Science and Technology

Solutions, Separation Techniques, and the PUREX Process for Reprocessing Nuclear Waste
Spent Fuel Rods

- Fission products that emit beta and gamma radiation
- Some fissionable U-235 and Pu-239
- Alpha emitters, such as uranium-234, neptunium-237, plutonium-238 and americium-241
- Sometimes some neutron emitters such as californium (Cf).
Nuclear Reprocessing

- Process to chemically separate and recover fissionable plutonium and uranium from irradiated nuclear fuel.

- **Purposes**
  - Originally reprocessing was used solely to extract plutonium for producing nuclear weapons.
  - The reprocessed plutonium can be recycled back into fuel for nuclear reactors.
  - The reprocessed uranium, which constitutes the bulk of the spent fuel material, can in principle also be re-used as fuel, but that is only economic when uranium prices are high.

- Nuclear reprocessing reduces the volume of high-level waste, but by itself does not reduce radioactivity or heat generation and therefore does not eliminate the need for a geological waste repository.

http://en.wikipedia.org/wiki/Nuclear_reprocessing
Nuclear Reprocessing

- Reprocessing of civilian fuel has long been employed in France, the United Kingdom, Russia, Japan, and India.
- Briefly done at the West Valley Reprocessing Plant in the United States.
- In October 1976, concerned about nuclear weapons proliferation, President Gerald Ford indefinitely suspended the commercial reprocessing and recycling of plutonium in the U.S.
- In March 1999, the U.S. Department of Energy (DOE) reversed its policy and signed a contract with a consortium to design and operate a mixed oxide (MOX) fuel fabrication facility. There are no customers yet.
• **PUREX** is a chemical method used to purify fuel for nuclear reactors or nuclear weapons.

• It is an acronym standing for Plutonium Uranium Redox or Plutonium Uranium Recovery by Extraction.

http://en.wikipedia.org/wiki/PUREX
Like Dissolves Like

• Polar substances are expected to dissolve in polar solvents.
  – For example, ionic compounds, which are very polar, are often soluble in the polar solvent water.

• Nonpolar substances are expected to dissolve in nonpolar solvents.
  – For example, nonpolar molecular substances are expected to dissolve in hexane, a common nonpolar solvent.
“Like Does Not Dissolve Unlike”

- Nonpolar substances are not expected to dissolve to a significant degree in polar solvents.
  - For example, nonpolar molecular substances are expected to be insoluble in water.

- Polar substances are not expected to dissolve to a significant degree in nonpolar solvents.
  - For example, ionic compounds are insoluble in hexane.
Liquid-Liquid Extraction

Typically performed in a separatory funnel:

Polar compounds will congregate in “aqueous” layer

Non-polar compounds will congregate in “organic” layer

Aqueous layer (polar things)

Organic layer (non-polar things)
PUREX Process

- Dissolve in 7 M HNO$_3$.
- Filter out solids.
- Combine with 30% tributyl phosphate (TBP) to form UO$_2$(NO$_3$)$_2$·2TBP and PuO$_2$(NO$_3$)$_2$·2TBP complexes.
- Extract with an organic solvent, such as kerosene. (It is normal to use more than one extraction cycle.)
  - UO$_2$(NO$_3$)$_2$·2TBP and PuO$_2$(NO$_3$)$_2$·2TBP complexes in nonpolar organic solvent.
  - Fission products, and transuranium elements americium and curium remain in the aqueous phase.

http://en.wikipedia.org/wiki/PUREX
Separation of U, Pu, and Fission Products

On to Uranium purification

Nonpolar solvent Layer

U and Pu complexes

On to Plutonium purification

Aqueous Layer

Fission products, minor actinides: discarded as “high level waste”
• Plutonium is separated from uranium in a separate extraction by treating the kerosene solution with aqueous iron(II) sulfamate, Fe(SO$_3$NH$_2$)$_2$, which reduces the plutonium to the +3 oxidation state. The plutonium passes into the aqueous phase.

• Variations on the PUREX process have been developed.

http://en.wikipedia.org/wiki/PUREX
One Sign of Reprocessing of Nuclear Wastes

- 2002 – China shipped about 20 tons of tributyl phosphate (TBP) to North Korea.
- Considered to be sufficient to extract enough material for three to five nuclear weapons