Pu Production

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Project on Managing the Atom,
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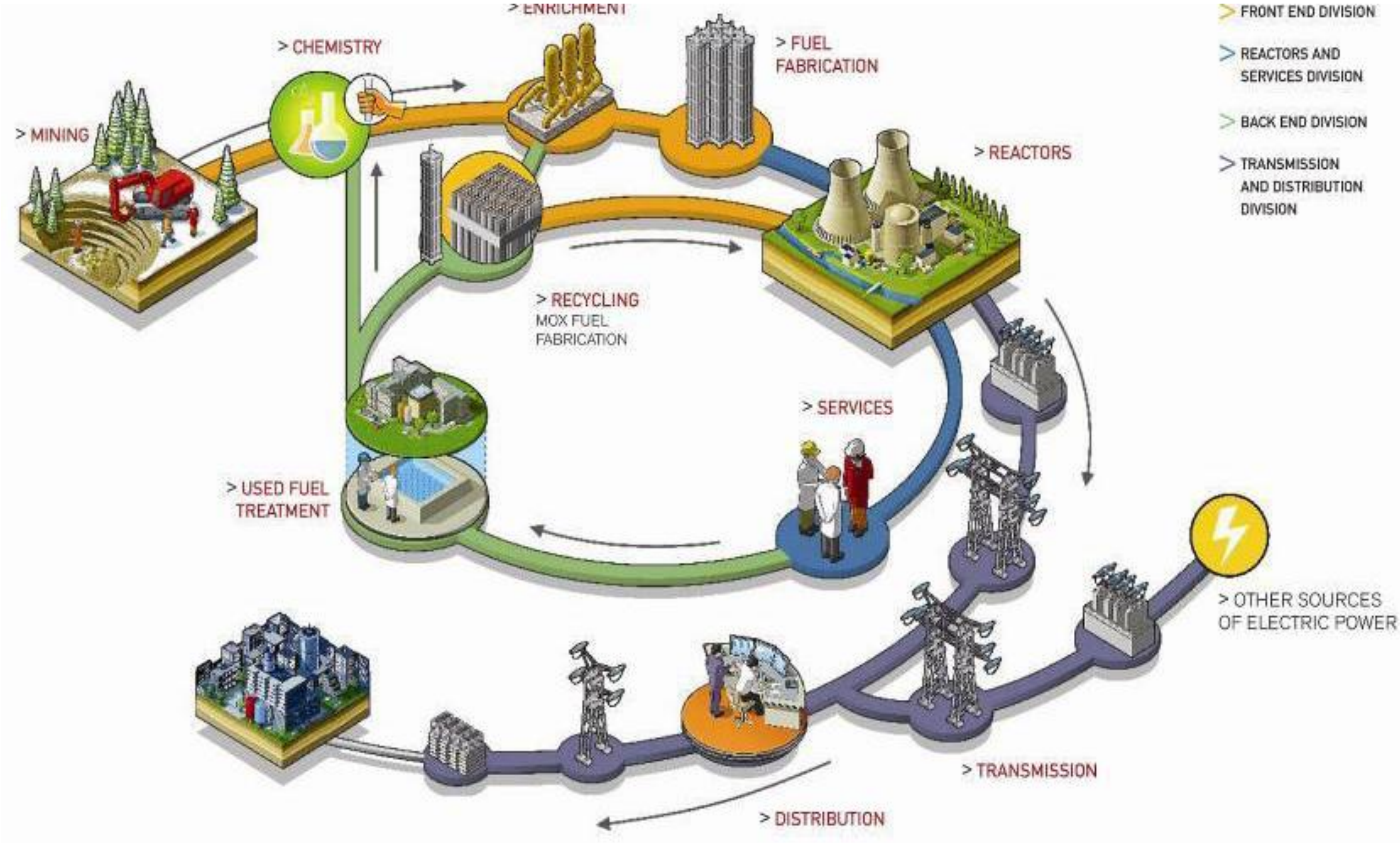
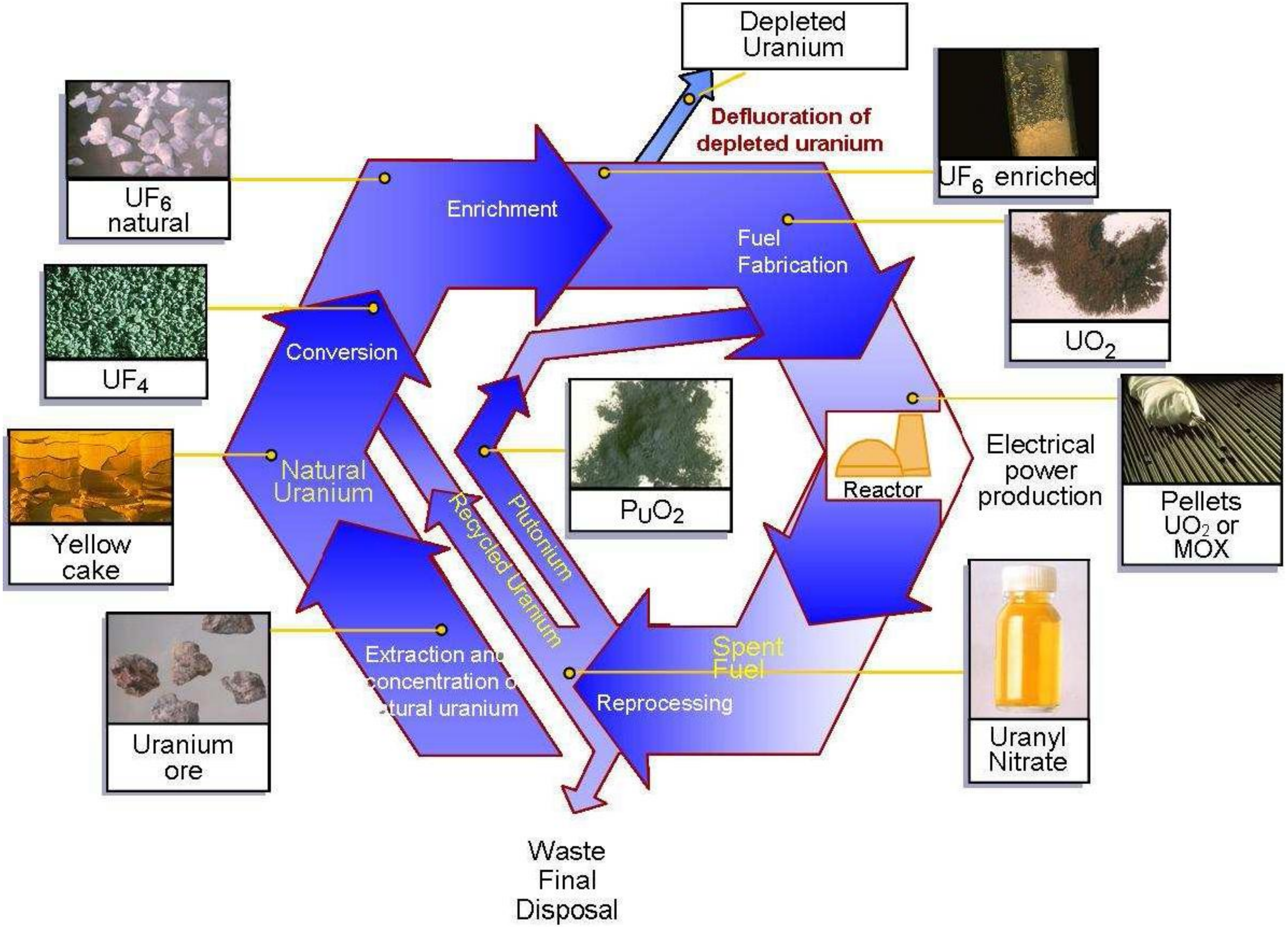
October 4, 2011



Where are we?
Nuclear Fuel Cycle


Depleted Uranium
Defluoration of depleted uranium
UF_6 natural
UF_6 enriched
Enrichment
Fuel Fabrication
UO_2
UF_4
Conversion
Yellow cake
Natural Uranium
P_UO_2
Plutonium
Recycled Uranium
Reactor
Electrical power production
Pellets UO_2 or MOX
Uranium ore
Extraction and concentration of natural uranium
Spent Fuel
Reprocessing
Uranyl Nitrate
Waste Final Disposal

Periodic Table of the Elements

- hydrogen
- alkali metals
- alkali earth metals
- transition metals
- poor metals
- nonmetals
- noble gases
- rare earth metals

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Background

Pu- Radioactive, chemical element, of the actinoid series of the periodic table, atomic no. 94 (94 protons) & several isotops.

It is the most important transuranium element because of its use as fuel in certain types of nuclear reactors and as an ingredient in nuclear weapons. Trace amounts of at least two plutonium isotopes (plutonium-239 and 244) can be found in nature

Plutonium, warm because of energy released in alpha decay, is a silvery metal that takes on a yellow tarnish in air.

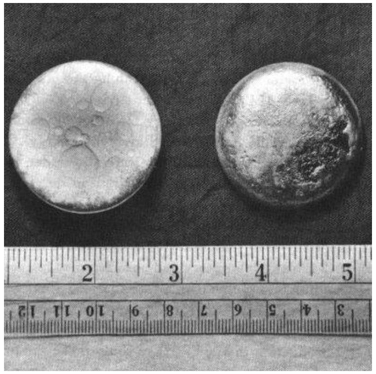
The element was first detected (1941) as the isotope plutonium-238 by Glenn T. Seaborg, Joseph W. Kennedy, and Arthur C. Wahl, who produced it by deuteron bombardment of uranium-238 in the 152-cm (60-inch) cyclotron at Berkeley, Calif.

and more..

it is fissionable, has a relatively long half-life (24,110 years)

Plutonium exhibits six forms differing in crystal structure and density (allotropes); the alpha form exists at room temperatures.

- Most stable isotope 244
- Melting point 639.5 °C (1,183.1 °F)
- Boiling point 3,235 °C (5,855 °F)
- Specific gravity (alpha) 19.84 (25 °C)
- Oxidation states +3, +4, +5, +6



Isotopes and compounds of plutonium are radioactive and accumulate in bones.

Even though alpha radiation cannot penetrate the skin, ingested or inhaled plutonium does irradiate internal organs. A commonly cited quote by Ralph Nader, states that a pound of plutonium dust spread into the atmosphere would be enough to kill 8 billion people. However, the math shows that one pound of plutonium could kill no more than 2 million people by inhalation.

The first plutonium production facility at what is now the Hanford site and later in the Savannah River site, too.

The world plutonium stockpile is estimated as about 500 tons.

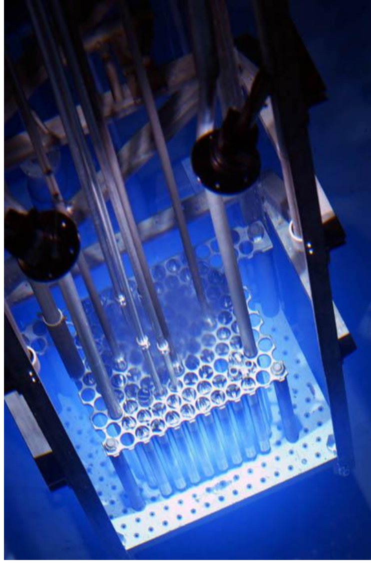
The first production reactor that made plutonium-239 was the X-10 Graphite Reactor. It went online in 1943 and was built at a facility in Oak Ridge that later became the Oak Ridge National Laboratory .

• Heavy water natural uranium (metal, oxide)
• Light water 5-20% enriched uranium (pressurized water, boiling water)
• The **CANDU**, short for **CANada Deuterium-Uranium reactor** is a Canadian-invented, pressurized heavy water.

Glove Box

Plutonium-239 and 241 are fissile, meaning the nuclei of their atoms can split when bombarded by neutrons, releasing energy, gamma radiation and more neutrons. These neutrons can sustain a nuclear chain reaction, leading to applications in nuclear weapons and nuclear reactors.

How it works?



- Uranium present in the fuel rods.

- Occasionally, when an atom of U-238 is exposed to neutron radiation, its nucleus will capture a neutron, changing it to U-239.

- This happens more easily with lower Kinetic Energy (as U-238 fission activation is 6.6MeV). The U-239 then rapidly undergoes two beta decays.

- After the ^{238}U absorbs a neutron to become ^{239}U it then emits an electron and an anti-neutrino by β^- decay to become Neptunium-239 (^{239}Np) and then emits another electron and anti-neutrino by a second β^- decay to become ^{239}Pu:

$$\mathrm{n} + {}^{238}_{92}U \rightarrow {}^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + e^- + \bar{\nu}_e$$

$${}^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + e^- + \bar{\nu}_e$$

spent fuel

When the spent fuel is discharged from nuclear reactor cores, it includes :

- ***Fissile material (235U, 239Pu, 241Pu),***

- ***Fertile material (238U, 240Pu),***

- ***Heavy isotopes neither fertile nor fissile (236U, 237Np, 242Pu, other transuranics), Fission products (the main source of big activity).***

Characteristics of the irradiated fuel

Composition of the LWR spent fuel assembly
1 LWR fuel assembly: 500 kg uranium before irradiation in the reactor

Recyclable material

U 475 to 480 kg (94 to 96 %)

Pu 5 kg (0.8-1 %)

Waste

FP 15 to 20 kg (3 to 5 %)

After irradiation*
* percentage varies with burn-up rate

Pu-240 some facts

Pu-240 has a high rate of spontaneous fission events (415,000 fission/s-kg), making it an undesirable contaminant. As a result, plutonium containing a significant fraction of Pu-240 is not well-suited to use in nuclear weapons;

it emits neutron radiation, making handling more difficult, and its presence can lead to a "fizzle" in which a small explosion occurs, destroying the weapon but not causing fission of a significant fraction of the fuel

<u>1 megawatt-day</u> (thermal energy release, not electricity output) of operation produces <u>0.9-1.0 gram of plutonium</u> in any reactor using 20-percent or lower enriched uranium; consequently, a 100 MW(t) reactor produces about <u>100 grams of plutonium per day</u> and could produce roughly enough plutonium <u>for one weapon every 2 months.</u>

Plutonium is classified according to the percentage of the contaminant plutonium-240 that it contains:

- **Supergrade** 2-3%
- **Weapons grade** less than 7%
- **Fuel grade** 7-18%
- **Reactor grade** 18% or more.

Pu-239 some facts

Pu is normally created in nuclear reactors by transmutation of individual atoms of one of the isotopes of uranium present in the fuel rods

Fission activity is relatively rare, so even after significant exposure, the Pu-239 is still mixed with great deal of U-238

Pu-239 has a higher probability for fission than U-235 and a larger number of neutrons produced per fission event, so it has a smaller critical mass.

Pure Pu-239 also has a reasonably low rate of neutron emission due to spontaneous fission (10 fission/s-kg), making it feasible to assemble a mass that is highly supercritical before a detonation chain reaction begins.

Moreover, Pu-239 and Pu-240 cannot be chemically distinguished, so expensive and difficult isotope separation would be necessary to separate them.

small percentage of plutonium-239 can be deliberately added to fresh nuclear fuel. Such fuel is called MOX (mixed oxide) fuel, as it contains a mixture of uranium oxide (UO_2) and plutonium oxide (PuO_2). The addition of plutonium-239 reduces or eliminates the need to enrich the uranium in the fuel.

Plutonium-gallium is used for stabilizing the δ phase of plutonium, avoiding the α-phase and α-δ related issues. Its main use is in pits of implosion nuclear weapons

reprocessing

The principle of spent fuel reprocessing generally adopted throughout the world is based on the separation of the different components by liquid/liquid extraction in tributyl phosphate (TBP) diluted in an alkane after the fuel has been dissolved in nitric acid.

The major steps in processing

1. **Receiving and storing** fuel prior to processing.

2. **Separating** the various components of used fuels and radioactive materials.

3. **Recovering** energy materials (uranium and plutonium) with a view to recycling them in the form of new fuels for the production of electricity.

4. **Waste conditioning**. Integrated in glass for safe, stable conditioning over the very long term, or compacted to reduce their volume **(???)**

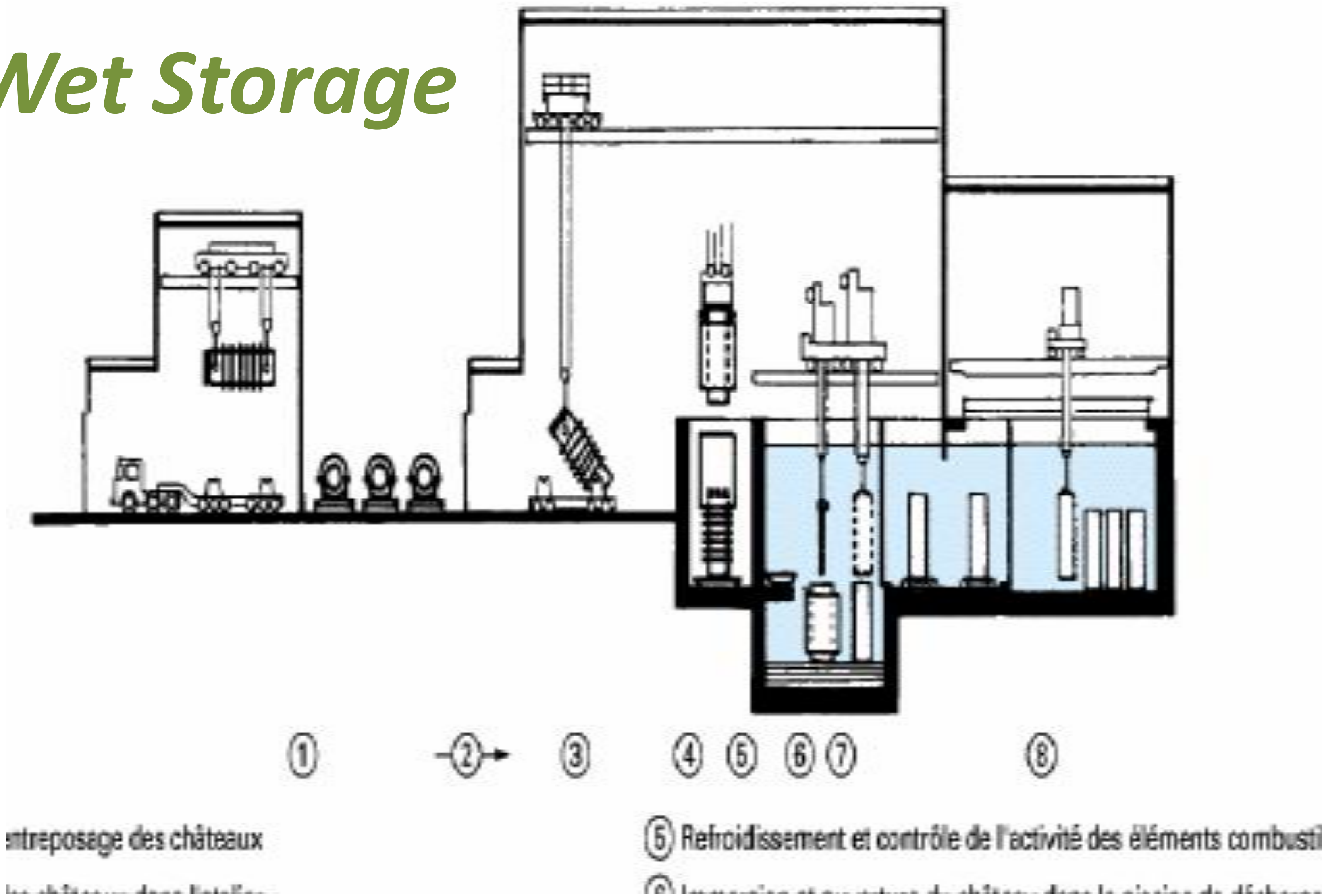
The safety of a reprocessing plant is based on:
• Design bases
• Operating procedures

A reprocessing plant is very different from a power reactor in terms of nuclear and industrial safety:
• No high temperatures
• No high pressure
• Static processes with long time constants

There are two predominant safety features:
Containment
Cooling


15
13

Wet Storage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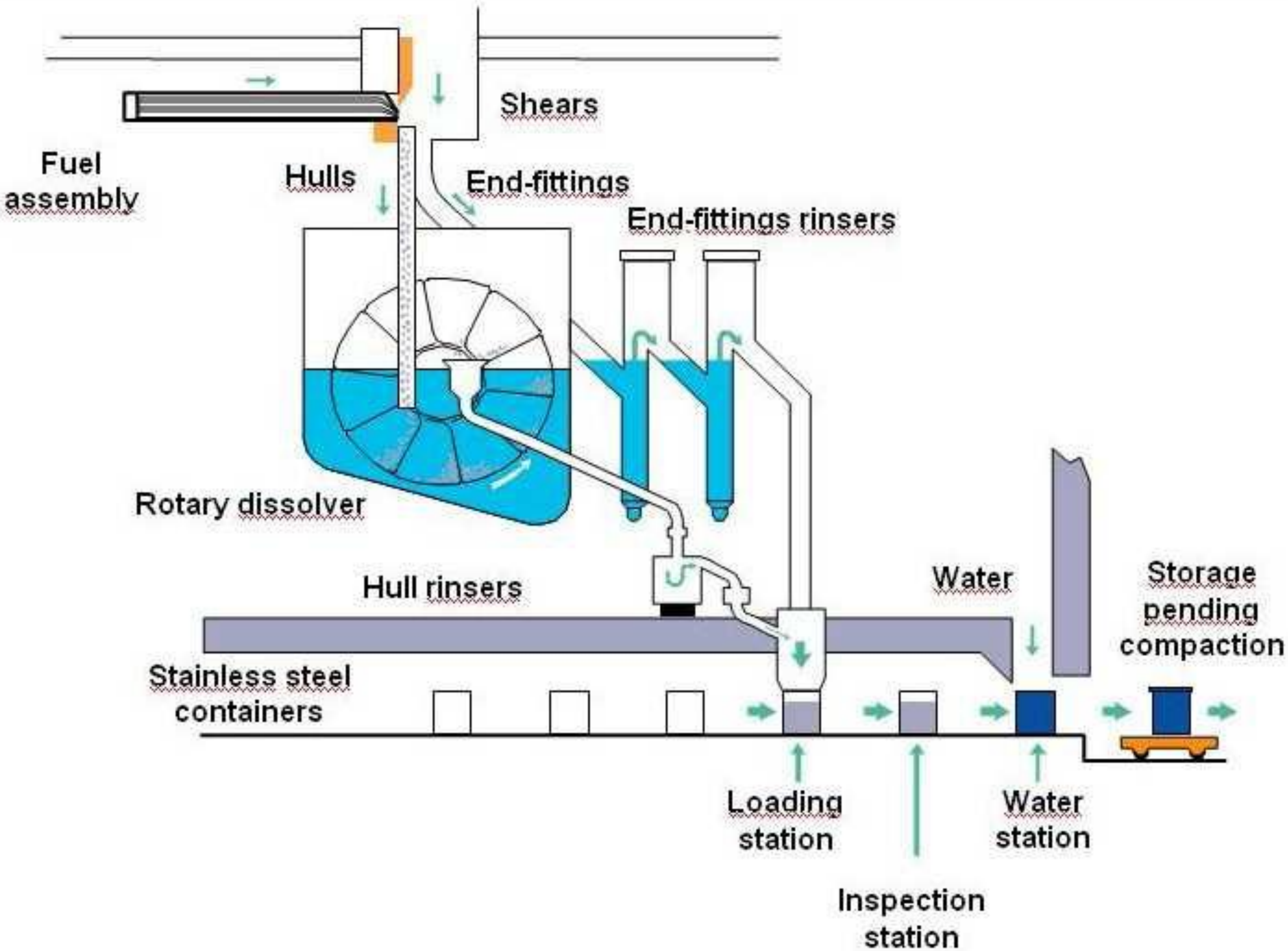
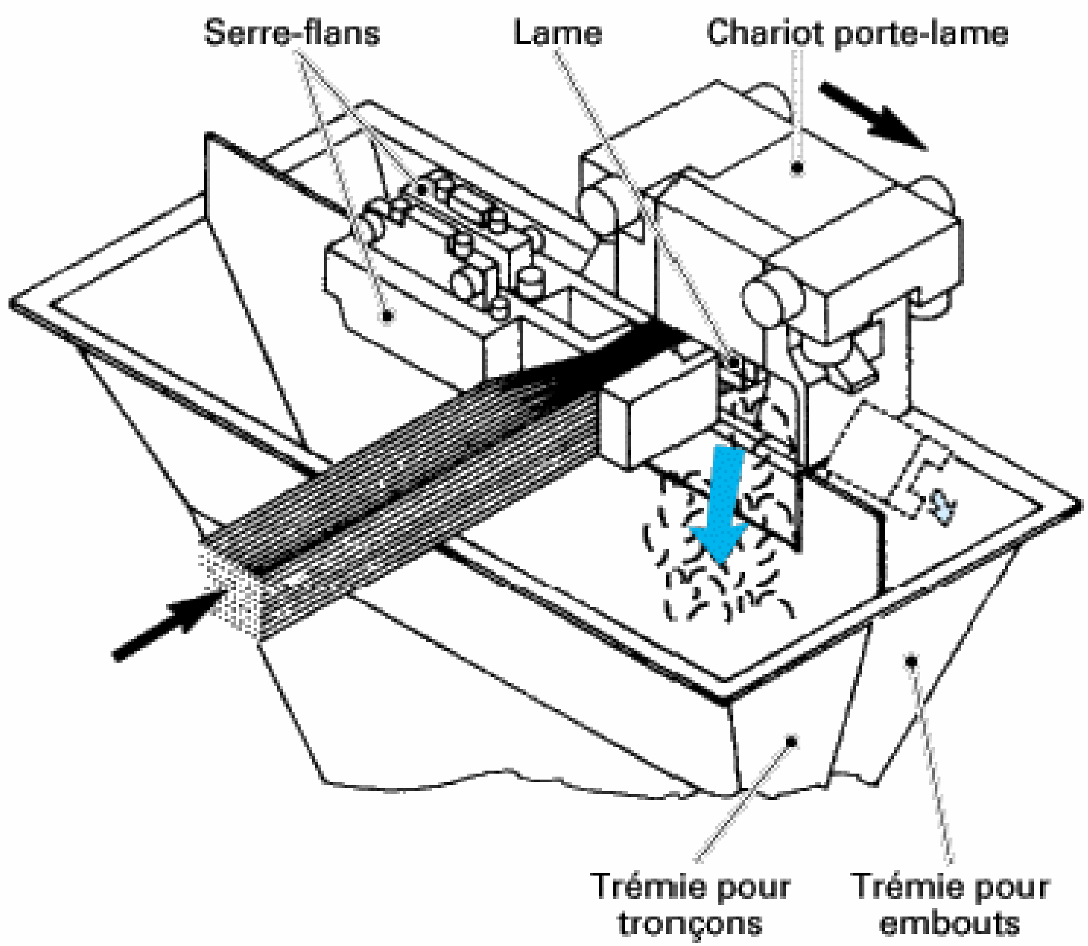
ntreposage des châteaux
5 Refroidissement et contrôle de l'activité des éléments combustib

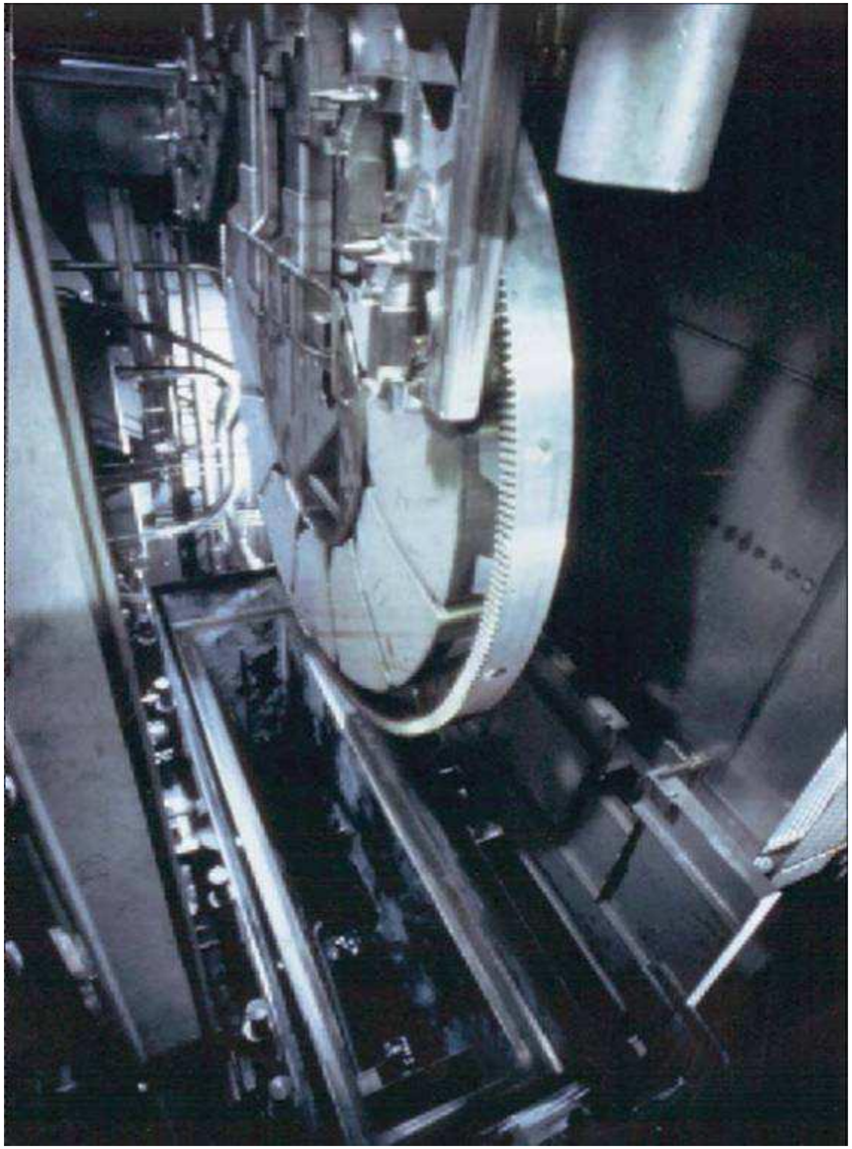


Shears
Fuel
assembly
Hulls
End-fittings
End-fittings rinsers
Rotary dissolver
Hull rinsers
Water
Storage
pending
compaction
Stainless steel
containers
Loading
station
Water
station
Inspection
station

Shearing – closer look

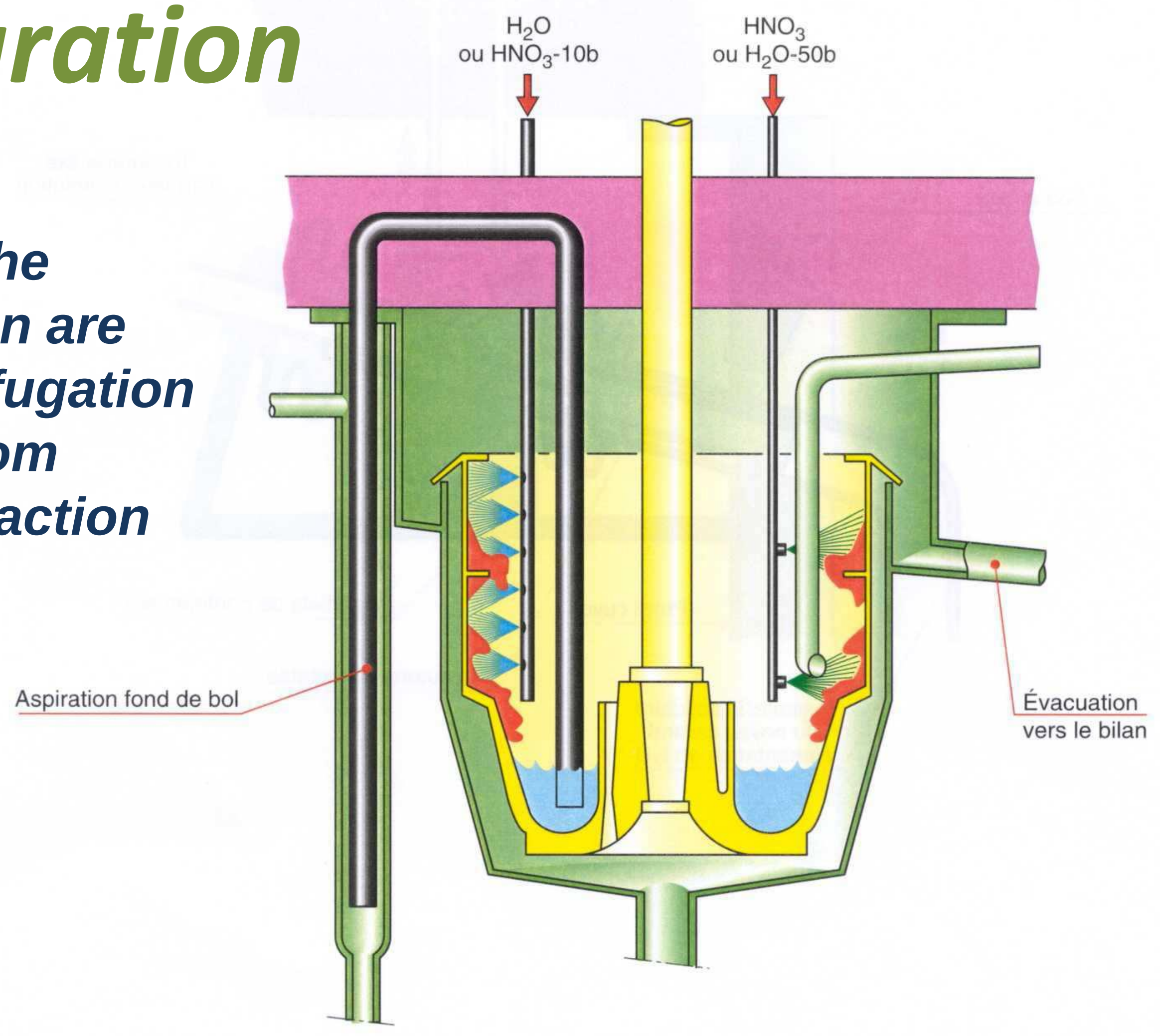


Rotary Dissolver

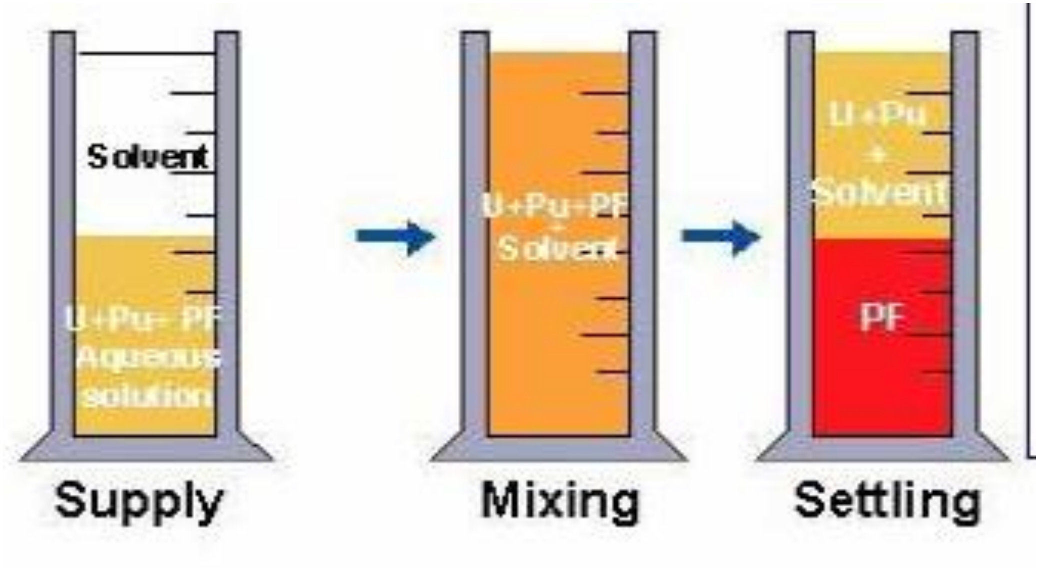


Solid Separation

Solids present in the dissolution solution are removed by centrifugation to prevent them from disturbing the extraction operations

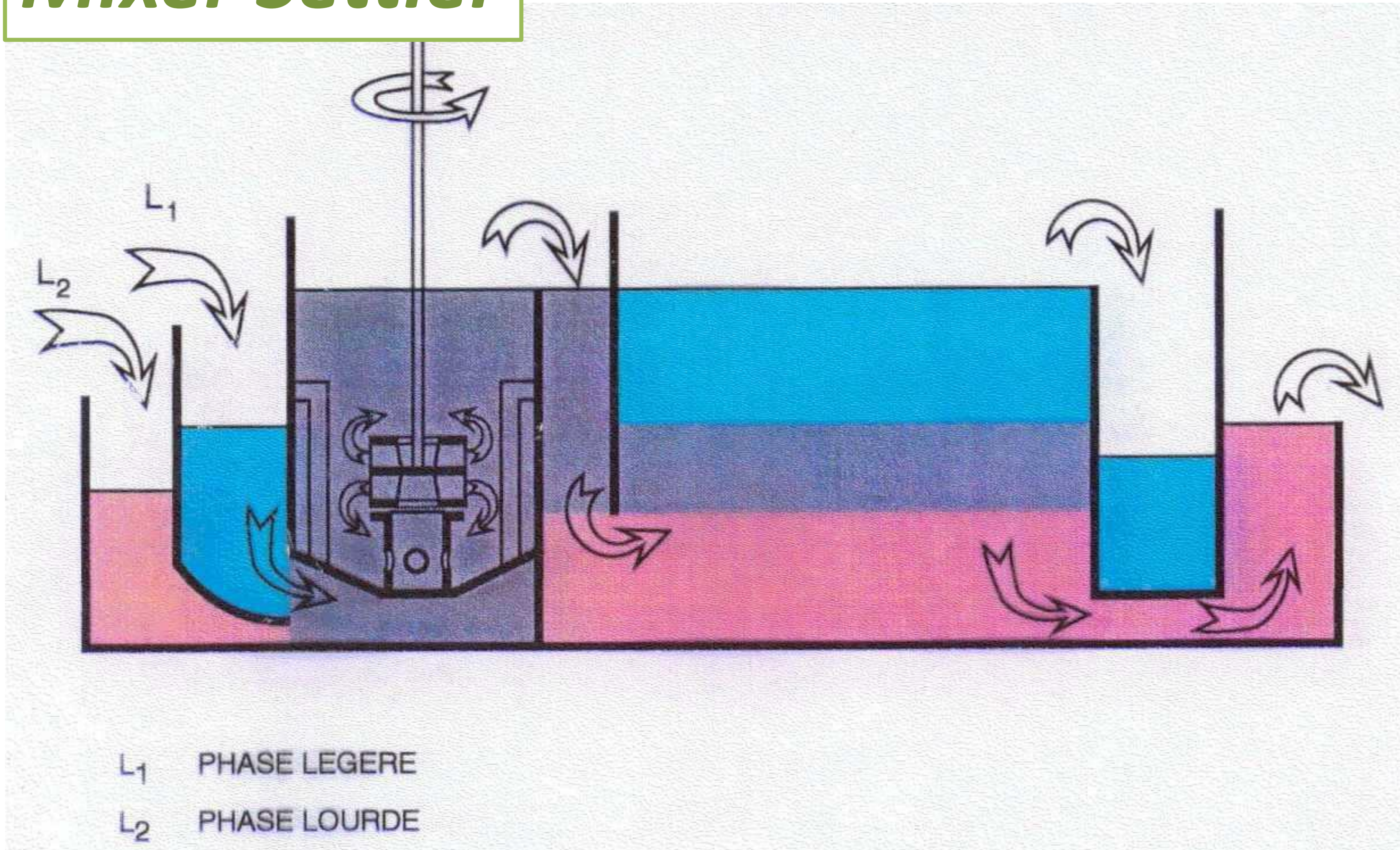


Extraction

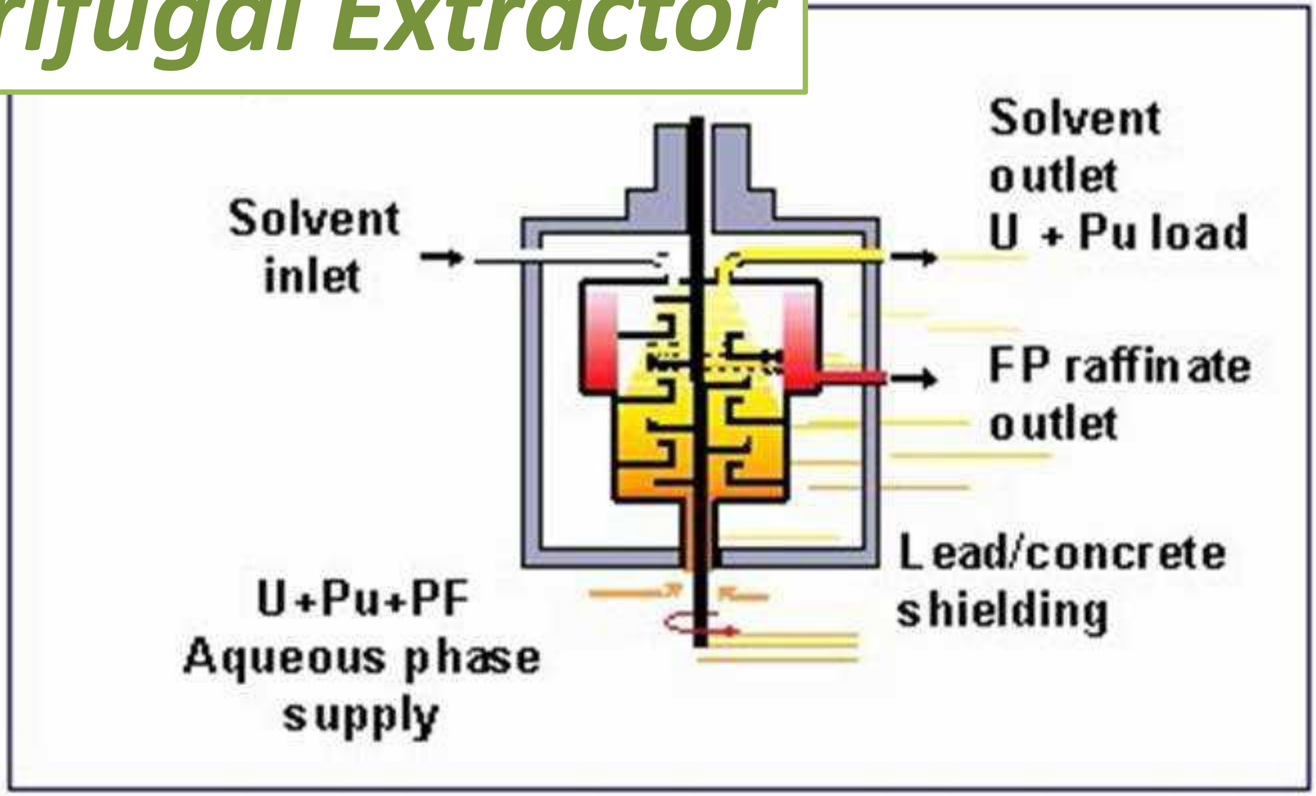


Extraction : transferring a solute from a liquid phase to another liquid phase not miscible with the first

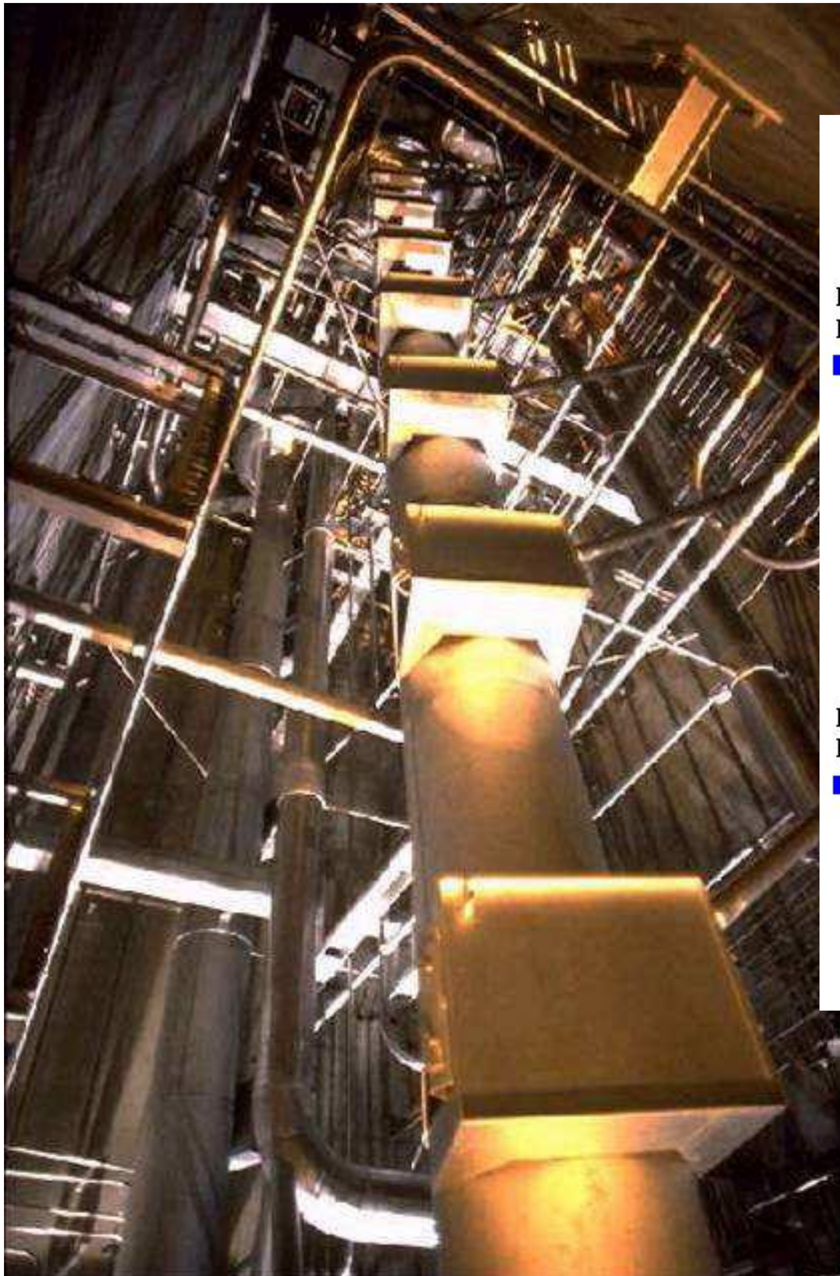
Mixer Settler

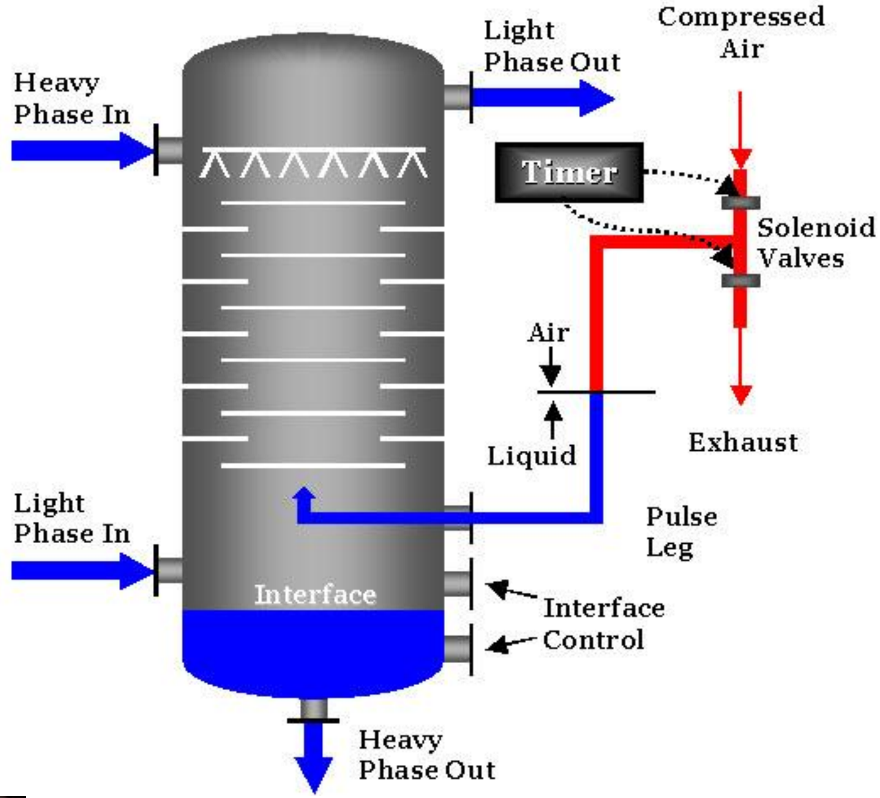


Centrifugal Extractor

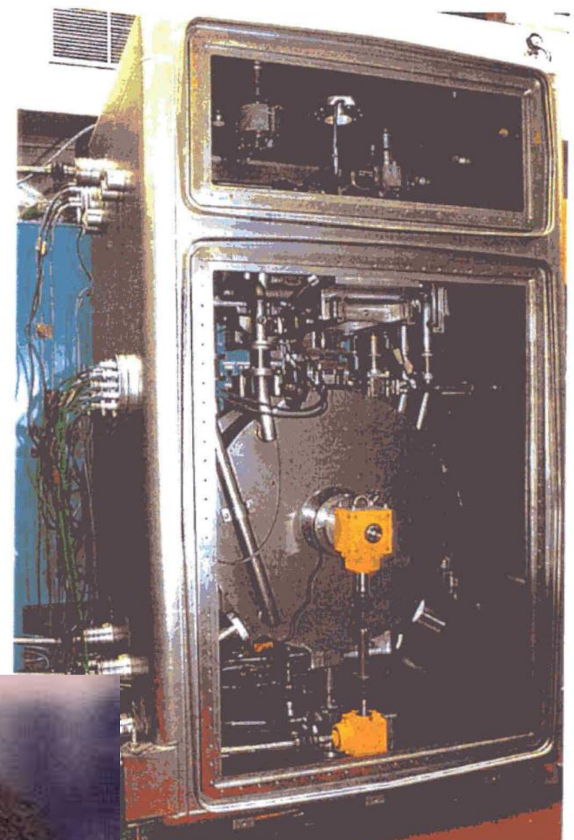


Pulsed Column





Chemical purification and Pu Oxide production



World reprocessing capacities

CAPACITIES IN OPERATION

Country	Location	Capacity (T/year)	Fuel	Commissioning
France	Marcoule, UP1	**800 to 1000**	**metal**	**1958** (stopped in 1997)
	La Hague, UP2	800 400	Metal Oxide	1967 (stopped) 1976 (stopped in 2002)
	La Hague, UP2-800	800	oxide + MOx	1994
	La Hague, UP3	800	oxide	1990
United Kingdom	Sellafield	1500 to 2000	metal	1964
	Sellafield Thorp	700-1200	oxide	1994
Germany	WAK	35	oxide	1970 (stopped in 1991)

Country	Location	Capacity (T/year)	Fuel	Commissioning
Japan	Tokai-Mura	140	oxide	1977
India	Trombay	100	heavy water or oxide	1975
	Tarapur	100		1977
Russia	Cheliabinsk	400	oxide	1976

CAPACITIES UNDER CONSTRUCTION OR TESTS

Country	Location	Capacity (T/year)	Fuel	Commissioning
Japan	**800**	**800**	oxide	2006
Russia	RT2 Krasnoyarsk	800	oxide	

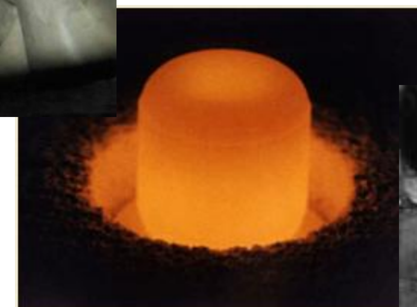
PLANT CANCELED

Country	Location	Capacity (T/year)	Fuel	Commissioning
Germany	Wackersdorf	350	oxide	

Proliferation aspects

knowledge

material



Glowing plutonium ingot. Source: DOE.

equipment