Review of Bubble Detector Measurements on Board the International Space Station

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1. Background

- Since January, 2006, with the intent to characterize the neutron component of the radiation field onboard ISS, as a part of Matroshka R project, series of experiments in different expeditions have been carried out using:

  - Spherical phantom designed by IBMP,
  - Space bubble dosimeters and space bubble spectrometers.

- After ISS 13-ISS-15, measurements with space bubble dosimeters continued in expedition ISS-16, ISS-18, ISS-19.

- Later in 2009, the first data was collect with the space bubble spectrometer under the experiment name Radi-N with a primary goal to determine the neutron spectrum at various location of the ISS.

- Space bubble dosimeters were positioned on/in the spherical phantom in order to establish the relationship between the neutron dose measured externally and internally.

- The phantom was located at various places throughout the ISS to evaluate the influence of its shielding (docking module and service module).

- In addition the contribution of charged particle to the bubble detector readings has been evaluated.

This presentation presents a Review of Bubble Detector Measurements on Board ISS

2. Experimental Apparatus

2.1.Space Bubble Detector and Bubble Reader

- To meet the space radiation measurement conditions, special space type bubble detectors were produced.
- The detector has 10 ml active volume with approximately 10^4 microscopic droplets giving a low sensitivity of 80 to 130 bubbles/mSv allowing the detector to be used for a longer period.
- The bubble counting was done automatically using a lightweight mini reader
- The apparatus has been described in several publications and previous WRMISS presentations

Figure1. Bubble detector before and after exposure

2. Experimental Apparatus_ continued

2.2. Spherical phantom

The spherical phantom to simulate the human body consists of :

- 350 mm in diameter, 32kg in mass and has 13 tissue–equivalent slices.
- A working jacket with 32 pockets for detector insertion
- Radial holes designed to facilitate the mounting of detectors on the surface and insertion inside the phantom at a depth of 105-165 mm.

Figure2. Spherical Phantom

3. Measurements

3.1. Measurements with personal bubble dosimeters

- The detectors were irradiated for approximately five days and counted immediately after exposure.

  Measurements were performed:

  - On the surface of the phantom (external dose)
  - Inside the phantom (internal dose)
  - At different locations, mainly, in Service module SM and Docking module DM (influence of shielding).

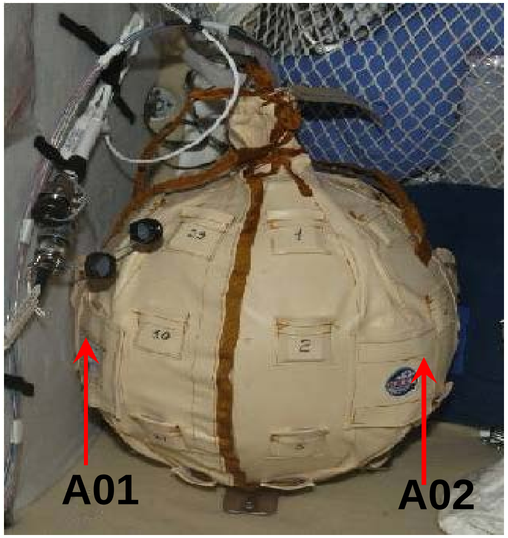


Figure2. Example of detector on the surface of the Spherical Phantom

- Data for ISS 13 to ISS-15 have been presented in previous WRMISS and published in [1]

[1] Machrafi, R. et al., *Neutron dose study with bubble detectors aboard the International Space Station as part of the Matroshka-R experiment*. Radiat. Prot. Dosimetry **133**(4), 200 – 207 (2009).

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements: ISS-16, ISS-18 and ISS-19

- Measurements took place in 2008 and 2009 and 6 sessions have been carried out (2 sessions in each expedition)
  - Measurements with 8 detectors were made with phantom located in the Pirs docking module:
    - 3 (three) Detectors were placed deep inside the phantom, and just under its surface, in order to compare the internal and external doses
    - 5(five) Other detectors were placed in the Russian service module.
  - The same eight space personal neutron dosimeter (SPND) detectors were used during all four sessions of ISS-18 and ISS-19
- The following detectors have been used:

Detector label	Serial number	S_{AmBe} (bubble/mSv)	S (bubble/mSv)
A01	8010	104±16	64±10
A02	8012	120±12	74±7
A03	8013	125±11	77±7
A04	8014	140±15	86±10
A05	8114	143±16	88±10
A06	8015	154±8	95±5
A07	8115	149±7	92±5
A08	8019	187±15	115±9

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements _ Detector Locations

The locations of detectors is as follow:

Detector label	ISS-16, session 8 ISS-18, session 2 ISS-19, session 1	ISS-16, session 9 ISS-18, session 1 ISS-19, session 2
A01/B01	Pirs module, inside phantom, facing phantom surface	Pirs module, inside phantom, facing phantom centre
A02/B02	Pirs module, inside phantom, facing phantom surface	Pirs module, inside phantom, facing phantom centre
A03/B03	Pirs module, inside phantom, facing phantom surface	Pirs module, inside phantom, facing phantom centre
A04/B04	Service module, starboard cabin	Service module, starboard cabin
A05/B05	Service module, starboard cabin	Service module, starboard cabin
A06/B06	Service module, close to the astronaut working desk	Service module, close to the astronaut working desk
A07/B07	Service module, close to the astronaut working desk	Service module, close to the astronaut working desk
A08/B08	Service module, on the ceiling	Service module, on the ceiling

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements _ Results

Data from session 8 on ISS-16 (on the surface of the phantom)

Detector label	B01	B02	B03	B04	B06	B07	B08
Sensitivity (bubbles/mSv)	123±12	117±19	111±12	111±21	99±9	93±6	86±10
Exposure time (min)	7450	7450	7450	7450	7450	7450	7450
Number of bubbles	72	71	64	105	73	71	48
Dose rate (μSv/day)	113±17	117±23	111±18	183±39	143±21	148±20	107±20

Data from session 9 on ISS-16 (inside the phantom)

Similar values

Detector label	B01	B02	B03	B04	B06	B07	B08
Sensitivity (bubbles/mSv)	123±12	117±19	111±12	111±21	99±9	93±6	86±10
Exposure time (min)	7070	7076	7072	7077	7074	7071	7076
Number of bubbles	92	67	69	100	86	64	57
Dose rate (μSv/day)	152±22	116±24	126±20	183±39	177±25	141±20	134±24

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements _ Results

Data from ISS-18, session 2 (on the surface of the phantom)

Detector label	A01	A02	A03	A04	A05	A06	A07	A08
Sensitivity (bubbles/mSv)	64±10	74±7	77±7	86±10	88±10	95±5	92±5	115±9
Exposure time (min)	6944	6946	6946	n/a	6947	6948	6950	6951
Number of bubbles	38	32	44	n/a	63	71	51	90
Dose rate (μSv/day)	123±27	90±18	118±21	n/a	148±25	155±20	115±17	162±21

Similar values

Data from ISS-18, session 1 (inside the phantom)

Detector label	A01	A02	A03	A04	A05	A06	A07	A08
Sensitivity (bubbles/mSv)	64±10	74±7	77±7	86±10	88±10	95±5	92±5	115±9
Exposure time (min)	7320	7311	7320	n/a	7324	7326	7321	7280
Number of bubbles	26	29	29	n/a	88	60	73	60
Dose rate (μSv/day)	80±20	77±16	74±15	n/a	196±30	124±17	156±20	103±16

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements _ Results

Data from ISS-19, session 1 (on the surface of the phantom)

Detector label	A01	A02	A03	A04	A05	A06	A07	A08
Sensitivity (bubbles/mSv)	64±10	74±7	77±7	86±10	88±10	95±5	92±5	115±9
Exposure time (min)	10018	10022	10022	10024	10024	10025	10026	10025
Number of bubbles	47	44	50	75	73	105	87	130
Dose rate (µSv/day)	105±22	85±15	93±16	125±20	119±19	159±17	136±16	162±19

Data from ISS-19, session 2 (inside the phantom)

Similar values

Detector label	A01	A02	A03	A04	A05	A06	A07	A08
Sensitivity (bubbles/mSv)	64±10	74±7	77±7	86±10	88±10	95±5	92±5	115±9
Exposure time (min)	9798	9796	9790	9809	9810	9792	9801	9793
Number of bubbles	60	43	45	77	88	97	72	85
Dose rate (µSv/day)	137±27	85±16	86±15	131±21	146±22	150±17	115±15	108±15

3. Measurements _continued

3.1. Personal Bubble dosimeters Measurements_ Comparison

- Data from the pairs of sessions for which the detectors were placed in the same positions have been summed to improve the statistics of the measurement.
- It provides a comparison of the dose deep inside the phantom and the dose just under the phantom surface.
- The observation that the dose rate at the surface of the phantom is similar to that at the centre of the phantom is also supported by measurements performed during ISS-15 (Figure 4)
- This is important because it upholds the idea that a dosimeter worn on the body provides an accurate assessment of the dose received by critical organs inside the body

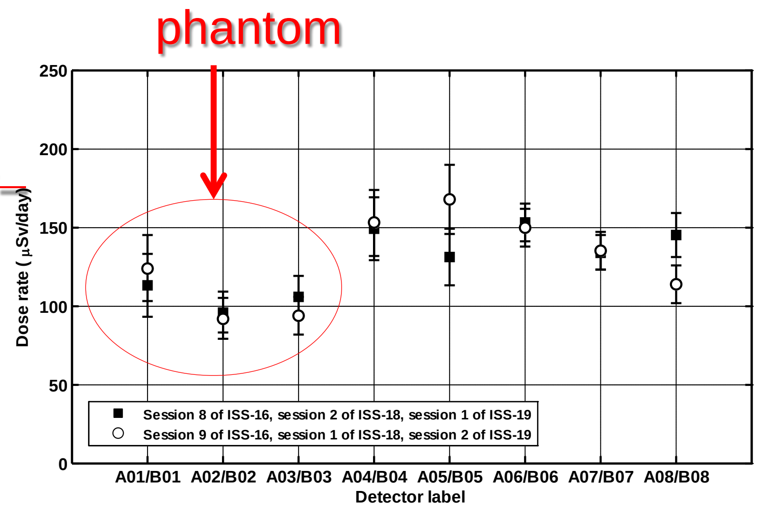


Figure3. Comparison of different session results

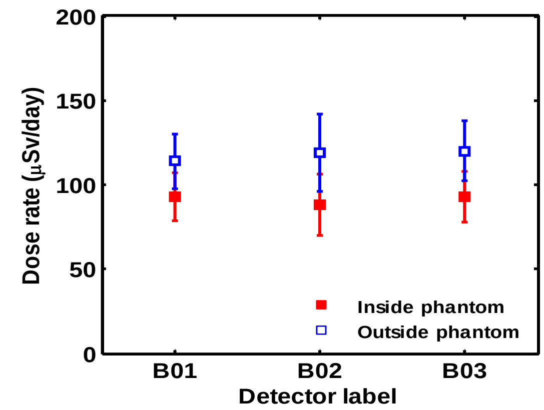


Figure 4. Internal to external dose in Service module ISS15

Module	surface	inside	Ratio
SM	118±33	91±27	0.77
PIRS	131±35	114±31	0.66

Internal to external dose in different module

Summary on Measurements with Personal Bubble Dosimeters

- Data suggest there is little difference in the dose received at the centre and on the surface of the phantom
- Dose rate in the service module is slightly higher than that in the phantom
- Some attenuation due to the phantom is expected However, secondary neutrons created in the phantom may offset phantom shielding
- Earlier measurements showed that the dose in the docking module is higher than that in the service module.
- The reading of the detectors on the surface of the phantom in both locations show a slight difference in the dose rate due to the difference in the shielding thicknesses.

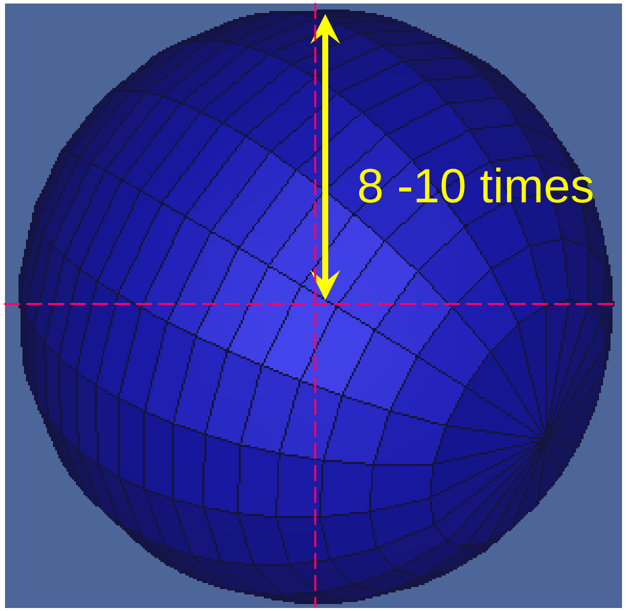


Figure5. Spherical Phantom

This difference can be due to:

- Either to neutron production by other process (charged particles)
- Production of neutrons by threshold reactions (n,2n) on the constituents of the phantom
- The slowing down process of neutrons through the phantom, which is less probable

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements

To clarify the difference between the internal and external doses, it is important to measure the neutron spectrum, if possible, on the surface and inside of the phantom. Part of such task has been done in ISS-20 and ISS-21

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements

- Space bubble spectrometer SBDS has been developed by BTI with CSA funding.
- SBDS consists of six detectors, with 6 thresholds (BDS-10, BDS-100, BDS-600, BDS-1000, BDS-2500, BDS-10000).
- To perform the measurements, a set of threshold bubble detectors (SBDS) was delivered and deployed on the ISS.
- 5 (five) experimental sessions have been performed in expeditions ISS-20 and ISS-21.

Dates of bubble-detector measurements on ISS-20 and ISS-21.

Session	Initialization date	Retrieval date
Matroshka	August 13th 2009	August 18th 2009
Session 1	September 6th 2009	September 13th 2009
Session 2	October 3rd 2009	October 10th 2009
Session 3	November 9th 2009	November 16th 2009
Thirsk*	**November 19th 2009**	**November 26th 2009**

* Robert Thirsk - Canadian Astronaut

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Detector Locations

- Locations of detectors used during ISS-20 and ISS-21 expeditions.

Session	A09	A10	SBDS
Matroshka	Service module P327	Service module P327	Service module P327
Session 1	Worn by Robert Thirsk	JEM sleeping quarters	Columbus 1A3
Session 2	Worn by Robert Thirsk	JEM sleeping quarters	US laboratory 1S4
Session 3	Worn by Robert Thirsk	JEM sleeping quarters	JPM 1F2 (water shield)
Thirsk	JPM 1F2 forward	JPM 1F2 inboard	JPM 1F2 forward

- A09 detector worn on person by Bob Thirsk
- A10 detector placed near sleeping quarters of Bob Thirsk in JEM 1F2

A09 Detector worn by Bob Thirsk

Detector A10 on JPM1F2 rack front (inboard of water wall)

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Results

Matroshka session on ISS-20

Detector label	A09	A10	A11	A12	A13	A14	A15	A16
Sensitivity (bubbles/mSv)	78±9	99±14						
Exposure time (min)	7417	7418	7418	7421	7422	7422	7422	7422
Number of bubbles	80	85	63	85	71	113	98	24
Dose rate (μSv/day)	200±33	166±29						

Bubble spectrometer

Session 1 on ISS-20.

Detector label	A09	A10	A11	A12	A13	A14	A15	A16
Sensitivity (bubbles/mSv)	78±9	99±14						
Exposure time (min)	9861	9865	9868	9872	9873	9874	9876	9878
Number of bubbles	120	102	82	107	111	130	137	27
Dose rate (μSv/day)	225±34	150±26						

Bubble spectrometer

Session 2 on ISS-21

Detector label	A09	A10	A11	A12	A13	A14	A15	A16
Sensitivity (bubbles/mSv)	78±9	99±14						
Exposure time (min)	10787	10789	10790	10793	10796	10799	10799	10800
Number of bubbles	120	97	76	141	110	140	110	35
Dose rate (μSv/day)	206±31	130±23						

Bubble spectrometer

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Results

Session 3 on ISS-21.

Detector label	A09	A10	A11	A12	A13	A14	A15	A16
Sensitivity (bubbles/mSv)	78±9	99±14						
Exposure time (min)	10071	10070	10070	10069	10074	10075	10074	10075
Number of bubbles	108	97	36	65	63	96	93	16
Dose rate (µSv/day)	199±31	140±24						

Bubble spectrometer

Robert Thirsk's personal project on ISS-21.

Detector label	A09	A10	A11	A12	A13	A14	A15	A16
Sensitivity (bubbles/mSv)	78±9	99±14						
Exposure time (min)	11289	11290	11292	11292	11291	11292	11292	11292
Number of bubbles	110	101	61	106	116	132	142	34
Dose rate (µSv/day)	180±28	130±22						

Bubble spectrometer

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Results

- The dose rate recorded by detectors A09 and A10 is presented in Figure 7.

- For the Matroshka session, both detectors record a similar dose rate, which is expected because the detectors were co-located in the Russian service module.

- A09 dose is higher for sessions 1 – 3 because this detector was worn and moved around the ISS, sampling higher dose rates in less shielded parts of the station, while A10 stayed in the sleeping quarters

- Thirsk's personal project, detectors A09 and A10 were placed on opposite sides of a water shield. A10 was on the inboard side of the water shield. The A09 dose is slightly higher than that recorded by A10.

- These data suggest that the water shield reduces the neutron dose rate on the inner side of the shield to 72±17% of its value on the outer side.

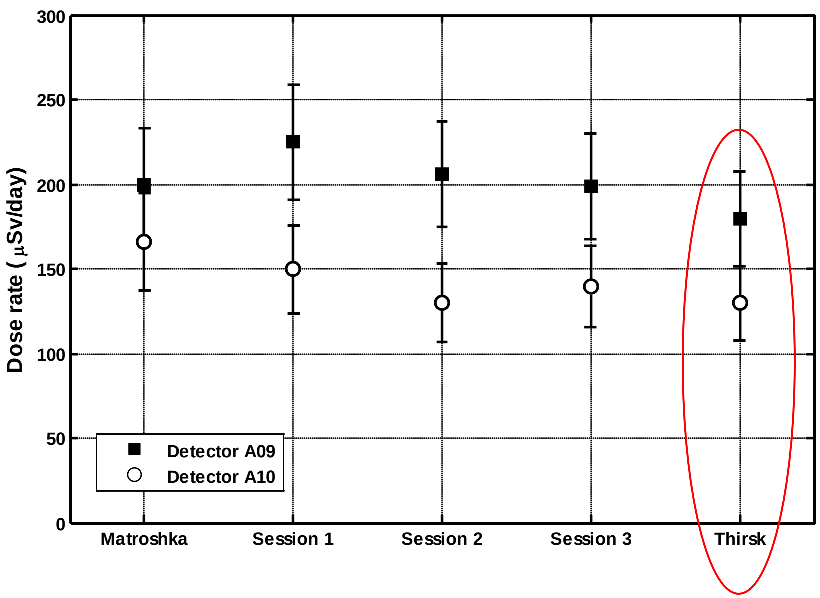


Figure7. dose-rate data from five sessions during ISS-20 and ISS-21

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Comparison

- It is useful to compare the dose rate recorded by the bubble detectors with TEPC.

- The best comparison of the bubble-detector, TEPC, and DB-8 dose rates can be obtained from the Matroshka session on ISS-20 because all three devices were co-located in the service module.

- The measured bubble-detector dose-equivalent rates are lower than those of the TEPC since TEPC records dose from all radiation.

- The comparison suggests that the neutron dose equivalent is approximately 30% of the total dose equivalent received, in good agreement with previous data[(2)].

- This also attests that Bubble detectors primarily record dose due to neutrons

Detector	A09	A10	TEPC
Dose rate (μGy/day)			277
Dose equivalent rate (μSv/day)	200±33	166±29	675

Comparison of dose and dose-equivalent rates measured with bubble detectors and TEPC

[(2)] Badhwar, G.D. (Ed.) *Recommendations of the Predictions and Measurements of Secondary Neutrons in Space Workshop, NASA/Johnson Space Center, September 28 – 30, 1998*. Published in part in Radiat. Meas. **33** (2001).

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Response Matrix

- Energy thresholds and response matrix were determined from fits to the response data (up to 20 MeV)
- Matrix is for a unit-sensitivity (1 bubble/mrem) detector
- Response matrix was extended to 300 MeV using iThemba data
- The response Matrix have been used to unfold the measured data and consequently to extract the dose value for each interval of energy

HISTOGRAM INTERVAL
bubble/n.cm^{-2}

thresholds

		j = 1 (0.06-0.25)	j = 2 (0.25-0.6)	j = 3 (0.6-2.0)	j = 4 (2.0-3.5)	j = 5 (3.5-15)	j = 6 (15-50)
BDS-10	i = 1	1.65E-05	4.00E-05	4.08E-05	4.08E-05	4.08E-05	4.08E-05
BDS-100	i = 2	0	3.00E-05	3.50E-05	4.00E-05	4.20E-05	4.20E-05
BDS-600	i = 3	0	0	2.00E-05	3.50E-05	4.20E-05	4.20E-05
BDS-1000	i = 4	0	0	0	4.00E-05	6.00E-05	1.20E-04
BDS-2500	i = 5	0	0	0	0	4.00E-05	1.10E-04
BDS-10000	i = 6	0	0	0	0	0	1.00E-04

HISTOGRAM INTERVAL
bubble/n.cm^{-2}

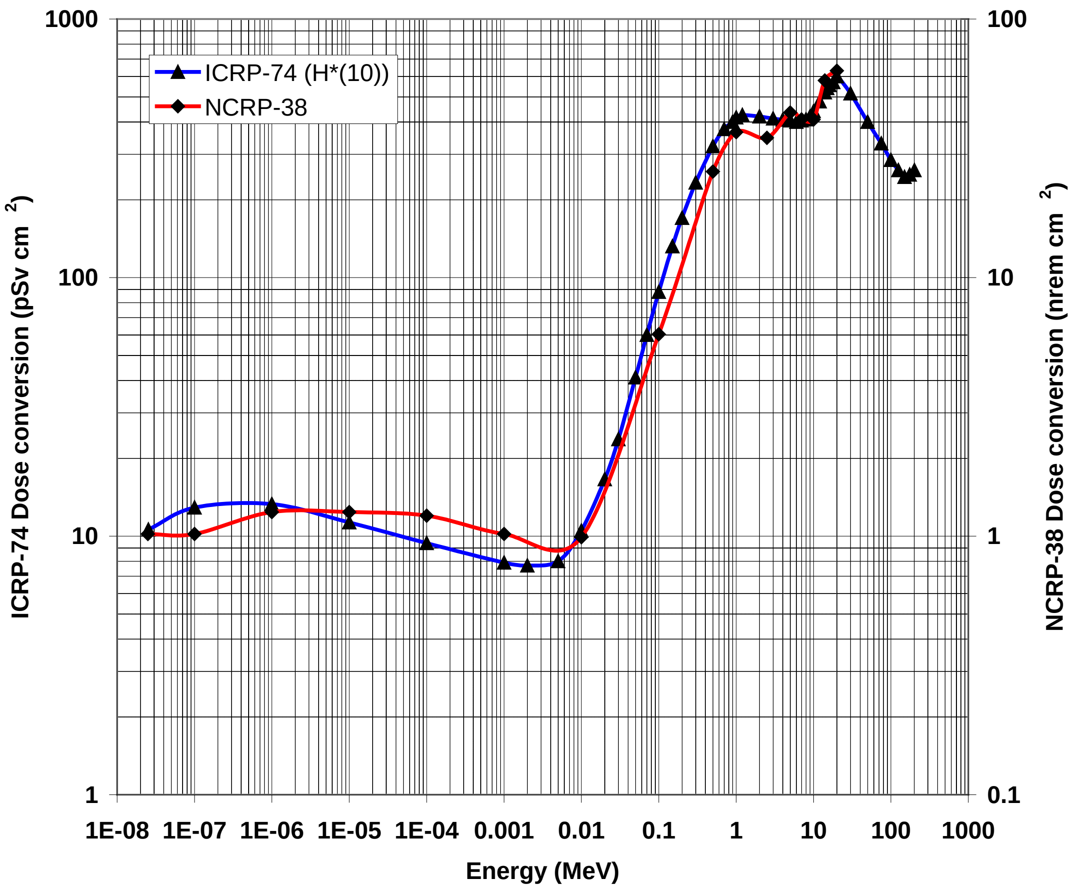
thresholds

		j = 1 (0.06-0.25)	j = 2 (0.25-0.6)	j = 3 (0.6-2.0)	j = 4 (2.0-3.5)	j = 5 (3.5-15)	j = 6 (15-300)
BDS-10	i = 1	1.65E-05	4.00E-05	4.08E-05	4.08E-05	4.08E-05	2.04E-05
BDS-100	i = 2	0	3.00E-05	3.50E-05	4.00E-05	4.20E-05	2.10E-05
BDS-600	i = 3	0	0	2.00E-05	3.50E-05	4.20E-05	2.10E-05
BDS-1000	i = 4	0	0	0	4.00E-05	6.00E-05	6.00E-05
BDS-2500	i = 5	0	0	0	0	4.00E-05	5.50E-05
BDS-10000	i = 6	0	0	0	0	0	5.00E-05

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Unfolding

- Dose rate has been be extracted from the unfolded spectra using dose-conversion coefficients of ICRP-74.
- The total dose was summed in all neutron energy intervals



3. Measurements _ Continued

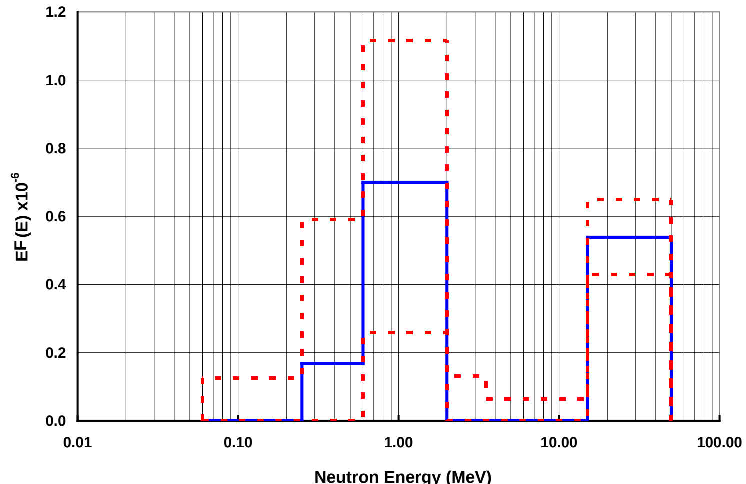
3.2. Bubble Spectrometer Measurements_ n-Spectra

- SBDS data were unfolded using the response matrix determined during characterization of the SBDS and the spectra has been obtained.

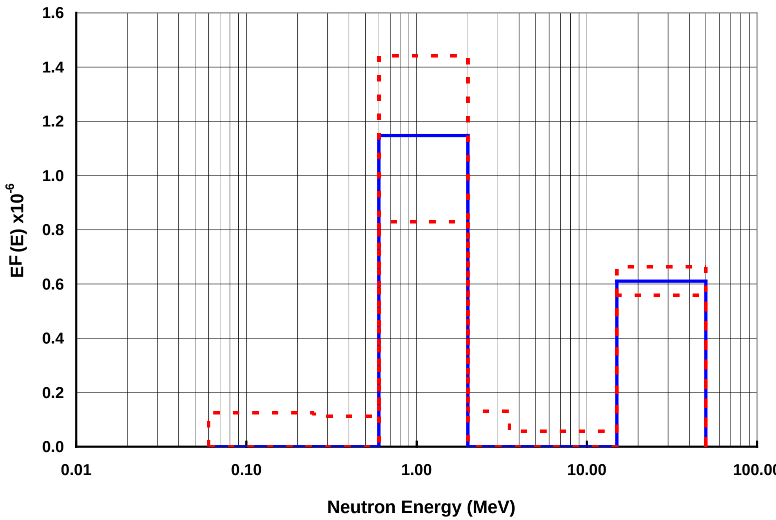
- Detailed comparison of the spectrum in different locations is not yet possible

- All spectra indicate the strong presence of a peak around 1 MeV, probably due to evaporation neutrons, and of high-energy neutrons above 10 MeV

- These set of data confirm previous space measurement using bubble spectrometer



Matroshka Session



All Sessions

3. Measurements _ Continued

3.2. Bubble Spectrometer Measurements_ Dose Result Summary

- Two dose-rate values are given for each session and for the sum of all sessions
  - H_{50} was obtained using the response matrix from 0 – 50 MeV
  - H_{300} was obtained using the extended response matrix from 0 – 300 MeV
- Percentage of the dose in the highest energy bin (i.e. dose greater than 15 MeV) is also provided

Dose Result Summary

Session	Matroshka	Session 1	Session 2	Session 3	Thirsk	Sum
H_{50} (μSv/day)	141^{+93}_{-65}	149^{+84}_{-80}	159^{+74}_{-56}	74^{+74}_{-47}	149^{+61}_{-45}	139^{+44}_{-28}
H_{50} > 15 MeV (%)	45	36	40	42	39	39
H_{300} (μSv/day)	140^{+93}_{-65}	149^{+84}_{-80}	158^{+73}_{-55}	74^{+74}_{-47}	148^{+60}_{-45}	138^{+44}_{-28}
H_{300} > 15 MeV (%)	44	36	39	41	39	38

Summary on bubble spectrometer measurements

- SBDS dose values are generally consistent with SPND results, and with measurements performed using other devices
- The results are also similar to those obtained using the BDS in earlier space missions
- Values of H_{50} and H_{300} are almost identical
  - Provides confidence in the extended response matrix and in the unfolding process in general
- Percentage of dose in the highest bin of the unfolded spectrum is almost constant across the 5 sessions and the sum of all sessions
- Data suggest that approximately 40% of the neutron dose received in space is due to high-energy neutrons above 15 MeV
- Similar to earlier measurements which suggested that more than 50% of neutron dose was due to neutrons with energy greater than 10 MeV

4. Charged Particle Contribution to Bubble Detector Readings _ **Remarks**

We have to note:

- That the previous comparison with TEPC data also shows a good agreement if we exclude the charged particle contributions to bubble detector reading.

- The neutron field observed in ISS is not greatly dependent on location (shielding). In contrast the charged particle field strongly depends on the locations.
- The dose values measured with bubble detector in different modules (different shielding) show an insignificant difference.

- Therefore if bubble detectors are to be sensitive to charged particles, the large difference between neutron and charged particles fields should be reflected in their readings, which is not the case.

4. Charged Particle Contribution to Bubble Detector Readings _ Summary

- A detailed study has been carried out in ref [3, 4] on the contribution of protons and heavy charged particles to the readings of bubble detectors

- a series of calculations, performed using the CREME Monte-Carlo code, have been performed and it show that the charged-particle contribution to the bubble count is negligible.

- The calculations suggest that a few percent or less of the observed bubbles are due to protons and heavy ions.

- This important result, which answers a long-standing question about the bubble-detector response, confirms that it is not necessary to correct for charged-particle contributions when calculating neutron dose measured by a bubble detector in space.

- We have to note that the previous comparison with TEPC data also confirm this finding

(3) B. J. Lewis[1], et al., Review of Bubble Detector Response Characteristics and Results from Space, Radiation Protection Dosimetry, September 2011, pp 1-21
(4) M.B. Smith et al., Measurements of the neutron dose and energy spectrum on the international space station during expeditions ISS-16 to iss-21, Radiation Protection Dosimetry (submitted, 2011)

Conclusion

- Data recorded with bubble detectors during the ISS-16, ISS-18, ISS-19, ISS-20, and ISS-21 expeditions have been analyzed.
- Series of measurements performed during the Matroshka-R project, and the new data support the notion that the dose rate close to the surface of the phantom is essentially the same as that closer to the centre of the phantom.
- This result is important because it implies that bubble detectors worn by a person provide an accurate reading of the dose received inside the body.
- The first spectroscopic measurements with the new SBDS have been performed during the ISS-20 and ISS-21 missions.
- These data has provided energy spectra and dose rates in reasonable agreement with previous measurements in space.
- The SBDS results obtained demonstrate that the new detectors are functioning as intended, that the unfolding process and response matrices are well understood, and that the SBDS is well suited for future measurements in space.
- A series of calculations, performed using the CREME Monte-Carlo code, have been presented which show that the charged-particle contribution to the bubble count is negligible. The calculations suggest that a few percent or less of the observed bubbles is due to protons and heavy ions.
- This important result, which answers a long-standing question about the bubble-detector response, confirms that it is not necessary to correct for charged-particle contributions when calculating neutron dose measured by a bubble detector in space.
- Data measured with water shielded detector suggest that the water shield reduces the neutron dose rate on the inner side of the shield to 72±17% of its value on the outer side.

Radiation Protection Dosimetry Advance Access published September 1, 2011

Radiation Protection Dosimetry (2011), pp. 1–21 doi:10.1093/rpd/ncr358

REVIEW OF BUBBLE DETECTOR RESPONSE CHARACTERISTICS AND RESULTS FROM SPACE

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Received January 25 2011, revised June 24 2011, accepted July 20 2011

A passive neutron-bubble dosemeter (BD), developed by Bubble Technology Industries, has been used for space applications. Both the bubble detector-personal neutron dosemeter and bubble detector spectrometer have been studied at ground-based facilities in order to characterise their response due to neutrons, heavy ion particles and protons. This technology was first used during the Canadian–Russian collaboration aboard the Russian satellite BION-9, and subsequently on other space missions, including later BION satellites, the space transportation system, Russian MIR space station and International Space Station. This paper provides an overview of the experiments that have been performed for both ground-based and space studies in an effort to characterise the response of these detectors to various particle types in low earth orbit and presents results from the various space investigations.

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