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1. INTRODUCTION

ELMy H-mode is the reference mode of operation for ITER. Confinement properties of this mode are intensively studied under various scenarios. Scenarios using impurity seeding and plasma shaping allow to reach simultaneously high confinement at high density while achieving good plasma edge properties. In this paper, we investigate the neutron emission from high density ELMy-H mode discharges, we apply a model to compare the prediction with measurements in order to understand the neutron production. Finally, we look at specific effects on neutron behavior which may arise from impurity injection or in highly shaped plasmas.

1.1 NEUTRON DIAGNOSTICS AT JET

The total neutron yield monitor consists of 3 pairs of fission chambers. The fission chambers measure the volume integrated emission rate of DD and DT neutrons. The chambers are calibrated with activation measurements. The neutron profile monitor consists of two cameras. The vertical camera contains nine collimated viewing channels in a fan-shaped array with nearly vertical view through the plasma. The horizontal camera has ten channels and a nearly horizontal viewing direction. Two sets of low energy resolution neutron spectrometers are provided so that D-D neutrons and D-T neutrons can be recorded separately. The reader can find further details about these systems in [3, 4].

2. MODELLING OF NEUTRON EMISSION

The total D-D neutron emission rate is usually broken up in three contributions:

$$Y_{tot} = Y_{th} + Y_{bt} + Y_{bb}$$

where Yth,Ybt and Ybb are the thermal, beam-plasma and beam-beam emission respectively. The neutron emission from high density ELMy H-mode discharges is largely dominated by the beam-plasma contribution which usually accounts for more than 90% of the neutron emission. The neutron emission profiles are broad. The profile peaked finess can be measured by the effective core-volume which is defined by the ratio between the total neutron yield and the maximum of the profile emissivity. In figure 1, the core volume time trace is shown for several investigated discharges. It goes up to $40m^3$ in high density ELMy H-mode discharges whereas it is typically between 15 and $20m^3$ in Hot ion H-mode and lower than $10m^3$ in optimized shear discharges [5].

2.1 MODELLING OF THE BEAM-PLASMA NEUTRON EMISSION

$$Y_{bt} = Kn_b \frac{n_d}{n_e} T_e^{\frac{3}{2}} <\sigma v>_{bt}$$

The expression above is the parametric form for the local beam-plasma neutron emission. The electron temperature T_e is the most sensitive parameter. n_d/n_e is the dilution factor. It decreases linearly when Z_{eff} increases. With the assumption of one main impurity Z_i, $\frac{n_d}{n_e} = \frac{Z_i - Z_{eff}}{Z_i - 1}$. n_b is the beam deposition profile (number of beam ions deposited per unit time and volume) and $< \sigma v>b_t$ is the beam-plasma reactivity.

2.1.1. Beam deposition

The beam deposition is not measured but calculated with various codes. The most complete treatment, including all known physical effects requires a complex transport code such as TRANSP[6]. It is non trivial to use and computationally intensive. Available TRANSP results are useful for spot-checks. CHEAP code[7] is part of the CXRS analysis. It is run on request. PENCIL code is part of the JET intershot analysis and is therefore readily available for all shots. PENCIL and TRANSP in JET high density plasmas were compared in a recent study and good agreement was found. We use the CHEAP code results when available and PENCIL code otherwise. A comparison of CHEAP and PENCIL results for one pulse is given in ¯gure 2. PENCIL code results match rather well CHEAP code results.

2.2. THE NEUTRON EMISSION MODELLING CODE

The Neutron Emission Modelling Code (NEMCO) is written in high level language MAT-LAB. It is a first order model using simplifying assumptions. Inaccuracy resulting from this simplified model is at a level below the uncertainties related to the experimental data. The LIDAR electron density and temperature measurements are adopted for the density and temperature radial profile. Neutron yield should be above 10^{15} n/s in order to have good pro¯le monitor data. The agreement between measured and predicted neutron emission within the overall uncertainty is usually possible when good LIDAR data are available. A first run with the dilution factor set to 1 ($n_d/n_e = 1$) is very instructive. The result should be an overestimate of the neutron emission, at an extent depending on the plasma impurity content. A signi¯cant discrepancy at this stage is most probably caused by poor quality LIDAR data. The last stage includes a model for the dilution factor. The code is useful for systematic study because it takes typically only one minute to run a discharge with calculated emission every 100ms. It is directly coupled to the JET database via the MDSPLUS data server. A systematic comparison with TRANSP will be possible when access to TRANSP run results become available trough MDSPLUS.

3. RESULTS OF THE MODELLING

Figure 3 shows the time trace of predicted and measured neutron (with $Z_i = 6$). The error on the measured neutron signal is about 10 percent[5]and the errors shown on the predicted neutron emission arise from errors on LIDAR data and PINIs data. We have investigated a set of ELMy H-mode discharges including discharges with and without impurity seeding and discharges with low, medium or high triangularity. Figure 4 shows for all the discharges the predicted (with $Z_i = 6$) versus measured neutron yield. Data are 0.1s averaged. There is an overall good match between the measured and predicted value regardless of the scenarios details. This in fact validates the ¯rst order model and the assumptions made. The neutron production depends linearly on the dilution factor and on the electron temperature to the power 3/2. Impurity seeding does not affect significantly the neutron emission compared to an unseeded case if the core electron temperatures of both discharges are the same. Figure 5 shows the predicted versus measured neutron yield for another set of discharges from campaign C7b. The two sets of points indicate two different choices of dilution factor (n_d/n_e) for the calculation. If the dilution factor is taken such as described in paragraph 2.1 with $Z_i = 6$ and line-average-Z_{eff}, it gives systematically too high dilution to be consistent with neutron measurements. The disagreement is reduced if line-average-Z_{eff} or higher Z main impurity is taken. Concerning the neutron emission profile characteristics, in high triangularity discharges we observe a °attening of the neutron emission profile both in seeded and un- seeded discharges whereas in low triangularity discharges with impurity seeding, a slight peaking of the pro¯le is observed.

CONCLUSIONS.

The modelling of a set of discharges with and without impurity seeding, with high and low triangularity gives results consistent with neutron measurement data. The electron temperature is the dominant factor for the neutron emission. The neutron emission depends linearly on the dilution factor (n_d/n_e). Therefore it is expected that the neutron emission is not decreased appreciably in impurity seeded discharges compared to unseeded discharges when the electron temperature profile is maintained. Moreover no significant dilution is observed. Profile characteristics are generally similar for impurity seeded discharges and unseeded discharges. During the beam heated phase, profile peaking is observed in seeded low triangularity discharges while profile flattening is observed in high triangularity discharges.

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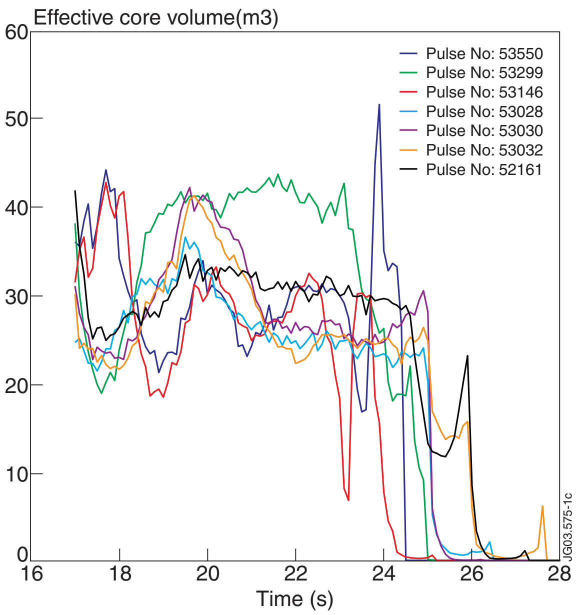

Figure 1: Effective core-volume

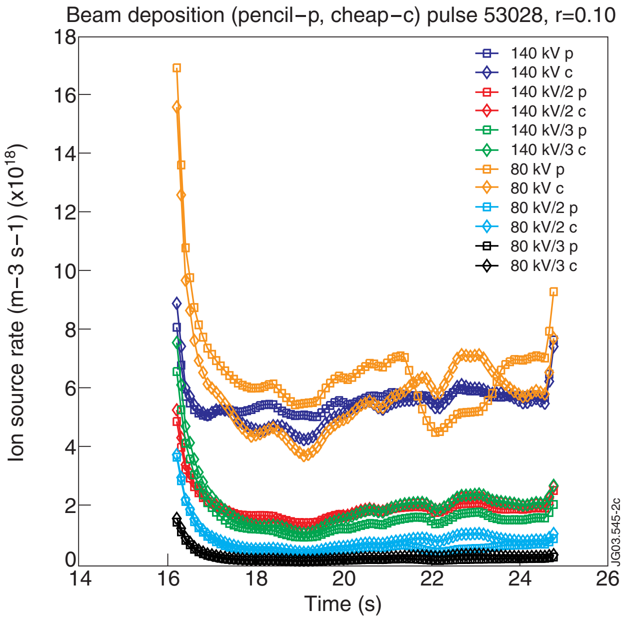

Figure 2: Beam deposition

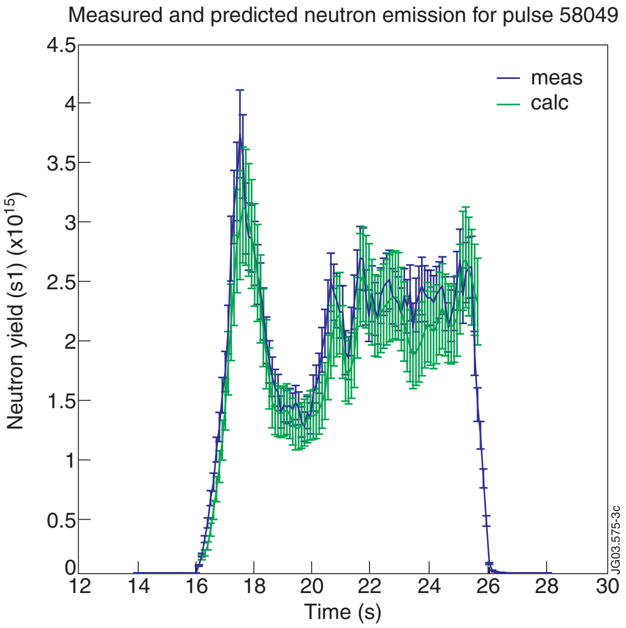

Figure 3: Measured and predicted neutron yield

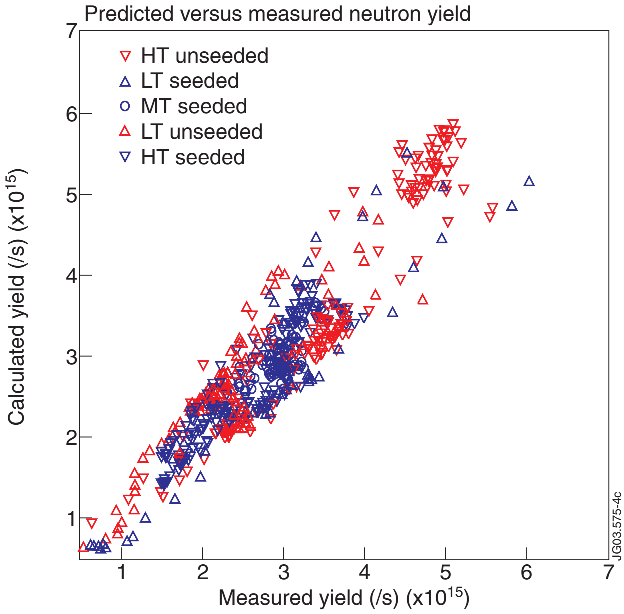

Figure 4: Database of modelled discharges

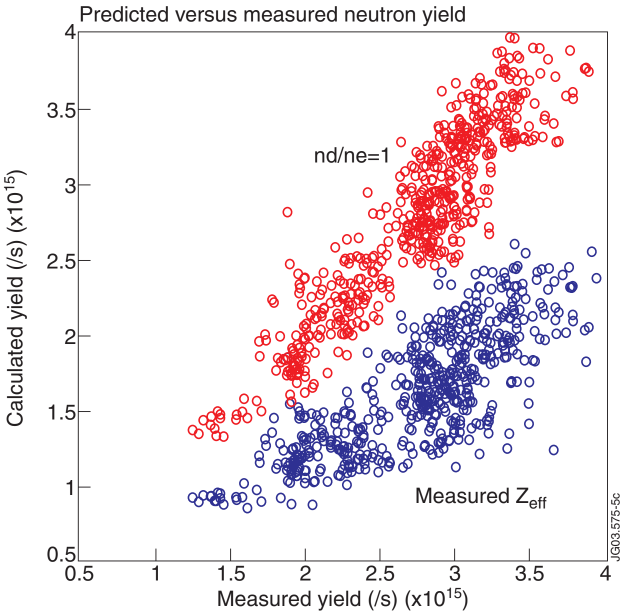

Figure 5: Measured/predicted yield in 5804X discharges