A PRACTICAL BERYLLIUM ACTIVATION DETECTOR FOR MEASURING DD NEUTRON YIELD FROM ICF TARGETS.

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A practical beryllium activation detector for measuring DD neutron yield from ICF targets

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A neutron activation detector based on the reaction $^9\text{Be}(n,\alpha)^6\text{He}(\beta^-)^6\text{Li}$ has been designed which could potentially allow DD yield determinations within a few minutes after an ICF implosion or other pulsed neutron event with precision comparable to methods currently in use in ICF experiments. The detector is based on previous work, but has been redesigned to allow use in a reentrant tube less than six inches in diameter, and to increase detection efficiency. The detector consists of beryllium rods imbedded in plastic scintillator and coupled to a photomultiplier tube. Neutrons interact with the beryllium to produce $^6\text{He}$, which decays by emission of a $\beta^-$ particle with a maximum energy of 3.51 MeV with a half life of 808 ms. The $\beta^-$ particles are counted, and a neutron yield is determined from the total activity produced. The short half life of $^6\text{He}$ will result in high specific activity and allow quick determination of the amount of $^6\text{He}$ produced.
I. Introduction

Neutron yield measurements provide a good indicator of the overall quality of an implosion in inertial confinement fusion (ICF) and the ability to accurately predict neutron yield is often cited as an indicator of the accuracy of implosion modeling. Neutron yield is also often used as a gross indicator of the success of an experiment with a large deviation from expected yield indicative of a potential problem.

Indium activation is a commonly used method for determining the yield of neutrons from deuterium fusion reactions. Neutrons are produced in the reaction D(d,n)He and have energy of 2.45 MeV. The activation reaction \(^{115}\text{In}(n,n')^{115m}\text{In}\) has a large cross section at 2.45 MeV and has a threshold which makes it insensitive to thermal neutrons. The half-life for the decay (4.486 h) is, however, long compared to the typical time between experiments (~1 h) preventing the maximum accuracy from being obtained on each experiment without using several detectors. In addition, it is generally necessary for the activation sample to be retrieved and transported to a counting station. Results then await analysis after the completion of the counting. Results are, therefore, not generally available in time to affect decisions for the following experiment.

Fast results have been obtained using silver activation (half lives of 24.4 s and 2.42 min for the two component decay) [1] and plastic scintillators coupled to photomultiplier tubes [2]. Silver activation is sensitive to thermal neutrons, making it difficult to transfer a calibration in the laboratory to an experimental facility due to the changes in scattering geometry. Plastic scintillators are difficult to calibrate directly, but have been used to give quick estimates of neutron yield.
based on cross calibration factors determined from experiments in which an absolutely calibrated neutron activation system was also used.

In this paper, an absolutely calibratable neutron activation system is described which utilizes the reaction $^{9}\text{Be}(n,\alpha)^{6}\text{He}(\beta^-)^{6}\text{Li}$. The reaction has a large cross section at the energy of DD neutrons, and has a high threshold ($E_n=0.67$ MeV), preventing activation by thermal neutrons, and reducing sensitivity to scattered neutrons. The short half life of $^6\text{He}$ (808 ms) allows full counting in a few seconds, allowing quick yield determinations. The energy of the $\beta^-$ particle produced in the decay of $^6\text{He}$ allows the $\beta^-$ particle to escape the beryllium activation sample. By imbedding the beryllium in plastic scintillator, the production of the $\beta^-$ particles can be counted, and a yield can be determined based on laboratory calibrations.

**II. Detector based on the reaction $^{9}\text{Be}(n,\alpha)^{6}\text{He}(\beta^-)^{6}\text{Li}$**

The reaction for the formation of $^6\text{He}$ has a threshold at $E_n=0.67$ MeV, and the cross section[3-7] rises monotonically until about $E_n=3$ MeV, and then falls at higher energy (Fig. 1). $^6\text{He}$ decays through the emission of a $\beta^-$ particle, with a half life of 808 ms. The $\beta^-$ particles have a maximum energy of 3.51 MeV, and an average energy of about 1.5 MeV. The cross section for the reaction is fairly large at the energy of DD neutrons, and $\beta^-$ particles are easily and efficiently detected using inexpensive plastic scintillators.

A neutron activation detector based on this reaction has been previously described in the literature[8]. This paper describes a modification of this detector which should offer greater detection efficiency, and would be more suited for use on Nova, Omega, or other neutron-producing facilities.
The detector would consist of a cylinder of plastic scintillator, five inches in diameter and 2.5 inches thick, inside which 73 beryllium rods would be placed (Fig. 2), coupled to a 5-inch diameter photomultiplier tube. Each beryllium rod would be 2 inches long and 0.25 inches in diameter. By keeping the diameter of each rod small, a high probability for detecting the $\beta^-$ particles is insured. This compact design would allow the detector to be inserted into a reentrant tube less than six inches in diameter. Since the detector efficiency decreases with the square of the distance from the neutron source, a compact device which could be introduced into a reentrant tube giving closer access to the source would allow higher efficiency for detecting neutrons.

Pulses of light would be detected as the $\beta^-$ particles created in the decay of $^6$He stop in the scintillator. These pulses would be detected by a photomultiplier tube and amplified by a high-quality spectroscopy amplifier. A discriminator would then select pulses of the appropriate size, and feed pulses to a multichannel scaler which would record the count rate from the detector vs. time. The detected decay curve could then be analyzed to reveal the amount of $^6$He produced. Neutron yield can be related to $^6$He decays detected by a calibration done using a neutron generator.

Since the detector would consist of an organic scintillator, a flash of light would be created at the time of the shot due to x rays and neutrons interacting in the scintillator. This could drain most of the charge from the photomultiplier tube and base, as well as the output filter capacitors of the high voltage supply if nothing is done to prevent this. In order to prevent a loss of charge from the supply, and to allow the PMT to recover quickly after shot time, the PMT would be disconnected from the HV supply prior to the shot, and reconnected a few
milliseconds afterward. The PMT base might need modification to ensure a quick recovery, as well. This method (Fig. 3) has been used for a similar system using lead activation to measure neutrons from the T(d,n)\(^4\)He reaction on earlier lasers [9].

Since the PMT will be off at the time of the shot, a fiducial marker of some type should be recorded to allow a determination of the actual shot time. This could be accomplished by feeding a 100 kHz to 1 MHz square wave to the multichannel scaler for about 10 ms after T\(_0\). This would result in 1000 to 10,000 counts over background and should provide an unambiguous identification of T\(_0\).

The efficiency of the detector can be estimated. The detector described above has a total beryllium volume of 117 cm\(^3\), corresponding to 1.45 \(\times\) \(10^{25}\) beryllium atoms. If the detector were located 50 cm from the target, then a yield of \(10^7\) DD neutrons would result in \(350\) \(^6\)He nuclei being created. A detection efficiency of only 30% is required to get 100 counts and a statistical uncertainty of 10%. This is about a factor of 30 lower yield than that at which the current indium activation system [1] used on Nova has a 10% statistical uncertainty.

### III. Conclusions

A neutron activation detector based on the activation of beryllium can be constructed which is efficient, fast, and automatic. Since this detector could be absolutely calibrated, it could be used to provide neutron yields from ICF implosion experiments. Results would be available within minutes after the shot, allowing decisions affecting subsequent shot to be made quickly.
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References


Figures

Figure 1: Cross section for the $^9\text{Be}(n,\alpha)^6\text{He}$ reaction from references [3-7] along with a smoothed fit to the data.

Figure 2: Arrangement of 73 beryllium rods in a cylindrical scintillator.

Figure 3: Block diagram of the Beryllium Activation System as described in the text.
Figure 1
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Figure 2
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Figure 3
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