STUDY OF DOSE DISTRIBUTION IN A HUMAN BODY IN ISS COMPARTMENTS WITH THE SPHERICAL TISSUE-EQUIVALENT PHANTOM

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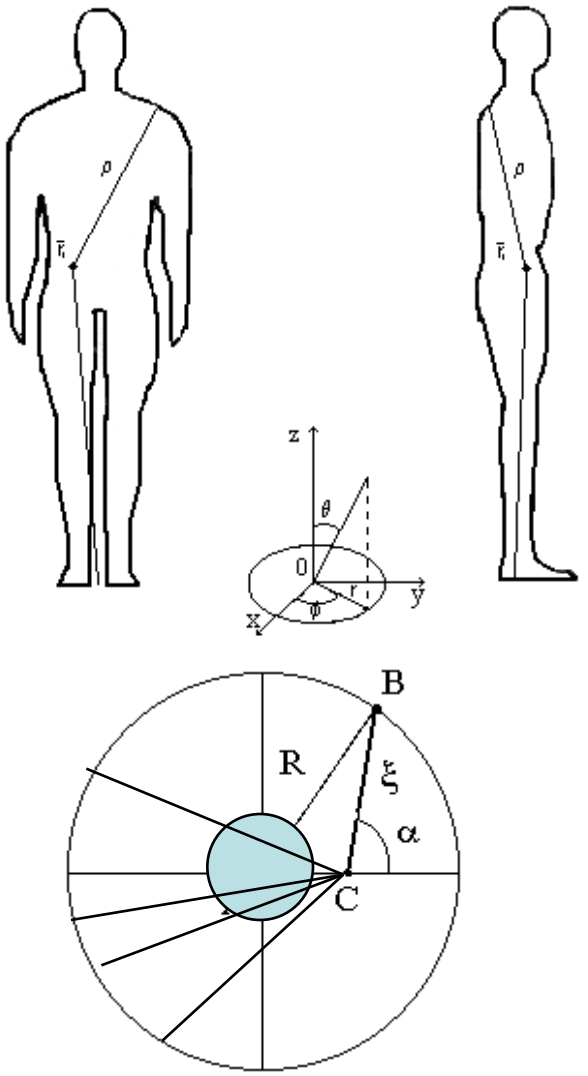
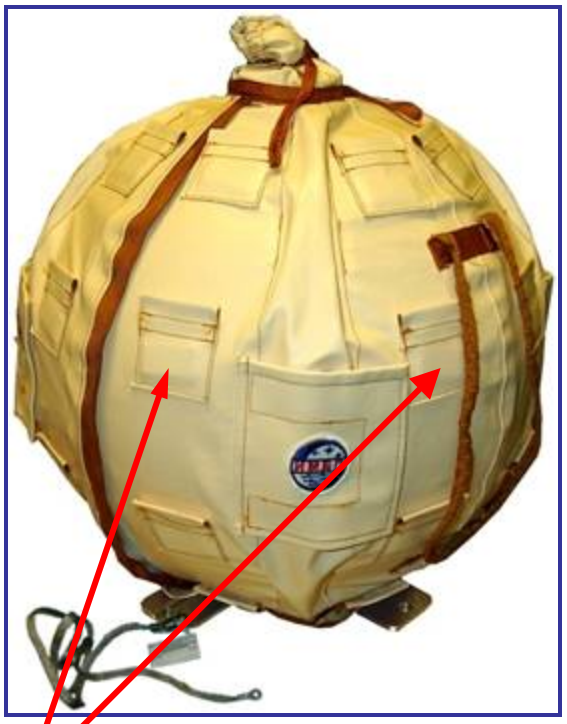
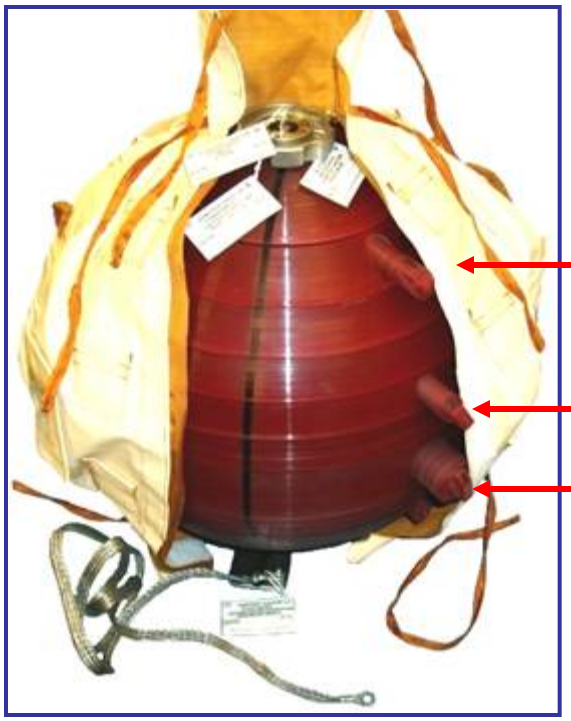
Self-shielding of critical organs in a human body

- We use the spherical phantom made from tissue equivalent matter
- External radius R=17.5 cm,
- Internal cave r=5 cm
- Different depths *d* in the phantom correspond to critical organ doses
- *p(ξ,d)* – shielding probability function:
  - ξ_{min}=d
  - ξ_{max}=2R - 2r -d



Spherical phantom
Size: 370x370x390 mm; mass: 32 kg

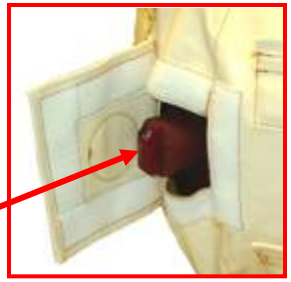




Working jacket with

LiF TLDs and
CR-39 in pockets

Container

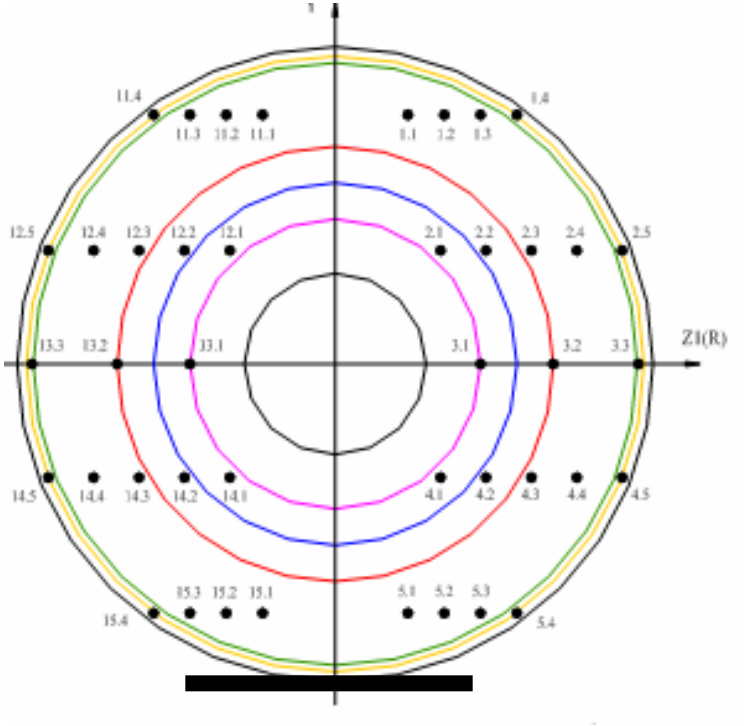


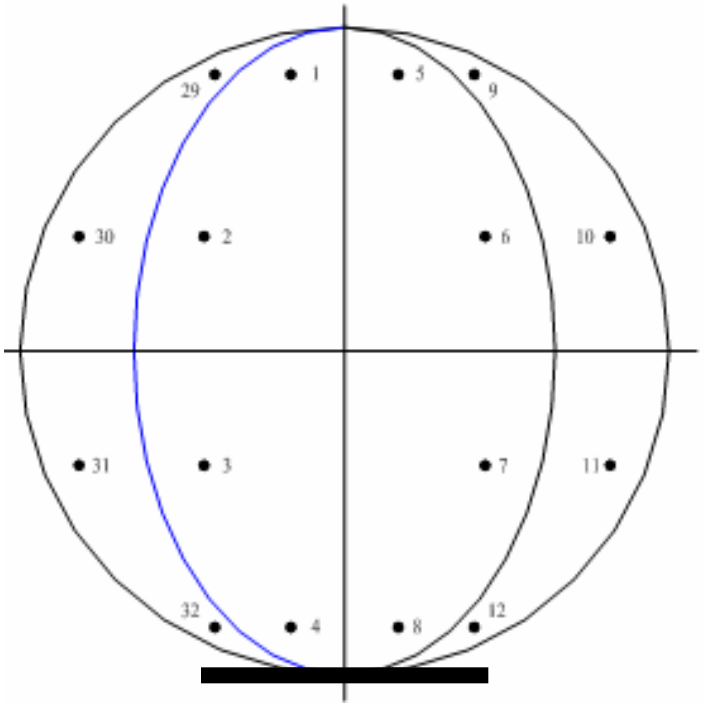
Containers

The spherical phantom package for Matroshka-R space experiment

1. **Working jacket**
2. **Container set**

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)*

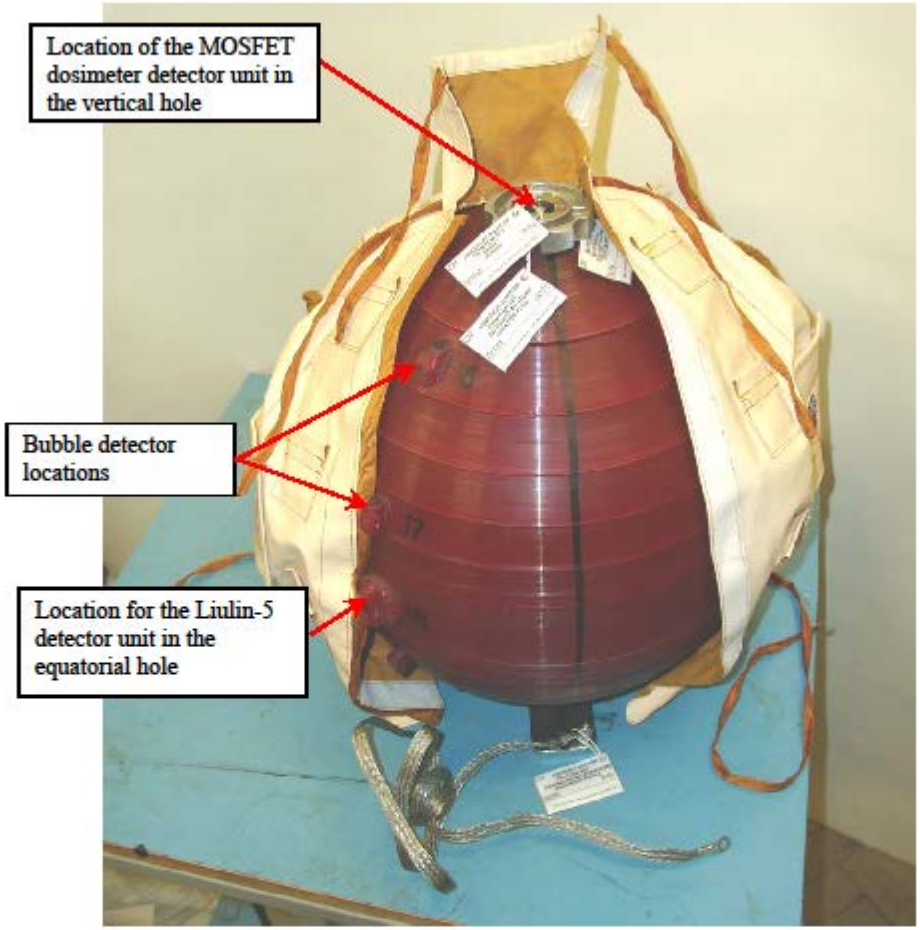
Participants of the experiment with spherical phantom (Matroshka-R)

Passive detectors

- IBMP (TLD only)
- NPI, Prague, Czech Republic (TLD + CR-39)
- NIRS, Chiba, Japan (TLD + CR-39)

Active detectors

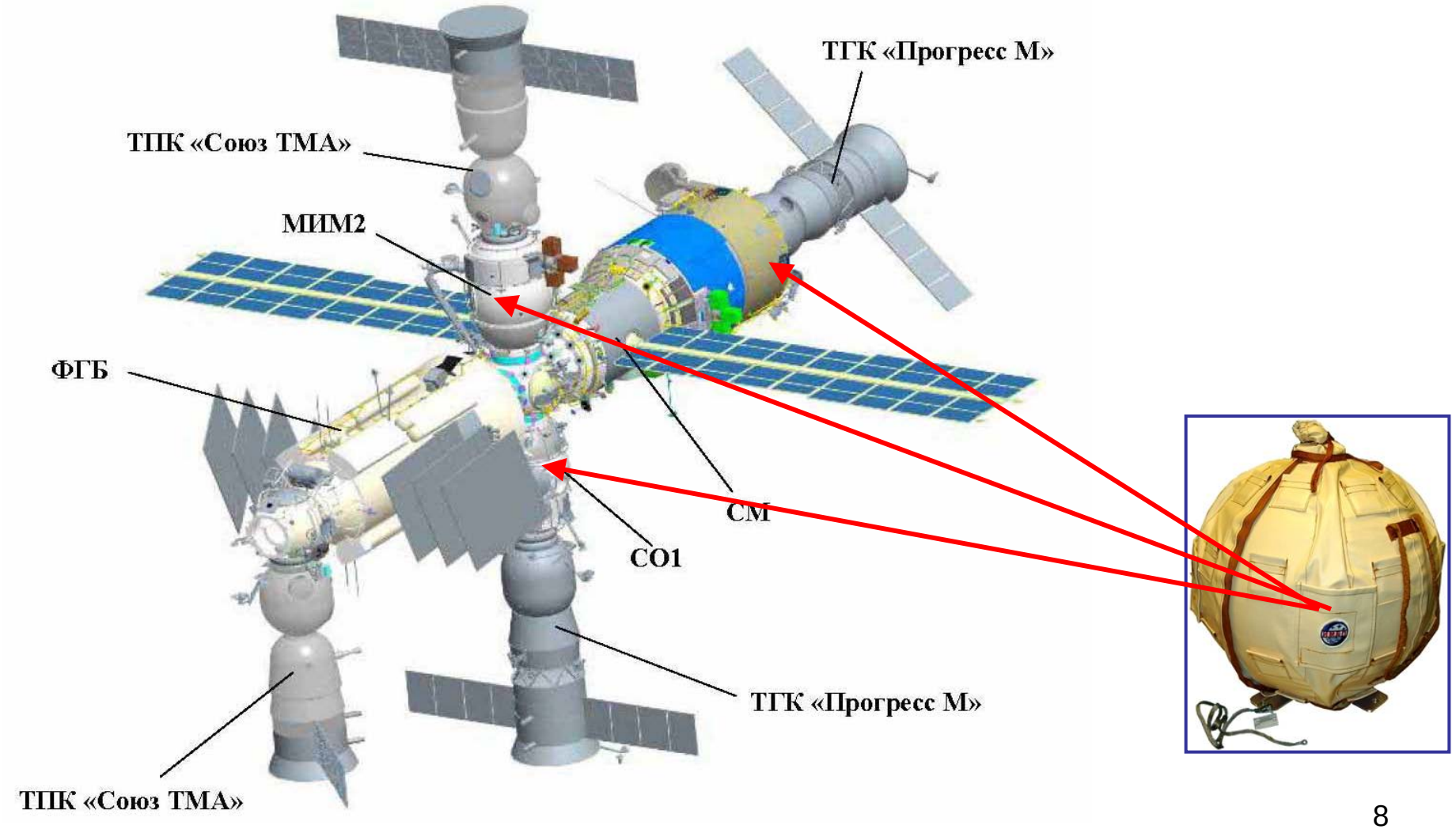
- Canadian Space Agency MOSFET and Bubble detectors
- STIL BAS, Bulgaria – Liulin-5 silicone detector telescope



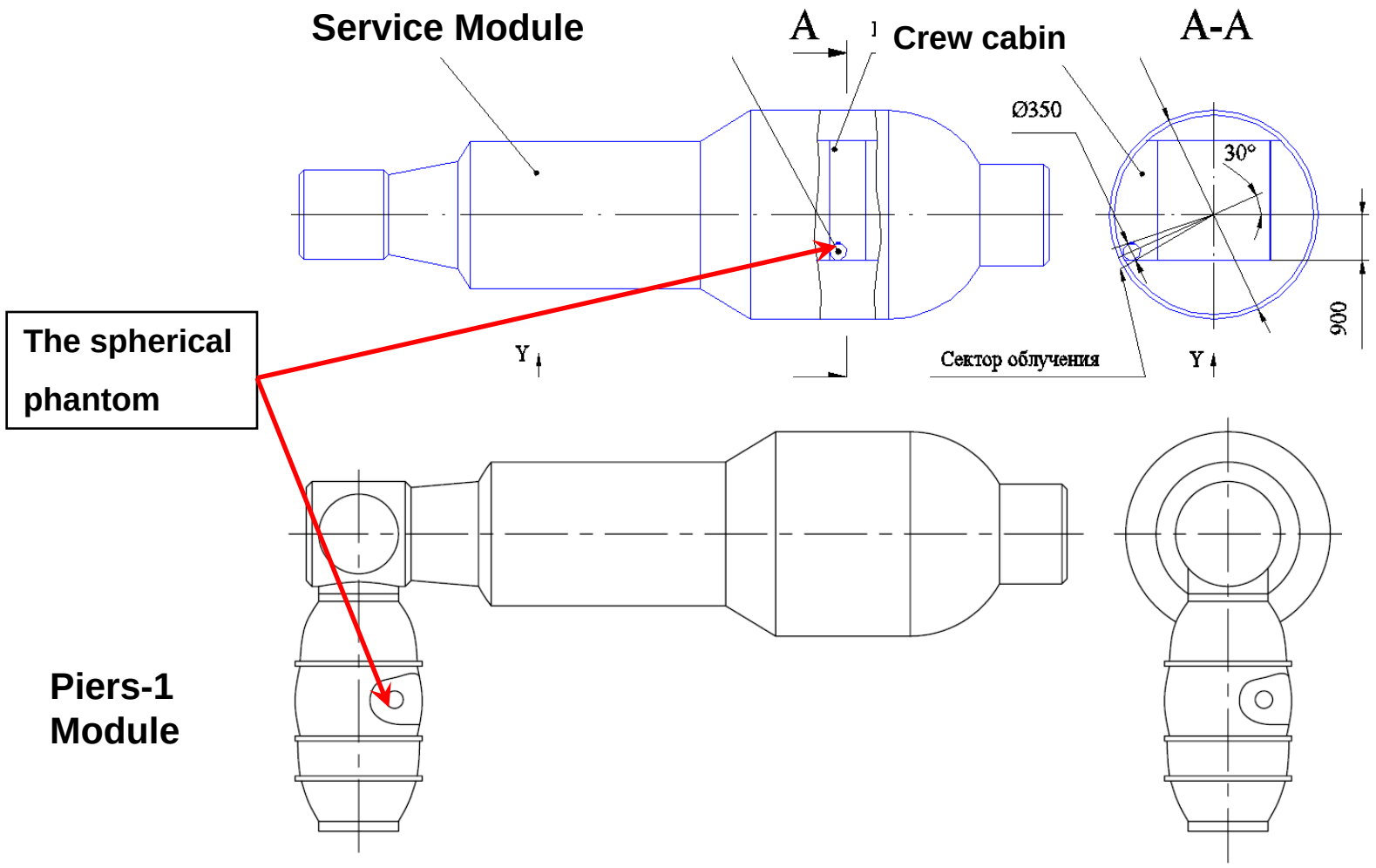
Experimental sessions with the spherical phantom

Number of session / Dates of exposure	Exposure duration, days	The phantom location
1) From Jan. 29, 2004 to Apr. 30, 2004	92	CQ of SM
2) From Aug. 11, 2004 to Oct. 10, 2005	425	CQ of SM
3) From May 12, 2007 to Feb. 20, 2008	285	Piers-1
4) From May 14, 2008 to Dec. 01, 2008	202	Piers-1
5) From May 07, 2009 to Oct. 11, 2009	158	Piers-1
6) From April 30, 2010 to Nov. 26, 2010	210	MIM-2
Total exposure duration	1372	

The spherical phantom locations in ISS



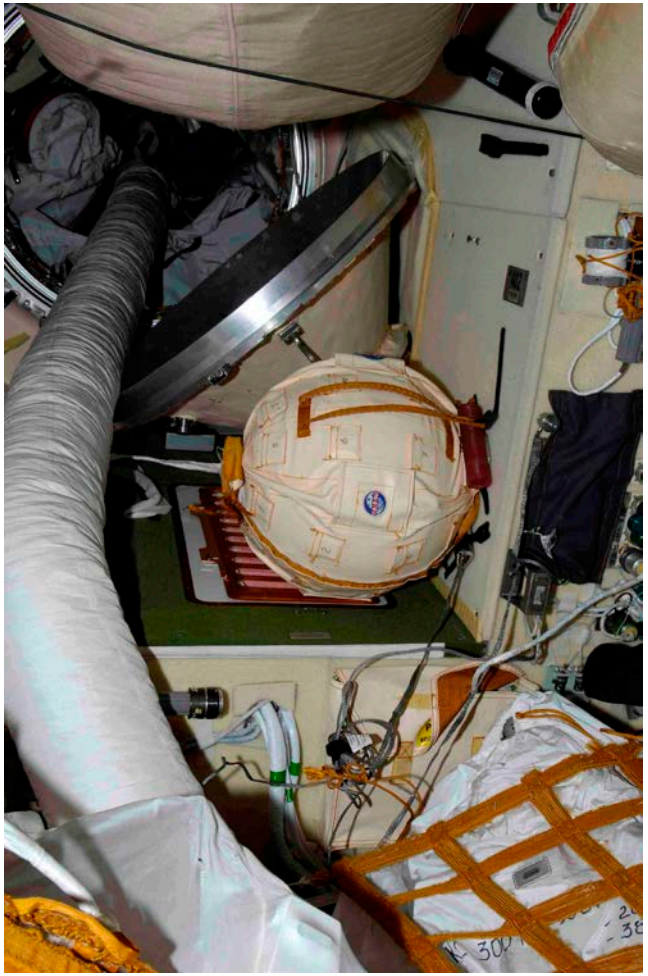
The spherical phantom locations in the Russian Segment of the ISS



The spherical phantom locations

In the star board crew quarter

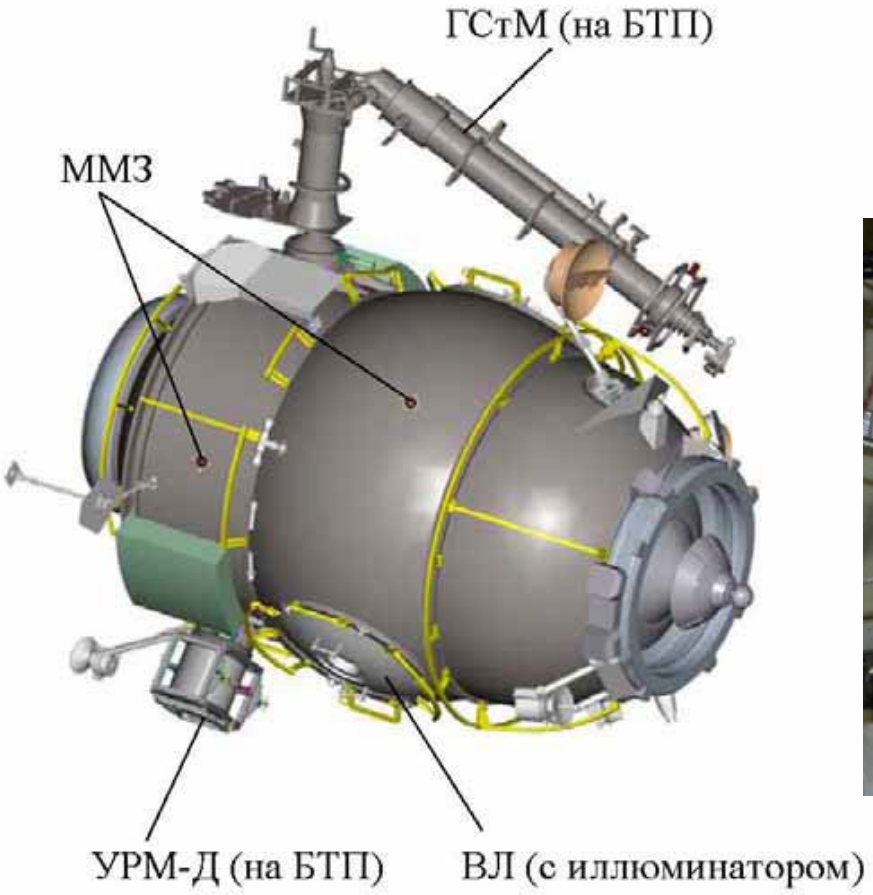
From Aug. 11, 2004 to Oct. 10, 2005



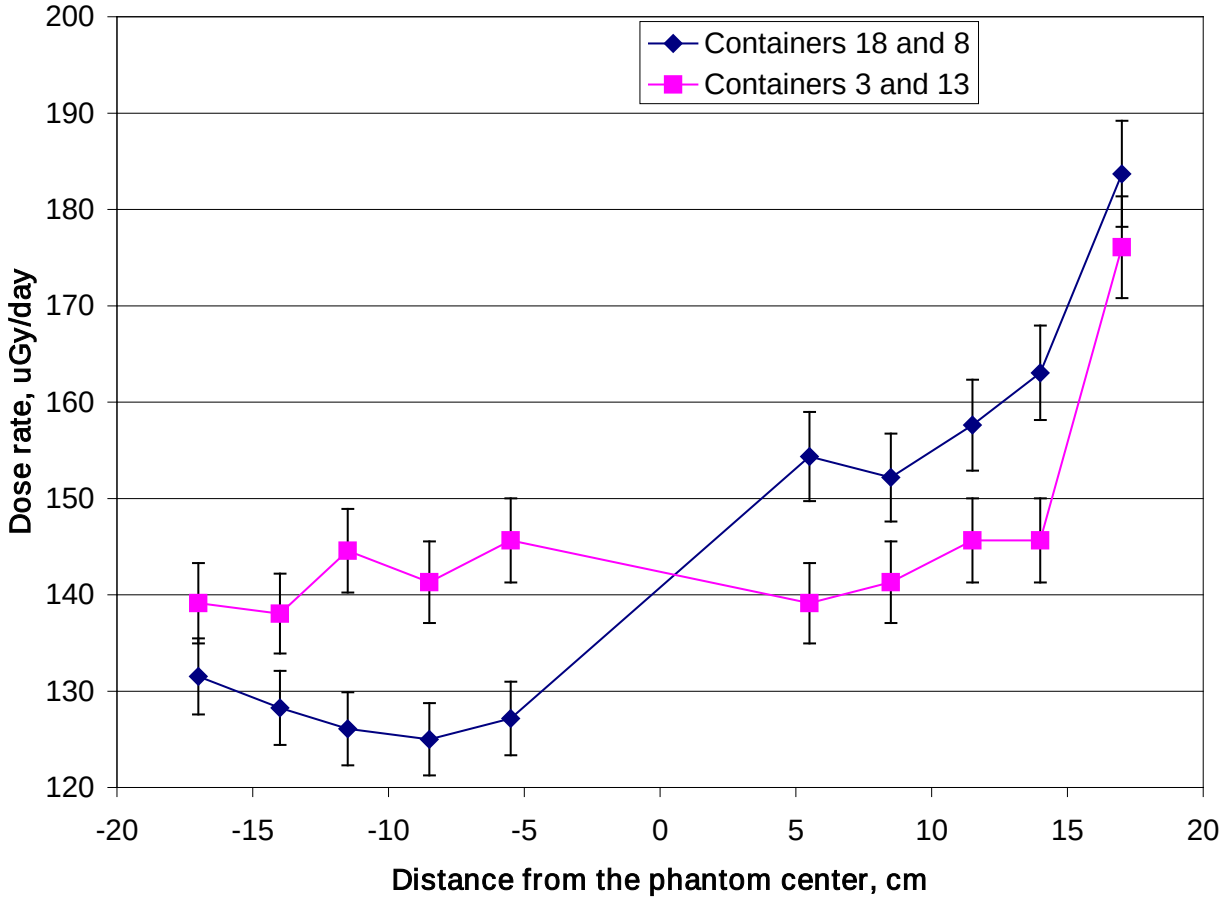
In Piers-1 module

From May 12, 2007 to Feb. 20, 2008

The spherical phantom in MIM-2 module (small scientific module 2)

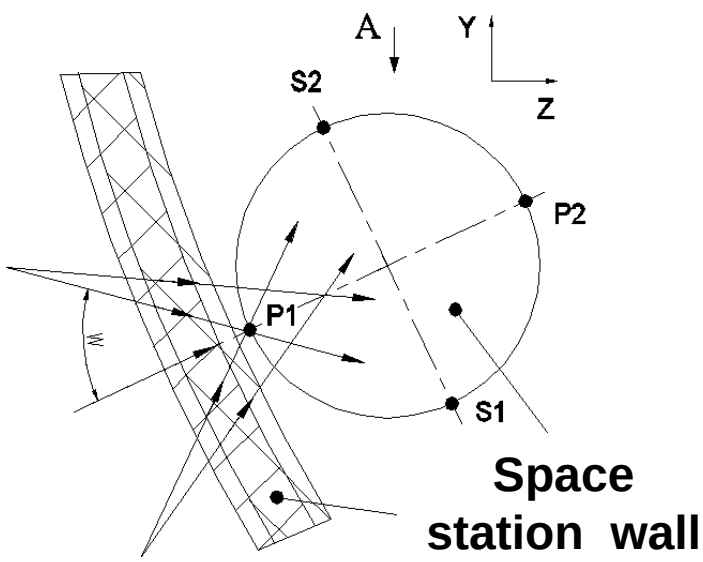


Dose rate measured in the equatorial containers of the phantom

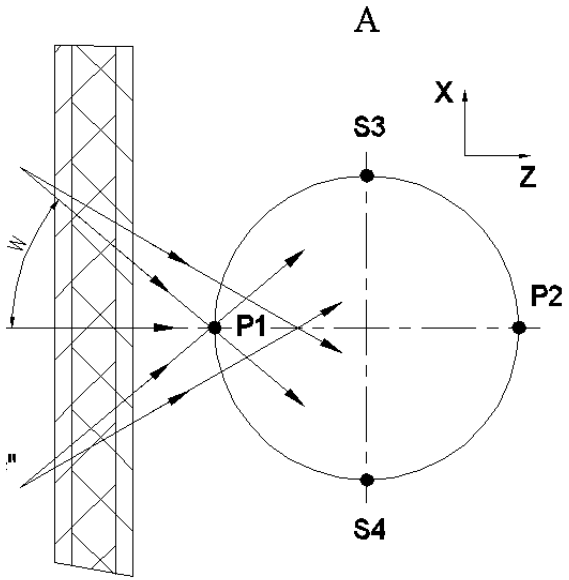


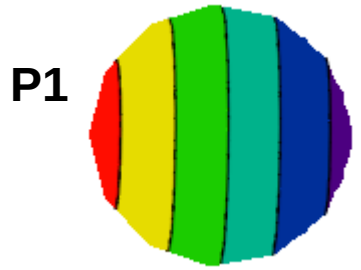
Crew cabin wall

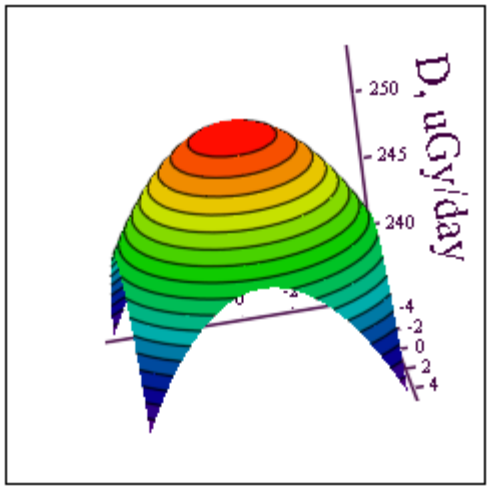
The spherical phantom near the space station wall



Space station wall







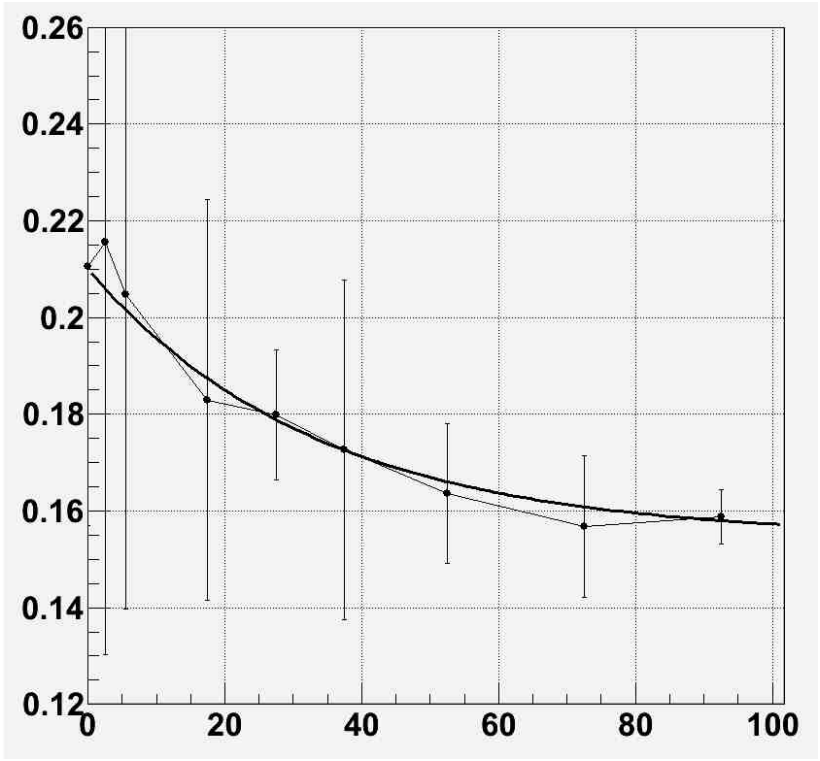
D(P1) = D_{max} D(P2) = D_{min}

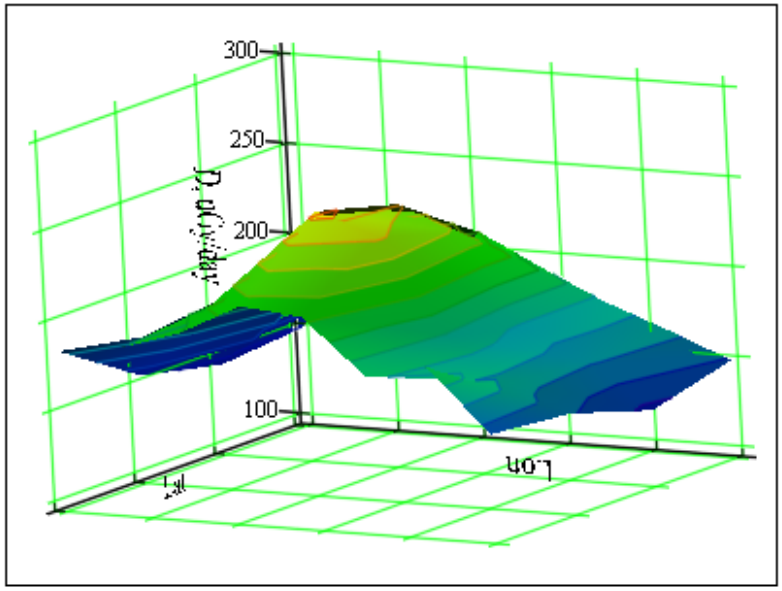
The dose distribution is symmetrical to the P1-P2 axis

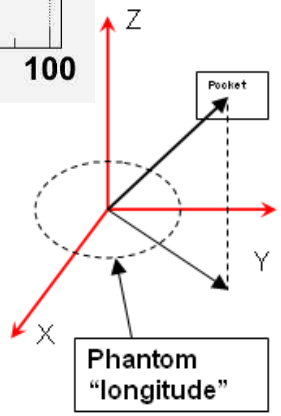
$$Dose(X,Y) = D_{\min} + (D_{\max} - D_{\min}) \cdot \sqrt{1 - (\frac{X^2}{175} + \frac{Y^2}{175})}$$

Surface dose and dose as a function of depth in the phantom (1)

Crew quarter (session 2, 425 day)







$D_{mean\text{-}surface}$ = 211 μGy/day

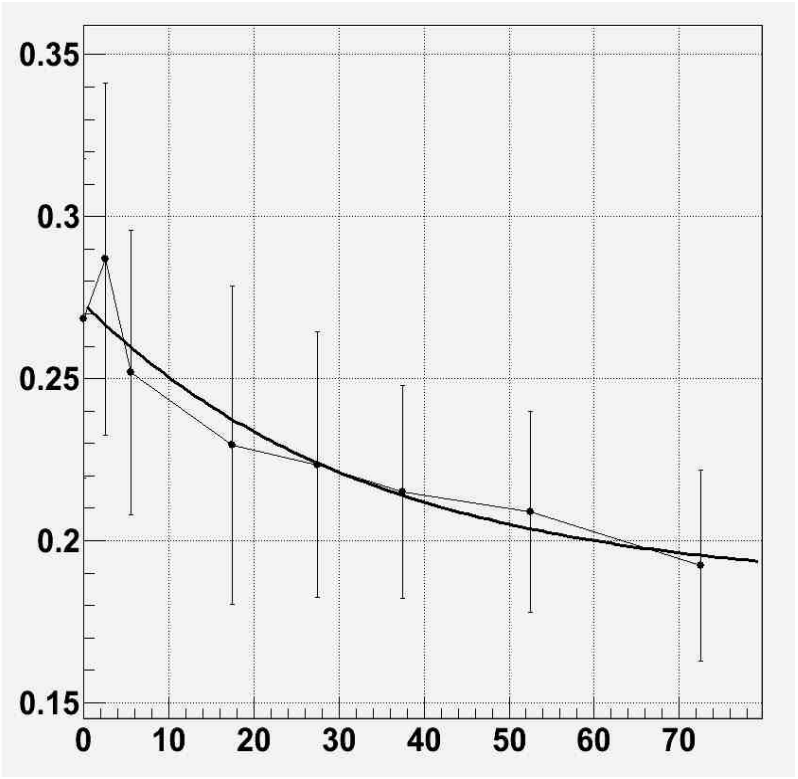
D_{min} = 137

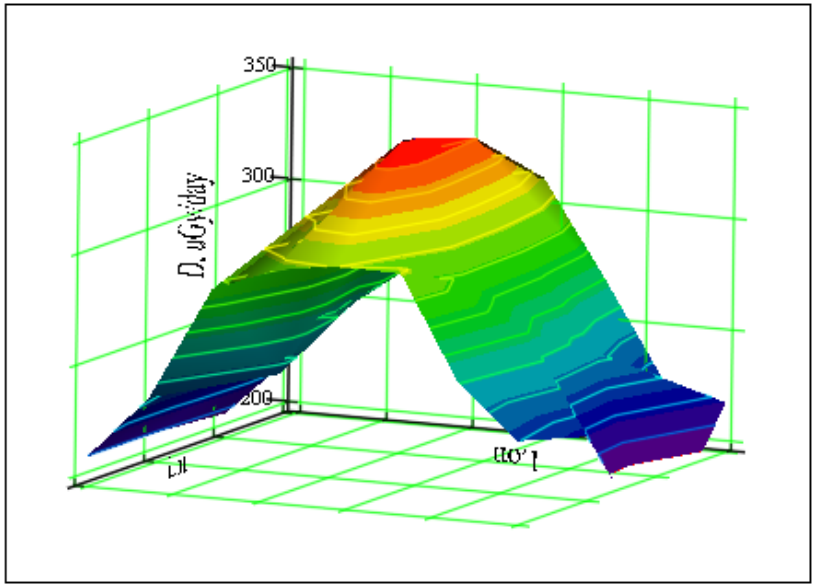
D_{max} = 253

D_{max}/D_{min} = 1.9

Surface dose and dose as a function of depth in the phantom (2)

Piers-1 (session 3, 285 days)





$D_{mean\text{-}surface}$ = 264 μGy/day

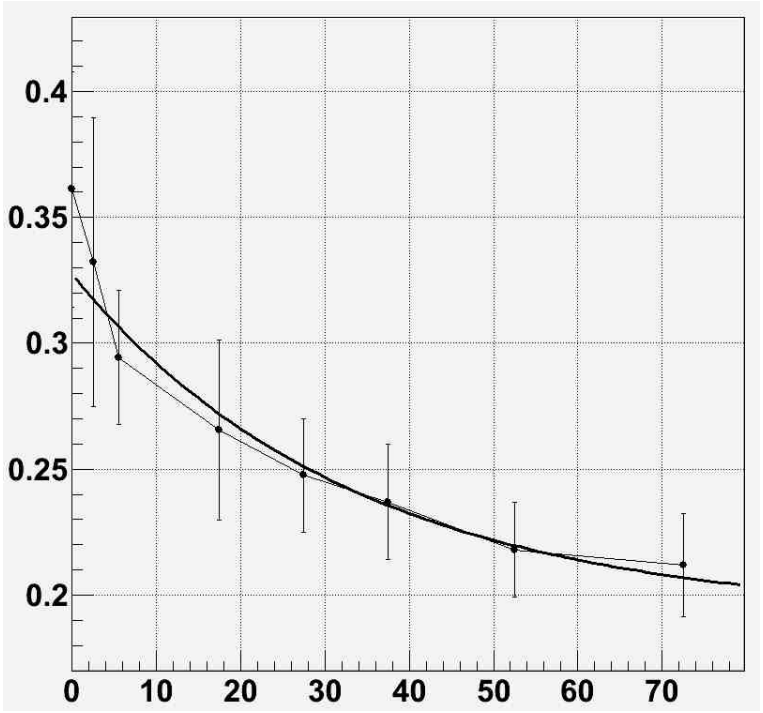
D_{min} = 163

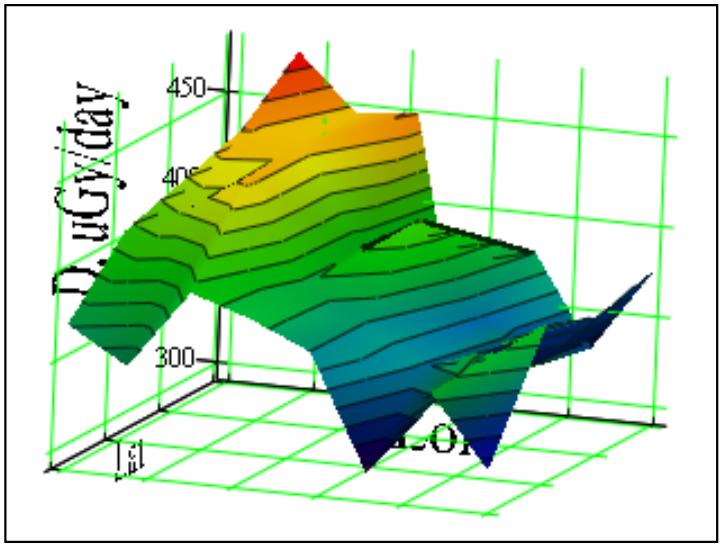
D_{max} = 352

D_{max}/D_{min} = 2.2

Surface dose and dose as a function of depth in the phantom (3)

MIM-2 module (session 6, 210 days)





$D_{mean\text{-}surface}$ = 264 μGy/day

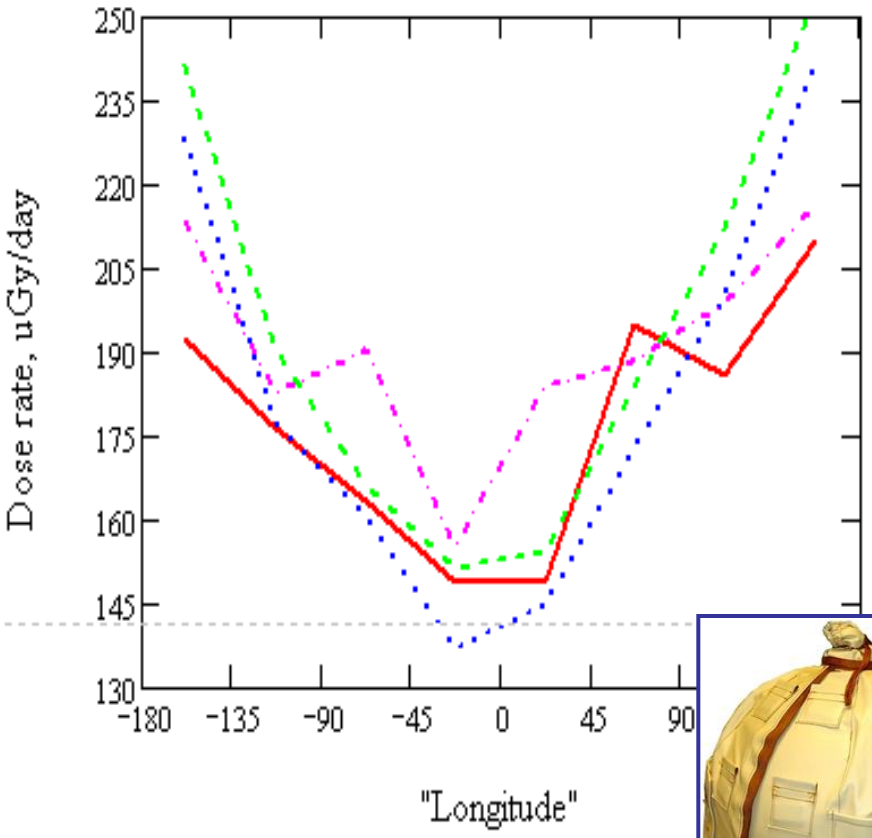
D_{min} = 295

D_{max} = 478

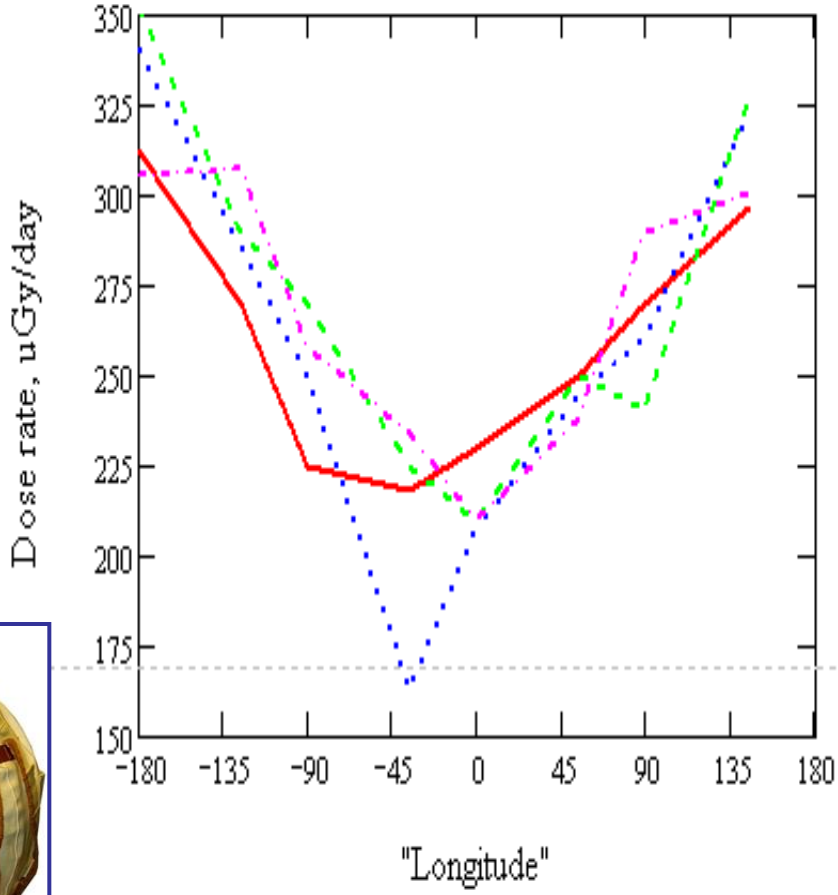
D_{max}/D_{min} = 1.6

Dose versus the pocket longitude

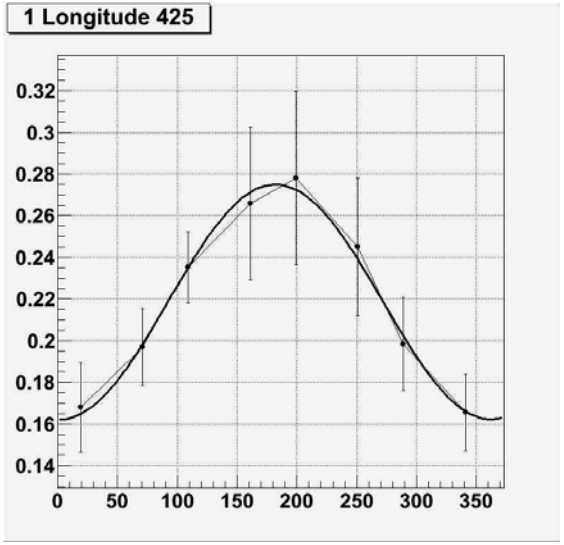
Crew quarter (session 2)

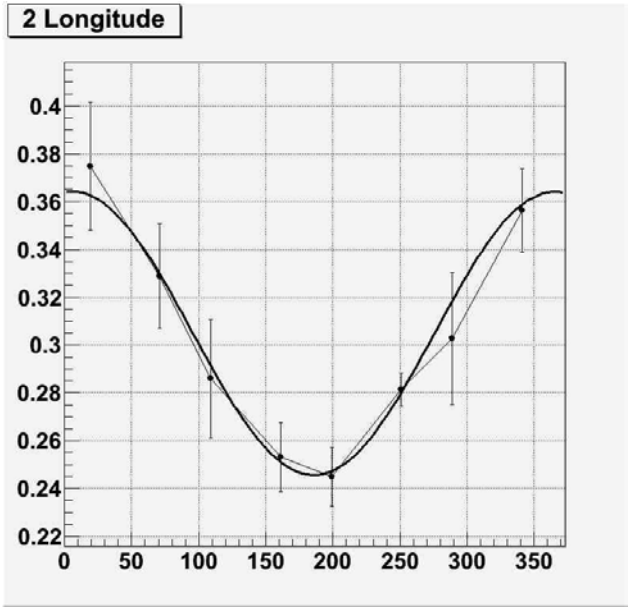


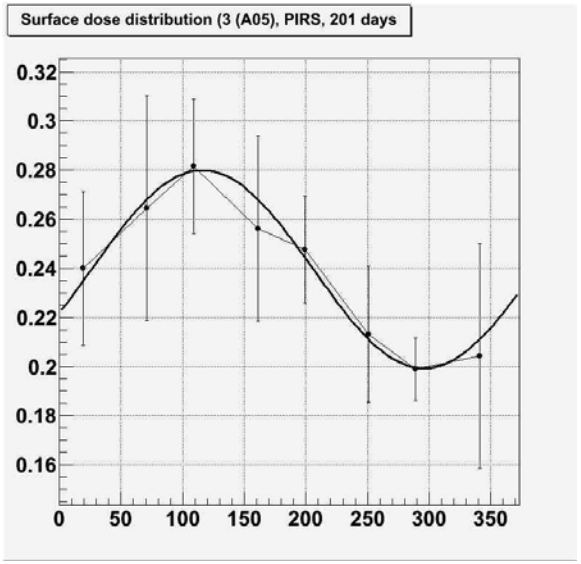
Piers-1 module (session 3)

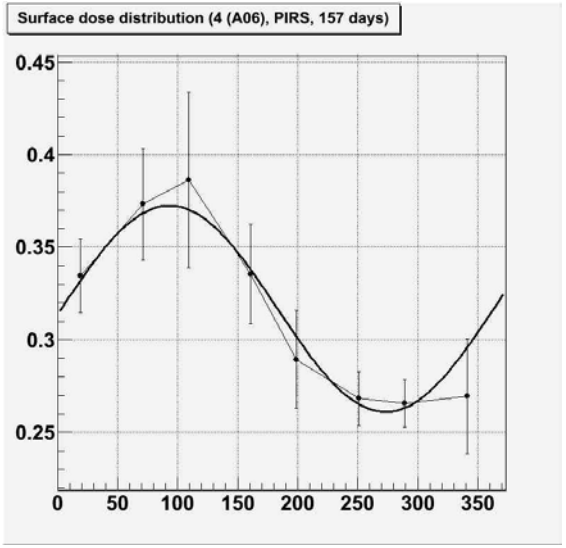


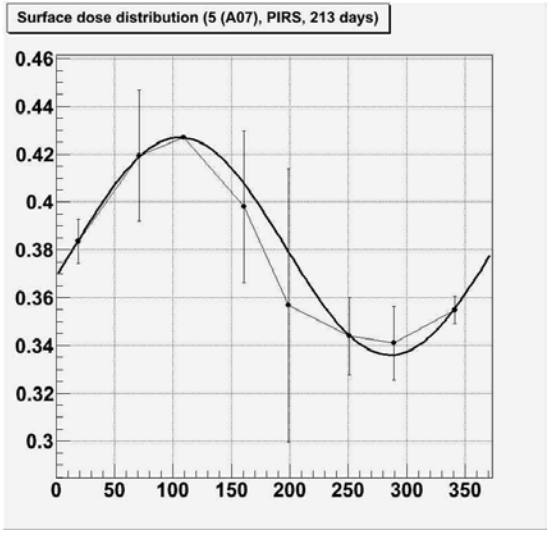
Dose versus the pocket longitude











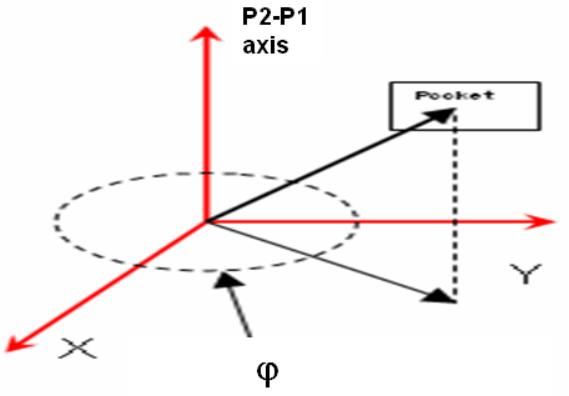
Parameterization of the dose distribution in the spherical phantom

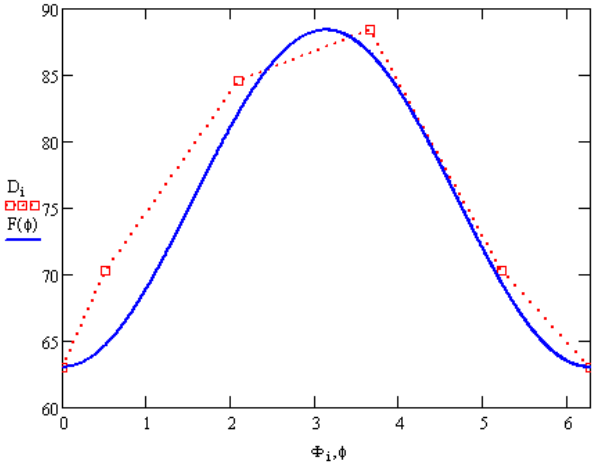
$$D(\theta) = D_{\min} + \frac{D_{\max} + D_{\min}}{2} + \frac{D_{\max} + D_{\min}}{2} \cdot \cos(\theta)$$

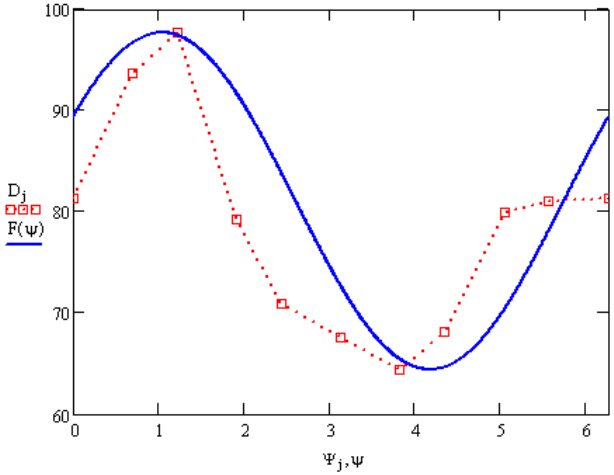
$$D(\varphi) = const$$

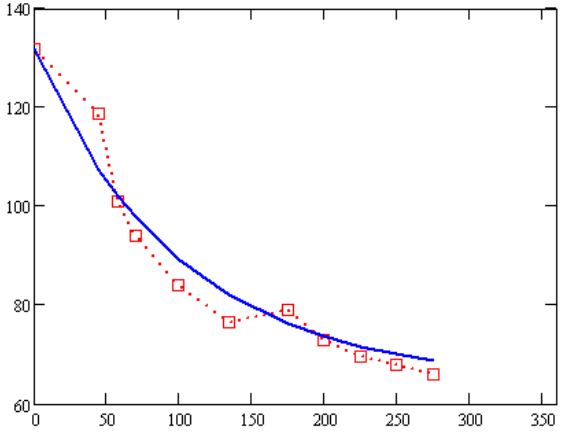
$F(d) = (D_{max} - D_{min})\ exp(-d/100) + D_{min}$,

d – depth in mm.





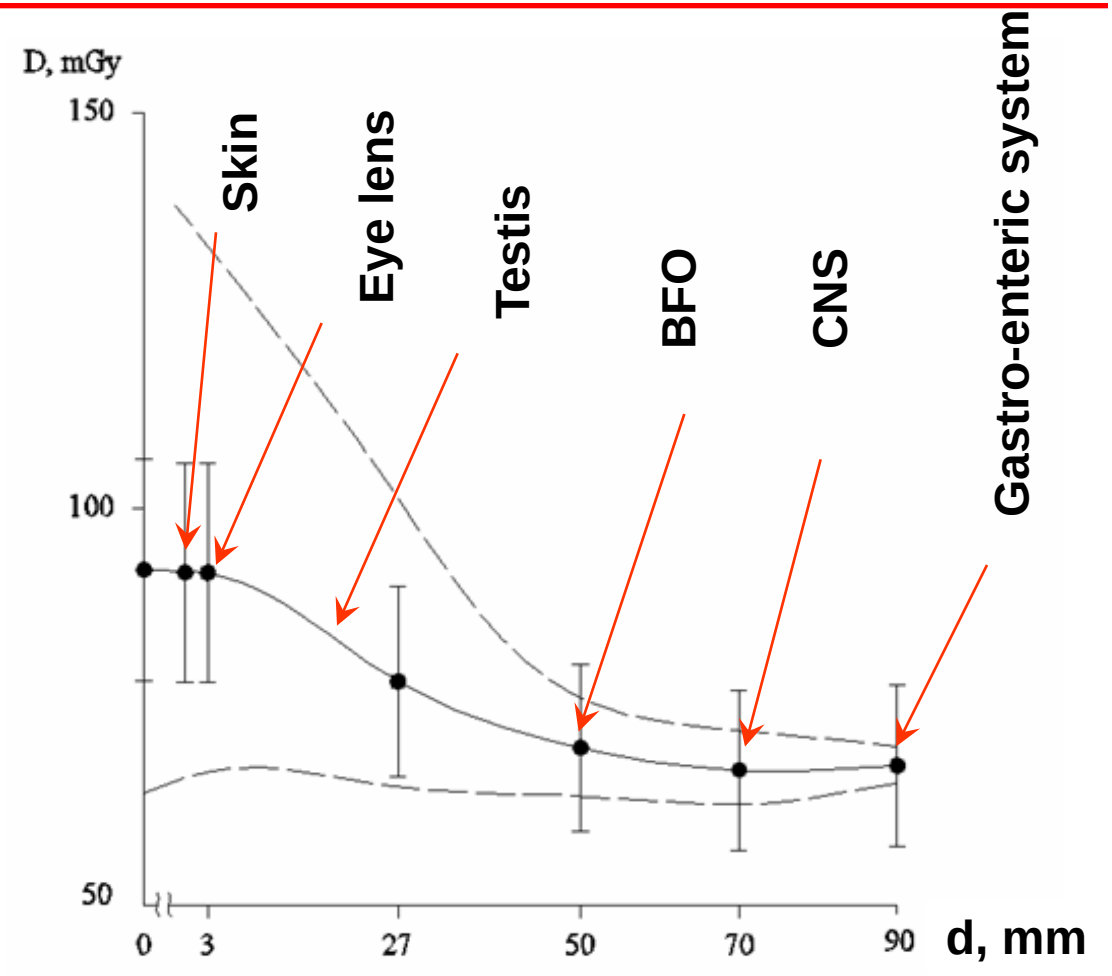




Depth along P1-P2 line, mm in tissue

Doses in critical organs as obtained in the spherical phantom (CQ)

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

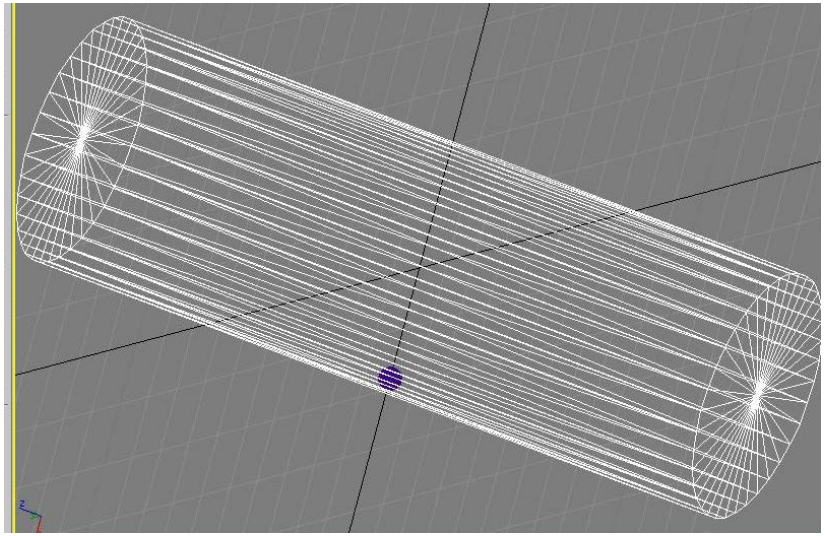


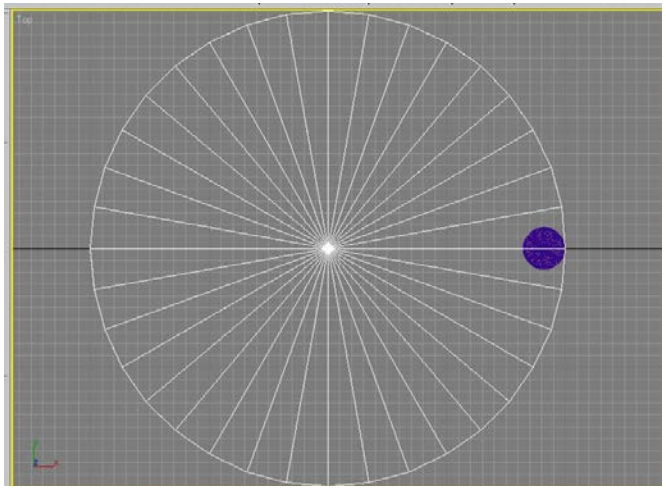
Mean-surface, mean-tissue, and effective dose estimation in ISS compartments

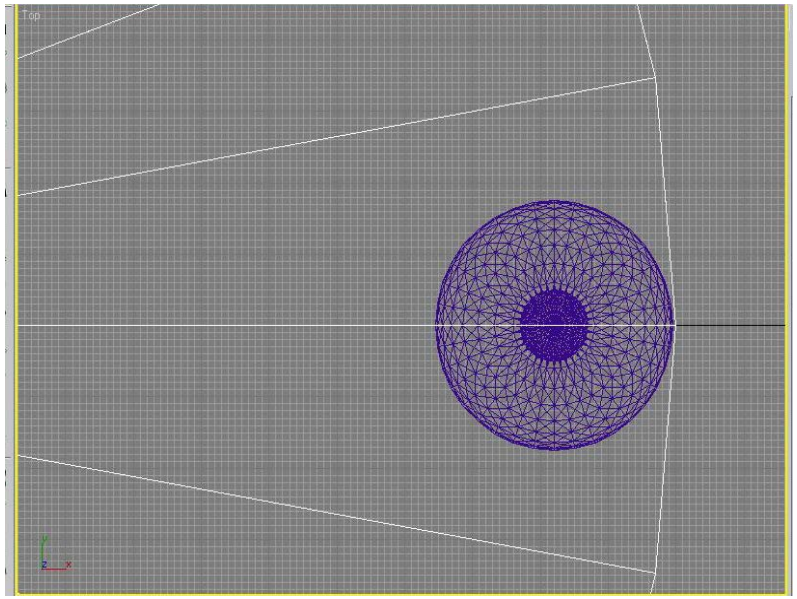
$$D_{mean-surface} = \frac{\int D_s(\vec{r})dS}{\int dS} \qquad D_{mean-tissue} = \frac{\int D(\vec{r})dm}{\int dm} \qquad D_{eff} = \sum_i w_i D_i$$

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

Some Simulation Efforts



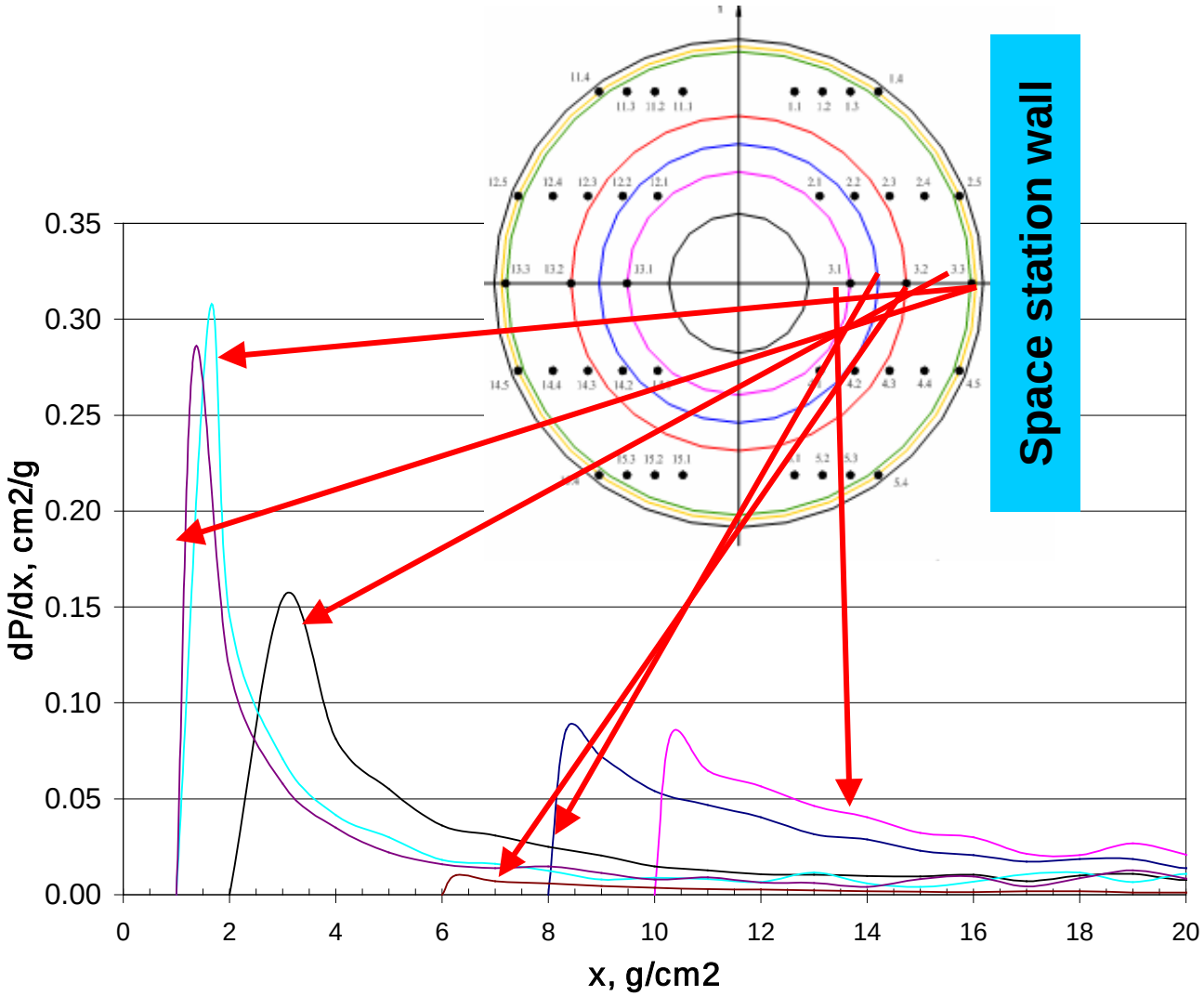




ISS Service module

- Mass 20 t
- Length 12 m
- Diameter 4 m
- Wall thickness 4 mm Al
- Mass of the shell 4.4 t
- Internal matter density 0.1 g/cm^3

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



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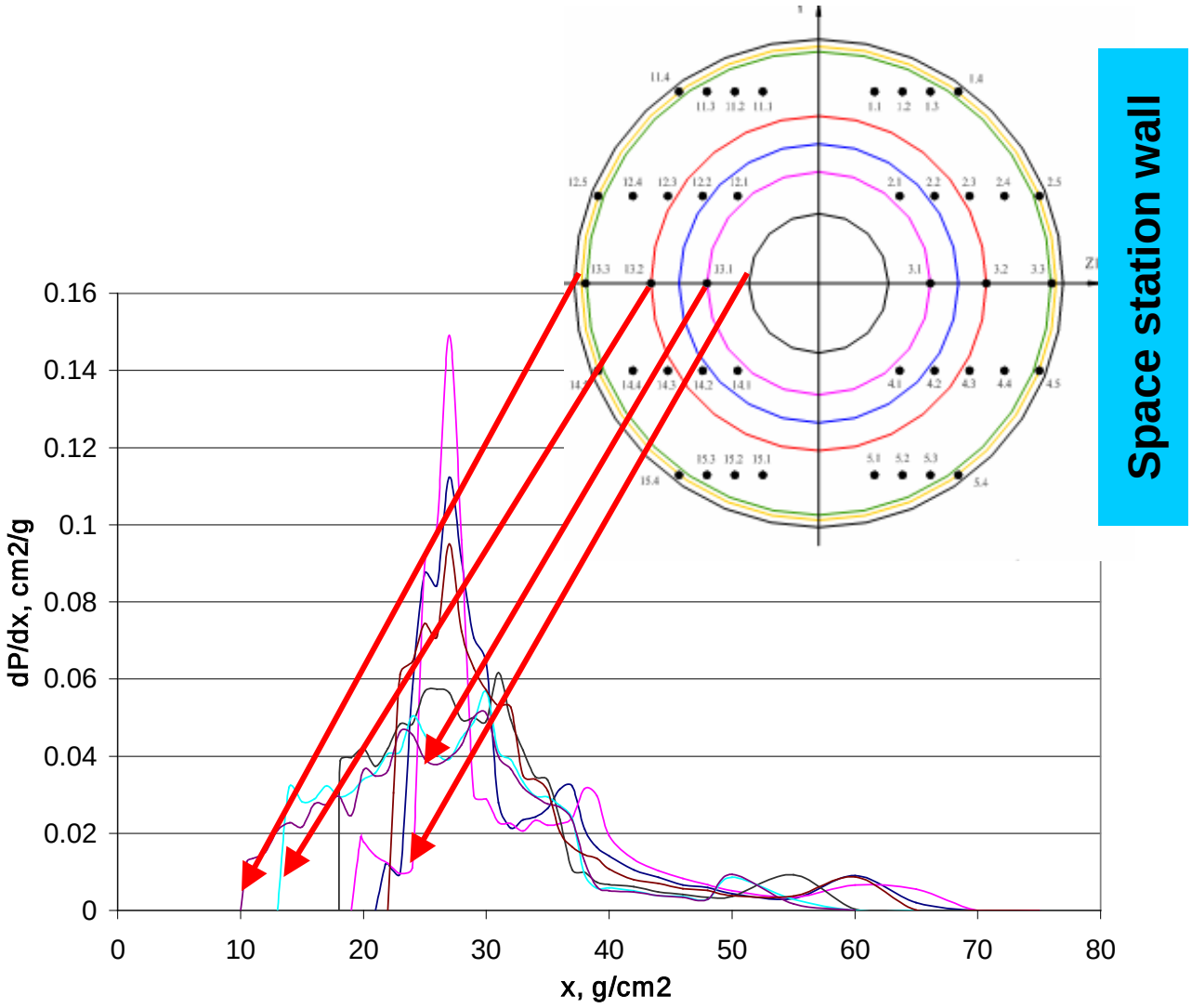
Some shielding functions for the sites of critical organs in the spherical phantom



Main Properties of the Spherical and Anthropomorphic Phantoms used in space flights

	Spherical phantom	Anthropomorphic phantom
Sex	Unisex	M
Mass	32 kg	The torso with head is about 60 kg
Size	35 cm diameter	The torso with head height is about 90 cm
Detector placement and retrieval	Easy retrieval of the detector containers from the radial holes without full disassembling; 0.5 h of the crew time	The detectors have special locations in each slice of the phantom. Full disassembling is required for the detector retrieval; about 8 h of the crew time
Chemical composition	H=8.6% N=2.6% C=32.3% O=56.5%	H=9.2% N=2.5% C=20.3% O=67.8%
Attitude to the station wall	No sensitive	Sensitive
Status	In ISS (MIM-2 module)	In USA (on ground)

Standard human chemical composition: H=10%, N=2.6%, C=61.3%, O=23.1%

Future projects with the space phantoms

- The spherical phantom will be installed and used in Kibo module (at least three sessions are planned from 2012 to 2015)
- Rando phantom will be delivered to IBMP from USA, supplied with new active and passive detectors on the basis of international collaboration
- New flight qualification tests of the Rando phantom should be carried out
- Delivery to ISS by Progress cargo spacecraft in 2015 as the earliest

Conclusion

- The spherical phantom and its tissue-equivalent material have passed the successful test in conditions of a real space flight at the Russian Segment of ISS for more than 7 years
- Critical organ doses and effective doses of a crew member in the Crew quarter, in Piers-1, and in MIM-2 module were estimated with the spherical phantom
- The estimated effective dose rates are from 10 to 15 % lower than the mean-surface dose on the phantom surface as dependent on the crew body attitude
- The spherical phantom of Matroshka-R type can be recommended for future space exploratory missions as a witness of the crew' radiation exposure in normal and disturbed conditions
- Other types of space phantoms (e.g. Rando type) should also be used in future space flight studies
- … a long road is in front of us