Radi-N and Radi-N2: Measurements of Neutron Radiation Using Bubble Detectors (2009 – 2020)

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Collaboration

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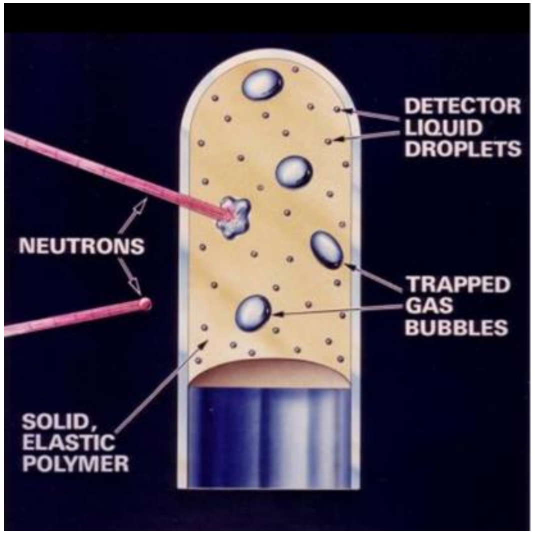
Bubble Detectors

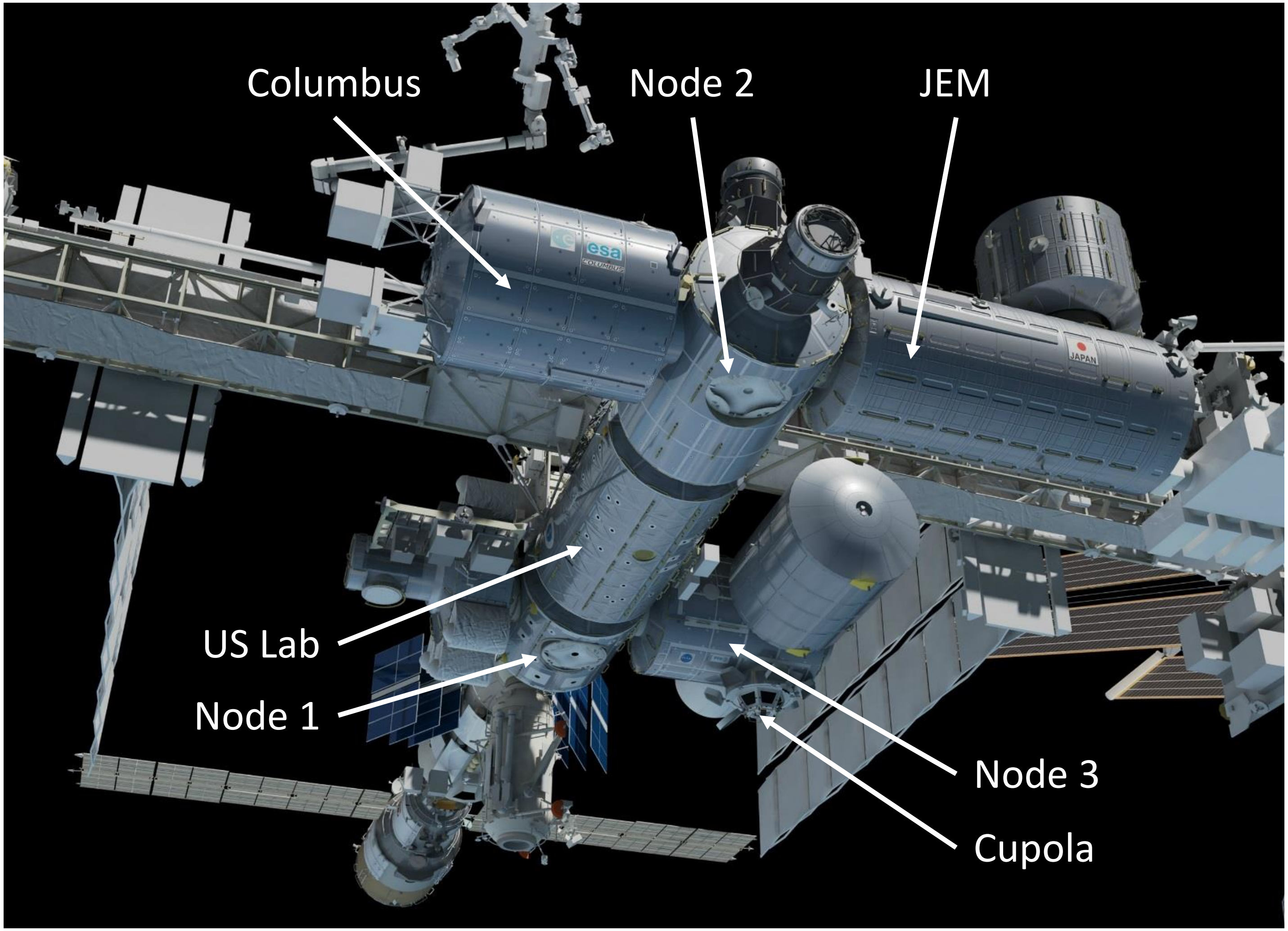
- Bubble detectors are passive dosimeters manufactured by Bubble Technology Industries
- They contain superheated liquid droplets dispersed in an elastic polymer gel
- Particles with high linear-energy transfer (LET) interact with the droplets to form bubbles
- Bubble detectors have been used to monitor neutrons in space since 1989 on recoverable Russian Biocosmos (Bion) satellites, the Mir space station, the space shuttle, and the ISS



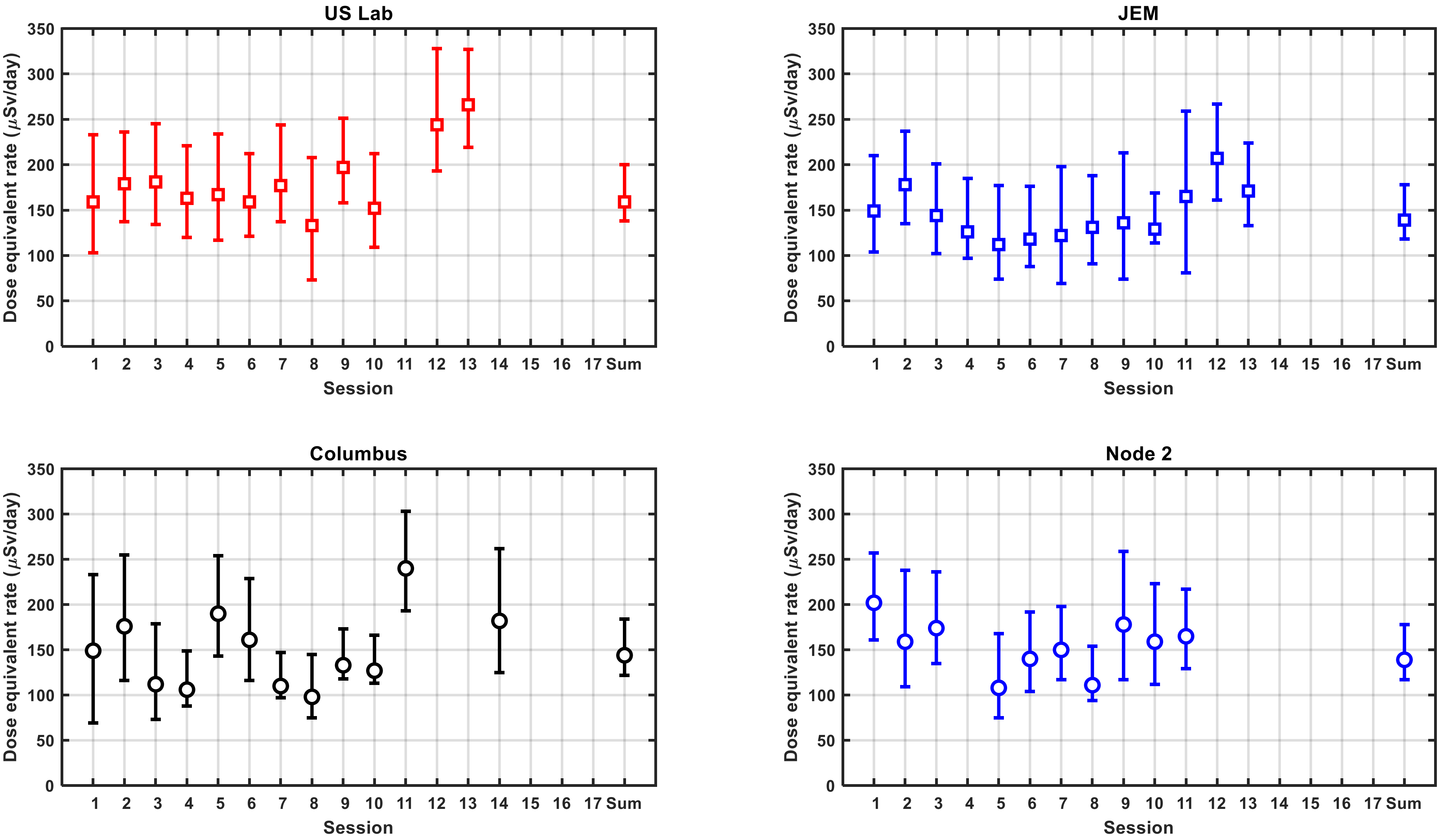
Space Bubble Detectors

- Two types of bubble detector were used to monitor neutrons for the Radi-N2 and Matroshka-R 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
  - This allows bubbles to grow slowly during a week-long measurement
- Detectors are temperature compensated
- Bubbles are counted with the space mini reader, developed and fabricated by BTI

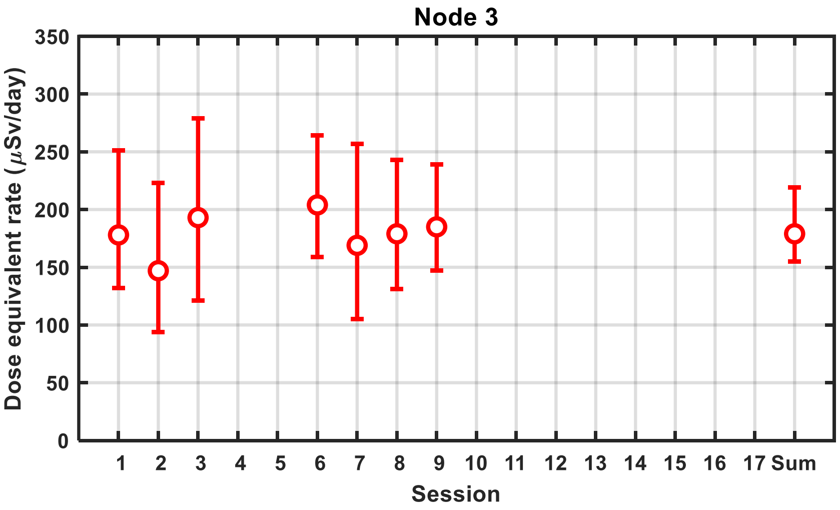
Radi-N2 Locations (USOS)

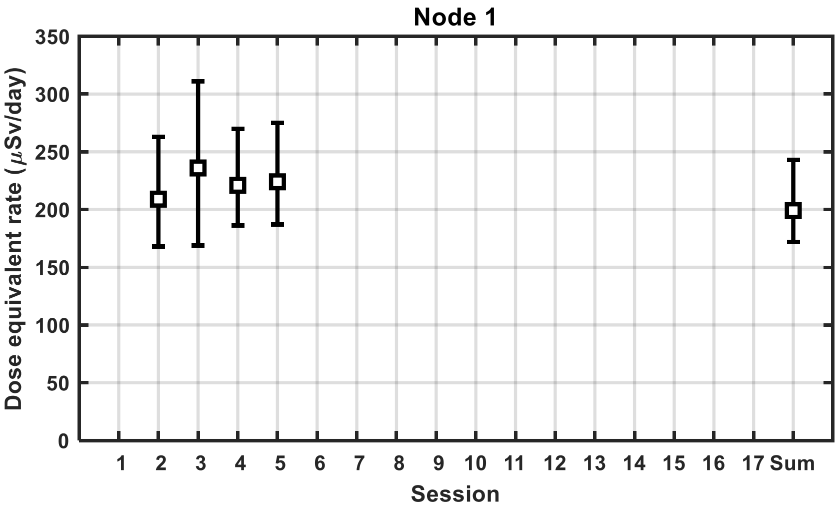


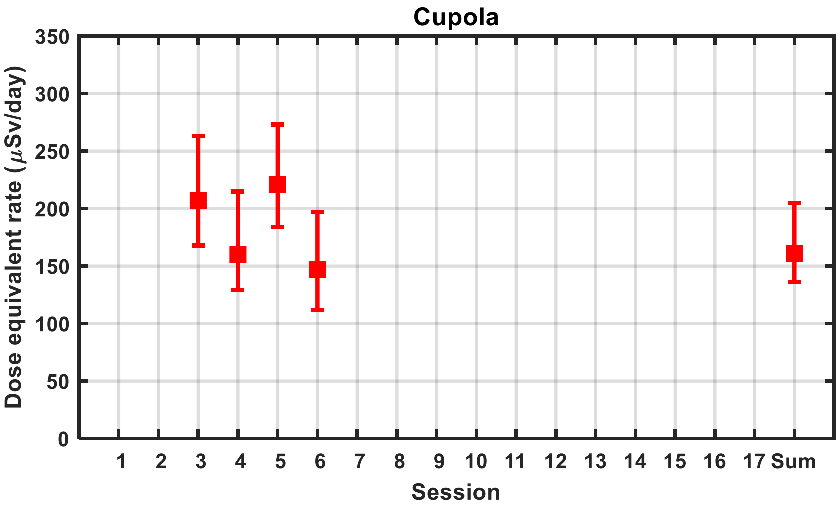
Radi-N and Radi-N2: SBDS Data



Radi-N and Radi-N2: SBDS Data

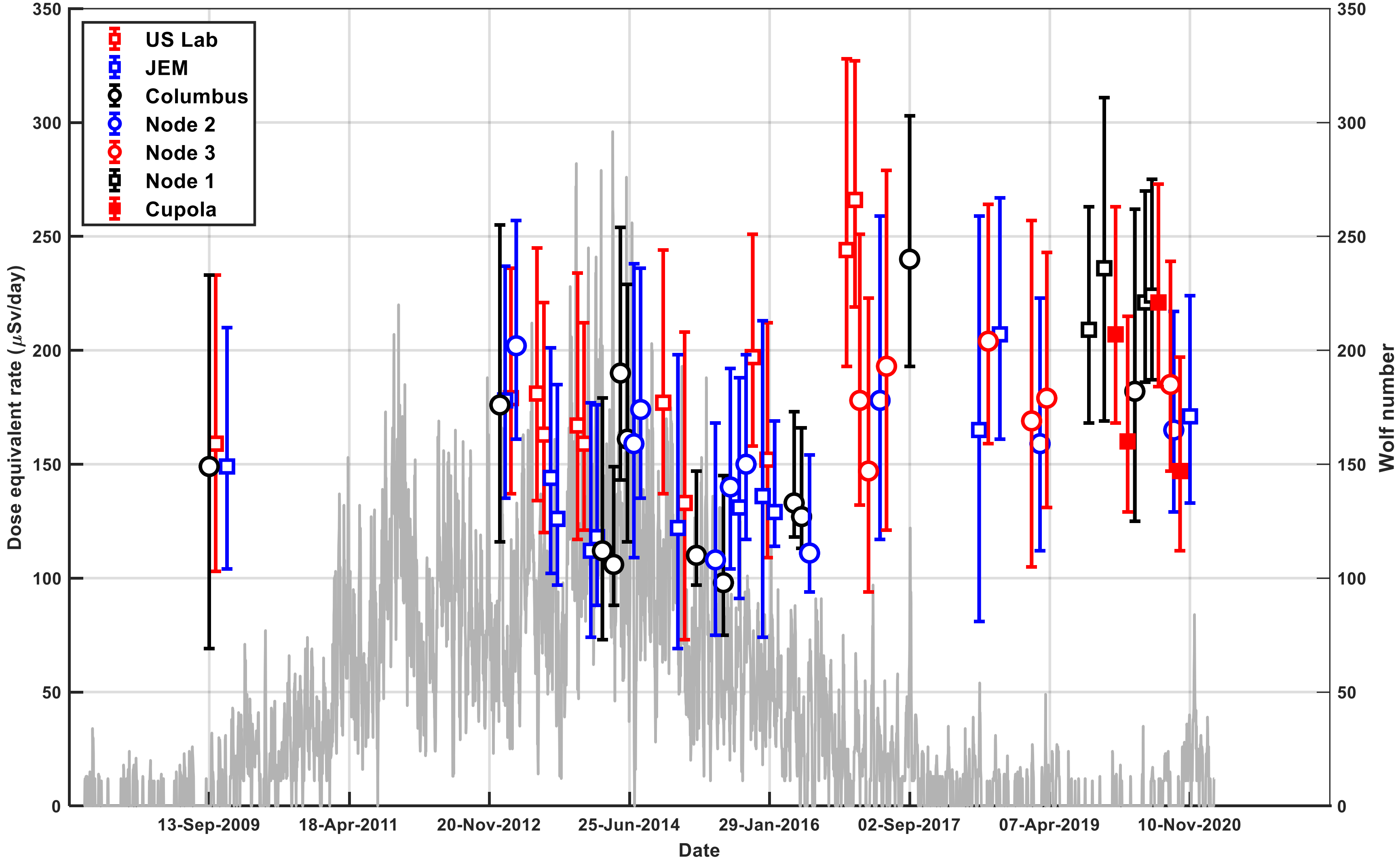




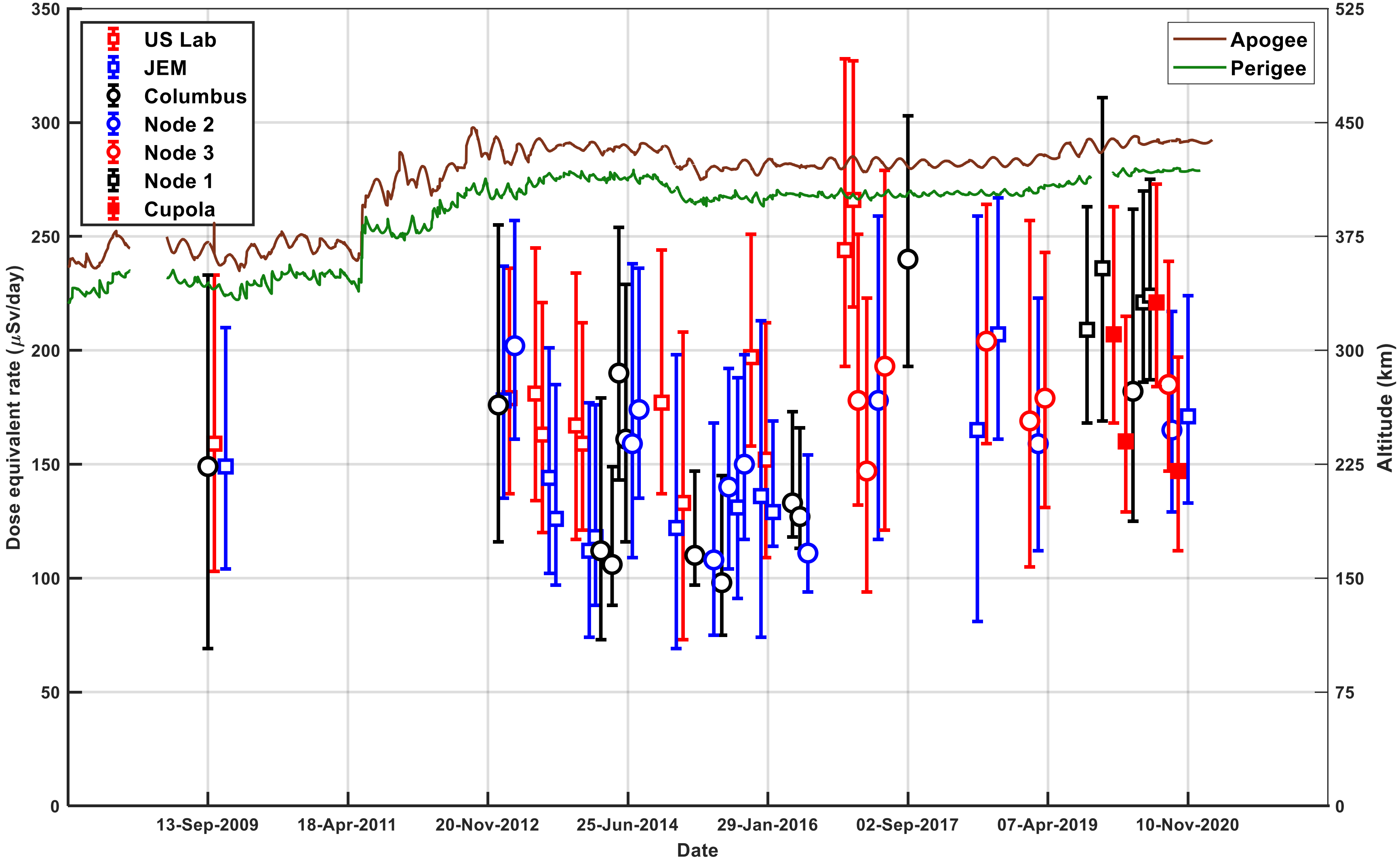


- A total of 75 week-long measurement sessions were conducted for Radi-N (2009) and Radi-N2 (2012 – 2020)
- The period 2009 – 2020 corresponds to a full solar cycle

Radi-N and Radi-N2: Solar Activity

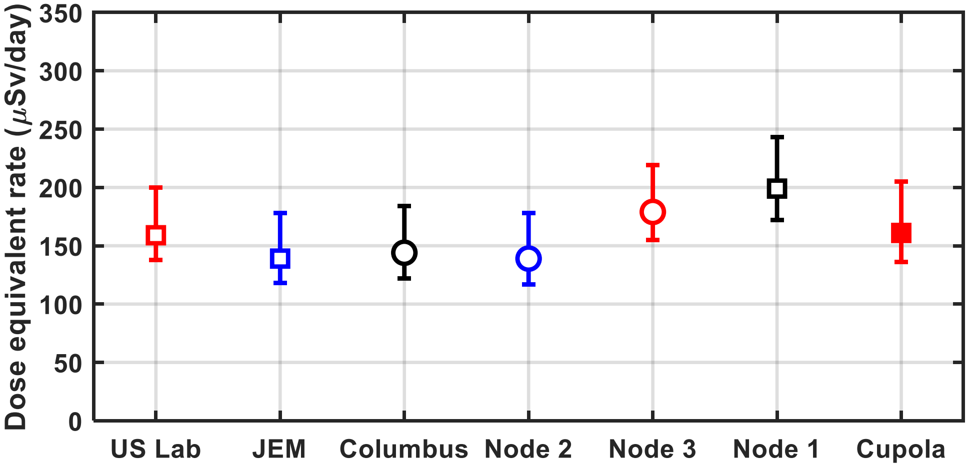


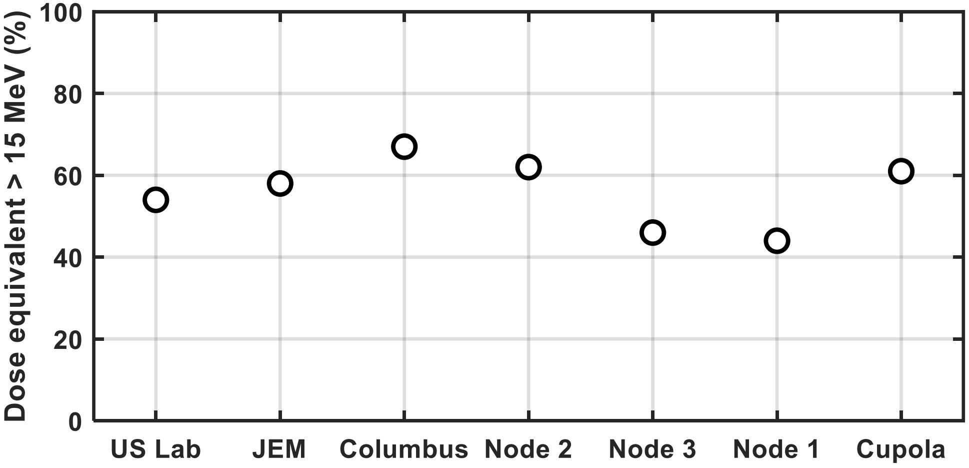
Radi-N and Radi-N2: Altitude



Radi-N and Radi-N2 Results

- The dose equivalent, summed over all sessions, shows some variation with location in the US segment
- The energy distribution of neutrons also appears to vary depending on location
- The data suggest that approximately 50% of the dose equivalent is due to neutrons with energy greater than 15 MeV
- This confirms the importance of high-energy neutrons for the health of astronauts



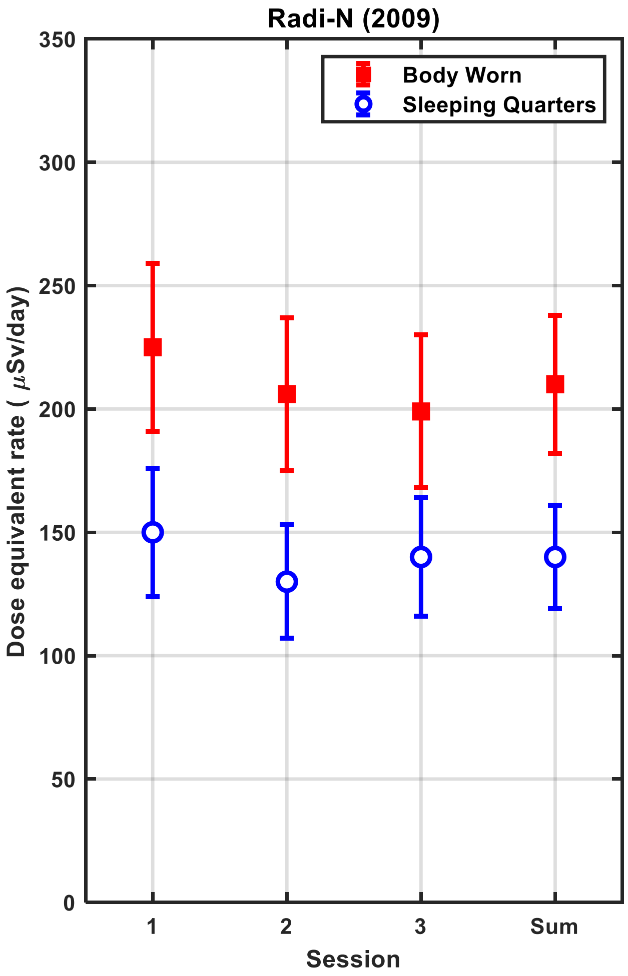


USOS Sleeping Quarters

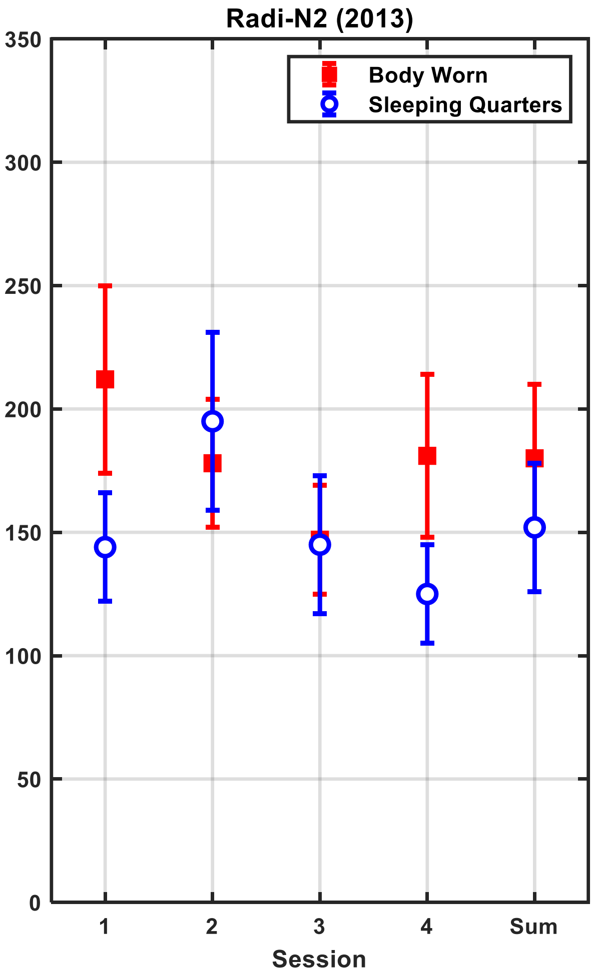
- When on board the ISS, Canadian astronauts conducted a series of measurements with one bubble detector (SPND) worn on the person and one detector located in the sleeping quarters
- These experiments were conducted three times: in 2009, 2013, and 2019
- The data provide a comparison of the neutron dose equivalent in the sleeping quarters to that accumulated during daily activities around the space station
- The results suggest that the shielding in the sleeping quarters is effective

Node 2 Sleeping Quarters

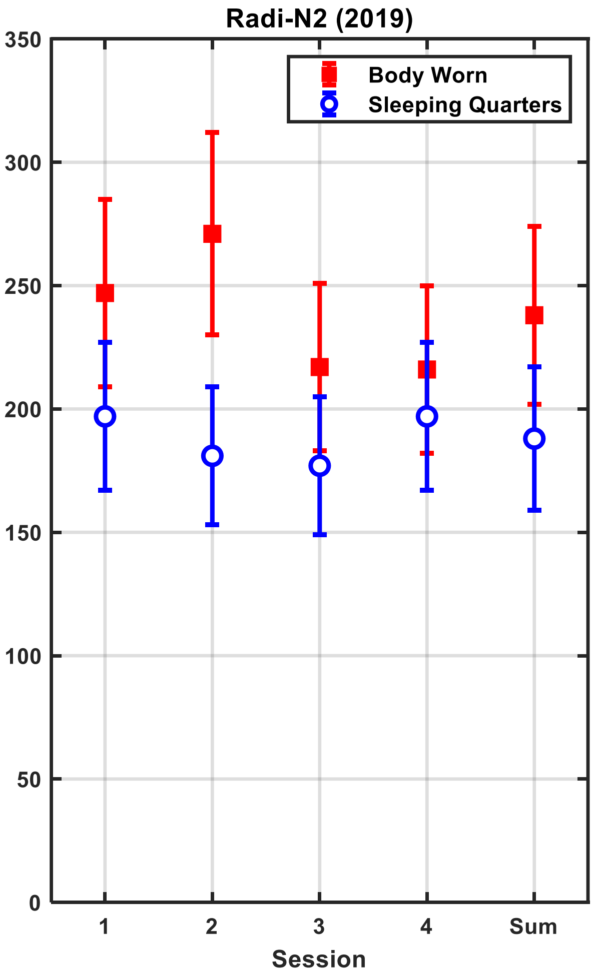
USOS Sleeping Quarters



ISS-20/21: JEM

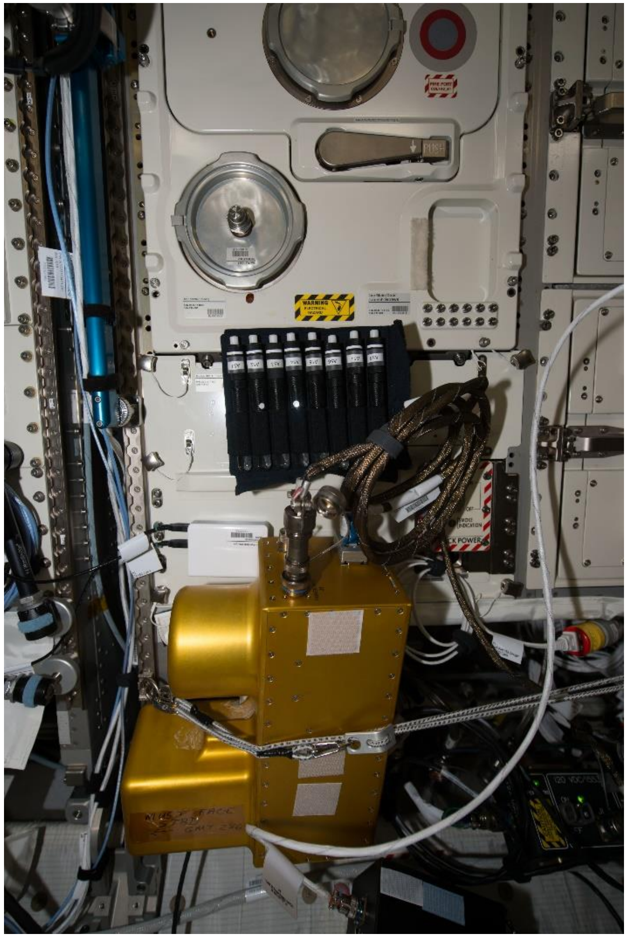


ISS-34/35: Node 2

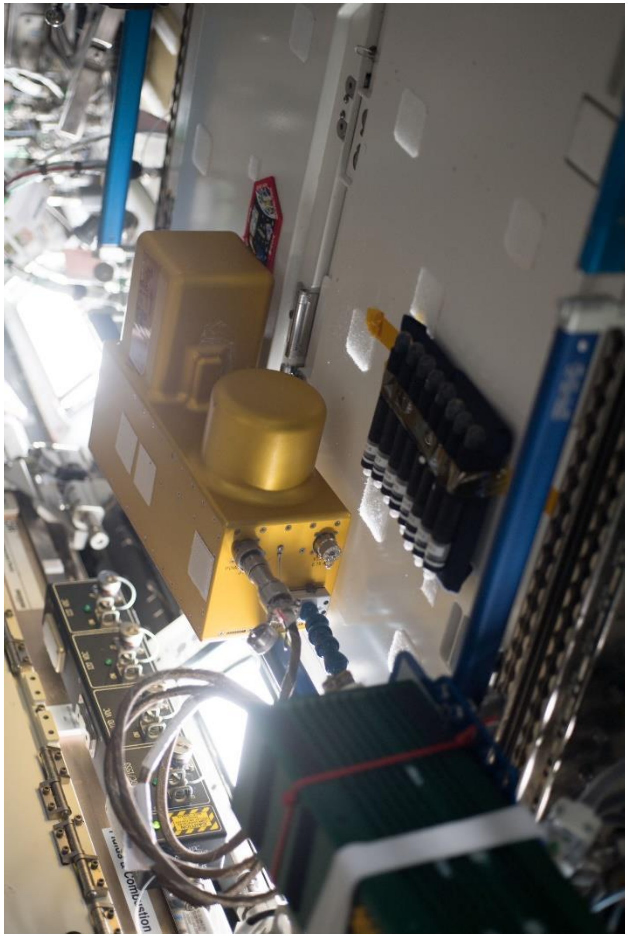


ISS-57/58 and 59/60: Node 2

Radi-N2 Co-Located with ISS-RAD



ISS-53/54 Session 2 (Columbus)



ISS-53/54 Session 4 (US Lab)

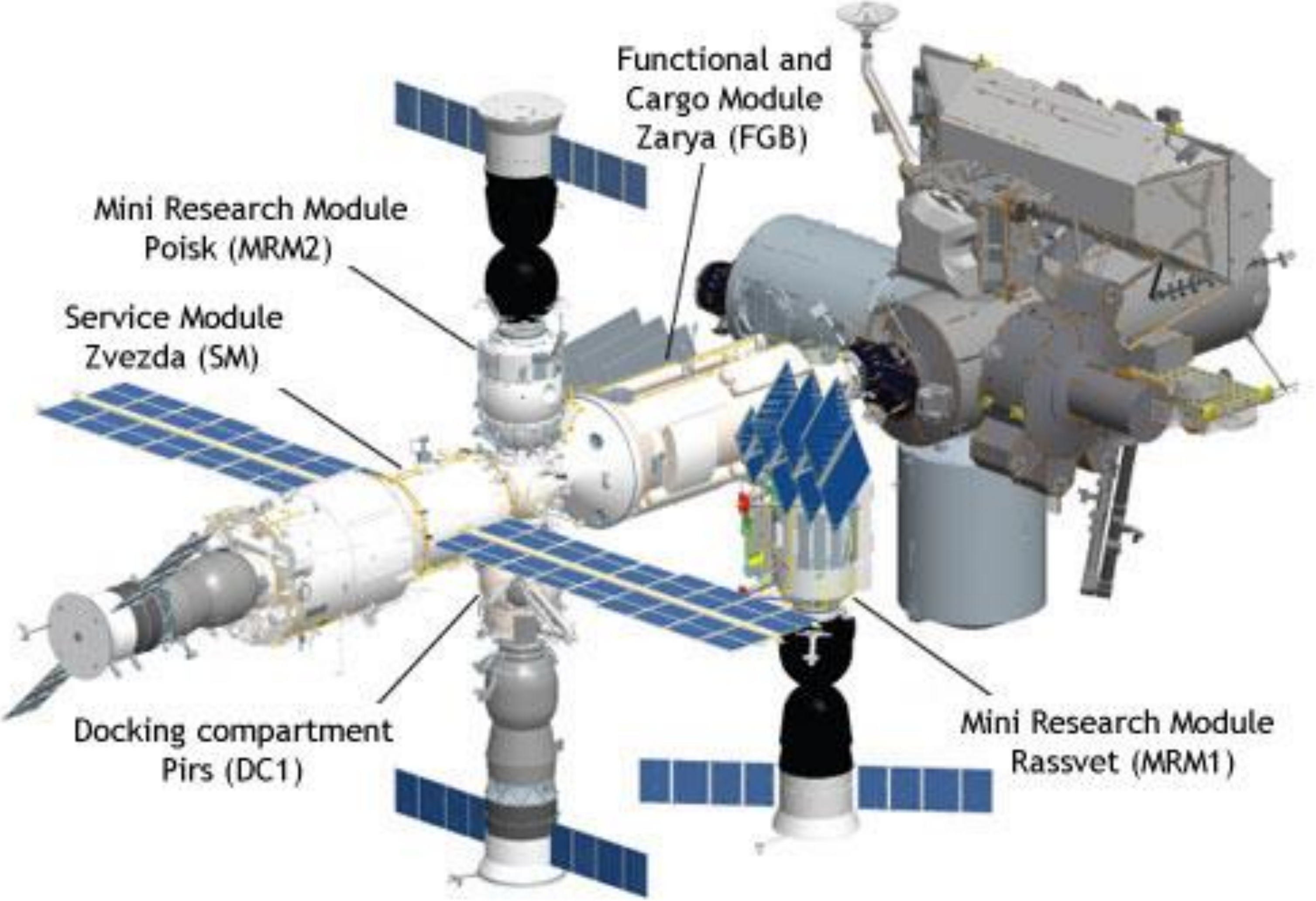
Comparison to ISS-RAD: ISS-49/50

- Radi-N2 and ISS-RAD were co-located in the US Lab for Sessions 3, 4, and 5 of ISS-49/50
- The ISS-RAD recorded dose equivalent values lower than those measured by the Radi-N2 bubble detectors
- This difference is understood because the ISS-RAD measures neutrons over a smaller energy range than the Radi-N2 bubble detectors

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.*

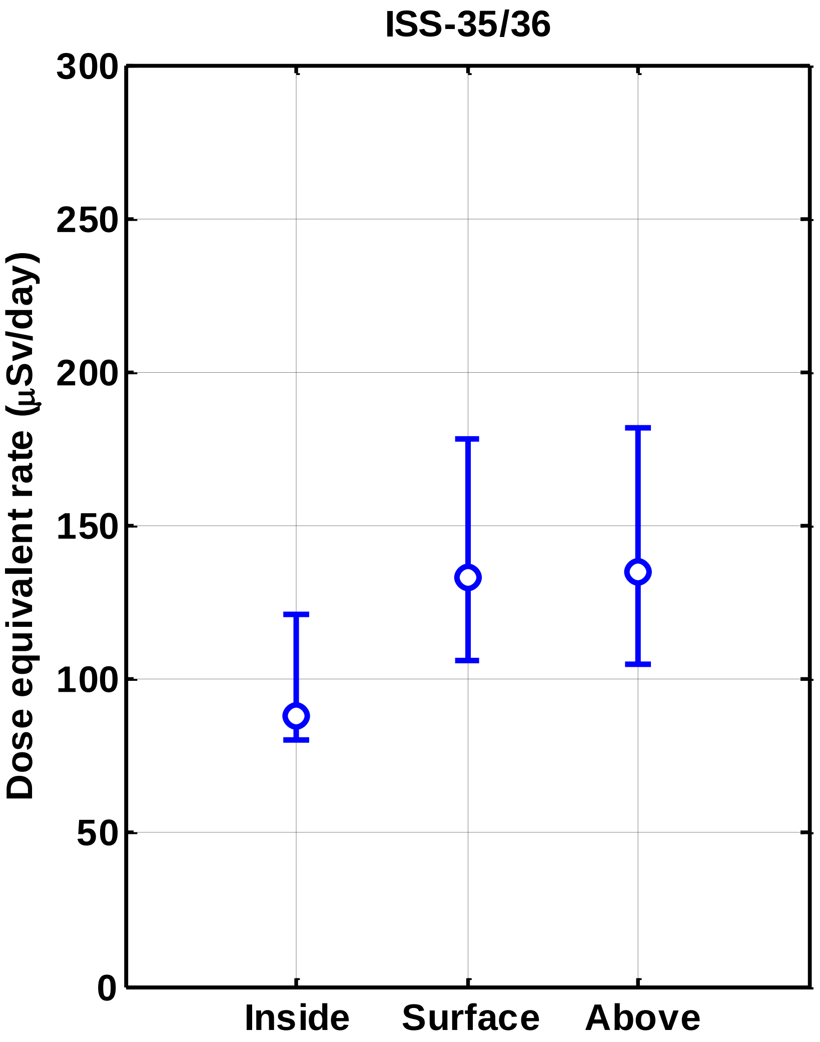
Matroshka-R Locations (ROS)

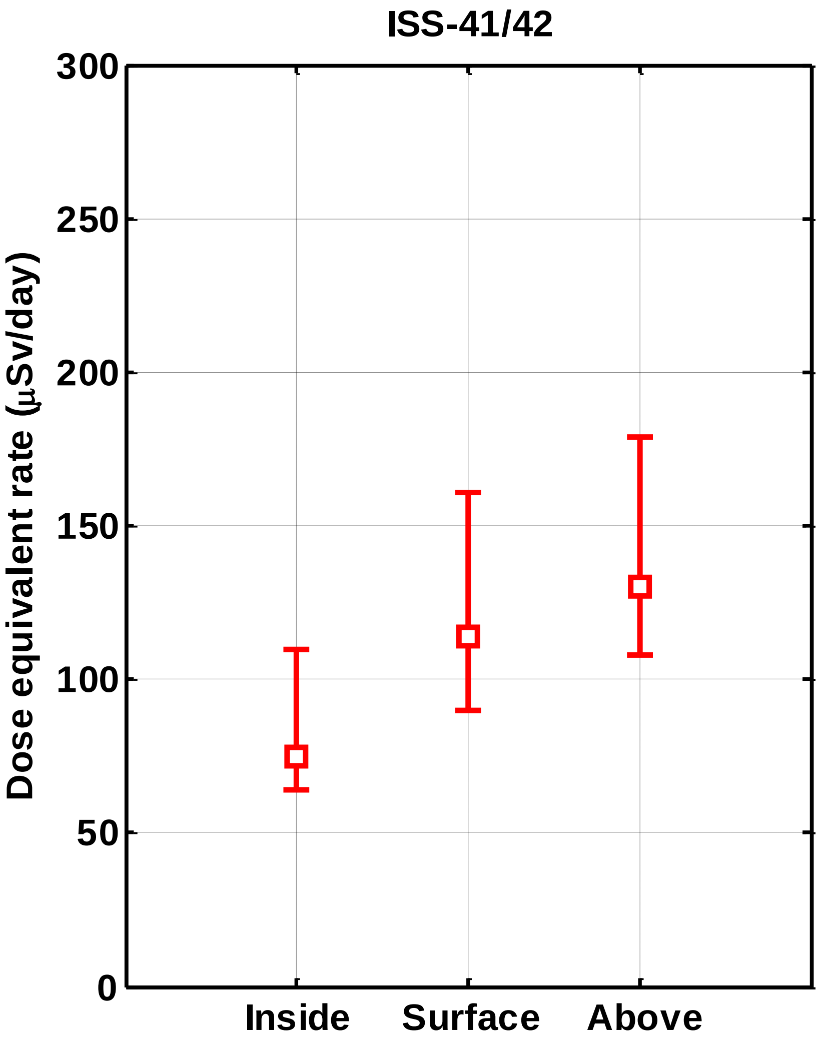


Matroshka-R: Phantom in MRM1

- A number of experiments were conducted in the Russian segment using a tissue-equivalent phantom
- The data from these measurements enable an evaluation of the absorption and production of secondary neutrons in the human body
- The spherical Matroshka-R phantom was located in MRM1
- An SBDS was located inside the phantom and on its surface
- SPNDs were also located inside the phantom and on the surface of the phantom

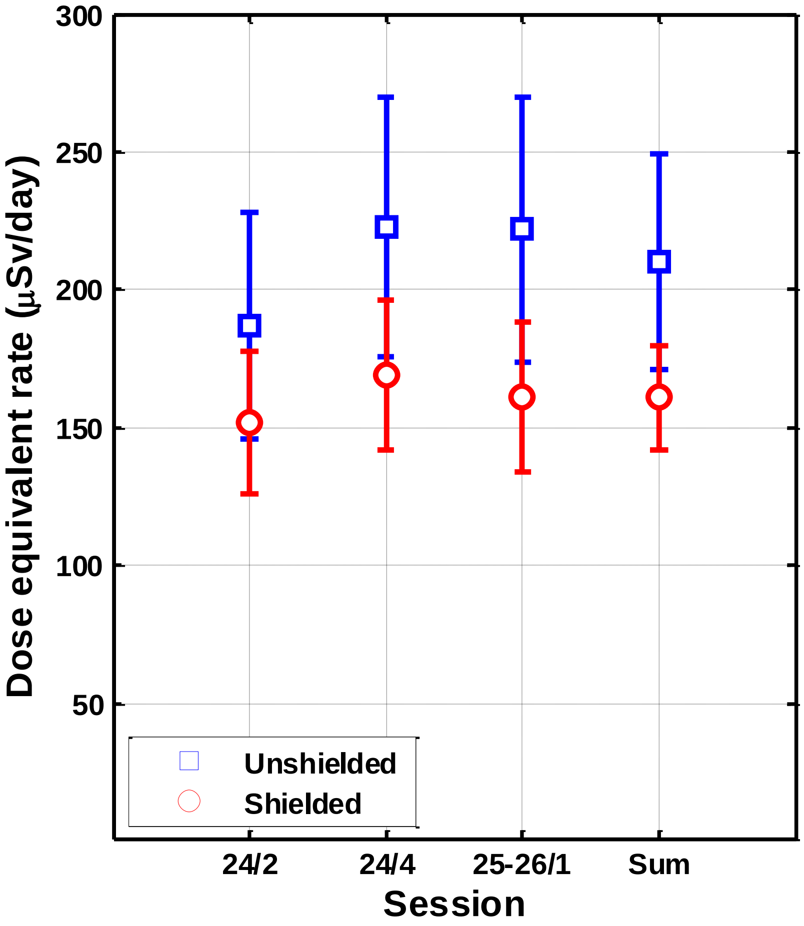
Phantom Results (SBDS)


ISS-35/36


ISS-41/42

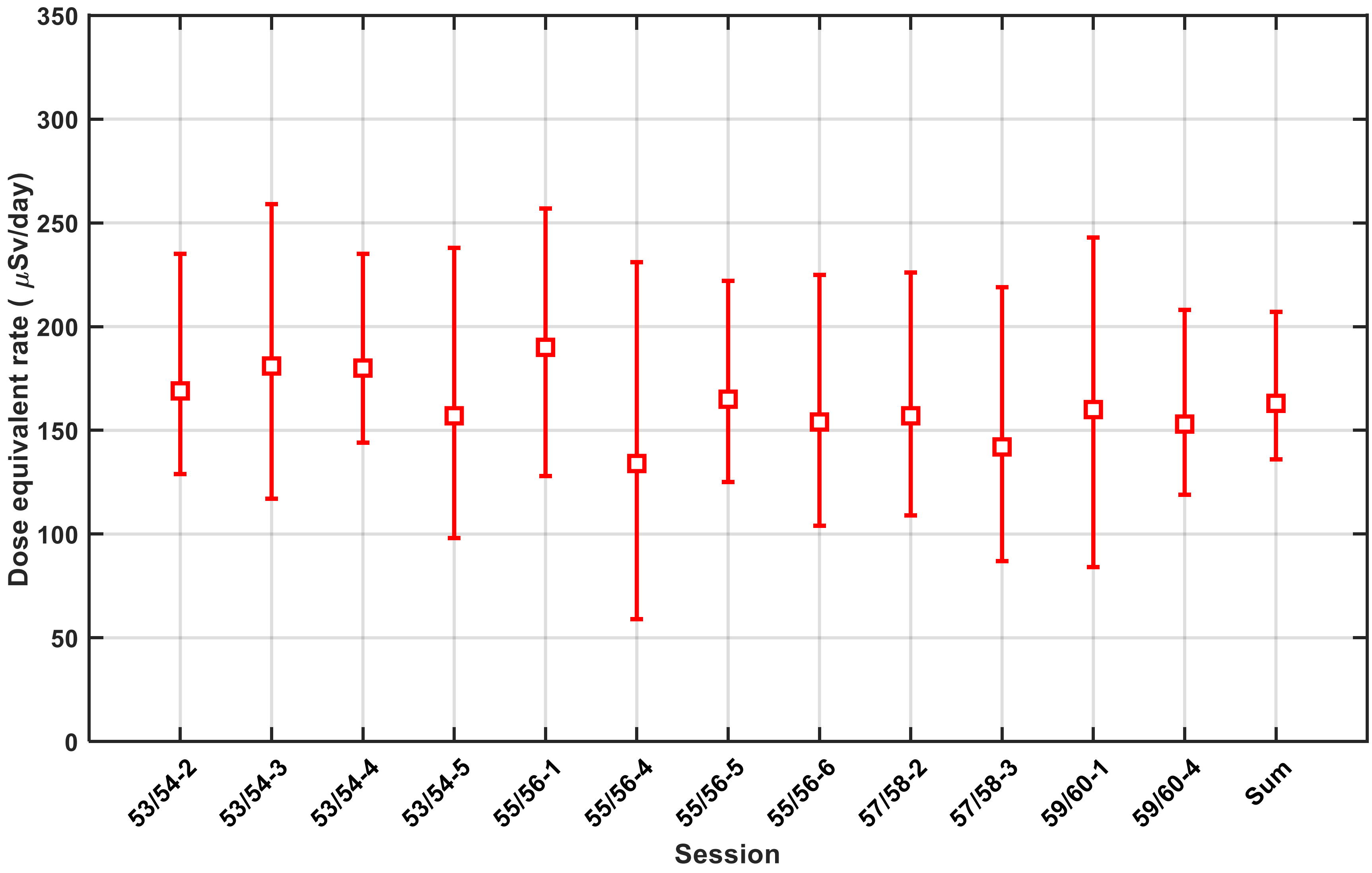
Hydrogenous Shielding

- A number of experiments were conducted using a hydrogenous radiation shield
- These measurements used an SBDS and SPNDs to show that the shielding reduced the measured neutron dose equivalent
- In this example, the dose equivalent behind the hydrogenous shield (on the cabin side) was 77 ± 17% of the unshielded value measured on panel 443 of the Service Module
- This is similar to a result (72 ± 17%) measured using bags of water in the JEM (ISS-20/21)



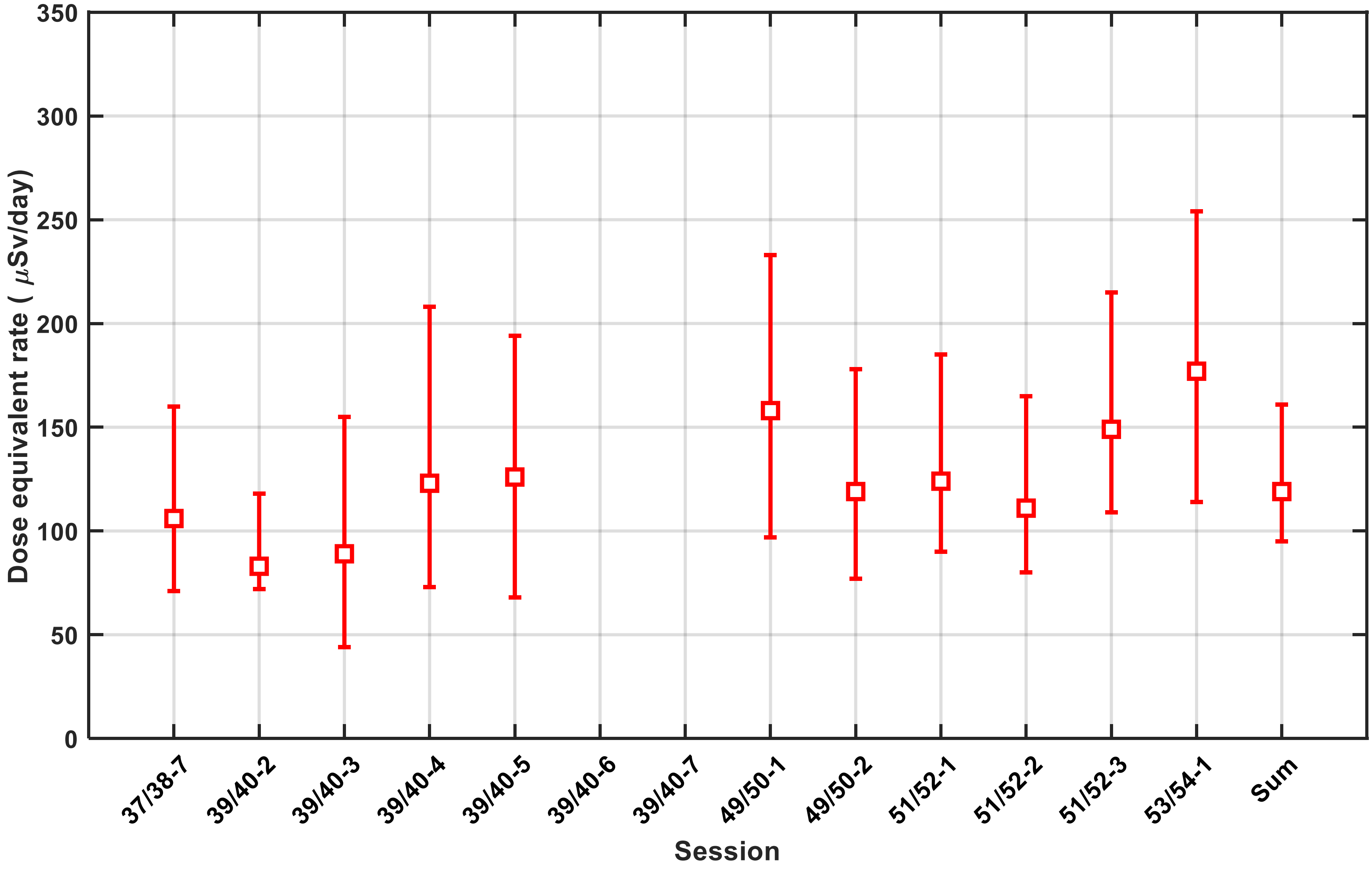
SPND results from ISS-24 and ISS-25/26

FGB: SBDS Data (Panel 426)



MRM2: SBDS Data

BTI BUBBLE Technology Industries



Key Outcomes (1)

- The measurements show that the neutron dose equivalent and energy spectrum are not strongly dependent on the location in the USOS
  - This is understood because the USOS modules are similar in size, construction, and loading
  - The production of secondary neutrons is therefore similar in each USOS module
  - Lower dose equivalent was recorded in smaller modules in the ROS, e.g., MRM2
- The neutron dose equivalent received in the astronaut sleeping quarters was less than that received during daily activities
  - This result confirms that the shielding around the sleeping quarters is effective
- A water shield deployed in the JEM (ISS-20/21) reduced the neutron dose equivalent by ~30%
  - This reduction was also measured in subsequent experiments using a hydrogenous shield in the ROS

Key Outcomes (2)

- The measurements suggest that solar activity has little effect on the neutron radiation field inside the ISS
    - This may be because many secondary neutrons are produced by charged particles in the South Atlantic Anomaly (SAA)
    - The population of charged particles in the SAA may not be strongly affected by changes in solar activity
    - Other neutrons are produced by high-energy cosmic rays, which are not strongly modulated by solar activity
- Similarly, the data suggest that altitude has little effect on the neutron radiation field inside the ISS
- Comparisons with other instruments (e.g., NASA's ISS-RAD and IV-TEPC) are generally well understood based on the energy ranges measured by the various devices

Key Outcomes (3)

- The neutron dose equivalent inside a tissue-equivalent phantom was less than that at its surface, as expected
- The neutron dose equivalent in the Russian Service Module was ~30% of the total recorded by other devices that are sensitive to all particle types
  - This confirms the importance of neutrons for radiation protection of astronauts
- The data suggest that approximately 50% of the dose equivalent is due to neutrons with energy greater than 15 MeV
  - This confirms the importance of high-energy neutrons for the health of astronauts
  - This observation motivates future measurements of high-energy neutrons using an electronic neutron spectrometer

Spectrometer for Deep Space

- BTI has started work on Phase A of the development of the Canadian Active Neutron Spectrometer (CANS)
- The starting point is an earlier Concept Study for the Compact Canadian Neutron Spectrometer (CCNS)
- The CANS will initially undergo a short Technology Demonstration on the ISS
- A second flight model will be deployed on the Lunar Gateway
- The CANS will operate autonomously and continuously, with time-stamped data telemetered to Earth for analysis
- Data will be provided to a science team and archived for use by others

CCNS conceptual design for the Lunar Gateway (2019)

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Acknowledgements

- We would like to thank the following for their important contributions
  - The astronauts and cosmonauts that performed the measurements
  - The CSA’s Operational Space Medicine Group, the IBMP, and NASA’s Space Radiation Analysis Group for supporting the experiments
  - Yuri Akatov, Vadim Arkhangelsky, Inna Chernykh, and Olga Ivanova for their invaluable contributions
  - The CSA and the Russian Space Agency for funding the work

- All Radi-N and Radi-N2 data collected during 2009 – 2020 will be made available through a Government of Canada data sharing site (Open Government portal)

List of Publications

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