Neutron Measurements using Bubble Detectors: ISS-39/40 and ISS-41/42

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Introduction: Space Radiation

- Radiation prediction, monitoring, and protection technologies are a key part of every space mission involving humans
- NASA’s Bioastronautics Roadmap identifies provision of radiation protection as one of the high-priority health and medical issues for exploration-class missions
  - Radiation protection is listed as one of three key areas for lunar missions, and one of eight for Mars missions
  - 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, real-time 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)
    - 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 inside a tissue-equivalent phantom was less than that at its surface
- Neutron dose in the Service Module was ~30% of the total recorded by other devices
- Solar activity and altitude did not have a strong influence on the neutron dose or energy spectrum

Radi-N (2009)
- First spectroscopic measurements
- Showed that neutron dose and energy spectrum were not strongly dependent on location
- Neutron dose received in sleeping quarters was less than that received during daily activities
- Water shield reduced the neutron dose 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
### List of Sessions: ISS-39 to ISS-42

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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>
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<td>MRM1</td>
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</table>
Radi-N2: SPND Dose Rate

Dose equivalent rate (µSv/day)

- Columbus
- Node 2
- US Lab
- JEM

Radi-N and Radi-N2: SBDS Data

Neutron energy (MeV)

Unfolded fluence
Maximum fluence
Minimum fluence

Neutron energy (MeV)

Neutron energy (MeV)

Neutron energy (MeV)

Neutron energy (MeV)
Radi-N and Radi-N2: SBDS Dose Rate

**US Lab**

**JEM**

**Columbus**

**Node 2**
Radi-N and Radi-N2: SBDS Dose Rate

- The SBDS dose rate, summed over all sessions, is very 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 neutron dose is due to neutrons with energy > 15 MeV
  - This number is higher than previously reported
- Changes in solar activity and ISS altitude since 2009 did not have a strong influence on the neutron dose
- Conclusions will be finalized once data have been acquired for a full solar cycle (2009 – 2020)
Matroshka-R: ISS-39 to ISS-42

• For Matroshka-R, a total of 17 sessions were conducted during ISS-39/40 and ISS-41/42
• Each used a spectrometer (SBDS) and two dosimeters (SPNDs)
• These measurements included
  – First extensive measurements in Mini Research Module 2 (MRM2)
  – Experiments using the Matroshka-R phantom in MRM1
MRM2: SBDS Dose Rate
MRM2: SPND Dose Rate

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

- SPND 1
- SPND 2

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Matroshka-R: Phantom in MRM1

- Measurements aimed to repeat an experiment conducted during ISS-35/36
- The phantom was located behind panel 206 in MRM1, as before
- The back-up SBDS was used inside the phantom and on its surface
  - It was only possible to insert three detectors into the phantom at a time
  - SBDS detectors alternated between the two locations
- The prime SBDS was used to measure the spectrum above the phantom (on panel 206) for three sessions
- SPNDs were also used on the phantom surface and above the phantom
SBDS Phantom Results

ISS-35/36

ISS-41/42

Dose equivalent rate (µSv/day)

Inside | Surface | Above

Dose equivalent rate (µSv/day)

Inside | Surface | Above
SPND Phantom Results

ISS-41/42: Phantom Surface

ISS-41/42: Above Phantom

Dose equivalent rate (µSv/day)

Session

0 50 100 150 200 250 300

1 2 3 4 5 6

SPND 1

SPND 2

Session

0 50 100 150 200

1 2 3 4 5 6

SPND 1

SPND 2
### ISS-43/44 and ISS-45/46

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FGB: Functional Cargo Block
Summary and Conclusions

- Bubble-detector experiments were performed for Radi-N2 and Matroshka-R during ISS-39/40 and ISS-41/42 (to March 2015)
- For Radi-N2, nine sessions were conducted, including all four USOS locations
  - The measured neutron dose is very similar in each of the four modules
  - SBDS data suggest that approximately 60% of the neutron dose 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
- Seventeen sessions were performed for the Matroshka-R experiment
  - First extensive measurements in MRM2
  - Experiments using the Matroshka-R phantom in MRM1, which provided good agreement with the earlier measurements from ISS-35/36
- Experiments are ongoing
  - Six sessions were performed during ISS-43/44 and six are scheduled for ISS-45/46
  - 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
BACK-UP SLIDES
Bubble Detector Response Function

Nomalised Response (bubble/n.cm$^{-2}$)

Neutron Energy (MeV)

- 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
- 150 keV/µm
Bubble Detector Response Function

![Graph showing the normalized response function of a bubble detector against neutron energy (MeV). The graph includes data points and a line representing 130 keV/µm. The x-axis represents neutron energy (MeV) on a logarithmic scale, ranging from $10^{-2}$ to $10^3$. The y-axis represents the normalized response (bubble/n.cm$^{-2}$) on a logarithmic scale, ranging from $10^{-7}$ to $10^4$. Data points are marked with circles, and error bars are shown for some data points. The line is a smooth curve that peaks around $10^{-1}$ MeV.](image-url)
ISS-22 to ISS-33: Solar Activity

Wolf Number
SPND 1
SPND 2

Dose Rate (µSv/day)
Phantom: Monte-Carlo Simulations

- Interactions in the phantom were investigated using Geant4 Monte-Carlo simulations
  - Inputs from Armstrong and CREME
  - Results suggest that most neutrons inside the phantom are due to neutron scattering
  - Protons and alpha particles also create neutrons

- Geant4 neutron dose in the phantom is 58% of that at the surface
  - Good agreement with the dose-rate reduction measured by the SBDS (66%) and SPNDs (73±17%)