Background from Cosmogenic Activation in the DM-ICE Dark Matter Experiment

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Abstract:
DM-ICE is a quarter-ton-scale dark matter experiment planned for deployment deep in the ice at the South Pole. This experiment will search for the expected annual modulation signature in the dark matter signal using low-background NaI(Tl) scintillating crystals. Cosmogenic activation of the detectors during transport to and storage at the South Pole (altitude 9,301 feet) has the potential to produce long-lived radioisotopes which will add a significant source of background and threaten the discovery potential of this experiment. In data from the presently operating DM-ICE17 detectors, we examine decaying regions of the spectrum to identify activated isotopes and estimate activation effects. We compare these activation estimates to our simulation for the DM-ICE17 detectors and discuss the effects on the full-scale DM-ICE experiment.

Dark Matter Direct Detection:
Seek to measure energy from nuclear recoil of WIMP scattering
- Look for distinctive dark matter signal features to enable background reduction
- Differentiate between recoil type (electron vs. nuclear)
- CDMS, CRESST, EDELWEISS, XENON
- Annual modulation
- DAMA, CoGeNT, CDMS
- Directional sensitivity

What will it take to unambiguously test the DAMA claim? The DM-ICE Idea
- Run an experiment with the same target material (NaI(Tl))
- Inherit identical detector effects, particle interaction
- Go to the South Pole to alter the experimental systematics
- Experience opposite (e.g. muons) or absent (e.g. temperature) seasonal effects
- DM-ICE is the only planned or operating dark matter detector in the Southern Hemisphere

South Pole Deployment Challenge – Cosmogenic Activation:
- Cosmic ray particles can activate radioactive isotopes through spallation and capture processes (neutron-dominated)
- Increased cosmic ray flux with altitude
- South Pole (9,186 ft.) and flight altitude
- Decreased shielding at lower geomagnetic rigidity
- Minimized at polar latitudes around Earth B-field poles

Cosmogenic Activation in NaI Crystals:
Activation rates simulated using ACTIVIA code
- Based on Silberberg & Tsao semi-empirical formula
- Overestimates production of metastable isotopes
- Expect numerous cosmogenic isotopes to persist into data run
- Look for regions of spectra with decaying rate

121I – An Absolute Calibration Point
- Highest production rate of all crystal cosmogenics
- via 121I(n,3n)121B and 121I(n,3n)122Xe interactions
- Half-life (T1/2 = 59.41 days) is long to survive data run, but short enough to provide noticeable monthly decay

Cosmogenic Activation in Steel Pressure Vessel:
Search for other crystal cosmogenic isotopes in 2 year data set only yielded 125XeTe
- Lower production rates and longer half-lives make identification more challenging
- Allows quantification of overestimate of metastable tetruthenium isotope production
- Places limits on production expected in full-scale detector

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Cosmogenic Activation in Steel Pressure Vessel:
Activation rates based on scaling of steel
activation measurements for GERDA
- Only significant feature expected in data is 835 keV gamma from 56Mn
- Long-lived 56Mn will decay away slowly

Prospects for Future Deployments:
DM-ICE full-scale detector (~250-kg) is planned for deployment within few years

Cosmogenic activation provides calibration points for energy spectrum of detector
- At cost of raising background level (~0.1 cpd/kg/keV in region of interest < 10 keV)
- Target rate is 1 cpd/kg/keV in ROI

Faster commissioning period will give more short-lived calibration lines
- e.g. 123I-Te and 121I (crystal), 11Cr (steel)

Mitigation strategies are being explored as part of detector planning
- Reduction of flight timing in shipping
- Reduced time spent on Pole surface (e.g. tunnel storage)

For more information on DM-ICE, please see:
J. Cherwinka A search for the dark matter annual modulation at the South Pole, Astroparticle Physics, 35 (2012) 749-754

Table 1: NaI activated isotopes.

<table>
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<th>Isotope</th>
<th>Peak</th>
<th>Decay</th>
<th>Half-life</th>
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<tbody>
<tr>
<td>123I</td>
<td>X-rays</td>
<td>6.08 d</td>
<td></td>
</tr>
<tr>
<td>121I</td>
<td>X-rays</td>
<td>5.59 d</td>
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</tr>
<tr>
<td>120I</td>
<td>X--rays</td>
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<tr>
<td>121B</td>
<td>X-rays</td>
<td>164 d</td>
<td></td>
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<tr>
<td>122Xe</td>
<td>X-rays</td>
<td>115 d</td>
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<td>122I</td>
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<td>126I</td>
<td>X-rays</td>
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<tr>
<td>127I</td>
<td>X-rays</td>
<td>31.4 d</td>
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Deployment locations of DM-ICE17 devices within the IceCube array at 2450m depth