DETERMINATION OF TRITIUM CONCENTRATION IN DT PLASMAS

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Abstract

An extensive period of deuterium/tritium operation (the DTE1 experiment) took place in the JET tokamak during 1997 [1]. The diagnostic capabilities at JET permitted the *relative* densities of deuterium and tritium to be determined sufficiently well that the fusion performance of the discharges could be interpreted unambiguously. However, a serious problem was found to be the darkening of optical windows (due to carbon/beryllium deposits) which has impeded the measurement of the effective charge of the plasma (Zeff) and, hence, the determination of *absolute* densities.

1. Introduction

In principle, the complete deuterium and tritium ion density profiles should be measured throughout all discharges so that the particle transport coefficients can be determined for all operating conditions encountered. The JET measurement capabilities depend on the conditions under which the discharges are run and the requirements can be relaxed when approximately equilibrium conditions prevail. Thus, at one extreme, the trace-tritium transport experiment [2] was performed: for this, the neutron profile monitor data acquired during tritium gas puffing into deuterium permitted the time evolution of the local tritium concentration to be determined and particle transport information to be derived. At the other extreme are the high performance experiments which commenced with 50:50 D:T fuelling mixtures and wall loading, applied strong simultaneous beam heating with deuterium and tritium neutral beams, used additional ICRF heating and were strongly edge fuelled with a varying mixture of deuterium and tritium gases. In this situation, the neutron emission is relatively insensitive to the fuel mixture. Hence, the transport properties of deuterium and tritium must be studied using specialized discharges, e.g. those with just one fuel or beam injection ion specie. Naturally, analytical codes (e.g. TRANSP [3]) invoke all available sources of diagnostic information to confirm the overall data consistency and (where appropriate) use the neutron emission to infer the correct D:T mixture.

2. Diagnostics

The diagnostics in routine operation at JET for measuring the time dependence of the tritium/(tritium + deuterium) density ratios for the entire duration of a discharge include:

- Spectroscopic observation of the Balmer D_α and T_α lines, which provides a convenient means of measuring the D-T isotopic ratio at the plasma edge [4]. The diagnostic views close to the divertor region, where the high neutral density provides a strong signal during X-point plasma configurations. However, the small separation and asymmetric lineshapes of the D_α and T_α lines makes their separation difficult at low (<5%) ratios of T/D.

- A Penning discharge is used to overcome the above difficulty by analyzing the spectrum of the exhaust gas from the divertor [5], when the low temperature of the discharge leads to reduced broadening and T, D and H may be distinguished. In general, very good correspondence is found between isotopic ratios in the sub-divertor gas and in the plasma.

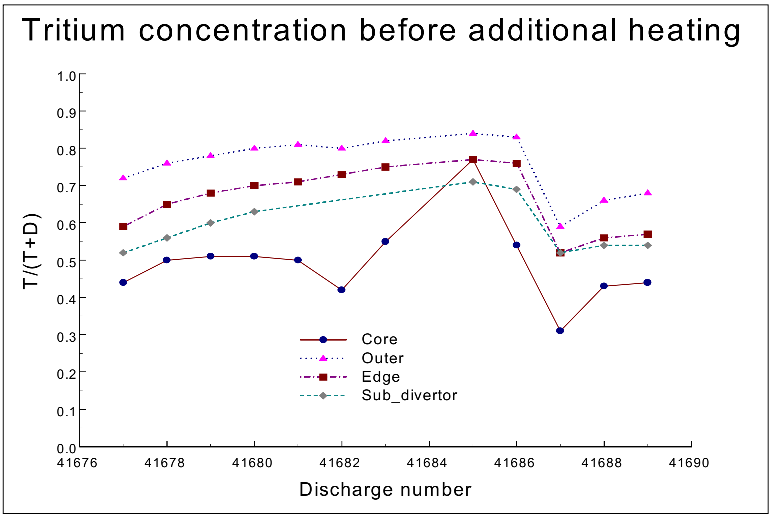
Further measurements that depend on operating conditions include:

- Active Balmer-α charge-exchange spectroscopic measurements for the special case of low density plasmas [6], with only a single neutral beam bank firing, have provided local relative plasma concentrations at several radial positions in the core of the plasma. This technique provided evidence of transient (up to 200 ms) tritium enhancement or depletion at the centre due to the fuelling from tritium or deuterium beams. Thereafter, the radial profiles are consistent with a constant tritium fraction across the plasma, that fraction also being consistent with the results from the edge diagnostics.
- neutral particle analysis of low energy particles by electrostatic deflection and time-of-flight [7]. These neutral particles originate from a zone 10 to 40 cm from the plasma edge, where the neutral density is appreciable and the temperature is high enough to permit the escape of the neutrals from the plasma. This diagnostic actually measures escaping fluxes of neutrals, so a conversion to particle densities is required. In addition, care has to be taken during additional heating to take into account the detection of non-thermal escaping neutrals (neutralizing beam ions or accelerated particles).
- Neutron measurements, comprising line-integrated neutron emission profiles and instantaneous neutron yields. For low tritium concentrations, the d-d neutrons can be distinguished from d-t neutrons and modelling [8] of the observed signals allows the deduction of the local tritium fraction since this is known to be small. At higher concentrations, the low fluxes of d-d neutrons can no longer be distinguished and the deduction of the tritium fraction from ohmic discharges is ambiguous. Nevertheless, the use of short periods of neutral injection of deuterium or tritium separately, before or after periods of intense combined heating if relevant, permit the core region tritium or deuterium densities (respectively) to be determined. Numerical analysis of the neutron data cannot provide accurate values for the tritium fraction for plasmas with comparable tritium and deuterium concentrations during combined heating with deuterium and tritium beams, especially for plasmas with dominant thermal neutron production, since the well-known ambiguity resurfaces.

The comparison of modelling predictions with neutron measurements clearly demonstrate the existence of peaked or hollow profiles of the tritium fractions for discharges with intense beam heating when the vacuum vessel walls are loaded with a tritium fraction different from that of the beam mix. As an example, consider the situation where the edge recycling may be composed primarily of deuterium while the plasma is heated with tritium beams. The edge diagnostics then indicate a deuterium-rich content while the TRANSP analysis of the neutron measurements shows a tritium-rich core for the entire duration of the discharge.

3. Conclusion

The various techniques used for determining the tritium fraction were in good agreement when the radial profiles were expected to be flat, i.e. for ohmic discharges and for other discharges when near steady-state conditions were achieved (wall loading being representative of the plasma fuel mix), and showed differences consistent with expected tritium radial profiles under non-equilibrium conditions. The diagnostic set permitted the tritium/(tritium + deuterium) fraction to be determined (directly or from numerical modelling) for all conditions, from trace injection up to nearly 100% tritium concentration. Nevertheless, improved local measurements are needed for transport studies.



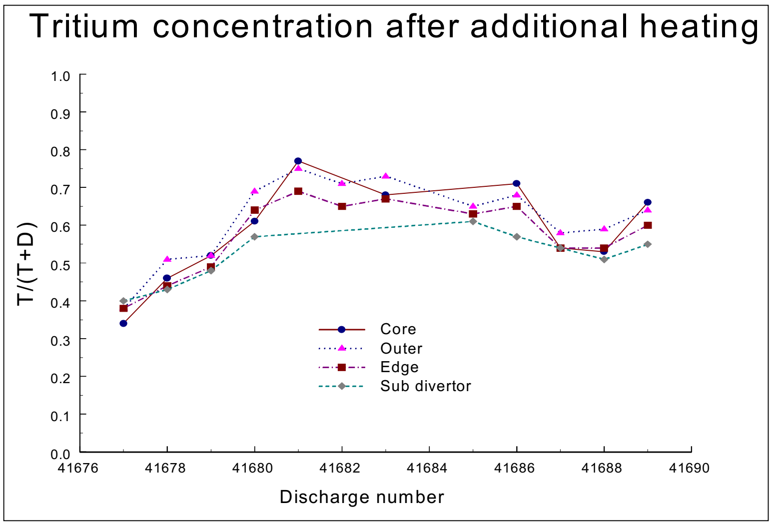


Figure: Tritium fractions determined from neutron emission during beam blips (core), compared with NPA (outer), edge and sub-divertor spectroscopy during early tritium gas puffing experiments. No active spectroscopy measurements were made because the tritium beam injector was not available. **(upper**) shows the situation prior to applying strong additional heating, while tritium gas puffing was taking place, whereas **(lower**) shows the situation after termination of additional heating and gas puffing.

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