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A TOF neutron spectrometer for measurement of the fuel ratio on ITER

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Abstract

The possibility of measurement of the fuel ratio with a neutron spectrometer for ITER was studied. In a neutronics calculation on the model of ITER, the possibility of separating the DD component from that of the DT reaction was examined. The separation in a neutron spectrum is possible at an appropriate measurement position with a collimator 1–3 cm in diameter. Design parameters of a TOF spectrometer for this purpose were considered. The optimum-scattered angle for geometric energy resolution is 35 degrees. The optimum thickness of the first scintillator and the optimum distance between first and second detectors are 0.8 cm and 80-120 cm, respectively, to cover the dynamic range of 10^4.

1. Introduction

Measurement of the ratio between deuteron and triton densities in a core plasma is required for burning control in the ITER. A measurement method using the DT/DD reaction ratio has been proposed [1]. In principle, DD neutrons (2.45 MeV) can be separated from DT neutrons (14.06 MeV) in an energy spectrum, but the former is affected by the scattered/energy-degradation components of DT neutrons. We considered the possibility of separation with a neutronics calculation using MCNP (Monte Carlo N-Particle Code).

The measurement location is assumed to be behind the Radial Neutron Camera (RNC) viewing the centre of the plasma. In addition, we propose a design for a TOF spectrometer optimised for the DT/DD reaction ratio measurement with MCNP.

2. Neutron Spectrum in a collimator

The simulation geometry for the neutronics calculation to obtain a neutron spectrum in a collimator installed in an equatorial port of ITER is shown in Fig. 1. This model is not a full torus, but encompasses one toroidal sector of 20 degrees with the assumption that all neutrons are reflected on the boundary surface. This assumption was shown to be appropriate by comparison of the neutron spectrum behind the vacuum vessel with that of a full model calculation. All the poloidal cross-sections inside the torus, including the plasma area, blanket area, SUS area and vacuum vessel, approximate ellipses. The collimator is a pillar 10 cm in inner diameter and 20 cm in outer diameter. The neutron fluxes in the collimator were investigated from 9.4 to 10.6 m in increments of 30 cm. The size of the collimator aperture was chosen so that sufficient statistics could be obtained for the Monte Carlo calculation. In a more realistic geometry, the inner diameter of the collimator should be 1–3 cm; such calculations are currently in progress. The neutron energy spectrum at 1060 cm (Fig. 3) showed that separation is possible if the measurement position is far from the centre of the plasma in the collimator and the neutron spectra are measured with energy resolution of 0.1–0.15 MeV.

3. TOF design

The TOF design geometry shown in Fig. 4 was studied by MCNP calculation. The first detector is called d0 and the second detector is called d1. A neutron thrown into the collimator is scattered in the d0 detector and the recoil proton is counted. The scattered neutrons are counted by the d1 detector. It is possible to measure velocity, *i.e.*, the energy of the neutron by the time lag between d0 and d1 detectors. On the TOF sphere, flight time is the same if the neutron velocity is fixed[2].

The results obtained with MCNP of the TOF design model are shown in Figs. 5, 6, 7 and 8. Fig. 5 shows the relation between geometric energy resolution of to the radius of the TOF sphere, L. Best energy resolution was obtained at an angle of 35 degrees. To have FWHM less than 0.15 MeV, L should be larger than 80 cm. Fig. 6 shows the energy spectrum converted from the time spectrum with time resolution of 0.1 ns. FWHM increased as distance between d0 detector and d1 detector became shorter. Fig. 7 shows the relation between d0 thickness and neutron flux within FWHM. At thickness greater than 0.5 cm, the relation deviated from linearity, and became saturated around 0.8 cm, due to the effect of multiple scattering inside d0. Fig. 8 shows the relation between neutron fluxes within FWHM and FWHM when the d0–d1 distance was varied from 80 cm to 180 cm and the d0 thickness was changed. There were many fluxes when FWHM was large and few fluxes with small FWHM. Flux and FWHM showed the best relation when the distance between d0 and d1 was 1.0 to 1.8 m.

4. Discussion and Conclusions

If the total number of neutrons emitted from the torus was assumed to be 1.7×10^{20} n/s, and the neutron flux at the d0 detector was about 3×10^9 n/s/cm^2. As the maximum counting rate capability of a fast organic scintillation counter is 10^9 n/s, the present detector size is too large, and the counting rate should be reduced by factor of 100. This can be realized by reducing both the detector size and collimator size by a factor of 3 to 10. Then, the effective neutron counts at the d1 detector would be 10^5 -10^3 n/s. If the d1 detector number is 10, we could measure the DD neutrons with a time resolution of 0.1 ns, or we could have a dynamic range of 10^4 with a time resolution of 1 s.

These results are useful for burning control in ITER. We are currently planning experiments to confirm the performance of the spectrometer. Part of the work has been done at JAERI/FNS as a Fellow of Advanced Science. This work was supported by MEXT under the Scientific Research of Priority Areas, “Advanced Diagnostics for Burning Plasma Experiment”. A part of the work was done at JAERI/FNS as the Fellow of Advanced Science.

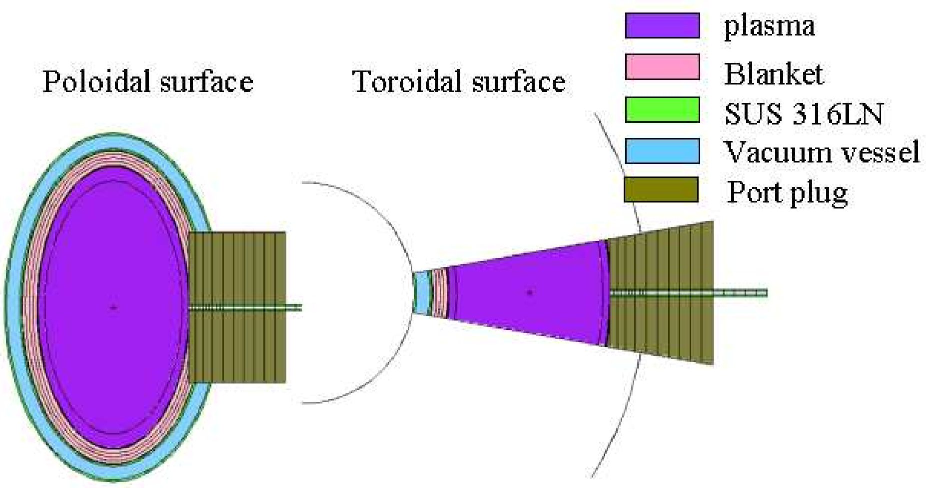
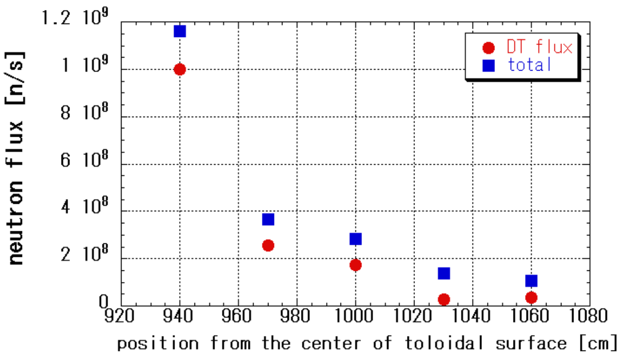


fig.1 ITER geometry



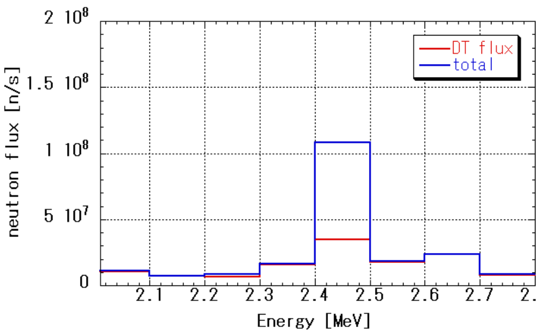


fig.2. neutron flux ratio in 2.4 – 2.5 MeV fig.3 neutron spectrum on 1060 cm

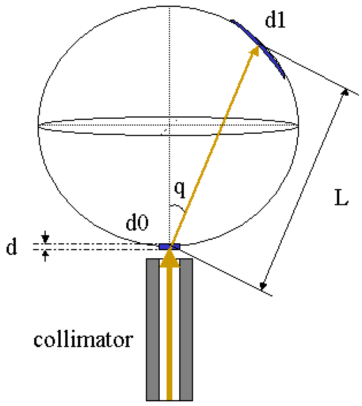


fig.4 TOF geometry

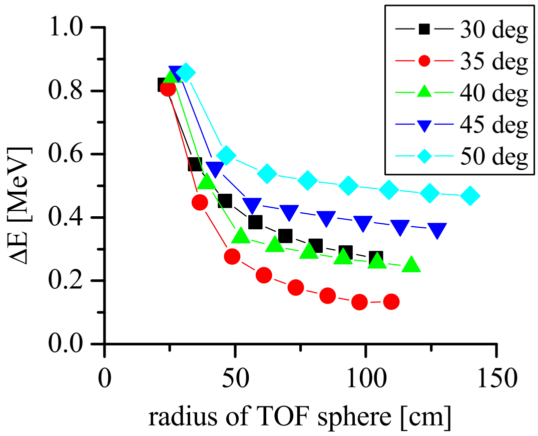


fig.5 geometric energy resolution

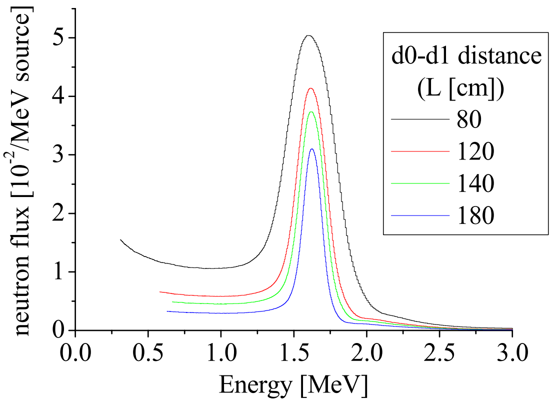


fig.6 energy spectrum (d=2.0 cm)

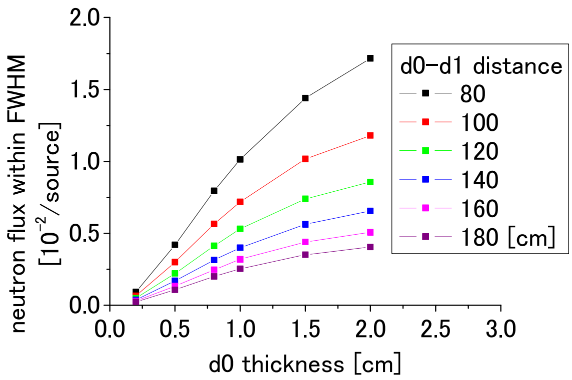


fig.7. neutron flux

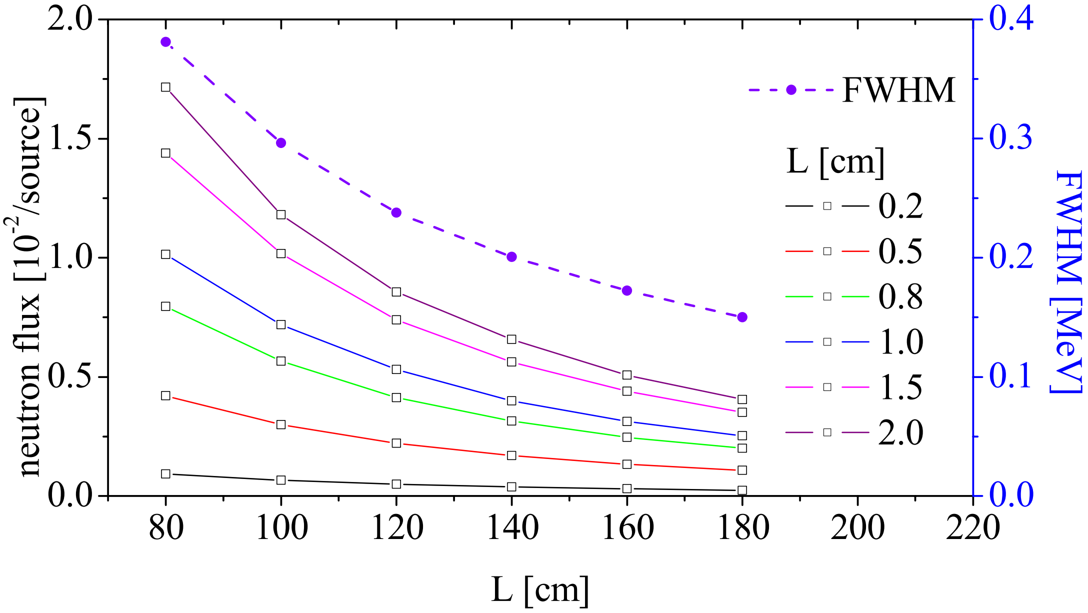


fig.8 relation neutron flux and FWHM

References

[1] J. Kallne et al., Rev. Sci. Instrum. 62 (1991), 2871

[2] M. Hoek et al, Fusion Engineering and Design 45 (1999) 437-453