NUCLEAR FUSION

Fusion is the nuclear process that occurs in stars due to lightweight atoms fusing together. This releases a lot of energy. Currently, a lot of research is going on to devise mechanisms to harness this energy on Earth in a controlled manner. The potential advantages of nuclear fusion energy include a long-term, sustainable, economical and safe energy source for electricity generation. Fuel is inexpensive and abundant in nature, while the amount of long-lived radioactive waste and greenhouse gases produced through fusion are minimal.

Fusion Energy Gain Factor: Q = P(fus) / P(heat)

Fuel needs to be hot enough for long enough for the fusion reactions to occur.

Tokamak - Toroidal chamber magnetic coils

- Ring donut shaped vessel with magnetic coils around it
- The fuel is heated inside to produce plasma
- Strong magnetic fields trap the plasma
- Need to hold it stable long enough for fusion reactions to occur
- Occurs at high temperatures
- Hot plasma is kept away from the walls by a magnetic field produced by two sets of coils that contain the plasma horizontally and vertically to avoid meltdown.
- Fast control systems change B to keep plasma trapped and stable

Spherical Tokamak - similar principle to tokamak with a more compact shape

- Higher efficiency - B is stronger closer to the centre, plasma is closer to the centre
- Better confinement - plasma is hotter for longer close to the centre
- Stability - less plasma instability which could cause heat leakage
- Current - produces stabilising current more efficiently, lesser input energy required

The toroidal and poloidal fields twist around each other to confine the plasma. The outer poloidal field by the third set of coils shapes and positions the plasma. The plasma is produced inside the torus-shaped vacuum chamber. When the ionised particles gain high enough energy, they overcome electrostatic repulsion and collide to release energy.

For fusion reactions to occur, the plasma needs to be four times as hot as the sun and thus requires very high initial energy, after which it can self-sustain. The plasma then generates neutrons that spin near the reactor walls and heats it. This heat is used to generate energy. Cooling the reactor requires a cryogenic cooling system utilising helium and liquid hydrogen.

Stellarators require less injected power to sustain the plasma, have greater design flexibility, and allow for simplification of some aspects of plasma control. However, these benefits come at the cost of increased complexity, especially for the magnetic field coils. Stellarators use extremely strong electromagnets to generate twisting magnetic fields that wrap the long way around the donut shape.