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D-D NEUTRON ENERGY SPECTRA MEASUREMENTS IN ALCATOR C

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ABSTRACT

Measurement of energy spectra of neutrons produced during high density ($\overline{n}_e > 2 \times 10^{14}$ cm^{-3}) deuterium discharges have been obtained[1] using a proton-recoil (NE 213) spectrometer. A two foot section of light pipe (coupling the scintillator and photomultiplier) was used to extend the scintillator into a diagnostic viewing port to maximize the neutron detection efficiency while not imposing excessive magnetic shielding requirements. A derivative unfolding technique was used to deduce the energy spectra. The results showed a well defined peak at 2.5 MeV which was consistent with earlier neutron flux measurements on Alcator C that indicated the neutrons were of thermonuclear origin[2].

INTRODUCTION

Regimes of operation in present day fusion devices result in copious production of fast neutrons. These fusion neutrons which emanate from the hot plasma core can not only give direct evidence of plasma having thermonuclear parameters, but also may allow determination of central ion temperatures a feature of prime importance in high density tokamaks such as the Alcator devices[3].

Under certain circumstances tokamak operation can lead to non-thermonuclear neutron emissions that can exceed expected thermonuclear rates[4,5,6], thus the origins of the neutron emissions must be determined.

Measurement of neutron energy spectra can provide information concerning neutron origins as well as information on plasma properties. The results described here were the first neutron spectra measurements from Alcator C and were obtained shortly after the first introduction of deuterium into the device. Alcator C had commenced tokamak operation in hydrogen fill for the first six months, at which time photonuclear neutron rates were routinely reduced to less than 10^6 n/sec[6]. Since the expected thermonuclear yields were to be approximately 10^{10} n/sec during the initial D-D operation, the spectrometer used for these experiments was chosen for its high efficiency rather than for maximum energy resolution. Specifically, the spectrometer consisted of a 5 cm X 5 cm NE 213 liquid organic[7,8,3] scintillator optically coupled to an RCA 8850 photomultiplier tube using a two foot section of cast acrylic lucite plexiglass rod. The location of the spectrometer in relation to Alcator C is shown in Fig. 1. Standard Ortec circuitry (Fig. 2) was used for n-γ pulse shape discrimination to allow pulse height analysis of neutron only pulses during the experiments.

RESULTS

Shown in Fig. 3 is a nominal spectrum ($\Phi(E)$ vs. E where $\Phi(E)$ = neutron flux at energy E in neutrons/cm^2-sec, and E = neutron energy in MeV) for a 1 keV D-D maxwellian plasma. The velocity distribution of the reacting deuterons gives rise to a doppler broadening of the spectral peak. The energy spectra for maxwellian velocity distributions has been calculated by Faust and Harris[9]. For a maxwellian deuterium plasma the width can be written as FWHM = 83.25 $(KT)^{1/2}$ keV, with KT in keV. The resolution of the high efficiency spectrometer used in this work was 20% or about 500 keV at 2.45 MeV. The efficiency of the detector however was approximately 10^4 times the efficiencies of the usual (H_{e3}, Li sandwich, etc.) high resolution spectrometers. Thus for the neutron rates expected during the early D-D operation, verification of the fusion origin of the neutron emissions was possible from data averaged over approximately ten shots.

To unfold the measured proton recoil spectra a derivative unfolding code[10] called FLYSPEC was used. Basically the flux Φ is given by

$$\Phi(E) = \frac{-E}{VTn_H} \cdot \frac{1}{\sigma_{np}(E)} \cdot \frac{dP(E)}{dE}$$

where $\Phi(E)$ = neutron flux at energy E (n/cm^2-sec)

$\frac{dP}{dE}$ = first derivative of the proton recoil distribution

V = detector volume (cm^3)

T = counting time (sec)

n_H = density of target protons (H atoms/cm^3)

σ_{np} = n-p elastic scattering cross section (cm^2)

The unfolded measured neutron energy spectrum from a high density Alcator C D_2 discharge is shown in Figure 4. The spectrum indicates a large 2.5 MeV peak neutron emission from the $D(D,n)He^3$ fusion reaction in accordance with expectations due to the low runaway electron levels (i.e., contributions due to photonuclear processes and the electro disintegration of deuterons were expected to be quite low). The ion temperature determined both by global neutron emission and charge exchange were approximately 800 eV. The agreement between neutron flux deduced and charge exchange deduced ion temperatures together with the corresponding measured 2.45 MeV peak in the neutron spectra is a clear confirmation that the majority of the neutron emissions for the typical Alcator C high density discharges are of thermonuclear origin.

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FIGURE CAPTIONS

Figure 1. The Alcator C device and relative positions of the spectrometer and neutron flux diagnostics.

Figure 2. Block diagram of the spectrometer instrumentation.

Figure 3. Calculated neutron energy spectrum for a 1 keV D-D (maxwellian) plasma.

Figure 4. Measured neutron energy spectrum from Alcator C high density deuterium discharge. The peak at 2.5 MeV together with the agreement between charge exchange and neutron flux deduced ion temperatures indicates that the neutrons are of thermonuclear origin.

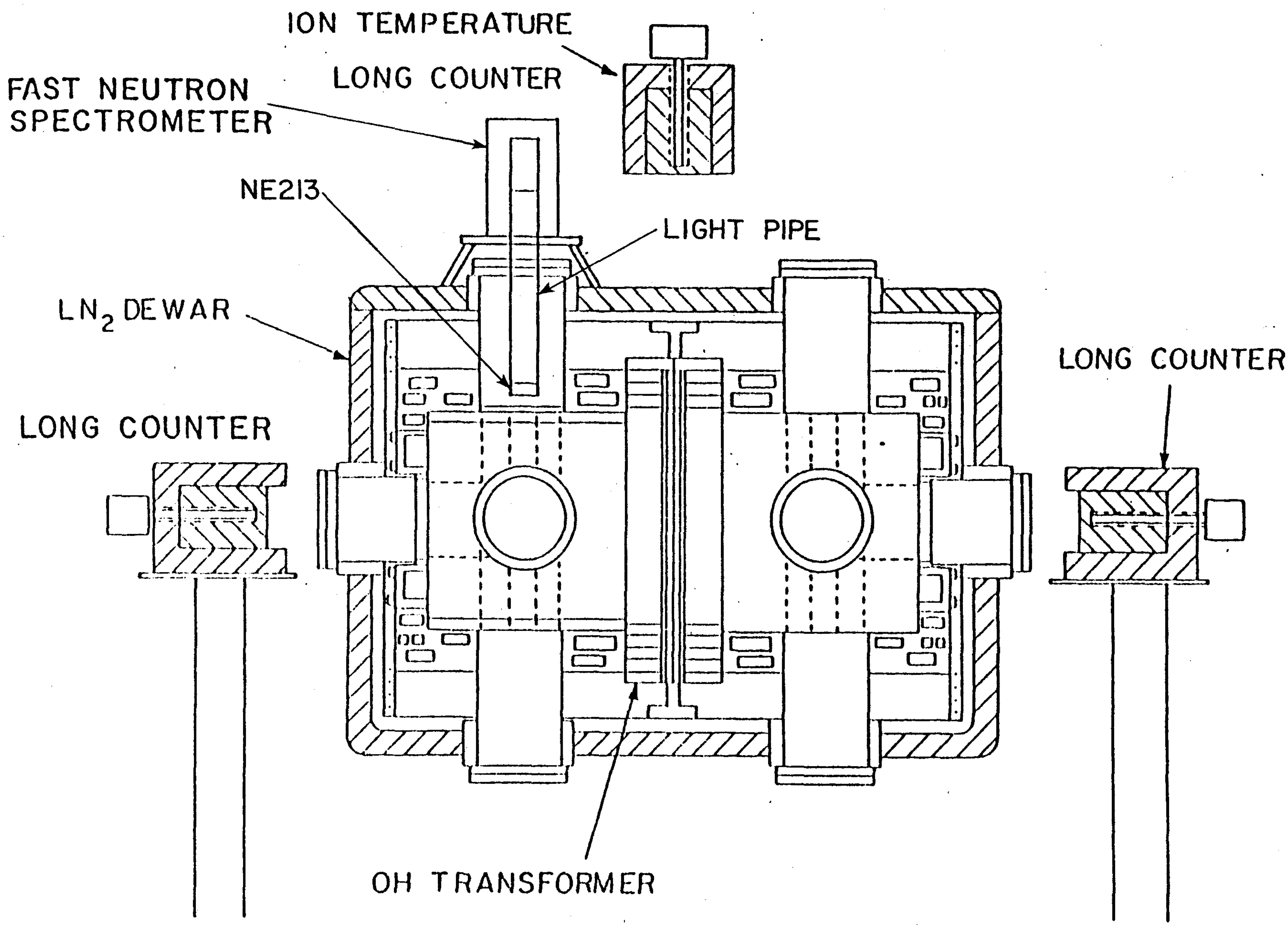
ION TEMPERATURE
LONG COUNTER
FAST NEUTRON
SPECTROMETER
NE213
LIGHT PIPE
LN_2 DEWAR
LONG COUNTER
LONG COUNTER
OH TRANSFORMER

FIGURE I

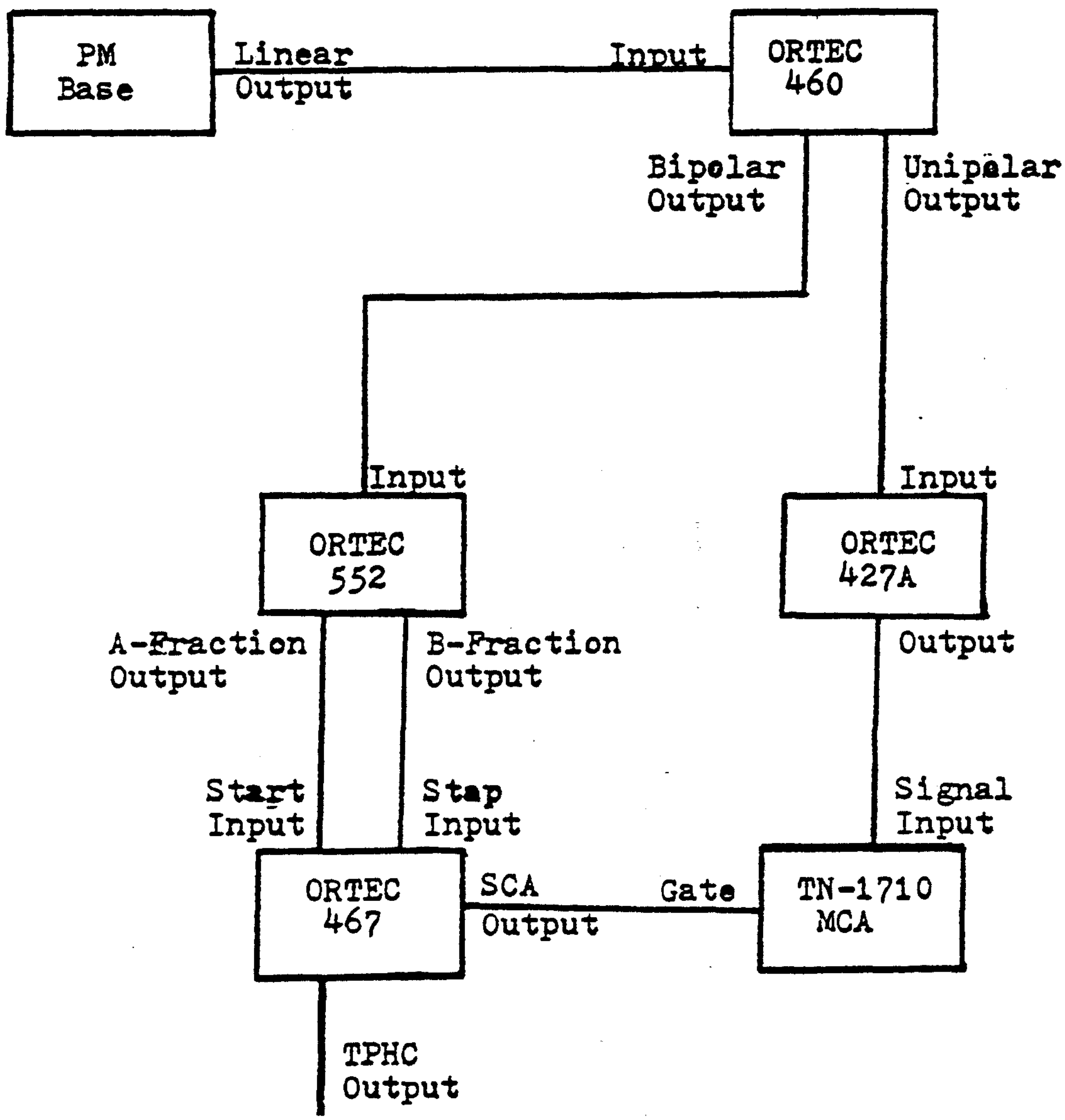
PM
Base
Linear
Output
Input
ORTEC
460
Bipolar
Output
Unipalar
Output
Input
ORTEC
552
Input
ORTEC
427A
A-Fraction
Output
B-Fraction
Output
Output
Start
Input
Stap
Input
Signal
Input
ORTEC
467
SCA
Output
Gate
TN-1710
MCA
TPHC
Output

Figure 2

FIGURE 3

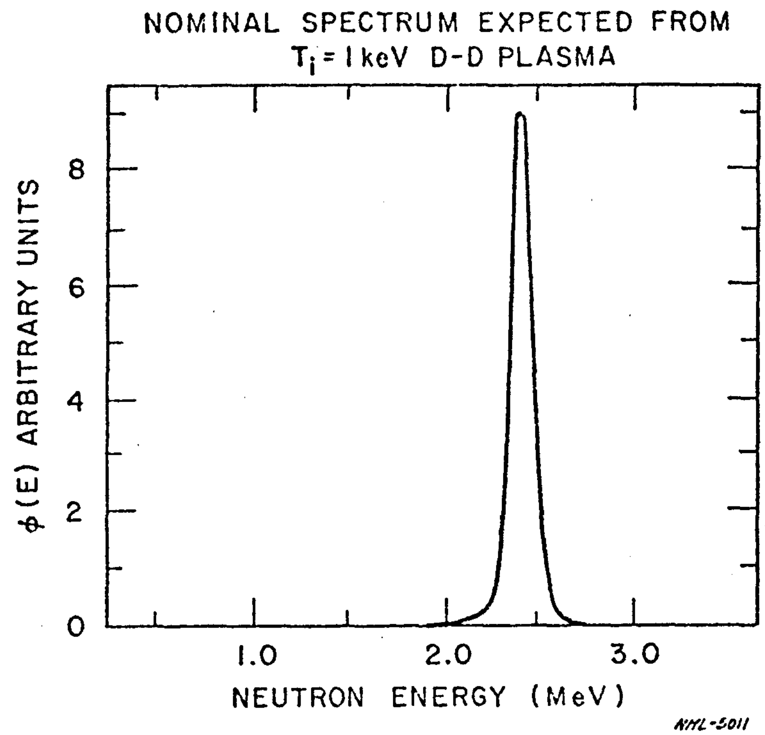

FIGURE 4