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*Supplement of*

## **Proliferation aspects of partitioning and transmutation (P&T) fuel cycles**

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# Proliferation Aspects of Partitioning and Transmutation (P&T) Fuel Cycles



# Overview

## Background

- Radioactive Waste
- Partitioning & Transmutation
- Proliferation

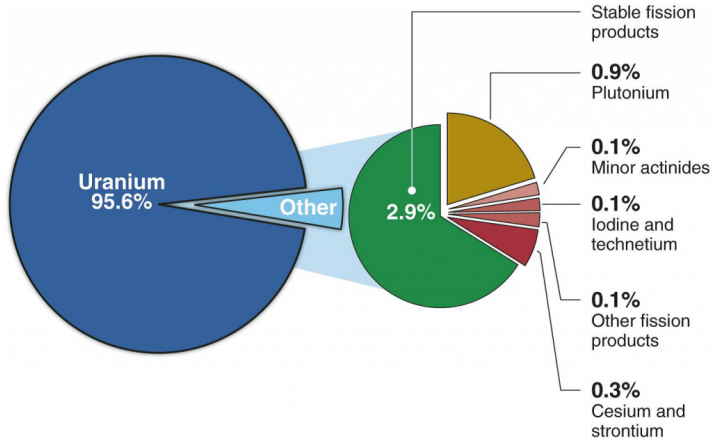
## P&T Fuel Cycle

- Fuel Fabrication Facilities
- Irradiation Facilities
- Reprocessing Facilities

## Summary

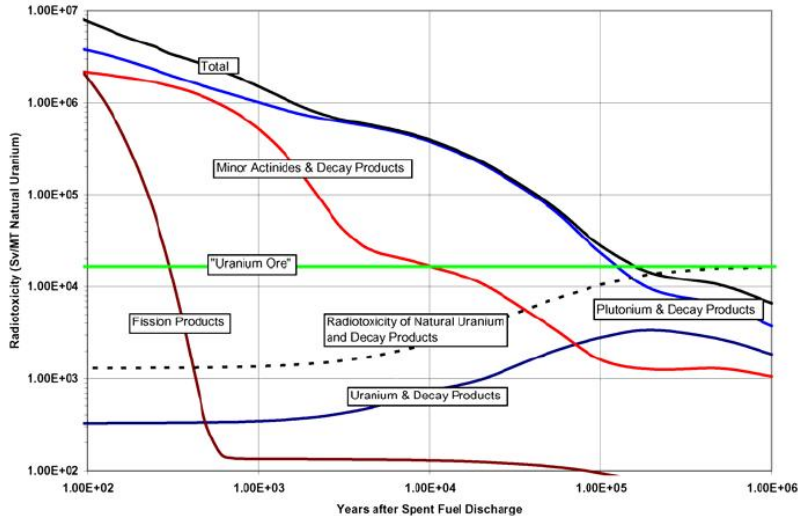
# High-level Radioactive Waste

1 GW LWR produces 30-50 t SNF / Year



Source: GAO analysis of DOE data.

# Radiotoxicity



Source: NEA/OECD, Physics and Safety of Transmutation Systems - A Status Report, 2006.

# Partitioning and Transmutation (P&T)

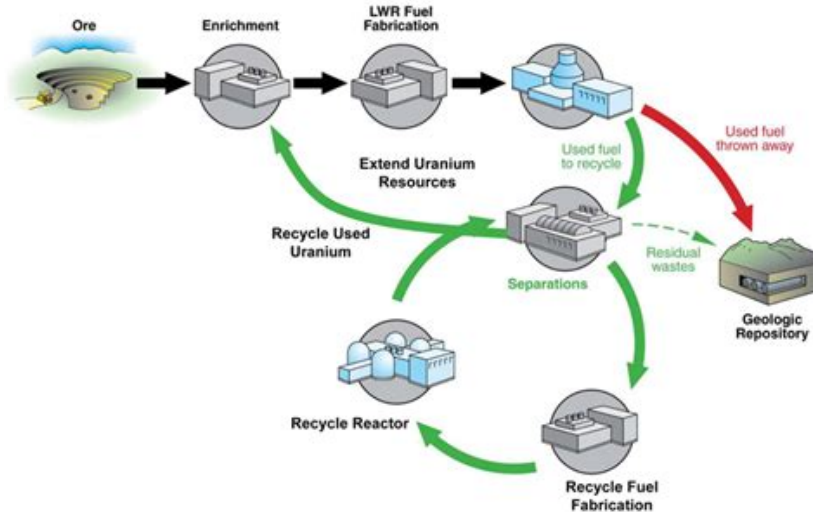
**Partitioning:** Separation of spent nuclear fuel into different material streams

- (short-lived) fission products
- Plutonium
- Minor Actinides (MA): Np, Am, Cm

**Transmutation:** Transformation of long-lived radionuclides into short-lived or stable isotopes

**Goal:** Significantly reduced requirements on long-term radioactive waste management

# Closed Nuclear / P&T Fuel Cycle



Source: <https://www.anl.gov/nse>

# Criteria for P&T Assessment

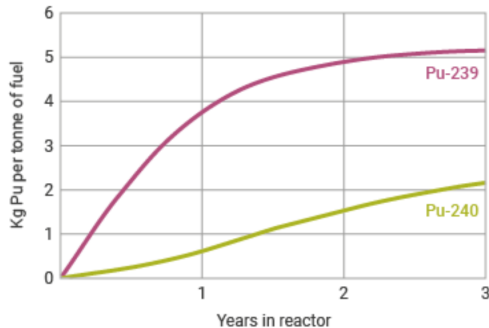
- Technology availability (needed R&D, development risks)
- Implementation period
- Effect on radioactive waste disposal (radiotoxicity vs. long-term safety, decay heat, volume)
- Overall energy production strategy (phase-out?)
- Risks
  - Safety (new reactor types, various fuel compositions, regulations...)
  - Safeguards (new measures needed)
  - Security (proliferation)



# Dual-use Character of Nuclear Technology



- Technologies originally invented during military programs
- Virtual nuclear weapon states
- separation between "civil" and "military" ...



**Every** civil nuclear energy program lowers the threshold for acquiring nuclear weapons.

# Proliferation

## Nuclear Material

- Uranium (highly enriched)
- Plutonium (high plutonium-239 content)

## Nuclear Technology & Know-how

- Enrichment capabilities
- Handling of spent fuel elements (hot material)
- Separation of plutonium and/or other fissile isotopes

## Know-how to build a weapon

# P&T Fuel Cycle

Fuel Fabrication Facilities

Irradiation Facilities

Reprocessing Facilities

# Fuel Fabrication

P&T-fuel contains high plutonium (and/or) minor actinide content.

## Options:

- Mixed-Oxide-Fuel (MOX)  
→ plutonium production due to uranium matrix
- Inert-Matrix-Fuel (IMF)  
→ plutonium + minor actinide reduction

## Problems:

- no radiation barrier for plutonium (and/or) minor actinides
- critical mass / significant quantity of minor actinides



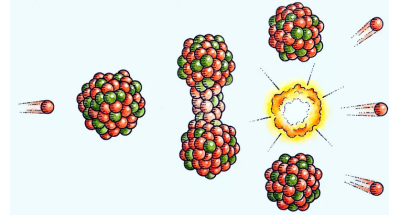
Source: TVEL

# Irradiation Facilities - Fast Neutrons

Fast (high energy) neutrons:  
→ more fission, less absorption

Originally developed to **breed** fissile material:

- Dual-use character
- needs reprocessing



Source: Dorling Kindersley

Options: Metal-cooled Reactors, Molten-Salt Reactors, Accelerator-Driven Systems

# Reprocessing

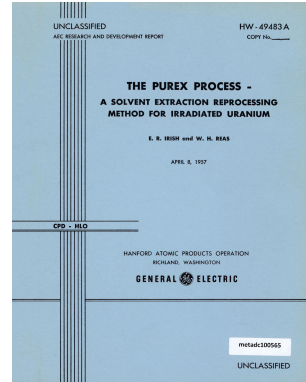
Chemical separation of fission products and actinides from spent nuclear fuel.

## Available at industrial-scale

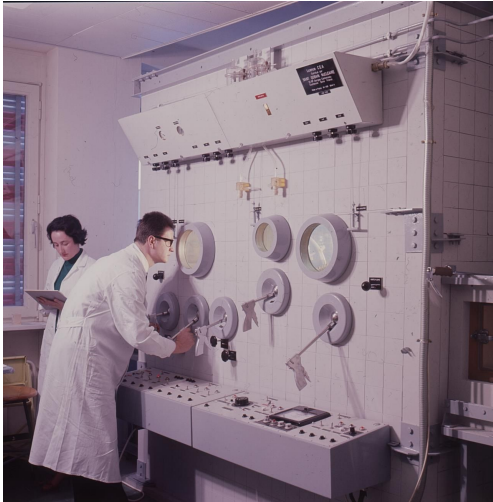
- Plutonium and Uranium Recovery by EXtraction (PUREX)
- Water / organic solvents

## P&T-Reprocessing

- extract Pu, U, minor actinides (separately?)
- lab-scale (g/year) at best
- Pyroprocessing



# Reprocessing and Proliferation



Source: IAEA Archive

Reprocessing Policy of the US:

“We will defer indefinitely the commercial reprocessing and recycling of plutonium produced in the U.S. nuclear power programs.”

President Carter (1977)

# Proliferation Resistance of Pyroprocessing



Energy Policy

Volume 144, September 2020, 111601



## Nuclear fuel reprocessing: Can pyroprocessing reduce nuclear proliferation risk?

[Seung Min Woo](#)<sup>a, d</sup>, [Sunil S. Chirayath](#)<sup>a, b</sup>  , [Matthew Fuhrmann](#)<sup>c</sup>

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## Pyroprocessing Is Reprocessing: U.S. Official

ARMS CONTROL TODAY

Daniel Horner

In what appears to be the U.S. government's strongest public statement to date on the issue, a Department of State official said last month that the U.S. government now views pyroprocessing, a spent fuel treatment process that South Korea is developing, as a form of reprocessing with proliferation risks similar to those of other forms.

In March 29 remarks at a nuclear policy conference in Washington, Richard Stratford, the State Department official who is responsible for U.S. nuclear cooperation agreements, said the Department of Energy "states frankly and positively that pyroprocessing is reprocessing. Period. Full stop." The Energy



# Summary

## P&T Fuel Cycles:

- fuel fabrication facilities that use separated fissile materials
- fast neutron reactors (irradiation facilities) that were originally designed to breed fissile material (not burn)
- reprocessing facilities that handle extremely radioactive material and separate fissile material from the fission products

Wishful thinking: we will solve that later!



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