New Results on Dose Distribution in a Human Body in ISS Compartments Obtained with the Tissue-Equivalent Spherical Phantom

Vyacheslav A. Shurshakov[1*], Raisa V. Tolochek[1], Ivan S. Kartsev[1], Vladislav M. Petrov[1], Vyacheslav I. Petrov[2], Boris V. Polenov[2], Igor V. Nikolaev[3], Svetlana I. Moskalyova[3]

(1) State Research Center of Russian Federation Institute of Biomedical Problems, Russian Academy of Sciences

(2) Scientific Center “SNIIP”, Moscow, Russia

(3) Rocket Space Corporation “Energia”, Moscow region, Russia

3rd Workshop on Radiation Monitoring for the ISS

KFKI Atomic Energy Research Institute,
24-26 March, 1998, Budapest, Hungary

DOSE RATE MEASUREMENTS IN MIR CORE MODULE COMPARTMENTS:
DOSE-A1 INSTRUMENT DATA AND MODEL ESTIMATIONS

Petrov V.M.[1], Tchernykh I.V.[1], Benghin V.V.[1], Kolomensky A.V.[1], Ivanov Yu.V.[1], Shurshakov V. A.[1], Filippychev S.A.[2], Lyagushin V.I.[3]

[1]State Research Center of the Russian Federation Institute for Biomedical Problems, Moscow 123007, Russia; shurshakov@mmcc.ibmp.rssi.ru
[2]Nuclear Physics Institute of Moscow State University
[3]Rocket Space Corporation ENERGIA

New Results on Dose Distribution in a Human Body in ISS Compartments Obtained with the Tissue-Equivalent Spherical Phantom

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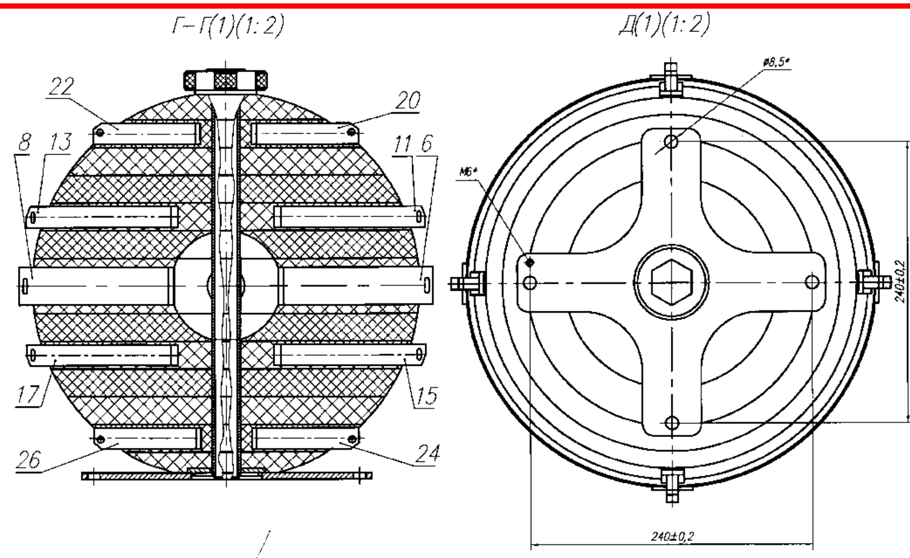
The Tissue-Equivalent Spherical Phantom

- The spherical phantom is made from tissue equivalent matter
- External radius R=17.5 cm,
- Internal spherical cave radius is r=5 cm
- Mass 32 kg
- Different depths *d* in the phantom correspond to critical organ sites
- *p*(ξ,*d*) – shielding probability function



Chemical composition
H=8.6%
N=2.6%
C=32.3%
O=56.5%

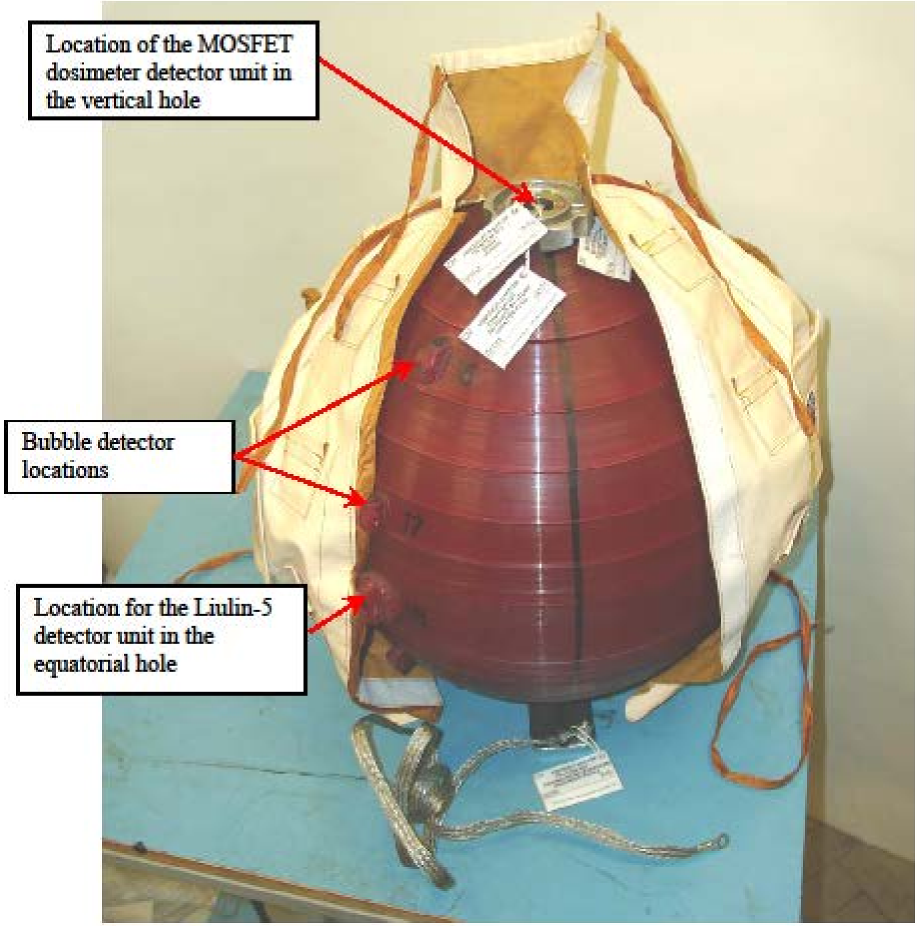
Matroshka-R Spherical Phantom is a Multi-User Experimental Facility

Passive detectors

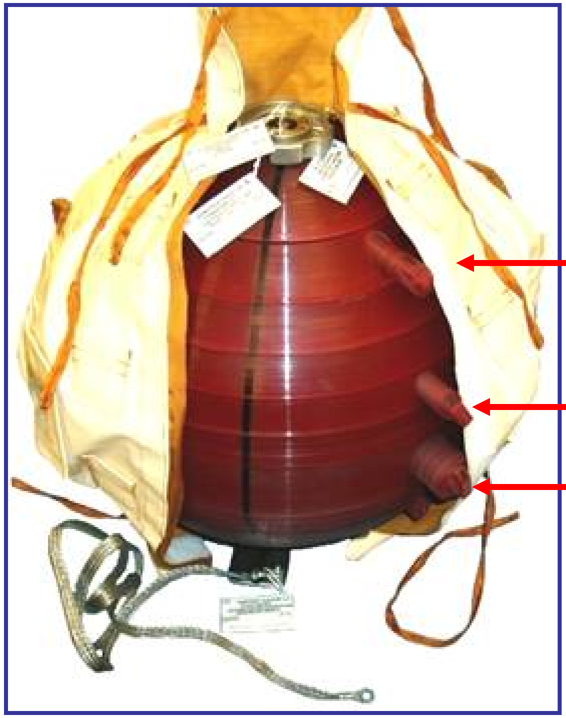
- IBMP (TLD only)
- NIRS, Chiba, Japan (TLD + CR-39)
- NPI, Prague, Czech Republic (TLD + CR-39)
- JAXA PADLES (when in Kibo only)

Active detectors

- Canadian Space Agency MOSFET and Bubble detectors
- STIL BAS, Bulgaria – Liulin-5 silicone detector telescope



Passive Detectors of the Spherical Phantom

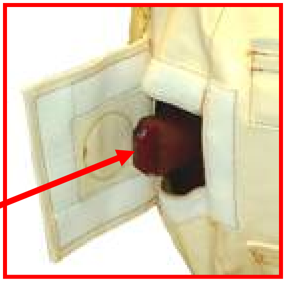


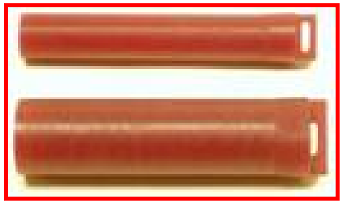
LiF TLDs and SSTD
CR-39 are also inside containers

Working jacket with

LiF TLDs and SSTD
CR-39 in the pockets

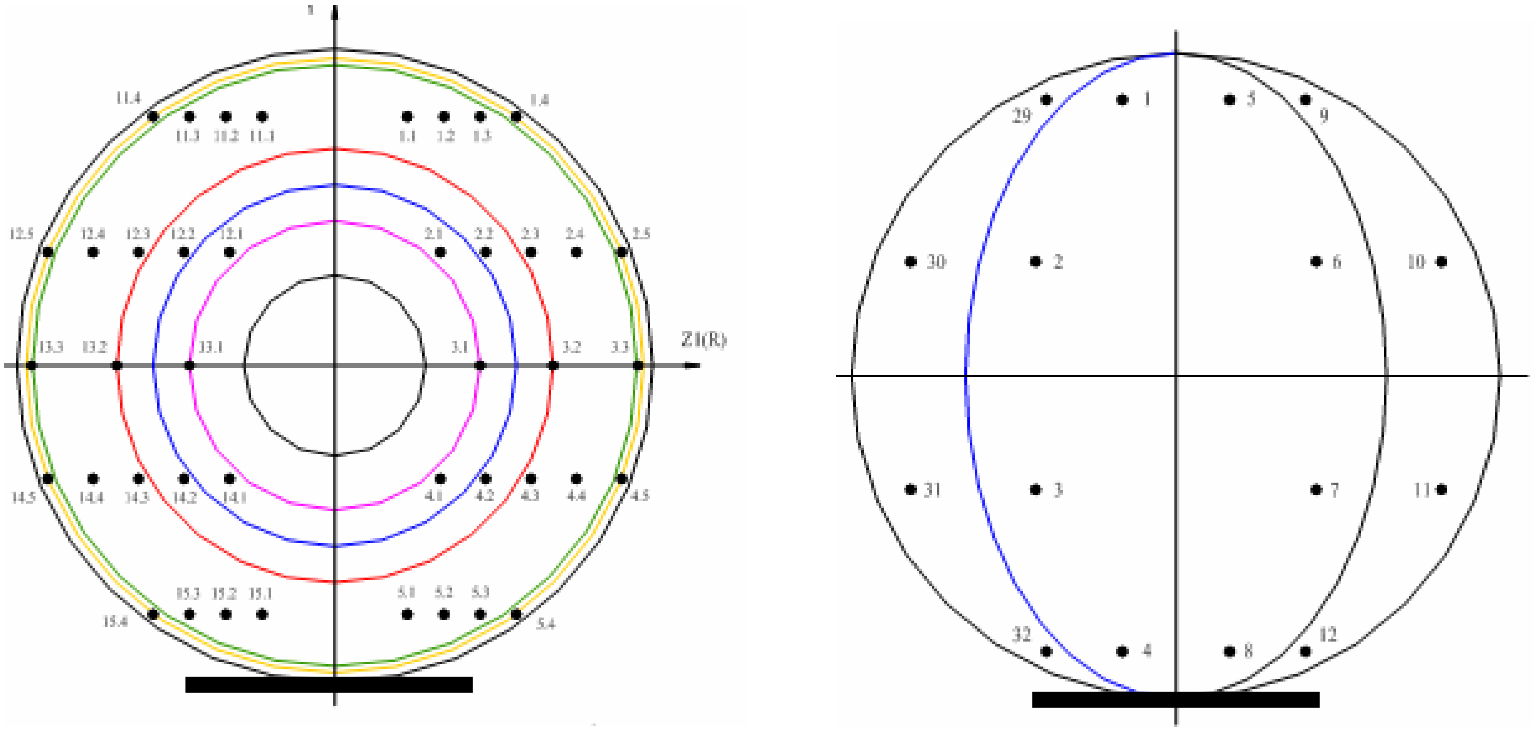
Container





МАТРЕШКА

Locations of the Containers and Jacket Pockets with Detectors



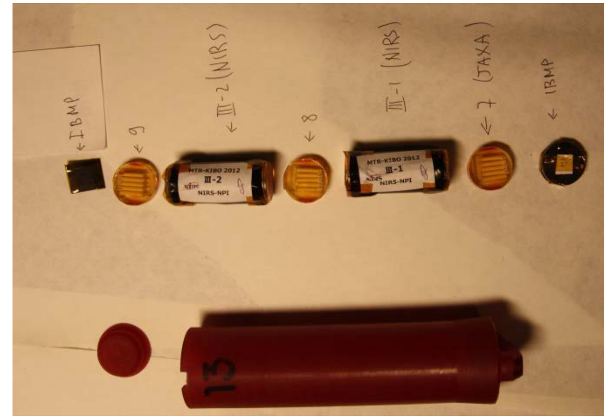
•**20 containers with the detectors inside the phantom**

•**32 pockets with the detectors on the phantom surface**

•**More than 500 LiF TLD in total and CR-39 type detectors**

•***D = D(depth, φ, θ)***

The Spherical Phantom Detector Package for Matroshka-R Space Experiment



20 containers

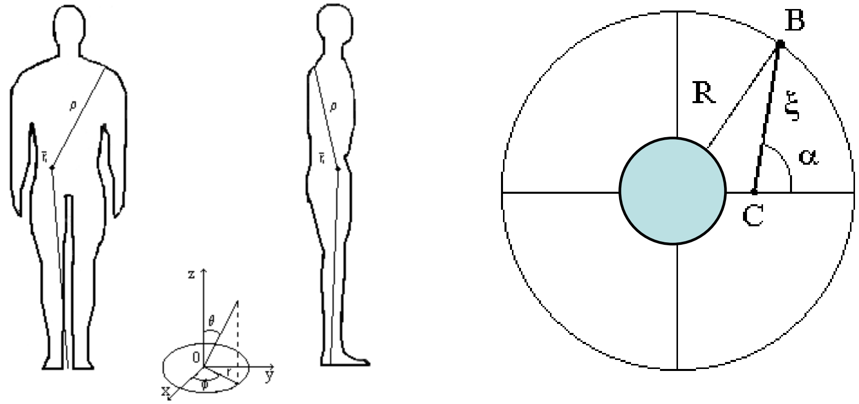
32 detector packages

Self-Shielding of Critical Organs in a Human Body

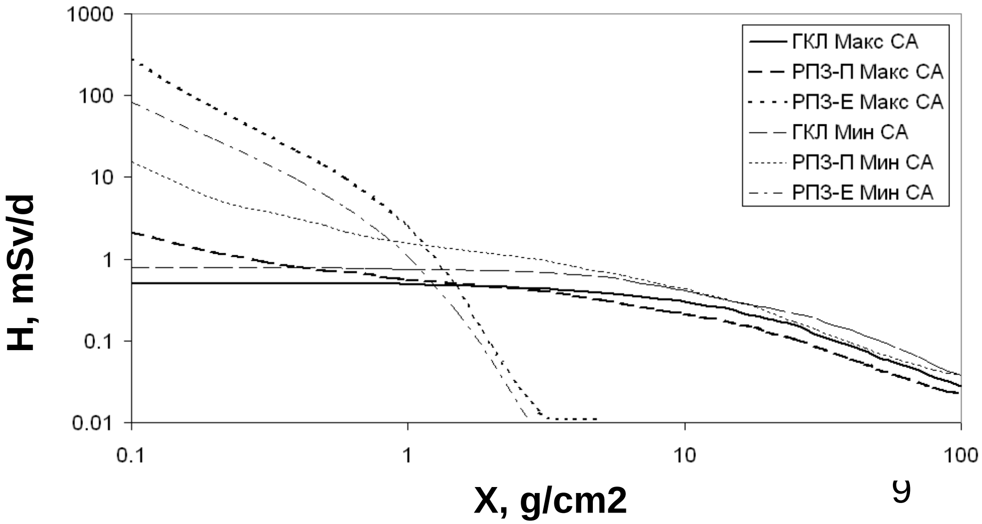
- $p(\xi,d)$ – shielding probability function:
- $p(\xi,d) = dP(\xi)/d\xi$
  - ξ_{min}=d
  - ξ_{max}=2R - 2r –d

  $H(x)$ – deph-dose curve

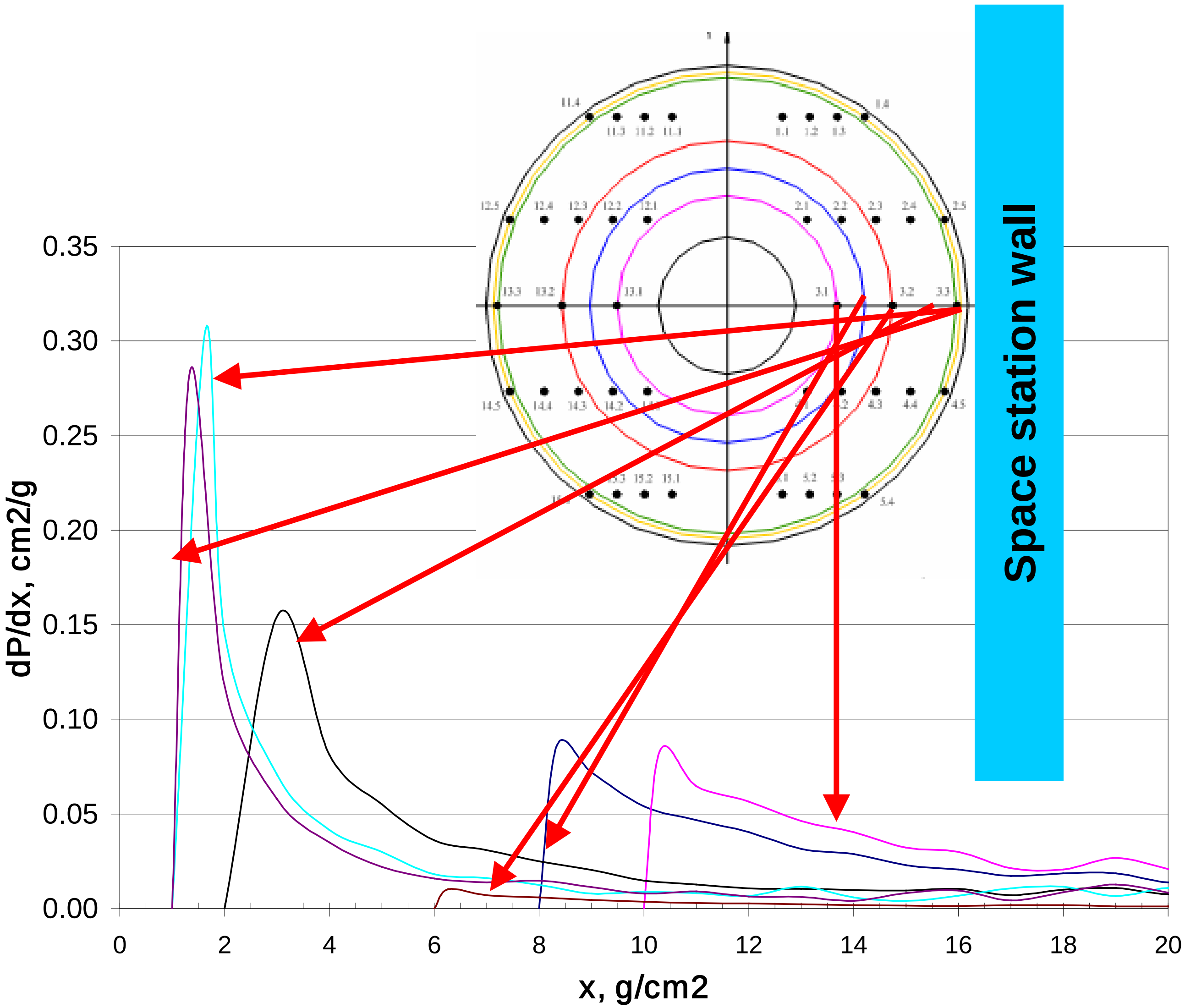
$$H(\vec{r}_0) = \int p(\vec{r}_0, x) \cdot H(x) dx$$

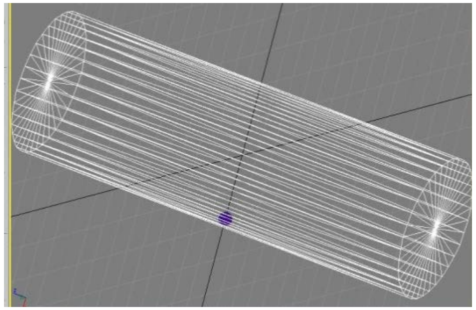


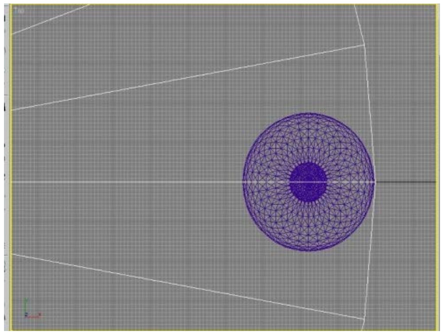
Organ	Depth in the spherical phantom, mm
Skin	0.1
Eye lens	3
Testis	18
BFO	50
CNS	70
GES	90



Theoretical Shielding Functions for the Sites of Critical Organs in the Spherical Phantom



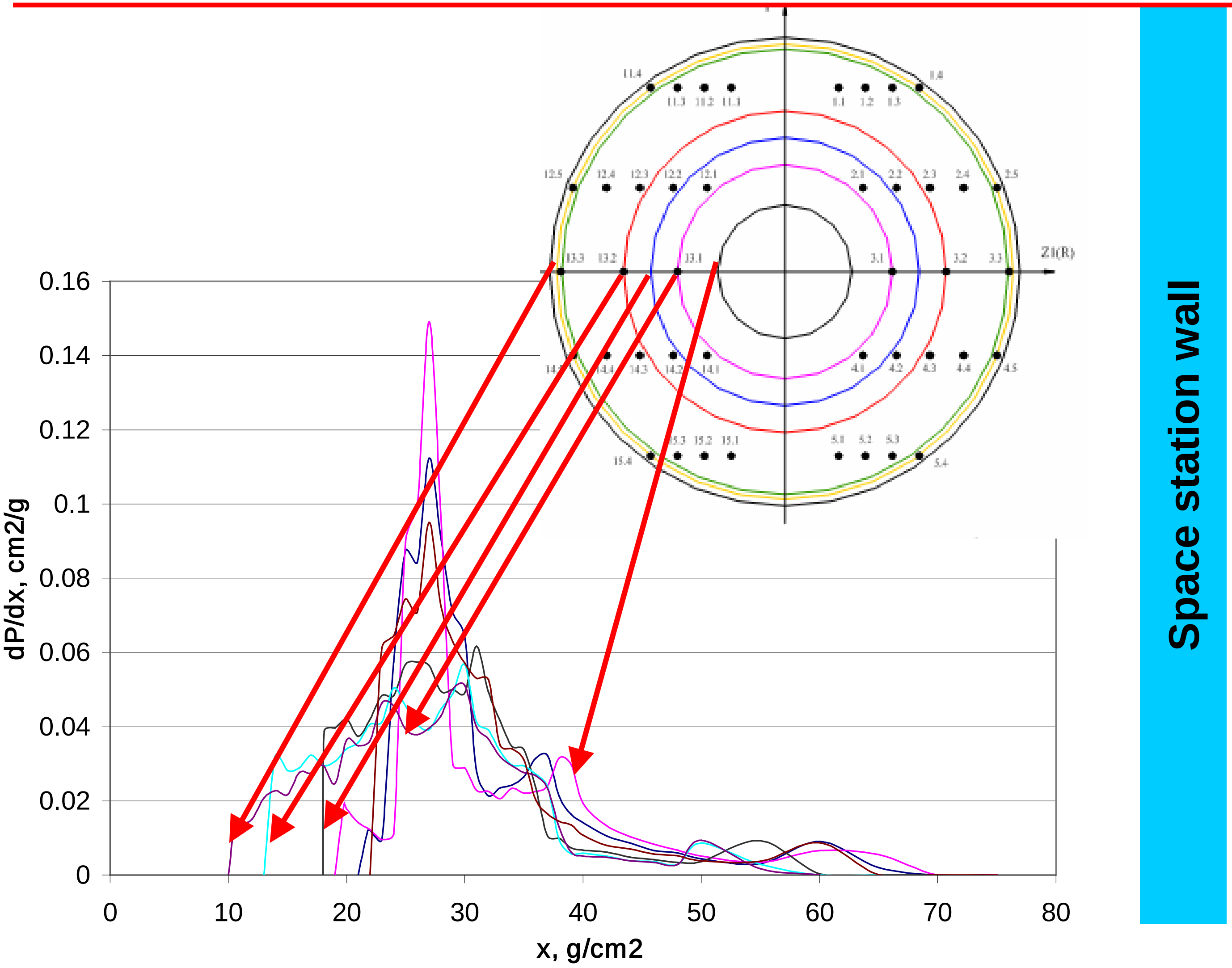




Wall thickness is 1.5 g/cm^2 only!

Theoretical shielding functions for the sites of critical organs in the spherical phantom

(from the opposite direction)



Some Ideas on Shielding Modeling

There are always some distortions in the shielding functions of ISS compartments

$$H(\vec{r}_0) = \int p(\vec{r}_0, x) \cdot H(x)dx$$

$$H(\vec{r_0}) = \int_{x_{min}}^{x_{max}} p(\vec{r_0}, x) \cdot H(x)dx = \int_{x_{min}}^{x_{eff}} p(\vec{r_0}, x) \cdot H(x)dx + \int_{x_{eff}}^{x_{max}} p(\vec{r_0}, x) \cdot H(x)dx$$

$$x_{min} < x_{eff} < x_{max}$$

$$H(\vec{r_0}) = H(low\ shielded) + H\ (high\ shielded)$$

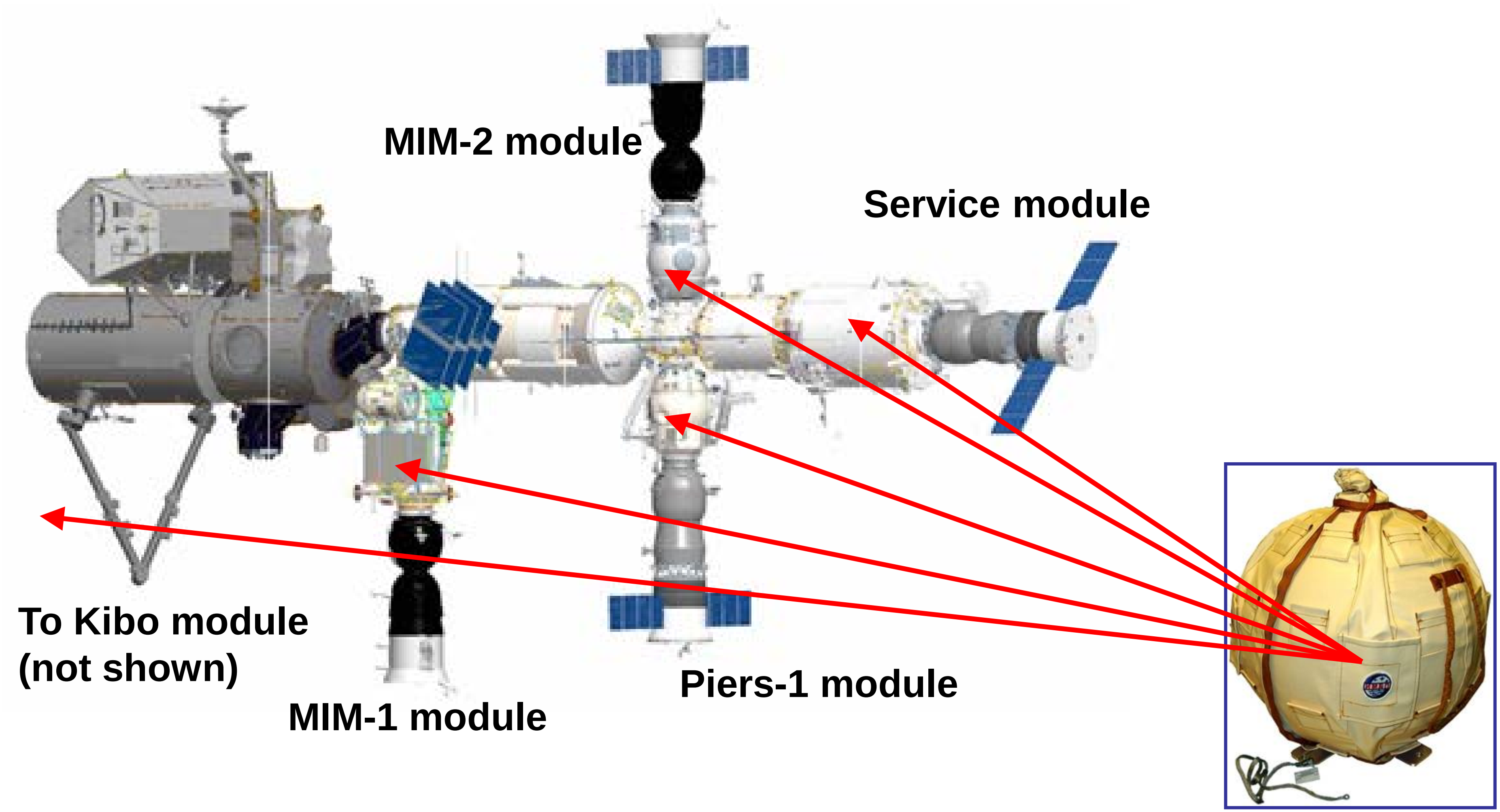
$$H(low\ shielded) \gg H\ (high\ shielded)$$

Experimental Sessions onboard the ISS with the Tissue-equivalent Spherical Phantom

Number of session / Dates of exposure	Exposure duration, days	The phantom location
1) From Jan. 29, 2004 to Apr. 30, 2004	92	Crew Quarter of Service Module
2) From Aug. 11, 2004 to Oct. 10, 2005	425	Crew Quarter of Service Module
3) From May 12, 2007 to Feb. 20, 2008	285	Piers-1 Module
4) From May 14, 2008 to Dec. 01, 2008	202	Piers-1 Module
5) From May 07, 2009 to Oct. 11, 2009	158	Piers-1 Module
6) From April 30, 2010 to Nov. 26, 2010	210	MIM-2 Module
7) From April 05, 2011 to Nov. 22, 2011	231	MIM-1 Module
8) From May 15, 2012 to Sep. 17, 2012	125	Kibo Module
Total exposure duration, days/years	1726/4.7	

In 5 ISS modules; during more than 9 years; about 5 years of exposure

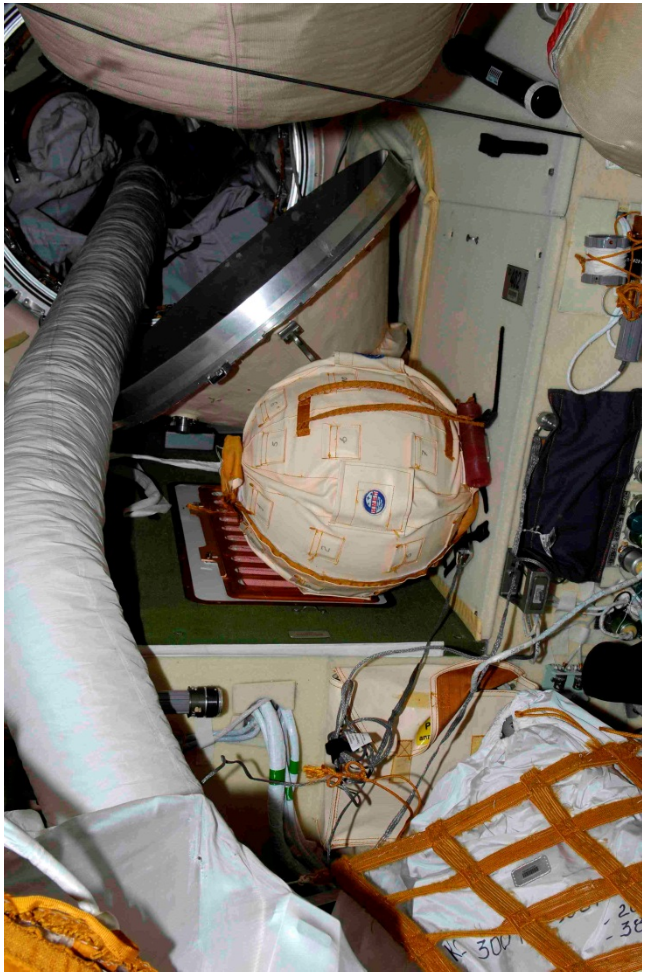
The Spherical Phantom Locations in ISS



The Spherical Phantom Locations

In the star board crew quarter

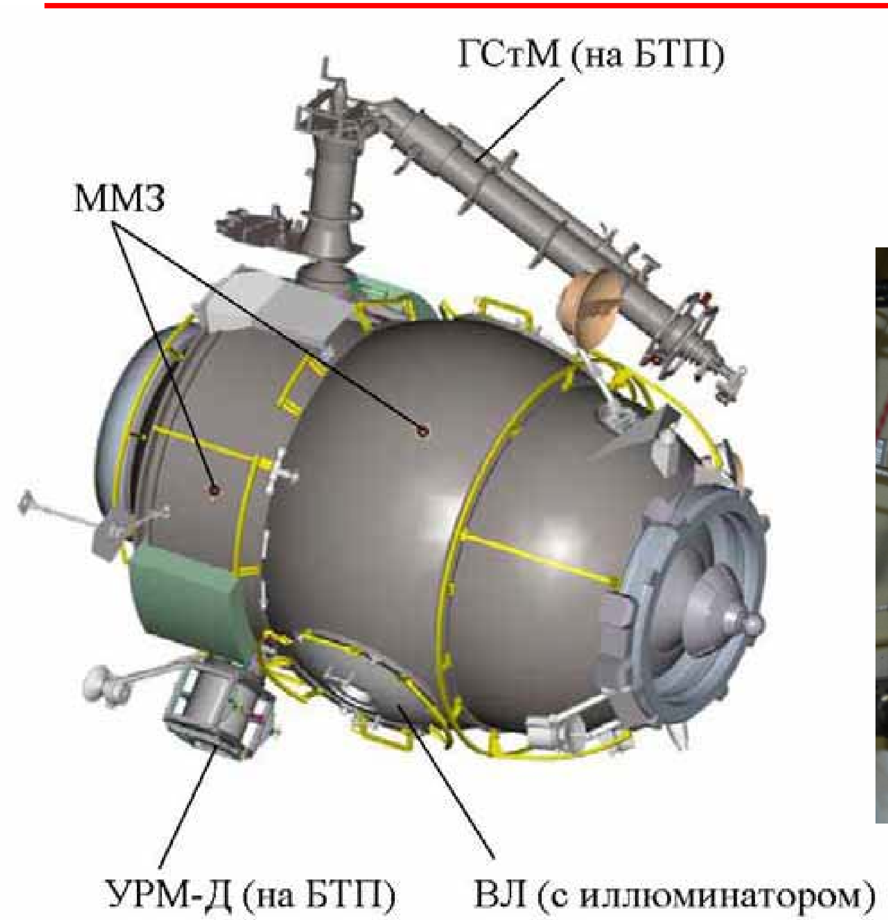
From Aug. 11, 2004 to Oct. 10, 2005

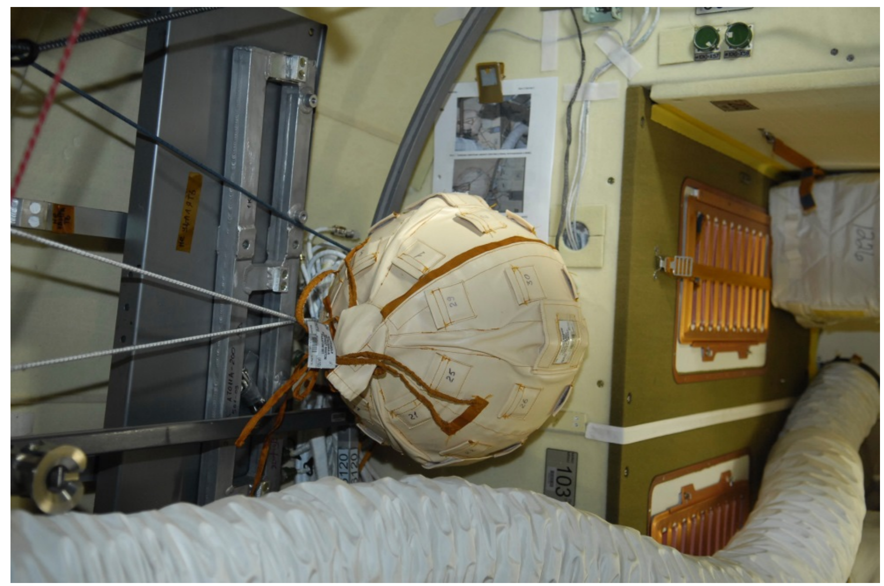


In Piers-1 module

From May 12, 2007 to Feb. 20, 2008

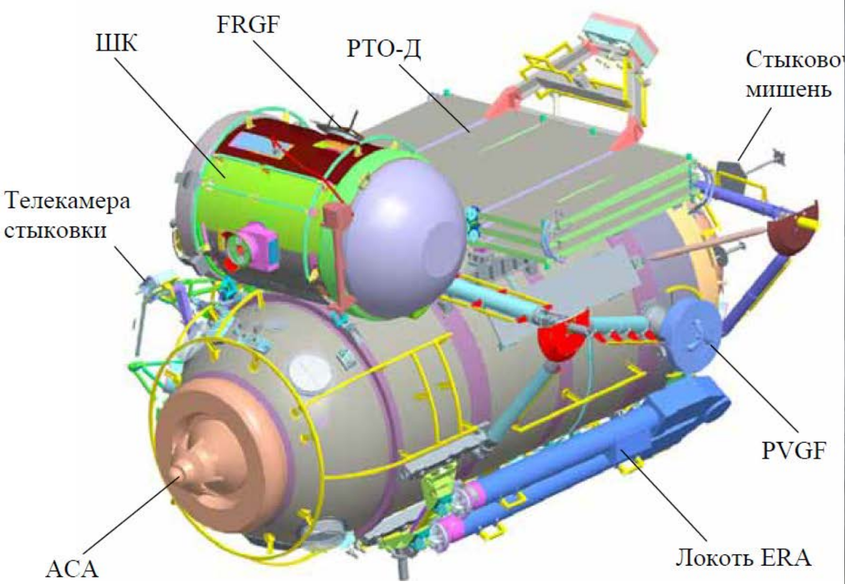
The Spherical Phantom in MIM-2 Module (Small Research Module 2)





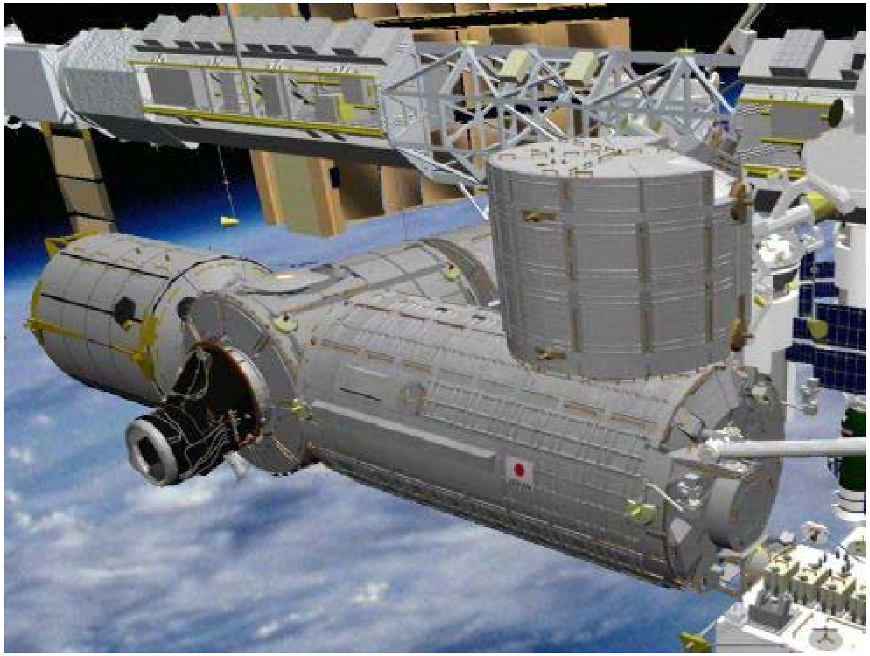
- Mass =3.7 t
- Volume=12.5 m^3

The spherical phantom in MIM-1 module (Small Research Module 1)

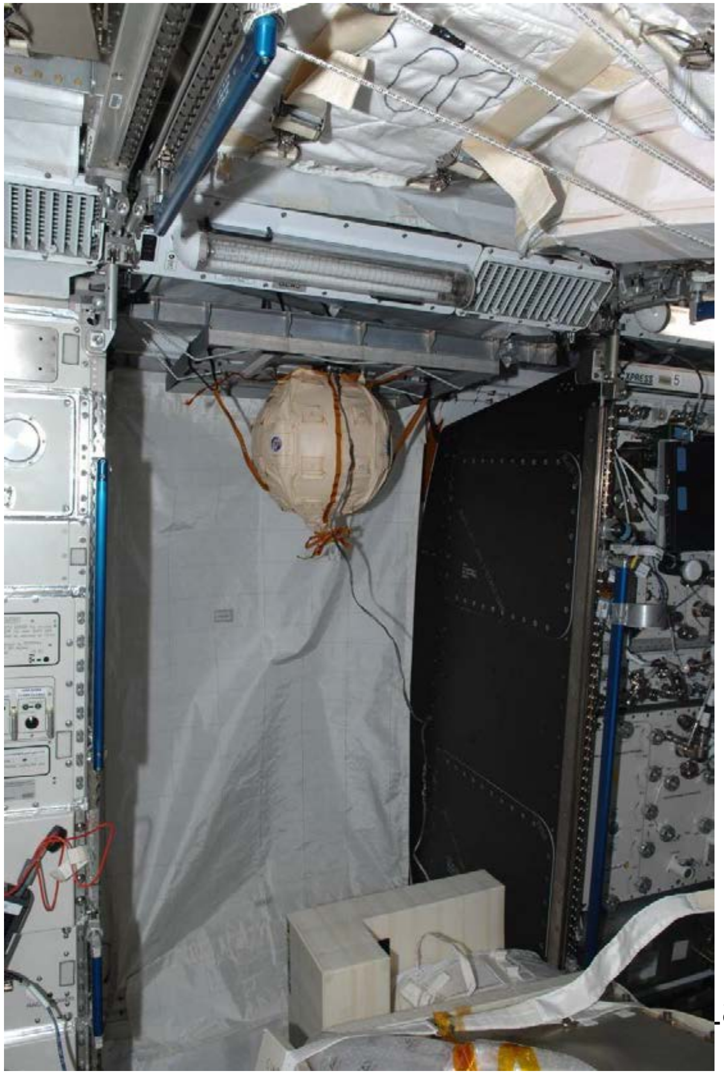


- Mass =7.9 t
- Volume=17.4 m^3

The Spherical Phantom in Kibo Module (in former Rando Phantom Location)

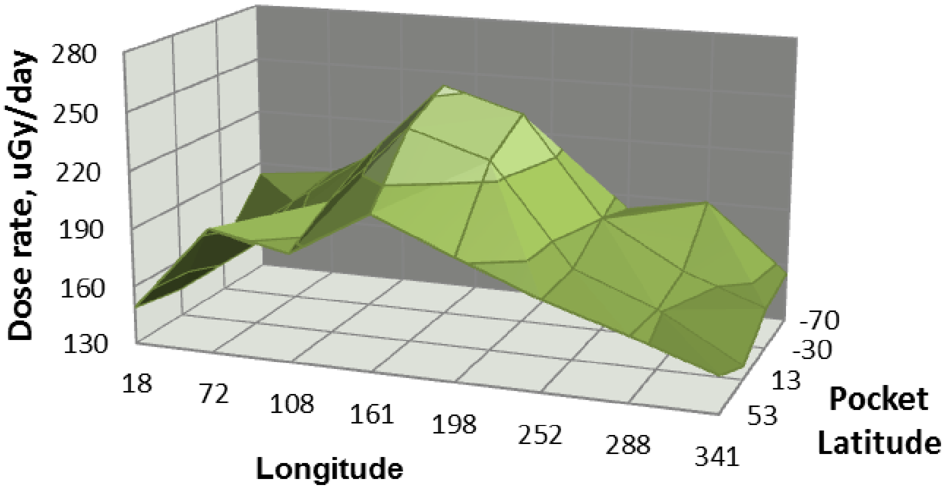


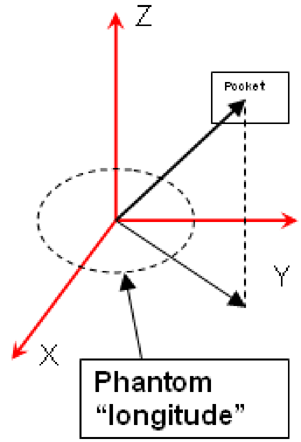
- M=27 t in total

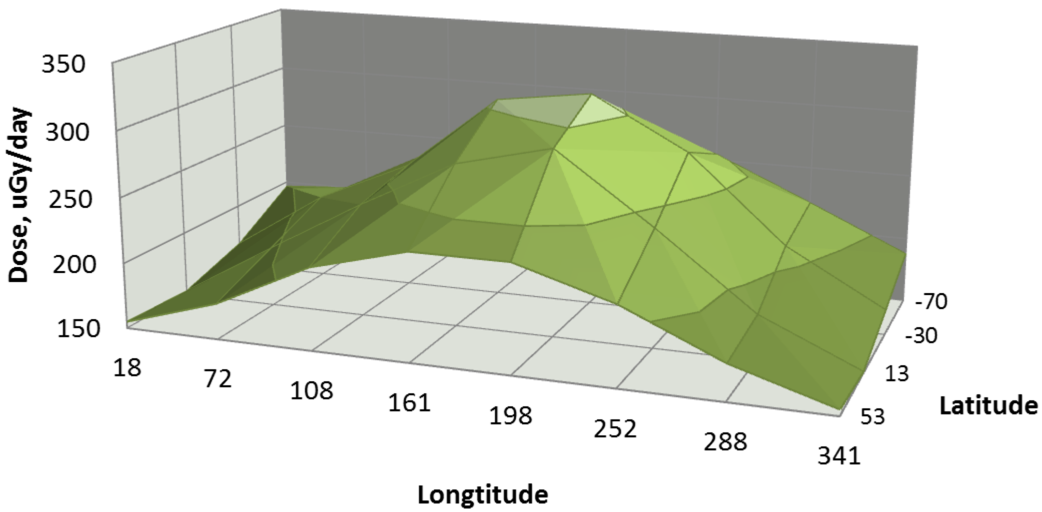


Dose rate measured in the pockets on the phantom surface

In the Service Module crew quarter, Session 1 and 2



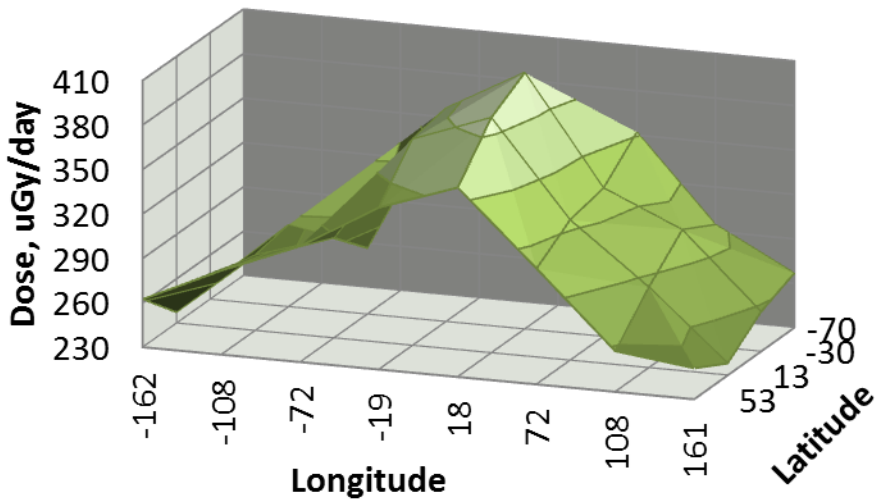


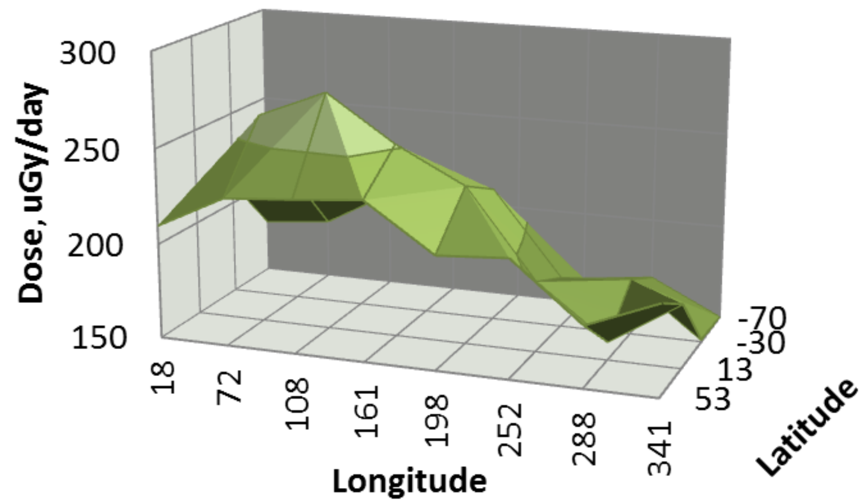


One maximum dose distributions

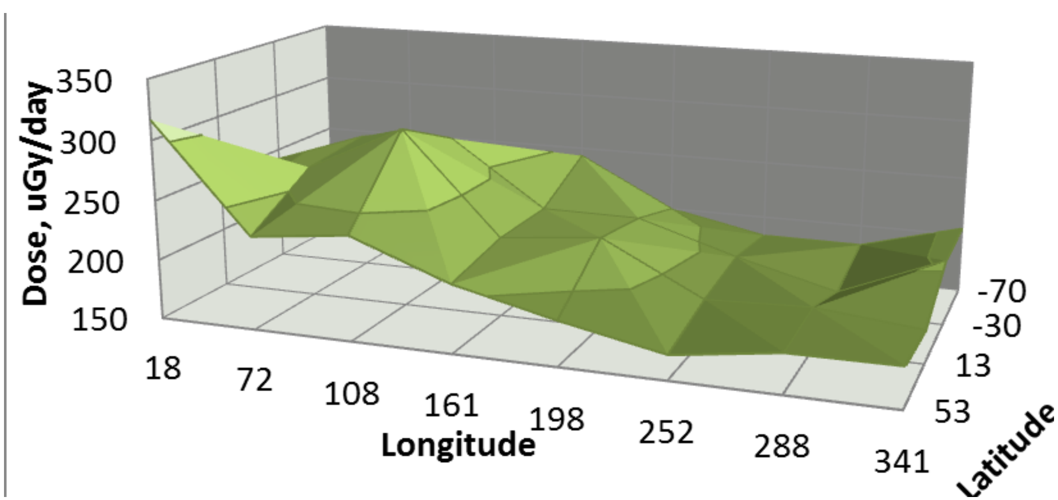
Dose rate measured in the pockets on the phantom surface

In Piers-1 module, Session 3 and 4

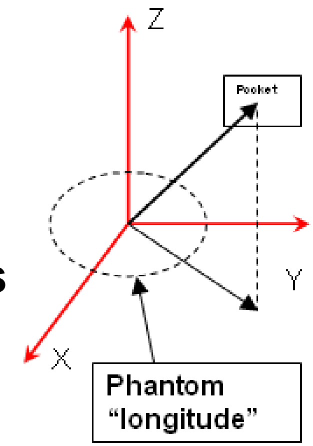




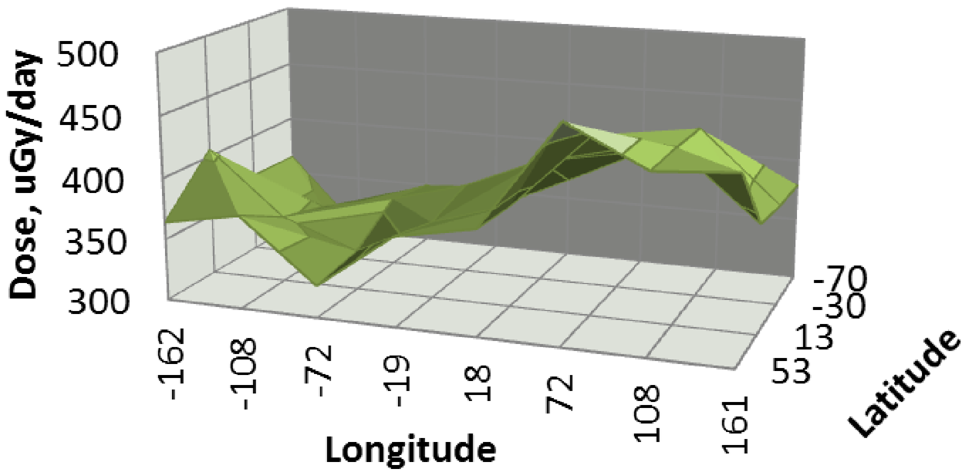
and 5



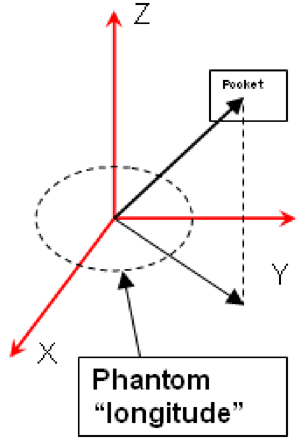
One maximum dose distributions

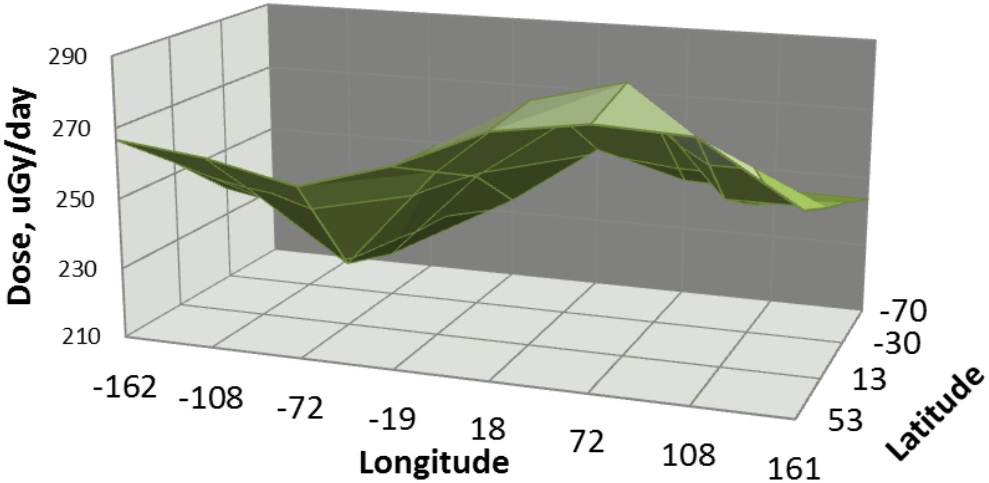


Dose rate measured in the pockets on the phantom surface



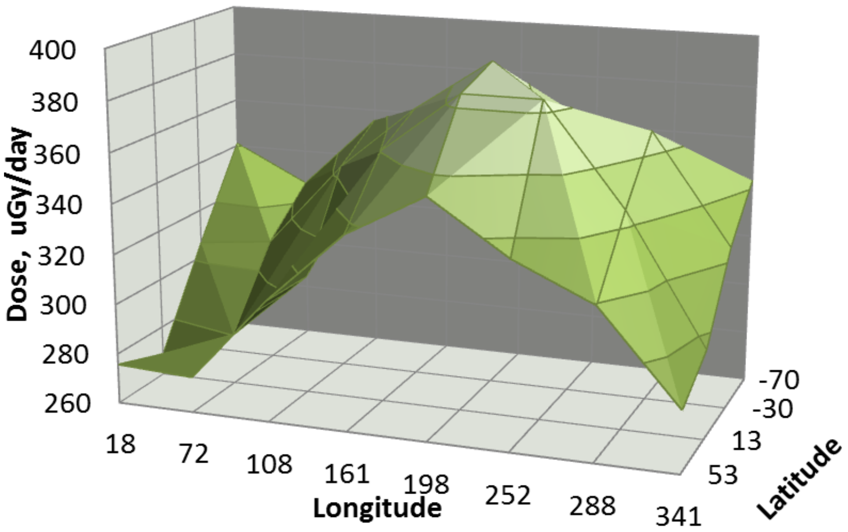
In MIM-2 module, Session 6

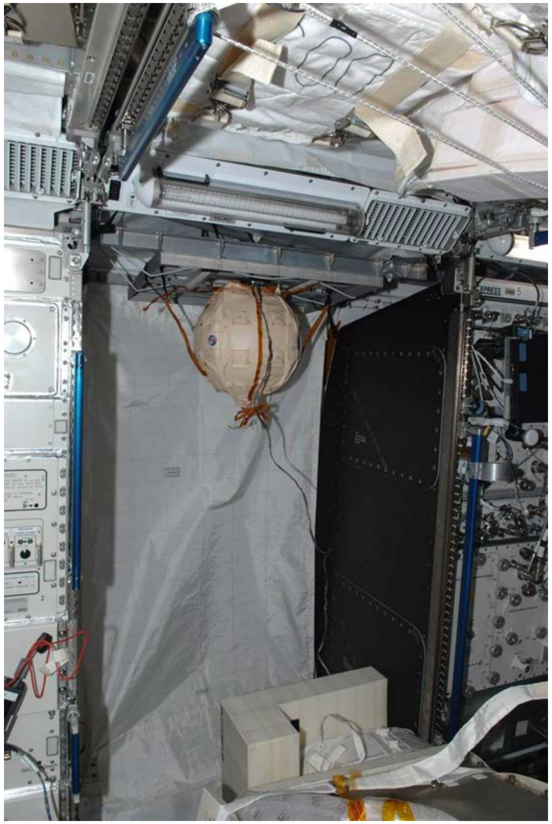




In MIM-1 module, Session 7

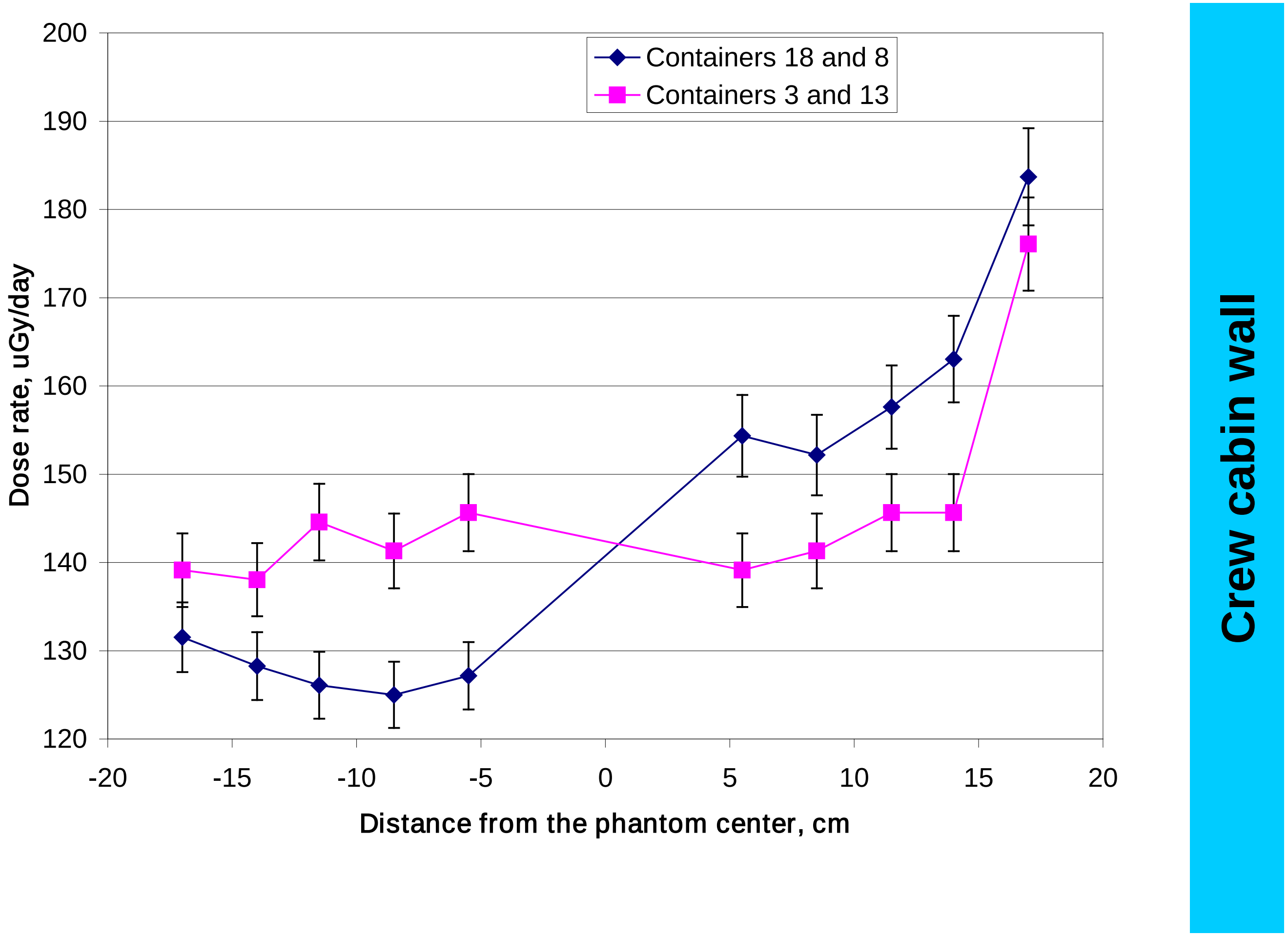
Dose rate measured in the pockets on the phantom surface in Kibo module





Two peaks were obtained in dose distribution

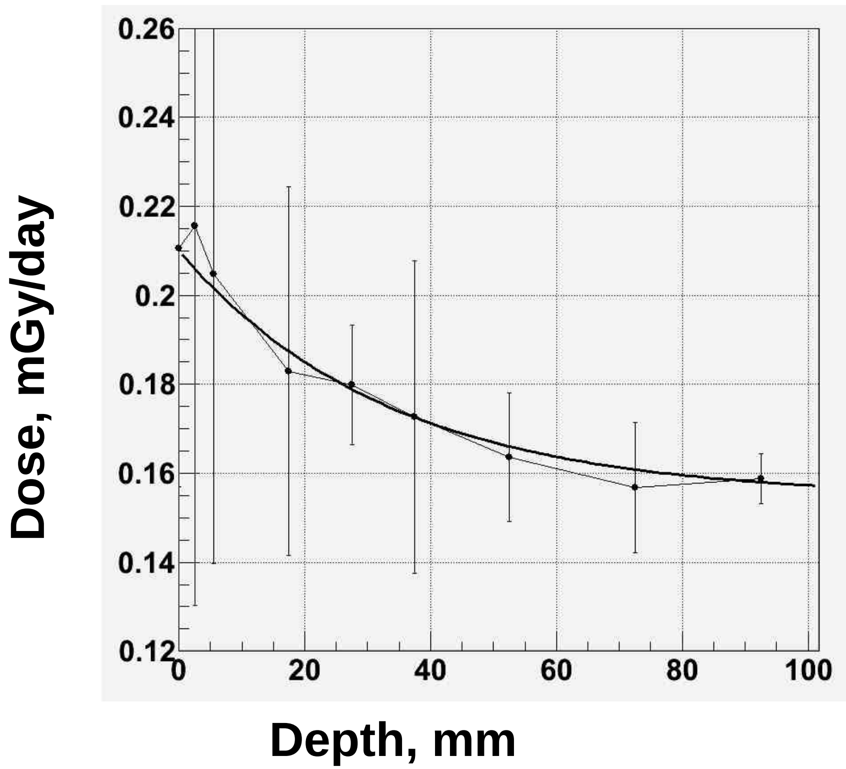
Dose Rate Measured in the Equatorial Containers inside the Phantom



(Session 1 in the Service Module crew quarter)

Surface Dose and Dose as a Function of Depth in the Phantom

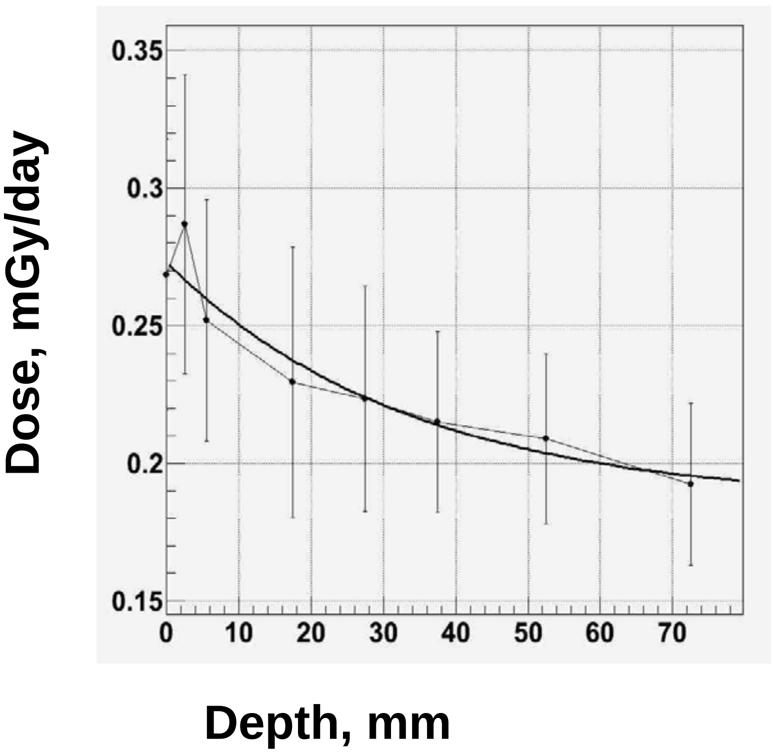
Crew quarter (session 2, 425 day)



$D_{mean\text{-}surface}$ = 220 μGy/day

D_{max}/D_{min} = 2.1

Piers-1 module (session 3, 285 days)



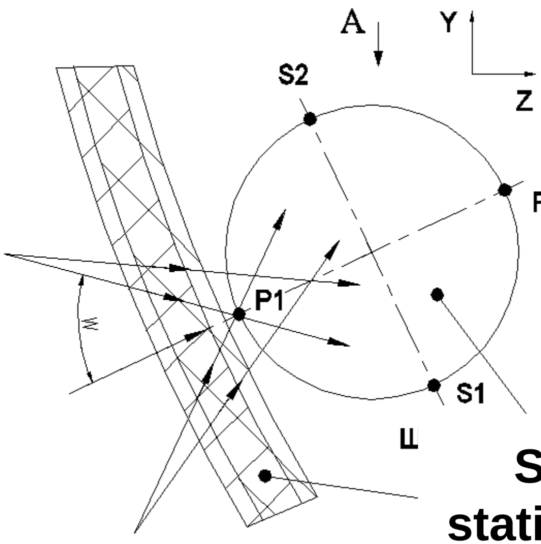
$D_{mean\text{-}surface}$ = 304 μGy/day

D_{max}/D_{min} = 1.7

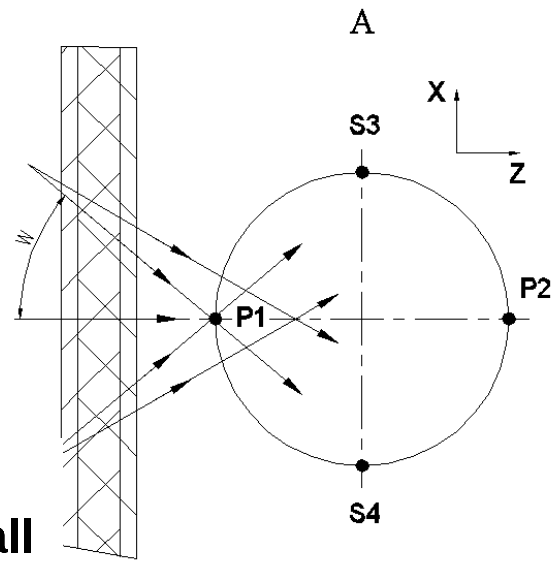
Min, Max, and Mean-Surface Doses in the Phantom, uGy/d

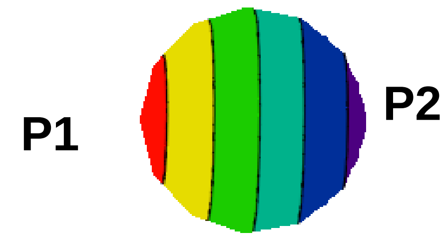
The phantom location	$D_{min,}$	$D_{max,}$	$D_{mean\text{-}surface}$	D_{max}/D_{min}
Crew Quarter of Service Module	164	303	223	1.9
Crew Quarter of Service Module	151	315	220	2.1
Piers-1 Module	238	403	304	1.7
Piers-1 Module	160	276	202	1.7
Piers-1 Module	169	317	218	1.9
MIM-2 Module	302	471	383	1.6
MIM-1 Module	213	286	252	1.3
Kibo Module	269	391	332	1.4

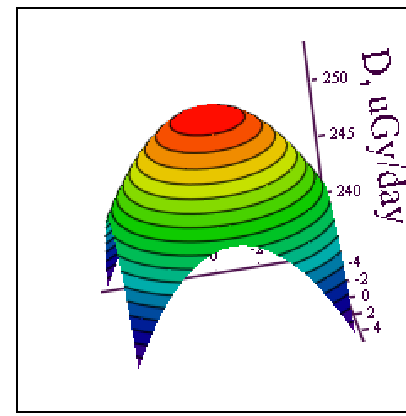
Geometry of the Spherical Phantom Exposure to Space Radiation near the Space Station Wall



Space station wall





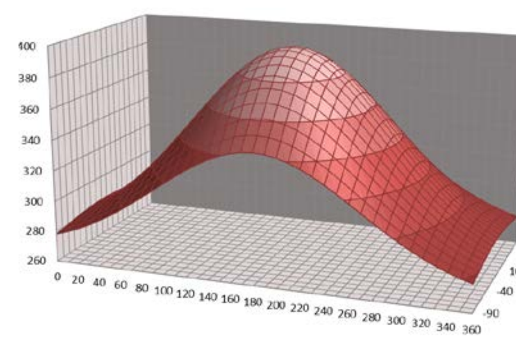


$D(P1) = D_{max}$ **$D(P2) = D_{min}$**

The dose distribution is symmetrical to the P1-P2 axis but additional peaks may exist

$$Dose(X,Y) = D_{\min} + (D_{\max} - D_{\min}) \cdot \sqrt{1 - \left(\frac{X^2}{175} + \frac{Y^2}{175}\right)}$$

$$Dose(x,y) = \sum_i \frac{D_i}{2\pi\sigma_{x_i}\sigma_{y_i}} e^{-\frac{(x-x_i)^2}{2\sigma_{x_i}^2}} e^{-\frac{(y-y_i)^2}{2\sigma_{y_i}^2}}$$



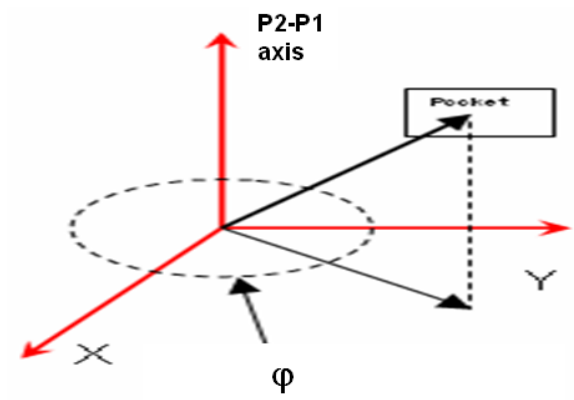
Parameterization of the dose distribution in the spherical phantom

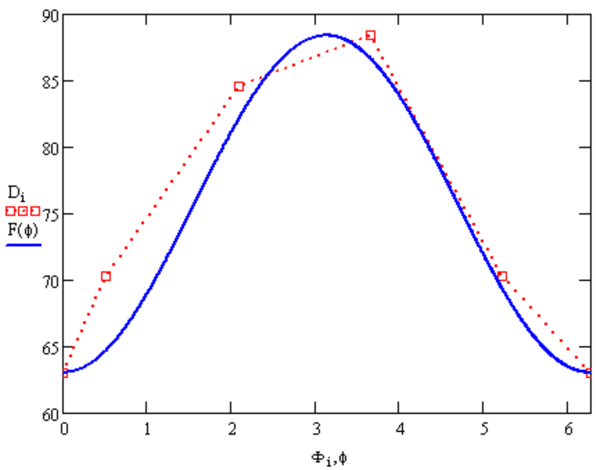
$$D(\theta) = D_{\min} + \frac{D_{\max} + D_{\min}}{2} + \frac{D_{\max} + D_{\min}}{2} \cdot \cos(\theta)$$

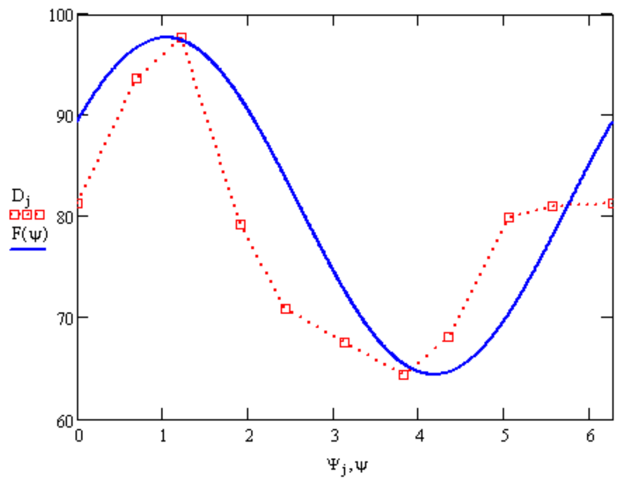
$$D(\varphi) = const$$

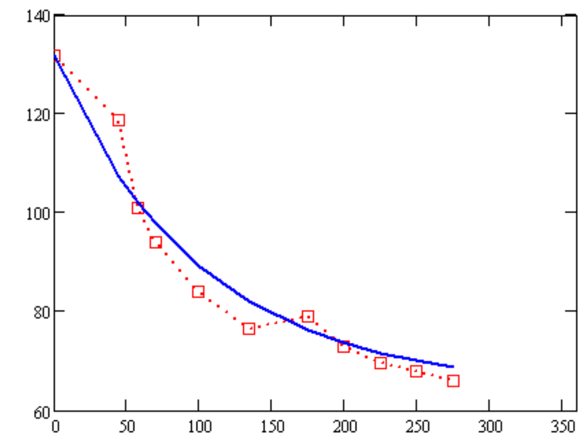
$$F(d) = (D_{max} - D_{min})\ exp(\ -d/100) + D_{min},$$

d – depth in mm.









Depth along P1-P2 line, mm in tissue

Mean-surface, Mean-tissue, and Effective dose Estimation in ISS Compartments

$$D_{mean-surface} = \frac{\int D_s(\vec{r})dS}{\int dS} \qquad D_{mean-tissue} = \frac{\int D(\vec{r})dm}{\int dm} \qquad D_{eff} = \sum_i w_i D_i$$

	Dose, mSv/day (QF=2.6)		
	Crew quarter	Piers-1 module	MIM-2
$D_{mean\text{-}surface}$	0.55	0.69	0.99
$D_{mean\text{-}tissue}$	0.45	0.56	0.87
D_{eff}	from 0.47 to 0.49	from 0.59 to 0.62	from 0.88 to 0.92

D_{eff} = (0.85 … 0.90) $D_{mean\text{-}surface}$
in undisturbed radiation conditions (no SEP events)

Future Projects with the Tissue-equivalent Phantoms

- The data set obtained with spherical phantom is not final. Measurements will be continued.
- The spherical phantom will be installed and used in Kibo module (at least one more session is planned from Sep. 2013 to March 2014)
- Rando phantom has been stored at IBMP after its recovery with the last Space Shuttle mission
- The Rando phantom with new passive and active detector set (but without its container) still can be used inside the space station
- New flight qualification tests of the Rando phantom should be carried out
- Delivery to ISS by Progress cargo spacecraft in 2017 as the earliest

3rd Workshop on Radiation Monitoring for the ISS
KFKI Atomic Energy Research Institute, 24-26 March, 1998, Budapest, Hungary

RECOMMENDATIONS

An update of the common models (trapped environment, geomagnetic cut-off and solar storm) is urgently needed, due to the discrepancy between models and measurements. A simple access routine to the models should be provided. More instrumentation on satellites is required to provide new data on proton and electron fluxes.

Distributed data base in a common format shall be used for detailed information, a common data base shall be established for all data in a reduced form. Criteria which information is required have to be set up.

Cross calibration is an indispensable work in order to allow for adequate data comparison. For calibrations HIMAC, AGS, Loma Linda facility and the CERN calibration field shall be used. Intercalibration onboard ISS is deemed necessary. Response functions has to be determined, uncorrected and corrected data need to be provided included correction procedure. For each detector system a common correction technology shall be used. Benchmarks - e.g. relativistic iron peak or CERN calibration field- relevant to the environment needs to be defined and used for proper testing of the instrument characteristics

Active and passive personal dose measurements are strongly recommended. The same holds for **measurements inside human phantoms.** The required tissue absorbed doses can be determined by combining the information of surface absorbed doses at the human body with depth dose data provided by the phantom measurements.

Recent results show that secondaries deliver a significant contribution to the dose. The high biological effectiveness of such components call for additional efforts. Fragmentation studies should therefore be intensified. Improved measurements of the neutron component is required especially at energies between 1 and 20 MeV and if possible also at higher energies. Advanced instrumentation is absolutely necessary.

Regular organisation of workshops dedicated for developing and modelling, measuring and evaluation technics significantly helps the improvement of dosimetry on the ISS.