Fusion – Within our Grasp?
By Samuel Ha

Meeting report: 14th Sept, Ashcroft Centre

The problem is rather stark: most of the World's energy usage is based on fossil fuels, and continued release of carbon dioxide into the atmosphere at the present rate will lead to catastrophic climate change within the lifetime of our children and grandchildren. Don't look to renewables for a substitute: we might indeed support a good fraction of our electricity consumption this way (and I hope we do) but that is a small fraction of the total consumption. Don't expect fission power (as used in current nuclear power stations) to be the answer either: we will indeed probably need a substantial contribution from nuclear to provide our electricity, but the UK alone would need about 300 nuclear stations to replace the rest. We are unlikely to get our hand on enough uranium to provide sufficient fuel - regardless of other considerations. Can we make significant reductions in energy consumption? It would have to be by about 90% (at least!): I doubt if any politician regards this as saleable to voters. Fusion power, however, uses fuel (deuterium and lithium) that is relatively cheap and easily available (e.g. in sea water), produces no long-lived radioactive waste and has few of the accident risks of fission power. (Radioactive by products decay in tens or hundreds of years rather than thousands and tens of thousands of years). Given that the appetite for energy appears unlimited, we also need a supply that is essentially unlimited, so is fusion the answer?

It turns out to be an exceptionally difficult technology: before the fuel starts to burn, it has to be raised to a temperature 10 times that at the centre of the Sun, and then it has to be held together at sufficient concentration until the reactions complete. Enormous superconducting magnets are required cooled to a fraction about absolute zero - so we have to have both the hottest and one of coldest places in the Solar System side by side (and kept apart). The confined energy wants to escape, and if it does it could wreck the power station - at a cost of many tens of billions of dollars. It is in fact hardly any wonder that the development of fusion power has taken many decades to reach its current state of play: the technical challenges have been formidable - but mountains have already been climbed. There is a strong and very reasonable expectation that the next internationally supported experimental device now under construction in France (ITER) will, sometime in the later 2020s, produce more in fusion output power than it consumes in electricity to create and confine the super-hot plasmas. So, are we there yet? Is it now within our grasp?

Not, I think, by a long way.

Real commercial power stations also have to produce more money than they consume. The fuel may be relatively cheap but everything else is very expensive. That means that a fusion power station needs to deliver decades of relatively trouble-free operation. There must be no expensive repairs. The must be no long periods when they cannot generate, because there will be no income to defray the interest on the exceptionally large loans taken out to fund construction. Unfortunately, many of the station's structures and materials may well be stressed beyond current experience, so a large programme of fusion power is unlikely to commence until a commercial demonstration reactor (at least one!) has shown that all the issues associated with production operation of a power station are surmountable. Realistically, we are looking at the latter half of this century (at the very earliest) before we see a real commercial power station, and many more decades before they could be built in significant numbers.

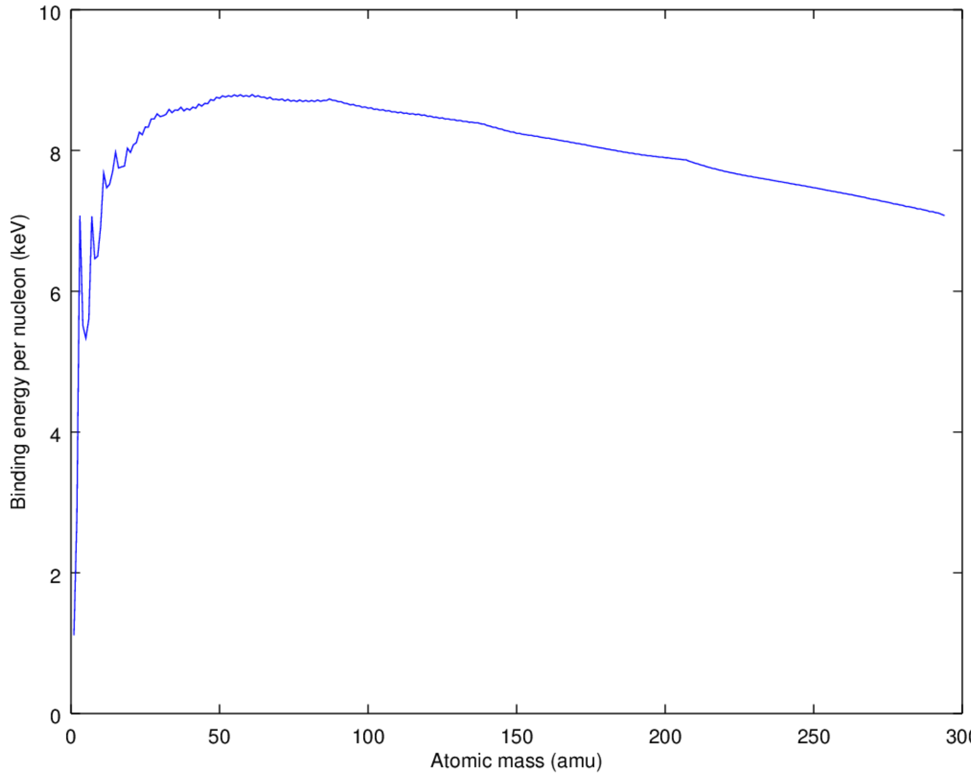
So, it may well be that the real challenges to be faced by fusion power are still in the future. I doubt that we can afford to wait 50 or 60 years for fossil fuel alternatives. We may have to accept such solutions as are available at the time (even if they are unpalatable) and commit our resources accordingly. I hope it is not the case, but I suspect that in 50 years significant amounts of fusion generation may still prove to be a long way away.

Fusion:

Overview and Current Progress

Samuel Ha

Introduction to Fusion



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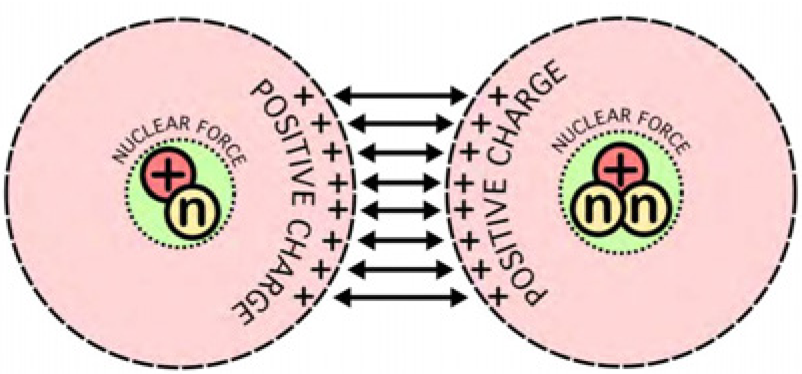
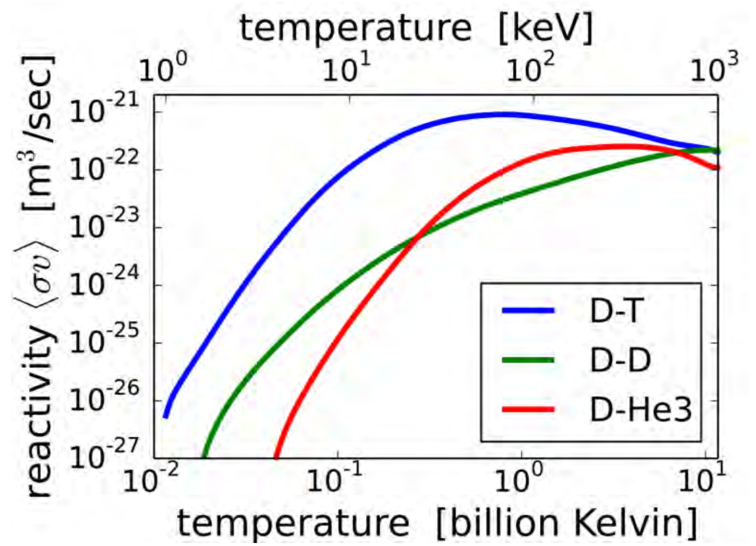
Challenges of Fusion

How to fuse atoms: Overcome electrostatic repulsion

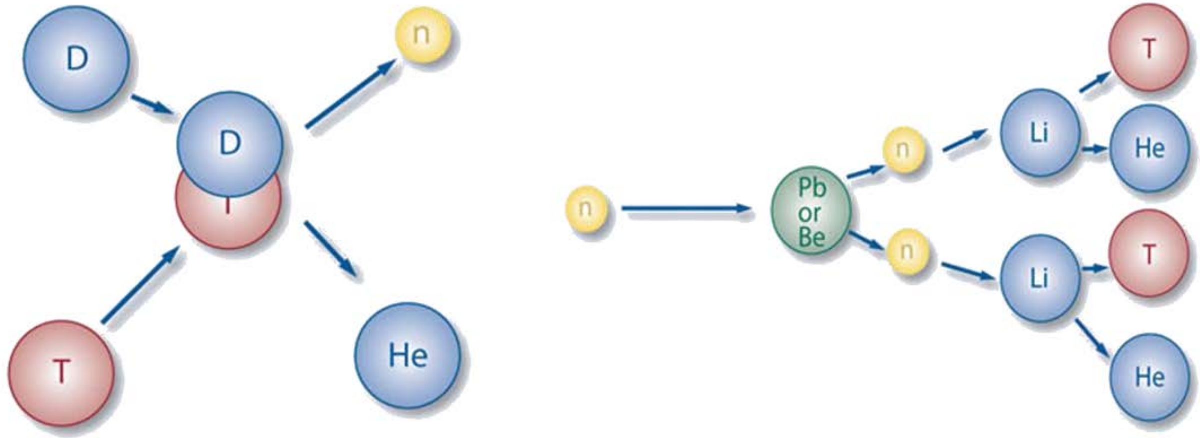
- Need to make nuclei travel fast, which means hot
- Gases break down into a plasma when heated to extreme temperatures
- Plasmas can be contained by magnetic fields





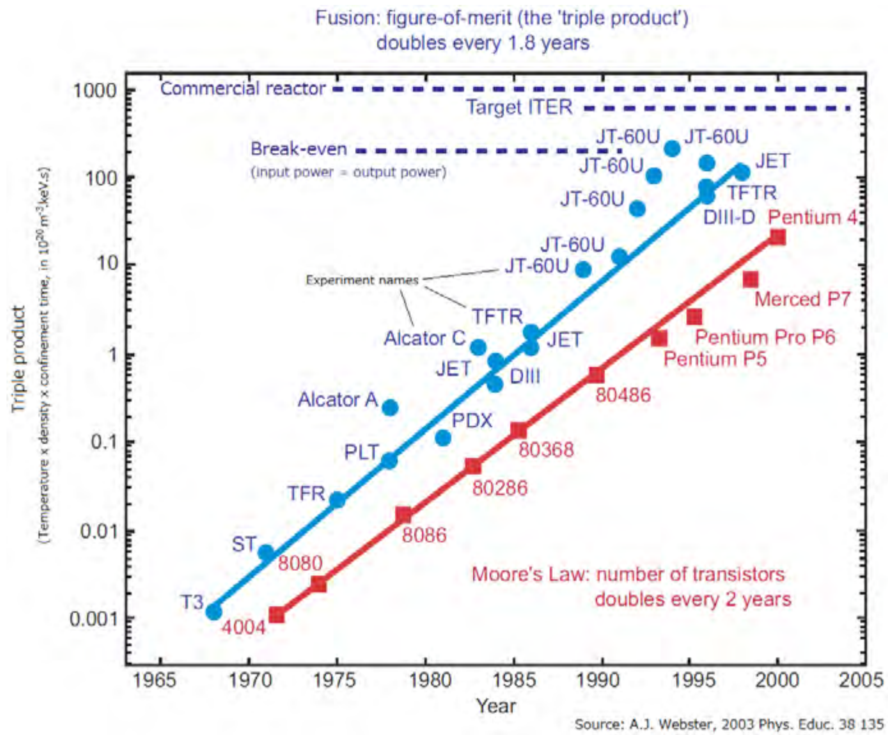
Challenges of Fusion

- Generating fuel
  - Capturing neutrons
  - Multiplying neutrons
  - Use nuclear reactions to generate tritium



Challenges of Fusion

- Reaction rate found to be dependent on three plasma properties:
  - Temperature (T)
  - Density (n)
  - Confinement Time (τ_E)



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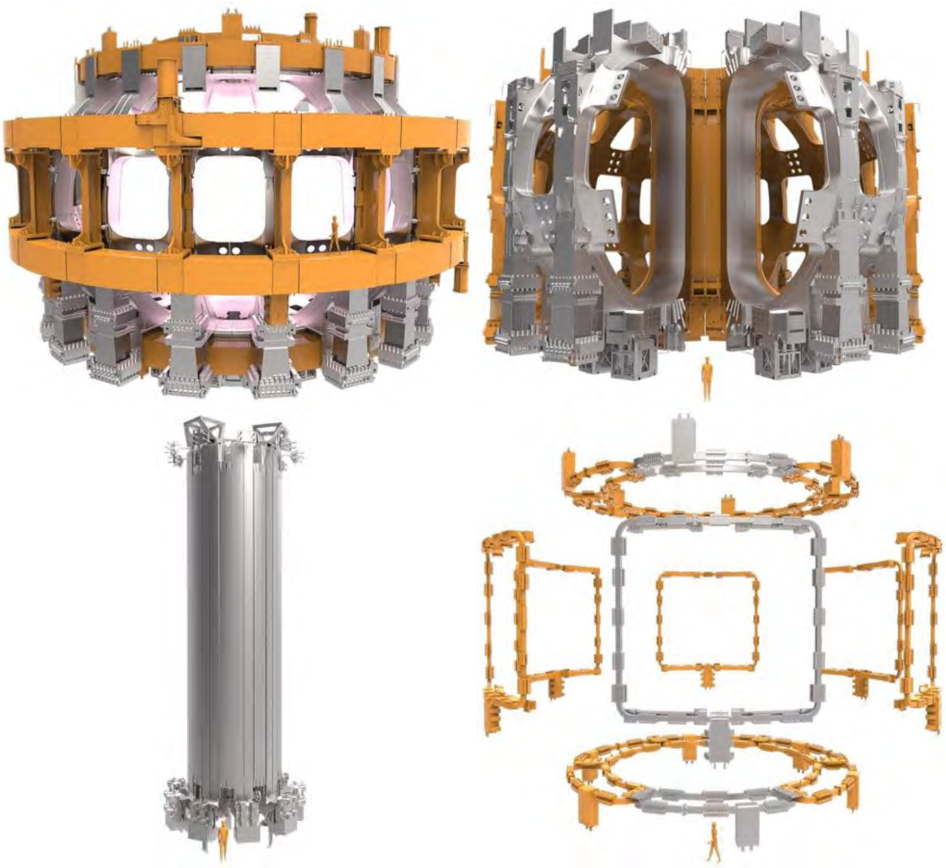
Challenges of Fusion

- How to improve the Triple Product:
  - Increase in temperature increases radiative losses
  - Increase in density requires stronger magnets
  - Increase in confinement time requires greater understanding of confinement and release mechanisms

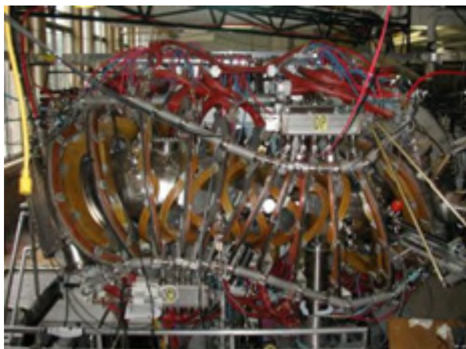
Challenges of Fusion

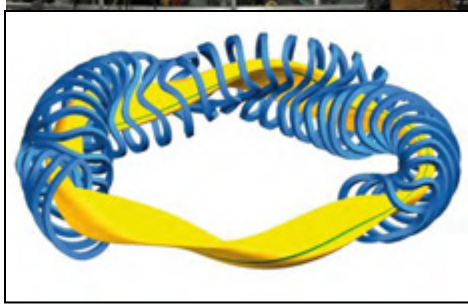
- Plasma Confinement
  - Poloidal and Toroidal field coils
  - Central Solenoid
  - Correction Coils
- Superconducting Magnets
  - Unprecedented manufacturing
  - Multiple systems with multiple functions

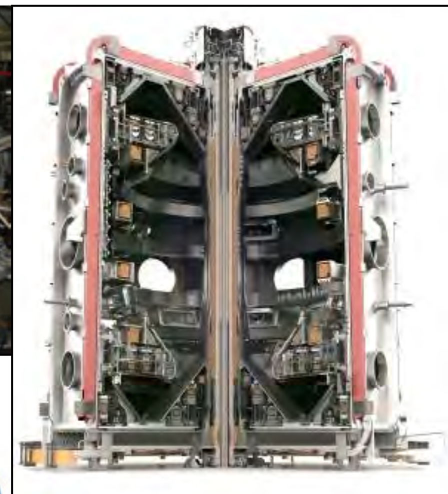


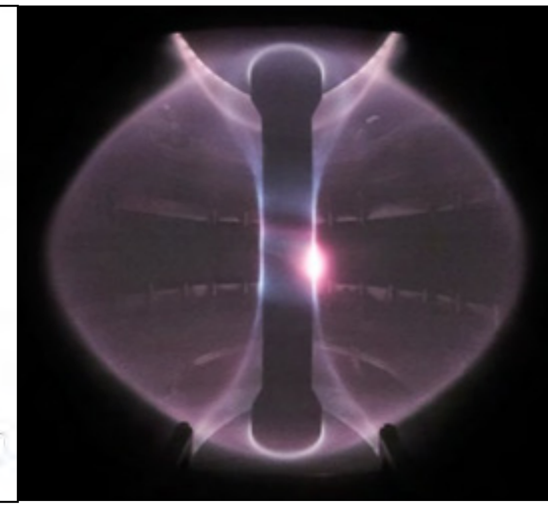
Challenges of Fusion

Many possible magnetic configurations









Power Generation

Fuel is highly abundant

- Deuterium is 0.016% of hydrogen on earth
  - 1 / 6420 hydrogen atoms
- Tritium is scarce, but can be generated
  - ${}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{3}_{1}T + \alpha \ (+4.8MeV)$
- Average laptop battery (~8g Li) + 5L of water = 55GJ of electricity (at 30% efficiency)

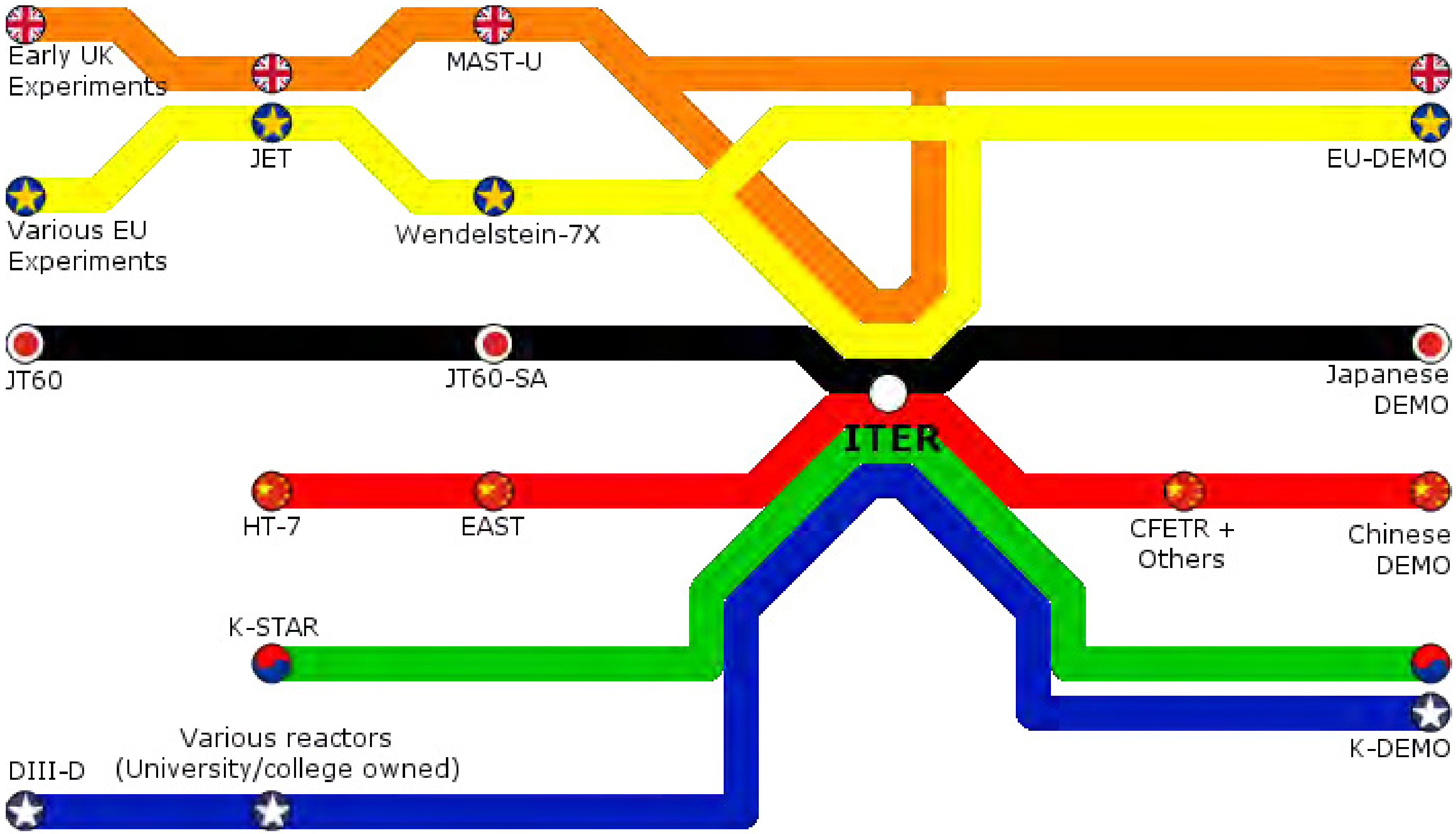
Power Generation

- Laptop battery (~8g Li) + ~5L tap water = ~55GJ of electricity
- UK annual **energy** consumption per capita: ~115GJ
- World supply of Lithium: >10B kg (10^{10}kg)

Future Perfect

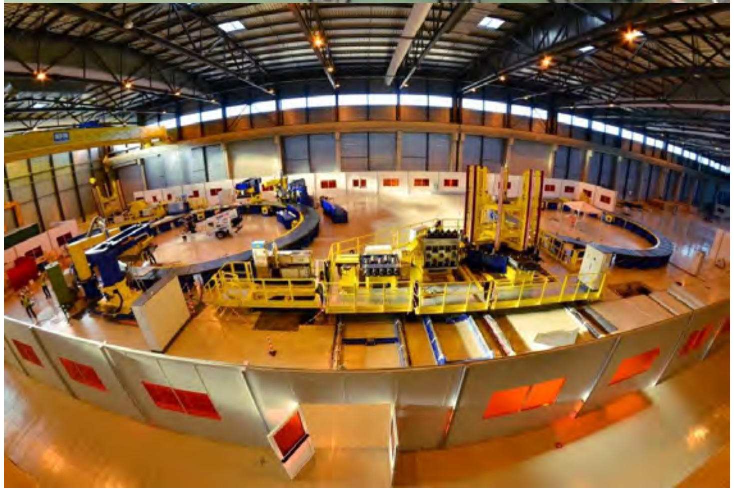
- Extreme challenges
  - Long term problems
- Near unlimited fuel supply
  - Long term solution

How do we get there?



How do we get there?

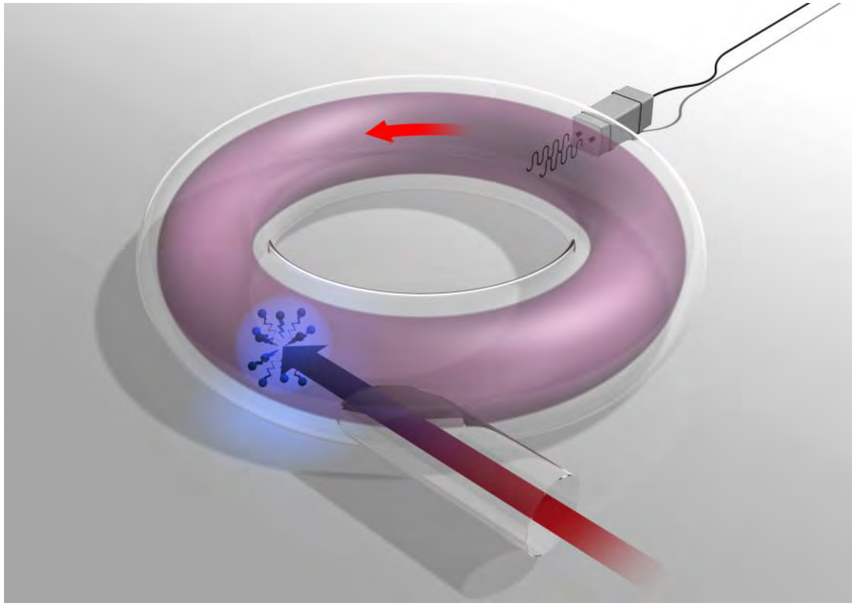
- ITER work continues
  - First TF coil delivered
  - Seismic damping pads installed
  - Building works continue throughout, new buildings finished often
  - Tritium storage tanks installed in lower basement
  - PF coil winding facility built and PF coils being manufactured



Questions?

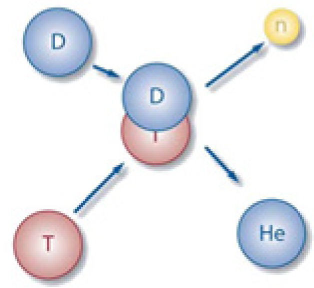
Heating Methods

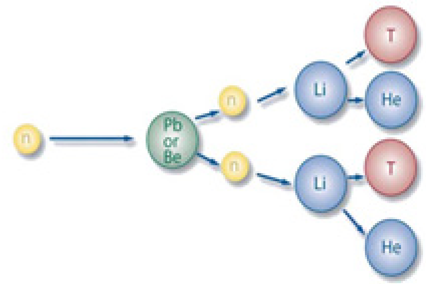
- Central Solenoid
  - Current induction in plasma
- Radio Frequency Heating
  - Similar to microwave
- Neutral Beam Injector
  - Fast beam of neutral particles

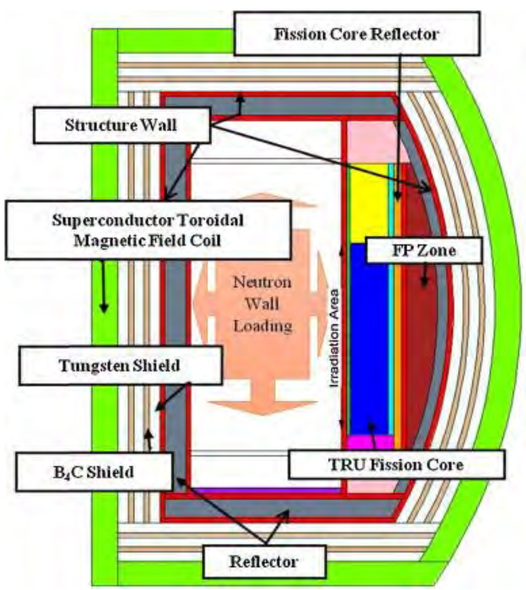


Fuel generation

- Blankets containing lithium and a neutron multiplier
  - Lithium enriched to 70~90% ^{6}Li, compared to 7.7% ^{6}Li for natural lithium
- Beryllium or lead as neutron multiplier
  - Beryllium pebbles
  - Molten lead-lithium
- Future development of ‘Hybrid’ systems







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