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Correlation of Neutron Anisotropy with Neutron Yield and Soft X-ray Production from a Plasma Focus

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Abstract

This paper presents a correlation of the neutron anisotropy with the total neutron yield and the soft X-ray production at different pressures of deuterium using a 3 kJ @ 15 kV Mather-type plasma focus device.

Our data show that at pressures below the neutron-optimized value of 4 mbar, both the anisotropy and the neutron yield have lower values, but the soft X-ray production is higher. Towards the optimum pressure, anisotropy increases with the neutron yield and both have their maximum values at the optimum pressure. The corresponding soft X-ray production decreases and has minimum value at the neutron-optimized pressure. Beyond the optimum pressure, both the anisotropy and the neutron yield decrease, and the soft X-ray production is enhanced. The correlation of the neutron anisotropy with the total neutron yield and the soft X-ray production shows a common trend regardless of the pressure; the higher the total neutron yield, the greater the neutron anisotropy and the lower the soft X-ray production.

Introduction

Neutron flux anisotropy is of paramount importance in the determination of the roles played by different neutron production mechanisms in plasma focus. The physical mechanisms of the *D-D* reaction are directly correlated to the ion distribution function responsible for the neutron production. From the anisotropy [1] of the neutron yield, it can be suggested that beam-target neutron generation is important, and a better understanding is required for the beam acceleration mechanism, the ion emitting zones in the system, the instant of ion beam emission and energy spectrum of the accelerated ions. The entire mechanism of the ion acceleration is yet to be clarified.

Different models have been suggested for the production of the neutrons in the plasma focus. Some models (e.g. boiler model) are based on the assumption that ions and electrons are thermalized in the plasma focus at energies of a few keV, and the anisotropy of the neutron yield results from plasma CM motion. On the other hand, the beam-target model considers a high current of charged particles accelerated in an electric field giving a different production mechanism. Accurate spectral distribution can distinguish between these models. However, the average value of the neutron anisotropy determined in our experiment is much higher than the expected value of 1.12 from the moving boiler model of Bottoms [2].

The X-ray emission characteristics depend strongly on the plasma focus device operating rØgimes and parameters (e.g. gas filling composition and pressure, stored energy, peak discharge current, driver impedance, electrode material, shape, profile and configuration, polarity of the inner electrode, etc.). Among them, the gas composition and filling pressure have the strongest influence. When deuterium is used, the working pressure for the highest X-ray yield does not coincide with the neutron-optimized output pressure [3, 4].

Experimental Set-up

Three detectors were used for the time-resolved neutron flux measurements. Each detector consists of a plastic scintillator and a photomultiplier tube. Each detector was enclosed in an aluminum casing.

The detector, referred to as PM1, was placed at a distance of 1.94 m in the axial direction (at 0^o with respect to the pinch). The other two (PM2 and PM3) were placed radially (at 90^o with respect to the pinch) at the distances of 1.94 m and 3.82 m, respectively.

To cut off most of the hard X-rays, lead sheets (3 mm thick) were placed in front of PM1 and PM2.

Figure 1 shows the schematic of the set-up for the time-resolved neutron and soft X-ray measurements.

Before placing the detectors at their respective positions, these detectors were normalized to give almost identical output when placed at the same distance from the focus. The anisotropy was measured by integrating the signals from PM1 and PM2, the two detectors placed at the same distance from the pinch region in the axial and the radial direction, respectively.

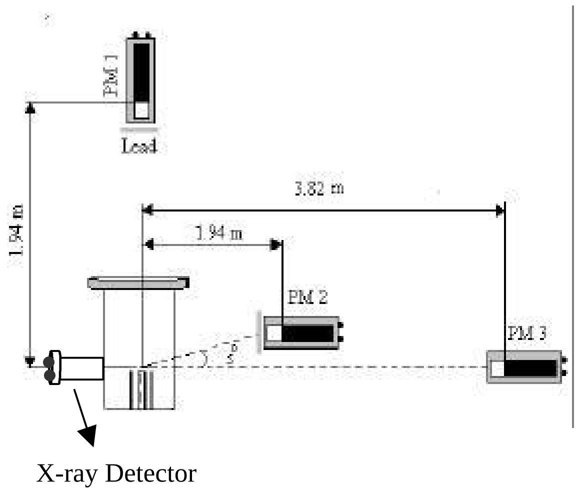

Figure 1: A schematic of the experimental set-up.

A two channel PIN diode soft X-ray spectrometer was employed for the time-resolved soft X-ray measurements.

The glass windows of the TO-18 casings of the BPX-65 diodes were removed, so that the diodes could be used for the X-ray detection. The spectrometer was fixed radially at a distance of 25 cm from the pinch zone. Two channels, one with 24 micron Mylar and the other with 24 micron Mylar plus the 10 micron copper, were chosen specifically because, when the plasma focus is operated in deuterium, the X-rays are emitted predominantly by free-free transition (Bremsstrahlung). The plasma spectrum is most likely to be contaminated by the copper impurities from the electrode. The soft X-ray production was determined by integrating the signal from the channel with the 24 μm Mylar filter.

Results and Discussion

The measured average neutron anisotropy was 1.48. This result is in fairly good agreement with the results reported by Tiseanu et. al. [5].

The neutron flux anisotropy was calculated for five different pressures 3.0, 3.5, 4.0, 4.5 and 5.0 mbar. The plots in Figure 2 show a similar trend for the variation in anisotropy and the total neutron yield as a function of pressure. For the neutron-optimised pressure (4 mbar), both the neutron yield and the anisotropy show their maximum values. At higher (higher than the optimum pressure) or lower (lower than the optimum pressure) pressures, there is a corresponding decrease both in the total neutron yield and the anisotropy. The reason may be related to the low neutron production in these regimes.

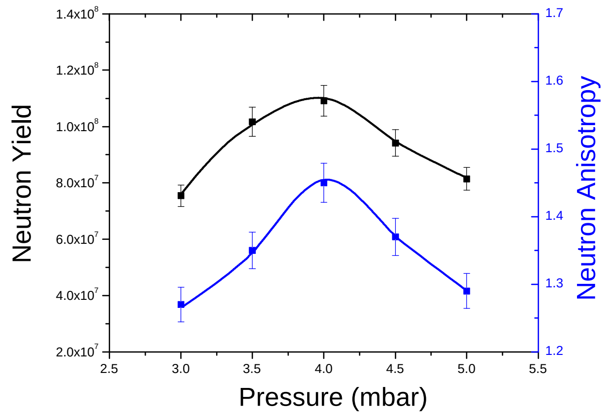

Figure 2: *Variation of the neutron anisotropy and the total neutron yield as a function of pressure.*

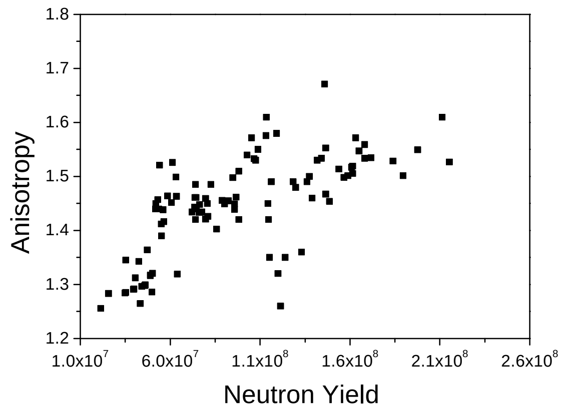

Figure 3: *Anisotropy as a function of the total neutron yield for neutron-optimised pressure.*

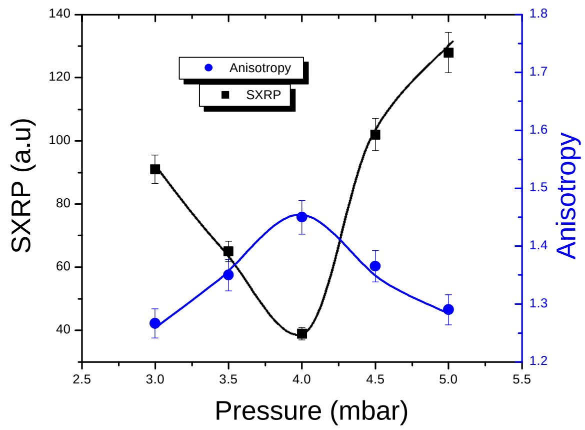

Figure 4: *Anisotropy and the soft X-ray production as a function of pressure.*

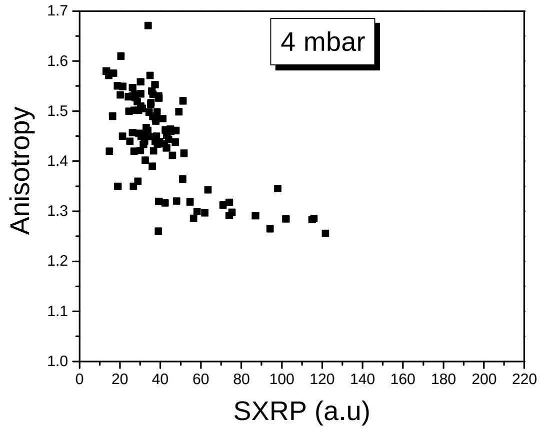

Figure 5: *Variation of the anisotropy with the soft X-ray production at neutron-optimised pressure.*

Figure 2 presents the variation of the anisotropy with the neutron yield. It is observed that the value of the anisotropy is higher for the discharges with higher neutron yield. Also, the neutron yield increases with the increase in the energy of the reacting deuterons [5]. Therefore, higher anisotropy values may also be related to the increase of the energy of the axially moving reacting deuterons in discharges with high neutron yield.

The experimentally observed anisotropy justifies the existence of strong axial deuteron beams (E_d ~ 80-250 keV), which are responsible for the production of the neutrons [6].

The low anisotropy values for the discharges with low neutron yield can be explained on the basis of the dependence of the neutron emission on the deuteron energy. The neutron emission in the forward direction is greater for high energy deuterons. The low value of the anisotropy in low neutron yield regime might be explained by the lack of accelerated particles within the ion Larmor sphere. But, this simple hypothesis cannot however be proven, because the plasma parameters in the ion micro sources are not known exactly.

The graph in Figure 4 shows the variation of the anisotropy and the soft X-ray production with pressure. It is seen that for lower (lower than 4.0 mbar) and higher (higher than 4.0 mbar) pressures, the soft X-ray production is higher as compared to the value at 4.0 mbar. The anisotropy has a lower value at lower and higher pressures as compared to the value at the neutron-optimised pressure. The low value of the anisotropy for higher and lower pressures is related to the low neutron yield in these regimes.

For the neutron-optimised pressure, it is clear from the graph in Figure 5 that the anisotropy decreases with the increasing value of the soft X-ray production. The decrease in the anisotropy is abrupt for discharges with lower X-ray production. For the discharges with higher X-ray production, the decrease in the anisotropy is not significant. This may be related to the low neutron yield in this regime.

Conclusions

An average value of 1.48 for the neutron anisotropy was determined in our experiments. For the neutron-optimised pressure, both the neutron yield and the anisotropy show their maximum values. The anisotropy is greater for discharges with higher neutron yield, regardless of the operating pressure. For the neutron-optimised pressure, the soft X-ray production decreases with the increasing value of the anisotropy. Thus, the increase in the neutron anisotropy is associated with an increase in the total neutron yield and a decrease in the soft X-ray production.

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