Physics basis of magnetic fusion reactors

Sibylle Günter
Max-Planck-Institut für Plasmaphysik

Nuclear fusion could play a major role in the energy mix during the second half of this century. The advantages of nuclear fusion, in particular for base load power stations, are obvious: the fuel is nearly unlimited and widely available, and - in contrast to fission - there is no possibility of a runaway reaction or meltdown. After more than 50 years of research, fusion has advanced to the decisive step on the way to a power plant: the international tokamak experiment ITER is designed to demonstrate the feasibility of net energy production from nuclear fusion reactions.

For a fusion reactor, matter has to be heated up to extremely high temperatures: more than 100 million degrees - about a factor of 10 hotter than the sun's core. At these temperatures the material is fully ionized. The charged particles can be confined by magnetic fields, which are also able to provide the required efficient heat insulation. For magnetic fusion reactions to be self-sustaining, the thermal insulation has to be a factor of 100 better than that of polystyrene - at temperatures, where the velocity of particles approaches one fifth of the velocity of light!

The current status of fusion research and the remaining scientific challenges will be discussed: The quality of heat insulation in a fusion device is mainly limited by the turbulent transport of heat and particles, driven by microscopic plasma instabilities. Macroscopic instabilities often destroy the magnetic field geometry if the plasma discharge is close to operational boundaries. The major new physics element for ITER and a future fusion device is the thermonuclear self-heating. The supra-thermal α particles with velocities well above the Alfvén velocity of background plasma are able to drive plasma instabilities, which in turn can expel the fast particles.