Matroshka-R and Radi-N2 Experiments using Bubble Detectors: ISS-47/48 and ISS-49/50

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Collaboration

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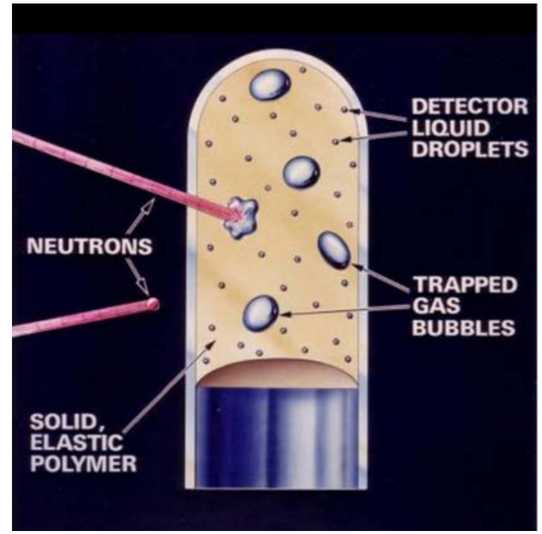
Introduction

- 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

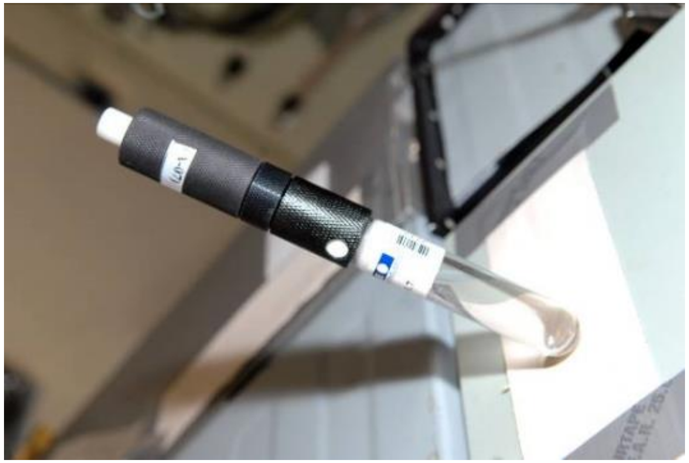
Bubble Detectors

- 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

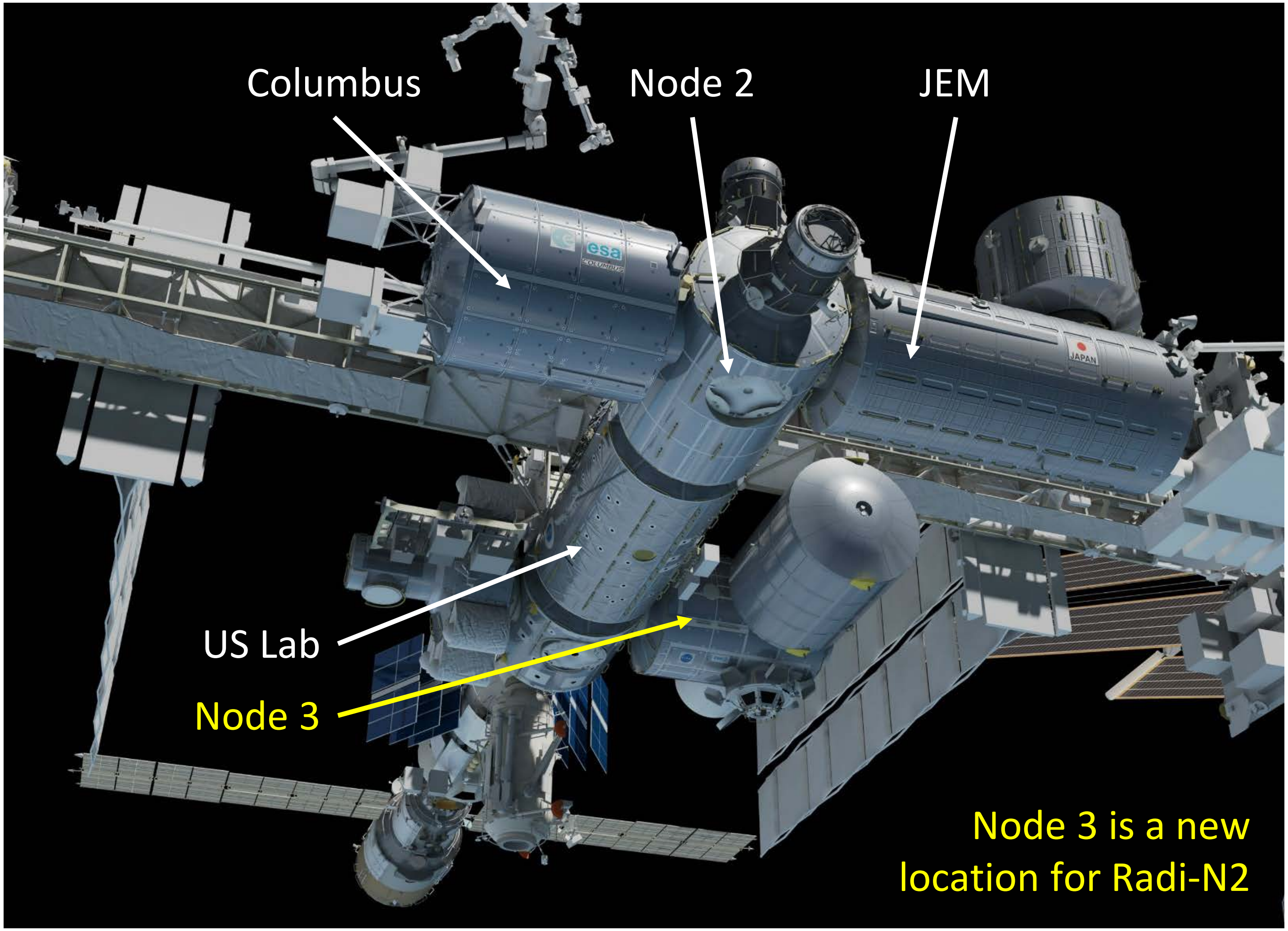


Space Bubble Detectors

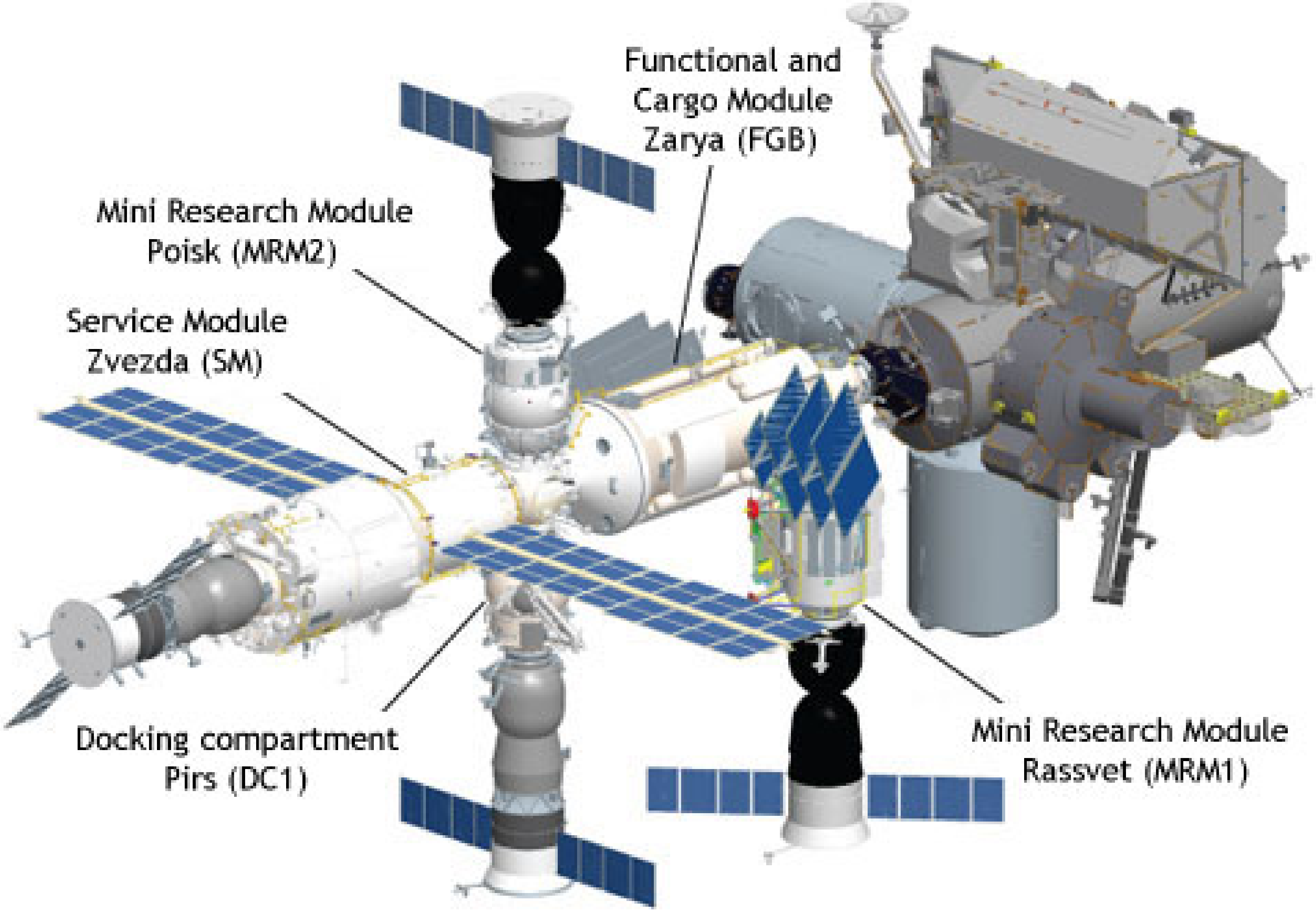
- Two types of bubble detector are used to monitor neutrons for the Matroshka-R and Radi-N2 experiments on the ISS
  - Space personal neutron dosimeter (SPND)
  - Space bubble detector spectrometer (SBDS), a set of six detectors, each with a different energy threshold, that provides a coarse neutron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



Radi-N2 Locations (USOS)



Matroshka-R Locations (ROS)



ISS Bubble-Detector Experiments

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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

ISS-47/48: List of Sessions

Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
47/48-1	8 March 2016	15 March 2016	Pirs	MRM1/phantom
47/48-2	6 April 2016	13 April 2016	Pirs	MRM1/phantom
47/48-3	3 May 2016	10 May 2016	Columbus	MRM1/phantom
47/48-4	3 June 2016	10 June 2016	Columbus	MRM1/phantom
47/48-5	6 July 2016	13 July 2016	Node 2	MRM1/phantom
47/48-6	10 August 2016	16 August 2016	MRM1/phantom	n/a

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; the replacement reader launched to the ISS on July 7th 2016

ISS-49/50: List of Sessions

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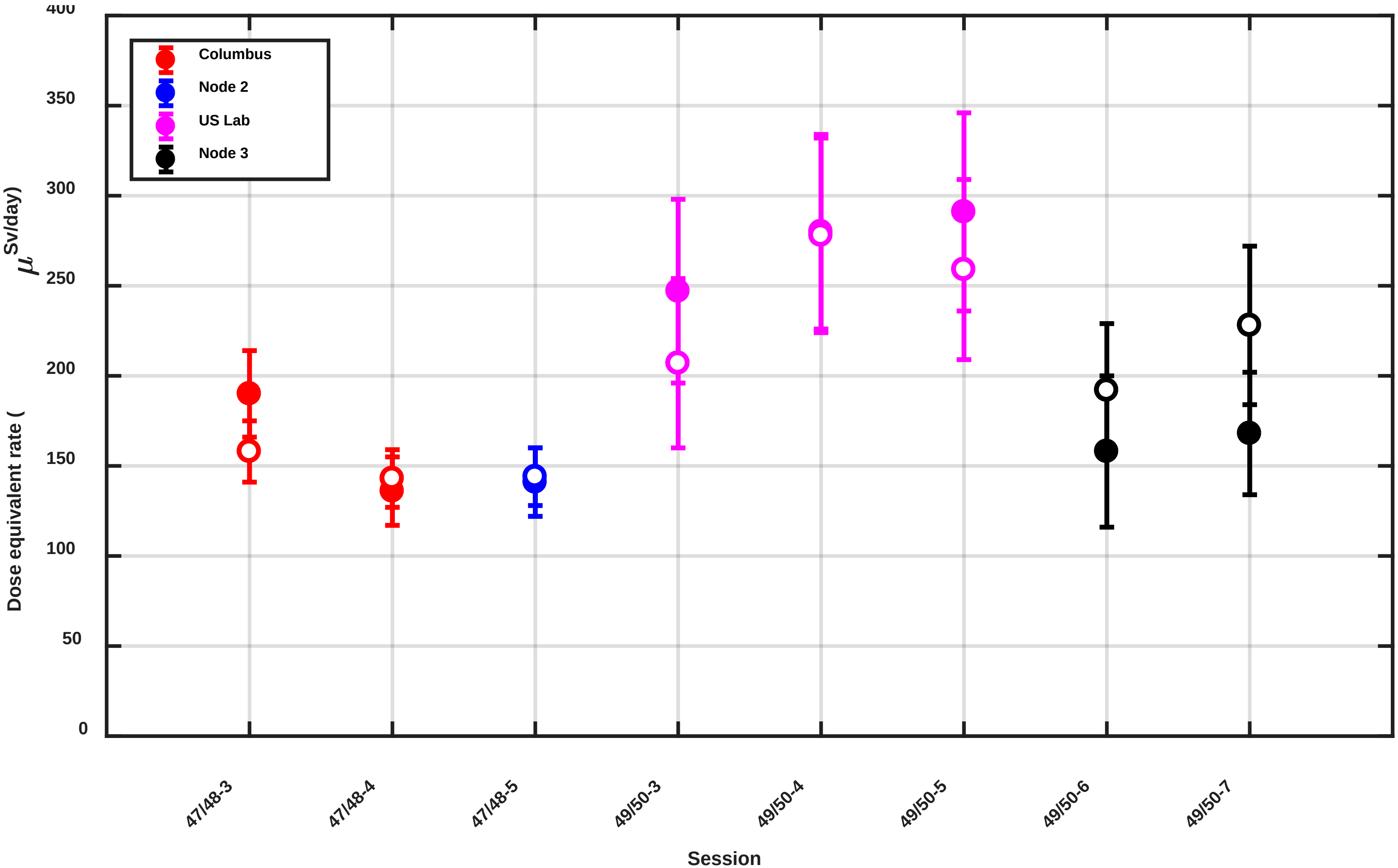
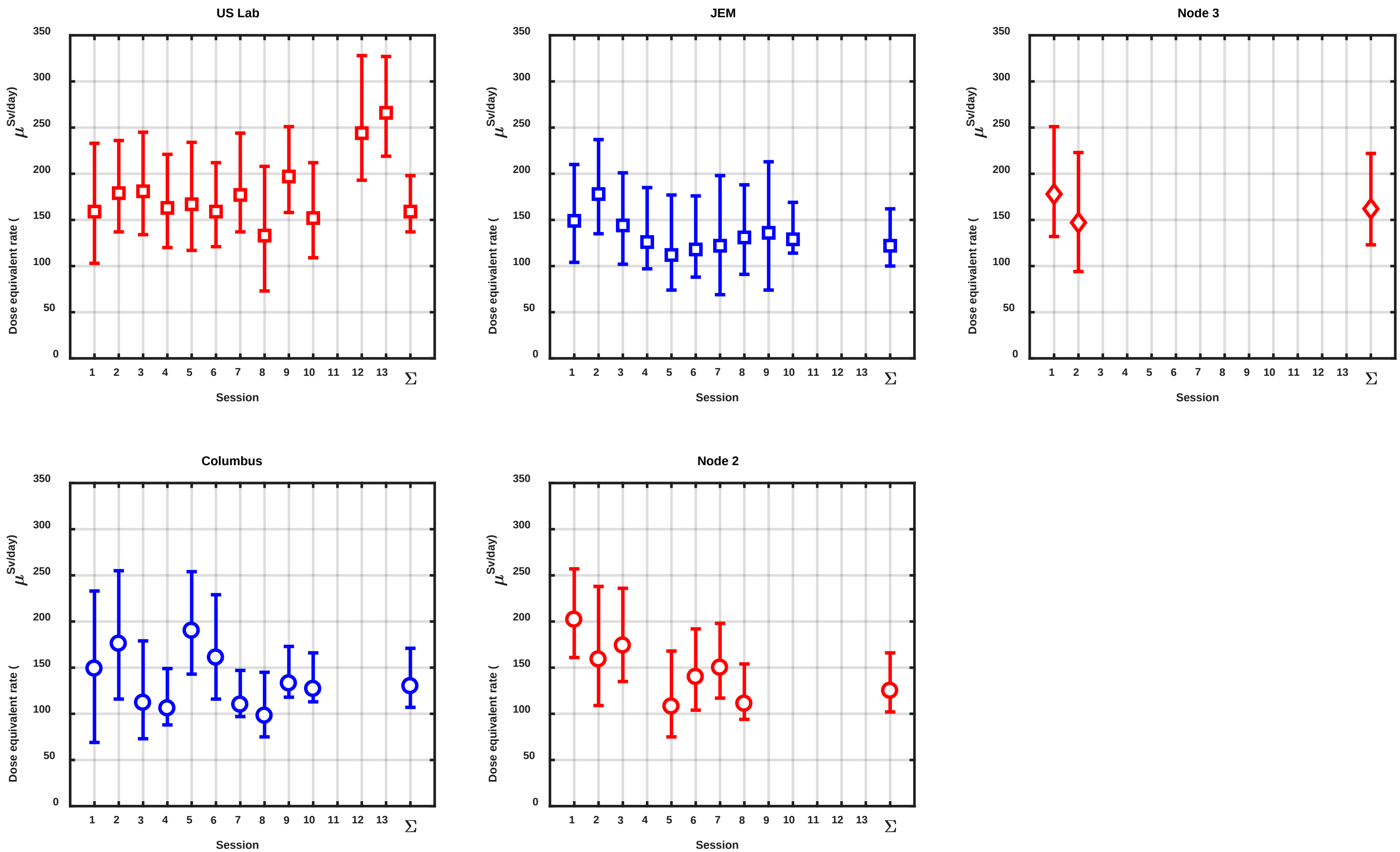
Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
49/50-1	9 September 2016	16 September 2016	MRM1	MRM2
49/50-2	7 October 2016	14 October 2016	MRM1	MRM2
49/50-3	7 November 2016	15 November 2016	US Lab	Service Module
49/50-4	8 December 2016	14 December 2016	US Lab	Service Module
49/50-5	11 January 2017	18 January 2017	US Lab	Service Module
49/50-6	31 January 2017	7 February 2017	Node 3	Service Module
49/50-7	8 March 2017	15 March 2017	Node 3	Service Module

The Radi-N2 detectors were co-located with NASA's ISS-RAD during Sessions 3, 4, and 5 in the US Lab
For Session 5, the IV-TEPC was co-located with Radi-N2 and the ISS-RAD

Radi-N2: Recent SPND Data

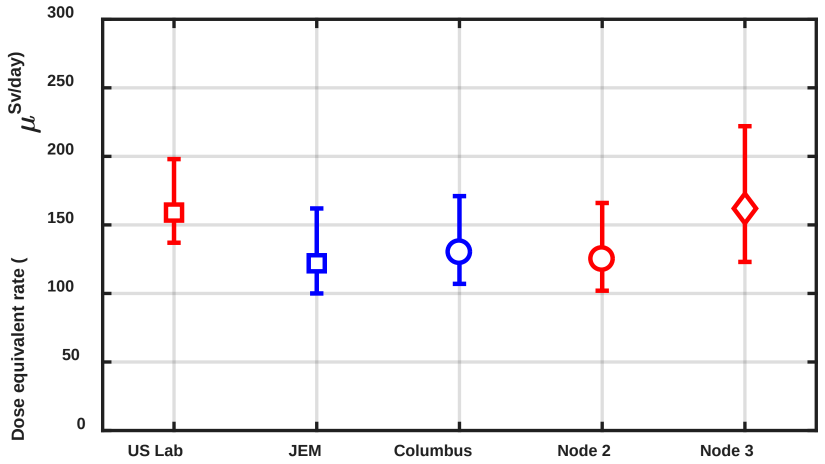


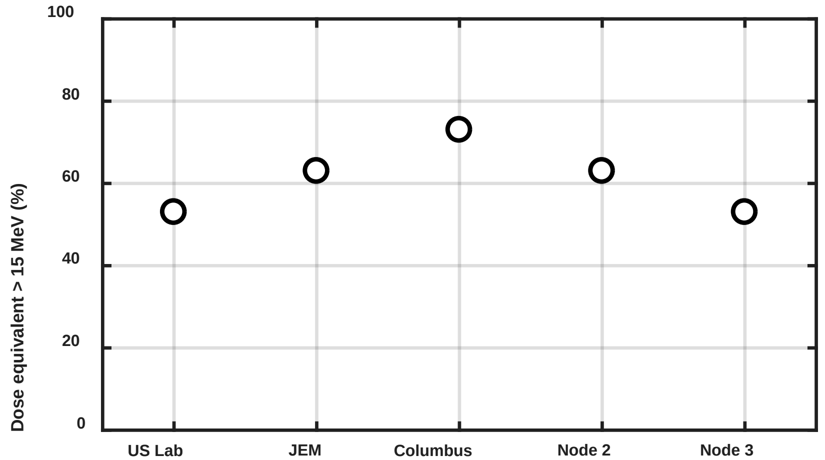
Radi-N and Radi-N2: SBDS Data



Radi-N and Radi-N2: SBDS Data

- The SBDS dose equivalent, summed over all sessions, is similar in each of the USOS locations used for Radi-N2
- The SBDS data suggest that ~60% of the dose equivalent is due to neutrons with energy > 15 MeV
- Changes in solar activity and ISS altitude since 2009 do not appear to have a strong influence on the neutron field
- Conclusions will be finalized once data have been acquired for a full solar cycle (2009 – 2020)





Comparison to ISS-RAD

- Radi-N2 and ISS-RAD were co-located in the US Lab for Sessions 3, 4, and 5 of ISS-49/50
  - Detectors were located on panel 1O3; earlier measurements were conducted on panel 1S4
- The ISS-RAD recorded dose equivalent values lower than those measured by the bubble detectors
- However, the ISS-RAD results are similar to earlier Radi-N2 measurements in the US Lab

Session	SBDS (μSv/day)	SPND 1 (μSv/day)	SPND 2 (μSv/day)	ISS-RAD (μSv/day)
49/50-3	n/a	247±51	207±47	140±1.4(stat)±4.04(sys)
49/50-4	244^{+84}_{-51}	280±54	278±54	137±1.65(stat)±4.13(sys)
49/50-5	266^{+61}_{-47}	291±55	259±50	139±1.58(stat)±4.15(sys)

ISS-RAD data from Leitgab et al.

Matroshka-R: ISS-47 to ISS-50

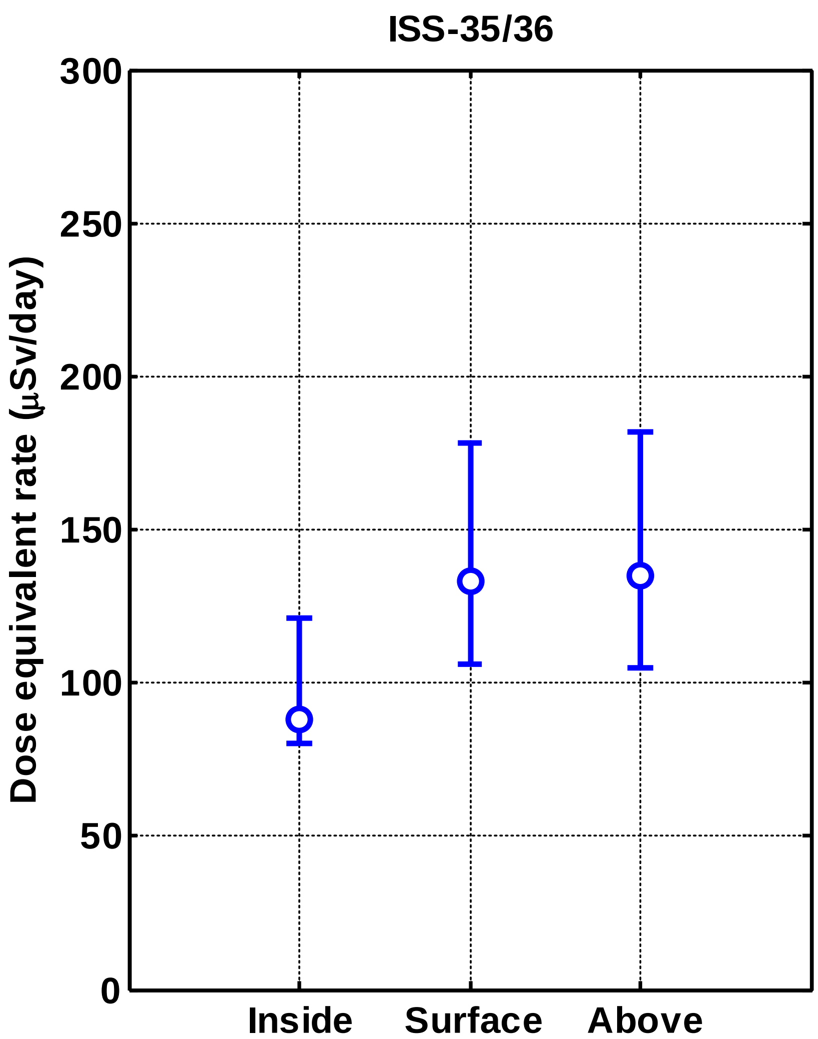
- For Matroshka-R, a total of 17 week-long measurements were conducted during ISS-47/48 and ISS-49/50
- Two sessions were performed in the Pirs docking module (on panel 402)
- Six sessions were conducted using the Matroshka-R phantom in MRM1
- Two pairs of sessions were performed to compare the neutron field in MRM1 and MRM2
- Five sessions were conducted in the Service Module, with the bubble detectors located next to the Russian R-16 instrument

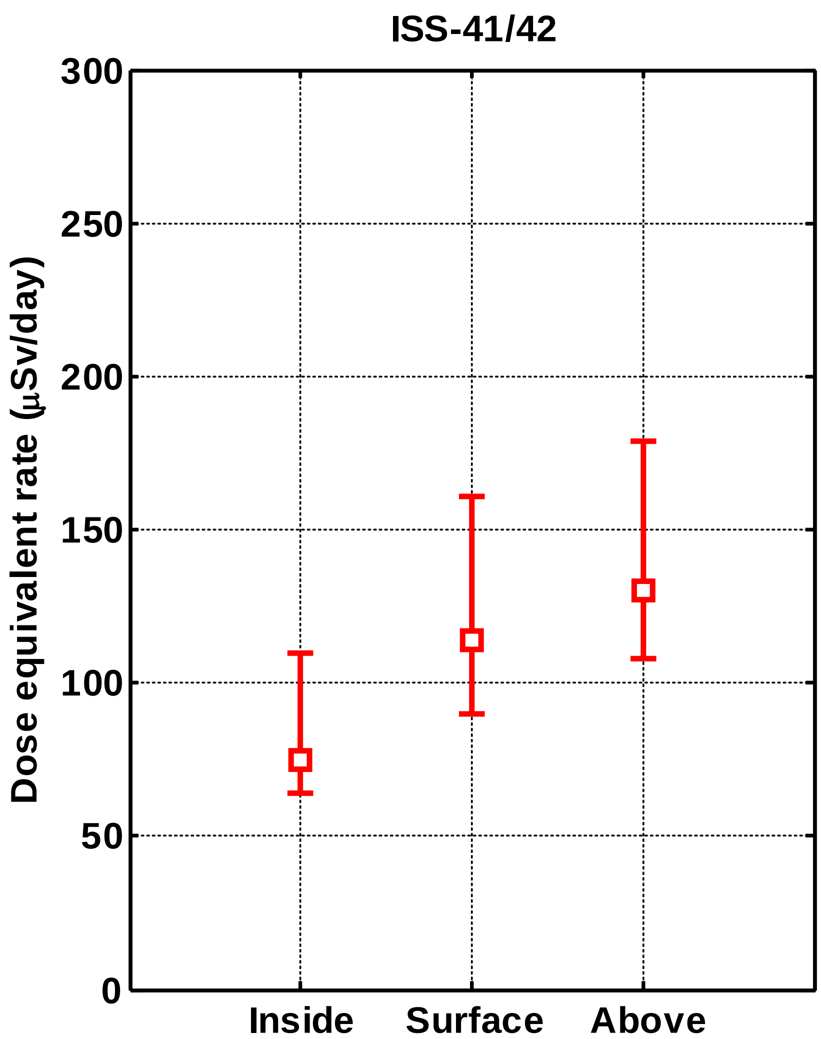
	Pirs Docking Module: Dose Equivalent Rate (µSv/day)		
Session	**SBDS**	**SPND A97**	**SPND A98**
47/48-1	120^{+69}_{-39}	143 ± 20	135 ± 16
47/48-2	104^{+41}_{-16}	124 ± 18	142 ± 16

Matroshka-R: Phantom in MRM1

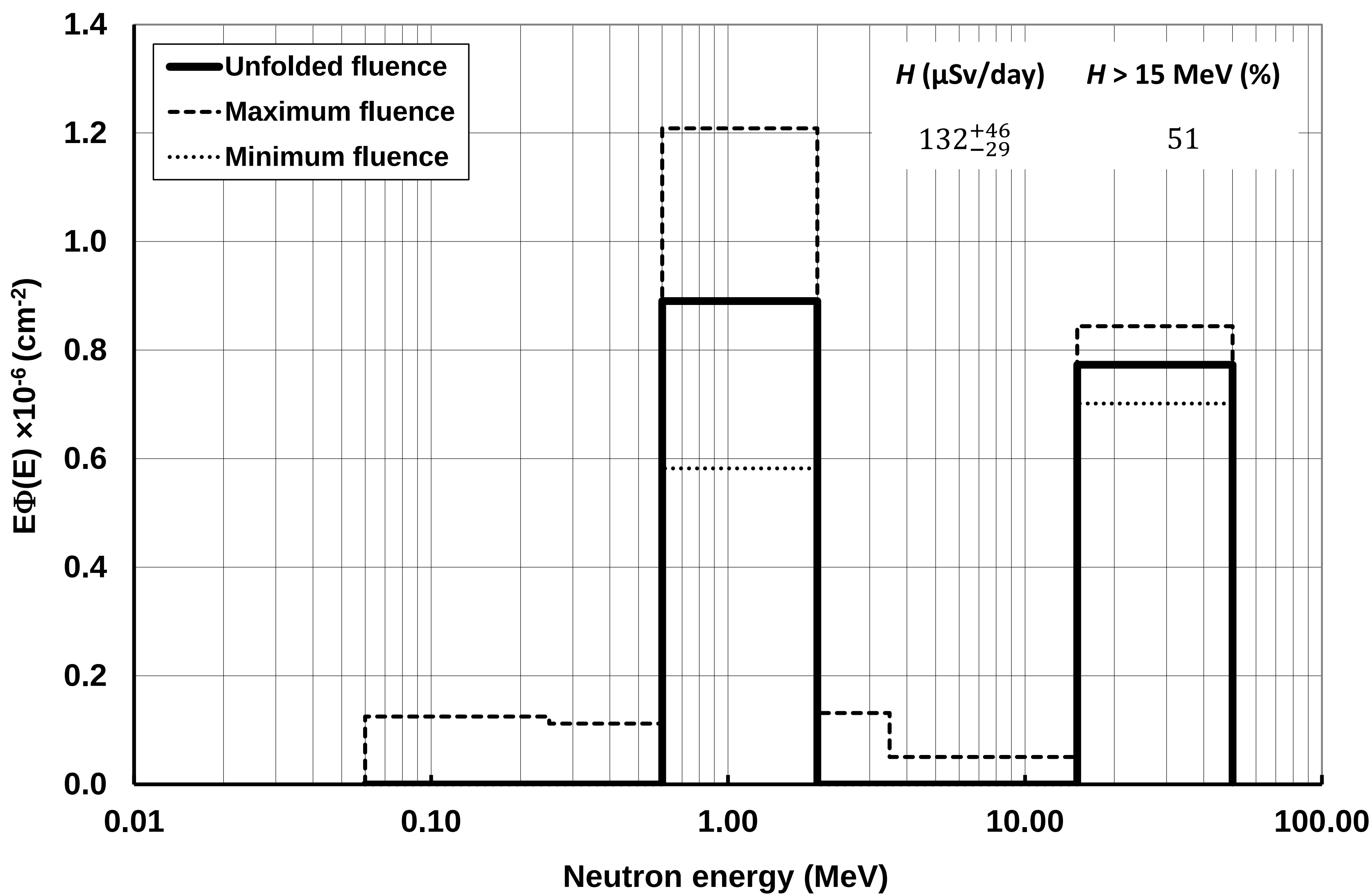
- Phantom experiments aimed to verify earlier measurements conducted during ISS-35/36 and ISS-41/42
- The Matroshka-R phantom was located behind panel 206 in MRM1, as for previous measurements
- The back-up SBDS was located inside the phantom and on its surface for a total of six sessions
  - Three SBDS detectors were inserted into the phantom at a time
  - SBDS detectors alternated between the two locations
- SPNDs were also located inside the phantom and on the phantom surface

Earlier Phantom Results (SBDS)





ISS-47/48: Phantom Surface (SBDS)



ISS-47/48: Inside Phantom (SBDS)

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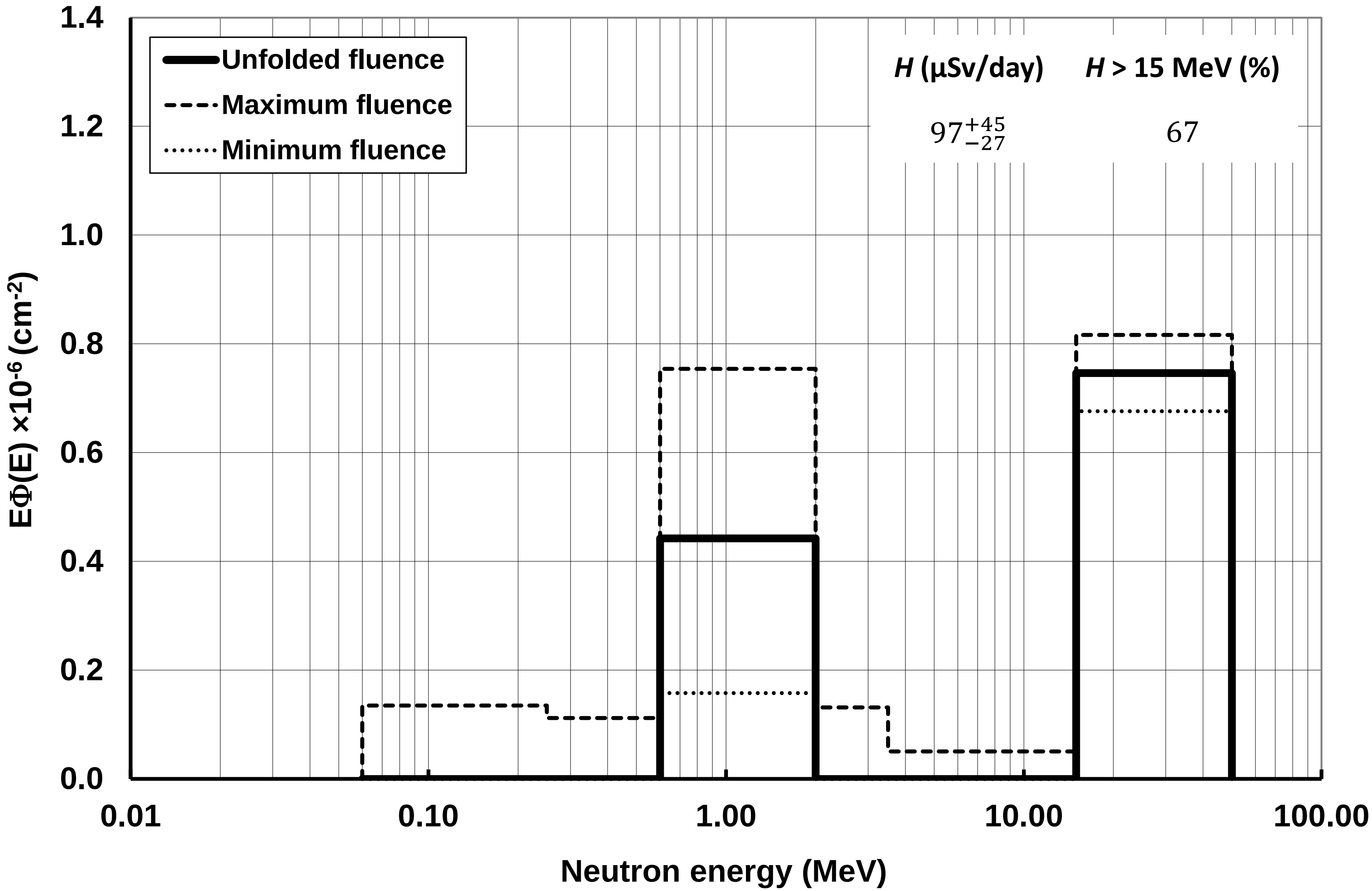

ISS-47/48 Phantom Results

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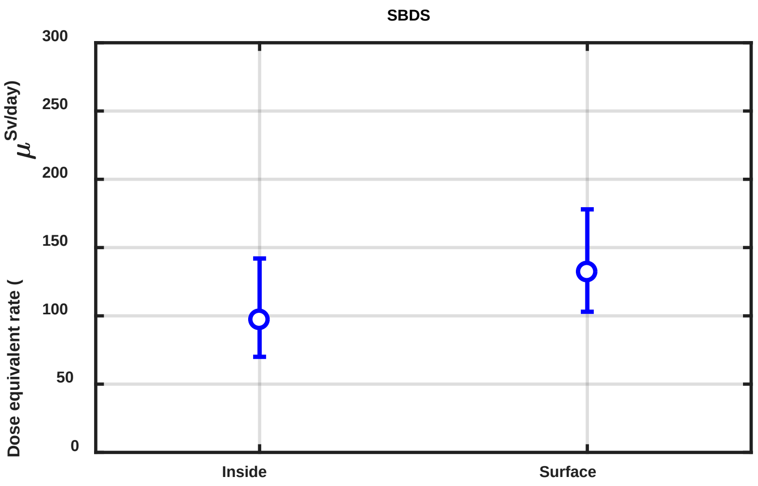
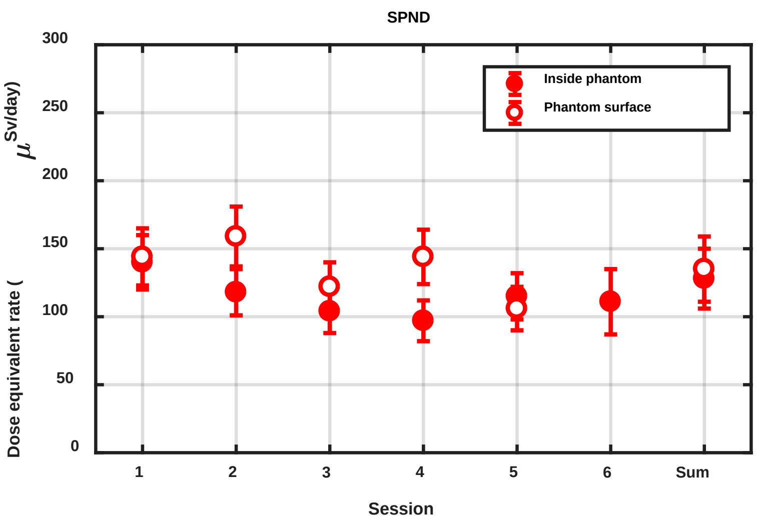
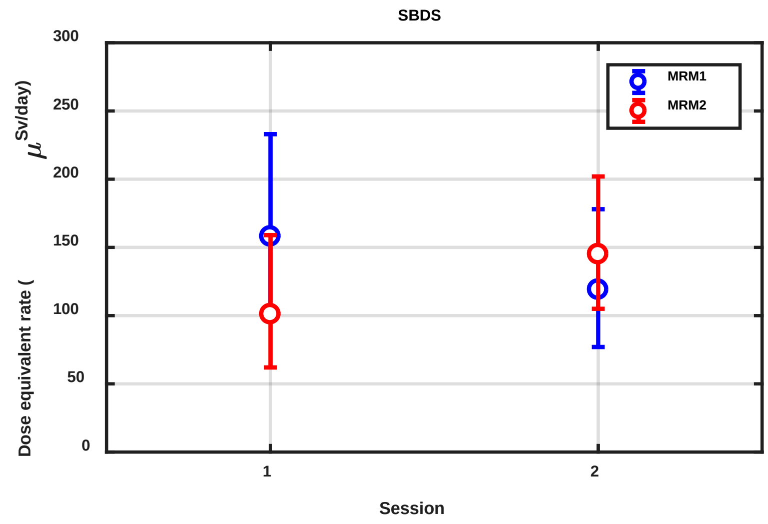
- The SBDS measurements suggest that the dose equivalent inside the phantom is 73% of the value at the phantom surface
- This is in good agreement with the earlier results from ISS-35/36 (66%) and ISS-41/42 (66%)
- The neutron spectra show that the fraction of high-energy neutrons inside the phantom is higher than at the surface of the phantom
- The SPND results show only a slight decrease in dose equivalent inside the phantom compared to at the phantom surface

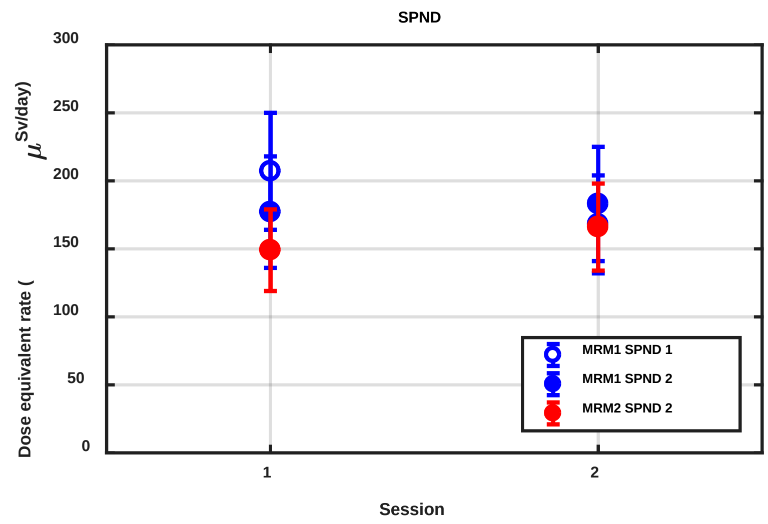




ISS-49/50: MRM1 and MRM2

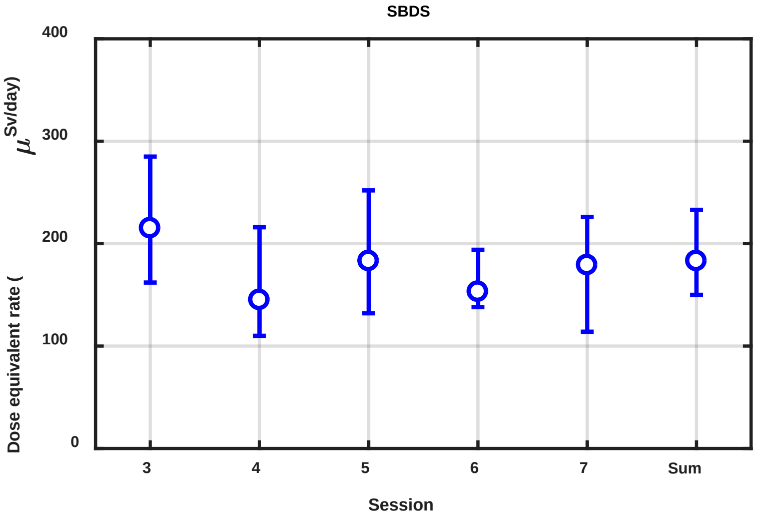
- During ISS-49/50, two sessions were performed to assess potential differences in the dose equivalent between MRM1 and MRM2
- These modules are located opposite each other; MRM1 is below the Service Module and MRM2 is above the Service Module
- The contribution of albedo neutrons in these two locations might therefore be different
- However, no significant differences in the data from the two locations were observed

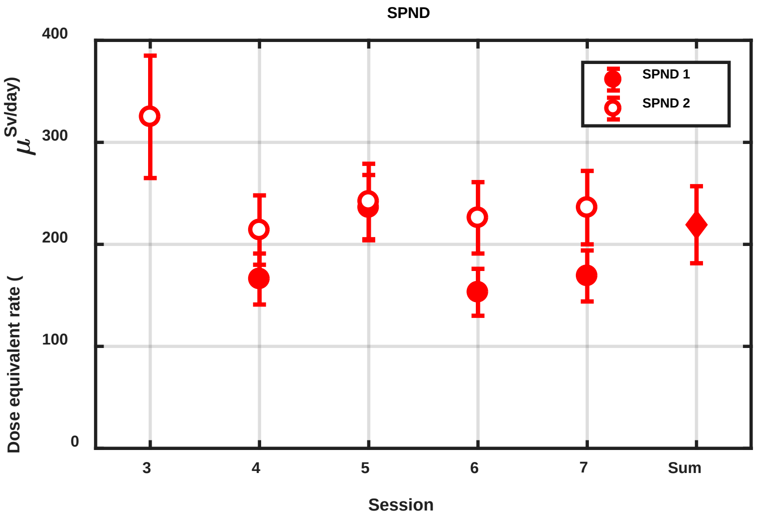




ISS-49/50: Service Module

- Five sessions were conducted in the Russian Service Module during ISS-49/50
- The detectors were located on panel 327, next to the Russian R-16 instrument
- The measured dose equivalent in the Service Module is slightly higher than that observed in the USOS modules
- The R-16 device typically measured 300 µGy/day during these measurement periods

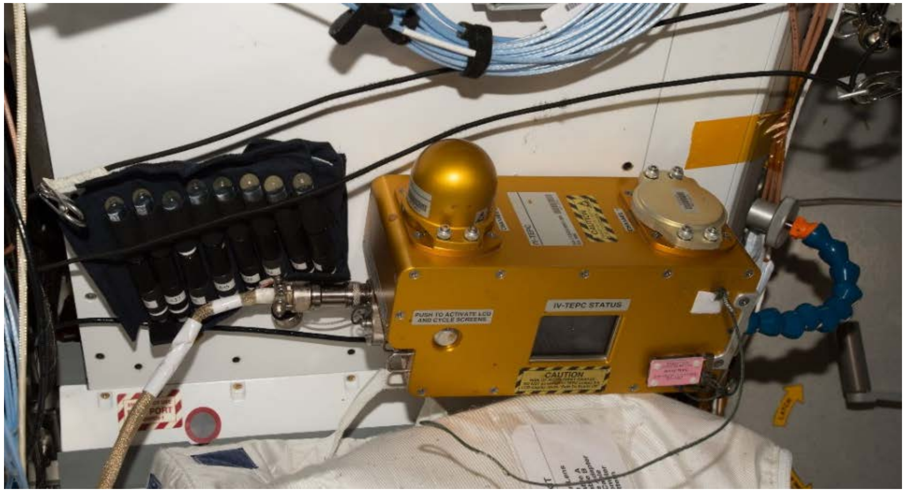


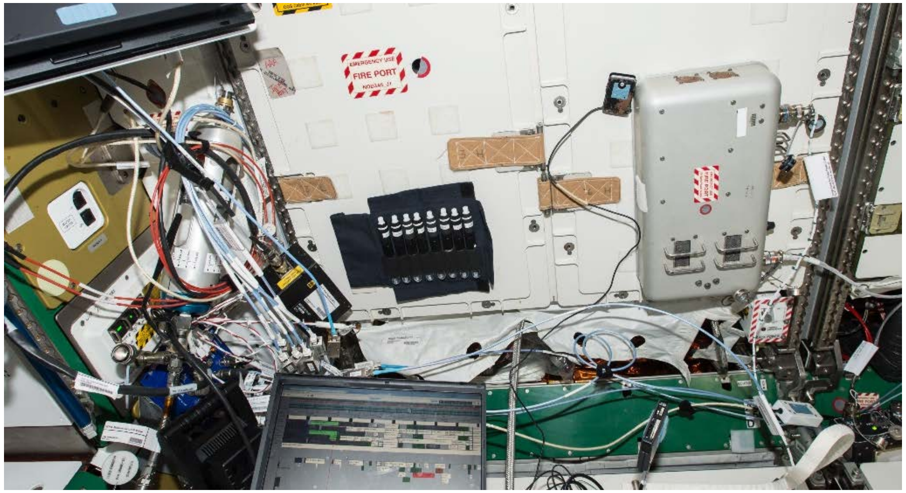


ISS-51/52 Measurements

Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
51/52-1	25 April 2017	2 May 2017	Node 2	MRM2
51/52-2	22 May 2017	29 May 2017	Node 3	MRM2
51/52-3	26 August 2017	2 September 2017	Columbus	MRM2

The Radi-N2 detectors were co-located with the IV-TEPC for Session 1 in Node 2
The bubble detectors were co-located with the ISS-RAD during Session 2 in Node 3 and Session 3 in Columbus





Plans for ISS-53/54

- For Radi-N2, four sessions are planned for the ISS-53/54 increment
  - Two sessions will be conducted in Columbus, co-located with the ISS-RAD
  - The locations for the third and fourth sessions are to be determined
- 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
- Matroshka-R measurements during ISS-53/54 will focus on experiments using the spherical phantom in MRM1
- The feasibility of experiments in the FGB module is also being investigated

Summary and Conclusions

- Bubble-detector experiments were performed for Radi-N2 and Matroshka-R during ISS-47/48 and ISS-49/50 (to March 2017)
- For Radi-N2, eight sessions were conducted in the USOS
  - The measured dose equivalent is similar in each location
  - 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
- Seventeen sessions were performed for the Matroshka-R experiment
  - Measurements with the Matroshka-R phantom confirmed earlier conclusions that the dose equivalent inside the phantom is ~70% of the value at its surface
  - Additional data were acquired in Pirs, MRM1, MRM2, and the Service Module
- Radi-N2 and Matroshka-R experiments are ongoing
  - More data were collected during ISS-51/52 and planning of measurements for ISS-53/54 is in progress

Acknowledgements

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- 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

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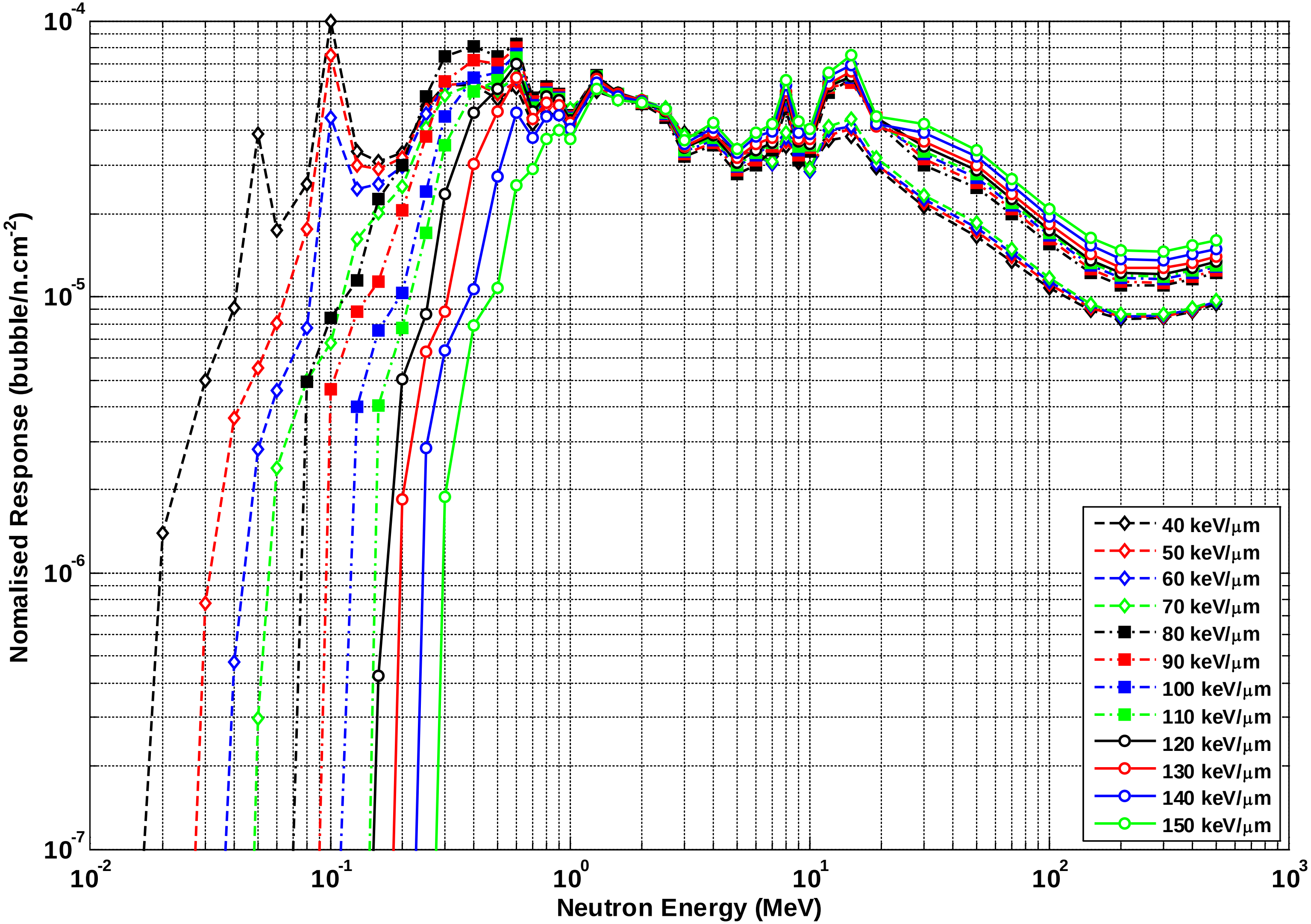
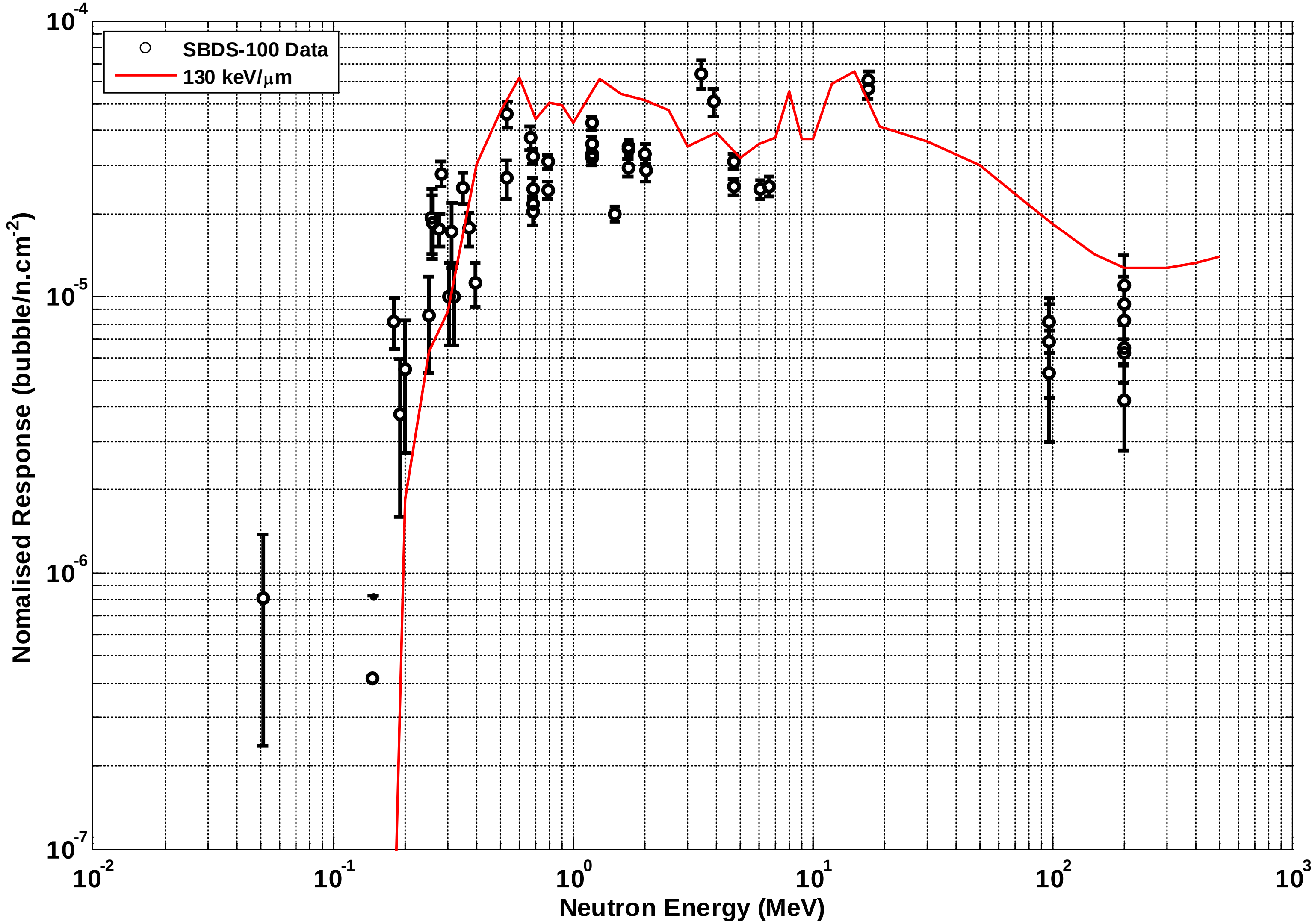
BACK-UP SLIDES

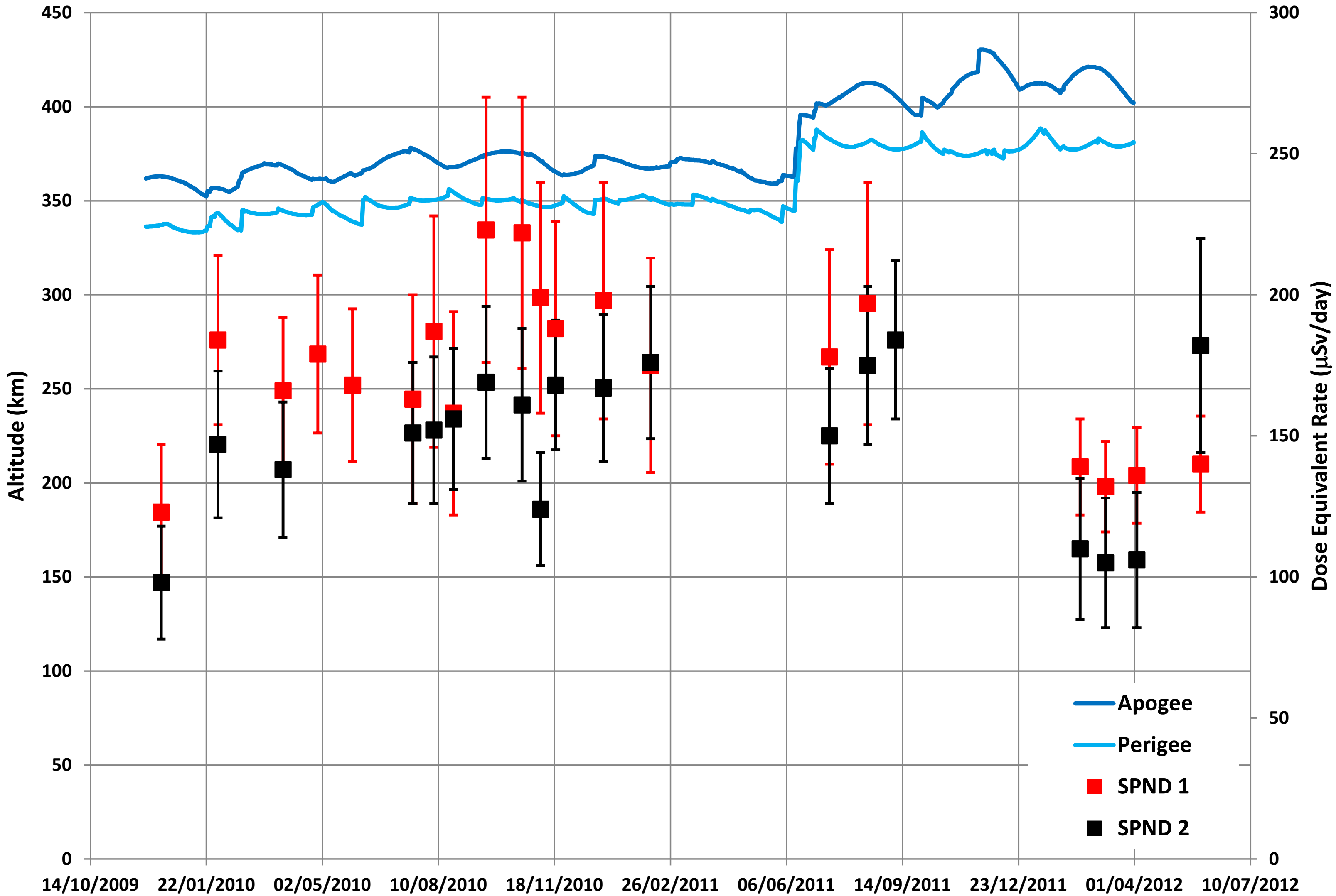
Bubble Detector Response Function



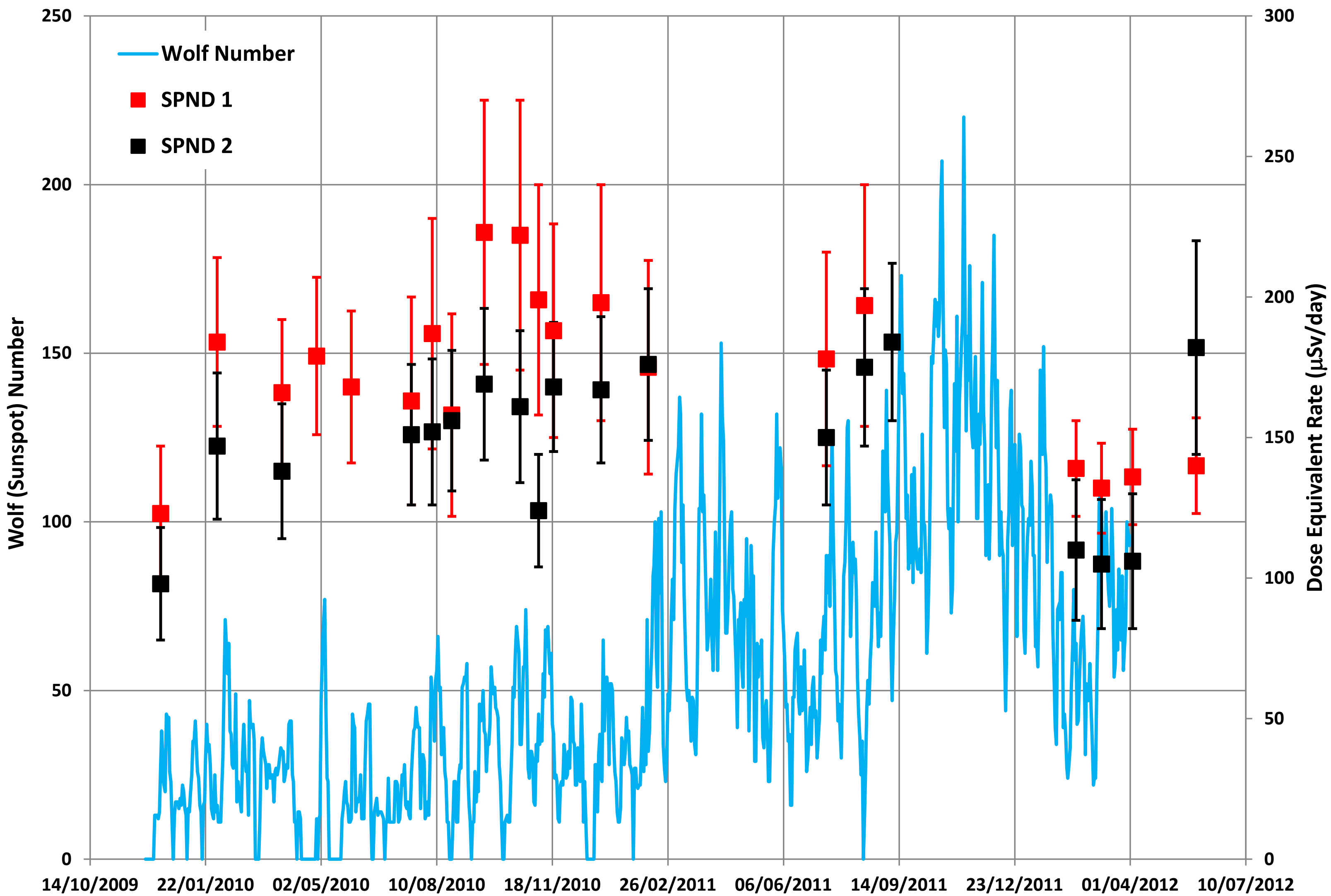
Bubble Detector Response Function



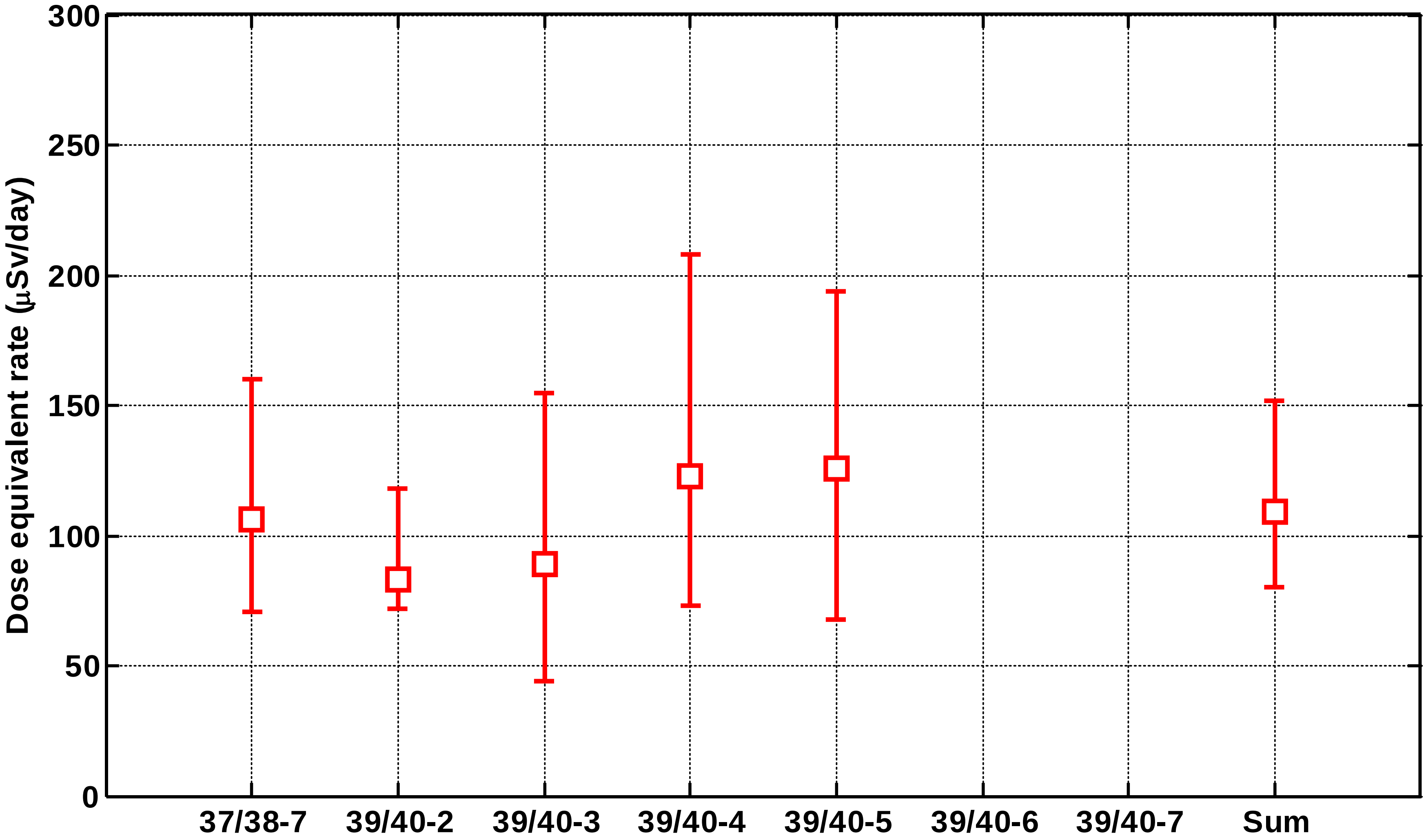
ISS-22 to ISS-33: Altitude



ISS-22 to ISS-33: Solar Activity



MRM2: SBDS Data



MRM2: SPND Data

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