Slow neutron detection without $^3$He: far ultraviolet noble-gas-excimer radiation induced by neutron reactions with $^6$Li and $^{10}$B

Patrick P. Hughes, Michael A. Coplan, Alan K. Thompson, Robert E. Vest, Jacob McComb, Amy Beasten, Mohamad I. Al-Sheikhly and Charles W. Clark

1Institute for Physical Science and Technology, University of Maryland (UMD)
2National Institute of Standards and Technology (NIST)
3Nuclear Engineering Program, UMD
4Joint Quantum Institute, NIST and UMD
Summary

We have quantified an efficient (30%) mechanism for channelling nuclear reaction energy into far ultraviolet radiation,

1 zero-energy neutron in ~1 atm noble gas

Source 3He, 6Li or 10B initiator

Gate

Drain

30,000 far ultraviolet photons out

and have implemented it in a package consistent with existing 3He and BF3 proportional counter architecture.
Outline

Original scientific motivation: understand the fate of the two atomic electrons in helium following the $^3\text{He}(n,tp)$ reaction

Observation of tens of Lyman alpha photons produced per absorbed neutron in a $^3\text{He}$ gas cell at atmospheric pressure

Lyman-alpha neutron detector published and patented – optical alternative to $^3\text{He}$ proportional counter

Amplification of far ultraviolet signal by factor of 1000 when heavier noble gases added to $^3\text{He}$ gas cell – due to noble-gas excimer emissions

Excimer mechanism validated for $^6\text{Li}$ and $^{10}\text{B}$ initiators – thin films and $\text{BF}_3$ gas – road to helium-free detector
Atomic electron excitation in nuclear reactions

What happens to the two atomic electrons in helium following the $^3\text{He}(n,tp)$ reaction?

Conversation with Tony Leggett: $^3\text{He} + n \rightarrow p + t + 764 \text{ keV}$ whereas electronic energies $\sim 100 \text{ eV}$ – but speeds of $p$, $t$ and electrons are comparable

Arif: “If you can find some independent atomic signatures, they might help us better quantify the reaction, which is very important for fundamental neutron dosimetry”

Lyman alpha detector package developed to search for excited states of atomic hydrogen in $^3\text{He}(n,tp)$ reaction cell
Lyman alpha detector package

Detect 2p – 1s radiation from excited H or T atoms produced by $^3\text{He}(n,tp)$ reaction products
10 Lyman alpha photons per reacted neutron

Due to series of charge-exchange and excitation collisions of the proton and triton reaction products

Prospective advantages of optical vs. gaseous electronics signals

<table>
<thead>
<tr>
<th>Attribute</th>
<th>LAND</th>
<th>Proportional Counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold detection rate</td>
<td>1 neutron/s</td>
<td>10 - 100 neutrons/s</td>
</tr>
<tr>
<td>Saturation detection rate</td>
<td>&gt;10³ neutrons/s</td>
<td>~10⁶ neutrons/s</td>
</tr>
<tr>
<td>Interference from non-neutron ionizing radiation</td>
<td>Readily suppressed with anti-coincidence techniques</td>
<td>Susceptible to false-positive electrical discharges</td>
</tr>
<tr>
<td>Operational modes</td>
<td>Pulse counting and current modes</td>
<td>Pulse counting mode only</td>
</tr>
<tr>
<td>Sensitivity to vibration and mechanical insult</td>
<td>Minimal with hardened detector package</td>
<td>Microphonic noise from anode wire at high voltage</td>
</tr>
<tr>
<td>Sensitivity to gas impurities</td>
<td>Optical mechanism insensitive to impurities</td>
<td>Electric discharge requires PPB gas purity</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>Minimal issues of alignment and assembly of COTS components</td>
<td>Exacting tolerances on anode wire diameter and wall surface finish</td>
</tr>
</tbody>
</table>

Number of Lyman alpha photons per reacted neutron vs. ³He pressure in cell
1000-fold amplification of far ultraviolet signals by addition of heavy noble gases

Number of far ultraviolet photons per reacted neutron vs. noble gas pressure.
Amplification mechanism: $X_2^*$ noble gas excimer emissions


Spectroscopy of $^3\text{He}(n,tp)$-induced excimer emissions

Absolute calibration of filter-detector pairs at the NIST SURF III Synchrotron Ultraviolet Radiation Facility.

Relative signal strength for various filters

Beyond $^3$He

In our first investigation, $^3$He served both as the initiator of the nuclear reaction *and* as the far ultraviolet amplification medium.

$^3$He is not that great as an amplification medium.

Nor is $^3$He especially wonderful as an initiator. We think that any nuclear reaction whose products have comparable energies to those of $^3$He($n,tp$).

We have now verified this for $^6$Li and $^{10}$B, using thin films and gas mixtures.
Thin Film Samples

$^{10}\text{Boron}$ 200 nm thick

$^{6}\text{LiCl}$ about 0.5 mm thick

Natural Boron 250 nm thick

Natural Boron 500 nm thick

$^{6}\text{Li}_2\text{CO}_3$ about 20 μm thick
$^6$Li Films

![Graph showing the number of photons per neutron reacted with particle escape as a function of gas pressure (kPa). The graph includes data for $^6$LiCl 0.5 mm thick lump with symbols for Argon (circles) and Xenon (squares).]
$^6\text{Li Films}$

Photon per Neutron Reacted with Particle Escape vs. Argon Pressure (kPa)

$^6\text{Li}_2\text{CO}_3$ Film
about 20 um thick
$^{10}$B Film

![Graph showing the relationship between Gas Pressure (kPa) and Photons per Neutron Reacted with Particle Escape for $^{10}$B Boron Film, 200 nm thick, with data points for Argon and Xenon gases.](image)
Natural B Films

Photons per Neutron Reacted with Particle Escape

Gas Pressure (kPa)

Natural Boron Film
250 nm thick

Argon

Xenon
Photoabsorption of BF3 measured at SURF III, May 2011