Calculation of Nuclear Fusion Power for a Toroidal Plasma Device with Magnetic Confinement

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The power of a magnetic confinement fusion reactor P [erg s^{-1}] and the fulfilment of the ignition criterion are quantitatively determined by the nuclear fusion reaction rate $R_{\alpha\beta}$ [cm^{-3}s^{-1}] integrated over the plasma volume using the known magnetic surface geometry:

$$P \propto \int R_{\alpha\beta}(\mathbf{r})d^3\mathbf{r} = \int R_{\alpha\beta}(\rho,\vartheta,\varphi)\left|J\right|d\rho d\vartheta d\varphi\,. \tag{1}$$

The nuclear fusion reaction rate, in turn, is proportional to the rate coefficient averaged over the velocity distribution functions of the reacting species by integrating over the six-dimensional velocity space:

$$R_{\alpha\beta} = n_\alpha n_\beta \int \sigma(\left|\mathbf{v}_\alpha - \mathbf{v}_\beta\right|)\left|\mathbf{v}_\alpha - \mathbf{v}_\beta\right| f_\alpha(\mathbf{v}_\alpha) f_\beta(\mathbf{v}_\beta) d^3\mathbf{v}_\alpha d^3\mathbf{v}_\beta\,. \tag{2}$$

Nuclear fusion cross sections are known from numerous experimental studies. Reacting species typical density profiles are known from diagnostic data. Neutral beam injection and ion cyclotron radiofrequency heating-induced fast ion distributions are essentially non-Maxwellian and angularly anisotropic. A substantial contribution to the nuclear fusion reaction rates for DT, DD and DHe^3 reactions is from suprathermal ions from high-energy distribution tails. The production and good confinement of fast ions play the essential role. Reliable experimental data and theoretical understanding of the formation of fast ion distribution tails are required.

Radial and angle dependence of the ion distribution function is studied experimentally by means of passive line-integral and also active localized charge exchange neutral particle diagnostics [1, 2]. Ideally, an extensive diagnostic database of this kind should enable one to predict the ion distribution function evolution for a given plasma discharge regime and heating method and time diagram on a certain device. Thus, a possibility exists to perform a correct calculation of the time evolution of the local fusion rate function using (2) and the fusion reactor power using (1).

An algorithm has been developed and realized as a FORTRAN code based on (1), (2) and nuclear cross section approximations from [3]. Particle density profiles and the magnetic surface geometry are used as input data. Either analytic ion distribution functions based on theoretical models, or experimentally obtained ion distributions may be used for the calculations. Reconstruction of the ion distribution function from charge exchange diagnostic data will be discussed and examples of nuclear fusion rate and power calculation will be presented. A detailed description of the calculation algorithm will be given.

[1] P.R. Goncharov, T. Ozaki, S. Sudo, N. Tamura et al., Rev. Sci. Instrum., **79** (2008).
[2] P.R. Goncharov, T. Ozaki, E.A. Veshchev, S. Sudo, Rev. Sci. Instrum., **79** (2008).
[3] H.-S. Bosch, G.M. Hale, Nucl. Fusion, **32**, 611 (1992).