A study of CR-39 track response to charged particles from NOVA implosions

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We have exposed CR-39 track recording material to a number of NOVA implosions. Radiation from the implosion passed through an array of ranging filters, which aided identification of the incident particles and their energies. The etching procedure was calibrated by including a piece of track exposed to DD protons from a small accelerator. For the same shots, we quantitatively compare the DD neutron yield with the DD proton yield determined from the track. In DT implosions, tracks produced by neutron interactions prevent observation of charged-particle tracks that are produced by the processes of knock on, secondary, or tertiary fusion. © *1997 American Institute of Physics.* [S0034-6748(97)57501-0]

Diagnostic instruments for measurement of the yield of energetic, charged particles from fusion implosions are under development.[1] Such diagnostics sensitive to the yield, areal density (fuel and core), and asymmetry of the implosions will be needed to understand and guide the target development necessary to achieve ignition and burn a fusion pellet. Depending on the yield and density attained in compression, various charged-particle reaction products can be exploited in such diagnostics. These include primary products, such as protons in DD fusion at low areal density. As areal density increases, higher-energy neutron knock-on products or secondary reaction products can be detected. At still higher areal density, energetic tertiary charged products will characterize the compressed fuel of igniting implosions.[2]

To guide this development effort, an experiment (Fig. 1) has been designed for NOVA using the charged-particle track recording material CR-39 to measure charged-particle production in DD and to assess the neutron backgrounds for DT implosions.[3] CR-39 was selected for its ease of implementation and its sensitivity to NOVA yields. The experimental set up includes a support (Fig. 2) which attaches to the 6-in. manipulators on the NOVA chamber and holds the CR-39 and the filter array. The filter array is included to establish the energy and type of particle producing tracks in the CR-39. The manipulators permit the positioning of the package at various distances from the target. The distance is chosen to give a distinguishable density of tracks on the CR-39 based on the expected reaction yield. For DD implosions at low areal densities, the filter array (Fig. 3) was selected to optimize CR-39 response to primary protons and tritons. In addition, a filter array for secondary protons (Fig. 2) was de-

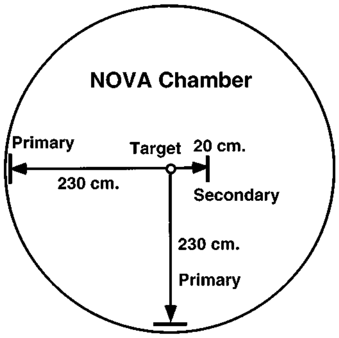

FIG. 1. Schematic plan view of NOVA experiments showing positioning of primary and secondary track detectors.

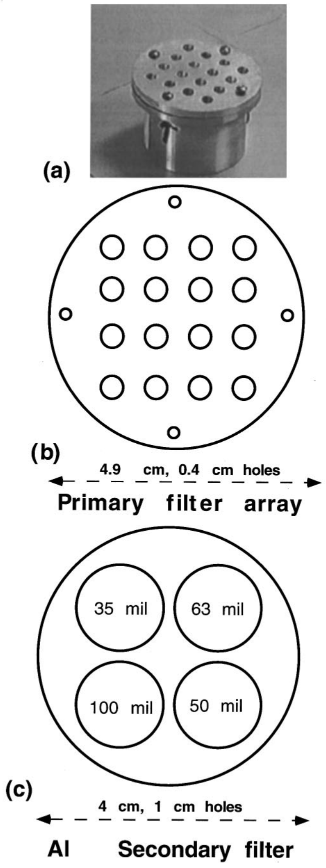

FIG. 2. CR-39 track detector: (a) assembly, (b) primary, and (c) secondary filter supports.

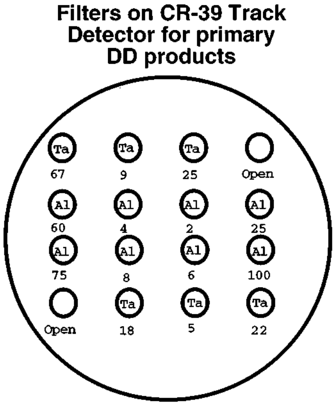

FIG. 3. Primary fusion product tantalum and aluminum filter array with filter thicknesses (microns) as seen by the incident flux.

signed. Filters of both tantalum and aluminum were employed to test for background from reactions in the filter material.

After exposure to an inertial confinement fusion implosion, the CR-39 was etched in 6N NaOH at a temperature of 80±0.2 °C for 3.5 h. This removes approximately a 9 μm layer from its surface and reveals the charged-particle tracks.

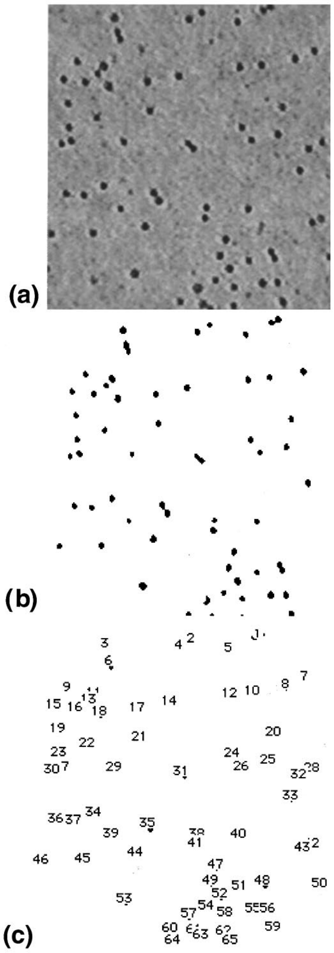

FIG. 4. Image analysis: (a) photomicrograph, (b) enhanced image, and (c) tracks identified. Tracks labeled 6, 31, 35, and 48 are double and can be distinguished by their major/minor axis ratios being greater than 1.

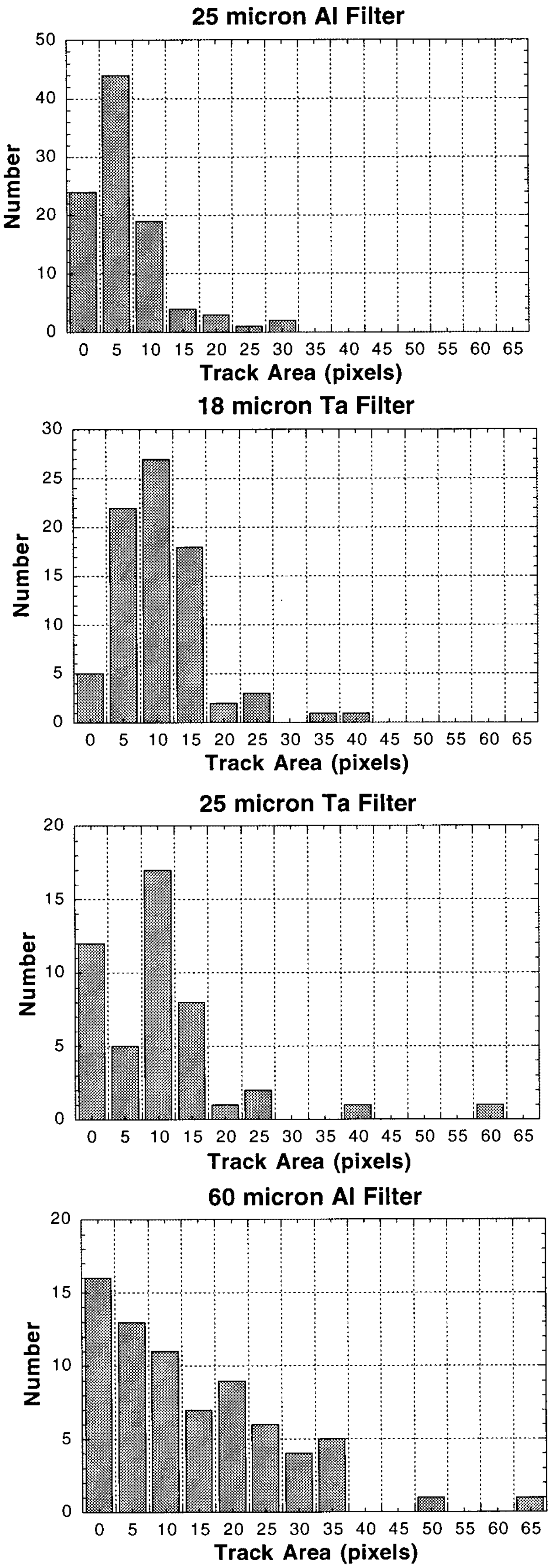

FIG. 5. Size distribution for tracks from shot TWP_MIT_06 for different foil materials and thickness. The average area (size) of the tracks increases and the distribution broadens with increasing energy loss in the filter.

Simultaneously, CR-39 exposed to a known flux of DD protons from a small accelerator is etched as a monitor of the sensitivity for detecting protons. The etched CR-39 is then photomicrographed, and digitized images are used to determine the proton flux. The images are then processed using NIH IMAGE (public domain image processing software.[4]) Image enhancement is accomplished by choosing a slice in image density which separates the tracks from the background noise in the image (Fig. 4). The analysis software then selects each contiguous set of pixels in a track and tabulates its area, position, major, and minor axes. Track sizes for filter thicknesses which did not range out the primary DD protons followed a systematic pattern of increasing average size and distribution width with increasing energy loss (Fig. 5). By comparing the image with the identified tracks, it is possible to remove obvious image defects so that the count is not biased. Overlapping tracks can be distinguished by their major/minor axis ratios being greater than unity.

The yield of protons derived from this track count, assuming uniform emission at all angles, is compared with the results from neutron diagnostics[5] for the three NOVA shots.

Shot ID	Neutron yield [indium activation (Ref. 5)]	Proton yield
TWP_ MIT_ 01	$1.0(\pm0.08)\times10^{10}$	$1.4(\pm0.2)\times10^{10}$
TWP_ MIT_ 02	$1.46(\pm0.09)\times10^{10}$	$2.7(\pm0.4)\times10^{10}$
TWP_ MIT_ 06	$0.84(\pm0.04)\times10^{10}$	$0.88(\pm0.1)\times10^{10}$

The error bars are statistical, and systematic errors remain to be evaluated. The difference in neutron and proton yields in shot 02 may be indicative of a systematic error not yet identified. One source of systematic error may arise from the difficulty in distinguishing true tracks from noise when the track size is small. We plan to explore this effect by changing the etch process to produce larger track sizes.

The etched CR-39 surface behind the thinnest filters had a frosted appearance and could not be used to identify DD triton tracks. The source of the tracks producing this ‘‘frost’’ is still under study.

Background track production and noise in the track images have not been reduced sufficiently to permit detection of the low yields of secondary or tertiary products from NOVA direct drive implosions. Further work will be done to enhance sensitivity to these particles and to design implosions with increased yields of secondary and tertiary products.

CR-39 neutron sensitivity makes measurements of charged particles from a DT implosion impossible without the use of shielding and magnetic transport to separate the charged particles from the neutrons. Measurements on DT implosions have been made to provide information that will help us design appropriate hardware approaches to separate charged particles from neutrons. Experiments using magnetic analysis and CR-39 detectors are being planned to further explore charged-particle diagnostics.[1]

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