Assessment of the Fast Particle Spectra for Tangential Spectrometer for H/He and DT ITER Operation

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TNS Synthetic Diagnostic

The study of fast ion behaviour in reactor conditions is among the major goals of the ITER project. Additional heating by neutral beam injection (NBI) and ion-cyclotron heating (ICH) creates population of suprathermal ions with anisotropic distribution in velocity space. The energy spectrum measurements of charge-exchange (CX) neutrals and neutrons made by the Tangential Neutron Spectrometer (TNS) contribute to the reconstruction of the fast ions' distribution function in combination with the radial measurements performed by neutral particle analyser (NPA), radial neutron camera (RNC) and high-resolution neutron spectrometer (HRNS) diagnostics. It will help to monitor the consequences of instabilities which cause the redistribution of fast ions in the plasma and assess their impact on plasma heating and current drive. Assessing the capabilities of diagnostics at various phases of ITER operation is an essential part of ITER research planning. In order to assess the required accuracy and resolution of the measurements of the TNS in all ITER scenarios we have developed a TNS SD, which consists of the part simulated the synthetic spectra and synthetic data for CODAC, required for dedicated measurements. Here we discuss just the first part of the SD, synthetic spectra of fast particles at the location of the TNS detectors. The developed TNS SD computational module takes into account realistic geometry and parameters corresponding to the TNS design: 3 lines of sight (LOS), aimed tangentially to magnetic axis in the equatorial plane of the vacuum vessel (figure 1b). The developed module enables simulation of the anisotropic spectra of the charge-exchange neutrals and neutrons originated from interactions between suprathermal and thermal particles using as an input profiles of plasma parameters, self-consistent plasma geometry and fast ion distribution function. It has the interface compatible with the ITER Integrated Modelling and Analysis Suite (IMAS) of codes [1] and thus can be used in the simulations of the ITER plasma evolution and plasma control system.

Modelling of CX atom spectra

Modelling of charge-exchange atom flux was conducted for the ITER helium half-field scenario (plasma current I_p = 7.5MA, toroidal magnetic field B = 2.65T) [3] for the H-mode He operation scenario with H^0-NBI of the energy E_{NBI} = 870 keV. In the low-activation phase the TNS will perform CX neutral spectroscopy. The fast ion distribution function, $f_{fast}(r,v,\mu)$, with, $v = |\boldsymbol{v}|$, $\mu = (\boldsymbol{vB})/|B|/v$, was simulated by ASTRA Fokker-Plank solver 2D in velocity space [2] for profiles expected in the ITER H-mode operation. The CX neutrals along the LOS are calculated by Monte-Carlo code Double [4] extended to the high energies and non-Maxwellian ions. Simulated spectra of CX neutral for 5 different LOS (fig.1a) are shown in figure 1b illustrates modelled spectra of escaping CX neutrals for several LOSs: blue and yellow lines illustrate the realistic TNS LOSs, green corresponds to the NPA LOS, red and violet lines illustrate the hypothetical “co-beam” TNS lines of sight.

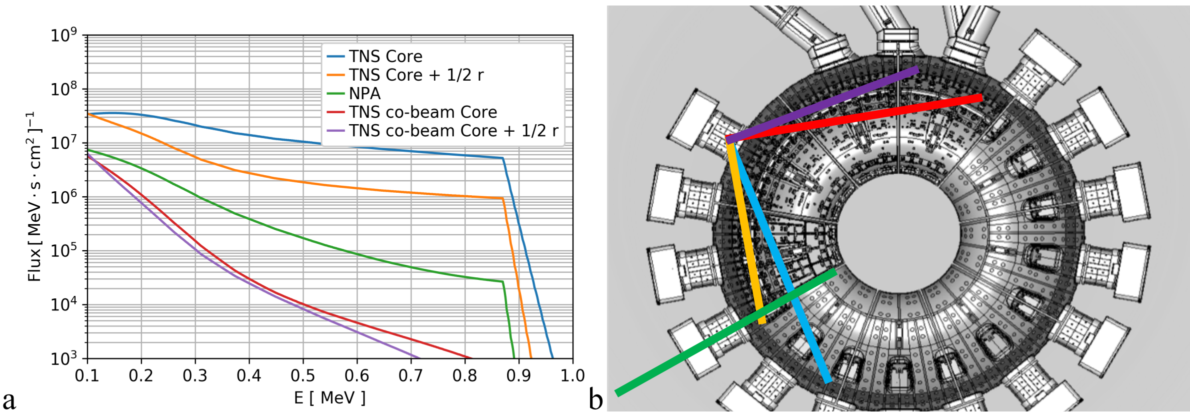

Fig. 1.CX neutral spectra (a) for different LOSs (b)

The flux of escaping CX neutrals is significantly higher for those lines of sight which have a magnetic surface intersection angle comparable with the pitch angles of the majority of fast ions’ population. Modelling results show that fast ion distribution function anisotropy has significant impact on spectra which could be registered by TNS detecting modules.

Sawtooth emulation

Simulation of sawtooth (ST) mixing was conducted in order to check the ability of TNS to detect fast ion redistribution caused by plasma instabilities. The sawtooth mixing is emulated as a redistribution of fast ions $f_{fast}(r,v,\mu) = f_{fast}(r_{max}/2,v,\mu)$ in the central zone

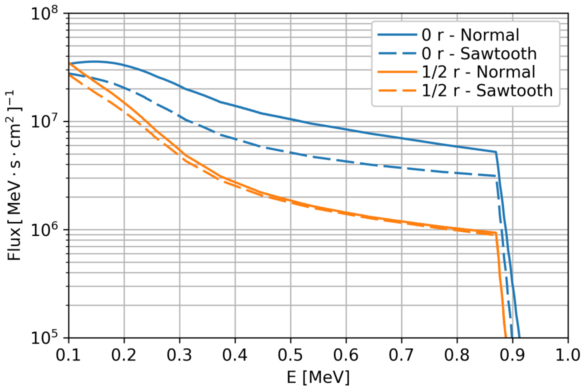

Figure 2: Impact of ST mixing on CX spectra

r ∈ [0; r_{max}/2]. The impact of the ST mixing the on the spectra is shown in figure 2 for on- and off-axis LOS of the TNS location (see figure 1). The ST mixing changes the high energy part of the neutral flux spectrum of on-axis TNS by a factor of 2, which is sufficient to detect the ST event with the help of the TNS.

Modelling of neutron spectra

Simulation of the neutron flux observed by TNS LOSs was conducted for the ITER baseline DT scenario with P_{fus} = 500 MW, 33 MW of the D^0-NBI heating at E_{NBI} = 1 MeV [5], with the shapes of sources of D_{th}-T_{th} neutrons and D_{beam}-T_{th} neutrons (figure 3).

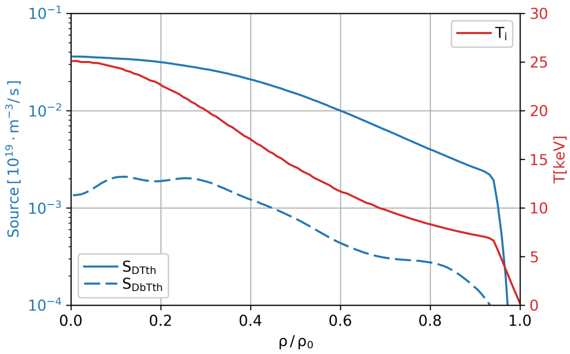

Figure 3. Ion temperature T_i and sources of D_{th}-T_{th} neutrons, S_{DTth} and D_{beam}-T_{th} neutrons, S_{DbTth}, in 15 MA 500 MW scenario. $T_i(0)$=25 keV

In order to calculate collimated 'beam-thermal' part of the observed spectra a direct reaction rate calculation approach was selected. This approach also employs explicit D-T fusion reaction kinematics [6]. Simulated spectra of uncollided neutrons by MCNP [7] for thermal-thermal $D_{th}T_{th}$ (S_{DTth}, green) and by TNS SD for D-beam-thermal-T (S_{DbTth}, orange) reactions and total spectra (S_{DTth} + S_{DbTth}, blue) before (solid line) and after (dashed line) the ST for on-axis TNS are shown in figure 4. The 'beam-thermal' neutron flux dominates at E~16 MeV, S_{DTth}>>S_{DbTth}. Thus, in the range E > 16 MeV it looks possible to detect the ST mixing.

Results of the modelling show significant impact of the suprathermal ion population on fast energy part of the spectra for uncollided neutrons (figure 5) even for the nominal flat-top density <n> ~ 10^{20}m^{-3}. Note that population of the fast D-ions, n_{Dfast} ~ $P_{NBI}T_e^{3/2}/n_e$, thus the beam-thermal part, S_{DbTth} ~$P_{NBI}T_e^{3/2}n_T/n_e$, does not depend on the plasma density directly in contrast to the 'thermal' part, S_{DTth}~ n^2. Thus, for low density phase of operation the accuracy of the ion temperature assessment could become worse (T_{iTNS} – core ion temperature assessed using energy range marked with green in figure 5).

Note that for present design of the TNS shielding the MCNP predicts significant amount of uncollimated scattered neutrons reaching detector from different directions. In that circumstances the anisotropy of the fast ions in the velocity space cannot be detected, meanwhile the spatial redistribution due to the STs looks still detectable.

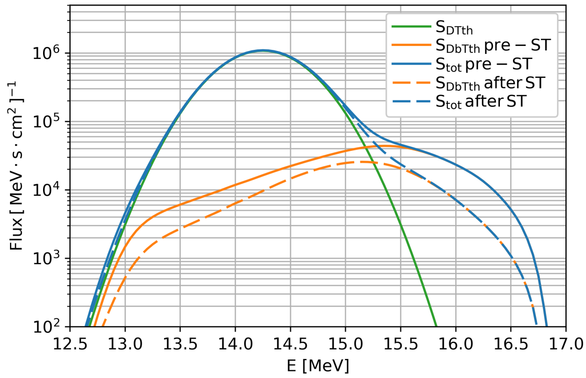

Figure 4. Simulated spectra of uncollided neutrons

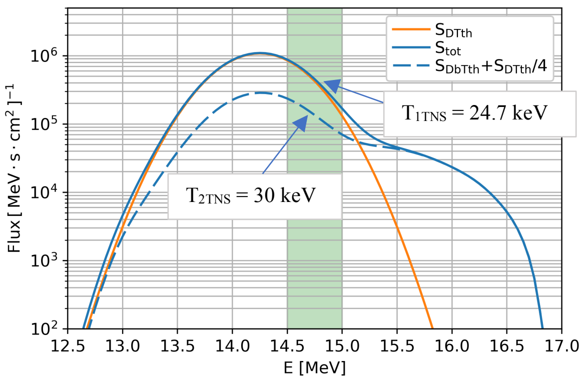

Figure 5. Impact of the S_{DbTth} spectra on the ion temperature assessment, $T_{i,TNS} = (dlnF/dE)^{-1}$

Conclusions

Developed tangential spectrometer synthetic diagnostic enables modelling of observed spectra for various scenarios of ITER operation. In low-activation phase simulation results show significant influence of supratermal ion population on observed CX atom spectra. Sawtooth emulation also shows the potential of TNS to detect consequences of plasma instabilities. Significant level of scattered neutrons tends to be a major issue during baseline DT scenarios of ITER operation. At the same time, fast ion population provides explicit impact on the observed collimated neutron energy spectra which, in turn, provides opportunities for deriving information on fast ion distribution function anisotropy and redistribution resulting from MHD instabilities.

Disclaimer: ITER is the Nuclear Facility INB no. 174. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

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