Neutral Particle Analysis on ITER-FEAT


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1. Introduction.
There are two important issues of Neutral Particle Analysis on International Thermonuclear Experimental Reactor (ITER-FEAT). First issue is the measurement of hydrogen isotope composition of the plasma on the basis of measurements of neutralized fluxes of corresponding hydrogen ions (protons, deuterons and tritons) in thermal energy range of few maximal ion temperatures (10 - 200 keV) [1]. It has to be one of the main tasks of the ITER-FEAT control system to provide optimal D/T ratio in the plasma. At the moment Neutral Particle Analysis seems to be the only method able to solve this problem.

Another issue of Neutral Particle Analysis is to measure confined D-T alpha particle distribution function by means of detection of He\(^0\) atoms energy spectra in MeV range [2].

2. Apparatus for Neutral Particle Analysis on ITER.

For these tasks we developed tandem of two Neutral Particle Analyzers –High Energy NPA (HENPA) for MeV range (0.1 – 4 MeV) and Low Energy NPA (LENPA) for thermal range (10 –200 keV). The sketch of NPA tandem is shown on Fig.1. Analyzers HENPA and LENPA both are viewing along main radius and through the same straight vacuum opening of diam 20 cm at the blanket face in ITER port # 11. Both analyzers can operate in parallel because LENPA is shifted horizontally to ensure independent line of sight. Specific features of the NPAs are following: A) Stripping in thin carbon (diamond) foils, B) Acceleration of secondary ions after the stripping (by applying the voltage of up to 100 kV to stripping foil and using proper focusing system) in LENPA. Acceleration provides more high amplitude of the ion signals to get sufficient signal/background ratio and helps to focus secondary ions after the stripping in the foil. It is not necessary to use acceleration in HENPA because of high energy of analyzed ions. C) Dispersion system based on E/B analysis. D) Specially programmed non uniform E and B fields to provide two dimensional focusing of analyzed ions. E) Scintillator detectors (CsI+Tl) having very low neutron & gamma sensitivity (10\(^{-7}\) pulse/neutron & gamma). The prototype of LENPA (ISEP NPA[3])
and prototype of HENPA (GEMMA NPA [4]) were installed and successfully used on JET. Neutral Particle Analysis has been included into the first priority list of ITER-FEAT diagnostics. The first stage on the integration of NPA tandem with neighboring diagnostic and other systems on ITER-FEAT has been made.

3. Isotope Composition Measurements.

Due to a rather large minor radius of the ITER-FEAT plasma (2 m) a question arises to which part of the plasma the isotope composition measurements provided by charge exchange diagnostics will relate. The other question is whether the requirements to the time resolution of \( n_d/n_t \) measurements which are set to be equal to 100 ms or better with accuracy \( \leq 10\% \) can be satisfied. The answer to this question is given by numerical simulation of the neutral particle fluxes emitted by ITER-FEAT plasma consisting 1:1 deuterium/tritium mixture [1]. Note that specific feature of ITER DT plasma is a presence of He ash resulting from deceleration of alpha particles generated in DT fusion reaction. He ash percentage can attain 5-10% of the total ion density. He ash consists of He\(^{+2}\) ions mainly but due to corona equilibrium there is some concentration of He\(^+\) ions in the plasma. In our simulation [1] in addition to neutralization of hydrogen ions due to recombination and charge exchange with hydrogen atoms we took into account also charge exchange with hydrogen-like He\(^+\) ions. This phenomena increases neutral particle fluxes emitted by ITER-FEAT by 5–7 times. Fig. 2 shows normalized emission functions of Do and To atoms versus minor radius for one of typical ITER-FEAT scenarios which has been got as the result of simulation. It is seen that measurements of \( 150 \text{ keV} \) atoms should be provided to obtain an information about the plasma core. Energy dependant measurements can yield radial distribution of the isotope ratio. Fig.3 presents the energy dependence of the deuterium and tritium atom LENPA count rate for fifty-fifty deuterium-tritium plasma which has been got as a result of simulation. LENPA parameters used for simulation are following: NPA collimator \( \omega S=1.3.\text{e}-4 \text{ cm}^2 \text{ strd} \), energy width of NPA channel \( \Delta E=0.1 \text{ E} \), detection efficiency \( K(E) = 0.05 – 0.9 \) in presented energy range. The concentration of He\(^+\) ions in the plasma center equal to \( 1.6.10^5 \text{ cm}^{-3} \). To get accuracy 10% of \( n_d/n_t \) measurements it is necessary to collect at least 100 counts in 100 ms time window what is equivalent to 1 kHz count rate. From fig.3 we see that the count rate needed to provide the required statistical accuracy for 150 keV T\(^0\) atoms can be obtained in ITER-FEAT plasma conditions. It makes possible \( n_d/n_t \)
measurements over the whole plasma cross section including plasma core in the ITER-FEAT reference discharge.


The measurements of the energy distribution of MeV He atoms (neutralized alphas) with the use of HENPA [2] can be used to study the fast confined alpha particle behavior. Here we briefly analyze the possibility of passive neutralization of fast confined alphas due to double electron capture from helium like beryllium and carbon ions.

NPA count rate of neutralized alphas can be estimated using following formula:

\[
N(E)(1/ce\gamma) = \int n_{\alpha}(E,r) \sum \sigma_i (n_i V_i) \Delta E \left(\cos(4\pi) \mu(E,r) \right) K(E) dL
\]

Here \(n_{\alpha}(E,r)\)-alphas distribution function, \(n_i\) and \(V_i\) - densities of helium-like ions and corresponding double electron capture cross-sections, \(\mu(E)\) – plasma transparency for alphas. Integration is along NPA observation line.

Fig. 4 shows calculated alpha-particle distribution function in ITER plasma core \(n_{\alpha}(E, r)\) within minor radius +/- 0.5 m [5]. In ITER-FEAT we expect \(n_e/n_{Be+4} = 1\%\), \(n_e/n_{C+6} = 1\%\). Ionization balance with ion transport (\(\tau = 3\) sec) in ITER plasma analyzed in [6] gives in this case \(n_{Be+2} = 2.3 \times 10^6\) cm\(^{-3}\), \(n_{C+4} = 1.6 \times 10^7\) cm\(^{-7}\). Fig. 5 shows HENPA count rates produced by passively neutralized fast confined alpha particles generated in the processes \(He^{2+} + Be^{2+} = He^0 + Be^{4+}\) and \(He^{2+} + C^{4+} = He^0 + C^{6+}\). Cross-sections of the reactions \(\sigma_i\) are taken from [6]. The parameters of Neutral Particle Analyzer are the same as in Fig. 3. Detection efficiency in presented energy range is equal to 1.0. It is seen that \(Be^{2+}\) ions and \(C^{4+}\) ions of presented density in the plasma can provide detectable flux of neutralized alphas of level \(10^4 - 10^5\) 1/s.

References:
Fig. 1 NPA Tandem developed for ITER. HENPA-at the left, LENPA at the right.

Fig. 2. Do,To Emissivity Functions.

Fig. 3. Do,To Count Rates in LENPA

Fig. 4. Alpha particle energy spectrum in ITER Plasma Core (Pfus=400MW).

Fig. 5. Neutralized Alphas Count Rate provided by helium-like Be and C ions.