Diagnostic systems developed in Ioffe Institute, St.Peterburg, Russia for ITER (Neutral Particle Analysis, Thomson Scattering in Divertor and Gamma Spectrometry)

M. Petrov, V. Afanasyev, S.Petrov, E. Mukhin, S.Tolstyakov, I.Chugunov, A.Shevelev

A.F.Ioffe Physical-Technical Institute, St.Petersburg, Russia

1.Introduction.

Ioffe Physical-Technical Institute, St.Petersburg, Russia is developing the diagnostic systems for ITER presented in the title of this paper as part of Russian obligation for ITER.

The main issue of Neutral Particle Analysis in ITER is to measure the hydrogen isotope composition of plasma on the basis of measurements of neutralized fluxes of corresponding hydrogen ions, namely protons, deuterons and tritons [1]. It has to be one of the main tasks of the ITER control system to provide optimal D/T ratio in the plasma for the most effective plasma burning. Because of that the NPA diagnostic had been included into the list of ITER diagnostics with a high priority. Another issue of Neutral Particle Analysis is to measure the distribution functions of the fast ions generated as a result of the additional heating and nuclear fusion reactions.

Divertor Thomson Scattering (DTS) [2] will be used for measuring electron temperature and density in the scrape-off layer in the outer leg of ITER divertor. The DTS data in the form of an array of discrete measurement points will provide the basis for the divertor 2D-plasma parameter simulation. Detailed measurements of electron parameters in ITER divertor will be an important part of the experimental program because it can be used for the monitoring and controlling of plasma attach/detach conditions. Particularly DTS can be included to feedback control of ITER plasma parameters and to protect the machine from the divertor overloading.

Gamma Spectroscopy [3] is based on the measuring of spectral lines in MeV range generated in nuclear reactions in the plasma. It allows to study MeV ions in ITER plasma. 2-D hard X-ray emission measurements is of special interest because in gives valuable information of confines alpha particles in DT ITER plasma and provide important information on the runaway electron beam location in the ITER plasmas in the MeV range.

2. Neutral Particle Analysis.

For the tasks mentioned above the 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) developing now in the Ioffe Institute. 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.

It has been already shown that measurements of Fuel Ratio on the basis of detecting of neutralized hydrogen ions in ITER can be made in thermal energy range with the use of analyzer LENPA [1]. New trend is to use for that suprathermal (MeV) energy range covered by analyzer HENPA. In this case the detecting by HENPA of neutralized knock-on ions generating in strong collisions of thermal deuterium and tritium ions with fusion alpha particles in MeV range can be used. Fig.1 shows calculated HENPA counting rates versus atoms energy. Solid lines – the signal of knock-on ions. Dash-dotted line – the signal of deuterium neutral heating beam (D-NBI). It is seen that energy range E > 1.2 MeV is free from the heating deuterium neutral beam and background neutron-gamma noise and can be used for the fuel ratio measurements.

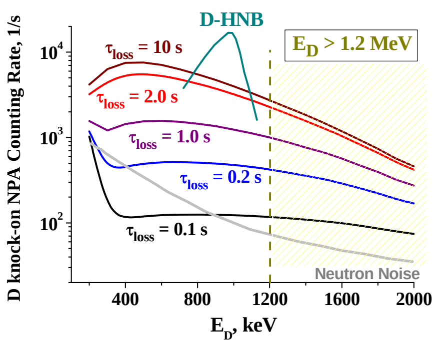

Fig.1 HENPA counting rates vs atoms energy

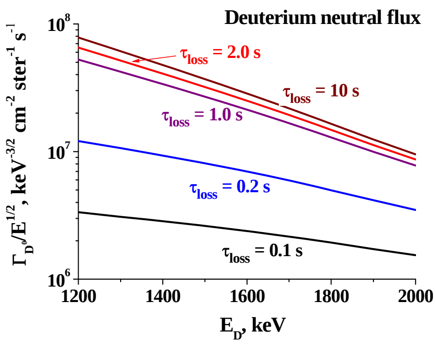

Fig.2 HENPA counting rates vs atoms energy for different alphas confinement time values.

Fig. 2 shows that alpha-particle confinement time has an influence both on the absolute magnitude and the energy dependence of the knock-on fluxes. So it is possible to get the information on the fast alpha-particle confinement time using NPA diagnostics data.

3. Thomson scattering in divertor

The DTS optical layout uses crossed probing and viewing beams with the front end laser launcher located beneath the divertor cassettes and the first collecting mirrors near the side wall of divertor port. Measurements of electron parameters in the ITER divertor will be used for the divertor 2D-plasma parameter simulation and for monitoring inter-mode transitions (e.g., attached/detached conditions of the divertor plasma). The further upgrade of

DTS diagnostics includes tuning or upgrade of hardware e.g. modification of laser and the laser launching system to study fast disturbances caused by ELMs. One of the challenges for divertor DTS is the requirement to measure electron temperature near 1eV where the recombination rate is equal and even more than the ionization rate. It is very important to show that the T_e is as low as the codes will predict it to be for the detached states. The triple grating polychromator with a high-degree of discrimination against stray light at the laser wavelength was developed [4] to meet the ITER requirements for measuring TS spectra corresponding to electron temperature from 0.3 eV range to thousand eV. For more efficient use of ITER ports we will perform the dual use of the DTS optical system for TS and LIF (Light Induced Fluorescence) diagnostics. The special filter polychromator [4] with separation of TS and LIF signals provides the combination of two diagnostics with the same collecting optical system. The front optical elements such as the first collecting mirror and the laser launcher are the most challenging diagnostic elements. Therefore, one of the most important points for TS diagnostics is on-line calibration procedure. Stepwise cross calibration is planed to estimate T_e, and absolute sensitivity of the detection system and thus to measure the absolute value of n_e. The use of Nd:YLF (1.047 μm) and Nd:YAG (0.946 μm) lasers were suggested [2] for DTS as calibration lasers supplementary to the fundamental Nd:YAG (1.0645 μm). The TS signals of the 1.064/1.047 laser pair were suggested for relative dual laser calibration of spectral channels operating in the 5 eV – 500 eV range whereas for the 500 eV – 5 keV range the ratio of 1.064/0.946 TS signals can be used. At the moment, the basic conceptual design of the diagnostic system as well as the concepts of the main hardware components are close to being completed. At the same time development of new codes and experimental data accumulation, the diagnostic concept must keep changing to meet the requirements that may arise.

4. Gamma Spectrometry.

Gamma-ray spectrometry can be used for diagnosis of both energetic ions and runaway electrons in ITER plasmas. In the first case radiation emitted in the result of nuclear reactions between fusion alpha particles and other fast ions is detected. In the second case, interaction of runaway electrons with plasma ions or tokamak structure materials generate Hard X-Ray (HXR) emission in the MeV range, which can be recorded with gamma-ray detectors. The gamma and HXR spectrometry routinely used in experiments on tokamaks JET, Globus-M, Tuman-3M etc. A numerical code (DeGaSum) has been developed for reconstruction of gamma-ray spectra recorded in fusion plasma experiments [5]. The code uses calculated detector response functions and distributions of HXRs induced by fast electrons in tokamak. The deconvolution of the discrete spectra allows identifying nuclear reactions, which give rise gamma-rays and calculating their intensities.

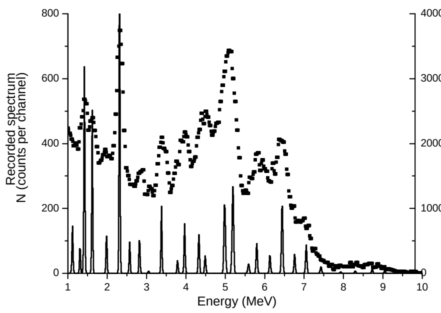

Fig.5. Results of processing the spectrum measured during JET discharge with ^{3}He ICRF heating [6]. The dots show the spectrum measured in the experiment; the solid line (peaks) illustrates the reconstructed spectrum [5].

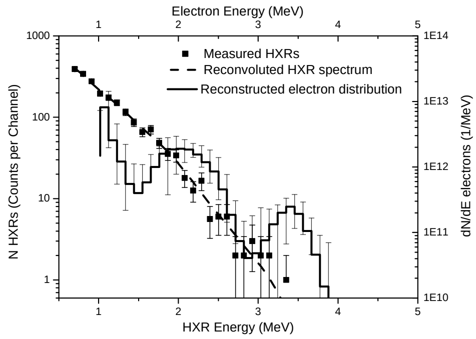

Fig.6. HXR spectrum recorded at Tuman-3M shot by NaI(Tl) detector (dots); dash line – HXR spectrum, corresponding to the electron distribution (solid line) reconstructed from the measured HXR.

Figure 5 presents the result of processing of spectrum in the JET discharge with ^{4}He plasma during the injection and the ion-cyclotron heating of ^{3}He impurity [7]. The interaction of accelerated ions with a carbon impurity induced the ^{12}C(^{3}He, pγ)^{14}N nuclear reaction in the plasma of gamma-rays that are appropriate to the nuclear transitions of the excited ^{14}N nucleus. In figure 5 the black line shows the spectrum measured in the experiment and the red line illustrates the reconstructed initial gamma spectrum [6]. Also, DeGaSum code can provide the runaway electron energy distribution using the recorded HXR spectra. Figure 6 shows HXR spectrum recorded during tokamak Tuman-3M shot (dots) and electron distribution (solid line) reconstructed by the DeGaSum code from the measured HXR spectrum. The deconvolution of HXR spectra allows obtaining the maximal energy of runaway electrons with accuracy, which satisfies the ITER Project Requirements, and to estimate runaway current in plasma.

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