Matroshka-R and Radi-N2 Experiments using Bubble Detectors: ISS-43/44 and ISS-45/46

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21st WRMISS, Noordwijk, the Netherlands

September 6th – 8th 2016
Collaboration

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Introduction

• Radiation prediction, monitoring, and protection technologies are a key part of every space mission involving humans
  – The risk to space crews due to radiation in deep space may be a serious obstacle to Mars missions

• Neutrons are of particular interest to radiation health and protection
  – Measurements indicate that neutrons may represent 30% of the biologically-effective radiation exposure in low-Earth orbit
  – A significant neutron contribution is also expected in deep space

• Bubble detectors have been used to monitor neutrons in space since 1989 on recoverable Russian Biocosmos (Bion) satellites, the Mir space station, the space shuttle, and the ISS
Bubble Detectors

- Bubble detectors are passive dosimeters manufactured by Bubble Technology Industries.
- They contain superheated liquid droplets dispersed in an elastic polymer.
- High-LET particles interact with the droplets to form bubbles.
- The elastic polymer retains the bubbles to allow visible detection of radiation.
- After each measurement, the bubbles can be recompressed and the detector can be reused.
Space Bubble Detectors

- Two types of bubble detector are used to monitor neutrons for the Matroshka-R and Radi-N2 experiments on the ISS
  - Space personal neutron dosimeter (SPND)
  - Space bubble detector spectrometer (SBDS), a set of six detectors, each with a different energy threshold, that provides a coarse neutron energy spectrum

- Space bubble detectors use a stronger polymer than terrestrial detectors
  - Allows bubbles to grow slowly during a week-long measurement

- Detectors are temperature compensated
- Bubbles are counted with the space mini reader located in the Russian segment
ISS Measurement Locations

Japanese Experiment Module (JEM)
US Laboratory
Node 2
Columbus
Russian Service Module

Image from NASA
ISS Bubble-Detector Experiments

Matroshka-R (2006 – present)
- Neutron dose equivalent inside a tissue-equivalent phantom was less than that at its surface
- Neutron dose equivalent in the Service Module was ~30% of the total recorded by other devices
- Solar activity and altitude did not strongly affect the neutron dose equivalent or energy spectrum

Radi-N (2009)
- First spectroscopic measurements
- Neutron dose equivalent and energy spectrum were not strongly dependent on location
- Neutron dose equivalent in the sleeping quarters was less than received during daily activities
- Water shield reduced the neutron dose equivalent by ~30%

Radi-N2 (2012 – present)
- Continued measurements in the same locations used for Radi-N
- Good agreement with Radi-N data
- Confirmed that solar activity and ISS altitude have little effect on neutron radiation inside the ISS
- Ongoing goal is to collect at least ten weeks of data in each module and to measure a full solar cycle

21st WRMISS, September 6th – 8th 2016
### ISS-43 to ISS-46: List of Sessions

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<thead>
<tr>
<th>Session</th>
<th>Initialization Date</th>
<th>Retrieval Date</th>
<th>Prime Location</th>
<th>Back-Up Location</th>
</tr>
</thead>
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<tr>
<td>43/44-1</td>
<td>24 March 2015</td>
<td>31 March 2015</td>
<td>Columbus</td>
<td>Service Module</td>
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<tr>
<td>43/44-2</td>
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<td>23 April 2015</td>
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<td>Service Module</td>
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<td>43/44-3</td>
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<td>26 May 2015</td>
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<td>Service Module</td>
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<tr>
<td>43/44-4</td>
<td>12 June 2015</td>
<td>18 June 2015</td>
<td>Node 2</td>
<td>Service Module</td>
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<tr>
<td>43/44-5</td>
<td>14 July 2015</td>
<td>21 July 2015</td>
<td>Columbus</td>
<td>Service Module</td>
</tr>
<tr>
<td>43/44-6</td>
<td>12 August 2015</td>
<td>19 August 2015</td>
<td>Node 2</td>
<td>Service Module</td>
</tr>
<tr>
<td>45/46-1</td>
<td>18 September 2015</td>
<td>25 September 2015</td>
<td>JEM</td>
<td>Service Module</td>
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<tr>
<td>45/46-2</td>
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<td>23 October 2015</td>
<td>Node 2</td>
<td>Service Module</td>
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<tr>
<td>45/46-3</td>
<td>13 November 2015</td>
<td>20 November 2015</td>
<td>US Lab</td>
<td>Service Module</td>
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<tr>
<td>45/46-4</td>
<td>24 December 2015</td>
<td>31 December 2015</td>
<td>JEM</td>
<td>Service Module</td>
</tr>
<tr>
<td>45/46-5</td>
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<td>20 January 2016</td>
<td>US Lab</td>
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<tr>
<td>45/46-6</td>
<td>12 February 2016</td>
<td>19 February 2016</td>
<td>JEM</td>
<td>Service Module</td>
</tr>
</tbody>
</table>
Radi-N2: SPND Dose Rate

![Graph showing dose equivalent rate (µSv/day) over sessions for different areas: Columbus, Node 2, US Lab, and JEM.](image)

Dose equivalent rate (µSv/day)

Session: 43/44-1, 43/44-4, 43/44-5, 43/44-6, 45/46-1, 45/46-2, 45/46-3, 45/46-4, 45/46-5, 45/46-6.
Radi-N and Radi-N2: SBDS Data
Radi-N and Radi-N2: SBDS Dose Rate

US Lab

Dose equivalent rate (µSv/day)

Session

JEM

Dose equivalent rate (µSv/day)

Session

Columbus

Dose equivalent rate (µSv/day)

Session

Node 2

Dose equivalent rate (µSv/day)

Session
Radi-N and Radi-N2: SBDS Dose Rate

- The SBDS dose equivalent, summed over all sessions, is similar in each of the four USOS locations
  - This observation is in good agreement with the SPND data
- The SBDS data suggest that ~60% of the dose equivalent is due to neutrons with energy > 15 MeV
  - This percentage is higher than previously reported
- Changes in solar activity and ISS altitude since 2009 did not have a strong influence on the neutron field
- Conclusions will be finalized once data have been acquired for a full solar cycle (2009 – 2020)
Matroshka-R: ISS-43 to ISS-46

- For Matroshka-R, a total of 14 week-long measurements were conducted during ISS-43/44 and ISS-45/46
- Each used a spectrometer (SBDS) and two dosimeters (SPNDs)
- All experiments occurred in the Russian Service Module
- These measurements included
  - First measurements on panel 239
  - Further experiments using a hydrogenous shield
  - Measurements in the least and most shielded locations in the Service Module
Matroshka-R: Panel 239

- Four sessions were conducted on panel 239 in the left crew quarter during ISS-43/44
- These were the first bubble-detector measurements in this location
- SPND and SBDS results are in good agreement with each other
- Dose equivalent for this location is similar to that measured elsewhere in the ISS
Many experiments were conducted using a hydrogenous shield during the ISS-22 to ISS-33 increments.

These measurements used SPNDs to show that the shielding reduced the neutron dose equivalent.

Dose equivalent behind the hydrogenous shield was $77 \pm 17\%$ of the unshielded value.

This is similar to a result ($72 \pm 17\%$) measured using bags of water in the JEM (ISS-21).
Matroshka-R: Hydrogenous Shielding

- Two sessions were performed during ISS-43/44 using two SBDS sets and four SPNDs
- Prime detectors were located on the illuminator side of the shield, while the back-up detectors were situated on the cabin side of the shield
- This was the first direct comparison of the neutron dose equivalent on each side of the hydrogenous shield
- As expected, the dose equivalent on both sides of the shield is lower than previous results from unshielded locations
- Dose equivalent in the two locations appears to be approximately the same
Matroshka-R: Least/Most Shielded

- During the six sessions of ISS-45/46, a shielding experiment was performed in the Service Module
- Based on extensive measurements and theoretical calculations, two locations have been identified that represent the least and most shielded locations in the Service Module
  - The least shielded location is on panel 121, near the big illuminator window
  - The most shielded location is on panel 435, near the crew working table
Matroshka-R: Least/Most Shielded

- Results indicate that the neutron dose equivalent at panel 121 and panel 435 is similar.
- This seems to contradict the conclusion that the two locations are the least and most shielded in the Service Module.
- However, the earlier observations were based on the total dose due to all radiation, not specifically due to neutrons.
- The bubble-detector results indicate that the production of secondary neutrons in the two locations is similar.
ISS-47/48 Measurements

- A further six pairs of sessions were conducted during the recent ISS-47/48 increment
- Three measurements were performed for Radi-N2: two in Columbus and one in Node 2
- Matroshka-R experiments focussed on improving counting statistics in and around the spherical phantom (behind panel 206 in the MRM1 module)
- A new mini reader launched to the ISS in July 2016 and successfully performed its first readings in August 2016
- Analysis of data from ISS-47/48 is in progress
### ISS-47/48: List of Sessions

<table>
<thead>
<tr>
<th>Session</th>
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<th>Retrieval Date</th>
<th>Prime Location</th>
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</tr>
</thead>
<tbody>
<tr>
<td>47/48-1</td>
<td>8 March 2016</td>
<td>15 March 2016</td>
<td>Pirs</td>
<td>MRM1/phantom</td>
</tr>
<tr>
<td>47/48-2</td>
<td>6 April 2016</td>
<td>13 April 2016</td>
<td>Pirs</td>
<td>MRM1/phantom</td>
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<td>10 May 2016</td>
<td>Columbus</td>
<td>MRM1/phantom</td>
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<td>9 June 2016</td>
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<td>MRM1/phantom</td>
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<tr>
<td>47/48-5</td>
<td>6 July 2016</td>
<td>13 July 2016</td>
<td>Node 2</td>
<td>MRM1/phantom</td>
</tr>
<tr>
<td>47/48-6</td>
<td>10 August 2016</td>
<td>16 August 2016</td>
<td>—</td>
<td>MRM1/phantom</td>
</tr>
</tbody>
</table>

For the six sessions with the phantom, two sets of four detectors alternated between the inside of the phantom and the phantom surface.
Session 6 included an inter-comparison of the original and replacement mini readers.
Plans for ISS-49/50

- Six pairs of sessions are planned for the upcoming ISS-49/50 expedition
- Radi-N2 is nearing its goal of collecting ten weeks of data in each of the four initial locations (US Lab, Columbus, the JEM, and Node 2)
- Experiments up to 2020 will aim to extend Radi-N2 to other USOS modules, while continuing surveys in the initial locations to assess a full solar cycle
- Measurements in Node 1, Node 3, and the Cupola have been discussed
- Radi-N2 sessions during ISS-49/50 are planned for the US Lab, Columbus, Node 2, and Node 3
- Some of these measurements will be conducted with bubble detectors co-located with NASA’s IV-TEPC and ISS-RAD
- Plans for ISS-49/50 in the Russian segment are being finalised
Summary and Conclusions

- Bubble-detector experiments were performed for Radi-N2 and Matroshka-R during ISS-43/44 and ISS-45/46 (to February 2016)
- For Radi-N2, ten sessions were conducted, including all four USOS locations
  - The measured dose equivalent is very similar in each of the four modules
  - SBDS data suggest that approximately 60% of the dose equivalent is due to neutrons with energy > 15 MeV
  - Variations in potential influence quantities such as solar activity and ISS altitude seem to have little effect on the neutron dose equivalent
- Fourteen sessions were performed for the Matroshka-R experiment
  - First measurements on panel 239
  - Further experiments using a hydrogenous shield
  - Measurements in the least and most shielded locations in the Service Module
- Radi-N2 and Matroshka-R experiments are ongoing
  - Six pairs of sessions were conducted for ISS-47/48 and six are planned for ISS-49/50
  - Plans up to 2020 are under discussion
Acknowledgements

• We would like to thank the following for their important contributions
  – The astronauts and cosmonauts who performed the measurements
  – NASA’s Space Radiation Analysis Group (SRAG) for supporting the experiments
  – The Canadian Space Agency and the Russian Space Agency for funding the work

• References for recent publications
Radi-N2: Recent SBDS Data

45/46-3 US Lab

45/46-4 JEM

43/44-5 Columbus

43/44-6 Node 2
Bubble Detector Response Function

![Graph showing normalized response function for different neutron energies.](image)

- Neutron Energy (MeV) scale is shown on the x-axis.
- Normalized Response (bubble/n.cm²) scale is shown on the y-axis.
- Different energy values are indicated with specific markers: 40 keV/µm, 50 keV/µm, 60 keV/µm, 70 keV/µm, 80 keV/µm, 90 keV/µm, 100 keV/µm, 110 keV/µm, 120 keV/µm, 130 keV/µm, 140 keV/µm, and 150 keV/µm.
Bubble Detector Response Function

[Graph showing the normalized response (bubble/n.cm$^{-2}$) against neutron energy (MeV) with data points and a curve for 130 keV/µm.]
ISS-22 to ISS-33: Solar Activity

Wolf (Sunspot) Number

Dose Equivalent Rate (µSV/day)

Wolf Number

SPND 1

SPND 2
MRM2: SBDS Dose Rate

Dose equivalent rate (µSv/day)

- 37/38-7
- 39/40-2
- 39/40-3
- 39/40-4
- 39/40-5
- 39/40-6
- 39/40-7
- Sum
MRM2: SPND Dose Rate

Dose equivalent rate ($\mu$Sv/day)

- SPND 1
- SPND 2

37/38-7 39/40-2 39/40-3 39/40-4 39/40-5 39/40-6 39/40-7 Sum