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MEASURING THE NEUTRON ENERGY SPECTRUM
OF LASER-FUSION TARGETS WITH CR-39

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MEASURING THE NEUTRON ENERGY SPECTRUM OF LASER-FUSION TARGETS WITH CR-39*

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ABSTRACT

We are developing a detector capable of measuring the neutron energy spectrum from a laser fusion target containing DT fuel. From such a spectrum the compressed areal density of the DT can be inferred by observing the fraction of 14.1 MeV neutrons down-shifted in energy by elastic scattering. The detector consists of a 0.1 cm thick Ta x-ray and debris shield backed by a 50-200 μ m polyethylene radiator followed by layers of CR-39. The energy of each neutron producing a knock-on proton in the radiator, that in turn creates a damage track in the CR-39, can be derived from the resultant track diameter, location, and orientation. We have analyzed the proton sensitivity and sample readability of 5 types of CR-39 in the energy range 3-11 MeV and have found a type fabricated by American Acrylics from a monomer made by a French company, Allymer, to be the most acceptable. Calibration curves were obtained for this plastic at energies of 3-15 MeV and dip angles ranging from 75 to 90 degrees. These curves were subsequently used to unfold a 14.7 MeV spectrum generated at the Livermore Rotating Target Neutron Source.

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KEYWORDS

Neutron spectrometer; laser fusion; CR-39; solid state nuclear track detectors

INTRODUCTION

Laser fusion involves the use of very powerful ($>10\text{TW}$) lasers to compress to densities 100 times that of lead and to heat to thermonuclear temperatures the deuterium and tritium contained in tiny ($200\text{ }\mu\text{m}$) glass micro-balloon targets. The efficiency of the fusion burn in such a target is proportional to the compressed areal density (ρR) of the fuel. Kacenjar et al. (1982) have used CR-39 to directly measure the fuel ρR by counting the number of recoil deuterons and tritons that have been elastically scattered out of the micro-balloon by the fusion neutrons. Because newer targets have thick walls that cannot be penetrated by these recoil fuel atoms, we are developing a detector capable of responding to the elastically scattered neutrons which easily escape the target. For highly compressed targets, the dominant neutron interaction is elastic scattering with the deuterium-tritium fuel. Therefore the fuel ρR can be estimated from

$$\rho R = 5.4 f/\epsilon \text{ (g/cm}^2\text{)}$$

where the factor 5.4 contains the cross-section and atomic weights and f is the fraction of 14.1 neutrons that have been elastically scattered. The fraction of scattered neutrons that can be observed by the detector ϵ depends on the detector response and on the neutron spectral shape. Typical values for f are expected to be about 1%. The background level can be ascertained by employing high-yield low-density targets that produce no signal due to scattering in the fuel. Contributions to the background in the energy range of interest (3-14 MeV) include TT neutrons, scattered neutrons from the target chamber walls, and effects from target produced x-rays. We describe here the first efforts in developing such a detector along with the results of a preliminary test.

DETECTOR DESIGN

The detector, placed a few centimeters from the target as shown schematically in figure 1, consists of a 1.0 mm thick tantalum shield to protect the track detector from x-rays and debris generated by the implosion. A 50 to 200 μm thick polyethylene radiator is used to produce recoil protons that in turn can produce damage tracks in the CR-39. Additional data are obtained by using two layers of 1 mm thick CR-39. The first layer serves to slow down the highest energy protons thus yielding larger and more readable tracks on the surface of the second layer.

After etching, the neutron energies E_n can be derived (using the equation shown in Fig. 1) from several parameters that describe the geometry of the tracks and the detector. From the major and minor axes and the off-center distance of the track apex, the recoil proton energy E_p and the dip angle $(\pi/2 - \gamma)$ can be determined with the aid of proton calibration curves. Additional parameters required are the angle with respect to a radial ϕ , the radial distance, k , the target-to-detector distance l , and the radiator thickness, t . Errors will be introduced by making the radiator thickness large because all elastic scattering events have been assumed to have occurred a distance $t/2$ into the radiator. Derivations of a similar equation used in connection with a neutron dosimeter are given by Frank, Benton, and Albergetti (1974).

Since it is necessary to accurately measure features of the tracks, the requirements on the CR-39 are quite demanding. To maximize registration sensitivity and track readability we evaluated 5 different types of CR-39 (described in Table 1) by exposing them to monoenergetic protons having energies of 3, 5, 8 and 11 MeV at dip angles ranging from 60

to 90 degrees. The CR-39 samples were etched in an unagitated bath of 6.25 N NaOH with 0.5% Dowfax surfactant at 70 degrees centigrade for 24 hours. From qualitative criteria we judged the CR-39 made from the Allymer monomer containing 0.01% anti-oxidant to be the most acceptable and convenient. We obtained this plastic with the aid of P.B. Price at the University of California, Berkeley.

EXPERIMENT

To provide an initial test we exposed the above described detector to 14.7 MeV neutrons generated by the Livermore Rotating Target Neutron Source (RTNS) and using the calibration curves of Fig. 2 we were able to unfold a simple neutron spectrum (Fig. 3). The neutron fluence was 4×10^7 n/cm² which produced 4×10^3 tracks/cm² thus yielding an efficiency of 10^{-4} tracks/neutron. For a parallel source of neutrons the equation in Fig. 1 simplifies to

$$E_n = E_p / (\cos \gamma)^2 .$$

The measured FWHM of the 14.7 MeV peak was 1.4 MeV compared to actual FWHM of 400 KeV. Further tests of the detector that are currently in progress include the placing various thicknesses of polyethylene in front of the detector in an effort to form neutron spectra having small differences from which we hope to recover the ρR of the scatterer. These tests have been done with both laser target and RTNS neutron sources.

CONCLUSION

We are demonstrating the feasibility of diagnosing the fuel ρR of a laser fusion target by measuring the deviation from a pure DT neutron spectrum due to elastic scattering in the fuel. We have chosen a type of CR-39 that appears most sensitive from proton calibrations. We have designed a detector having a tantalum shield, polyethylene radiator, and CR-39 track detector and have partially demonstrated its utility by measuring a 14.7 MeV spectrum.

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Table 1. CR-39 Samples Tested

Monomer	Initiator	Additives	Manufacturer
Allymer	2% IPP	.01% anti-oxidant	American Acrylics
Allymer	2% IPP	1% DOP + .01% anti-oxidant	American Acrylics
Allymer	7% CHPC	None	Pershore
Allymer	7% CHPC	1% DOP	Pershore
PPG	2% IPP	None	American Acrylics

$$E_n = E_p \frac{\ell^2 + k^2 - tk \tan \gamma \cos \varphi - t\ell + \left(\frac{t}{2 \cos \gamma}\right)^2}{\left[k \sin \gamma \cos \varphi + \ell \cos \gamma - \frac{t}{2 \cos \gamma}\right]^2}$$

Fig. 1 Schematic representation of detector used to measure energies of neutrons emitted from a laser fusion target. The neutron energy can be found from the recoil proton energy E_p and various parameters describing the geometry of the detector and the etch pit.

Fig. 2 Calibration curve produced by normally incident protons. This curve and curves describing other track geometry parameters at various angles and energies were used to unfold a 14.7 MeV neutron spectrum.

Fig. 3 Ar. unfold of a 14.7 MeV neutron spectrum obtained at the Livermore rotating target neutron source.