Neutron Measurements using Bubble Detectors during the ISS-22 to ISS-36 Expeditions

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Bubble Technology Industries

18th WRMISS

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Collaboration

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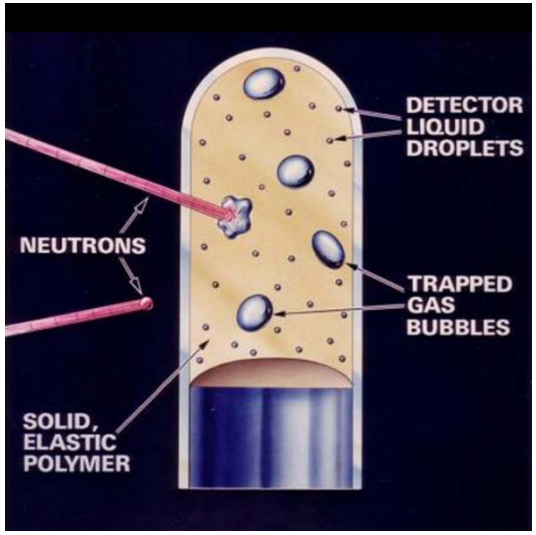
Introduction

- 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 International Space Station (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 re-used



Space Bubble Detectors

- Two types of space bubble detector have been used to monitor neutrons on the ISS
  - Space personal neutron dosimeter (SPND)
    - 0.1 – 50 MeV energy range
  - Space bubble detector spectrometer (SBDS)
    - Set of six detectors
    - Each has a different energy threshold
    - 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 long (e.g., one-week) measurement
- Detectors are temperature compensated
- Bubbles are counted with the space mini reader located in the Russian segment

Response to Charged Particles

- Bubble detectors are sensitive to charged particles (protons and heavy ions) as well as neutrons
- The proton sensitivity has been measured experimentally
- Using this sensitivity and CREME calculations of particle fluxes incident on the ISS, calculations of the charged-particle contribution to the bubble count on the ISS have been performed
- These calculations suggest that an upper limit of a few percent of bubbles recorded on the ISS is due to charged particles
  - This is primarily because there are more neutrons than charged particles inside the ISS with the right energy to interact with the bubble detector efficiently
- No correction for charged particles is applied in analysis of bubble-detector data from the ISS

M. Takada et al., Radiat. Prot. Dosimetry 111(2), 181 – 189 (2004)
H.R. Andrews et al., Radiat. Prot. Dosimetry 120(1 – 4), 480 – 484 (2006)
B.J. Lewis et al., Radiat. Prot. Dosimetry 150(1), 1 – 21 (2012)
M.B. Smith et al., Radiat. Prot. Dosimetry 153(4), 509 – 533(2013)

ISS Measurement Locations

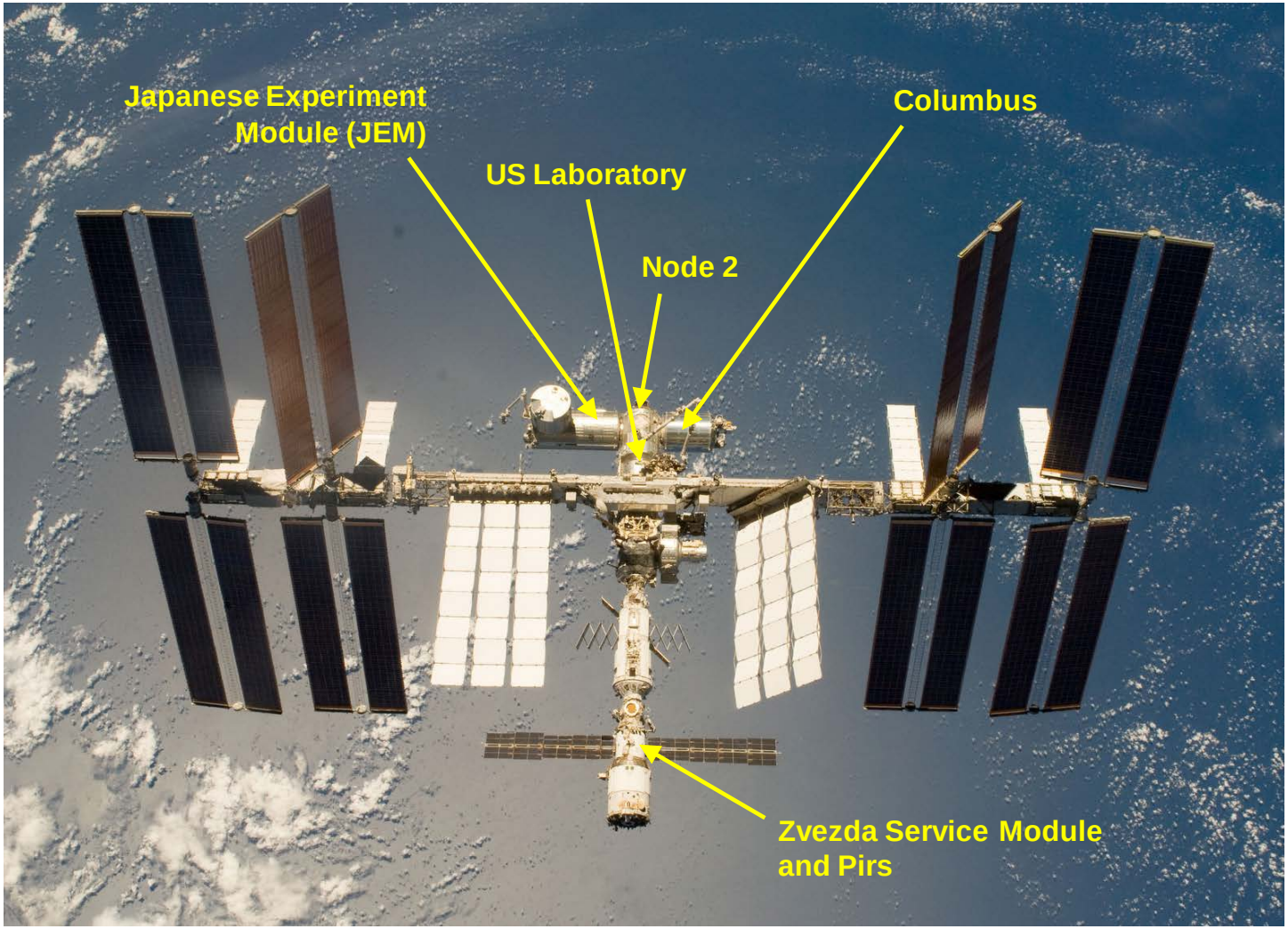
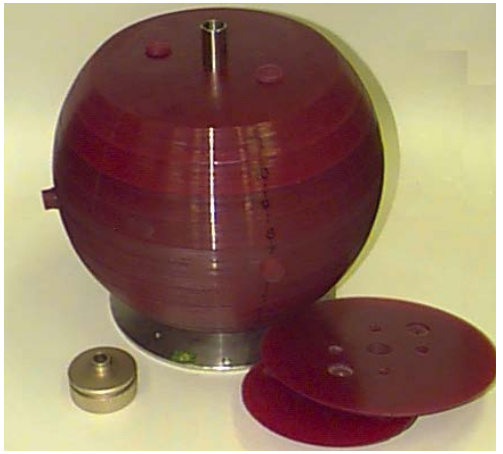


Image from NASA

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 phantom located in the Russian segment
- Phantom measurements using SPNDs indicated that the neutron dose inside the phantom was only slightly less than that at its surface
  - This is an important result because it upholds the concept that a bubble detector worn on the body provides an accurate assessment of the neutron dose received by critical organs inside the body



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 and ISS-21 (2009)

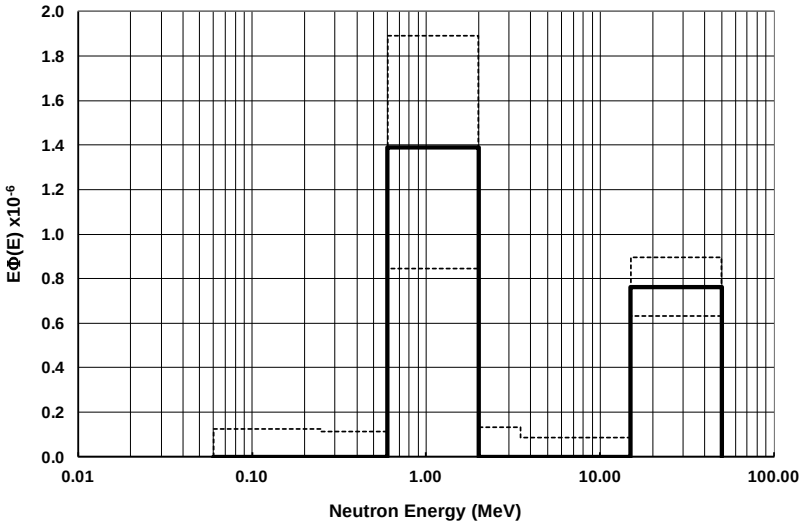
- The SBDS was used for the first time during ISS-20
- Experiments were performed with an SBDS in various ISS modules
  - Russian Service Module (SM), Columbus, US Laboratory, and Japanese Experiment Module (JEM)
  - This included the Radi-N experiments
- Two dosimeters (SPNDs) were used simultaneously with the SBDS
  - One placed in the sleeping quarters and one worn on the body
- Some measurements used water to investigate shielding of neutrons

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)

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



Typical SBDS spectrum recorded in the JEM. Peaks around 1 MeV and above 10 MeV are observed

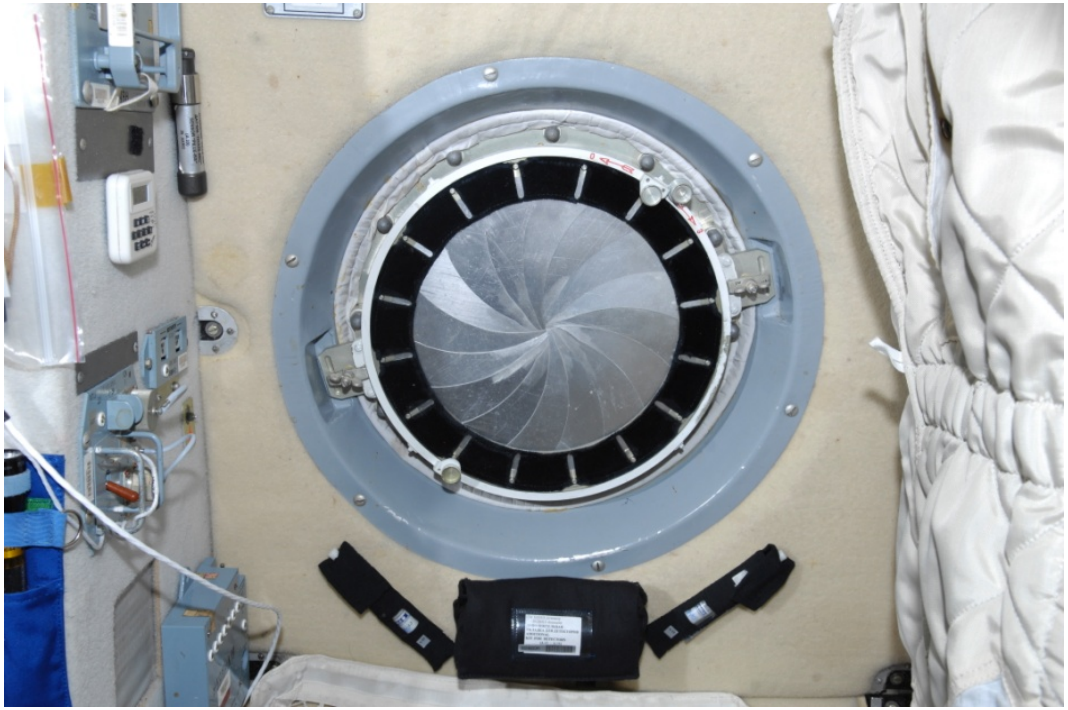
ISS-22 (2009) to ISS-33 (2012)

- 32 experimental sessions (approximately one week each) were performed during ISS-22 to ISS-30
- All measurements were made in the Russian segment of the ISS
  - Experiments used SPNDs and an SBDS
  - Some experiments used water shielding
- Useful data were not recorded for all detectors in all sessions because of detectors reaching the end of their life
  - Typical useful lifetime of a bubble detector is nine months
  - Unreliable data have been removed from the current analysis

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

Index	SBDS Location	SPND 1 Location	SPND 2 Location	Sessions
1	Pirs, panel 1	Pirs, inside phantom	Pirs, inside phantom	1
2	SM, panel 443, below illuminator	SM, left of the SBDS	SM, right of the SBDS	3
3	SM, panel 240	SM, left of the SBDS	Not used	1
4	SM, on top of water shield	Left of SBDS, panel 442 (unshielded)	Right of SBDS, on top of water shield	2
5	SM, on water shield (cabin side)	Left of SBDS, panel 443 (unshielded)	Right of SBDS, on water shield	3
6	SM, on water shield (between shield and illuminator)	Left of SBDS, panel 443 (unshielded)	Right of SBDS, on water shield	22

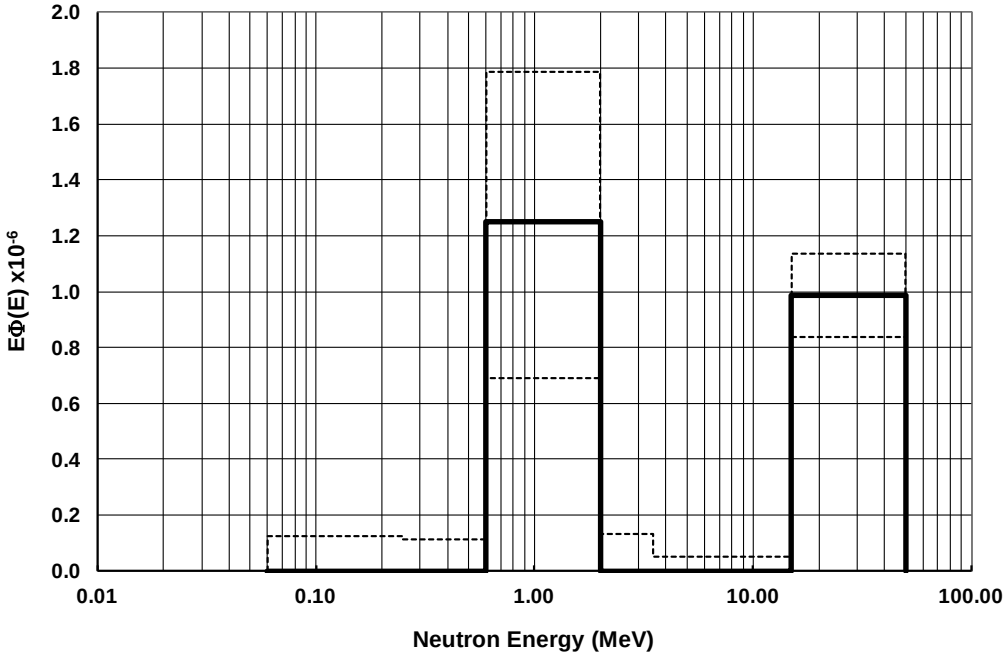
ISS-22 (2009) to ISS-33 (2012)



Detectors in configuration 2 (above) and configuration 4 (right) in the Russian SM

ISS-22 to ISS-33: SBDS Dose Rate

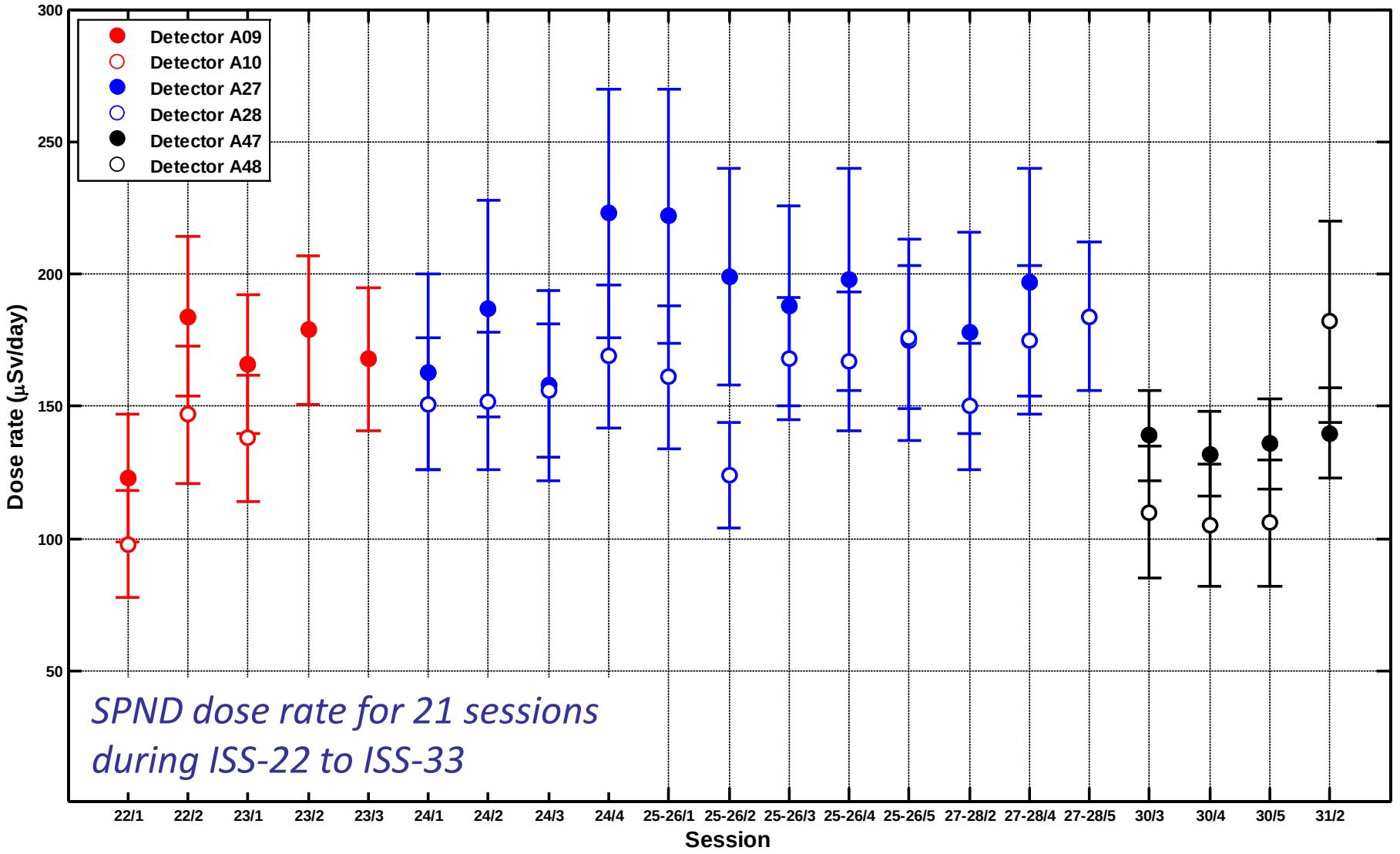
Spectrum from ISS-24 Session 4 (configuration 5)



SBDS dose rate for 10 sessions during ISS-22 to ISS-33

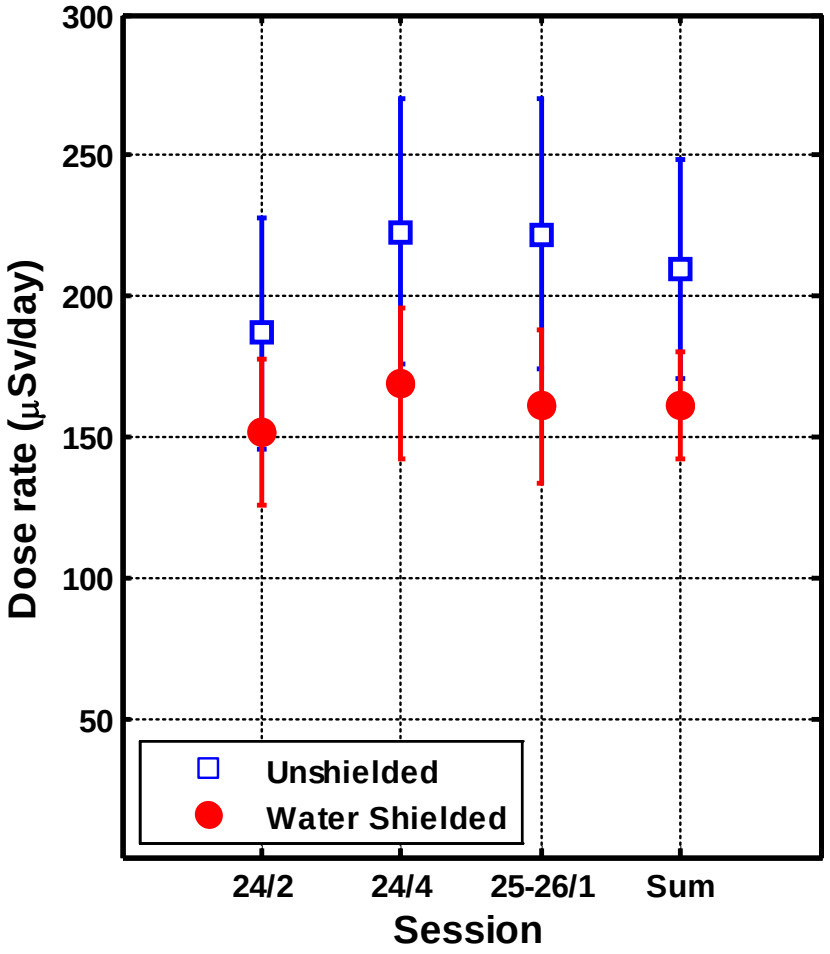
Session	Dose Rate (μSv/day)
ISS-22 Session 1	132^{+98}_{-61}
ISS-22 Session 2	159^{+80}_{-52}
ISS-23 Session 1	125^{+59}_{-33}
ISS-24 Session 1	235^{+74}_{-59}
ISS-24 Session 2	228^{+72}_{-58}
ISS-24 Session 3	231^{+70}_{-57}
ISS-24 Session 4	177^{+69}_{-54}
ISS-25-26 Session 1	218^{+73}_{-58}
ISS-25-26 Session 2	168^{+50}_{-40}
ISS-30 Session 3	126^{+60}_{-41}

ISS-22 to ISS-33: SPND Dose Rate

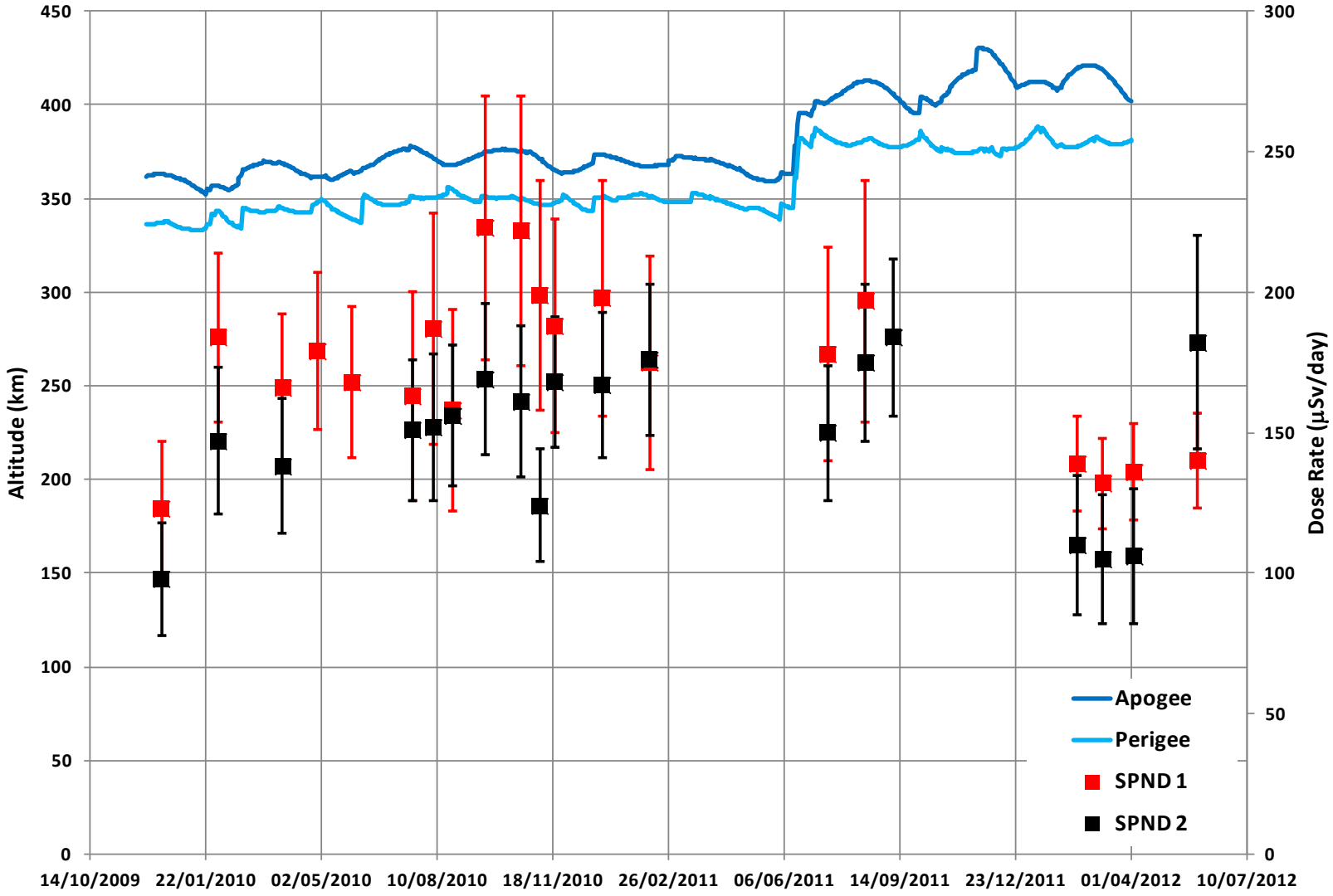


ISS-22 to ISS-33: Water Shielding

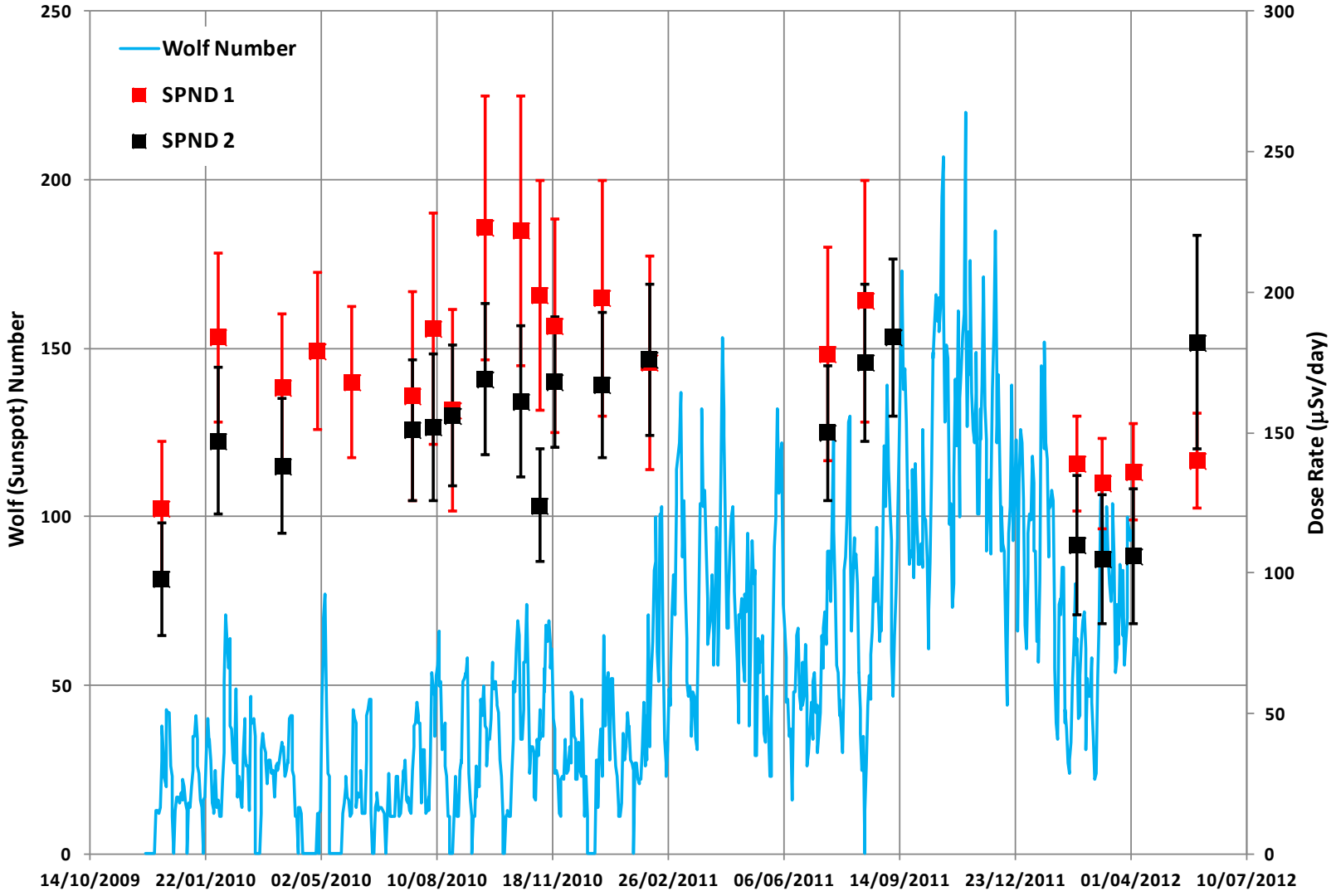
- Data for configuration 5 provide a measure of the effect of water shielding on the neutron dose
- For three sessions, one SPND was behind the water shield and a second SPND was in an unshielded location on the wall
- The neutron dose behind the water shielding was 77 ± 17% of the unshielded neutron dose
- This is similar to the value (72 ± 17%) measured using a water shield in the JEM (ISS-21)



ISS-22 to ISS-33: Altitude



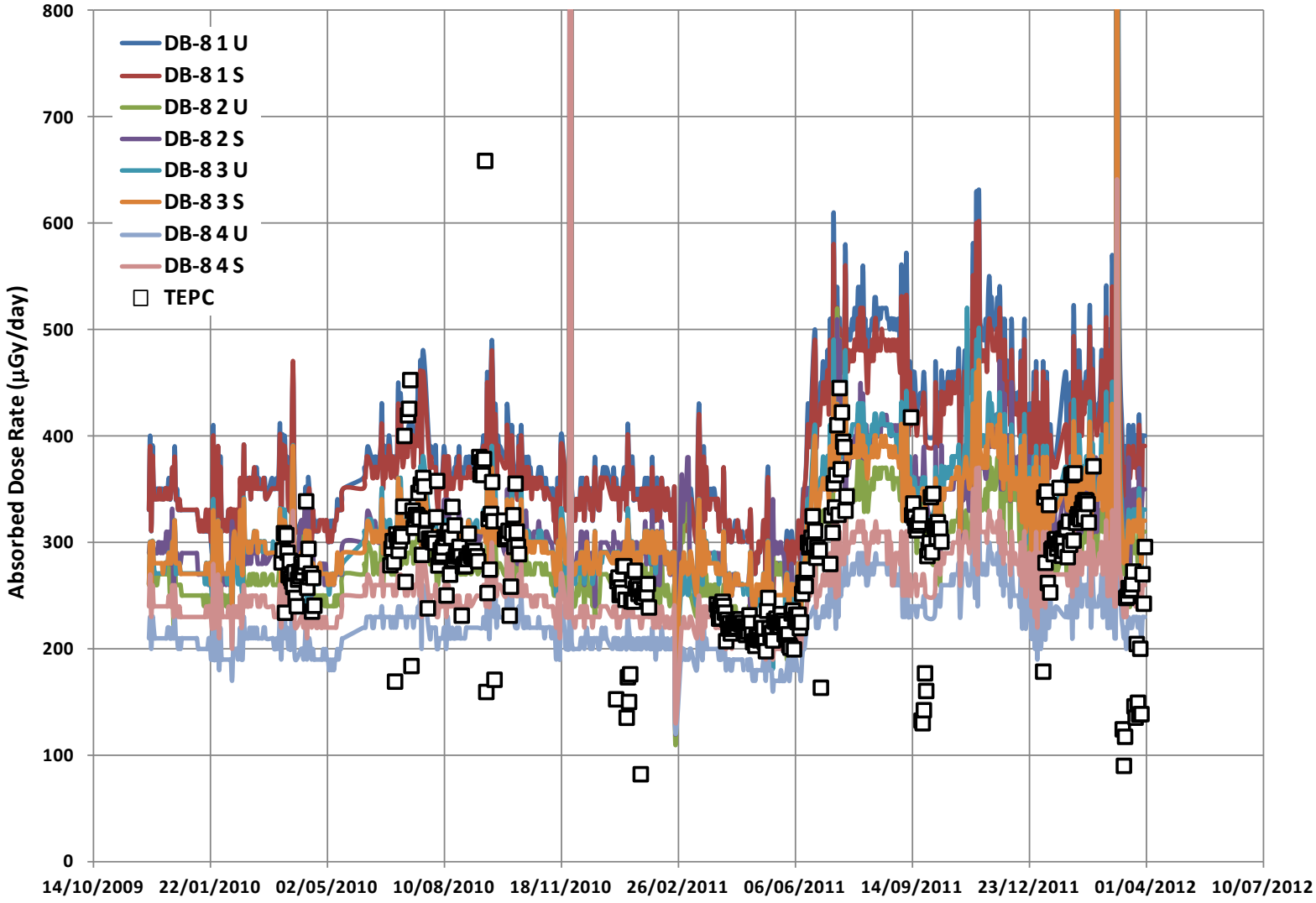
ISS-22 to ISS-33: Solar Activity



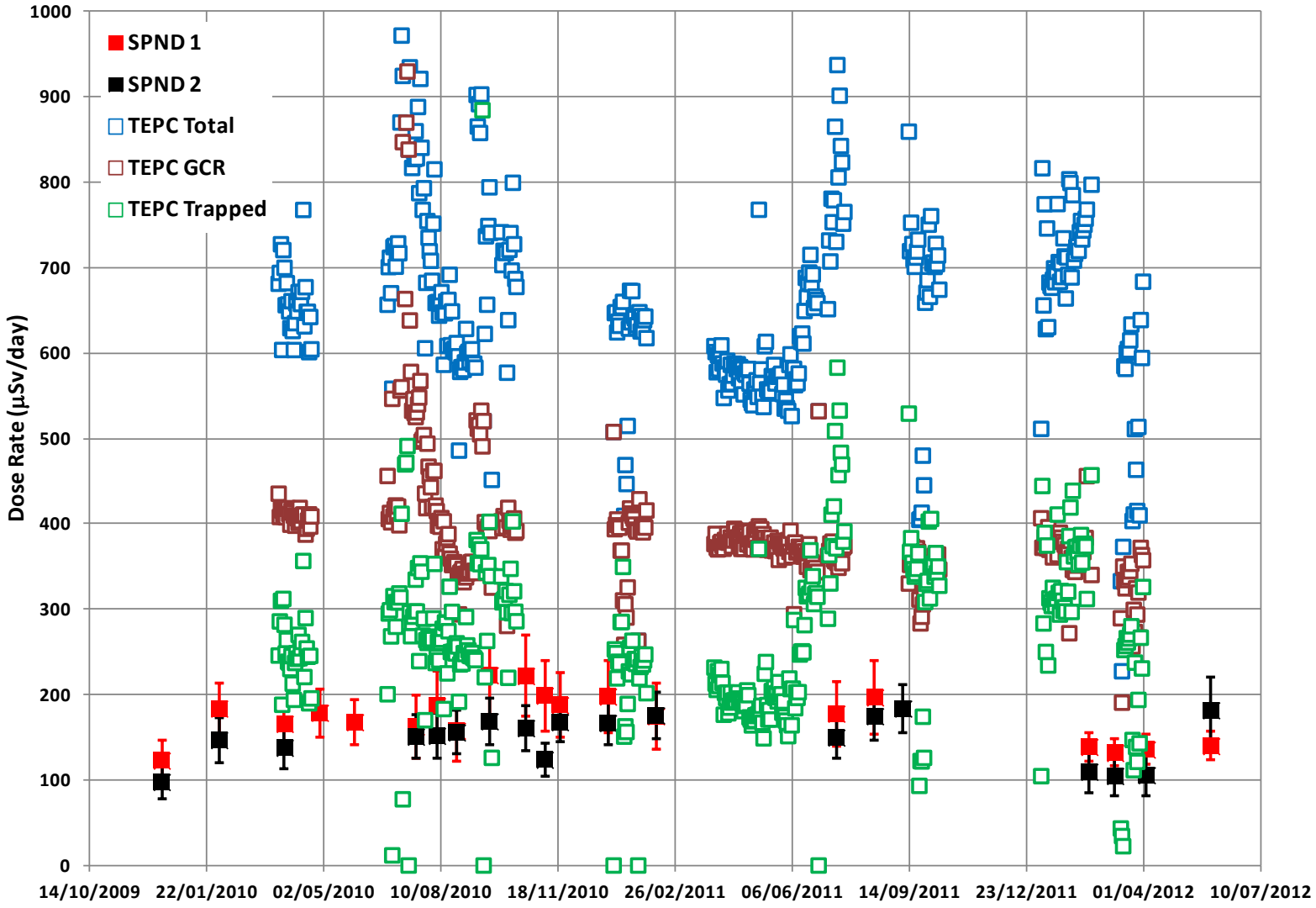
ISS-22 to ISS-33: DB-8 and TEPC

- Bubble-detector data have been compared to the readings of the DB-8 (silicon) dosimeters and the ISS tissue-equivalent proportional counter (TEPC)
- Four DB-8 dosimeters are installed in the Russian segment
  - Each provides an unshielded (U) and shielded (S) absorbed dose in µGy
- The TEPC moved around the ISS during the period of these measurements
  - Data are shown for the Russian SM (panel P327) only
  - The TEPC provides absorbed dose (µGy) and dose equivalent (µSv) for galactic cosmic rays (GCR), trapped radiation, and solar events
- The TEPC and DB-8 absorbed dose rates are in good agreement
- The bubble-detector neutron dose equivalent is ~30% of the TEPC total, in agreement with earlier measurements

ISS-22 to ISS-33: DB-8 and TEPC



ISS-22 to ISS-33: SPND and TEPC



ISS-34 (2012/2013)

- Four sessions took place during ISS-34 under the experiment name Radi-N2
- The goal was to repeat the 2009 Radi-N experiments as closely as possible
- For the four sessions, an SBDS was placed in Columbus, the JEM, the US Laboratory, and Node 2
- Two dosimeters (SPNDs) were used simultaneously with the SBDS measurements: one was placed in the astronaut's sleeping quarters and one was worn on his body
- A second SBDS and two SPNDs were used in the Russian SM at the same time as the Radi-N2 measurements

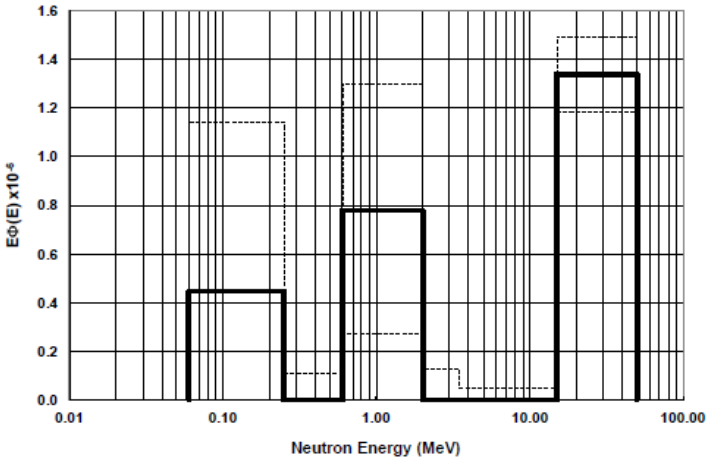
Photograph used with permission of Chris Hadfield

Budapest: February 18th 2013

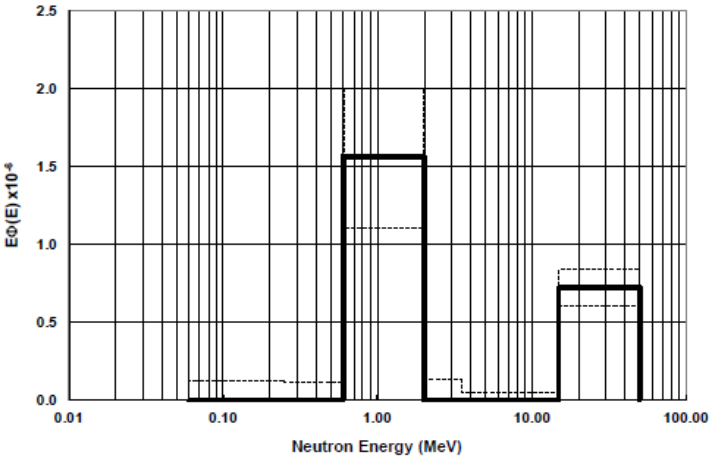
Image from Twitter

ISS-34: Radi-N2 Energy Spectra

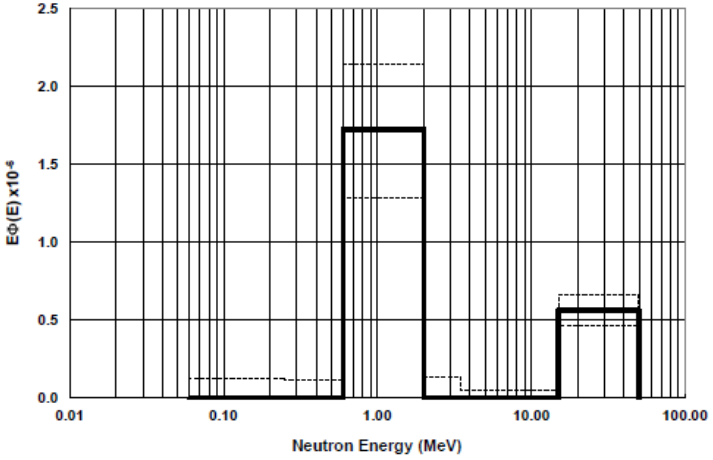
Session 1 - Columbus



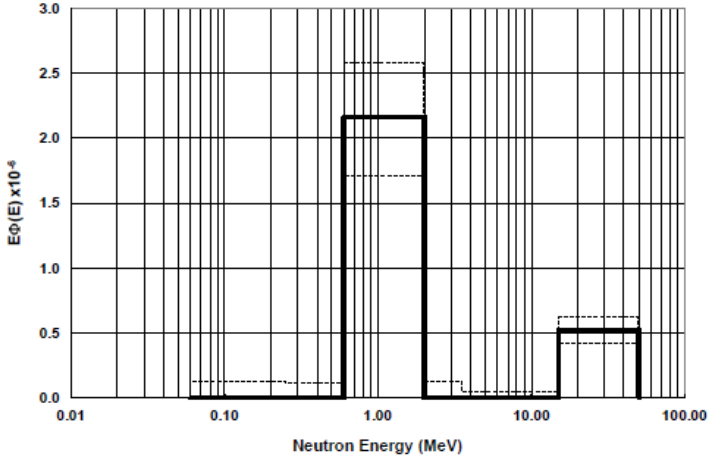
Session 2 - JEM



Session 3 – US Laboratory



Session 4 – Node 2



ISS-34: Dose Rate

BTI BUBBLE Technology Industries

Radi-N2 (USOS)

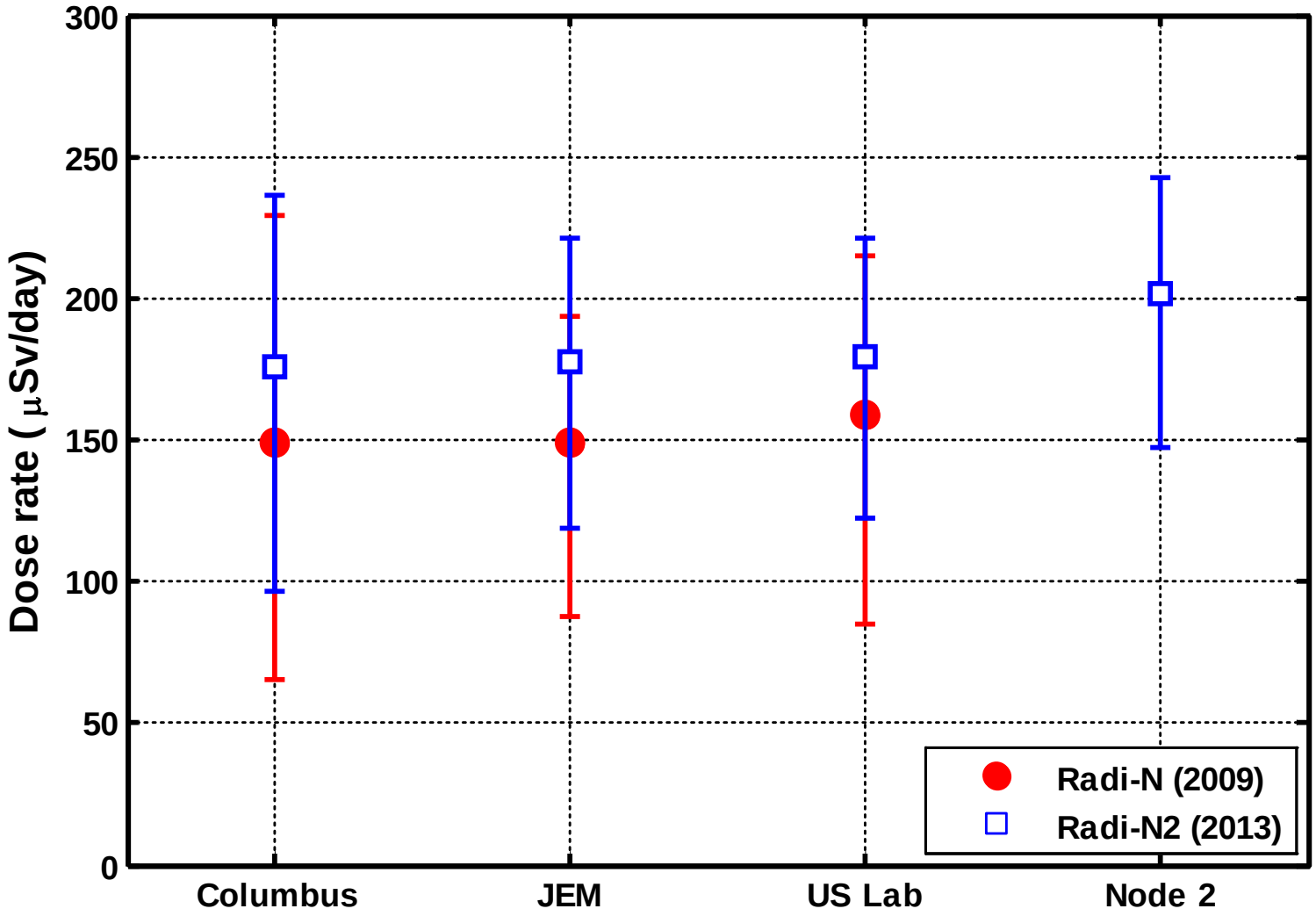
Session	SBDS Dose Rate (μSv/day)	SPND A97 Dose Rate (μSv/day)	SPND A98 Dose Rate (μSv/day)
1	176^{+79}_{-60}	212±38	144±22
2	178^{+59}_{-43}	195±36	178±26
3	179^{+57}_{-42}	145±28	147±22
4	202^{+55}_{-41}	181±33	125±20

Russian Service Module

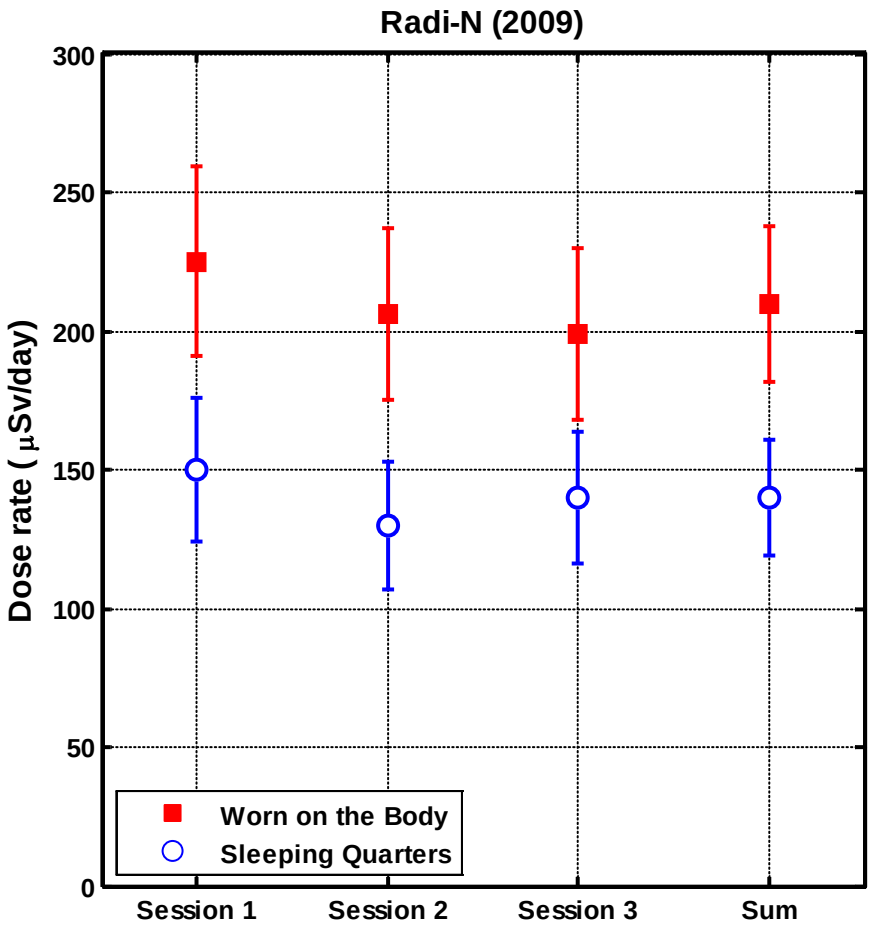
SPND A07 and A08 were co-located with the Russian SBDS

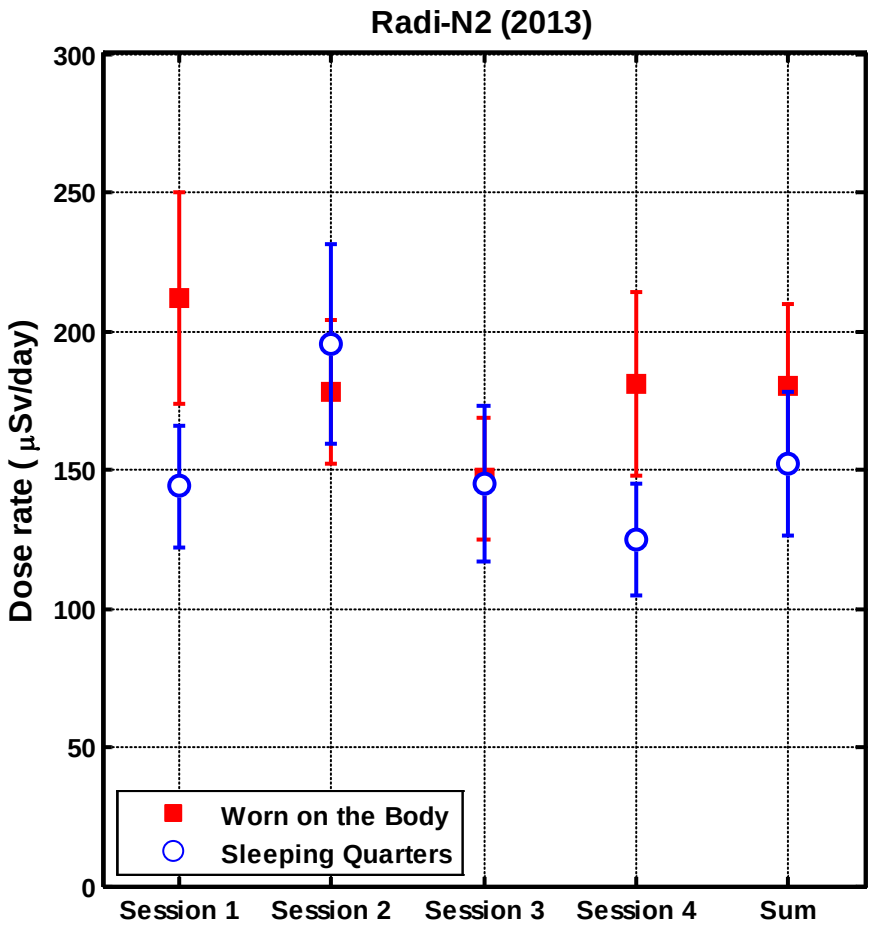
Session	SBDS Dose Rate (μSv/day)	SPND A07 Dose Rate (μSv/day)	SPND A08 Dose Rate (μSv/day)
1	144^{+75}_{-58}	151±22	149±24
2	228^{+45}_{-19}	150±22	153±25
3	126^{+58}_{-41}	148±22	132±22
4	154^{+41}_{-15}	187±26	166±26

SBDS Dose Rate (Radi-N and Radi-N2)



SPND Dose Rate (Radi-N and Radi-N2)

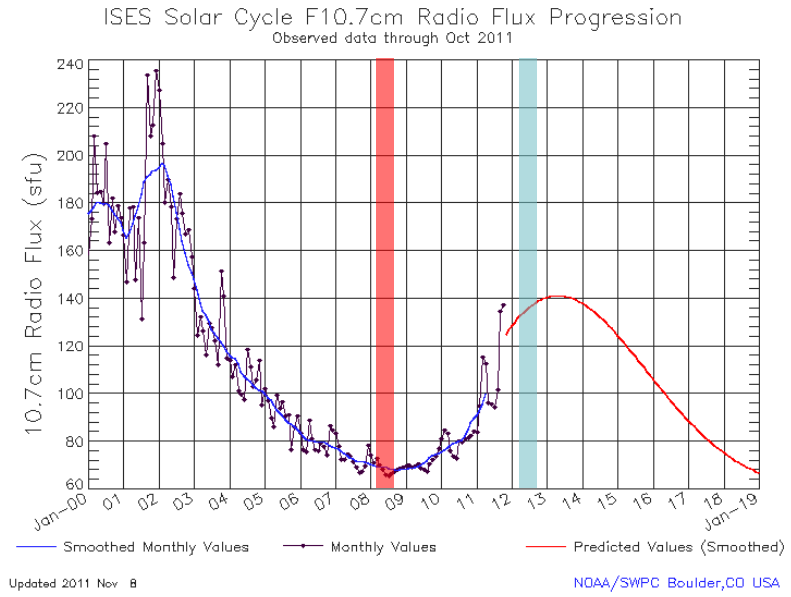




Dose Rate (Radi-N and Radi-N2)

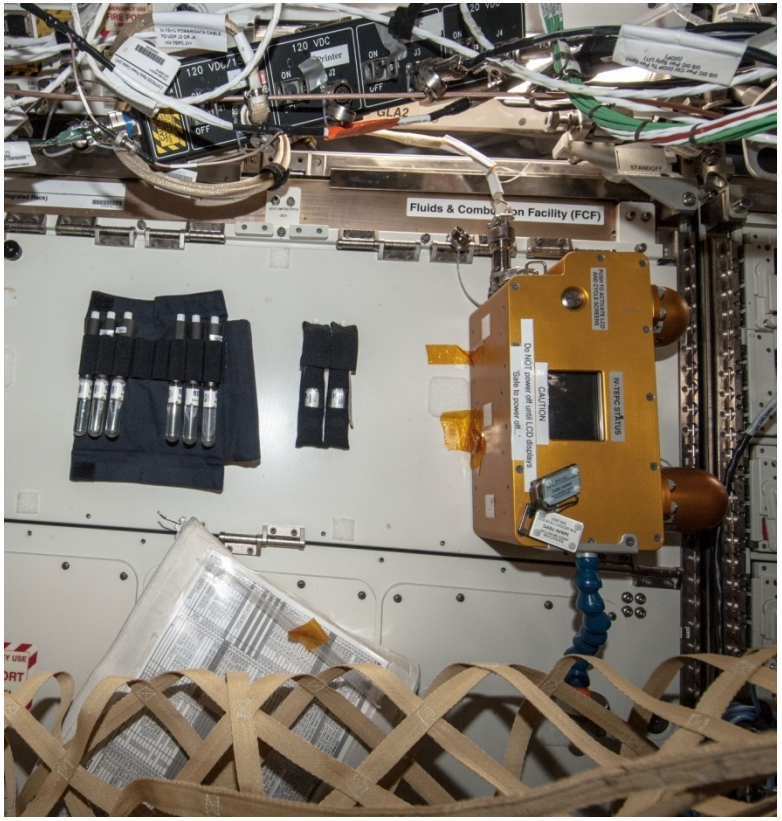
- For Radi-N2, neutron dose received in the Node-2 sleeping quarters was lower than that received by the crewmember during daily activities
  - This is similar to the results from Radi-N, although the effect is less pronounced for Radi-N2
- The SPND results from daily activities were similar in 2009 and 2013
- The SBDS results from 2009 and 2013 were also similar
- The difference in solar activity between 2009 and 2013 does not seem to have a strong effect on the neutron dose

Expedition 20/21 (May 27th 2009 – December 1st 2009)
Expedition 34/35 (November 26th 2012 – May/June 2013)



ISS-36 and Future Plans

- Ongoing experiments aim to repeat the Radi-N2 measurements
- Measurements in the Russian segment are also continuing using a second set of detectors
- The goal is to improve measurement statistics for each of the ISS locations
- Four sessions were completed during the ISS-36 mission
  - Two measurements in the US Laboratory, two in the JEM, and four in the Russian segment
- If possible, four similar sessions will be performed during each of Expedition 37/38, 39/40, and 41/42 (a total of 12 more sessions)



Bubble detectors with the IV-TEPC in the US Laboratory, June 27th 2013

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