3D Dose Distribution Measurements by Passive Detectors in the Columbus Module

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Introduction – DOSIS-3D

- Follow up experiment of the Dosis Project (2009-2011)
- Goal: obtaining 3 dimensional dose distribution information at different locations and shielding conditions
  - Active parts: DOSTEL-1 and DOSTEL-2 dosimetry telescopes
  - Combined passive detector packages at 11 locations
    (TLDs: low LET radiation, SSNTDs: high LET radiation >10 keV/µm)
- 6 completed phases since 2012
Introduction – Space Weather

• Systematic decrease of neutron count rate → decreasing number of high LET GCR particles

• Increased solar activity between 2014 and 2015
Detector Packages

MTA EK stack 1
- 6 pcs of TLDs (3 x $^6$LiF, 3 x $^7$LiF)
- 2 layer of SSNTDs

MTA EK stack 2
- 8 pcs of TLDs (4 x $^6$LiF, 4 x $^7$LiF)

Passive Detector Package 1
at 10 locations + x, y, z

Passive Detector Package 2
at 10 locations + x
Detector Packages - Locations

Detectors arranged in 3D

Star CONE (X direction)

← Forward
Method

• **SSNTD**: etching in 2 steps in 6 N NaOH solution at 70 °C
  (TASTRAK material, produced by TASL, Bristol, U.K.)
  - pre-exposure irradiation ($^{210}$Po) → etched off layer
  - **6 h etching**: high LET particle tracks become visible
    (circular and elliptical tracks measured automatically + HZE tracks measured manually)
  - **15 h etching**: low LET particle tracks become visible
    (only circular and elliptical tracks measured automatically)
  → final LET spectra obtained from the combined 6h & HZE & 15h results

• **TLD**:
  (MTS-N, MTS-6, MTS-7)
  - pre-exposure annealing at 400 °C (1 h) and 100 °C (2 h)
  - readout by a Harshaw 2000 instrument
    (evaluation based on the dosimetric (5th) peak)
  - post-exposure annealing at 400 °C (1 h) and 100 °C (2 h)
  - detectors individually calibrated using a $^{137}$Cs source
Results – Track Detectors (D)

- The Y and Z orientations were not constant

<table>
<thead>
<tr>
<th></th>
<th>3D/1</th>
<th>3D/2</th>
<th>3D/3</th>
<th>3D/4</th>
<th>3D/5</th>
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<tbody>
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<td>Z</td>
<td>Y</td>
<td>Y</td>
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<td>Y</td>
<td>X</td>
<td>Y</td>
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PDP 1 Package (D)

Absorbed Dose Rate (μGy/d)

- X cone varied

Graph showing absorbed dose rate for different boxes and orientations.
Results – Track Detectors (H)

• The Y and Z orientations were not constant

PDP 1 Package (H)
Results – Track Detectors (D)

- $D_{fwd} < D_{aft}$ tendency in most phases

PDP 1 Package (D)

Boxes listed according to increasing $D$
Results - LET spectra

3D/1: highest overall dose rate
- box-2: highest dose rate
- box-3: lowest dose rate

3D/3: lowest overall dose rate
- box-2: highest dose rate
- box-3: lowest dose rate

Very few particles over 200 keV/µm

- Space weather conditions were the same in average
- ~ 5 km higher altitude during 3D/3
- Differences in shielding?
Results – Thermoluminescent Detectors

- The Y and Z orientations were not constant

<table>
<thead>
<tr>
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<th>3D/3</th>
<th>3D/4</th>
<th>3D/5</th>
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<tr>
<td>Y</td>
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<td></td>
<td>Z</td>
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</table>

PDP 1 Package

Absorbed Dose Rate (μGy/d)

- 3D/1 MTS-6
- 3D/1 MTS-7
- 3D/2 MTS-N
- 3D/2 MTS-6
- 3D/3 MTS-7
- 3D/4 MTS-6
- 3D/4 MTS-7
- 3D/5 MTS-6
- 3D/5 MTS-7

<table>
<thead>
<tr>
<th>Box 1</th>
<th>Box 2</th>
<th>Box 3</th>
<th>Box 4</th>
<th>Box 5</th>
<th>Box 6</th>
<th>Box 7</th>
<th>Box 8</th>
<th>Box 9</th>
<th>Box 10</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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<td></td>
<td></td>
<td>cone</td>
<td>varied</td>
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</table>
Results – Thermoluminescent Detectors

Dosimetric package

PDP 2: smaller differences of D in the successive phases

\[ \sigma_D \text{ in average in the boxes: } MTS-6: \pm 15 \mu\text{Gy/d}; MTS-7: \pm 12 \mu\text{Gy/d} \]

PDP 1: twice as high deviation of D

\[ \sigma_D \text{ in average in the boxes : } MTS-6: \pm 31 \mu\text{Gy/d}; MTS-7: \pm 27 \mu\text{Gy/d} \]
Latest Results – 3D/5 TLD & SSNTD combined

- Convolution of low LET (≤ 10 keV/μm) and high LET (≥ 10 keV/μm) portions of radiation using the TLD (MTS-7) and SSNTD results → total D, total H, average Q

### Latest Results

<table>
<thead>
<tr>
<th>Box No.</th>
<th>Average Q</th>
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<tbody>
<tr>
<td>1</td>
<td>2.60</td>
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<tr>
<td>2</td>
<td>2.58</td>
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<td>3</td>
<td>2.85</td>
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<td>8</td>
<td>2.67</td>
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<td>9</td>
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<tr>
<td>10</td>
<td>2.68</td>
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<tr>
<td>X (cone)</td>
<td>2.57</td>
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<tr>
<td>Y (ovhd)</td>
<td>2.56</td>
</tr>
<tr>
<td>Z (aft)</td>
<td>2.54</td>
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</table>

3D/5 (PDP 1)

- D full range
- D under 10 keV/μm

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Conclusions

• *Space weather*: increasing solar activity between 2014 and 2015 decreasing neutron monitor signal (Oulu) $\rightarrow$ decreasing number of high LET GCR particles

• *Changes in the altitude*
  - 3D/1 $\rightarrow$ 2: + 10 km
  - 3D/3, 4, 5 $\rightarrow$ ± 5 km

• The dosimetric values are influenced by the different shielding conditions of the boxes (*same tendency of dose rates at the locations* in all phases)

• The orientation of the 3D package was not constant $\rightarrow$ difficult to correlate the observed results

• Dose rates were *tendentiously lower in the forward direction* than in the aft in most phases (presumably due to the shielding differences)

• Open question: 3D/3 – very few high LET particles ($\rightarrow$ low D)?
Thank you for your attention!

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Passive Dosimetry Laboratory

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