Preliminary results of SI2 experiment obtained by PADC track etch detectors

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Position of the AERI detectors in the middle of the box

The PADC sheets (marked with blue: 25, 24, 23, 21, 22) were placed close to the bottom of each stack → nearly in the same positions
Etching of the detectors in 6 N NaOH, 70°C

Detector material: polyallyl-diglycol-carbonate (PADC, TASTRAK, Bristol, UK)

Surface: 36 x 18 mm²

Thickness: 1 mm

1st step: 6h etching to measure the short range, high LET particles, 8 µm removal

2nd step: 15 h etching to measure lower LET & GCR particles, 20.1 µm removal
Investigations by optical microscope

1. Semi-automatic measurements using the VIRGINIA image analyzer → minor and major axes and other geometrical and optical parameters of the tracks

2. Manual measurements of long range HZE particle tracks → minor and major axes, projected range, depth
Calibration – converting the track etch rate ratio \( (V) \) obtained from the track parameters into LET

\[
\text{LET} = -99.8424 + 125.00172 V - 15.28166 V^2 + 2.04636 V^3, \quad r^2 = 0.9961
\]

\[
\text{LET} = -96.35071 + 114.90343 V - 7.77194 V^2 + 1.27248 V^3, \quad r^2 = 0.9926
\]
Expressions used during the calculations

**Differential flux**
\[ \Phi_D(L) = f_c(L) \frac{dN(L)}{dLET} (d\Omega AT)^{-1} \]

\[ \Phi_D(L) = \Phi_6(L) \text{if}\Phi_6(L) \geq \Phi_{15}(L) \text{otherwise}\Phi_D(L) = \Phi_{15}(L) \]

**Absorbed dose in water**
\[ D = \Omega \times 1.6 \times 10^{-6} \times T \times \sum (\Phi_D(L) \times \bar{L} \times dLET) \]

**Dose equivalent**
\[ H = \Omega \times 1.6 \times 10^{-6} \times T \times \sum (\Phi_D(L) \times \bar{L} \times Q(L) \times dLET) \]

**Averaged quality factor**
\[ Q = H / D \]

- \( dN(L) \) - group fluence
- \( dLET \) - LET interval
- \( d\Omega \) - possible solid angle of the incident particle
- \( A \) - scanned surface of the detector
- \( f_c(L) \) - LET and dip-angle dependent correction factor
- \( f_c(L) \) - mean LET
- \( Q(L) \) - LET dependent quality factor
- \( T \) - exposure time
LET spectra obtained on the PADC detector sheets
6h etching time

particle flux (cm$^{-2}$ d$^{-1}$ sr$^{-1}$ keV$^{-1}$ μm$^{-1}$)

LET in water (keV$\mu$m$^{-1}$)
Results obtained after 6 h etching
Lower limit of detection threshold: \(~17.5\) keV/\(\mu\)m

<table>
<thead>
<tr>
<th>Label</th>
<th>(D \pm 1\sigma) (mGy)</th>
<th>(H \pm 1\sigma) (mSv)</th>
<th>D rate (\pm 1\sigma) ((\mu)Gy/day)</th>
<th>H rate (\pm 1\sigma) ((\mu)Sv/day)</th>
<th>Q (\pm 1\sigma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>2.40 (\pm 0.18)</td>
<td>42.53 (\pm 1.87)</td>
<td>14.87 (\pm 1.14)</td>
<td>263.65 (\pm 11.61)</td>
<td>17.75 (\pm 0.58)</td>
</tr>
<tr>
<td>22</td>
<td>2.19 (\pm 0.37)</td>
<td>40.76 (\pm 5.98)</td>
<td>13.57 (\pm 2.24)</td>
<td>252.69 (\pm 37.07)</td>
<td>18.65 (\pm 0.35)</td>
</tr>
<tr>
<td>23</td>
<td>2.53 (\pm 0.03)</td>
<td>44.56 (\pm 0.45)</td>
<td>15.68 (\pm 0.19)</td>
<td>277.06 (\pm 3.45)</td>
<td>17.67 (\pm 0.01)</td>
</tr>
<tr>
<td>24</td>
<td>2.43 (\pm 0.08)</td>
<td>43.99 (\pm 1.14)</td>
<td>15.06 (\pm 0.47)</td>
<td>266.54 (\pm 7.09)</td>
<td>17.71 (\pm 0.08)</td>
</tr>
<tr>
<td>25</td>
<td>2.39 (\pm 0.13)</td>
<td>43.27 (\pm 3.35)</td>
<td>14.82 (\pm 0.79)</td>
<td>268.25 (\pm 20.81)</td>
<td>18.09 (\pm 0.44)</td>
</tr>
</tbody>
</table>
Combined results of 6h and 15 h etching
Lower limit of detection threshold: ~10 keV/μm
Only the evaluation of detector no. 21 has been completed

<table>
<thead>
<tr>
<th>Label</th>
<th>D ±1σ (mGy)</th>
<th>H ±1σ (mSv)</th>
<th>D rate ±1σ (μGy/day)</th>
<th>H rate ±1σ (μSv/day)</th>
<th>Q ±1σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>4.47 ± 0.16</td>
<td>54.22 ± 0.64</td>
<td>27.70 ± 0.97</td>
<td>336.13 ± 3.96</td>
<td>12.14 ± 0.28</td>
</tr>
</tbody>
</table>
### D, H and Q on the ISS
#### LET $\geq 10$ keV/µm

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mission date</th>
<th>Location</th>
<th>D rate $\pm 1\sigma$ (µGy/day)</th>
<th>H rate $\pm 1\sigma$ (µSv/day)</th>
<th>Q $\pm 1\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRADOS-1</td>
<td>02.24. – 31.10.2001</td>
<td>SM, P443</td>
<td>38.8 ± 8.2</td>
<td>324.8 ± 3.6</td>
<td>8.4 ± 1.8</td>
</tr>
<tr>
<td>BRADOS-3</td>
<td>02.02. – 28.10.2003</td>
<td>SM, P443</td>
<td>34.8</td>
<td>310.2</td>
<td>8.9</td>
</tr>
<tr>
<td>BRADOS-5</td>
<td>28.02. – 11.10.2005</td>
<td>SM, P443</td>
<td>27.0 ± 1.6</td>
<td>211.4 ± 14.4</td>
<td>7.9 ± 0.1</td>
</tr>
<tr>
<td>SI2</td>
<td>12.05. – 21.10.2007</td>
<td>SM at Matroshka-R</td>
<td>27.7 ± 0.9</td>
<td>336.1 ± 3.9</td>
<td>12.1 ± 0.3</td>
</tr>
</tbody>
</table>
Parameters after 8 µm surface removal:
minor axis: 17.81 µm
major axis: 18.21 µm
projected length: 185.46 µm
depth: 345.00 µm
calculated length: 396.49 µm
incident angle: 27.08°
LET > 1000 keV µm⁻¹

These long range tracks of HZE particles were not included in the dose calculations. Their track density was found small, ~ 43 cm⁻², versus the evaluated track density of 5860 cm⁻², measured, for instance on detector No. 23.
Distribution of the manually measured HZE tracks
detector No. 23

- GCR Fe peak at 137 keV µm⁻¹
- the higher LET particles need to be identified
- particles found above 1000 keV µm⁻¹
- the dose contribution is negligible (~ 1%)
Acknowledgement

The authors would like to thank the opportunities to take part in the calibration runs at BNL and HIMAC, in the BRADOS and Space Intercomparison-2 missions. Thanks for the work of all those who organized and performed these experiments.

References


Thanks for your attention!