Study of the detector efficiency of MAST neutron camera

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Introduction

The determination of the absolute efficiency of the neutron detectors used in the Neutron Camera (NC) at MAST [1] is necessary for an accurate comparison of the experimental data with the measurements predicted by theoretical modelling of the neutron emission. The aim of this work is to determine the detector efficiency of the EJ301 liquid scintillators used in the NC using a combination of theoretical models to describe the detectors' properties and of experimental measurements obtained with the NC at MAST. For a given impact parameter p (tangency radius) and a given neutron emissivity $S(R,Z)$, the NC measure the neutron count rate, a quantity which is proportional to the volume integral Ψ_p of $S(R,Z)$ within the field of view of each Line of Sight (LoS). The proportionality factors are the detector efficiency ε and the attenuation in stainless steel stainless steel η (for thickness 3 mm). The focus of this work is on the determination of the neutron detector efficiency and an example of how it relates to the synthetic neutron emissivity $S_{SYN}(R,Z)$ is given by sawtooth activity.

Neutron detector's efficiency

The detector efficiency has been calculated using a Monte Carlo code NRESP from Physikalisch-Technische Bundesanstalt (PTB) [2] for a NC detector active area 10 cm^2 and 1.5 cm thick for different energy thresholds (E_{TH}). The calculation has been assumed that the proton light output function is the one determined by Verbinski [2]. The efficiency at different E_{TH} was calculated as:

$$\varepsilon(E_{TH}) = \int_{E_{TH}} R(E_p, E_n)\,\Gamma(E_n)\,dE_p$$

where $R(E_p, E_n)$ is the response function matrix for recoil proton energies E_p calculated with the NRESP code assuming mono-energetic neutrons with energies E_n in the range 0.05 – 10.00 MeV in steps of 50 keV and folded with the energy resolution function whose parameters $\alpha = 16.47$, $\beta = 16.19$, $\gamma = 4.03$ have been measured experimentally [3]. $\Gamma(E_n)$ is the simulated neutron energy spectrum per MAST neutron for DD reaction and it is shown in

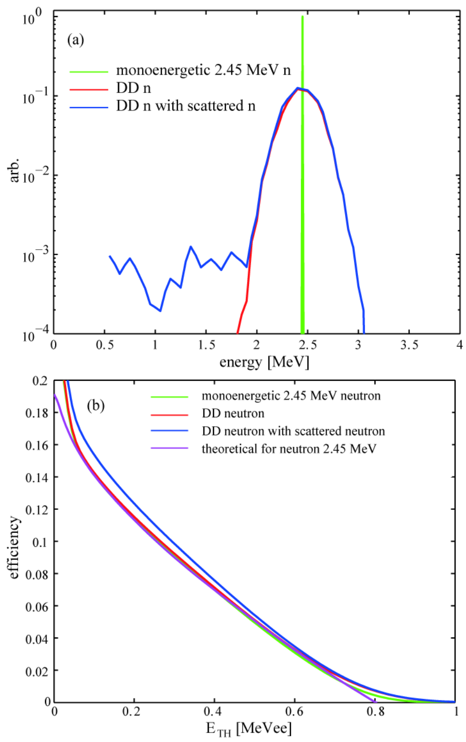

Figure 1. Panel(a) The monoenergetic 2.45 MeV neutron (green), The simulated DD neutron (red) and the DD neutron contributed with scattered neutron (blue). Panel(b) The detector efficiency obtained with the NRESP response function matrix multiplied with the neutrons spectrum in panel(a), and theoretical expression (magenta).

figure 1(a) for direct neutrons (red), direct neutrons plus the scattered neutron contribution (blue) compared to a monoenergetic 2.45 MeV neutron (green). The calculated $\varepsilon(E_{TH})$ of the neutron spectrum in figure 1(a) is shown in figure 1(b) together with the theoretical expression (magenta) which takes into account multiple neutron scattering on H and C [4]. Good agreement is found between NRESP and theoretical value which $\varepsilon =$ 13.78 $\pm$0.76 % and ε = 7.40 $\pm$0.50 % for energy threshold 0.11 MeVee and 0.38 MeVee respectively (corresponding to neutron energies of 0.7 MeV and 1.5 MeV). The detector efficiency in this work is 7.40 % for neutron above 1.50 MeV.

Comparison with experimental data

A series of four similar discharges (26448, 26451, 26453 and 26458) was selected for which the impact parameter *p* was in the range 0.2 - 1.2 m. The global plasma parameters are shown in figure 2; (a) plasma current is 0.5 MA, (b) the NBI power is 2 MW. The neutron yield rate from the fission chamber (FC) is 0.50×10^{14} s^{-1}. These discharges have been used to study the sawtooth oscillations effect

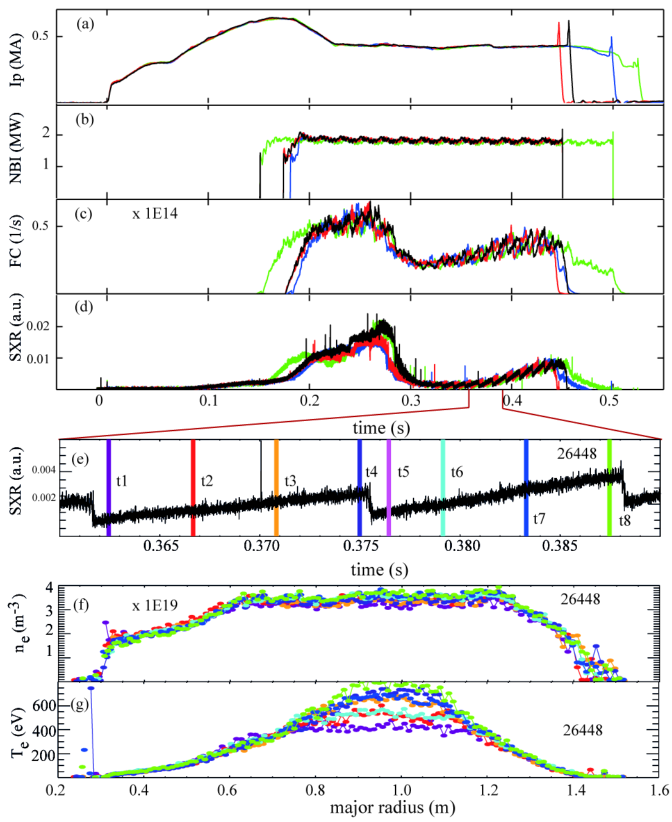

Figure 2. Time traces for MAST pulses 26448 (green), 26451 (blue), 26453 (red) and 26458 (black): (a) plasma current I_p, (b) NBI, (c) neutron yield as measured by the FC and (d) soft x-ray. Panel (e) shows the soft x-ray of plasma 26448. Panel (f) and (g) show electron density and electron temperature in specific time of interest.

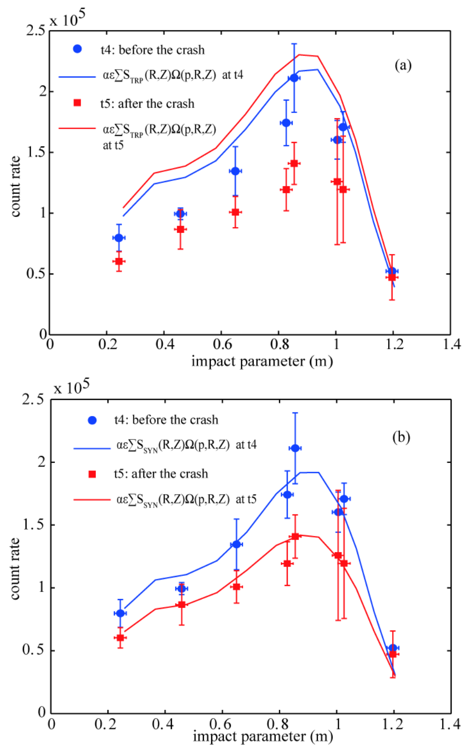

Figure 3. Comparison between the experimentally measured before SXR crash at t_4 = 0.374 s (blue circles) and after SXR crash at t_5 = 0.378 s (red squares) in figure 2(e). Panel(a) lines show the count rate obtained by TRANSP neutron emissivity $S_{TRP}(R,Z)$. Panel(b) lines show the calculation which obtained by $S_{SYN}(R,Z)$ which improve to matching the experimental with the calculated detector efficiency in figure 1(b) and the attenuation in stainless steel .

on the neutron emissivity profile [5]. Panel (e) show the time selection of the studies the SXR crash which have significant effect on the electron temperature (panel (f) electron density, (g) electron temperature). The measured neutron count rates before (blue circles) and after (red squares) the crash as a function of the impact parameter are shown in figure 3. The count rate have been simulated as:

$$\Psi_p = \eta \varepsilon \sum S(R,Z)\Omega(p;R,Z)$$

where η = 0.91 and $\Omega(p;R,Z)$ is the solid angle for given p. For this set of discharges, TRANSP simulations of the flux-averaged neutron emissivity have been carried out however without taking into account a proper model of the sawteeth as show in example of count rate in figure 3(a) at time t_4 (before the SXR crash; blue line) and t_5 (after the SXR crash; red line). To improve the match between experimental and modelled data, the TRANSP neutron emissivity has been modified thus obtaining a synthetic neutron emissivity $S_{SYN}(R,Z)$ for a better match with the experimental NC count rate. The $S_{SYN}(R,Z)$ was based on flux surfaces calculated by TRANSP and on a simple Gaussian function:

$$S_{SYN}(R,Z) = A\exp[-(\frac{r}{\sigma})^{\gamma}]$$

where A, σ and γ are the parameters used to match the experimental count rate, r is the normalized minor radius. An example of count rate at time t_4 and t_5 is shown in figure 3(b) where A is 2.58 × 10^7 and 1.80 × 10^7 $m^{-3}s^{-1}$, σ is 0.27 and 0.30 and γ is 2.20 and 2.00 for t_4 and t_5 which $\chi 2$ = 1.86 and 1.20 respectively.

The predicted total neutron yield Y_{model} was calculated as:

$$Y_{model} = 2\pi R \sum_{R,Z} S_{SYN}(R,Z)\Delta R \Delta Z$$

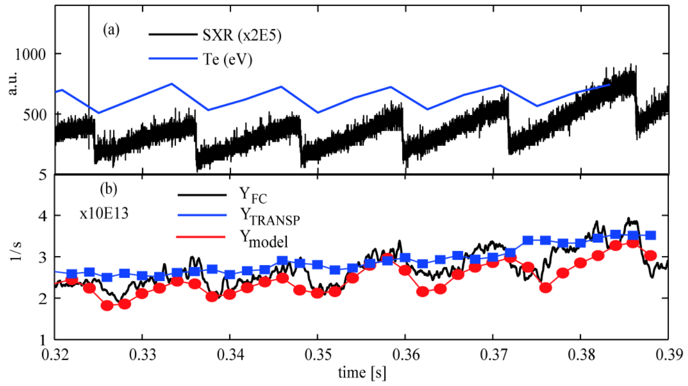

Figure 4. Panel(a) shows time traces of SXR (black) and electron temperature (blue) of plasma discharges 26448 between time 0.32 – 0.39 s. Panel(b) shows the preliminary comparison between total neutron yield of MAST FC (black), TRANSP estimated (blue) and the Y_{model} of NC which obtained by the $S_{SYN}(R,Z)$ which improve to matching the to the experimental included the detector efficiency and the attenuation in stainless steel.

where R is the major radius. The $S_{SYN}(R,Z)$ was evaluated to match the NC neutron experimental profile together with the detector efficiency and α as used in figure in figure 3(b). The predicted total neutron yield is shown with red circles in figure 4(b) together the neutron yield Y_{FC} as measured by the FC (black line) and the neutron yield estimated by TRANSP (blue squares). The average proportionality constant between the predicted total neutron yield Y_{model} and the FC measured one is $Y_{model} / Y_{FC} \approx 0.94 \pm 0.05$ for the whole time interval 0.32 - 0.39 s. Figure 4(a). is the time traces of SXR sawtooth oscillations (black) and the electron temperature (blue).

Discussion and conclusions

The efficiency as determined by NRESP has been validated against theoretical predictions by comparing the experimental count rate with modified TRANSP predictions taking into account the attenuation of the 3 mm thick stainless steel fan. Good agreement has been found.

References

[1] M. Cecconello *et al*., Rev. Sci. Instrum. **81**, 10D315 (2010)
[2] G. Dietze and H. Klein, PTB Report PTB-ND-22, ISSN 0572-7170 (1982).
[3] S. Sangaroon *et al*., 38th EPS Conference on Plasma Phys. Strasbourg, **35G**, P5.045 (2011).
[4] J.L. Fowler *et al.*, Nucl. Instr. and Meth. **175**, 449 (1980)
[5] M. Cecconello *et al*., Nucl. Fusion. **52** (2012) *accepted for publication*.

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