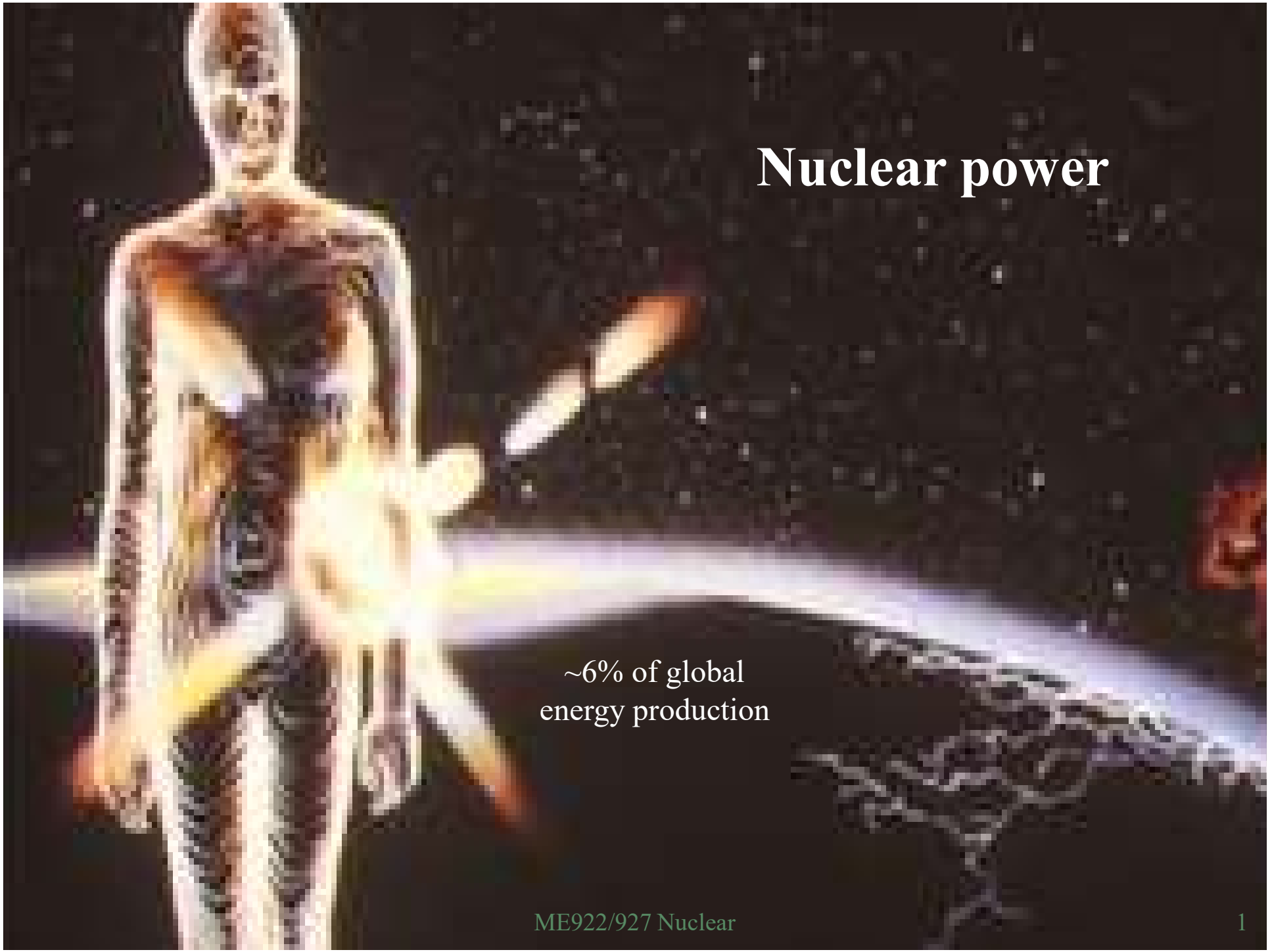
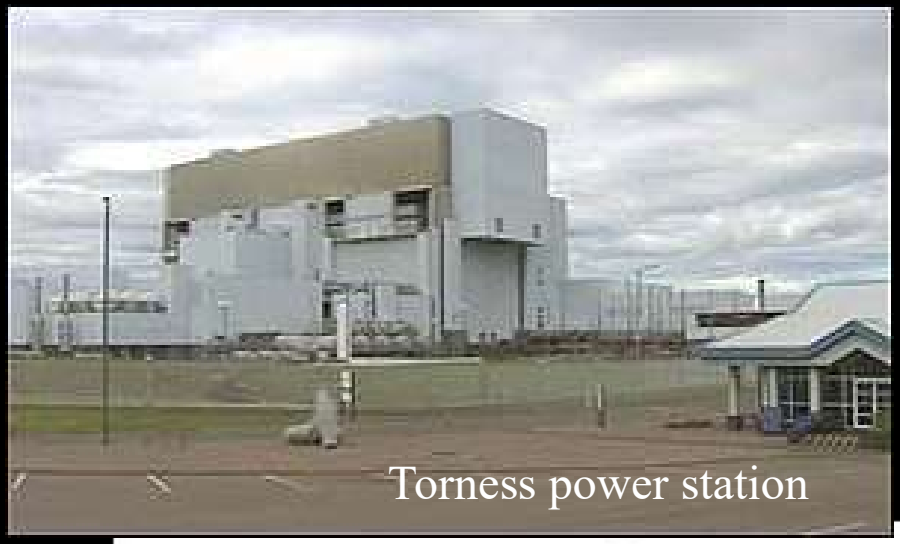
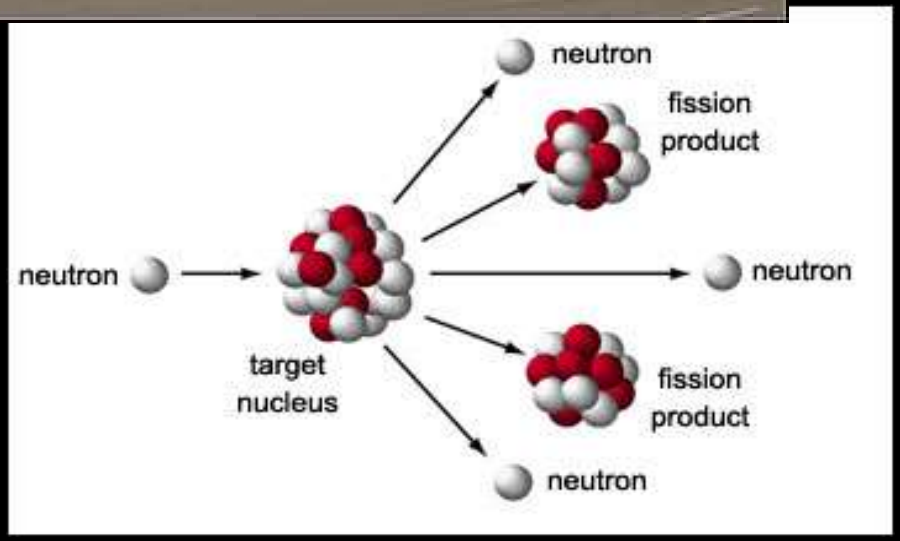


Nuclear power

~6% of global
energy production

The process

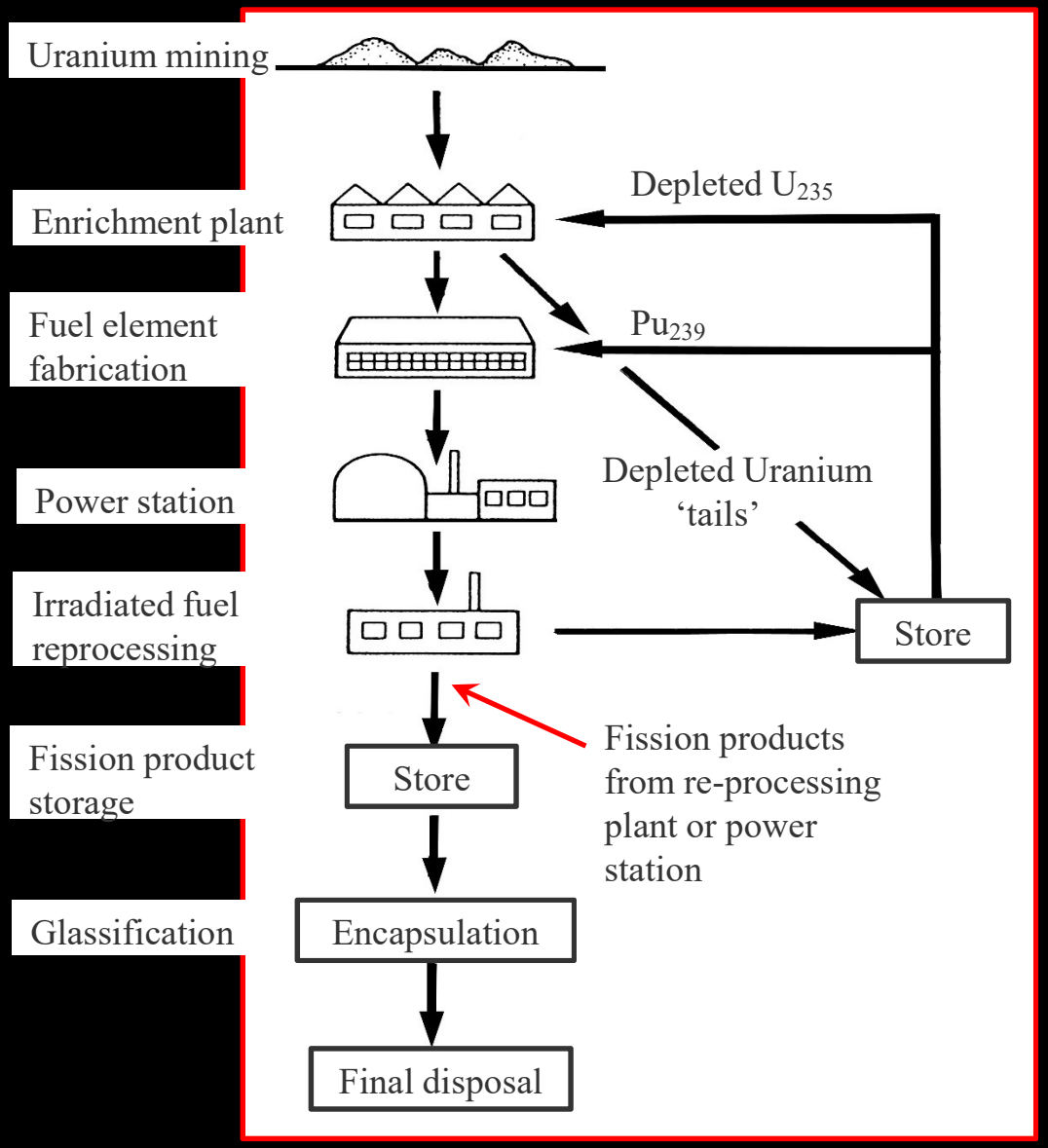




- The production of electricity by nuclear fission.
- The impact of a neutron with a U_{235} nucleus causes the fission process, from which come fission products, more neutrons and heat.
- In the recent past about 50% of Scotland's electricity was derived from nuclear power.
- A single fusion event produces 100 million times more energy that a single photon event in a PV cell.
- 10 tonnes of fuel (0.5 m3) produces 400,000 million kWh of energy with no emissions.

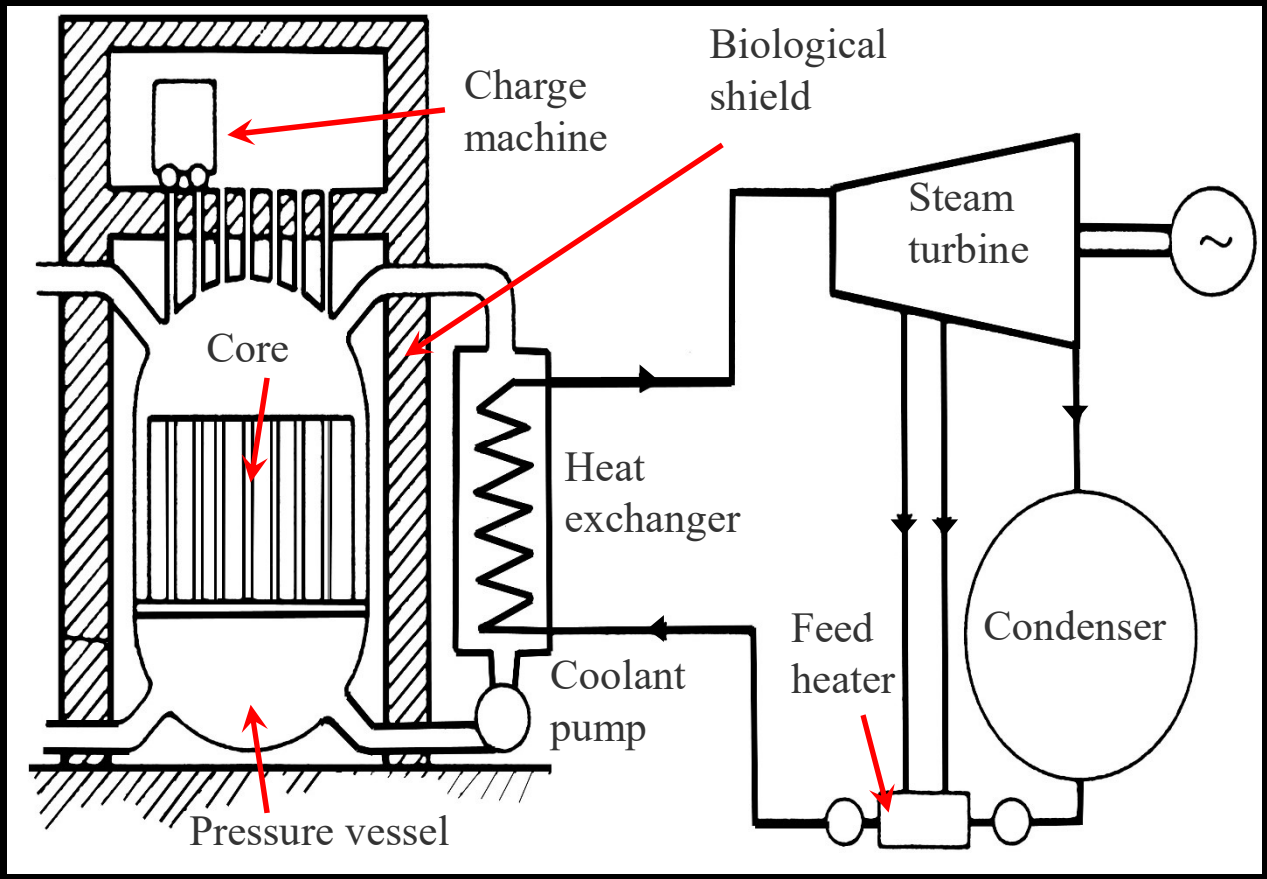
Nuclear fuel cycle

- Spent fuel elements require short-term storage to cool them down before handling.
- Spent fuel re-processing:
  - better use of limited uranium resources;
  - transportation of nuclear materials greatly increased.
- Some materials remain dangerous for very long periods and must be kept away from the biosphere.
- How do we do this, and where do we put them?



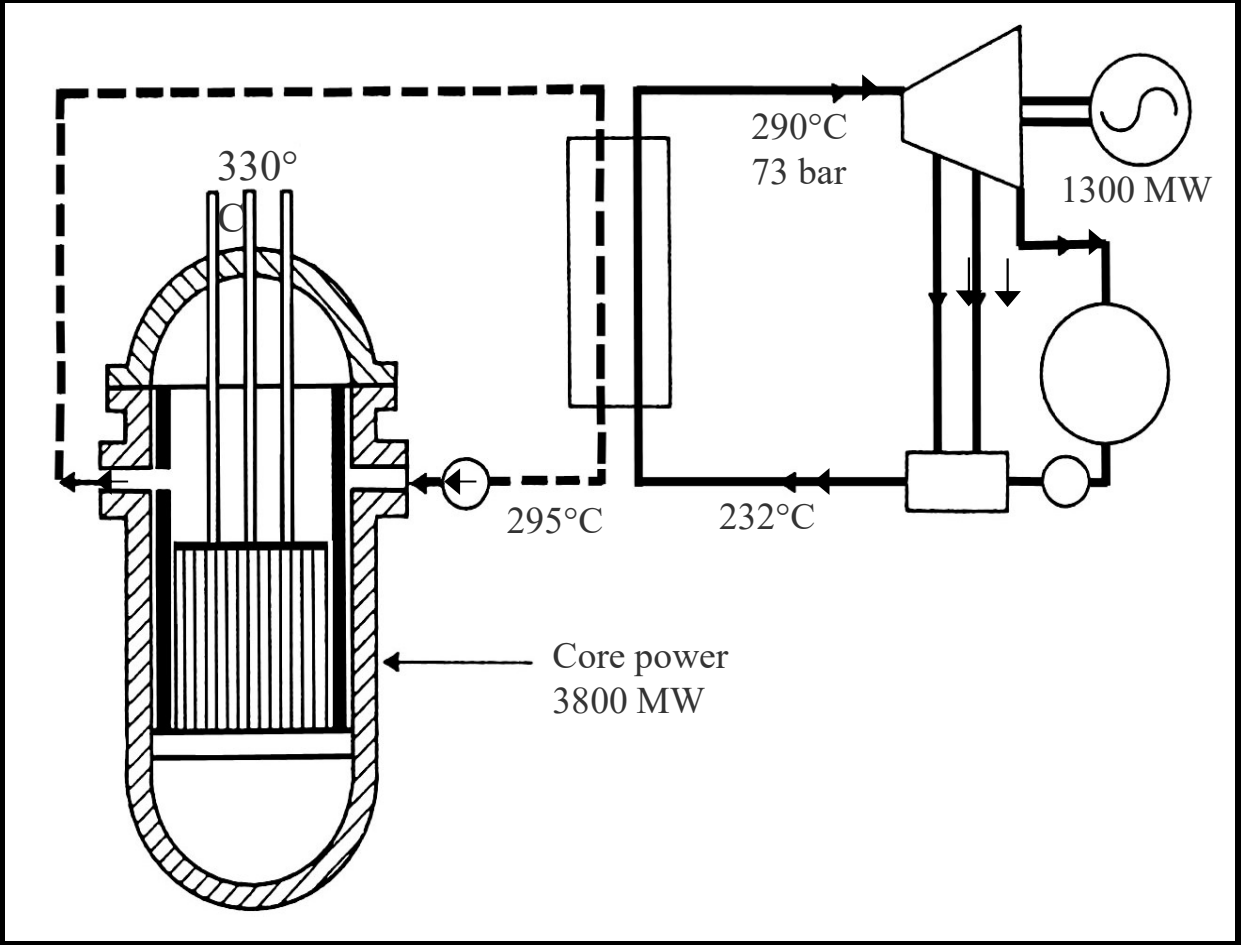
Commercial reactor components

- Two-stage cooling with heat exchanger.
- Conventional steam turbine power plant within the second stage.



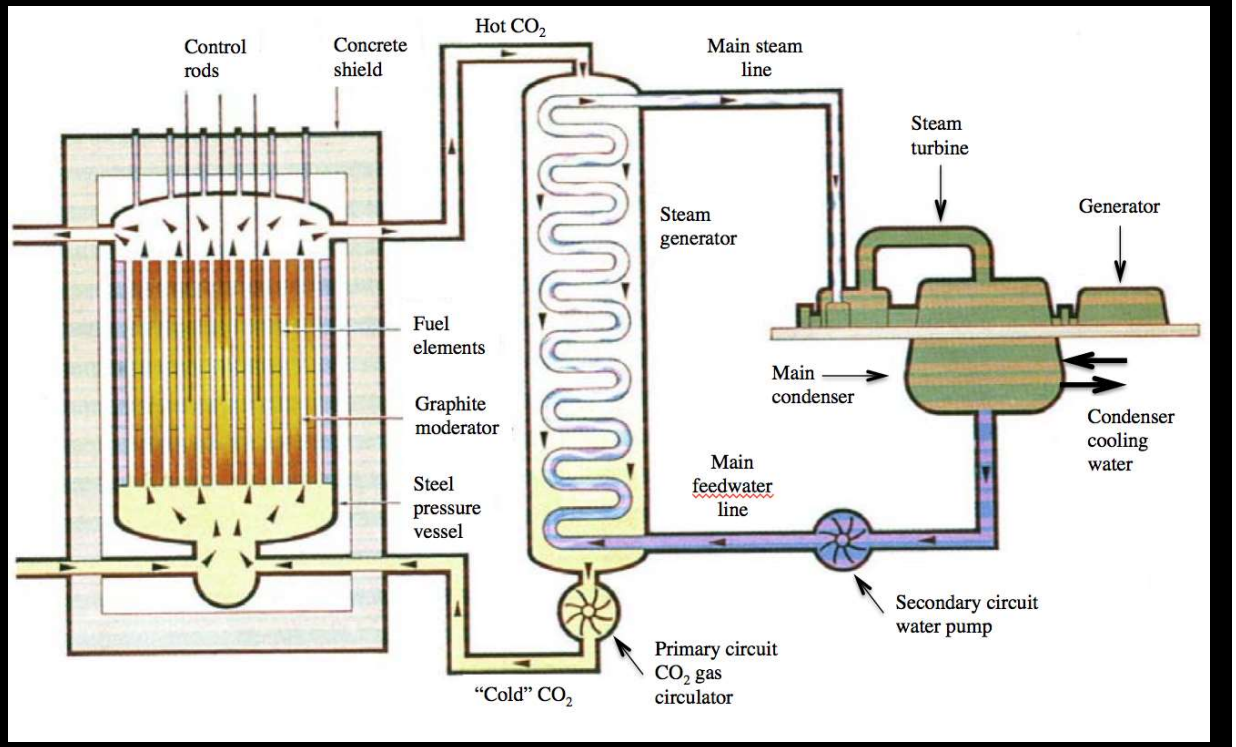
Pressurised Water Reactor (PWR)

- Water is used as both moderator and coolant, with the water in the core in liquid form at about 150 bar, 330°C.
- Note the disparity between power produced in the core and the electrical power output; reactor efficiency is around 35%.



UK reactors

- UK has traditionally specialised in gas-cooled reactors, with the early Magnox design followed by the advanced gas-cooled reactor (e.g. Hunterston A and B, respectively).
- Both types used graphite as the moderator and CO_2 as the coolant at about 25 bar, 370°C (Magnox) and 40 bar, 650°C (AGR).
- Thermal efficiencies were about 32% and 41% respectively.



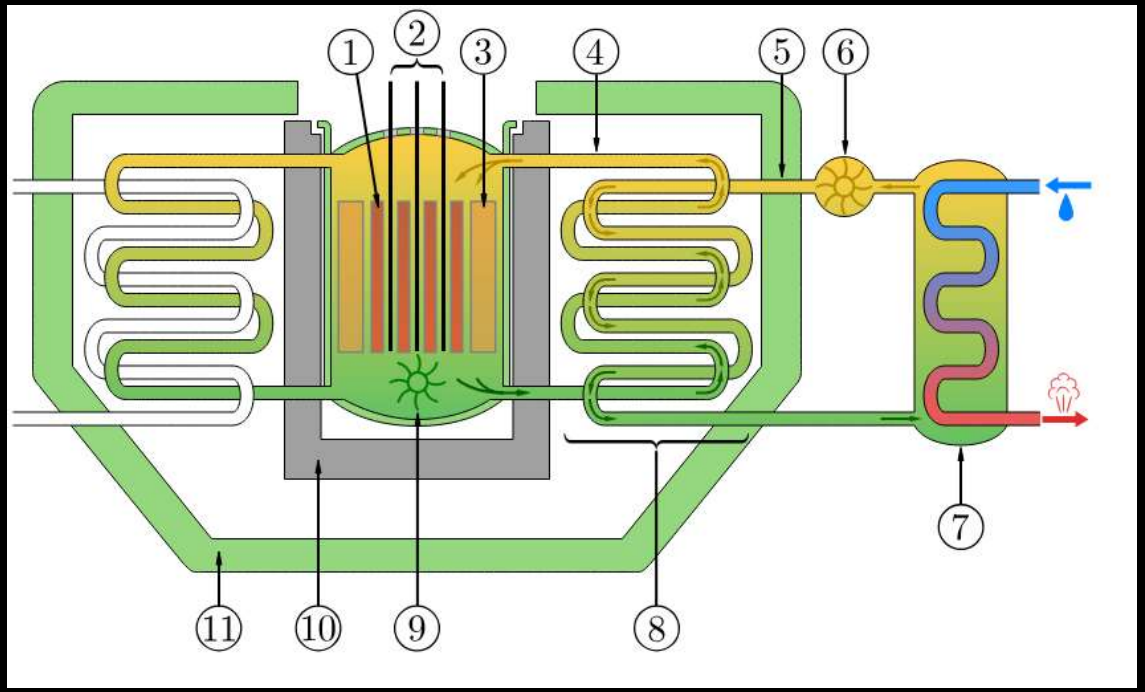
Breeder reactors

- Generate more fissile material than it consumes.
- Can burn almost all of its fuel while generating less waste than a normal reactor (which consumes less than 1% of its uranium fuel).
- Can use thorium, which is more abundant than uranium.
- Fast breeder reactors (FBR) are initially charged with plutonium, thereafter requiring only natural (or depleted) uranium as input to its fuel cycle.
- Some have argued that without breeder reactors supplying fuel for more numerous thermal power plants, nuclear power will remain a relatively small contributor to our energy needs.

Superphénix in France (1984-1998), at 1200 MWe, the largest FBR yet built.

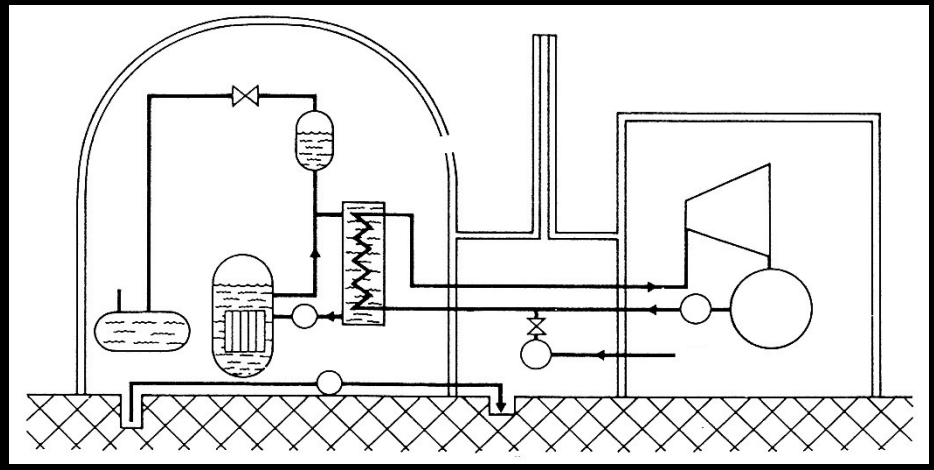
Dounreay Fast Breeder Reactor (1957 – 1994)

- 1 Fissile Pu-239 core
- 2 Control rods
- 3 U-238 Breeder blanket
- 4 Primary NaK coolant loop
- 5 Secondary NaK coolant loop
- 6 Secondary NaK circulator
- 7 Secondary heat exchanger
- 8 Primary heat exchanger
- 9 Primary NaK circulator
- 10 Boronised graphite neutron shield
- 11 Radiation shield



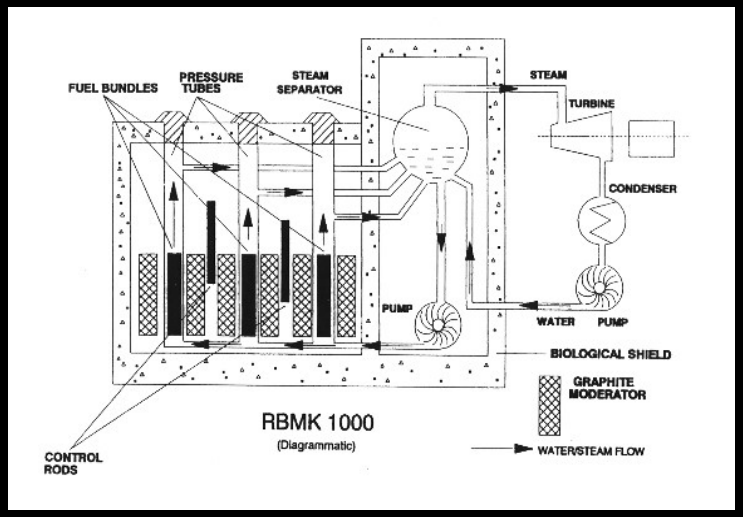
Three Mile Island, USA

- 1979: Destruction of Pressurised Water Reactor, largely as a result of operator error.
- Minor release of radio-active material, no injuries.
- Halted nuclear expansion in USA for ~10 years.



Chernobyl

- RBMK (Reactor Bolshoy Moshchnosty Kanalny) pressurised, water-cooled reactor with individual fuel channels.
- Unusual design, with several shortcomings (combination of graphite moderator and water coolant).
- April 26 1986 explosion and fire resulting in 31 deaths.
- Reactor now encased in concrete.
- Major modifications have been made to the 15 RBMK reactors still in operation.



Fukushima

- Disabled by a magnitude 9 earthquake and 15 m tsunami on 11 March 2011.
- 3 reactor cores suffered melt-down.
- 20,000 people killed by the natural disaster, no fatalities at the reactor site.
- Plant decommissioned with a clean-up bill ~$50 billion.

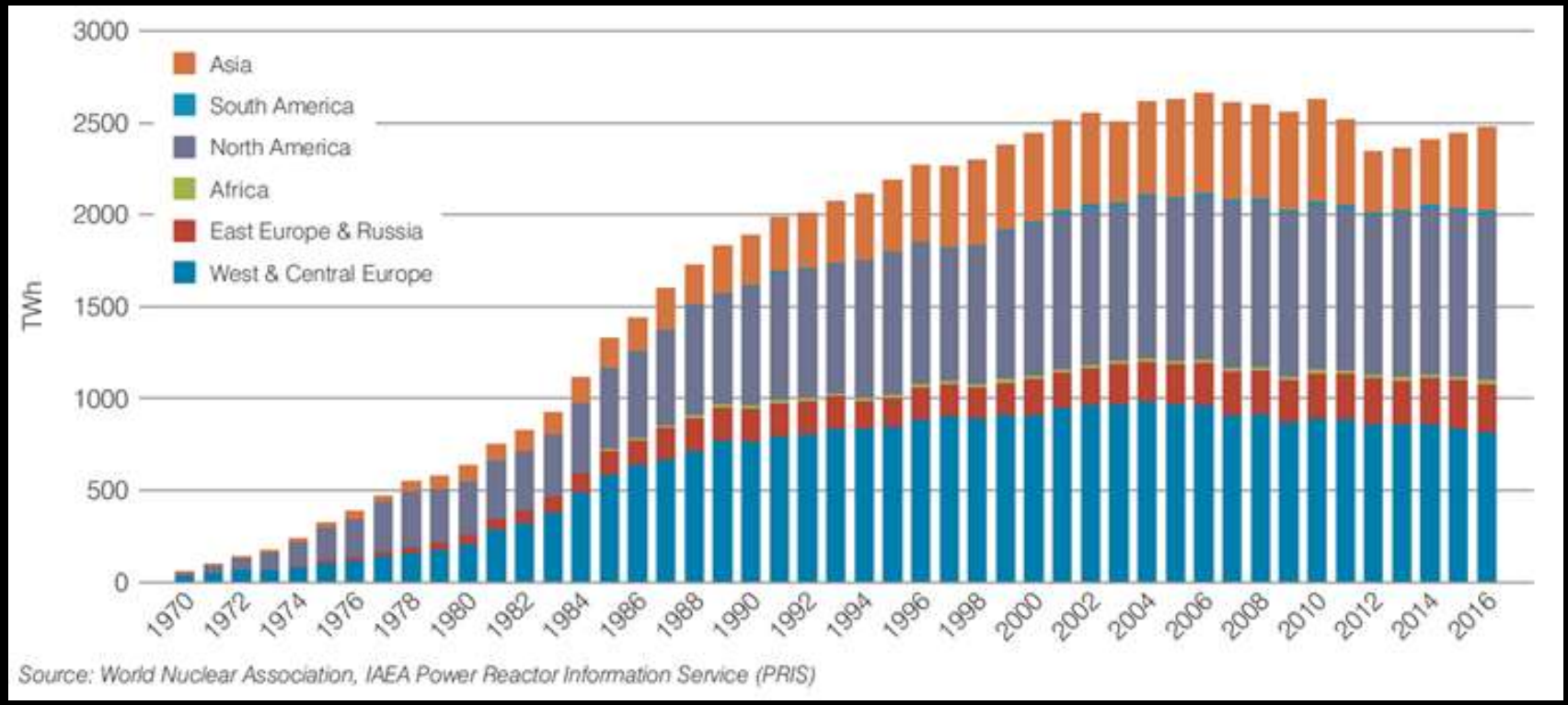
Nuclear power in Europe

- The number of operational commercial reactors is shown for each country.
- Nuclear-free countries are indicated in white.
- In Western Europe, only France remains firmly committed to nuclear power.
- Under construction: Finland 1; France 1; Russia 11; Slovak Republic 2; Ukraine 2.

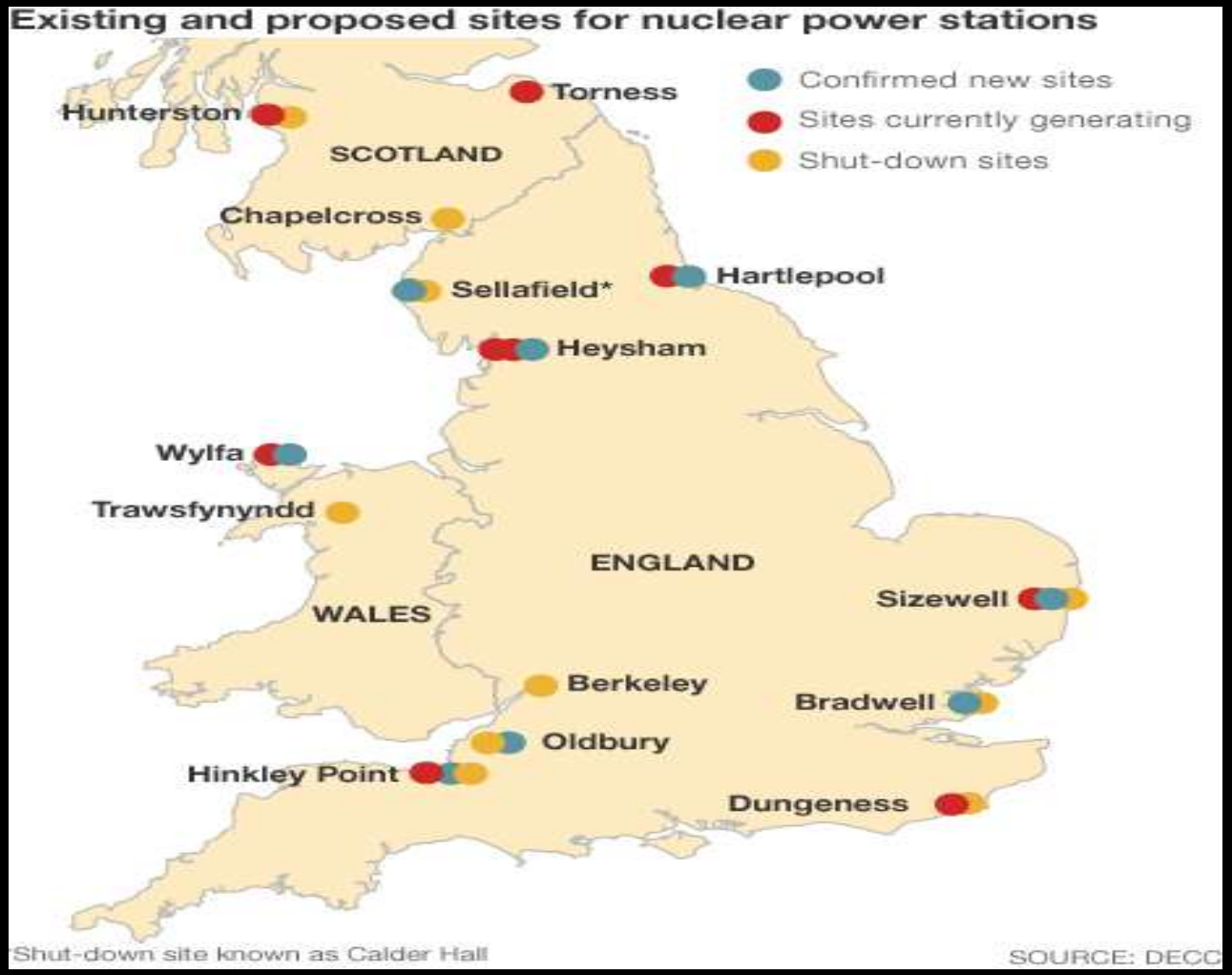
Total capacity: ~164 GWe

Nuclear power world-wide

- Peak output in 2006.
- Fukushima disaster (2011) had a dramatic impact on output.
- Growth in Asia, rest of the world static.

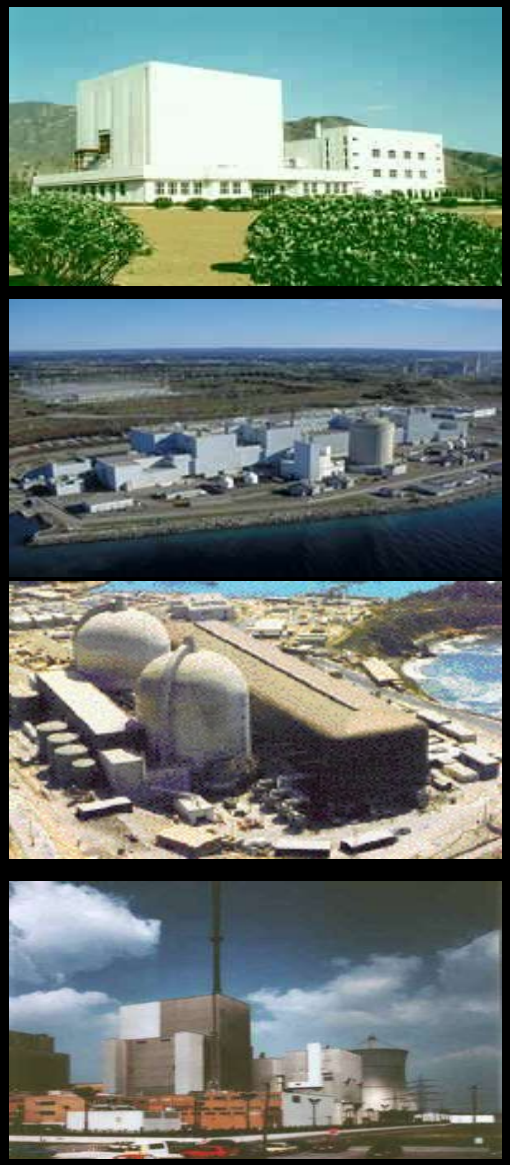


New UK nuclear power



Issues

- Primary waste is spent uranium fuel rods.
- Entire US inventory generated over the past 50 years weights 59,000 tonnes corresponding to a volume of 3,375 m^3 (i.e. a cube with 15 m side).
- Uranium is a non-renewable resource:
  - ~7.5 million tonnes economically minable (~230 years worth);
  - increases to ~460 years with spent fuel reprocessing;
  - or ~30,000 years if breeder reactors were used to create more radioactive fuel;
  - seawater contains 4.5 billion tonnes of dissolved uranium (~60,000 years worth);
  - minable thorium (used breeder reactors to produce uranium) has reserves estimated at 5.9 million tonnes.



Nuclear fusion

- Abundant fuel supply (sea water).
- 1g equivalent to 45 barrels of oil.
- Little radioactive waste.
- Astronomical temperatures required.
- Commercial by 22nd century?