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S. Conroy, G.Ericsson, C. Hellesen, J. Källne, E. Ronchi, H. Sjöstrand, G. Gorini,
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The TOFOR Neutron Spectrometer for High-Performance Measurements of D Plasma Fuel Ion Properties

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M. Gatu Johnson[1], L. Giacomelli[1], A. Hjalmarsson[1], M. Weiszflog[1], E. Andersson Sundén[1], S. Conroy[1], G. Ericsson[1], C. Hellesen[1], J. Källne[2], E. Ronchi[1], H. Sjöstrand[1], G. Gorini[3], M. Tardocchi[3] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*Uppsala University, Department of Neutron Research, 75120 Uppsala, Sweden (EURATOM-VR)*
[2]*Uppsala University, Department of Engineering Sciences, 75120 Uppsala, Sweden (EURATOM-VR)*
[3]*Physics Department, Milano-Bicocca University, and Istituto di Fisica del Plasma del CNR, Milan, Italy (EURATOM-ENEA-CNR)*
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ABSTRACT.
The impact of scattered neutrons on the total flux reaching the TOFOR spectrometer at JET has been studied to allow for improvement of the data analysis. The scattered neutrons are demonstrated to contribute significantly to the flux. This will have implications for any neutron diagnostic on ITER.

1. INTRODUCTION

The TOFOR spectrometer [1,2,3] was designed, constructed and then installed in the JET roof laboratory for the purpose of measuring the 2.5MeV neutron emission from $d+d\rightarrow{}^3He+n$ reactions. The collected neutron spectra can be analyzed using the tools of Neutron Emission Spectroscopy (NES) to yield, e.g., information on ion temperature and the velocity states of the fuel ions.

The main design goal with TOFOR was to optimize the count rate achievable with the time-of-flight technique. TOFOR implements the proven constant time-of-flight sphere concept with the additional features of segmenting the in-beam detector in five layers to allow for higher count rate and using specially developed PC cards to make dead-time free recording of all detected events possible.

Detailed neutron transport modeling of the setup was performed to find the optimal balance between practicality, energy resolution and efficiency requirements. The energy resolution is 7.4% and the projected maximum count rate 0.5MHz [4].

The analysis of neutron spectra measured with TOFOR is performed with the help of a response function R that relates the measured flight-times t_{tof} to the incident neutron energies E_n. R can be divided in two parts; the neutron response $R_n(t_{tof}, E_n)$ is based on the neutron transport modeling of the instrument and the pulse response $R_p(t_{tof}, E_n)$ includes the effects of proton energy loss in the detectors and signal processing in the electronics system on the measured time signals. R_n has been produced for the incident neutron energy interval E_n = 1 to 7MeV.

The accuracy in the analysis of TOFOR data depends on how well the response function describes the instrument and how well the analysis models used describe the measurement scenario. Fig.1 shows the result of NES analysis of TOFOR data from the NB heated interval from 65 to 72s for JET Pulse No: 70034. The fit represents the result of fitting a thermal and a high-energy NB component [5] to the spectrum.

The neutron transport model used as the basis for the analysis in this case only takes into account the direct neutron flux from the plasma. As can be seen, the fit severely underestimates the contribution to the spectrum from neutrons on the high time side of the peak. This paper investigates the effect of the backscattered neutrons on the measured spectrum.

2. THE SCATTERED COMPONENT

TOFOR views the JET plasma vertically through a collimator in the roof laboratory floor. Direct neutrons emitted from the JET plasma in the upward direction as well as neutrons scattered on the torus walls and into the instrument sight line will reach the instrument. The characteristics of the scattered neutron flux have been investigated through MCNP simulations. The MCNP model used incorporates the geometry of the JET vessel, with the lower vertical port filled with inconel and a 1 cm layer of carbon added on the structure to account for the divertor tiles. The neutron source is a $1m^2$ square on the plasma axis with toroidal symmetry assumed.

To confirm the validity, the results from simulations for a uniform D plasma with a 2.5keV temperature have been applied to Ohmic TOFOR data.

Figure 2 shows the MCNP result and, for comparison, a simple Gaussian, both folded with the response function and fitted to Ohmic TOFOR data. The spectrum is summed over JET Puslse No's: 69550 to 70750 with any plasma periods having auxiliary heating applied excluded. The MCNP result with the scattered flux taken into account matches the data better. TOFOR t_{tof} corresponding to 180^o elastic scattering of 2.5MeV neutrons on Fe and C are centered at 66.8 and 76.2ns, while that for direct neutrons is centered at 65ns. The C peak is visible in the spectrum; the Fe peak adds a broadening on the low energy side of the main peak. The broadening of the fitted simple Gaussian corresponds to a 4.5keV plasma, i.e., warmer than expected from the Ohmic JET discharges. This is due to the Fe scattered component not being taken into account.

The fraction of indirect to total neutron flux integrated from 1.0 to 2.6MeV in the simulation for a 2.5keV plasma is 12%. This corresponds to an intensity ratio between the 2.5MeV peak and the C peak in the spectrum of about 25.

The scattered component has been simulated for incident neutron energies in the interval 1.975-3.025MeV to allow for inclusion of the component in NES analysis of NB heated JET discharges.

Adding the scattered component in the fit for JET Pulse No: 70034 (compare Fig.1) yields the result shown in Fig.3. The temperature of the thermal component comes out lower than for the fit in fig.1 as is to be expected. The broader spectrum of incident neutron energies in the NB heated case causes the scattered component to be smeared out compared to the Ohmic case (Fig.2). The C peak is no longer clearly visible.

3. IMPLICATIONS FOR ITER

The demonstrated impact of the scattered flux on the neutron spectrum means that this component needs to be taken into account for ITER as discussed in [6]. It will have implications for the design of any neutron diagnostic and raises the issue of whether it will be possible to distinguish the 2.5MeV signal in a DT plasma.

Using the JET MCNP model described above to simulate both 14 and 2.5MeV fluxes from a 2.5keV plasma source yields the result shown in Fig.4. Here, the total 14MeV rate is assumed to be 10^{18} and the 2.5MeV rate 1/400 of that.

As can be seen, the 2.5MeV peak is heavily obscured by the 14MeV scattered flux. The collimation for TOFOR is essentially 20 m [4], which makes the results valid on an ITER relevant scale. To distinguish the 2.5MeV peak would require diagnostics with both high energy resolution and ability to deal with a high DT flux.

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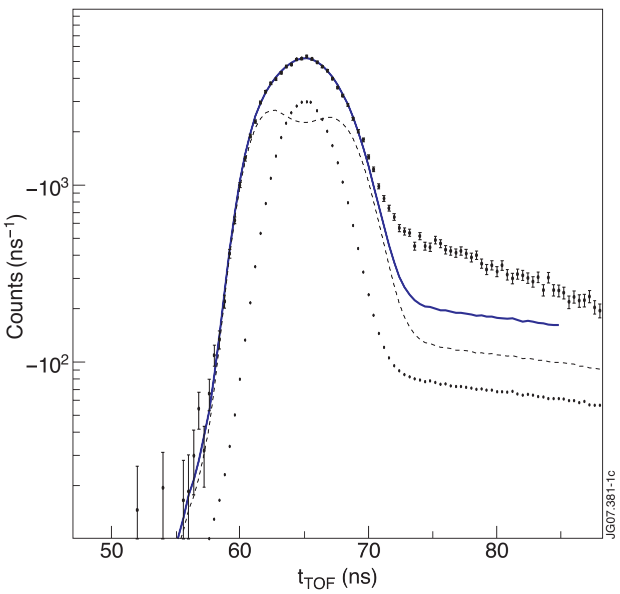

Figure 1: Fitted t_{tof} spectrum for NB heated JET Pulse No: 70034. The measurement points represent the TOFOR counts integrated from 65 to 72s, the solid curve the fitted sum of thermal (dotted) and HE-NB (dashed) components.

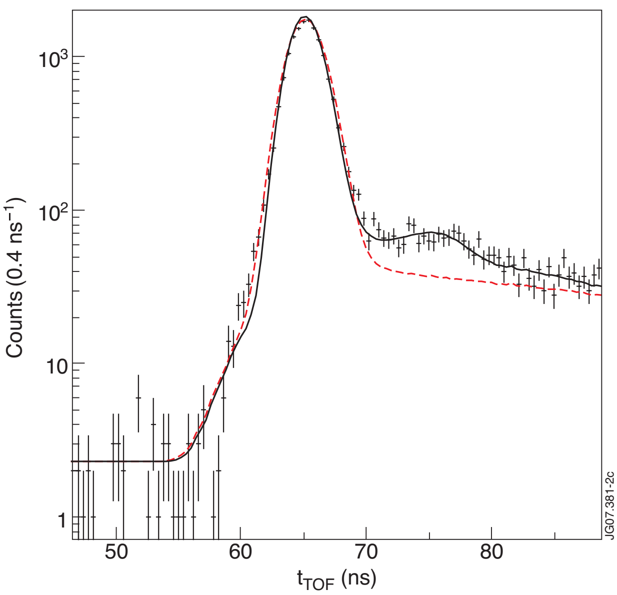

Figure 2: TOFOR t_{tof} spectrum for Ohmic parts of JET Pulse No’s: 69550 to 70750 (summed). The solid curve represents a fit using the MCNP data for a 2.5keV plasma. For comparison, a fit using a simple Gaussian component to describe the 2.5MeV neutron peak is shown (dashed curve)

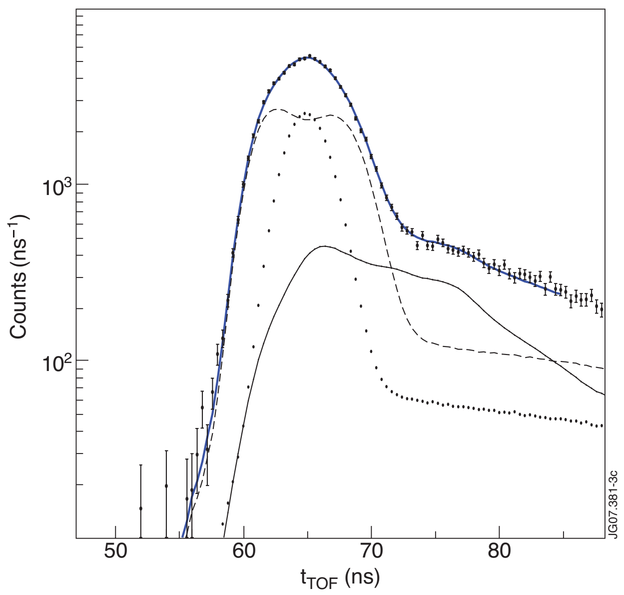

Figure 3: Fitted t_{tof} spectrum for NB heated JET Pulse No: 70034 integrated from 65 to 72s with the scattered neutron component included. The top solid curve represents the sum of a thermal (dotted), an HE-NB (dashed) and the scattered (solid broad) component.

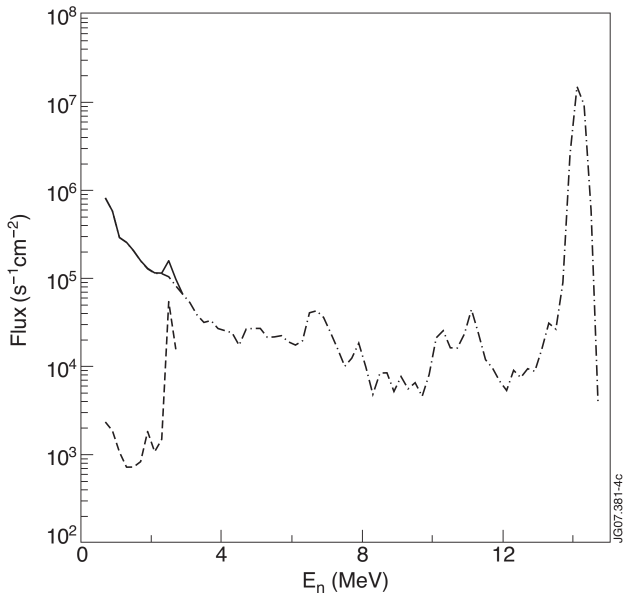

Figure 4: Simulated total 14MeV (dash-dot) and 2.5MeV (dash) fluxes for the TOFOR sight line from a JET DT plasma. Also shown is the sum (solid).