A proposal on CR-39 PNTDs analysis for space radiation dosimetry

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Discrepancy of LET spectrum and dose results obtained by CR-39 PNTDs

Preliminary results of CR-39 PNTDs measured by some Institutes in the DOSIS-I experiment have some discrepancies on LET spectra and dose results of \( \pm > 40\% \) (T. Berger, 15\textsuperscript{th} WRMISS presentation)

- Difference of material
- Difference of track measurement and analysis methods

For the understanding of such discrepancies...

Verify the variation of dose result by:

1) Position dependency
2) Analyzing area size dependency
3) Track selection criteria dependency

Trials were done as the part of work in DOSIS-I
Typical “NIRS method” for space radiation dosimetry

- **Detector**: HARZLAS/TD-1 (0.9 mmt)
- **Etching condition**: 7mol/l NaOH 70°C 8hr
  \[ \Rightarrow \text{Bulk etch: } 14.7 \mu m \]
- **Scanning**: - HSP-1000 microscope x20 (0.35mm/pix res.)
  - Area size 4mm²
- **Analysis**:  - Semi-automatic analysis by PitFit software
  - Select only penetrating track by eye
    (i.e. taking no over-etched track)
  - Track registration sensitivity \( (S=V_t/V_b-1) \) is obtained using the track size of opening-mouth:

\[
S \equiv \frac{V_t}{V_b} - 1 = \sqrt{\frac{16B^2D^2}{(4B^2-d^2)^2}} + 1 - 1
\]

\( (D: \text{major axis, } d: \text{minor axis, } B: \text{bulk etch}) \)
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\((D: \text{major axis}, d: \text{minor axis}, B: \text{bulk etch})\)
1) Position dependency

Trial 1

- Difference of dose results for the measurement position on the detector with the detector size of 16mmx16mm
- Analysis at different 3 positions (#1, #2, #3)
- Analyzing area size for each position is 2mmx2mm
Dose results for different 3 positions. LET threshold: 10 keV/µm.

<table>
<thead>
<tr>
<th></th>
<th>D [mGy]</th>
<th>H [mSv]</th>
<th>D rate [uGy/d]</th>
<th>H rate [uSv/d]</th>
<th>Q</th>
<th>Track density [cm(^{-2})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>2.1 ± 0.1</td>
<td>24.1 ± 2.6</td>
<td>15.1 ± 1.0</td>
<td>177.8 ± 19.4</td>
<td>11.8 ± 1.5</td>
<td>6432</td>
</tr>
<tr>
<td>#2</td>
<td>2.1 ± 0.2</td>
<td>27.6 ± 2.9</td>
<td>15.8 ± 1.1</td>
<td>203.5 ± 21.5</td>
<td>12.9 ± 1.6</td>
<td>6308</td>
</tr>
<tr>
<td>#3</td>
<td>2.2 ± 0.2</td>
<td>30.2 ± 3.1</td>
<td>16.2 ± 1.2</td>
<td>222.2 ± 22.5</td>
<td>13.7 ± 1.7</td>
<td>6184</td>
</tr>
</tbody>
</table>

Remarkable dose dispersion was not found for position difference of 16 mm x 16 mm in size.
2) Analyzing area size dependency

Trial 2

Difference of dose results for the difference of area size: 4 mm$^2$ and 12 mm$^2$
Dose results for 4mm$^2$ and 12mm$^2$ area sizes. LET threshold: 10 keV/\(\mu\)m.

<table>
<thead>
<tr>
<th></th>
<th>D [mGy]</th>
<th>H [mSv]</th>
<th>D rate [uGy/d]</th>
<th>H rate [uSv/d]</th>
<th>Q</th>
<th>Track density [cm$^{-2}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4mm$^2$</td>
<td>2.1 ± 0.1</td>
<td>24.1 ± 2.6</td>
<td>15.1 ± 1.0</td>
<td>177.8 ± 19.4</td>
<td>11.8 ± 1.5</td>
<td>6432</td>
</tr>
<tr>
<td>12mm$^2$</td>
<td>2.1 ± 0.1</td>
<td>27.3 ± 1.7</td>
<td>15.7 ± 0.6</td>
<td>201.2 ± 12.2</td>
<td>12.8 ± 0.9</td>
<td>6308</td>
</tr>
</tbody>
</table>

- 3 times measurement statistics (4mm$^2$→12mm$^2$):
  - LET range: <366 keV/\(\mu\)m@4mm$^2$ → <447 keV/\(\mu\)m@12mm$^2$
  - Remarkable dose dispersion was not found (within error bar)
  - Detected number of penetrating track over 500 keV/\(\mu\)m:
    - 4 mm$^2$ → 0 event
    - 12 mm$^2$ → 1 event
# This 1 event data was not included in the results because the measured track registration sensitivity (S) is too high to be out of range in our method (Limitation of S measurement in NIRS method is S<20)
Calibration of NIRS CR-39 PNTD (TD-1)

- Measurable range of track registration sensitivity (S) is $S=0.01\sim20$ in our analysis method
- Calibrated LET range is from 5 to 450 keV/µm (proton~Krypton)
For detecting very high LET particles over 500 keV/µm, how large are size of CR-39 should we analyze?

We need to analyze about 10 times area size for detecting a very high LET (>∼500 keV/µm) penetrating particle comparison with a Fe track, because its abundance is about 10^{-1} for Fe abundance.

RRMD-III / STS-89 (Doke et al., 2001)

Very high LET penetrating particles >∼500 keV/µm

Fig. 10. LET distribution for GCR particles observed by RRMD-III on board STS-89.
Possibility of “self-calibration” of LET spectrum using relativistic Fe peak appeared around 135 keV/\(\mu m\)

Relativistic Fe peak appeared on the LET spectrum can be used as self-calibration of CR-39 PNTDs during on-flight, because the Fe peak is obvious evidence of GCR component marking on the LET spectrum.

RRMD-III / STS-89
(Doke et al., 2001)

Very high LET penetrating particles >~500 keV/\(\mu m\)

Fig. 10. LET distribution for GCR particles observed by RRMD-III on board STS-89.
3) Track selection criteria

Trial 3 Comparison of dose results by the track selection

[case-1] Only penetrating tracks are analyzed

[case-2] All tracks are analyzed including over-etched tracks

(a) [case-1] Reject

(b) [case-2] Include

*Primary tracks passing through the detector*
*Short range tracks stopped near the surface*

*NIRS method*
[case-1] Only penetrating tracks are analyzed
[case-2] All tracks are analyzed including over-etched tracks

Dose results for 2 case of track selection. # Area size: 12 mm²

<table>
<thead>
<tr>
<th></th>
<th>D [mGy]</th>
<th>H [mSv]</th>
<th>D rate [uGy/d]</th>
<th>H rate [uSv/d]</th>
<th>Q</th>
<th>Track density [cm⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>2.1 ± 0.1</td>
<td>27.3 ± 1.7</td>
<td>15.7 ± 0.6</td>
<td>201.2 ± 12.2</td>
<td>12.8 ± 0.9</td>
<td>6308</td>
</tr>
<tr>
<td>Case-2</td>
<td>2.9 ± 0.1</td>
<td>39.6 ± 2.0</td>
<td>21.7 ± 0.8</td>
<td>291.7 ± 15.1</td>
<td>13.5 ± 0.9</td>
<td>8106</td>
</tr>
</tbody>
</table>

- Dose equivalent rate obtained by taking all tracks including over-etched tracks ([case-1]) is +45% larger than the case by taking only penetrating track ([case-2])
- Treatment of over-etched tracks largely contributes to the dose variation
How to treat over-etched tracks

- Considerable candidate of such over-etched track is short range track produced by the proton-induced target fragmentation reaction.

- For the precise measurement of short range tracks:
  - AFM method
  - 3D track determination method etc.

  → There are some difficulties for routine monitoring
  → Need to research for the quantitative evaluation of additional dose contribution

- For the convenient way to include short range tracks:
  - Short and long etching combination method
  → Need to determine adequate bulk etch condition and how to combine both data
**Summary**

**Position dependency**

Remarkable dose dispersion was not found for position difference of 16 mm x 16 mm in size.

**Analyzing area size dependency**

- Increase of statistics to be 3 times (4 mm\(^2\) → 12 mm\(^2\)) did not make a remarkable change of dose results.
- We need to analyze about 10 times area size for detecting a very high LET (>\(\sim 500\text{keV/}\mu\text{m}\)) penetrating particle comparison with a Fe track.

**Track selection criteria dependency**

- Dose equivalent rate obtained by taking all tracks including over-etched tracks is +45% larger than the case by taking only penetrating track.
- How to treat over-etched tracks is important.
Suggestion of discussion for making guide line on CR-39 analysis

1. Analyzing area size
   - Recommendation of statistics (analyzing area size) for detecting very high LET particles (penetrating) >500 keV/µm

2. How to treat the over-etched tracks
   - Common methodology for the routine monitoring of daily dose e.g.) short and long etching combination
     * Common condition of bulk etch
     * Common way to combine the data from short & long etchings

Working Group Prepare the Guideline on CR-39 Analysis (all of you agree)

Nakahiro will be back…soon!
Back up slides
T. Berger, 38th COSPAR presentation

**DOSIS - CR-39 Preliminary results**

- **Fluence** $[\text{cm}^2\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}\mu\text{m}]$

- **LET in H$_2$O** $[\text{keV}^{-1}\mu\text{m}]$

- Legend:
  - AERI
  - NPI
  - IFJ
  - DLR
  - JSC
### DOSIS – CR-39 Preliminary results

<table>
<thead>
<tr>
<th>LET range [keV/μm]</th>
<th>D [mGy]</th>
<th>H [mSv]</th>
<th>Q [mean]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TeV</td>
<td>10 – 446</td>
<td>6.36</td>
<td>77.75</td>
</tr>
<tr>
<td></td>
<td>8.2 – 366</td>
<td>3.424</td>
<td>34.28</td>
</tr>
<tr>
<td>AEKI</td>
<td>10 – 1000</td>
<td>4.07</td>
<td>39.35</td>
</tr>
<tr>
<td>DLR</td>
<td>10 – 3305</td>
<td>5.13</td>
<td>71.216</td>
</tr>
<tr>
<td>NASA</td>
<td>10 - 2600</td>
<td>5.08</td>
<td>53.80</td>
</tr>
</tbody>
</table>
Variation of LET spectrum for each etching level

Enhancement of flux at high LET region for short etching

\[ \text{Flux} \left[ \text{cm}^2 \cdot \text{sr} \cdot \text{sec} \cdot \left( \text{keV} / \mu \text{m} \right) \right] \]

\[ B = 53.1 \mu \text{m} \text{ (24hr)} \]
$H > LET$ (mSv)

Rejected over-etched tracks

All tracks

LET in water [keV/µm]