Ninth Workshop Solar Influences on Magnetosphere, Ionosphere and Atmosphere
Sunny Beach, Bulgaria, June 3, 2017

Comparision of Liulin-MO dosimeter radiation measurements during ExoMars 2016 TGO cruise to Mars and dose estimations based on galactic cosmic ray models.

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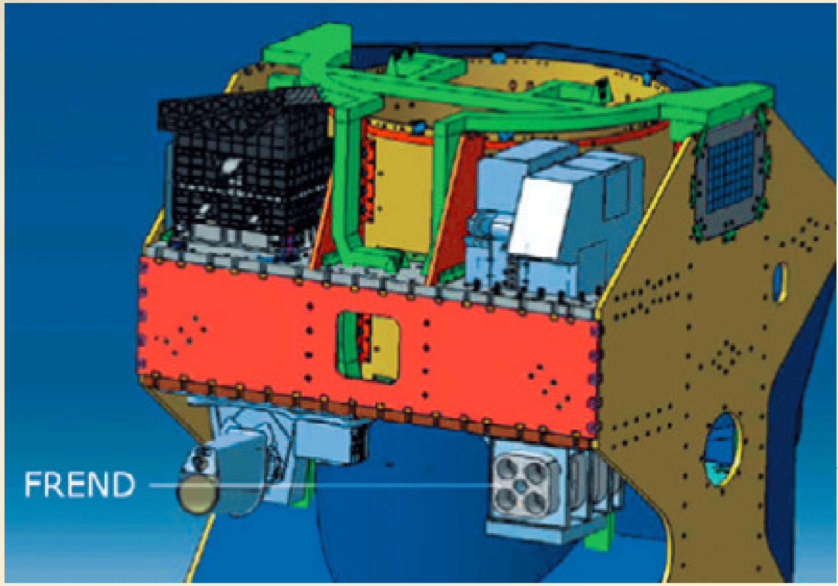
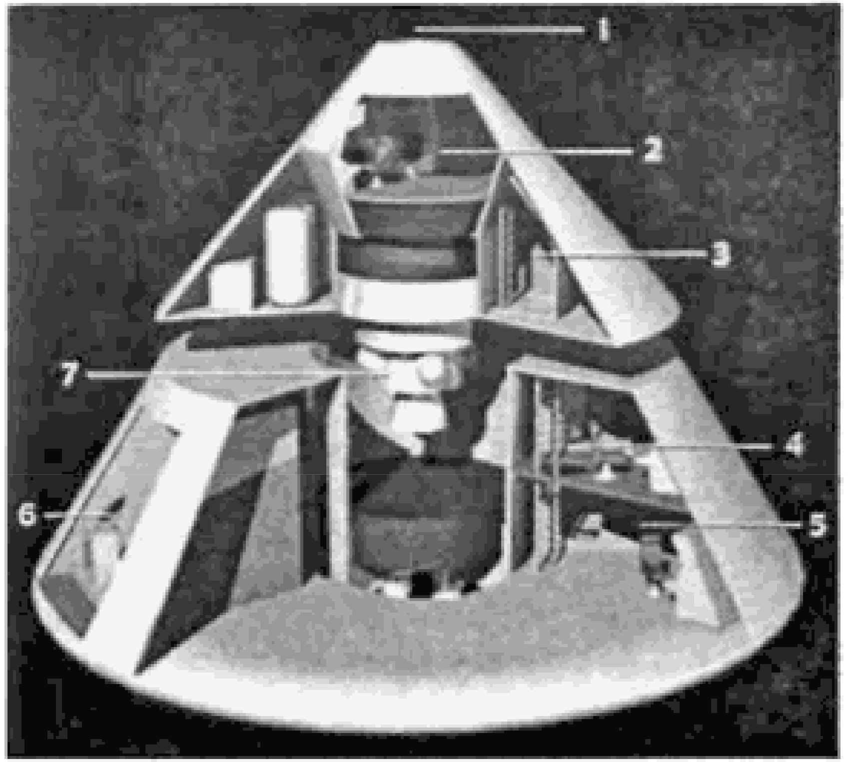
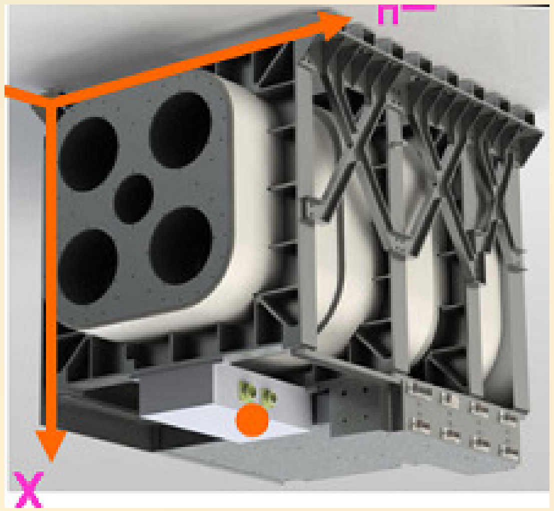
Target: Radiation environment estimation applicable for manned Mars missions.





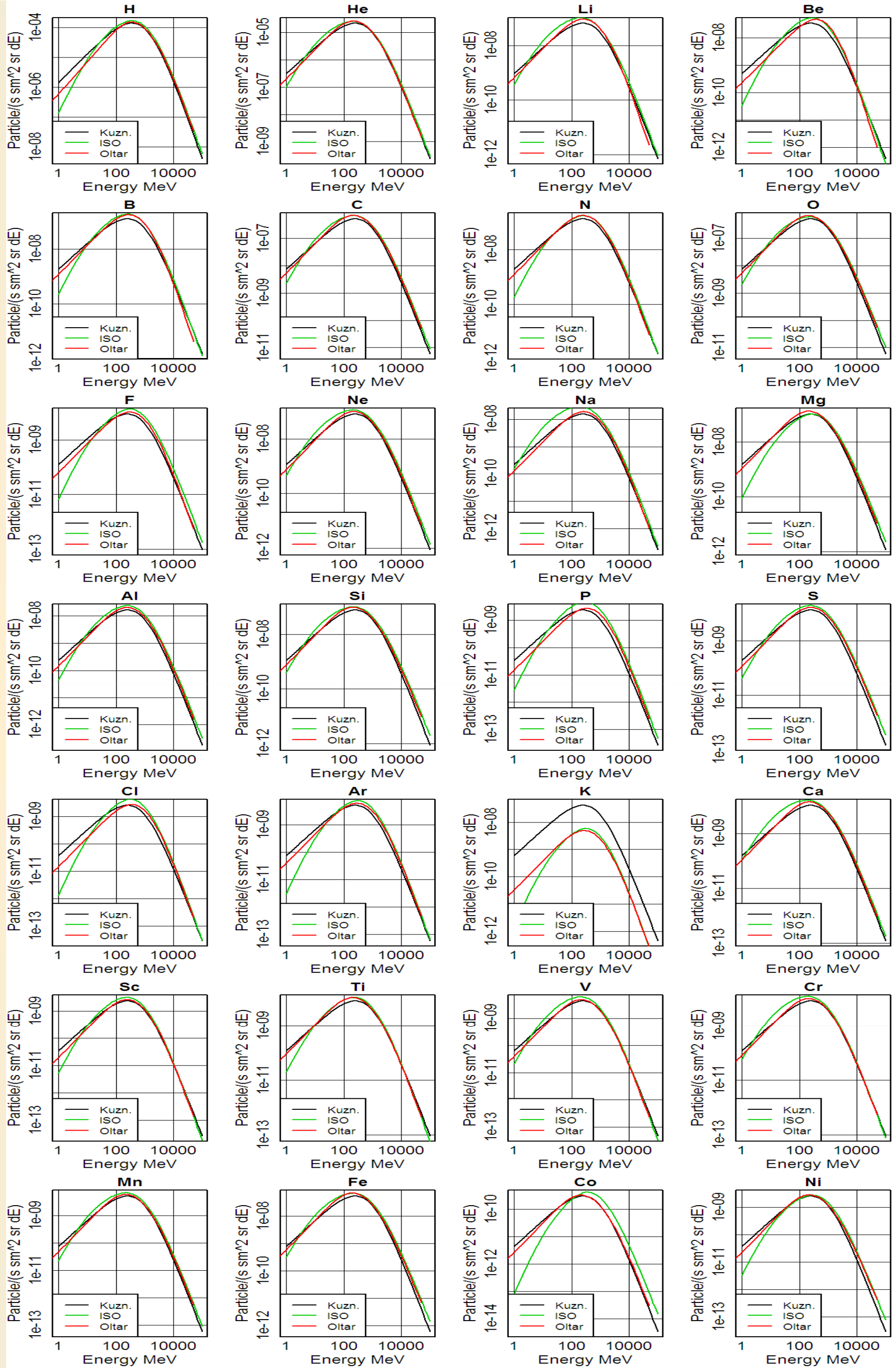
Компоновка посадочного модуля «Mars Excursio n Module» (проект «Apollo-X—NERVA»): 1 - стыковочный узел, 2 - центр управления, 3 - переходной тоннель, 4 - пультовая, 5 - лаборатория, 6 - гараж для марсохода, 7 – двигатель возвращаемой ступени



http://www.xliby.ru/istorija/bitva_za_zvezdy_2_kosmicheskoe_protivostojanie_chast_i/p7.php

Galactic cosmic ray models

- The Badhwar–O'Neill GCR model. O'Neill, P.M. Badhwar–O'Neill 2010 galactic cosmic ray flux model—Revised. IEEE Transactions on Nuclear Science 57 (6), 3148–3153, 2010.
- International standard ISO/DIS 15390
  ISO 15390. Space environment (natural and artificial) – galactic cosmic ray model, 2004.
- SINP-2017 GCR model



The Badhwar–O'Neill Galactic cosmic ray model brief description

$$\frac{j(r,E)}{E^2 - m^2} = \frac{j_0(r_B, E + Ze\phi)}{(E + Ze\phi)^2 - m^2}$$

Where: j_0 is the local interstellar spectrum
φ - the deceleration potential

$$j_l = j_0 \beta^{\delta} (E + E_0)^{-\gamma},$$

where E and E_0 are, respectively, the particle kinetic and rest energy and/or nucleon, and δ; γ, and j_0 are the fitting parameters for each charge group

$$\phi(r,t) = \frac{1}{3} \int_r^{r_B} \frac{\vec{V}_w(r',t)}{\kappa(r',t)} dr'$$

where r_B is the radial extent of the heliosphere, *k* is the diffusion coefficient, and V_w is the solar wind velocity.

ISO 15390 galactic cosmic ray model brief description

GCR particle rigidity spectra $\Phi_i(R,t)$ (s.m2.sr.GV)$^{-1}$ for particles of rigidity R at moment t are calculated as

$$\Phi_i(R,t) = \frac{C_i \times \beta^{\alpha_i}}{R^{\gamma_i}} \times \left[\frac{R}{R + R_o(R,t)}\right]^{\Delta_i(R,t)}$$

$$R_0\left\{\overline{W}\left[t - \Delta t(n,R,t)\right]\right\} = 0.37 + 3\times 10^{-4} \times W^{1.45}\left[t - \Delta t(n,R,t)\right]$$

where $\Delta_i(R,t)$ is a dimensionless parameter calculated as

$$\Delta_i(R,t) = 5.5 + 1.13\frac{Z_i}{|Z_i|} M(W,n) \times \frac{\beta R}{R_o(R,t)} \exp\left(-\frac{\beta R}{R_o(R,t)}\right)$$

The lag, $\Delta T(n,R,t)$, of GCR flux variations relative to solar activity variations

$$\Delta T(R,n,t) = 0.5\left[T_+ + T_-(R)\right] + 0.5\left[T_+ - T_-(R)\right] \times \tau(\overline{W})$$

SINP-2017 galactic cosmic ray model brief description

The formula for calculating the particle flux F(z)(E,t) for any time t and over the entire range of energy E can be represented as

$$F^{(z)}(E,t) = A^{(z)} * E^{-\gamma} * \Psi^{(z)}(E,t)$$

where $\Psi^{(z)}(E,t)$ is a function depending on energy E as well as time t. We will call $\Psi^{(z)}(E,t)$ the "deceleration function".

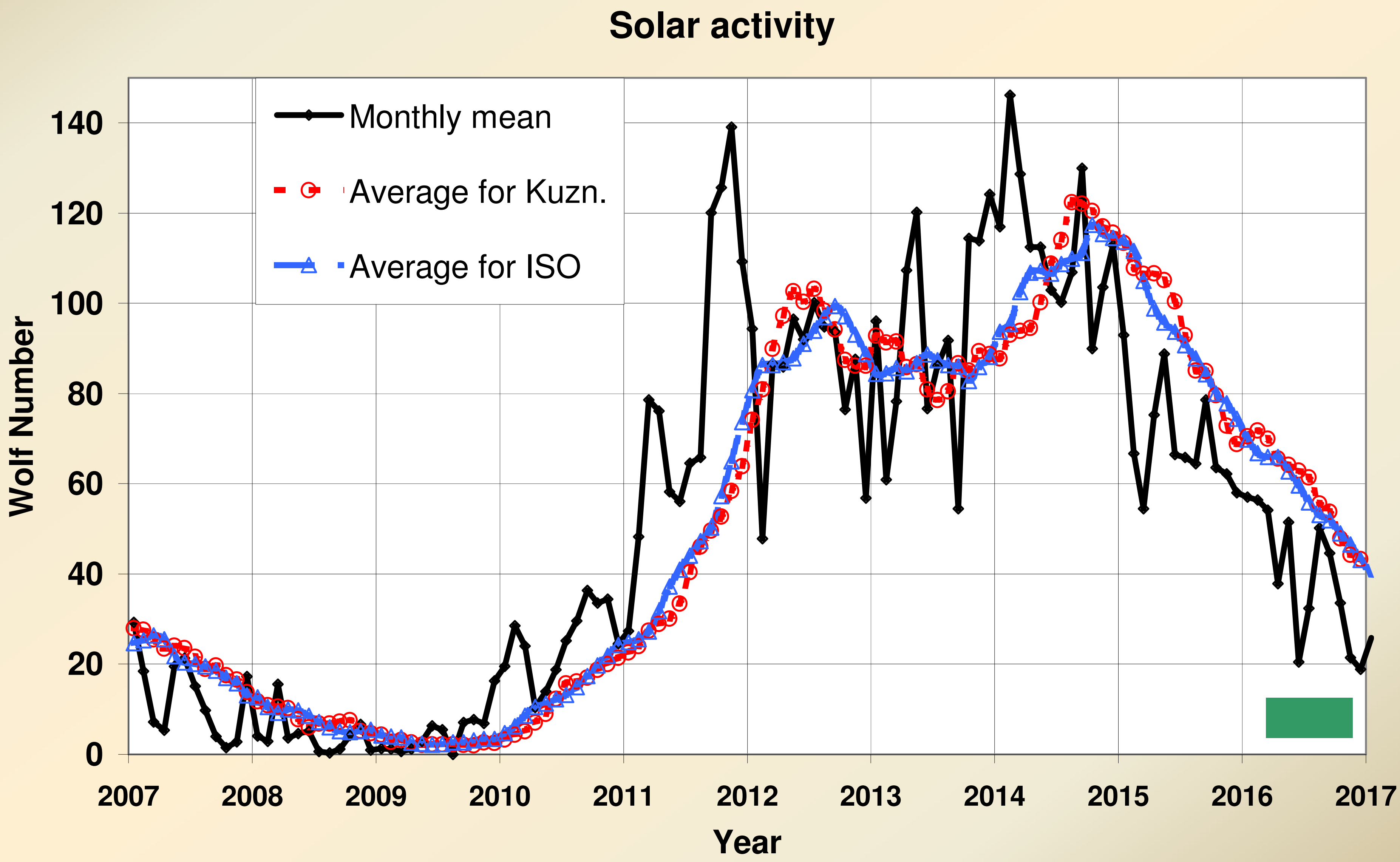
$$\Psi^{(z)}(E,t) = \left(\frac{E}{E + \varepsilon^{(z)}(t)} \right)^{3.7}$$

where $\varepsilon^{(z)}(t)$ is a deceleration potential (in MeV/nucleon) depending on time t.

$$\varepsilon^{(z)}(t,r) = \varepsilon_0^{(z)}(r) + k^{(z)}(r) \cdot W(t - \Delta t) = \varepsilon_0^{(z)} r^{-\alpha} + k^{(z)}(1 - r/120) \cdot W(t - \Delta t)$$

Е.П. Попова, Н.В. Кузнецов, М.И. Панасюк. Прогнозирование потоков ГКЛ для будущих космических миссий. – Известия РАН, серия физическая, т.81, №2, с.199-202, 2017.(in press)

Solar activity level



Dose and particle spectra beyond shielding

$$D = \int_E \varphi(E) \frac{dE}{dx}(E)\,dE$$

Where: $\varphi(E)$ - particles spectra in the point of interest;

$\frac{dE}{dx}(E)$ - particle energy losses (the stopping power S)

The stopping power S is adequately described by the Bethe-Bloch formula. The range of the ion is evaluated from the stopping power as:

$$R(E) = \int_0^E \frac{dE'}{S(E')}$$

The simplest way to evaluate particles spectra beyond shielding – to calculate them with R(E) relation.
But it isn't take into account nuclear collisions.

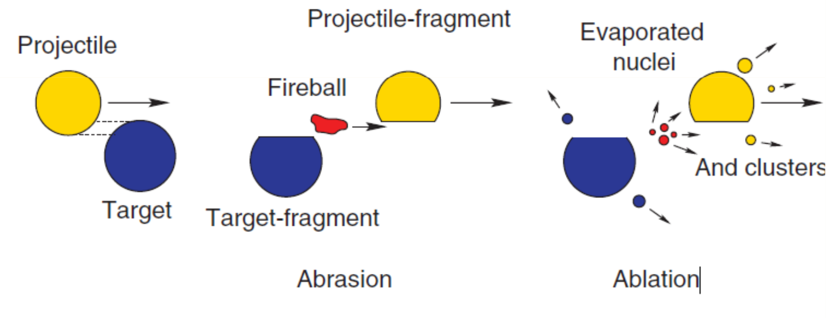


FIG. 16 (color). Illustration of the abrasion-ablation model.

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Francis A. Cucinotta
Physical basis of radiation protection in space travel
REVIEWS OF MODERN PHYSICS, VOLUME 83, OCTOBER–DECEMBER 2011

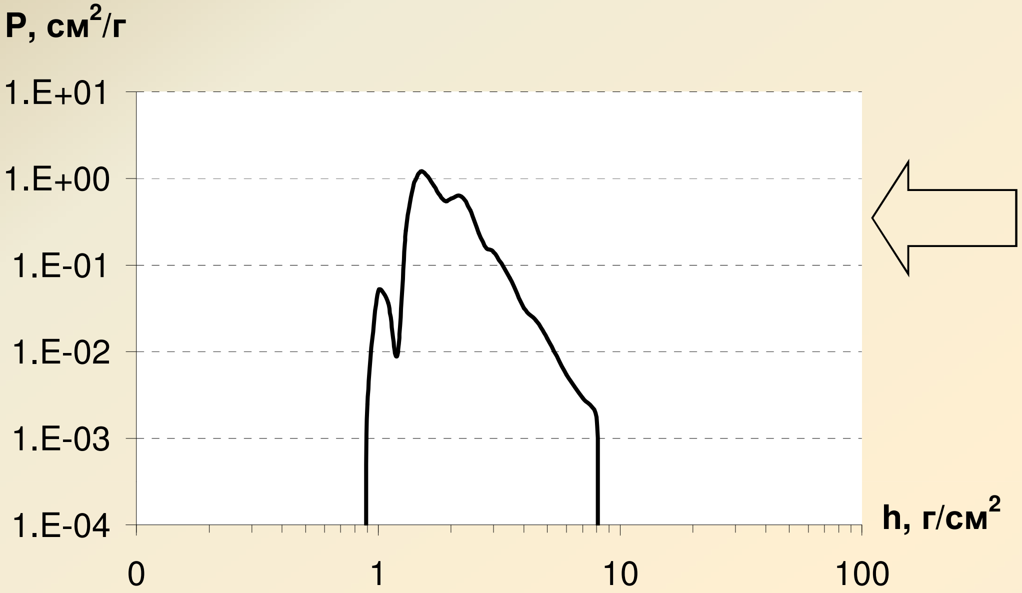
Calculation spectra beyond shielding

**“The description of the passage of high-energy particles through matter can be made using Boltzmann-type transport equations that treat the atomic and nuclear collisions that alter particle energy and types.
As an alternative, Monte Carlo (MC) computer codes sample from interaction processes for individual primaries or their secondary’s to develop histories of charged particle passage and energy deposition in materials.”**

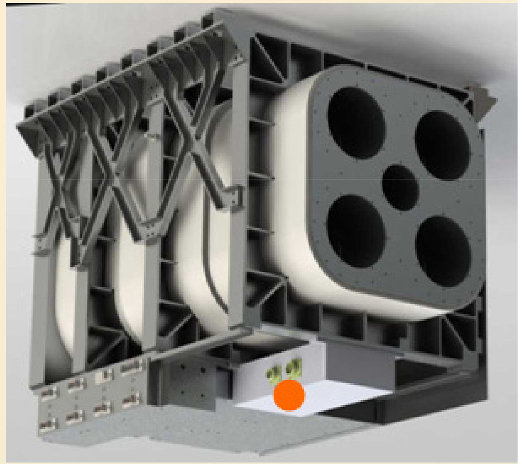
Marco Durante, Francis A. Cucinotta Physical basis of radiation protection in space travel

NASA has developed a Boltzmann equation approach for HZE nuclei transport denoted as the HZETRN code
https://oltaris.larc.nasa.gov/projects/5219/qsubs/23483

Shielding function for point located between the detectors "Liulin-MO"



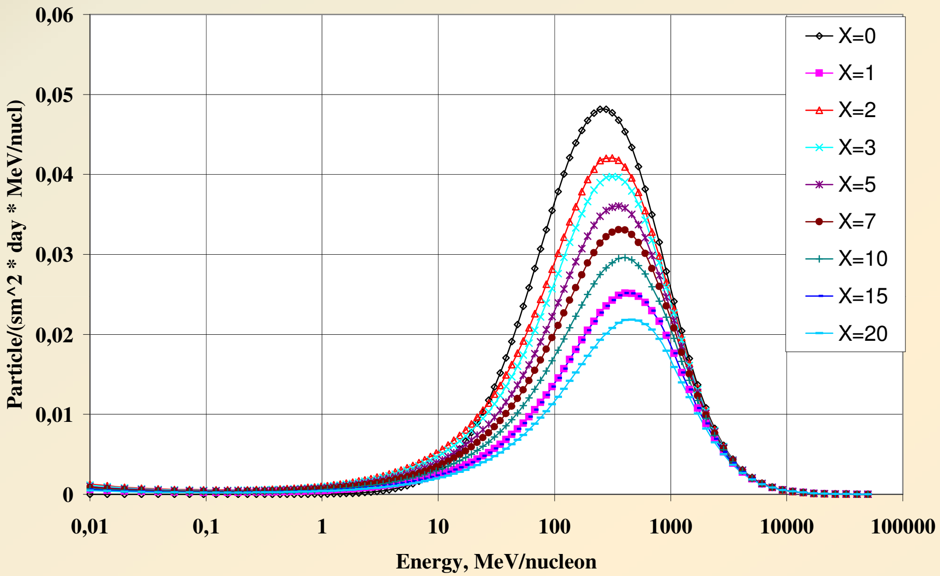
Shielding with elements of the "Liulin-MO“ dosimeter



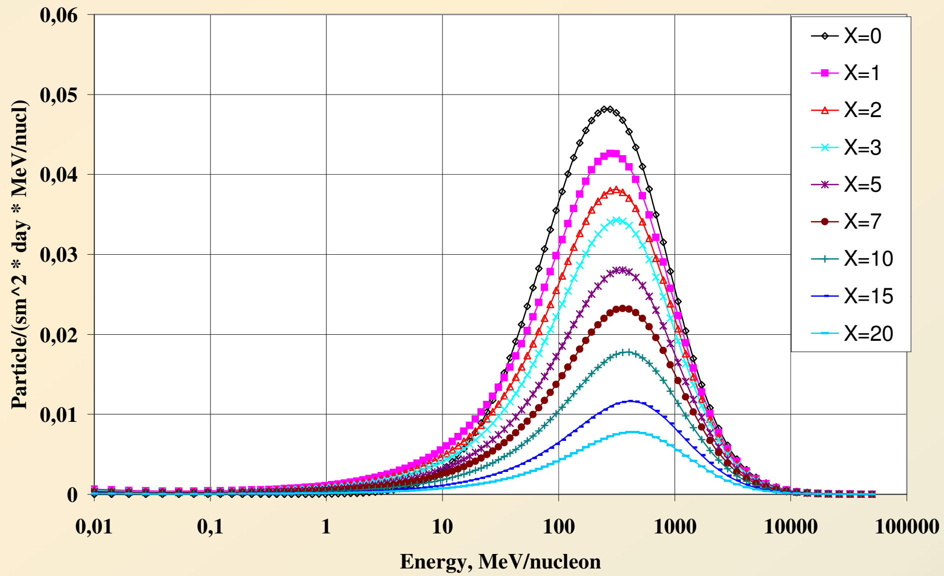
Shielding with "Liulin-MO" and "FREND" elements

Calculation Fe-56 spectra beyond shielding

Calculation Fe-56 spectra with R(E) relation



Calculation Fe-56 spectra with NASA Oltaris site



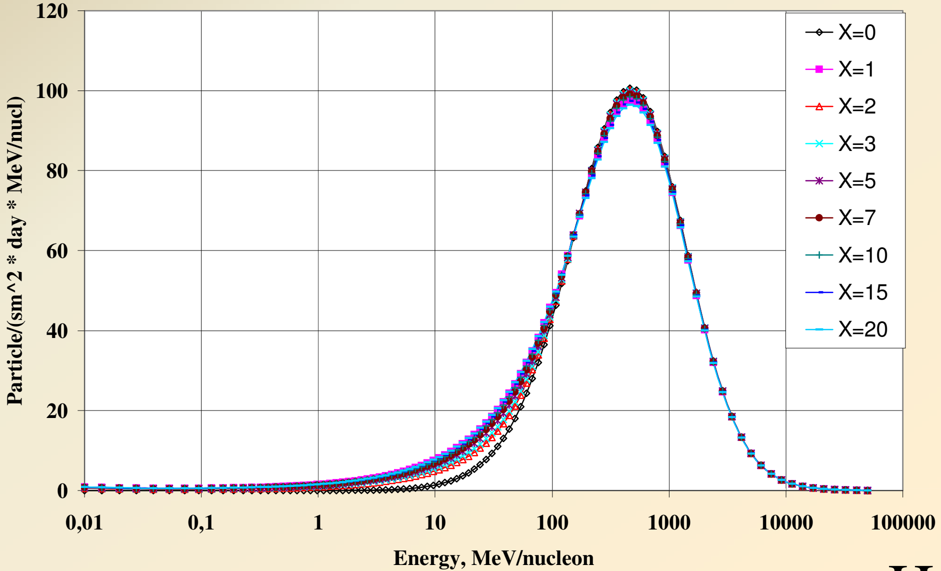
The both case were used the same ISO 15390 spectra for March 2013 year.

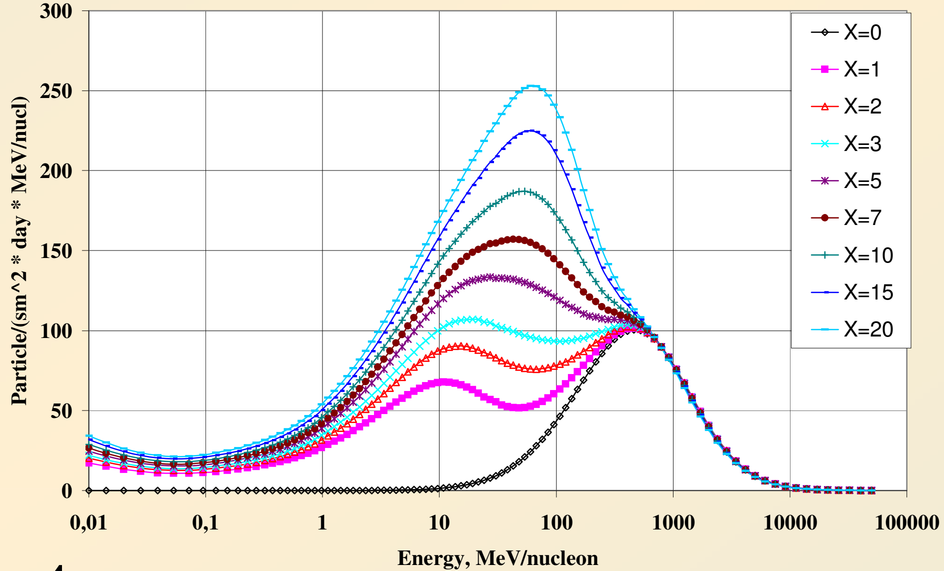
Calculation proton and He-4 spectra beyond shielding

Calculation with R(E) relation

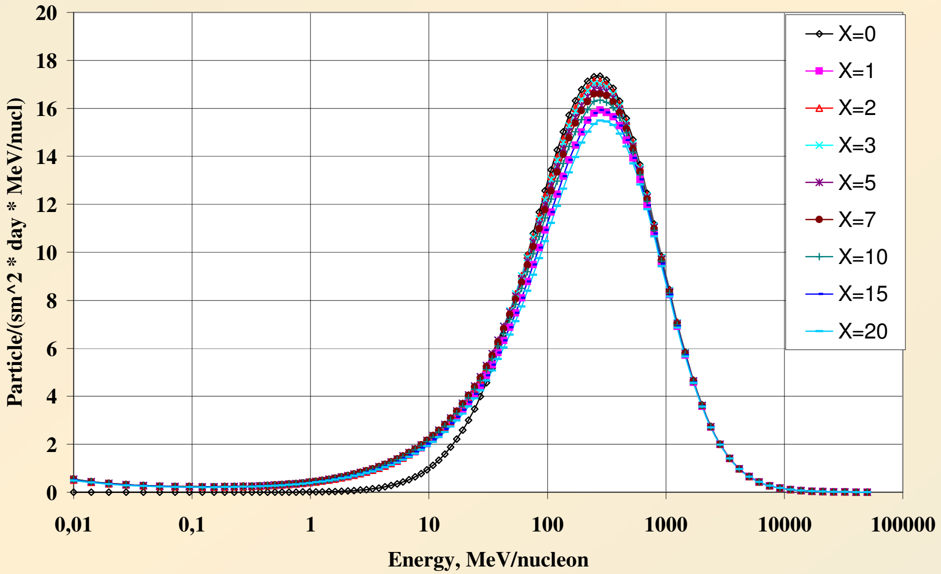
Calculation with NASA Oltaris site

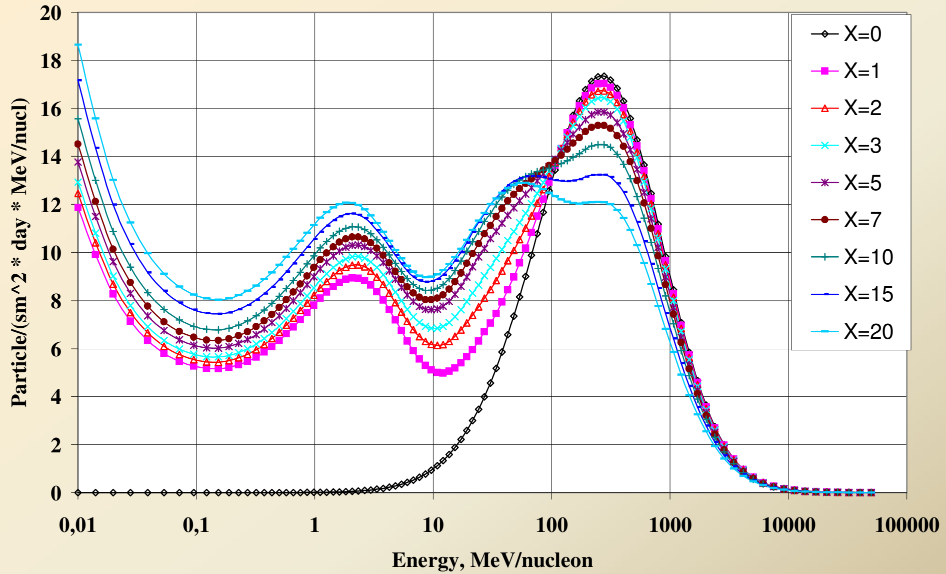
Protons





He-4





Heavy ion fragmentation and neutrons production

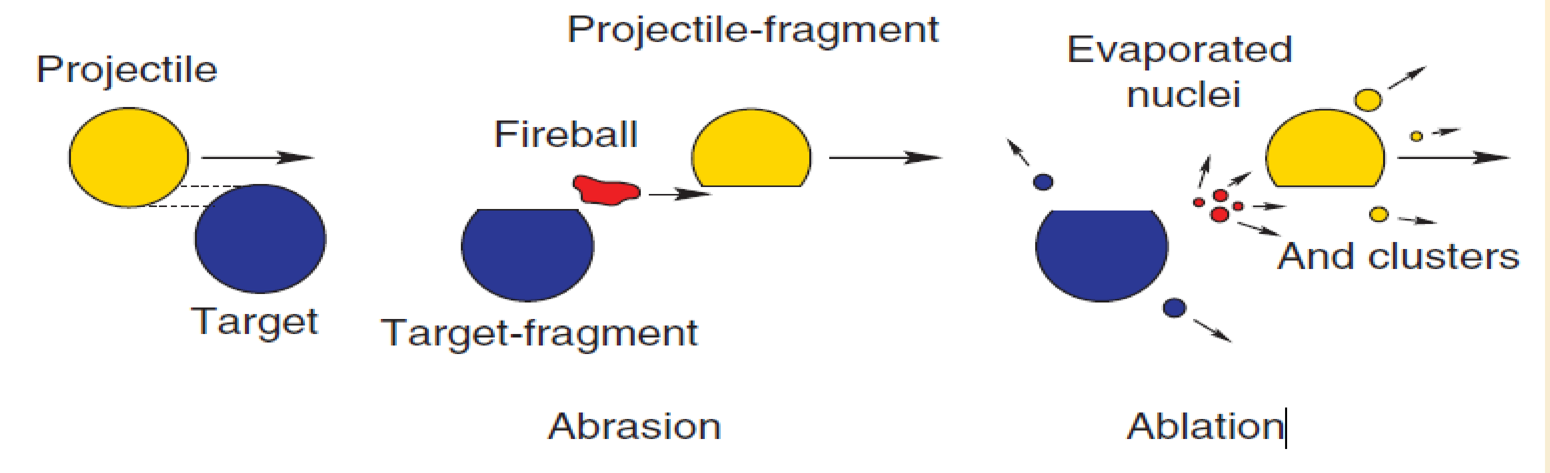


FIG. 16 (color). Illustration of the abrasion-ablation model.

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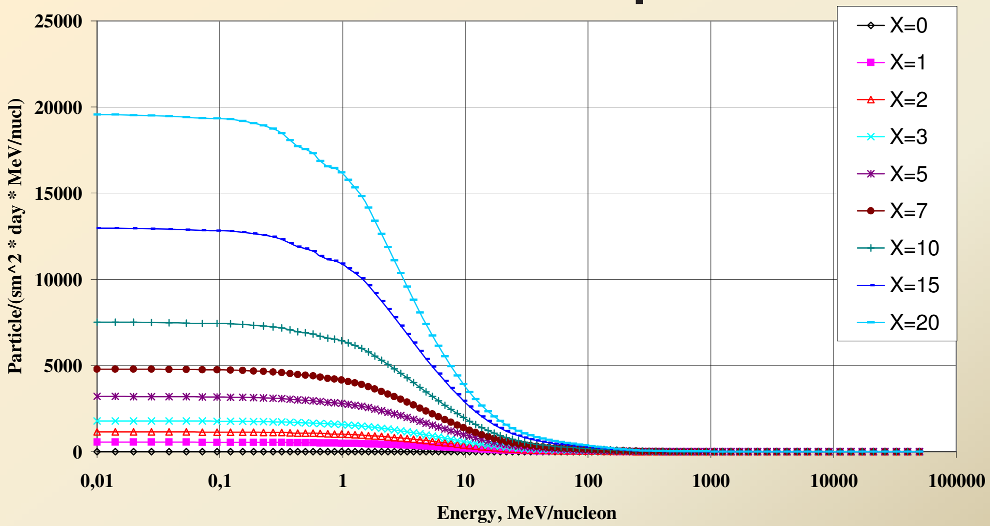
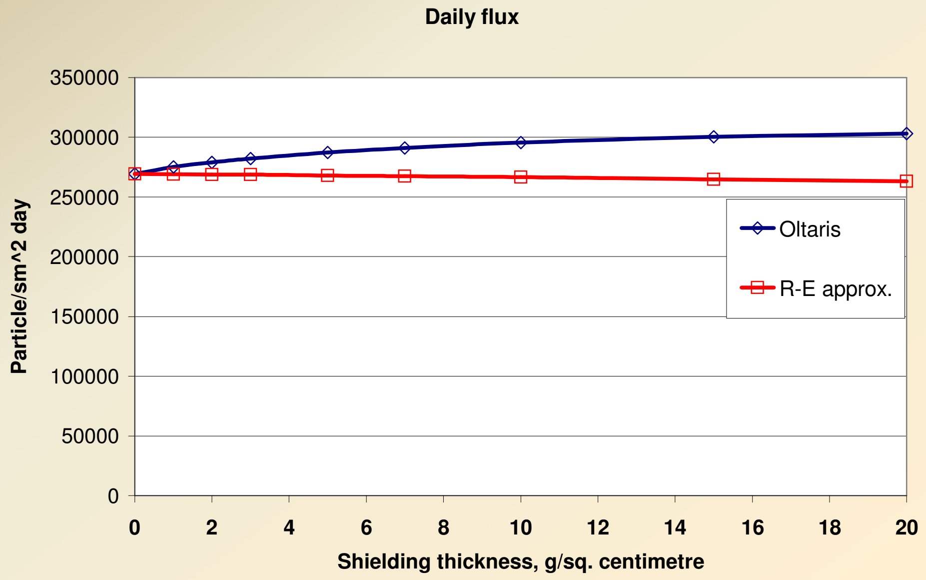
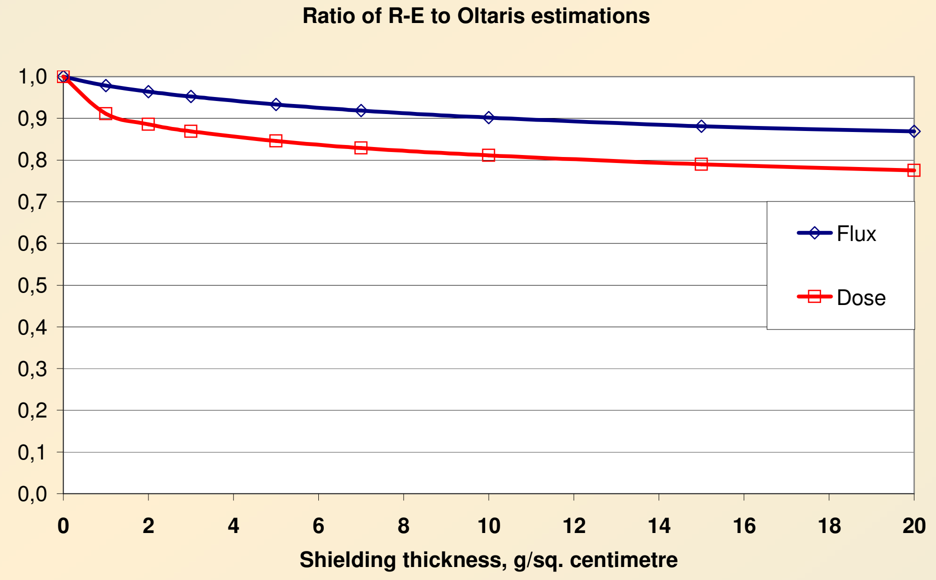
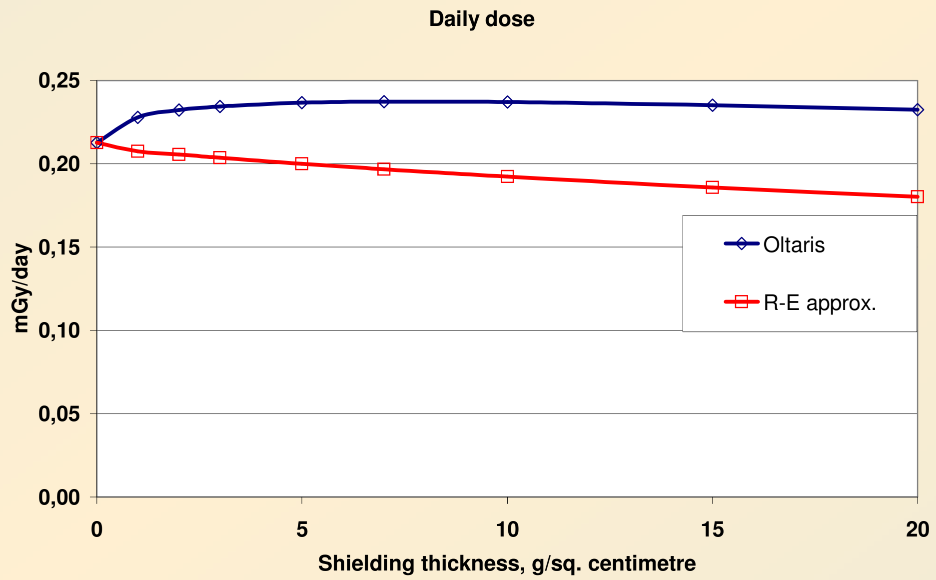
Neutrons spectra

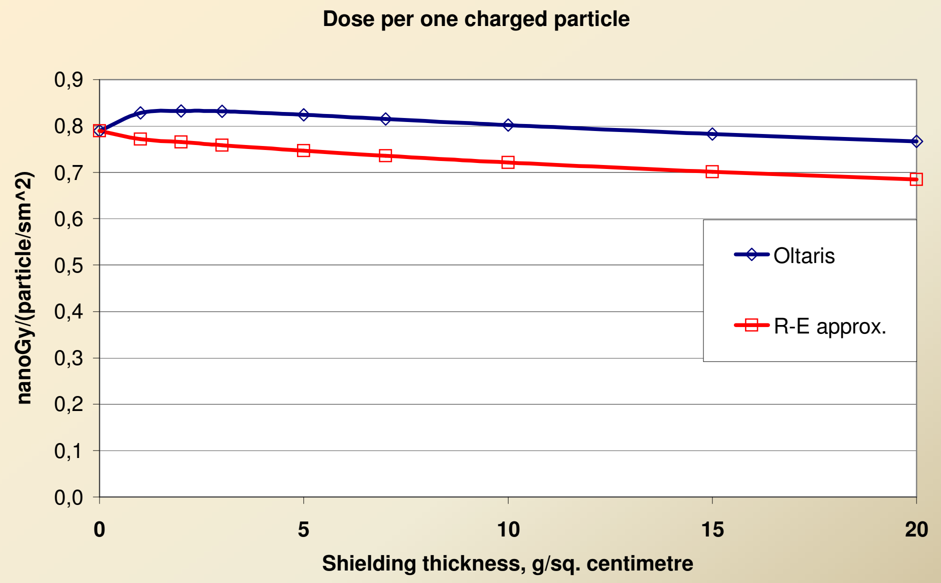


Comparison of R-E approximation and Oltaris results

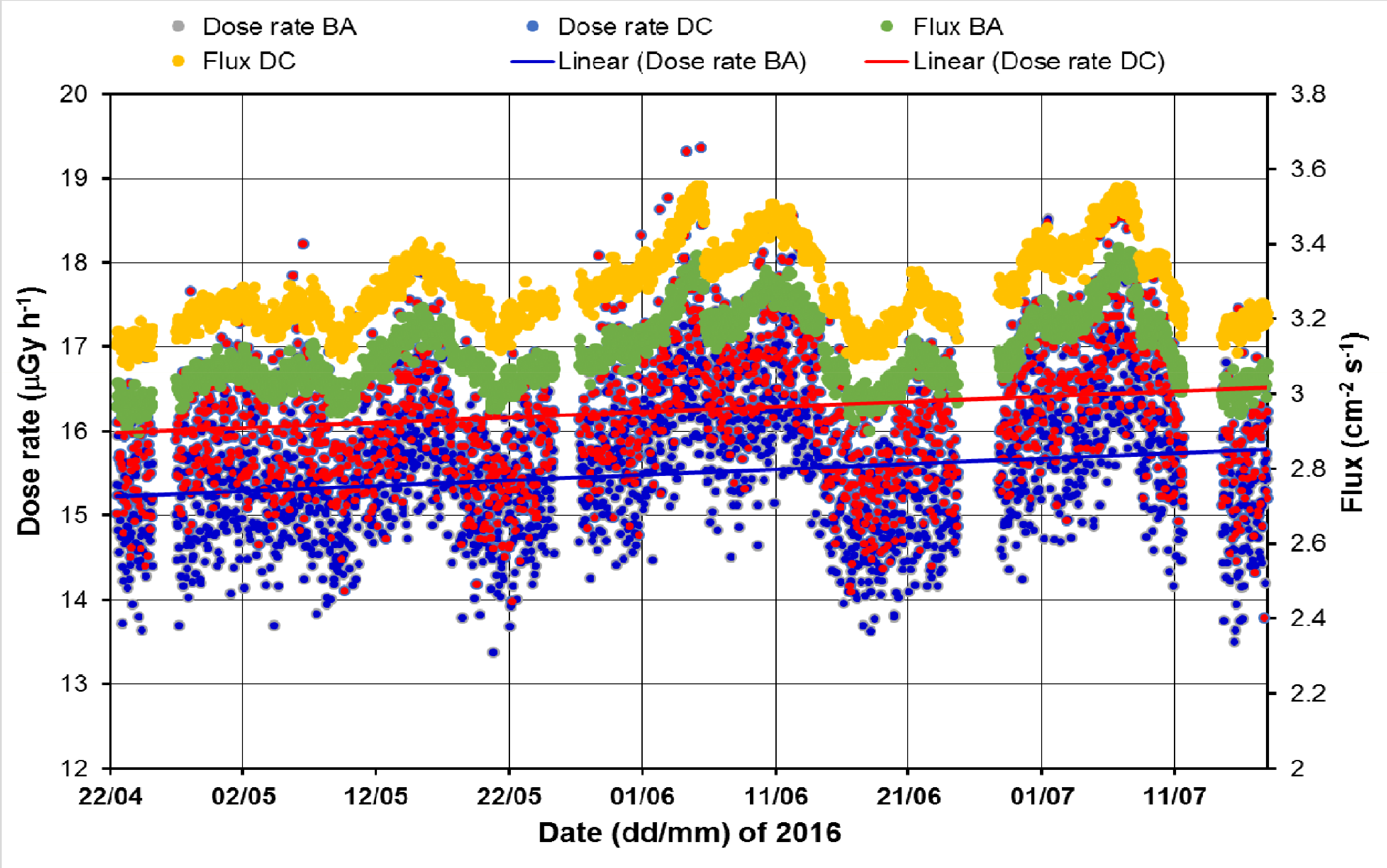






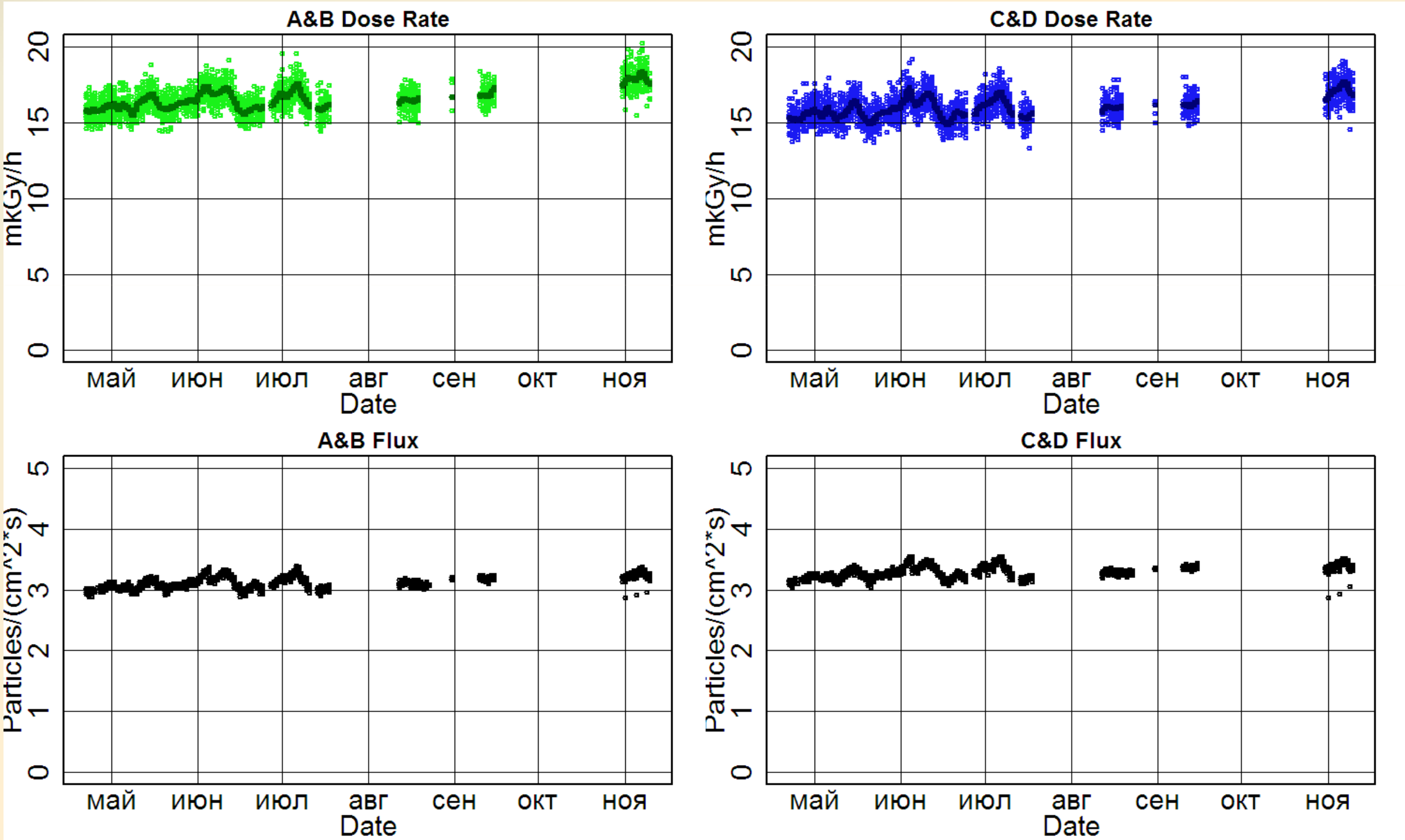


Fluxes and dose rates recorded in the perpendicular detectors B(A) and D(C) of <u>Liulin-MO</u>

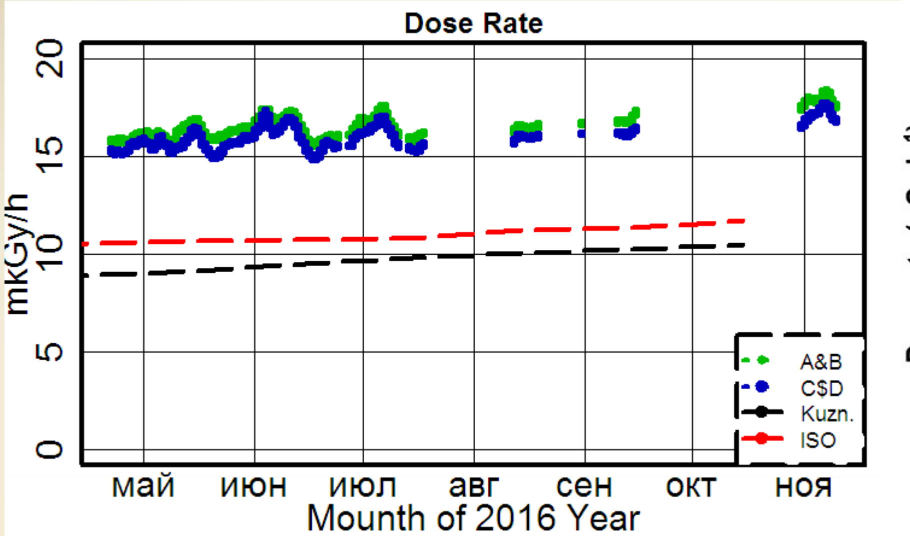


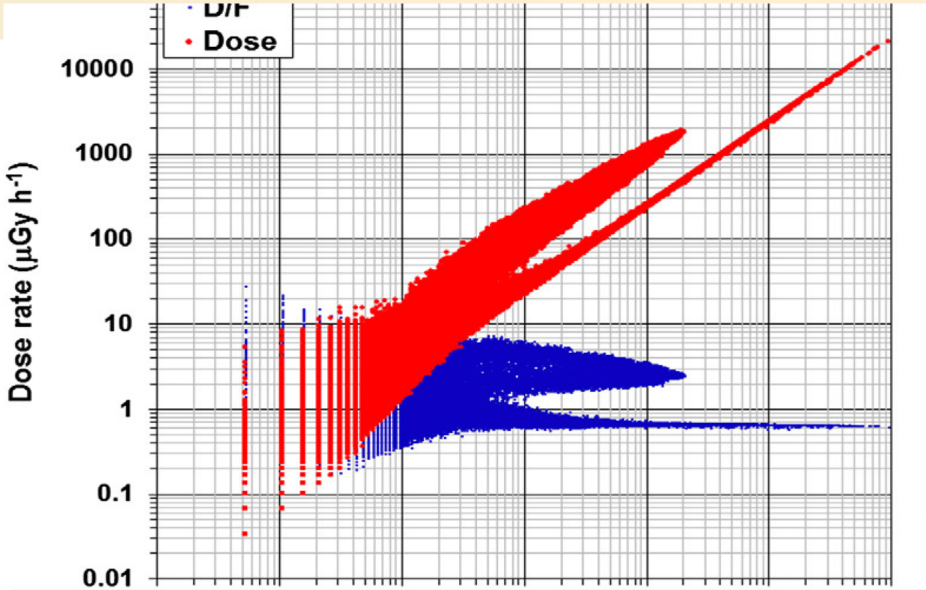
Data for 22.04 ÷ 18.07. 2016

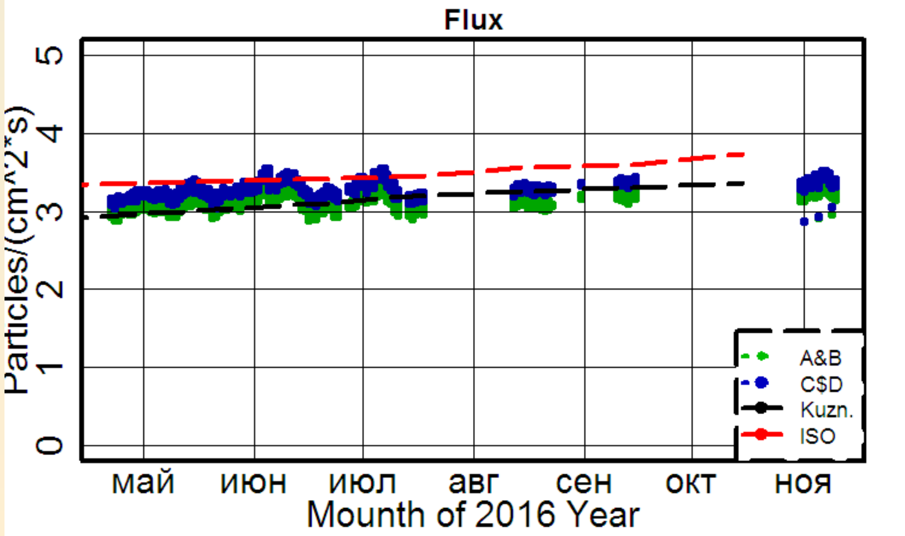
The same graphs - fluxes and dose rates recorded with <u>Liulin-MO</u>



Comparison of measured and calculated fluxes and dose rates







	Dose, mGy/day	Flux, #/s	nanoGy /# cm^2
SINP-17	0,238	3,4	0,81
ISO	0,262	3,7	0,82
Lul A&B	0,372	3,2	1,35
Lul C&D	0,390	3,3	1,37
RAD	0,332	3,7	1,04

Flux definition

N=G F

Где: N – counts rate, #/s

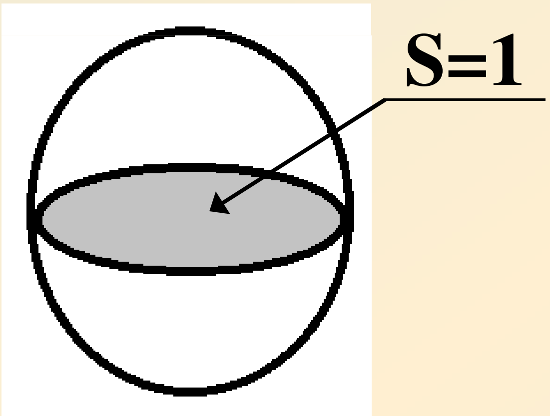
G – geomfactor, см^2

F – flux, particles/(s см^2)

For isotropic radiation field

G=S/2

Where: **S** – detector's sensitive area squire

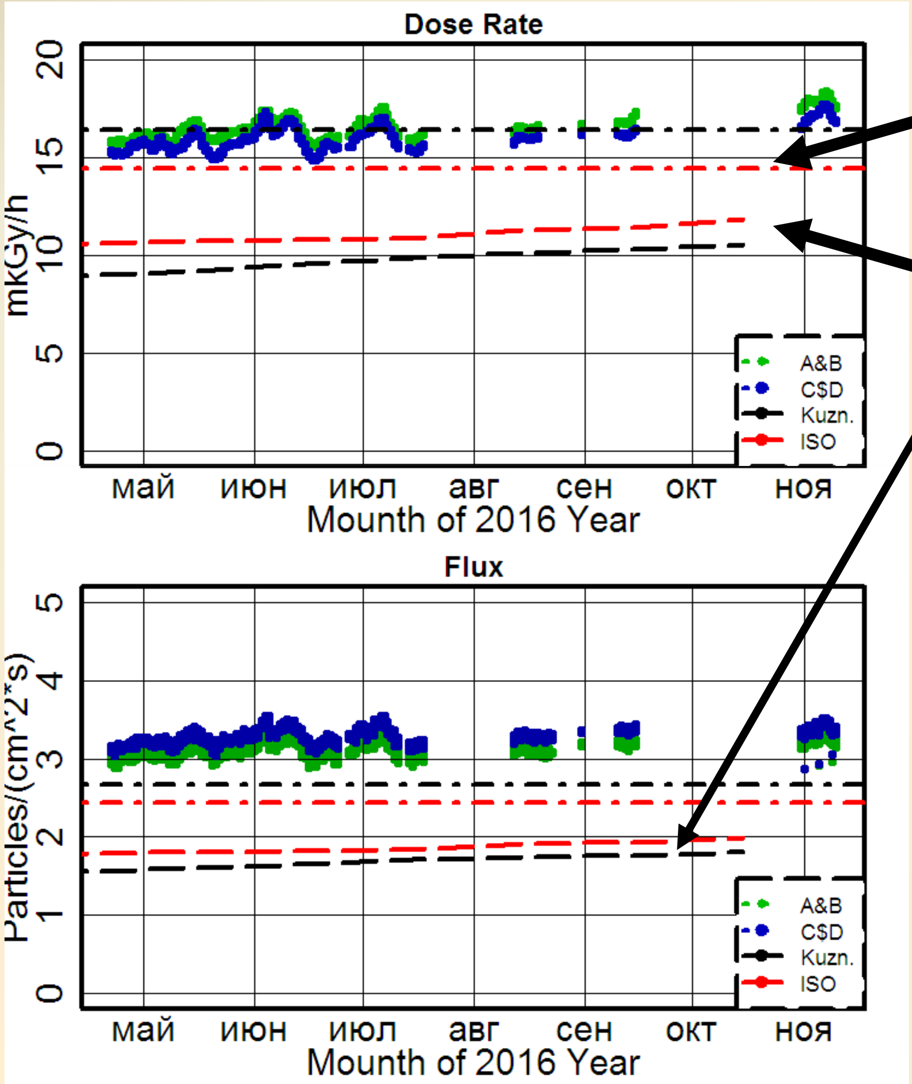


Standard definition – flux is the number of particles crossing sphere with unit cross section for 1 second. (We will be mentioned it as spherical flux.)

Planar flux may be defined as the number of particles crossing planar detector with unit squire for 1 second.

$$F_{Planar} = \int_{4\pi} \frac{F_{Spheric} \bullet |\cos(\theta)|}{4\pi} d\Omega = \frac{1}{2} F_{Spheric}$$

Comparison of measured and calculated fluxes and dose rates– recalculation to «planar» fluxes



Estimation for zero Solar activity level.

Estimation for real Solar activity level.

To achieve a satisfactory agreement between estimations and measurements, it was necessary to set the zero Solar activity level.

Conclusion

- Comparison between the calculated estimations of GCR charged particles fluxes and absorbed dose with Liulin-MO dosimeter measurements revealed the need to clarify the term "flux" of the particles. To exclude the confusion is proposed to use two values: "spherical" flux and "planar" flux widely used in describing of experimental data.

- When the results were recalculated to the "planar" flux parameter, the calculated values were almost twice lower than the measured values. To achieve a satisfactory agreement between estimations and measurements, it was necessary to set the zero solar activity level, which was not observed during the TGO flight.

Благодаря!

Thank you for your attention!