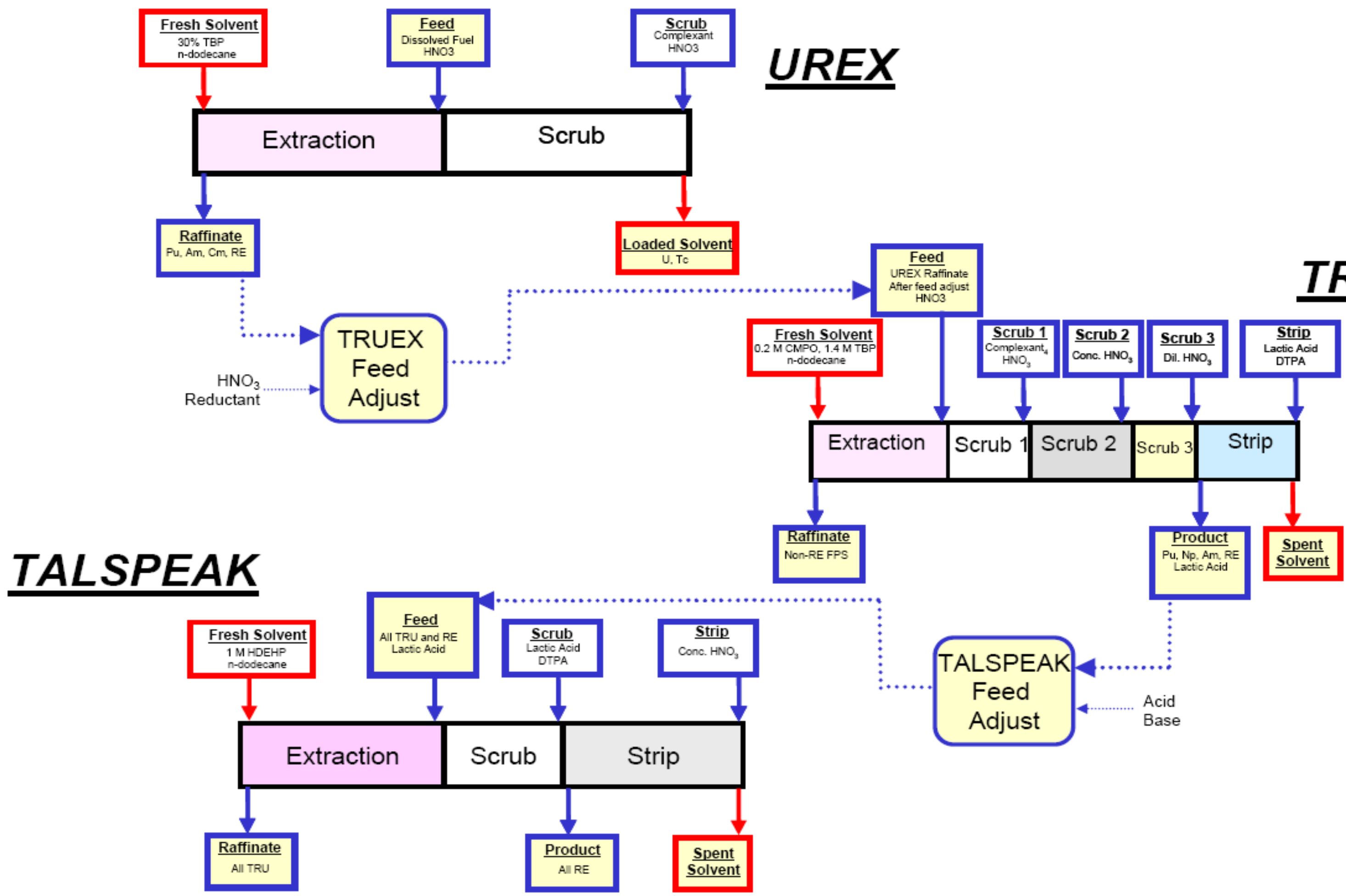
The fuel is removed from the reactor due to fuel depletion, poisons-(low reactivity) and damage. Typical spent fuel has

U238	95%	U235	0.8%
U236	0.4%	Pu 239	0.65%
PU 241	0.25%	Fission products	2.9%

- In a reprocessing facility the used fuel is separated into its three components: uranium, plutonium and waste, containing fission products.
- Reprocessing enables recycling of the uranium and plutonium into fresh fuel, and produces a significantly reduced amount of waste (compared with treating all used fuel as waste).
- In all stages reprocessing the critical mass of fissile material is not achieved and radioactivity is contained.

Urex +1a Process (Process Schematic)

The UREX+1a demonstration flowsheet



Courtesy of Argonne National Laboratory

Urex +1a Process (Efficiency)

Element	*Recovery Eff.*	*Remarks*
Uranium	99.9992%	Non-TRU (<100 nCi/g)
Technetium	98.3%	Soluble Tc
Cesium	>99.2%	
Strontium	>99.9%	
Plutonium	>99.99%	Total lanthanide content of transuranics <0.05% (DF>2,000)
Neptunium	>99.99%	
Americium	>99.99%	
Curium	>99.999%	

Courtesy of Argonne National Laboratory

Urex +1a Process

Process Benefits

- **Does not extract Plutonium as a single product**
- **Allows for Uranium to be recycled or disposed as low level waste**
- **Separates Cs/Sr for decay storage**
- **Only Tc, rare earth, and mixed fission products need to be stored in long term storage**

Cooling of Spent Fuel

- The spent fuel is contained in a pool of water
- The pools helps to remove decay heat and provide radiation shield
- The cooling helps :

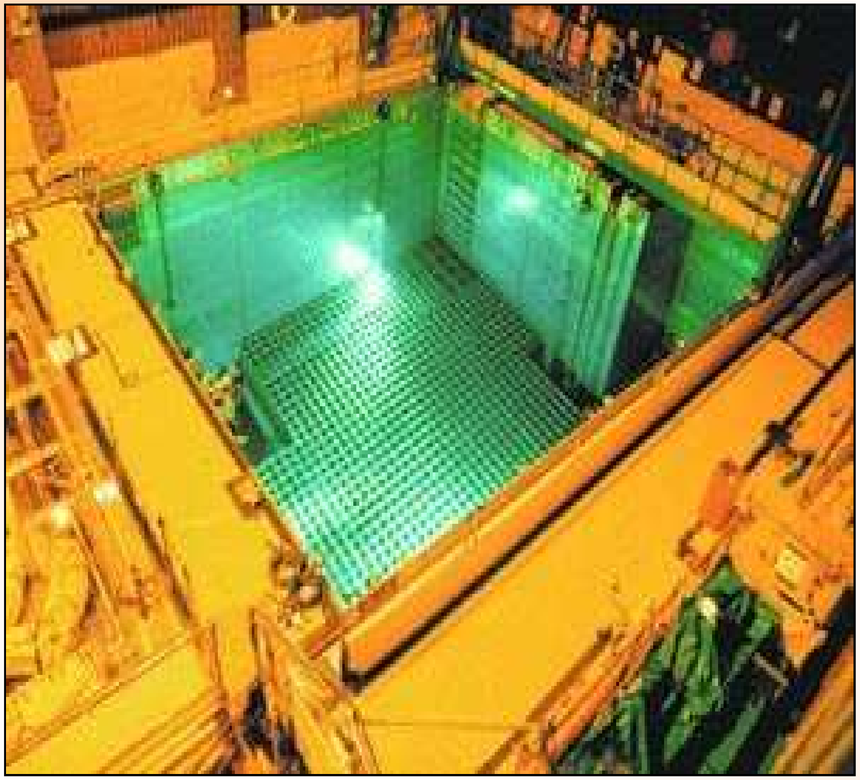
(1) Fission products of short or moderately short half life decay completely,

(2) Overall beta and gamma activities are reduced to level at which radio-analytical decomposition of reprocessing agents is tolerated,

(3) Certain undesirable heavy elements decay into elements which can be separated from desirable products

- Minimum cooling period is 150 days

Spent Nuclear Fuel Pool



Keep spent fuel rods under at least 20 feet of water to provide adequate shielding from the radiation for anyone near the pool

Spent Fuel Pools were designed as TEMPORARY storage for fuel while short lived isotopes decay (<1 yr)

TABLE 8.8. MAJOR CONTRIBUTIONS TO RADIOACTIVITY OF SPENT LWR FUEL AFTER 150 DAYS COOLING

Nuclide	Half-Life, years	Main Decay Mode	Activity	
			Ci/1000 kg U	Bq/1000 kg U
Fission Products				
Strontium-89	0.14	β	9.6×10^4	3.6×10^{15}
Strontium-90	29	β	7.7×10^4	2.8×10^{15}
Zirconium-95	0.18	β, γ	2.8×10^5	1.0×10^{16}
Niobium-95	0.095	β, γ	5.2×10^5	1.9×10^{16}
Ruthenium-106	1.0	β	4.1×10^5	1.5×10^{16}
Cesium-134	2.05	β, γ	2.1×10^5	7.7×10^{15}
Cesium-137	30	β, γ	1.1×10^5	4.1×10^{15}
Cerium-144	0.78	β, γ	7.7×10^5	2.8×10^{16}
Promethium-147	2.6	β	9.9×10^4	3.7×10^{15}
Heavy-Element Isotopes				
Plutonium-238	88	α	2.8×10^2	1.0×10^{13}
Plutonium-239	24,400	α	3.3×10^2	1.2×10^{13}
Plutonium-240	6,540	α	4.8×10^2	1.8×10^{13}
Plutonium-241	14	β	1.1×10^5	4.1×10^{15}
Plutonium-242	387,000	α	1.36	5.0×10^{10}
Americium-241	433	α, γ	2.0×10^2	7.4×10^{12}
Americium-243	7,370	α, γ	17.4	6.4×10^{11}
Curium-242	0.45	α, sf*	1.5×10^4	5.5×10^{14}
Curium-244	18	α, sf*	2.5×10^3	9.3×10^{13}

*Significant spontaneous fission accompanied by neutron emission.

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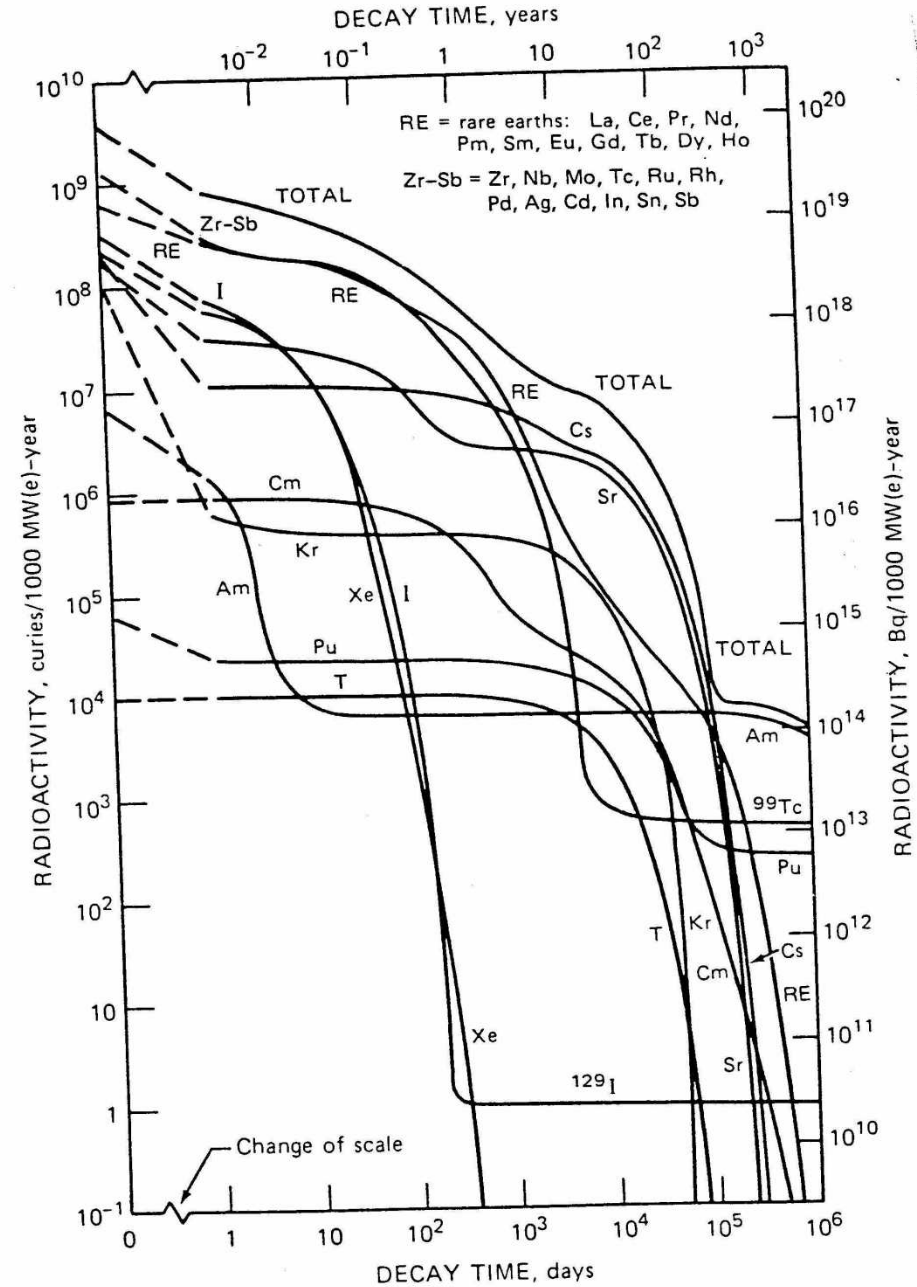

Fig. 8.13. Radioactivity of waste from uranium fuel reprocessing, based on a burnup of 2.85 TJ/kg U (33,000 MW·d/1000 kg) and 99.5 percent plutonium removal (T. H. Pigford [24]).

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Half life 6.75 days

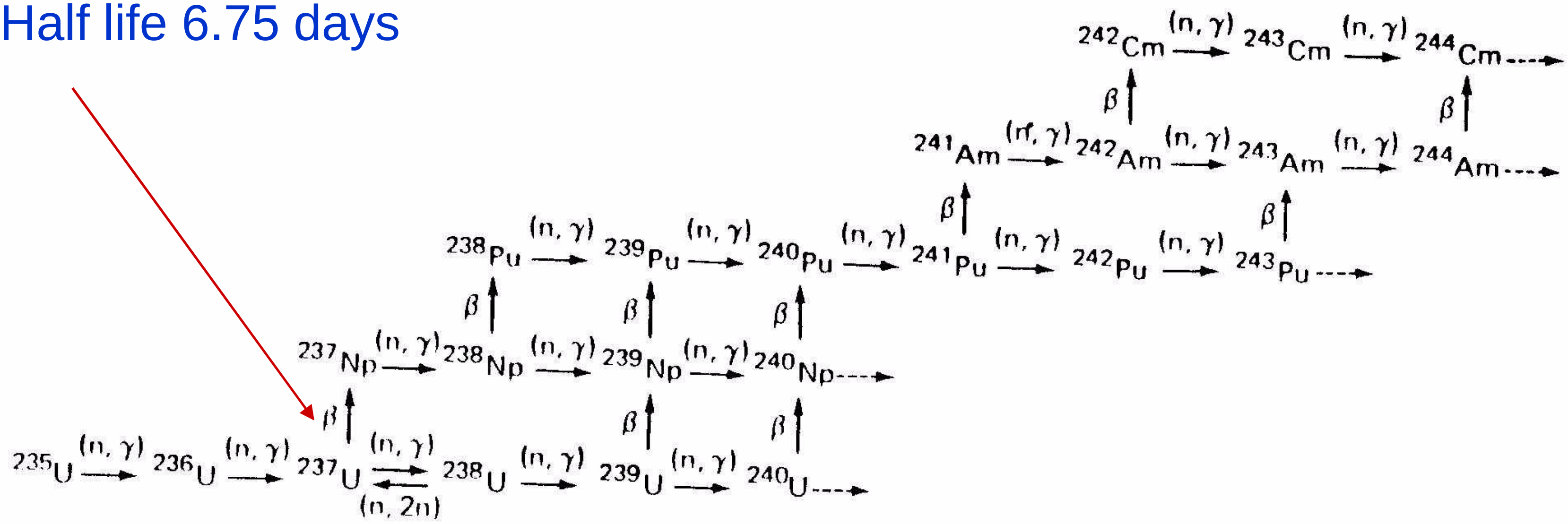


Fig. 8.9. Heavy-isotope buildup in uranium. (Unless otherwise indicated, the nuclides are alpha-particle emitters.)

Need longer cooling period

Half life 6.6 hours

Half life 27 days

Half life 24 days

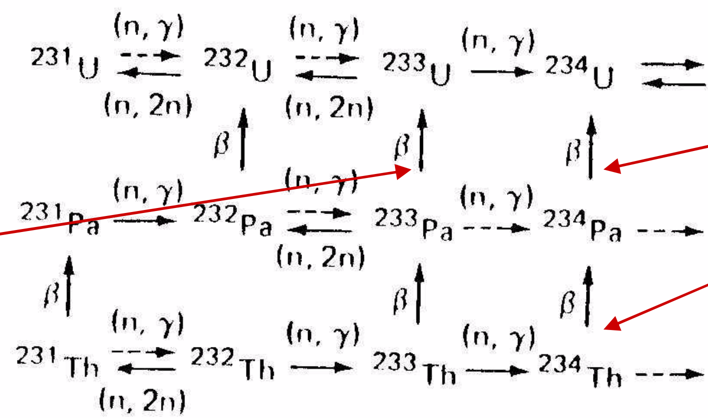
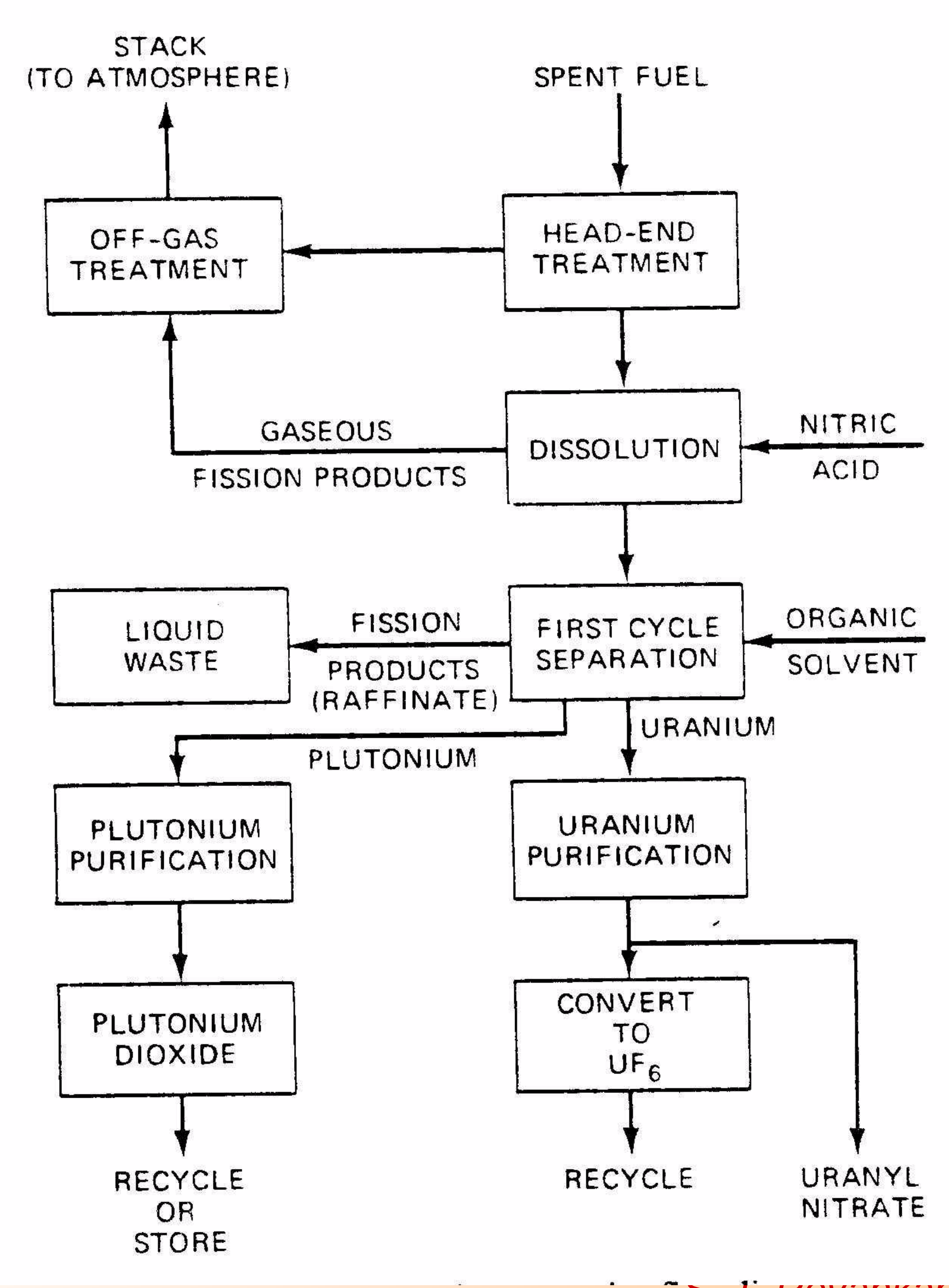


Fig. 8.10. Heavy-isotope buildup in thorium. (Unless otherwise indicated, the nuclides are alpha-particle emitters.)

Spent Fuel Reprocessing



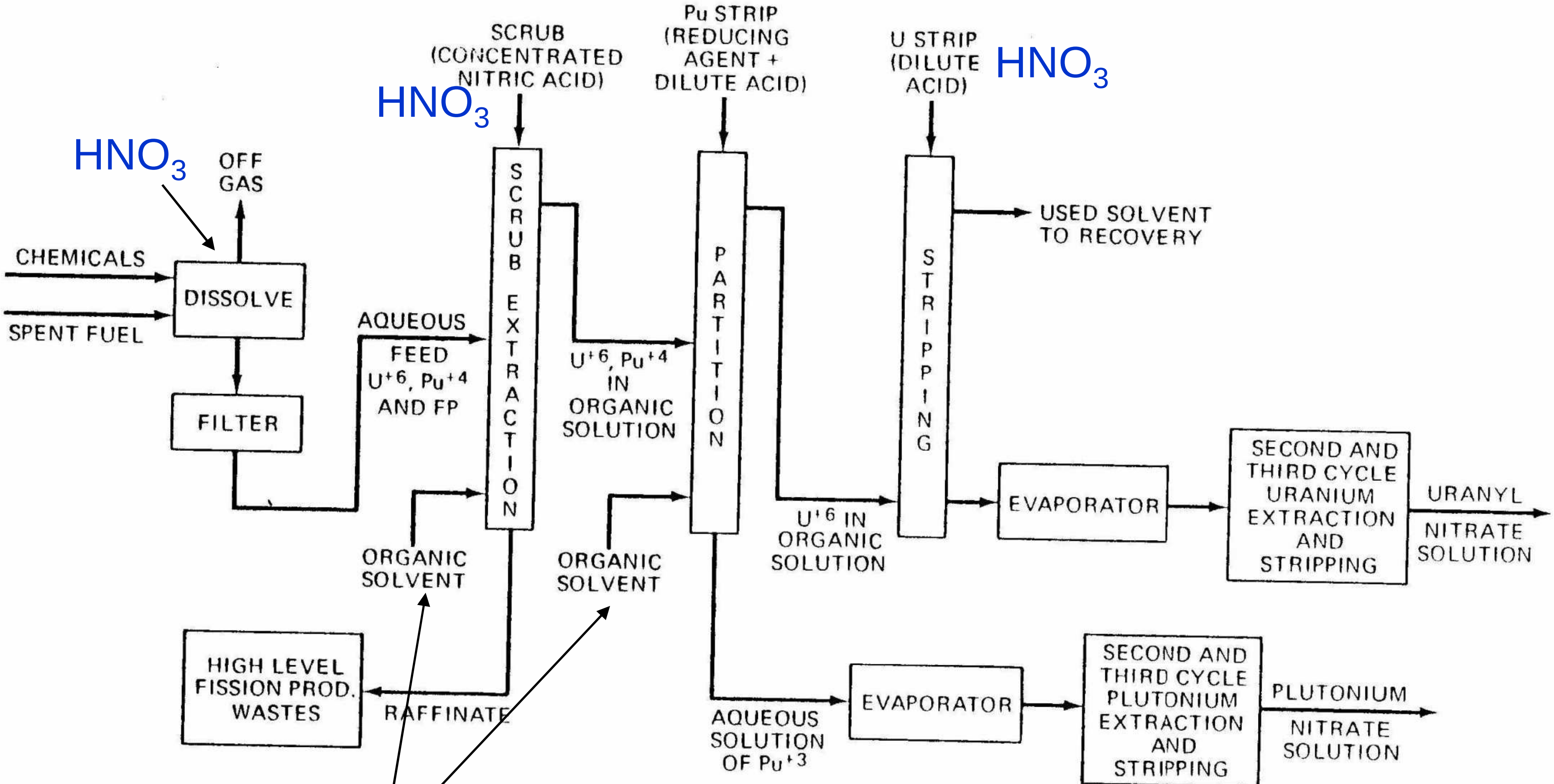
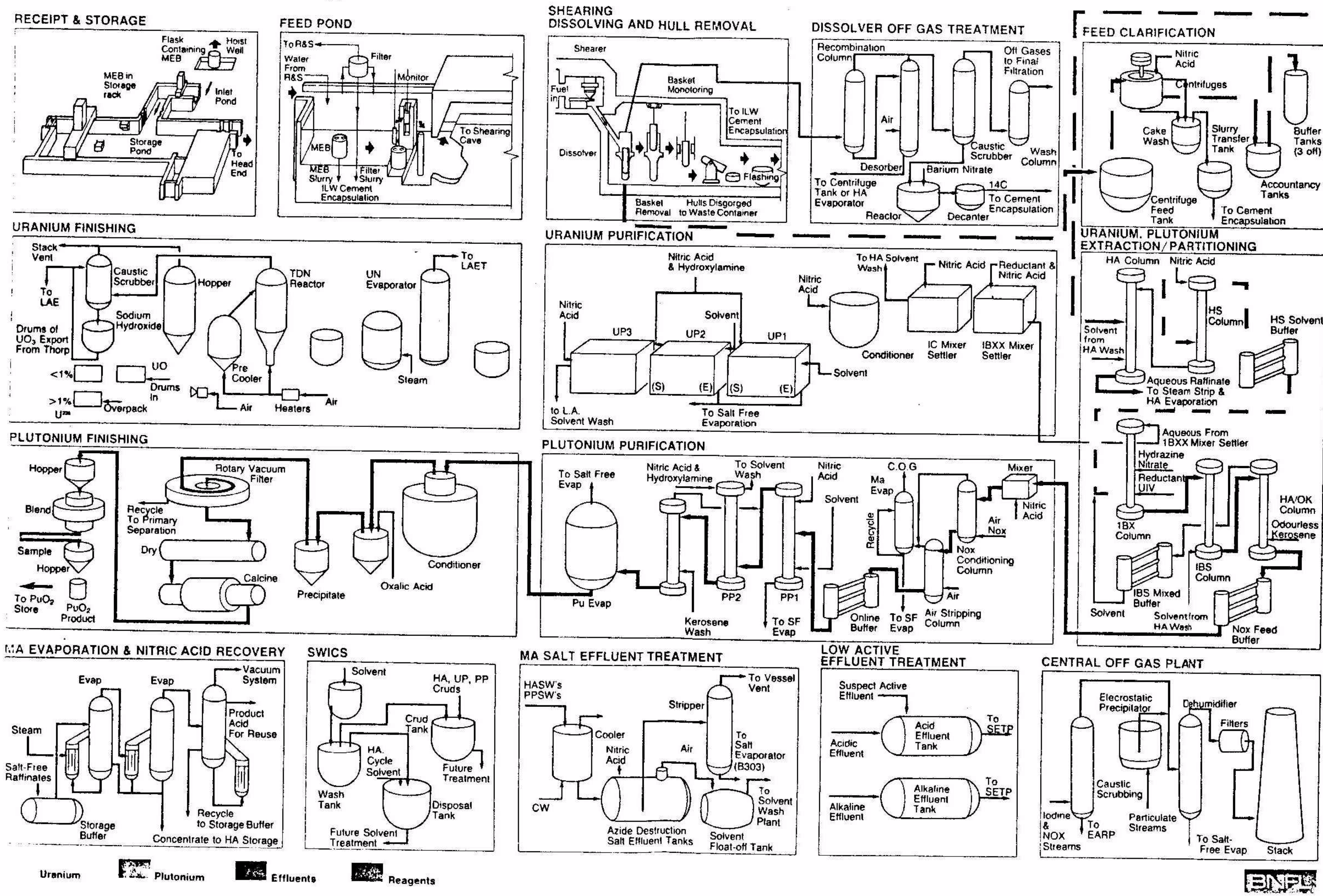


Fig. 8.12. Outline of Purex process for spent-fuel reprocessing.

TBP(tributylphosphate)

THORP Reprocessing



Sources

“Advanced Spent Fuel Processing Technologies for the Global Nuclear Energy Partnership”, Argonne National Laboratory, 27 September 2006.

“Preliminary Results of the Lab-Scale Demonstration of the UREX+1a Process Using Spent Nuclear Fuel”, Argonne National Laboratory, 3 November 2005