PARTICLE TRANSPORT IN STEADY-STATE ELMY H-MODES STUDIED BY TRACE TRITIUM INJECTION DURING JET DTE-1

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1. Introduction

Trace amounts of tritium (1-5 % of the deuterium content) have been puffed into steady-state ELMy H-Mode discharges (puff duration 50 msec, τ_E in the series ranges from 0.2-0.5 sec). The transport properties of the edge and core plasma, and the dynamic response of the tritium fraction in the wall, determine the evolution of the 14 MeV neutron emission in space and time following these puffs. These experiments represent the first measurement of fuel ion transport in an ITER relevant regime. In this paper, we outline the method used to analyse the data, and identify which transport parameters can be measured.

2. Measurements and analysis technique

The neutron profile monitor has been absolutely calibrated to provide 2.5 MeV and 14 MeV neutron brightness profiles and neutron yields with associated error bars (counting statistics plus 10% relative calibration). The rate of forward and back scattering events that give rise to additional signals are calculated using a Monte-Carlo neutron transport code (MCNP) [1]. The integration time of the data points is 50 msec.

We derive transport coefficients for tritium by performing a least-squares fit of model parameters to the chordal data (see Fig. 1) during the transient phase of the profile time evolution. This approach also enables the error propagation from the neutron data through to the model parameters, taking into account covariances in model parameters.

We use a $1^1/_2$-D transport model (SANCO) with diffusive and convective terms. The transport coefficients are set radially constant within five zones (see Fig. 3). The innermost zone ($0.0<r/a<0.35$) represents a sawtooth average, and the outermost zone ($0.95<r/a<1.00$) represents the transport barrier on one hand, and an ELM average on the other hand. The intermediate zones have their borders at r/a=0.55 and 0.75. In each zone at least two neutron chords have their minimum r/a along their line of sight.

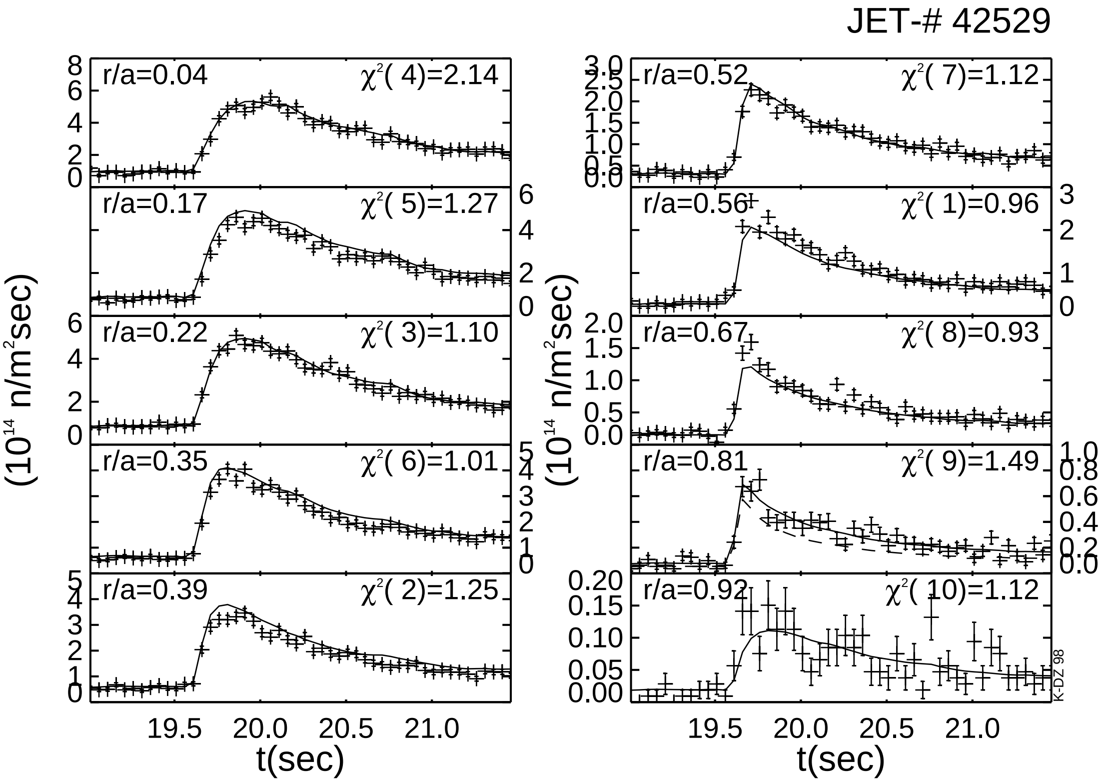


Fig. 1: *Achieved fit for each channel, indicating the minimum r/a value along each line-of-sight and the achieved χ^2 (Overall χ^2=1.37). Note, that for the innermost channel (#4), the fit is worse since the sawtooth oscillations are not included in the model. For the outermost two channels, there is a strong contribution to the signal from forward and back scattering. For channel #9, the true brightness is indicated by the dashed line. For channel #10 the signal is entirely due to scattering events.*

3.1. Fast particle model and neutron reactivities

The measured 2.5 MeV brightness profiles and those predicted for the thermal-thermal and beam-thermal reactions do not agree, see Fig. 2. Specifically, the codes in use at JET (TRANSP and CHEAP) over predict the signal levels in the outer channels (0.5<$(r/a)_{Min}$<0.8) of the neutron profile, by up to a factor two. For the outermost channel with $(r/a)_{Min}$=0.92, the codes predict up to a factor ten more than is measured. We therefore modify the prediction for beam-thermal reactions, see Fig. 2. The magnitude of the correction is outside the errors introduced into the model by the input data (mainly dilution and electron temperature, noting that to first order beam-thermal emissivity is independent of electron density).

Three more observations support the introduction of this correction. 1) The systematic over prediction of the 2.5 MeV yield increases from typically 20% at 50% thermal-thermal fraction to 40% at 90% thermal-thermal fraction. 2) When we use the uncorrected function in the analysis of the 14 MeV signal, we predict a burst of neutrons in channels #9 and #10, overshooting the measured signal by a factor up to 4 and 10, respectively. This burst can not be removed by changes in model parameters. 3) When we use the tritium transport coefficients to predict the deuterium equilibrium profile, with only the edge influx as a parameter to match the central density, we obtain good agreement with the observed profile shape. If, however, we use the uncorrected beam-thermal emissivity, a strong inward pinch is required to explain the 14 MeV brightness profile. Its magnitude is inconsistent with the deuterium equilibrium profile.

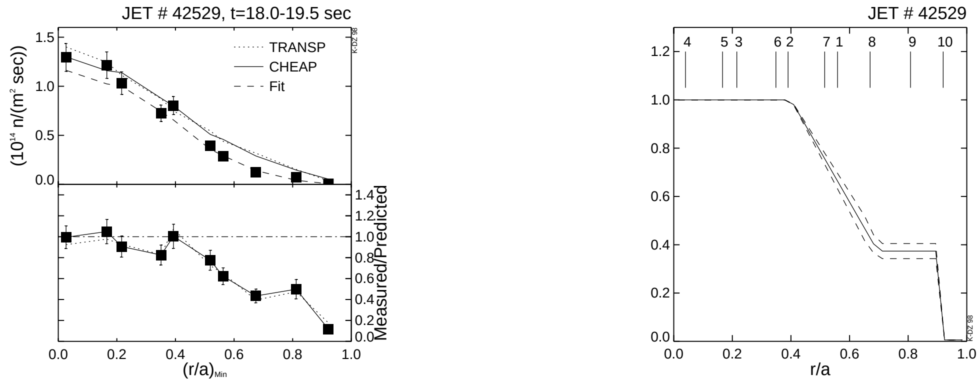


Fig. 2: *Left: Measured and predicted 2.5 MeV brightness profile with and without correction to beam-thermal emissivity, Right: Radial function used to correct the beam-thermal emissivity. The closest approach of the line of sight for the channels of the horizontal camera is marked.*

3.2. Tritium fraction in neutral influx

The 14 MeV neutron signals several seconds after the puff, before the end of the steady-state phase of the discharge, are higher than just before the puff. Two explanations are possible. 1) The signal may still be in the tail of an exponential decay, which would return to the original value several confinement times later. 2) The fraction of tritium in the neutral influx has increased as a result of the puff. The analysis based on the latter assumption gives a significantly better fit to the data. The transport coefficients are only able to describe simultaneously the rate of rise of the signal, and a higher steady-state level after the puff, if the tritium wall flux is increased in the model. The exact shape in time of this increase is unknown, and we use a step function with the final level as a further free parameter of the model.

3.3. Significance of pinch term and mass dependence of transport

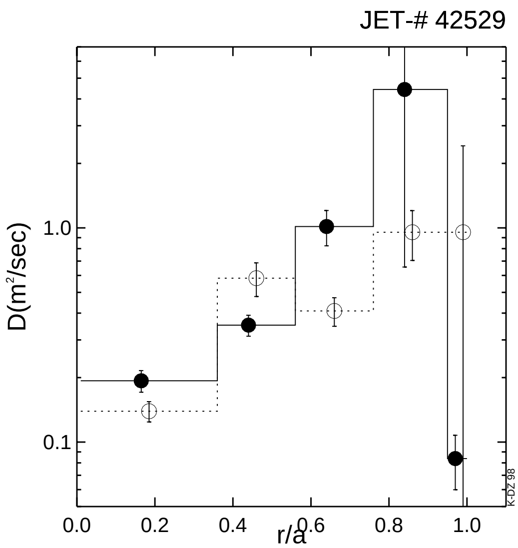
The pinch term is not significant when the analysis is based on the 14 MeV neutron data alone. Specifically, we obtain an inward pinch for $0.75<r/a<0.95$ of $v=-0.55\pm0.50$ m/sec, whilst further inside the plasma the value of v is smaller and the error bar encompasses $v=0$. In this paper we report results obtained based on the assumption $v=0$ for all radii.

Using the derived tritium diffusion coefficient to predict the deuterium equilibrium profile with beam fuelling (known) and wall influx (free parameter), requires $v=-0.5$ m/sec for 0.75<r/a<0.95. Therefore, the transport coefficients (D and v) for tritium and deuterium are the same within the measurement uncertainties.

3.4. Nature of transport barrier

We have explored whether the dynamic behaviour in these transient experiments can be used to distinguish, if the transport barrier is diffusive or convective. For this series of experiments the two cases were indistinguishable. Specifically, both assumptions result in different sets of free parameters (see Fig. 3), but are able to describe the 14 MeV neutron emission equally well. Any combination of diffusive and convective transport barriers is also consistent with the neutron data. The exact values of D and v in the barrier region depend on the choice of barrier width.

Fig. 3: *Diffusion coefficient for the two extreme cases.* ***Open circles****: Convective transport barrier, v=0 for 0.0<r/a<0.95, v=-31±12 for 0.95<r/a<1.0, (χ^2=1.42).* ***Filled circles****: Diffusive transport barrier, v=0 for 0.0<r/a<1.0, (χ^2=1.37)*



4. Conclusions

1) The beam-thermal fusion reactivity is lower for r/a>0.5 than is calculated by TRANSP and CHEAP.
2) The fraction of tritium in the steady-state wall influx increases after the puff.
3) Diffusive transport only (r/a<0.95) can describe the 14 MeV neutron data, a pinch term is not significant. A weak interior pinch is required for the deuterium profile shape.
4) There is no evidence from these experiments for a mass dependence on the transport for hydrogen isotopes.
5) An edge transport barrier is required to describe the tritium behaviour. The barrier could be diffusive, convective, or any combination thereof.

Reference

[1] M.J. Loughlin et al.: *12th Topical Conf. on High Temp. Plasma Diagn.*, Princeton, 1998.