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ABSTRACT.
An evaluation of three different candidate techniques for a 14MeV High Resolution Neutron Spectrometer for a high power fusion device is presented. The performance is estimated for a modelled neutron emission for ITER plasma scenario 4. As performance indicators we use the estimated time-resolution achieved in measurements of three plasma parameters, namely, the ion temperature, the intensity of neutron emission due to neutral beam–thermal plasma interactions and the intensity of the so-called alpha knock-on neutron tail. It is found that only the MPR technique can deliver results on all three parameters with reasonable time resolution.

1. INTRODUCTION

Neutron diagnostics are an important tool in assessing the performance of high power fusion devices [1]. In particular, neutron spectrometers can supply detailed information on the state of fuel ions and confined alphas. Neutron monitors and so-called cameras are part of ITER's credited (i.e., budgeted) diagnostic systems, while a final decision on a High Resolution Neutron Spectrometer (HRNS) is still to be taken. In this contribution we evaluate three different techniques for a 14MeV HRNS, namely, the Magnetic Proton Recoil (MPR), Time of Flight (ToF) and liquid scintillator (NE213). The evaluation is based on modelling of the neutron emission in a specific standard ITER scenario (S4). The techniques are evaluated based on their ability to measure three plasma parameters, pertaining to the ion temperature (T_i), the non-thermal (nt) fraction in Q (Q_{nt}/Q_{tot}) and the alpha number density (n_α).

2. MODELLED NEUTRON EMISSION

The information contained in the neutron emission is illustrated by model calculations for ITER scenario 4 (steady state, 9MA, slight negative shear, P_{fus} = 338MW, P_{NB} = 34MW, Q = 5) as shown in Fig.1(a). The calculation is for a HRNS in equatorial port cell 1, at about 18m from the centre of the machine, with a 300mm aperture in the First Wall (FW), tapering off to 10cm^2 at the spectrometer. The neutron emission is dominated by a Gaussian-shaped component from the thermal plasma (green), with a weak component due to neutral beam-thermal plasma reactions (BP, red) and an even weaker component due to alpha knock-on neutrons (AKN, blue). The width of the thermal peak reflects the ion temperature, the width of the BP distribution is determined by the NB injection energy (1MeV) and pitch angle, and the shape of the AKN is given by a model assuming classical slowing down of the fusion-born 3.5MeV alphas. In Fig.1(b) we show the situation for a hypothetical burning plasma, composed of only thermal and AKN components.

By measuring the intensities and shapes of the neutron emission components (Thermal, BP and AKN), neutron spectroscopy can provide (line-integrated) information on a number of plasma parameters. Here we will restrict our study to the width of the thermal peak, pertaining to the ion temperature (T_i), the intensity of the heating component (I_{NB}), which determines the contribution to the fusion power from non-thermal (nt) sources (Q_{nt}/Q_{tot}), and the intensity of the AKN component (I_{AKN}), which gives information on alpha number density and plasma self-heating.

3. REQUIREMENTS ON HRNS

In order to access the full range of plasma parameters available to neutron spectroscopy (Fig.1), the prime requirement on a HRNS is a very high sensitivity, meaning that weak components on the 10^{-4} level of the main emission peak must be discernible above any interfering background. Secondly, due to the weak intensity of the heating and alpha induced emissions, a very high count-rate of useful events is required to provide data of simultaneous good time resolution and accuracy; this demands an instrument of high count-rate capability. The energy bite of the spectrometer should cover the range 11–18MeV. The instrumental resolution should be <5% (FWHM) although a poor resolution can to a certain degree be compensated by a well-known response function and high counting statistics. Operational stability (providing stable energy calibration) is a major concern, since even small fluctuations in the energy scale can induce large errors in the information extracted on the weak components.

4. INSTRUMENT CONSIDERATIONS

A number of neutron spectrometry techniques for fusion applications have been tested under quite different conditions over the years. During JET's full-scale DT campaign (DTE1) in 1997, instruments of the MPR, ToF (TANSY), Thin-foil Proton Recoil (TPR - TANDEM) and (natural) diamond type were tested [2]. The MPR was put to the toughest test in terms of signal count rates (up to 610kHz useful counts) and environmental conditions. More recently, the ToF technique has been tested under more challenging conditions with the TOFOR installation at JET, where signal rates of up to 40 kHz have been recorded, and rates up to 400kHz are anticipated in conditions with full JET heating power. We thus consider the MPR and ToF techniques as proven under conditions approaching those on ITER, and we select them for the present study. In addition, the considerable interest in so-called compact spectrometers motivates including also an NE213 system. We also consider the diamond (in particular those produced with the Chemical Vapour Deposition technique) and TPR techniques as very interesting, although at present not fully proven, possibilities. The MPR technique is modelled after the one at JET, with a flux efficiency 1.5×10^{-4} cm^2 and 4% (FWHM) energy resolution; this can represent all techniques with an ideal Gaussian response function. The hypothetical 14MeV ToF instrument is modelled after JET's TOFOR spectrometer, with modifications to achieve 5% resolution. The response function, modelled with MCNP, exhibits low and high flight time tails due to multiple scattering events in the hydrogen and carbon nuclei of the instrument's scintillators. Another limitation is a rate-dependent background of random coincidences in the ToF spectrum. For the NE213 a response function given by the NRESP7 code is used [3], here with about 5% pulse height resolution. The high sensitivity of NE213 to stability variations (photomultiplier tube gain) is a major concern, but not included here.

5. PERFORMANCE POTENTIAL OF DIFFERENT TECHNIQUES

For the standard S4 ITER scenario, the count rates for the three instruments were 1MHz for MPR, 400kHz for ToF, and 1MHz for NE213. The MPR rate is determined by the 300mm FW aperture, while for the ToF and NE213 techniques the count rate capability is the limiting factor. Perfect instrument stability was assumed. The extraction of plasma parameters was done with synthetic data analyzed using the so-called forward method, where three components (corresponding to the thermal, BP and AKN distributions), each with a free parameter corresponding to T_i, I_{NB} and I_{AKN}, are fitted to the data [4]. The total number of counts required to achieve the ITER specified accuracy level was determined and the corresponding time resolution given by the instrument's count rate. Results are presented in Table 1.

For the burning plasma scenario (Fig.1(b)), the time resolution in the I_{AKN} measurement for the MPR is 200ms, due to the removed interference of the NB component.

DISCUSSION AND CONCLUSIONS

The results presented in Table 1 are obtained with idealized assumptions, i.e., no background and perfect stability. In reality, each instrument will have a sensitivity that is limited by both response function and background. For example, experience from JET has shown that the sensitivity set by background in the upgraded MPR instrument is at the level 10^{-5} to 10^{-6} of the peak amplitude. In fact, the MPR at JET has already observed the AKN distribution in less favourable conditions than those presented here [5]. The main limiting factors for the ToF technique, random coincidences and multiple scattering, are inherent in the method and already part of this analysis. For the NE213, the combination of background interference, non-ideal response function and stability limitation would in practice make measurements of the NB and AKN components inaccessible. In view of this we believe that only the MPR technique can deliver information on all three ITER relevant plasma parameters considered here. A suitable neutron diagnostic system for a high power fusion device, such as ITER, would consist of a 14MeV MPR-type spectrometer for the highest yield conditions, complemented by a 2.5MeV ToF instrument for the initial D phase of operations. Provisions should be taken for installing a suitable high-efficiency 14MeV instrument for low-power conditions, e.g., of diamond or TPR type, to be decided on when experimental information for a more complete performance evaluation is available. We have found no interfacing issues that would prevent such a system on ITER.

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REFERENCES

[1]. A.V. Krasilnikov et al., Nucl. Fus. **45** (2005) 1246

[2]. O.N. Jarvis, NIM A **476** (2002) 474, and references therein

[3]. G. Dietze, H. Klein, Report PTB-ND-22, Braunschweig, Germany, 1982

[4]. E. Andersson Sundén et al., “Evaluation of spectral unfolding techniques ...”, these proceedings

[5]. J.Källne et al., Phys Rev Lett **85** (2000) 1246

	Time resolution to achieve ITER accuracy in measurement of parameter; T_i = 20keV, I_{NB} = 6.9%, I_{AKN} = 0.5%		
Technique (dE/E, FWHM)	**T_i (10%)**	**I_{NB} (10%)**	**I_{AKN} (20%)**
MPR (Gaussian, 4%)	<*1ms*	20ms	~2.5s
ToF (MCNP, 5%)	10ms	~1s	(–)
NE213 (NRESP7, 5%)	80ms	(5s)	(–)

() Practically inaccessible due to response function, background and stability issues

Table 1: Performance in terms of time resolution achieved for set ITER accuracy level of three neutron spectrometer techniques in the ITER reference position, for scenario S4 (Fig.1(a))

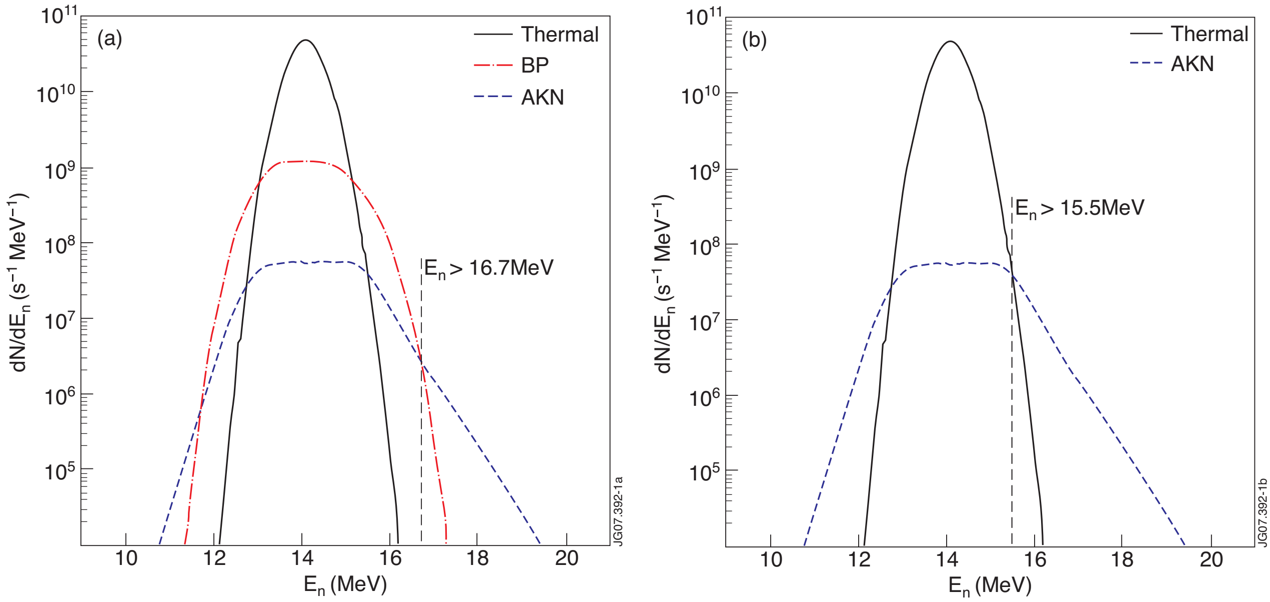

Figure 1: Examples of modelled neutron emission energy spectra at the ITER reference (radial) HRNS position for ITER reference scenario 4. (a) Neutron energy spectrum divided into Thermal (green), BP (red) and AKN (blue) components, (b) same as in (a) but without NB component (high-Q).