MEASUREMENTS OF CHARGED FUSION PRODUCTS IN ASDEX

H.-S. Bosch, U. Schumacher, G. Becker, H. Brocken, A. Eberhagen, D. Eckhartt, G. Fussmann, O. Gehre, J. Gernhardt, G. v.Gierke, E. Glock, O. Gruber, G. Haas, J. Hofmann, A. Izvozchikov[1] G. Janeschitz, F. Karger, M. Keilhacker[2], O. Klüber, M. Kornherr, K. Lackner, M. Lenoci[3], F. Leuterer, G. Lisitano, F. Mast, H.M. Mayer, K. McCormick, D. Meisel, V. Mertens, E.R. Müller[2], H. Murmann, H. Niedermayer, J.N. Noterdaeme, A. Pietrzyk[4], W. Poschenrieder, H. Rapp, H. Riedler, H. Röhr, J. Roth, F. Ryter[5], E. Speth, F. Schneider, C. Setzensack, G. Siller, P. Smeulders[2], F. Söldner, K. Steinmetz, K.-H. Steuer, O. Vollmer, F. Wagner, F. Wesner, D. Zasche

Max-Planck-Institut für Plasmaphysik
Association Euratom-IPP, D-8046 Garching

For normal deuterium operation in ASDEX ($A = 4.1$, $I_p = 250$ - 400 kA) the charged fusion products from the D–D reactions (3 MeV proton, 1 MeV triton and 0.8 MeV ^{3}He) escape from the plasma on helical orbits to the upper part of the vessel. Since slowing–down can be neglected in ASDEX, the protons and tritons escape on identical orbits, because the trajectory depends only on the product $m \cdot \vec{v}$. The measurements of the charged fusion products give information on the ion temperature, fusion yield, and plasma behaviour [**1**,**2**].

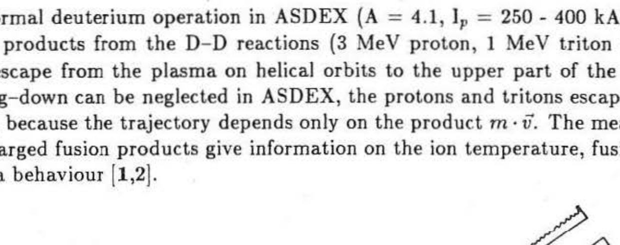


Fig.1: Part of the ASDEX cross-section with the manipulator on the right and a projection of a 3 MeV proton trajectory.
For the measurement the detector is brought near to the plasma on the dotted line.

The charged fusion products were measured for ASDEX deuterium plasmas by using a surface barrier detector or nuclear emulsion foils, installed on a manipulator. Figure 1 shows the ASDEX cross-section with the movable detector and a projection of a 3 MeV

---

[1] Academy of Sciences, Leningrad, USSR, [2] assigned to JET Joint Undertaking, [3] ENEA Frascati, Italy, [4] University of Washington, Seattle, USA, [5] CEN Grenoble, France

proton trajectory. For measurements with the surface barrier detector it is necessary to have sufficient electrical shielding and to keep the distance between the detector and the preamplifier short.

With the surface barrier detector , it is possible to measure the flux and the energy spectrum of the 3 MeV protons, and that of the 1 MeV tritons, either. The electric and magnetic distortions of the spectrum (about 50 keV) are monitored by a pulser signal, that is additionally fed into the preamplifier. By fitting the spectra with a Gaussian profile, we get a spectral width, that can be corrected with respect to the straggling in the Al foil and the noise broadening, which is measured by the width of the pulser peak. This corrected width, for the protons as well as for the tritons, is related to the ion temperature by the equation

$$\Delta E\ (FWHM) = 91.6 \cdot \sqrt{T_i}, \quad \Delta E, T_i\ in\ keV.$$

Figure 2 gives examples of a proton and a triton spectrum. The spectra demonstrate that both widths (not yet corrected for the straggling) are about the same, and hence they yield the same ion temperature. The time dependence of the temperature, evaluated from the proton spectra for a neutral-beam (H^0)-heated discharge in deuterium, is given in Fig. 3 in comparison with the temperature deduced from the neutron flux.

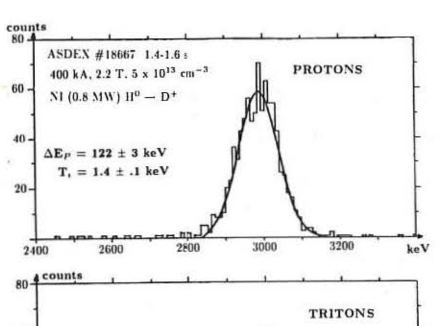
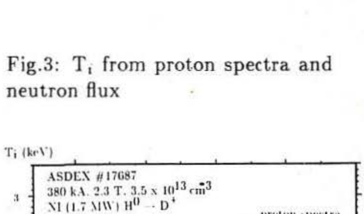


Fig.2: Spectra of protons and tritons

Fig.3: T_i from proton spectra and neutron flux



In principle, measurements of the tritons are of great interest, since their lower energy makes the spectrum more sensitive to the reaction conditions than the proton spectrum. However, the observation of the tritons is only possible in discharges with a low level of X-rays because these cause a background at the low energies that may cover the triton spectrum. Moreover, the surface barrier detector application is limited by the saturation of the preamplifier in discharges with high background levels.

Because of the influence of the strong magnetic fields in a tokamak the measurements of charged fusion products have to be supported by detailed particle trajectory calculations. They describe the phase space transformation of the charged fusion particles from the plasma to the detector. For measurements of the particle fluxes it is necessary to calculate the efficiency of the collimated detector [**3**], and for the spectra it is important to know which particles (characterized by birth radius and pitch angle) can reach the detector. To get this information about the phase space of the observed charged fusion particles, we calculate their trajectories in the opposite direction, i.e. from the detector into the plasma. For each point of the orbit the distance from the plasma centre and the pitch angle are calculated and then the point is stored in a matrix of these phase space coordinates. This is done for different directions through the collimator, weighted with the collimator transparency. Doing this, one gets a phase space probability for the measurement of charged fusion products that depends on the charge and energy of the particle, on the magnetic fields in the plasma, and on the orientation of the collimator. An example of such a probability calculation is given in fig. 4a, and it is obvious, that in this case the detector measures particles from the whole plasma volume, mainly starting perpendicularly to the plasma axis. In this case (pitch angle of about 90°) the influence of the poloidal field is very small, and so the details of the current distribution are of no importance. Measurements of the ion temperature are done with this collimator orientation.

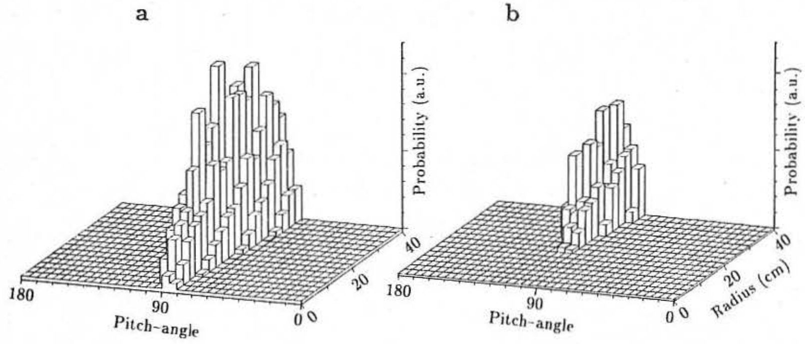


Fig.4a,b: Phase space probabilities for different collimator orientations
Calculation for ASDEX, $I_P = 400$ kA, $B_T = 2.7$ T, $\beta_p = 0.5$

Turning the collimator by 20° results in the probability distribution given in Fig. 4b, which measures only particles born at radii ≥ 20 cm, while the pitch angles are nearly the same as in Fig. 4a. This dependence of the phase space distribution on the collimator orientation can be used to deduce the fusion emission profile from the flux measurements at different orientations.

This procedure can be applied to look for the fast deuterium ions created by LH waves in ASDEX at densities above about 2.8 x 10^{13} cm^{-3} [**4**]. Figure 5a gives an example of a typical spectrum from such a discharge at a collimator orientation as in Figure 4a. The spectrum of the protons and that of the tritons show a superposition of a wide spectrum on the expected thermal peak. These central peaks (ΔE about 100 keV) correspond to the Maxwellian plasma bulk with an ion temperature of about 700 eV. The wider parts of the spectra (about 600 keV wide) are produced by the fast ions generated by the LH waves. The velocity of these deuterium ions is mainly directed in the poloidal plane and their energy is in the range of 25 keV. Since the fusion reactivity at these energies is about 5 orders of magnitude higher than at 700 eV the number of these fast ions must be correspondingly smaller.

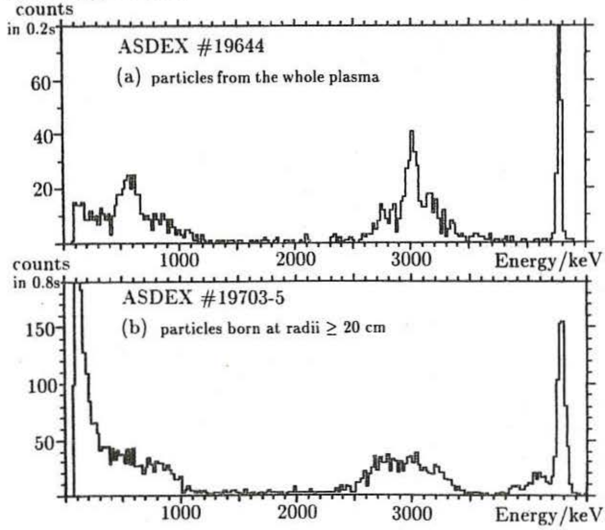


Fig.5a,b: Spectra for two ASDEX–discharges with different collimator orientations. $I_P = 400$ kA, $B_t = 2.7$ T, $n_e = 3.9 \times 10^{13}$ cm^{-3}, LH (1.3 GHz) $P_{RF} = 900$ kW

With a collimator orientation as in Figure 4b (where only particles from the outer regions are detected) we obtain the spectrum given in Figure 5b. As expected, the spectra generated by the bulk ions are not detected any more. Since the contribution of the fast ions appears nearly unchanged, however, one must conclude that the fast ions are created by the LH waves in the outer plasma regions, confirming the results from CX measurements [**5**].

REFERENCES

1. Nagle D.E., Quinn W.E., Ribe F.L., Riesenfeld W.B., Phys.Rev. **119** (1960), 857–862.
2. Strachan J.D., in "Diagnostics for Fusion Reactor Conditions", EUR 8351-I-EN, Varenna, 1982, pp. 383–400.
3. Heidbrink W.W., Strachan J.D., Rev. Sci. Instr. **56** (1985), 501–518.
4. Eckhartt D., et al., 4th Int. Symp. Heating in toroidal Plasmas, Rome 1984 **I**, 501–512.
5. Ryter F., in "RF–Applications to Tokamaks", EUR 10333-EN, Varenna, 1985, pp. 746–751.