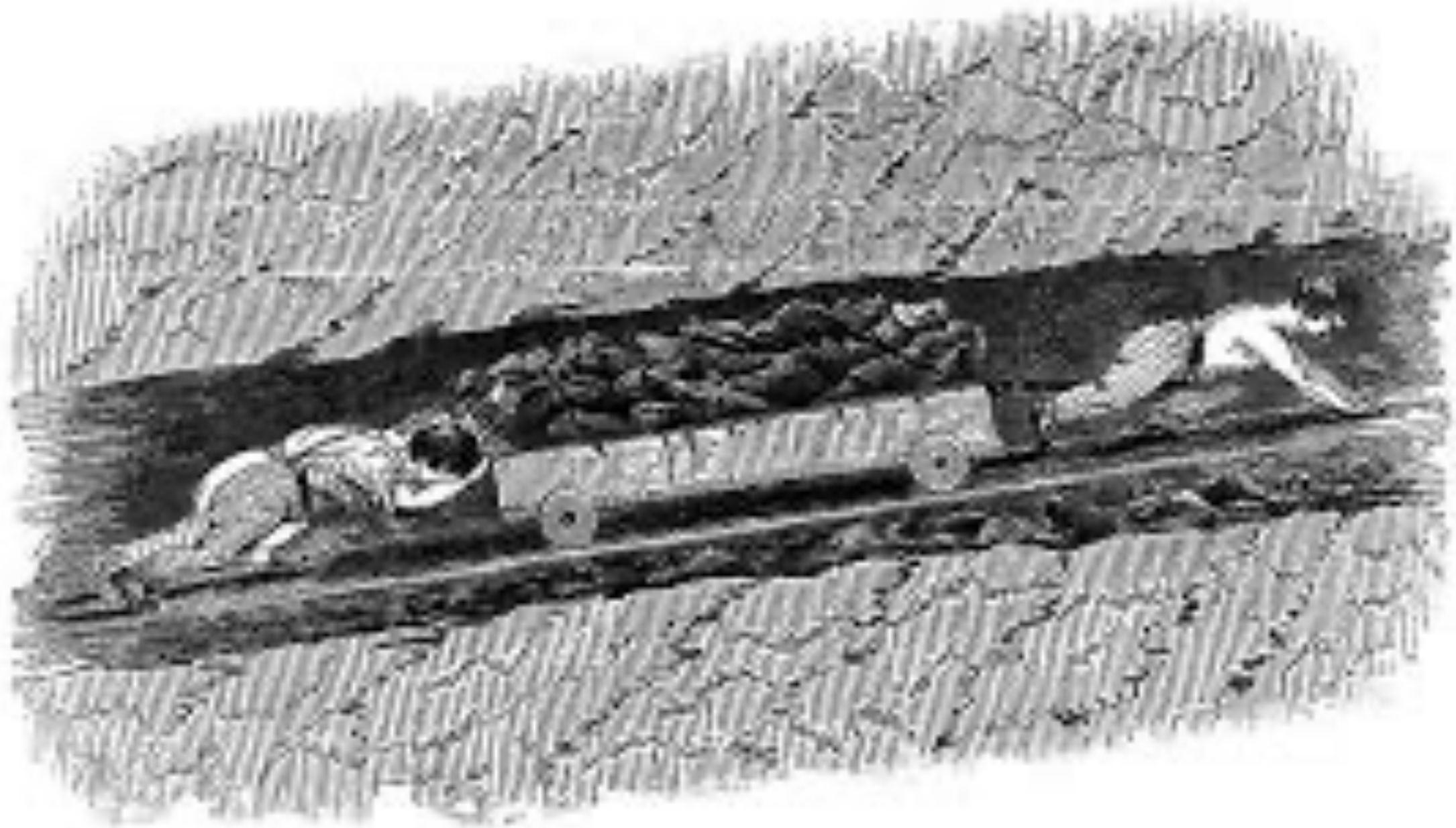


Nuclear Power

Past, Present and Future

The Personal Perspective of a Nuclear Engineer

The Past - Victorian England



The Past - 1960s



The Past - 10 years ago



gettyimages®
Credit: NIGEL RODDIS

The Past - UK figures

UK coal production peaked
in 1913 at 287 MT

1300 deep mines and 92 surface mines
>1 million people employed

1957	>200 MT
2025	<100 kT

The Past - UK figures for workers

1850 and 1950

1400 deaths per year

in explosions, roof collapses and suffocation

1950 and 2000

320 deaths per year

in mine accidents

+untold suffering of millions of ex-miners

and 100,000s of deaths from lung diseases

The Present - wider issues

Deaths from respiratory illnesses amongst the population from airborne pollution

Global Warming caused by the CO₂ emitted when the coal is burned

~1,000,000,000 standard shipping containers full of fossil fuels are burned each year

2025 global fossil fuel CO₂ emissions
38 GT (up 1.1% on 2024)

1960 to 2000

Nuclear Power - Magnox Reactors

Civil nuclear power began in 1964 in the UK

Reactors optimised for electricity production run by the CEGB

8 Magnox power stations in the UK each with 2 reactors

Berkeley in 1964 and including Sizewell A in 1966

This design was exported by UK industry to Italy and Japan
France had similar a bit later at 3 sites

This drawing, entitled NUCLEAR POWER, was prepared by the Central Electricity Generating Board, London, W.C. 2, England.

Nuclear Power

NUCLEAR POWER is produced within an impenetrable shielded core (see 1) of fuel rods and moderators (see 2) and (see 3). The heat generated is transferred to a gas by reactor (see 4) and (see 5). The gas is then used to drive a turbine (see 6) which is connected to a generator (see 7) which produces electricity (see 8). The gas is then cooled (see 9) and the cycle is repeated.

Sizewell Principal Data

Performance

Number of reactors	2
Net output	280-16 MW/ reactor
Net efficiency	30.5%
Heat transferred to gas by reactor	647.5 MW/ reactor
Heat transferred to steam in boiler	103.5 MW/ reactor
Gross generator output	211.6 MW/ reactor
Cycle efficiency (gross output)	33.0%
Cycle efficiency (net output)	33.0%
Circulator power to generator	21.94 MW/ reactor
Auxiliary load (other than main gas circulator)	1.70 MW/ reactor

Core and Fuel

Weight of uranium	320.4 tonnes/ reactor
Weight of moderator	320.4 tonnes/ reactor
Core size (incl. reflector)	43 ft x 24 ft
Planned radius	15 ft
Leakage pitch, square	3.45 in
Graphite channel diameter	1.1 in
Fuel rod diameter	0.4 in
Fuel element length	41 in
Number of elements per channel	7
Maximum core temperature	453°C
Average output channel rating	288.4 kW
Normal maximum uranium temperature (at channel inlet)	359.5°C
Mean heat generation/ max heat generation (ratio)	0.675
Mean heat generation/ max heat generation (ratio)	0.718
Mean fuel rating	2.54 MW/ fuel
Mean fuel rating	4.54 MW/ fuel
Mean fuel life	320 MW/ tonne
Pressure vessel diameter	43 ft 6 in
Pressure vessel thickness	4 1/2 in

Boilers and Turbines

Number of boilers	2
Boiler diameter	32 ft 6 in
Boiler length	42 ft
Total length	11 ft 6 in
HP steam pressure	720 lb/ sq in
HP superheater outlet temperature	388.4°C
LP steam pressure	220.5 lb/ sq in
LP superheater outlet temperature	400.9°C
LP steam pressure	400.9 lb/ sq in
LP steam temperature	393.4°C
LP steam pressure	400.9 lb/ sq in
LP steam temperature	393.4°C
LP steam pressure	400.9 lb/ sq in
LP steam temperature	393.4°C
Y-axis	29 in dia
Total steam flow/ reactor	2.824 lb/ s x 10 ⁶
Ratio of HP steam flow/ total steam flow	0.1544
Fuel feed temperature	120.4°C
Turbine exhaust pressure	0.539 lb/ sq in
Number of main turbines	2
Output of each main turbine	124.75 MW

Circulators

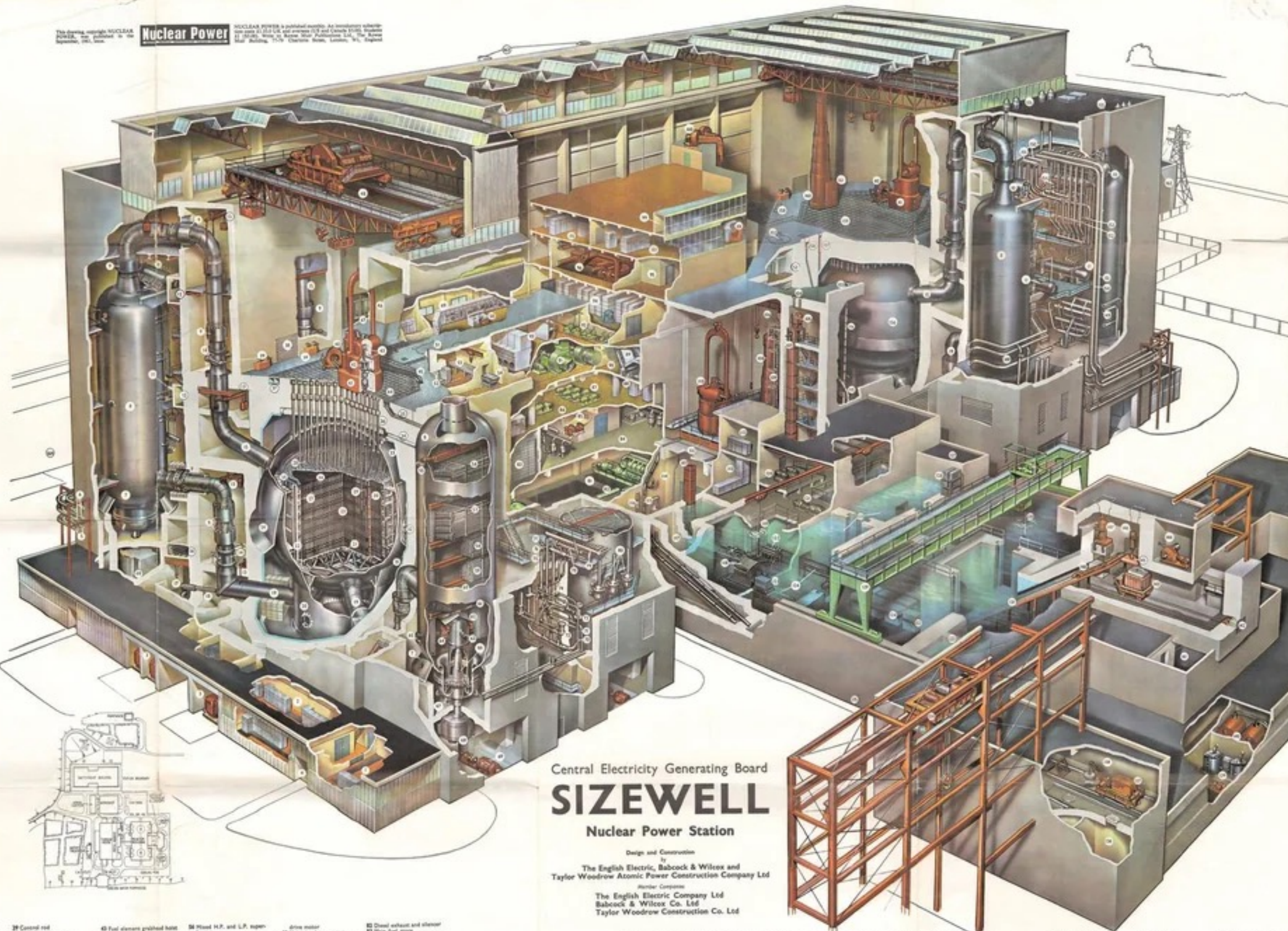
Number of circulators	2
Type of circulator	Vertical, single stage, axial, with variable stagger inlet guide vanes
Drive	Vertical, axial, single stage, axial, with variable stagger inlet guide vanes

Gas Circuit

Reactor gas inlet pressure	278.8 lb/ sq in
Reactor gas inlet temperature	214.7°C
Reactor gas outlet temperature	400.9°C
Total gas flow/ reactor	9534 lb/ s
Total gas circuit pressure drop	11.50 lb/ sq in
Pressure drop across reactor	3.52 lb/ sq in
Pressure drop across fuel elements	4.30 lb/ sq in
Centre channel mass flow at channel inlet	7000 lb/ s
Flowing and drying bypass flow, % of reactor gas flow	0.5

Civil Engineering Data

Height of reactor building	152 ft
Length of reactor building	352 ft
Mean thickness of concrete main shield	3 ft 6 in
Mean thickness of concrete supply duct shield	5 ft
Distance across face of main shield	12 ft 7 in
Height of concrete main shield	96 ft
Thickness of pile cap	11 ft 6 in
Foundation of reactor building	Reinforced concrete mat 228 ft x 106 ft x 9 ft thick
Turbine hall overall dimensions	Approx 385 ft x 140 ft x 90 ft high
Pumphouse dimensions	123 ft wide x 133 ft
Circulating water flow	27 x 10 ⁶ gal/ h



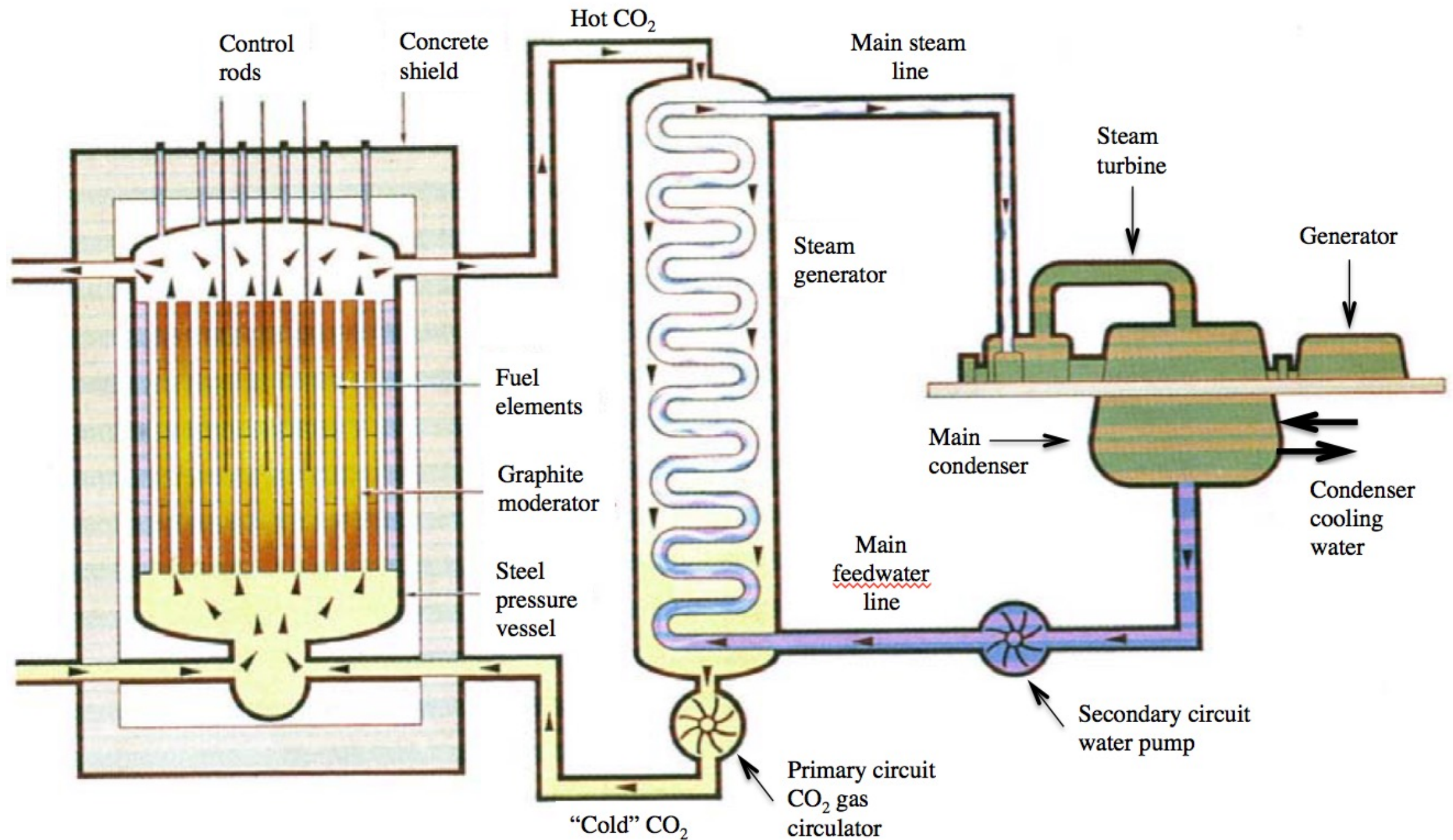
Central Electricity Generating Board SIZEWELL Nuclear Power Station

Design and Construction by
The English Electric, Babcock & Wilcox and
Taylor Woodrow Atomic Power Construction Company Ltd
Builder Companies
The English Electric Company Ltd
Babcock & Wilcox Co. Ltd
Taylor Woodrow Construction Co. Ltd

- | | | | | | | | | | | | |
|--|---------------------------------|--------------------------------------|------------------------------------|--------------------------------------|--|---|---|-------------------------------------|---|---------------------------|---------------------------------------|
| 1 Gas circulator instrument and control room | 13 Counterweight supports | 29 Control rod | 43 Fuel element gripper belt drive | 54 Wood H.P. and L.P. superheater | 82 Diesel exhaust and silencer | 103 Switchgear for maintenance shop and services | 120 Pond water circulating | 137 Guide vanes for steam generator | 156 Pressure vessel No. 1 | 47 Goods lift | 134 Underwater slip carrying conveyor |
| 2 Gas circulator instrument room | 14 Isolating valves | 30 Fuel elements | 44 No. 1 reactor pile up | 55 H.P. boiler tanks | 83 CO ₂ auxiliary equipment room | 104 Fuel discharge shaft | 121 Emergency discharge loading jet pump | 138 Camshaft operating room | 157 Pressure vessel inspection emergency viewing position | 48 Sub-fuel store | 135 Fuel element storage slip |
| 3 Auxiliary transformers | 15 Gas outlet ducts | 31 Side wall cooling pipe | 45 Services to fueling machine | 56 High temperature H.P. superheater | 84 CO ₂ auxiliary equipment room | 105 Building machine for fuel elements | 122 Fuel element guide rail removal machine | 139 Oil drum filling tank | 158 Fuel element storage slip | 49 Fuel preparatory rooms | 136 Fuel element storage slip |
| 4 Emergency exit | 16 Debris removal corridor | 32 Thermal column | 46 Fueling machine lifting beam | 57 L.P. boiler | 85 Vacuum pumps | 106 Maintenance workshop | 123 Fuel element guide rail removal machine | 140 Acid and alkali plant | 159 Fuel element storage slip | 50 Fuel preparatory rooms | 137 Fuel element storage slip |
| 5 L.P. and H.P. feed water to boilers | 17 Debris removal duct | 33 Pressure vessel No. 1 | 47 Fueling machine lifting beam | 58 L.P. boiler | 86 Reactor safety circuit motor generator sets | 107 Conveyor for irradiated fuel elements | 124 Fuel element storage slip on under-water conveyor | 141 Auxiliary gas circuit pipework | 160 Fuel element storage slip | 51 Fuel preparatory rooms | 138 Fuel element storage slip |
| 6 L.P. and H.P. steam to turbines | 18 Gas inlet ducts | 34 Cooling air passage to stand pipe | 48 Goods lift | 59 H.P. boiler | 87 Reactor safety circuit motor generator sets | 108 Fuel element storage slip on under-water conveyor | 125 Fuel element storage slip on under-water conveyor | 142 Auxiliary gas circuit pipework | 161 Fuel element storage slip | 52 Fuel preparatory rooms | 139 Fuel element storage slip |
| 7 Turbine support grid | 19 Pressure vessel support beam | 35 Pressure vessel standpipes | 49 Pin up crane | 60 L.P. boiler | 88 Fuel element storage slip on under-water conveyor | 109 Fuel element storage slip on under-water conveyor | 126 Fuel element storage slip on under-water conveyor | 143 Auxiliary gas circuit pipework | 162 Fuel element storage slip | 53 Fuel preparatory rooms | 140 Fuel element storage slip |
| 8 Gas duct below joint | 20 Gravitational motor | 36 Service trough | 50 Central control room | 61 H.P. boiler | 89 Fuel element storage slip on under-water conveyor | 110 Fuel element storage slip on under-water conveyor | 127 Fuel element storage slip on under-water conveyor | 144 Auxiliary gas circuit pipework | 163 Fuel element storage slip | 54 Fuel preparatory rooms | 141 Fuel element storage slip |
| 9 Gas duct below joint | 21 Gravitational motor | 37 Service trough | 51 Control engineer's desk | 62 H.P. boiler | 90 Fuel element storage slip on under-water conveyor | 111 Fuel element storage slip on under-water conveyor | 128 Fuel element storage slip on under-water conveyor | 145 Auxiliary gas circuit pipework | 164 Fuel element storage slip | 55 Fuel preparatory rooms | 142 Fuel element storage slip |
| 10 L.P. steam drum | 22 Gravitational motor | 38 Service trough | 52 Fuel loading facility, reactor | 63 H.P. boiler | 91 Fuel element storage slip on under-water conveyor | 112 Fuel element storage slip on under-water conveyor | 129 Fuel element storage slip on under-water conveyor | 146 Auxiliary gas circuit pipework | 165 Fuel element storage slip | 56 Fuel preparatory rooms | 143 Fuel element storage slip |
| 11 L.P. steam drum | 23 Gravitational motor | 39 Service trough | 53 Fuel loading facility, reactor | 64 H.P. boiler | 92 Fuel element storage slip on under-water conveyor | 113 Fuel element storage slip on under-water conveyor | 130 Fuel element storage slip on under-water conveyor | 147 Auxiliary gas circuit pipework | 166 Fuel element storage slip | 57 Fuel preparatory rooms | 144 Fuel element storage slip |
| 12 Shielded gallery | 24 Gravitational motor | 40 Service trough | 54 Fuel loading facility, reactor | 65 H.P. boiler | 93 Fuel element storage slip on under-water conveyor | 114 Fuel element storage slip on under-water conveyor | 131 Fuel element storage slip on under-water conveyor | 148 Auxiliary gas circuit pipework | 167 Fuel element storage slip | 58 Fuel preparatory rooms | 145 Fuel element storage slip |
| | 25 Gravitational motor | 41 Service trough | 55 Fuel loading facility, reactor | 66 H.P. boiler | 94 Fuel element storage slip on under-water conveyor | 115 Fuel element storage slip on under-water conveyor | 132 Fuel element storage slip on under-water conveyor | 149 Auxiliary gas circuit pipework | 168 Fuel element storage slip | 59 Fuel preparatory rooms | 146 Fuel element storage slip |
| | 26 Gravitational motor | 42 Service trough | 56 Fuel loading facility, reactor | 67 H.P. boiler | 95 Fuel element storage slip on under-water conveyor | 116 Fuel element storage slip on under-water conveyor | 133 Fuel element storage slip on under-water conveyor | 150 Auxiliary gas circuit pipework | 169 Fuel element storage slip | 60 Fuel preparatory rooms | 147 Fuel element storage slip |
| | 27 Gravitational motor | 43 Service trough | 57 Fuel loading facility, reactor | 68 H.P. boiler | 96 Fuel element storage slip on under-water conveyor | 117 Fuel element storage slip on under-water conveyor | 134 Fuel element storage slip on under-water conveyor | 151 Auxiliary gas circuit pipework | 170 Fuel element storage slip | 61 Fuel preparatory rooms | 148 Fuel element storage slip |
| | 28 Gravitational motor | 44 Service trough | 58 Fuel loading facility, reactor | 69 H.P. boiler | 97 Fuel element storage slip on under-water conveyor | 118 Fuel element storage slip on under-water conveyor | 135 Fuel element storage slip on under-water conveyor | 152 Auxiliary gas circuit pipework | 171 Fuel element storage slip | 62 Fuel preparatory rooms | 149 Fuel element storage slip |

1960 to 2000

Nuclear Power - Magnox Reactors



1960 to 2000

Nuclear Power - Magnox Reactors

Natural Uranium fuel
Graphite as moderator
CO₂ gas as coolant
Steel Pressure Vessel

Steam at 400°C
Thermal efficiency was around 30%
On-load refuelling

Stable 24/7 electricity throughout the year
often without any interruptions for many months

1975 Magnox produced 11% of the UK electricity

1975 - 2030

Nuclear Power - Advanced Gas Cooled Reactors

7 AGR stations designed and built starting in 1976

3% enriched uranium fuel

Graphite as moderator

CO₂ gas as coolant

Concrete Pressure vessel

Steam temperature is 540°C

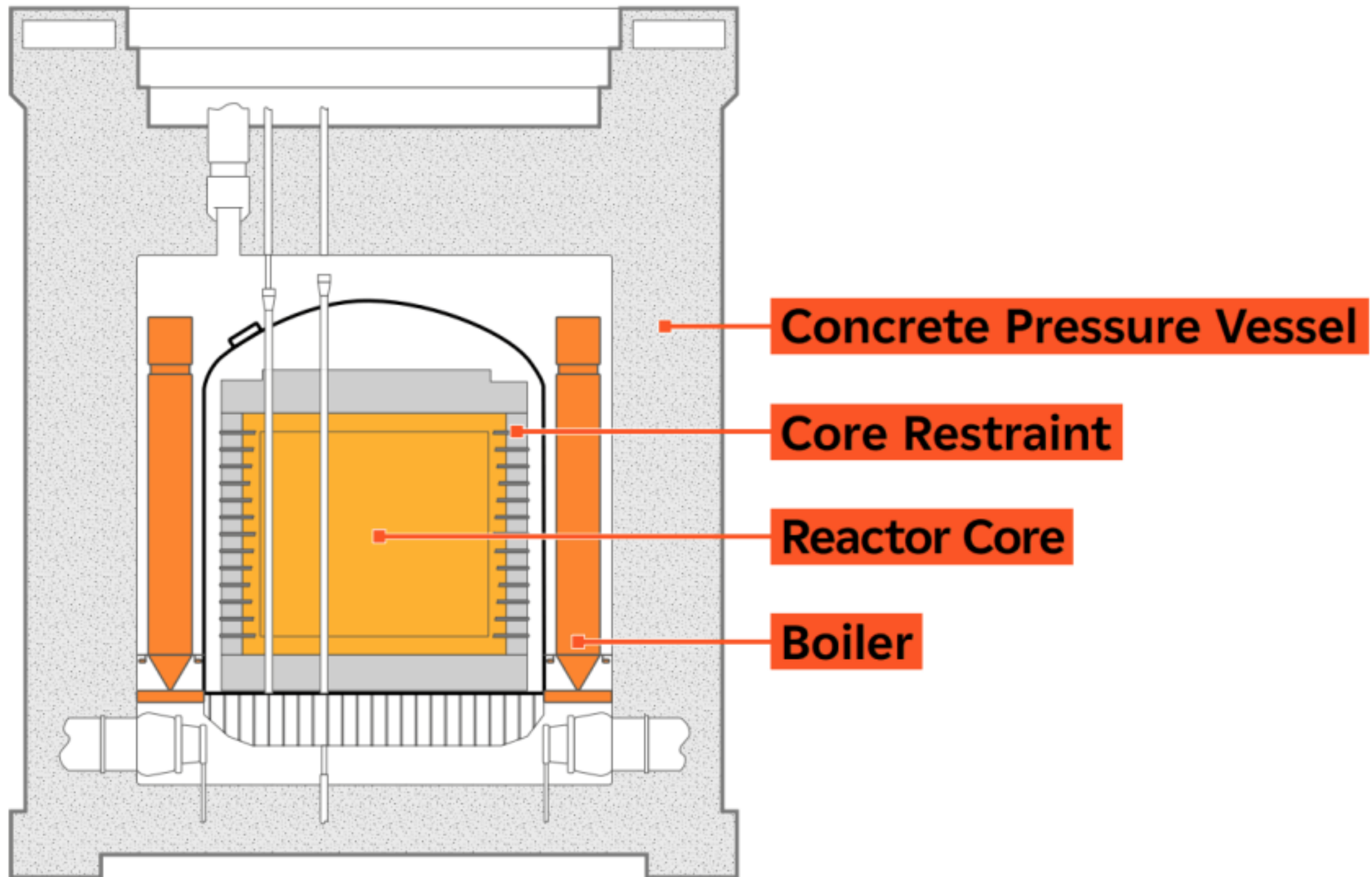
Thermal efficiency above 40%

(cf Magnox stations: 400°C and 30%)

2x the electrical output

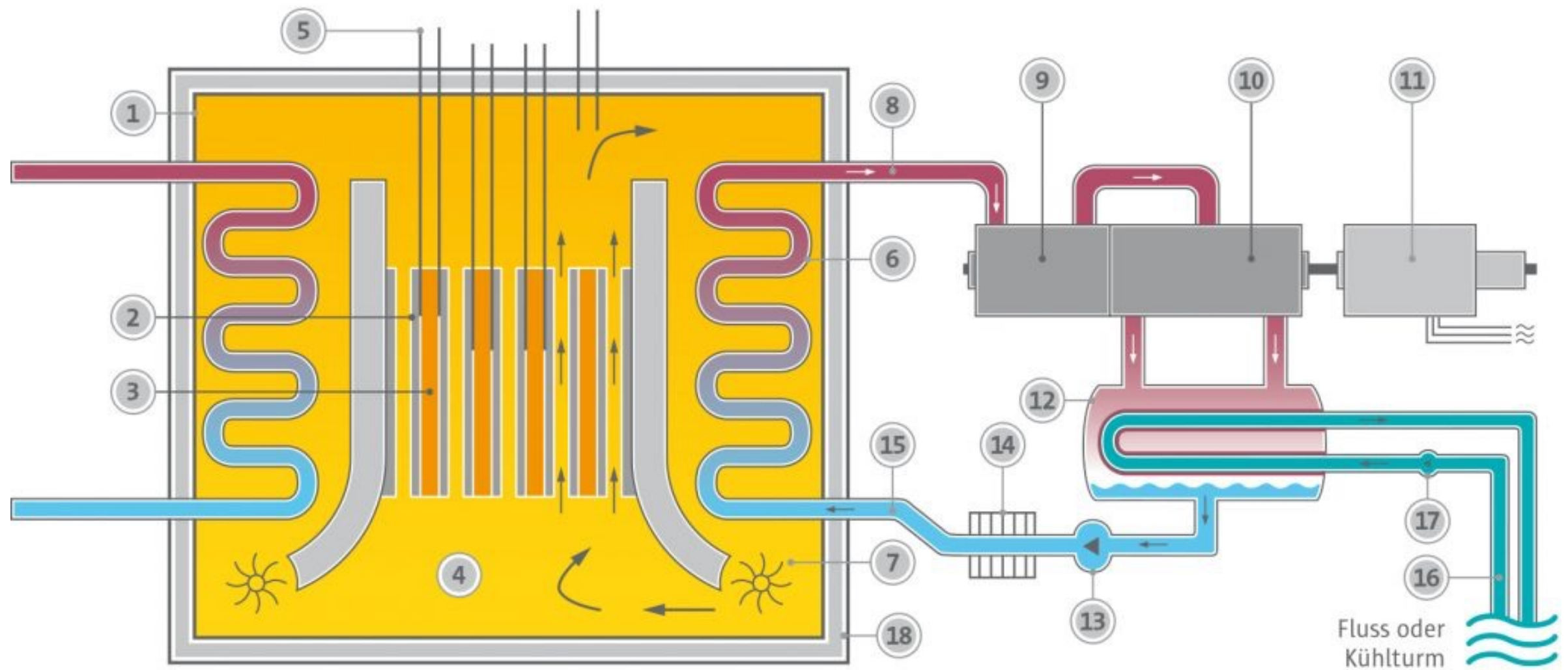
1975 - 2030

Nuclear Power - Advanced Gas Cooled Reactors



1975 - 2030

Nuclear Power - Advanced Gas Cooled Reactors



1975 - 2030

Nuclear Power - Advanced Gas Cooled Reactors



1975 - 2030

Nuclear Power - Advanced Gas Cooled Reactors

Despite some real advantages
no other country uses this reactor type commercially

AGRs produce base-load electricity

In 1995 AGRs and Magnox reactors
produced 25% of UK electricity

Of the original 7 stations, 4 are still operating in 2026

The Present

Nuclear Power - Pressurised Water Reactors

1960s USA chose Water Cooled Reactors

~1975 France, Germany, Japan, the USSR, Sweden and Belgium

Only the UK, Canada and the USSR developed other designs

In the 1970s and 80s European policy was to burn more coal
Following privatisation UK policy was to burn more gas

There was a dip in demand across the country

Nuclear power station building paused in the UK

The Present

Nuclear Power - Pressurised Water Reactors

Finally the UK chose PWRs in the early 80s

A programme of 4 stations was planned

There was a Public Inquiry lasting 3 years before building was given the go-ahead

In the end only 1 reactor station at Sizewell B was built

By any standard, Sizewell B has been very successful over the last 40 years

The Present

Nuclear Power - Pressurised Water Reactors

National energy independence is an issue that favours nuclear power

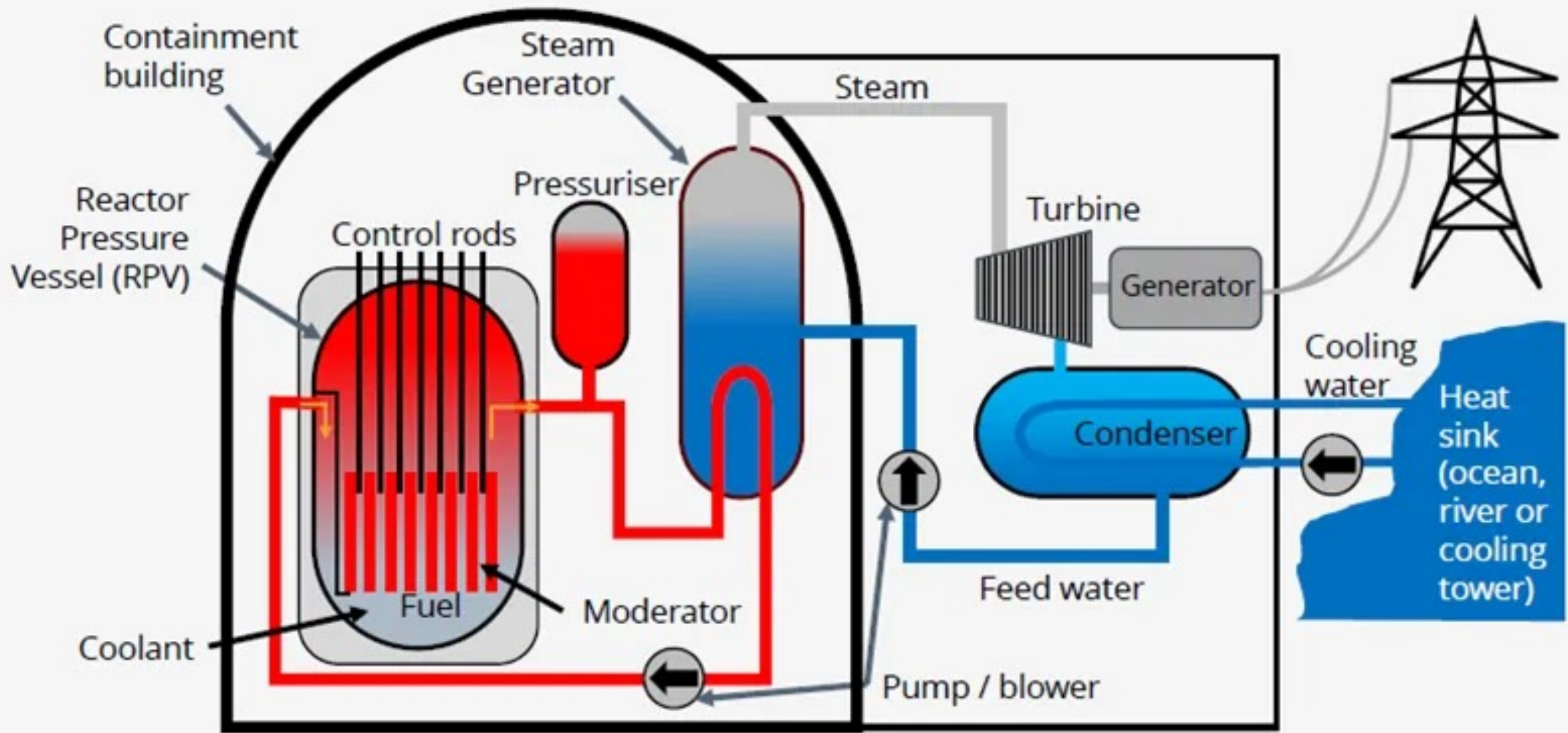
Global Warming became to be seen as more of a problem so there is a drive towards “Net Zero”

Also many environmentalists (who were previously opposed) came round to understand that well managed nuclear power should have a role in the energy mix in the UK

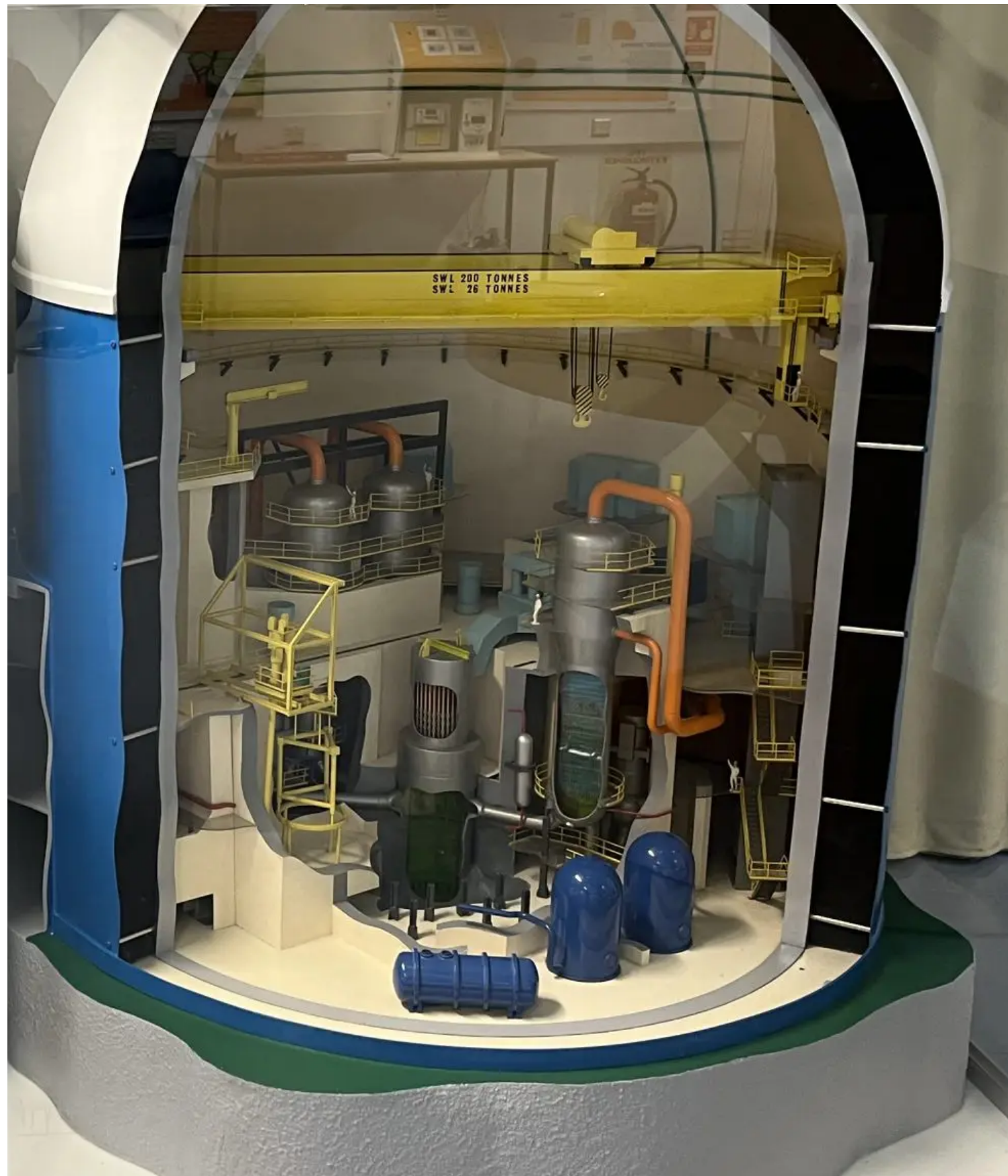
So, in the 2020s work began on an upgraded PWR design

A twin reactor station at Hinkley Point C in Somerset is now under construction and an identical twin reactor station at Sizewell C is being built. When complete in Sizewell B and C will together produce 10% of the electricity needed in the UK

The Present - Sizewell B



The Present - Sizewell B



Future - Nuclear Power

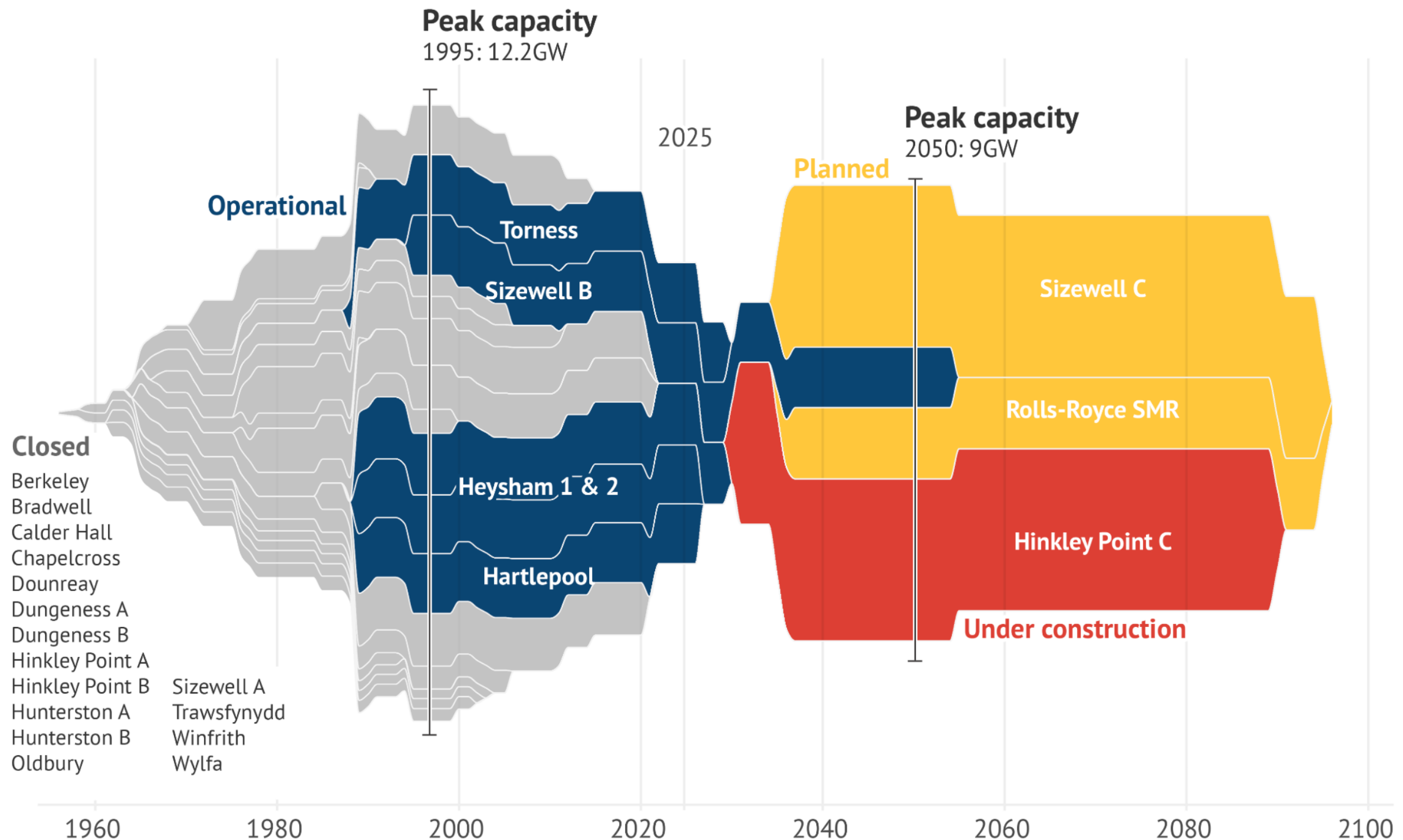
Hinkley Point C



Past/Present/Future - Nuclear Power

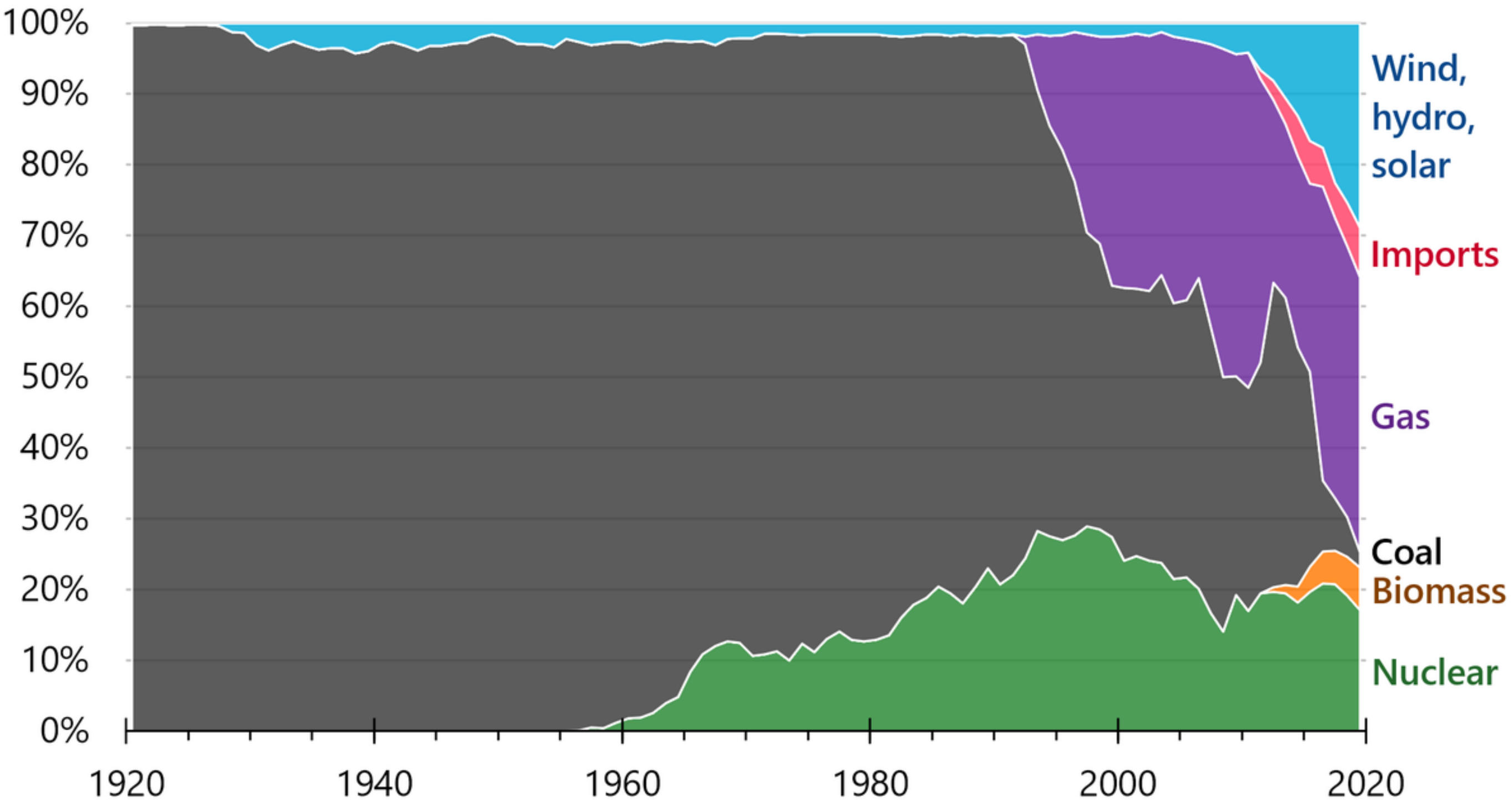
The rise, fall and rise of UK nuclear capacity over eight decades

Operational capacity, gigawatts (GW)



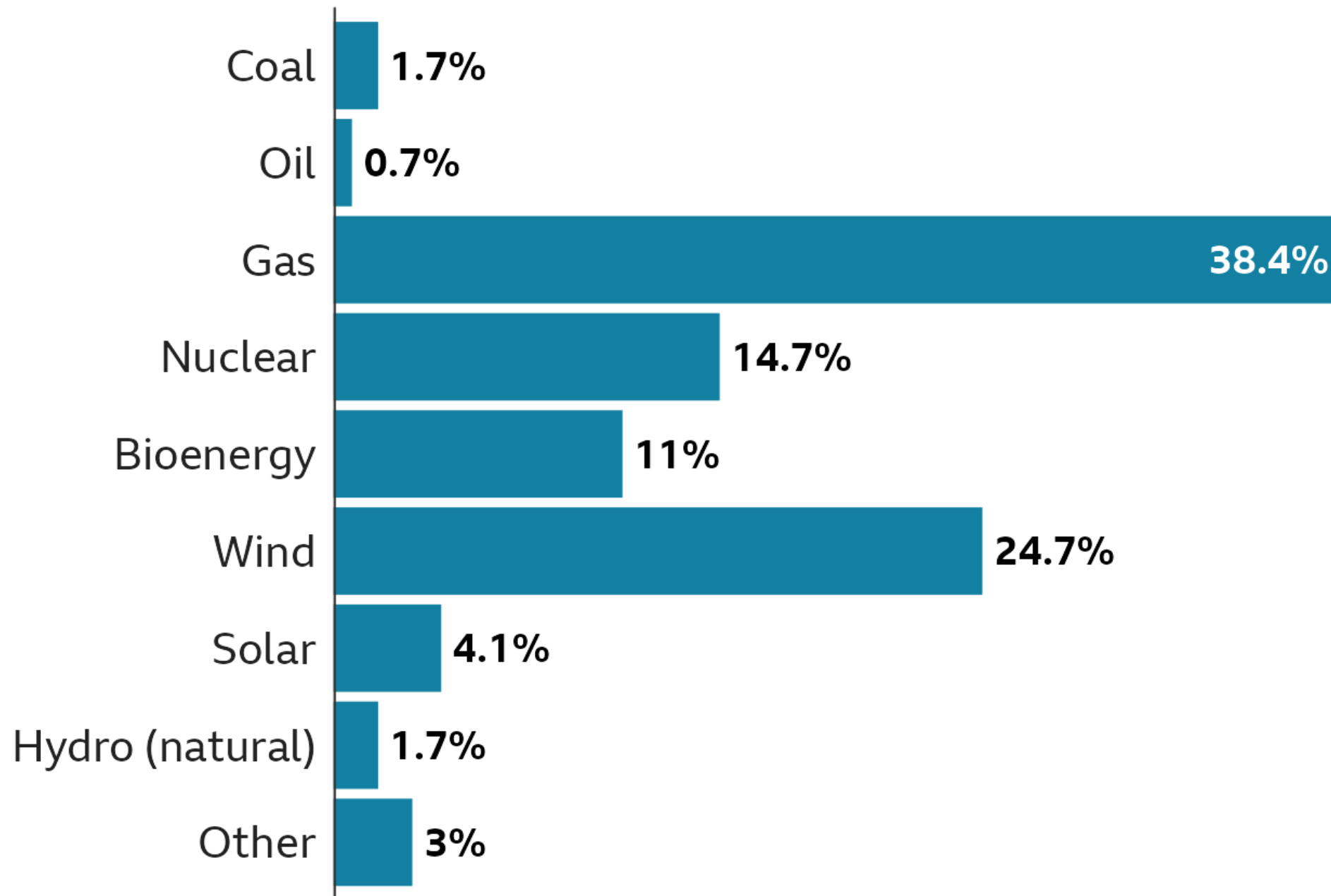
Source: World Nuclear Association and Carbon Brief analysis

The Present - UK Generation Mix



The Present - Electricity Generation

% of generation by fuel type in the UK in 2022

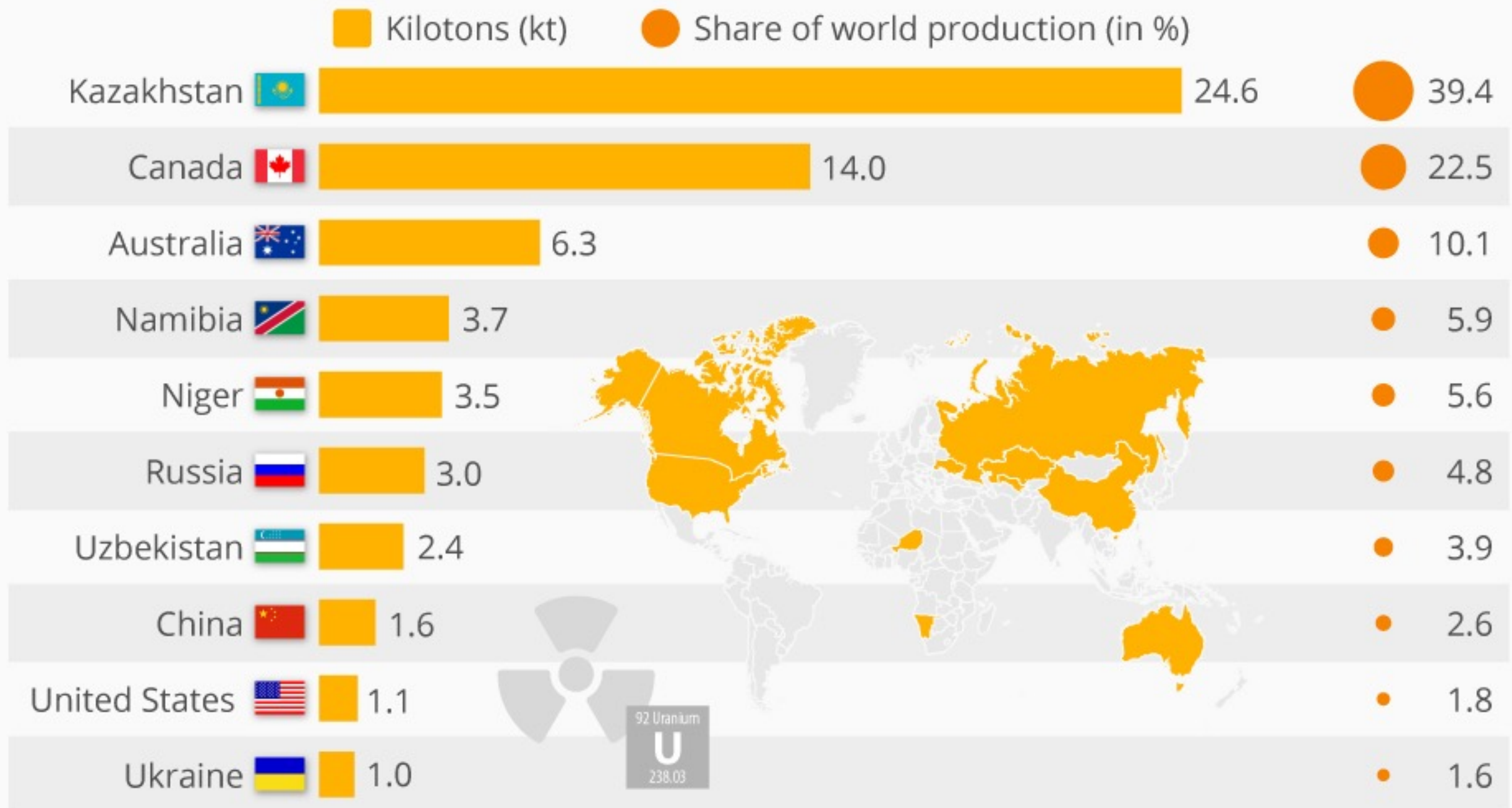


Note that 'other' includes pumped storage and alternative sources

Source: Department for Energy Security and Net Zero

The Present - World Uranium Supply

Ranking of countries with the largest production volume of uranium in 2016 (in kilotons)



The Present

Nuclear Power - Safety - Radioactive Waste



Nuclear Power - Safety Concerns

1a. Nuclear accidents

People fear a **reactor accident** in which:

- Radioactive material escapes into the air and water
- Large areas become unsafe for people
- Cleanup is difficult and expensive

How avoided:

All operations and maintenance work follows approved procedures carried out by highly trained staff

Very positive open safety culture in the industry

Strong government regulation

International cooperation and information exchange

Reality:

Very few nuclear accidents in many decades

Nuclear Power - Safety Concerns

1b. Nuclear accidents

Very few nuclear accidents in many decades ...

Three Mile Island - USA 1979 - A steam leak in the reactor building wrote the power station off and making the plant safe has been very costly. However the reactor building containment worked as designed, and only a minuscule amount of radioactive material was discharged. Although a massive financial loss no one was hurt.

Chernobyl - Soviet Union - 1986 - this was a big one! An unauthorised commissioning test was performed by operators. I see this as a result of the political/management/cultural system at the time which in so many respects is anathema to UK/ Western European/ USA culture... the reactor design was not built anywhere else; the testing that was done was completely reckless and so different to the robustness of UK operations procedures; and the response was slow and again contrary to UK management culture.

Fukushima - Japan - 2011. The reactors shut down correctly when the near record Richter 9 magnitude seismic event occurred, however, some minutes later the 14m tsunami overtopped the 10m high protection wall. Water ingress disabled some safety systems and the operators were not able to keep the reactors and fuel cool in the hours following shutdown. Some radioactive material was discharged to the atmosphere and this required the emergency evacuation of more than 100,000 people. Although a massive financial loss no one was hurt by radiation (although there were deaths in the evacuation process and by the stress caused). Some villages are still in an exclusion area. The recovery is costly but well managed with international involvement. (Unconnected with the power station, on the day of the tsunami elsewhere along the coast around 20,000 people were killed and 200,000 people lost their houses and more lost their livelihoods.)

Nuclear Power - Safety Concerns

2a. Radioactive waste

People fear **radioactive waste** because it stays dangerous for a long time

How to avoid harm:

- Efficient controls at source
- Storage and isolation
- Long-term storage underground in engineered sites

Reality:

Little waste produced considering the amount of electricity produced

All of it is managed (only minuscule amounts discharged to air and sea)

The hazard of radioactivity diminishes with time

Nuclear Power - Safety Concerns

2b. Radioactive waste categories

Low level - hazard equivalent to domestic waste
steel drums and sent to a special engineered landfill site

Intermediate level - needs isolation for 50 years or so
concrete canisters and sent to a special engineered landfill site

High level is stored at site until the heat given off and its radiation level diminishes and is then vitrified to stabilise it for underground burial

Note:

Radioactivity is all around us

All rocks are radioactive - some dangerously so

The fuel comes from mining *naturally occurring* radioactive rocks

High level waste is processed into *artificial* radioactive rocks for burial

Nuclear Power - Safety Concerns

3. Risk of radiation exposure

People fear exposure to radiation and getting cancer if something goes wrong

How avoided:

All operations and maintenance work follows approved procedures carried out by highly trained staff

Very positive open safety culture in the industry

Strong government regulation

International cooperation and information exchange

Plants built to survive earthquakes, floods, etc.

Systems used to protect against terrorism, cyber attacks, theft, etc.

Reality:

Very few nuclear incidents in many decades

Future - Nuclear Power

Hinkley Point C but Sizewell C will be similar

