Imperial College London

Key Issues for New Nuclear

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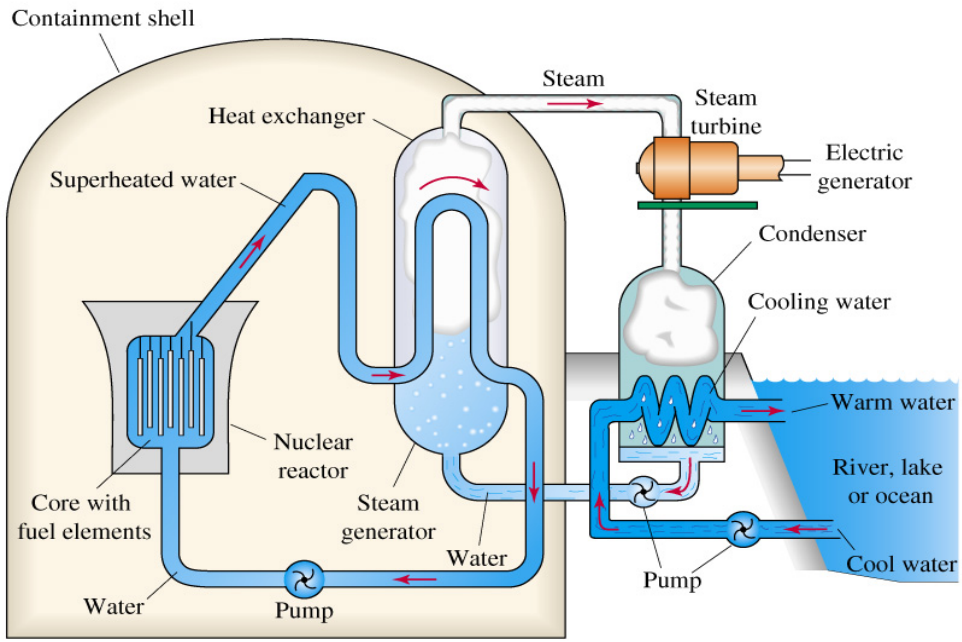
The Questions as Posed

- What are the options in the short, medium and long term?
- Is nuclear transitional?
- How much can it deliver? When will nuclear deliver?
- Is nuclear sustainable?
- What is the (relative) environmental impact?
- What are the obstacles to implementation?
- What research do we need to carry out?
- Where should we be in 2020, 2050 2100 and beyond?

Nuclear Energy is Controversial

- Nuclear energy has been generated in the UK for 50 years, safely and reliably with minimal impact on the environment.
- Nuclear waste will remain active for 100,000 years and we have no proven solution for this problem.



Generic PWR Reactor

- While the public may be willing to accept new nuclear in general terms, the willingness of the individual to accept the proximity of new build is doubtful. The public does not understand the issues surrounding nuclear power and has a strong sense of risk.

Fission: Release of Energy

- Once the neutron has caused the nucleus to split, the two fission products repel and flay apart with great velocity.

- Collisions of the heavy ion fission fragments with the host matrix (UO_2) causes *damage*, which may anneal, and other processes that are converted into phonons (heat).

- A fission event releases ~ 200,000,000 eV of energy.

  e.g. U-235 + n $\longrightarrow$ Ba-141 + Kr-92 + 3n + 170 MeV

- A chemical reaction releases ~ 1 eV of energy.

  Nuclear fuel is a very compact energy source.

- Thermal to electric conversion efficiencies are not dissimilar.

Designs and performance: past, present and future

History Lesson

Electricity was generated for the first time by a nuclear reactor on December 20, 1951 at the Experimental Breeder Reactor I (EBR-I) near Arco, Idaho, producing enough electricity to power four 200-watt light bulbs. It went on to produce about 100 kW and power its building.

History Lesson

- The world's first commercial nuclear power station, Calder Hall in Sellafield, England was opened in 1956, a gas-cooled Magnox reactor with an initial capacity of 50 MW (later 200 MW).

- The Shippingport Reactor a LWBR pressurized water reactor, was the first commercial nuclear generator to become operational in the US in 1957. It operated for 25 years. Decommissioning finished in 1988; the site was cleaned-up and released for unrestricted use.

(Source: A Technology Roadmap for Generation IV Nuclear Energy Systems U.S. DOE Dec 2002)

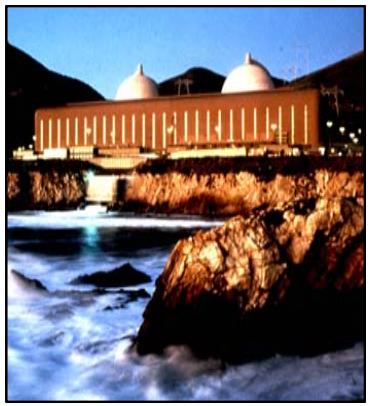
Generation I

Early Prototype Reactors

- Magnox
- Shippingport
- Dresden

Generation II

Commercial Power Reactors



- LWRs: PWR, BWR
- CANDU
- AGR

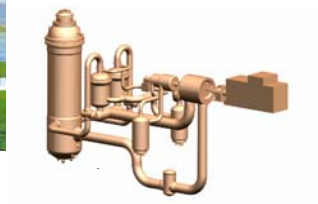
Generation III

Advanced LWRs

- ABWR
- AP600/AP1000
- EPR

Generation III+

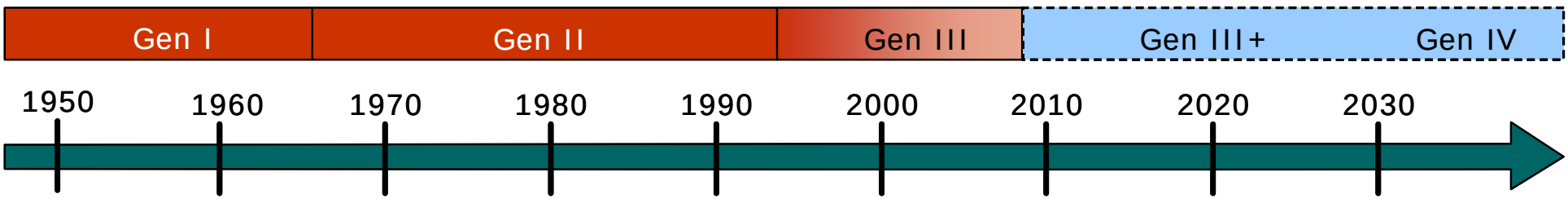
Evolutionary Designs



- PBMR
- IRIS

Generation IV

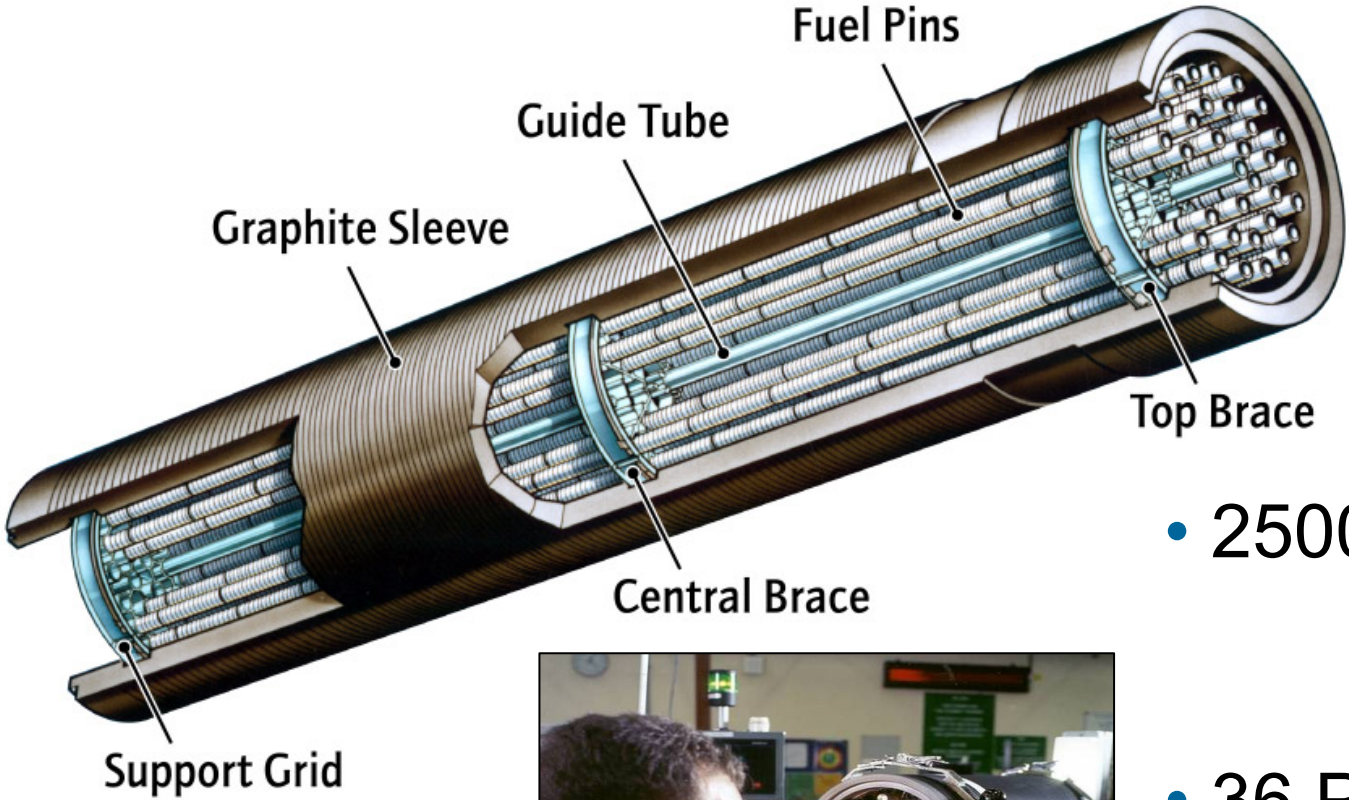
- Highly Economical
- Enhanced Safety
- Minimize Wastes
- Proliferation Resistant



Reactor Types: Magnox

- Large volume core
- Bespoke reactor and fuel designs
- Natural uranium, not enrichment
- Low burn-up 5 GWd/t
- Reprocessing to recover U but also Pu

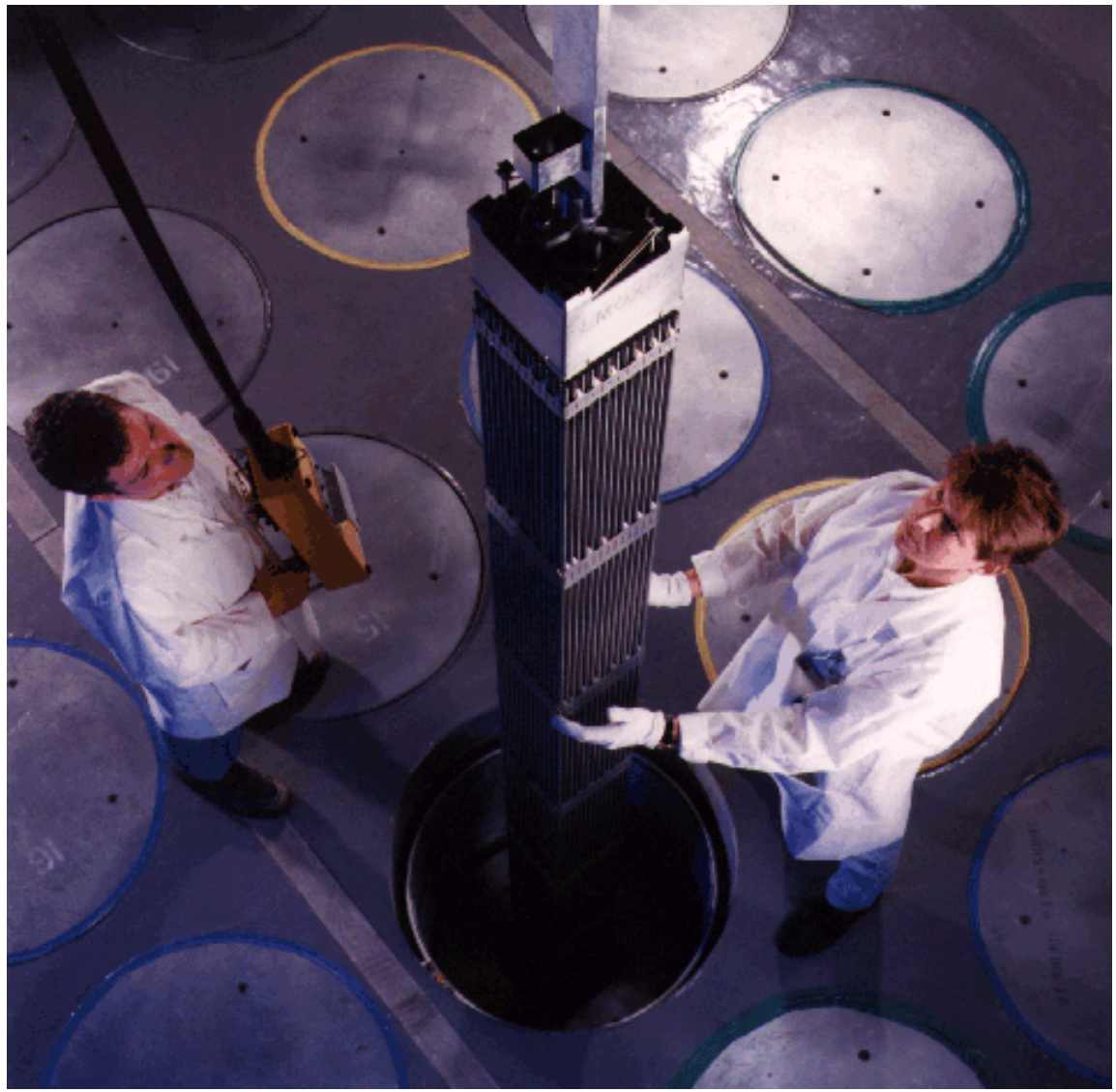
Reactor Types: AGR



- 2500 Fuel Assemblies per core
- 36 Pins per assembly
- Burn-up 26 GWd/t

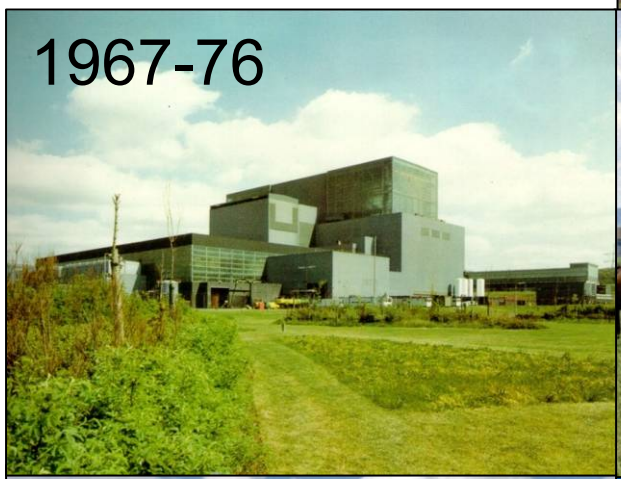
Reactor Types: PWR

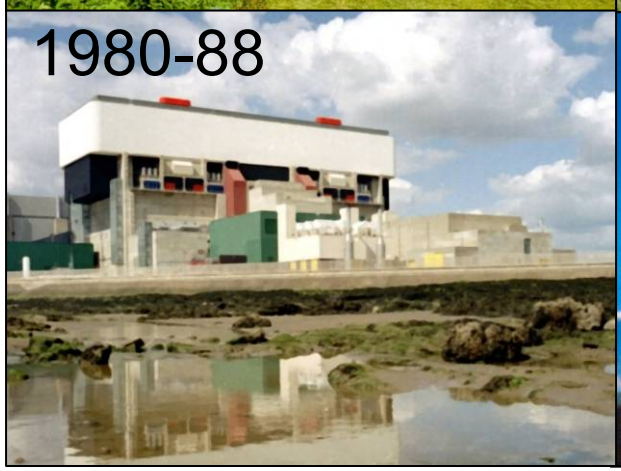
- 193 Fuel Assemblies per core
- ~200 Pins per assembly
- Burn-up 40 GWd/t

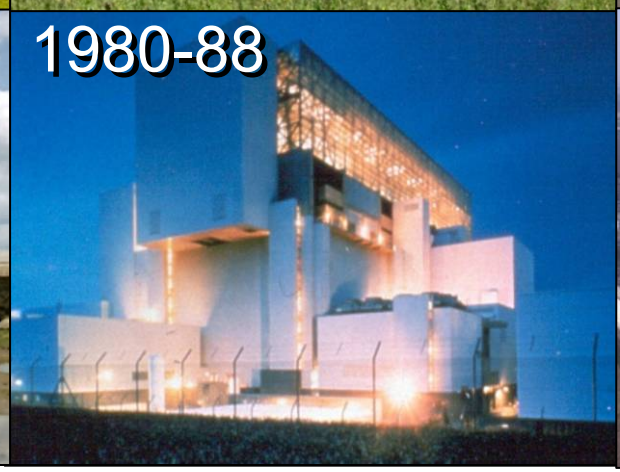


Existing Nuclear Stations and their construction dates.

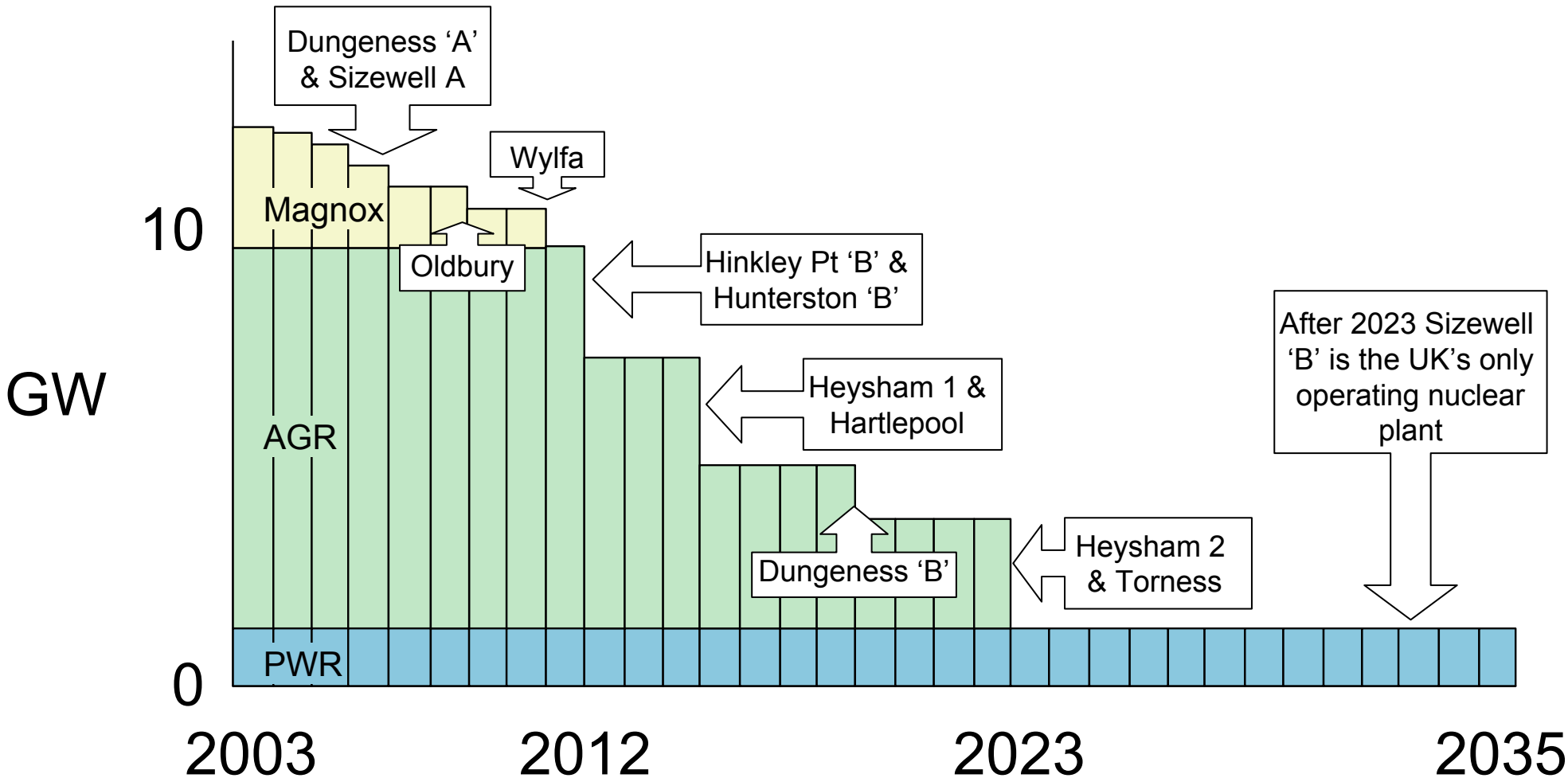
17% of total UK electricity needs







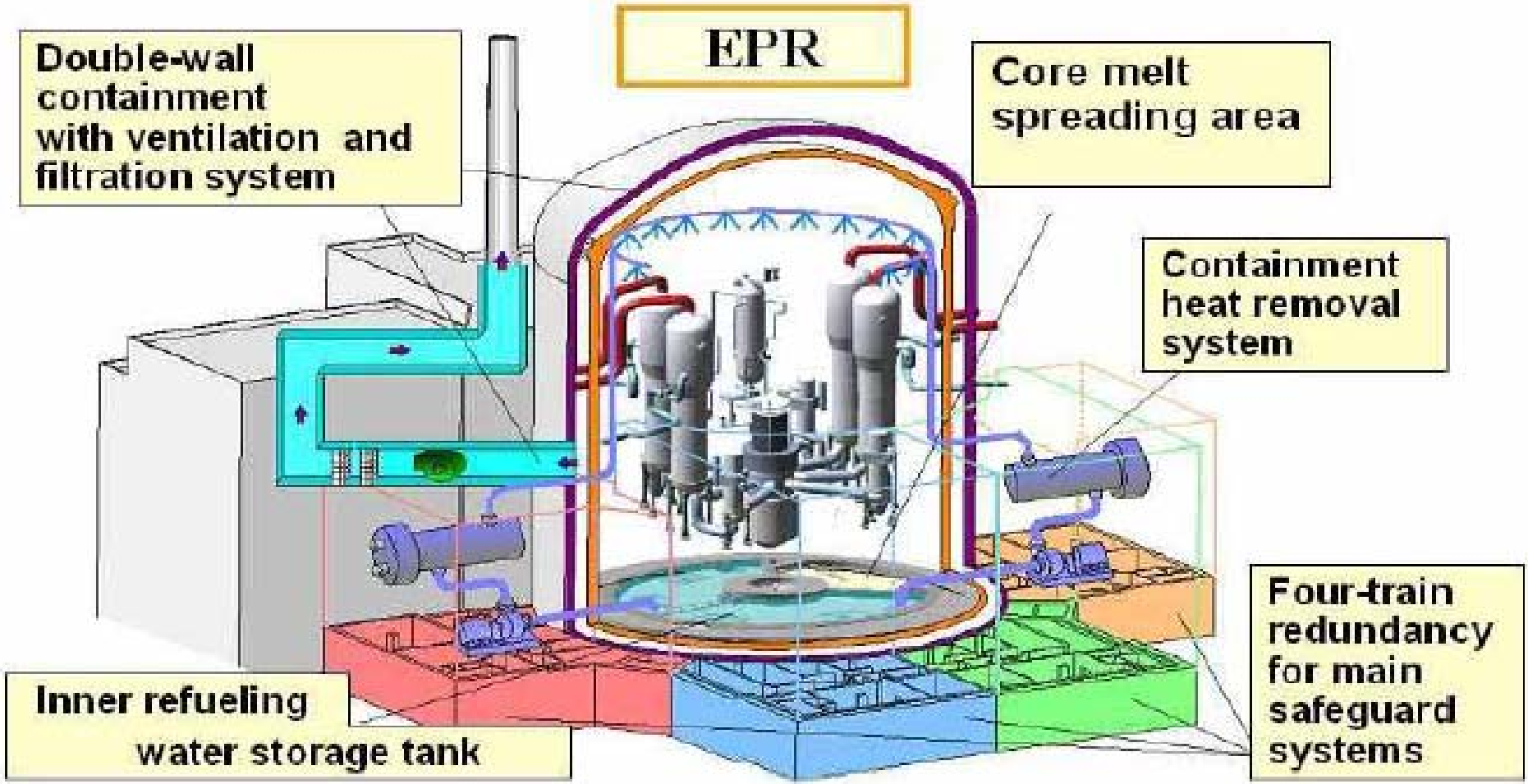
UK Nuclear Station Lifetimes predicted in 2003



Possible new build plant (UK)

- EPR – European, ‘More of the same but better’
- ABWR – General Electric stretch version of their existing BWR
- AP600 – Westinghouse, ‘Radical rethink but using existing parts
- AP1000 – A stretched version of the AP600
- ACR1000 – Advanced CANDU Reactor, light water cooled, 2% enriched fuel
- APWR – Mitsubishi Heavy Industries
- ATMEA 1 – 1000 MWe, evolutionary 3-loop PWR, joint venture between AREVA and Mitsubishi Heavy Industries
- APR1400 – KHNP (Korea Hydro & Nuclear Power Company)/Doosan 4000MWth four loop
- (Later: Pebble bed, Gen IV, ……)

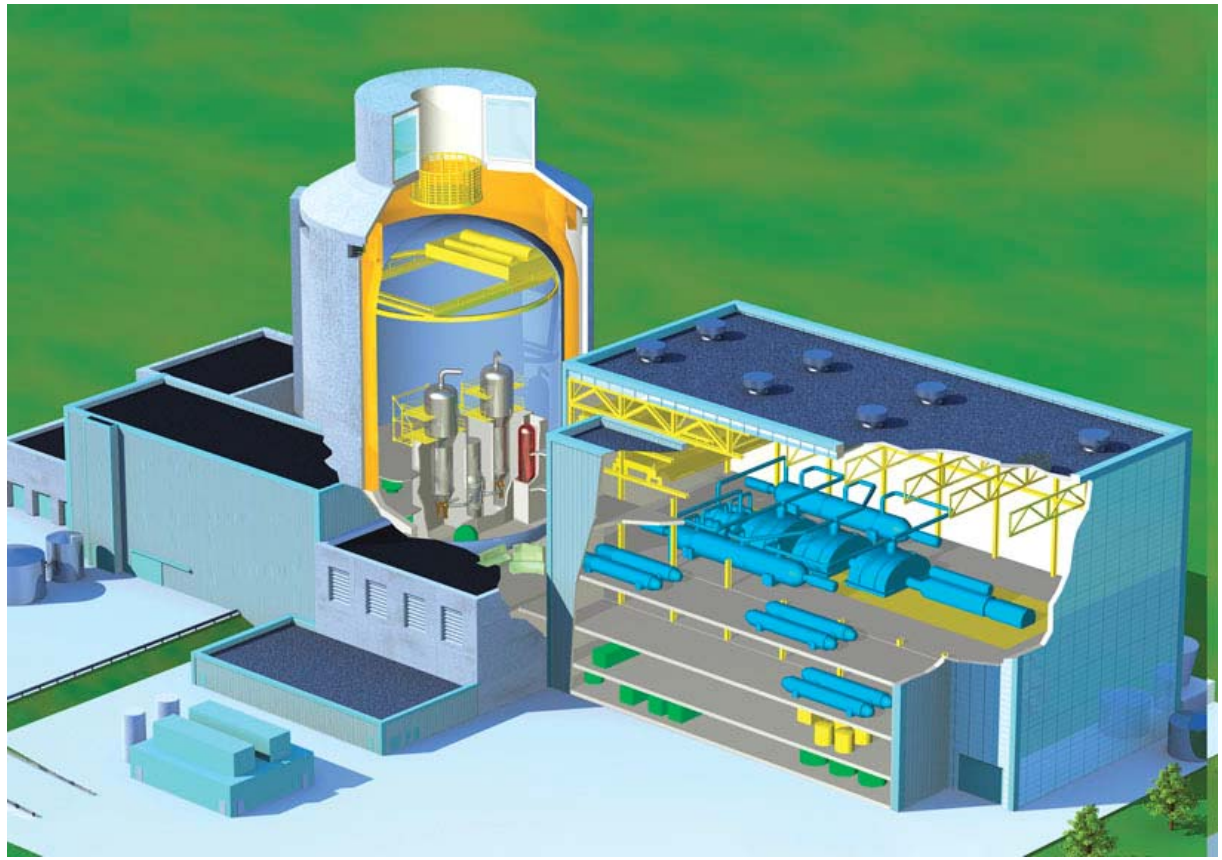
The Near Future: EPR



The Near Future: AP1000, Gen III+?

Incorporates advanced Passive Features

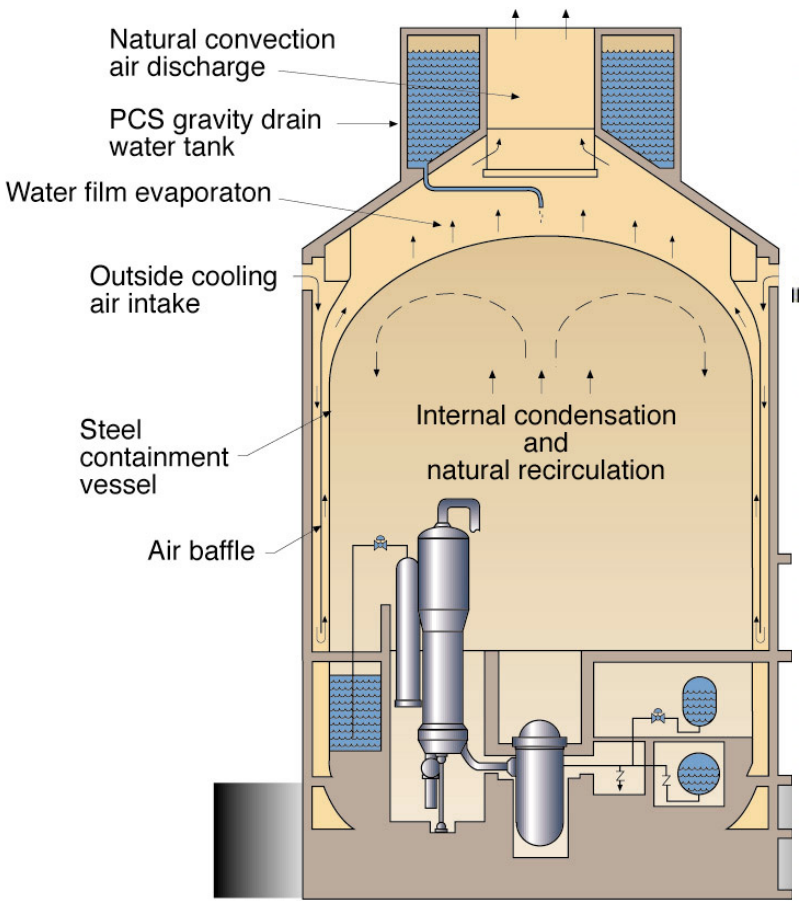
- Largely uses existing components
- Natural effects such as gravity used to provide passive safety
- Reduced power density
- Much simpler design
- Reduced waste arisings
- Reactor plant ⅓ land use size of conventional PWR, though turbine hall similar.

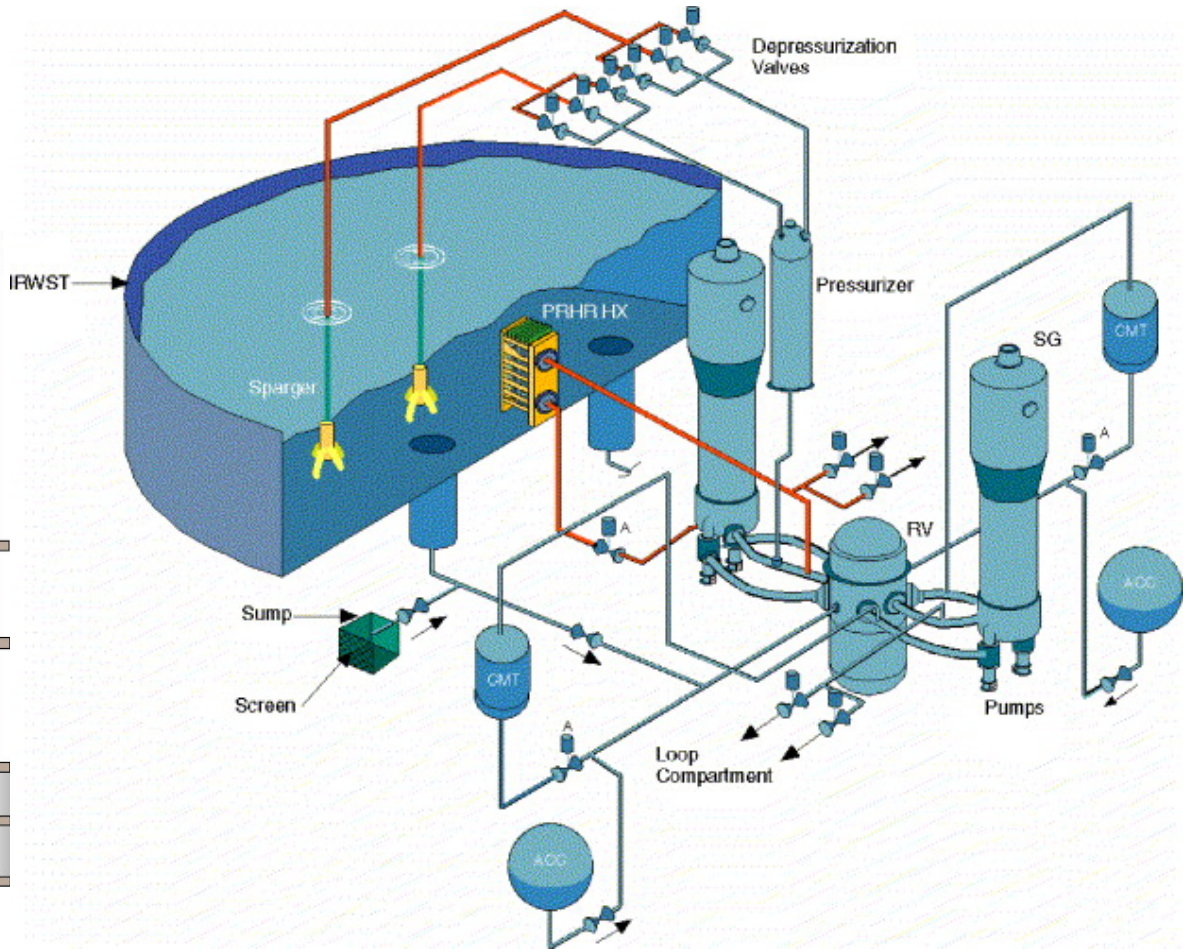


- AP600 has received final design approval from the US NRC, AP1000 well on way to doing so

The Near Future: AP1000

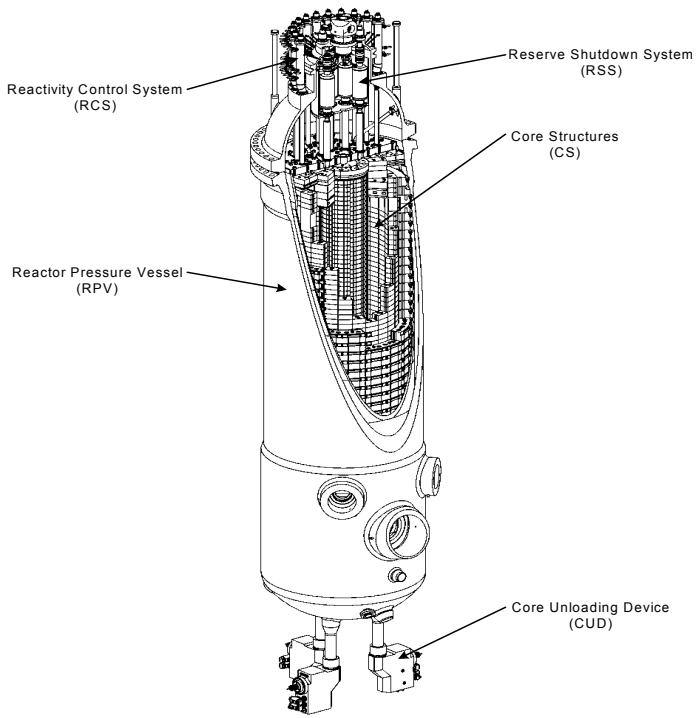
Incorporates advanced Passive Features



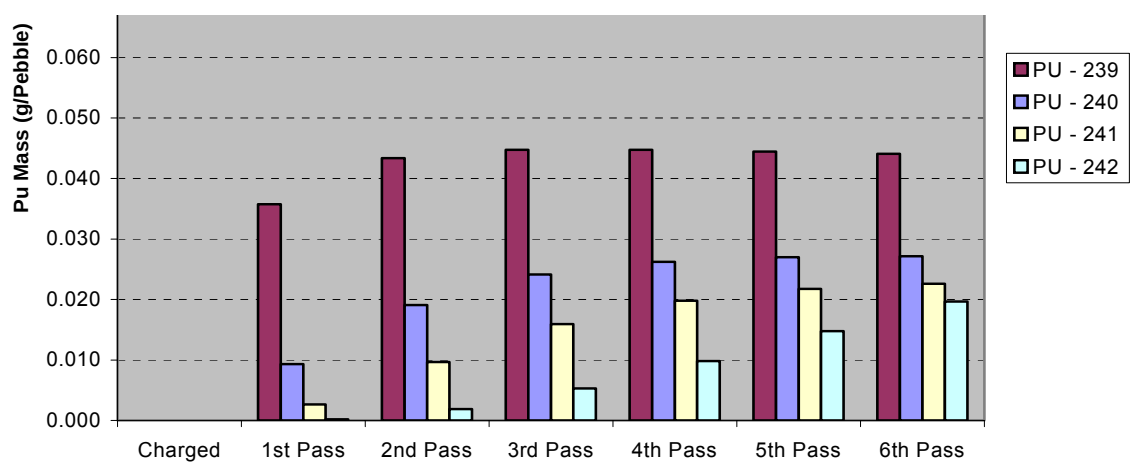


Pebble Bed Modular Reactor (PBMR)

Generation III+ or perhaps early IV

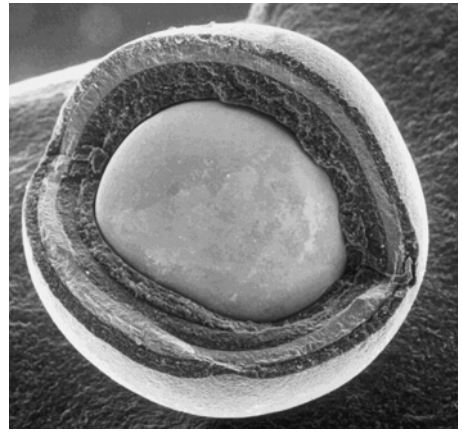


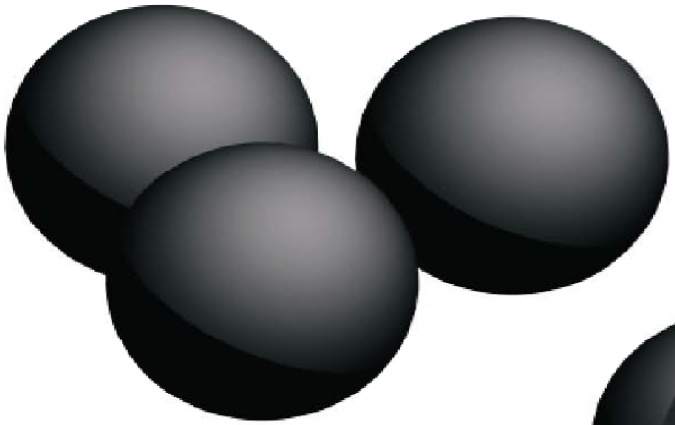
Main safety objective is to preserve the integrity of the fuel under all conditions i.e. the fuel must not be heated (or degraded by some other means) to a point where actinides or fission products can escape.



Fuel design also provides a degree of proliferation resistance.

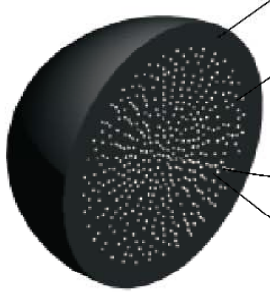
Fuel element design for PBMR





Dia. 60mm

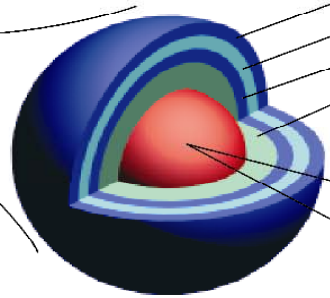
Fuel Sphere



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

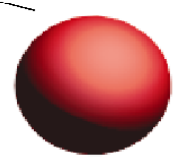
Porous Carbon Buffer 95/1000mm

Dia. 0,92mm

TRISO

Coated Particle

Tristructural-isotropic



Dia.0,5mm

Uranium Dioxide

Fuel Kernel

Generation IV

Gas-Cooled Fast Reactor (GFR)

Helium-cooled reactor with fast neutron spectrum and a "closed fuel cycle”. The breeder concept leads to improved use of the nuclear fuel by two orders of magnitude compared to current thermal reactors.

Lead-Cooled Fast Reactor (LFR)

Liquid metal cooled (lead or lead/bismuth) with a fast-neutron spectrum and a "closed fuel cycle" and a wide range of unit sizes from small "batteries" up to large single plants.

Sodium-Cooled Fast Reactor (SFR)

Fast-neutron reactor and a "closed fuel cycle". This reactor type should mainly serve to eliminate highly radioactive waste, plutonium and other actinides.

Molten Salt Reactor (MSR)

Thermal neutron spectrum and a "closed fuel cycle", where the uranium fuel is dissolved in the sodium fluoride salt coolant that circulates through graphite core channels.

Supercritical-Water-Cooled Reactor (SCWR)

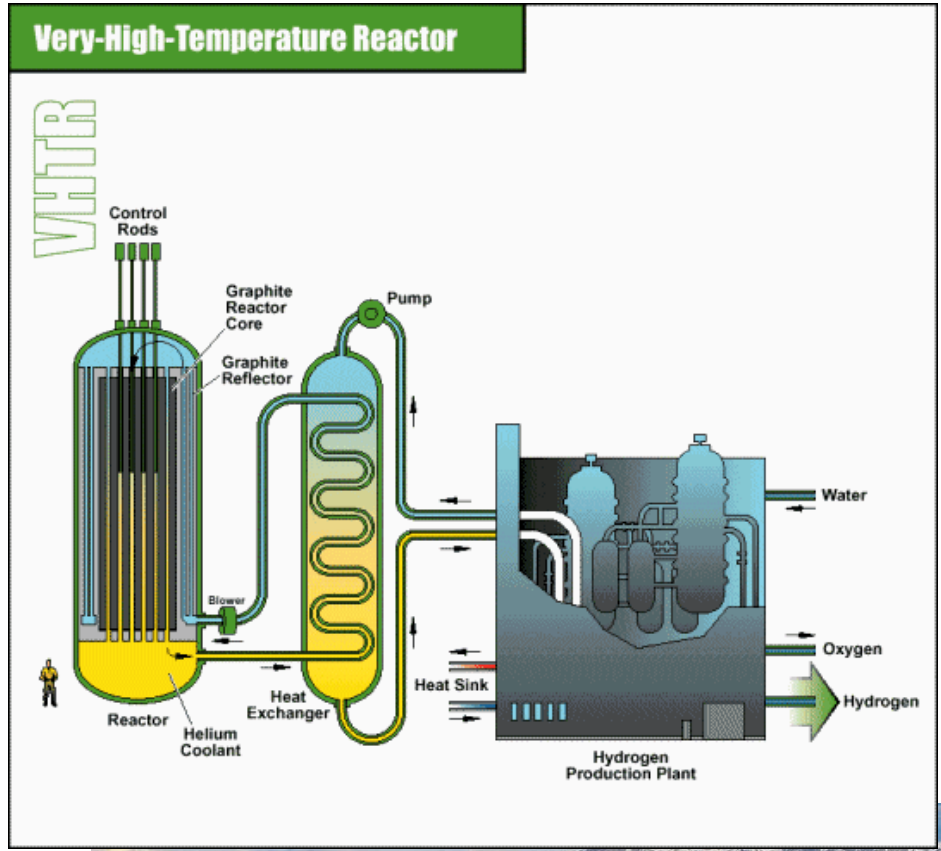
High-temperature, high-pressure water cooled reactors that operate at pressures and temperatures at which there is no difference between liquid and vapor phases. This reactor type was designed mainly to generate cheap electricity.

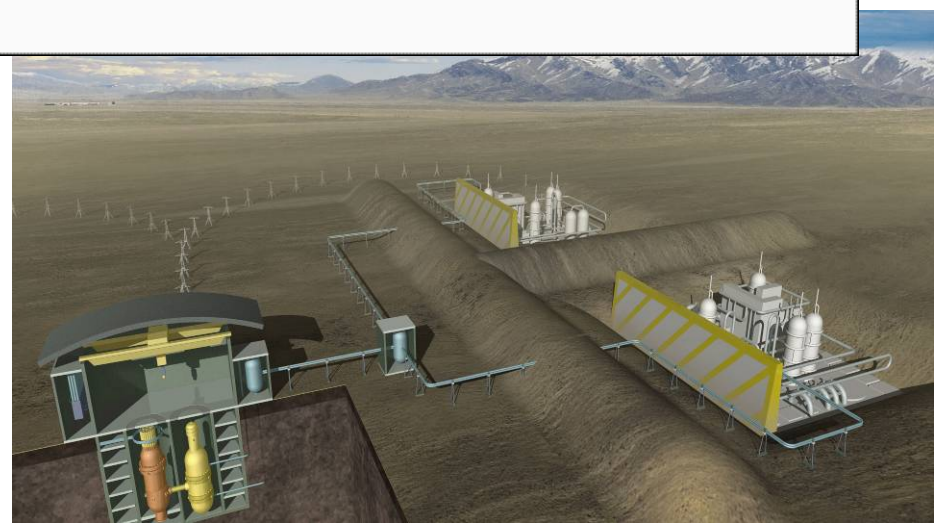
Very-High-Temperature Reactor (VHTR)

Uses a thermal neutron spectrum and a once-through uranium fuel concept. The main purpose of this gas-cooled reactor type is the generation of power, hydrogen and process heat.

Generation IV

- Very high temperature, He gas-cooled reactor that is capable of producing electricity or H_2, or both.
  - Outlet Temperature of 850-950ºC
  - Passively Safe





Current Research and Development Focus:

- Increase the burn-up of fuels – longer times in-pile impacts on cladding, greater burn-up requires better retention of fission products.
- High temperature fuels and reactor materials irradiation performance – materials under more extreme conditions.
- Design and safety methods development and validation – design for remove and replace, passive safety, reduce uncertainty and hence the need for conservatism.
- Advanced energy conversion and high-temperature H_2 production.
- Waste form and repository performance – immobilization and durability; all aspects of radionuclide transport.

Sustainability

…in the short, medium term or long term?

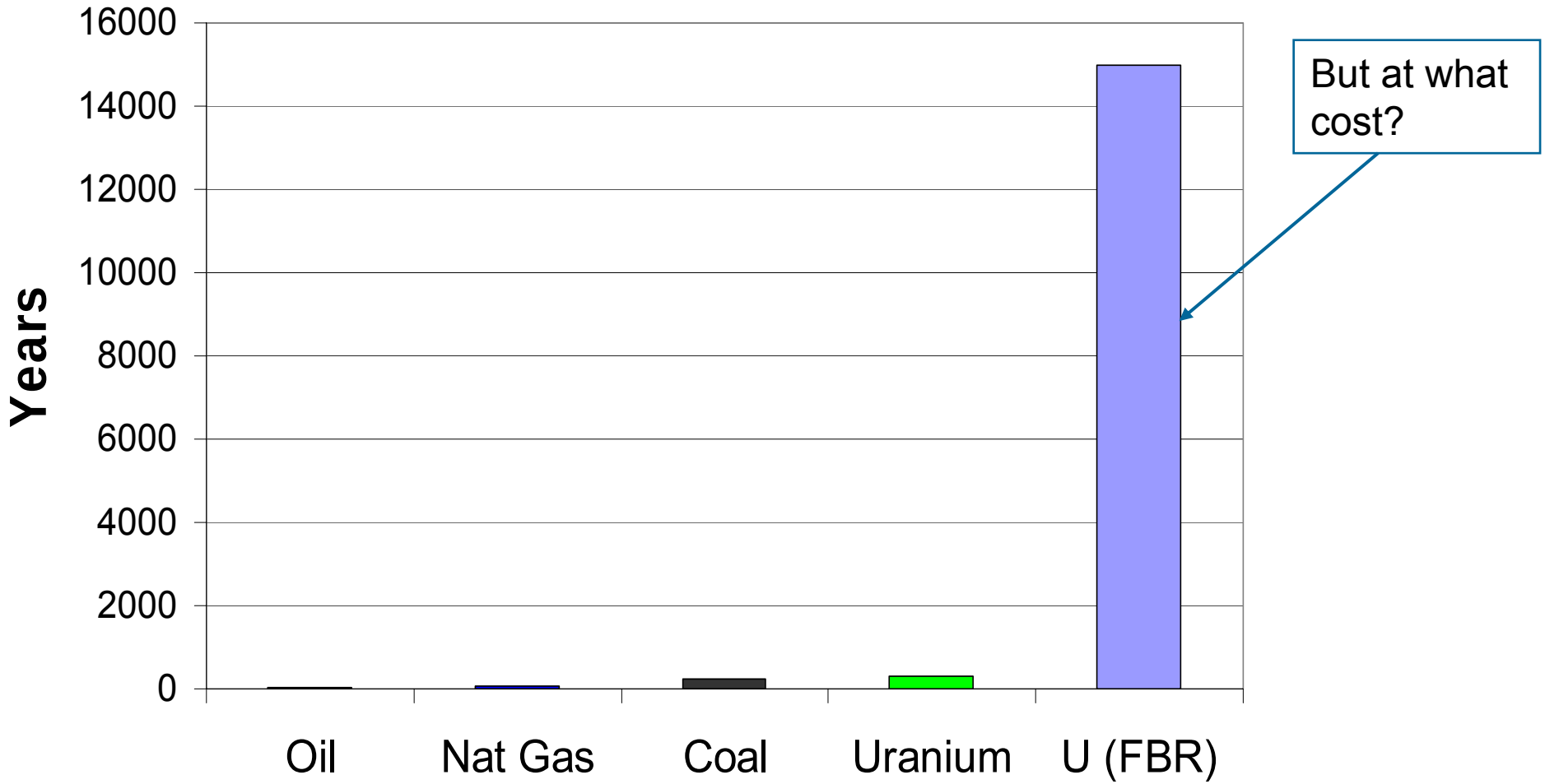
Where does the Uranium Come From?

- Uranium is present at an abundance 2 - 3 parts per million in the Earth's crust, which is about 600 times greater than gold and about the same as tin. In a geological sense uranium is not scarce.
- Ores with a uranium content of several percent do exist, but many deposits have a uranium content between 0.1% and 0.2%.
- Canada produces 28% and Australia 23% (although Australia has far larger known resources). Kazakhstan is the third largest supplier producing 10% followed by Russia and Namibia who produce 8% each.
- In 2005 eight mining companies accounting for 78% of production: Cameco 20%, Rio Tinto (13%), and Areva (12%).
- 50 mines in 16 countries produce more than 40,000 tonnes of uranium per year.
- Cameco's McArthur River is an underground mine which started up in 2000 producing 7,200 tU/yr making it the largest mine, producing 17% of world supplies. There are plans to triple the output of the Australian Olympic Dam, to about 12,700 tU/yr.
- World total production in tU/year: 2002 (36,063) 2003 (35,613) 2004 (40,251) 2005 (41,702) 2006 (39,429).

Resource Sustainability

- To achieve sustainability, the combined effects of mineral exploration and technology development must create known resources at least as fast as they are being used.
- At the moment uranium is mined from relatively high grade ore, eventually lower grade ores will be exploited. However, the price of Uranium would have to increase by over a factor of 3 before it would have any significant impact of the cost of electricity generated from Nuclear Power.
- Although uranium minerals are not scarce, increased demand sustained over decades will eventually cause a depletion of economically viable uranium sources.
- Better use of present resources can be achieved through: reprocessing of spent fuel, increased enrichment leading to higher fuel burn-up, use of a thorium fuel cycle (there is four times the amount of Th than U), improved reactor efficiency, use of fast breeder reactors (leading to a “closed” fuel cycle rather than the present “open” fuel cycle.

Potential for Long Term Use of Uranium

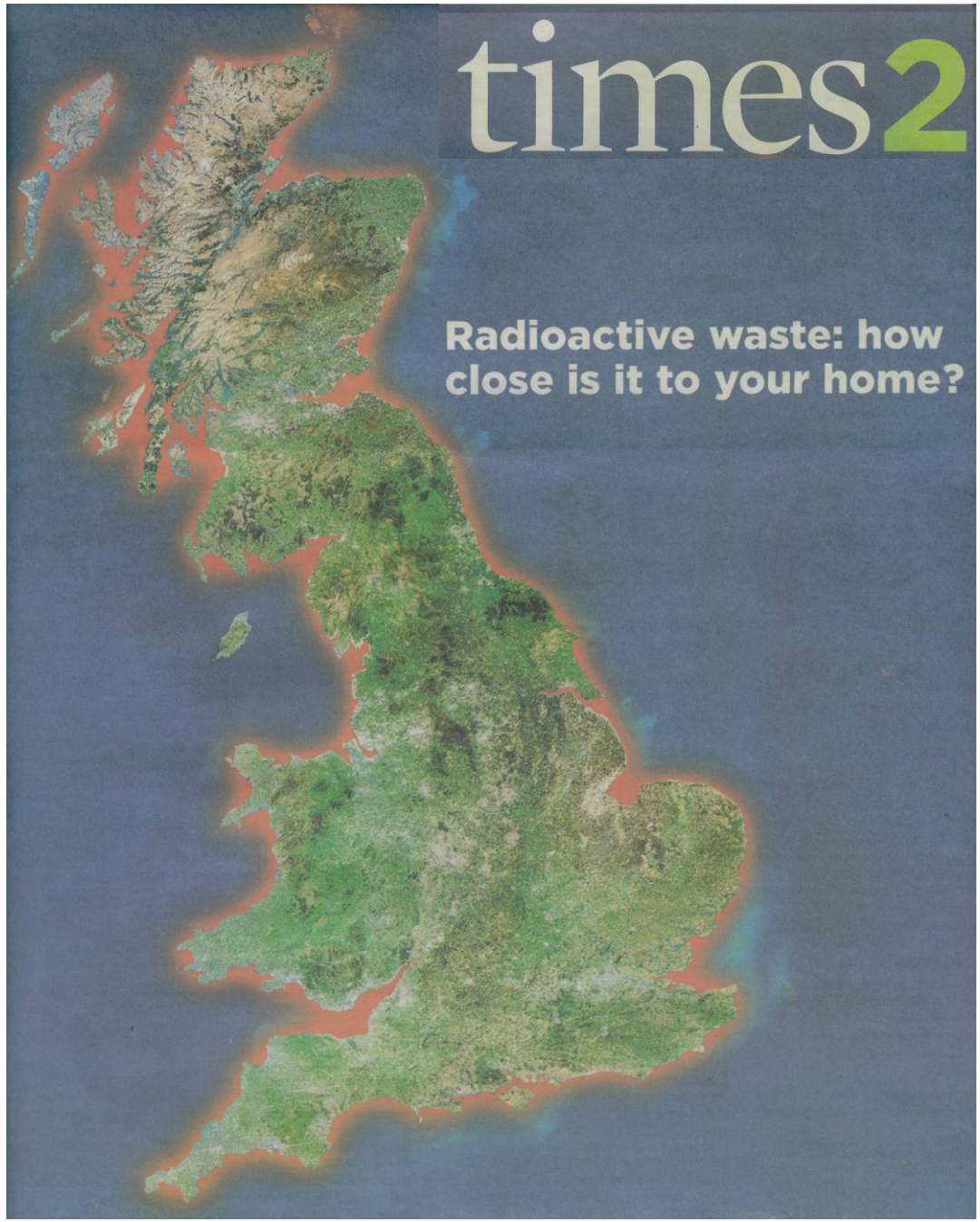


So, what do we need to facilitate new reactor build?

- Continue to follow the US lead and begin the process of licensing a choice of reactors for construction on existing UK nuclear sites rather than a site by site licence (pre-licensing).
- Continue to consider amendments to the planning process.
- The role of nuclear power as a low greenhouse gases emitting technology should be recognised in a similar manner to other equivalent technologies.
- Designate a site for a long-term repository for nuclear waste.
- Address the international skills shortage.

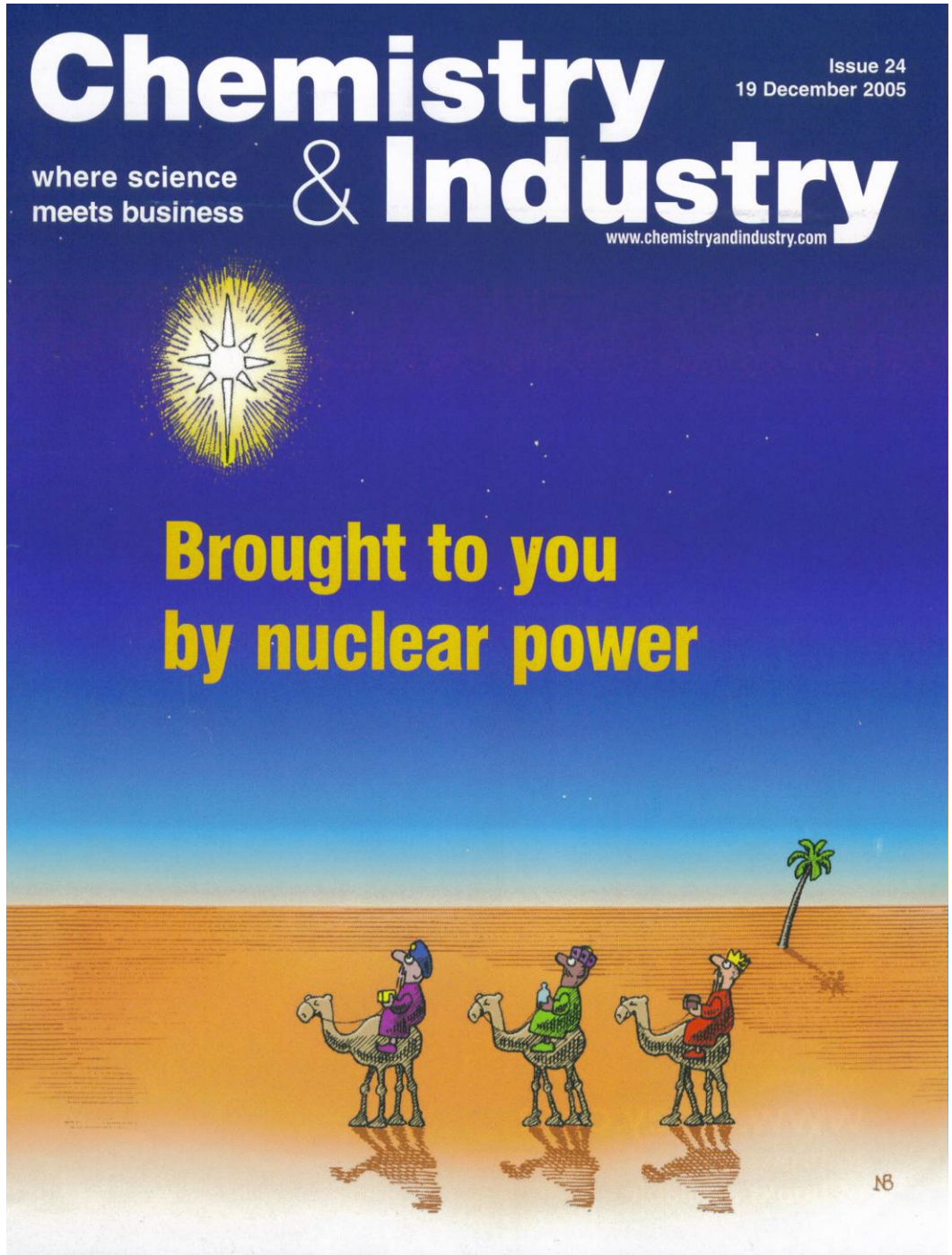
And finally, engage more effectively with the media.

So we get a little less of this…..



The Times

January 16th 2006

…but a little more of that.

Christmas Special 2005