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Investigation of the Plasma Focus Device as a Pulsed Neutron Source

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Abstract

A Dense Plasma Focus (DPF) device is studied as a radiation sources such as X-ray, proton, electron and neutron, as the most powerful laboratory neutron source. DPF-device is investigated as a neutron source with pure deuterium gas in the electric Probe Applications Laboratory (ePAL) of Hanyang University. This device is composed of a capacitor bank (32μF), a spark gap switch, and two electrodes along with electrical circuits. Charging voltage is 16kV and the typical discharge peak current is about 183kA. The generated neutrons with different deuterium filling pressure are measured with the different electrode lengths by means of the bubble neutron dosimeter (BD-PND: Bubble Technology Industry). The maximum neutron yield is estimated about 6.4×10^{8} n/shot with pressure of ~3 Torr.

1. Introduction

DPF-device is based on the z-pinch phenomenon of plasma, which is caused by self-generating azimuthally high magnetic induction of high current in axial direction. A plasma sheet generated on the insulator which separates the two electrode travels along the coaxial cavity, and the z-pinch phenomenon is occurred on top of the electrode. The DPF-device has been developed for experiment of the thermonuclear fusion device and plasma instability in earlier time. However, it is researched on the radiation generator (soft x-ray, x-ray laser, ion beam, e-beam neutron, etc.) more than the thermonuclear fusion device [1] [2] [3] [4] [5] [6] [7].

In general, the neutron generation from the DPF-device is explained by two mechanisms: either neutrons are produced by fusion reaction (m=0 instability), or the beam-target mechanism due to the acceleration of non-thermal ions in the necks by strong induction electric fields, which is still a subject of discussion [1].

In this work, the neutron emission from the DPF-device is observed with different deuterium filling pressure by using the bubble neutron dosimeter (BD-PND) and the neutron yield is reported. The neutron yield is increased with the pressure from 1Torr to 3Torr, and saturated over 3Torr region. The maximum neutron yield from current experiment is observed as 6.4×10^{8} n/shot at the pressure of ~3Torr.

2. Experimental Set-up

The DPF-device used in this work is a small Mather-type plasma focus device schematically shown in Fig. 1, which is energized by 32μF, 40kV capacitor charged at 16kV (4kJ). The discharge peak current is 183kA, and the quarter time period is 4.15μs. The inner electrode of 20mm diameter has hollow-type at the end to reduce interaction between electron beam from the DPF-device and electrode surface [8]. It is surrounded by sixteen 10mm copper rods forming a cathode of inner diameter 70mm. During the study six different electrode lengths 145mm, 160mm, 170mm, 180mm, 205mm, and 220mm are used to see the neutron yield dependence on the deuterium filling pressure. The quartz insulator sleeve, with a breakdown length of 13mm, is located between inner electrode and outer electrode. The field distortion spark gap switch is connected the inner electrode to the positively charged terminal of the capacitor bank.

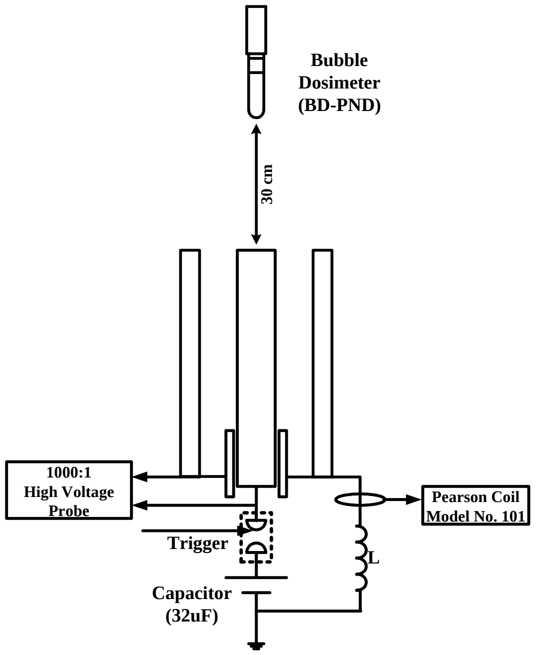
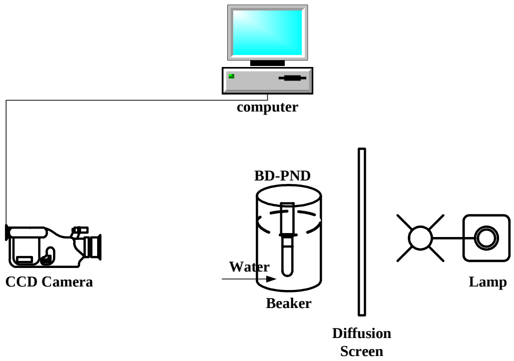


Figure 1. Schematic diagram of the DPF-device

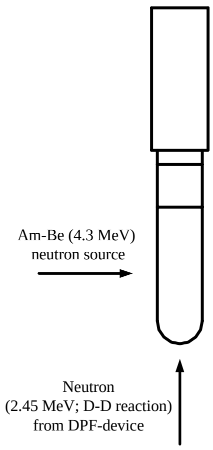
Discharge voltage is measured with high voltage probe between inner and outer electrode, and current is measured with Pearson coil of model No. 101. Due to allowed maximum current (50kA) of Pearson coil, the ground line of the DPF-device was divided as seven and the discharge current is measured from one with the coil. For neutron measurement, the bubble neutron dosimeter (BD-PND: BTI) is used. It is located 30cm from the inner electrode head. The bubble neutron dosimeters have advantages of fusion neutron measurements: i) high response to neutrons with various energy, ii) flat response curve depending on the neutron energy above threshold, iii) insensitive to gamma-radiation, and iv) no effect on the electrical or magnetical noise [9]. The bubble is counted by means of CCD camera and Image-Pro Plus program (Media Cybermetics, Inc.). Bubble neutron dosimeter and counting system are shown in Fig. 2.

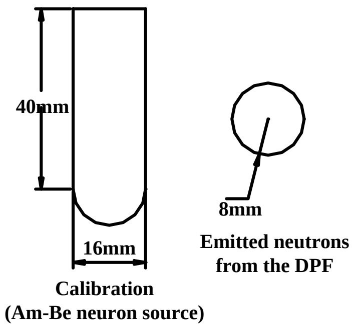


(a) (b)

Figure 2. (a) Neutron Bubble Dosimeter (BD-PND: Bubble Technology Industry),
(b) Schematic diagram of the bubble counting system

Before neutron measurement from the DPF-device, the BD-PND is calibrated with Am-Be neutron source (4.3MeV) in the KAERI. It is over sensitive about 20%, therefore this is compensated in real calculation of the neutron yield. The cross section of the bubble dosimeter is shown in Fig. 3. The neutron yield is calculated with considering the cross-section and response curve with the neutron energy for the BD-PND. This response curve is shown in Fig. 4. The calibration factor is 9.819×10^{4} n/cm^{2} per 10μSv in BD-PND.





(a) (b)

Figure 3. (a) Irradiated neutron direction for the BD-PND,
(b) Effective BD-PND cross-section

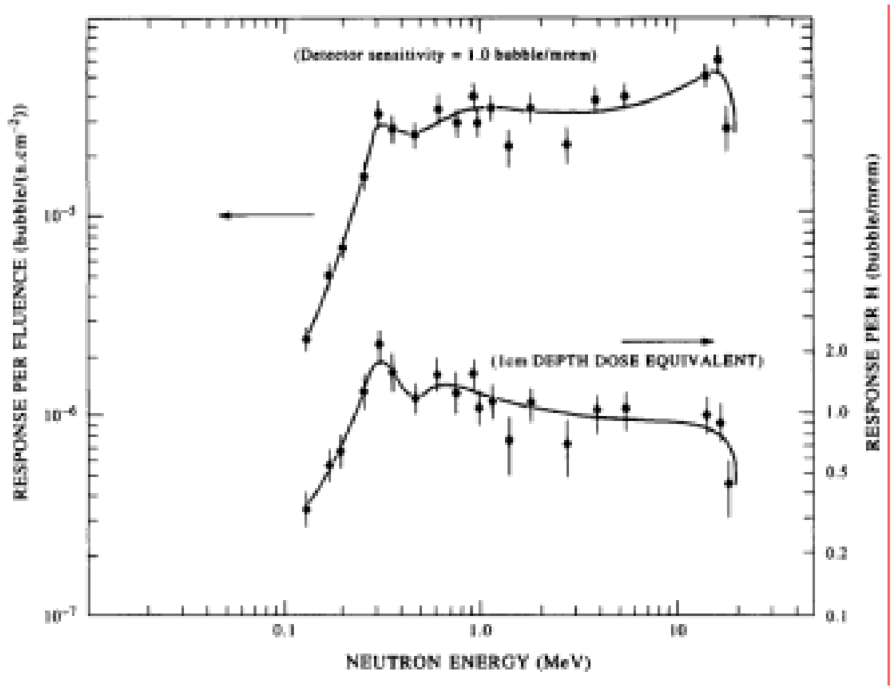


Figure 4. Neutron response curve for BD-PND

; Conversion from fluence to dose equivalent based on NCRP Report No. 38 [10] [11]

3. Experimental Results and Data Analysis

The characteristic axial transit time is explained using a snow-plow model,

$$t_p = \left[\frac{4\pi\left(c^2-1\right)}{\mu \ln c} \right]^{1/2} \frac{z_0 \rho_0^{\;1/2}}{\left(I_0/a\right)} \qquad (1)$$

where, $c = b/a$, b is outer electrode radius, a is inner electrode radius, μ is permeability, z_0 is length of inner electrode, I_0 is characteristic current, ρ_0 is gas filling pressure [12]. The plasma is focused well, when the plasma and driven current are arrived at the same time on top of the inner electrode (i.e. the magnetic induction becomes maximum). This means that the plasma axial transit time is equal to the quarter time period. Fig. 3 shows relations between filling pressure and electrode length at the quarter time period. For the neutron yield dependence on the filling pressure only, the different six electrode lengths are used and shot for five times each electrode length.

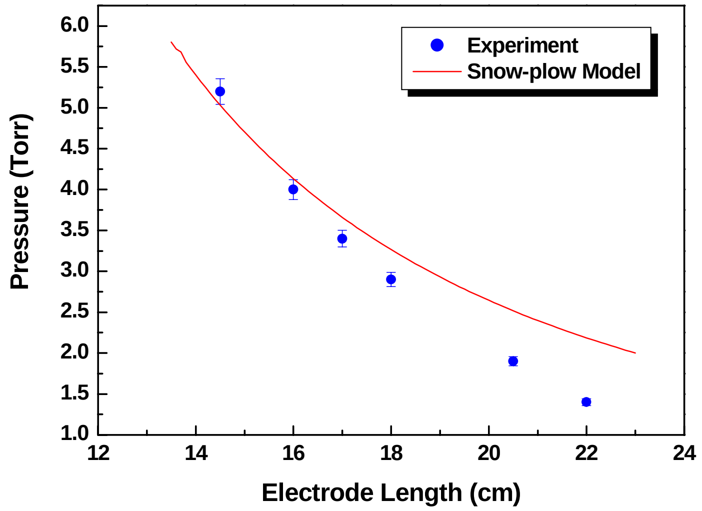


Figure 5. Optimum deuterium filling pressure for different electrode lengths

When the plasma is focused, the impedance is increased because of the compression of the plasma column. Therefore, the voltage spike and current dip are observed, and it is shown in Fig. 6.

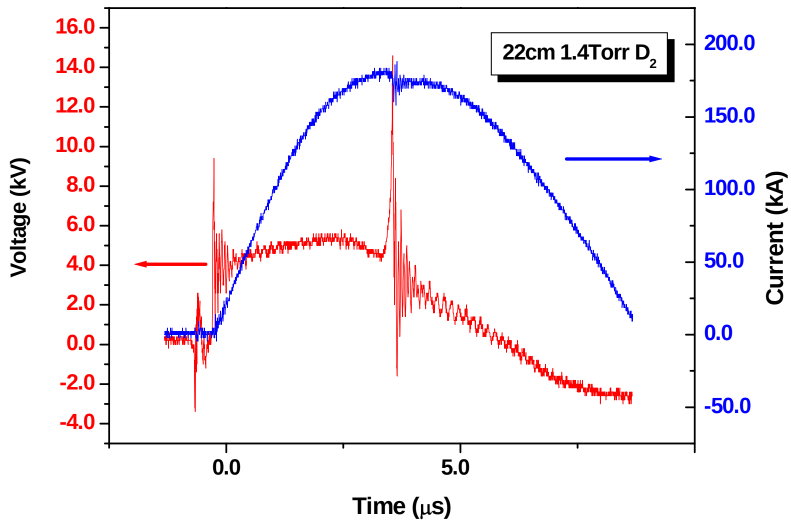
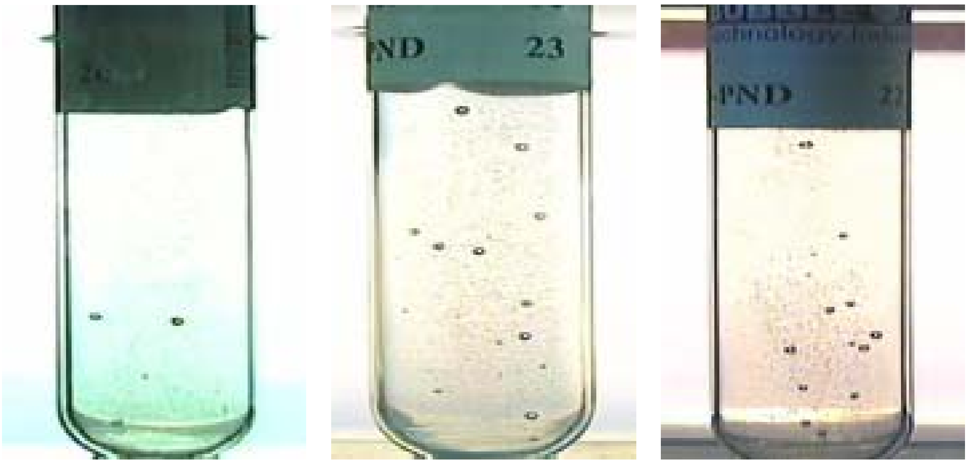


Figure 6. Voltage spike and Current drop signal measured in DPF-device

The neutrons at the energy of 2.45MeV are generated from the DPF-device by D-D reactions. Fig. 7 shows the neutron image by means of BD-PND in 4kJ DPF-device at a distance of 30cm from the inner electrode head. The number of a label on BD-PND means the bubble numbers per 10μSv.



(a) (b) (c)

Figure 7. Neutron-bubble Image

(a) Electrode length: 22cm, Pressure 1.4 Torr-D_2,

(b) Electrode length: 16cm, Pressure 2.9Torr-D_2,

(c) Electrode length: 14.5cm, Pressure: 5.2Torr-D_2

The total neutron yield is presented in Fig. 8 with different pressure; these are assumed that the neutrons are generated isotropically from the inner electrode head (focus region). The neutron yields have tendency to saturate at a pressure about ~3Torr, and the maximum total neutron yields are 6.4×10^{8} n/shot in this condition.

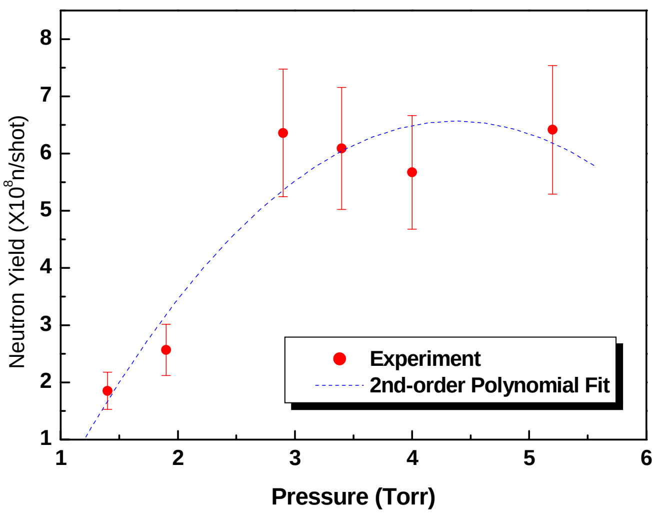


Figure 8. Dependence of the average neutron yield with the deuterium filling pressure

4. Conclusions and Future Work

The optimization conditions in a different electrode length are found, and the neutron yield is estimated in these conditions. The total neutron yield increases with the pressure of filling gas and tends to be saturated around 3 Torr. The maximum neutron yield is observed around 6.4×10^{8} (n/shot) at the pressure ~3Torr. In future, the neutrons will be measured at different angle from the inner electrode axis and different charged voltage (different stored energy).

Acknowledgment

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