Nuclear Power Generation

Past, Present & Future

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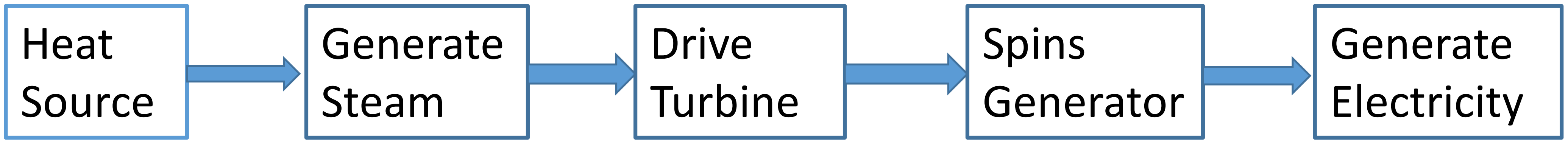
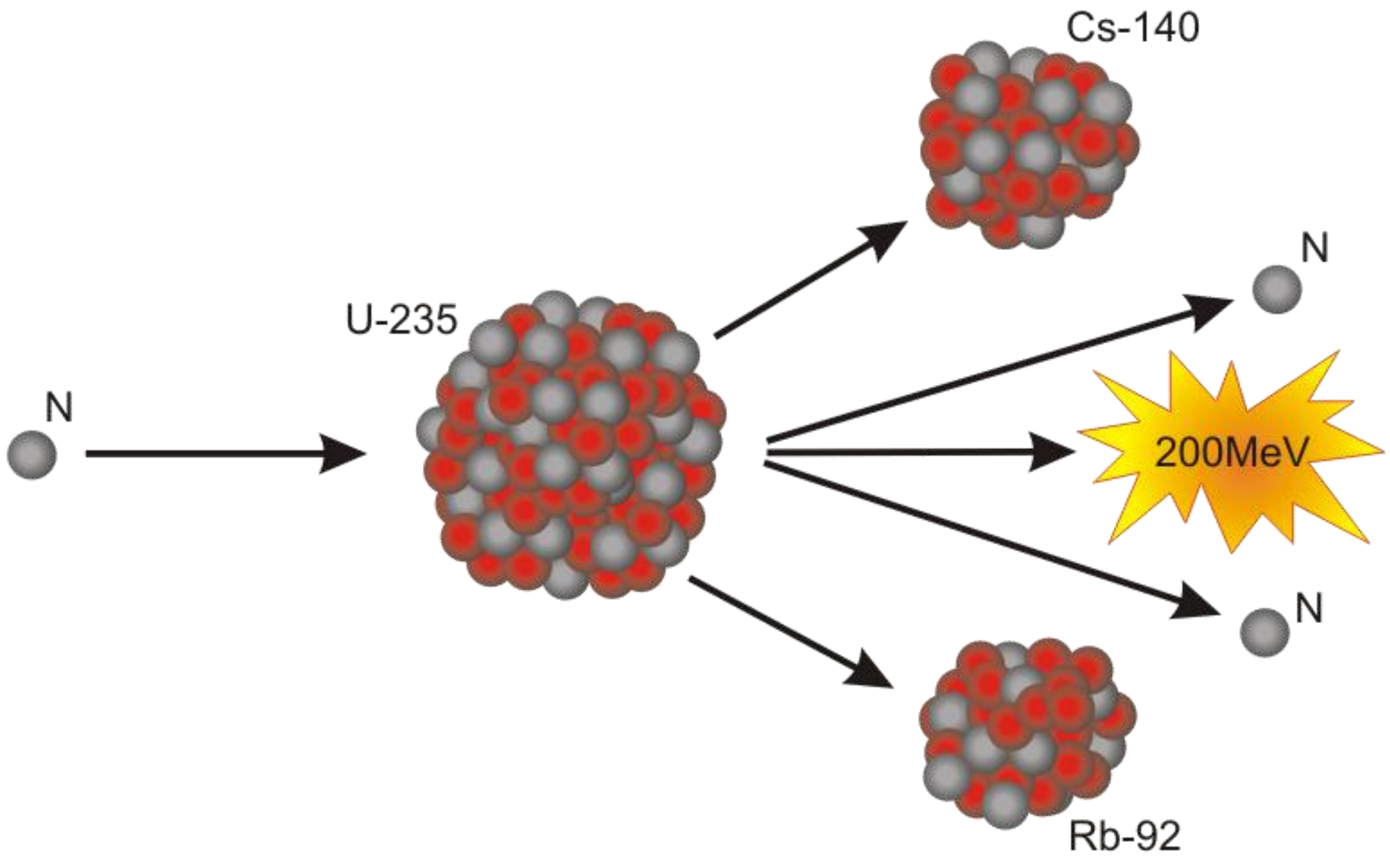
Overview of Nuclear Power Technology

- Core generation technology same as fossil fuel powered stations
- Use thermodynamic cycle to generate mechanical power
- Mechanical power converted to electrical power by a dynamo or alternator

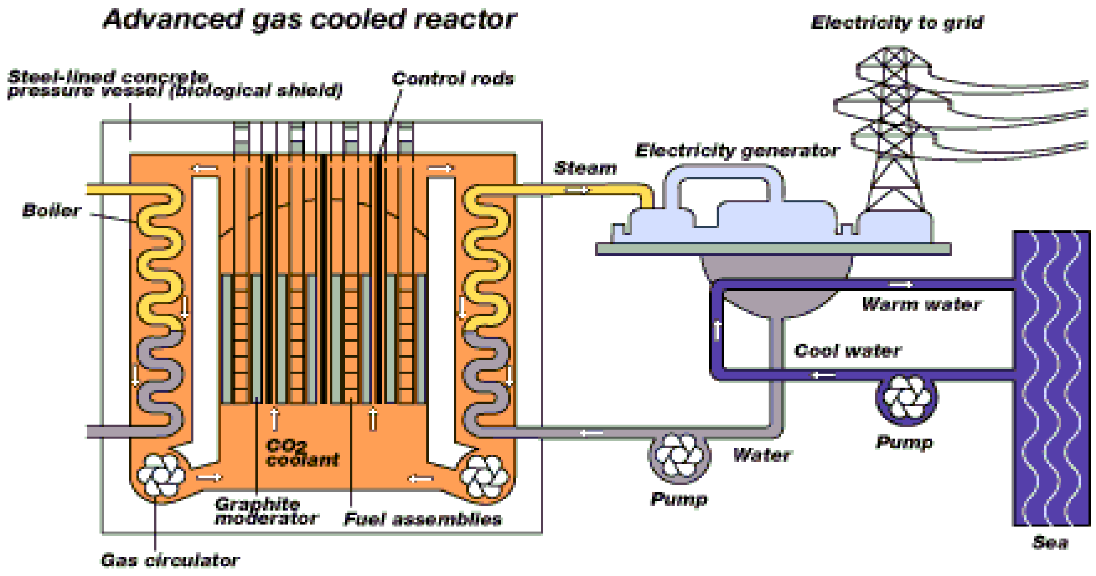

Heat Source
Generate Steam
Drive Turbine
Spins Generator
Generate Electricity

Nuclear Fission Reactors



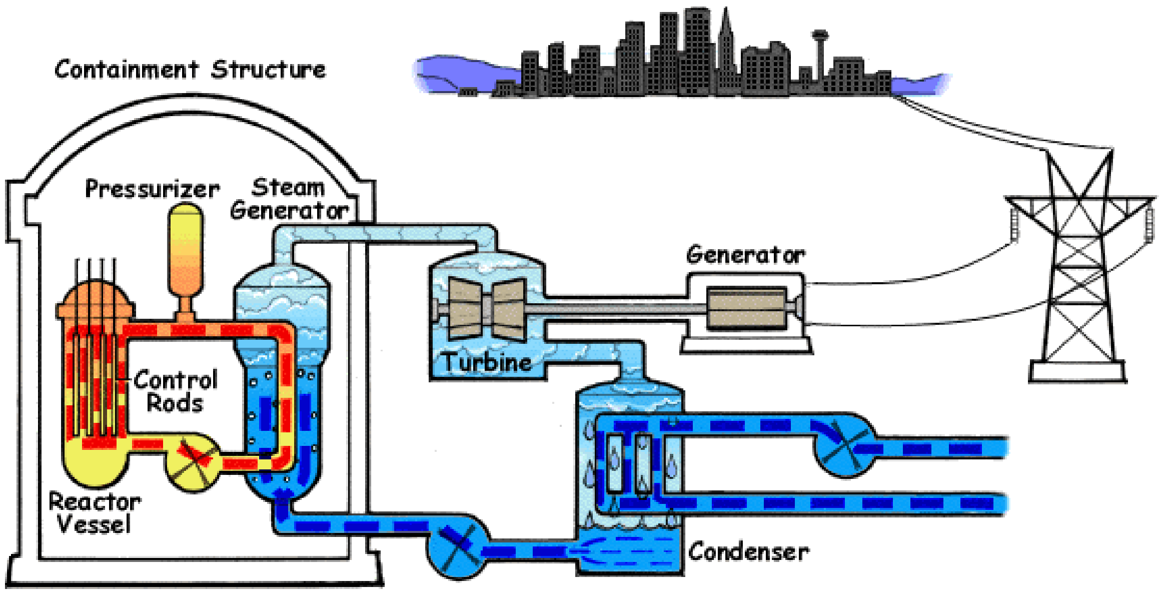
1st Generation Nuclear Stations

❖ British Technology
- Gas cooled Reactors - MAGNOX and AGR
- Low power density
- CO_2 at medium pressure & temperature to transfer heat from reactor to boiler
- Graphite moderator



2nd Generation Nuclear Stations

- ❖ American Technology
  - Water cooled reactors – PWR (most common reactor type currently in operation)
  - Derived from the US naval reactors
  - Water at high pressure is heat transfer medium & moderator
  - Higher power density than gas cooled reactors



Other 2nd Generation Stations

- Boiling Water Reactors – No 2ndry water loop, steam generated in reactor fed directly to turbine (2nd most common design in current use)
- Pressurised Heavy Water Reactor – Burns unenriched U 👍 but produces more Pu 👎
- RBMK - Hybrid graphite moderated water cooled. Inherent design flaw ⇨ Chernobyl !!
- VVER (Water-Water Energetic Reactor) - Russian designed PWR that adopted western safety features and practices

In total there are 441 nuclear power stations operating around the world

3rd Generation Nuclear Power Stations

These are station designs currently being built or in advanced planning stage

- EPR (European Pressurised Reactor) – a PWR updated to provide additional safety & security including lessons learnt from the Three Mile Island and Fukushima accidents and to be cheaper to build and operate.
- AP1000 - a PWR update by Westinghouse with enhanced safety through stronger containment and adoption of more passive rather than active safety features.
- VVER1200 - an updated version of the VVER1000 design with all power, electrical and control systems contained within a structure capable of withstanding large aircraft impact & passive core cooling systems.
- ACPR1000 - a PWR from the Chinese General Nuclear Power Group based originally on a French design and incorporating improved containment and safe shutdown systems

Future Designs

There are numerous technologies currently proposed or being researched. The goal of these new designs is to build reactors that:

- Are more reliable with passive rather than active safety systems
- Burn fuel (uranium) more efficiently (processed U is expensive & refuelling requires lengthy shutdown)
- Produce less radioactive spent fuel & waste
- Are cheaper to build & operate

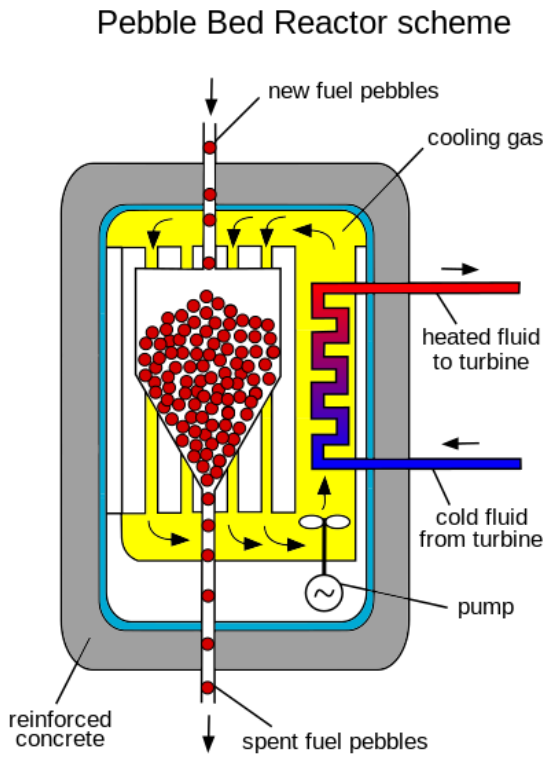
Some designs currently being investigated are:

Fast Breeder Reactors (FBRs)

- Fast Breeder Reactors simultaneously generate power and create new fuel that can be burnt in the reactor
- Prototype Fast Breeder reactors have already been built in the UK, USA, France, Russia, India & Japan.
- Most of these are R&D reactors but some (in UK, France & Russia have produced or are producing electrical power into the supply grids)
- The plus points of FBRs is that they are very efficient in using fuel and they burn up the long lived radioactive elements in the spent fuel thus reducing long term radioactive waste problem
- The minus points are they are technically complex & they can be used to generate Plutonium

Pebble Bed Reactors

- A very simple reactor design using a fuel bed of spherical fuel pellets (about size of an orange)
- A gas cooled reactor
- Operates at very high temperatures c800ºC & is therefore thermodynamically efficient
- Has inherent safety features & fuel and reactor good to at least 1500ºC
- Fuel production and waste processing difficult & dust



Liquid Metal Cooled Reactors

- Numerous examples of liquid metal cooled reactors in existence e.g. most FBRs, Soviet submarine reactors
- Metals used include Sodium, Sodium/Potassium, Lead & Mercury
- + points are: low pressure coolant loops, efficient heat exchange, good shielding, low neutron capture
- - points are: lead is toxic, sodium + water!!, instrumentation difficult, it all goes solid when cold

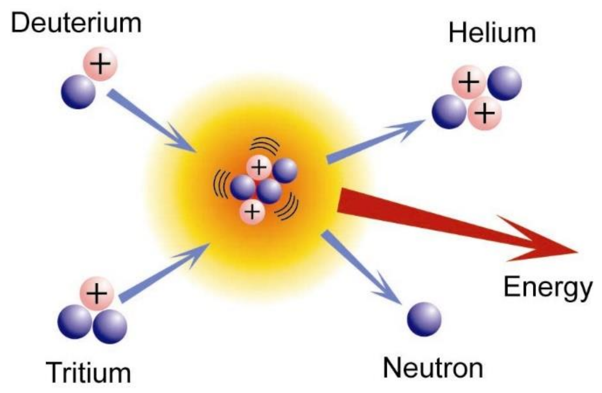
Travelling Wave Reactors

- Basically a type of breeder reactor where a reaction wave moves through a core converting ‘fertile’ material to ‘fissile’ fuel and then burning it up.
- In theory a reactor could be loaded with fuel, sealed and then run for 40-50 years ending up with short half life waste products
- Problem is that no one has come up with a workable engineering design for such a reactor

Fusion Reactors

Using the processes that power the sun

- Fusing together hydrogen atoms to make helium + a lot of power
- Requires a lot of energy to achieve fusion reaction
- Sun uses immense pressures & temperatures to achieve this
- Easier to fuse hydrogen isotopes deuterium or tritium
- Need a machine that creates very very high temperatures (100 million ^{o}K) and a sufficiently high pressure at the same time



Magnetic Confinement (Toruses, Tokamaks & Stellarators)

- Early experiments such as UK experimental reactor ZETA failed to achieve conditions required for fusion
- Deuterium or Tritium plasma needs to be confined at v high temperatures >100 million ^{o}K
- Later designs such as Russian Tokamak more successful at achieving required density/Temperature/Time product for fusion reaction
- JET (Joint European Torus) at Culham currently largest operational Tokamak has achieved fusion with +ive power balance of up to 16 MW
- ITER (International Thermonuclear Experimental Reactor) at Saint-Paul-les-Dorance planned to become operational in 2020 anticipated to generate 500MW output from an input of 50MW

Inertial Confinement

- Alternative to magnetic confinement
- Fires high energy light or particle beams at small beads of Du/Trit fuel from multiple directions crushing them to generate v high temps & pressures
- In some ways simpler than the big MC machines but have not yet achieved ignition

Prospects of Fusion Power?

- ITER should show that Fusion Power reactors are possible to create
- Radioactive waste would be much reduced and arms proliferation issues eliminated
- Enormous practical engineering problems to overcome
- Stations would be mega expensive to build
- Realistically need 40-50 years before a fusion power generating station could be constructed & operating