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Relaxation of the DNBI Deposited Particles in the TCV Plasmas

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ABSTRACT.

The paper presents results of a high-energy fast ion population relaxation in the TCV. The fast hydrogen ions are created by diagnostic neutral beam (DNB) deposition in plasma. In the NPA measurements the increase of the neutral particle flux was correlated with DNB current. By taking that the observed flux increase to be the result of charge-exchange (CX) of the DNB deposited particles on the plasma neutrals, the NPA can be used to observe the DNB deposited ion energy distribution. The measurements of CX spectrum were performed for a range of plasma parameters with a modulated diagnostic neutral beam, the characteristics of DNB deposited ion population are sensitive to the plasma parameters (electron temperature, electron and neutral density profiles).

1. EXPERIMENT LAYOUT.

The neutral particle analyser [1,2] on TCV views the plasma centre along a vertical chord (Fig.1). It consists of 5 energy channels with electrostatic discrimination. The NPA voltage sweeps the energy channels to measures neutral particle energies in the range of (0.6→8 keV).

The DNBI on TCV has a maximum extraction voltage (E_0) of 52 kV [3] with an effective beam current of up to 3 A. The beam is usually pulsed with a 12→150 ms duty period and was installed on the TCV Tokamak for CXRS ion temperature measurements [4]. The TCV beam consists of ~50% of the neutrals with full energy (E_0), ~27% of $E_0/2$, ~18% of $E_0/3$ and ~5% of ~$E_0/18$ (beam current fractions). The ~80 kW injected power is small compared to the TCV ohmic power (250 kW – 1 MW). The beam has a divergence of 0.7^0 and a gaussian cross section (~7 cm diameter). The beam is injected horizontally at an angle to the machine center of 11.25^0. The toroidal angle between DNB and NPA TCV sections is 67.5^0.

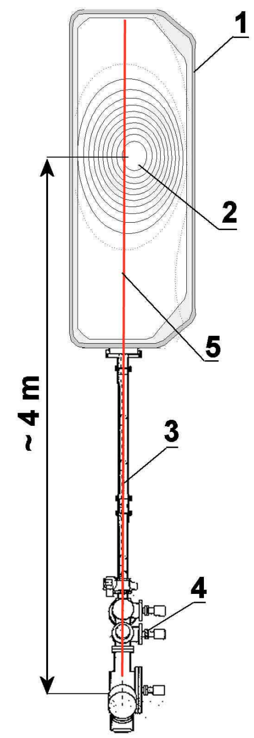

Fig1: NPA layout, 1-TCV vacuum chamber, 2-plasma, 3-NPA duct, 4-NPA, 5-view line.

2. NPA ION TEMPERATURE MEASUREMENT.

In the standard regime of NPA measurements (Fig.2), the high energy tail of CX atoms entering the analyzer was observed to increase during DNB injection (Fig.3). For a Maxwellian ion energy distribution, the ion temperature $\boldsymbol{T_i}$ is proportional to the logarithm of the "charge exchange spectrum" ($\boldsymbol{F_{dc}(E)}$) slope: $\frac{E}{T_i}+\frac{3}{2}\ln(T_i)\sim-\ln\left(\frac{J(E)}{\sigma_{cx}(E)\cdot E}\right)=-\ln(F_{dc})$ [5], where ***J(E)*** is the energy spectrum of neutrals entering the NPA collimating system. Putting $\boldsymbol{F_{dc}(E)}$ in on a semi-log plot one should obtain a straight line whose slope reflects the ion temperature. In most situations the plasma does not have a unique ion temperature and the attenuation from neutral creation to the NPA is not negligible. The mean free path with respect to the sum of CX and impact ionisation increases with increasing the neutral energy. The result is that the "CX spectrum" measured by this "passive" technique is not linear on a semi-log plot. The low energy tail of the "CX spectrum" is dominated by the cold edge regions ($\sigma_{abs}\cdot n_e\cdot a_{pl}>>1$). For moderate plasma conditions in a Tokamak, $n_e\cdot a_{pl}/T_i\sim10^{19}m^{-2}keV^{-1}$ [6] the core ion temperature can be measured by fitting the CX-spectrum with a simple exponential in the energy range of ~ 3 to 10 $\boldsymbol{T_i}$. In general, the small decrease of $\boldsymbol{T_i(0)}$ that results from the contributions to the CX flux from regions outside the plasma centre is partially compensated by the increasing of $\boldsymbol{T_i(0)}$ associated with increased attenuation of low energy neutrals escaping from the plasma. $\boldsymbol{F_{dc}(E)}$ fitted by the straight line in on a semi-log plot ($\boldsymbol{3T_i<E<10T_i}$) for DNB "OFF-phase" gives an ion temperature with a statistical error 1-5%.

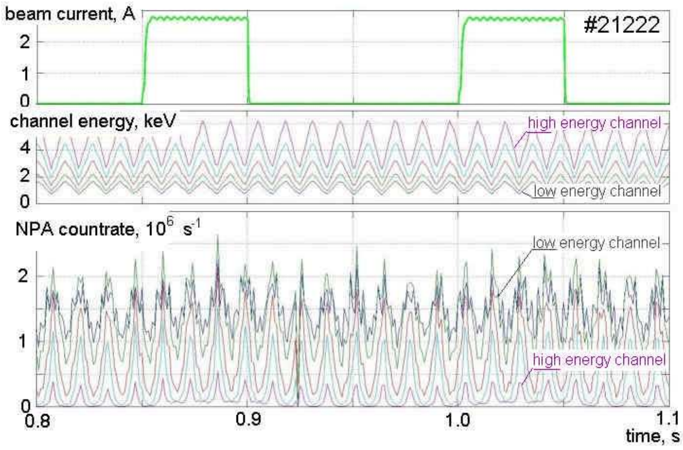

Fig.2 Modulation of the DNBI current, NPA analyzing voltage and counter traces from NPA channels.

It was proposed that the increase of high energy CX flux to NPA is the result of charge–exchange of the DNB deposited particles whose energy distribution function is ***~1/E***. For the DNB "ON-phase" the "CX-spectrum" was well fitted by the sum of a Maxwellian and ***1/E*** ion energy distribution. With this assumption it was found that the measured "NPA ion temperature"

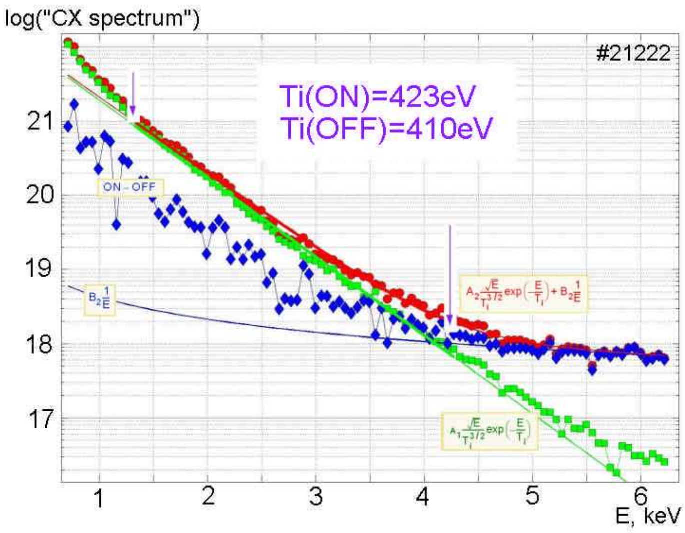

Fig.3: The NPA "CX spectrum" for ON (red) and OFF (green) DNBI phases with ion spectrum fitting.

increases during DNBI pulses (Fig.3) by 2-10%.

3. NPA MEASUREMENT WITHOUT ENERGY SWEEP.

To examine the effect of DNB deposition, a series of experiments was performed, in which the NPA was operated with fixed analysis energies (Fig.4). The increase of the NPA signals was correlated with DNBI modulation and for all energy channels. To improve the statistics the time frames of NPA traces during the current flat top of plasma discharge (few DNBI pulses) were summed, shown in Fig.5. The measured time shift between the increased CX flux from the plasma and DNBI modulation ranged from 2→40 ms. The delay and decay times (Fig.6) of the CX fluxes are a few ms. A 0-space-dimensional numerical model was constructed to describe the relaxation of the DNB deposited particles in collisions with plasma ions and electrons at a fixed, and realistic, temperatures (Fig.6). It is based on a solution of kinetic equation for energy distribution function [7].

The time characteristics of NPA counting strongly depend on the plasma density ($1\rightarrow8\times10^{19}$ m^{-3}) and electron temperature (0.3→1.5 keV). The fast ion relaxation (52→2 keV) is dominated by the electron drag. The time shift between increasing of CX flux and DNB injection is found to be proportional to the ion energy loss time $\tau_{ie}^{E} \sim T_e^{3/2}/n_e$. The dependence of "time shift" between 5th (6.24 keV) NPA channel counter trace and beam current on the parameter $T_e^{3/2}/n_e$ is shown in Fig.7.

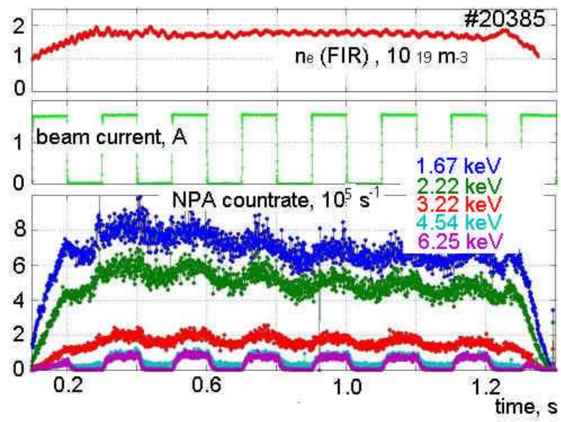

Fig.4: Variation of the NPA counting during modulated DNB injection.

4. CONCLUSIONS.

Comparison with experimental results allow us to conclude that :

- Increase of the high energy tail of CX neutral flux during DNB injection can indeed be explained by CX of fast hydrogen ion population produced as a result DNB deposition in plasma.
- The relaxation of fast ions is determined by their Coulomb collisions with electrons and plasma deuterium and impurity ions.
- For TCV ohmic shots 70-90% of the DNB absorbed power goes to the electrons so

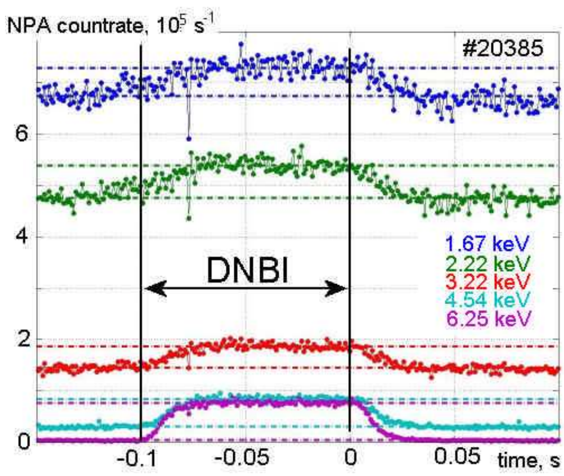

Fig.5: NPA countrate increasing during DNB injection.

the plasma ion power from the DNB is only 5-15% of that from the plasma electrons.

- The energy transfer from the DNBI deposited ions to plasma ions increases the NPA ion temperature by only 2-10%.
- The "time shift" between DNB current and increasing of high-energy tail of CX neutral flux from plasma depends on the plasma parameters and is proportional to $\tau_{ie}^{E} \sim T_e^{3/2}/n_e$.

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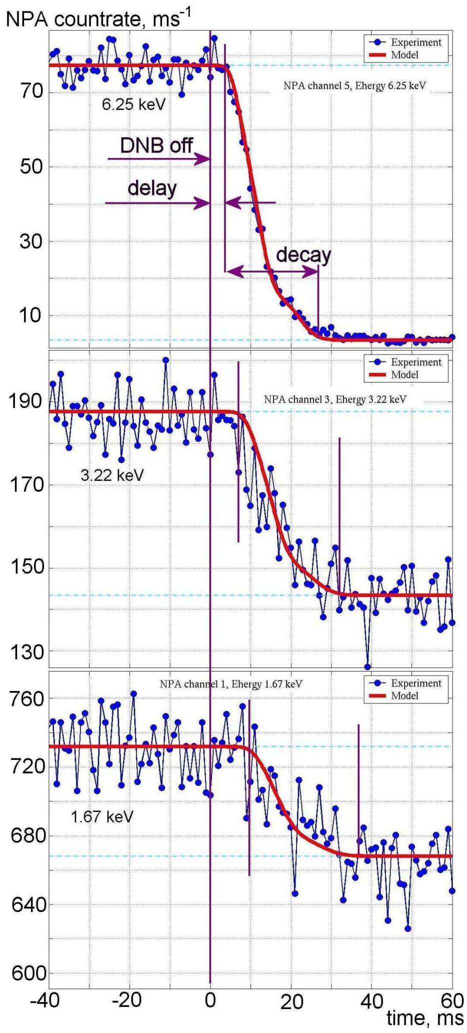

Fig.6: Comparison of NPA counting traces and modelling for signal decreasing after DNBI switching off.

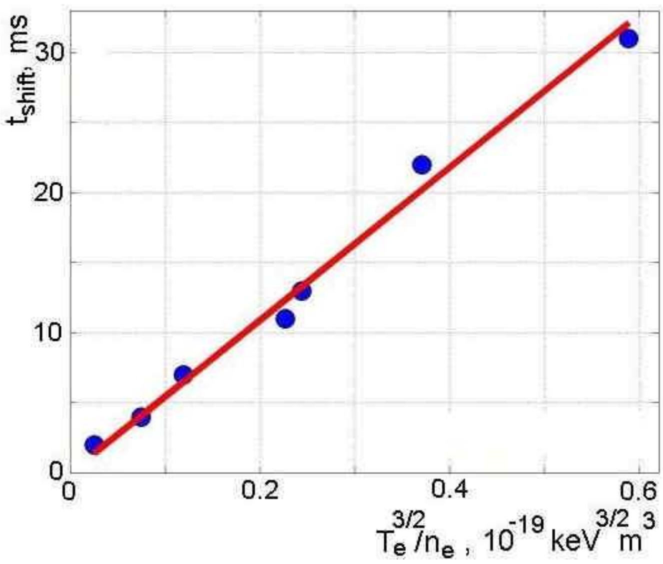

Fig.7: "Time shift" between 5th (6.24 keV) NPA channel counter trace and beam current vs. $T_e^{3/2}/n_e$ parameter.