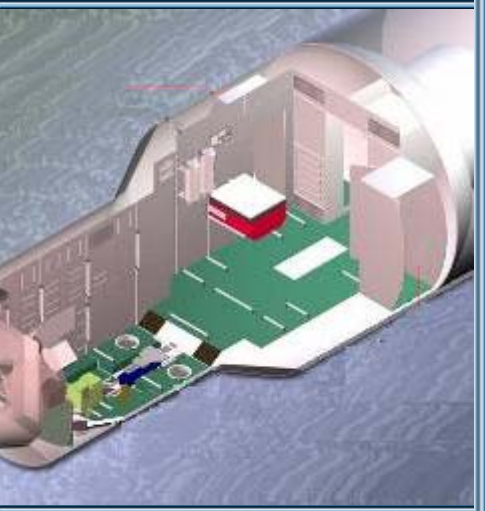

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Radi-N Measurements of Neutron Radiation on the International Space Station

M.B. Smith, K. Garrow, R. Machrafi, H.R. Andrews, H. Ing
Bubble Technology Industries

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Rocket Space Corporation, "Energia", Moscow region, Russia

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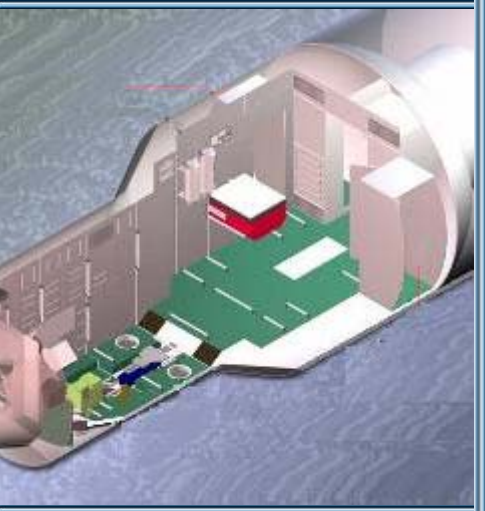

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Radi-N Neutron Field Study

- Radi-N is carried out within the Matroshka-R framework
- Radi-N science team
  - Canadian Space Agency
  - Bubble Technology Industries (BTI)
  - Institute of Biomedical Problems (IBMP)
  - RSC-Energia
  - With International Partner support
- Bubble Detectors have been cleared to enter all USOS segments of the ISS

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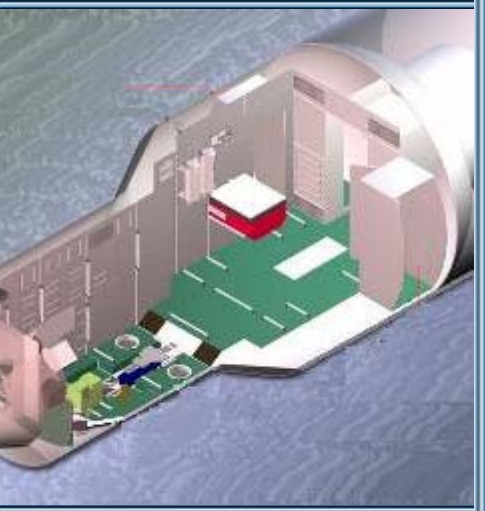

Matroshka-R Measurements

- Previous measurements have been made using bubble detectors during the ISS-13, ISS-14 and ISS-15 missions, as part of the Matroshka-R experiments*
- Measured neutron dose variations with location in the ISS
- Determined neutron dose variations on and in a spherical phantom
- Established relationship between the neutron dose measured externally to the body and the dose received internally

** R. Machrafi et al., Radiation Protection Dosimetry (2009), Vol. 133, No. 4, pp. 200–207*

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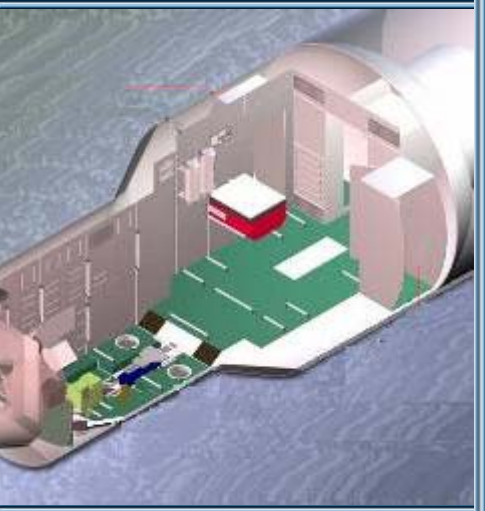
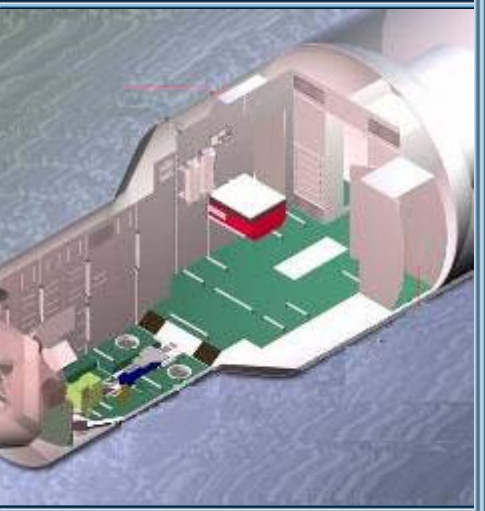


Radi-N Neutron Field Study

- **Radi-N Objectives:**

  i) characterize the neutron spectrum aboard the ISS using a new bubble-detector spectrometer (BDS) developed for space applications

  ii) map out neutron field variations and determine average dose and field symmetry within several ISS modules



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Radi-N Neutron Field Study

Purpose: will assist in optimizing both radiation health risk countermeasures and shielding scenarios

Neutrons are of particular interest to radiation health since they have a relatively high biological effectiveness and have not been well characterized by operational monitoring

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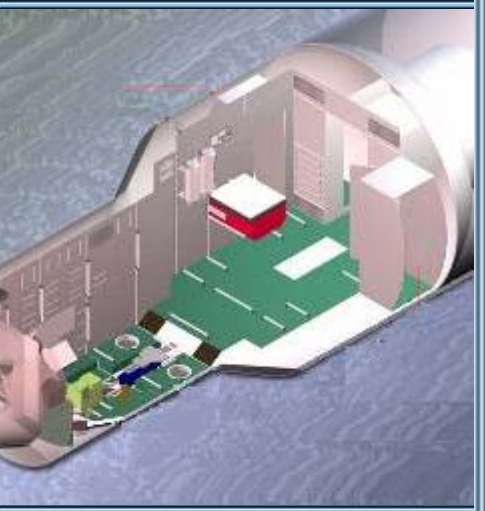

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Experimental Apparatus

- Space bubble detectors (SBD's):

  - Test-tube-shaped neutron dosimeter developed by Bubble Technology Industries Inc. (BTI)

  - Microscopic liquid droplets form bubbles of trapped gas upon contact with neutrons

  - Number of bubbles can be auto-counted using a reader and is indicative of the neutron radiation field intensity

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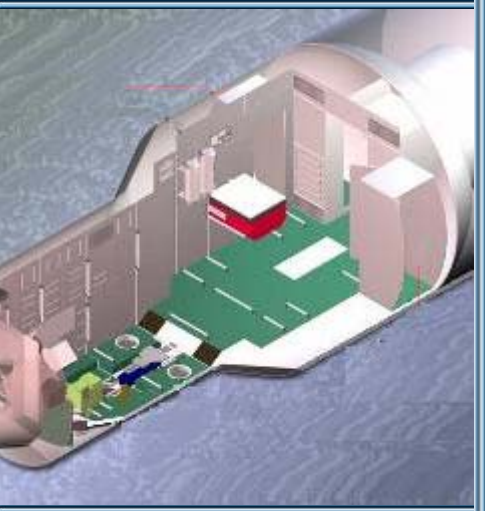

Experimental Apparatus

- Space bubble detectors:
  - BDS consisting of six detectors with six energy thresholds
  - Two bubble-detector personal neutron dosimeters (PND's)
  - Currently aboard ISS (delivered on Progress 34P)

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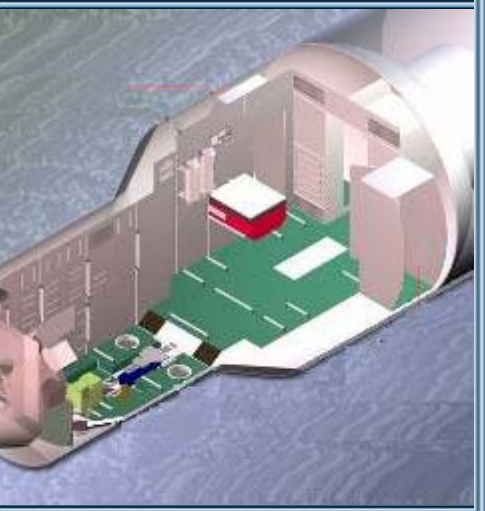
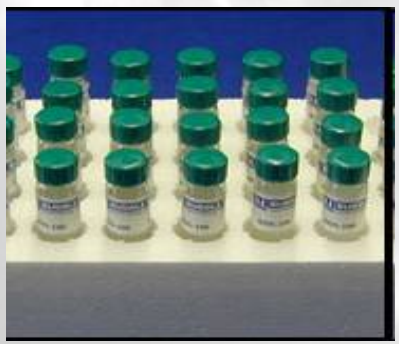


Experimental Apparatus

- The space BDS is based on a commercial BTI product
- The commercial BDS is unsuitable for space applications for three major reasons
  - Special detector formulation is required for space
  - Detector response is temperature dependent, so all measurements must be performed at 20 °C
  - Recompression chamber is required to re-zero detectors



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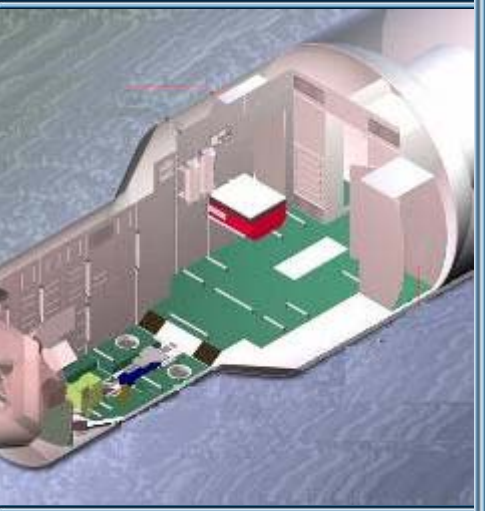
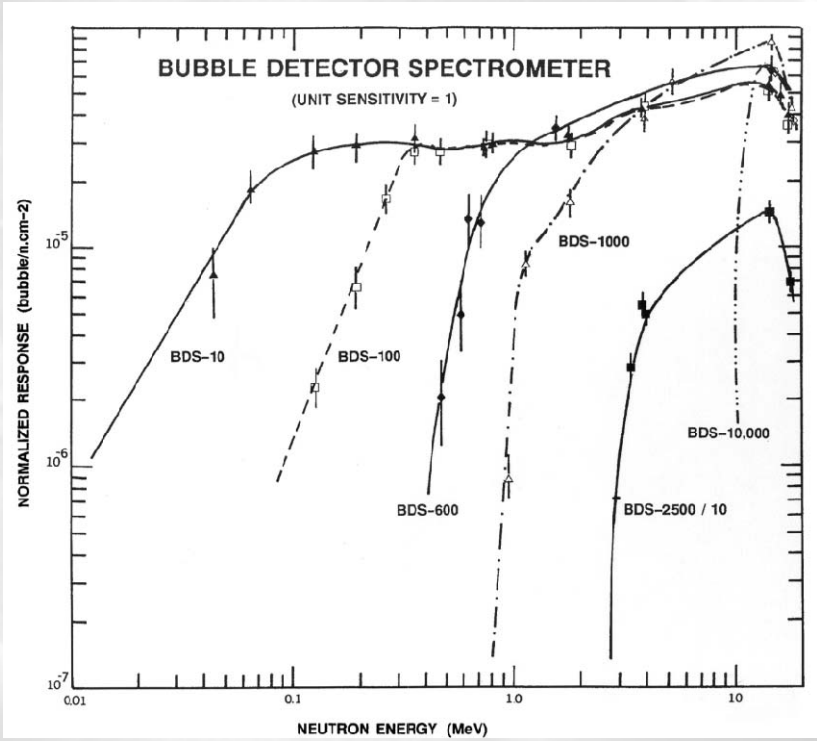


Experimental Apparatus

- Bubble counts from the six detectors can be unfolded to obtain the energy spectrum of neutrons



Measured response functions for commercial BDS

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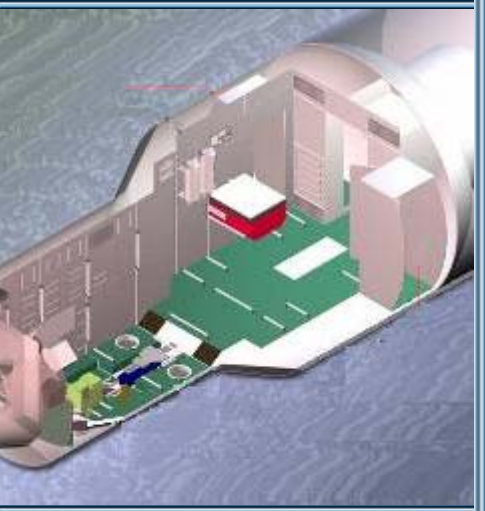
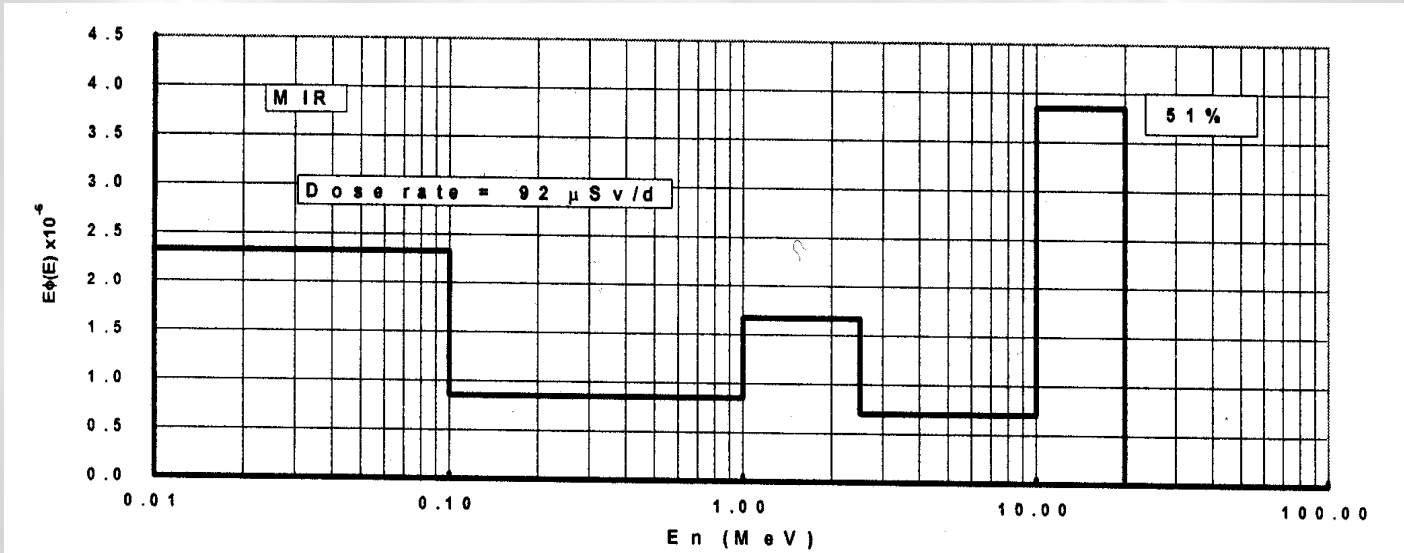


MIR Neutron Exposure (Nov 92-Jan 93) (BTI)

- BDS: 150 μSv/d
  (with CERF calibration factor, 1.62)



- TLD Measurements (Badhwar)
  - 260 μGy/d x 2.5 (average TEPC quality factor) x 20% (neutron fraction of charged particle dose equivalent) = 130 μSv/d

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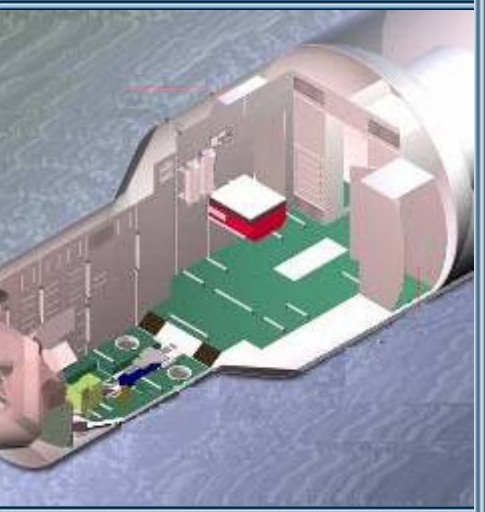

Experimental Apparatus

- A new space BDS has been developed
  - Space formulation
  - No recompression chamber required
  - Temperature compensation applied
    - Detector response is unaffected by temperatures in the range 20 – 30 °C (appropriate for the ISS)
- Detectors were calibrated using an AmBe source (1.13×10^7 n/s) at BTI's Chalk River facility
  - Temperature compensation tested from 20 – 37 °C
- Extensive testing was performed at the DRDC-Ottawa accelerator
  - Monoenergetic neutron beams (50 keV to 14 MeV)
  - Energy thresholds investigated as a function of temperature

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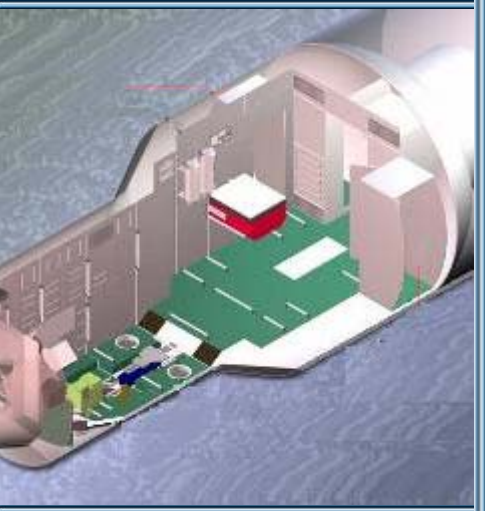
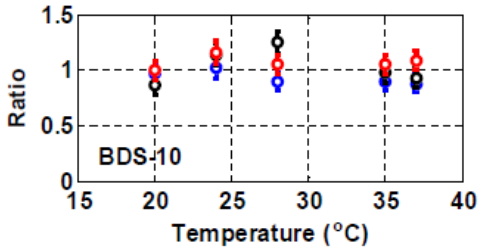
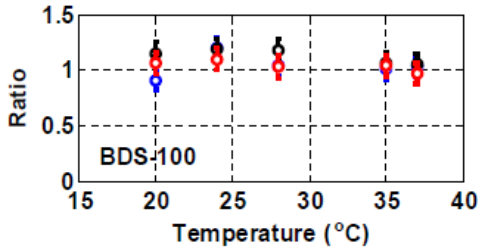
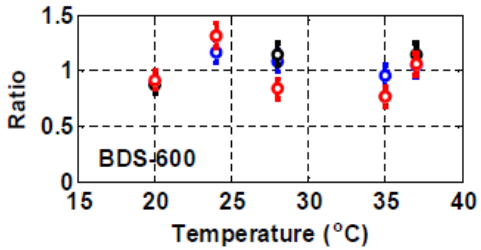


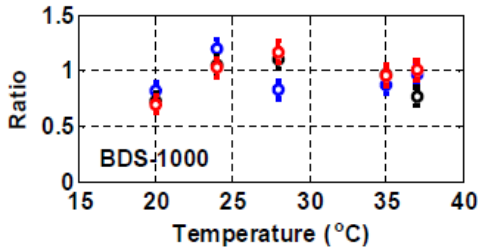
Experimental Apparatus

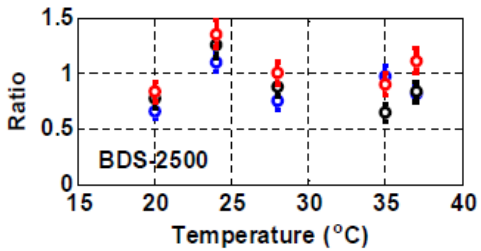
- Temperature compensation measured at BTI's facility











BDS-10000 compensation checked with neutron beams at DRDC

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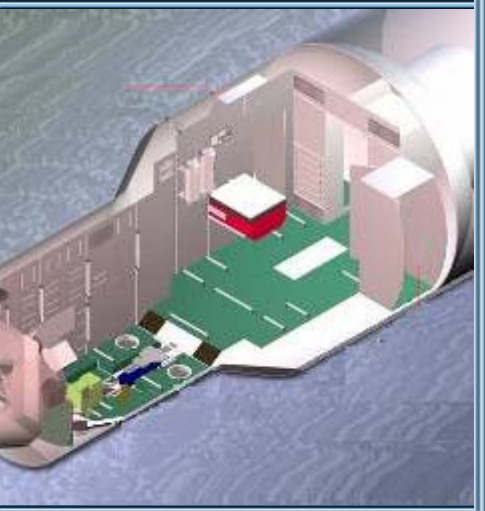
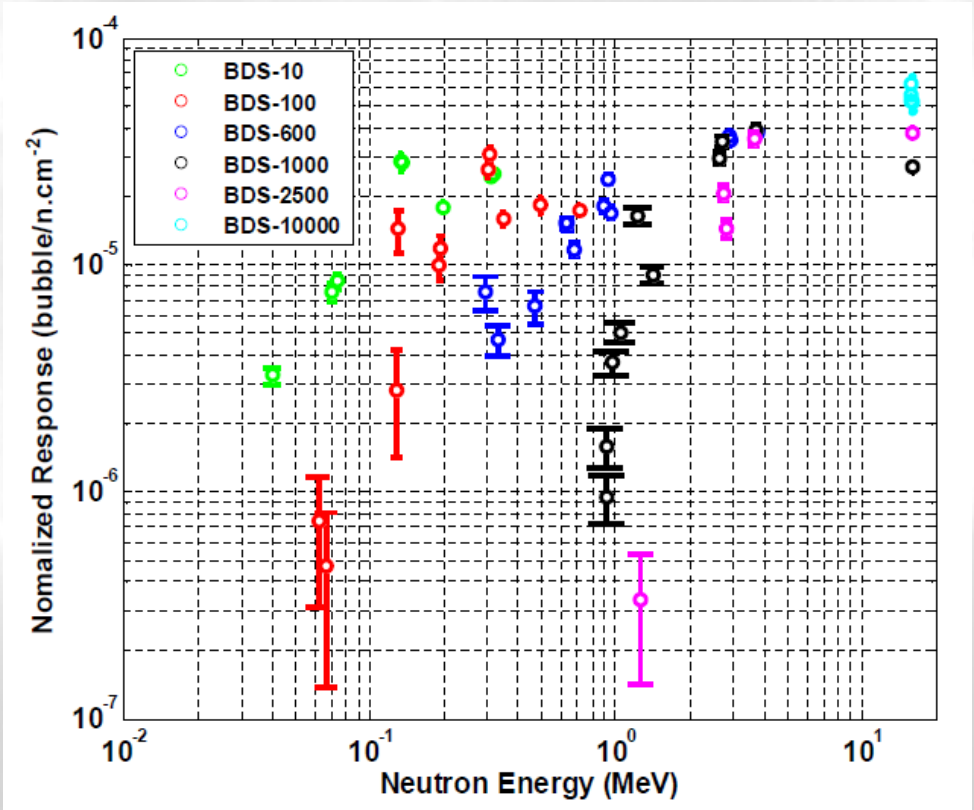


Experimental Apparatus

- Energy thresholds measured at DRDC for new space BDS



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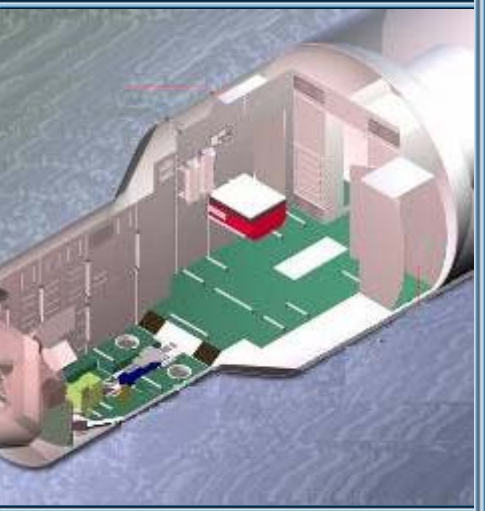

Experimental Apparatus

- Energy thresholds (approximate) used for space BDS in the Radi-N experiment:

Energy Threshold	Average Sensitivity (bubbles/mrem over 20 -37 °C)
10 keV	1.1
100 keV	1.4
600 keV	1.6
1 MeV	1.9
2.5 MeV	1.5
10 MeV	0.37

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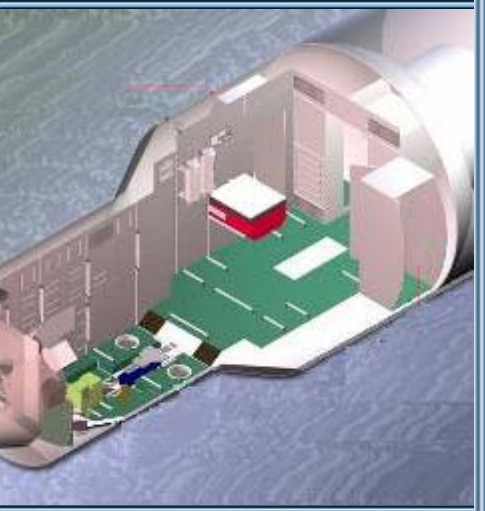
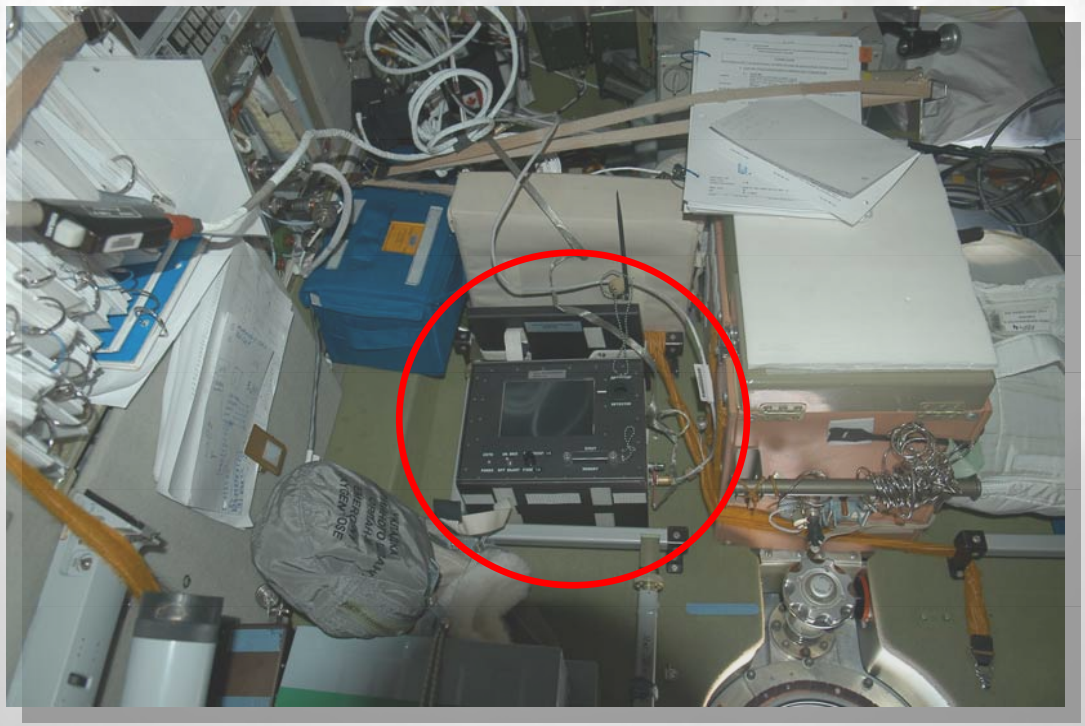


Experimental Apparatus

- Bubble reader:
  - Already aboard ISS (Russian Segment)



Source: Bubble Technology Industries
http://www.bubbletech.ca/radiation_detectors_files/bdr.html

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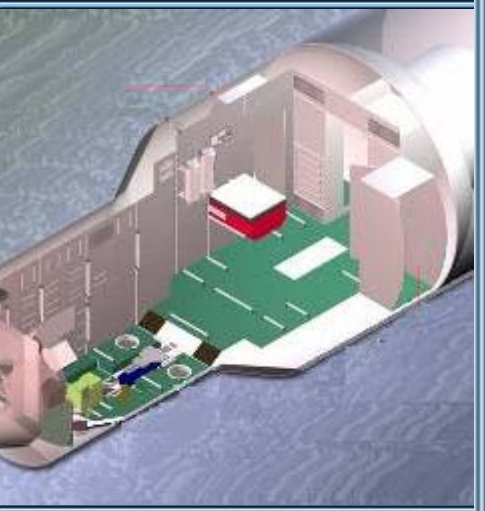

Radi-N Measurements

- Approach for BDS measurements
  - Six detectors are deployed in one pouch
  - Simultaneous measurements allow the determination of the energy spectrum of neutrons
  - Duration of each measurement is 5 – 7 days
  - For future data comparison six spectrometric detectors should always be deployed next to the ISS tissue-equivalent proportional counter (TEPC)

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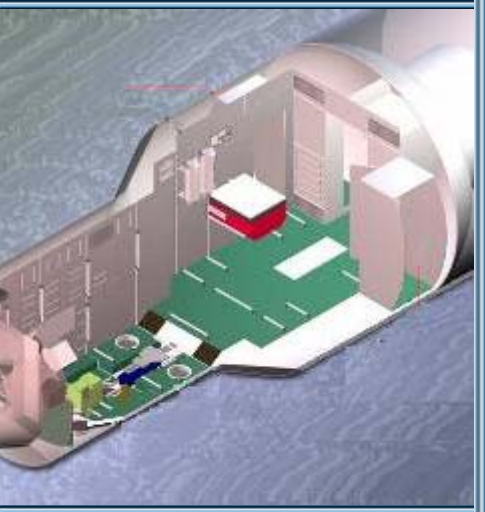

Radi-N Measurements

- On-orbit operations:

	Description	Attended	Unattended
Activity 1	Experiment unstow and activation	54 min	-
Activity 2	SBD initialization & deployment	20 min	-
Activity 3	Photograph locations	10 min	-
Activity 4	Experiment execution	-	5-7 days
Activity 5	Retrieve SBD's and read out	31 min	-
Activity 6	Experiment deactivation and stow	39 min	-

Cosmonaut assistance is requested

Performed by Canadian astronaut

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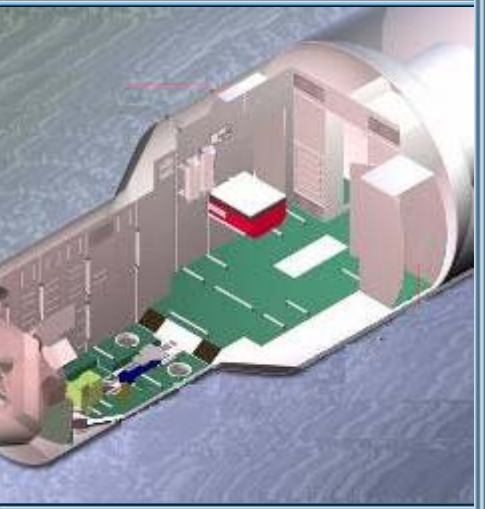

Radi-N Schedule

- **Session 1:** took place Aug 13th - 18th 2009. All eight detectors (six BDS detectors and two PND's) were placed in the service module next to the TEPC
- **Session 2 (September 2009):** Six spectrometric detectors deployed to Columbus. One PND is worn by Canadian astronaut and one placed in his sleeping quarters in the Japanese experiment module (JEM)
- **Session 3 (October 2009):** Six spectrometric detectors deployed to JEM. One PND is worn by Canadian astronaut and one placed in his sleeping quarters in the JEM

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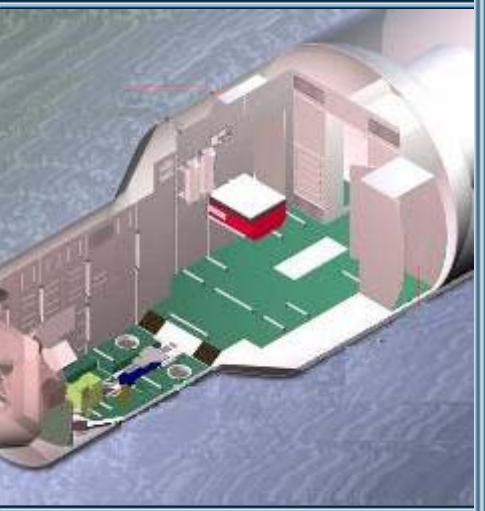

Data from Session 1

- Data analysis is ongoing
  - BDS data will be unfolded to produce neutron spectrum
  - PND data will be used to provide dose indication
- Results will be compared to previous measurements

Detector Designator	A09	A10	A11	A12	A13	A14	A15	A16
Detector Serial Number	4713	4716	4111	4214	4316	4419	4515	4604
Detector Type	PND	PND	BDS-10	BDS-100	BDS-600	BDS-1000	BDS-2500	BDS-10000
Exposure Time (minutes)	7417	7418	7418	7421	7422	7422	7422	7422
Number of Bubbles	80	85	63	85	71	113	98	24

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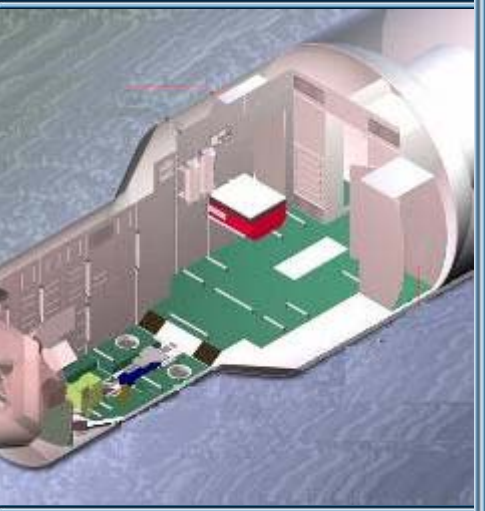

Conclusions

- First measurements with the new space BDS have been performed on the ISS
- Measurements are ongoing and will continue until October 2009
- Data analysis is ongoing

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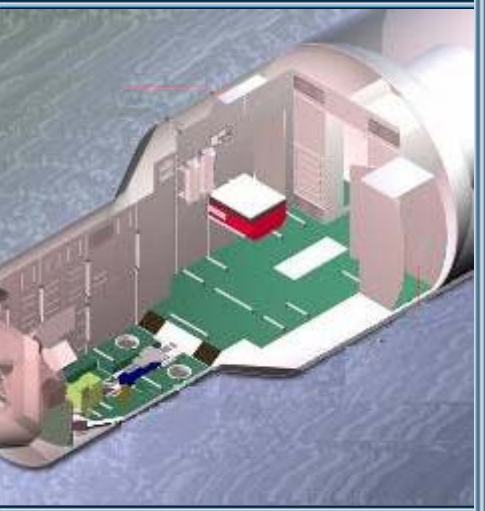

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3. H.R. Andrews, R.A. Noulty and H. Ing , F. d’Errico, B.J. Lewis , L.G.I. Bennett, A.R. Green, LET Dependence of Bubble Detector Response to Heavy Ions , 14th International Conference on Solid State Dosimetry, Yale University, New Haven, CT, 27 Jun-2 Jul 04 & Rad. Prot. Dos., Vol. 120, No. 1-4, (2006) pp. 480-484.
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