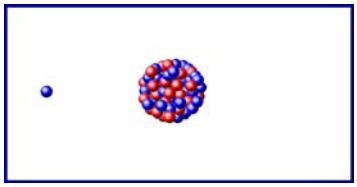
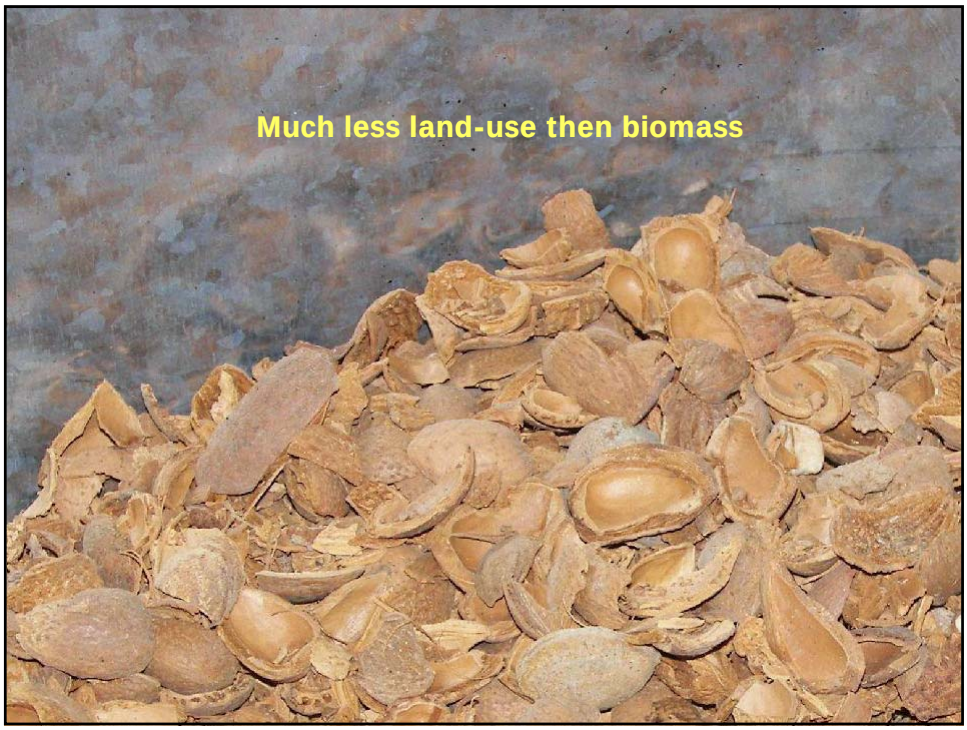
The road to sustainable nuclear energy

Jan Leen Kloosterman, Physics of Nuclear Reactors, TU-Delft
28-10-2009



Much more reliable then wind


Much less land-use then biomass

Much cheaper then solar

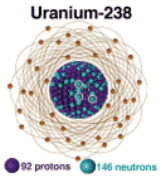
Works also in the Netherlands

Contents

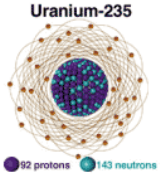
- Principles of nuclear power
- Principles of nuclear safety
- Characteristics of nuclear waste
- The nuclear fuel cycle now and in the future
- Uranium resources

Uranium isotopes

Not fissile

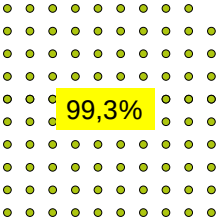


extra neutrons - heavier

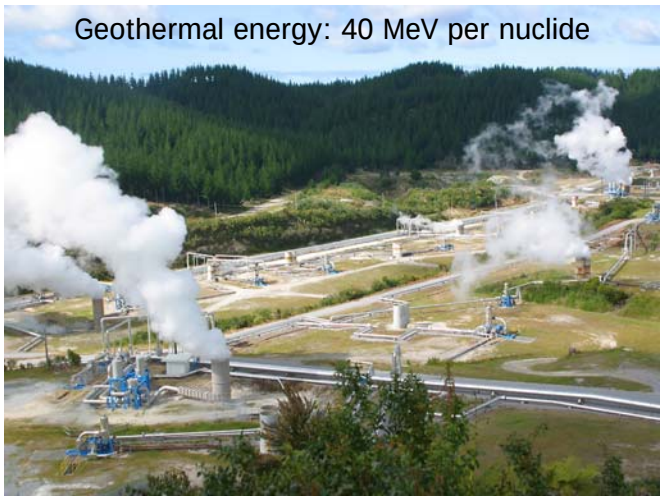


lighter and more active

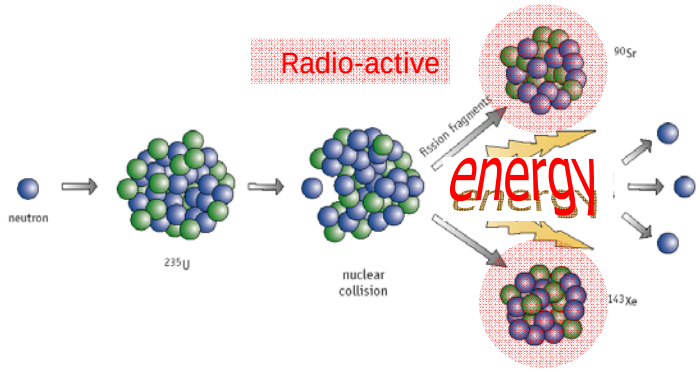
Fissile → Good fuel



How to extract energy from Uranium



Nuclear fission



200 MeV per nuclide

Fossils equivalent to 1 gram of U235

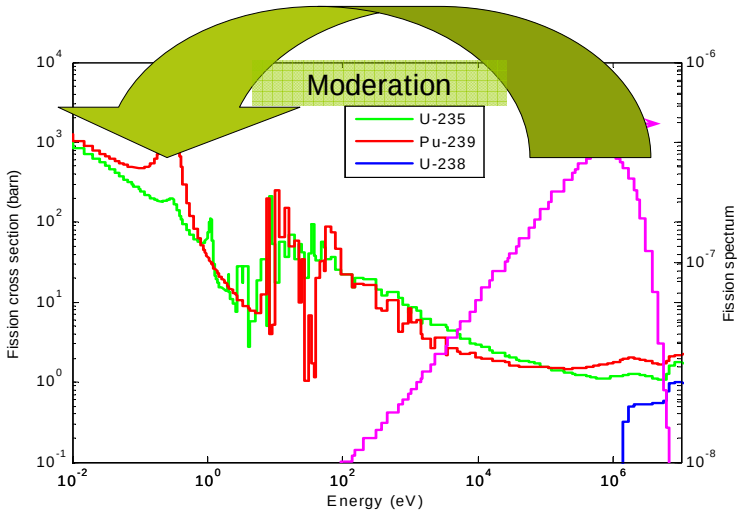
Gasoline

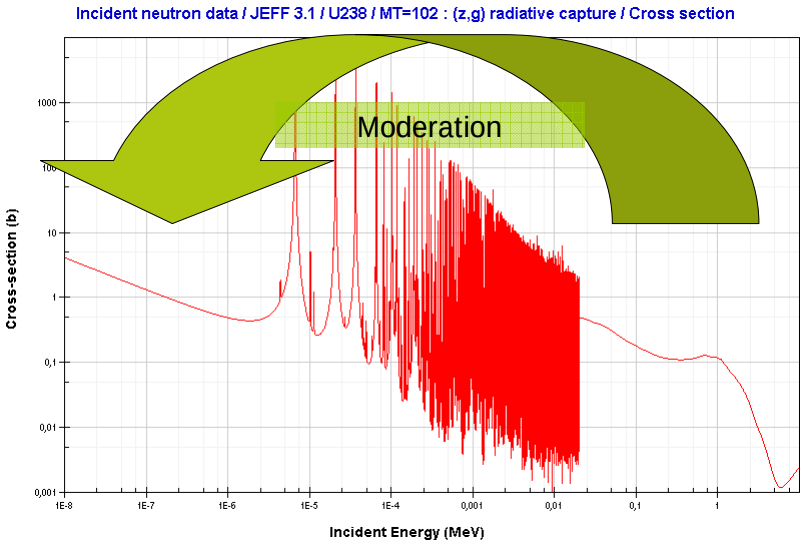
2500 liter

Coal

3000 kg

Fission cross section

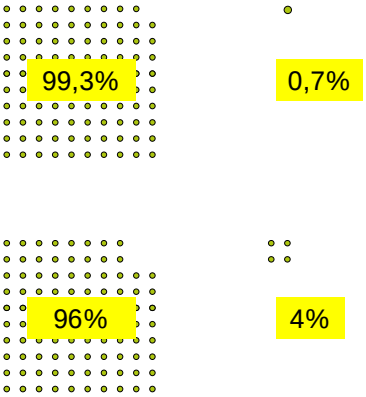


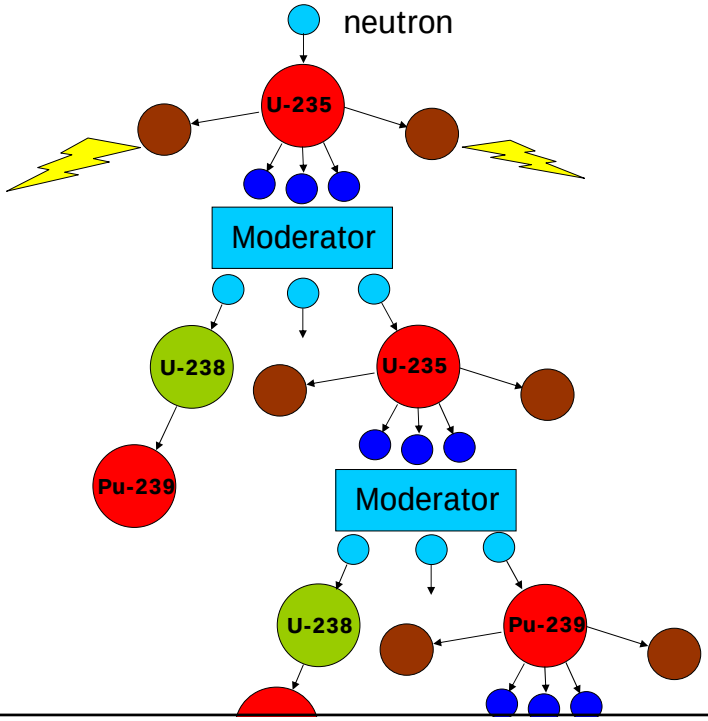


Fuel composition

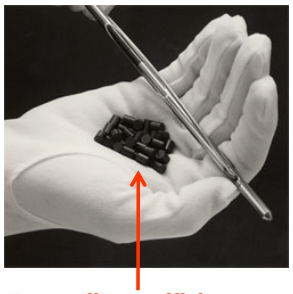
Natural uranium

4% enriched uranium in nuclear fuel

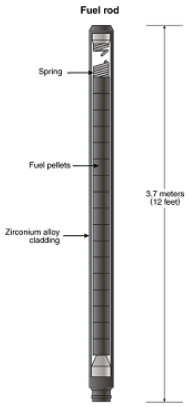




Fuel assembly of a PWR

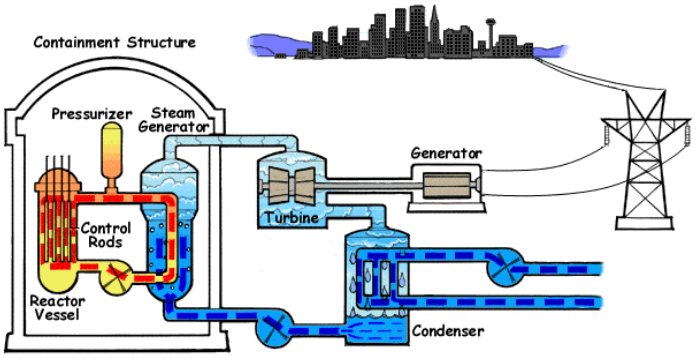


Two pellets sufficient to generate all electricity for a Dutch family per year



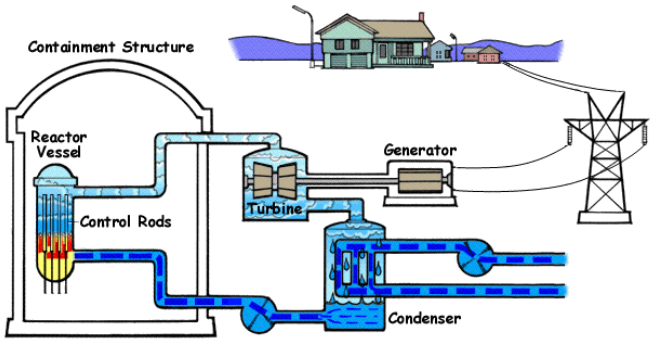
Pressurized Water Reactor

'Borssele'

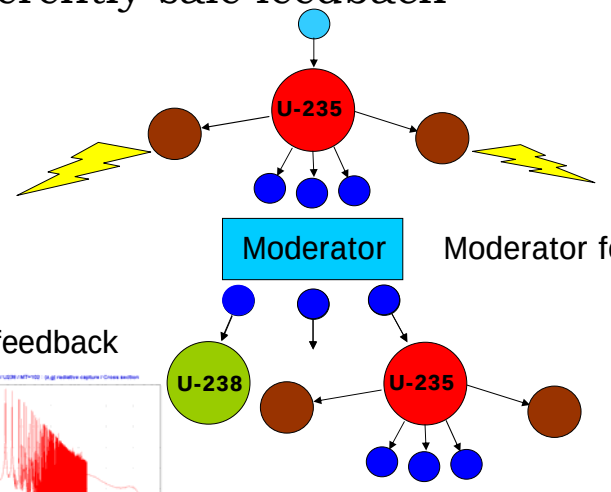


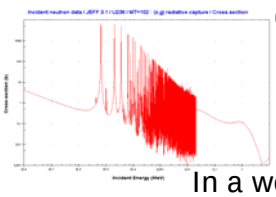
Boiling Water Reactor

'Dodewaard'



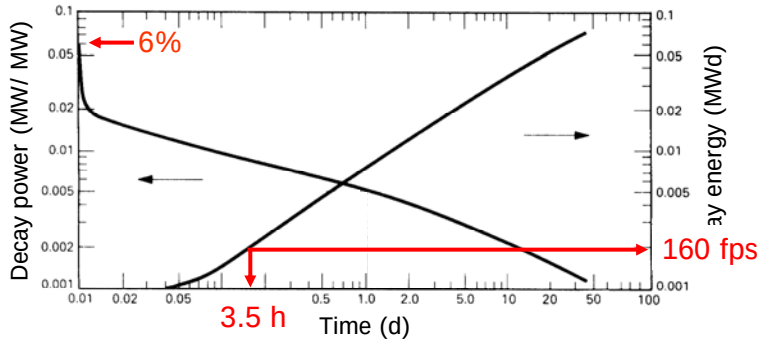
Inherently safe feedback





In a well-designed nuclear power plant, the negative feedback mechanisms always dominate

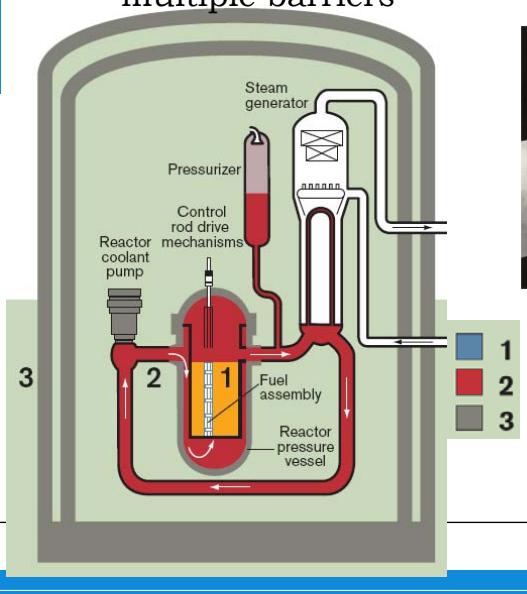
Decay heat production

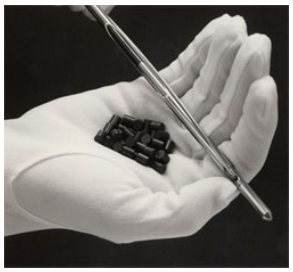


Source: ORNL

Safety of Nuclear Power Plants

multiple barriers



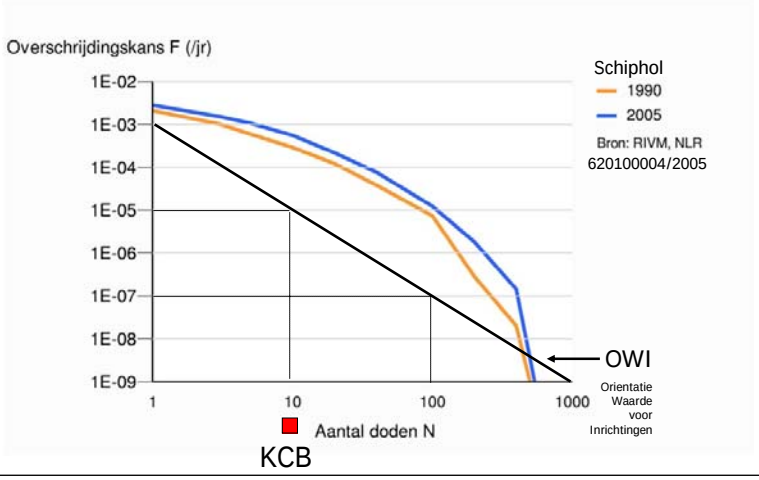


1 Fuel (pellet and cladding)

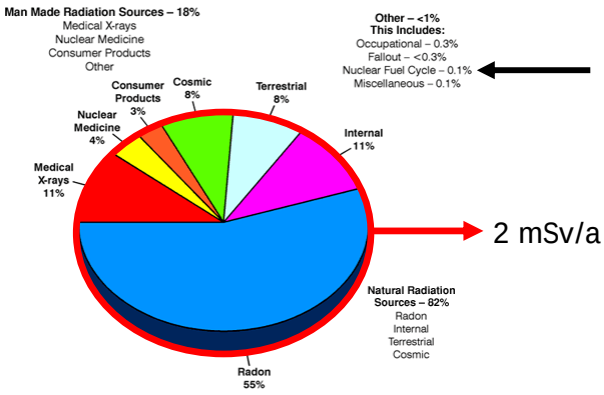
2 Primary system (steel)

3 Containments (2x concrete + steel)

Group risk industrial activities



Radiation Exposure to the Public

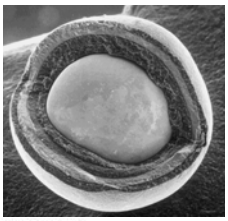


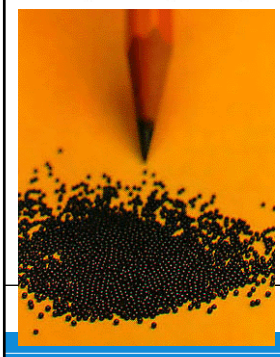
The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987.

This chart shows that natural sources of radiation account for about 82% of all public exposure while man-made sources account for the remaining 18%.

TRISO coated fuel particles

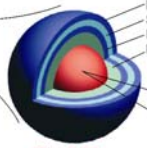
Dia. 60mm
Fuel Sphere





5mm Graphite layer
Coated particles imbedded in Graphite Matrix

Section

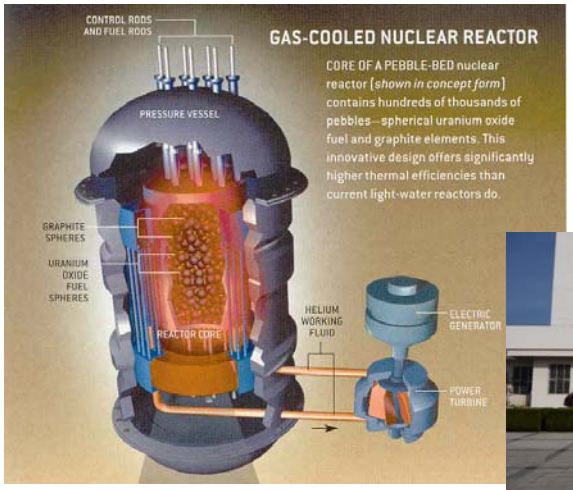


Pyrolytic Carbon 40/1000mm
Silicon Carbide Barrier Coating 35/1000mm
Inner Pyrolytic Carbon 40/1000mm
Porous Carbon Buffer 95/1000mm

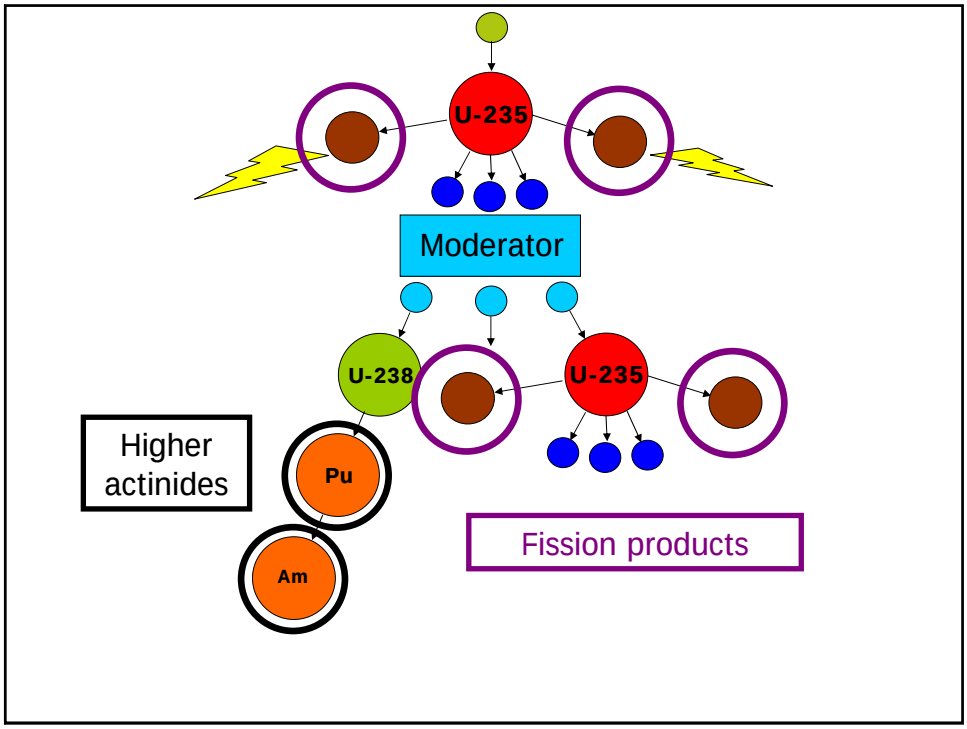
Dia. 0,92mm
TRISO
Coated Particle

Dia.0,5mm
Uranium Dioxide
Fuel Kernel

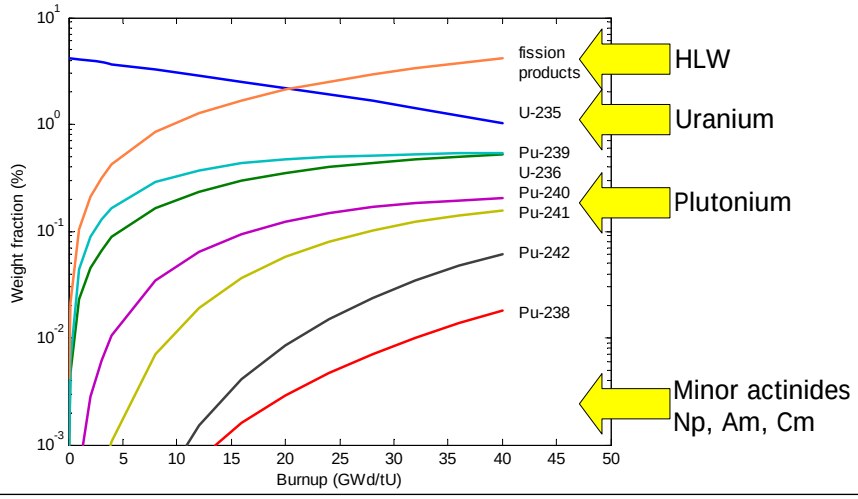
High Temperature Reactor (HTR)



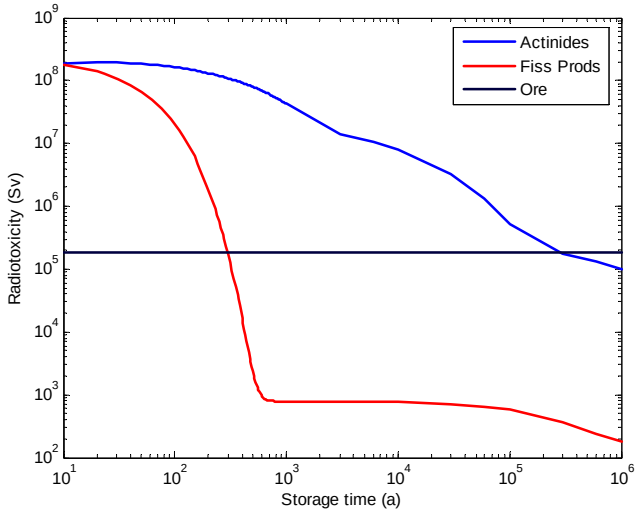
HTR-10, China



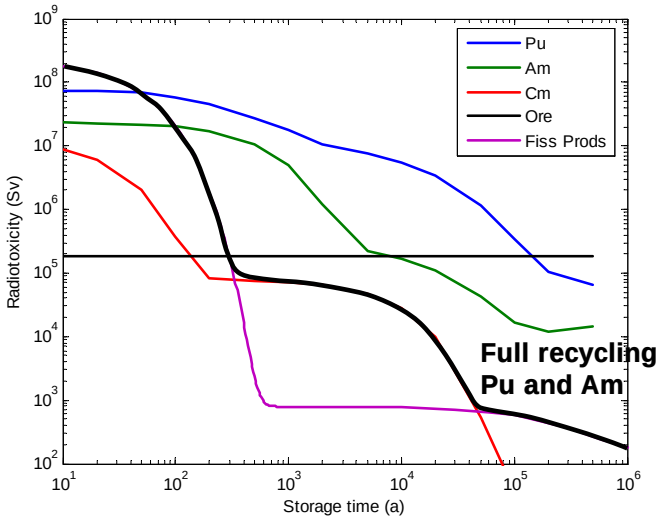
Spent fuel composition



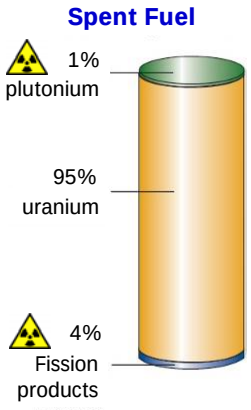
Radiotoxicity of spent fuel



Radiotoxicity per element



Spent fuel composition



Fast reactors

Phenix (F)

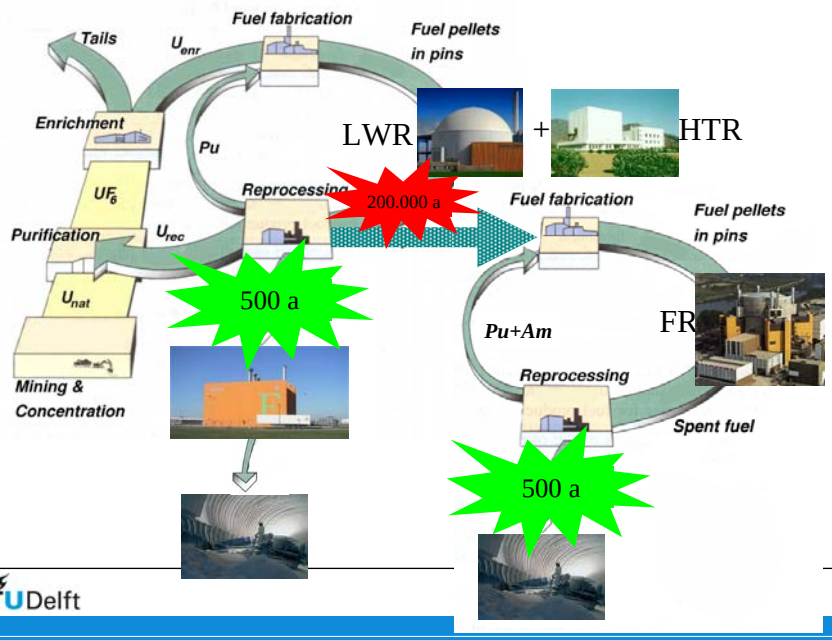
Super-Phenix (F)

Monju (Jp)

BN-600 (R)

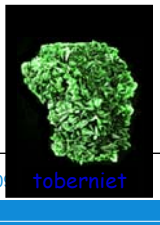
China Experimental Fast Reactor

Nuclear fuel cycle



Uranium resources

- The Earth's crust contains 40x as much uranium as silver.
- Cheap Uranium (up to 130 USD/kg): 5.5 million tons; enough for 80 years (0.15 ct/kWh)
- For the double price: 55 million tons; enough for 800 years. Using fast reactors 50,000 years.
- Uranium as by product from phosphate deposits: 22 million tons
- Uranium from seawater(450 USD/kg): 4 billion tons enough for millions of years.



Conclusions

- LWRs and Generation-IV reactors can never "explode".
- Decay heat should always be removed to avoid fuel damage.
- The resulting group risk of nuclear energy is very small.

- Plutonium is a good fuel and should be recycled.
- Fast reactors can reduce the required storage time of nuclear waste to 1000 years or less.
- Fast reactors can be used to fully exploit natural uranium.

- There is enough uranium for many thousands of years.
- The exploitation of thorium will quadruple these resources.
- Nuclear energy can contribute to a sustainable energy supply.