# PROPOSED MAGNETIC PROTON RECOIL NEUTRON SPECTROMETER UPGRADE (MPRU)

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The Magnetic Proton Recoil (MPR) neutron spectrometer was installed at the Joint European Torus (JET) in 1996. The present prototype instrument is designed for 14-MeV neutrons. Its capability as a neutron emission spectroscopy (NES) diagnostic was demonstrated during the Deuterium-Tritium Experimental (DTE1) campaign in 1997 and it has since been continuously used during subsequent D-plasma operation. In this paper we describe an upgrade of the spectrometer's focal plane, recoil-proton detector and radiation shield. The MPRu is intended to make it possible fully to exploit the MPR capabilities in the forward JET experimental programme and to demonstrate the potential role of NES diagnostics in the next step fusion experiments such as planned with ITER.

The MPR instrument, its data acquisition, monitoring and control systems, as well as the calibration and data reduction procedures, have been described elsewhere[1]. The use of fast plastic scintillators as detectors, in the form of a 37-element hodoscope, and simple signal-handling electronics, has ensured that the high count-rate capability of the instrument is well matched to the high neutron flux offered by the position close to the plasma. This made it possible to reach count rates up to 611 kHz during the world record pulse with $P_{fus}$=16.1 MW (with a neutron rate of $Y_n = 6 \cdot 10^{18}$ n/s) in 1997. High count rate can be used for time resolved measurements and is a prerequisite to reach the high sensitivity needed to observe weak components in the neutron spectrum. Thus, high sensitivity is attained by a combination of high count rate, providing sufficient counting statistics, and efficient background suppression, i.e., a high signal to background (S:B) ratio. With the present MPR, it has been possible to perform detailed studies of auxiliary (ICRH or NB) heated plasmas[2] and to make the first observation of the so-called Alpha Knock-on Neutron (AKN) emission[3], the latter being the imprint of the energetic alpha particles in the neutron spectrum. Additional information contained in the neutron emission can be accessed if the instrumental sensitivity is further increased.

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To fully exploit the potential of the MPR technique, the measurement sensitivity should be increased, which is the purpose of the MPRu project. This will be done by reducing the interference from the ambient background as well as extending the measurement range down to neutron energies of about 1.5 MeV. This will make it possible to cover the full range of fusion neutron energies, including the 2.5- and 14-MeV peaks of dd- and dt-reactions, as well as the extended spectrum of back-scattered neutrons. The most challenging objective is to measure the 2.5-MeV neutron emission from DT-plasmas. To this end, a new recoil-proton detector will be developed with high background immunity over the full energy range. In addition, the radiation shield surrounding the instrument will be reinforced.

The present concrete radiation shield has a plasma-facing wall that is 1.5 m thick; other walls are at least 0.7 m. The shielding design is based on MCNP calculations, which includes a detailed model of the MPR and the JET structures. The calculations agree within a factor of 2 with experimental results[4], which gives confidence in the model used and provides a good basis for assessing the effect of adding shielding in selected places. We have thus identified two regions where quite limited amounts of extra shielding material would reduce the background at the detector by a factor of 10. The rest of the increased sensitivity relies on detector improvements.

For many investigations of the 14-MeV neutron emission, from both D and DT plasmas, the main limitation up to now has been the counting statistics. This was the case for the studies of the Triton Burn-up Neutron (TBN) emission from pure D-plasmas[5] as well as for ohmic DT plasmas. Similarly, counting statistics did not always permit time-resolved studies of auxiliary heated discharges. In the AKN studies the signal was so weak that the measurement limit was set by background. Future experiments with JET-EP (enhanced performance) could reach neutron rates higher than those of DTE1, which would permit an extension of the AKN studies if the detector background were to be reduced; the quality of other studies could be improved as well.

The sensitivity of the instrument is a function of high count-rate capability and efficient background rejection. To be specific: a detector channel in the central part of the neutron spectrum (close to 14 MeV) registers approximately $10^4$ signal events per $10^{18}$ produced plasma neutrons which represents a comfortably high ratio of S:B $\approx 10^3$:1 even with the use of a fairly relaxed pulse-height discrimination setting. The background intensity is rather constant over the hodoscope so the S:B ratio follows the signal intensity which decreases rapidly for the off-center channels, for instance, towards higher energy. However, the background interference can in this case be reduced by applying tighter pulse-height discrimination, which, together with a background correction step in the off-line data analysis, leaves a remnant of about 0.1 events for $Y_n=10^{18}$, or, S:B $\approx 10^5$:1.

The MPR spectrometer can be set to measure neutrons in the energy range $E_n$ = 0 - 19 MeV by changing the magnetic field. The flux detection efficiency, $\varepsilon$, depends on the desired energy resolution and is $\varepsilon=5\cdot10^{-5}$ cm$^2$ for14-MeV neutrons at a resolution of 2.5% (FWHM), corresponding to the Doppler broadening at $T_i$=4 keV. For 2.5-MeV neutrons, $\varepsilon$ is $2\cdot10^{-5}$ cm$^2$ at 5 % resolution. For the same resolution, the 2.5-MeV count rate is lower by a factor of about 8 due to efficiency and another factor 100 due to the reaction rate differences between DT and D plasmas. Still, an attempt was made in 1999 to observe the 2.5-MeV neutrons from D-plasmas with the prototype MPR in order to explore the S:B conditions[6]. A 2.5-MeV spectrum could indeed be measured from which a Doppler

broadening was determined corresponding to an ion temperature of $T_i$=11 keV, in line with expectation. The relative background was determined to be S:B≈1:10 which indicates that the background must be reduced a factor $>10^3$ to obtain data of desired quality.

Analysis of the recorded pulse height spectra showed that the background was mainly due to electrons coming from γ-rays undergoing Compton scattering in the structures surrounding the detector. Most electrons that hit a detector pass straight through and produce a peaked pulse height distribution, which happens to be similar to that of stopped 2.5-MeV protons. The electron distribution is determined by the scintillator thickness, which was chosen to match the range of 14-MeV protons. However, to stop 2.5-MeV protons takes only a twentieth of the present thickness of 2.8 mm so a thickness reduction would practically eliminate the electron background. Combined with shielding reinforcements and improved signal selectivity, as discussed below, the factor of $10^3$ reduction in background should be achieved. Moreover, it is estimated that with a thinner detector, background due to 2.5-MeV (dd) and 14-MeV (TBN) neutrons, as well as γ-rays from neutron capture, should contribute at the $<10^{-3}$ level in the relevant energy region. Thus, the anticipated reduction of the Compton electron component should in itself result in measurements with the desired data quality.

To measure the 2.5-MeV neutron emission from DT plasmas is a greater challenge than that from D-plasmas because of the much higher relative background. First, the signal of 2.5-MeV neutrons is about 100 times weaker than the 14-MeV signal. Second, experience from DTE1 shows that the background is about a factor $10^4$ stronger in the 2.5-MeV region. Thus, to obtain data of the same quality as in the present 14-MeV measurements, an S:B improvement of more than six orders of magnitude might be necessary. With MPRu, the improved measurement situation should allow for exploratory measurements with S:B ratios of the order 1:10, similar to the pilot study performed with the original detector in pure D plasmas. Additionally, important studies of the scattered neutron component could be made in a wide energy range, $1.5 < E_n < 19$ MeV.

Reducing the background to obtain S:B ratios of 100 or better probably requires the design of a dedicated 2.5-MeV spectrometer. Such an instrument could be much more compact than the present MPR, which would allow for both more efficient passive background shielding and the use of smaller detector dimensions, thus further reducing the active volume susceptible to background. Improvements in detector design could also contribute. The studies made possible with the MPRu should contribute significantly to the knowledge base needed to design such a spectrometer, and pave the way for assessing the feasibility of using a dual-arm MPR spectrometer as a fuel ion density diagnostic.

We will investigate the possibility to replace the present monolayer scintillators of the hodoscope with laminated ones in a so-called phoswich arrangement[7]. The use of phoswich detectors would permit the successful 14-MeV measurements to continue, and at the same time open the field for measurements of the 2.5-MeV neutron emission.

Each phoswich element consists of a thin front scintillator of about 200 μm thickness to stop protons of up to 3 MeV. To this is attached a 2.6-mm thick back scintillator, stopping 14-MeV protons. The two layers respond differently to ionizing radiation in terms of pulse shape, with a fast response from the thin layer and a slow response from the thick. This property makes it possible to distinguish the contribution from each layer even when they are connected to the same photomultiplier tube, as would be the case here (Figure 1).

Recoil protons from 2.5-MeV neutrons are distinguished by requiring a signal (of known light yield) from the front layer, while the second layer in this case acts as a veto. This should reject most background induced by heavy charged particles of energies above say 3 MeV and practically eliminate electrons as discussed earlier. For 14-MeV measurements, a pulse from both layers is required. Here it is important to make efficient use of the quite limited light yield from the front layer and careful design of the scintillator readout arrangement will be necessary.

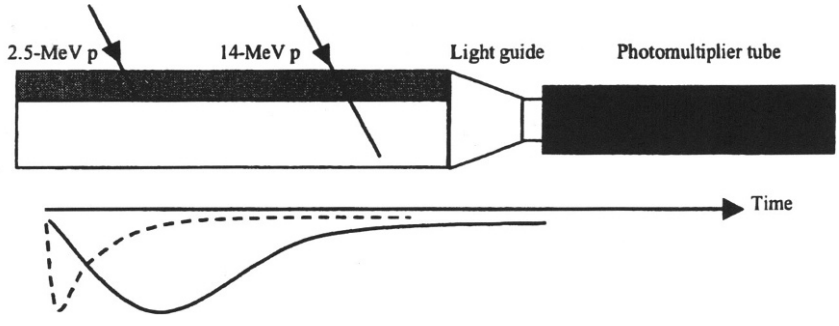


**Figure 1.** Schematic side view of a phoswich scintillator connected via a light guide to a single photomultiplier tube (top, not to scale); signal shapes from the front (dashed) and back (solid) scintillator layers (bottom).

To fully exploit the potential of neutron emission spectroscopy (NES) in the forward JET programme (and in extension, on ITER), we propose an upgrade of the Magnetic Proton Recoil neutron spectrometer (MPRu) with respect to its detector and radiation shield. The upgrade aims at increasing the sensitivity of the instrument by *reducing the background* in the measurements of 14-MeV neutrons from both DT and pure D plasmas, as well as *extending* the range of high-quality measurements to include 2.5-MeV neutrons from pure D plasmas. MPRu measurements would also provide an experimental basis for determining the feasibility of using the MPR technique for studies of the 2.5-MeV neutron emission in DT plasmas, which, if successful, would establish the MPR as a fuel density diagnostic.

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