The High Density Approach for Fusion

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Demonstration of fusion ignition is a major scientific and technical goal for controlled fusion. Until the fundamental physics of fusion burning have been confirmed by experiments, the defining concepts for a fusion reactor must remain uncertain. Other factors would also have to be taken into account, such as the method for extracting fusion energy, self-breeding of tritium, and material technology. Nevertheless, the ignition process will be similar for any magnetically confined, predominantly thermal plasma. Heating methods and control strategies for ignition, burning, and shutdown all need to be establish in near term ignition experiments where pulse durations exceed all the plasma main characteristic time scales.

One of the key design criteria for compact, high field experiments comes from the observation that the scaling of the α-particle power density is, for the temperature range of interest, $P_\alpha = \varepsilon_\alpha n_D n_T \langle\sigma_F \mathrm{v}\rangle \propto n^2 T^2 \propto \beta_p^2 \bar{B}_p^4$, where $\bar{B}_p^4$ is the average poloidal field and $\beta_{p,}$ in practice, takes values that are limited by stability considerations within a relatively small range. For this reason, as well as for reasons of confinement, for a given geometry of the machine, it is appropriate to operate with the highest plasma currents I_p possible. Furthermore, the high plasma density regimes discovered by the high magnetic field experiments (Alcator's, FT's) have both outstanding confinement characteristics and degree of purity: ignition can be reached at relatively low temperatures in regimes of relevance for future reactors, where $T_i \cong T_e$, and far from the known operational limits. At the same time, in regimes close to ignition, the thermonuclear instability can set in with all its associated non linear effects, and control methods can be experimented with the application of modest amounts of ICRH auxiliary heating.

Fusion creates more neutrons per energy released than fission or spallation, therefore DT fusion facilities have the potential to become the most intense sources of neutrons for material testing. Compact, high field, high density devices could be envisaged for this purpose making full use of the intense neutron flux that they can generate, without reaching ignition. The practical possibility of extending the duration of the plasma pulse by means of appropriately shaped magnet coils is discussed, and the requirements for a Neutron Source Tokamak are presented.