Optimization of Radiation Impact on Cosmonaut Body during EVA Based on the East-West Asymmetry Effect of High Energy Trapped Protons

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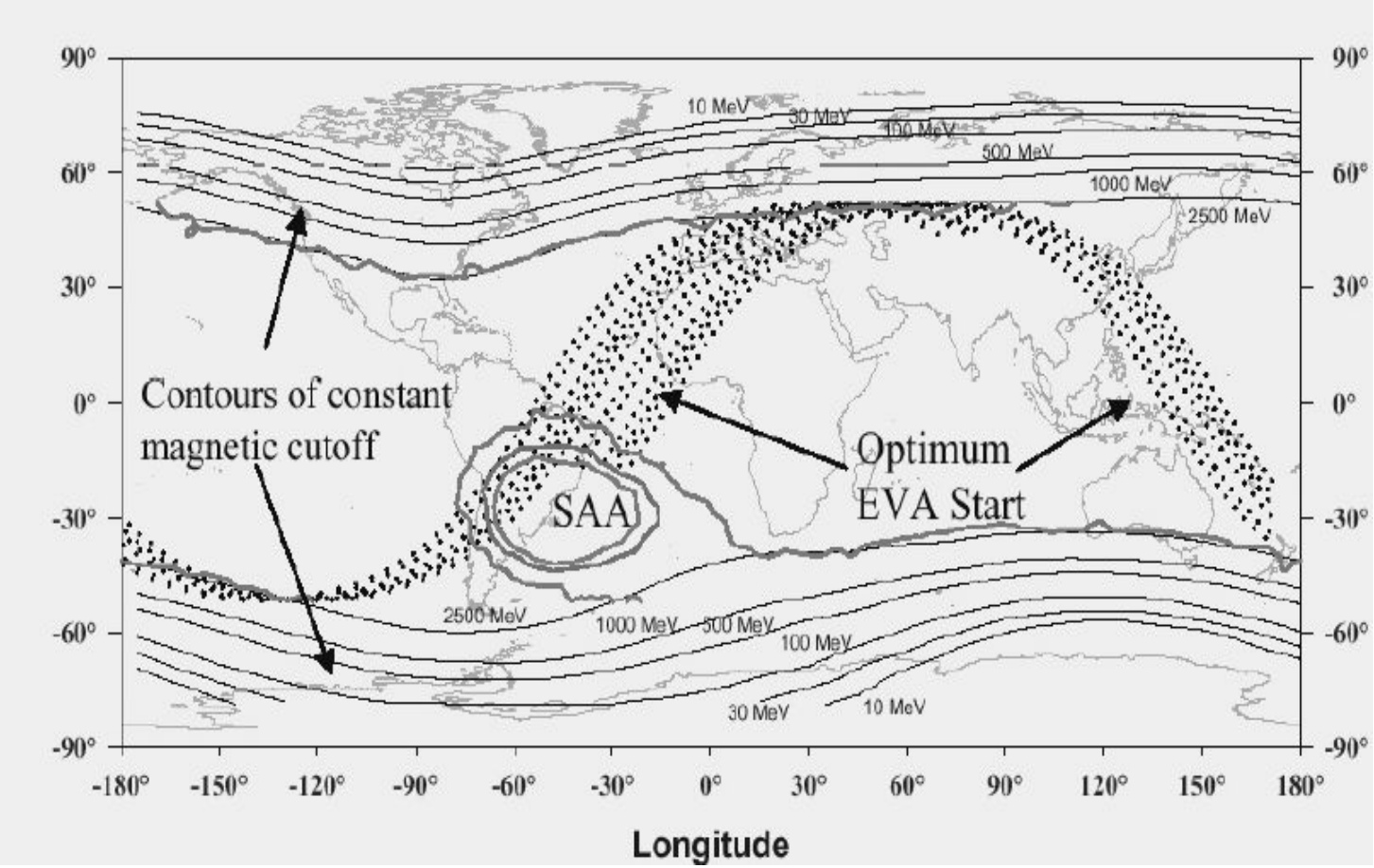
Spacesuit for EVA

- the spacesuit plays a critical role in shielding astronauts from EVA radiation exposures
- ALARA = As Low As Reasonable Achievable

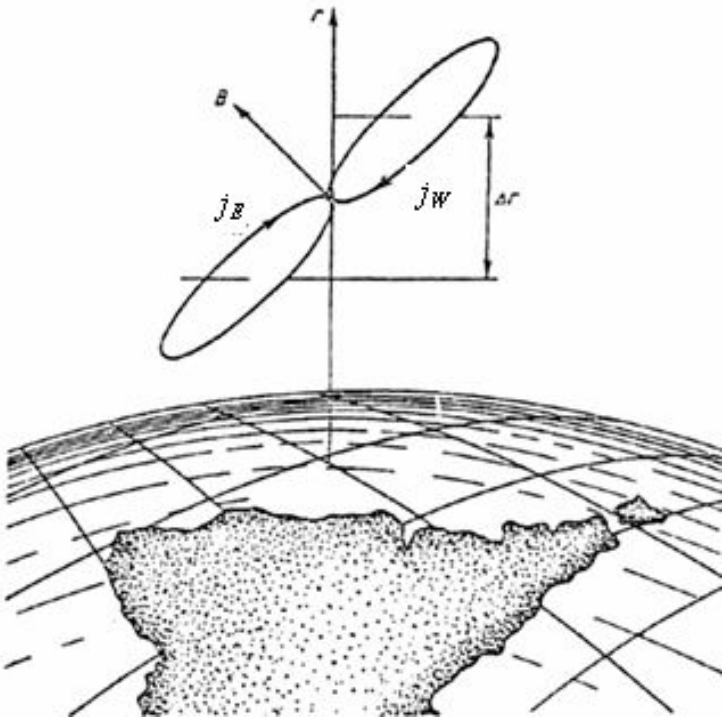
ORLAN-M (eagle) - the RSA spacesuit for EVA and the Russian human body phantom

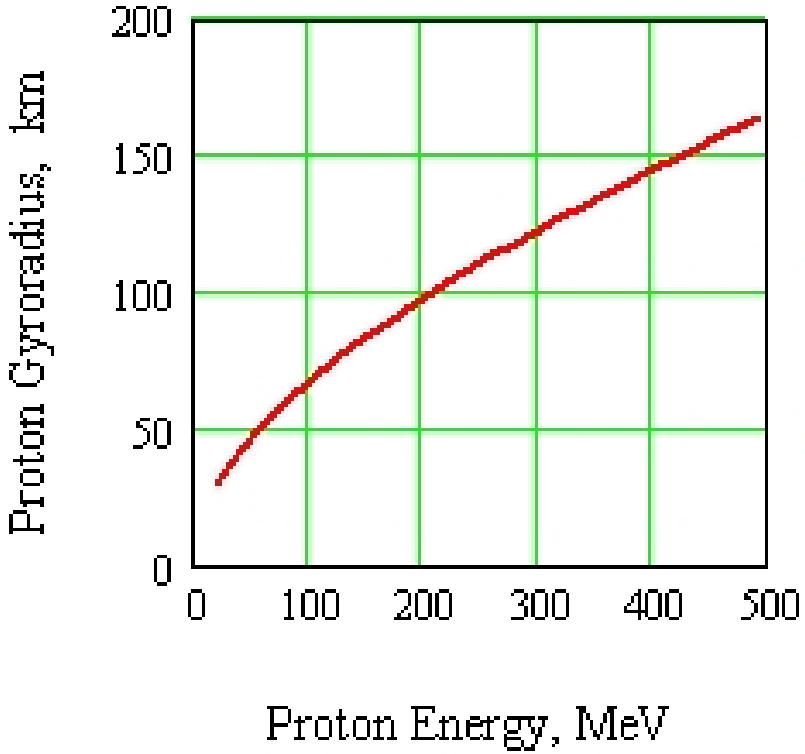
Minimizing EVA Dose by Changing Start Time of the EVA (early or late egress)



A.S.Johnson et al., (JSC NASA) Minimizing Space Radiation Exposure during Extra-vehicular Activity, *Adv. Sp. Res., 2004*

East-West Asymmetry Effect of High Energy Trapped Protons





J_p(from the west) > J_p(from the east)

$\rho(h) \sim \exp(-h/H)$

The atmospheric scale height at 350 km altitude (typical ISS orbit) is 40 km for solar min and 70 km for solar max, $R_p \geq H$

Theoretical approach to obtain the directional flux from AP-8 model

Proton gyroradius $$R(E,\alpha) = \frac{p(E)\cdot\sin(\alpha)}{e\cdot B} \qquad p(E) = \sqrt{\left(E^2 + {m_p}^2\right)} - {m_p}^2$$

Differential directional proton flux $$j_p(E,\alpha,\phi) = \frac{j(E)}{C(E)}\cdot\sin(\alpha)^k \cdot e^{R(E,\alpha)\cdot\frac{\cos(I)}{H}\cdot\sin(\phi)}$$

- j(E) is AP8 omnidirectional flux;
- α - pitch angle, $\alpha_c < \alpha < 180^0-\alpha_c$; α_c is the loss-cone halfopening
- ϕ - phase angle in a plane normal to magnetic field (Larmor gyration plane), $0 < \phi < 360^0$, ϕ=0 at zenith direction
- I is magnetic field inclination angle,
- C(E) - normalization function

$$C(E) = \int_0^{2\cdot\pi}\int_0^{\pi} \sin(\alpha)^{k+1}\cdot e^{R(E,\alpha)\cdot\frac{\cos(I)}{H}\cdot\sin(\phi)}\, d\alpha\, d\phi$$

More analytical relationships

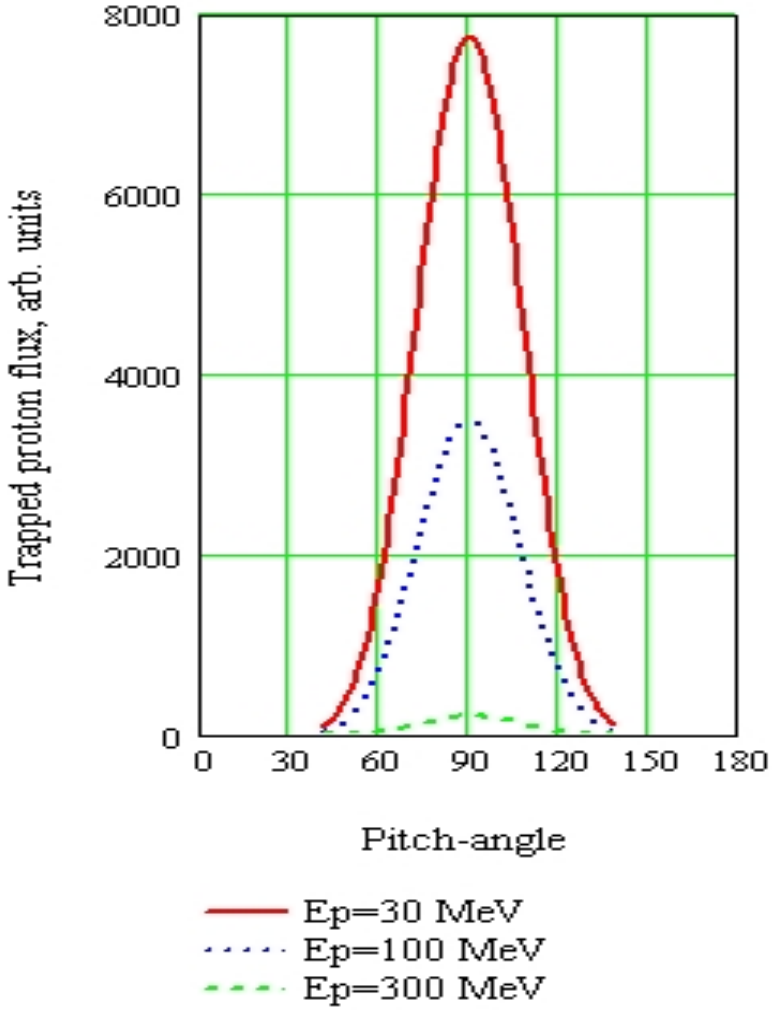
$$j(E) = \int_0^{2\pi} \int_0^{\pi} j_p(E, \alpha, \phi) \cdot \sin(\alpha)\, d\alpha\, d\phi$$

$$j_{west}(E) = \frac{j(E)}{C(E)} \cdot \int_0^{\pi} \int_0^{\pi} \sin(\alpha)^{k+1} \cdot e^{R(E,\alpha) \cdot \frac{\cos(I)}{H} \cdot \sin(\phi)}\, d\alpha\, d\phi$$

$$j_{east}(E) = \frac{j(E)}{C(E)} \cdot \int_{\pi}^{2\pi} \int_0^{\pi} \sin(\alpha)^{k+1} \cdot e^{R(E,\alpha) \cdot \frac{\cos(I)}{H} \cdot \sin(\phi)}\, d\alpha\, d\phi$$

$$j(E) = j(west) + j(east)$$

Pitch-angle dependence: the same for any proton energy and solar cycle time



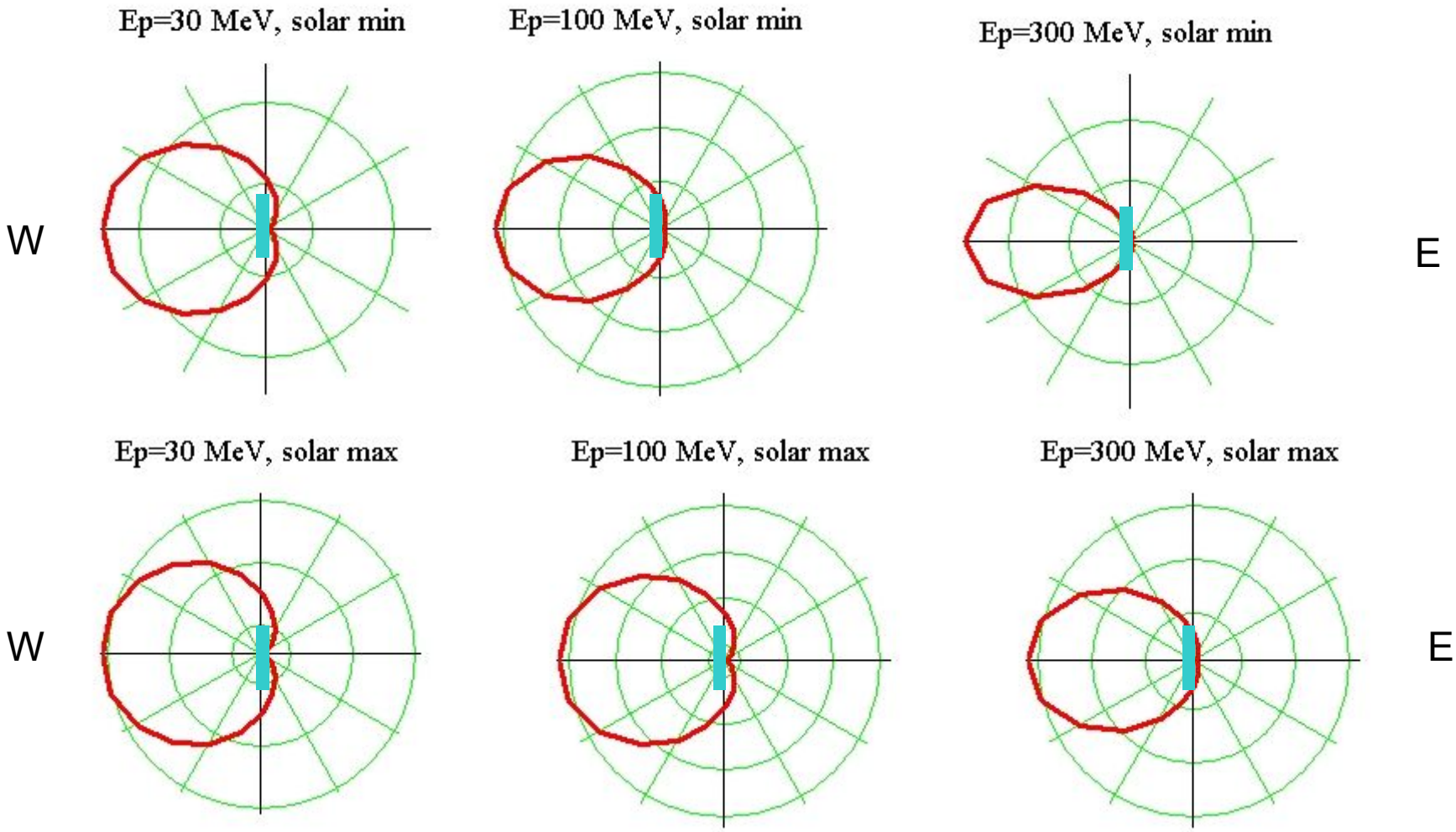
J(B) is AP8 omnidirectional flux

$$j(\alpha_0) = \frac{-B_p^{\left(\frac{3}{2}\right)}}{2\cdot\pi^2}\cdot\int_{B_p}^{B_{lc}}\left[\frac{d}{dB}\left(\frac{J(B)}{B}\right)\right]\cdot\frac{1}{\left(B-B_p\right)^{\frac{1}{2}}}\,dB$$

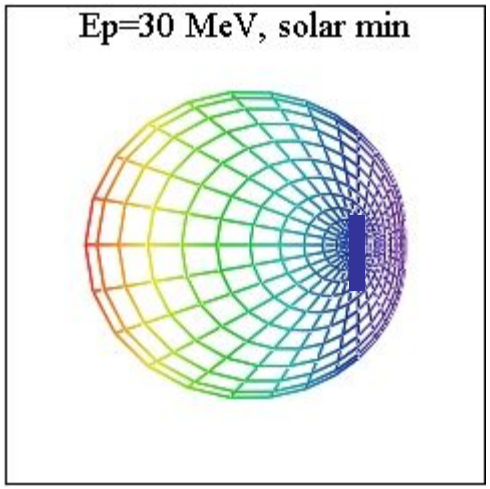
$$B_p = \frac{B_0}{\left(\sin(\alpha_0)\right)^2}$$

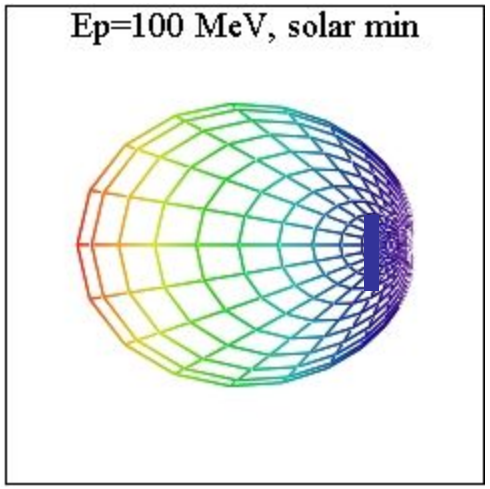
$j(\alpha) \sim (\sin(\alpha))^k$, *k* is from 5 to 15

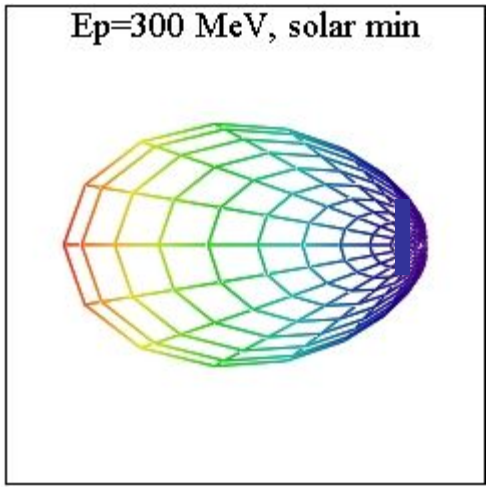
Phase angle dependence



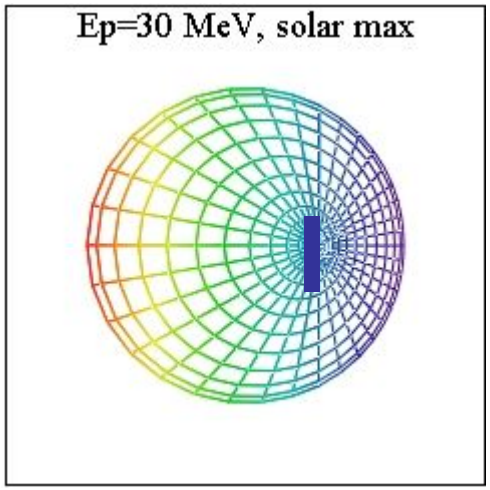
3-D visualization of the angular dependences

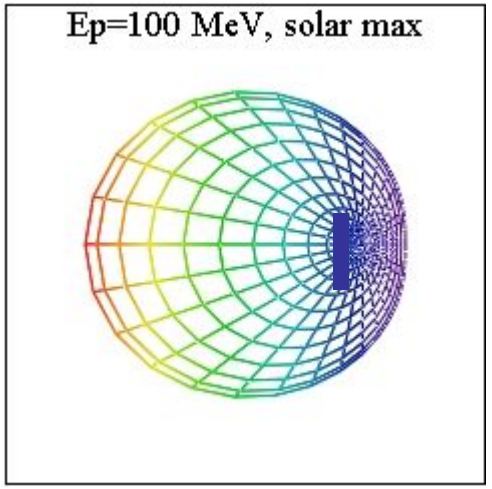


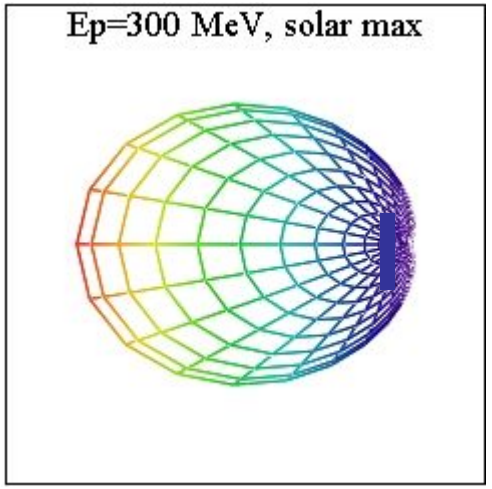




W E

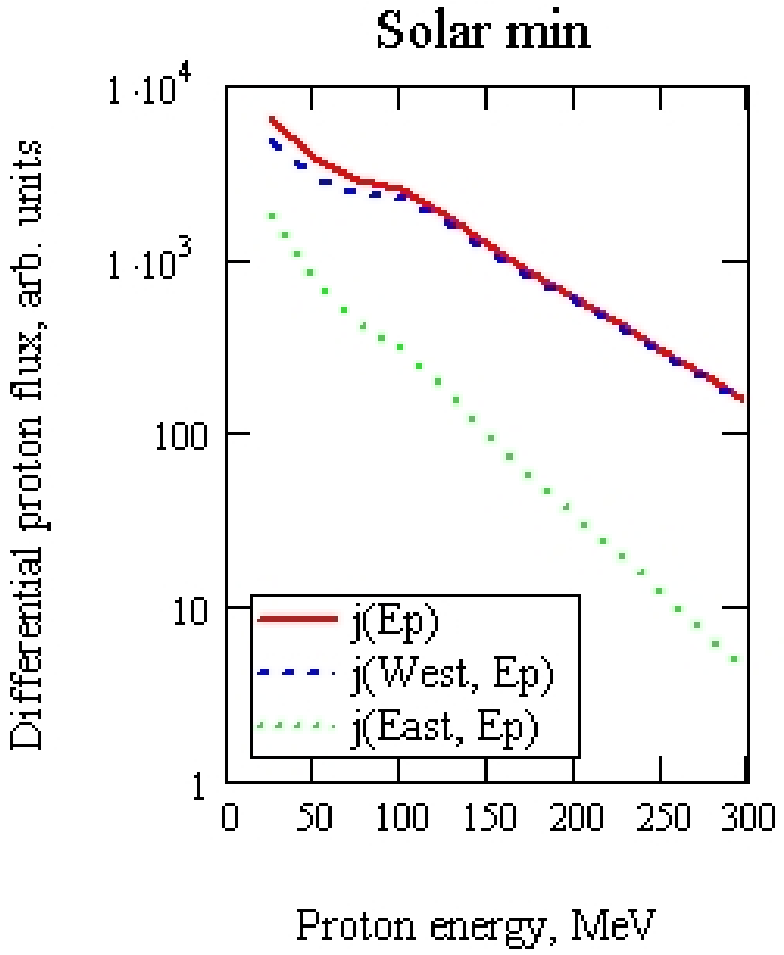


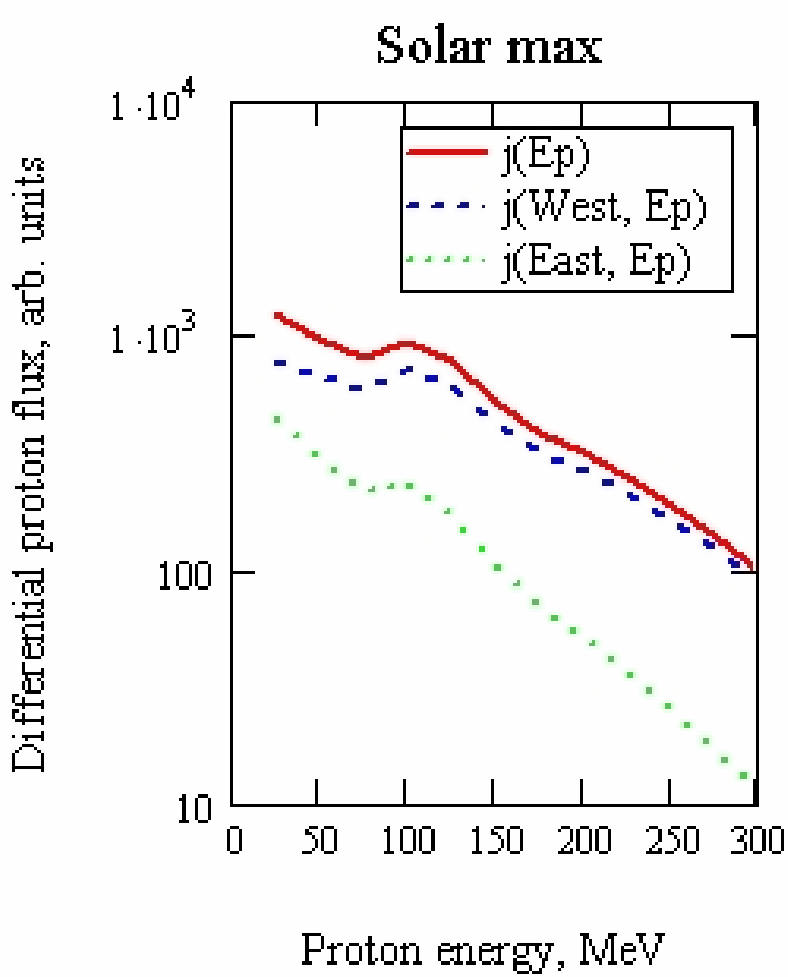




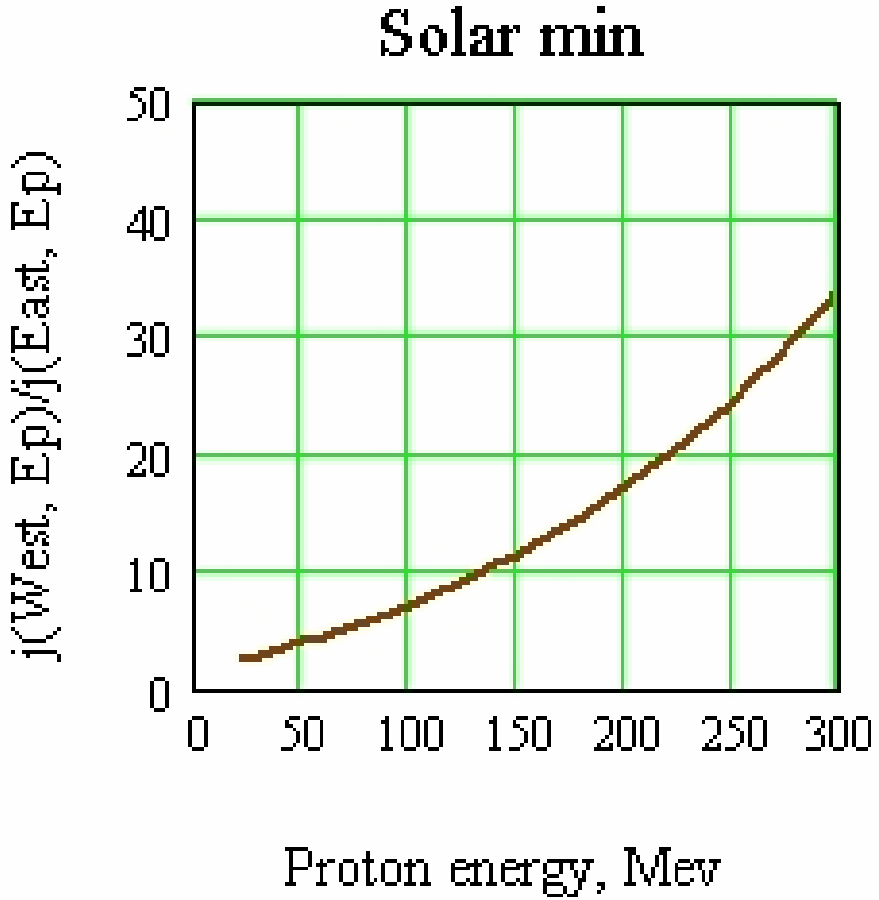
W E

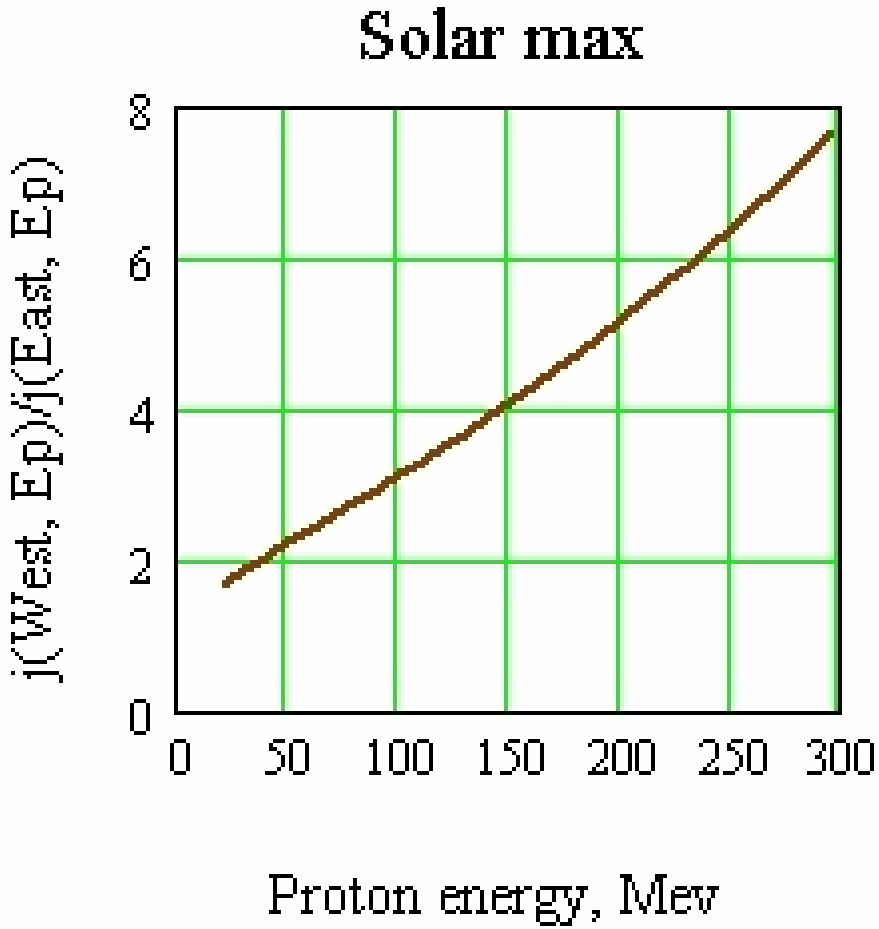
Relationship between the west and east differential proton fluxes





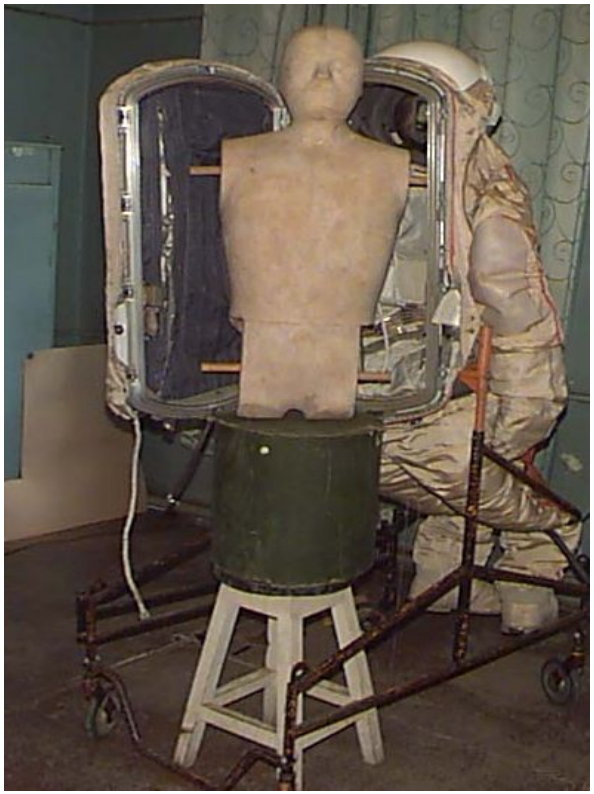
Ratio j_p(West)/j_p(East)





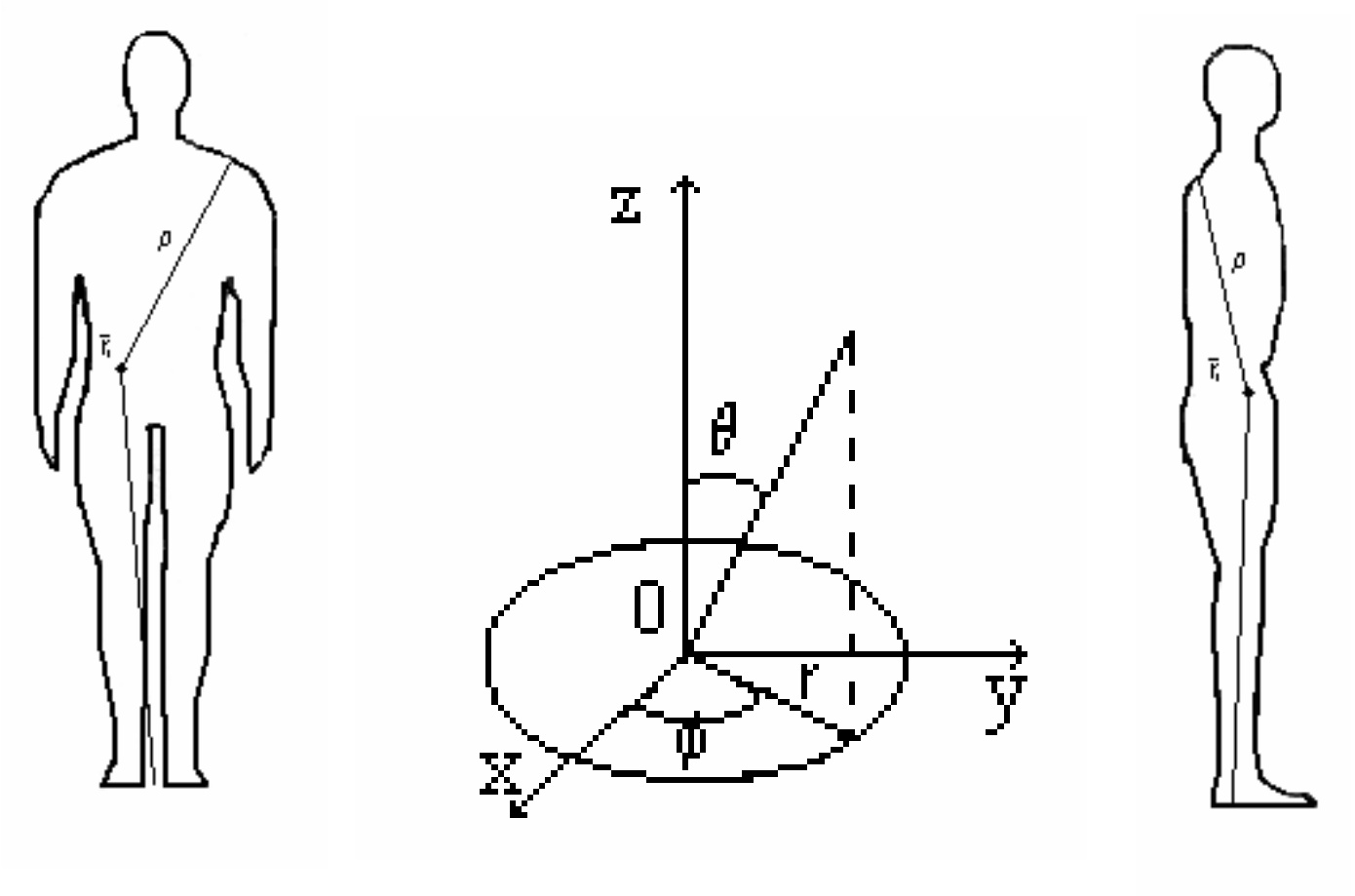
On ground ORLAN-M Spacesuit Shielding Studies

- Cs^{137} gamma-absorption method
- (Sr^{90}+Y^{90}) beta-absorption method

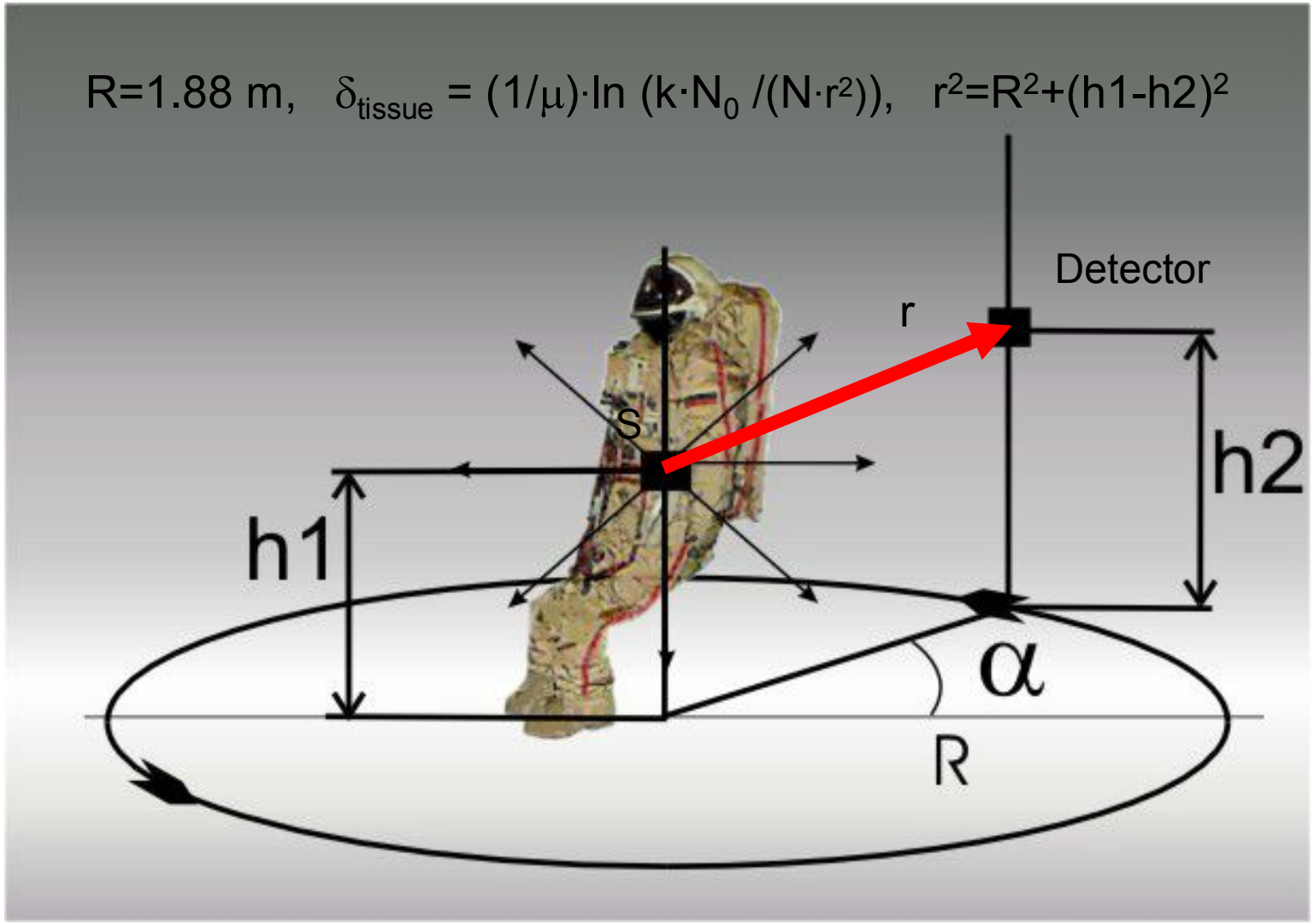


Anthropomorphic phantom in cylindrical coordinate system {z, r, φ} used for body self-shielding calculations

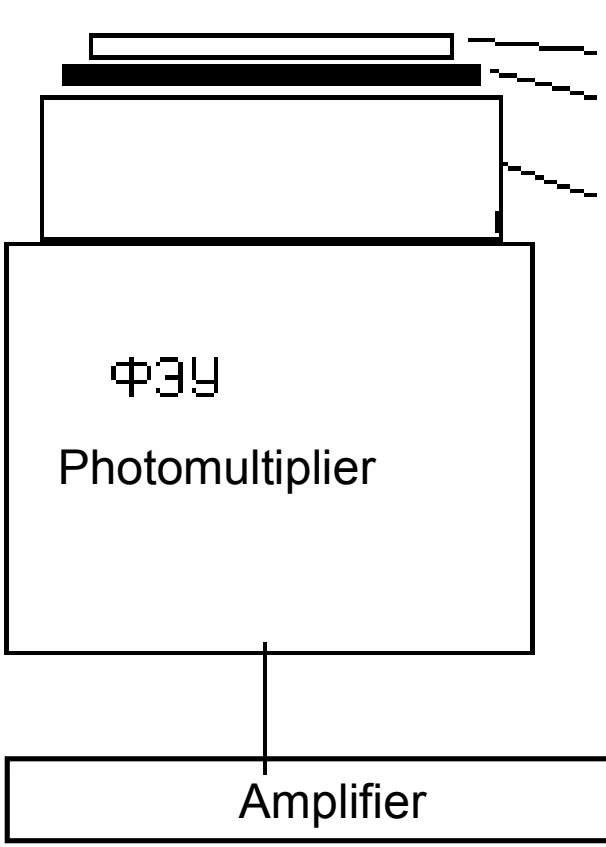
$$\rho = \sqrt{r_0^2 + r_1^2 - 2r_0 r_1 \cos(\varphi_1 - \varphi_2) + (z_1 - z_0)^2}$$



Cs^{137} gamma-absorption method



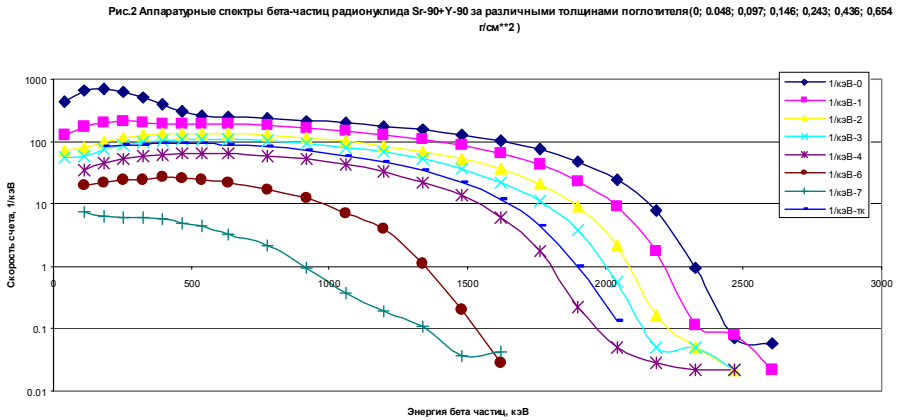
(Sr^{90}+Y^{90}) beta-absorption method



Beta source

Spacesuit tissue, δ

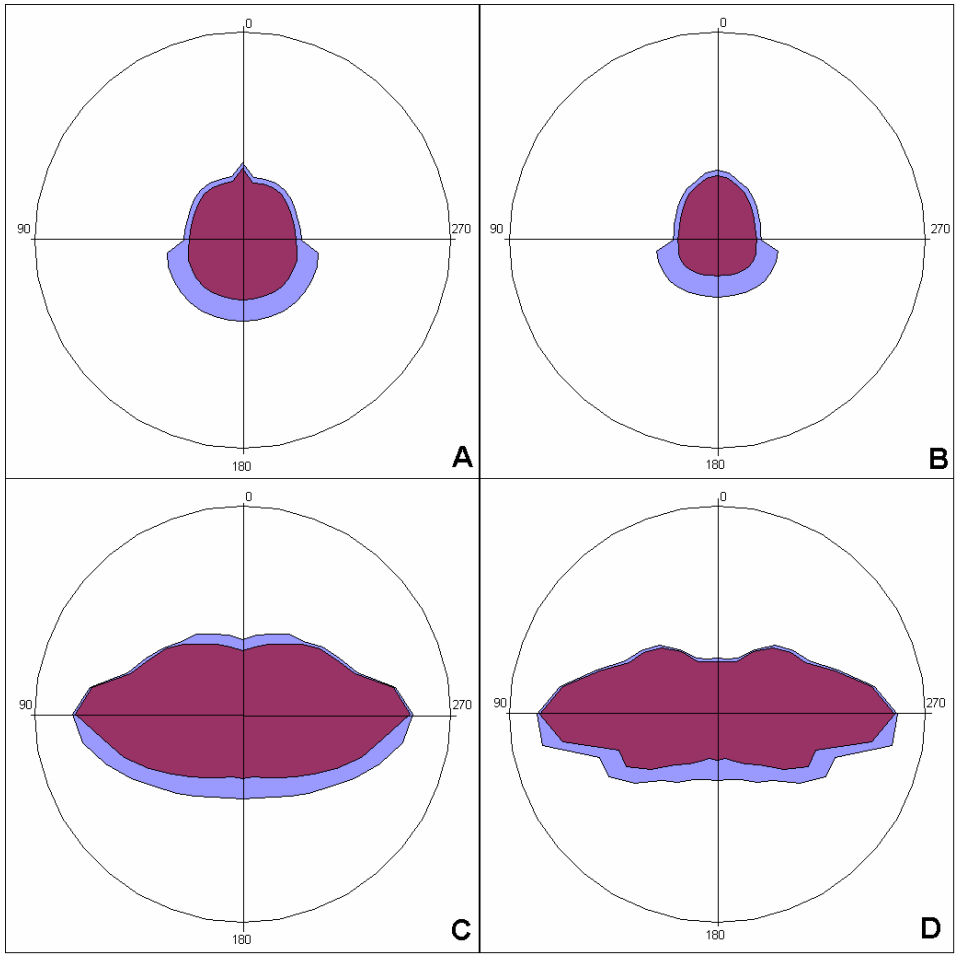
Scintillator



$\delta_{\text{arm/leg spacesuit tissue}} = 0.21\ \text{g/cm}^2$

Orlan-M Spacesuit + Phantom cross-sections

Z = 1569 mm (head)



Z = 1498 mm (neck)

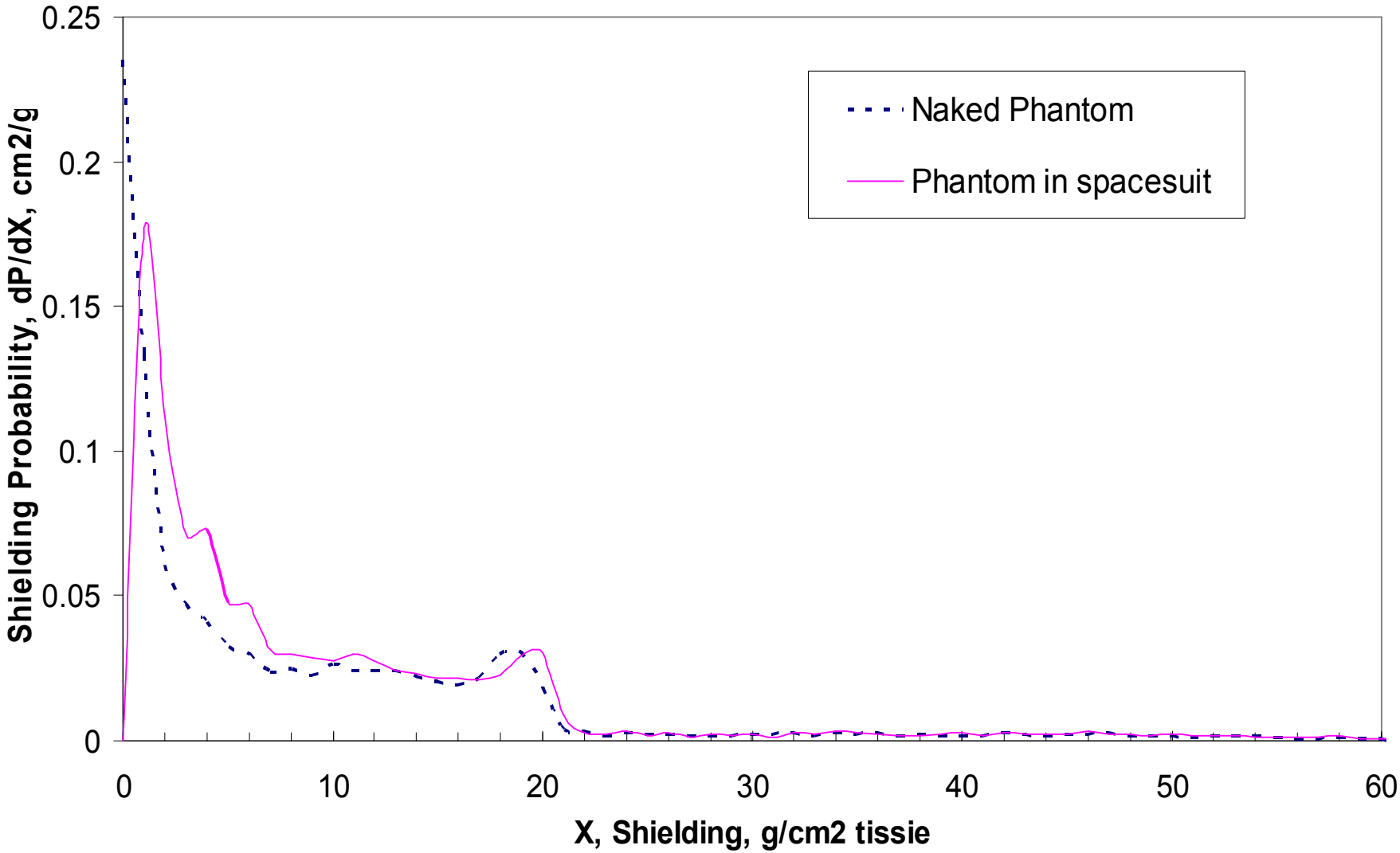
Z = 1315 mm (chest)

Z = 834 mm (bottom of the body)

The ORLAN-M spacesuit shielding

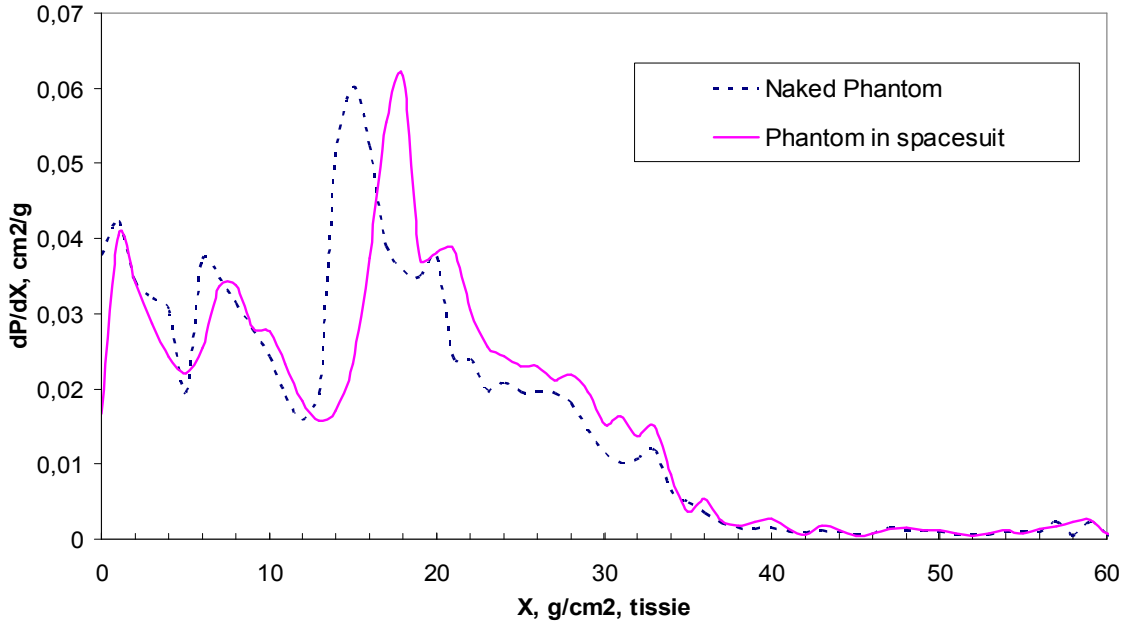
Spacesuit part	Min shielding, g/cm^2	E_e min, MeV	E_p min, MeV
Arm/leg tissue (with water cooler tubes)	0.4	1.1	20
Helmet	0.5	1.4	23
Cuirass (chest)	1.9	4.8	46
Cuirass (back)	3.5	8.7	65

Eye Lens Shielding function

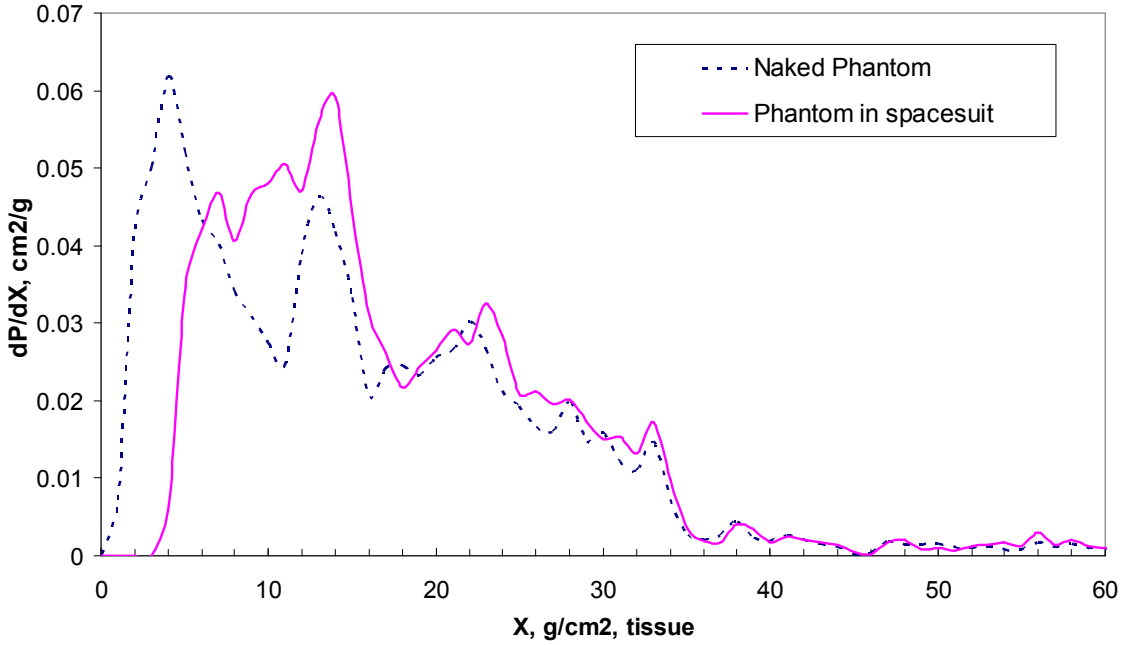


BFO Shielding Functions

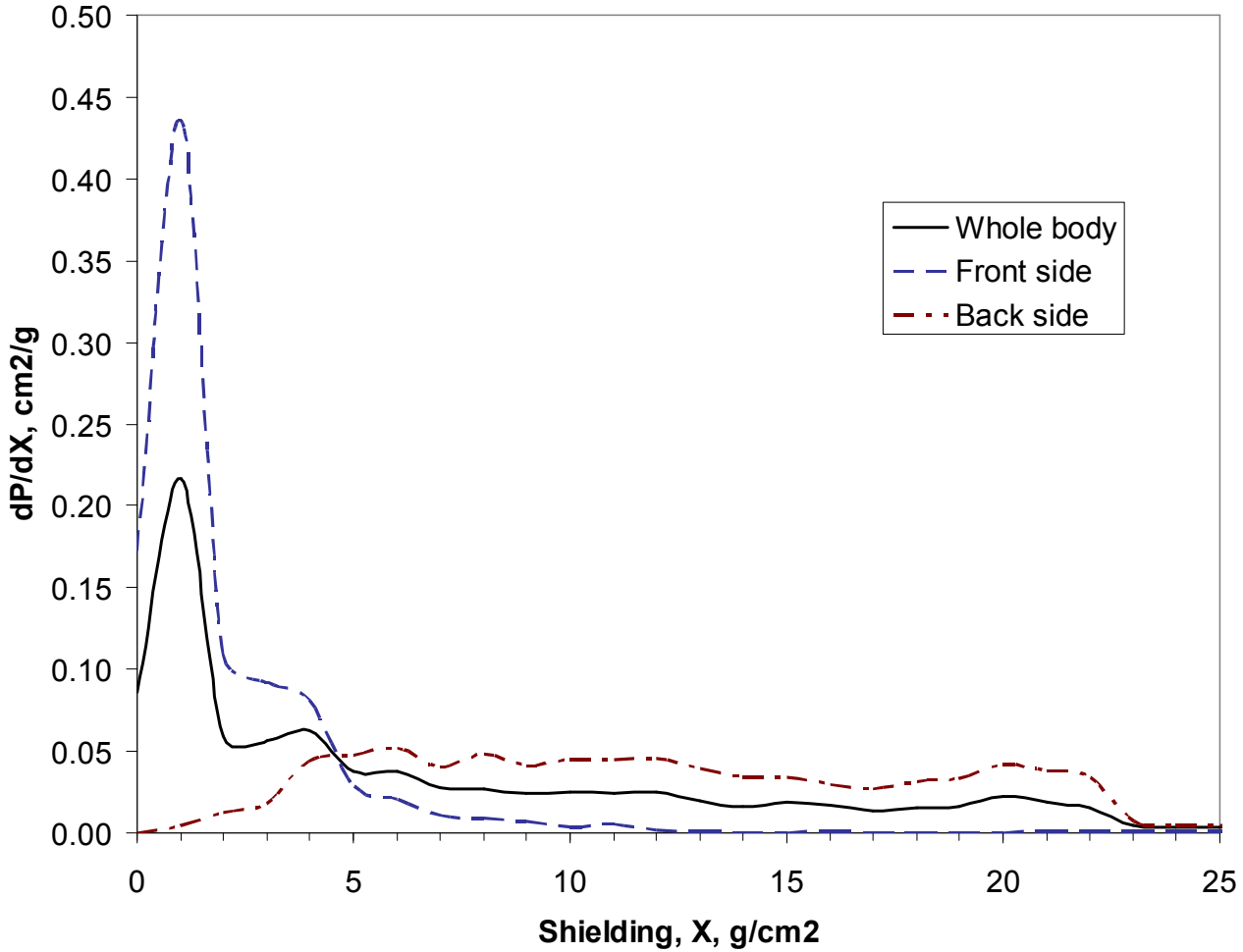
Chest



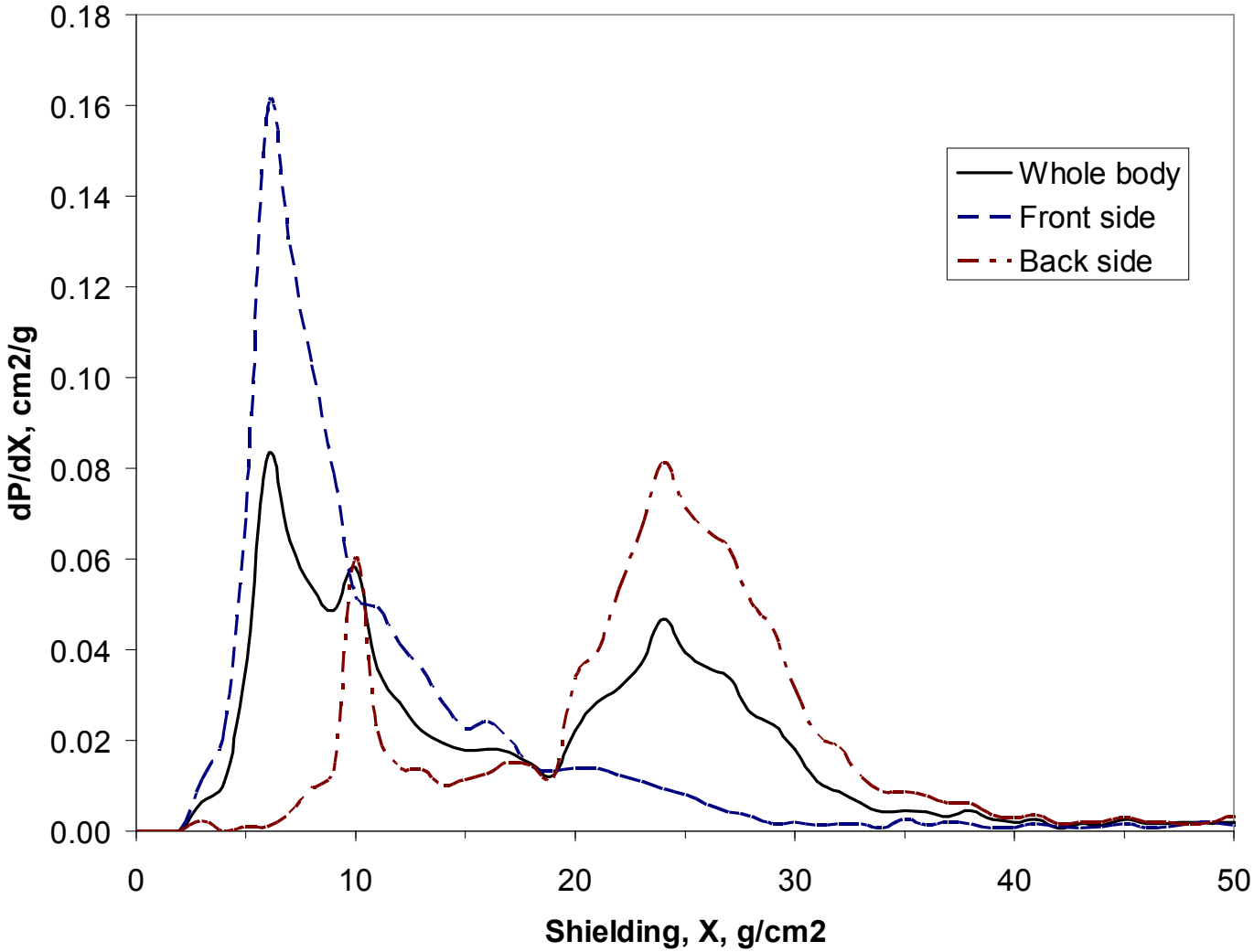
Back



Eye lens shielding functions when in ORLAN-M spacesuit

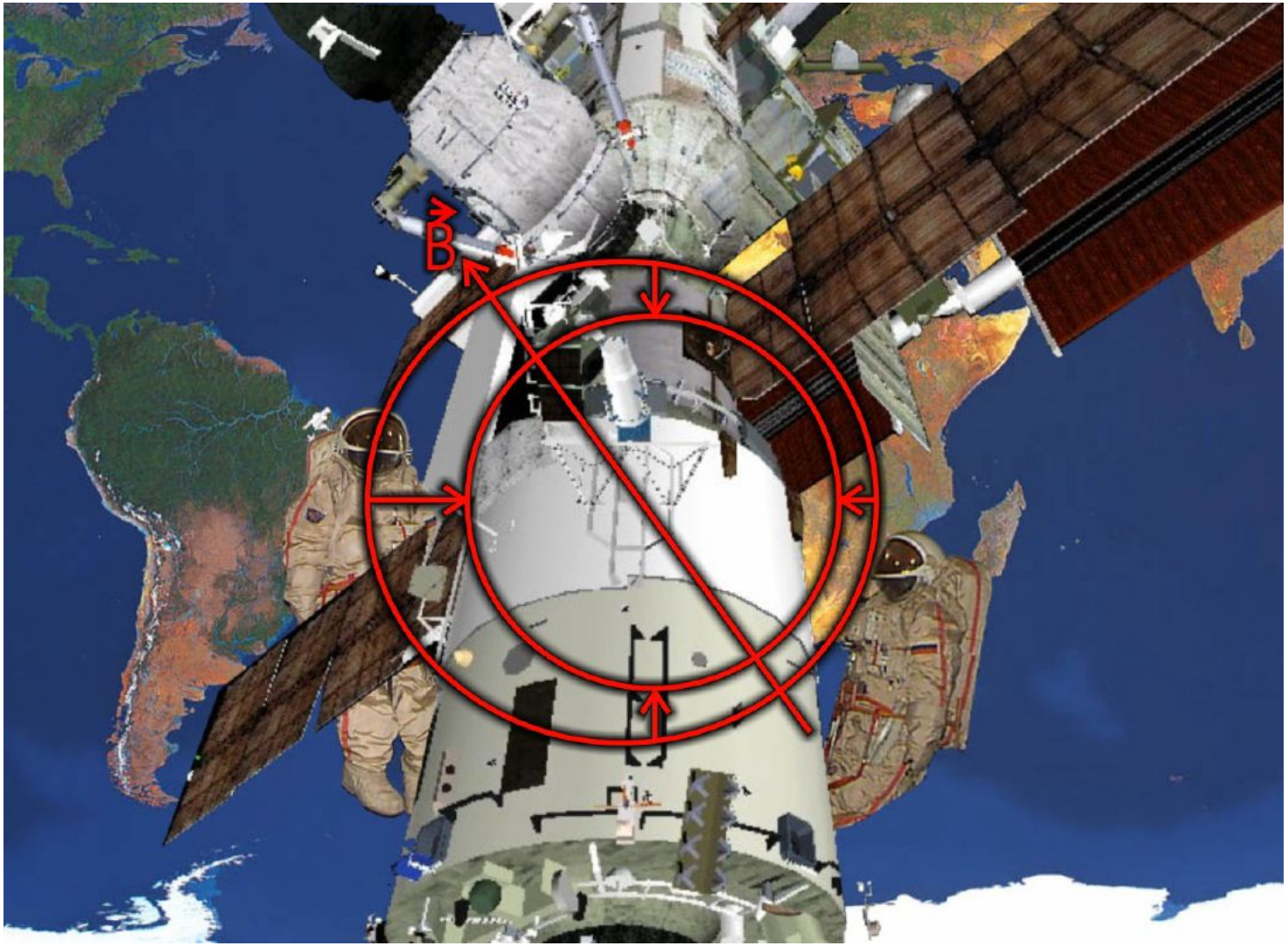


Testis shielding functions when in ORLAN-M spacesuit



EVA Doses and East-West Asymmetry of trapped protons

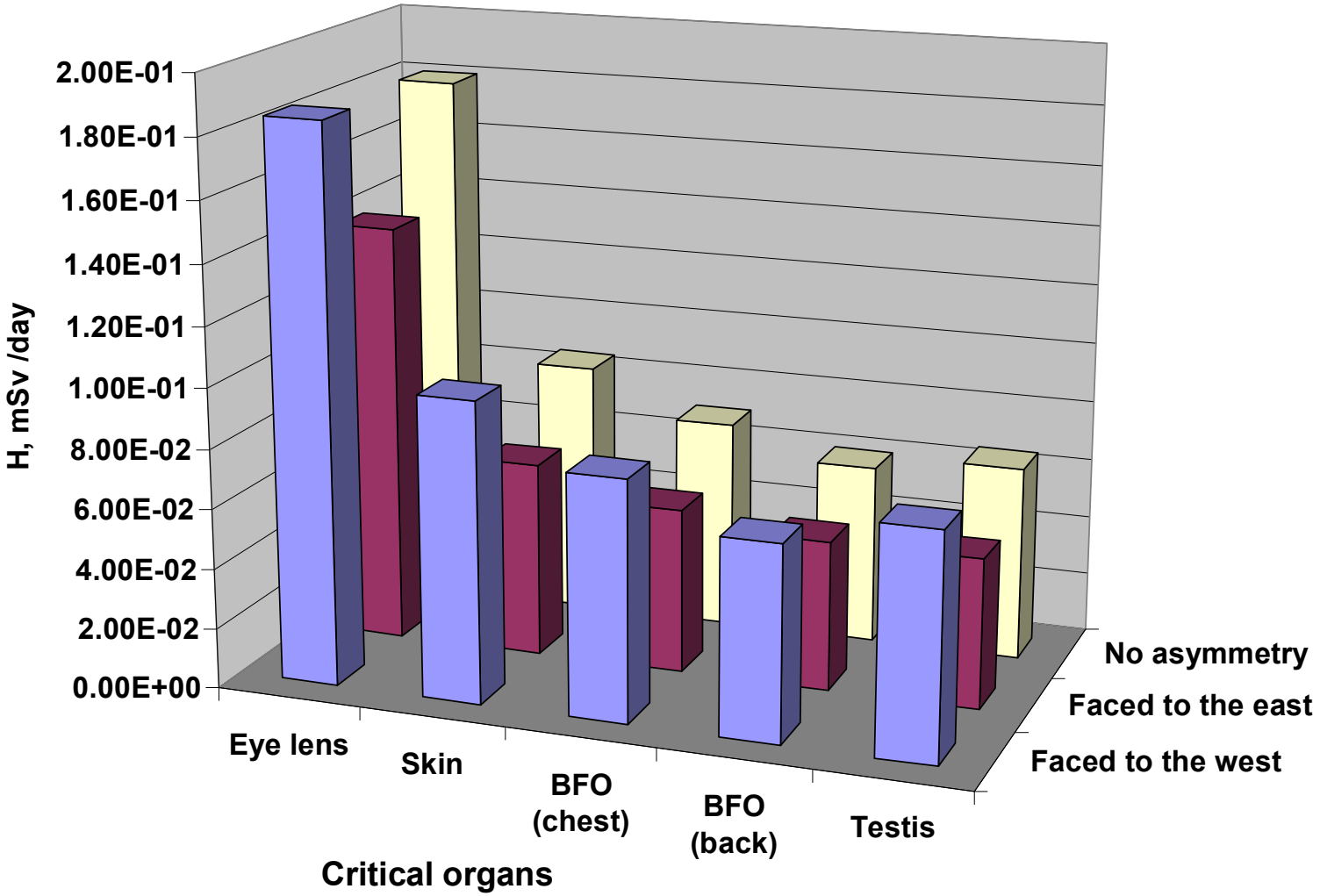
W



E

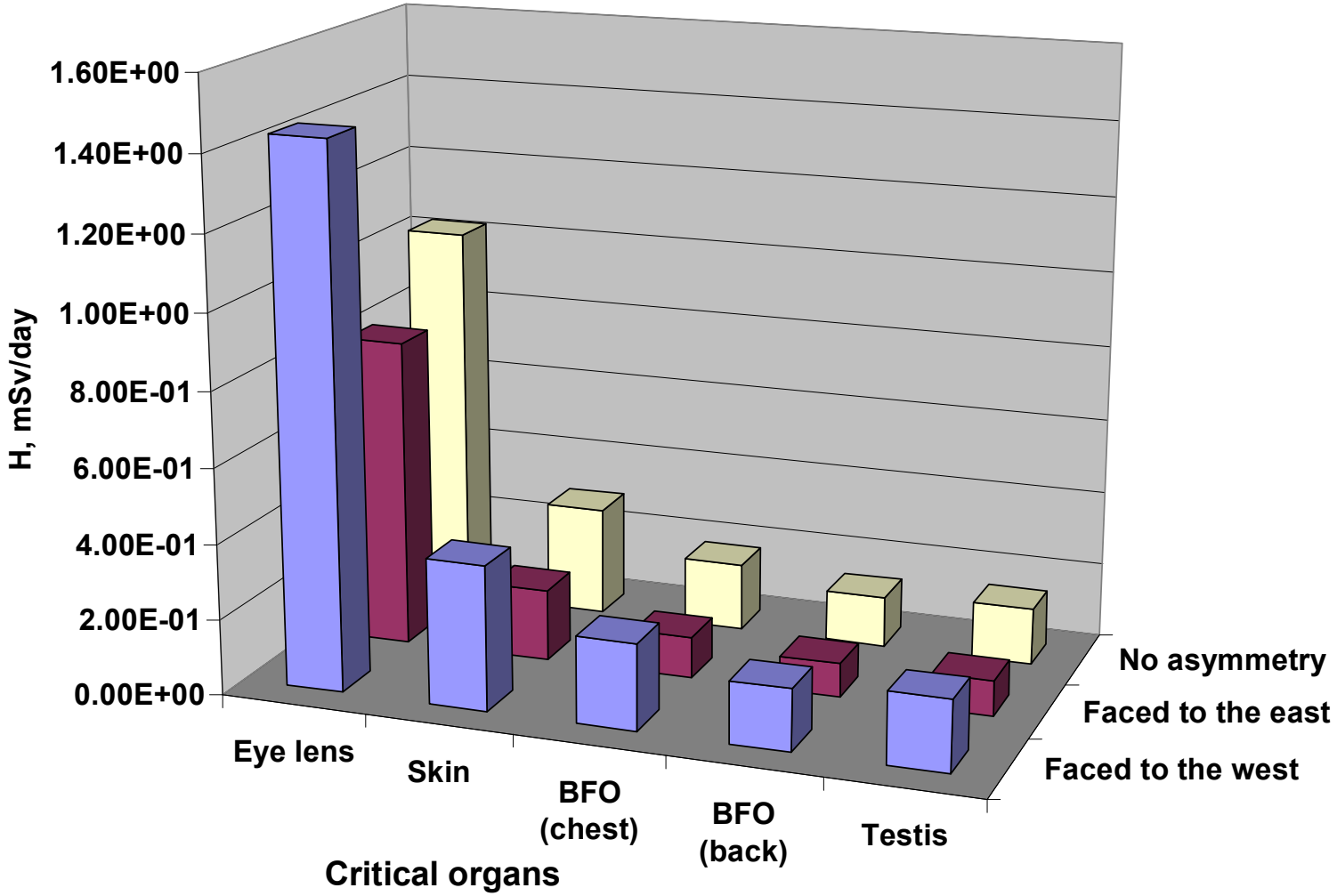
Trapped Proton Doses in ORLAN-M Spacesuit

Solar Max, H=350 km

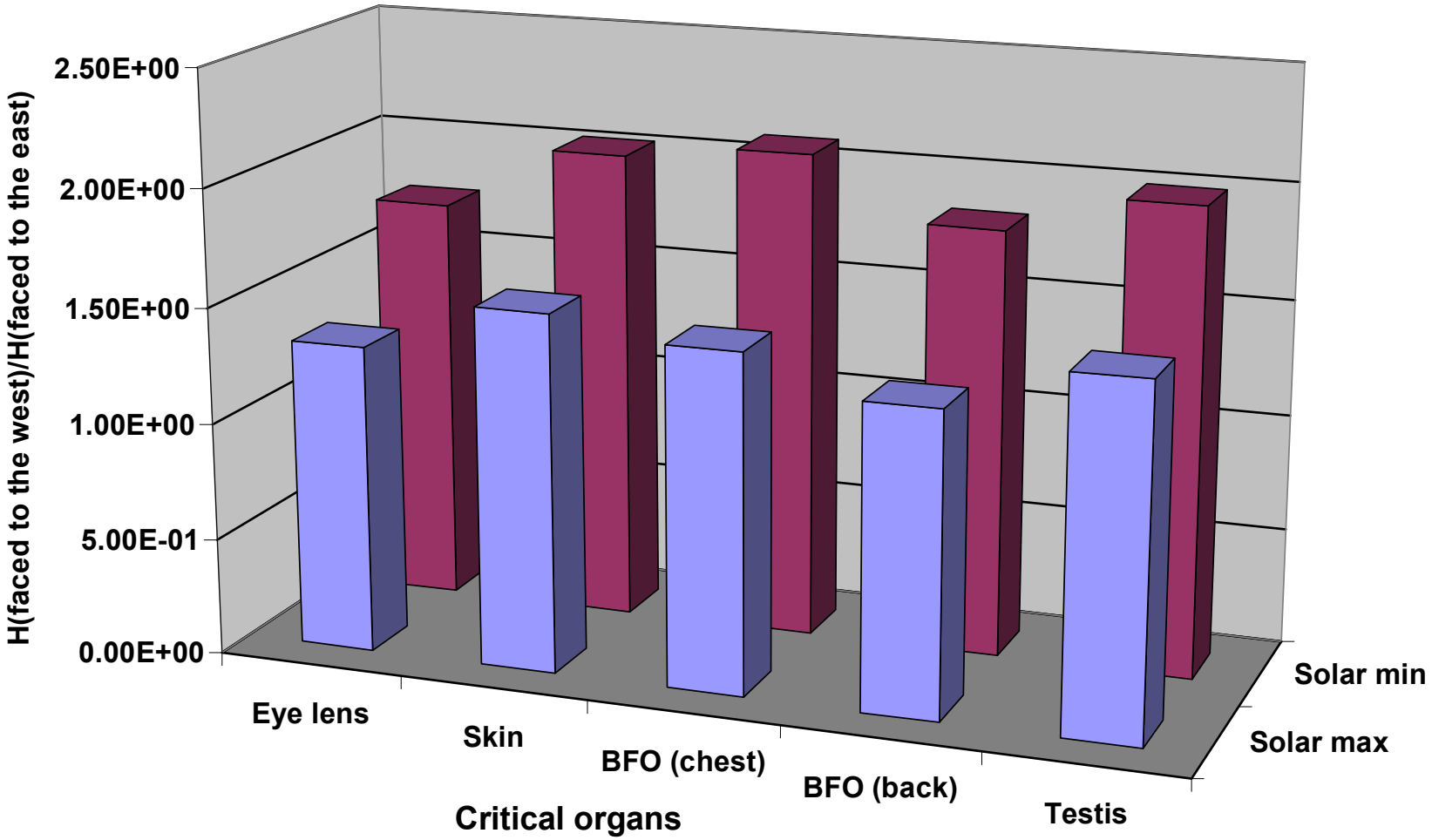


Trapped Proton Doses in ORLAN-M Spacesuit

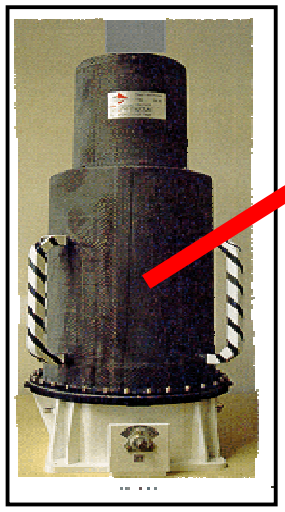
Solar Min, H=350 km

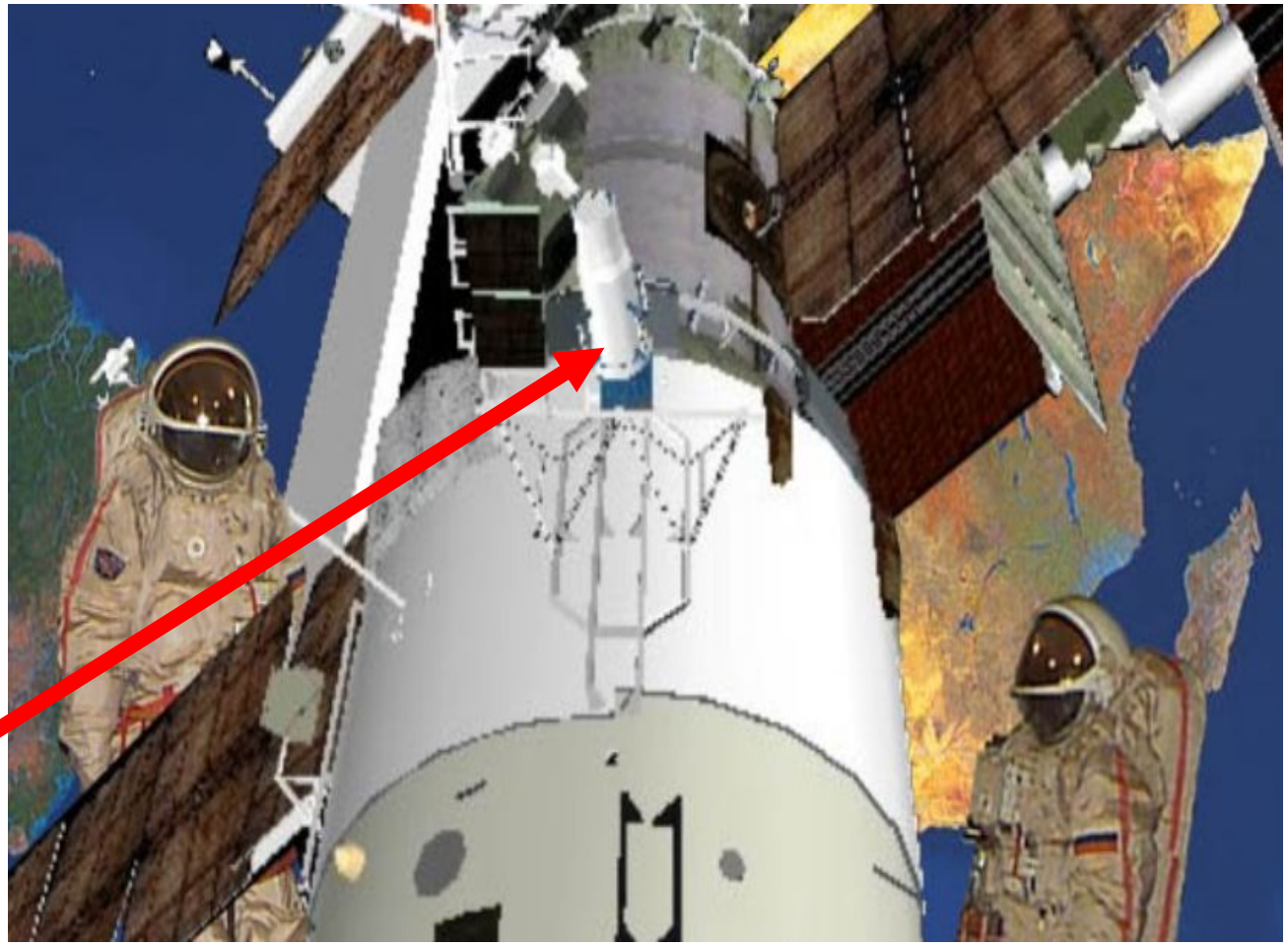


H(faced to the west)/H(faced to the east)



Matroshka-phantom





Dose Cost of the Matroshka Torso Installing and Removal as Obtained with Pille-ISS

- EVA date - Feb. 27, 2004; EVA duration – 4 hours
- EVA main purpose – installing of the Matroshka Torso phantom (ESA-RSA experiment)
- D_{EVA}(Crew member #1)=0.21 mGy;
- D_{EVA}(Crew member #2)=0.15 mGy

EVA date – Aug. 19, 2005; EVA duration – 4 hours
EVA main purpose – removal of the Matroshka Torso phantom
D_{EVA}(Crew member #1)=0.27 mGy;
D_{EVA}(Crew member #2)=0.31 mGy

Conclusions

- An approach to the description of trapped proton angular distribution is proposed
- ORLAN-M Shielding model is developed based on on-ground experimental studies;
- EVA Dose calculations are done for a crew member faced to the west and to the east at solar min and max

Conclusions

New data on the East-West asymmetry effect are expected from

- Matroshka Torso experiment
- Liulin-ISS, Liulin-5
- CPDS (Charged Particle Directional Spectrometer, NASA)
- TRITEL (Three directional TELescope, Hungary)
- …

Conclusion

- Sometimes it is much better to be faced to the East rather than to the West…