GNEP Spent Fuel Processing; Waste Streams and Disposition Options

Global Nuclear Energy Partnership

Nuclear Waste Technical Review Board
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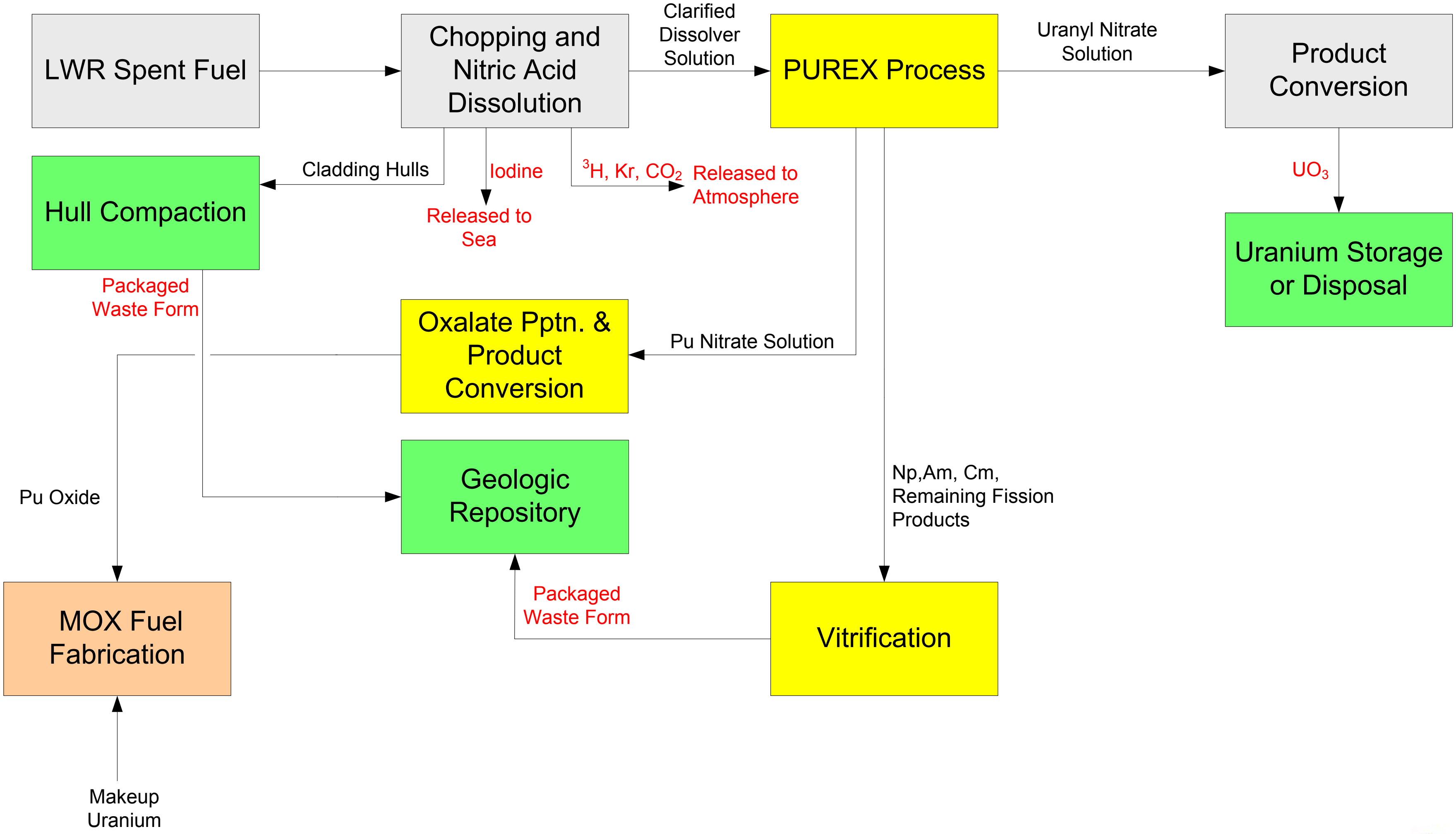
Reprocessing Plants in Operation or Planned Today

Country	*Location*	*Capacity, t/y*
China	Jiuquan	25
	(Planned, 2020-2025)	800
France	LaHague (UP2-800, UP-3)	1,600
India	Trombay	60
	Tarapur	210
	Kalpakkam	300
Japan	Tokai-mura	100
	Rokkasho-mura	800
Russia	Chelyabinsk (Mayak, RT-1)	400
	(Planned, 2025)	1,000
United Kingdom	Sellafield B205	1,500
	Sellafield THORP	1,200
United States	CFTC (Planned, 2020-2025)	2,500

Contemporary Plants use the PUREX Process



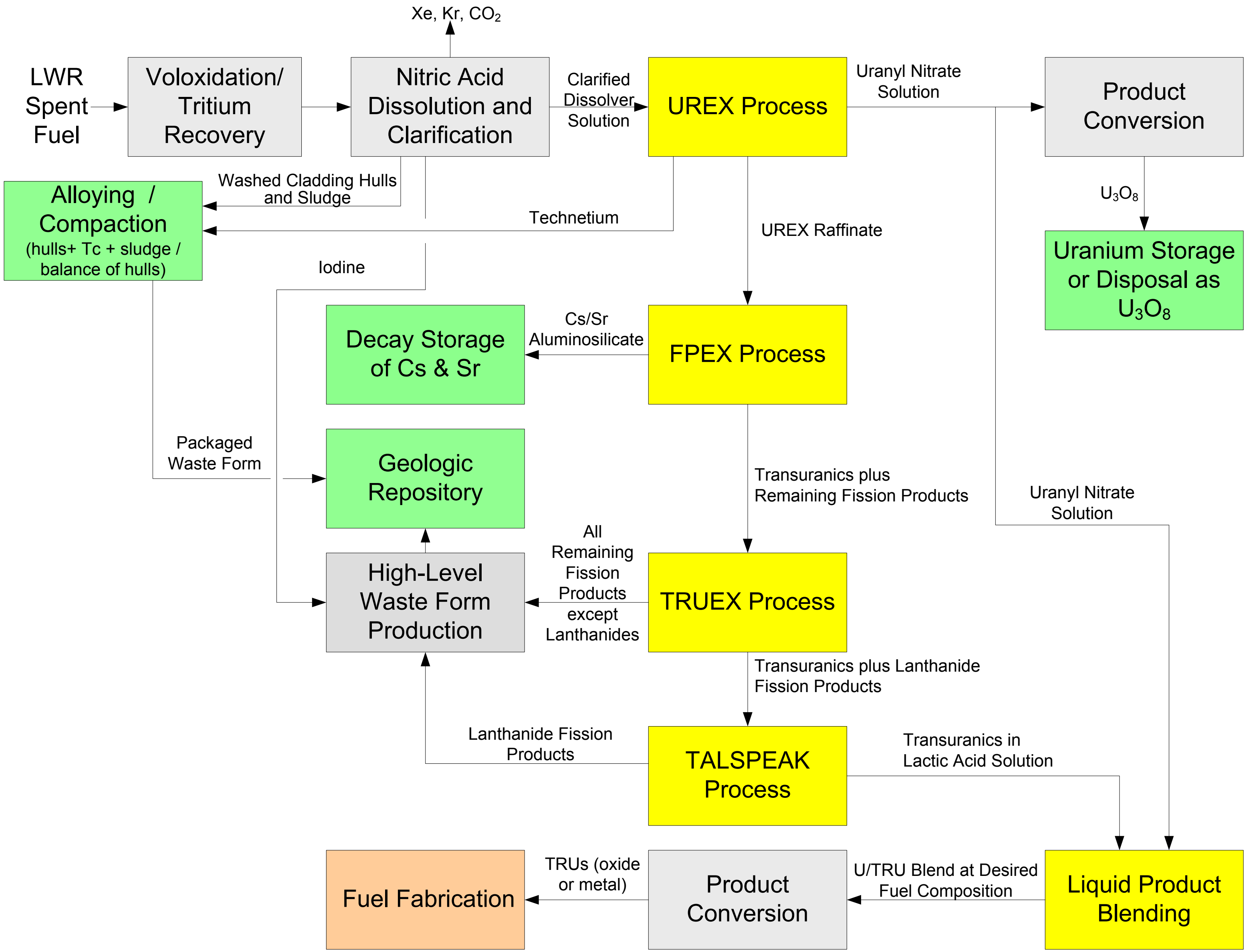
Issues with the PUREX Process

- Process is well-understood and proven to be commercially viable
- Pure plutonium stream is separated; civil use of this material is against national policy of the United States – mixed oxide fuel will be used for disposition of excess weapons plutonium in commercial reactors, however
- Minor actinides are sent to waste, greatly increasing its radiotoxicity and volume
- Major heat-generating radionuclides go into the high-level waste stream; no benefits to heat management in a geologic repository
- Minor modifications to the process (e.g., recombining uranium and plutonium streams) are easily subverted for clandestine production of plutonium

Design of GNEP Process for Treatment of LWR Spent Fuel

- Generation of no high-level liquid wastes requiring extended underground tank storage
- "Limited emissions" goal
  - Recovery of I, Kr, ^3H, $^{14}CO_2$
- Added fuel cycle costs to amount to minimal increase in the busbar cost of electricity; efficient operation at high throughput
- Efficient removal, > 95%, and immobilization of long-lived fission products (specifically iodine and technetium) to reduce repository dose rate
- Ten-fold or greater reduction in high-level waste volume relative to direct disposal of spent fuel
- Integrated process: ≥99.9% removal of transuranics and short-lived fission products (Cs, Sr) to reduce radiotoxicity and heat load; no separation of pure plutonium

UREX+1a Process (Current GNEP Reference)



Xe, Kr, CO_2

LWR Spent Fuel

Voloxidation/ Tritium Recovery

Nitric Acid Dissolution and Clarification

Clarified Dissolver Solution

UREX Process

Uranyl Nitrate Solution

Product Conversion

U_3O_8

Uranium Storage or Disposal as U_3O_8

Washed Cladding Hulls and Sludge

Alloying / Compaction (hulls+ Tc + sludge / balance of hulls)

Technetium

UREX Raffinate

Iodine

Decay Storage of Cs & Sr

Cs/Sr Aluminosilicate

FPEX Process

Packaged Waste Form

Geologic Repository

Transuranics plus Remaining Fission Products

Uranyl Nitrate Solution

High-Level Waste Form Production

All Remaining Fission Products except Lanthanides

TRUEX Process

Transuranics plus Lanthanide Fission Products

Lanthanide Fission Products

TALSPEAK Process

Transuranics in Lactic Acid Solution

Fuel Fabrication

TRUs (oxide or metal)

Product Conversion

U/TRU Blend at Desired Fuel Composition

Liquid Product Blending

Laboratory-Scale Testing of the UREX+1a Process

(July 2006, 1 kg LWR spent fuel; solvent extraction process segment only; feed material: Cooper [BWR, 34 GWd/t] and H.B. Robinson [PWR, 76 GWd/t])

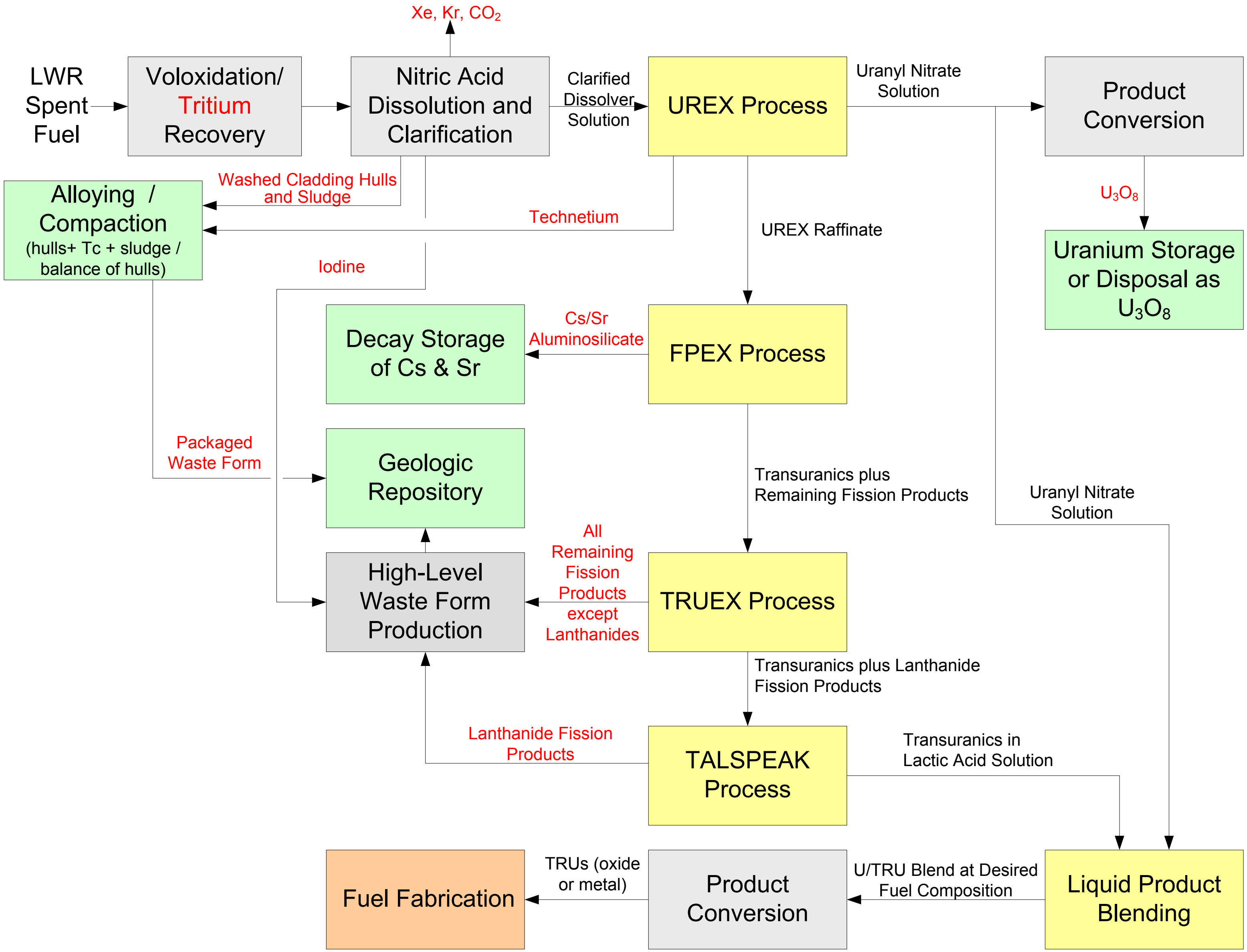
Element	*Recovery Eff.*	*Remarks*
Uranium	99.9992%	Non-TRU (<100 nCi/g)
Technetium	95.5%	Soluble Tc
Cesium	>99.85%	
Strontium	99.1%	
Plutonium	>99.998%	Total lanthanide content of transuranics <0.05% (DF>2,000)
Neptunium	>99.992%	
Americium	>99.97%	
Curium	>99.9993%	

UREX+ Process: Possible Variations

Process	*1st Product*	*2nd Product*	*3rd Product*	*4th Product*	*5th Product*	*6th Product*	*7th Product*
UREX+1	**U** **(highly purified)**	**Tc, I** **(LLFPs, dose issue)**	**Cs,Sr** **(short-term heat mgmt.)**	**Other FPs**	**TRU+Ln** **(temporary storage)**		
UREX+1a	**U** **(highly purified)**	**Tc, I** **(LLFPs, dose issue)**	**Cs,Sr** **(short-term heat mgmt.)**	**FPs** **(including lanthanides)**	**TRU** **(group extraction)**		
UREX+2	**U** **(highly purified)**	**Tc, I** **(LLFPs, dose issue)**	**Cs,Sr** **(short-term heat mgmt.)**	**Other FPs**	**Pu+Np** **(for FR recycle fuel)**	**Am+Cm +Ln** **(temp. storage)**	
UREX+3	**U** **(highly purified)**	**Tc, I** **(LLFPs, dose issue)**	**Cs,Sr** **(short-term heat mgmt.)**	**FPs** **(including lanthanides)**	**Pu+Np** **(for FR recycle fuel)**	**Am+Cm** **(heterogeneous targets)**	
UREX+4	**U** **(highly purified)**	**Tc, I** **(LLFPs, dose issue)**	**Cs,Sr** **(short-term heat mgmt.)**	**FPs** **(including lanthanides)**	**Pu+Np** **(for FR recycle fuel)**	**Am** **(heterogeneous targets)**	**Cm** **(storage)**

- All processes provide the same repository benefits
- UREX+1 and UREX+1a are designed for homogeneous recycle of all transuranics to fast spectrum reactors
- UREX+2, +3 and +4 are designed for heterogeneous recycling, possibly as an evolutionary step, to preclude the need for remote fabrication of fuel

UREX+1a Process: Waste and Storage Products



LWR Spent Fuel

Voloxidation/ Tritium Recovery

Nitric Acid Dissolution and Clarification

Xe, Kr, CO_2

Clarified Dissolver Solution

UREX Process

Uranyl Nitrate Solution

Product Conversion

U_3O_8

Uranium Storage or Disposal as U_3O_8

Washed Cladding Hulls and Sludge

Technetium

Alloying / Compaction
(hulls+ Tc + sludge / balance of hulls)

Iodine

UREX Raffinate

Decay Storage of Cs & Sr

Cs/Sr Aluminosilicate

FPEX Process

Packaged Waste Form

Geologic Repository

Transuranics plus Remaining Fission Products

Uranyl Nitrate Solution

High-Level Waste Form Production

All Remaining Fission Products except Lanthanides

TRUEX Process

Transuranics plus Lanthanide Fission Products

Lanthanide Fission Products

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Transuranics in Lactic Acid Solution

Fuel Fabrication

TRUs (oxide or metal)

Product Conversion

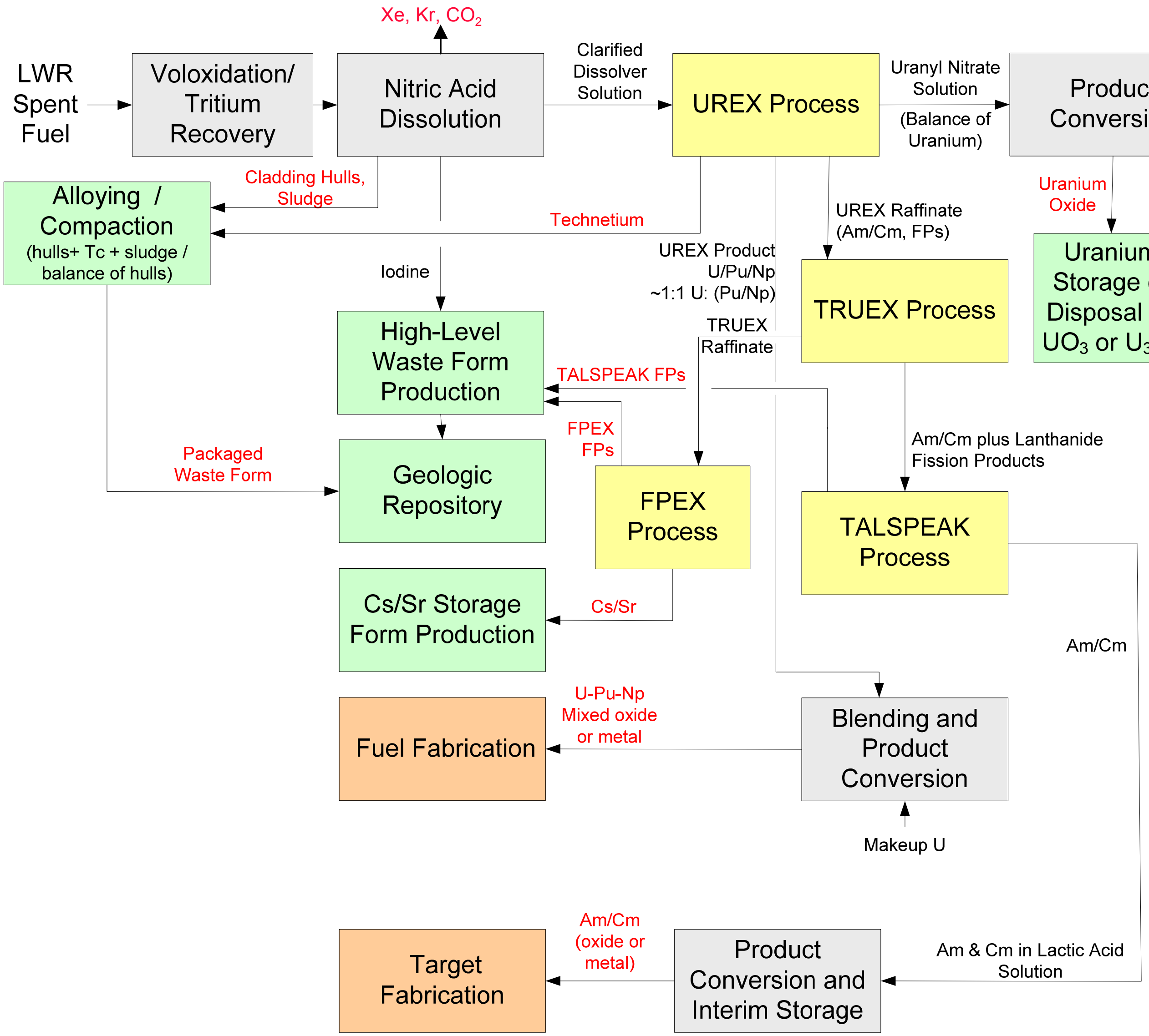
U/TRU Blend at Desired Fuel Composition

Liquid Product Blending

Alternative Process

- UREX+1a process is a group TRU extraction process that requires remote fabrication of the TRU recycle fuel
- Remote fuel fabrication will almost certainly result in higher fuel fabrication costs (relative to glovebox fabrication of U-Pu MOX fuel)
- Technologies for remote fabrication will not be available at a high level of technological maturity for a number of years
- Therefore, an alternative process (UREX+3) is being considered that would recycle U-Pu-Np as fast reactor fuel, with Am being transmuted in dedicated target assemblies; Cm can be separated for storage and decay to Pu/Am

UREX+3 Process



LWR Spent Fuel

Voloxidation/ Tritium Recovery

Xe, Kr, CO_2

Nitric Acid Dissolution

Clarified Dissolver Solution

UREX Process

Uranyl Nitrate Solution

(Balance of Uranium)

Product Conversion

Uranium Oxide

Uranium Storage or Disposal as UO_3 or U_3O_8

Cladding Hulls, Sludge

Technetium

Alloying / Compaction

(hulls+ Tc + sludge / balance of hulls)

Iodine

UREX Product U/Pu/Np ~1:1 U: (Pu/Np)

UREX Raffinate (Am/Cm, FPs)

TRUEX Process

TRUEX Raffinate

High-Level Waste Form Production

TALSPEAK FPs

FPEX FPs

Am/Cm plus Lanthanide Fission Products

Packaged Waste Form

Geologic Repository

FPEX Process

TALSPEAK Process

Cs/Sr

Cs/Sr Storage Form Production

Am/Cm

U-Pu-Np Mixed oxide or metal

Fuel Fabrication

Blending and Product Conversion

Makeup U

Am/Cm (oxide or metal)

Target Fabrication

Product Conversion and Interim Storage

Am & Cm in Lactic Acid Solution

Waste and Product Streams: Present Plans for Disposition

- Tritium: collect as tritiated water, incorporate in grout and encapsulate
- Cladding hulls (greatest volume contributor to HLW):
  - Largest fraction: wash (target: non-TRU), compact and encapsulate
  - Portion: use as matrix material for technetium/UDS alloy
- Technetium: recover in metallic form, combine with undissolved solids and a fraction of the cladding hulls, dispose as a metallic HLW form
- Xenon/krypton: immobilize in zeolite or clathrates, dispose as HLW; potential for xenon-krypton separation is being studied
- Carbon-14: recover as CO_2, convert to carbonate and dispose as HLW

Waste and Product Streams: Present Plans for Disposition (continued)

- Iodine: trap in silver-coated zeolite, convert to potassium iodate and dispose as HLW
- Uranium: store in drums for future use (re-enrichment, recycle to fast reactors) or disposal as LLW
- Cesium/strontium: recover at high level of purity, immobilize in an aluminosilicate mineral matrix and store until radionuclides have decayed to levels acceptable for disposal as LLW
- Residual fission products (lanthanides and transition metals): most have decayed to stable isotopes; lanthanides are good glass-formers and can be vitrified at high level of waste loading; transition metals may be better combined with the recovered technetium and alloyed with Zircaloy cladding hulls

UREX+1a/+3 Processes: Projected Waste Generation for Every 100 Metric Tons of Spent Fuel Processed

Waste Stream	Waste Composition	Category	Volume, m^3
Uranium	U_3O_8 powder	(Storage)	18
Cesium/strontium	Cs/Sr aluminosilicate	(Storage)	1.1
Hulls + Tc, sludge	Zr-Fe based alloy	HLW	0.6
Compacted hulls	Non-TRU Zr	HLW	6.1
U losses	Borosilicate glass	HLW	1.0 - 3.4
TRU losses	Borosilicate glass	HLW	0.06
Iodine	Potassium Iodate	HLW	0.018
Krypton	Zeolite/aluminosilicate	HLW	0.014
Tritium	Grout	HLW	<0.01
Lanthanide FPs	LABS glass	HLW	0.31
Carbon-14	Sodium carbonate	HLW	0.034

For comparison, 100 tons of untreated spent fuel has an unpackaged volume of 45 m^3

Future Improvements

- Cladding hulls comprise the largest part of the estimated high-level waste volume
- Studies are in progress to evaluate the potential for recycling zirconium for production of LWR fuel cladding
- Industrial suppliers have indicated the feasibility of fabricating cladding with small content of ^{93}Zr
- Other activation products are removed in the chloride volatility process used for Zr recovery

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- On the other hand, a ten-fold reduction in high-level waste volume may be more than adequate; the compacted hulls and hardware are not significant contributors to the repository heat load