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Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).

ABSTRACT.

Triton Burn up Neutrons (TBN) have long been used to infer the confinement properties of α particles in the JET tokamak [1]. 1MeV tritons from the d+d->t+p reaction have similar orbits to 3.5MeV α's which makes them suitable for simulation of certain α particle confinement properties, e.g. prompt losses. Only confined tritons can contribute to the TBN emission. Hence triton losses will lead to a reduction in the TBN emission which can be observed experimentally.

On JET new plasma regimes are being investigated which have relatively low plasma current. In some cases the current profile can be hollow. That is the case, for instance, of the so-called advanced regimes [2], which can feature a plasma core with depleted current. The confinement of a particles and, more generally, of fast ions, is strongly affected by the poloidal magnetic field, its profile and the magnetic plasma topology.

In this contribution we present the results of analysis of TBN measurements in H-mode plasmas of JET. These plasmas have a canonical current profile and provide a reference against which advanced regimes can be compared. The data refer to the period October 2000-May 2002.

1. EXPERIMENT AND DIAGNOSTICS

The main experimental information is provided by time resolved neutron yield measurements where the total (dd+dt) yield is measured by a set of fission chambers and the dt neutrons are measured with a silicon detector. Both systems are calibrated by comparison with absolute, time-integrated neutron measurements performed with an activation system. An example of dd and dt time traces is shown in Figure 1, which also shows the result of a simulation based on standard triton slowing down physics (see below). The yield measurements are complemented by neutron camera measurements - providing the dd neutron emission profile used for the simulation - and neutron spectrometry measurements. The latter have the important task of establishing the presence of dt neutron emission processes different from TBN. Indeed, the Magnetic Proton Recoil spectrometer data [3] (see Figure 2) provides a clear decomposition of the neutron spectrum in a TBN component and a weaker but non-negligible component due to residual tritium from previous DT experimental campaigns [3]. The ratio of TBN/total neutron emission is $\eta = 82\%$ in the data of Figure 2. The residual tritium component has been observed to decrease with time over the 6-year period following the DT experiments in 1997. Some correlation of the residual tritium content with plasma operation and condition has also been found as a result of the present analysis. The correlation is between the plasma impurity content and the tritium content: plasmas with higher Z_{eff} have also a higher content of residual tritium. This is detrimental for the TBN studies, as it provides an extra component to the 14 MeV signal which needs to be subtracted in order to know the absolute TBN yield.

A high Z_{eff} value is also detrimental for the TBN analysis for a more fundamental reason: the burn-up fraction – given by the ration of the dt and dd yields integrated over time, $\rho = N_{dt}/N_{dd}$ - is proportional to the deuterium relative concentration in the plasma (n_d/n_e). Higher Z_{eff} values mean lower concentration and larger uncertainties in n_d/n_e, which propagate linearly to the simulated

burn-up fraction. For this reason only plasmas with $Z_{eff} < 2.5$ have been considered here. Another constraint is the neutron statistics, which needs to exceed a practical threshold that is set here at 2×10^{15} dd neutrons. This restricts the analysis to a set of 112 discharges of the so-called S1 Task Force, most of them in H-mode confinement. Other discharges from other Task Forces with $Z_{eff} < 2.5$ are not included in the present analysis in order to ensure a more homogeneous data set. The measured burn-up fraction values, $\rho_{exp} = N_{dt}/N_{dd}$, are shown in Figure 3. The plasma current values span the range 1-3MA. In this range the data show a gross empirical trend given by $\rho_{exp}[\%] = I_p[MA]/2$ and a large scatter around this trend.

2. DATA ANALYSIS

For the analysis of the ρ_{exp} data we use a simplified model implemented by two simulation codes. The triton confined fraction, f_c, is assumed to be independent of time and is determined once per plasma discharge from first-orbit simulations performed with the Monte Carlo code McOrbit. The code uses the experimental magnetic equilibrium and neutron emissivity profile to calculate the triton orbits. Orbits that hit the wall are assumed to be lost. Losses at the 50% level are found to be typical of 1 MA plasmas; at 2 and 3 MA the losses are about 20% and 10%, respectively. The f_c values for all discharges are plotted in Figure 4 and show a well-defined current dependence with some scatter due to various causes including different neutron emissivity profiles.

The second code used for the analysis, TRAP-T, calculates the time-resolved TBN emission assuming no triton losses. Each triton is assumed to slow down and react at its birth point; i.e. no orbit effect is included in the simulation, but the dd emissivity and other plasma parameter profiles affecting the triton slowing down are taken into account. The simulations provide a good match of the dt trace at high currents, as shown by the example in Figure 1. Note that the agreement between data and simulation is not as extraordinarily good as Figure 1 would suggest: the residual tritium contributes about 15% of the total dt emission but this was not included in the simulation. On the other hand a 15% effect is well within the experimental uncertainties when considering a single plasma discharge.

Evidence of triton losses manifests itself in the TBN data by taking the ratio ρ_{sim}/ρ_{exp} between the experimental ρ_{exp} values and corresponding simulated value ρ_{sim} from TRAP-T, which assumes no losses. This is shown in Figure 5 and follows a current dependence not dissimilar to f_c in Figure 4. Here the effect of a 15% residual tritium contribution to the dt yield would be to raise the "perfect agreement" line above unity to the level marked by a dashed line. With this effect taken into account the data shows that the experimental TBN yield is roughly half of what expected at $I_p = 1$ MA and approaches the expected value at the highest currents.

A more quantitative comparison of the current dependences seen in Figures 4 and 5 can be obtained by introducing a corrected burn-up fraction $\rho_{exp}' = (N_{dt}/N_{dd})*\eta$ and the corresponding simulated quantity $\rho_{sim}' = \rho_{sim}*f_c$. The ratio ρ_{exp}'/ρ_{sim}' is shown in Figure 6. The ratio is convincingly close to unity at high current. At lower currents the data are scattered but suggest $\rho_{exp}' < \rho_{sim}'$ by 10-

20% (but note that $\rho_{exp}'/\rho_{sim}' = 1$ is not incompatible with the data given the large uncertainties). Neoclassical (collisional) triton losses are being investigated as a possible loss mechanism that can lead to observable levels of fast ion losses.

CONCLUSIONS.

The standard TBN emission model with first orbit triton losses provides an accurate description of the TBN in JET H-mode plasmas with plasma currents I_p above 2MA. This confirms earlier results obtained in JET at currents $I_p > 3MA$.

The simulated first orbit losses amount typically to 50, 20 and 10% at I_p = 1, 2 and 3MA, respectively.

Below 2 MA additional losses (such as due to "neoclassical" Coulomb collisions) could also play a role and should be investigated theoretically.

A similar analysis can be performed on Advanced Regimes and will be the subject of future work.

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[2]. "Special issue on Advanced Tokamak Research in EFDA-JET during 2000-2001 experimental campaigns", Plasma Physics Controlled Fusion **44** (2002) 1031.

[3]. "Neutron Emission Spectroscopy at JET – Results from the MPR Spectrometer" (G.Ericsson, L.Ballabio, S.Conroy, J.Frenje, H.Henriksson, A.Hjalmarsson, J.K‰llne, M.Tardocchi), Review of Scientific Instruments **72** (2001) 759.
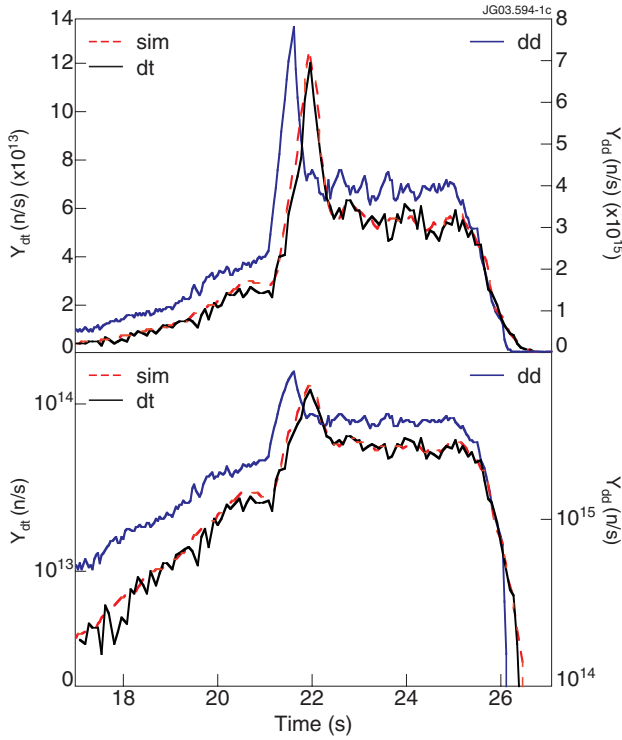
Figure 1: Time resolved dd (left) and dt (right) neutron yields for JET plasma Pulse No: 52958 (I_p= 2.6MA) plotted on a linear (top) and log (bottom) scale. The dashed line is the simulated dt yield from triton burn up.

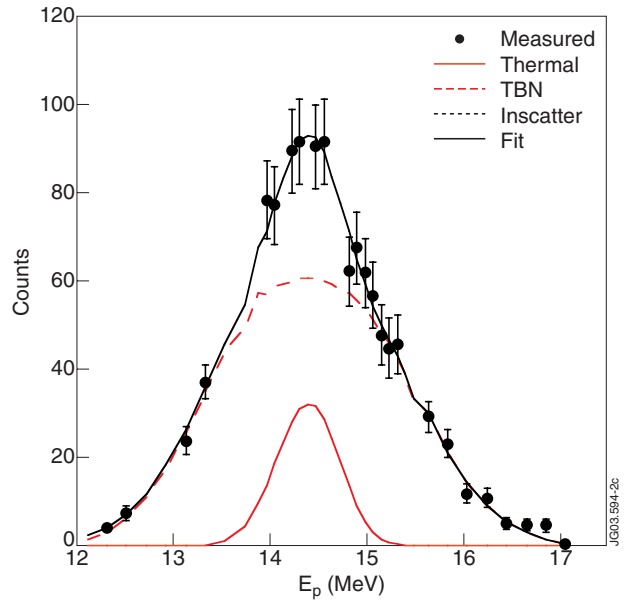*Figure 2: Analysis of neutron spectrum for a set of selected plasma discharges with Z_{eff}<2.5 (see text). The fitted line is the sum of a broad component from triton burn up (TBN) and a narrow component due to residual tritium (Thermal). Barely visible is a very small third component due to neutron scattering (Inscatter). The TBN/(Thermal+TBN) ratio is η=0.82.*
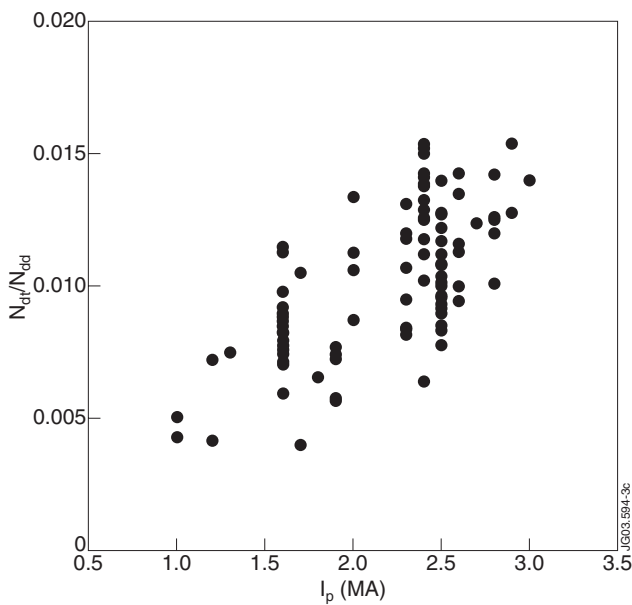

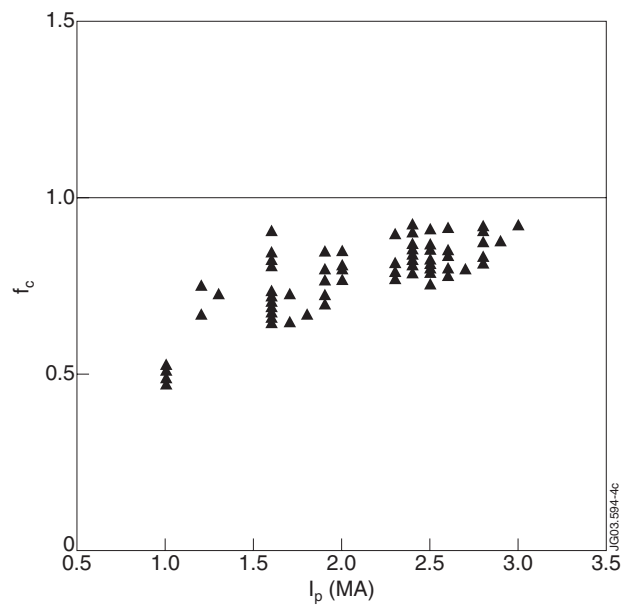*Figure 3: Ratio of dt and dd neutron yields from a reduced set of plasma discharges plotted versus plasma current.*

Figure 4: Confined fraction of tritons according to First Orbit simulations for the same plasma discharges of Fig.3 plotted versus plasma current.
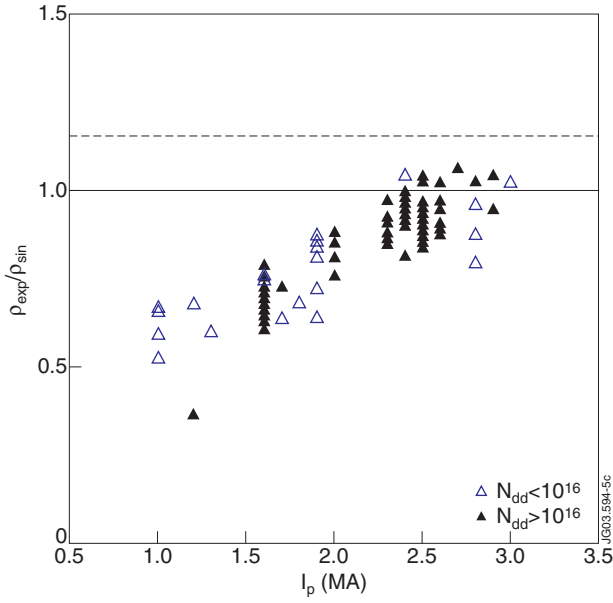
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Figure 5: Ratio of experimental and simulated burn up fraction for the same plasma discharges of Fig.3. Open and full triangles are for total dd neutron yields below and above 10^{16} neutrons, respectively. The full line marks the unity ratio expected under conditions of perfect triton confinement. The dashed line marks the level expected due to contamination from residual tritium (see text).
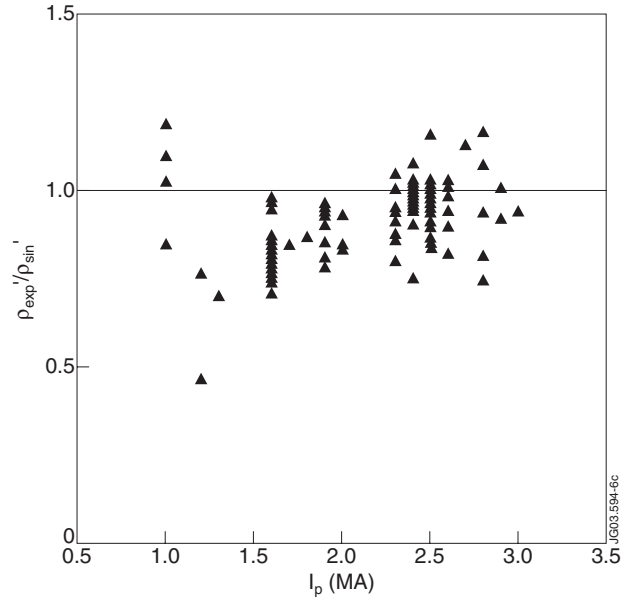
Figure 6: Ratio ρ_{exp}'/ρ_{sim}' for the same plasma discharges of Fig.3 plotted versus plasma current. Here $\rho_{exp}' = \rho_{exp}*\eta$ and $\rho_{sim}' = \rho_{sim}*f_c$ where $\rho_{exp} = N_{dt}/N_{dd}$ and ρ_{sim} are the (uncorrected) experimental and simulated burn up fractions, respectively, $\eta = 0.85$ is a correction factor for residual tritium, and f_c is the confined fraction of tritons from Monte Carlo orbit simulation.