§21. Fusion Power and Neutron Yield from Toroidal Magnetically Confined Plasma

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The correct calculation of nuclear fusion power and neutron yield requires an accurate knowledge of velocity distributions of the interacting nuclei. A very large contribution to the reaction rate is due to suprathermal high-energy particles. The ion distribution function in NBI and ICRF heated plasma is substantially non-Maxwellian, anisotropic and spatially nonuniform. Thus, obtaining reliable space-resolved [1] and angle-resolved [2] experimental data on fast ion distribution tails is of paramount importance among the laboratory diagnostics and computational tasks to study the perspective of a device as a fusion reactor.

A numerical code has been developed to calculate the fusion rate, plasma-volume-integral power, total neutron yield and neutron loads for a toroidal magnetic confinement device using either theoretical or experimentally obtained fast nuclei kinetic energy distributions. Ion heating efficiency and fast ion confinement effects on high energy distribution tails and the resultant fusion power can be estimated on the basis of experimental data. Nuclear reaction cross-sections and the magnetic surface geometry are also required as input data. Either an MHD equilibrium code output or approximate analytic equilibria can be used.

The algorithm [3] is used to calculate the neutron yield and integral nuclear fusion power

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

where $R_{\alpha\beta}$ is the local reaction rate and the integration is performed over the plasma volume. The reaction rate is proportional to the rate coefficient averaged over the distribution functions of the interacting nuclei by integration in 6-dimension velocity space

$$R_{\alpha\beta} = n_\alpha n_\beta \int \sigma(v) v f_\alpha(\mathbf{v}_\alpha) f_\beta(\mathbf{v}_\beta) d^3\mathbf{v}_\alpha d^3\mathbf{v}_\beta\,, \qquad (2)$$

where $v = \left|\mathbf{v}_\alpha - \mathbf{v}_\beta\right|$. Theoretical distributions are obtained by solving Fokker-Planck equation with Coulomb collision integral. Experimental probability density functions for particle energies can be estimated from NPA diagnostic data using the appropriate mathematical processing techniques.

An example for azimuthally symmetric magnetic configuration with R_{ax} = 3.6 m and elliptical isolines with horizontal minor radius a = 0.4 m and elongation κ = 2 is shown for simplicity with $n_D = n_T = 10^{14}$ cm^{-3}. Maxwellian target tritons at 5 keV and isotropic deuteron distributions shown in Fig 1 (a) are assumed in this example so that A and (1-A) determine the percentage of D particles from bulk Maxwellian (5 keV) population and classical slowing down "tail" from 150 keV NBI. Fig. 1 (b) shows that the presence of 5% suprathermal deuteron population leads to more than 20 time increase in the fusion power P compared to the pure Maxwellian case. Ion tail reconstruction from a pseudorandom particle energy sample is shown in Fig. 2.

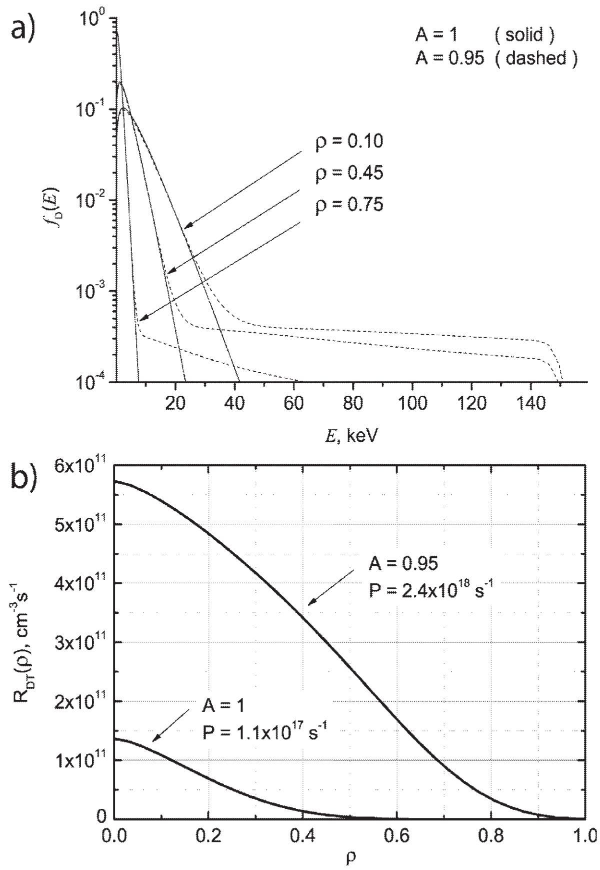

Fig. 1. (a) Deuteron energy distribution function in the undistorted Maxwellian case for A = 1 and in the presence of suprathermal "tail" with A = 0.95; (b) radial profiles of $T(D,n)He^4$ reaction rate for thermal tritons and two deuteron energy distributions.

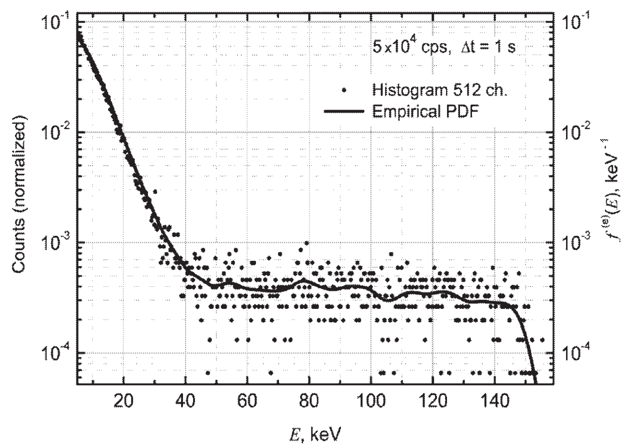

Fig. 2. Empirical probability density function and histogram for a numerically simulated sample of pseudorandom particle energies.

1) Goncharov, P.R., Ozaki, T. et al., Rev. Sci. Instrum., **79** (2008) 10F312

2) Goncharov, P.R., Ozaki, T. et al., Rev. Sci. Instrum., **79** (2008) 10F311

3) Goncharov, P.R., P1-44, 18th International Toki Conference, December 8-12, 2008