Current Status of Tertiary Neutron Diagnostic by Carbon Activation

511-keV Coincident Counts

Normalized to $7.4 \times 10^{13}$

Time (s)

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31st Annual Anomalous Absorption Conference
Sedona, AZ
3–8 June 2001
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The present carbon activation system can be used for $\rho R$ measurements of DT cryogenic targets on OMEGA.

- The $\rho R$ of cryogenic targets can be determined from the tertiary neutron yield.

- We perform several tests on OMEGA to study background and contamination signal of carbon activation.

- For these tests we use DT-filled glass targets with very low $\rho R$ that don’t produce tertiary neutrons.

- Carbon disks were purged in vacuum at 1000°C and filled with different gases: Ar, N$_2$, CO$_2$, and air.

- Purification and proper packaging reduced the false signal from contamination and secondary reactions to an acceptable level.
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:
  \[ n + D \rightarrow n' + D' \ (0–12.5 \text{ MeV}) \]
  \[ n + T \rightarrow n' + T' \ (0–10.6 \text{ MeV}) \]

- Tertiary, in-flight fusion reaction:
  \[ D' \ (0–12.5 \text{ MeV}) + T \rightarrow \alpha + n'' \ (12–30 \text{ MeV}) \]

- For NIF, the yield of tertiary neutrons is proportional to $\rho R$. 
Carbon is a good tertiary activation material

- The \((n, 2n)\) reaction in \(^{12}\text{C}\) has a threshold of about 20 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 \(^{12}\text{C} (n,2n) ^{11}\text{C}\)](https://example.com/cross-section.png)

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>
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.
- The carbon disks were cooled and stayed in a gas atmosphere for 24 hours.
- The carbon disks were then sealed in vacuum bags.
- The vacuum bags were opened 7 to 10 min before the laser shot.
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
The present carbon activation system can be used for $\rho R$ measurements of OMEGA cryo-DT targets.

\[
\begin{align*}
\text{Solid angle} &= 2.25 \times 10^{-3} \\
\text{Efficiency} &= 20\% \\
\text{Activation/incident neutron} &= 4 \times 10^{-2} \\
\text{Counts/produced neutron} &= 1.8 \times 10^{-5}
\end{align*}
\]

At yield $= 10^{14}$ and $\rho R = 0.1 \text{ g/cm}^2$ 3600 counts will be detected.
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 yield in these tests was from $4 \times 10^{13}$ to $9.6 \times 10^{13}$. 
With purification and proper packaging the contamination signal from carbon disk can be reduced substantially.

- Expected number of counts from OMEGA DT cryo target is about 2660.
The importance of “sandwich” can be explained by the process shown here.

- Plastic bag: ~2 \times 10^{10} 14-MeV neutrons
- Carbon foil: ~3 \times 10^6 protons
- Carbon disk: ~1.5 \times 10^3 13N-producing reactions

The reaction indicated is \( ^{12}\text{C}(p, \gamma)^{13}\text{N} \).
Pure samples, packaging, and handling procedures are all important for carbon activation diagnostics.

Different factors in order of importance:

- Use pure carbon sample, without internal contamination.
- Carbon disk should be wrapped in a plastic bag to prevent external contamination.
- “Sandwich” carbon disk to shield from protons.
- Minimize disk contact with air before shot.
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