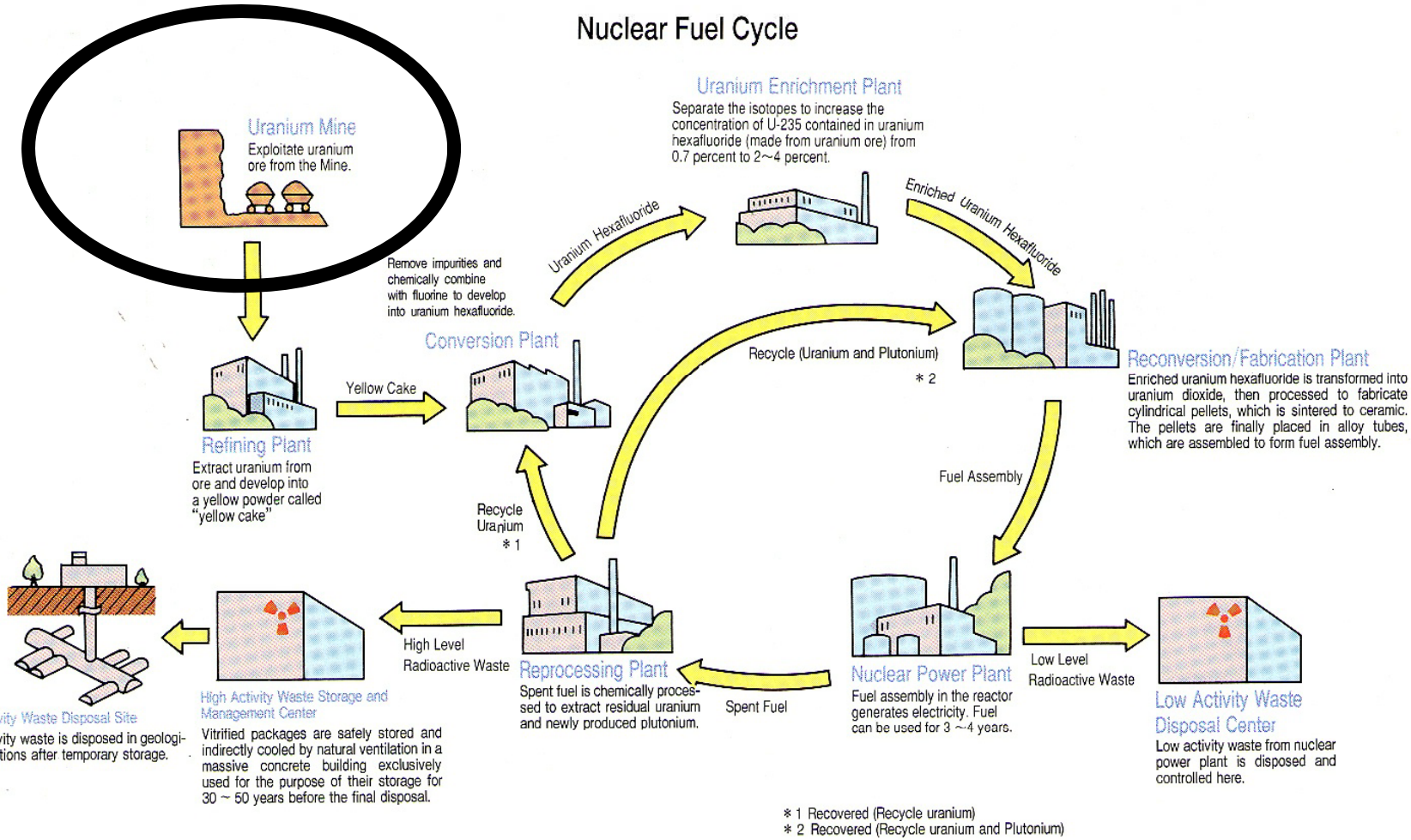
The Nuclear Fuel Cycle

Mike Ehinger

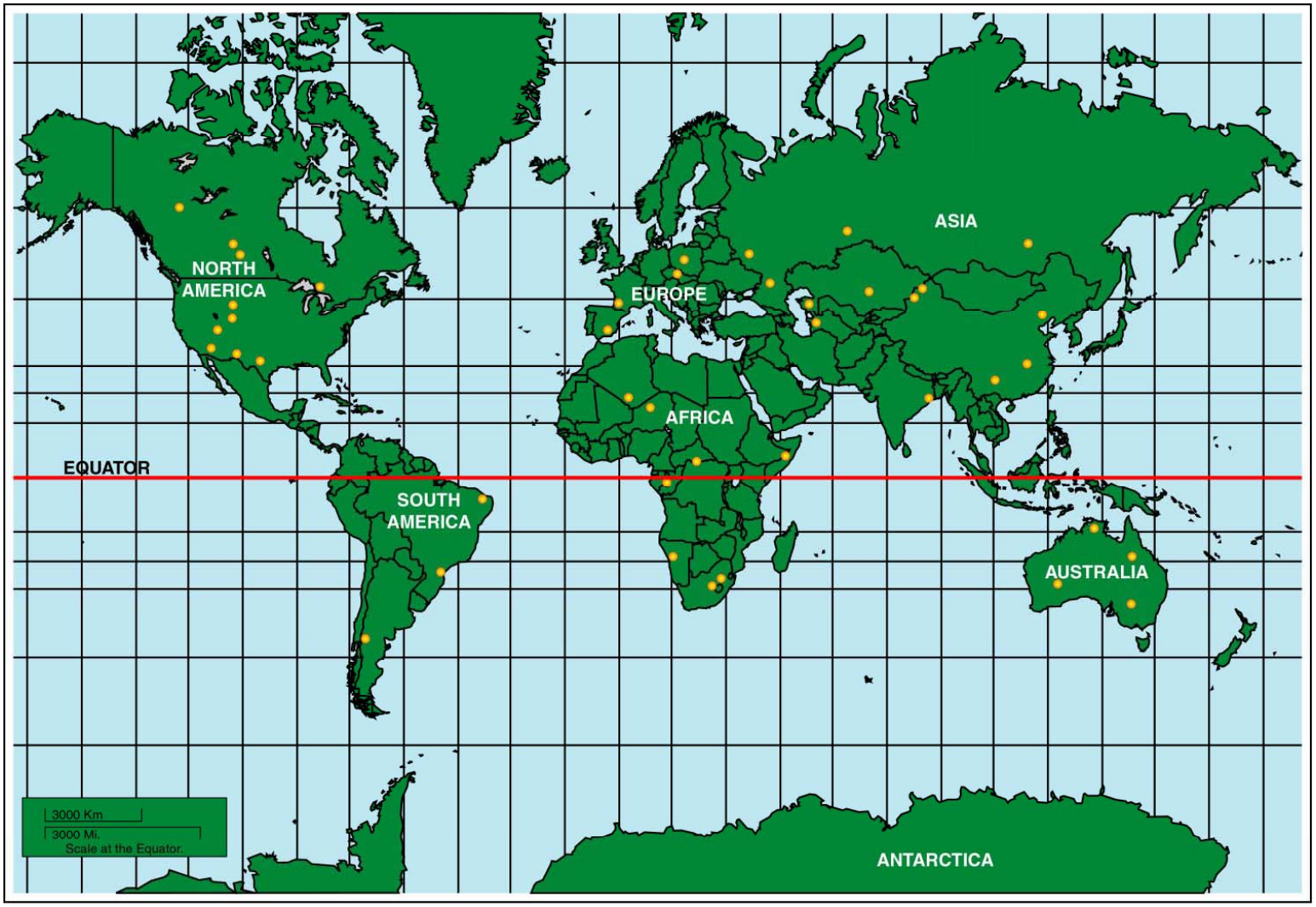
December 15, 2008

Nuclear Fuel Cycle



* 1 Recovered (Recycle uranium)
* 2 Recovered (Recycle uranium and Plutonium)

Uranium is Everywhere

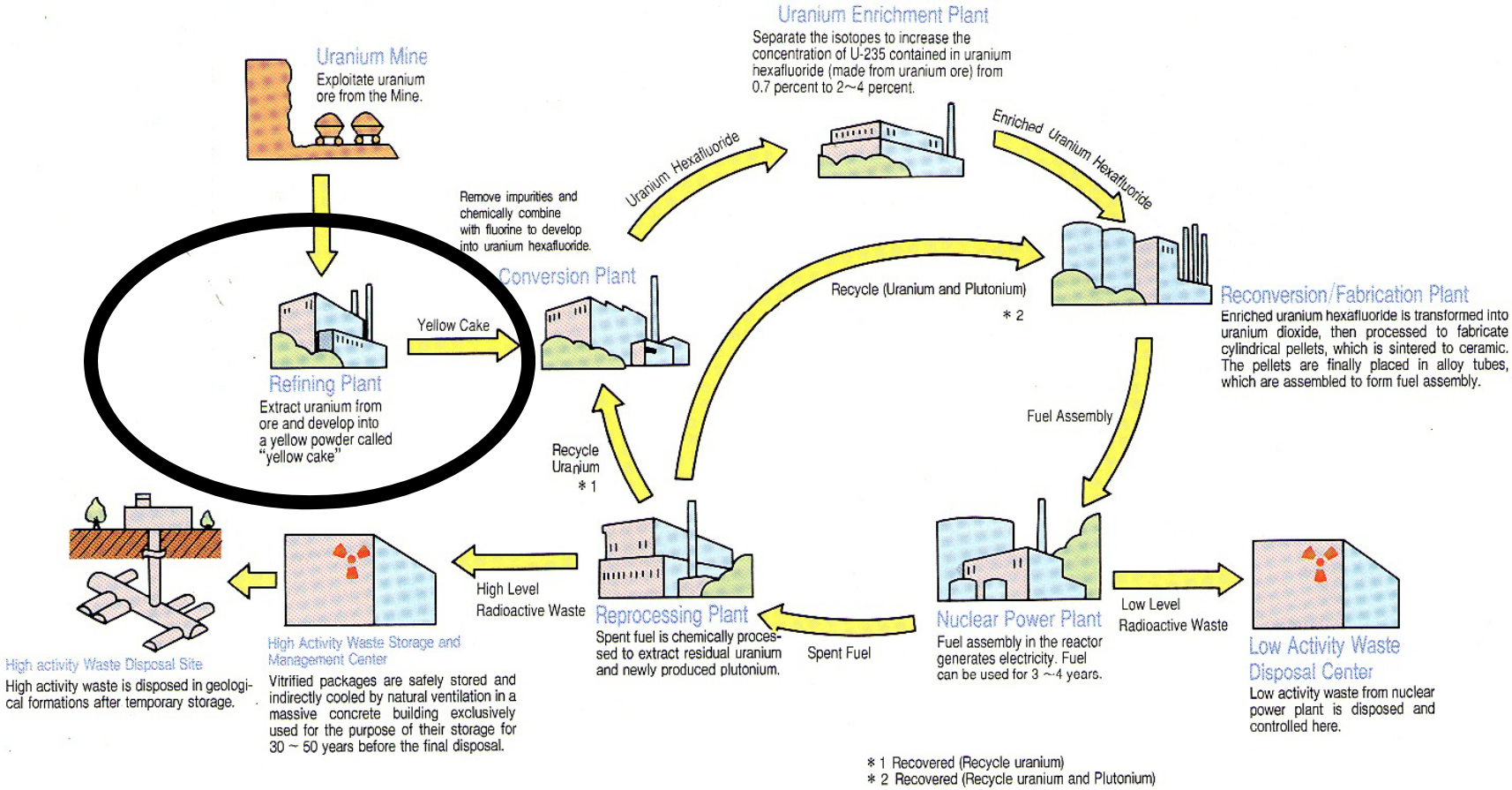


- Type of mine dictated by geology and richness of deposit
  - Open pit (strip mining)
  - Shaft mining
  - Injection mining (“in situ” mining)
  - Etc.

Even from seawater and fertilizer

- Technology similar to any other mining activity
- Uranium deposits are (generally) dilute
  - 0.2 to 0.3% uranium oxide (or equivalent)
  - Uraninite, carnotite, monazite, pitchblende…

Nuclear Fuel Cycle



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PROCESSING ORE = BIG EQUIPMENT

Rock crusher

Slurry pumps

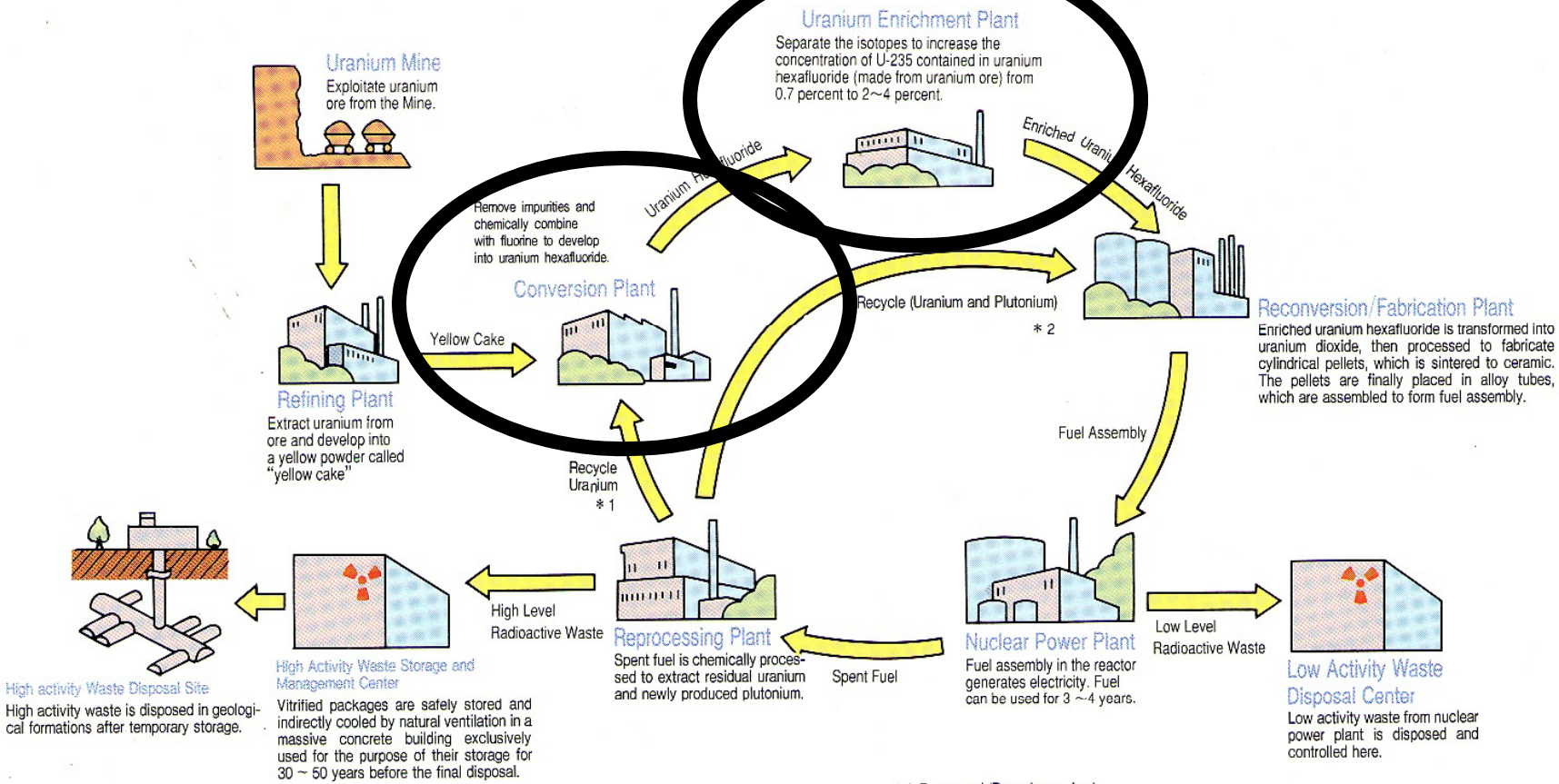
Leaching

Make the product

= "yellow cake"

pure uranium oxide powder

Nuclear Fuel Cycle



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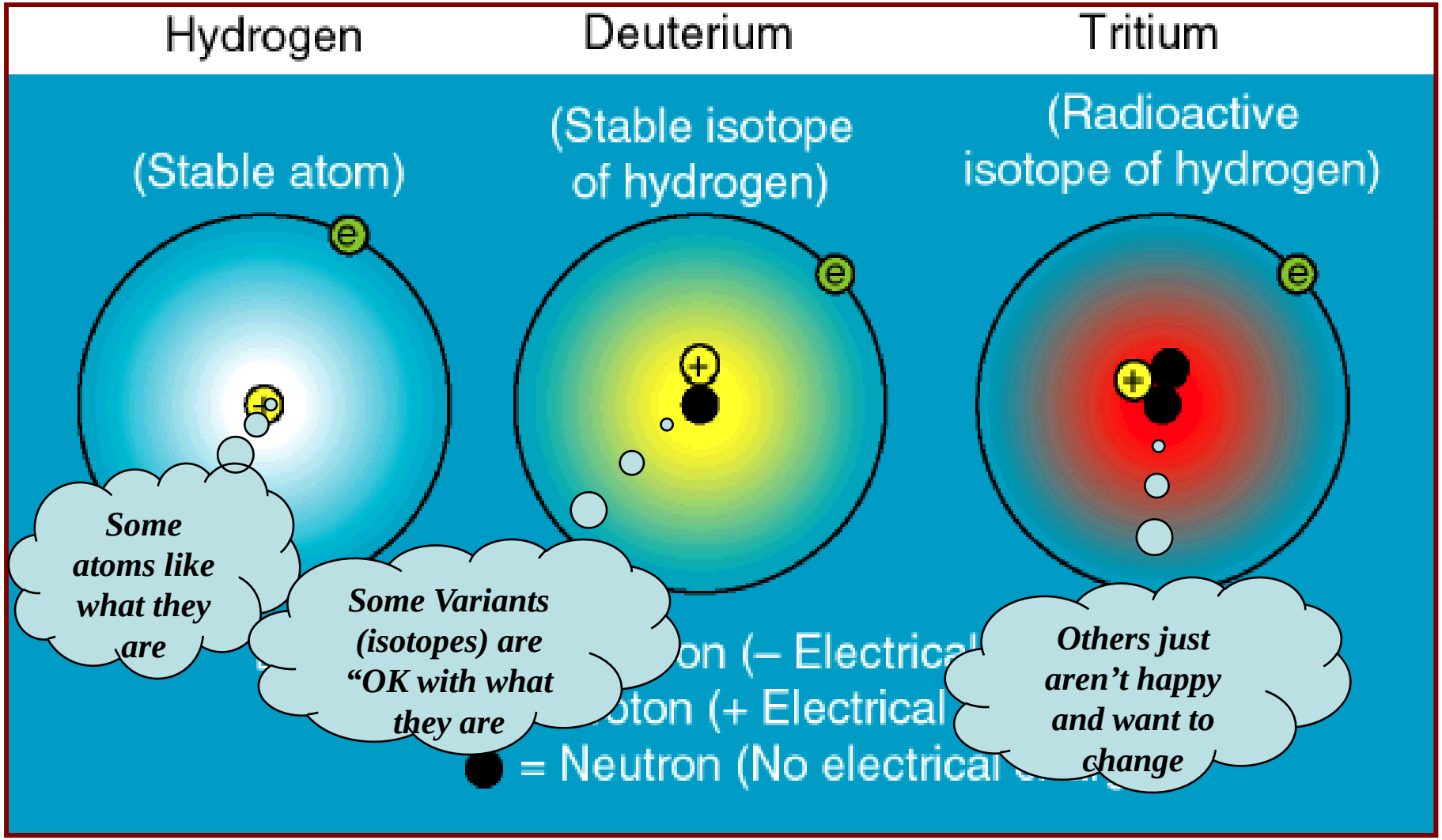
We have to say something about "nuclear", "fission", "chain reaction", reactors, bombs, etc.



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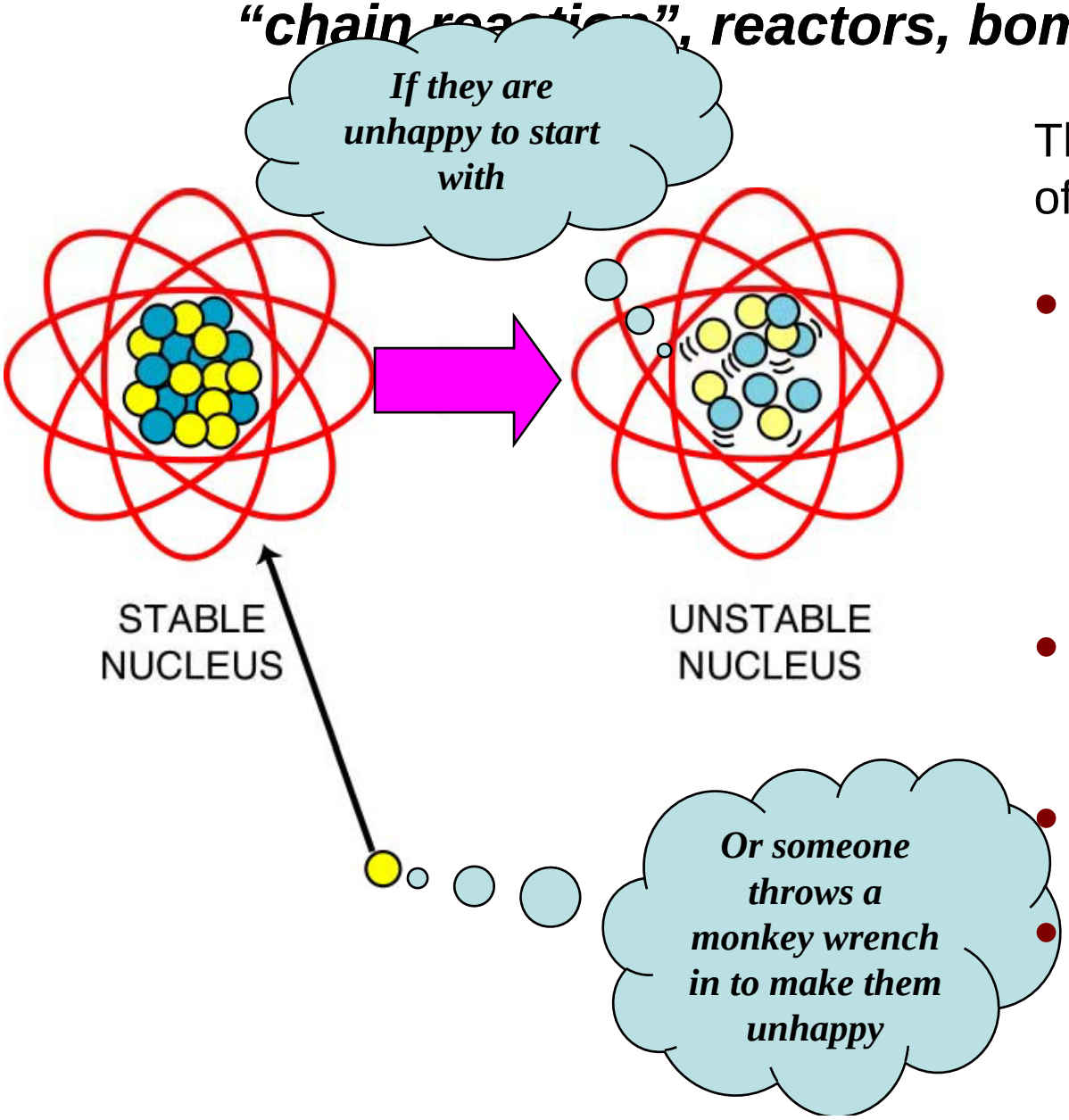
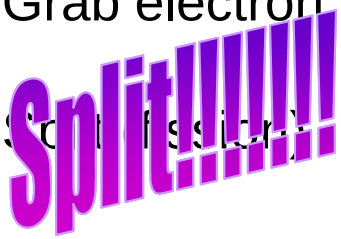


They'll do any or all of the following

- Emit particle
  α
  β
  Positron
  Neutron
- Emit EM radiation
  γ
- Grab electron
- Split (fission)



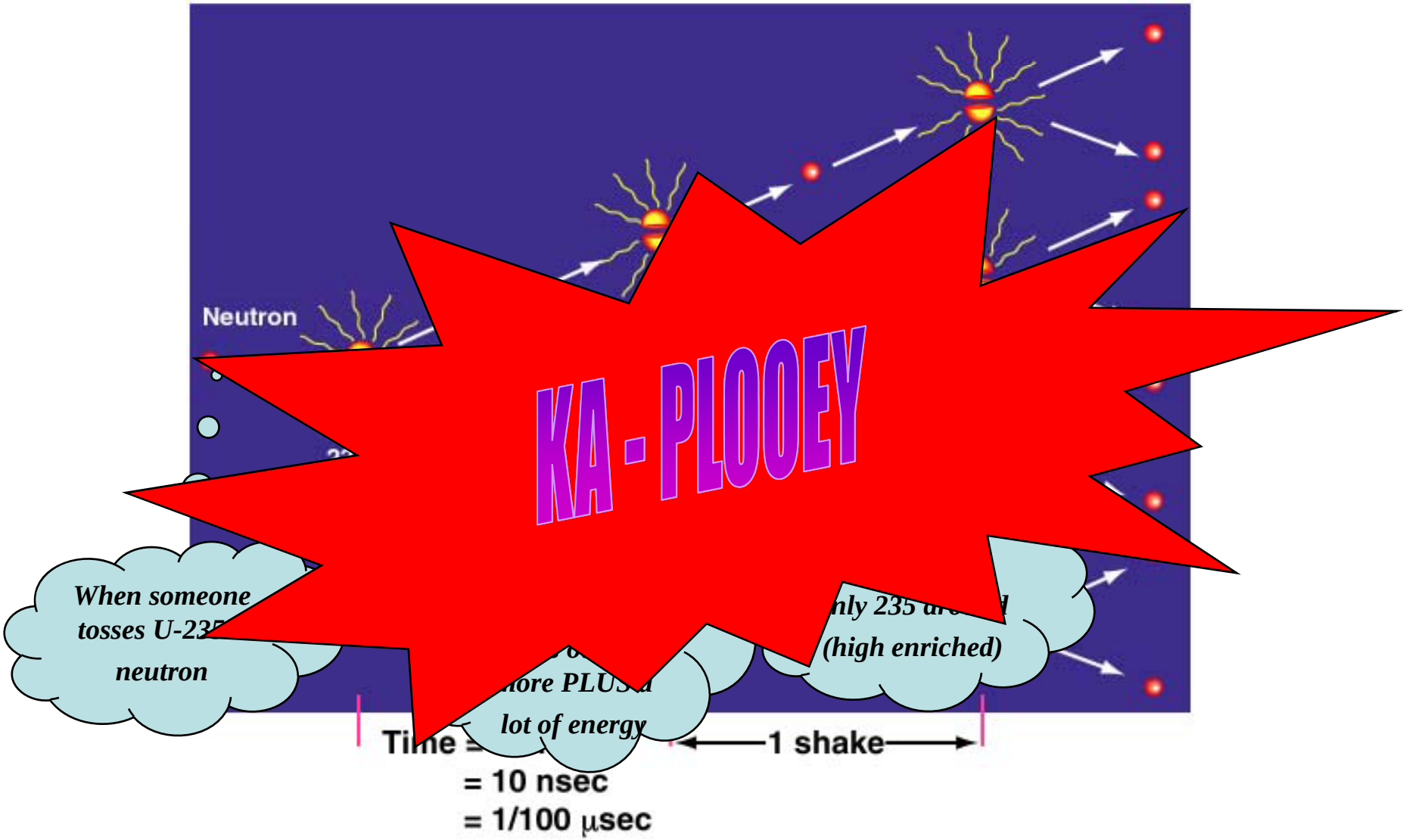
We have to say something about "nuclear", "fission", "chain reaction", reactors, bombs, etc.

U-235, is also pretty happy but has a hidden "split personality" (he is "fissionable")

Isotope	Half-life	
Tritium (Hydrogen-3)	12.3 years	Released during processing of irradiated target. Used in fusion and boosted-fission weapons Produced by neutron irradiation of lithium-6. Generated in heavy water reactors.
Carbon-14	5.77 thousand years	Used to estimate age of organic materials. Released during reprocessing of irradiated fuel.
Krypton-85	10.8 years	Released during reprocessing of irradiated fuel.
Iodine-129	17 million years	Released during reprocessing of irradiated fuel. Absorbed by thyroid gland.
Iodine-131	8.0 days	Released during reprocessing of irradiated fuel. Absorbed by thyroid gland.
Xenon-135	9.1 hours	Neutron poison produced during reactor operation.
Polonium-210	138 days	Produced by neutron irradiation of natural bismuth (bismuth-209). Used with beryllium in internal neutron generators.
Radon-222	3.8 days	Produced in decay chain of uranium-238.
Uranium-235	710 million years	Natural fissile isotope of uranium.
Uranium-238	4.5 billion years	Predominant isotope of uranium.
Neptunium-237	2.1 million years	Produced by neutron irradiation of uranium-235
Plutonium-238	89 years	Produced by neutron irradiation of [illegible] thermoelectric generators (RTG[illegible]) generators.
Plutonium-239	24 thousand years	Produced by neutron irr[illegible]
Plutonium-240	6.6 thousand years	Produced by neutron irr[illegible]

U-238 is really happy, and won't get very upset if someone messes with him (he's pretty sociable)

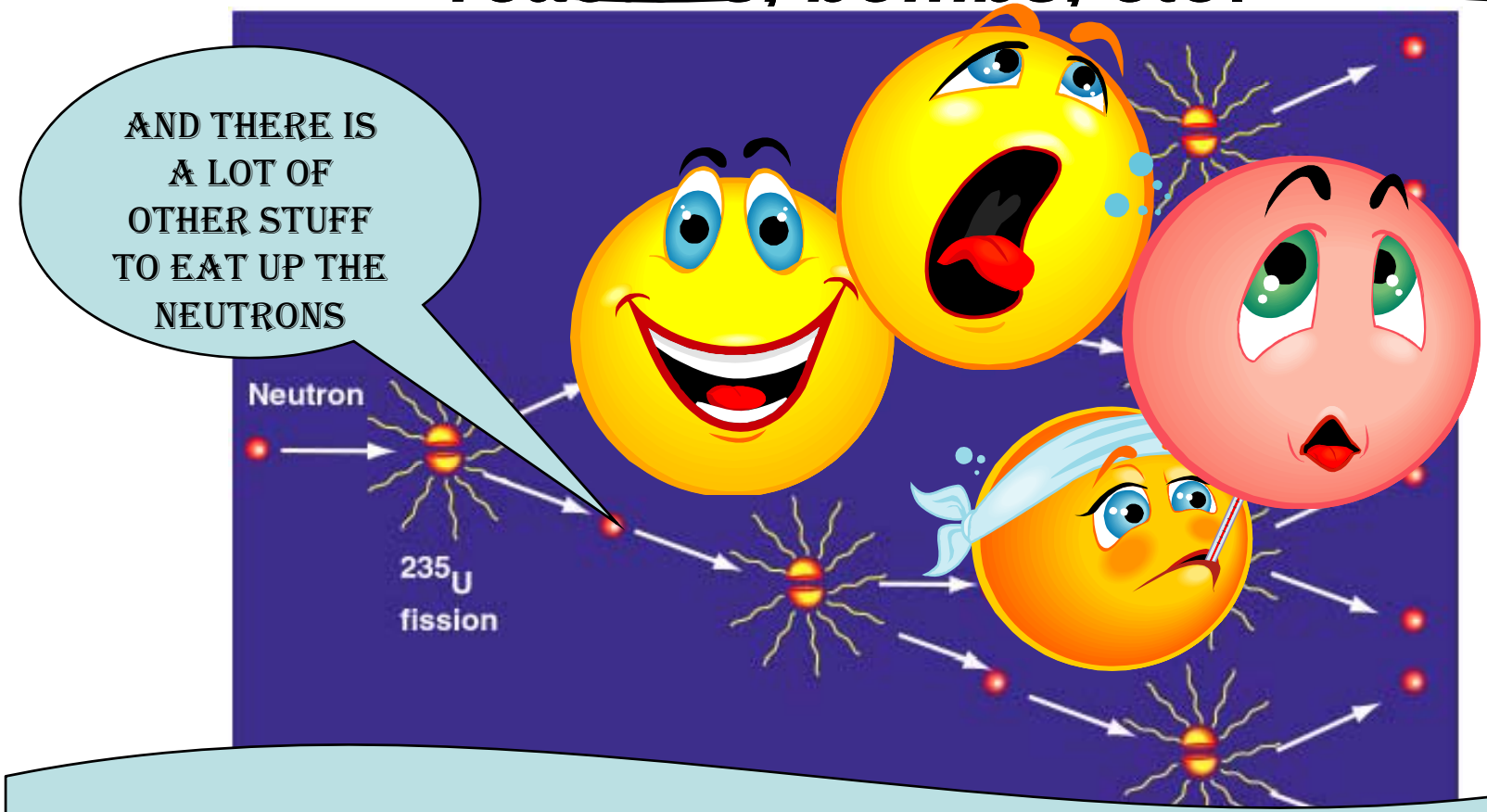
We have to say something about "nuclear", "fission", "chain reaction", reactors, bombs, etc.



We have to say something about

FORTUNATELY, ONLY 0.711% OF ALL URANIUM IS U-235 WITH THE SPLIT PERSONALITY

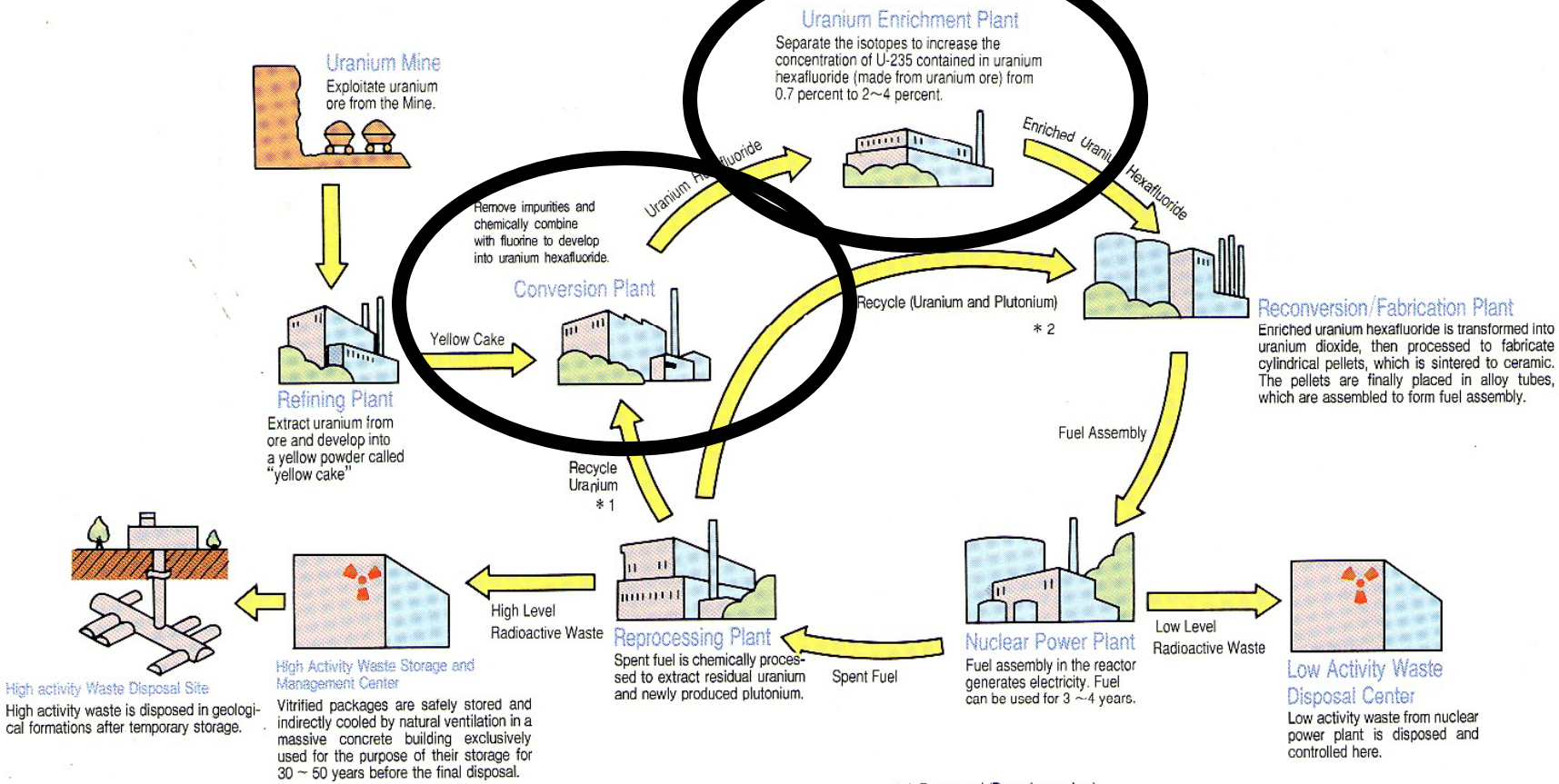
reactors, bombs, etc.



We design reactors with low %U-235
and enough other "happy materials"

= 10 nsec
= 1/100 μsec

Nuclear Fuel Cycle



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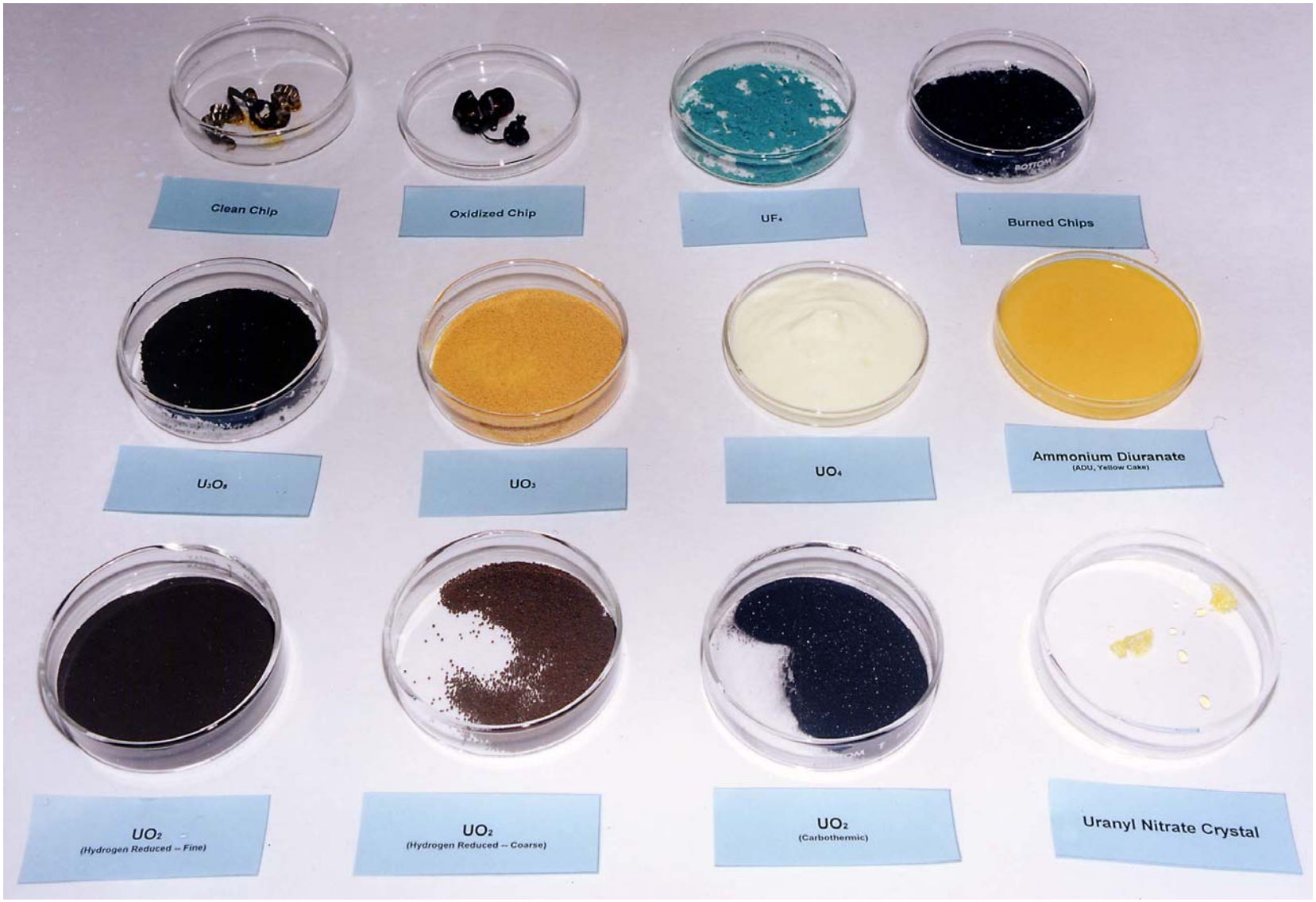
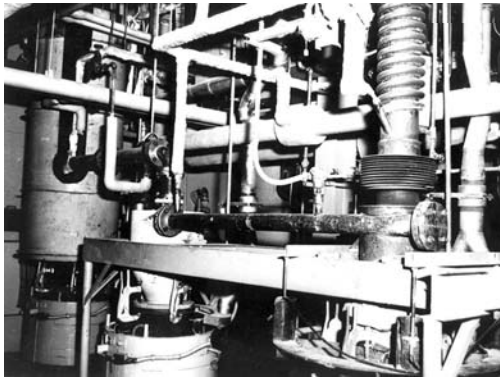
Uranium can be a colorful compound during conversion

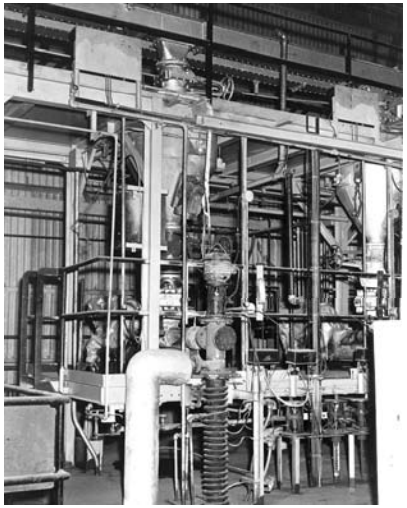


Chemical Purification

UF6 product

Fluorination

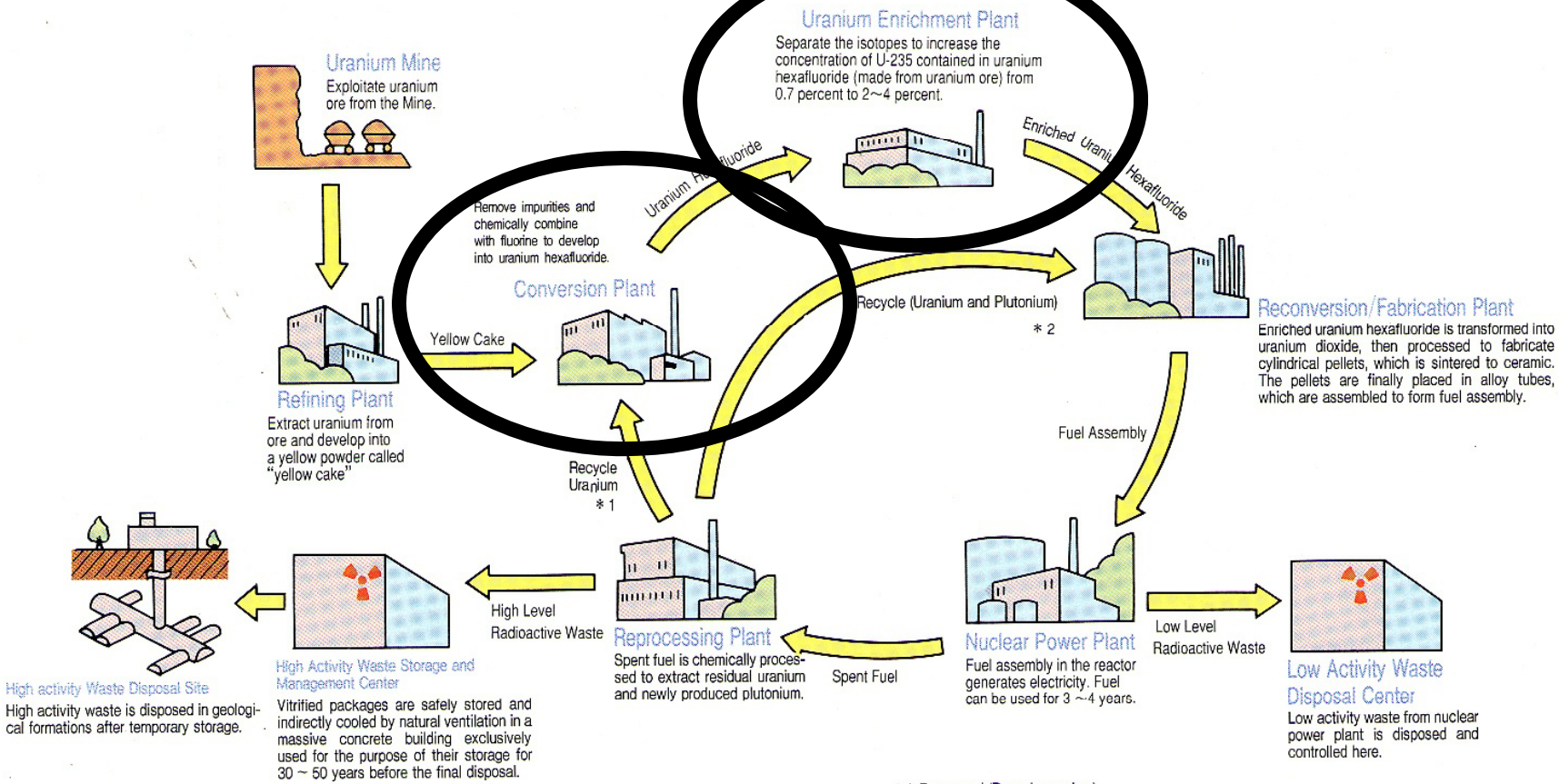




UF_6 Plant

Allied Signal Corporation Metropolis, IL

Nuclear Fuel Cycle



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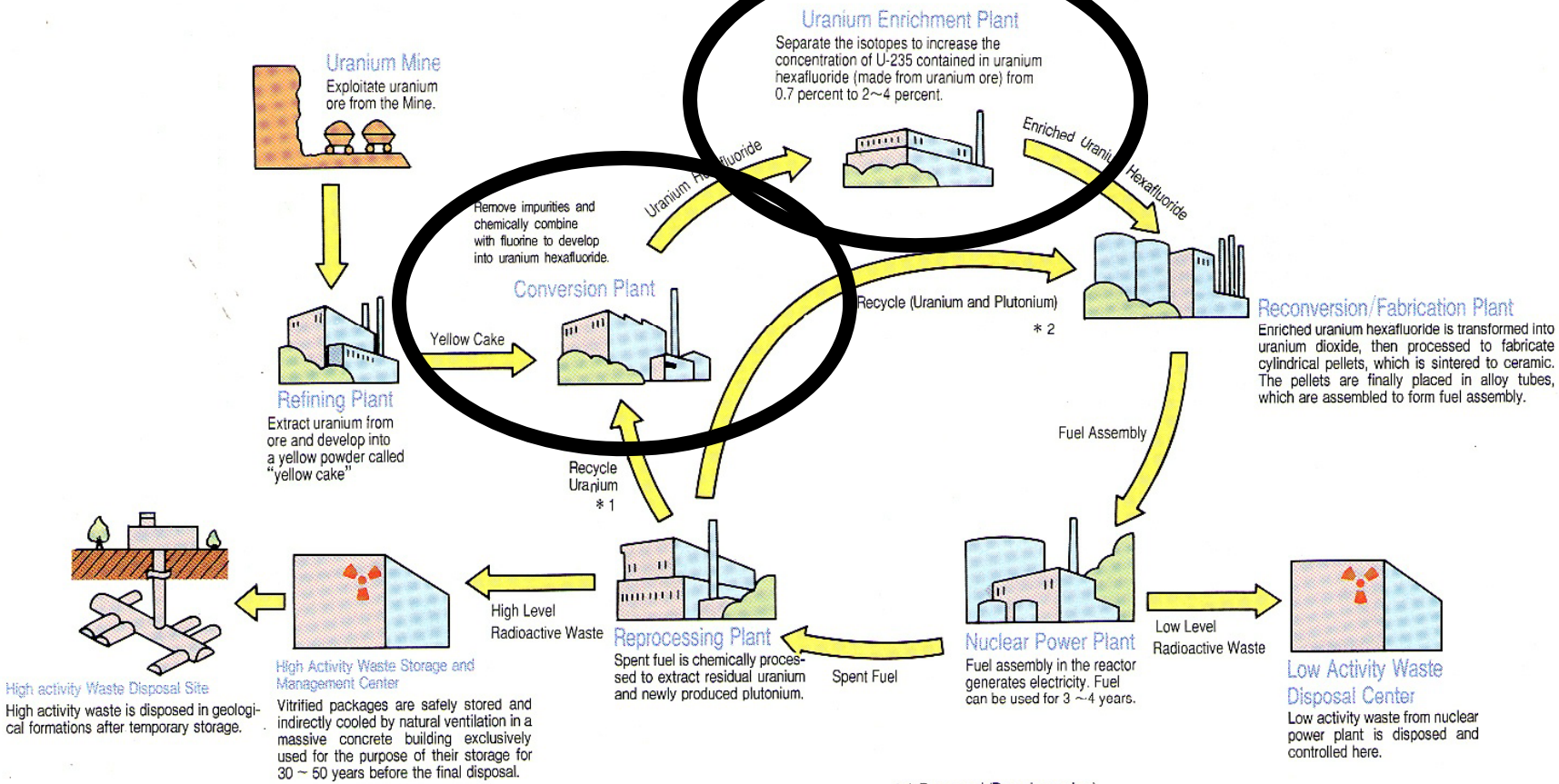

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Uranium Enrichment

- Uranium as found in nature is called natural or normal uranium
- Its isotopic composition is:

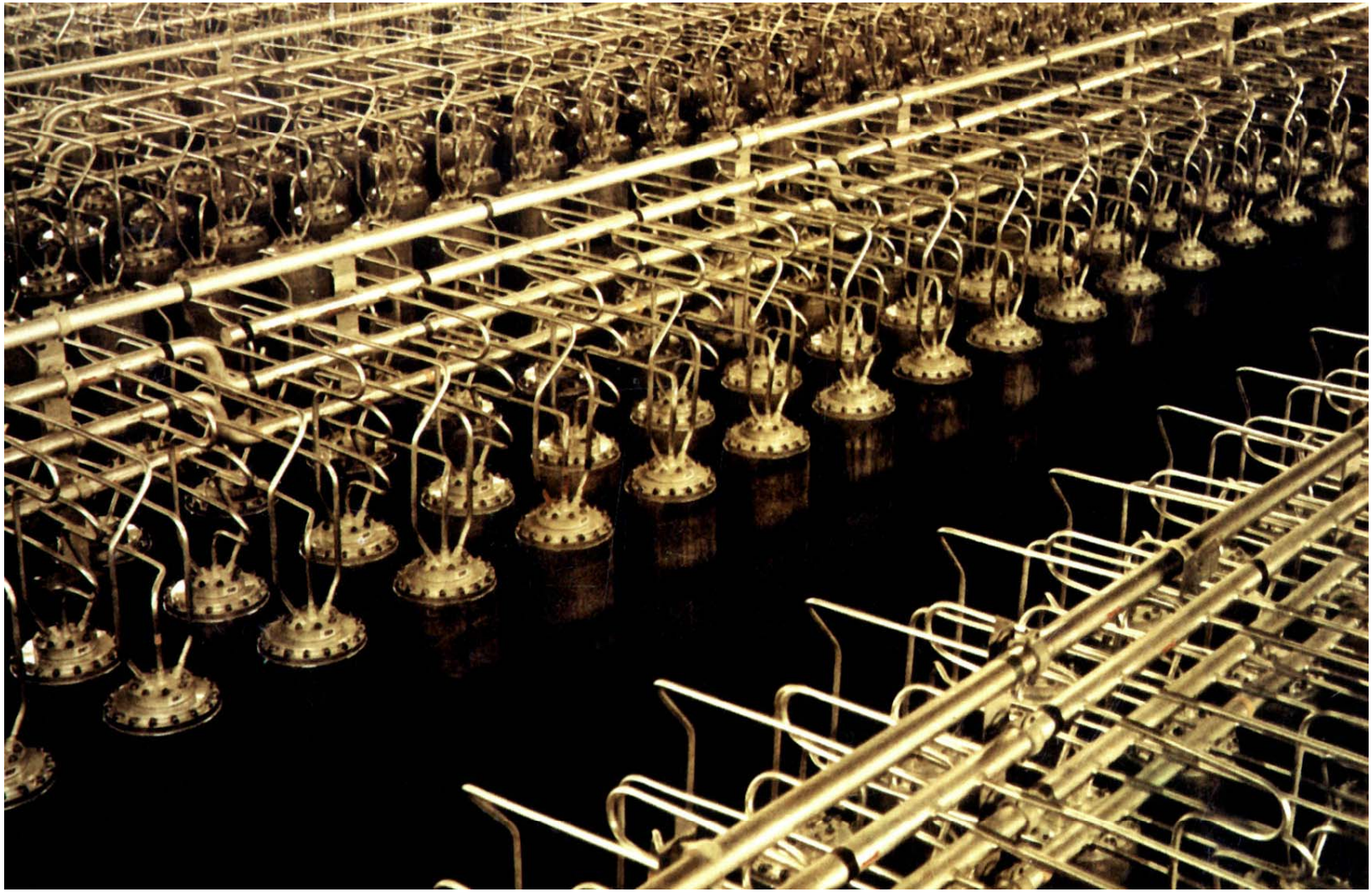
0.0054%	^{234}U (92 protons, 142 neutrons)
0.72%	^{235}U (92 protons, 143 neutrons)
99.3%	^{238}U (92 protons, 146 neutrons)

- Higher concentrations of ^{235}U are needed for many applications
  - Light water reactors (LWRs): about 3%
  - Submarine fuel: greater than 90%
  - Weapons: greater than 90%
- Concentration of the ^{235}U isotope above its natural value is called uranium enrichment

There are many ways to enrich

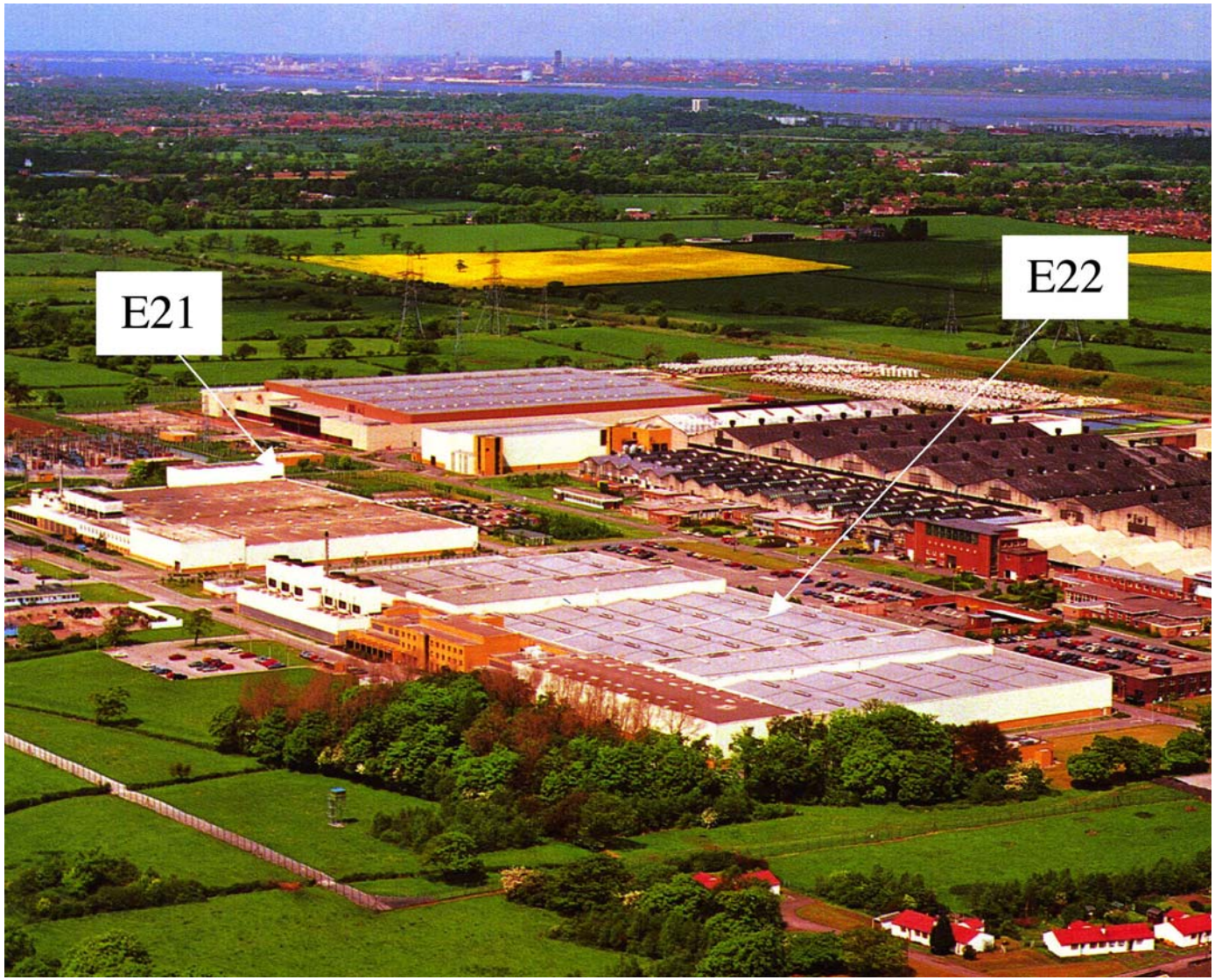
- Gas Centrifuge
- Gaseous Diffusion
- Electromagnetic Isotope Separation
- Laser
- Chemical/Ion Exchange
- Aerodynamic
- Plasma

Centrifuge Cascades at Almelo



US Gas Centrifuge Plant (GCEP)

Centrifuge Plant At Capenhurst



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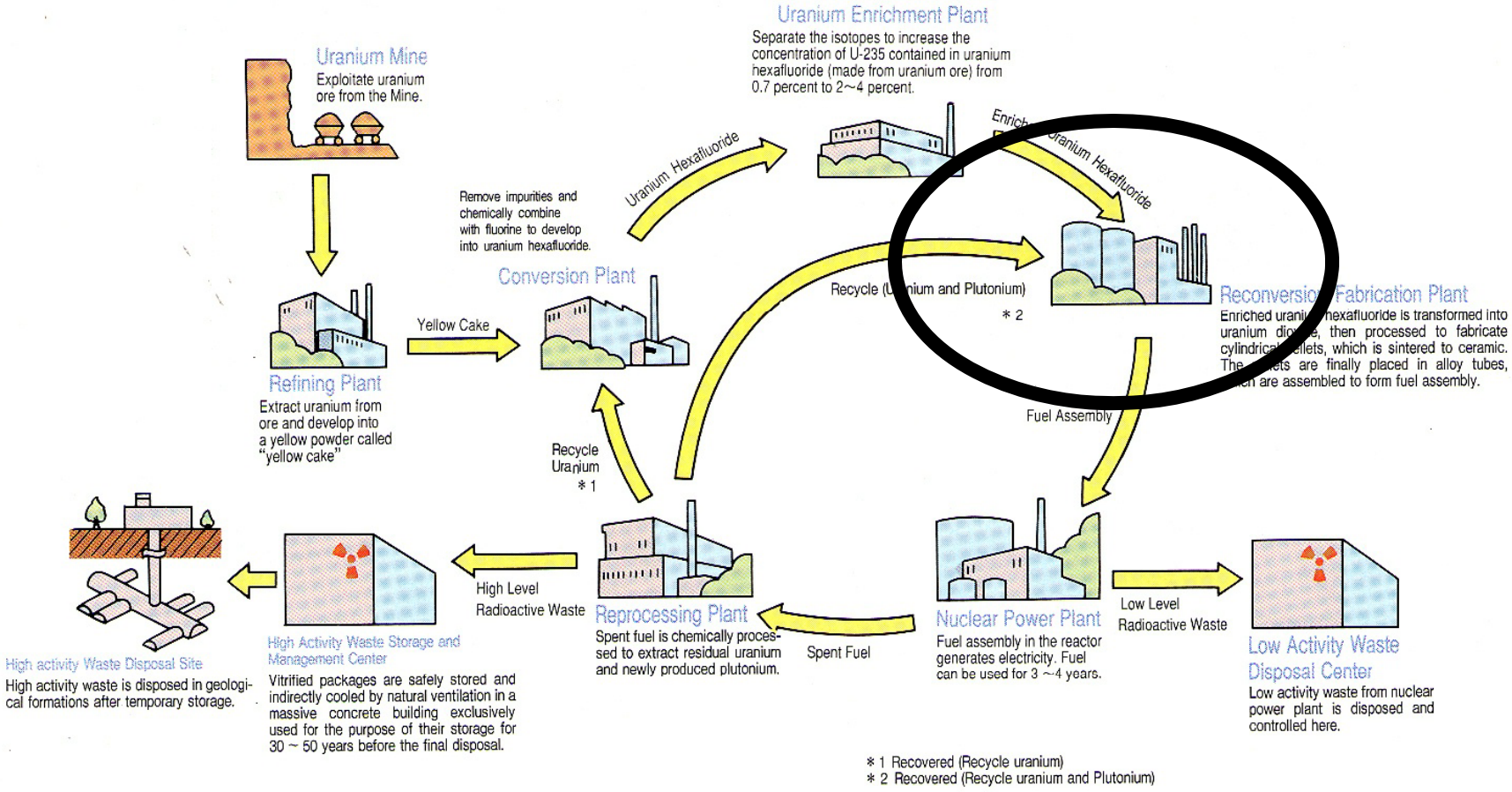

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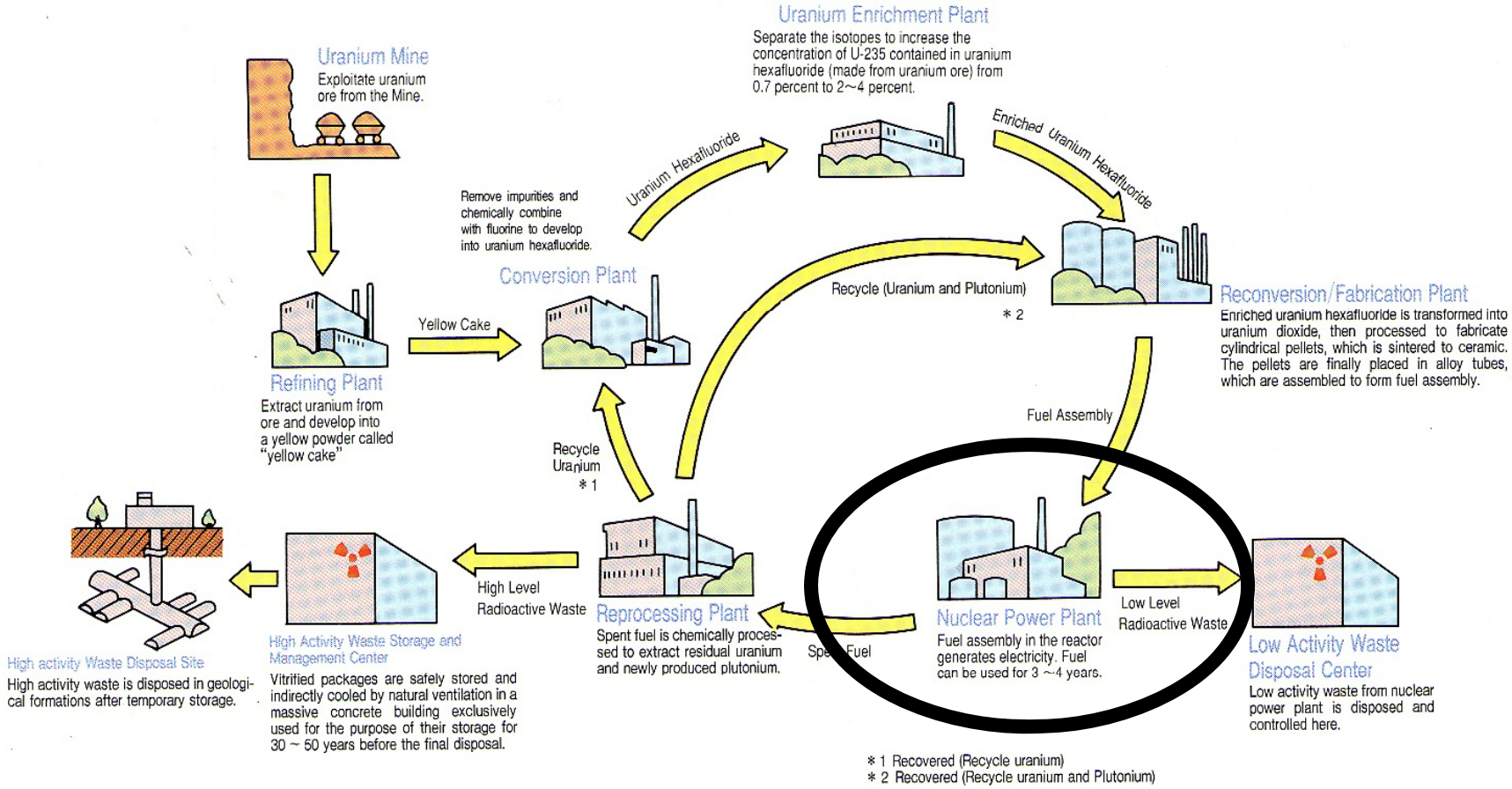

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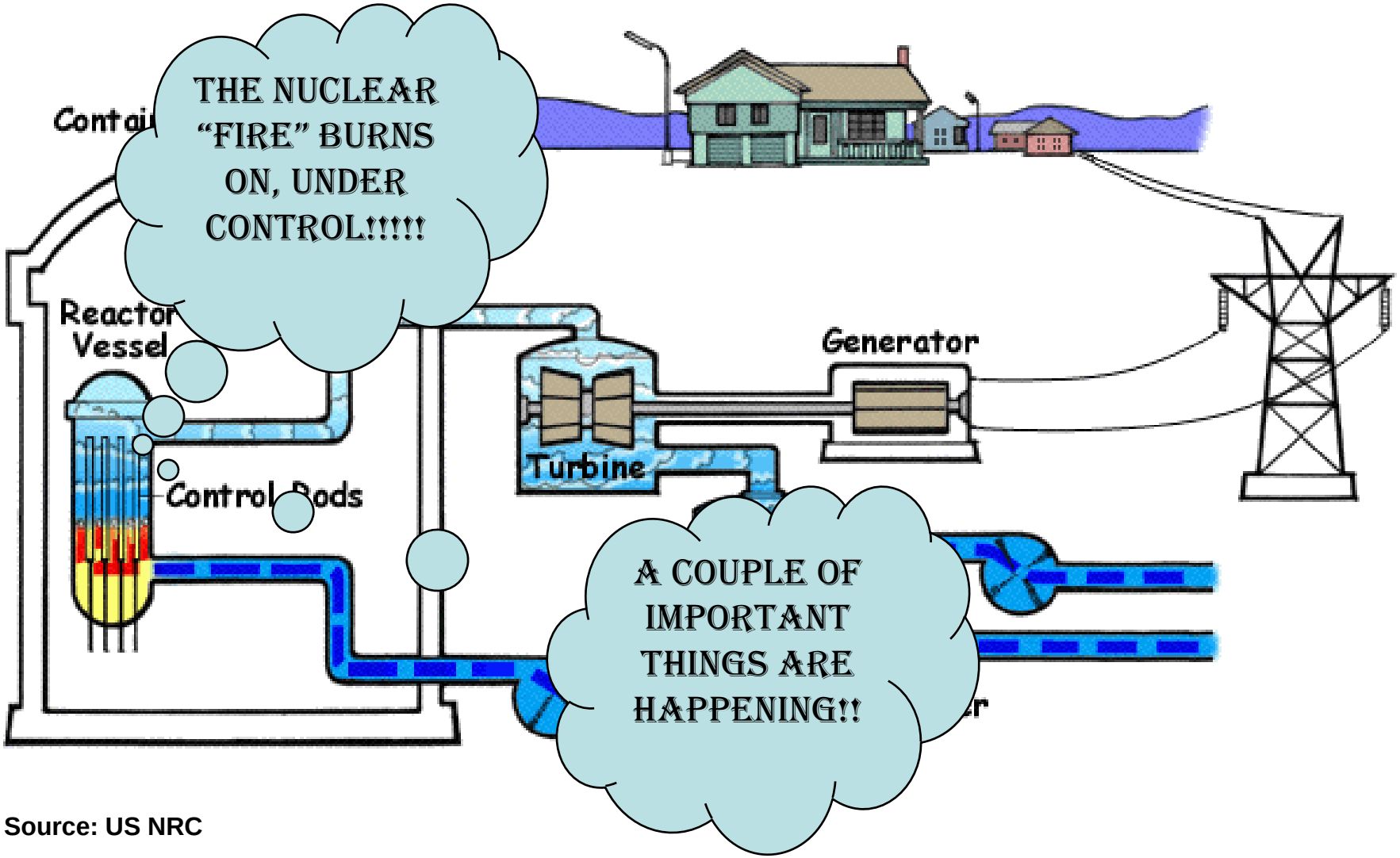
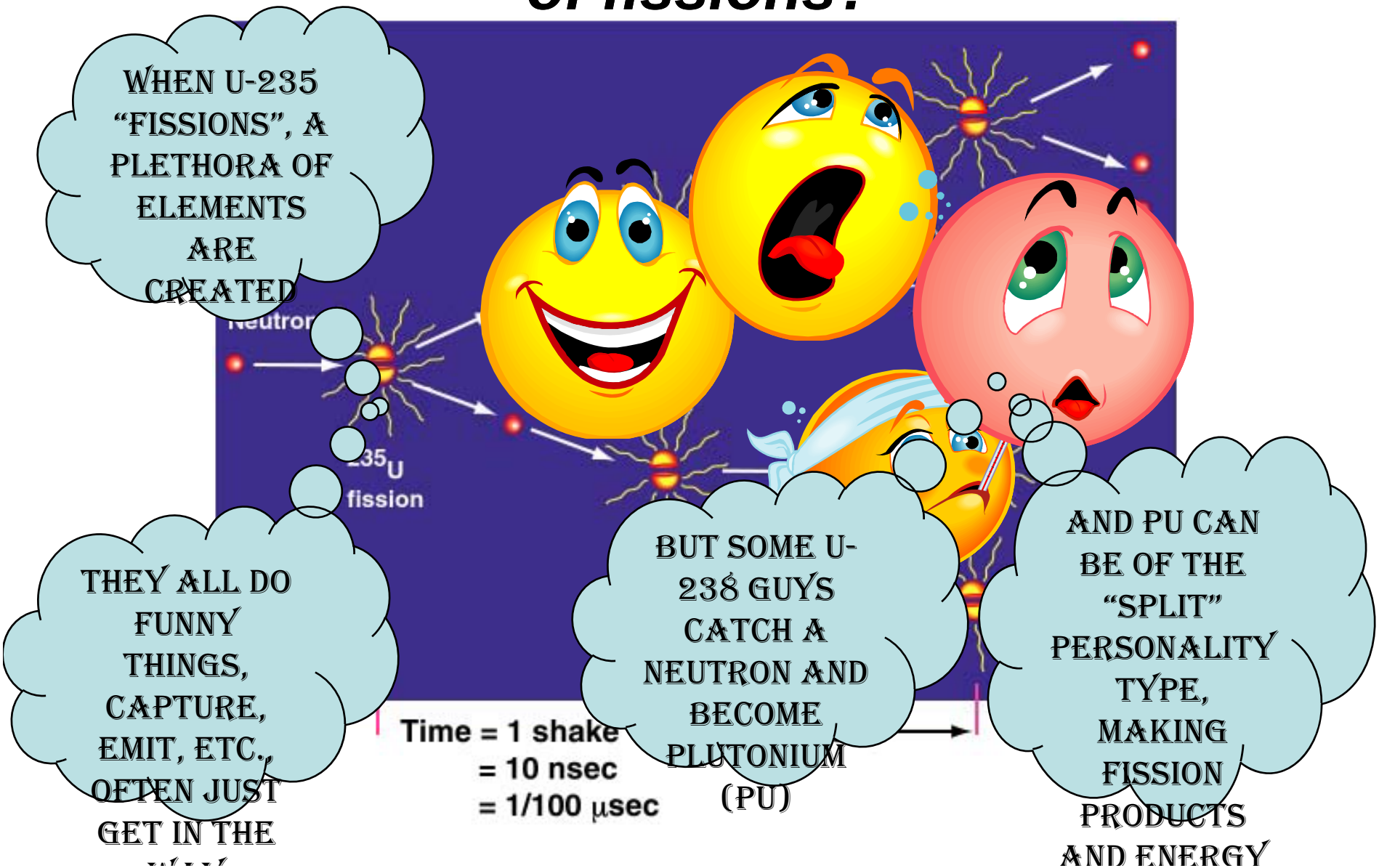
BWR System Schematic



Source: US NRC

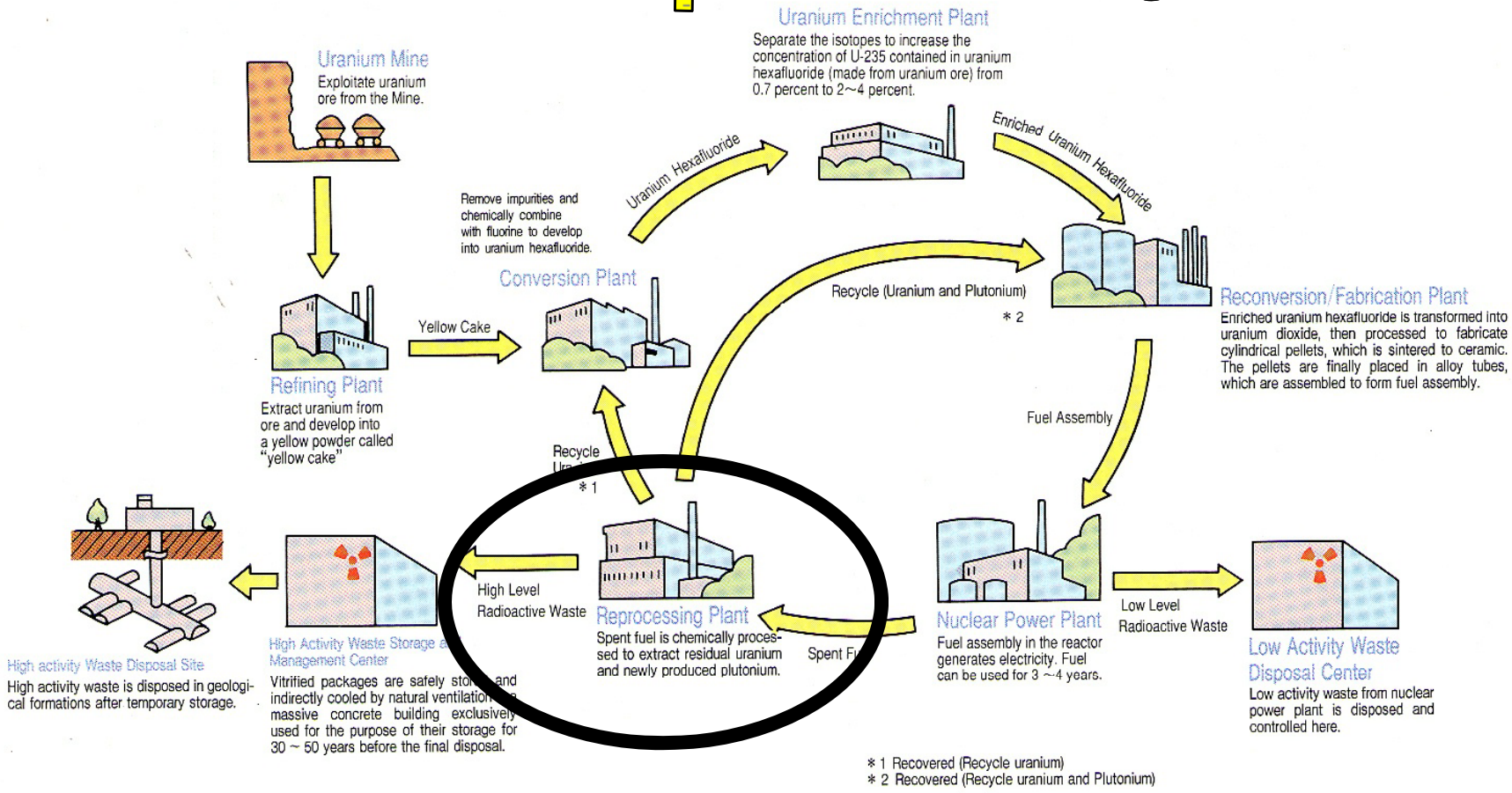
Remember our guys controlling the rates of fissions?



But after a few years in the reactor

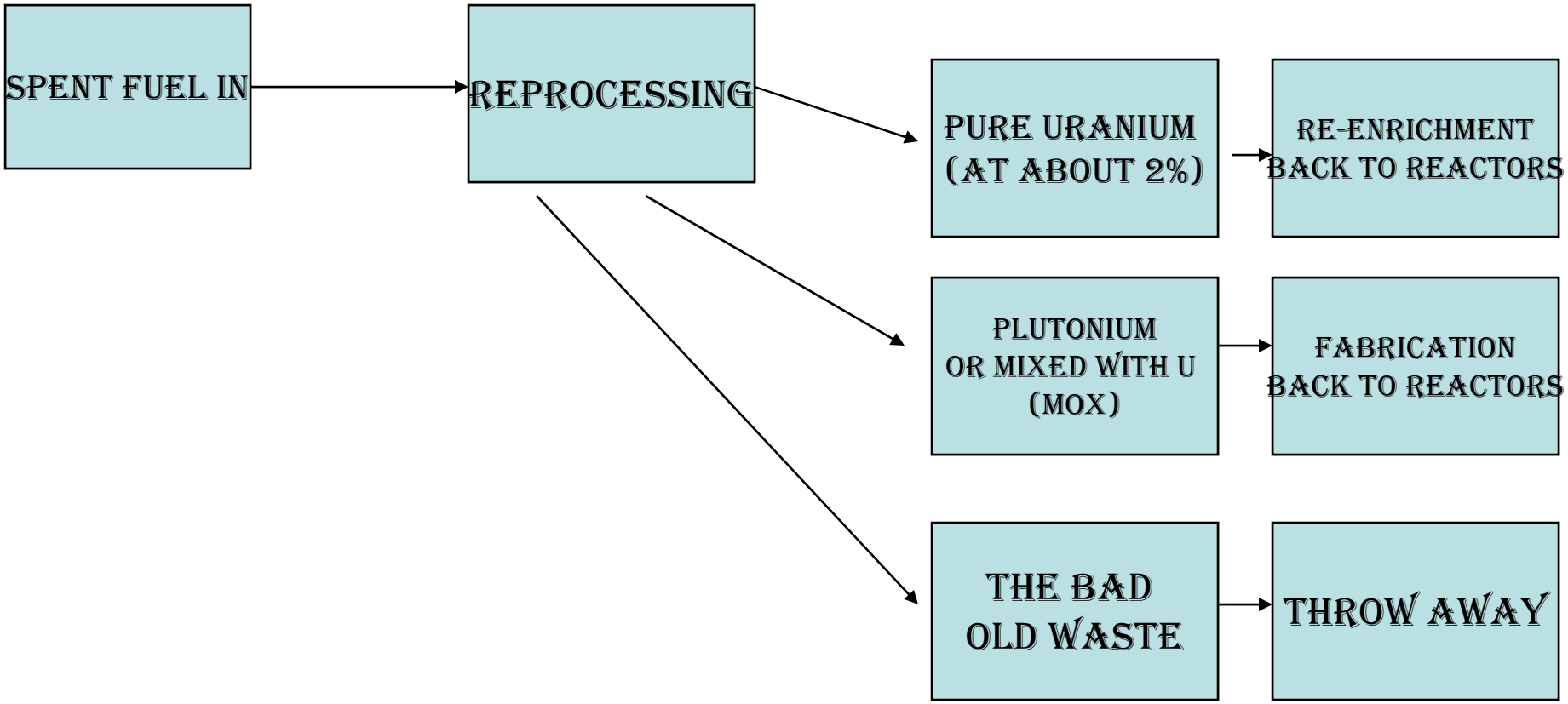
- We have “burned” about 4 of 5% of the U-235
- About 1-2% of U-238 has become “split personality Pu
- And the rest is the fission product “ash”
  - Think of ash in a wood fire – the embers are still there if we get rid of the ash
  - Or…Smokey the bear douses it with water!!!!

Enter Reprocessing!!!!!



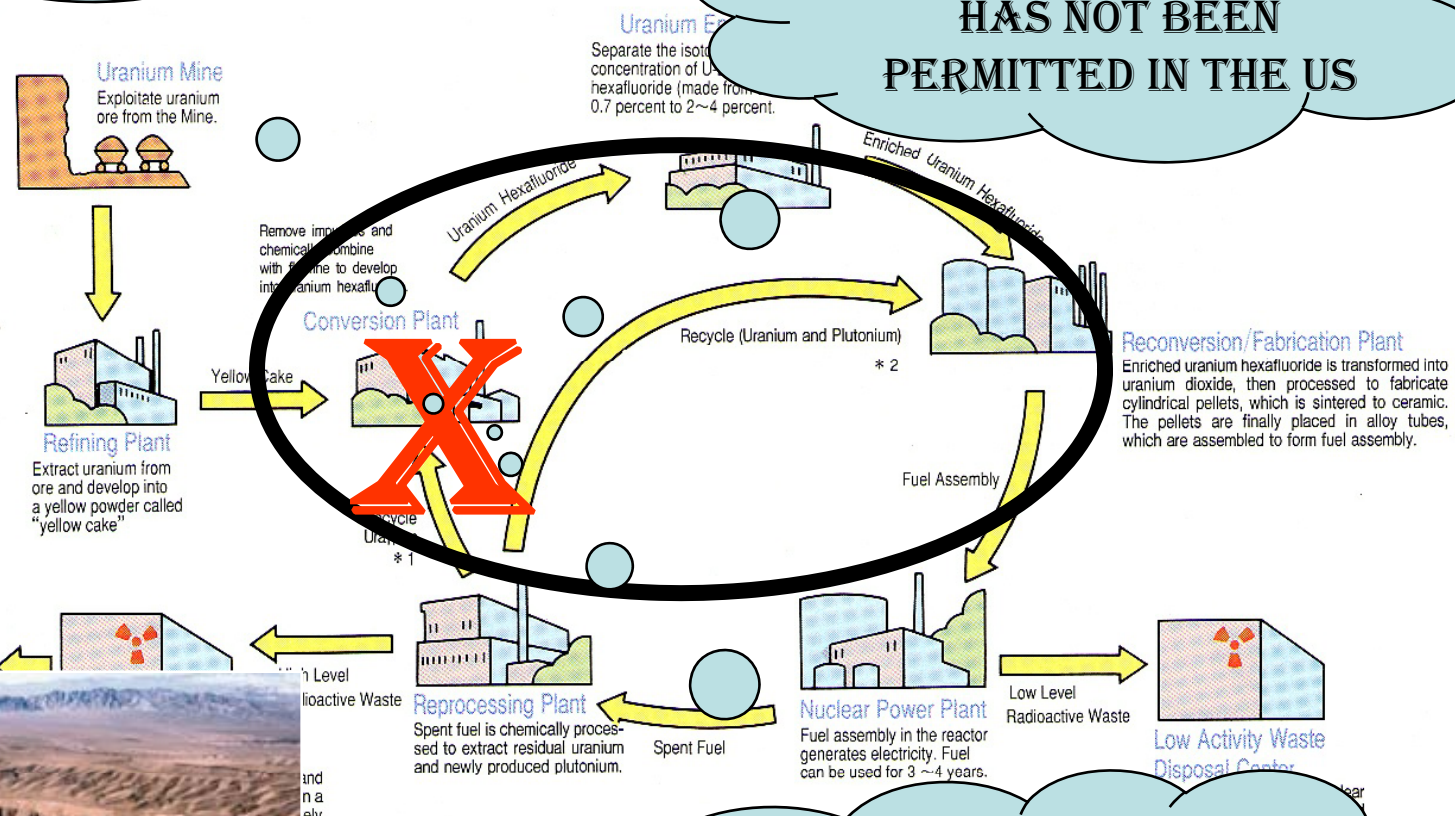
I don't have a good picture here

Reprocessing!!!



THIS IS WHAT A LOT OF THE WORLD IS DOING

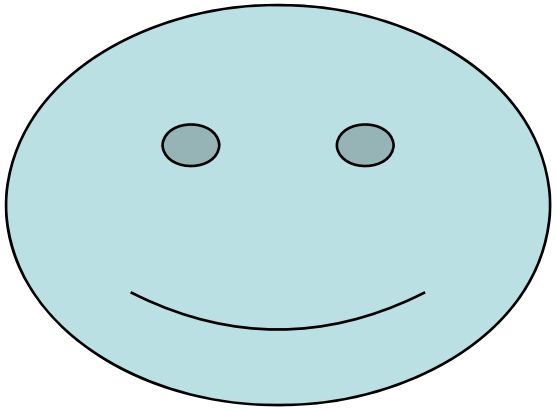
SINCE 1976/77 (FORD/CARTER) THIS HAS NOT BEEN PERMITTED IN THE US



OUR CURRENT POLICY IS TO THROW AWAY SPENT FUEL
HAVE YOU HEARD OF YUCCA MOUNTAIN?

The Global Nuclear Energy Partnership

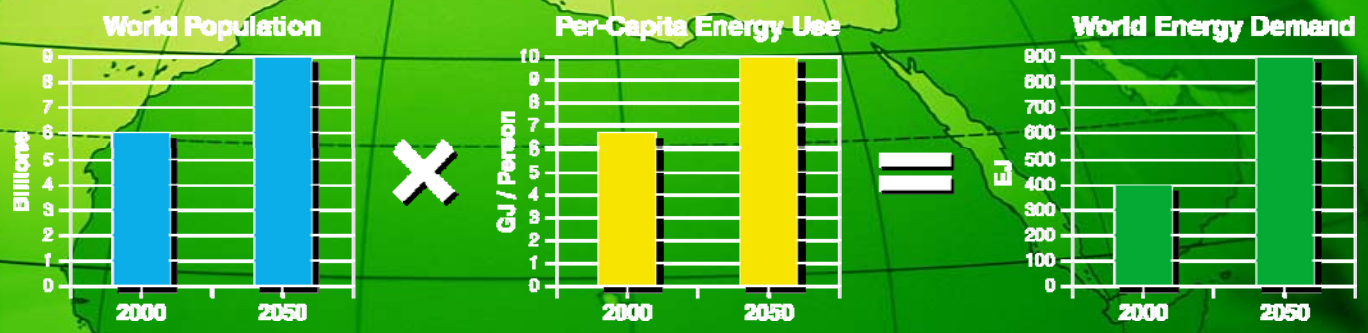
There is something on the horizon



Greater Energy Security in a Safer, Cleaner World

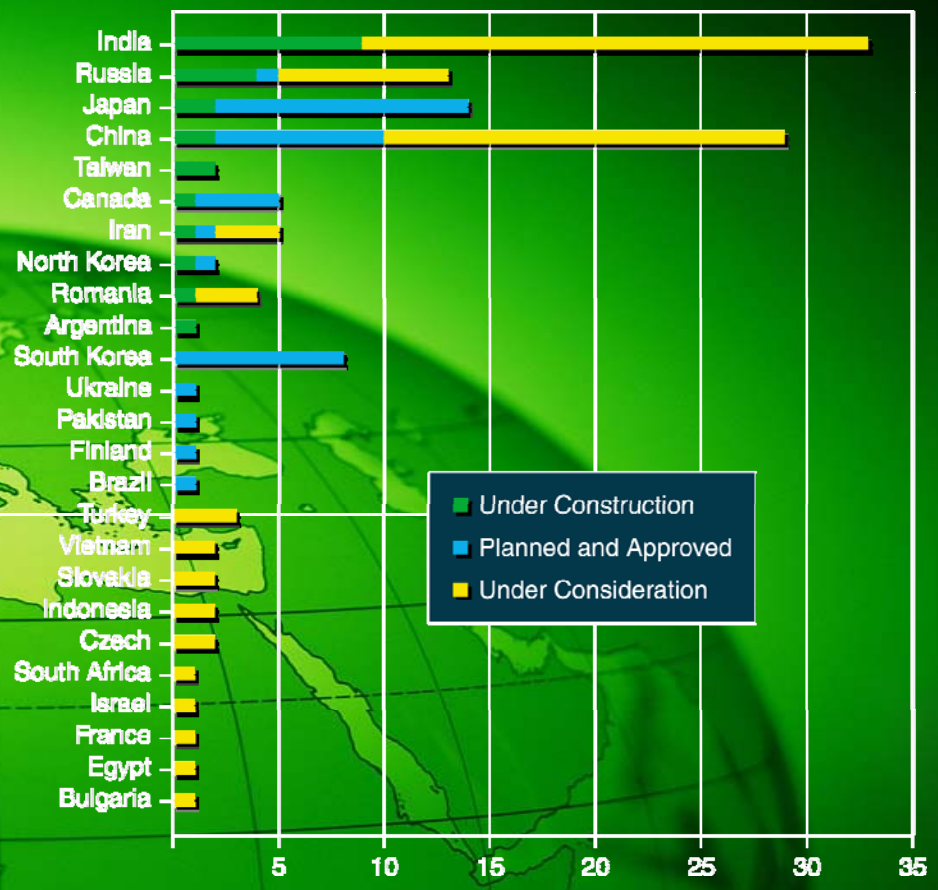
Challenges: Global Energy Demand

- A reliable energy supply is the cornerstone of sustained economic growth and prosperity
- World energy demand is expected to more than double by 2050
- An expansion of nuclear energy is a key to meeting this demand while reducing air pollution and greenhouse gases



World Nuclear Expansion: U.S. Role

- Over 130 reactors are being built, planned, or under consideration world-wide
- U.S. has not ordered a reactor for decades, despite an existing fleet of over 100 reactors
- The U.S. should be in a position to influence how these facilities are designed, constructed, and operated
  - Safety
  - Waste disposal
  - Proliferation-resistance



The Initiative

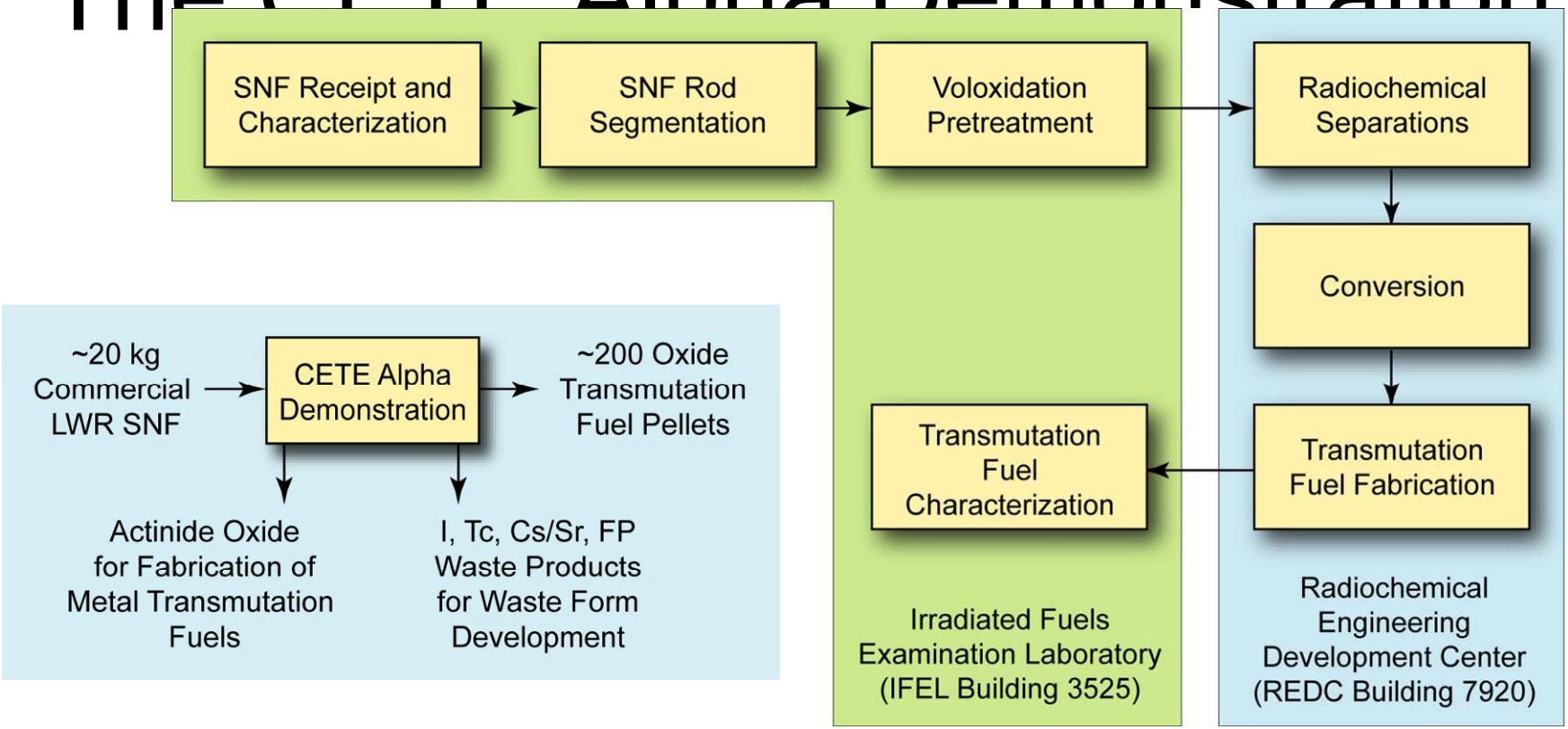
- Expand Nuclear Energy
  - Build reactors at home and abroad for energy, to reduce carbon, and achieve development
- Recycle Nuclear Fuel & Reduce Nuclear Waste
- Enhance Nonproliferation Arrangements

SO YOU MAY HEAR MORE TALK OF A "CLOSED FUEL CYCLE" IN THE FUTURE

"So tonight I announce the Advanced Energy Initiative… We will invest more in… clean, safe nuclear energy."

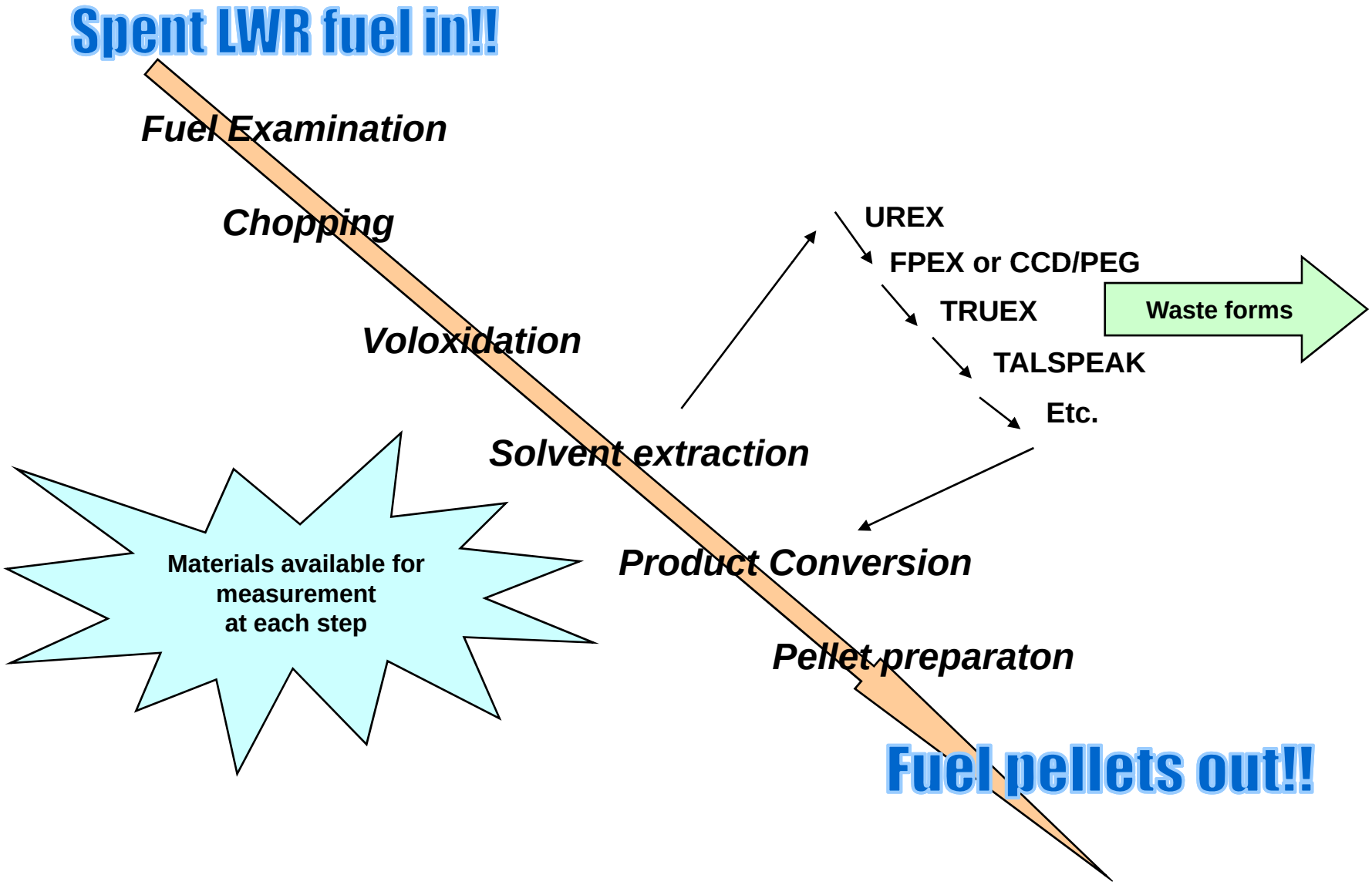
President Bush, 01/2006

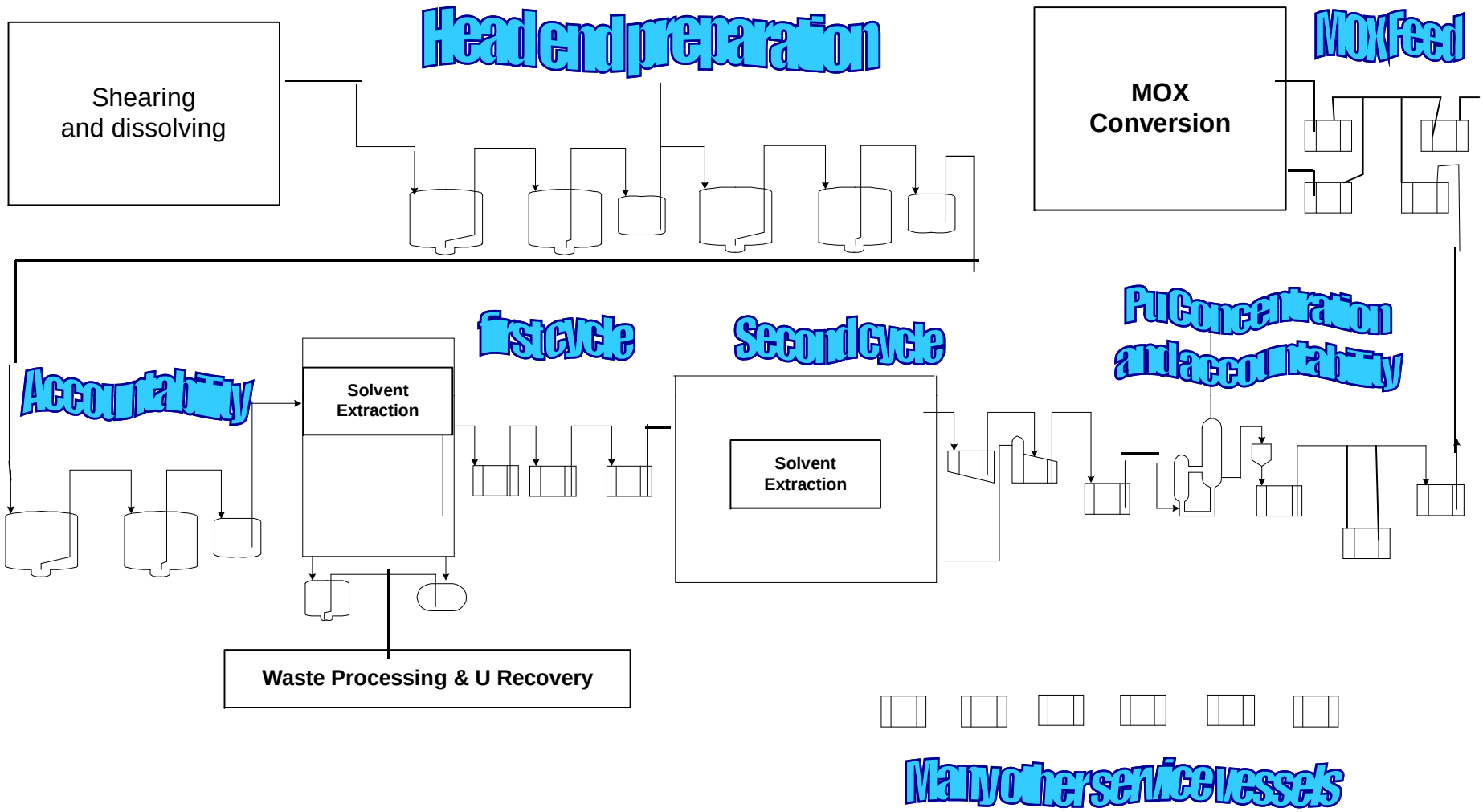
The CETE Alpha Demonstration



- A Coupled-End-to-End demonstration
  - from SNF receipt to TRU fuel pellets and waste products.
- Process at least 20 kg SNF
  - in at least 4 campaigns over 30 months

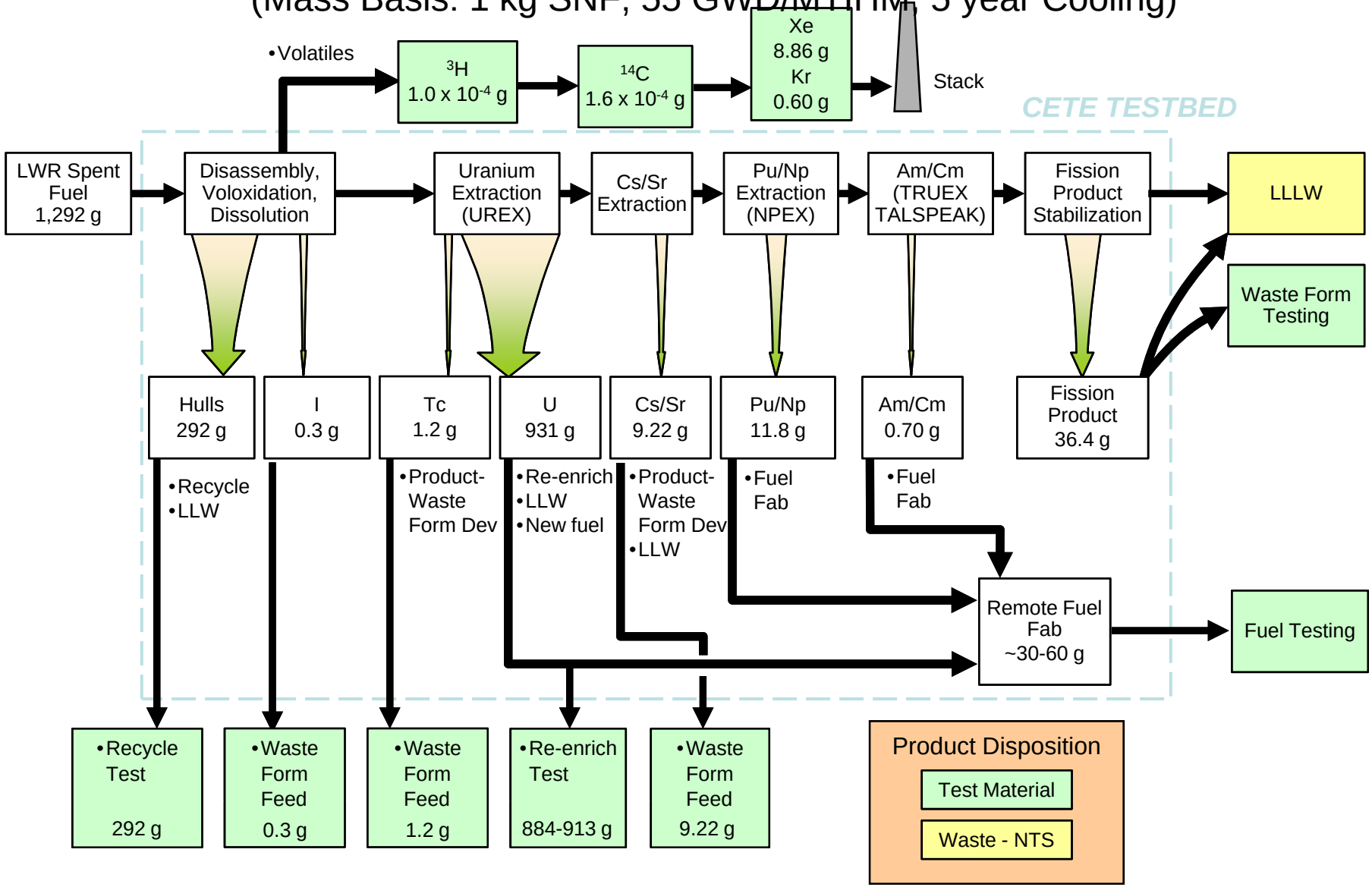
What is Coupled End to End?




Shearing
and dissolving
Head end preparation
MOX
Conversion
MOX Feed
Accountability
Solvent
Extraction
first cycle
Second cycle
Solvent
Extraction
Pu Concentration
and accountability
Waste Processing & U Recovery
Many other service vessels

GNEP CETE Processing Demonstration

(Mass Basis: 1 kg SNF; 55 GWD/MTIHM; 5 year Cooling)



Discussion???????