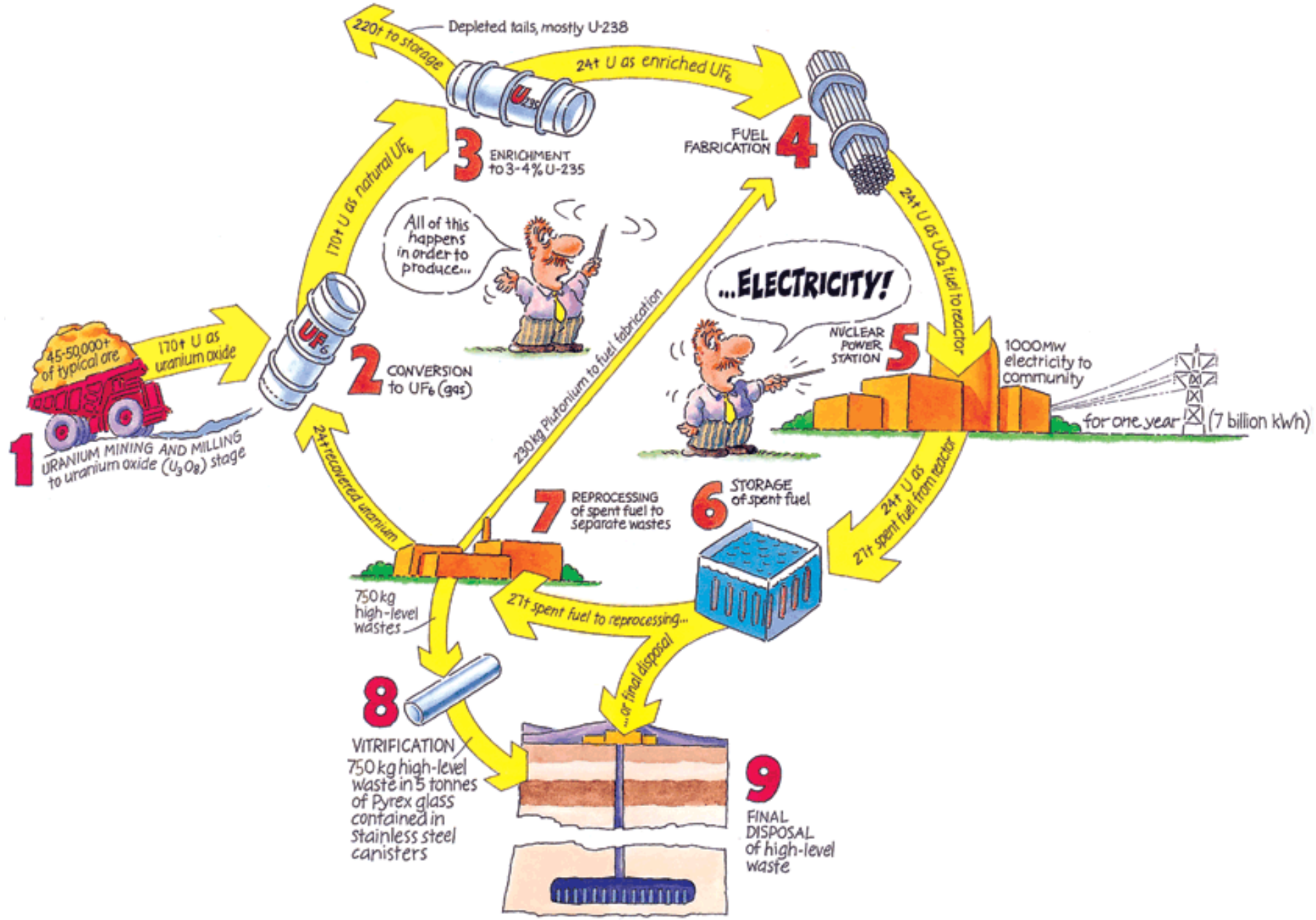
The Nuclear Fuel Cycle

Mary Lou Dunzik-Gougar, PhD

ANS Teachers' Workshop

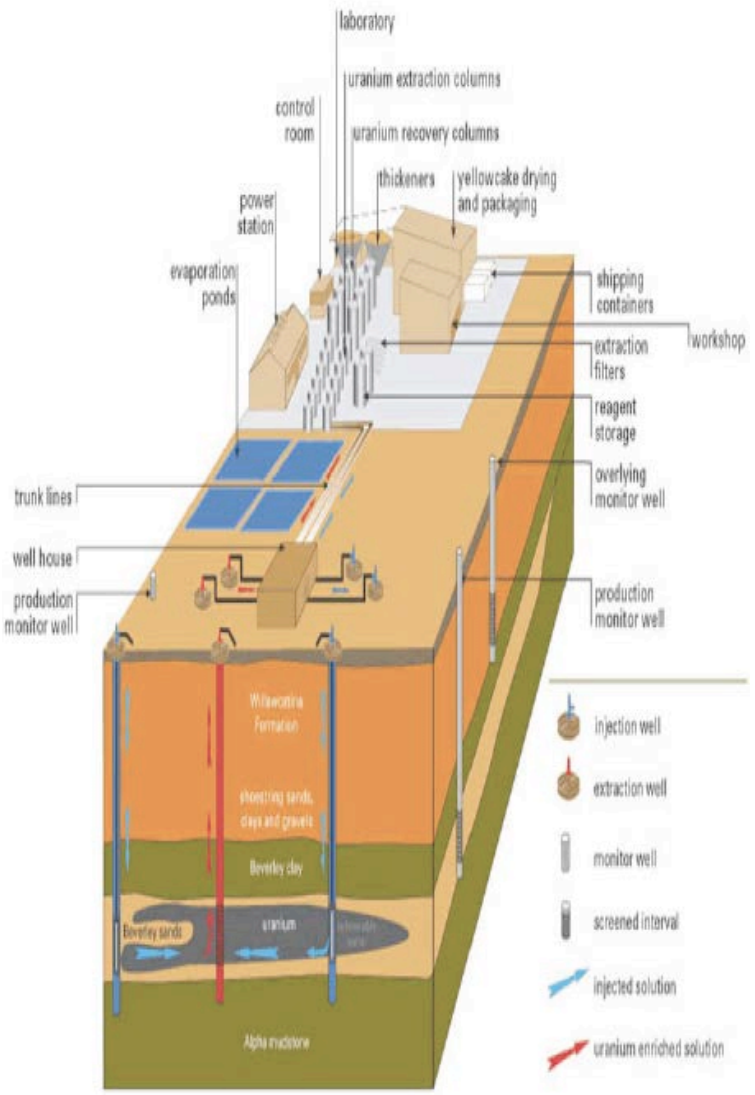
2012


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

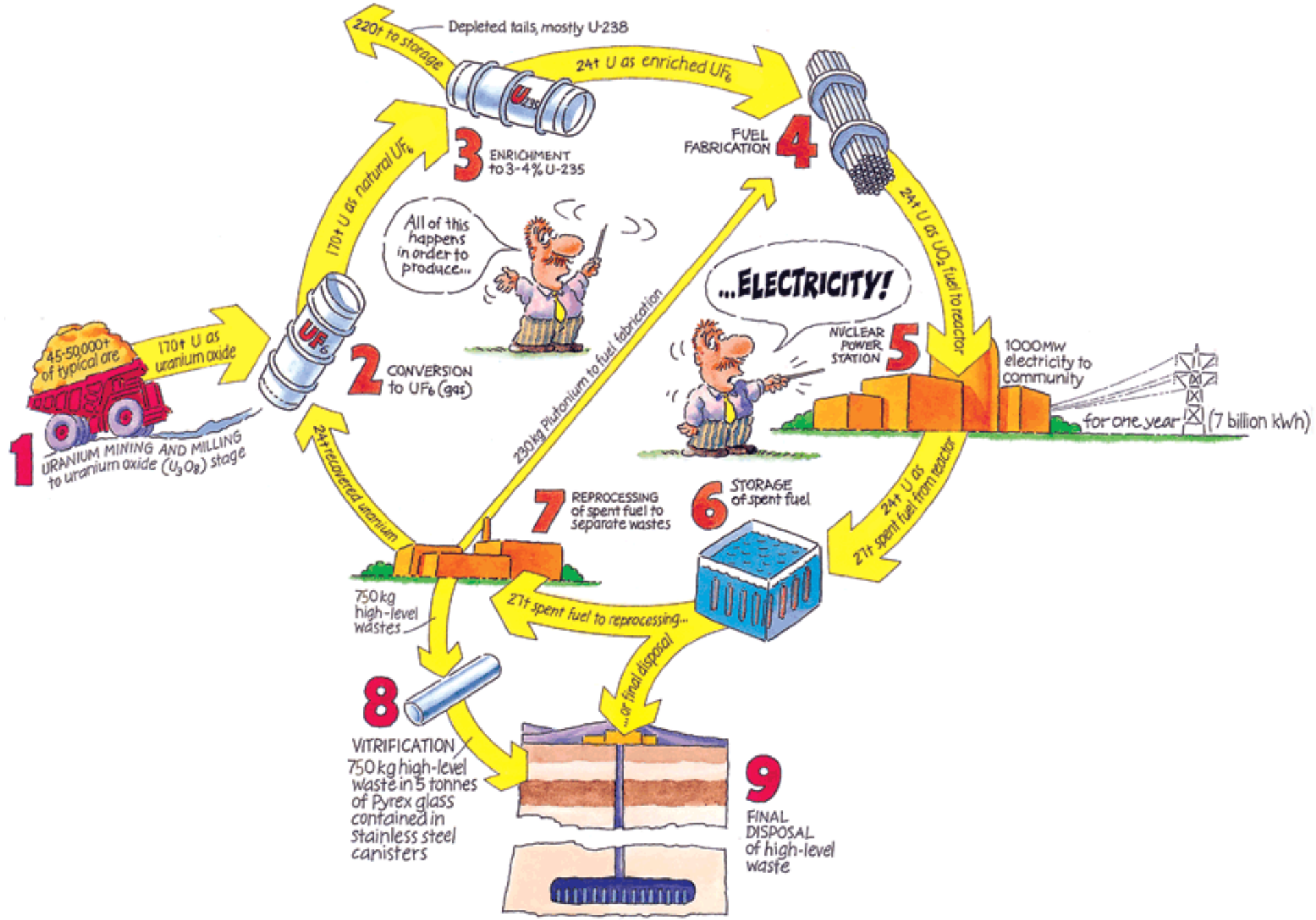
Uranium Mining

Open pit (strip) mining

Underground mining



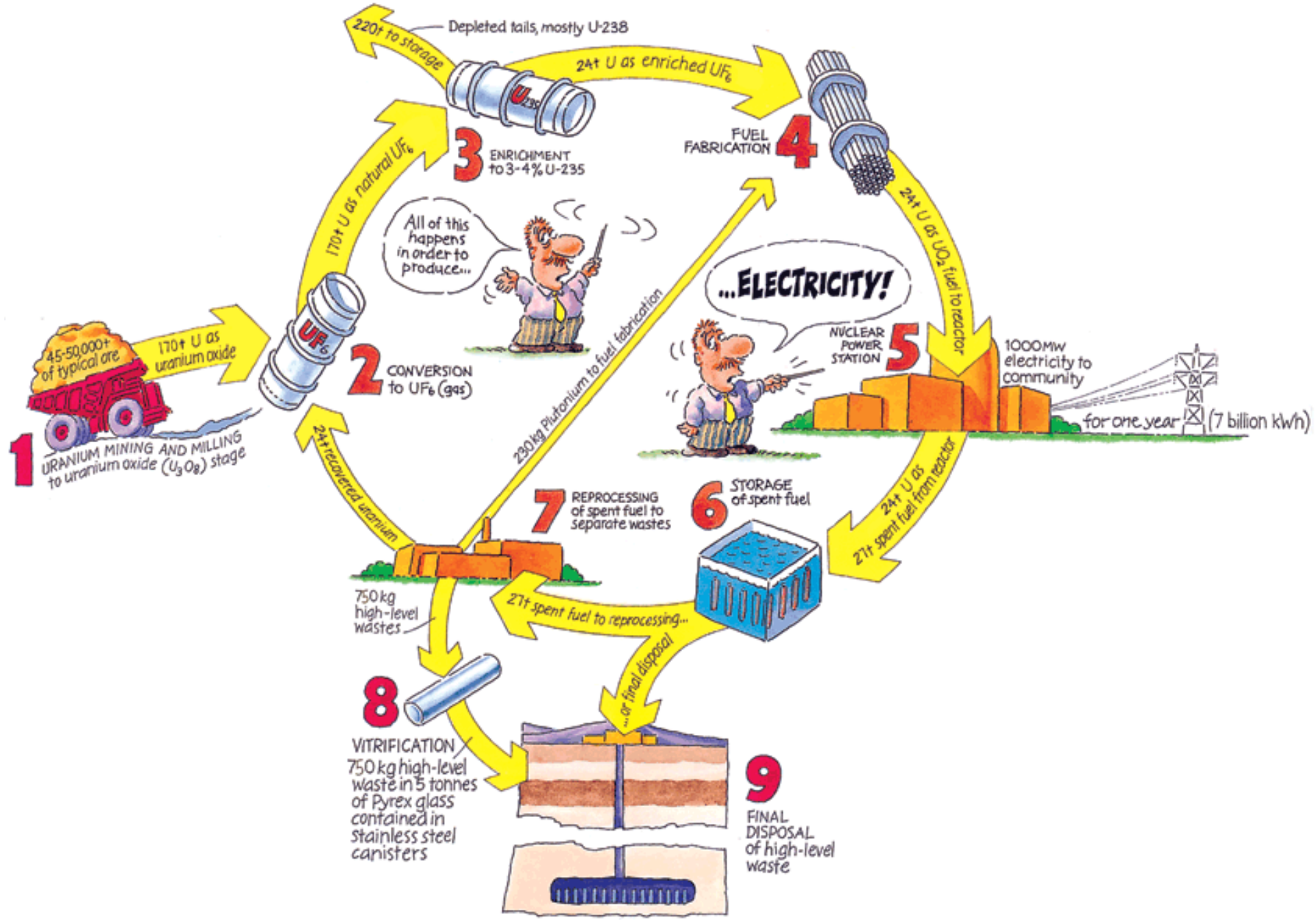
In situ leaching


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

Uranium Milling

- Ore is crushed
- Uranium is separated

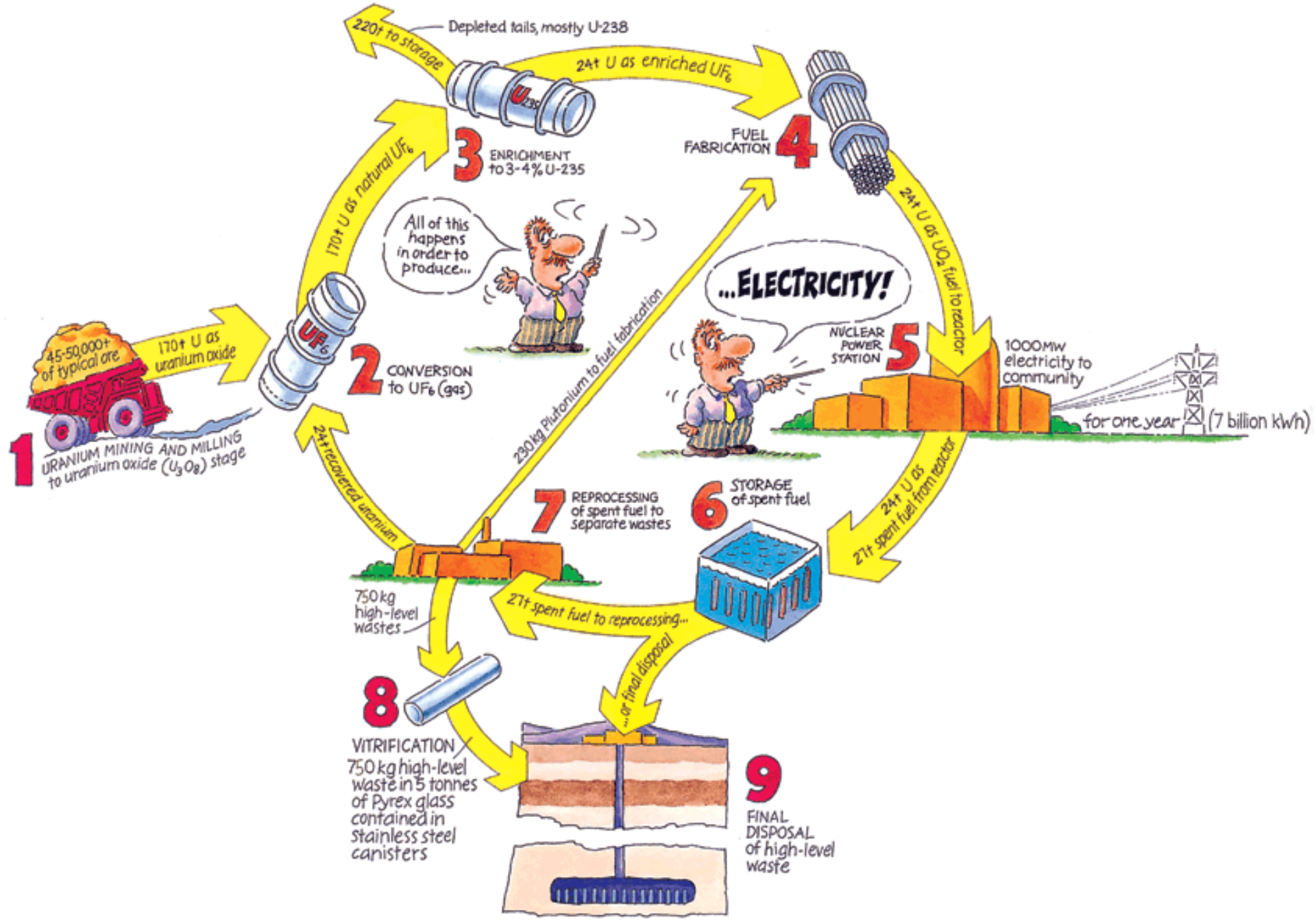
- U_3O_8 “yellow cake” produced


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

Uranium Conversion (to UF_6 gas)

- Impurities removed
- Uranium combined with fluorine
- UF_6 gas produced
  - Gaseous form facilitates enrichment

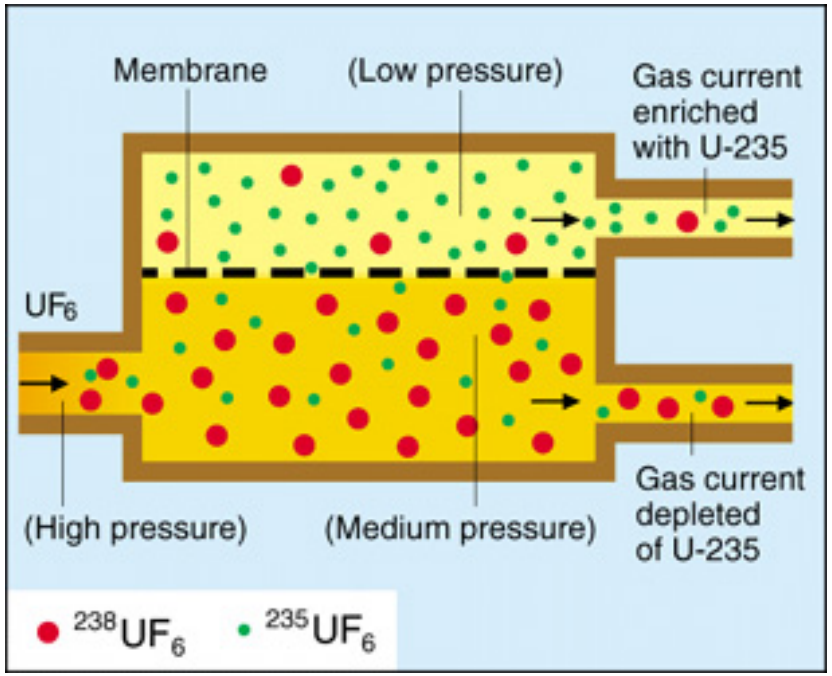

UF6 containers


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

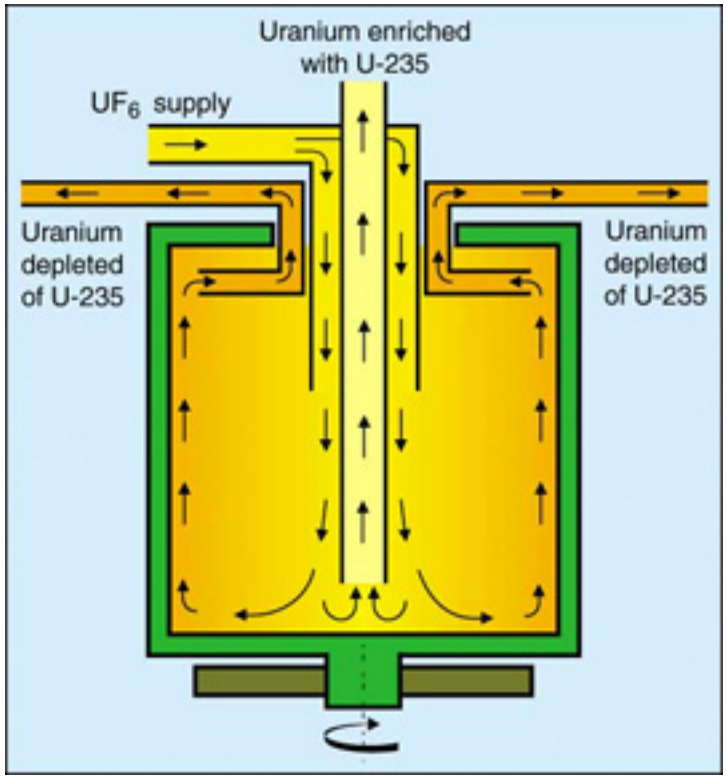
U Enrichment

- Natural U is > 99% ^{238}U and only ~ 0.7% ^{235}U

- Separation of $^{235}UF_6$ and $^{238}UF_6$ based on (very small) mass difference

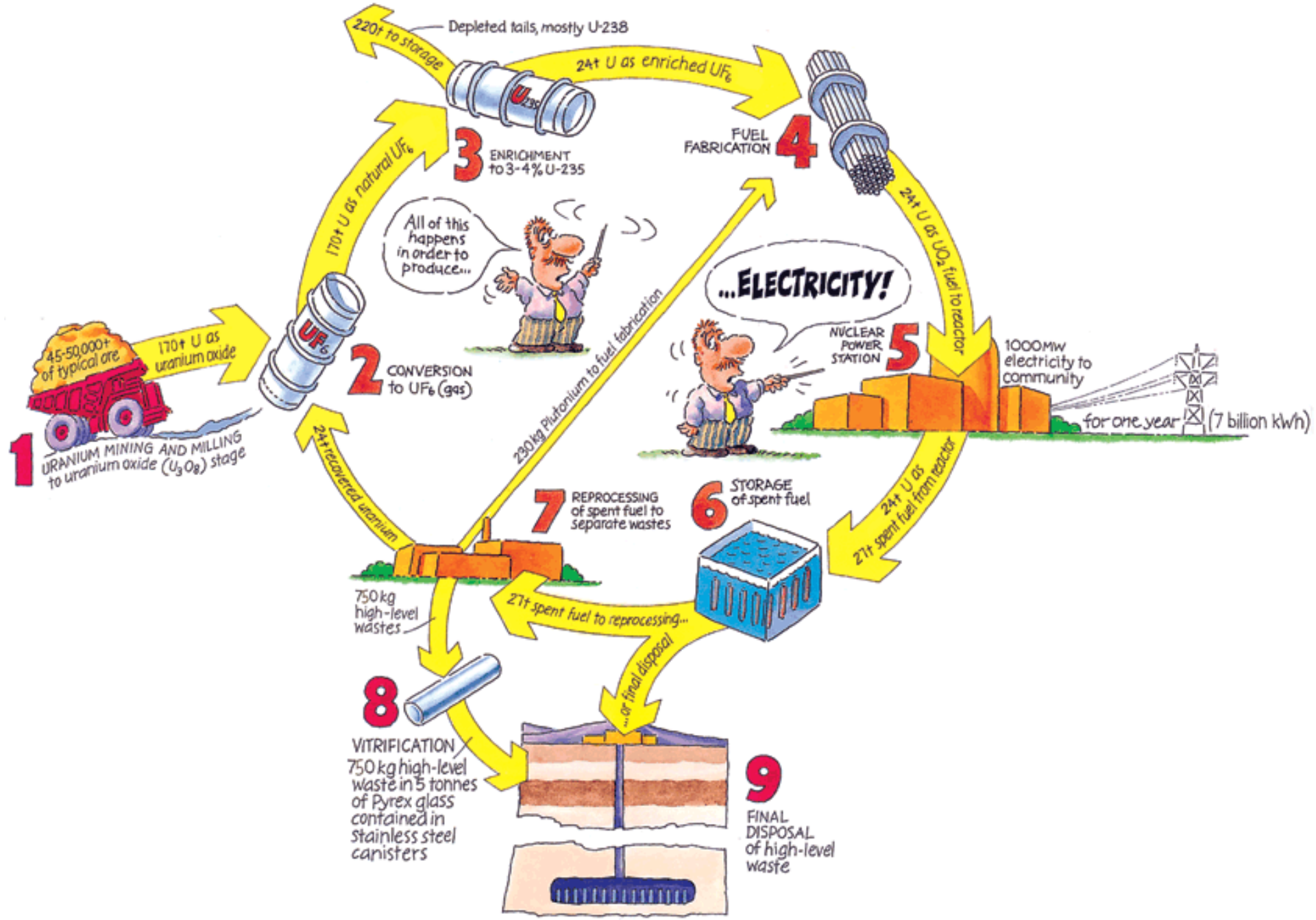


Diffusion



Centrifugation

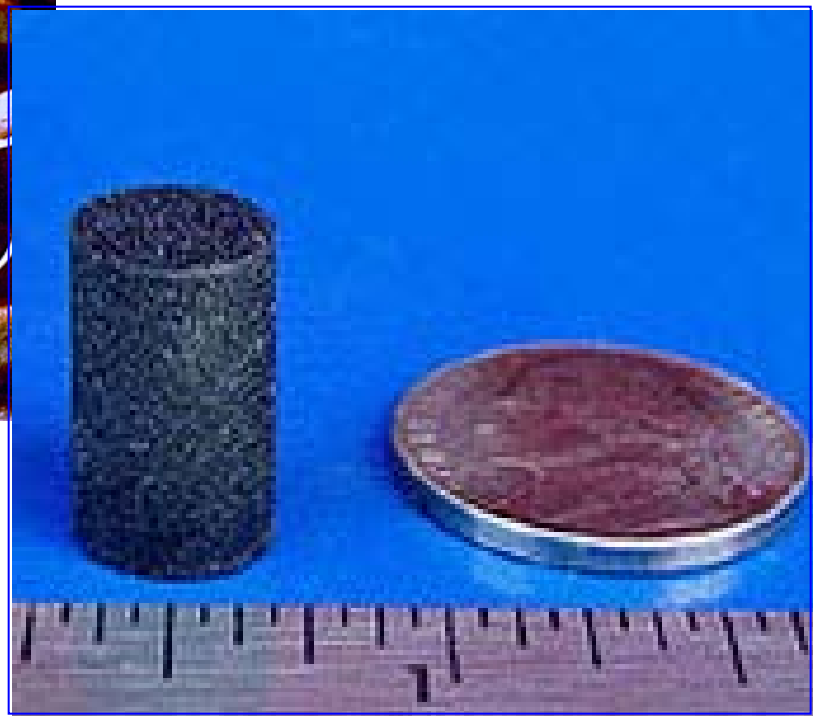
- UF_6 enriched from 0.7% ^{235}U to 3%-5% ^{235}U


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

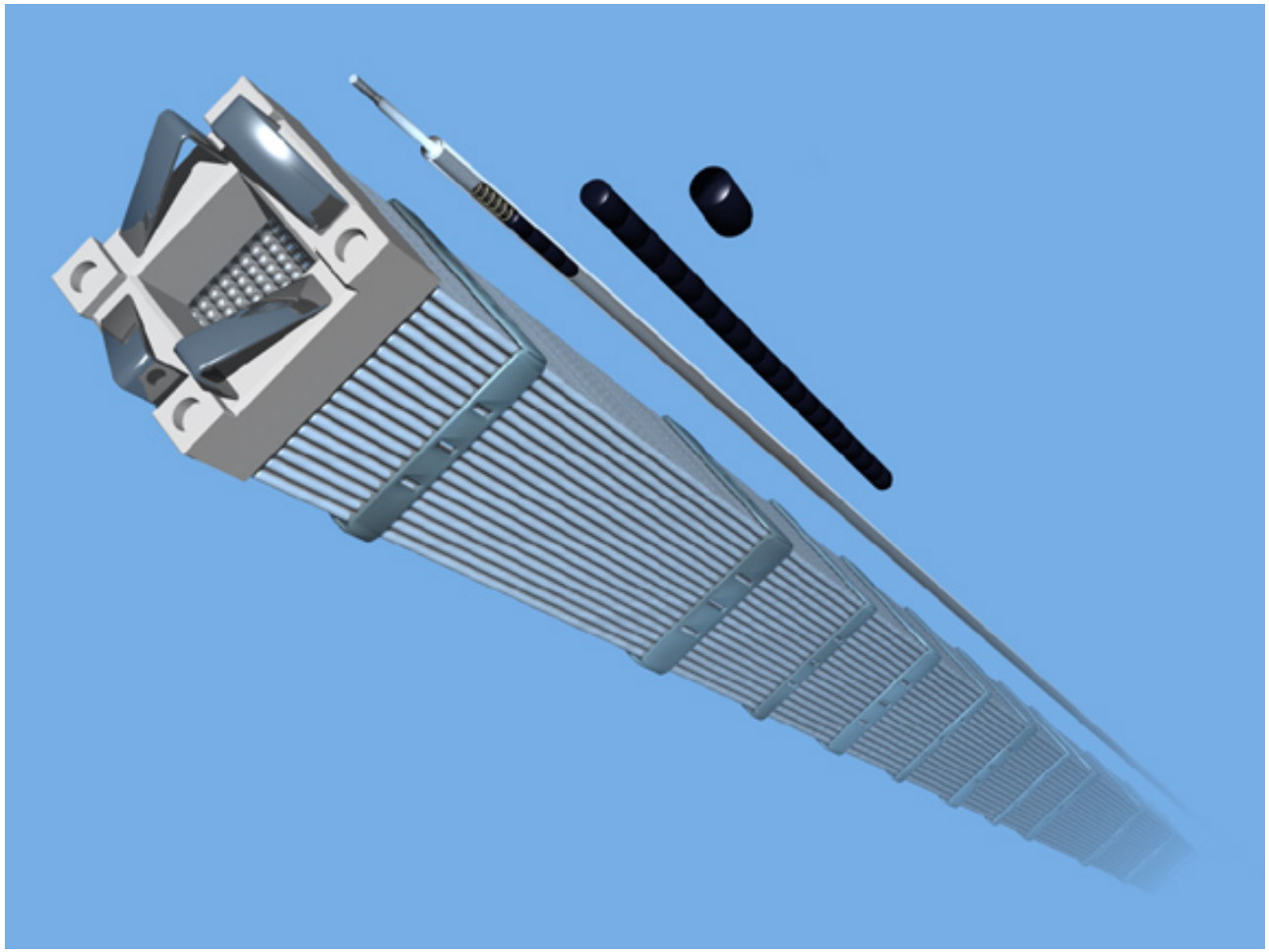
Fuel Fabrication

Enriched UF_6 gas converted to uranium oxide (UO_2) solid

Uranium Oxide Ceramic Fuel Pellets

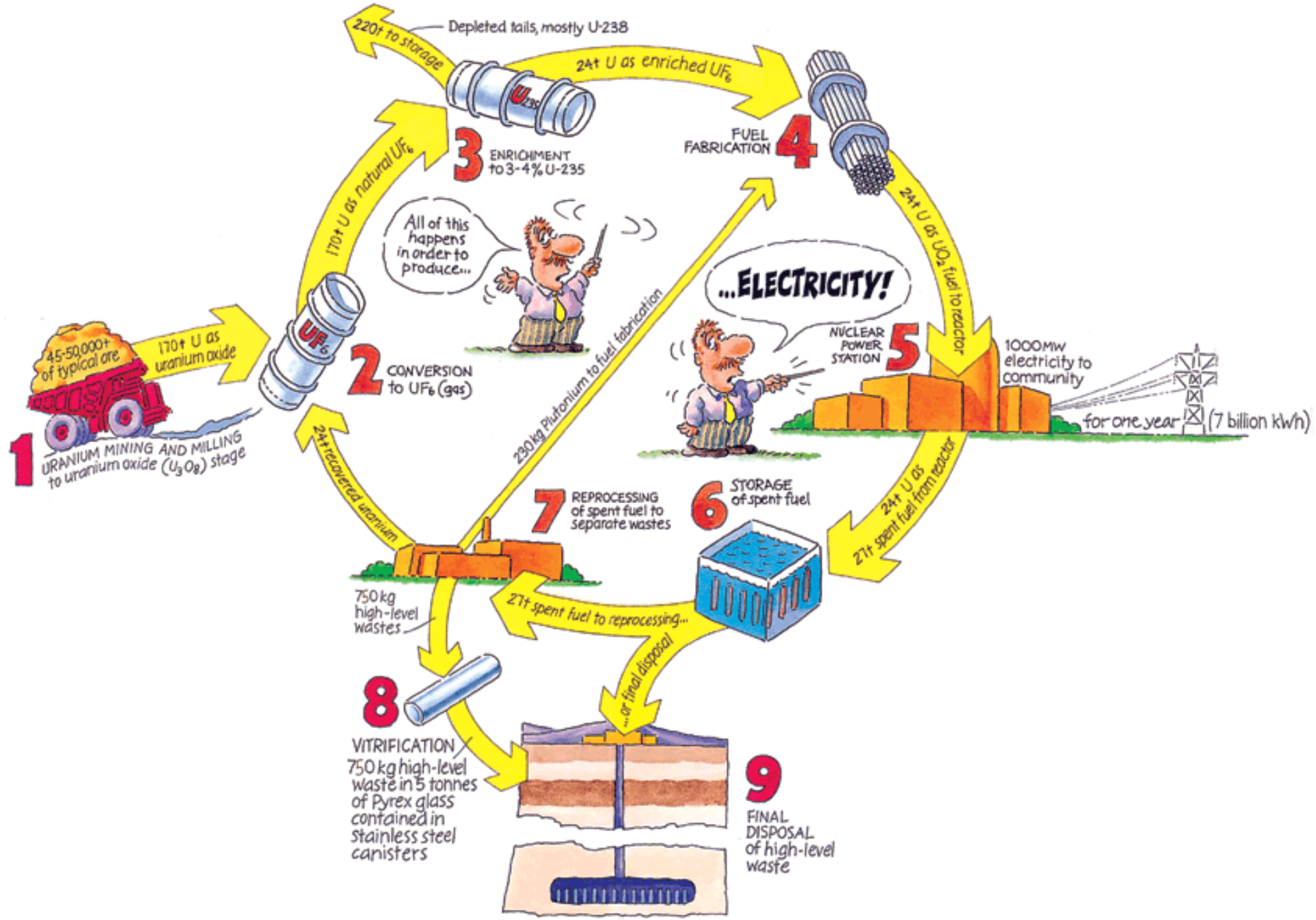


Fuel rods filled with **ceramic pellets** are grouped into **fuel assemblies**



Fuel Fabrication

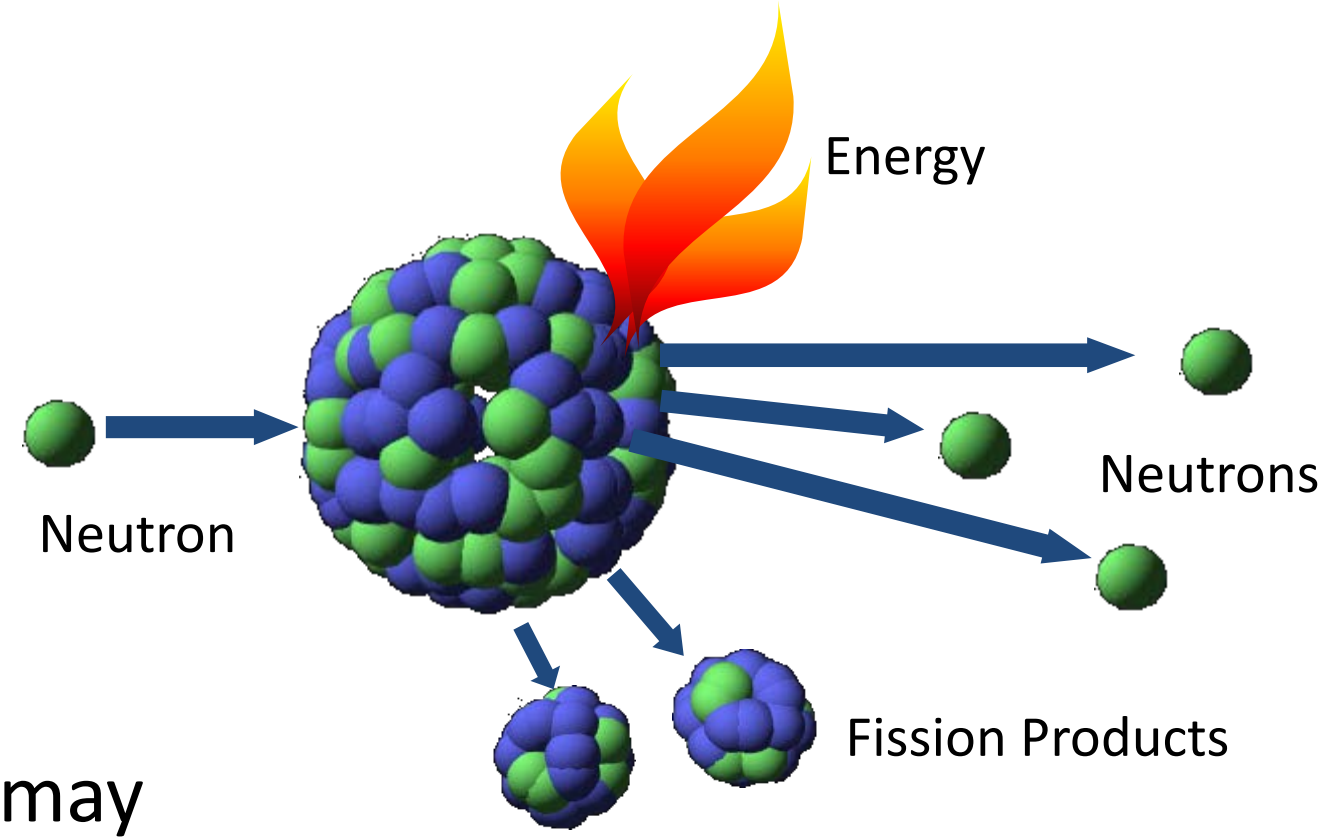
A pressurized water reactor fuel assembly


Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

Reactors

Diablo Canyon nuclear power plant in the U.S.

In the reactor, ^{235}U fissions to produce . . .

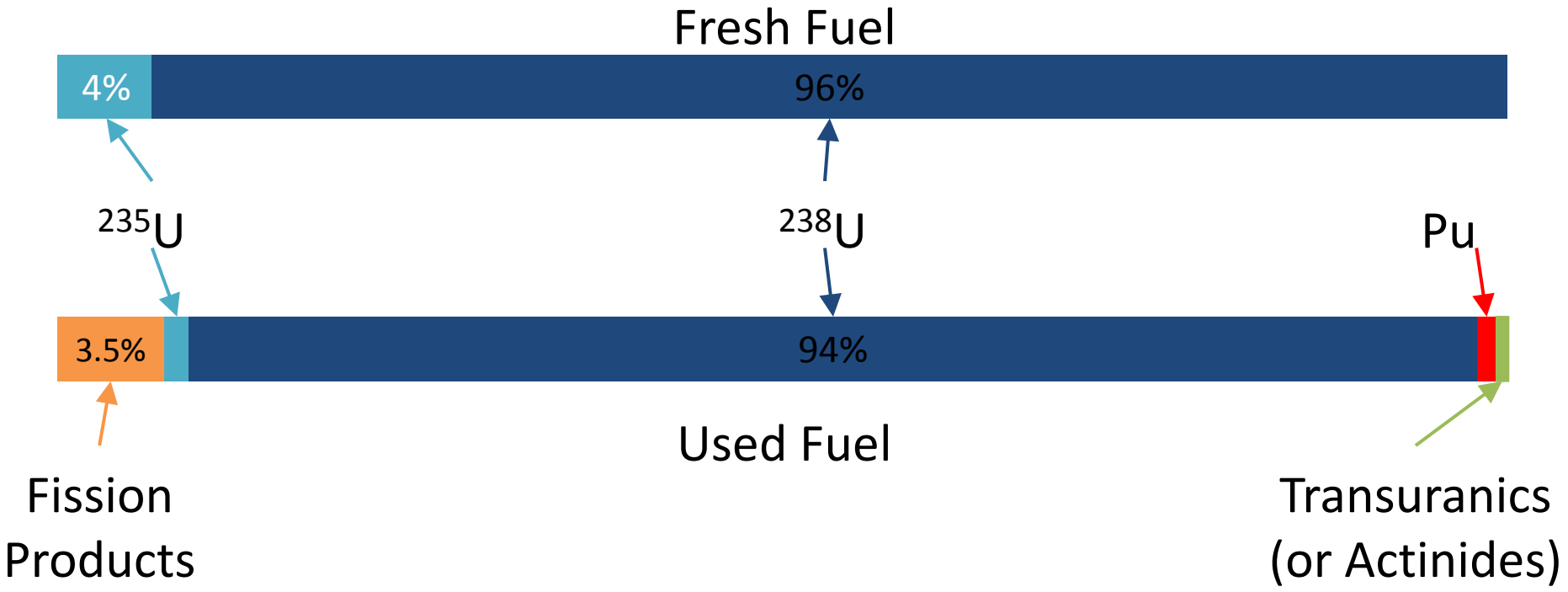


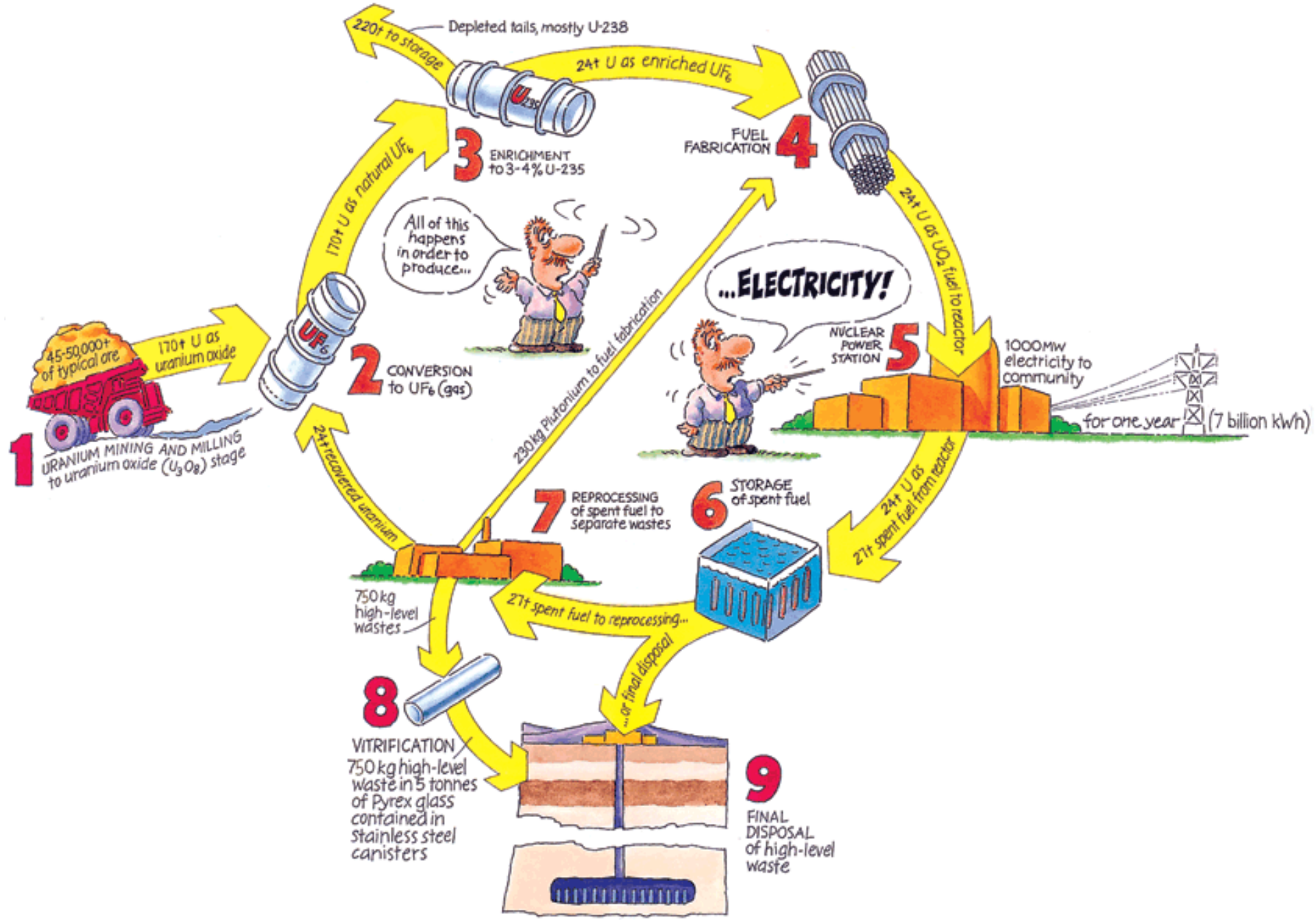
Neutrons may

- Cause new fissions to occur
- Be absorbed to form unstable, radioactive nuclide

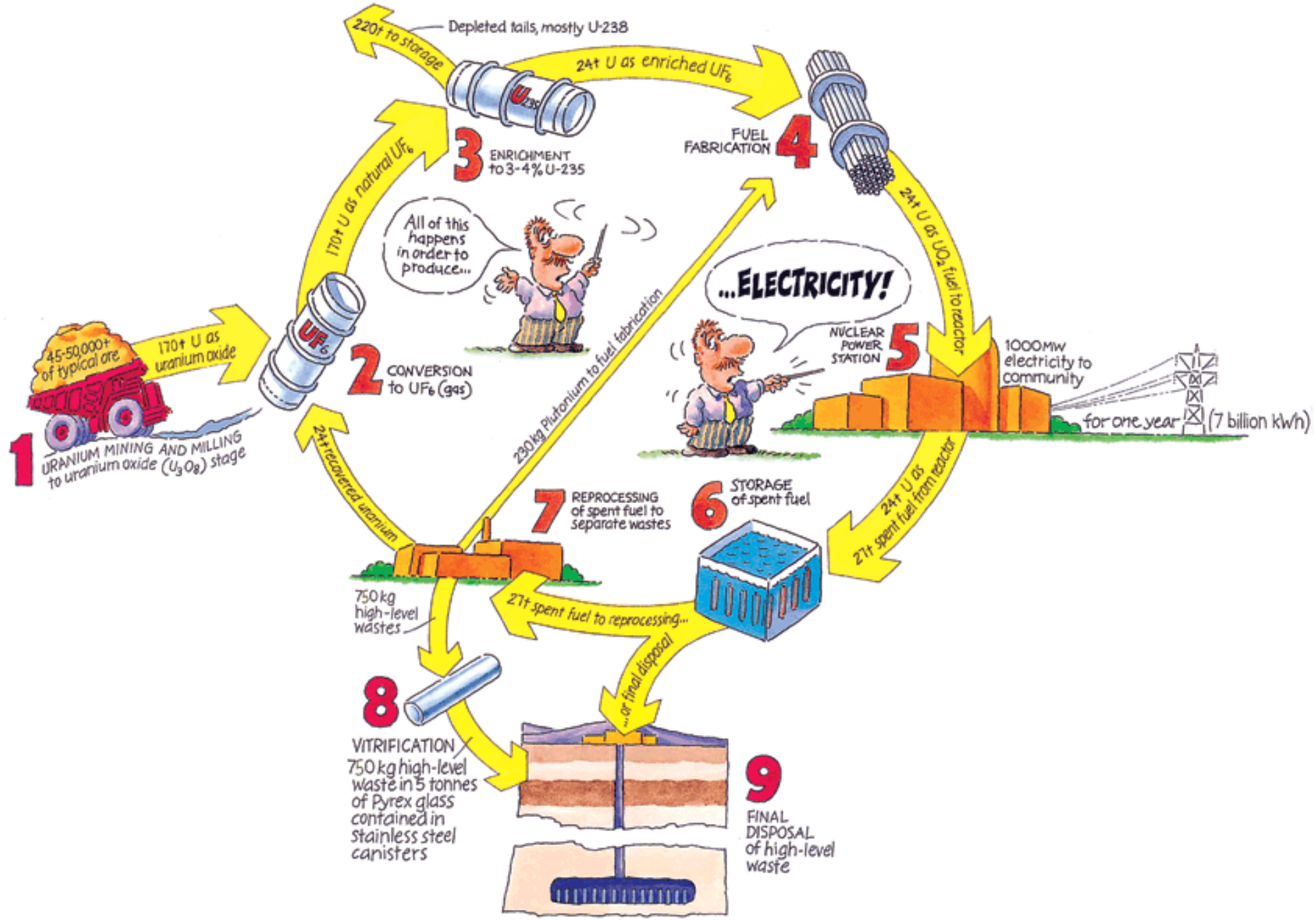
Fuel Consumption in the Reactor

- Fuel is in reactor for 4 – 6 years
- U consumed, fission products and transuranics (mostly Pu) produced

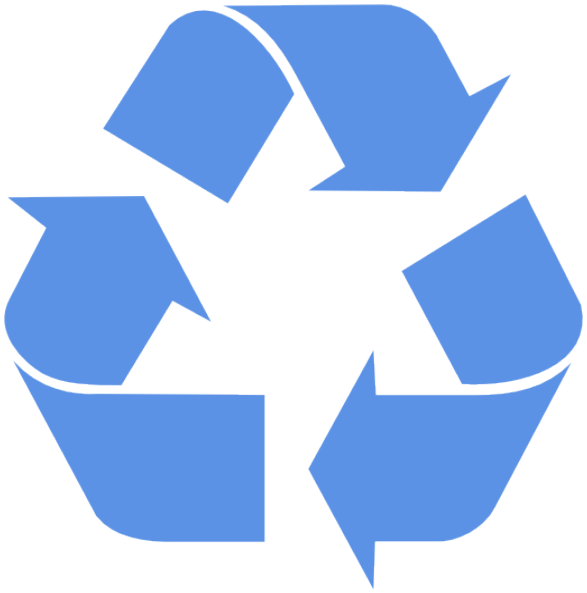


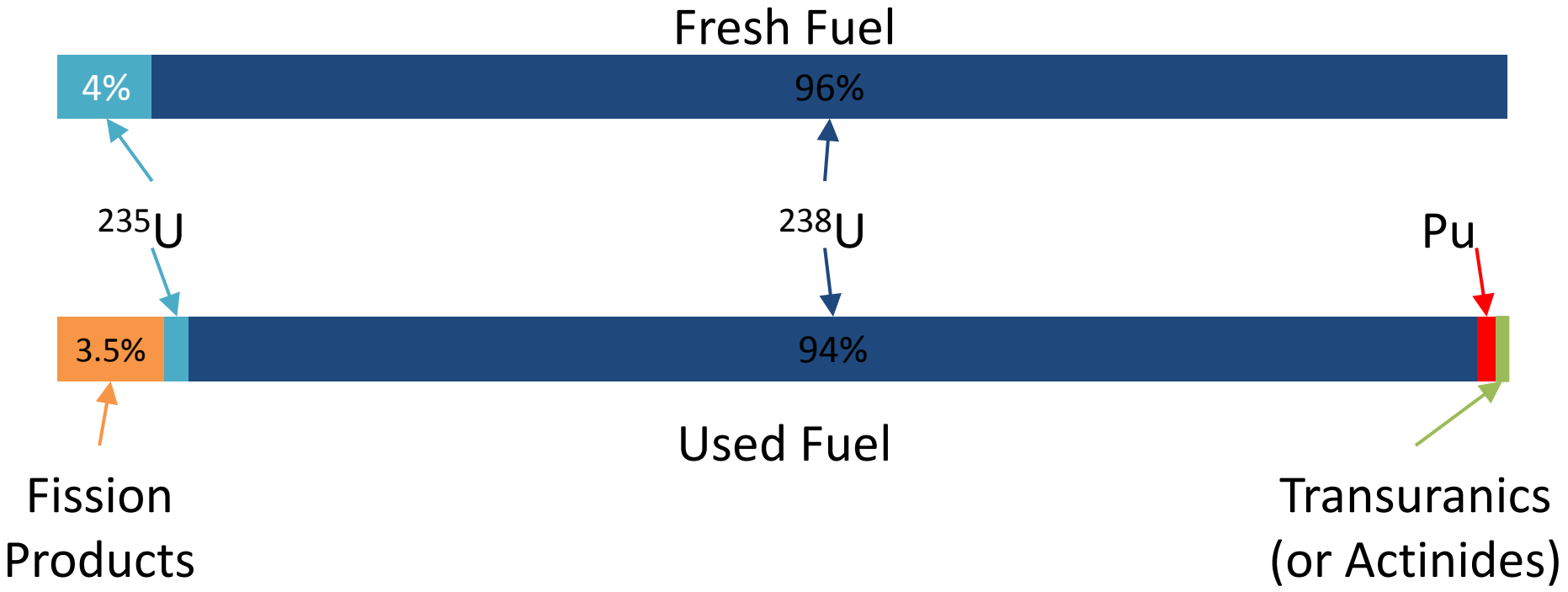

Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

- Used fuel first stored in pool at least 5 years
  - o Cooling and shielding
- Older fuel can move to dry casks
  - o Air cools
  - o Steel and concrete shields

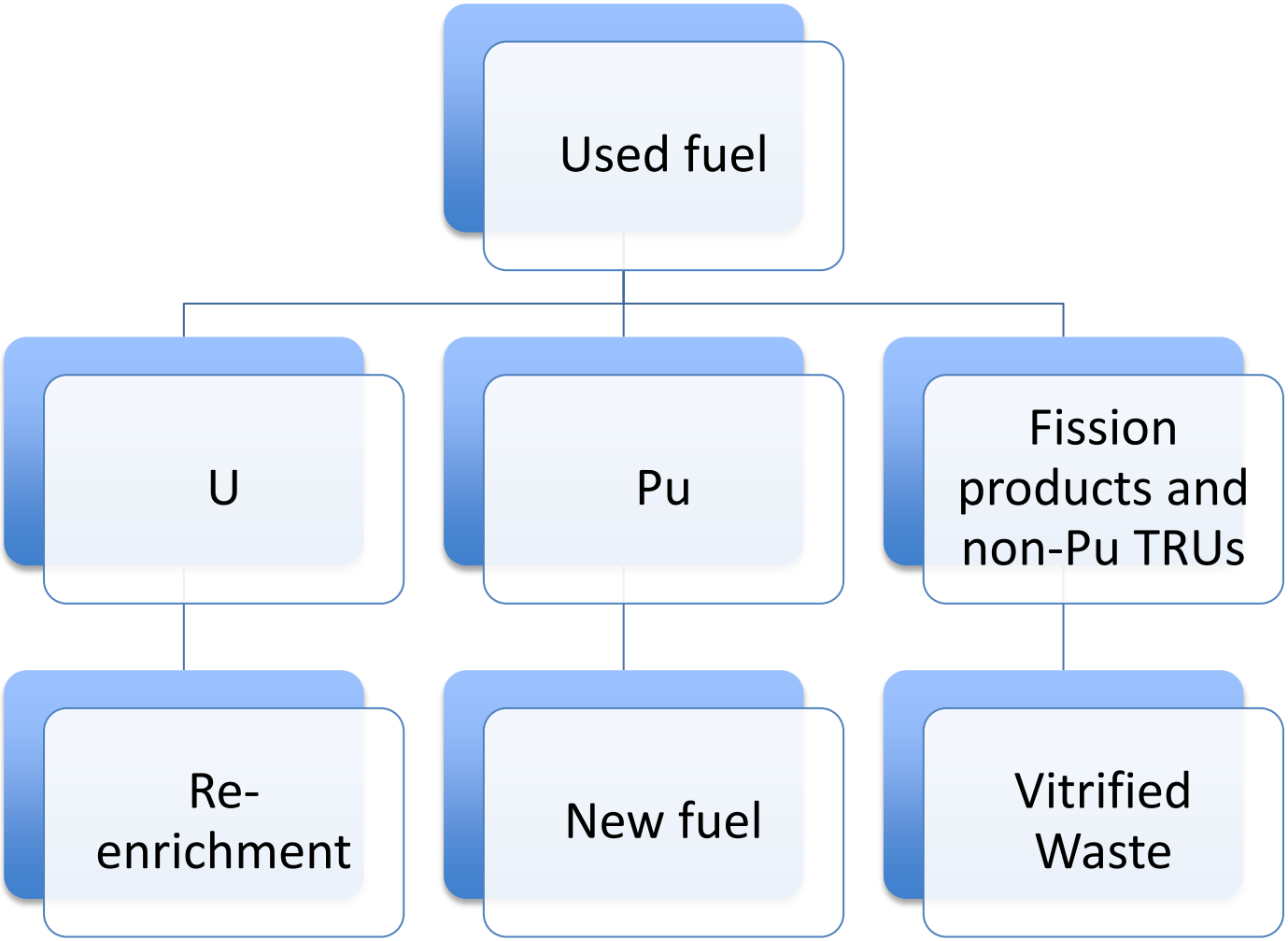

Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

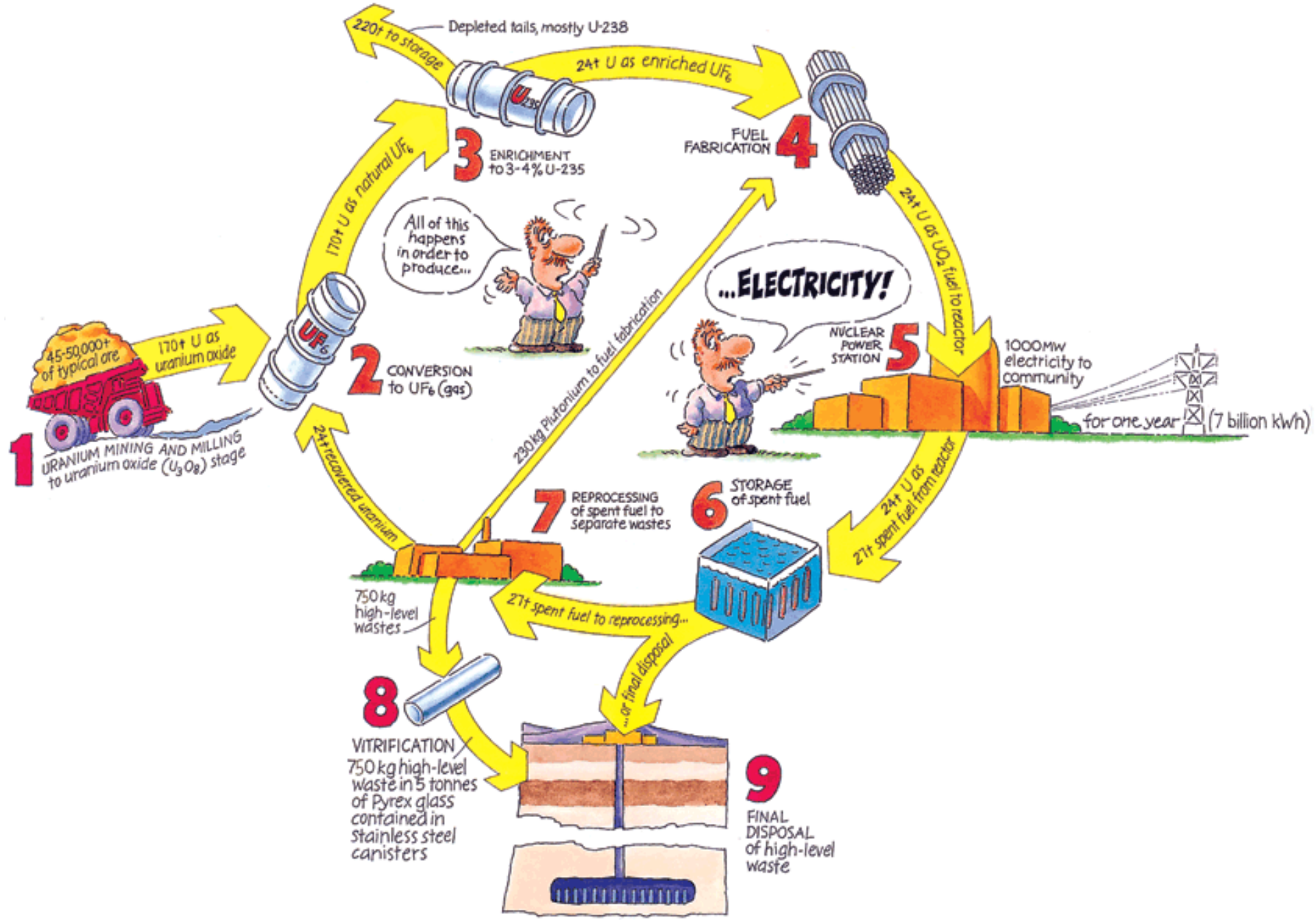
Fuel recycle/reprocessing



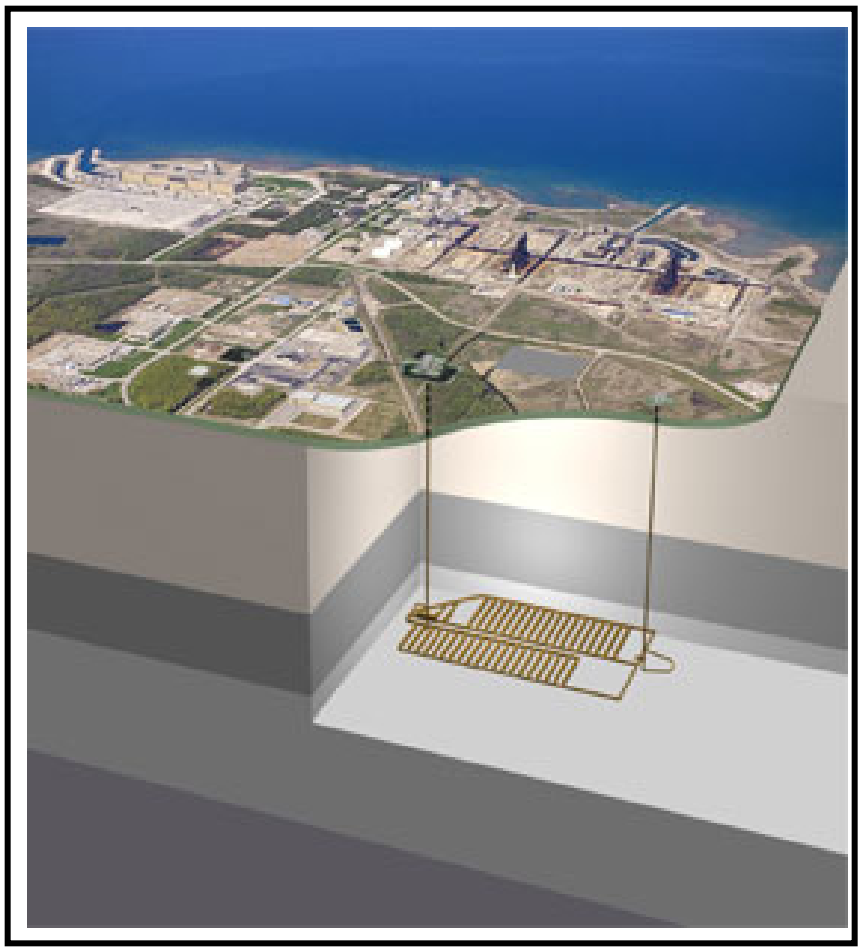


Fuel recycle/reprocessing




Depleted tails, mostly U-238
220t to storage
24t U as enriched UF_6
3 ENRICHMENT to 3-4% U-235
FUEL FABRICATION 4
170t U as natural UF_6
All of this happens in order to produce...
...ELECTRICITY!
24t U as UO_2 fuel to reactor
45-50,000t of typical ore
170t U as uranium oxide
2 CONVERSION to UF_6 (gas)
NUCLEAR POWER STATION 5
1000MW electricity to community
for one year (7 billion kWh)
1 URANIUM MINING AND MILLING to uranium oxide (U_3O_8) stage
230kg Plutonium to fuel fabrication
24t recovered uranium
7 REPROCESSING of spent fuel to separate wastes
6 STORAGE of spent fuel
24t U as 27t spent fuel from reactor
750kg high-level wastes
27t spent fuel to reprocessing...
...or final disposal
8 VITRIFICATION 750kg high-level waste in 5 tonnes of Pyrex glass contained in stainless steel canisters
9 FINAL DISPOSAL of high-level waste

Geologic Repository



- The choice of countries worldwide

- U.S. has studied Yucca Mt., Nevada as potential location