Tertiary Neutron Measurements by Carbon Activation

43rd Annual Meeting of the American Physical Society
Division of Plasma Physics
Long Beach, CA
29 October–2 November 2001

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The present carbon activation system is ready for $\rho R$ measurements of DT cryogenic targets on OMEGA.

- In 2001 we created a purification facility and a packaging method to reduce the contamination signal in the carbon samples.

- A new carbon activation counting station at 120 m from the target eliminates direct background from OMEGA shots.

- Recent experimental results have demonstrated that background and contamination can be reduced to a level adequate for tertiary neutron measurements on OMEGA.
Outline

Current status of the tertiary neutron diagnostic by carbon activation

- Introduction
- Carbon as an activation material
- Carbon purification
- Experimental setup
- Experimental data
- Interpretation of experimental data
- Conclusion
Measurement of tertiary neutrons can be used to determine the $\rho R$ of ICF targets

- **Primary DT fusion reaction:**
  \[ D + T \rightarrow \alpha + n \ (14.1 \text{ MeV}) \]

- **Secondary, 14.1-MeV neutrons scatter elastically in the fuel:**
  \[ n + D \rightarrow n' + D' \ (0 \text{ to } 12.5 \text{ MeV}) \]
  \[ n + T \rightarrow n' + T' \ (0 \text{ to } 10.6 \text{ MeV}) \]

- **Tertiary, in-flight fusion reaction:**
  \[ D' \ (0 \text{ to } 12.5 \text{ MeV}) + T \rightarrow \alpha + n'' \ (12 \text{ to } 30.0 \text{ MeV}) \]
  \[ T' \ (0 \text{ to } 10.6 \text{ MeV}) + D \rightarrow \alpha + n'' \ (9.2 \text{ to } 28.2 \text{ MeV}) \]

- For OMEGA, the yield of tertiary neutrons is proportional to $(\rho R)^2$.
- For the NIF, the yield of tertiary neutrons is proportional to $\rho R$. 
The present carbon activation system can be used for $\rho R$ measurements of OMEGA cryo-DT targets.

Solid angle $= 2.25 \times 10^{-3}$  
Efficiency $= 20\%$  
Activation/incident neutron $= 4 \times 10^{-2}$  
Counts/produced neutron $= 1.8 \times 10^{-5}$

At yield $= 10^{14}$ and $\rho R = 0.1$ g/cm$^2$; 3600 counts will be detected.
The carbon is a good tertiary activation material

- The $(n, 2n)$ reaction in $^{12}\text{C}$ has a threshold of 18.7 MeV.
- $^{11}\text{C}$ has a half-life of 20.3 min and emits positrons that produce two 511-keV gamma rays upon annihilation.

**Experimental cross section $^{12}\text{C} (n,2n) ^{11}\text{C}$**

The carbon must be very pure for tertiary activation

- Any contamination material that produces a positron emitter by interaction with 14.1-MeV neutrons will be the background for carbon activation.

- Since primary neutron yield is about $10^6$ larger than tertiary yield, contamination should be less than one part per million.

- Contamination levels producing the same decay signal as carbon:

<table>
<thead>
<tr>
<th>Material</th>
<th>Reaction</th>
<th>$N_{\text{cont.}}/N_{\text{carbon}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>$^{63}\text{Cu} \ (n,2n) \ ^{62}\text{Cu}$</td>
<td>$1.7 \times 10^{-8}$</td>
</tr>
<tr>
<td>Cu</td>
<td>$^{65}\text{Cu} \ (n,2n) \ ^{64}\text{Cu}$</td>
<td>$3.5 \times 10^{-7}$</td>
</tr>
<tr>
<td>N</td>
<td>$^{14}\text{N} \ (n,2n) \ ^{13}\text{N}$</td>
<td>$8.2 \times 10^{-7}$</td>
</tr>
<tr>
<td>Ni</td>
<td>$^{58}\text{Ni} \ (n,2n) \ ^{57}\text{Ni}$</td>
<td>$1.6 \times 10^{-5}$</td>
</tr>
<tr>
<td>Cr</td>
<td>$^{50}\text{Cr} \ (n,2n) \ ^{49}\text{Cr}$</td>
<td>$1.7 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

In our earlier experiments $N_2$ was the biggest source of contamination.
A carbon purification facility was built at the State University of New York at Geneseo

- Carbon disks were baked in vacuum at 1000°C for 8 hours to remove water and nitrogen.
- The disks stay under vacuum for 12 hours while cooling, to prevent fires.
- Oven was back filled with high-purity argon for 24 hours.
- Carbon disks were then sealed in vacuum bags in a glove bag with extra argon pressure.
The OMEGA copper activation system is used for primary DT yield measurements, secondary yield measurements, and carbon activation R & D.

Automatic pneumatic retractor
Cu/C disk: 76-mm diam × 9.5 mm
Disk-to-target distance: 40 cm
Carbon activation tests were carried out on the 30-kJ, 60-beam OMEGA laser system

- Glass-shell targets filled with 20 atm of DT were used in implosion experiments.
- These targets have very low $\rho R$ and do not produce tertiary neutrons.
- A 1-ns square laser pulse shape was used in these studies.
- Primary DT neutron yield was measured by a neutron-time-of-flight (nTOF) scintillating counter.
- The neutron yields in these tests ranged from $4 \times 10^{13}$ to $9.6 \times 10^{13}$. 
The background from high-yield shots in the counting station itself was eliminated on OMEGA.

A new counting station was set up at 120 m from target.
With the “sandwich” packaging, the contamination signals are below 50 counts.
The importance of “sandwich” can be explained by the process shown here.

Plastic bag

- $\sim 2 \times 10^{10}$ 14-MeV neutrons

Carbon foil

- $\sim 3 \times 10^6$ protons
- $^{12}\text{C}(p, \gamma)^{13}\text{N}$ producing reactions

Carbon disk

- $\sim 1.5 \times 10^3$ $^{13}\text{N}$-producing reactions
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