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Nuclear activation measurements of High energy deuterons from a small plasma focus

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ABSTRACT

High-energy deuterons from a small (1.7 kJ) plasma focus device were studied by nuclear activation of a boron-carbide target. The ratio of $^{10}B(d,n)^{11}C$ and $^{12}C(d,n)^{13}N$ yields indicates a deuteron spectrum decreasing rapidly between 400 keV and 1 MeV. This spectrum could take the form of $dN_d/dE \propto E^{-n}$ with $n \approx 9$.

1. Introduction

Plasma focus (PF) devices are essentially a form of Z-pinch. The PF consists of two coaxial cylindrical electrodes in a gas filled chamber connected, via a high voltage switch, to a capacitor bank. When the high voltage is applied across the electrodes, breakdown of the gas occurs across an insulator sleeve and current flows. The magnetically driven current sheath is accelerated along the device axis towards the open end of the electrodes. Finally, the current sheath sweeps around the end of the inner electrode by the radial inward $J \times B$ force. The sheath then collapses radially with azimuthal symmetry. At the time of maximum compression (pinch phase), a hot and dense magnetized plasma column is formed. This pinch column is a strong source of energetic electron and ion beams. When operated with deuterium gas, intense bursts of neutrons from DD fusion reactions are observed.

In the present work, intense beams of deuterons with energies from 400 keV to 1 MeV are observed for the 1.7 kJ NX2 plasma focus device. Such energetic deuterons have only previously been reported for PF devices with stored energies many times greater, e.g. (76 kJ) [1] and (18 kJ) [2].

A number of models for the acceleration mechanism have been proposed, including compressional heating in the neck of $m = 0$ instability [3], the influence of anomalous resistance [4], and fast magnetosonic shock waves [5]. However the ion acceleration mechanism within the plasma focus pinch column is still far from being well understood. Many previous plasma focus experiments have concentrated on the characteristics of the neutron yield (e.g. emission time and anisotropy), but since the bulk of fusion neutrons are produced by relatively low energy deuterons ($\leqslant$ 100 keV), the neutron characteristics are not very informative with regard to the high energy tail of the deuteron spectrum.

By contrast with neutron measurements, nuclear activation by energetic deuterons of low-Z target materials provides a direct and unambiguous diagnostic for high energy deuteron emission. The nuclear activation technique has been employed with plasma focus devices [1,2] as well as a variety of other pulsed plasma devices [6–10]. Nuclear activation of a boron-carbide (B_4C) target is used in this work, for the first time, to investigate deuteron beams from a plasma focus. The two nuclear reactions responsible for the activation are $^{10}B(d,n)^{11}C$ and $^{12}C(d,n)^{13}N$. The main reasons for using a boron-carbide as a target are: (i) it is an extremely hard ceramic and suffers negligible ablation due to the hot plasma jet; (ii) the thick target yields of ^{11}C and ^{13}N are significantly different for deuterons energies up to 1 MeV; (iii) consequently the ^{11}C and ^{13}N yield ratio is a sensitive function of the incident deuteron energy; (iv) ^{11}C and ^{13}N are pure $\beta+$ emitters, leading to the emission of

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511 keV annihilation gamma-rays; (v) consequently the measured yield ratio is independent of the gamma-ray detection efficiency. Table 1 lists some parameters relevant to the activation of boron-carbide.

2. Experimental setup

The NX2 device [11] is a high repetition rate (up to 16 Hz) small Mather-type plasma focus with a 27.6 μF capacitor bank coupled to the PF electrodes through four pseudo-spark switches. The total system inductance is 26 nH. Throughout these experiments the NX2 was operated with 10 mbar deuterium gas and 11 kV charging voltage (stored bank energy of 1.7 kJ). Lee's model [12,13] has been applied to the analysis of the voltage and current traces obtained for these operating conditions. The main parameters resulting from this analysis are: plasma pinch column dimensions of 2 mm diameter and 11 mm length, pinch duration of 70 ns, plasma pinch temperature of 0.5 keV, peak circuit current of 300 kA, and a peak pinch current of 190 kA. The number density of the deuterons given by Bennett equilibrium in the pinch is 1.9×10^{19} cm^{-3}.

Table 1
Parameters relevant to the nuclear activation of the boron-carbide target B_4C (density 2.52 g/cm^3).

Nuclear reaction	$^{10}B(d,n)^{11}C$	$^{12}C(d,n)^{13}N$
Reaction Q-value (MeV)	+16.47	−0.28
Threshold Energy: E_{th} (MeV)	none	0.328
Target nuclide	^{10}B	^{12}C
natural abundance (%)	19.6	98.9
number density (cm^{-3}) in B_4C	4.31×10^{21}	5.43×10^{21}
Activated nuclide	^{11}C	^{13}N
Half-life (min)	20.33	9.97
Decay constant, λ (min^{-1})	3.41×10^{-2}	6.95×10^{-2}
$\beta+$ end-point energy (MeV)	0.96	1.20

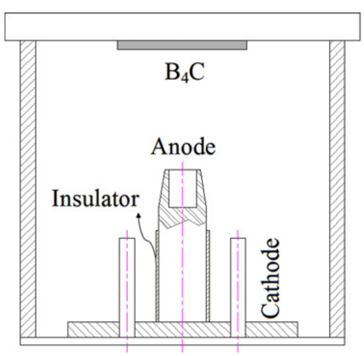

Fig. 1. Schematic diagram of the experimental setup for activation of the B_4C target in the NX2 plasma focus device.

As shown in Fig. 1, the boron-carbide target (8 cm diameter and 0.6 cm thick) was located on the forward PF axis at a distance of 10 cm from the PF pinch (subtending a solid angle of $\Omega = 0.45$ sr). Four experimental runs were performed under the same PF conditions. Each run comprised a sequence of 30 shots fired at 1 Hz repetition rate. The target was then removed from the PF chamber and placed in contact with a BGO scintillation detector connected to a Multi-Channel Analyzer (MCA) system. The MCA system accumulated energy spectra for six consecutive 10 minute intervals. Each spectrum was corrected for MCA dead-time (never more than 0.8%) and a background subtraction performed. A typical background subtracted spectrum is shown in Fig. 2 (inset). For each spectrum the number of counts in the 511 keV photopeak was determined by integration. Fig. 2 also shows the count vs. time plot for run No. 4, representing the mixed decay of ^{11}C and ^{13}N.

In order to check for an increase in the room-background due to the neutron yield, several series of PF shots were fired under the same conditions as above, but without extracting the boron-carbide target from the PF chamber. The BGO scintillation detector was located in the same position as for the main activation measurements (several meters from the NX2). An unexposed boron-carbide target was placed on the BGO detector to provide the same attenuation of room-background as occurs in the main experiments. No significant difference was observed between the spectra collected by the BGO/MCA system under these conditions and the normal room-background. Hence the background subtraction step was performed using the normal room-background (scaled for a 10 minute interval). In order to check for ablation of the B_4C tar-

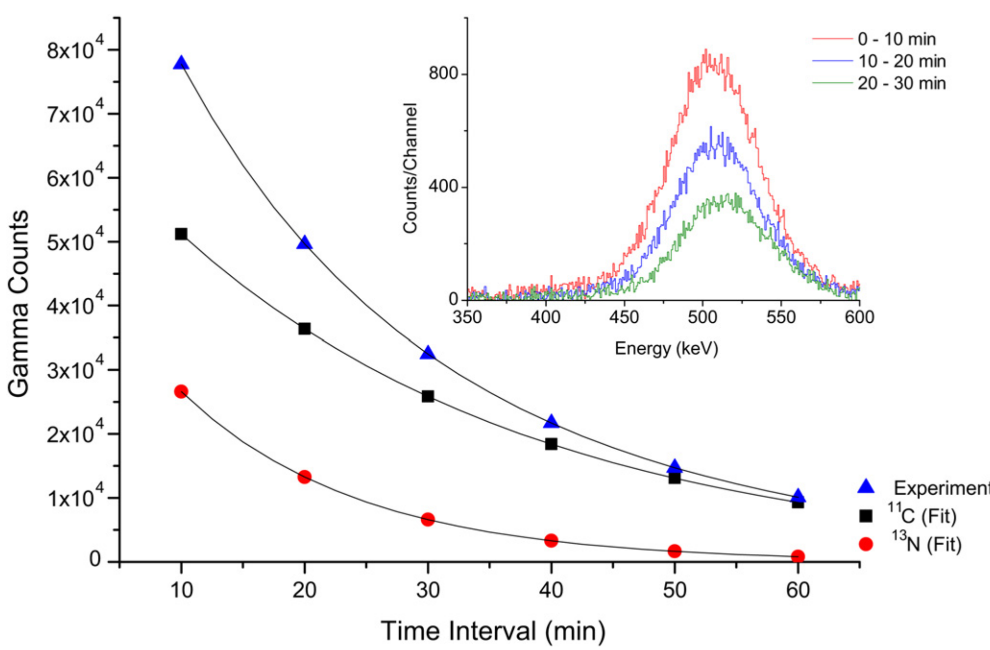

Fig. 2. (Main) Plot of experimental decay data (▲), and weighted least squares fitted contributions from ^{11}C (●) and ^{13}N (■) decay. (Inset) Typical background-subtracted gamma-ray energy spectrum collected over the first three (of six) consecutive 10 minute intervals, following B_4C target activation.