Neutron Measurements using Bubble Detectors: ISS-34 to ISS-40

WRMISS-19

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Collaboration

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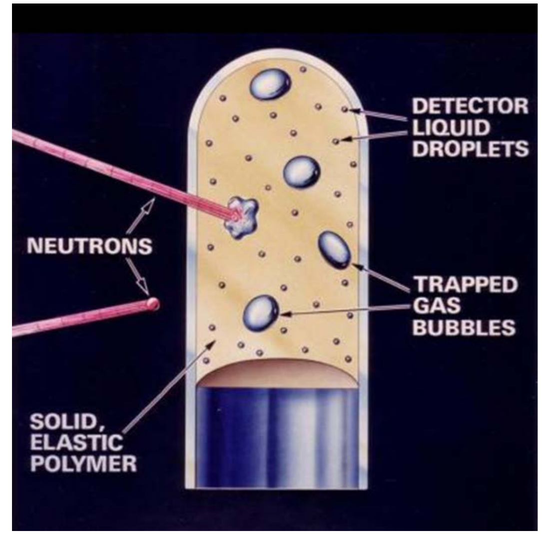
Introduction

- Radiation prediction, monitoring, and protection technologies are a key part of every space mission involving humans
- 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 neutron dosimeters manufactured by Bubble Technology Industries
- They contain superheated liquid droplets dispersed in an elastic polymer
- Neutrons interact with the droplets to form bubbles
- The elastic polymer retains the bubbles to allow visible detection of neutron radiation
- After each measurement, the bubbles can be recompressed and the detector can be reused



Space Bubble Detectors

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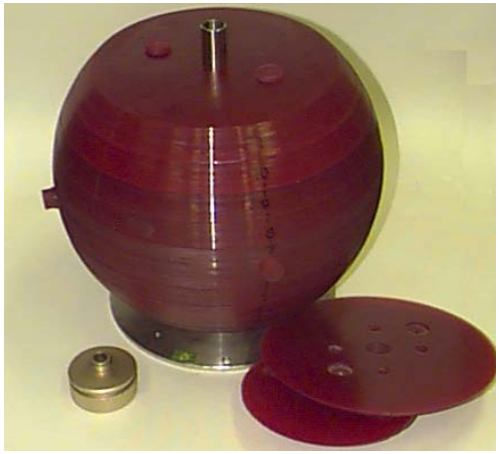
- Two types of space bubble detector are used to monitor neutrons on the ISS
  - Space personal neutron dosimeter (SPND)
  - Space bubble detector spectrometer (SBDS)
    - Set of six detectors, each with a different energy threshold
    - Data unfolding provides a coarse neutron energy spectrum (0.06 – 50 MeV)
- 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-13 (2006) to ISS-19 (2009)

- Bubble detectors have been used on the ISS since ISS-13 as part of the international Matroshka-R experiment
- Early experiments used the spherical Matroshka-R phantom located in the Russian segment
- Phantom measurements using SPNDs indicated that the neutron dose inside the phantom was slightly less than that at its surface



R. Machrafi et al., Radiat. Prot. Dosimetry 133(4), 200 – 207 (2009)
M.B. Smith et al., Radiat. Prot. Dosimetry 153(4), 509 – 533 (2013)

ISS-20/21 (2009)

- The SBDS was used for the first time during ISS-20/21
- Experiments were performed with an SBDS and two SPNDs in four modules
  - Russian Service Module
  - Columbus
  - US Lab
  - Japanese Experiment Module (JEM)
- This included the Radi-N experiment in the USOS modules
  - Goal of Radi-N was to compare the neutron dose and energy spectrum at different locations in the USOS

Photograph used with permission of Dr. Robert Thirsk

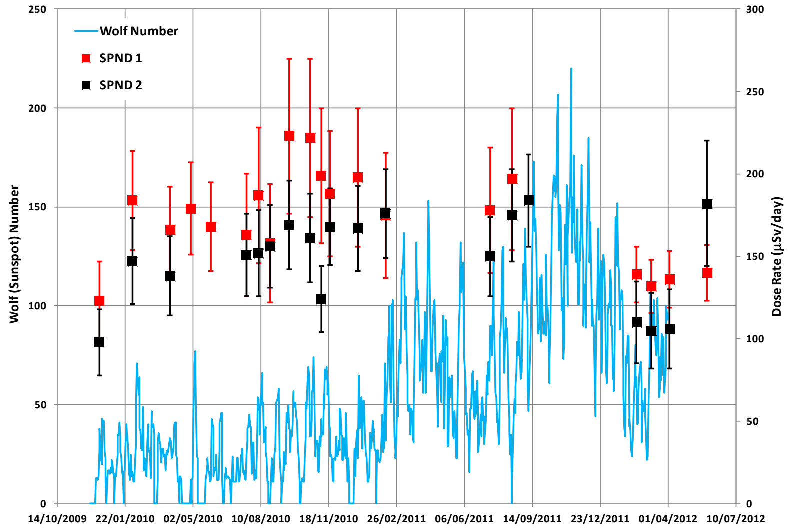
M.B. Smith et al., Radiat. Prot. Dosimetry 153(4), 509 – 533 (2013)

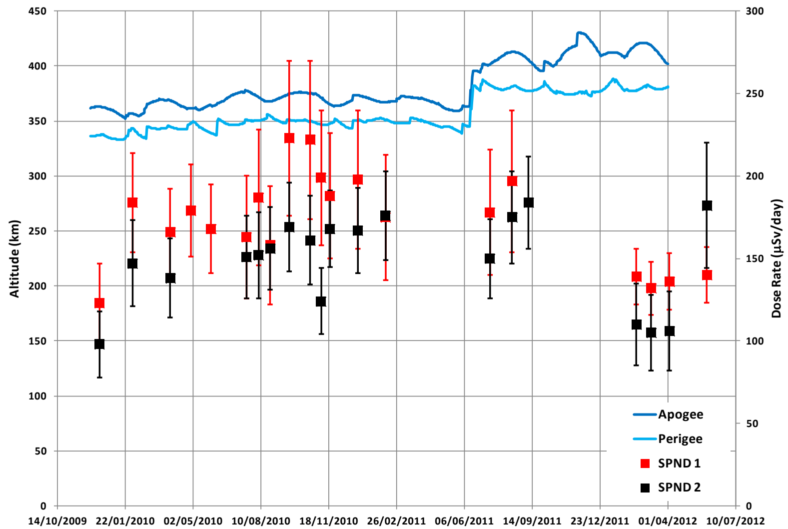
ISS-20 and ISS-21 (2009)

- Neutron energy spectra agreed well with previous measurements, and did not show a strong dependence on the location in the ISS
- Neutron dose received in the sleeping quarters (JEM) was less than that received during daily activities
- A water shield in the JEM reduced the neutron dose on the inner side of the shield to 72±17% of the value on the outer side
- Neutron dose equivalent was approximately 30% of the total recorded by the ISS TEPC
- Approximately 40% of the neutron dose measured was due to high-energy neutrons (> 15 MeV)

ISS-22 (2009) to ISS-33 (2012)

- 32 experimental sessions (approximately one week each) were performed during ISS-22 to ISS-33
- All measurements were conducted in the Russian segment
- A hydrogenous shield reduced the neutron dose on the cabin side of the shield to 77±17 % of the dose at an unshielded location
- It was shown that solar activity and ISS altitude did not seem to have a strong influence on the neutron dose or energy spectrum inside the ISS





M.B. Smith et al., Radiat. Prot. Dosimetry doi:10.1093/rpd/ncu053 (2014)

List of Sessions: ISS-34 to ISS-38

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Session	Initialization date	Retrieval date	Location 1	Location 2
34/35-1	27 December 2012	3 January 2013	Columbus	Service Module
34/35-2	18 January 2013	25 January 2013	JEM	Service Module
34/35-3	11 February 2013	18 February 2013	US Lab	Service Module
34/35-4	5 March 2013	12 March 2013	Node 2	Service Module
35/36-1	3 April 2013	10 April 2013	Service Module	Service Module
35/36-2	1 May 2013	8 May 2013	MRM1	MRM1
35/36-3	30 May 2013	6 June 2013	US Lab	MRM1
35/36-4	27 June 2013	5 July 2013	US Lab	MRM1
35/36-5	12 July 2013	19 July 2013	MRM1	MRM1
35/36-6	25 July 2013	2 August 2013	JEM	MRM1
35/36-7	23 August 2013	30 August 2013	JEM	MRM1
37/38-1	16 September 2013	23 September 2013	MRM1	MRM1
37/38-2	15 October 2013	22 October 2013	MRM1	MRM1
37/38-3	15 November 2013	22 November 2013	US Lab	Service Module
37/38-4	11 December 2013	19 December 2013	Service Module	US Lab
37/38-5	9 January 2014	16 January 2014	Service Module	JEM
37/38-6	4 February 2014	11 February 2014	Service Module	JEM
37/38-7	26 February 2014	5 March 2014	MRM2	Columbus

ISS-34/35 (2012/2013)

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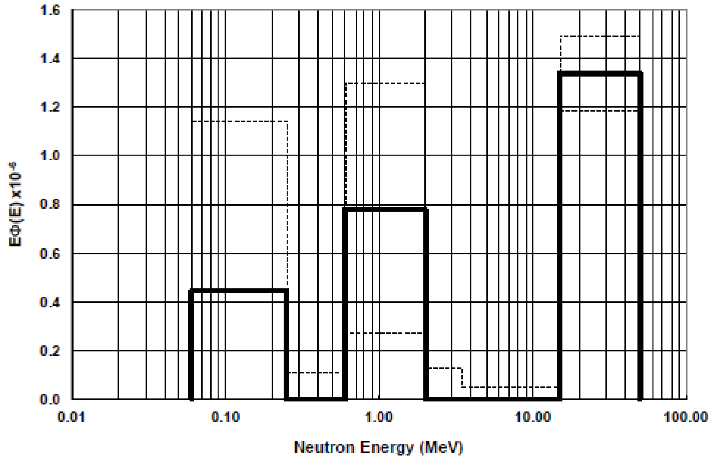
- The Radi-N2 experiment started during ISS-34/35 with four sessions in the USOS
- The goal was to repeat the 2009 Radi-N experiments as closely as possible
- For the four sessions, an SBDS was placed in Columbus (1A3), the JEM (JPM1F3), the US Lab (1S4), and Node 2 (P3)
- Two SPNDs were used simultaneously with the SBDS measurements
  – One was placed in the astronaut’s sleeping quarters (in Node 2) and one was worn on his body
- A second SBDS and two SPNDs were used for four sessions in the Russian Service Module at the same time as the Radi-N2 measurements

Photograph used with permission of Chris Hadfield

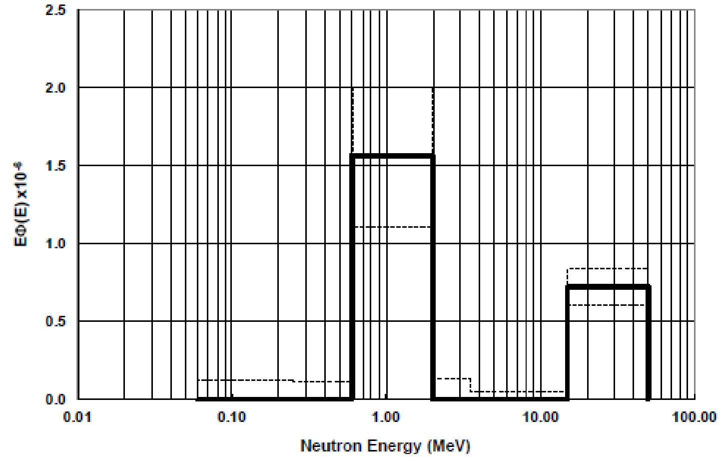
Canadian astronaut Chris Hadfield with bubble detectors, January 2013

ISS-34/35: Radi-N2 Energy Spectra

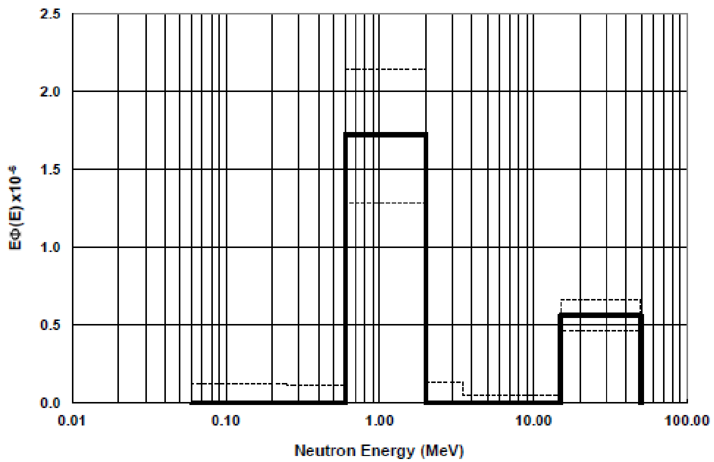
Session 1 – Columbus 62%



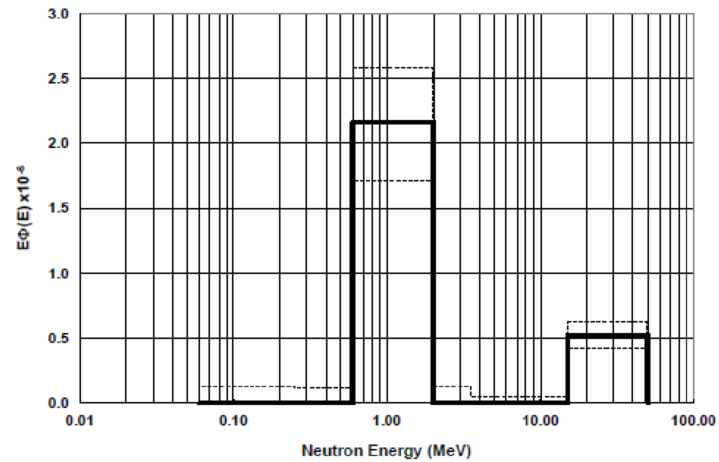
Session 2 – JEM 35%



Session 3 – US Lab 28%



Session 4 – Node 2 22%



ISS-34/35: Dose Rate

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Radi-N2 (USOS)

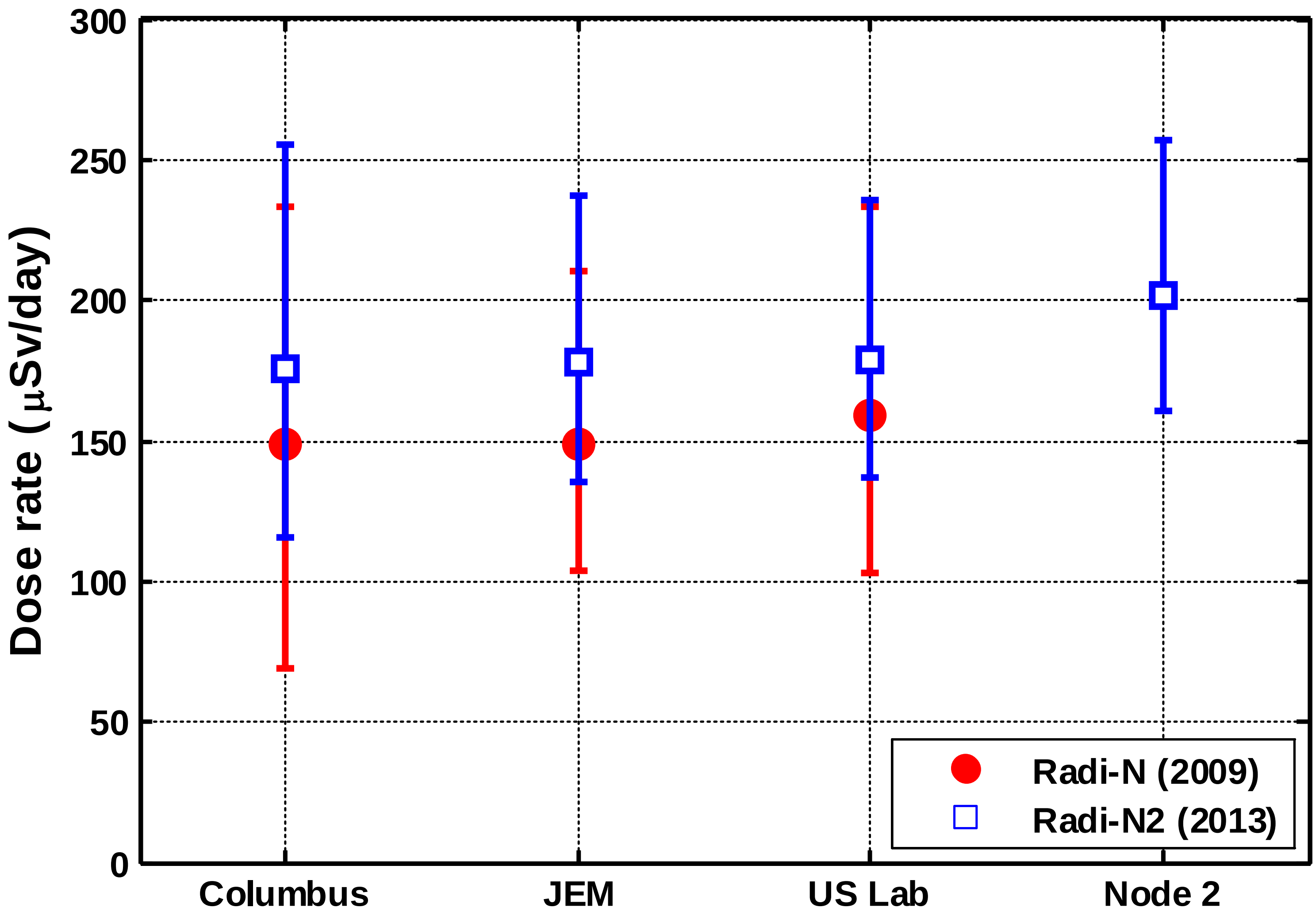
Session	SBDS Dose Rate (μSv/day)	SPND A97 Dose Rate (μSv/day)	SPND A98 Dose Rate (μSv/day)
1	176^{+79}_{-60}	212±38	144±22
2	178^{+59}_{-43}	195±36	178±26
3	179^{+57}_{-42}	145±28	147±22
4	202^{+55}_{-41}	181±33	125±20

Russian Service Module

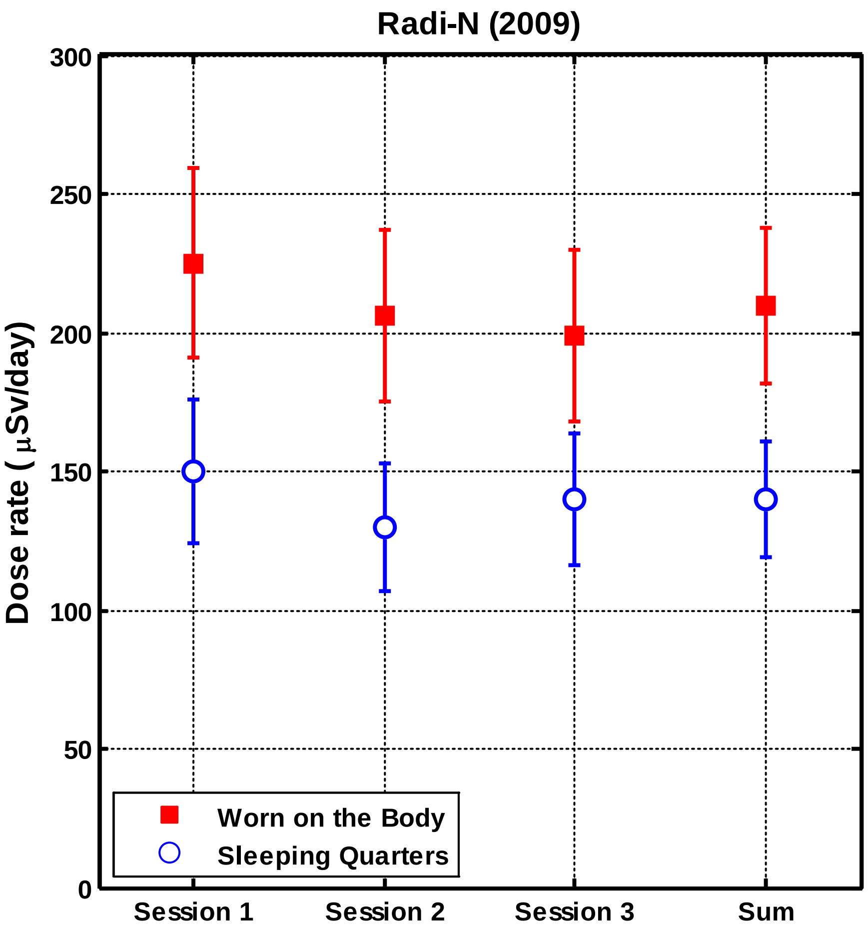
Session	SBDS Dose Rate (μSv/day)	SPND A07 Dose Rate (μSv/day)	SPND A08 Dose Rate (μSv/day)
1	144^{+75}_{-58}	151±22	149±24
2	228^{+45}_{-19}	150±22	153±25
3	126^{+58}_{-41}	148±22	132±22
4	154^{+41}_{-15}	187±26	166±26

SPND A07 and A08 were co-located with the Russian SBDS

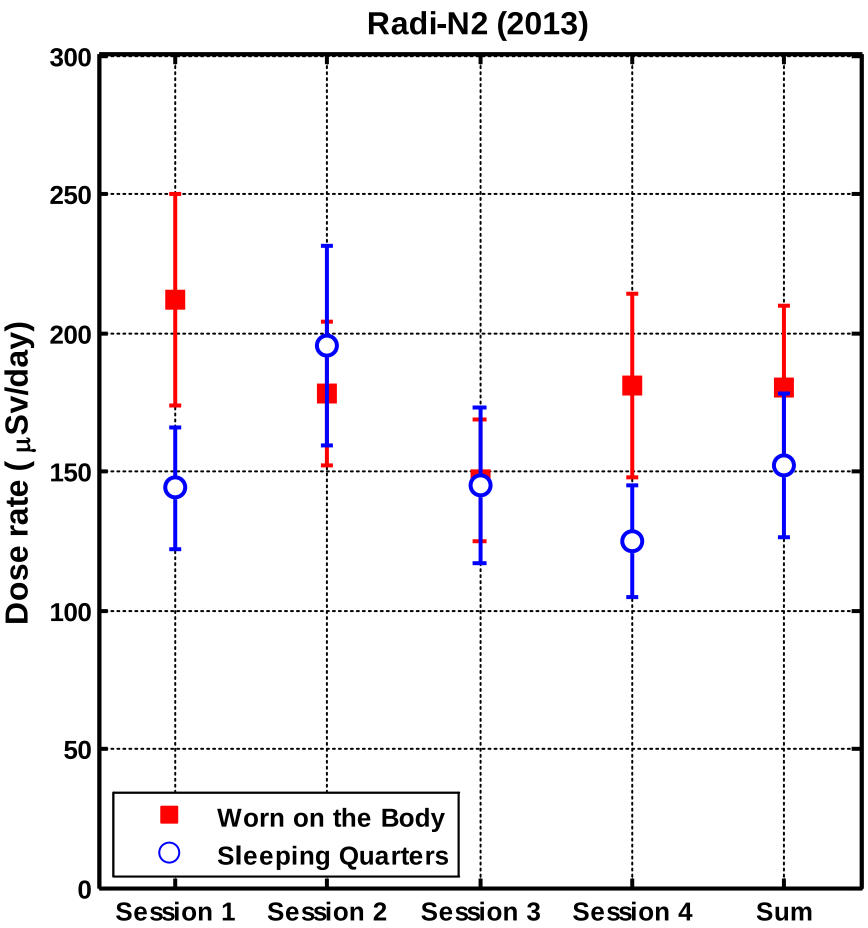
SBDS Dose Rate: Radi-N and Radi-N2



SPND Dose Rate: Radi-N and Radi-N2



ISS-20/21 (JEM Sleeping Quarters)



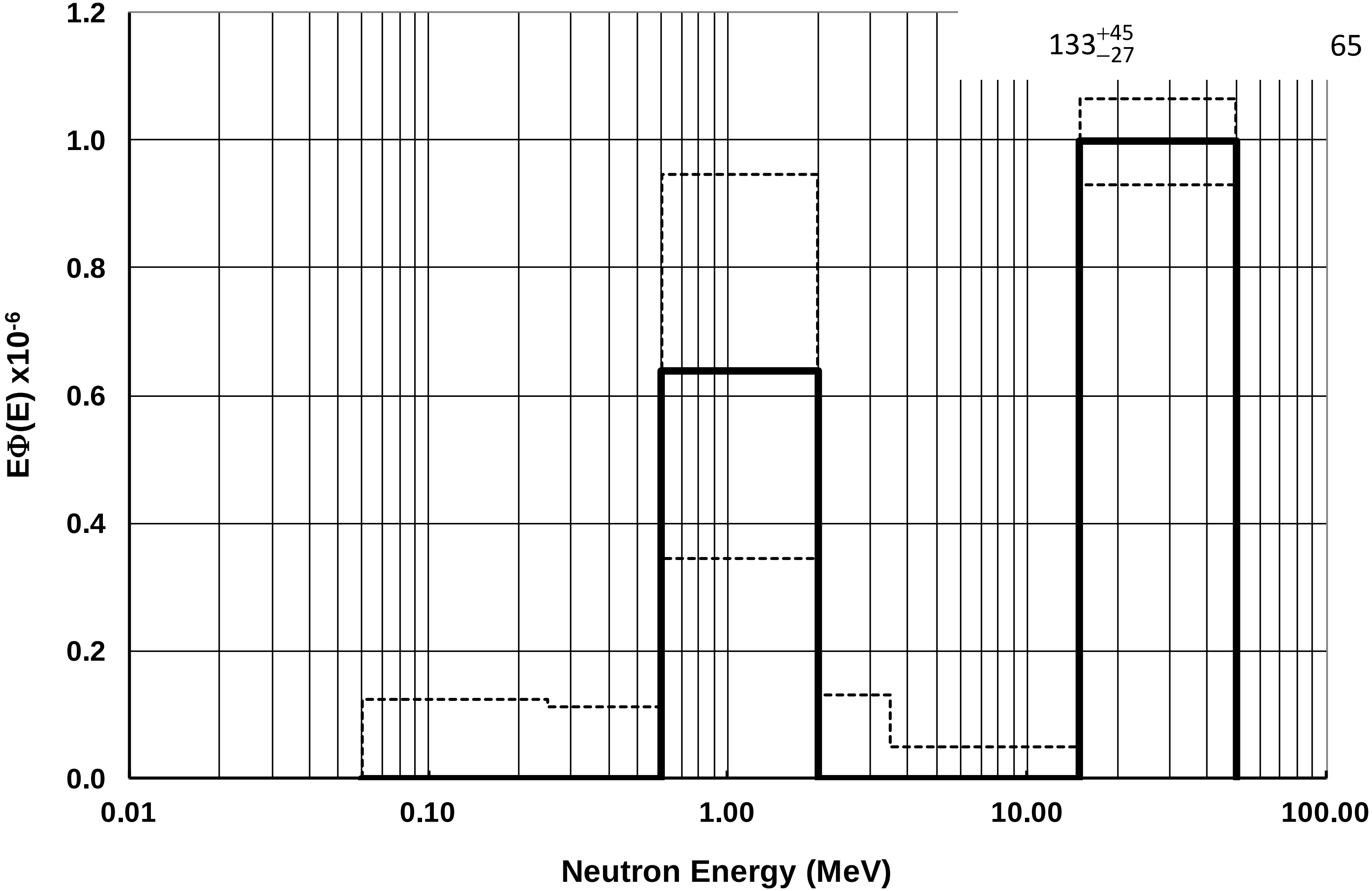
ISS-34/35 (Node-2 Sleeping Quarters)

ISS-35/36 (2013)

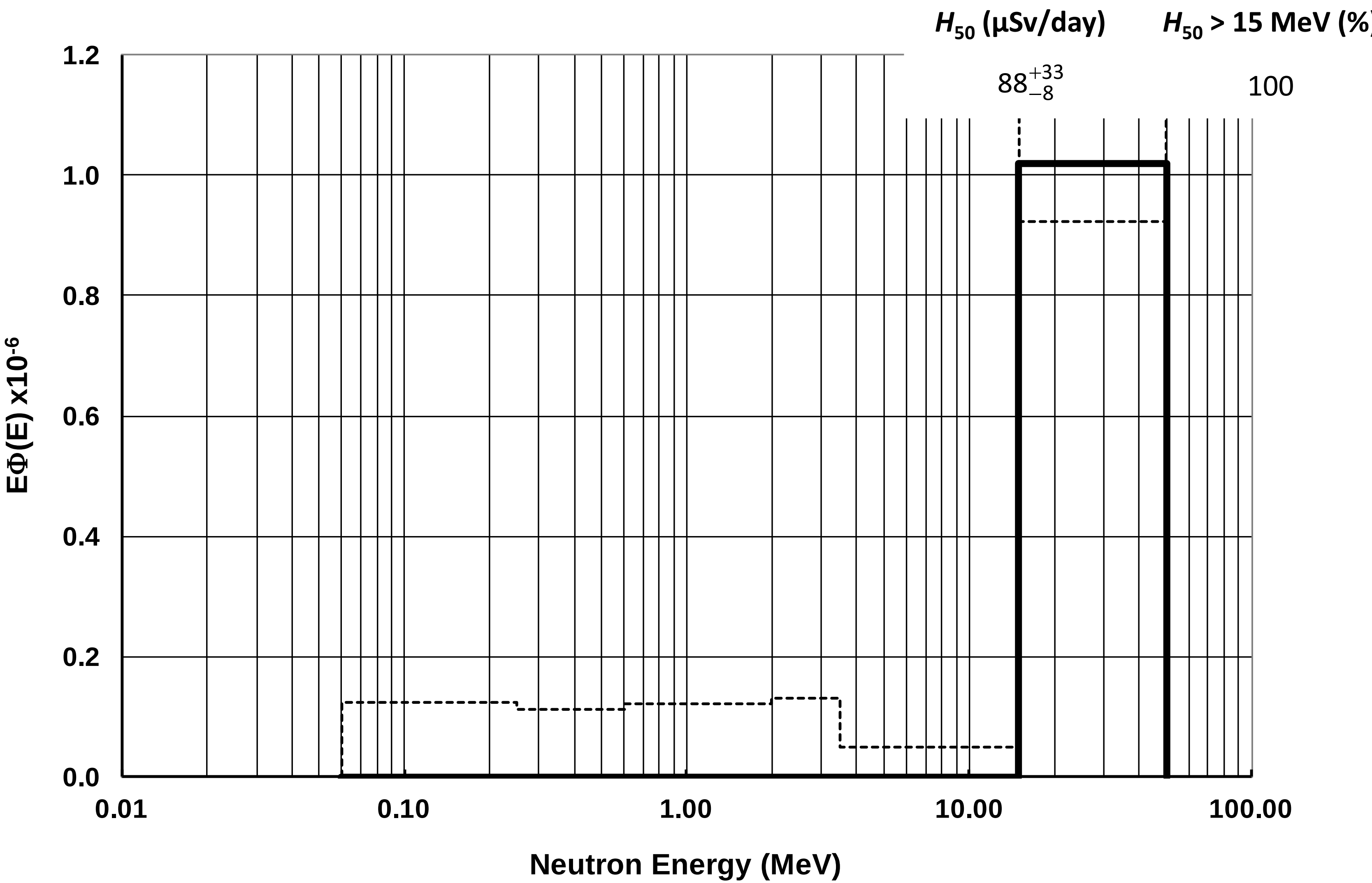
- Radi-N2 continued during ISS-35/36
  - Two sessions in the US Lab
  - Two sessions in the JEM
  - SPNDs and the SBDS were co-located
- The ongoing goal of Radi-N2 is to collect ten weeks of data in each of the four USOS locations
- Ten week-long sessions were performed in the Russian segment
  - Included the first measurements using the SBDS in and around the spherical Matroshka-R phantom
  - Phantom was located in Mini Research Module 1 (MRM1)
- Phantom experiments also included the first two sessions of ISS-37

ISS-35/36: Phantom Surface (Sum)

H_{50} (µSv/day)	H_{50} > 15 MeV (%)
133^{+45}_{-27}	65

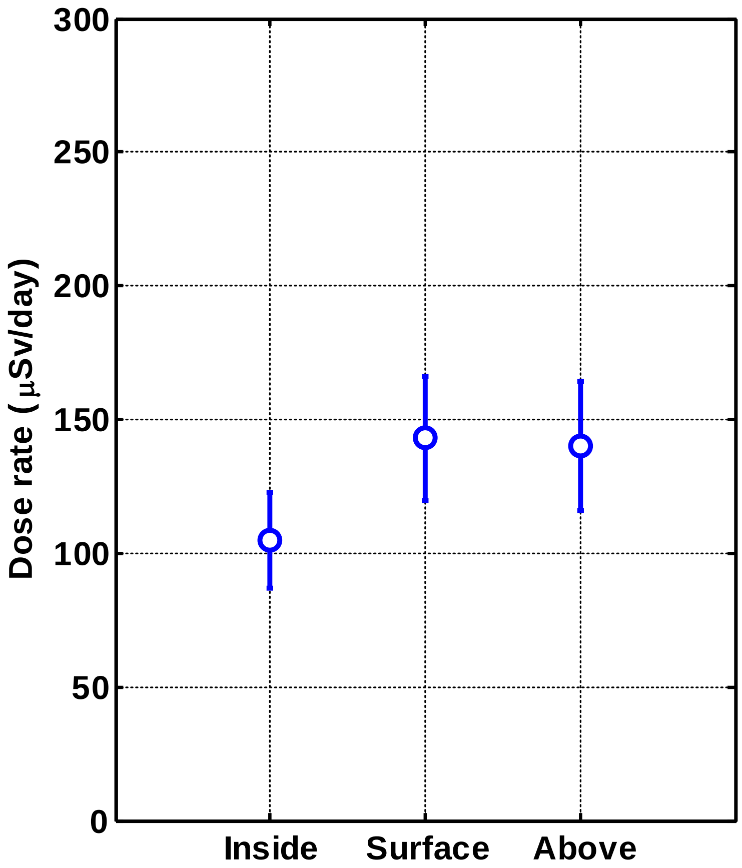


ISS-35/36: Inside Phantom (Sum)



ISS-35/36: Phantom Data

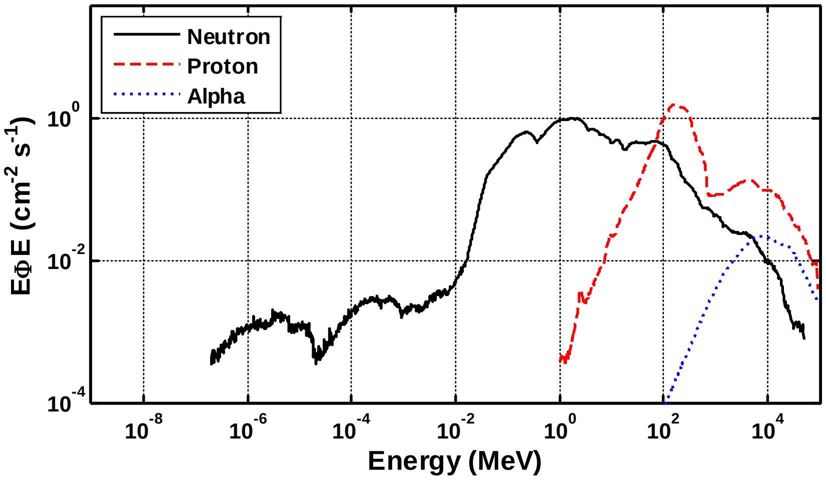
- SBDS data suggest that the neutron dose in the phantom is 66% of the dose at the phantom surface
- SPND data suggest that the dose in the phantom is 73±17% of the surface dose
- The results agree well with earlier SPND results (ISS-13 to ISS-19)
- The energy spectrum inside the phantom appears to be different from that at the surface (and elsewhere in the ISS)
  - Data suggest that neutrons inside the phantom are of higher energy than those outside the phantom
  - The phantom may attenuate low-energy neutrons, while secondary neutrons are created in the phantom

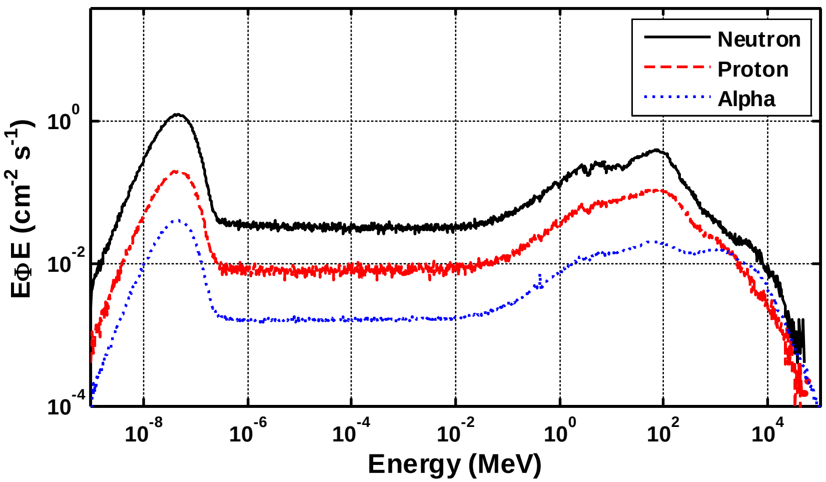


Summed SPND phantom data

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%)





T.W. Armstrong and B.L. Colborn., Radiat. Meas. 33(3), 229 – 234 (2001)

ISS-37/38 (2013/2014)

- Five Radi-N2 sessions were performed during ISS-37/38
  - Two sessions in the US Lab
  - Two sessions in the JEM
  - One session in Columbus
- By the end of ISS-37/38, six weeks of data had been collected in the JEM and the US Lab
- A further nine measurements were performed in the Russian segment
  - Four in MRM1 (as part of the phantom experiments)
  - Four in the Service Module
  - One in MRM2

ISS-37/38 Dose Rates

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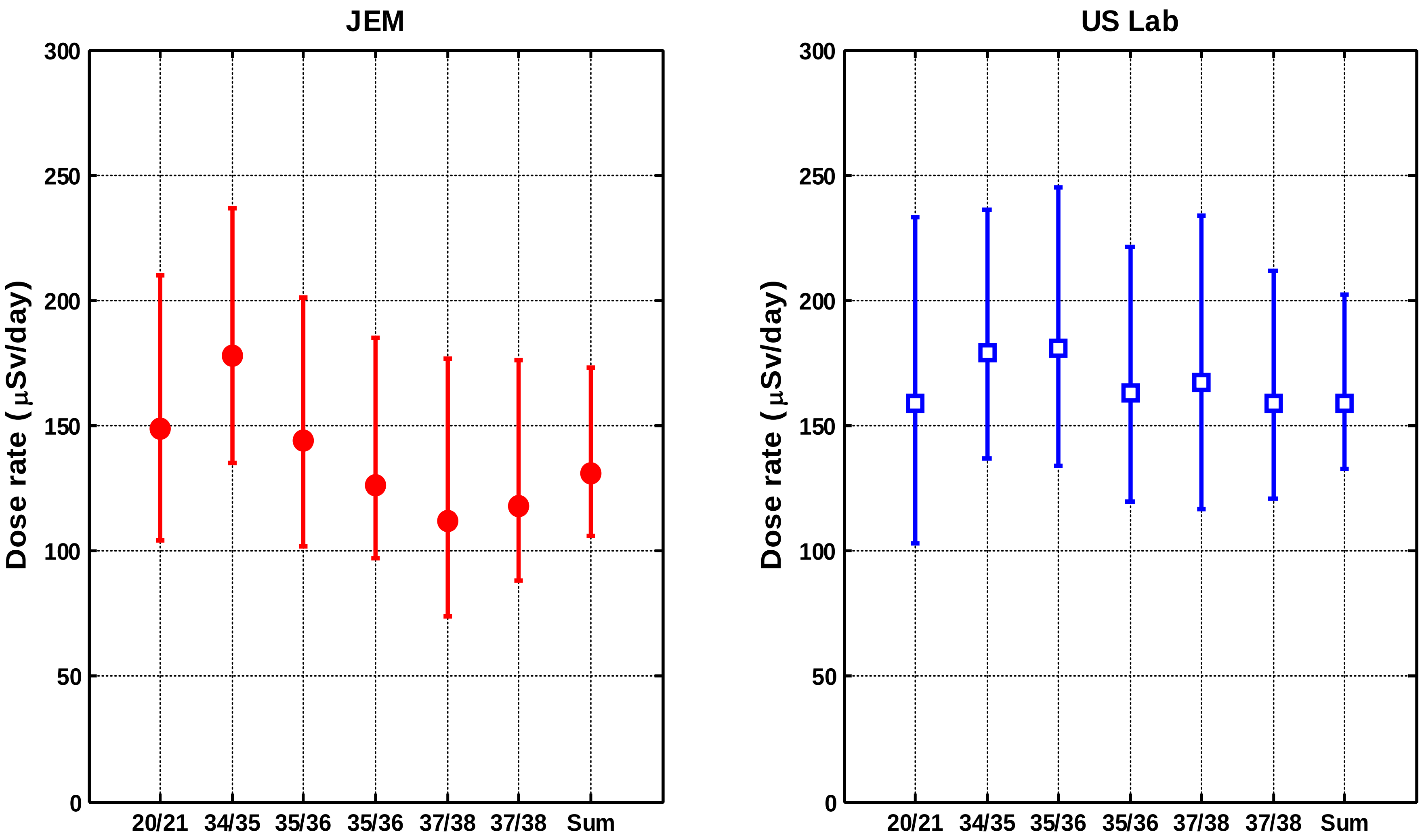
Radi-N2 (USOS)

Session	SBDS Dose Rate (μSv/day)	SPND 1 Dose Rate (μSv/day)	SPND 2 Dose Rate (μSv/day)
3	144^{+75}_{-58}	128±25	169±25
4	159^{+53}_{-38}	150±25	154±23
5	112^{+65}_{-38}	117±21	137±21
6	118^{+58}_{-30}	159±27	184±27
7	112^{+67}_{-39}	165±27	103±17

Russian Segment

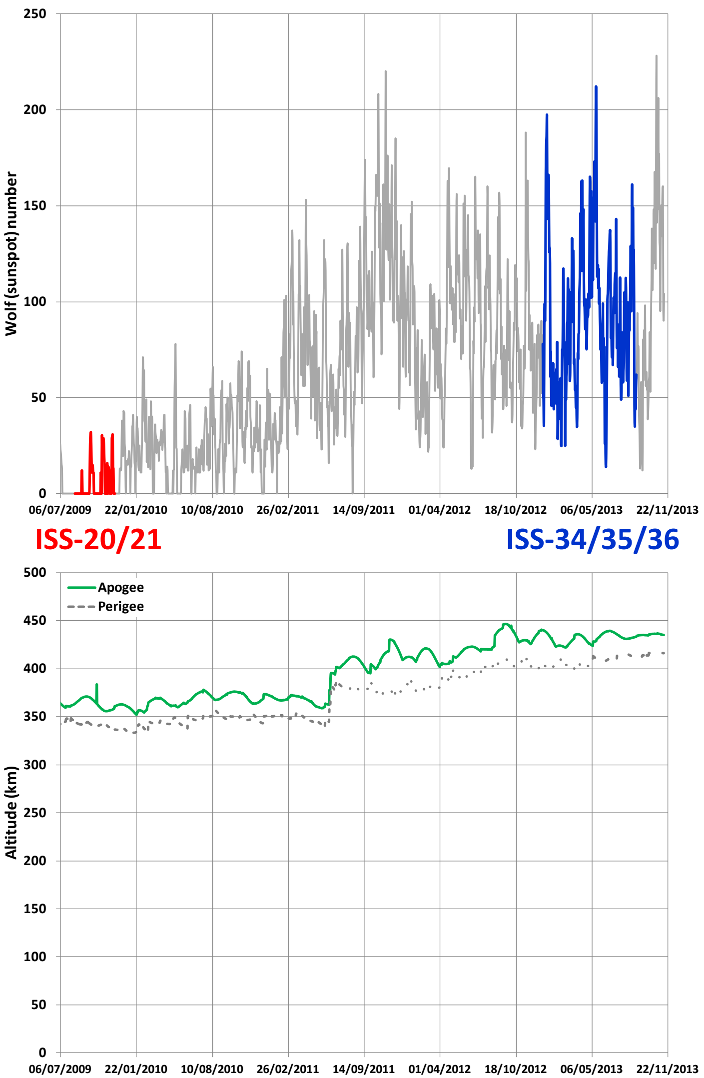
Session	SBDS Dose Rate (μSv/day)	SPND 1 Dose Rate (μSv/day)	SPND 2 Dose Rate (μSv/day)
3	176^{+41}_{-16}	144±21	160±26
4	154^{+39}_{-15}	103±16	132±20
5	151^{+39}_{-15}	138±19	127±20
6	179^{+42}_{-16}	141±20	143±22
7	106^{+54}_{-35}	106±16	114±18

SBDS: JEM and US Lab



Radi-N2: Influence Quantities

- The SPND and SBDS results from Radi-N and Radi-N2 are similar
- The increase in solar activity between 2009 and 2013 did not seem to have a strong influence on the neutron dose
- Similarly, the neutron dose seems unaffected by the increased ISS altitude
- These observations agree with results from the Russian segment (ISS-22 to ISS-33)
- Influences on neutron dose may not be observable for two reasons
  - The effects of solar activity and ISS altitude tend to cancel each other
  - Recent solar maximum was weak



ISS-39/40

- 14 sessions were conducted during the ISS-39/40 mission
- Six measurements for Radi-N2
  - Three sessions in Columbus and three in Node 2
- Eight measurements in the Russian segment
  - Shielding experiment in the Service Module using two sets of detectors
  - Six sessions in MRM2

Session	Initialization date	Retrieval date	Location 1	Location 2
39/40-1	21 March 2014	28 March 2014	Service Module	Service Module
39/40-2	14 April 2014	21 April 2014	Columbus	MRM2
39/40-3	12 May 2014	19 May 2014	Columbus	MRM2
39/40-4	10 June 2014	17 June 2014	Columbus	MRM2
39/40-5	7 July 2014	14 July 2014	Node 2	MRM2
39/40-6	4 August 2014	11 August 2014	Node 2	MRM2
39/40-7	3 September 2014	9 September 2014	Node 2	MRM2

ISS-41/42

- A further 12 sessions are planned for ISS-41/42 (October 2014 – March 2015)
- Measurements for Radi-N2 will restart in the US Lab
- Experiments in the Russian segment will include
  - Further measurements in the Matroshka-R phantom
  - Investigation of shielding in the Russian sleeping quarters using two SPNDs

Summary: ISS-34 to ISS-40

- Data were collected for Radi-N2 and Matroshka-R during ISS-34 to ISS-40
- Radi-N2 aims to collect ten weeks of data in each of four USOS locations
  - By the end of ISS-40, six sessions had been collected in Columbus, the JEM, and the US laboratory, and four sessions had been conducted in Node 2
  - Results so far demonstrate good consistency for each location and agree well with previous measurements
  - Variations in potential influence quantities such as solar activity and ISS altitude seem to have little effect on the neutron dose
- In the Russian segment, measurements included the first characterization of the energy spectrum inside the Matroshka-R phantom
  - Data suggest that the neutron dose inside the phantom is approximately 70% of the dose at its surface
  - The energy spectrum in the phantom contains a higher proportion of high-energy neutrons than the spectrum outside the phantom
  - Matroshka-R measurements were extended to MRM1 and MRM2
- Radi-N2 and Matroshka-R experiments will continue into ISS-41/42 and beyond

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