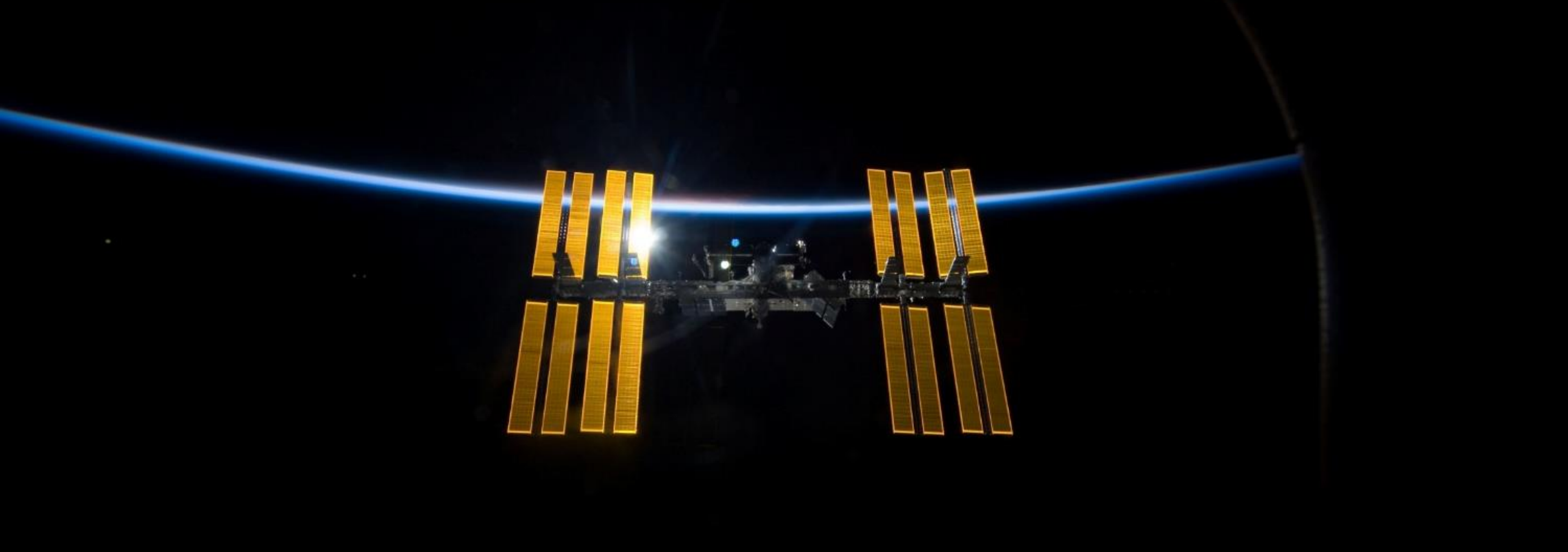
Matroshka-R and Radi-N2 Experiments using Bubble Detectors: ISS-43/44 and ISS-45/46



Martin Smith, Bubble Technology Industries

21st WRMISS, Noordwijk, the Netherlands

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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

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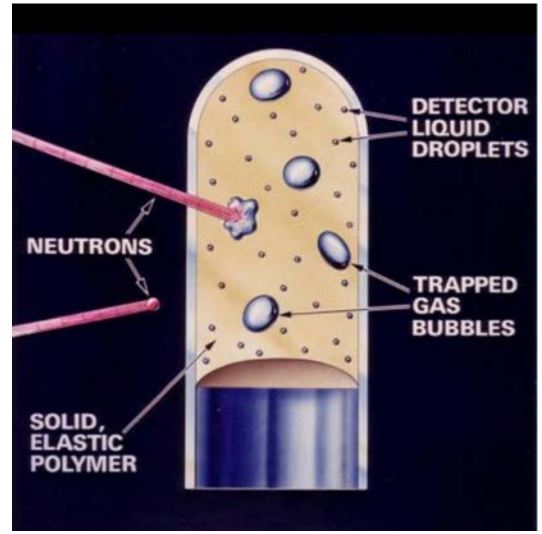
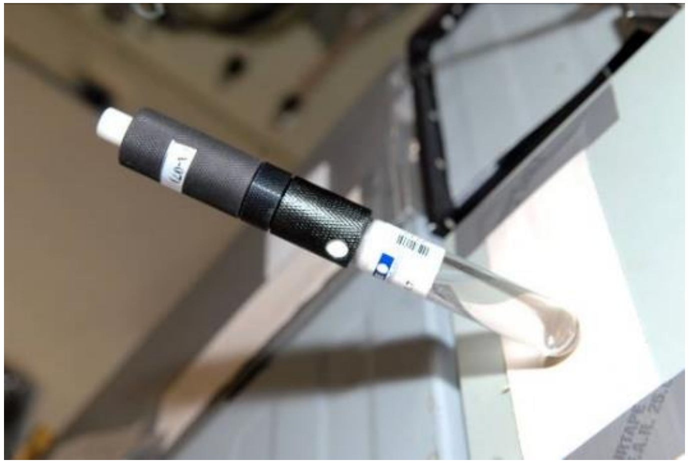
- Bubble detectors are passive dosimeters manufactured by Bubble Technology Industries
- They contain superheated liquid droplets dispersed in an elastic polymer
- High-LET particles interact with the droplets to form bubbles
- The elastic polymer retains the bubbles to allow visible detection of radiation
- 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

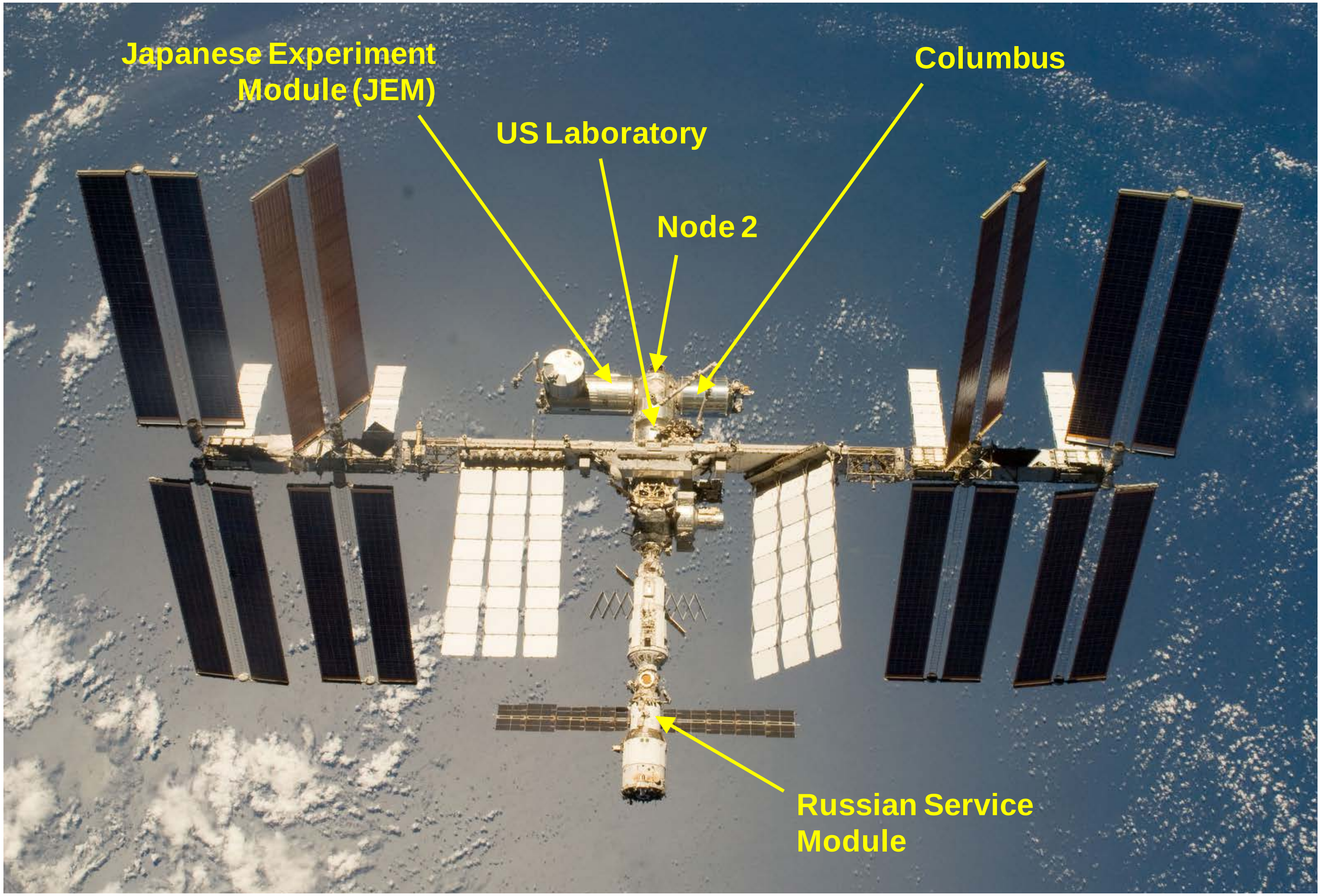


Image from NASA

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

Photograph used with permission of Dr. Robert Thirsk

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%

Photograph used with permission of Chris Hadfield

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-43 to ISS-46: List of Sessions

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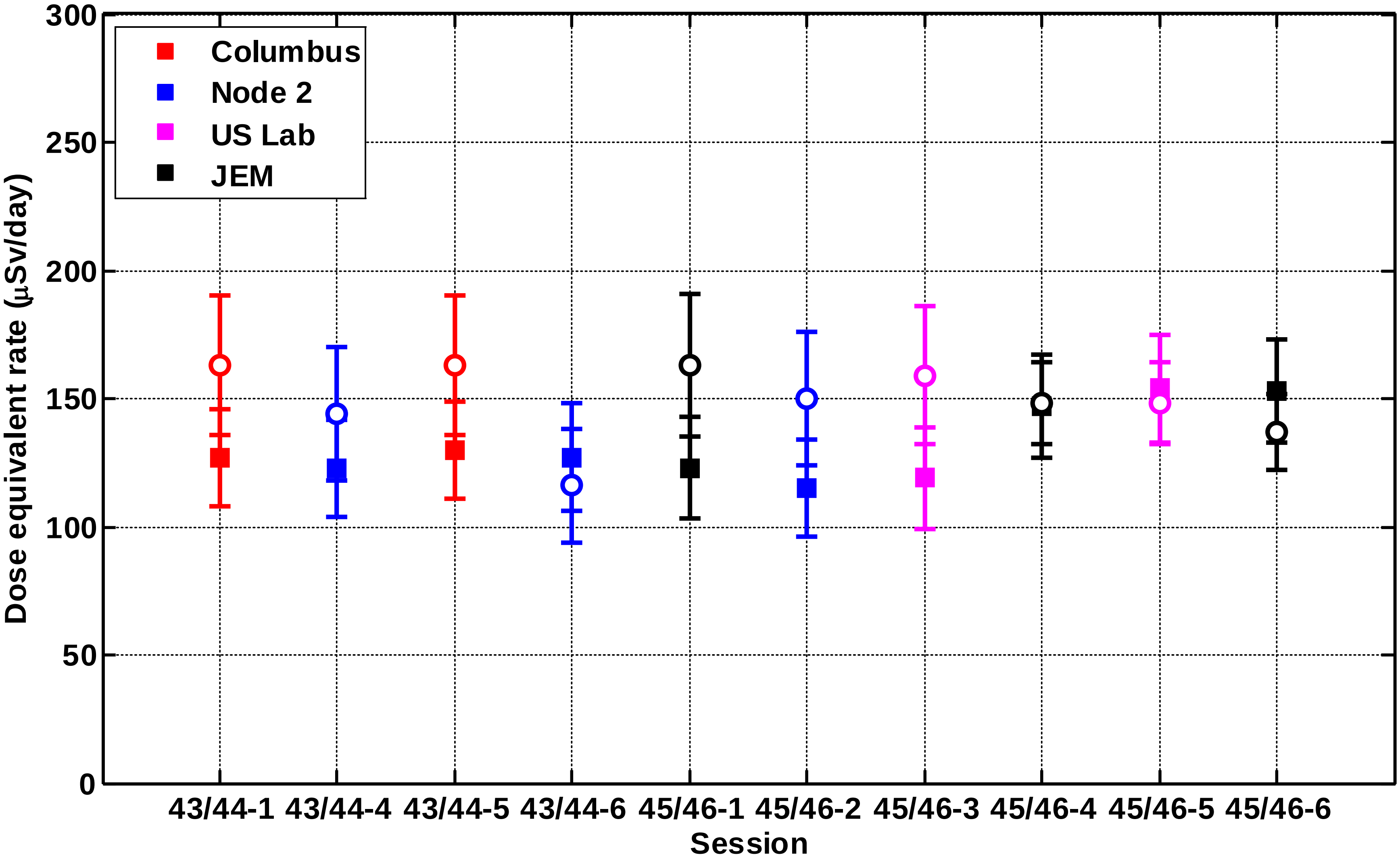
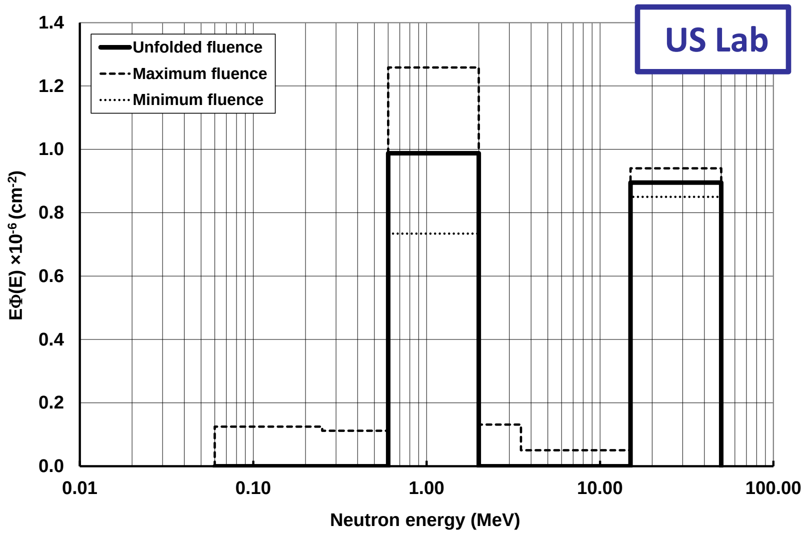
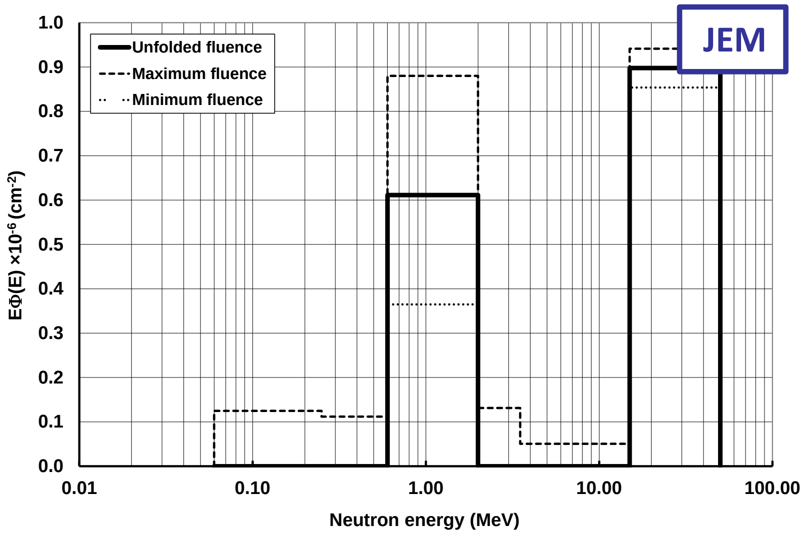
Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
43/44-1	24 March 2015	31 March 2015	Columbus	Service Module
43/44-2	16 April 2015	23 April 2015	Service Module	Service Module
43/44-3	19 May 2015	26 May 2015	Service Module	Service Module
43/44-4	12 June 2015	18 June 2015	Node 2	Service Module
43/44-5	14 July 2015	21 July 2015	Columbus	Service Module
43/44-6	12 August 2015	19 August 2015	Node 2	Service Module
45/46-1	18 September 2015	25 September 2015	JEM	Service Module
45/46-2	16 October 2015	23 October 2015	Node 2	Service Module
45/46-3	13 November 2015	20 November 2015	US Lab	Service Module
45/46-4	24 December 2015	31 December 2015	JEM	Service Module
45/46-5	13 January 2016	20 January 2016	US Lab	Service Module
45/46-6	12 February 2016	19 February 2016	JEM	Service Module

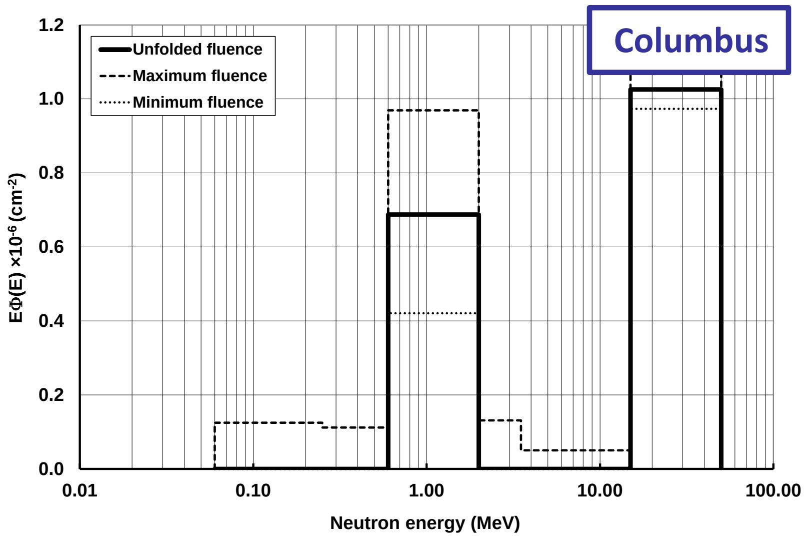
Radi-N2: SPND Dose Rate

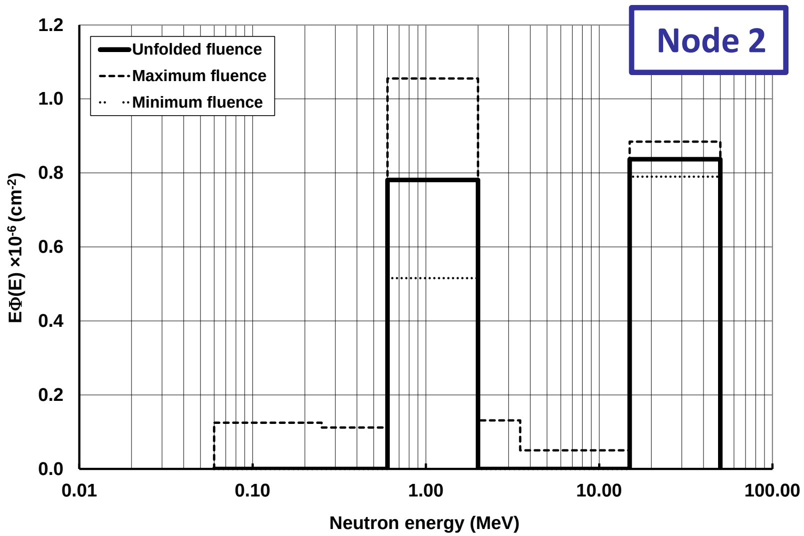


Radi-N and Radi-N2: SBDS Data









Radi-N and Radi-N2: SBDS Dose Rate

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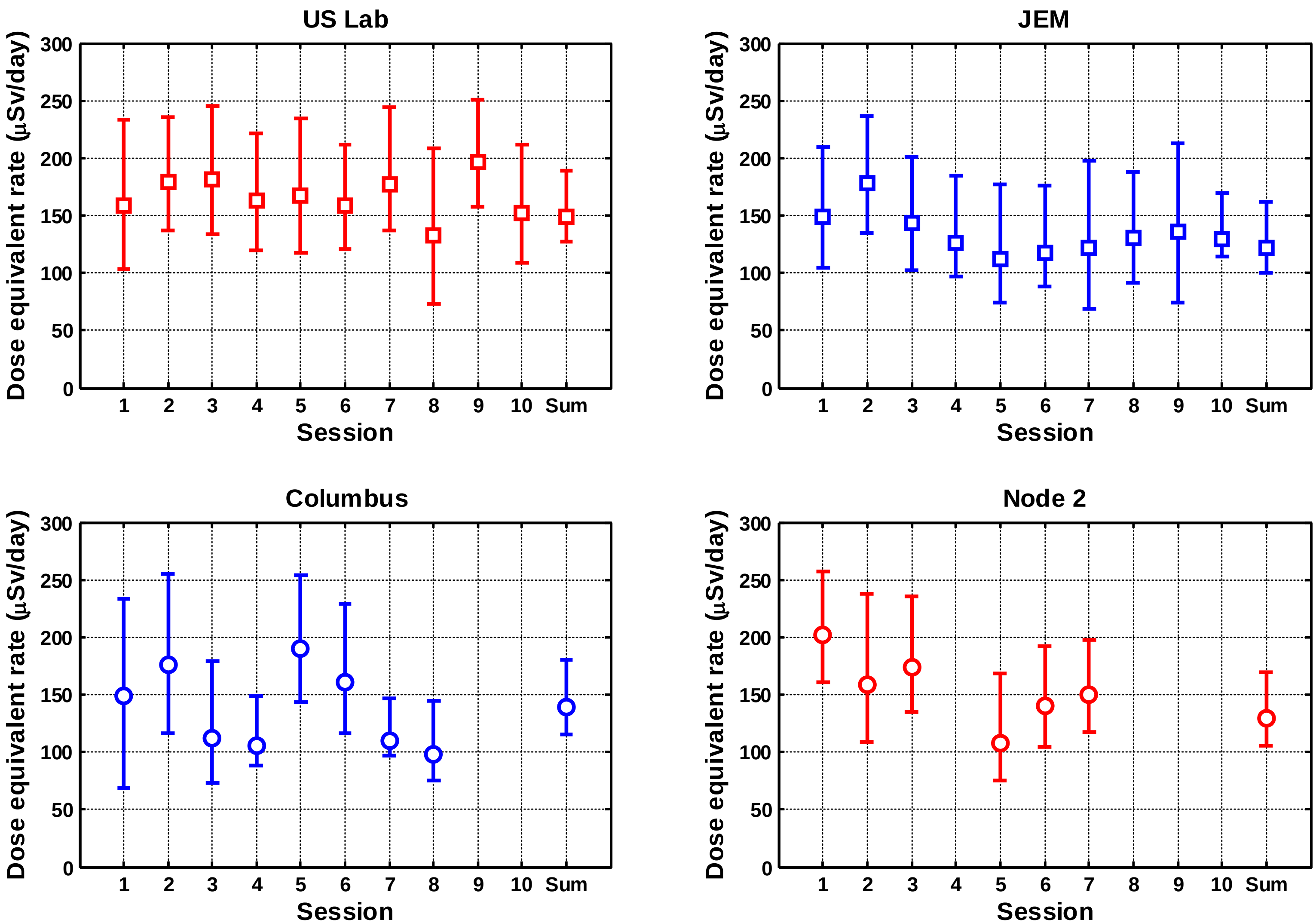
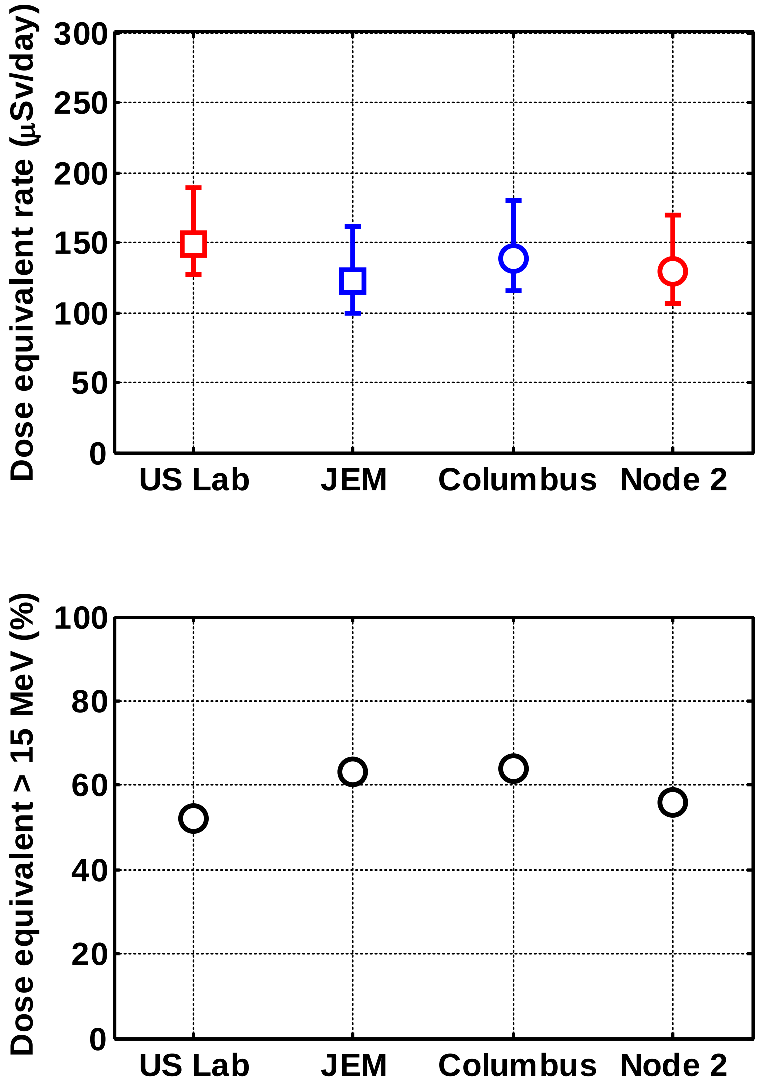


Radi-N and Radi-N2: SBDS Dose Rate

- 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)



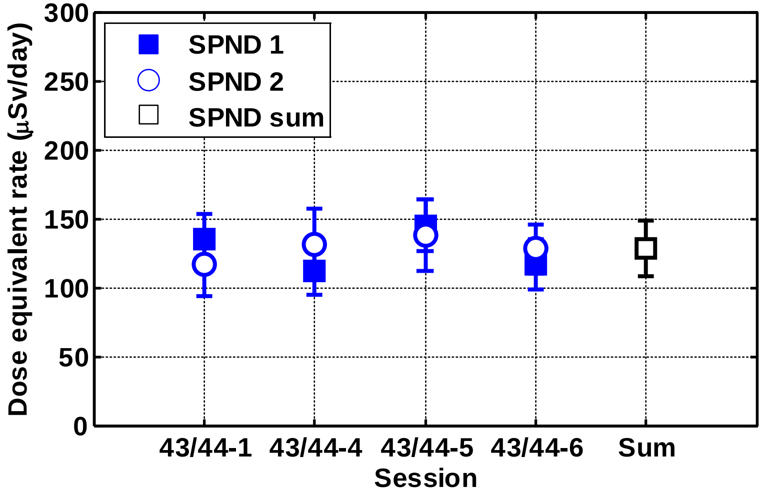
Matroshka-R: ISS-43 to ISS-46

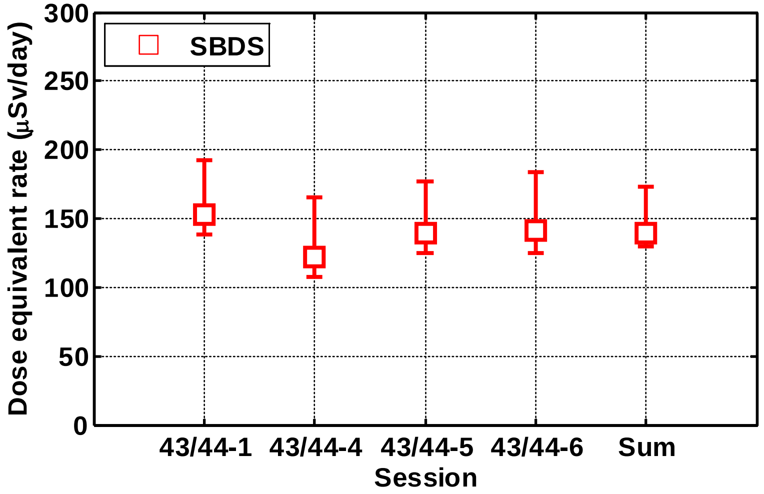
- For Matroshka-R, a total of 14 week-long measurements were conducted during ISS-43/44 and ISS-45/46
- Each used a spectrometer (SBDS) and two dosimeters (SPNDs)
- All experiments occurred in the Russian Service Module
- These measurements included
  - First measurements on panel 239
  - Further experiments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

Service Module, panel 239

Matroshka-R: Panel 239

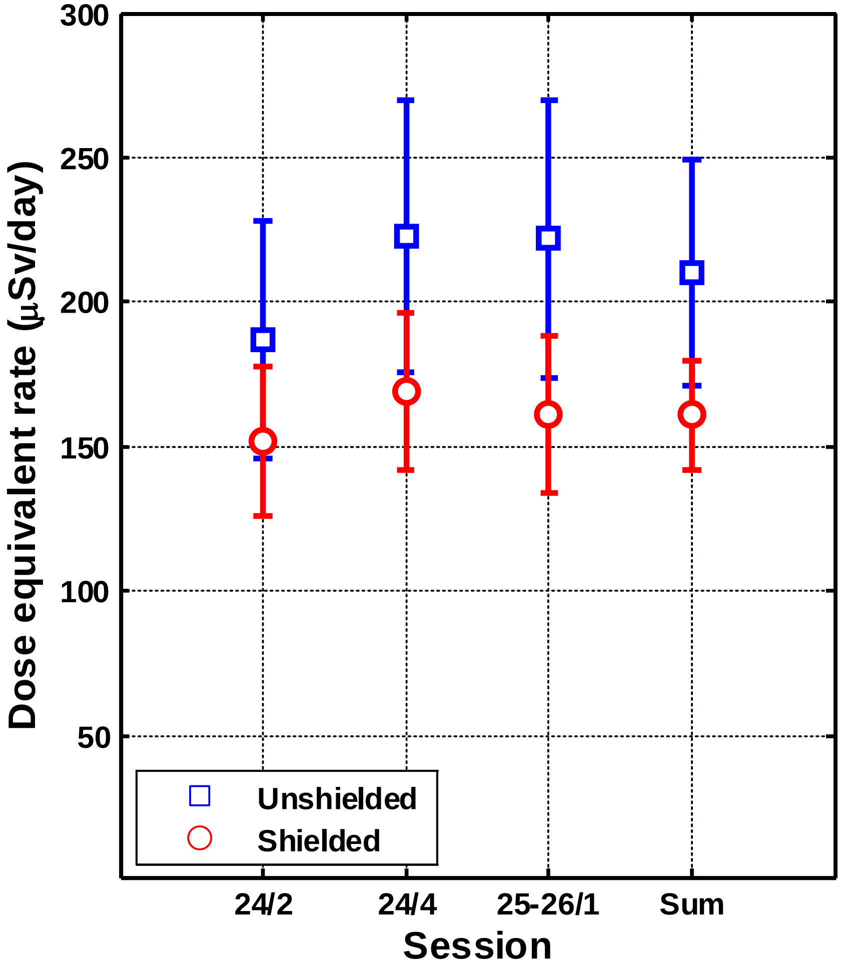
- Four sessions were conducted on panel 239 in the left crew quarter during ISS-43/44
- These were the first bubble-detector measurements in this location
- SPND and SBDS results are in good agreement with each other
- Dose equivalent for this location is similar to that measured elsewhere in the ISS





Matroshka-R: Hydrogenous Shielding

- 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 ± 17% of the unshielded value
- This is similar to a result (72 ± 17%) measured using bags of water in the JEM (ISS-21)



SPND results from ISS-24 and ISS-25/26

Matroshka-R: Hydrogenous Shielding

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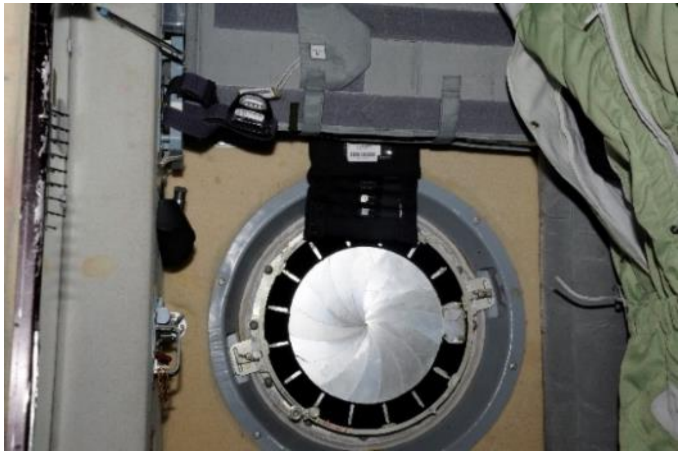
- Two sessions were performed during ISS-43/44 using two SBDS sets and four SPNDs
- Prime detectors were located on the illuminator side of the shield, while the back-up detectors were situated on the cabin side of the shield
- This was the first direct comparison of the neutron dose equivalent on each 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



Illuminator side of the shield

Cabin side of the shield

Matroshka-R: Hydrogenous Shielding

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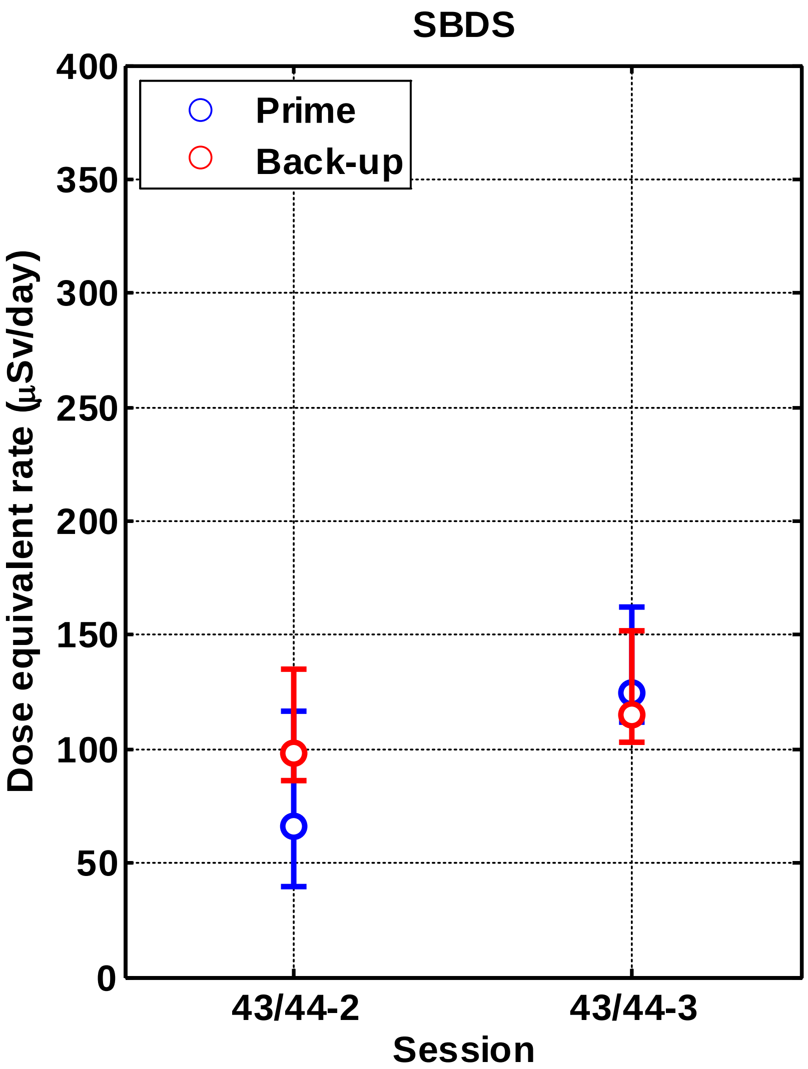

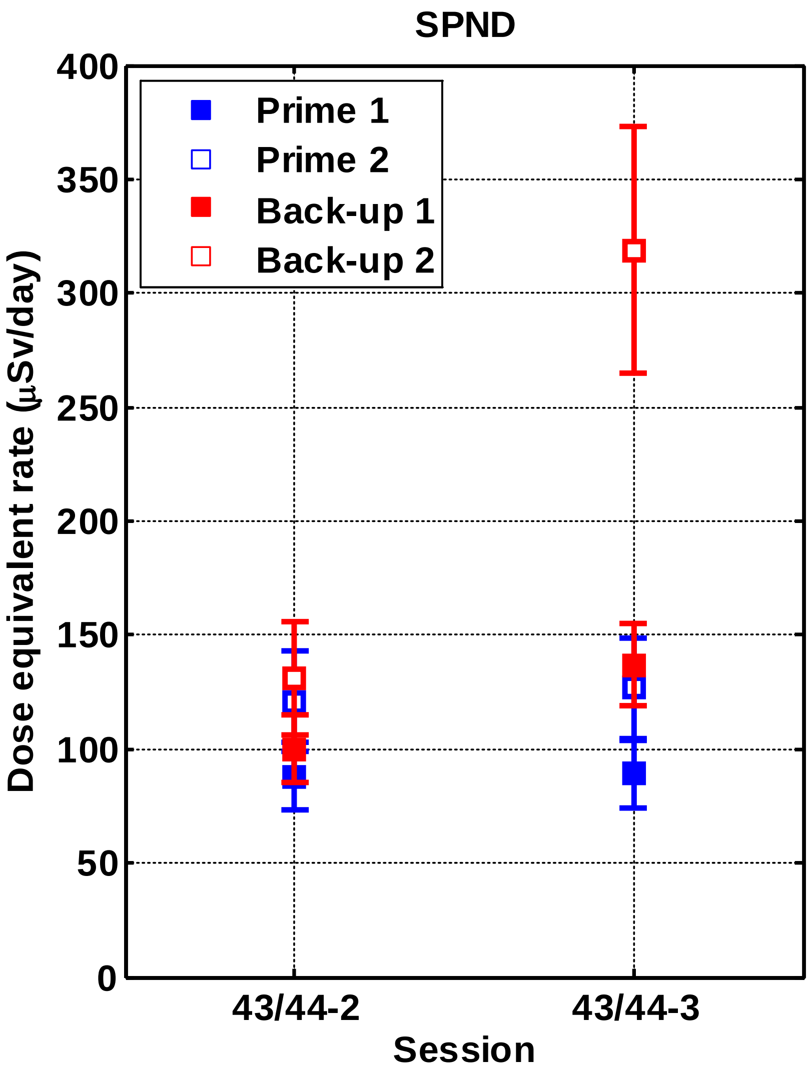

Matroshka-R: Least/Most Shielded

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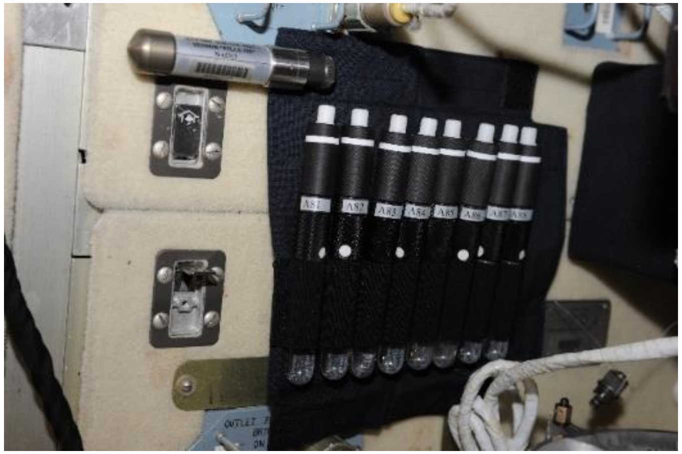
- During the six sessions of ISS-45/46, a shielding experiment was performed in the Service Module
- Based on extensive measurements and theoretical calculations, two locations have been identified that represent the least and most shielded locations in the Service Module
  - The least shielded location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

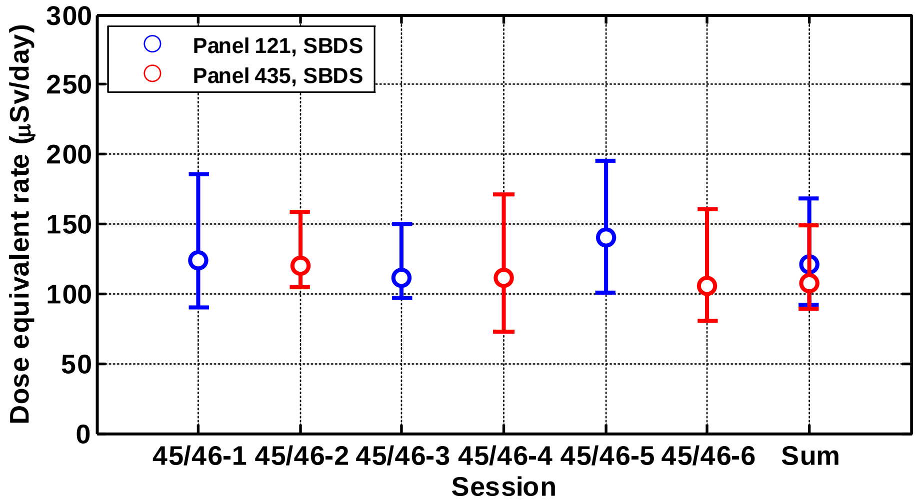
Least shielded, panel 121

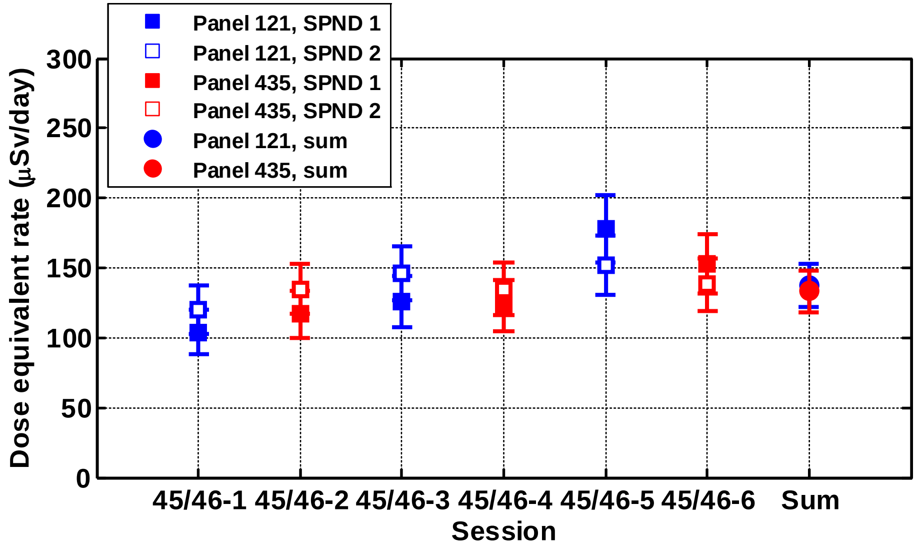


Most shielded, panel 435

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

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	2 June 2016	9 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

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

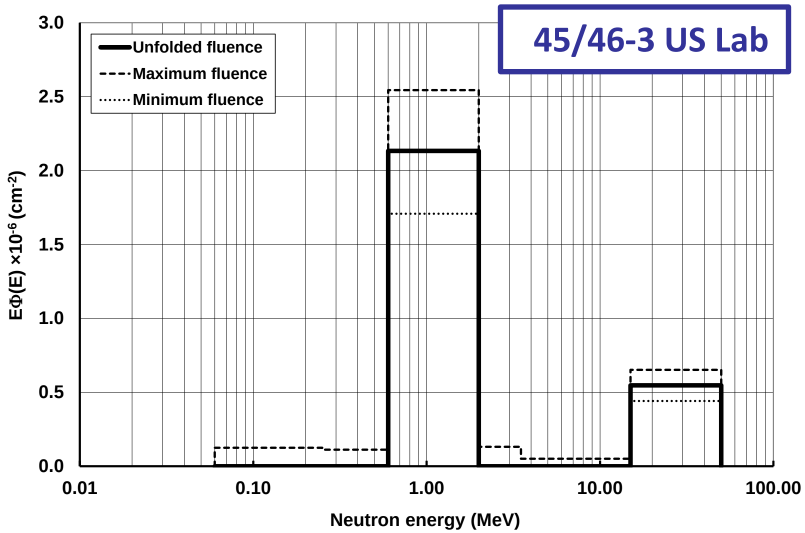
- We would like to thank the following for their important contributions
  - The astronauts and cosmonauts who performed the measurements
  - NASA's Space Radiation Analysis Group (SRAG) for supporting the experiments
  - The Canadian Space Agency and the Russian Space Agency for funding the work

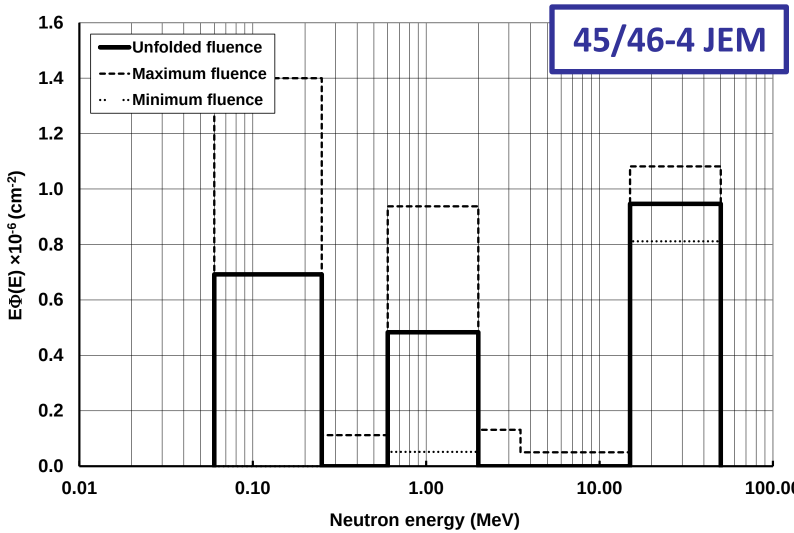
- References for recent publications

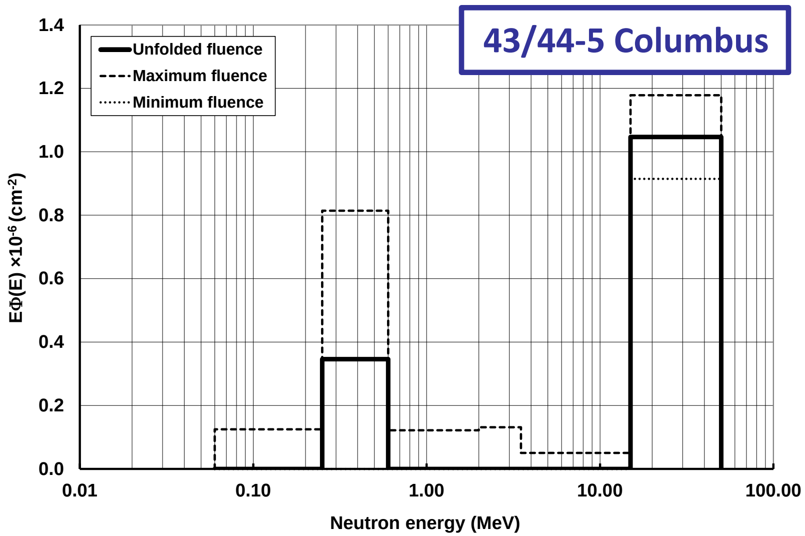
  - R. Machrafi et al., Radiat. Prot. Dosim. 133(4), 200 – 207 (2009)
  - B.J. Lewis et al., Radiat. Prot. Dosim. 150(1), 1 – 21 (2012)
  - M.B. Smith et al., Radiat. Prot. Dosim. 153(4), 509 – 533 (2013)
  - M.B. Smith et al., Proc. 65th IAC, IAC-14.A1.4.3 (2014)
  - M.B. Smith et al., Radiat. Prot. Dosim. 163(1), 1 – 13 (2015)
  - M.B. Smith et al., Radiat. Prot. Dosim. 164(3), 203 – 209 (2015)
  - M.B. Smith et al., Radiat. Prot. Dosim. 168(2), 154 – 166 (2016)

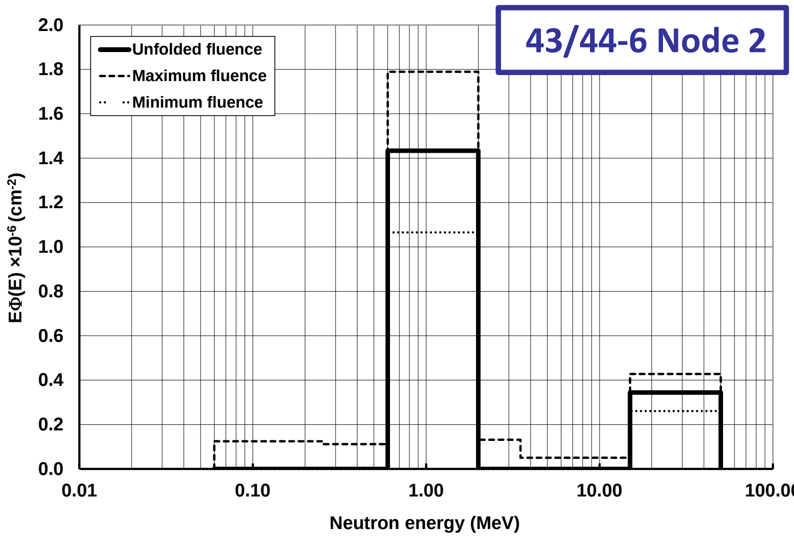
BACK-UP SLIDES

Radi-N2: Recent SBDS Data









Bubble Detector Response Function

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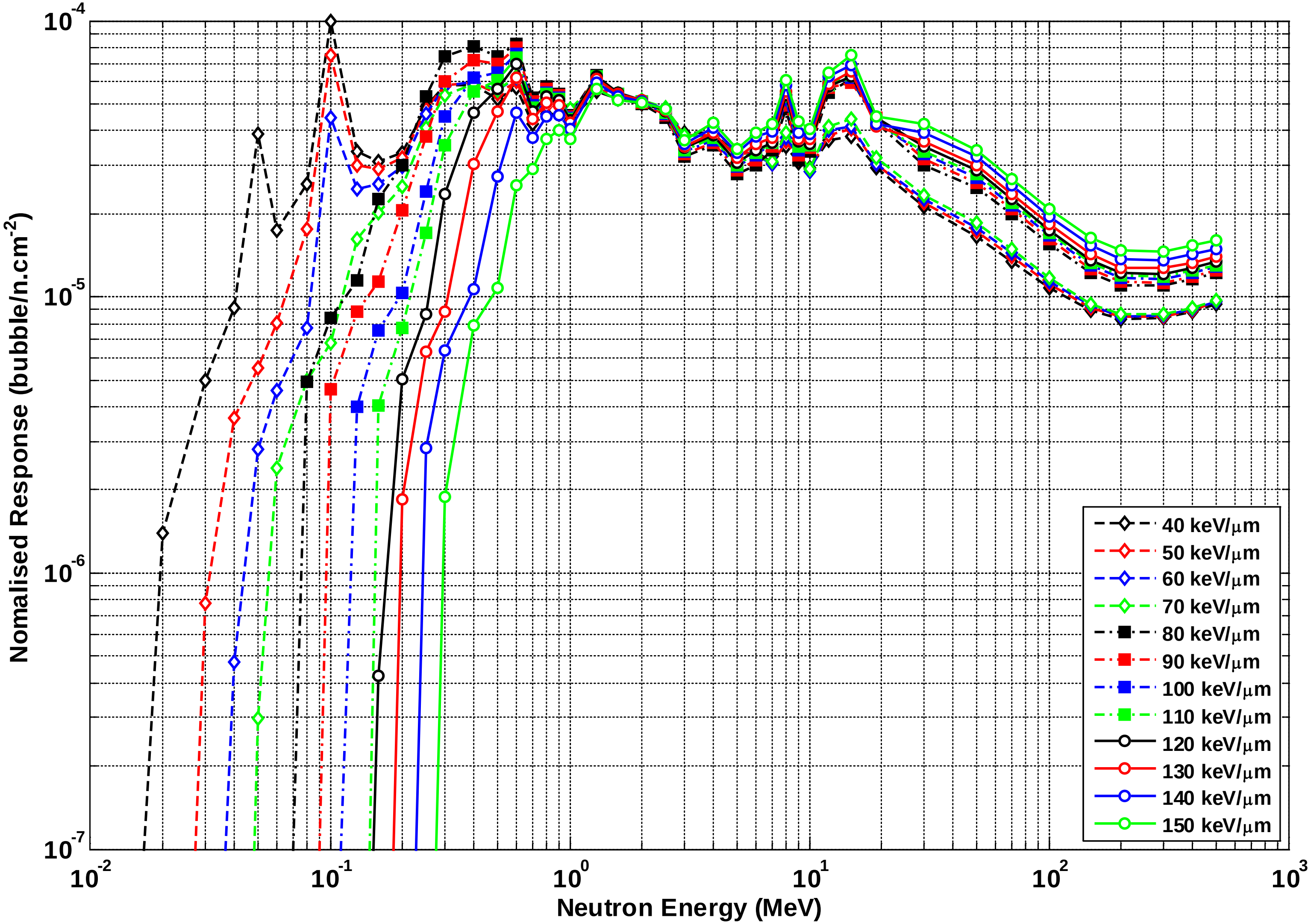
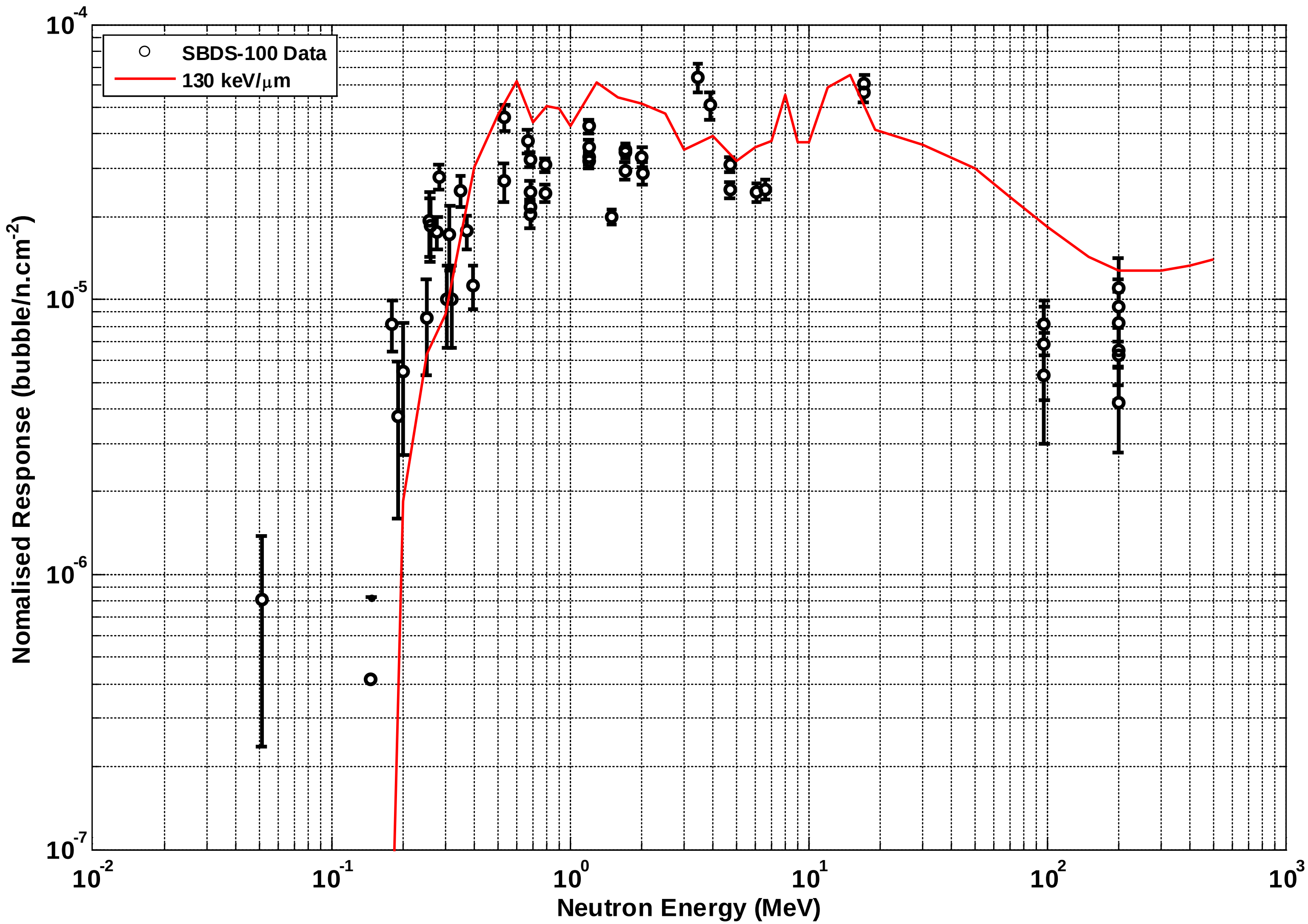


Bubble Detector Response Function



ISS-22 to ISS-33: Altitude

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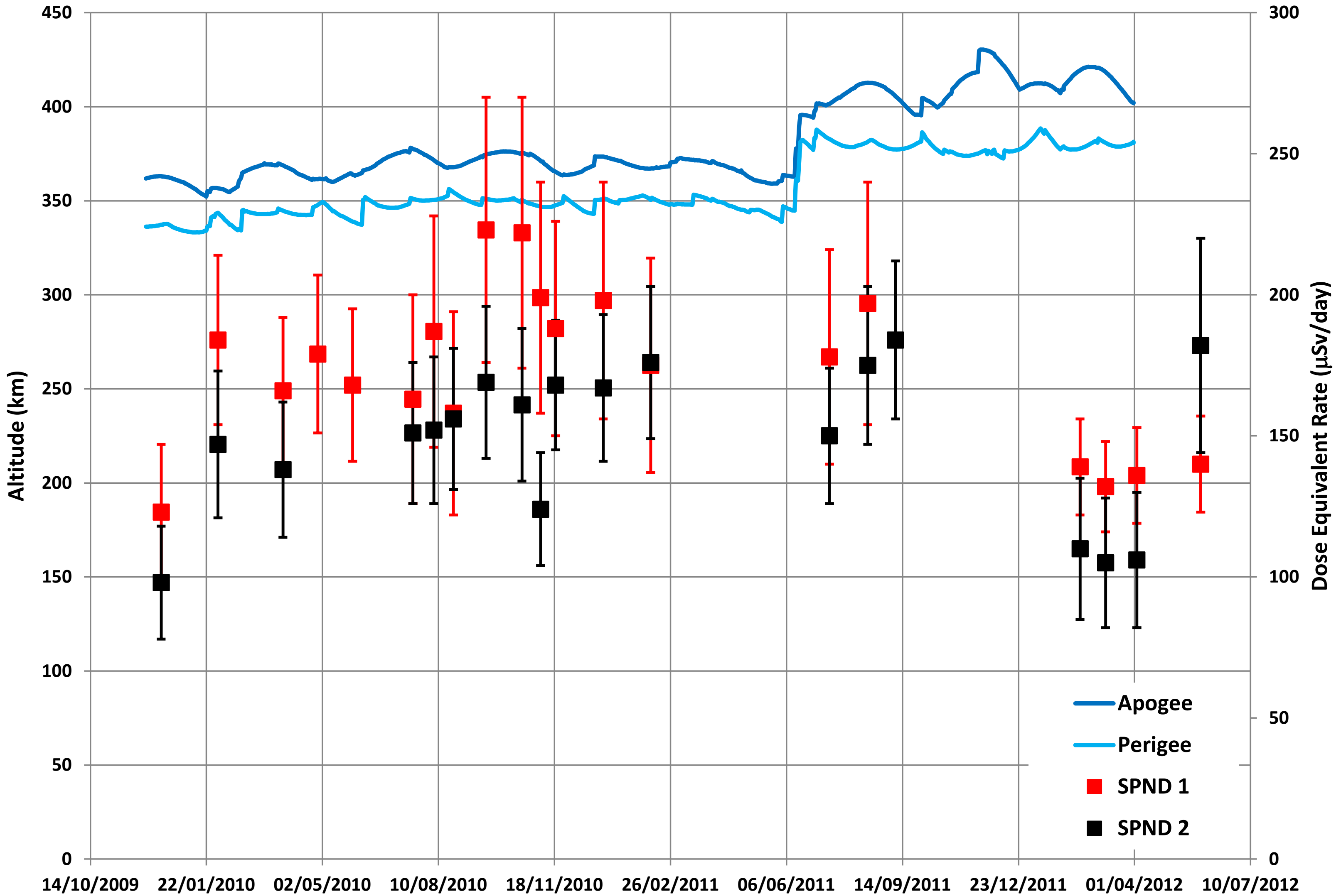

ISS-22 to ISS-33: Solar Activity

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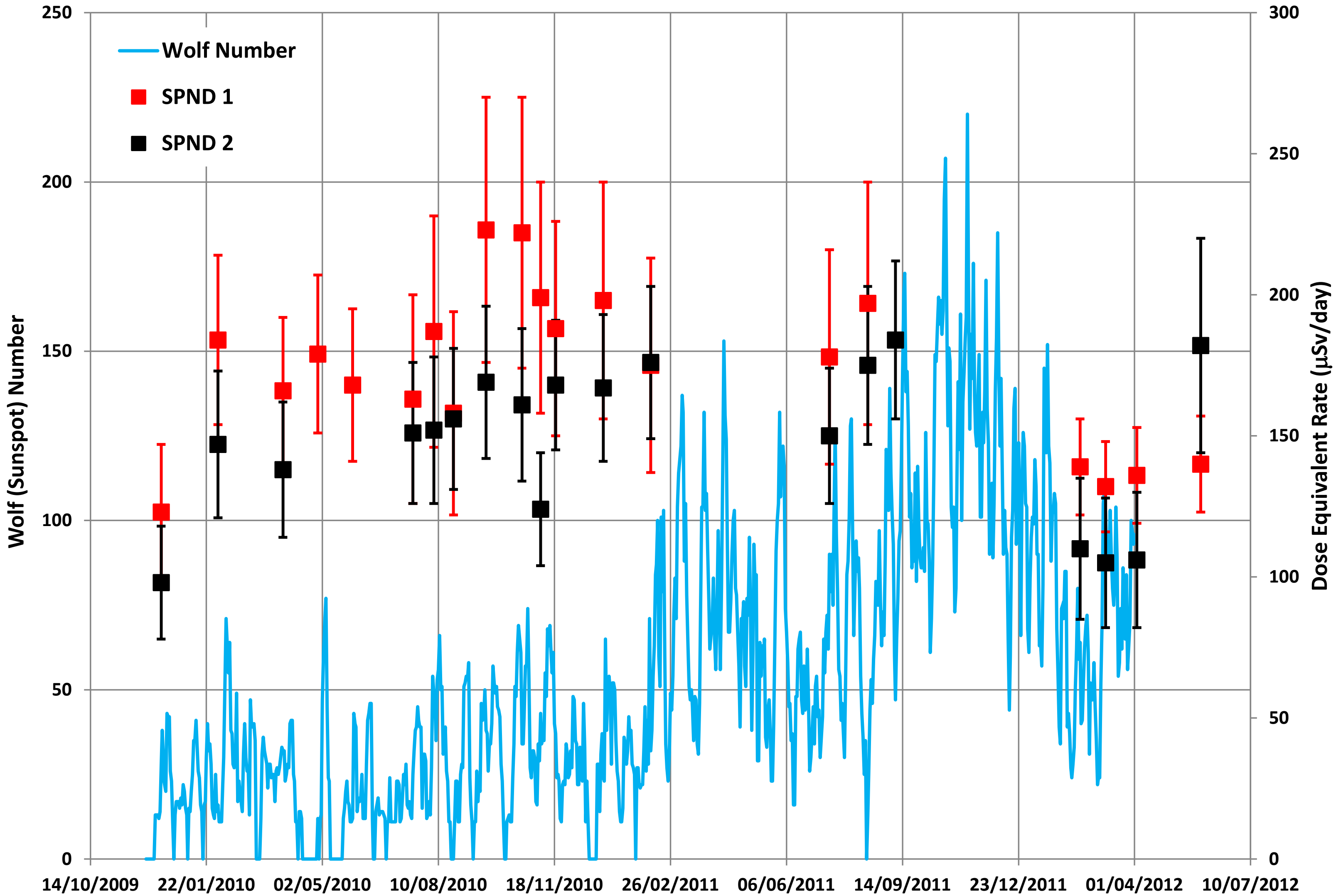
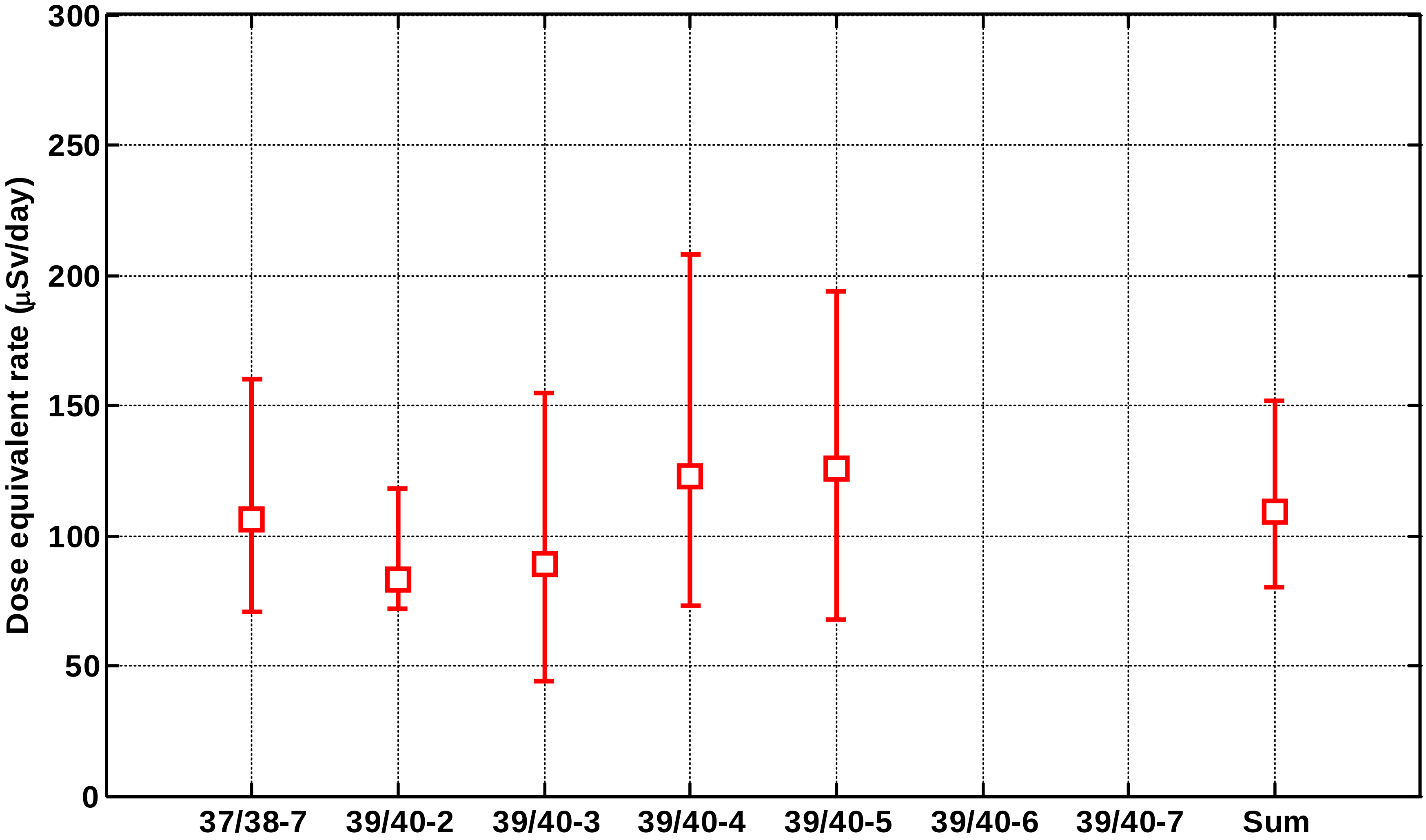


MRM2: SBDS Dose Rate



MRM2: SPND Dose Rate