Cosmogenic tritium activation

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Slides taken from:
R. Saldanha (PNNL) and R. Thomas (UC)
3H problem

Current level

DAMIC-M Goal

• 3H Q-value: 18 keV
• 3H half-life: 12 years
• Created by spallation process driven by cosmogenic neutrons on the surface.
• Best guess cross section limits sea-level exposure of DAMIC-M detectors to ~2 months.

Should directly measure!

Other cosmogenic isotopes: $^{22}$Na, $^7$Be, $^{26}$Al.

<table>
<thead>
<tr>
<th>Material</th>
<th>Isotope</th>
<th>Production Rate (atoms/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>$^3$H</td>
<td>80</td>
</tr>
<tr>
<td>Si</td>
<td>$^3$H</td>
<td>125</td>
</tr>
</tbody>
</table>
Cosmogenic Production Rate of Tritium

One can calculate the predicted cosmogenic production rate of tritium on silicon and compare to values published in the literature.

Values vary by about one order of magnitude mostly due to cross-sections.

### Calculated in this work

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Production Rate [atoms/g$^{28}$Si]/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silberberg &amp; Tsao</td>
<td>0.104</td>
</tr>
<tr>
<td>TENDL 2015</td>
<td>0.142</td>
</tr>
<tr>
<td>ENDF BVIII</td>
<td>0.042</td>
</tr>
<tr>
<td>Geant4 QGSP_INCLXX</td>
<td>0.438</td>
</tr>
<tr>
<td>Geant4 Shielding</td>
<td>0.104</td>
</tr>
</tbody>
</table>

### Published Estimates

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Production Rate [atoms/g$^{28}$Si]/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mei 2016 ACTIVIA II</td>
<td>0.109</td>
</tr>
<tr>
<td>Mei 2016 ACTIVIA I</td>
<td>0.057</td>
</tr>
<tr>
<td>Mei 2016 Geant4</td>
<td>0.027</td>
</tr>
<tr>
<td>Jared</td>
<td>0.415</td>
</tr>
<tr>
<td>SuperCDMS 2017</td>
<td>0.125</td>
</tr>
</tbody>
</table>

These two pairs should be the same value.
The LANSCE ICE House neutron beam has very similar spectral shape to the cosmic neutron flux between 20 MeV and 600 MeV.

LANSCE Neutron beam flux is \(~ 1.1 \times 10^8\) times larger
(1 second beam exposure \(~ 3.5\) yrs sea-level exposure)
LANSCE Neutron Beam

Due to the extremely high neutron flux, the activation rate from the LANSCE beam is high
~ 0.02 Bq/g/day of irradiation
~ $10^5$ dru/day of irradiation
(1 dru = 1 ev/kg/day/keV)

Compare to the cosmic ray saturated activity
~ $10^{-6}$ Bq/g/day
~ 5 dru

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Production Rate [atoms/g($^{28}$Si)/day]</th>
<th>Activation Rate [Bq/g($^{28}$Si)/day]</th>
<th>Activation Rate [dru/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silberberg &amp; Tsao</td>
<td>$1.15 \times 10^7$</td>
<td>$2.10 \times 10^{-2}$</td>
<td>$1.01 \times 10^5$</td>
</tr>
<tr>
<td>TENDL 2015</td>
<td>$1.59 \times 10^7$</td>
<td>$2.80 \times 10^{-2}$</td>
<td>$1.34 \times 10^5$</td>
</tr>
<tr>
<td>ENDF BVIII</td>
<td>$4.68 \times 10^6$</td>
<td>$8.00 \times 10^{-3}$</td>
<td>$3.84 \times 10^4$</td>
</tr>
<tr>
<td>Geant4 QGSP_INCLXX</td>
<td>$4.44 \times 10^7$</td>
<td>$7.90 \times 10^{-2}$</td>
<td>$3.79 \times 10^5$</td>
</tr>
<tr>
<td>Geant4 Shielding</td>
<td>$9.51 \times 10^6$</td>
<td>$1.70 \times 10^{-2}$</td>
<td>$8.16 \times 10^4$</td>
</tr>
</tbody>
</table>
Bulk CCD Irradiation

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Activation Rate [Bq/g(²⁸Si)/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silberberg &amp; Tsao</td>
<td>6.90E-02</td>
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<tr>
<td>TENDL 2015</td>
<td>1.03E-01</td>
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<tr>
<td>ENDF BVIII</td>
<td>3.04E-02</td>
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<tr>
<td>Geant4 QGSP_INCLXX</td>
<td>2.55E-01</td>
</tr>
<tr>
<td>Geant4 Shielding</td>
<td>5.37E-02</td>
</tr>
</tbody>
</table>

Background rate in CCD bulk
~ 2.6x10⁻² Bq/g

20 hour irradiation will give a signal to background ratio of ~ 1 (8) in the case of the lowest (highest) cross-section

Radiation damage concerns

DAMIC CCDs previously irradiated with 400 MeV protons at 2×10¹⁰ protons/cm²

CCDs for the SNAP* satellite irradiated with 12.5 and 55 MeV protons at 10¹¹ protons/cm²

Performance losses (resolution) are acceptable for our purpose.

Equivalent to ~15 hours of irradiation on 4FP30R neutron** beam

In order to balance the signal to background ratio vs radiation damage concerns, we are requesting a total of 3 days of beam time with a staggered exposure of 3 CCDs.

**CCD # 1**
- 15 hour exposure
- Signal:Bkgd $\sim 0.8 - 6$
- Radiation damage 1x of previously tested fluence

**CCD # 2**
- 30 hour exposure
- Signal:Bkgd $\sim 1.5 - 12$
- Radiation damage 2x of previously tested fluence

**CCD # 3**
- 60 hour exposure
- Signal:Bkgd $\sim 3 - 24$
- Radiation damage 4x of previously tested fluence
Status

- Proposal was submitted to Los Alamos earlier this year (PNNL, UW, UC).
- We were awarded beam time 19\textsuperscript{th}–23\textsuperscript{rd} September.
- On going preparations: 2k x 4k CCD packaging + testing, CCD holder for beam line, considering ESD-safety precautions at LANSCE beam line (humidity, CCD handling, etc.)
- Also started activities to measure the activation of $^{22}\text{Na}$ and $^{7}\text{Be}$ activation from a previous LANSCE run (next slides).
Irradiated wafers

- R. Saldanha (PNNL) has ongoing campaign to measure the cosmogenic activation of $^{40}$Ar at LANSCE.
- In their last beam run they brought three silicon wafers that were irradiated with the neutron beam.
- Two wafers were kept at PNNL to screen with HPGe $\gamma$ counter while the third was sent to UC for screening with a CCD.
PNNL Gamma Counting

Wafers counted for 6.65 days in CASCADES Ge counter

Measured rates of 2 wafers (combined) as of 19th Feb 2018:

$^7\text{Be}$: $1.91 \pm 0.06$ (stat) Bq
$^{22}\text{Na}$: $2.84 \pm 0.04$ (stat) Bq

(corrected for gamma branching ratios)
UChicago Measurement Setup

- Taped activated wafer to copper holder and placed directly above front-illuminated DAMIC42 CCD at UChicago
- Also measured background using unactivated blank wafer
Measurements Results

- Took 6.34 days of exposure for activated wafer
- Took 12.77 days of exposure for blank wafer
Fit results

Best Fit Parameters

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$^{22}\text{Na}$</th>
<th>$^{7}\text{Be}$</th>
<th>$^{3}\text{H}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity (Bq)</td>
<td>$1.3 \pm 0.4$</td>
<td>$0.5 \pm 94$</td>
<td>$259 \pm 50$</td>
</tr>
<tr>
<td>Activity (Bq/g)</td>
<td>$0.34 \pm 0.09$</td>
<td>$0.147 \pm 24$</td>
<td>$67 \pm 13$</td>
</tr>
</tbody>
</table>

Compare to $1.42 \pm 0.02$ Bq from $\gamma$ counting