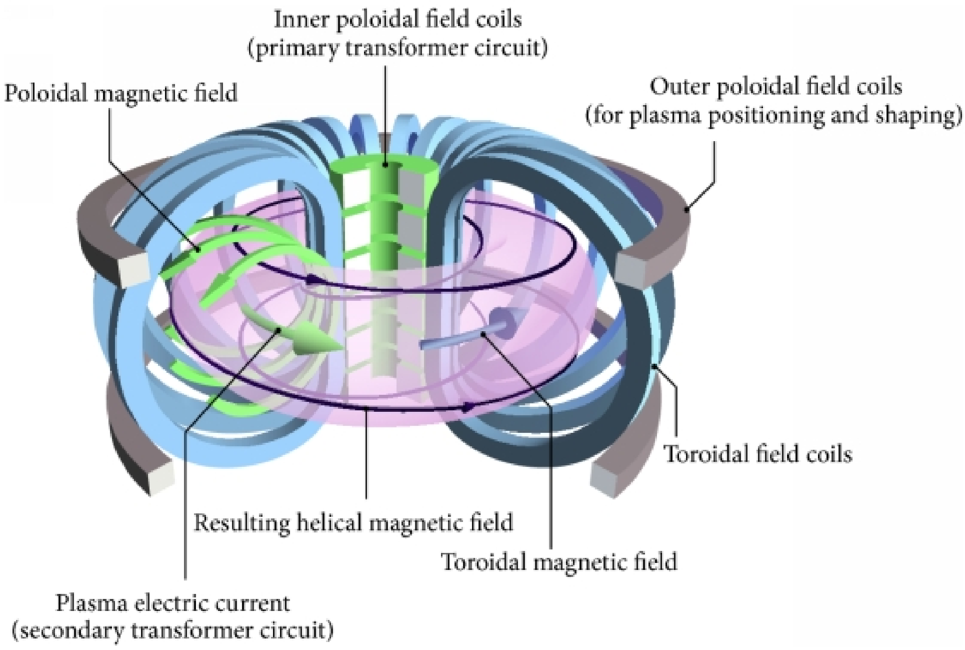

Figure 1: Tokamak - Schematic [Wikipedia contributors(2020)]

Tokamaks are machines with a strong magnetic field whose mission is to, one day, become fusion reactors fueling clean and safe power plants. The basic task of a tokamak reactor is to heat and confine its fuel, a 50:50 mixture of deuterium and tritium, allowing thermonuclear fusion reactions to take place. These reactions generate heat (14.1 MeV per reaction) which is subsequently converted into electricity via the standard steam-turbine cycle.

One of the main challenges in current tokamak research is to confine the burning fuel. Although the fuel is very thin (its density is 5-8 orders of magnitude lower than the density of air), its temperature is extremely high, up to ∼100 million K. This is to ensure that when deuterium and tritium nuclei collide, they have sufficient energy to overcome the repulsive electrostatic barrier and fuse, hence *thermonuclear* fusion. Such high temperatures mean that the fuel is in the state of plasma, a collection of ionized nuclei and free electrons, and also that it must never directly touch the reactor walls. (For one, the plasma would cool down and cease to exist; for two, the reactor walls might melt.) Tokamaks confine the fuel using the Lorentz force $q\mathbf{v} \times \mathbf{B}$, which forces charged particles to rotate around magnetic field lines rather than travel across them freely. Thus the strong magnetic field confines the plasma in the center of the tokamak chamber.

The basic structure of a tokamak is shown in figure 1 (more information can be found e.g. in [Wesson(1999)]). Tokamaks comprise three essential parts: a vacuum chamber, toroidal field coils, and a transformer. The *vacuum chamber* (or vacuum vessel) has the shape of a torus of the size approximately 1-20 m across; its purpose is to contain the plasma while allowing limited access through diagnostic ports. Around the vacuum chamber are wrapped dozens of *toroidal magnetic field coils*, which generate the confining toroidal magnetic field B_t (0.5-5 T). Finally, the *transformer* creates and heats the plasma by inducing a loop voltage U_{loop} (several V) inside the vacuum chamber and then driving a plasma current I_p (kA to MA).

Because of this structure, the duration of tokamak plasma existence is intrinsically limited. The plasma can only exist so long as the plasma current I_p is driven, because the ohmic heating $P_{OH} = U_{loop}.I_p$ sustains its high temperature in spite of continuous heat losses. (It also ensures plasma stability, but that is outside the scope of this manual.) And since driving a current in the secondary coil (plasma) requires a monotonically changing current in the primary coil (shown in figure **??**), which cannot be done forever, at some point the primary coil current reaches a maximum and the transformer stops transforming. Presently the plasma current dies out, the plasma cools down, electrons and ions recombine into a neutral gas and the plasma ceases to exist. Therefore, tokamak plasmas are created in so called *discharges*, or *shots* for short. Discharge duration strongly depends on the machine — on GOLEM it is < 20 ms, on the largest machines it is > 1 s.

References

[Wesson(1999)] John Wesson. The science of JET. In *JET Reports*, pages JET–R(99)13. 1999. URL `http://www.iop.org/Jet/fulltext/JETR99013.pdf`.

[Wikipedia contributors(2020)] Wikipedia contributors. Tokamak — Wikipedia, the free encyclopedia. https://en.wikipedia.org/w/index.php?title=Tokamak, 2020. [Online; accessed 29-March-2020].