UCRL 86030
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UCRL--86030

DE82 011057

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Compression Measurements of Laser-Fusion TargetsS.M. Lane, J.H. Dellis, C.K. Bennett, and
E.M. CampbellThis paper was prepared for submittal to the
IEEE 1981 Nuclear Science Symposium in San
Francisco, October 21-23, 1981.

October, 1981

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Summary

Direct drive laser fusion targets consisting of DT gas encapsulated in glass microshells produce 14.1 MeV neutrons that can interact with silicon-28 nuclei in the glass to produce a 2.2 minute aluminum-28 activity. From the number of ^{28}Al nuclei created and the neutron yield, the compressed glass areal density can be found. To determine the number of activated atoms created, we collect approximately one-half of the target debris on a thin metal foil which is transferred to our beta-gamma coincidence detector. This detector consists of a 25 cm x 25 cm NaI(Tl) crystal having a 5 cm x 15 cm well. We have recently built a miniature proportional counter that fits into this well and is used to detect beta particles. It is constructed of .025 cm thick copper and has nine separate chambers through which methane flows. The coincidence background is 0.14 cpm and the measured beta efficiency is 45%. We are now building a .0125 cm thick counter made of aluminum having a predicted efficiency of > 90%.

Introduction

The density-radius product $\langle\rho R\rangle$ of the direct drive target fuel is the quantity in inertial confinement fusion that characterizes the quality of the confinement and thermonuclear burn. Recently, neutron activation techniques have been used to measure the pusher attenuation length, $\langle\rho\mu R\rangle$.^{1,2,3} From the pusher $\langle\rho\mu R\rangle$ the fuel density (and hence fuel $\langle\rho R\rangle$) can be inferred with the aid of computer models.

The neutron activation technique works in the following way. In an imploded laser fusion target consisting of DT gas encapsulated in a glass microshell, the thermonuclear neutrons activate the ^{28}Si atoms in the glass via the $^{28}\text{Si}(n,p)^{28}\text{Al}$ reaction. A portion of the debris from the exploding target is collected on 20 μm thick titanium foil that lines a 5-cm-diam by 16.5-cm-long aluminum cylinder (collector) placed near the target (Fig. 1). To redirect the debris onto the foil a 5-cm-diam reflector is placed opposite the collector. The collector housing can be extracted rapidly from the evacuated target chamber and transferred to a radiation detector. The fraction of collected debris is found from a ^{24}Na tracer in the target.⁴

The number of detected ^{28}Al decays, N , can be related to an average $\langle\rho\mu R\rangle$ by

$$\langle\rho\mu R\rangle = \frac{N}{Yof \left(\frac{A}{A_0}\right) \epsilon \eta e^{-\lambda t} (1 - e^{-\lambda \Delta t})}$$

where Y is the neutron yield, o is the reaction cross section, f is the fraction of ^{28}Si atoms in the pusher, A_0 is the average atomic weight of the pusher, A_0 is Avogadro's number, ϵ is the detection efficiency, η is the fraction of collected debris, λ is the ^{28}Al decay constant, t

is the sample loading time, and Δt is the counting time. Typically 50-500 activated atoms are created in the most interesting targets which translates to 5-50 detected events. This small signal places a premium on low-background and high efficiency detectors.

Aluminum-28 decays by the emission of a 0.0-2.3 MeV beta particle and a 1.78 MeV gamma ray. To detect these decays we require a coincidence between our 25-cm-diam by 25-cm-long NaI(Tl) detector, having an aluminum photopeak efficiency of 40%, and a beta detector located in the 5-cm-diam, 15-cm-deep well of the NaI(Tl) crystal. The collector foil is placed inside of the beta detector. In the past we have used an NE102 plastic floor to detect the beta particles but recently we have substituted a miniature proportional counter that reduces the background by a factor of 4-5. This article will describe the proportional counter.

Proportional Counter

The proportional counter, shown in figures 2 and 3 was constructed of copper and consists of a single inner chamber and eight separate outer chambers each with a central 25 μm wire held at a potential of +4 kV above the grounded chamber walls. The collector foil to which the radioactive target debris is attached is placed in the space between the inner and outer chambers. The wall thicknesses of the inner and outer chambers are 330 μm and 254 μm , respectively. Methane, at atmospheric pressure, flows through the detector at a rate of 60 cc/min.

The proportional counter detection efficiency was measured by irradiating a 5 cm x 5 cm x 25 μm piece of aluminum foil with thermal neutrons to produce ^{28}Al . Counting rates are given by

$$\begin{aligned} N_\beta &= \epsilon_\beta A \\ N_\gamma &= \epsilon_\gamma A \\ N_{\beta\gamma} &= \epsilon_\beta \epsilon_\gamma A - N_\beta N_\gamma \tau \end{aligned}$$

where N_β , N_γ , $N_{\beta\gamma}$ are the beta, gamma, and the coincidence count rates; ϵ_β and ϵ_γ are the β and γ detector efficiencies; A is the ^{28}Al activity; and τ is the resolving time (0.1 μsec). The counting rates were measured after placing the ^{28}Al source on the inner surface of a collector foil and centered between the two ends of the proportional counter. The above equations were then solved to obtain the beta efficiencies shown in Table 1. For comparison, the plastic detector has a measured efficiency of 85%.

Table 1. Detection Efficiencies for Aluminum-28 Beta Particles

Detector	Measured	Calculated
Inner Copper	0.16	0.19
Outer Copper	0.29	0.34
Inner Aluminum	0.43	0.41
Outer Aluminum	----	----

Because the background increased at low energies, discriminators were adjusted to allow the counter to respond to signals in the 0.2-3.0 MeV range. The background count rate in this energy window was 0.14 cpm compared to 0.56 cpm with the plastic detector.

Computer Model

The efficiency of the proportional counter was estimated from a simple Monte Carlo computer model that used the Katz-Penfold estimate of electron ranges⁵. Electrons having an energy distribution identical to the ^{28}Al beta spectrum were launched in random directions from the source. Regions representing the aluminum source, the titanium collector foil, and the walls of the counter were included. All beta particles reaching the sensitive detector region with an energy above 32 eV, the ionization threshold for methane, were considered to be detected. The results of these calculations overestimated the measured efficiencies by about 20%.

High Efficiency Counter

We have also built a 150 μm thick aluminum inner detector. The efficiency of this detector was measured to be 43% which agreed well with the computer model. The measured background was the same as for the copper inner detector. Based on these results, a complete aluminum detector with 125 μm thick walls adjacent to the collector foil is being designed. It has a calculated efficiency of > 90% and should afford a considerable improvement over the plastic fluor system.

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Fig. 1 Radioactive target debris is collected following a high power laser irradiation of a glass microshell target.

Fig. 2 The collector foil is shown between the eight separate chambers of the outer detector and the single inner detector of the proportional counter.

Fig. 3 The outer detector of the miniature proportional counter, shown on top, is constructed of 254 μm copper while the inner detector is made of 330 μm copper. A more sensitive version of similar design, being built of 125 μm aluminum, will be more transparent to ^{28}Al beta particles.

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