TOMSK POLYTECHNIC UNIVERSITY

Fundamentals of Nuclear Fuel Cycle

Lecturer
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Radioactive waste

the leftovers from the use of nuclear materials for the production of electricity, diagnosis and treatment of disease, and other purposes

Waste	Characteristics
Very low level waste (VLLW)	concrete, plaster, bricks, metal, valves, piping *etc*
Low-level waste (LLW)	paper, rags, tools, clothing, filters *etc*, small amounts of mostly short-lived radioactivity; power density <2kW
Intermediate-level waste (ILW)	resins, chemical sludges metal fuel cladding, higher amounts of radioactivity power density <2kW
High-level waste (HLW)	long-lived and short-lived highly radioactive components, used nuclear fuel, fission products and transuranic elements, power density >2kW

Radioactive waste

- Liquid
- Solid
- Gaseous

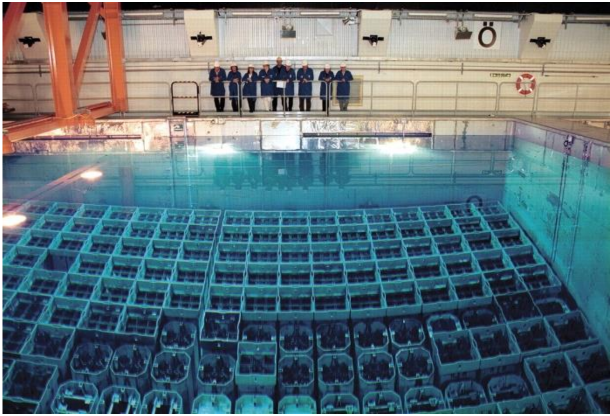
Activity, kBq/kg			
Category	β	α	Transuranic
LLW	$<10^3$	<100	<10
ILW	$10^3 - 10^7$	$10^2 - 10^6$	$10 - 10^5$
HLW	$>10^7$	$>10^6$	$>10^5$

Spent nuclear fuel

Or used nuclear fuel, is nuclear fuel that has been irradiated in a nuclear reactor. It is no longer useful in sustaining a nuclear reaction in an ordinary thermal reactor.

Specific features:

1. Criticality
2. Radiation safety
3. Decay heat power



Time after shutdown	1s	100s	100 hrs.
Power of reactor,%	6.5	3.2	0.33

1 year – 0.023 %

SNF management

- Subcritical state
- Heat removing and cooling
- Zero-damage-on-storage
- Radiation safety

Interim spent fuel storage in **Spent fuel pools (SFP)**

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Transportation to Reprocessing plant or final repository

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Storage before reprocessing or disposal

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Reprocessing

↓

Disposal

Principles of Radioactive Waste Management

IAEA:

- Protection of human health
- Protection of the environment
- Protection beyond national borders
- Protection of future generations
- Burdens on future generations
- National legal framework
- Control of radioactive waste generation
- Radioactive waste generation and management interdependencies
- Safety of facilities

Waste Management

Steps

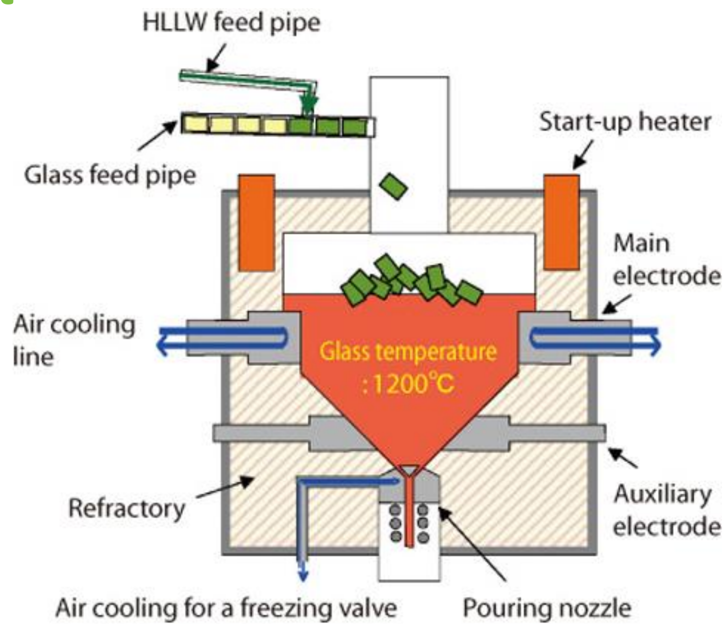
- Waste sorting
- Treatment and compaction
  - decontamination
  - pressing
  - incineration
  - plasma-chemical processing
- Conditioning
- Transportation
- Storage and disposal

Waste Management

Steps

- Conditioning Vitrification

Borosilicate glass
Phosphate glass



Waste Management

Steps

- Conditioning Cementation

Portland cement (mixture of SiO_2, CaO, Al_2O_3, etc)
Masonry cement (Portland cement + $Ca(OH)_2$)
Portland sodium silicate cement

Waste Management

Steps

- Conditioning

Bituminization

Bitumen

Waste Management

Steps

- Conditioning

Mineral (Ceramic) Matrixes

zircon,
zirconolite,
perovskite,
yttrium-aluminum garnet (IAG),
britholite,
monazite,
pyrochlore

Waste Management

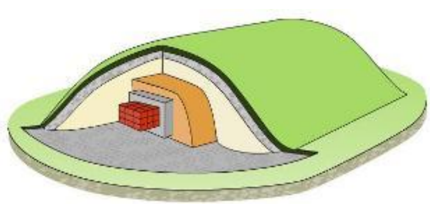
Steps

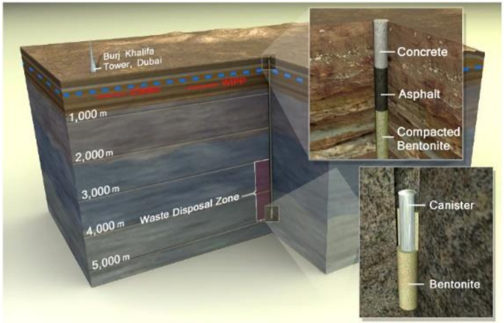
- Storage and disposal

Repositories

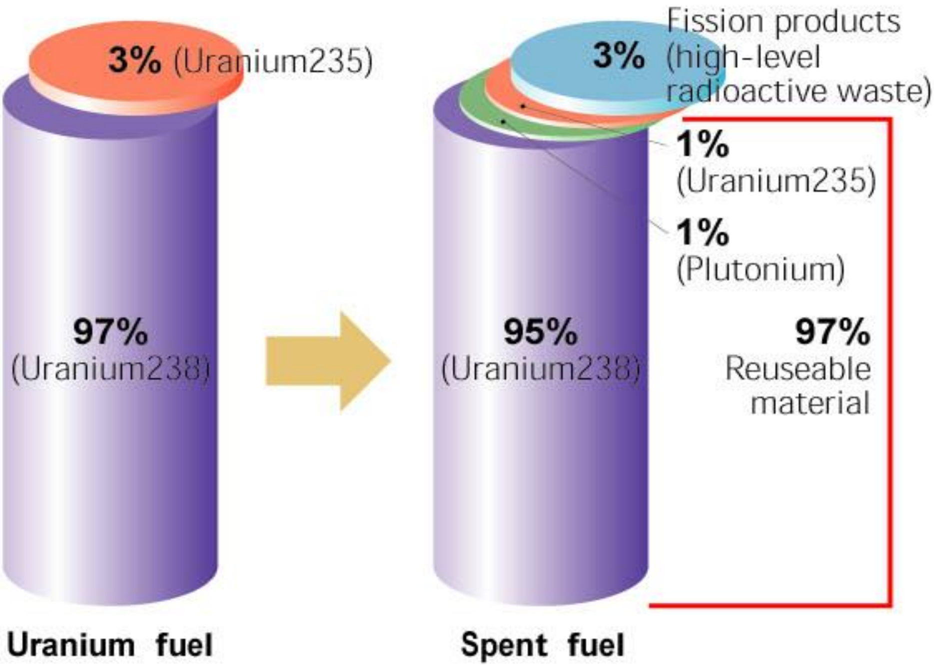
Near Surface Disposal - at ground level, or in caverns below ground level (at depths of tens of meters)

Deep geological repository - at depths between 250m and 1000m for mined repositories, or 2000m to 5000m for boreholes





Reprocessing of SNF



Reprocessing of SNF

World reprocessing capacity (t/yr)

LWR fuel	France	1600
	UK	900
	Russia	400
	Japan	800
Other fuel	India (PHWR)	330

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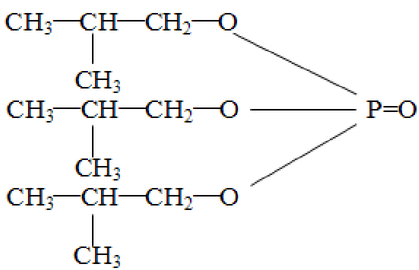
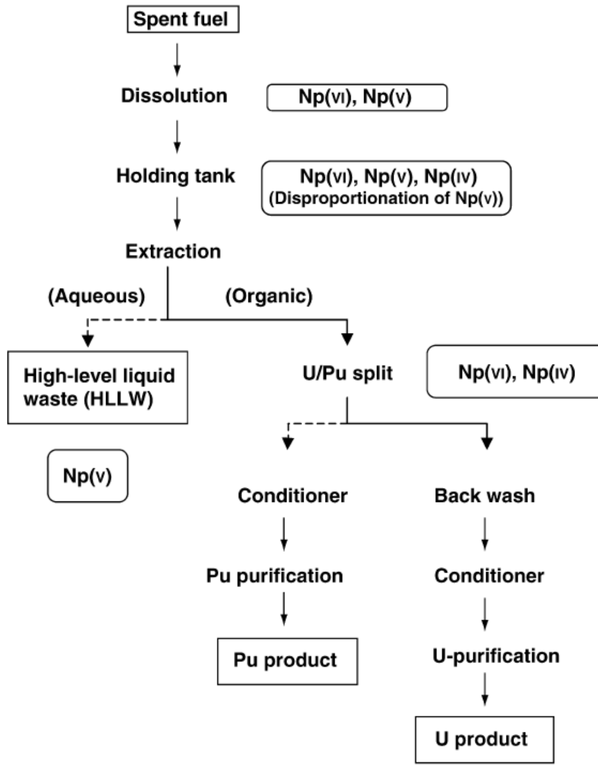
Reprocessing of SNF

PUREX

Plutonium uranium refining by extraction

TBP





Reprocessing of SNF

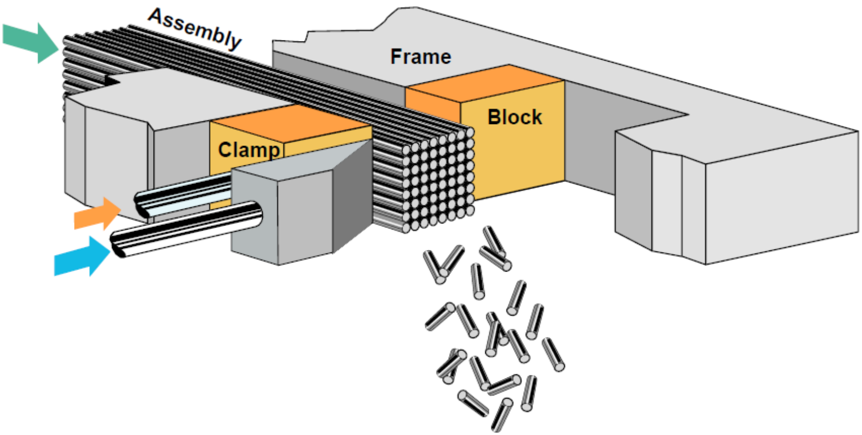
PUREX

- **Tri-butyl phosphate forms soluble complexes with uranyl nitrate and plutonium nitrate (neutral species of U(VI) and Pu(IV))**
- **Spent fuel is dissolved in nitric acid and is then mixed with a solution of TBP in a hydrocarbon diluent (immiscible with aqueous phase)**
- **At higher nitric acid concentrations (>0.5 M) the plutonium and uranium partition to the organic (solvent) phase while most of the metals and fission products stay in the aqueous phase**
- **Once separated from the fission products, the solvent can be mixed with another aqueous solution of low acidity (<0.01 M) and the uranium and plutonium will partition back to the aqueous phase.**
- **To separate plutonium from uranium, a reductant is added to the aqueous stream, reducing Pu(IV) to Pu(III), which is not soluble in the organic solvent and partitions to the aqueous phase while U(VI) remains in the solvent**

Reprocessing of SNF

PUREX

Fuel Decladding

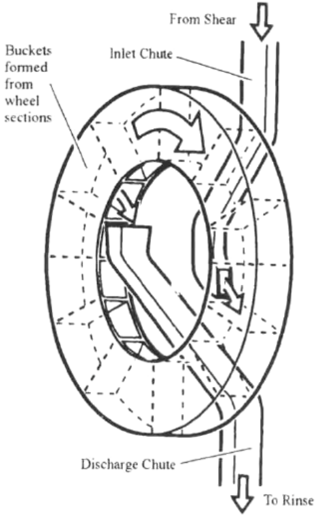


Reprocessing of SNF

PUREX

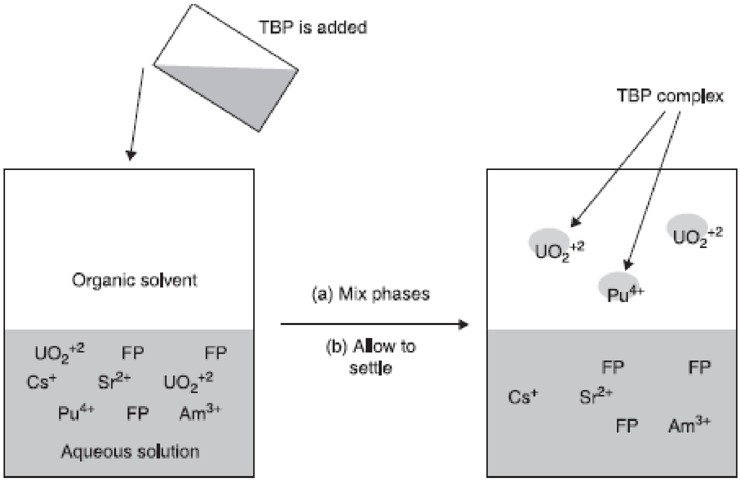
Dissolution/ feed clarification

- Nitric acid dissolves UO_2 pellet from cladding hull, forming $UO_2(NO_3)_2$ in solution
- Dissolver product contains approx. 300 g/l uranium
- Releases radioactive off-gas (iodine, krypton, xenon, carbon-14, small amounts of tritium)
- Undissolved solids are removed by centrifugation before transfer to extraction process



Reprocessing of SNF

PUREX



$$UO_2^{2+} + 2NO_3^- + 2TBP \rightleftarrows UO_2(NO_3)_2 \bullet 2TBP$$

$$Pu^{4+} + 4NO_3^- + 2TBP \rightleftarrows Pu(NO_3)_4 \bullet 2TBP$$

Reprocessing of SNF

PUREX

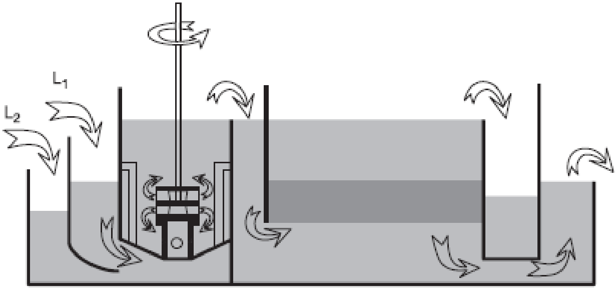
Uranium/Plutonium separation

U^{+6} is separated from Pu using the selective reduction of Pu to the trivalent state by adding U^{4+}

$$2Pu^{4+} + U^{4+} + 2H_2O = 2Pu^{3+} + UO_2^{2+} + 4H^+$$

Extraction technology

- Mixer-settlers
- Pulsed columns
- Centrifugal extractor



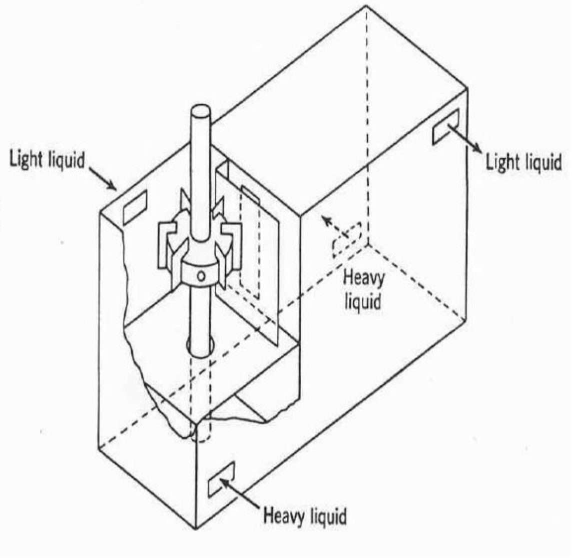
L_1 organic phase
L_2 aqueous phase

Reprocessing of SNF

PUREX

Mixer Settlers

- Discrete stage units (with efficiencies < 1)
- Low capital cost
- Requires large amount of floor space (but low headroom)
- Large solvent inventory
- Long residence times

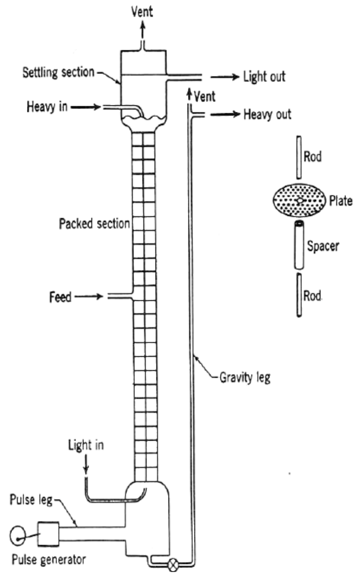


Reprocessing of SNF

PUREX

Pulse Extraction Column

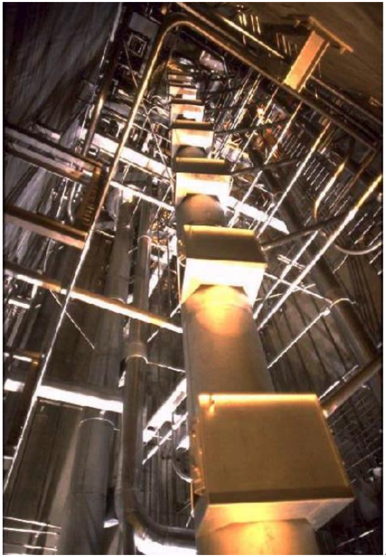
- Several feet of column needed for one theoretical stage
- Low capital cost
- Requires large amount of head space (40-50’), but little floor space
- Moderate solvent inventory
- Long residence times



Reprocessing of SNF

PUREX

Pulse column at La Hague UP3 plant



Reprocessing of SNF

PUREX

Centrifugal Contactors

- Each unit near one theoretical stage
- Higher capital cost
- Requires little headroom or floor space, but requires remote maintenance capability
- Small solvent inventory
- Short residence times