Secondary Neutron and Cosmic Ray Studies on the ISS Using SSNTD Stacks, BRADOS Projects, 2001 - 2003

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### Brados-1 stack composition

<table>
<thead>
<tr>
<th>Layer No.</th>
<th>Material</th>
<th>Density, g/cm³</th>
<th>Thickness, µm</th>
<th>Thickness, mg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 3, 5</td>
<td>CR-39</td>
<td>1.3</td>
<td>1180</td>
<td>153.4</td>
</tr>
<tr>
<td>2</td>
<td>Ti</td>
<td>4.52</td>
<td>50</td>
<td>22.6</td>
</tr>
<tr>
<td>4</td>
<td>Macrofol</td>
<td>1.28</td>
<td>195</td>
<td>24.5</td>
</tr>
</tbody>
</table>

Total thickness: 507.3 mg/cm², Area of 1 sheet: 10 cm²

7 of them were placed at different positions in the Service Module

**Stacks launched on** 24-02-2001 by Progress 244  
**248 days flight time**  
**Returned to Earth on 31-10-2001 by Sayouz TM-32**
Composition of BRADOS - 3 stacks

Top

- Al, 240 micron cover
- CR-39, 1mm
- Lexan, 1mm
- CR-39, 1mm
- Ti, 100 micron n, p converter, p filter
- Al, 240 micron cover
Three-focal presentation of tracks originated from $^{12}\text{C}(n,n',3\alpha)$ interaction in CR-39, exposed at CERF in CR position (TASTRAK, 6n NaOH, 70 °C, 12 h etching)

<table>
<thead>
<tr>
<th>REACTION</th>
<th>THRESHOLD ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}\text{C}(n,3\alpha)$</td>
<td>15 MeV</td>
</tr>
<tr>
<td>$^{12}\text{C}(n,T)$</td>
<td>10 MeV</td>
</tr>
<tr>
<td>$^{12}\text{C}(n,D)$</td>
<td>8 MeV</td>
</tr>
<tr>
<td>$^{12}\text{C}(n,p)$</td>
<td>5 MeV</td>
</tr>
</tbody>
</table>
**We learnt from CERF exposures**

Conversion factor for H* is 1.19 $\mu$Sv cm$^2$, (depends on the operation parameters)

Response for C an O recoils: $R=2.4 \times 10^{-6}$

Response for charged particle production: $R=4.8 \times 10^{-7}$

Valid for the neutron spectrum at CERF facility, concrete roof position

TASTRAK CR-39, etched in 6 N NaOH at 70 °C for 6 h
### Data

<table>
<thead>
<tr>
<th>Data</th>
<th>ISS</th>
<th>CERF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averaged energy in MeV, $E_{\text{threshold}}=1$ keV</td>
<td>3.38</td>
<td>46.8</td>
</tr>
<tr>
<td>Fluence ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_{\text{threshold}}=1$ keV</td>
<td>0.134</td>
<td>0.557</td>
</tr>
<tr>
<td>$200 \text{keV} &lt; E &lt; 20 \text{MeV}$</td>
<td>0.509</td>
<td>0.456</td>
</tr>
<tr>
<td>$E &gt; 5$ MeV</td>
<td>218</td>
<td>312</td>
</tr>
<tr>
<td>$E &gt; 5$ MeV</td>
<td>453</td>
<td>350</td>
</tr>
<tr>
<td>$200 \text{keV} &lt; E &lt; 20 \text{MeV}$</td>
<td>365</td>
<td>406</td>
</tr>
</tbody>
</table>

The diagram shows the fluence per unit log energy (lethargy) for different energy thresholds and energy ranges, with the data represented by the graph overlays for ISS and CERF.
Table 2 The neutron ambient dose equivalent rates at different position in the Zvezda (Service) modul of the ISS, measured during the BRADOS 1, 2 & 3 (B1, B2, B3) experiments.

<table>
<thead>
<tr>
<th>Location in the Service module: box and panel numbers</th>
<th>A11</th>
<th>A12</th>
<th>A13</th>
<th>A14</th>
<th>A15</th>
<th>A16</th>
<th>Orthogonal position</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>H* rate μSv/d</td>
<td>52</td>
<td>39</td>
<td>47</td>
<td>54</td>
<td>73</td>
<td>68</td>
<td>63</td>
<td>B1*</td>
</tr>
<tr>
<td></td>
<td>37.8</td>
<td>42.0</td>
<td>26.4</td>
<td>29.5</td>
<td>36.1</td>
<td>31.2</td>
<td>35.7</td>
<td>B1^</td>
</tr>
<tr>
<td></td>
<td>18.9</td>
<td>27.4</td>
<td>21.8</td>
<td>21.0</td>
<td>19.8</td>
<td>-</td>
<td>29.0</td>
<td>B2^</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>44</td>
<td>-</td>
<td>35</td>
<td>35</td>
<td>27</td>
<td>-</td>
<td>B3**</td>
</tr>
</tbody>
</table>

* Palfalvi et al, 2004a, the neutron energy range considered was between 200 keV and 20 MeV, measured by SSNTD stacks.
** Palfalvi et al, present work, the neutron energy range considered was between 200 keV and 20 MeV, measured by SSNTD stacks.
^ Berger, 2003, total neutron dose, obtained by TLD measurements applying HTR technique.
Neutron fluxes

$\phi > 1 \text{ keV} \quad 2.42 \text{ cm}^{-2} \text{ s}^{-1}$, \hspace{1em} Brados-1, Panel 443 *

$\phi > 1 \text{ keV} \quad \sim 5 \text{ cm}^{-2} \text{ s}^{-1}$, \hspace{1em} Armstrong, calculated

$1 \text{ keV} > \phi > 5 \text{ MeV} \quad 2.1 \text{ cm}^{-2} \text{ s}^{-1}$, *

$\phi > 5 \text{ MeV} \quad 0.32 \text{ cm}^{-2} \text{ s}^{-1}$, * ($\sim$12% of total)

$200 \text{ keV} > \phi > 20 \text{ MeV} \quad 1.24 \text{ cm}^{-2} \text{ s}^{-1}$, *
BRADOS-1, 248 days, 6N NaOH 70 °C 20 h
Measure track parameters

Over etched?
  Yes → Calculate Vt/Vb from reduced ΔL/Δh
  No → Continue etching

Stopping within the sheet?
  Yes → Calculate Vt/Vb from a, b and h
  No → Are you sure?
     Yes → Calculate Vt/Vb from ΔL/Δh or from a, b, h
     No → Calculate Vt/Vb from a set of a, b and h

Stopping within the stack?
  Yes → From Vt/Vb
       Based on calibration calculate LET
       Calculate LET spectrum
       Calculate absorbed DOSE and H
  No → Calculate Vt/Vb from a set of a, b and h
3DTrack formation dynamics, after Nikezic, 2003.
Reduced track diameter vs. Residual Path length

Short range particles, circular tracks

Eye guide only
Stack No. 1> Panel 443
shielding ~ 10 g/cm²

Stack No. 4> Panel 457
shielding ~ 15 g/cm²
\[ \text{LET} = 6.91 + 63.8x(V-1) + 0.833(V-1)^2 \]
The width of a LET interval is 5 keV/μm, the LET values are shown at the geometrical mean of the LET interval. The total number of tracks on Stack No. 1 upper sheet was 368, on Stack No. 4 it was 216, collected on 10 cm² area, during BRADOS-1, 248 days experiment.
LET spectra, BRADOS-1, 248 days

Planar fluence vs. LET (keV/μm)

H (μSv/d) = 267.9 315.3

p. 443 p. 457
Greetings to everybody from...

(Averaged age 28.2)
277 tracks, 420 cm², 248 days