Time variation of dose quantities obtained by passive dosimeters onboard International Space Station

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Background

Passive dosimeters consisting of CR-39 PNTD and TLD are utilized as a space radiation dosimeter in ISS

- Small, lightweight and easy handle to monitor dose for person with low cost and without electric power
- No information on time (non real-time monitoring)

If passive dosimetry is carried out to monitor dose in several batches through a few years, is it possible to look at the time variation of dose quantities using them and show the consistency of dose results with the active detectors?
Biotrack space experiments

- Piers-1 module in International Space Station
- Passive dosimeters
  - CR-39 (HARZLAS/TD-1) PNTD
  - TLD-100 (LiF)
- 6 experiments with different terms between Jan. 2007 and Oct. 2008 (~2yrs)
- All of experiments (we call BE01~BE07) have been carried out in the same position using the same detectors
Time line charts of Biotrack space experiments (BE)

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Flight Schedule</th>
<th>Day [day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE01</td>
<td>Jan. 19, 2007 - Apr. 21, 2007</td>
<td>92</td>
</tr>
<tr>
<td>BE03</td>
<td>Jan. 19, 2007 - Apr. 19, 2008</td>
<td>455</td>
</tr>
<tr>
<td>BE05</td>
<td>Oct. 10, 2007 - Apr. 19, 2008</td>
<td>191</td>
</tr>
</tbody>
</table>

Objectives

- Verifying the time variation of dose quantities in ISS using Passive dosimeters with different durations.
- Comparing with the data of other active detectors.
By extracting and merging different or overlapped terms, exposure duration can be separated to 4 terms (I~IV)
Dose derivation using CR-39 and TLD

Absorbed dose: \( D_{\text{Total}} \) [mGy]

\[
D_{\text{Total}} = D_{\leq 10\text{keV/\(\mu\)m}} + D_{>10\text{keV/\(\mu\)m}} \\
= (D_{\text{TLD}} - \kappa D_{\text{CR-39}}) + D_{\text{CR-39}} \\
= D_{\text{TLD}} + (1 - \kappa) D_{\text{CR-39}}
\]

Dose equivalent: \( H_{\text{Total}} \) [mSv]

\[
H_{\text{Total}} = D_{\leq 10\text{keV/\(\mu\)m}} + H_{>10\text{keV/\(\mu\)m}} \\
= (D_{\text{TLD}} - \kappa D_{\text{CR-39}}) + H_{\text{CR-39}}
\]

Mean quality factor: \( Q_{\text{Mean}} \)

\[
Q_{\text{Mean}} = H_{\text{Total}} / D_{\text{Total}}
\]

\( \kappa \): proportional constant

(Doke et al., 1995)

10 keV/\(\mu\)m

LETrater [keV/\(\mu\)m]

ICRP-60

CR-39

TLD
LET spectra obtained by CR-39

![Graphs showing LET spectra for different samples labeled BE01 to BE07. Each graph represents a different period of measurement, from Jan. 19, 2007, to Apr. 19, 2008, with specific dates for each sample. The x-axis represents LET in water [keV/µm], and the y-axis represents dN/dL [cm²·sr·sec·(keV/µm)] on a logarithmic scale.]
## Results of dose quantities

<table>
<thead>
<tr>
<th>Term [DOY]</th>
<th>$D_{\text{Total}}$ [mGy]</th>
<th>$D_{\text{Total}}$ rate [mGy/day]</th>
<th>$H_{\text{Total}}$ [mGy]</th>
<th>$H_{\text{Total}}$ rate [mSv/day]</th>
<th>$Q_{\text{Total}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>21.8±0.6</td>
<td>237.2±7.0</td>
<td>58.7±1.5</td>
<td>637.5±16.2</td>
<td>2.7±0.1</td>
</tr>
<tr>
<td>II</td>
<td>51.6±2.5</td>
<td>280.5±13.4</td>
<td>93.5±4.9</td>
<td>508.3±26.5</td>
<td>1.8±0.1</td>
</tr>
<tr>
<td>III</td>
<td>58.3±3.0</td>
<td>323.7±16.5</td>
<td>100.2±7.7</td>
<td>556.8±42.7</td>
<td>1.7±0.2</td>
</tr>
<tr>
<td>IV</td>
<td>70.9±3.2</td>
<td>377.2±17.1</td>
<td>189.1±9.8</td>
<td>1006.0±52.0</td>
<td>2.7±0.2</td>
</tr>
</tbody>
</table>

*Separated to 4 terms (I~IV)*
Time variations with solar activities

- Using BE06 data for Term IV
- Using BE07 data for Term IV

![Graph showing time variations with solar activities](image-url)

- D_{Total} [µGy/day]
- H_{Total} [µSv/day]
- Q_{Total}

Sunspot number

Solar wind velocity [km/sec]

$\langle |B| \rangle$ [nT]

DOY since 2007
2007~2009: Decreasing the solar activity

Long-term solar activity

Cycle-23

This work

Increasing GCR intensity @ 2007→2009

Proton: GOES-NOAA

Proton fluence $[\text{cm}^{-2} \cdot \text{day} \cdot \text{sr}]$

DOY since 2007

Proton E>100MeV (GOES-NOAA)

Heavy: ACE-CRIS

Flux $[\text{cm}^{-2} \cdot \text{sr} \cdot \text{sec} \cdot \text{MeV}/\text{n}]$

E=100~500 MeV/n (ACE/CRIS)
Comparison with ACE-CRIS data (GCR data)

Increasing rate:
\[
\left( \frac{D_{IV}}{D_I} \right)_{\text{This work}} \approx +160\% 
\]

Exceed over +45%

Increasing rate:
\[
\left( \frac{D_{IV}}{D_I} \right)_{\text{ACE-CRIS}} \approx +115\% 
\]

Effect of thick shielding inside ISS ??

This work

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\[
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Effect of thick shielding inside ISS ??

Cal. from ACE-CRIS level 2 data
Comparison with DB-8 detector in ISS

This work

Using BE06 data for Term IV
Using BE07 data for Term IV

DB-8 data from Benghin et al., 37th COSPAR 2008
Absorbed dose rate [µGy/day]

CR-39+TLD (This work)
DB-8 No 1 Starboard Side / Behind Board No 410 (Unshielded)
DB-8 No 1 Starboard Side / Behind Board No 410 (Shielded)
DB-8 No 2 Port Side / Behind Board No 244 (Cabin) (Unshielded)
DB-8 No 2 Port Side / Behind Board No 244 (Cabin) (Shielded)
DB-8 No 3 Starboard Side / Behind Board No 447 (Cabin) (Unshielded)
DB-8 No 3 Starboard Side / Behind Board No 447 (Cabin) (Shielded)
DB-8 No 4 Starboard Side / Behind Board No 435 (Unshielded)
DB-8 No 4 Starboard Side / Behind Board No 435 (Shielded)

DB-8 data from Benghin et al.,
37th COSPAR 2008

Preliminary
Time variation of absorbed dose and increasing rate obtained by this work are consistent with the results obtained by DB-8 detector within error bar.

→ One factor of dose excess compared with ACE data is thought to be due to the shielding inside ISS or contribution of trapped particles in radiation belt.
Summary

- Using 6 data (BE01~BE07) with different durations between Jan. 2007 and Oct. 2008 (~2yrs), the time variation of dose quantities using passive dosimeters (CR-39+TLD) was verified.

- Dose quantity from I to IV terms was increase tendency and the increasing rate of absorbed dose is ~+160% ($D_{IV}/D_{I}$ ratio), which is not consistent with the estimation of GCR intensity increase (~115%) obtained by ACR-CRIS.

- Increasing rate obtained by this work is good agreement with the data by DB-8 inside same cabin.

- The discrepancy with GCR data obtained by ACE might be explained by the effect of thick shielding inside ISS or contribution of trapped particles in radiation belt.
Principle of track detection in CR-39

Detector response (S):

\[ S \equiv \frac{V_t}{V_b} - 1 = f(\text{LET}) \]

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

→ Absorbed dose (D)
Dose equivalent (H)