Section 2
PROGRESS IN LASER FUSION

2.A A Direct Measurement of Fuel ρR

We are examining a new diagnostic that provides a direct measurement for ρR in the DT fuel [3,4,5]. The method uses the fact that 14 MeV neutrons, produced in DT fusion reactions, can elastically scatter from one of the deuterium or tritium ions before leaving the fuel region. The number of such knock-on reactions is directly proportional to the ρR of the fuel, and thus, a measurement of their number represents a direct determination of the fuel ρR.

The relation between the number of knock-ons and fuel ρR is determined in the following way: the number of elastic collisions Q produced by Y 14 MeV neutrons is:

$$Q = (N_d \sigma_d + N_t \sigma_t) <R> Y$$

Here, N_d and N_t are the number densities for deuterium and tritium; σ_d and σ_t are the respective cross sections for elastic scattering with a 14 MeV neutron (.92 and .62 barns); and $<R>$ is the average distance for a neutron to traverse the fuel. For equimolar DT this expression yields:

$$\rho <R> = 5.4 \ Q/Y \ g/cm^2$$

Thus, the ratio of the number of knock-ons to the number of 14 MeV neutrons determines ρR of the fuel.

Knock-on deuterons and tritons can be detected with the solid-state track-detector, CR-39.[6] One possible experimental configuration is shown in Figure 7. The first tantalum filter is used to block ions from the blow-off plasma and 3 MeV protons from the DD reaction. About 20% of the knock-on particles will penetrate the filter. Of these, about ½ will be in the energy window of the track detector. Determining the fraction of detected knock-ons is an essential part of the diagnostic and will be discussed below. There is no need to separate the deuteron and triton signals.

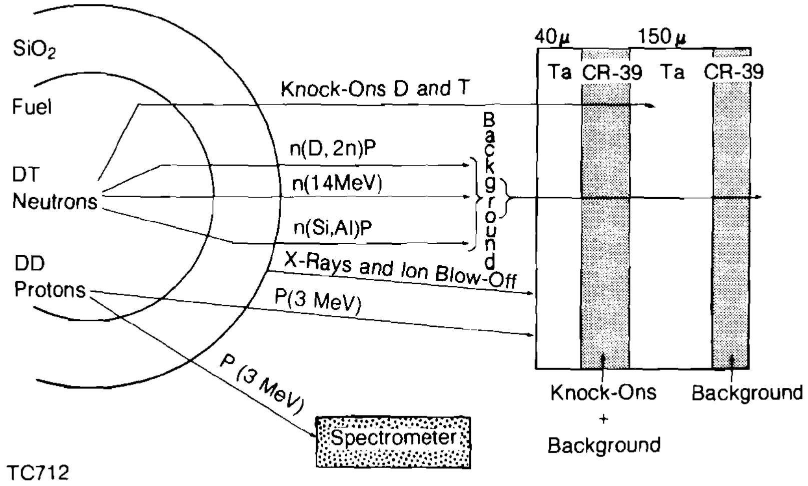

Figure 7 *Schematic of the knock-on ρR measurement experiment.*

Some sources of background are also shown in Figure 7. These include the production of protons from (n,p) reactions by neutrons in the fuel, tamper, filter, and track detector. The tracks produced by all these reactions are estimated to be considerably less than the knock-on signal. Further, some of the background tracks can be separated out easily according to their diameter or trajectory. The amount of other background tracks can be estimated by using a filter thick enough to stop the knock-on signal but not the background from high-energy protons. This background can then be measured with an additional track detector.

A possible source of background not shown in Figure 7 is MeV protons that can be produced from the laser-target interaction. These can be produced even from nominally hydrogen-free targets–presumably from contamination on the surface. Energies greater than 3 MeV are necessary to produce a background signal. Such energetic protons have been observed at Livermore[4], but not from the ZETA laser system. If they should occur on the higher power Omega system, it will be necessary to employ target cleaning techniques within the target chamber before each shot.

An essential part of the diagnostic is determining what fraction of the knock-ons have been detected by the track detector. A difficulty arises because the knock-ons are produced with a continuum of energies (0 - 10.6 MeV for tritons), resulting from different neutron impact parameters. Further, the energy spectrum has peaks and valleys due to an anisotropic differential cross section for elastic scattering. There is no a priori way to know which part of the spectrum will be in the energy window of the track detector, as the spectrum can be shifted and distorted due to energy loss in the target (mainly the tamper). An example of how the fraction of detected knock-ons varies with tamper density and temperature is shown in Figure 8. The results were obtained from computer simulations which calculated the distortion and shift of the knock-on spectrum as it moved through the fuel, tamper and tantalum filter. Windows for

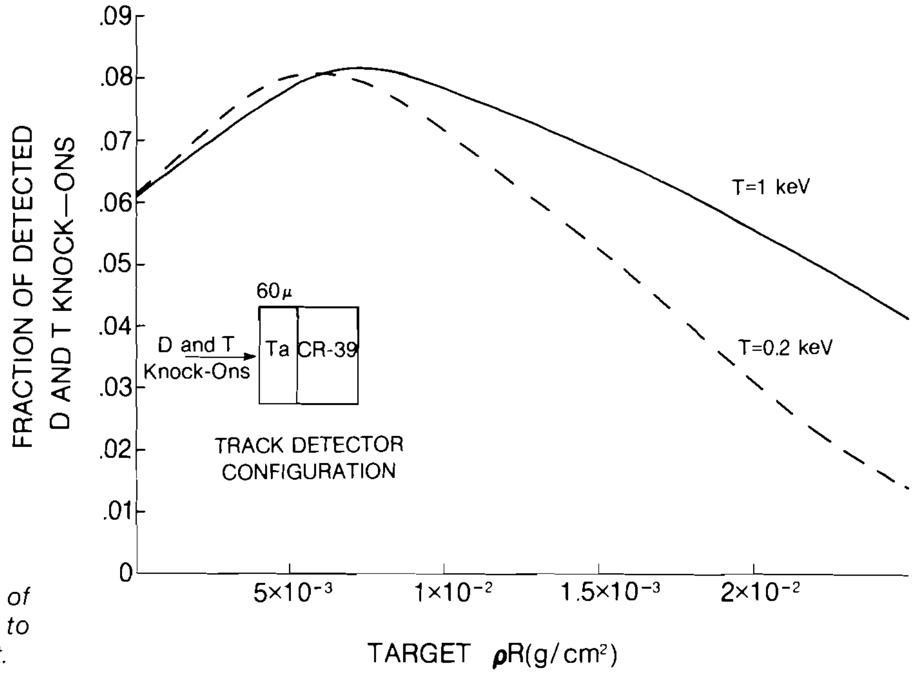

Figure 8 *Variation in the fraction of detected knock-ons due to energy loss in the target.*

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the track detectors have been determined to be 2-4 MeV for deuterons and 3-6 MeV for tritons. Different windows will change the results quantitatively, but the qualitative features will remain the same.

A 60 μm Ta filter was found to be optimum for the low to medium ρR cases, $0 < \rho R \lesssim 10^{-2}$ g/cm^2. In this range the fraction of detected knock-ons was found to vary by about ± 15%, which will introduce the same percentage error in the inferred value for fuel ρR. The reason for variation is that the part of the spectrum in the track-detector window changes from a valley to a peak and back to a valley as ρR increases. The tantalum thickness chosen shows the minimum variation.

The uncertainty in this ρR range can be reduced in two ways: 1) by correlating the fraction of knock-ons with the energy loss of protons produced in the DD fusion reaction (3.02 MeV), and 2) by using a double track-detector configuration. DD protons are useful because their velocity is very close to the velocity of the knock-on particles detected in Figure 8. Hence, their energy loss is very similar to the energy loss of the knock-ons and determines fairly well which part of the spectrum is in the track detector window. The variation with ρR can be smoothed with a double track-detector configuration. It can be adjusted so that when the knock-on peak moves out of one detector, it enters the other.

Results for a double track-detector configuration are shown in Figure 9. As seen, the variation is now so smooth that correlation with the DD proton is not even necessary. However, it is necessary to at least see the proton because the curve drops off sharply for target conditions that stop the proton, i.e. $\rho R \gtrsim 0.02$ g/cm^2. The error bars show the variation that can result from different temperatures in the tamper and from electrostatic fields that can be produced by the laser-target interaction[7]. Over the range, $\rho R \lesssim 0.01$ g/cm^2, the uncertainty is only about 5% which makes this diagnostic look very attractive for near term experiments.

For higher ρR, we can no longer use the DD protons to correlate distortion of the knock-on spectrum, as they will be absorbed in the target. Instead, we can use protons from secondary He^3 - D reactions, which should be sufficiently