Results from ISS-RAD

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ISS-RAD Concept

• “CPD” = Charged Particle Detector, nearly identical to MSL-RAD.

• “FND” = Fast Neutron Detector, dedicated boron-loaded, capture-gated plastic scintillator optimized for detecting 0.5 to 10 MeV neutrons.

• ISS-RAD total mass = 9 kg, compare to 1.5 kg for MSL-RAD.
  • FND is 3 kg, interface board at bottom is 1.5 kg.
  • Self-shielding of CPD & shielding by FND affects dose rates and $<Q>$. 
Self-Shielding of $A \times B$ Field of View

- Particles coming in from top pass through $\sim 0.2 \text{ g cm}^{-2}$ to get in the FOV.
- From below, pass through $\sim 25 \text{ g cm}^{-2}$ to reach A (most of mass is BGO).
- A large share of heavy ions coming in through F fragment before reaching the FOV.
- GEANT4 modeling $\rightarrow$ correction factor may be needed for $<Q>$.  
- Work being done by Ana Firan at JSC.
# Survey Locations

<table>
<thead>
<tr>
<th>Dates</th>
<th>Location</th>
<th>Top of telescope pointing</th>
</tr>
</thead>
</table>
| 2/1/16 – 3/1/17 | US Lab 1O3 (Extended ACO) | Forward (~ 330 days)  
|                 |                       | Nadir (26 days)  
|                 |                       | Aft (30 days)  |
| 3/1/17 – 5/16/17| Node 3 A5             | Zenith (32 days)  
|                 |                       | Forward (23 days)  
|                 |                       | Starboard (20 days)  |
| 5/16/17 – 8/16/17| JPM 1D5              | Port (35 days)  
|                 |                       | Zenith (28 days)  
|                 |                       | Starboard (28 days)  |
| 8/16/17 – 11/10/17| Columbus 1A2        | Zenith (34 days)  
|                 |                       | Port (24 days)  
|                 |                       | Starboard (28 days)  |
| 11/10/17 – 2/1/18| US Lab 1O3           | Forward (68 days)  
|                 |                       | Port (28 days)  
|                 |                       | Starboard (24 days)  
|                 |                       | Aft (35 days)  |
| 2/1/18 – 5/3/18 | Columbus 1A2         | Forward (29 days)  
|                 |                       | Nadir (55 days)  
|                 |                       | Zenith (27 days)  |
| 5/3/18 – present| US Lab 1O3           | Forward (29 days)  
|                 |                       | Port (31 days)  
|                 |                       | Starboard (31 days)  
|                 |                       | Port (current)  |
Dose Measurements

- GCR dose rate is a little sensitive to position & orientation, SAA dose rate much more. SAA share of dose ranges from 36% (Lab) to 59% (JPM).
- Note B “omnidirectional” dose rate is shown.
- Slowly rising GCR dose rates are due to weakening solar modulation.
September 2017 SPE

- Figure from The Solar Particle Event on 10 September 2017 as observed onboard the International Space Station (ISS), T. Berger et al.
- SEPs only reached ISS when passing through regions where $R_{VC} < 1$ GV.
- Cumulative SPE dose in RAD $\sim 1.5x$ DOSTEL compared to $\sim 1.1x$ in quiet time.
<Q> Measurements

• Because of issues with incomplete charge collection in the A detector on high-LET events, must use telemetered pulse-height event records and select BxC coincidence events for analysis.

• Low-LET events are heavily prescaled to reduce data volume — factor of 30 is typical, but factor autonomously increases when rates get high as in SAA. As a result:
  • Few events from SAA are telemetered.
  • <Q> results may over-represent GCR.
• Factor self-adjusts, trying to keep weekly data volume ~ constant at 50 MB (25 MB CPD, 25 MB FND).

• Workaround will be implemented soon - turn off auto adjust, use constant factors. Should ~ double number of events from SAA.
<Q> Results

• <Q> varies from ~ 1.8 to 3.5.
• Statistical errors are driven by small statistics at high LET.
<Q> Results

- Results look reproducible within errors at a given location.
<Q> Results

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Results

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\( \chi^2 \) for agreement between pairs of points is 5.8 for 4 df, reasonable assuming environments are \( \sim \) constant.
<Q> by Location

- Average over orientations for each location.
- Standard deviation of measurements shown to capture variations in <Q> by orientation.

<table>
<thead>
<tr>
<th>Location</th>
<th>&lt;Q&gt;</th>
<th>St. Dev.</th>
<th># data points</th>
</tr>
</thead>
<tbody>
<tr>
<td>USLab</td>
<td>2.17</td>
<td>0.16</td>
<td>8</td>
</tr>
<tr>
<td>Node3</td>
<td>2.15</td>
<td>0.39</td>
<td>3</td>
</tr>
<tr>
<td>Columbus</td>
<td>2.70</td>
<td>0.20</td>
<td>6</td>
</tr>
<tr>
<td>JPM</td>
<td>2.76</td>
<td>0.51</td>
<td>3</td>
</tr>
</tbody>
</table>
Telescope vs. Omnidirectional Dose Rates

- Omnidirectional dose rates are ~ insensitive to orientation as particles from all directions contribute.
- Telescope dose rate uses dose obtained from A×B LET spectrum obtained for <Q> calculation.
- Accounting for Earth’s shadow at 410 km, extrapolate to solid angle of

\[ \Omega = 4\pi (1 - 0.33) \]

- Telescope dose rates are ~ 50% larger than omnidirectional.
- Correlation/anti-correlation not obvious — two populations?
\(<Q>\) and Telescope Dose Rate

- Trend is \(~\) consistent with effect of SAA driving up dose rate and reducing \(<Q>\).
  - Shielding of CPD by FND may be significant for SAA.
  - Comparatively large telescope dose rates may be due to extrapolating from a cone that has smaller average shielding and sees more SAA.
- Trend also consistent with behavior of GCR in Al shielding as depth increases: dose increases, \(<Q>\) decreases.
Summary of $\langle Q \rangle$

- Recall earlier point re: detector asymmetry and possible need for upward, model-based correction.

- No similar effect in MSL-RAD since heavy ions only come from above.

- Uncertainties in $\langle Q \rangle$ driven by fluctuations in small numbers of high-LET events, as shown by correlation of $\langle Q \rangle$ with propagated statistical errors.

- Less than 1 event/day for LET greater than 100 keV/micron even in places where $\langle Q \rangle$ is large, so for ~30-day measurement there is a $\sim \pm 20\%$ uncertainty in this region.
Check of Omnidirectional Dose Rate

- Data from period of IV-TEPC/RAD co-location.
- RAD omnidirectional data from B, converted to H$_2$O with factor of 1.25.
FND Status & Results

- Boron-loaded plastic detects neutrons via capture gating.
  \[ ^{10}B + n \rightarrow ^{4}He + ^{7}Li + \gamma \]
- Decay pulse appears ~ few microseconds after first pulse & produces a characteristic amplitude that is used to track gain & make corrections.
Unfolded Neutron Energy Spectrum from FND

- Work by Martin Leitgab.
- Highest energy bin is impacted by boundary effects in the unfolding; work in progress to improve.
- Significant variations with location.
Neutron Dose Equivalent

- Location dependence: US Lab and Node3 are similar, JPM ~35% lower, COL 15% lower; data through May 2018.
- Lower neutron rates in JPM and Columbus are consistent with higher charged-particle $\langle Q \rangle$'s measured by CPD in those locations (less shielded).

<table>
<thead>
<tr>
<th>Locations</th>
<th>Total Orb. Avg. Data</th>
<th>Flux $[n/cm^2/s]$</th>
<th>$H^*(10)$ dose eq. rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Lab 2016-2017</td>
<td>4.5</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Node 3 2017</td>
<td>4.3</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>JPM 2017</td>
<td>3.3</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>COL 2017</td>
<td>3.4</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>US Lab 2017/2018</td>
<td>4.4</td>
<td>147</td>
<td></td>
</tr>
<tr>
<td>COL 2018</td>
<td>3.8</td>
<td>127</td>
<td></td>
</tr>
</tbody>
</table>
Charged & Neutron Dose Equivalents

- Neutron share ranges from 14% to 23%.
- Charged particle rates may be slightly overestimated due to prescaling issue — recall GCR may be over-represented in event samples used for $<Q>$.
Conclusions

• ISS-RAD continues to work well.
• Minor hardware issues are easily worked around in ground analysis.
• For charged particles, dose rates & $<Q>$ yield H.
• For FND neutrons, unfolded energy spectrum yields H. Neutron share 14-23% depending on location.
• Charged particle H rate is 0.5 to 0.76 mSv/day, similar to 0.4 to 0.7 mSv/day range found by MSL-RAD on Mars.