

The road to sustainable nuclear energy

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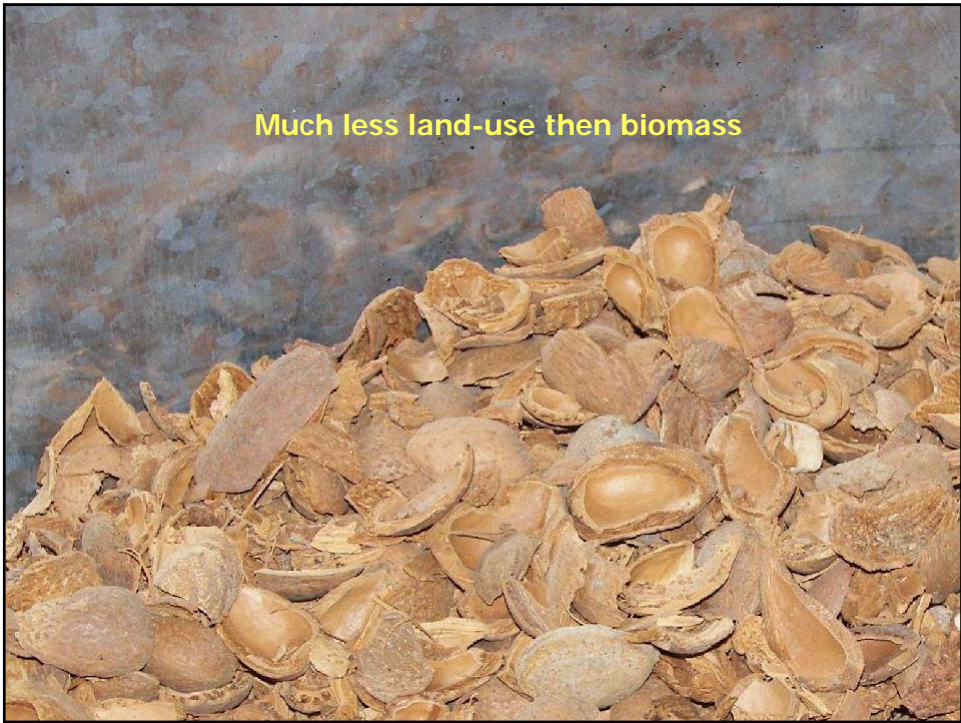


Much larger reserves than oil and gas





Much more reliable then wind



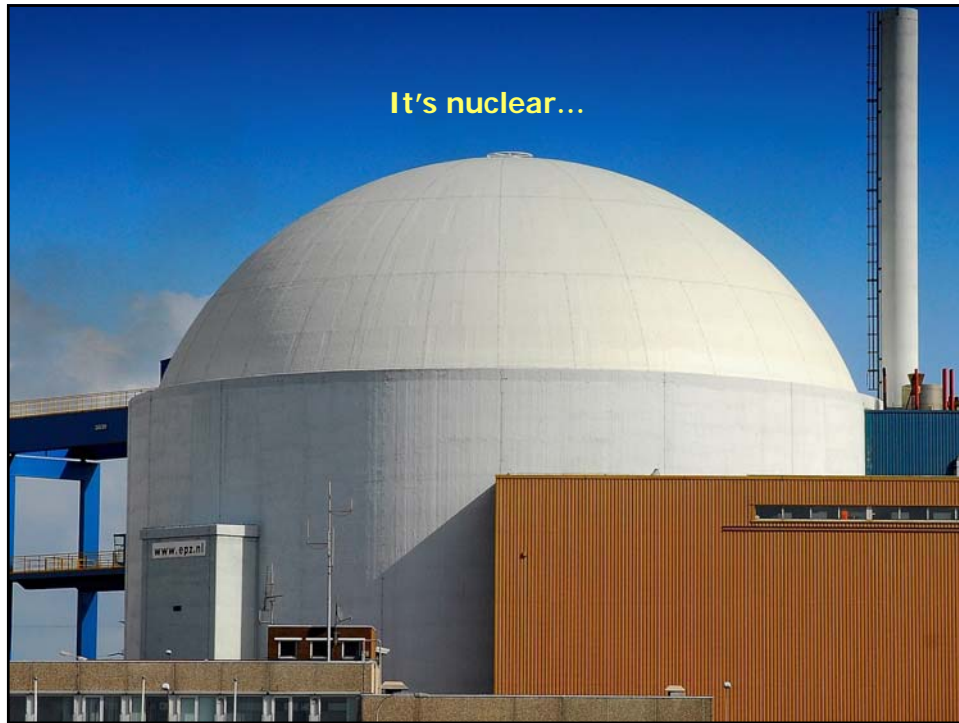
Much less land-use then biomass



Much cheaper then solar



Works also in the Netherlands

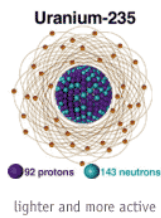
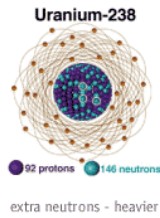


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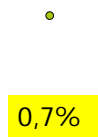
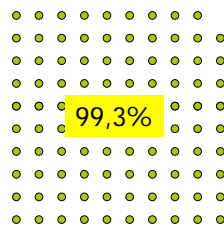
- Principles of nuclear power
- Principles of nuclear safety
- Characteristics of nuclear waste
- The nuclear fuel cycle now and in the future
- Uranium resources

Uranium isotopes

Not
fissile

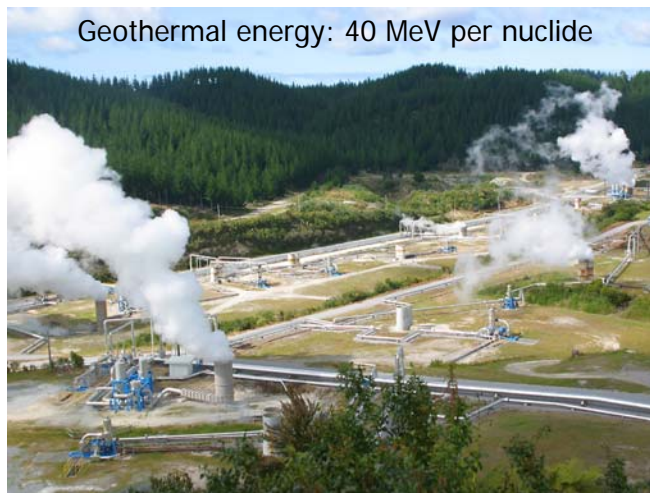


Fissile →
Good fuel

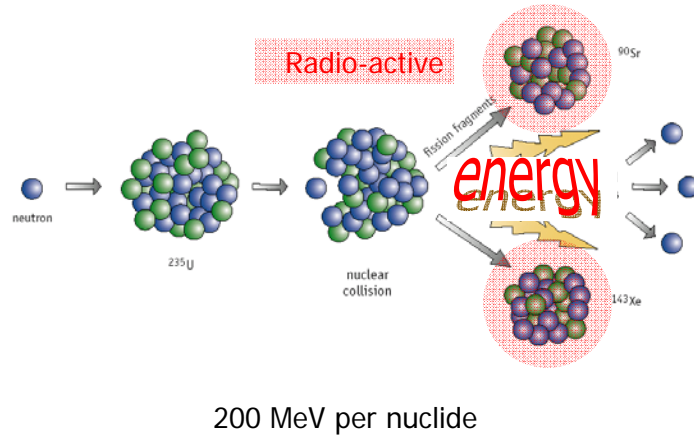


How to extract energy from Uranium

Geothermal energy: 40 MeV per nuclide



Nuclear fission



Fossils equivalent to 1 gram of U235

Gasoline



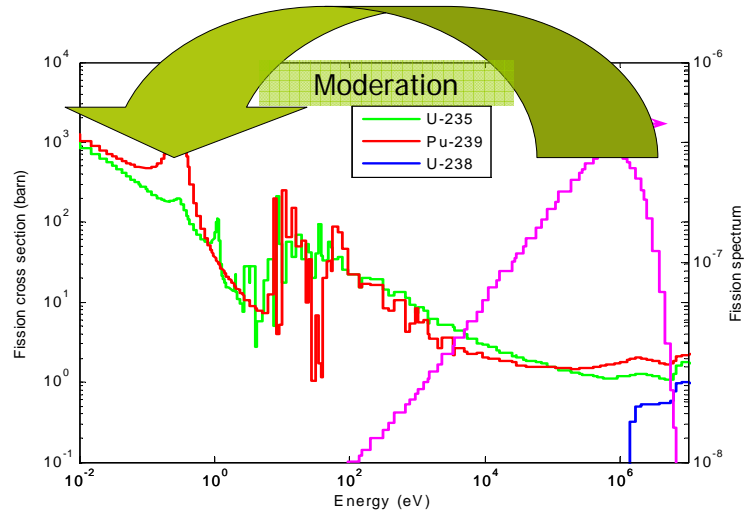
2500 liter

Coal

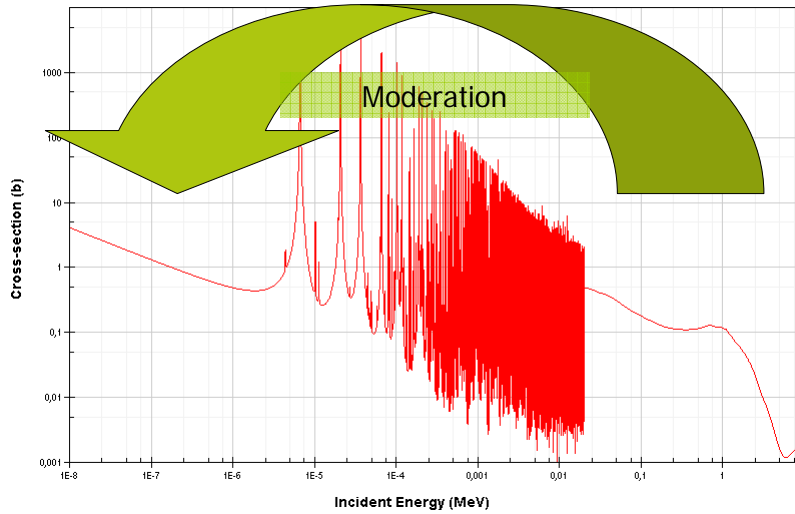


3000 kg

Fission cross section



Incident neutron data / JEFF 3.1 / U238 / MT=102 : (z,g) radiative capture / Cross section

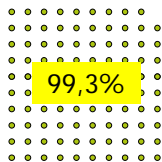


Fuel composition



Natural uranium

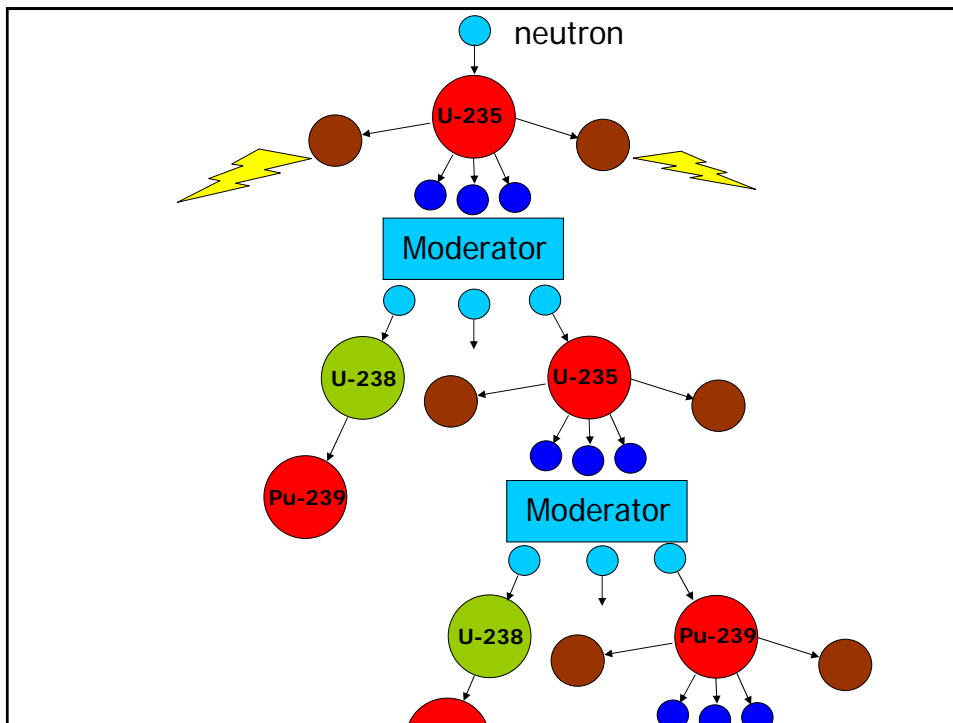
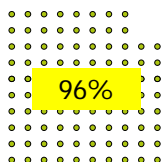
U-238



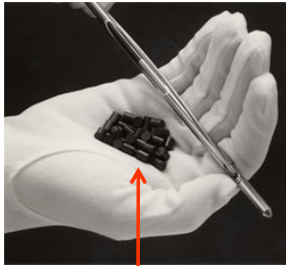
U-235



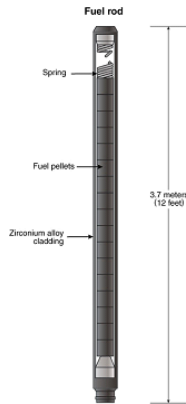
4% enriched uranium in nuclear fuel



Fuel assembly of a PWR



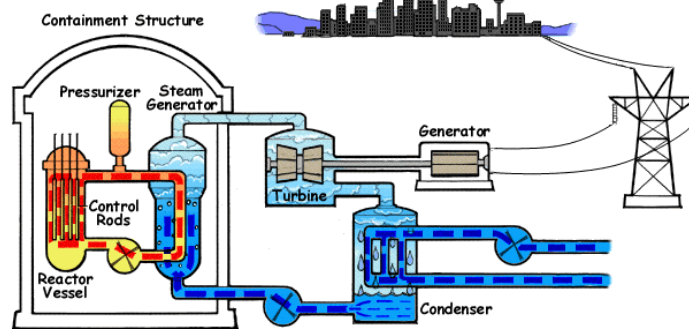
Two pellets sufficient to generate all electricity for a Dutch family per year



Pressurized Water Reactor



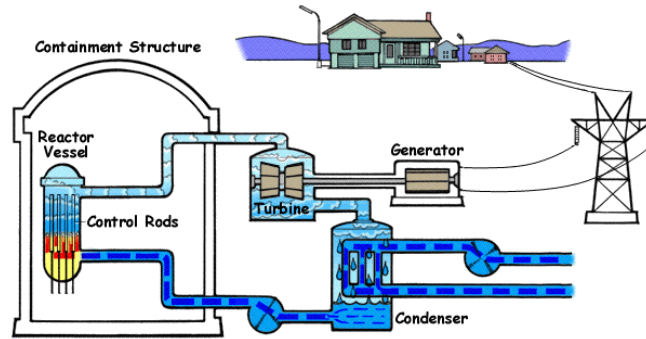
Borssele



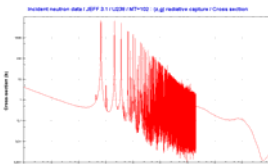
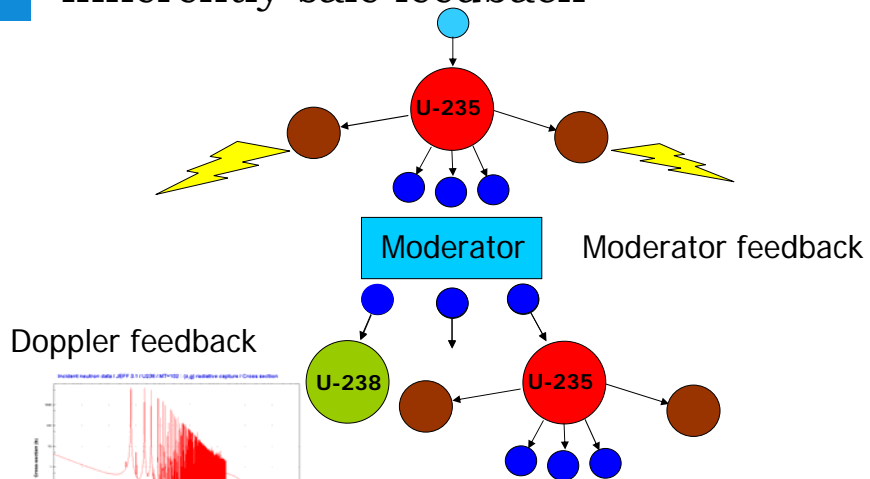
Boiling Water Reactor



'Dodewaard'

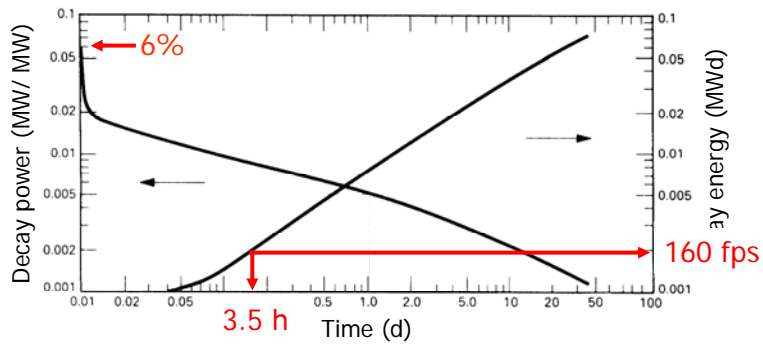


Inherently safe feedback



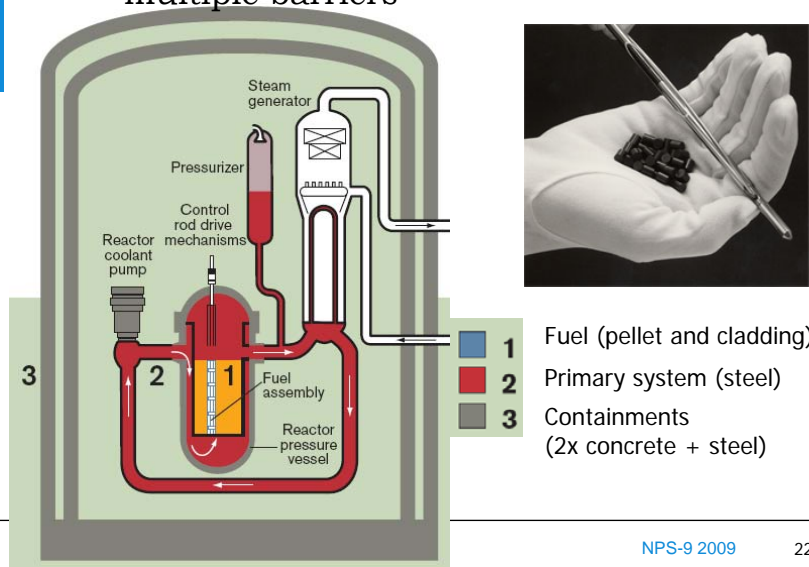
In a well-designed nuclear power plant, the negative feedback mechanisms always dominate

Decay heat production



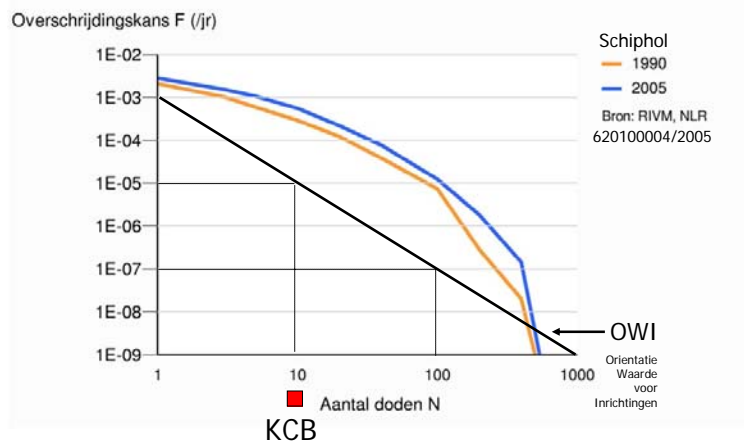
Source: ORNL

Safety of Nuclear Power Plants multiple barriers

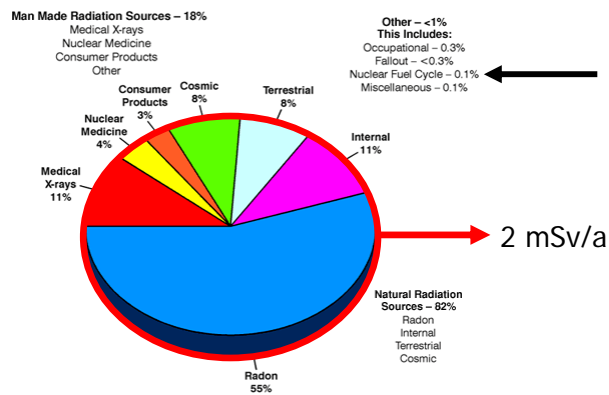


- 1 Fuel (pellet and cladding)
- 2 Primary system (steel)
- 3 Containments (2x concrete + steel)

Group risk industrial activities

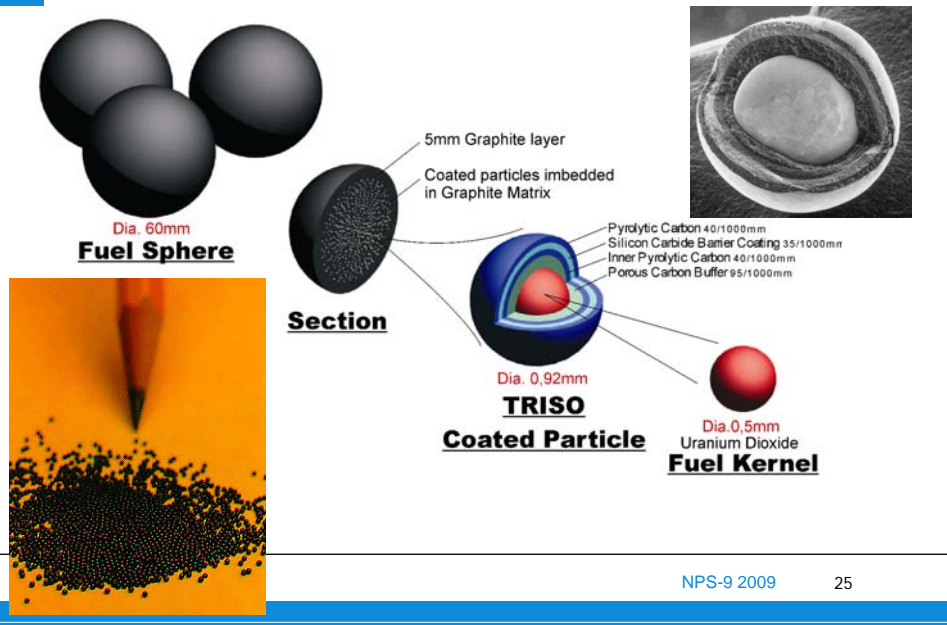


Radiation Exposure to the Public

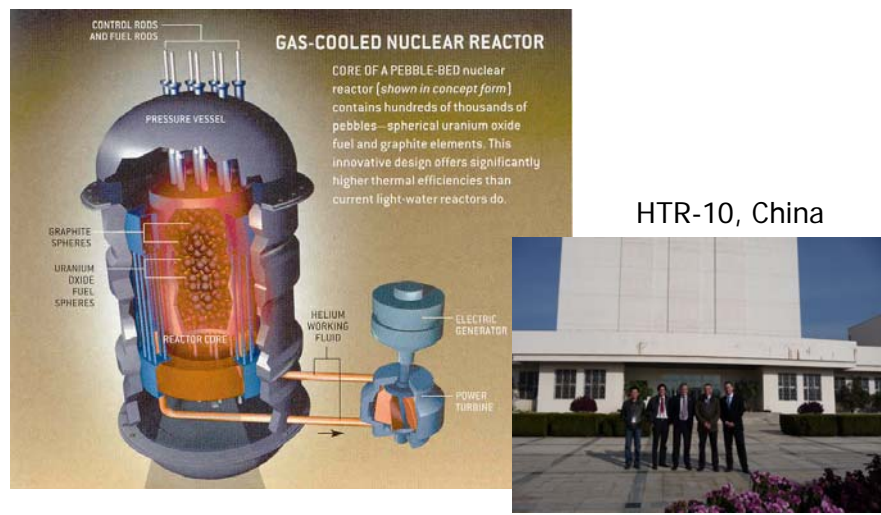


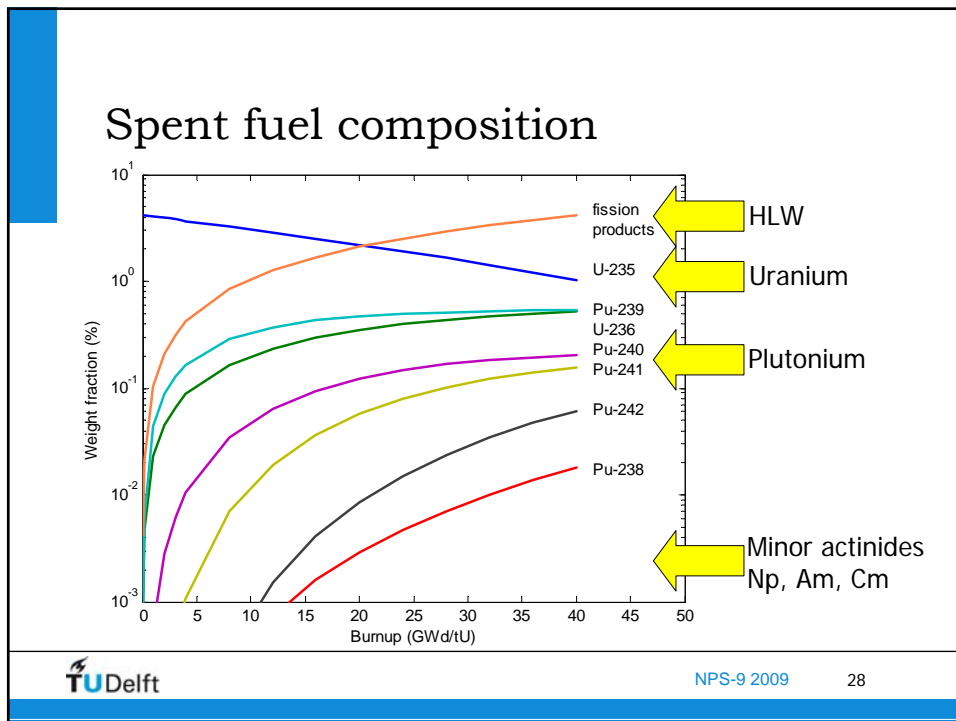
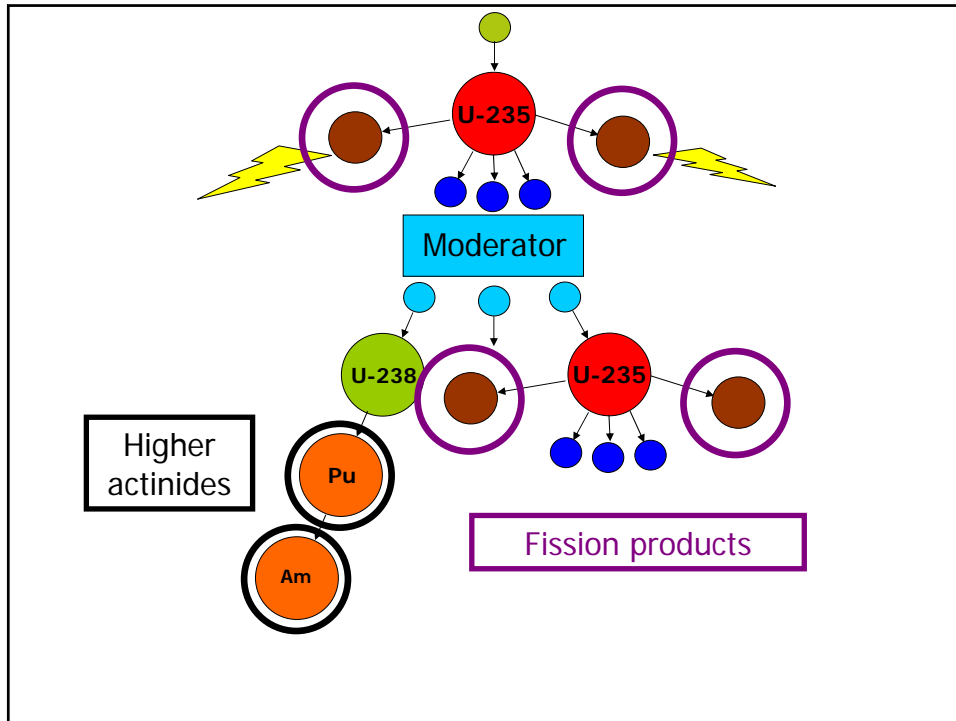
The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987. This chart shows that natural sources of radiation account for about 82% of all public exposure while man-made sources account for the remaining 18%.

TRISO coated fuel particles

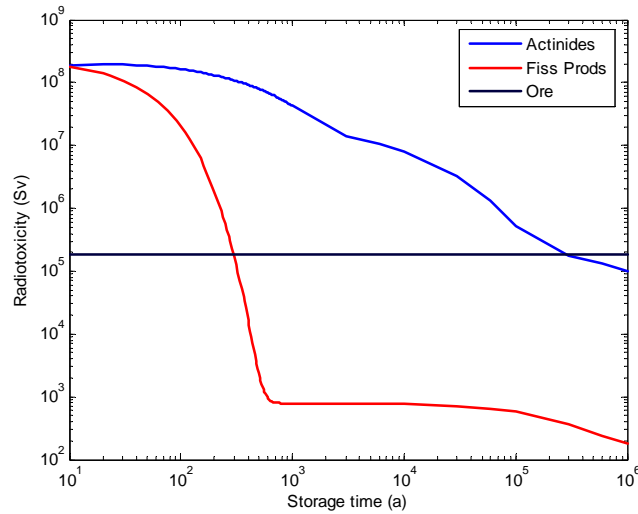


High Temperature Reactor (HTR)

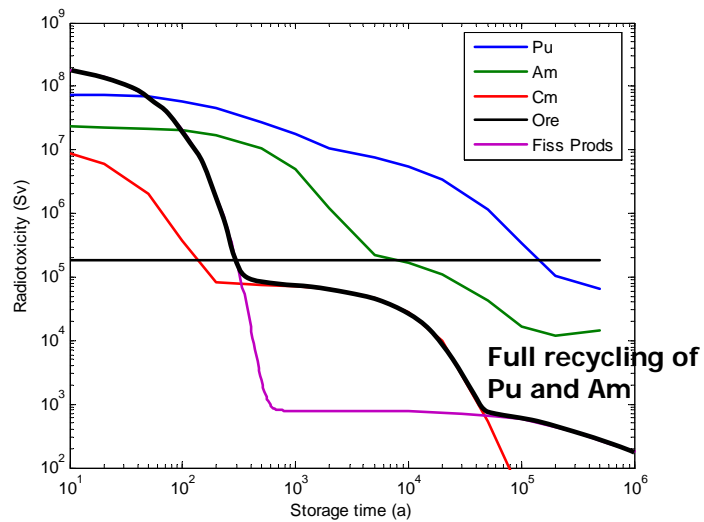




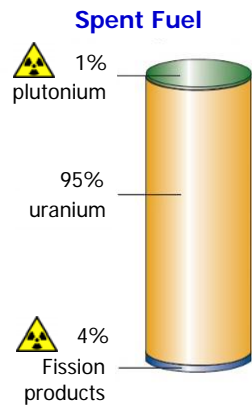
Radiotoxicity of spent fuel



Radiotoxicity per element



Spent fuel composition



Fast reactors



Phenix (F)



Super-Phenix (F)



Monju (Jp)

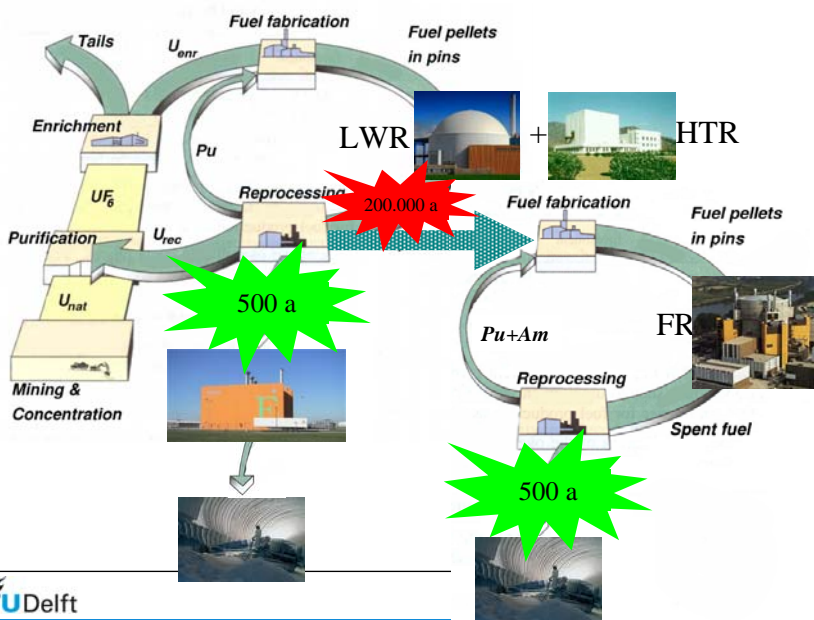


BN-600 (R)

China Experimental Fast Reactor

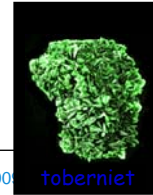


Nuclear fuel cycle



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.