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Measurement of the fusion power with the MPR neutron spectrometer in the TTE and DTE1 experiments at JET

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1. INTRODUCTION

An essential diagnostic task in a fusion experiment is the measurement of the total neutron yield rate from which the fusion power and energy can be determined. These parameters are the main performance indicators of the success of fusion experiments, and traditionally they have been determined with neutron yield monitors such as fission chambers or silicon diodes calibrated with activation systems [1]. Such yield monitors have been installed and successfully used in most fusion experiments including JET. A substantial fraction of the neutron flux reaching the activation system is due to scattered neutrons, so the yield calibration relies on neutron transport calculations. These calculations contribute to the involved uncertainties, which will increase with the size of the fusion device and hence constitute a problem in burning plasma machines such as ITER. For these reasons, a new independent method for the absolute determination of the neutron rate has been developed, based on the measurement of the direct neutron flux with a high-resolution spectrometer. The measurement of the direct neutron flux makes it possible to quantify the uncertainty. The new method is based on an absolute neutron flux measurement and does not require any cross-calibration with other neutron systems.

In a fusion plasma of mixed deuterium (D) and tritium (T), both 2.5-MeV neutrons from the d+d $\rightarrow$ He^3+n reaction and 14-MeV neutrons from the d+t $\rightarrow$ α+n reaction are produced; the latter will dominate for tritium concentration exceeding a few percent. In mixed DT plasma of low tritium content, it is necessary to distinguish the 2.5-MeV and 14-MeV neutron emission in order to determine the fusion power. To this category belongs the trace tritium experiment (TTE) conducted at JET in October 2003, where the new method to determine the fusion power was tested for 14-MeV neutron measurements in a 2.5-MeV neutron background. We also report on the results of the new method obtained in the main DT experiment (DTE1) of 1997, which allowed a comparison with the total neutron yield as determined with the calibrated fission chamber system.

2. METHOD

The new method makes use of the Magnetic Proton Recoil (MPR) neutron spectrometer [2] and the JET neutron cameras [3]. The MPR is used to perform an absolute measurement of the collimated neutron flux (F_n) received from the JET plasma (se Figure 1). This flux is determined from the measured MPR count rate (C_n) by taking into account the flux detection efficiency (ε), i.e., $F_n=C_n/\varepsilon$. The inputs to ε include the n+p elastic scattering cross-section, the spectrometer ion optics and the recoil proton detection efficiency. All these are well known quantities with quantifiable uncertainties. It is also essential to have good control of the scattered admixture in the measured flux, which is a small (a few %) and accountable part of the MPR count rate. From the plasma source to the detection in the MPR, the plasma neutrons have to pass intervening materials, which cause flux attenuation (a) and scattering (s). These effects were determined with neutron transport calculations using the standard MCNP code. Finally, the neutron flux in the MPR line of sight has to be related to the total neutron yield. For this, a profile factor divided in two parts is used; p_{REF} for a plasma of normal profile and Δp to account for deviations from the reference. Thus, the neutron yield is determined by $Y_n = F_n \cdot p_{REF} \cdot (1+\Delta p) \cdot s \cdot a$. Here, all factors are determined from empirically measured or known values with quantifiable errors.

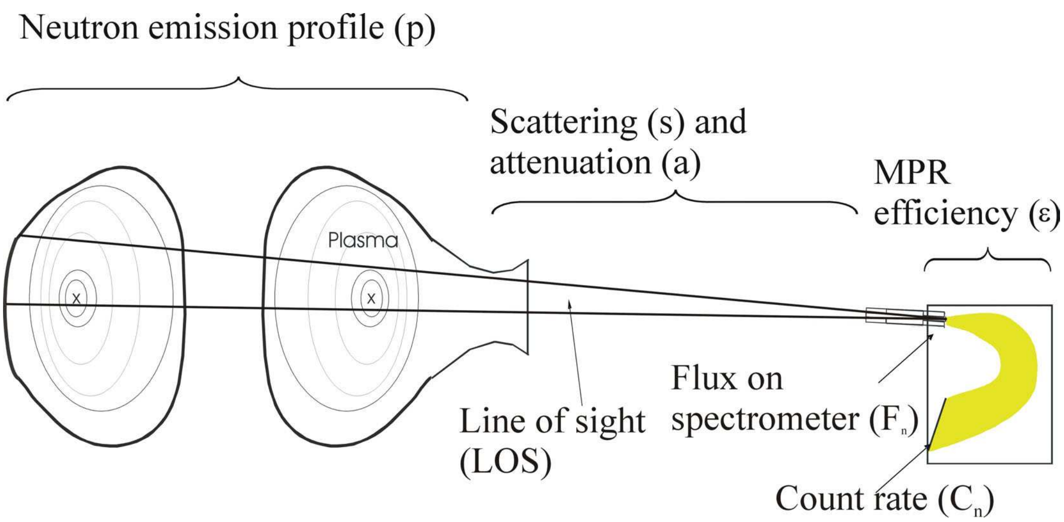

Figure 1 The components important for the determination of the JET neutron Yield.

3. RESULTS

The method outlined above was used in the JET TTE experiment to provide information on neutron yield for 14-MeV neutrons after each experiment for $Y_n \approx 10^{13}$ neutrons and up to a recorded maximum of about $Y_n \approx 10^{16}$ n. These represent the integrated yields for discharges as the possibilities for time resolved measurements were limited by counting statistics. The results for the TTE campaign are presented in Figure 2, where they have been plotted against the results obtained with silicon diode detectors. The two systems show good agreement over the measured dynamic range of about 1000, while in absolute terms the silicon diodes give 9% lower results than the MPR; this is within the combined uncertainties of the two systems. The absolute value of the profile effect factor, Δp, averaged at 0.10 for the TTE discharges. This effect has been accounted for in the presented data.

The main data bank for MPR neutron spectrometry studies was obtained in the DTE1 experiments. Here the neutron yield rates were much higher than for TTE (with a record of $6 \cdot 10^{18}$ n/s) so that the yield rate $Y_n(t)$ could be determined as a function of time for individual discharges. Some of the results obtained are shown in Figure 3, plotted against the results obtained with the fission chambers. The chambers record all neutrons including those from d+d reactions, but since the d+t reactions dominate by a factor 100, the fission chambers measure practically the same quantity as the MPR. It should first be noted that the MPR data are shown for the two cases before and after taking into account the variation in the profile factor (i.e., Δp). This shows that profile variations accounts for most of the scatter in the data, which form an almost straight line in the range $Y_n = 3 \cdot 10^{15}$ n/s to $Y_n = 6 \cdot 10^{18}$ n/s. In absolute terms, the fission chambers give an yield value that is about 7 % lower than that of the MPR. The systematic error of the MPR results is determined to be 5.5 % while that of the fission chambers is estimated to be 10 %, which is the same as for the silicon diodes used during TTE [1]; the measurements thus agree, within uncertainties.

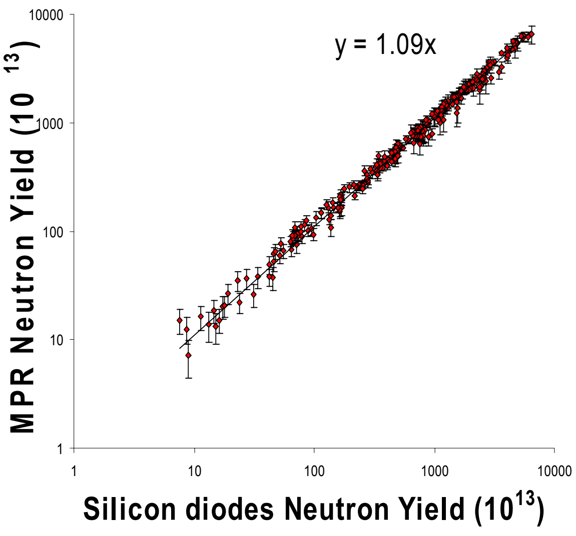

Figure 2 The pulse-integrated neutron yield data from the TTE campaign. Data from the silicon diodes are compared to MPR data.

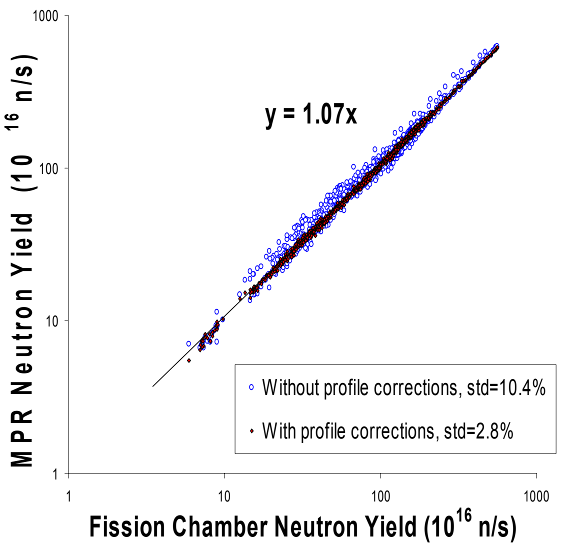

Figure 3 The 50 ms time resolved data from the DTE1 campaign. MPR data compared to fission chamber data. The importance of using profile corrections is illustrated.

4. CONCLUSIONS

A new method for the absolute determination of the JET yield rate of 14-MeV neutrons based on absolute neutron flux measurement with the MPR spectrometer and the emission profile from neutron cameras, has been demonstrated for discharges produced in 1997 during DTE1 and in 2003 during TTE. An upgrade of the MPR (MPRu) is under development as part of the JET EP program which will allow absolute measurement of the yield rate of both 2.5-MeV or 14-MeV neutrons from d+d and d+t reactions, and hence the fusion power of D plasmas or DT plasmas of any mixing ratio.

5. REFERENCES

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