ISCRA 2017

International Symposium on Cosmic Rays and Astrophysics

20 – 22 June 2017, MEPhI, Moscow, Russia

Long time radiation environment variation on ISS orbit and radiation risk estimations

Долговременные вариации радиационной обстановки на орбите МКС и оценка степени радиационного риска

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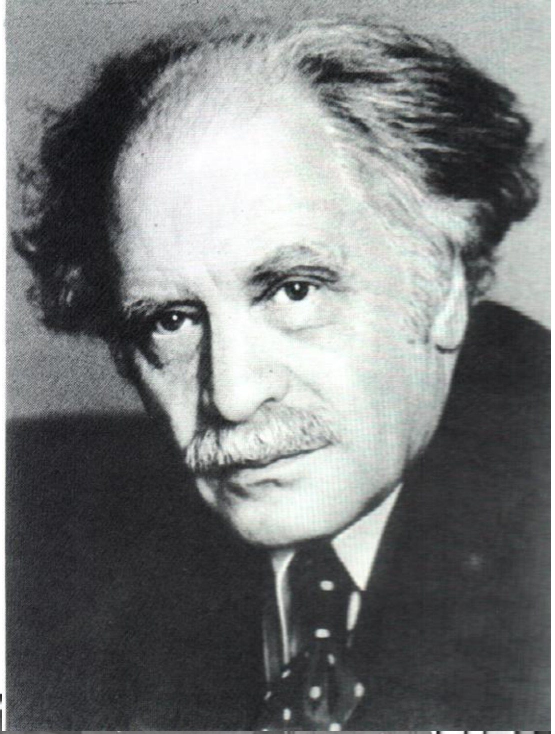
O.Yu. Nechaev[2], N.V. Kuznetsov[2].

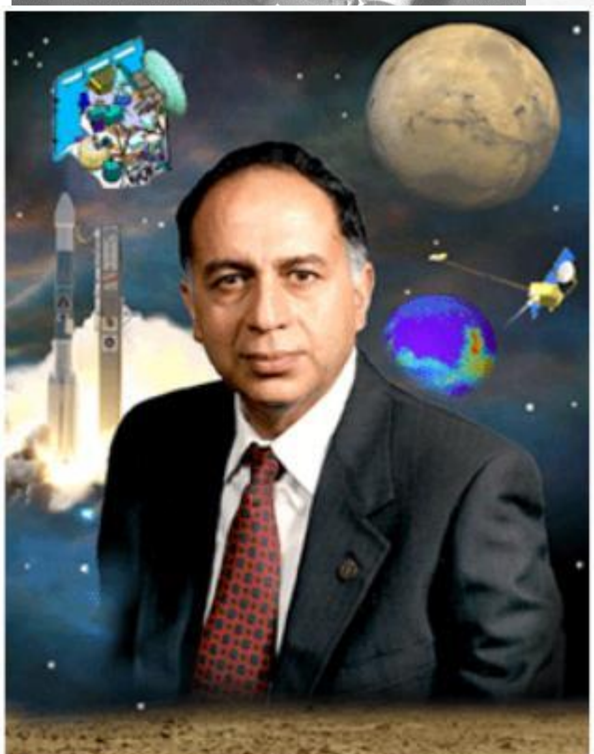
1) Moscow, State scientific center of Russian Federation - Institute of bio-medical problems of the Russian academy of sciences

2) Moscow, Skobeltsyn Institute of Nuclear Physics of the Moscow State University

A few of a history



Е.Е.Ковалев



Units used for radiation measurements

Absorber dose unit: Gy
1 Gy = 1 Joule / 1 kg

Old unit: Rad
1 rad = 0.01 Gy

Equivalent dose unit: Sv
For gamma-rays 1 Sv=1Gy

Old unit: ber – biological equivalent of rad
1 ber = 0.01 Sv

Mortal human dose 5 Gy =500 rad for man with weight 80 kg deposit 400 Joule to his body.

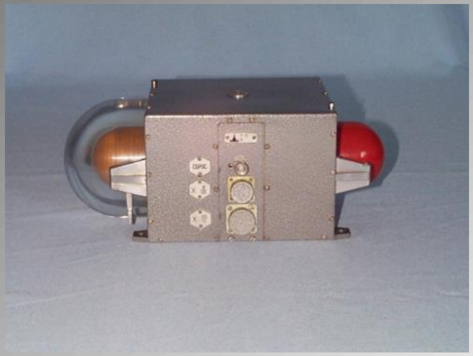
5 Gy * 80 kg = 400 Joule

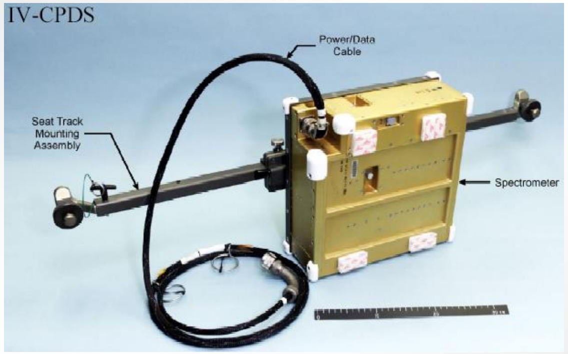
The same energy deposit one spoon of a hot tee.

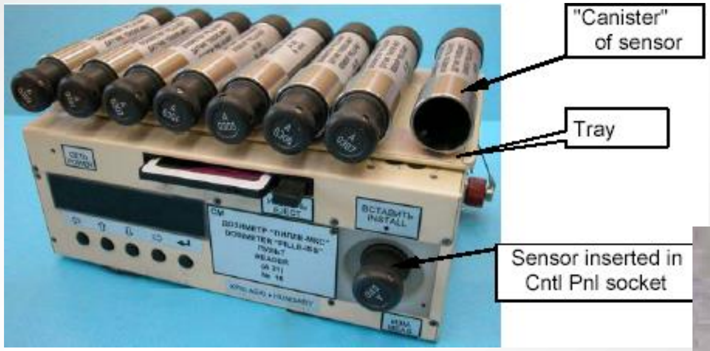
0.005 kg*4180 $\frac{J}{Kg \bullet {}^{o}C}$*(56 ºC-36.6 ºC) =405 Joule

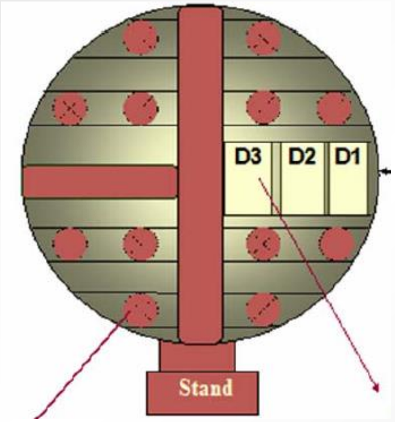
Water specific heat

The radiation monitoring devices on the ISS







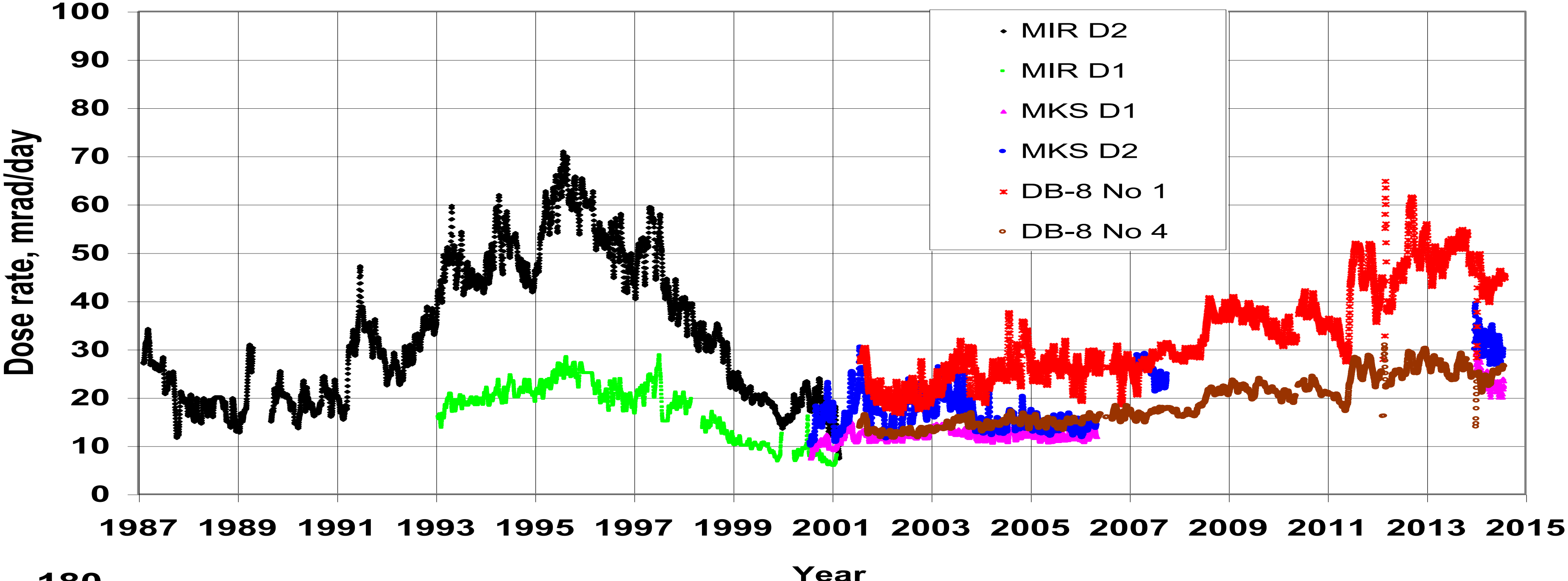


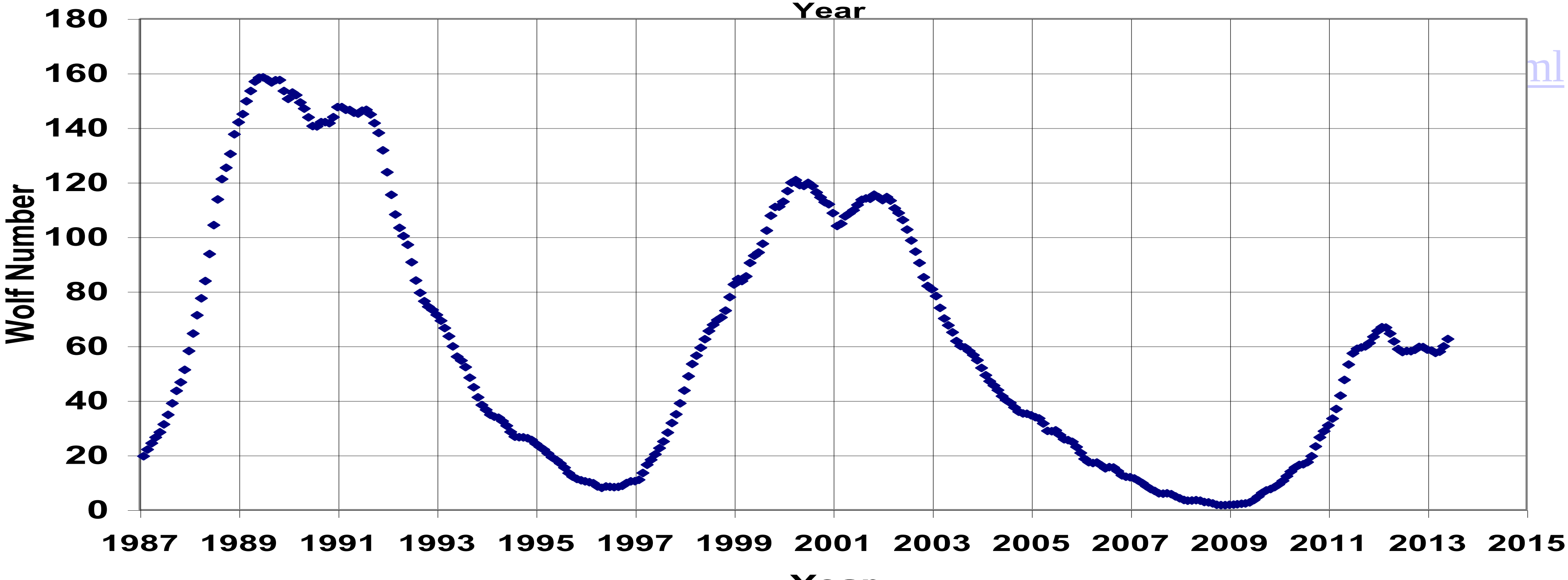
Spherical Tissue-equivalent phantom

Size: 370x370x390 mm;
mass: 32 kg

20 containers inside and 32 detector packages on the surface

Anthropomorphic phantom





ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-indices/sunspot-numbers/international/tables/daily-sunspot-numbers/table_international-sunspot-numbers_monthly-smoothed.txt

Вид дозиметра Р-16

Чувствительными элементами дозиметра являются 2 ионизационные камеры, заполненные аргоном .
Одна из камер имеет дополнительный экран из оргстекла толщиной 3 г/см^2.

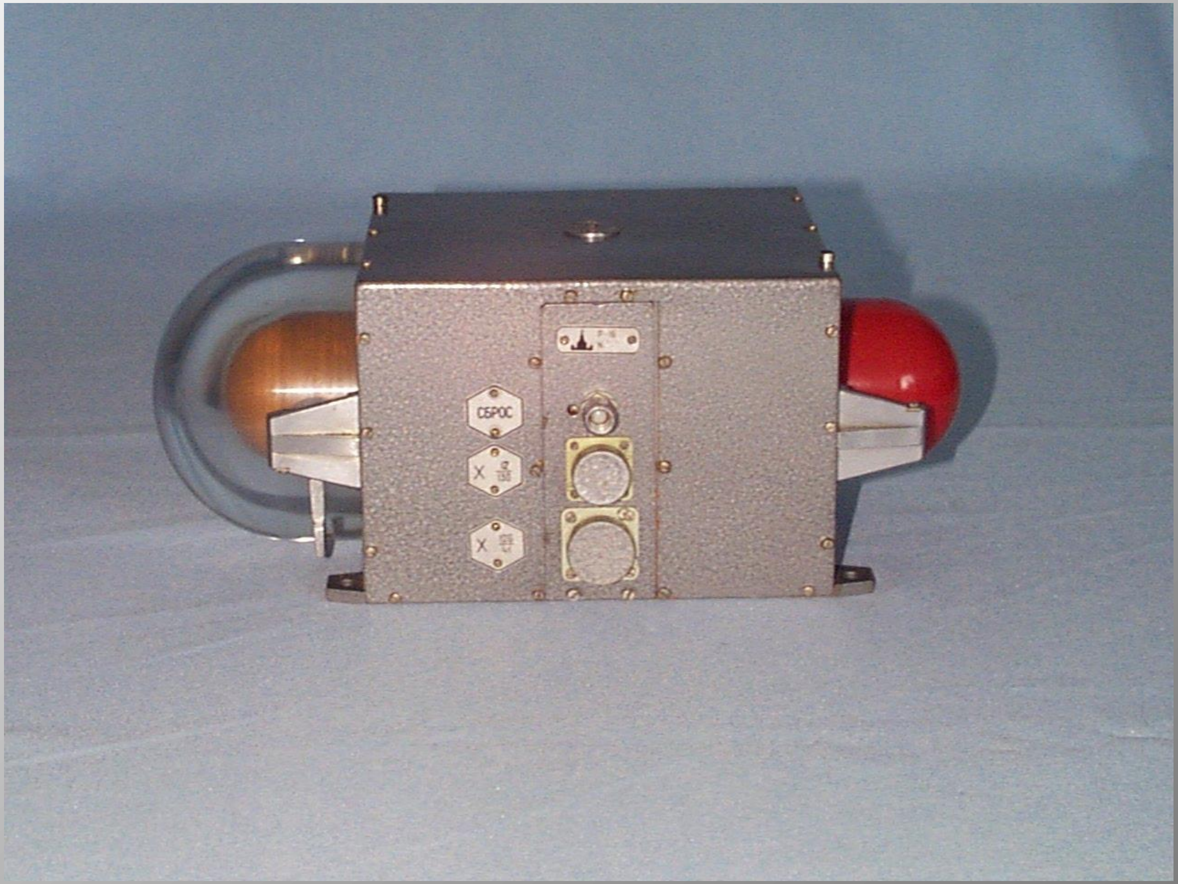
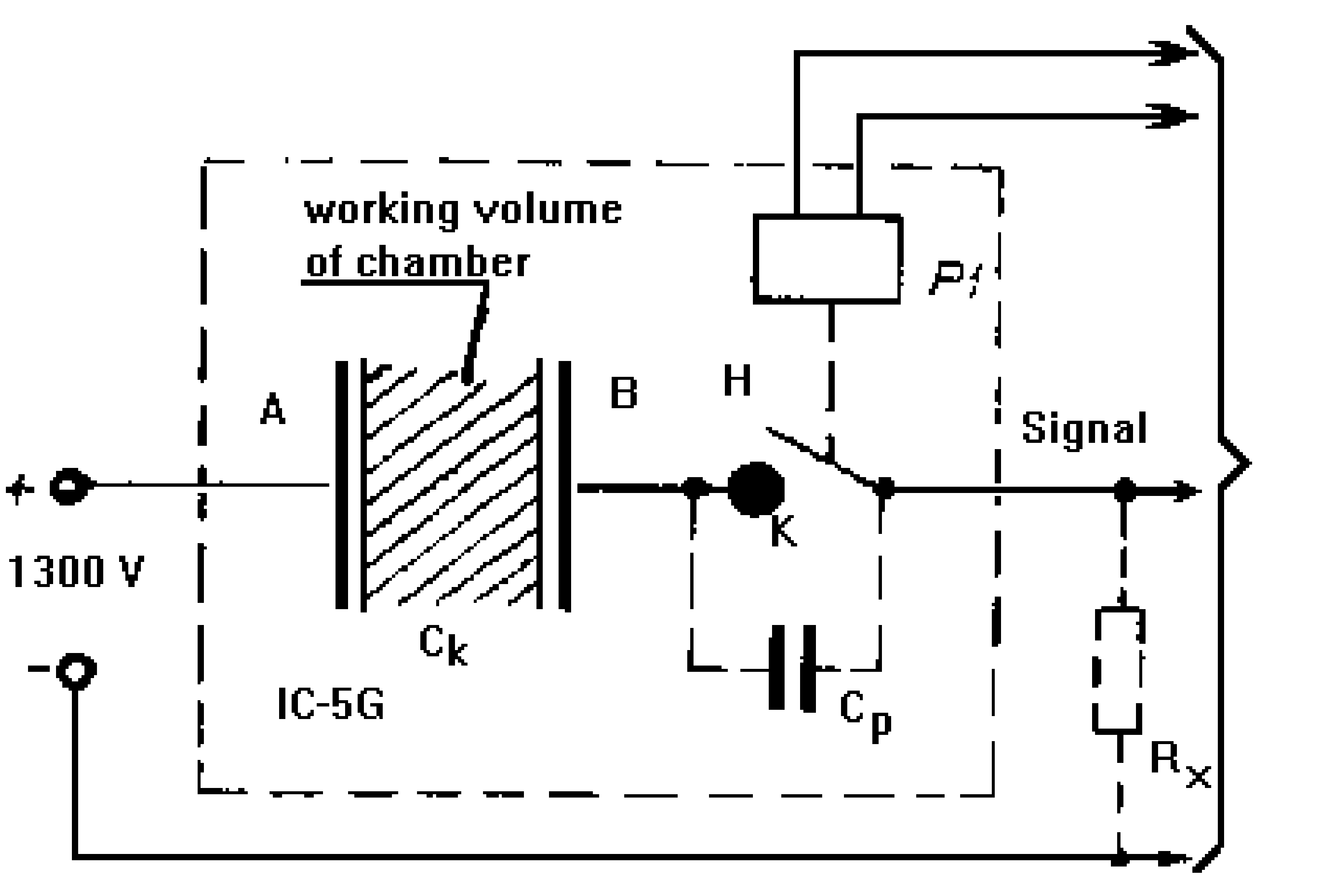


Схема регистрации дозы дозиметром Р-16



Dosimeter with semiconductor detector

Авторское свидетельство 766289 (СССР), Дозиметр ионизирующих излучений. /Маркелов В.В., Редько В.И. –Заявл. 14.9.1978, № 2664909/18

USSR patent No 766289 Dosimeter of ionizing radiation. V.V. Markelov, V.I. Redko. Accepted September 14, 1978, No 2664909/18

V.V. Markelov, V.I. Redko. Hight sensitive dosimeter for space radiation. Kosmicheskye Issledovaniya (Space research) 1982 vol. 19, No 2, pp. 316 – 319.

Маркелов В.В., Редько В.И. Высокочувствительный дозиметр космических излучений. – Космические исследования, 1982, т. 19, №2, с. 316-319.

Configuration of the Radiation Monitoring System (RMS)

Each DB-8 unit consist of two dosimeters with semiconductor radiation detectors

UU and DCU made for processing and analysis of the data obtained

Utility Unit (UU)

Data Collection Unit (DCU)

To central control desk computer

Commands

The power supply

DB-8

R-16

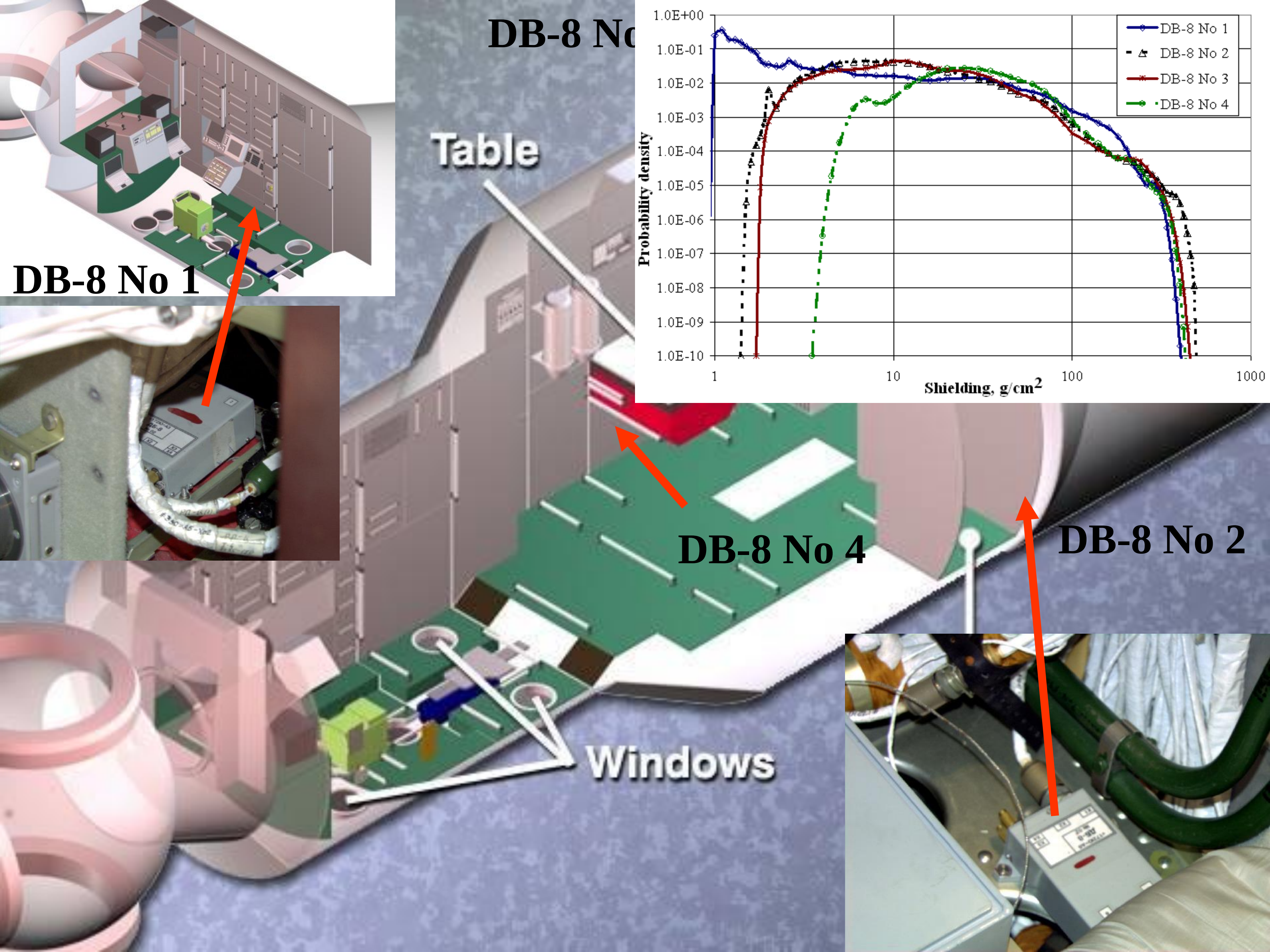
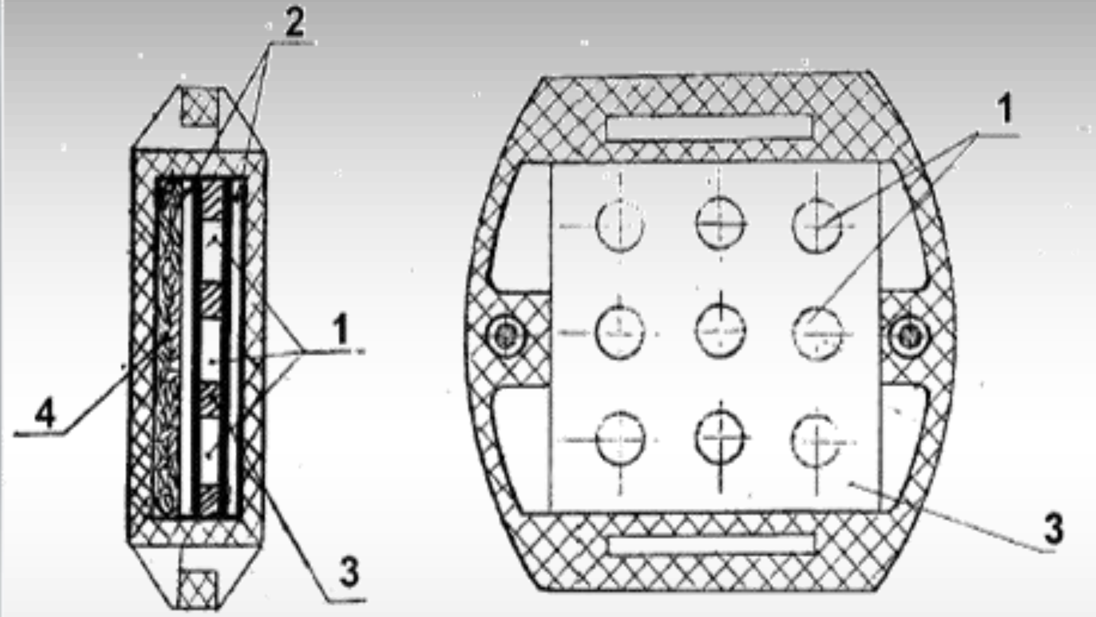


Table
DB-8 No 1
DB-8 No 4
DB-8 No 2
Windows
Probability density
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1
10
100
1000
Shielding, g/cm2
DB-8 No 1
DB-8 No 2
DB-8 No 3
DB-8 No 4

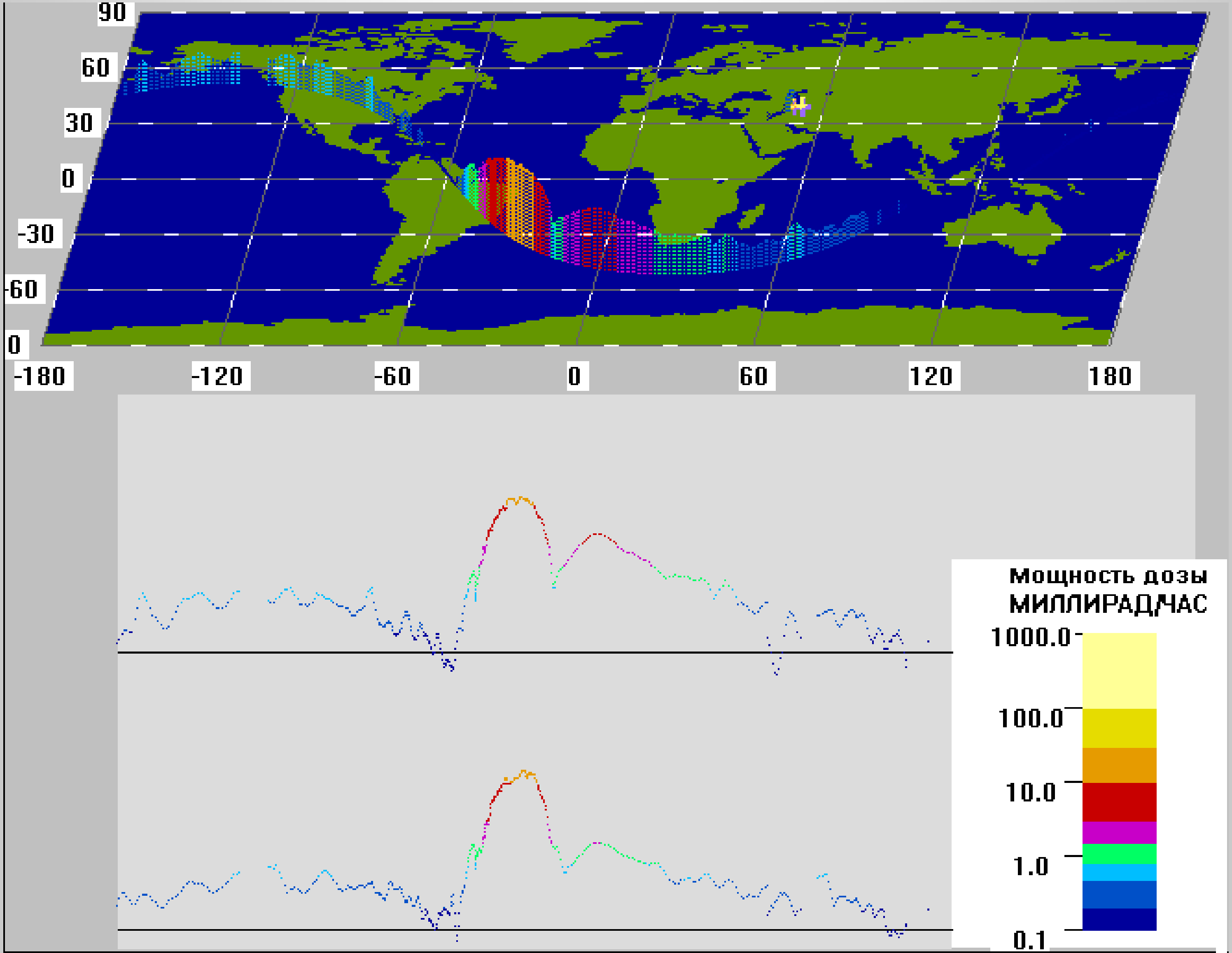
ID3-ISS individual dosimeter



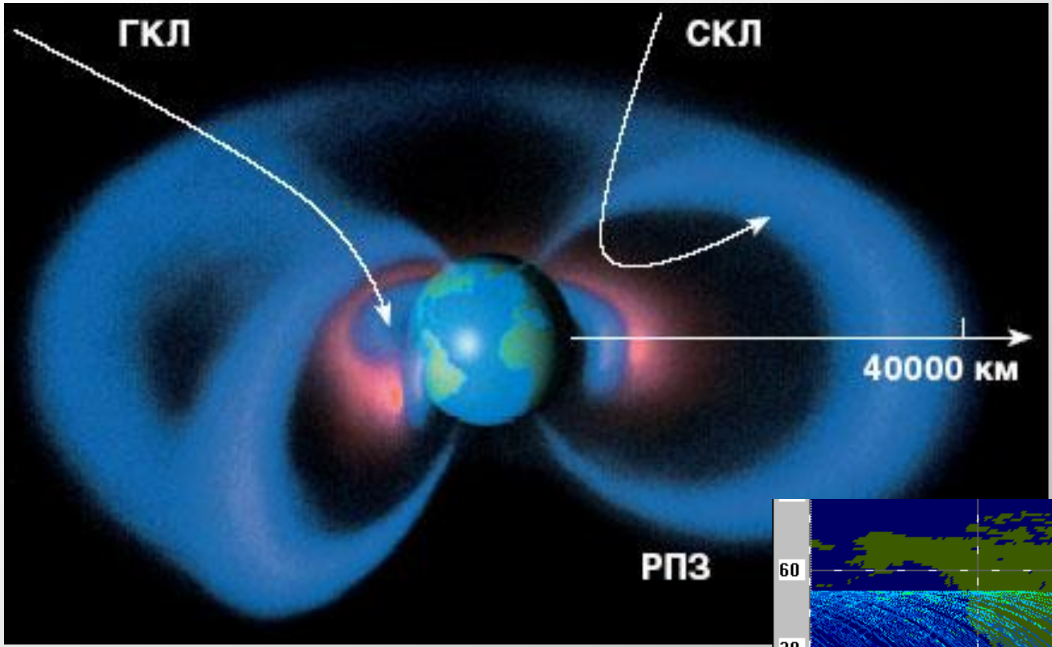
1. TL Detectors
2. CR-39 layers
3. TLD Holder
4. Set of the dry seeds

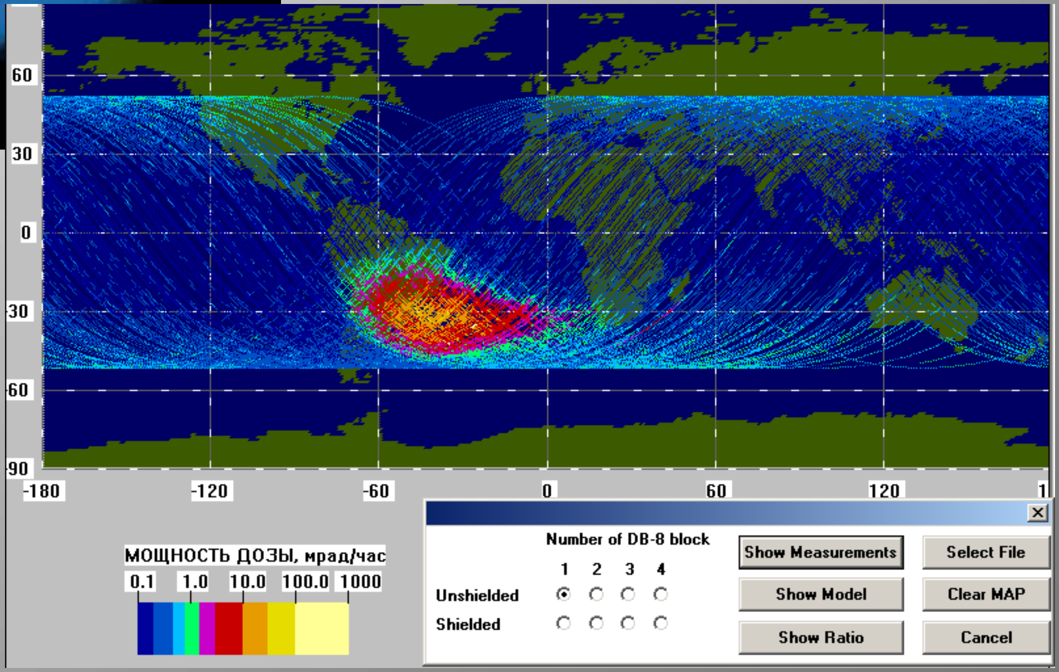
(2) Methodology of Analysis

Dose rate during SAA crossing measured November 1 2003 with DB-8 #1.

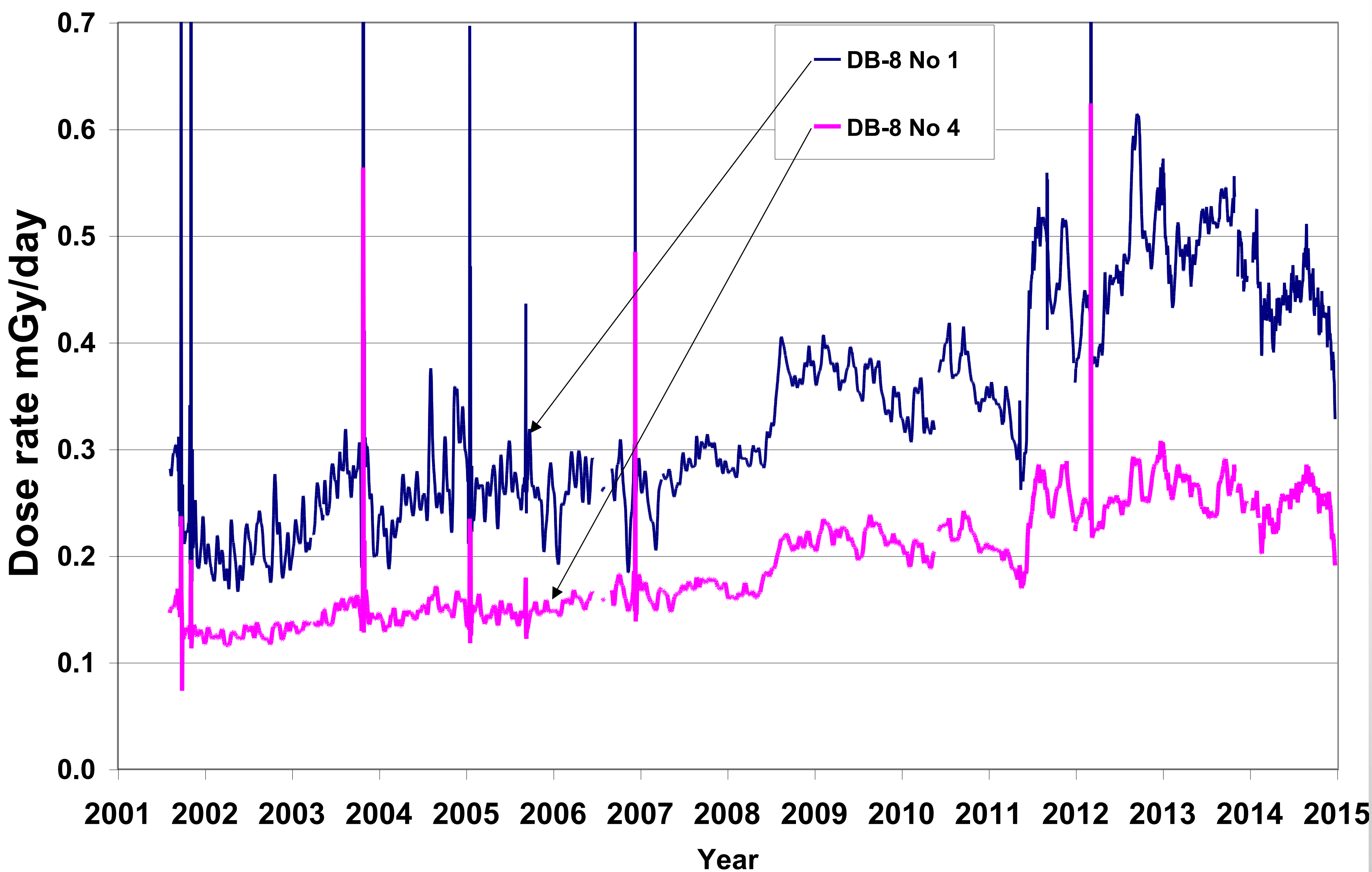


Main sources of radiation on ISS flight altitude

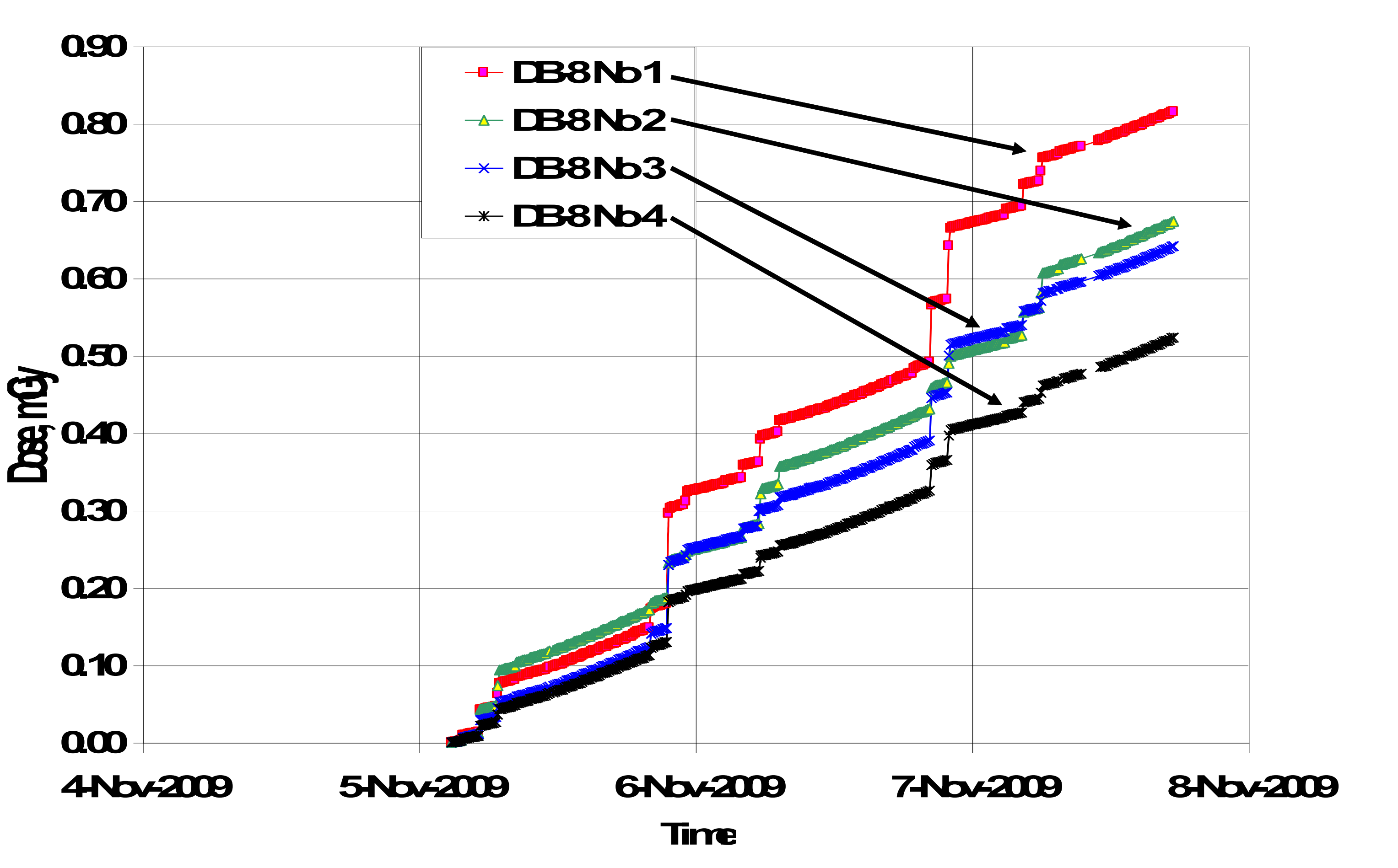




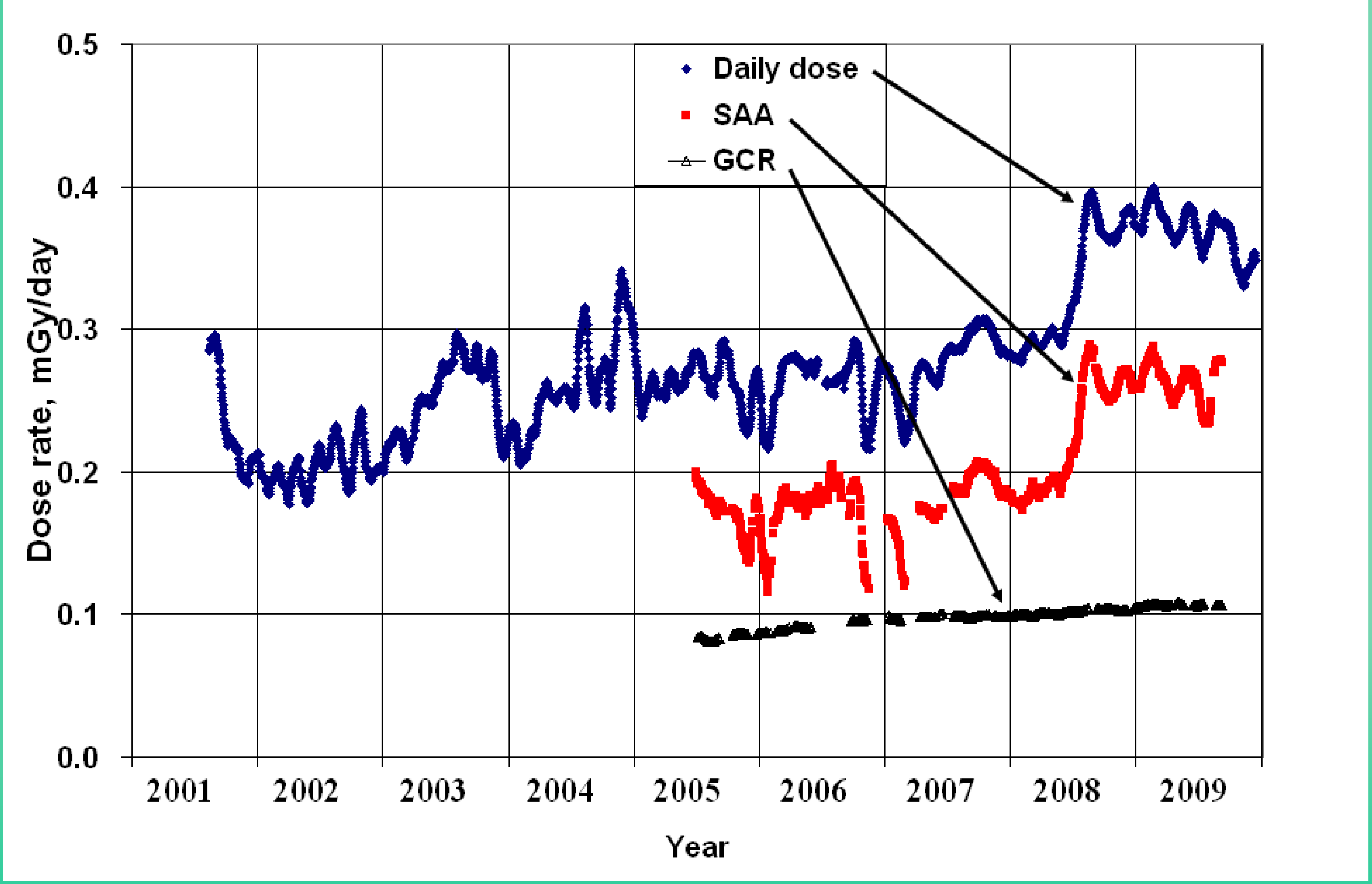
Dose rate measured from August 2001 to December 2014 with DB-8 units # 1 and # 4 unshielded detectors



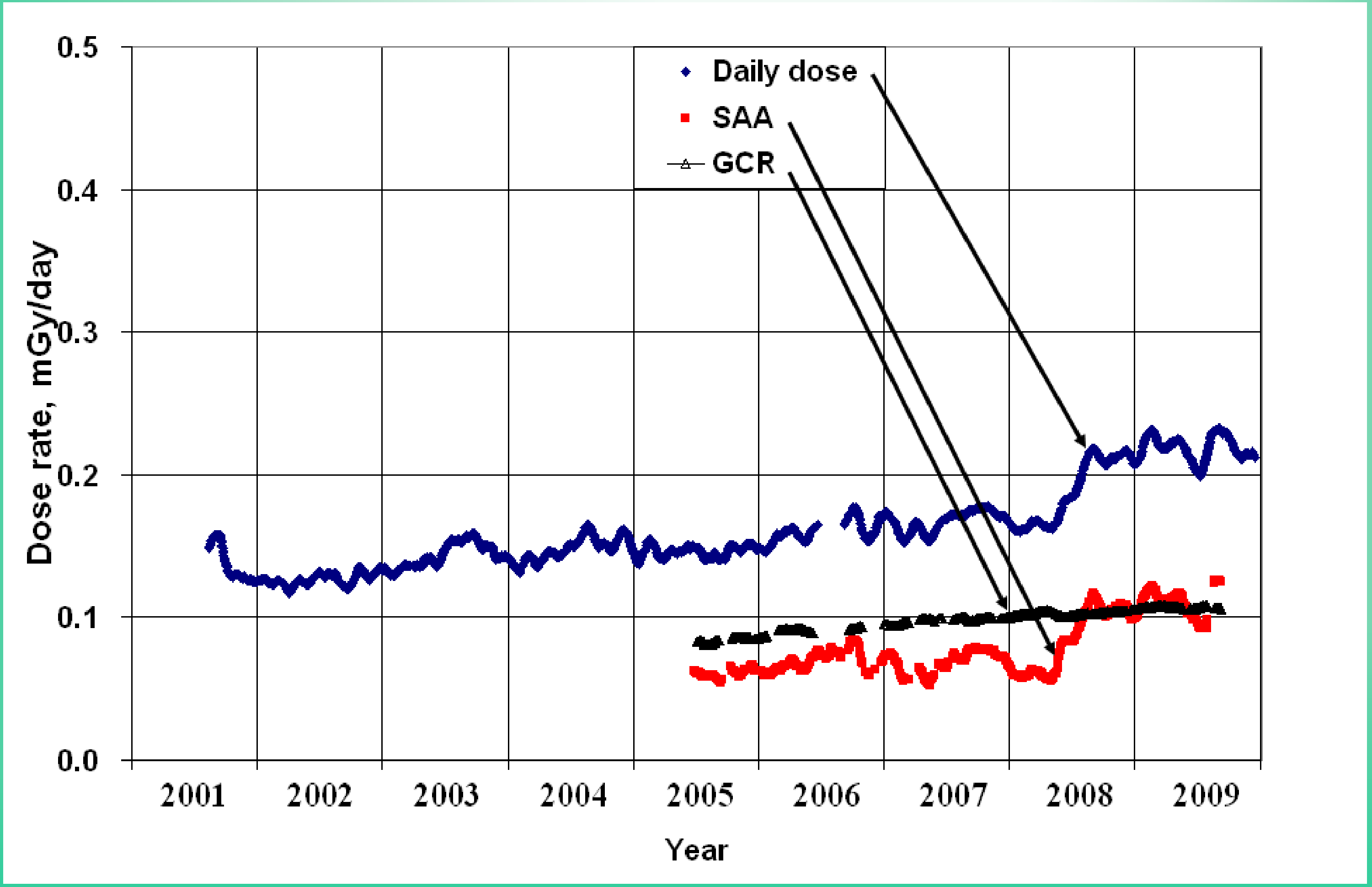
The dose accumulation in the locations of DB-8 detectors.



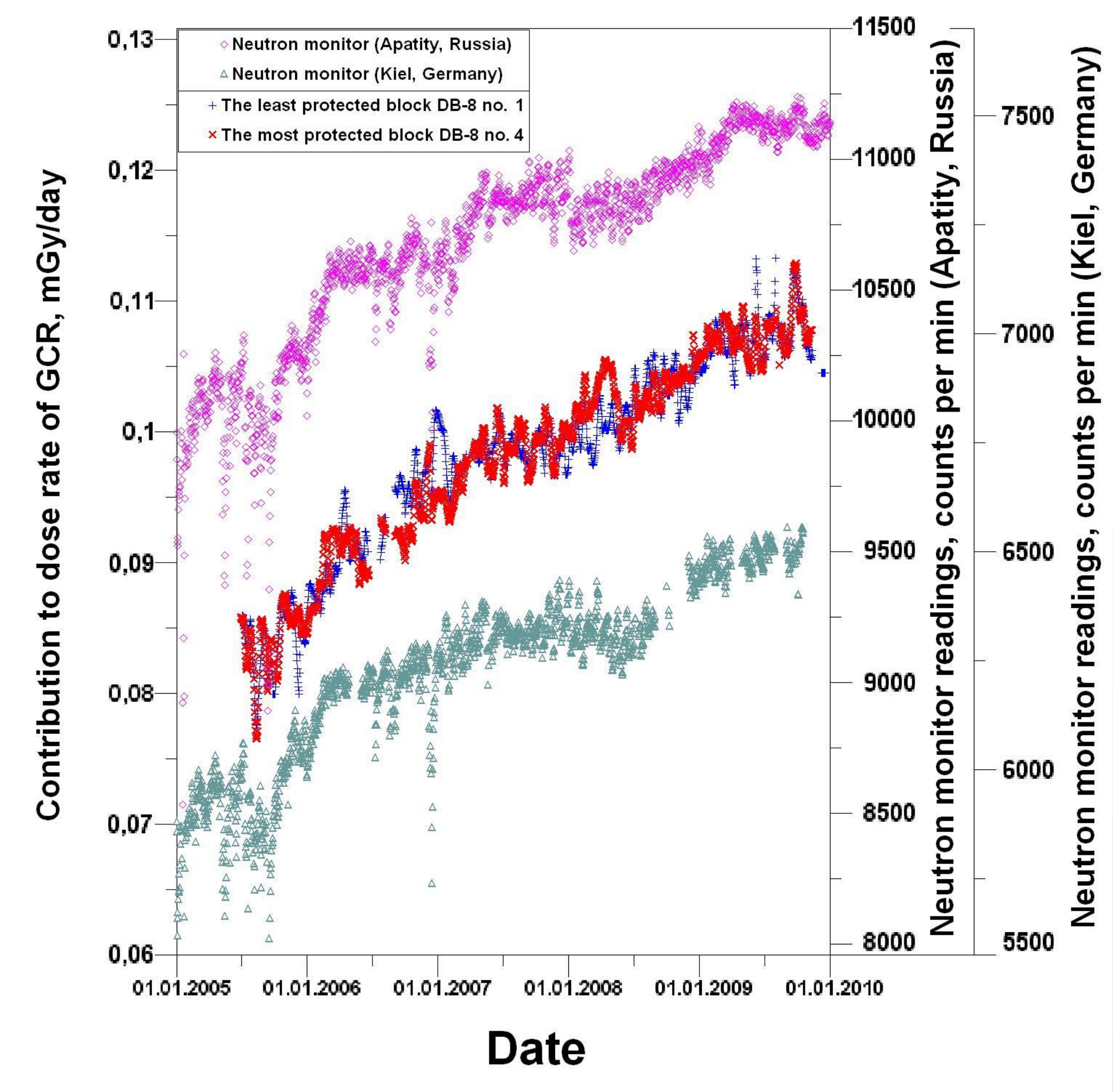
Daily dose measured with unshielded detectors of the DB-8 No 1. Contribution to the daily dose caused by ERB and GCR



Daily dose measured with unshielded detectors of the DB-8 No 4. Contribution to the daily dose caused by ERB and GCR



Comparison of GCR contribution to daily dose with the data of neutron monitors



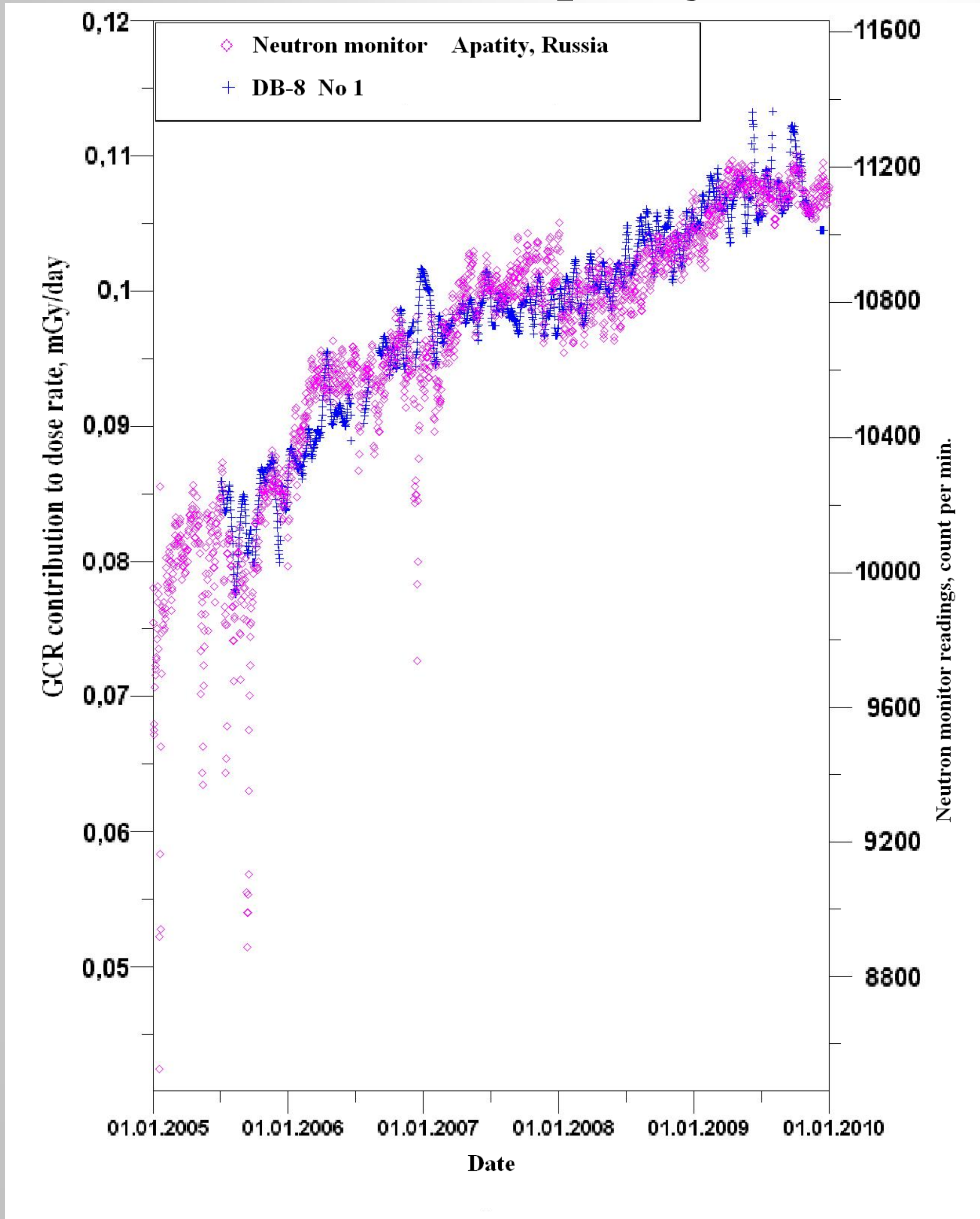
Value of GCR contribution to daily dose for period from middle of 2005 until middle of 2009 increased from 0.08 to 0.11 mGy/day.

The variations of neutron monitor data and GCR contribution to daily dose are similar

http://pgia.ru/data/nm/

http://cr0.izmiran.rssi.ru/kiel/main.htm

Comparison of GCR contribution to daily dose with the Apatity neutron monitor data

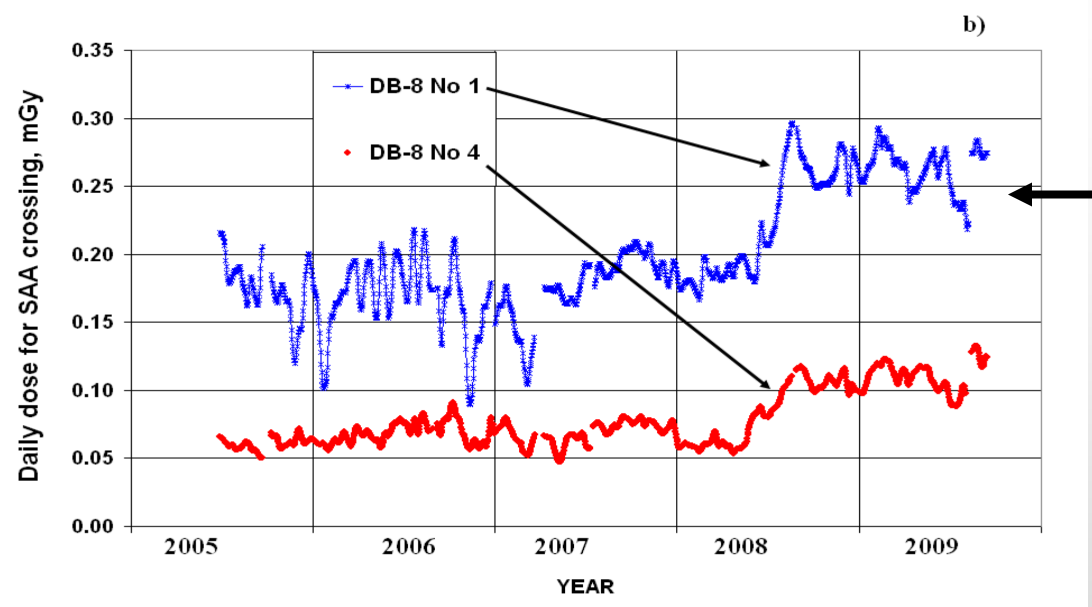


A special scale for Apatity neutron monitors data is used

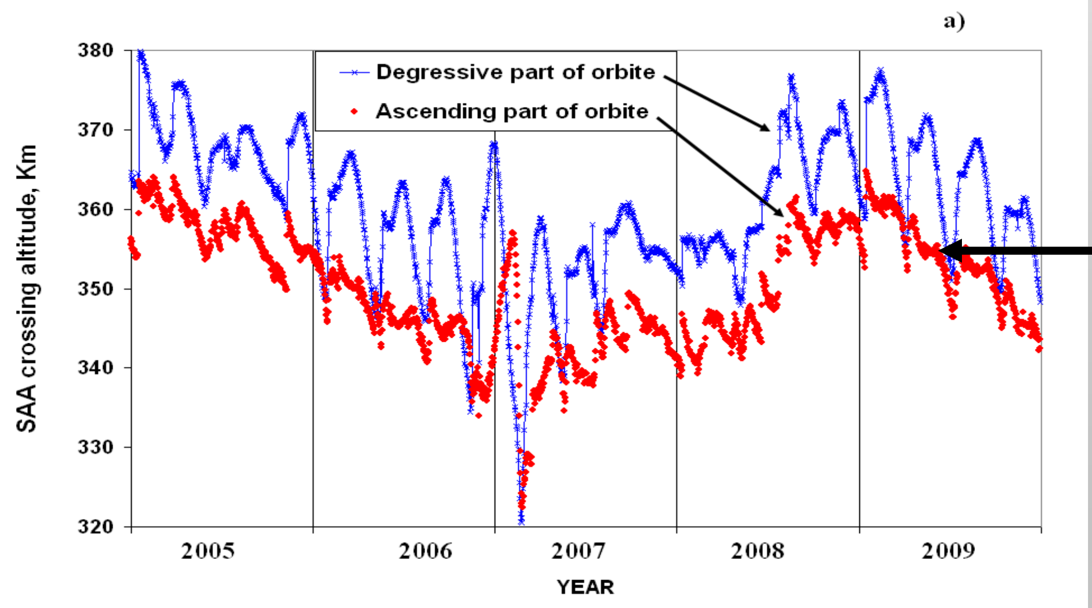
Range of neutron monitor data variation is 6% - 10% against 30% variations of GCR contribution to daily dose on ISS

GCR contribution to absorbed dose in range **0.08 – 0.11 mGy/day in Si** is in a tolerable accordance with absorbed dose rates calculation about **0.085 mGy/day in water** / D. Matthian, T. Berger, G. Reitz, Organ shielding and doses in Low-Earth orbit calculated for spherical and anthropomorphic phantoms, Advances in Space Research 52 (2013) 528–535

ERB contribution to daily doses versus altitude of SAA crossing

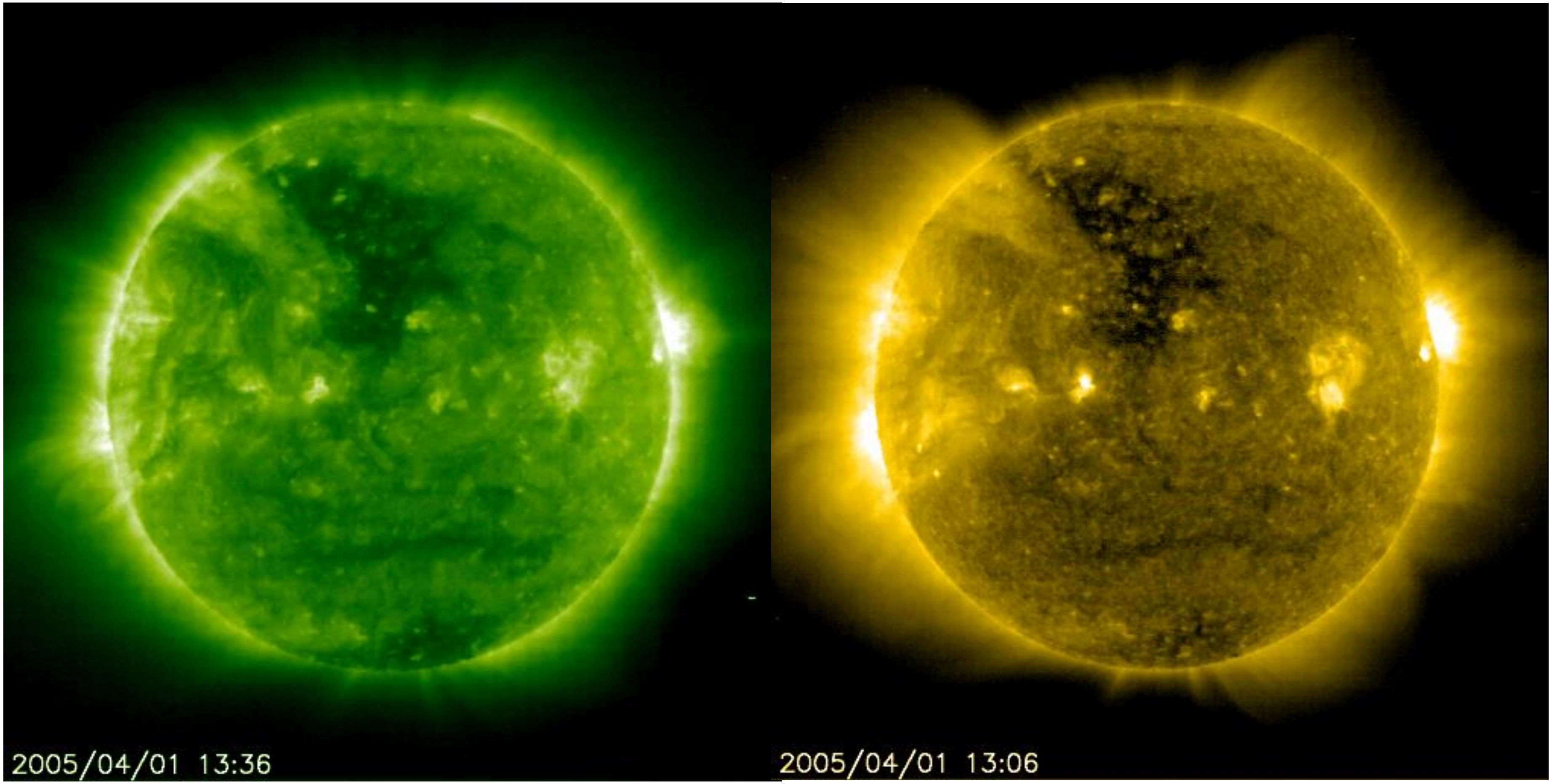


The ERB contribution to daily doses

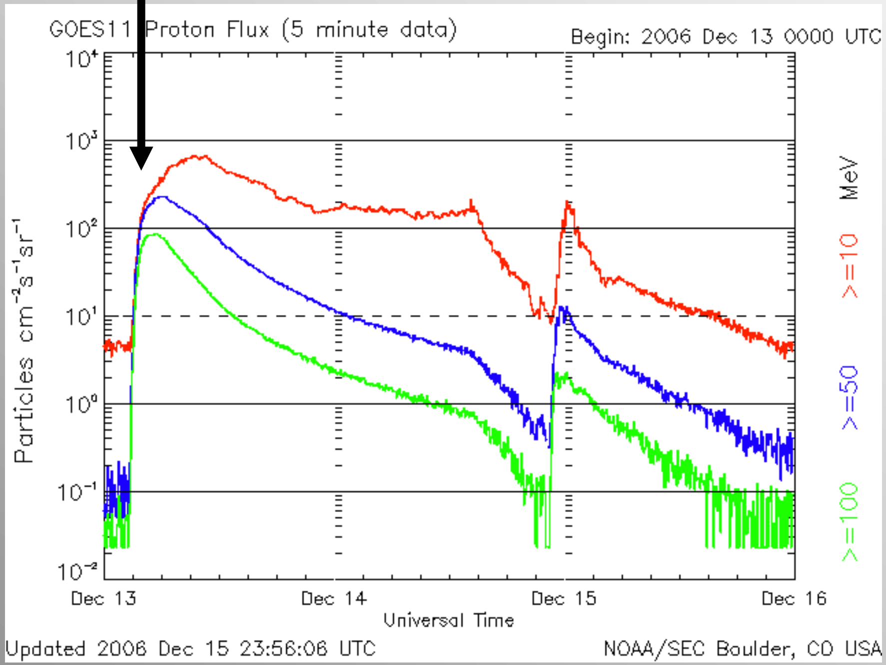


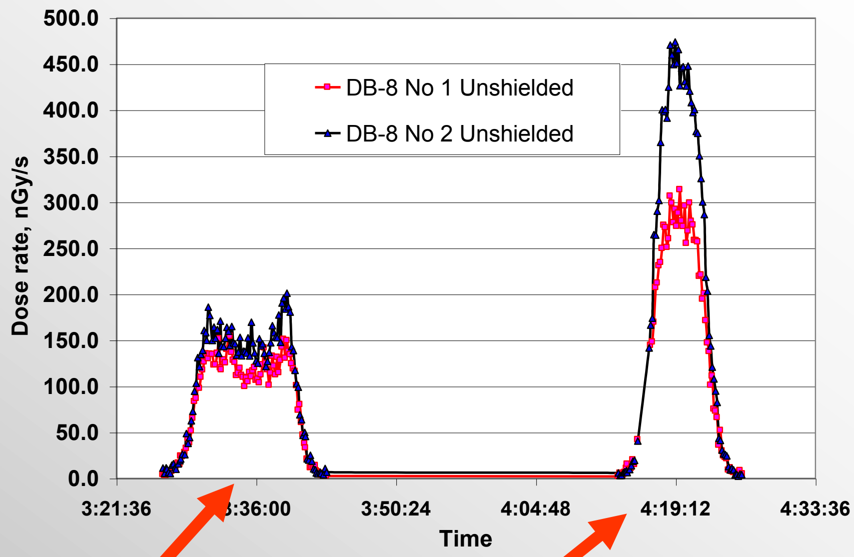
Altitude of SAA crossing by ISS

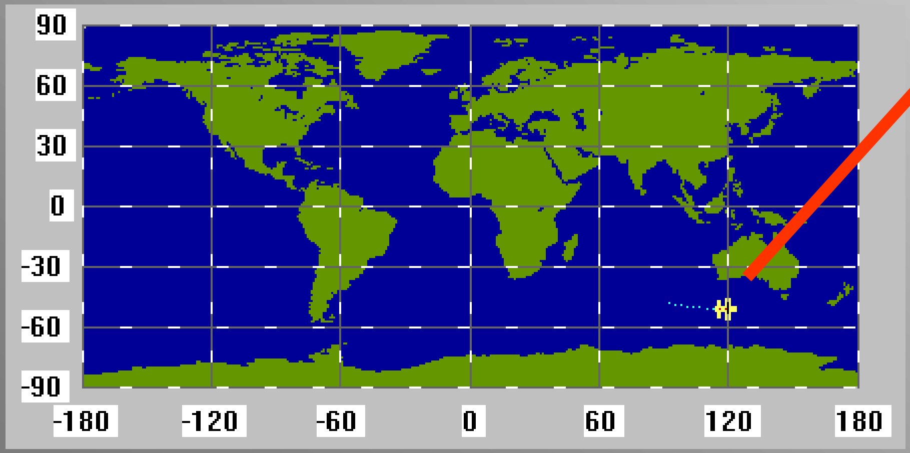
SPE influence on radiation environment

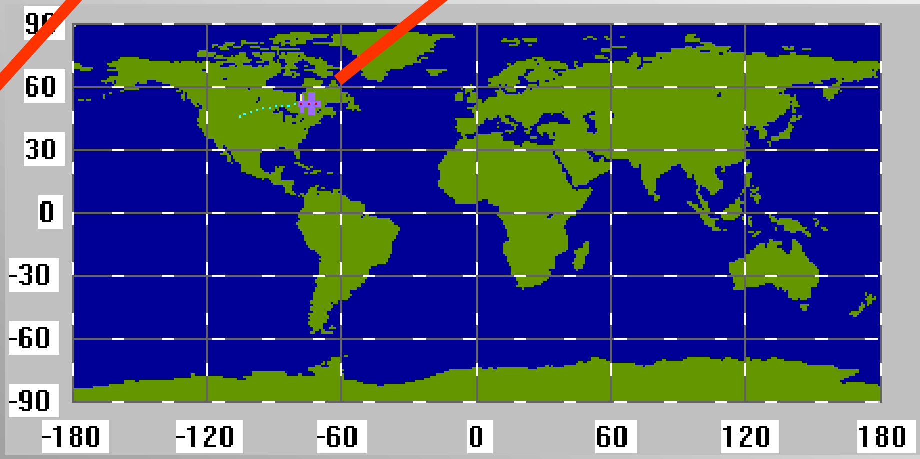


SPE December 13, 2006

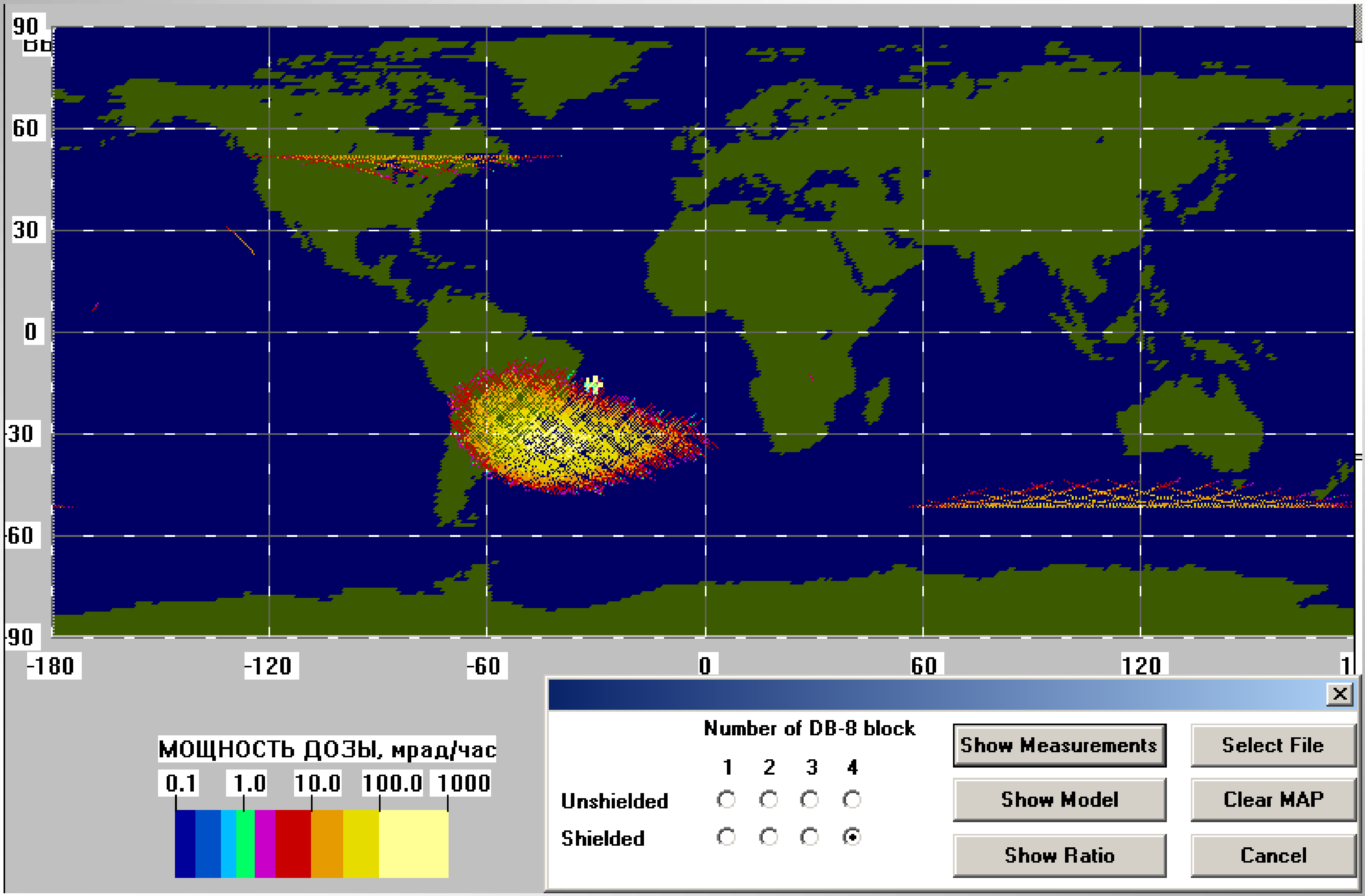




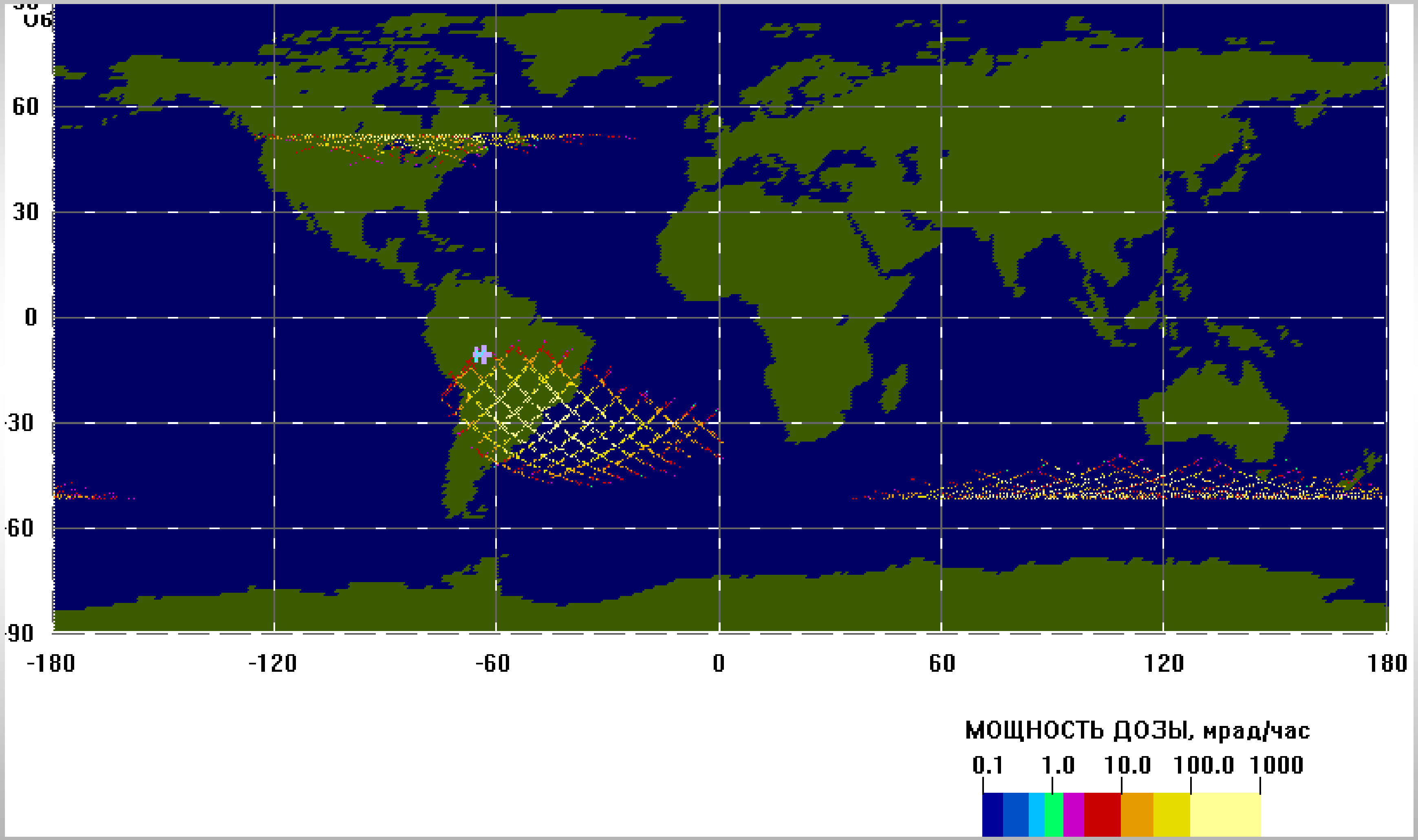




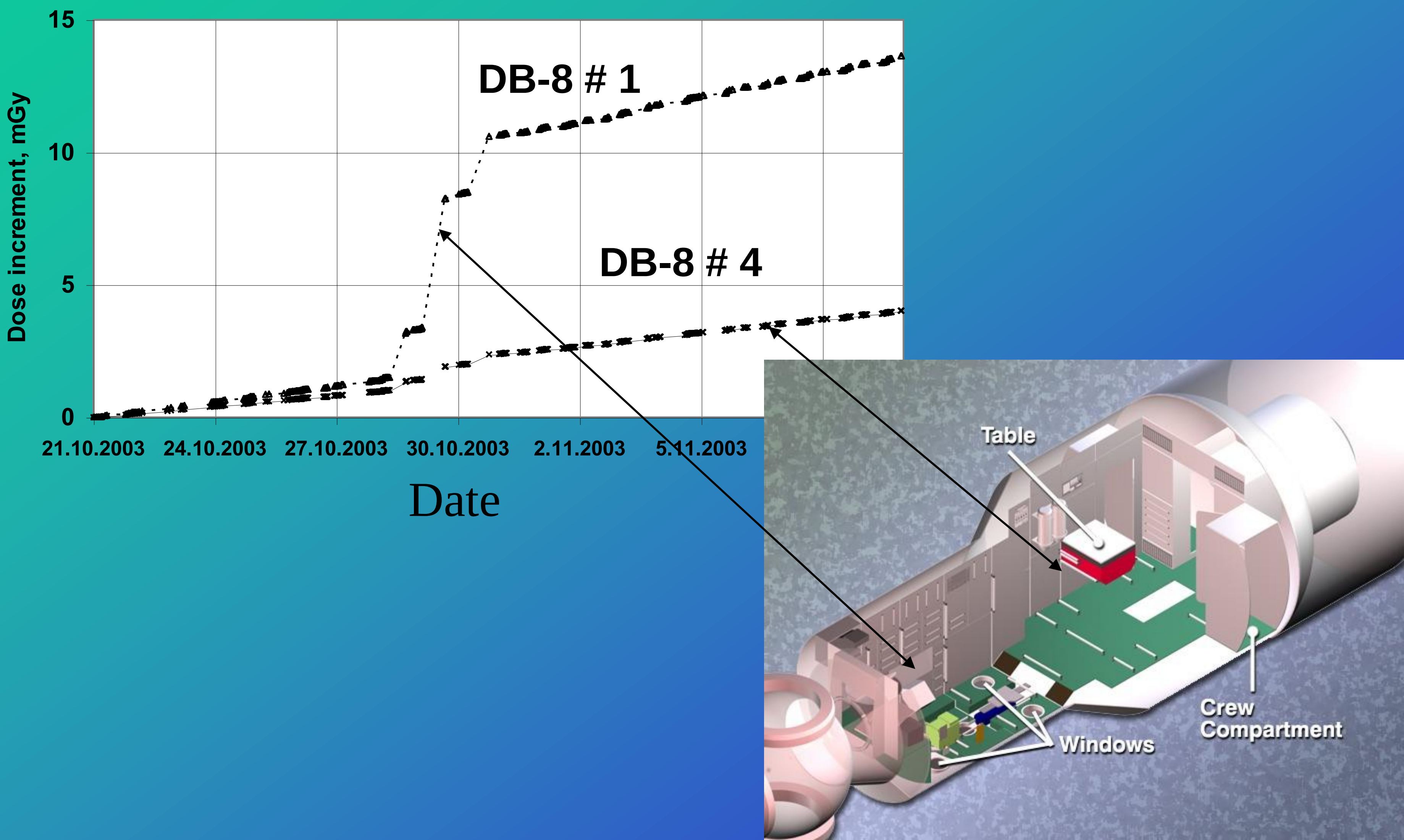
Planetary distribution of dose rate measured in fast mode in September 2005.



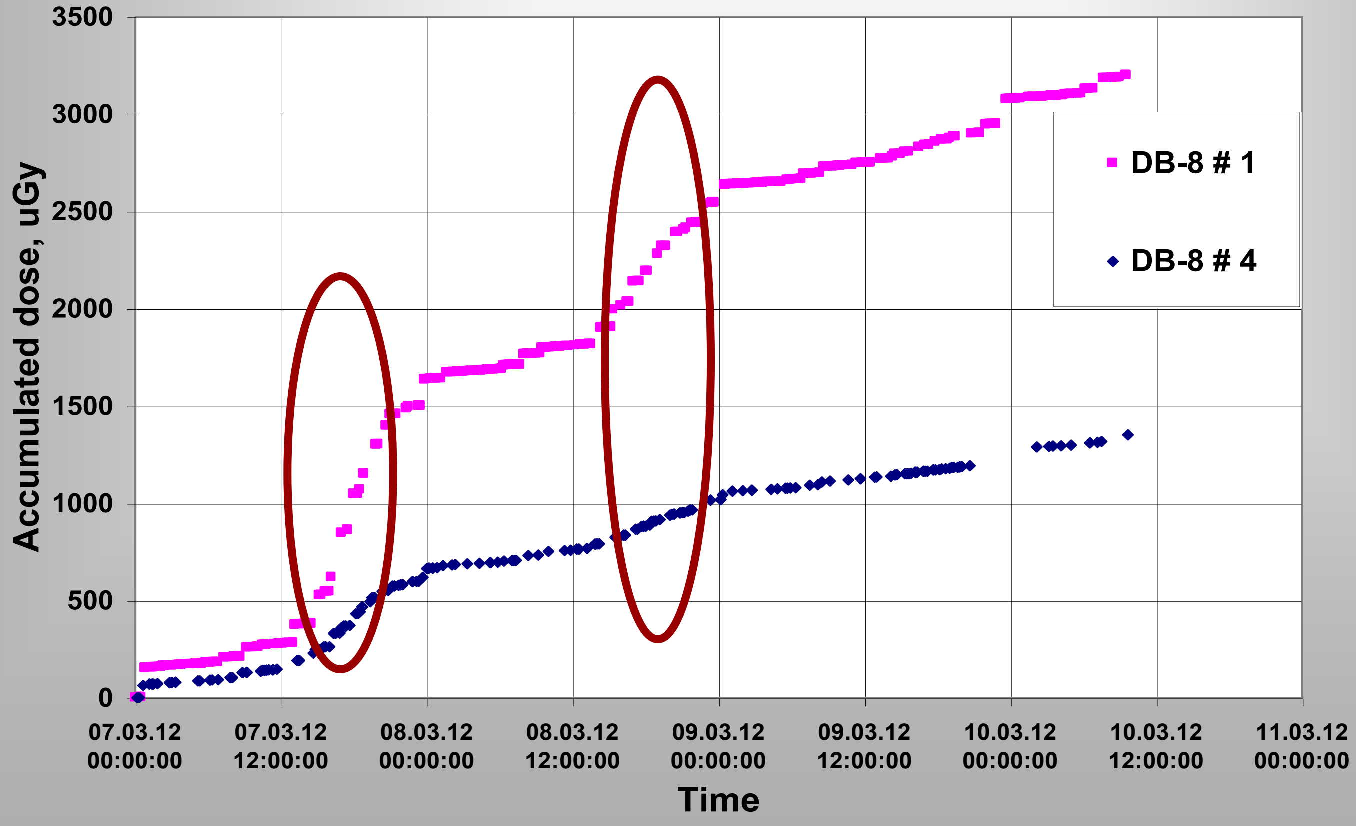
Improved dose rate area in the first decade of March 2012



Dose for October 28 and 29, 2003 SPE
measured with unshielded detectors



The dose accumulation during SPE March 7 2012 measured with DB-8 #1 and #4.



SPE doses onboard "MIR" and ISS measured with R-16 / DB-8

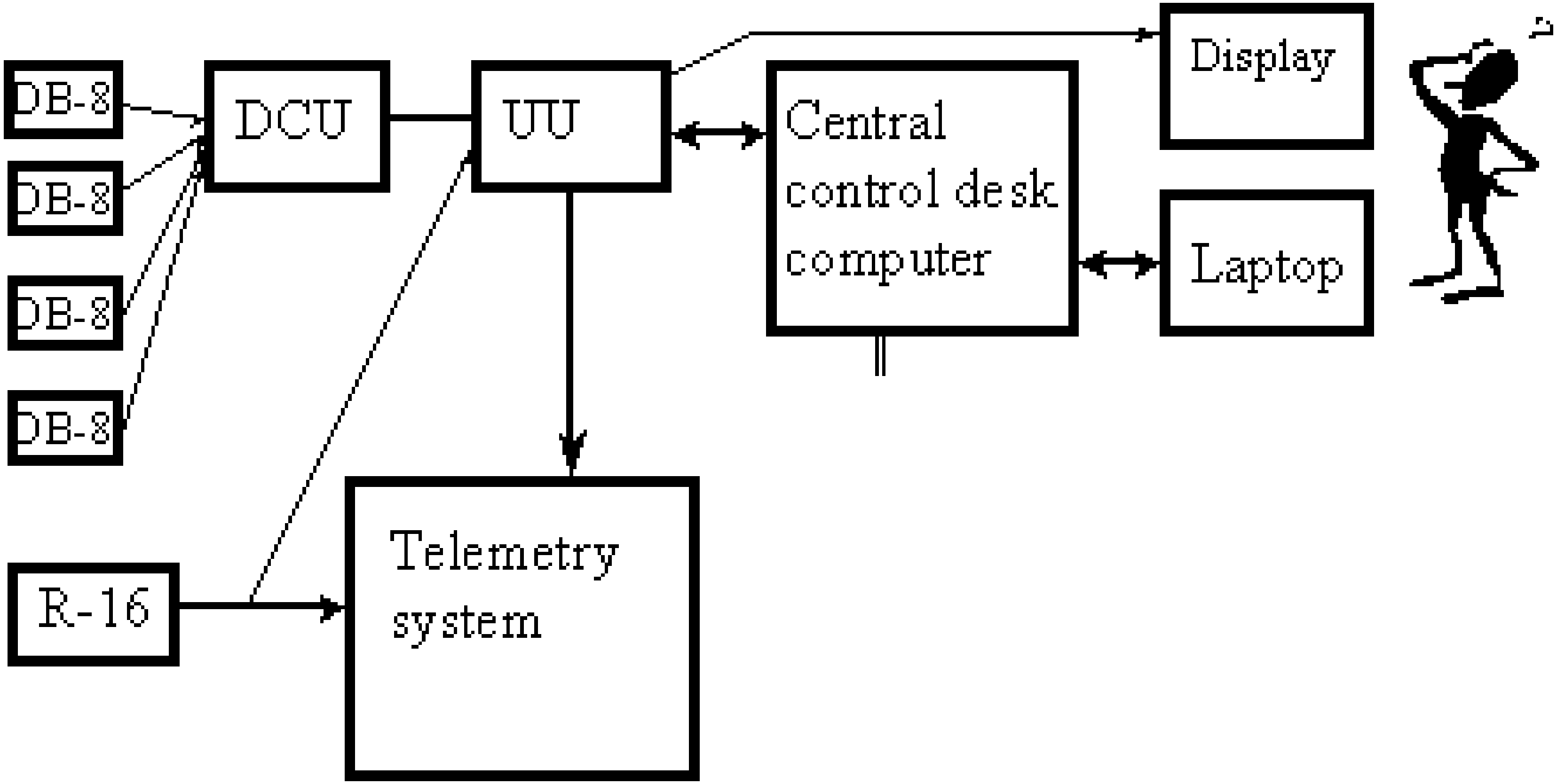
Date	MIR mGy	ISS mGy		Date	ISS mGy
07.03.1989	0.35			18.04.2001	0.16
23.03.1989	0.20			25.09.2001	2.78
28.09.1989	4.65			04.11.2001	4.08
19.10.1989	27.20			22.11.2001	0.46
23.10.1989	3.00			26.12.2001	3.22
25.10.1989	1.70			21.04.2002	1.32
24.05.1990	0.20			28.10.2003	6.37
23.03.1991	2.45			29.10.2003	7.90
04.06.1991	0.60			04.11.2003	0.56
11.06.1991	2.05			10.11.2004	0.26
15.06.1991	0.75			16.01.2005	0.81
20.04.1998	0.35			20.01.2005	0.21
14.07.2000	7.80			08.09.2005	0.33
08.11.2000	2.80	1.40		06.12.2006	
02.04.2001		0.17		13.12.2006	0.51
15.04.2001		0.50		07.03.2012	1.84

SPE doses measured with DB-8, mGy

Date	DB-8 # 1		DB-8 # 2		DB-8 # 3		DB-8 # 4	
	Unshiel	Shielded	Unshiel	Shielded	Unshiel	Shielded	Unshiel	Shielded
2001/09/24	**1.57**	**0.99**	**1.25**	**0.96**	**0.54**	**0.21**	**0.19**	**0.15**
2001/11/04	**2.66**	**1.31**	**1.18**	**0.49**	**0.84**	**0.54**	**0.08**	**0.04**
2003/10/28	**1.71**	**1.19**	**0.82**	**0.52**	**0.87**	**0.69**	**0.31**	**0.30**
2003/10/29	**6.82**	**3.14**	**3.00**	**1.18**	**2.11**	**1.35**	**0.67**	**0.52**
2005/01/17	**0.81**	**0.67**	**0.31**	**0.55**	**0.63**	**0.29**	**0.18**	**0.10**
2005/01/20	**0.21**	**0.18**	**0.13**	**0.14**	**0.13**	**0.14**	**0.08**	**0.07**
2005/09/08	**0.33**	**0.28**	**0.20**	**0.24**	**0.26**	**0.20**	**0.09**	**0.08**
2006/12/13	**0.51**	**0.47**	**0.67**	**0.67**	**0.43**	**0.42**	**0.32**	**0.32**
2012/03/07	**1.84**	**1.58**	**1.26**	**1.59**	**1.56**	**1.07**	**0.57**	**0.55**

On board algorithm of radiation expose forecasting for ISS Radiation monitoring system

Block scheme of the radiation monitoring equipment of the RMS development and accompanying on board devices



NEUTRONS CONTRIBUTION
TO COSMONAUTS EXPOSURE

MEASUREMENTS OF NEUTRON ENVIRONMENT INSIDE AND OUTSIDE the ISS

- V. Lyagushin[1,2]
- A. Kozyrev[1]; M. Litvak[1]; A. Malakhov[1]; I.Mitrofanov[1]; M.Mokrousov[1]; A.Sanin[1]; V.Tretyakov[1]; A.Vostrukhin[1];
- V. Arkhangelsky[3]; I. Chernykh[3]; V. Petrov[3]; V. Shurshakov[3];
- R. Machrafi[4]
- L. Toomi[5]

1) Space Research Institute, Russia;
2) Rocket and Space Corporation «Energy», Russia;
3) Institute of Biomedical Problem, Russia;
4) University of Ontario Institute of Technology, Canada;
5) Canadian Space Agency, Canada.

Agence spatiale canadienne Canadian Space Agency

WRMISS 15 "Villa Mondragone Conference Center",
via Frascati 51, Monte Porzio Catone 7-9th September 2010

Conclusions of Lyagushin's presentation

2. Neutron dose rate inside ISS in the energy range from 0.2 to 10 MeV is:

- **Inside worker compartment from 0.08 to 0.13 mSv/day as dependent on shielding and increasing with thickness**
- **On the surface of spherical phantom is practically the same to dose inside worker compartments,**
- **Inside the spherical phantom at the depth of 10-15 cm the dose rate is 1.2-1.3 times lower than on the surface**

3. The neutron field profile inside and outside ISS is of difficult character and it should be studied in future.

BUBBLE-DETECTOR MEASUREMENTS OF NEUTRON RADIATION IN THE INTERNATIONAL SPACE STATION: ISS-34 TO ISS-37

M. B. Smith1, S. Khulapko, H. R. Andrews, V. Arkhangelsky, H. Ing,
M. R. Koslowksy, B. J. Lewis, R. Machrafi, I. Nikolaev and V. Shurshakov

Radiation Protection Dosimetry (2015), pp. 1–13

Results:

•Neutron dose rate from 0.13 to 2.2 mSv/day;

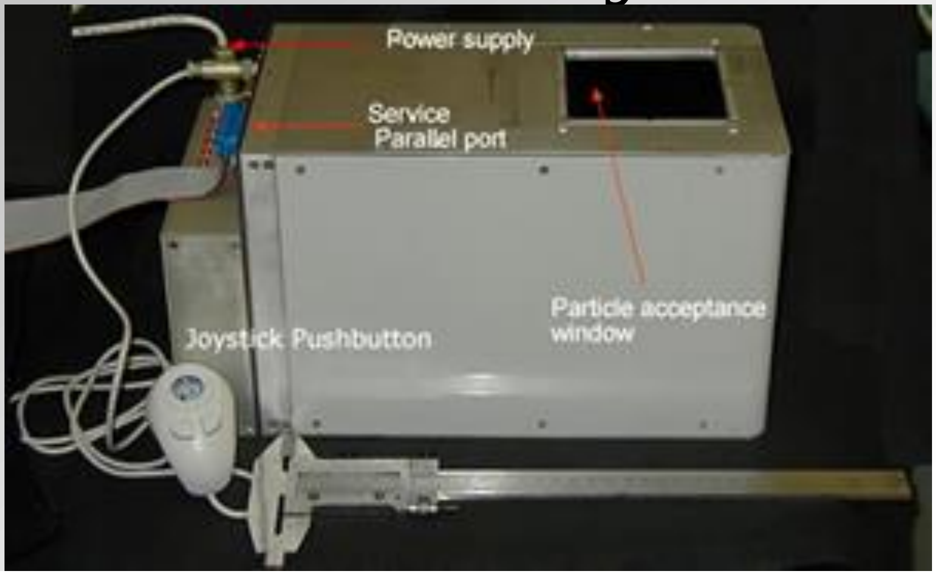
•Inside the spherical phantom at the depth of 10-15 cm the dose rate is 0.73 from the surface dose rate;

•Mean measured dose rate inside the spherical phantom is 0.105 mSv/day;

Crister Fuglesang and the AST-spectrometer

S116E06539

Heavy ions environment



Relative nuclear abundances from C to Fe and integrated flux inside the Russian part of the ISS with the Sileye-3/Alteino experiment

O Larsson1 , VV Benghin[2], M Casolino[3,4], IV Chernikch[2], L di Fino[3,5], C Fuglesang1, M Larosa[3,5], B Lund-Jensen[1], L Narici[3,5], IVNikolaev[2], VMPetrov[2], P Picozza[3,5], C de Santis[3,5] and V Zaconte[3,5]

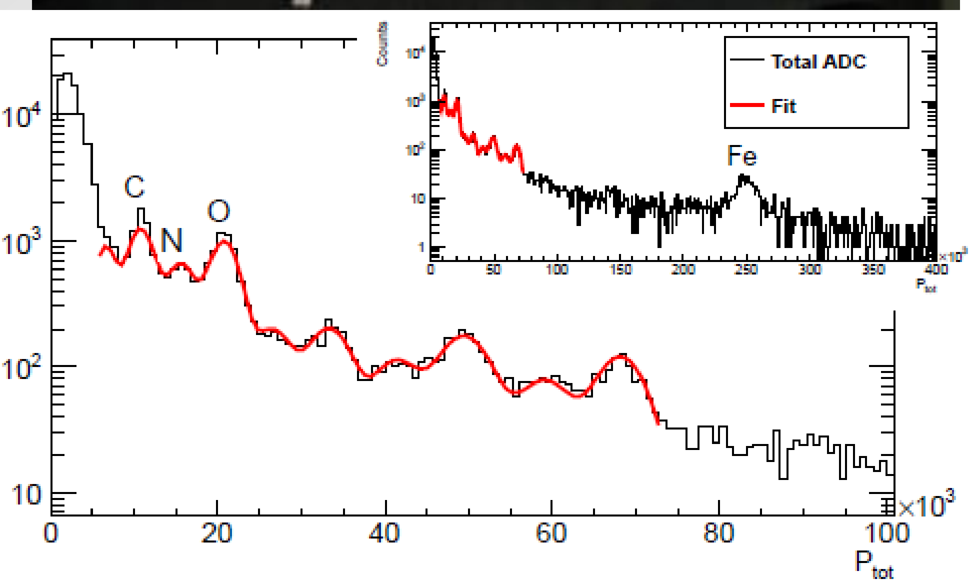
[1]Royal Institute of Technology, Albanova University Center, SE-10691, Stockholm, Sweden

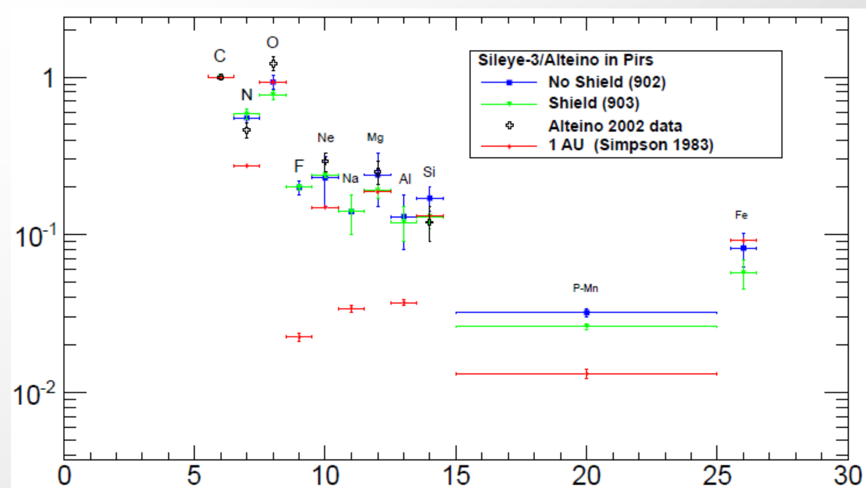
[2]Institute for Biomedical Problems, Moscow, Russia

[3]INFN sect. Roma Tor Vergata, Rome, Italy

[4]RIKEN, Wako, Saitama, Japan

[5]University of Rome Tor Vergata, Rome, Italy





F(Z≥6) 52000 - 250000 ions/(cm^2•Year) **F(Z=26) 1300 - 6000 ions /(cm^2•Year)**

Typical radiation environment levels on ISS

GCR 0.1 mGy/day

ERB 0.25 mGy/day

SCR, max. 36.5 mGy/Year

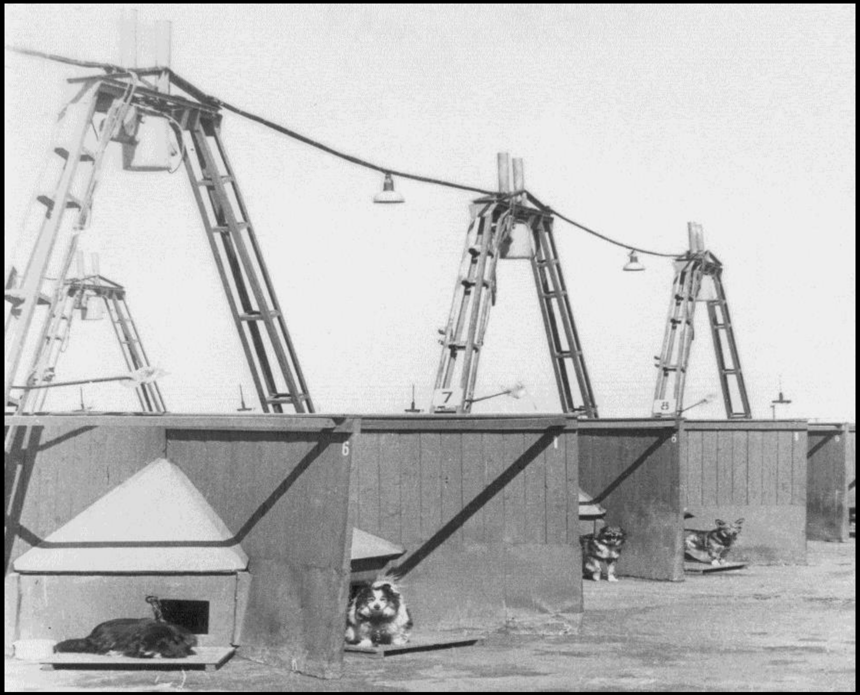
Neutrons 0.105 mSv/day

Heavy ions 250000 ions/(cm^2•Year)

Possible in-flight radiobiological effects

Effect	Responsible system	A dose threshold value
early radiation sickness with dizziness, nausea, vomiting, diarrhea	whole body	500 mSv
Changes in blood forming system	blood forming system	500 mSv
Significant decrease in cosmonauts' work capacity and vitality during a flight	blood forming system	1.5 Sv
Impairment of capacity for work, induced by the skin damage	Skin	5 Sv

SPECIAL 14-years EXPERIMENT FOR DETEMINATION RADIATION DANGEROUS LONG TERM SPACE MISSION TO MARS AND ASSESSMENT OF CREW RADIATION RISK



Already in 1966 year was begin chronic experiment in which 250 dogs were exposed to gamma-radiation during 3 and 6 years on 22 hours per day. In this experiment dose and dose rate varied to simulate galactic cosmic ray (GCR) dose and dose from stochastic irradiation caused by solar cosmic rays (SCR) during long term space mission to Mars. A mean-tissue equivalent dose rate in 1; 2 and 3-th groups of animals simulate GCR dose was consisted 21, 62 and 125 cZv/year respectively.

(Shafirkin A.V., Grigoriev Yu.G., 2009)

The "generalized dose"

To determine the hazard of the cosmic radiation impact and the probability of the lowering of a spacecraft crew working capacity during a flight and possible distant post-flight unfavorable effects it was used a specific dosimetric functional which allows to reduced a complicated nature of space irradiation to the conditions of the standard radiation impact. Such a functional called the generalized dose H has been designed. The acute radiation effects during a manned space flight and dangerous long term consequences are associated with forming pathological changes in essentially different critical organs and tissues of an organism distinguished by the time for the development of damages, their localization and the rate of recovery processes. That is why values of generalized dose should be calculated separately, based on the these set of coefficients, respectively, for nearly the in-flight effect H_N and later long term consequences H_L :

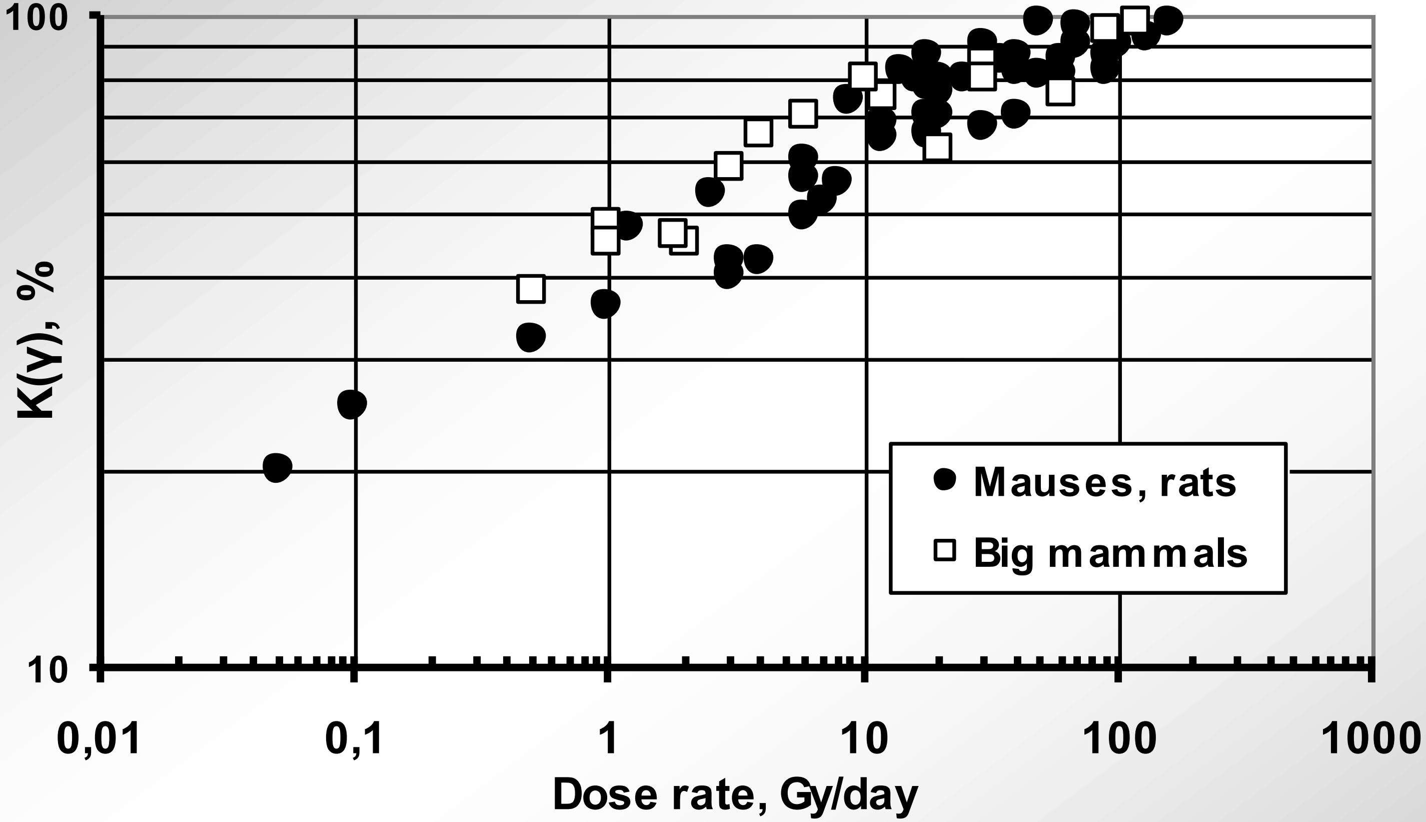
$$H_N = \left(\sum_{i=1}^{n} Di\,[Gy] * QF_{Ni} * TF_{Ni} * SF_{Ni}\right) * MF_N$$

$$H_L = \left(\sum_{i=1}^{n} Di\,[Gy] * QF_{Li} * TF_{Li} * SF_{Li}\right) * MF_L$$

Where Di is a mean-tissue absorbed dose;

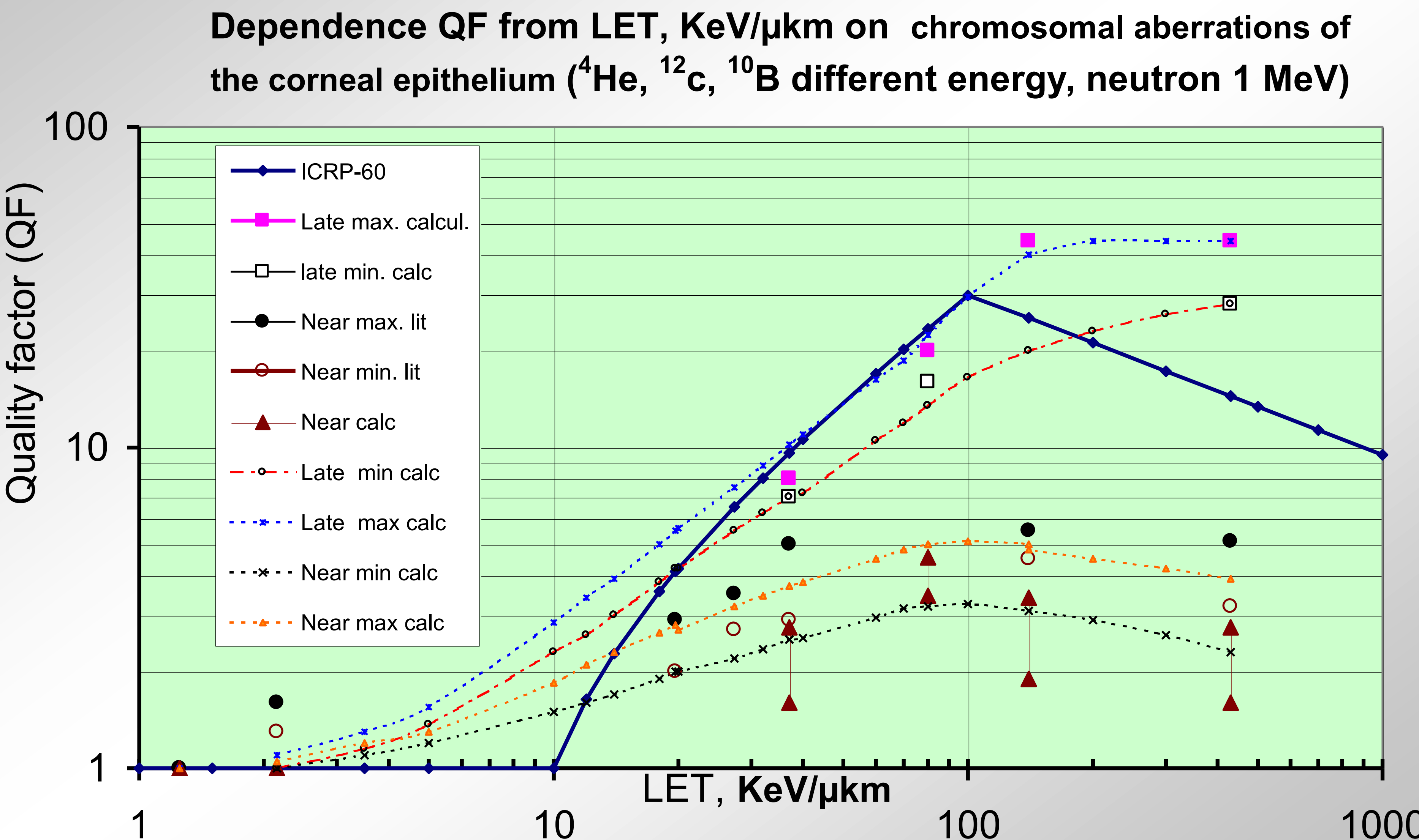
QF_{Ni} and QF_{Li} are quality factors of ionizing radiation, respectively, for in-flight and late radiobiological effects from the *i-th* source of irradiation; TF_{Ni} and TF_{Li} are coefficients of temporal nonuniformity of radiation exposure accounting for the influence on the effects of a dose rate and the pattern of temporal dose distribution; SF_{Ni} and SF_{Li} are coefficients of spatial nonuniformity of irradiation, considering a dose distribution pattern inside a human body and converting the effects of nonuniform irradiation to the effects of uniform radiation exposure, respectively, for the in-flight and late effects from the *i-th* source of radiation exposure in the space; MF_N and MF_L are modification coefficients of radiation response of an organism through the additional effects caused by nonradiation factors during a flight.

The time factor (TF) estimation

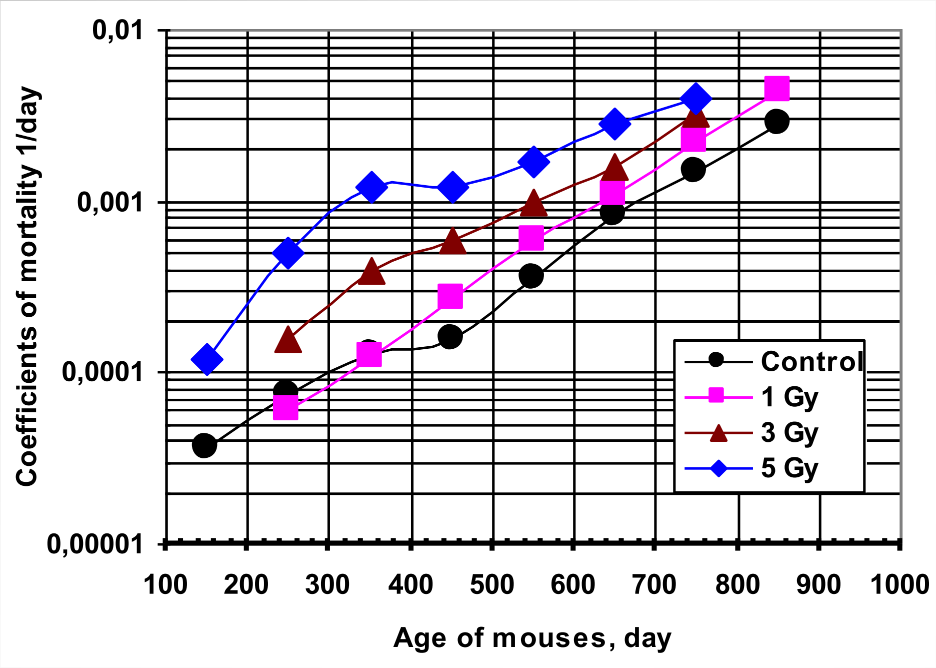


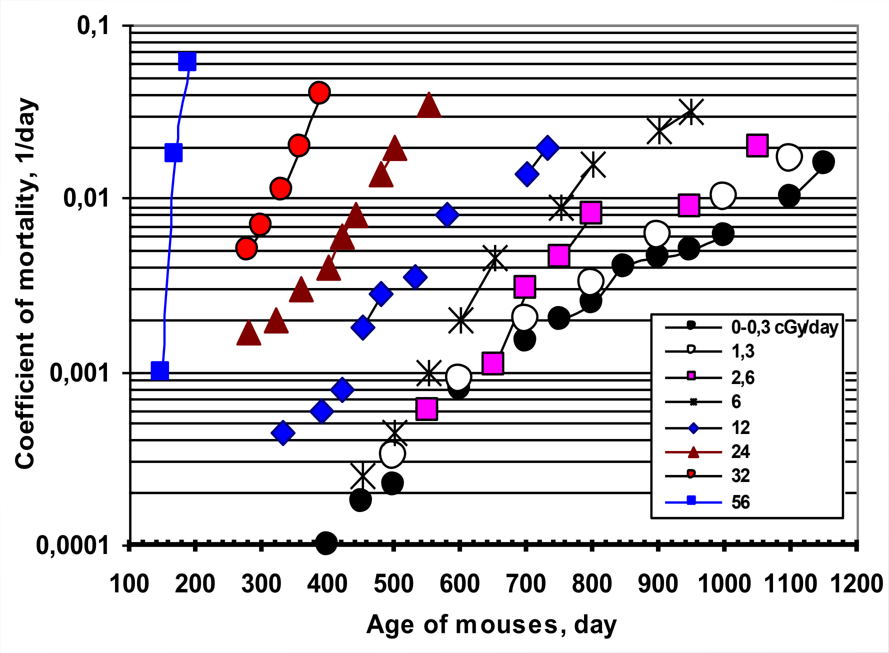
.Efficiently reaction of blood form system (%) from dose rate, connected with quick recovery processes in cell level (experiments on big mammals and small laboratory animals

Quality factor estimation



Dependence mortality rate mouse from age after acute exposure in different doses, Gy (A) and after chronic exposure mouse to radiation at various dose rates cGy/day (B)





On Figures are.showed facility of model for description some experimental dates after acute exposure from the different doses and after chronic exposure to radiation at various dose rates. On basis experimental data was received evaluated significance coefficient B (B = 0,09 1/Zv).

Descent values total volume of compensatory reserves organism and increase mortality rate

$$Q(t) = Q_0 \exp(-\lambda_0 t)$$

$$\mu(t) = \mu(t_0) \exp(\lambda_0 t)$$

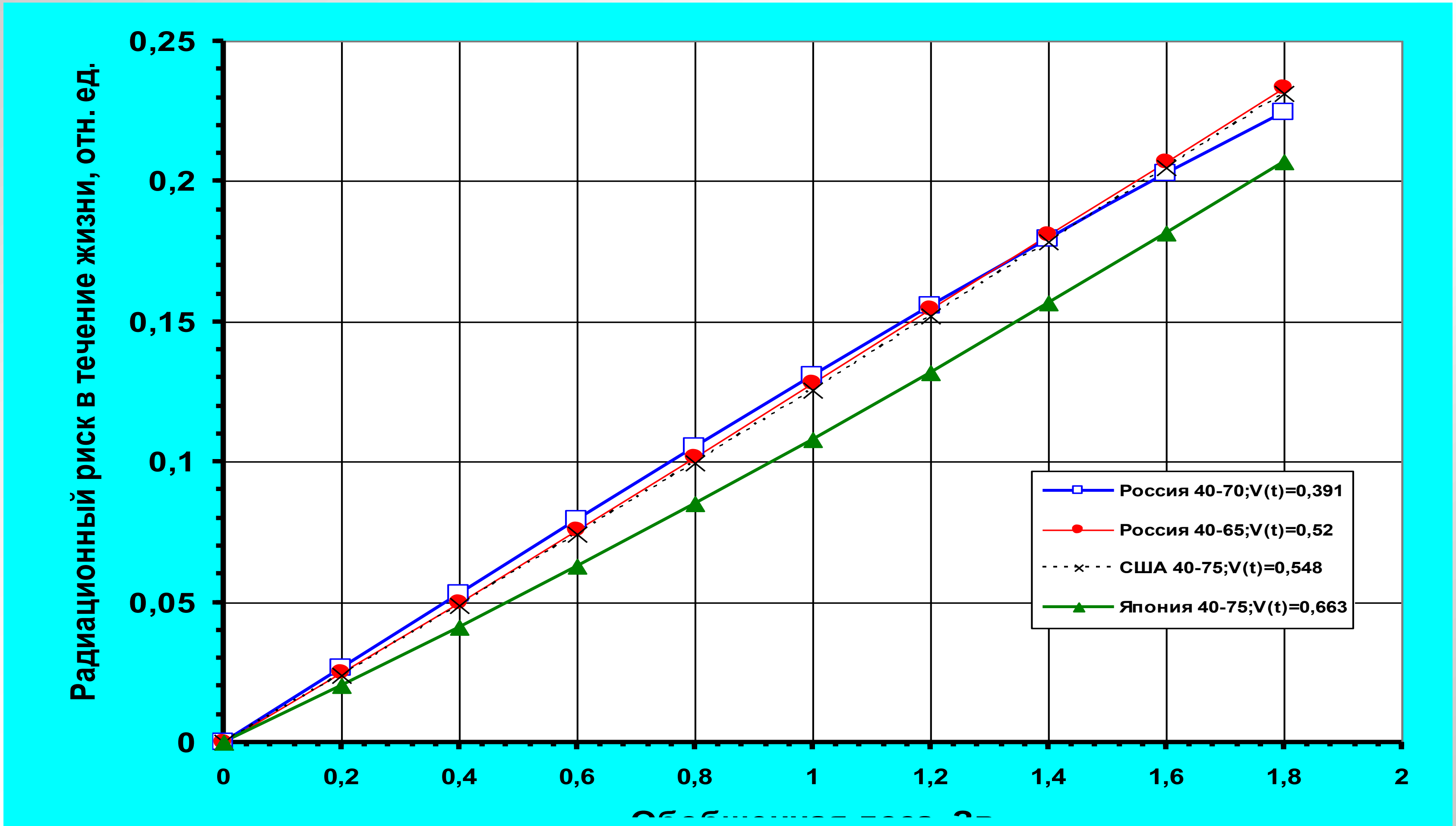
$$Q(t) = Q_0 \exp(-\lambda_0 t - B_p H_L)$$

$$\mu^{rad}(t) = \mu(t_0) \exp(\lambda_0 t + B_p H_L)$$

The total radiation risk and lifetime decreasing estimations

- The demography risk generally calculated with equation:
- $$V(T) = \exp\left\{-\int_t^T \mu(\tau)d\tau\right\} = \exp\{-[\mu(t)/\lambda_0]\cdot[\exp\{\lambda_0(T-t)\}-1]\}$$
- The total radiation risk was calculated with used of the model for radiation-induced mammals death rate, which determines the obligate variations of the compensatory reserves of organism due to radiation impact
- $$Vrad\,(T) = \exp\left\{-\int_t^T \overline{\mu}rad\,(\tau)\,d\tau\right\} = \exp\{-[\mu(t)/\lambda_0]\ \exp(BH_0)\ [\exp\{\lambda_0(T-t)\}-1]\},$$
- where $\mu rad\,(\tau) = \mu(\tau)\exp(BH_0)$.
- Coefficient B was determinated 0,36 1/Sv.
- Summary radiation risk to age T=70 year is R= Vrad (T), - V(T)
- and lifetime decreasing estimations calculated with equation:
- $$\Delta T = \overline{T} - \overline{T}rad = \int_t^{\infty} V(\tau)d\tau - \int_t^{\infty} Vrad(\tau)d\tau$$

Dependence lifetime total radiation risk from generalized dose, Sv for cosmonauts RUSSIA, USA and Japan with start of flight in age 40 years

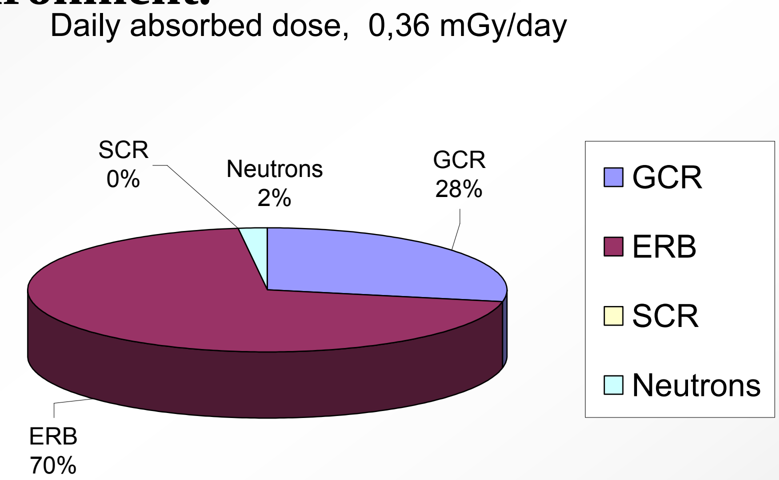


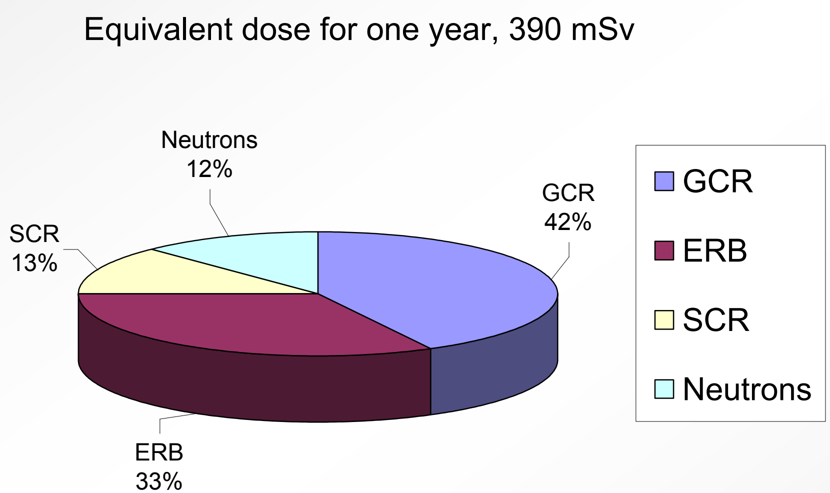
The generalized dose, Sv

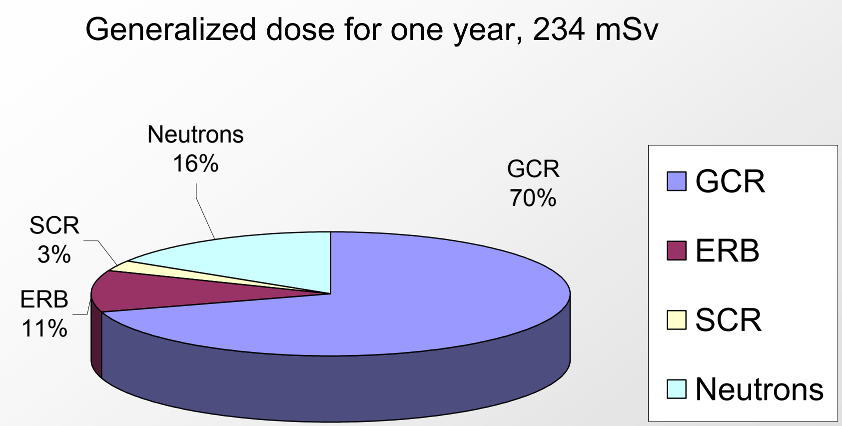
The radiation risk estimation for ISS year's flight
for typical radiation environment.

Initial parameters:

GCR daily abs. dose 0.1 mGy/day
ERB daily abs. dose 0.25 mGy/day
SCR, Y abs. dose 36.5 mGy/Year
Neutrons daily equ 0.105 mSv/day
Heavy ions 250000 ions/(cm^2•Year)







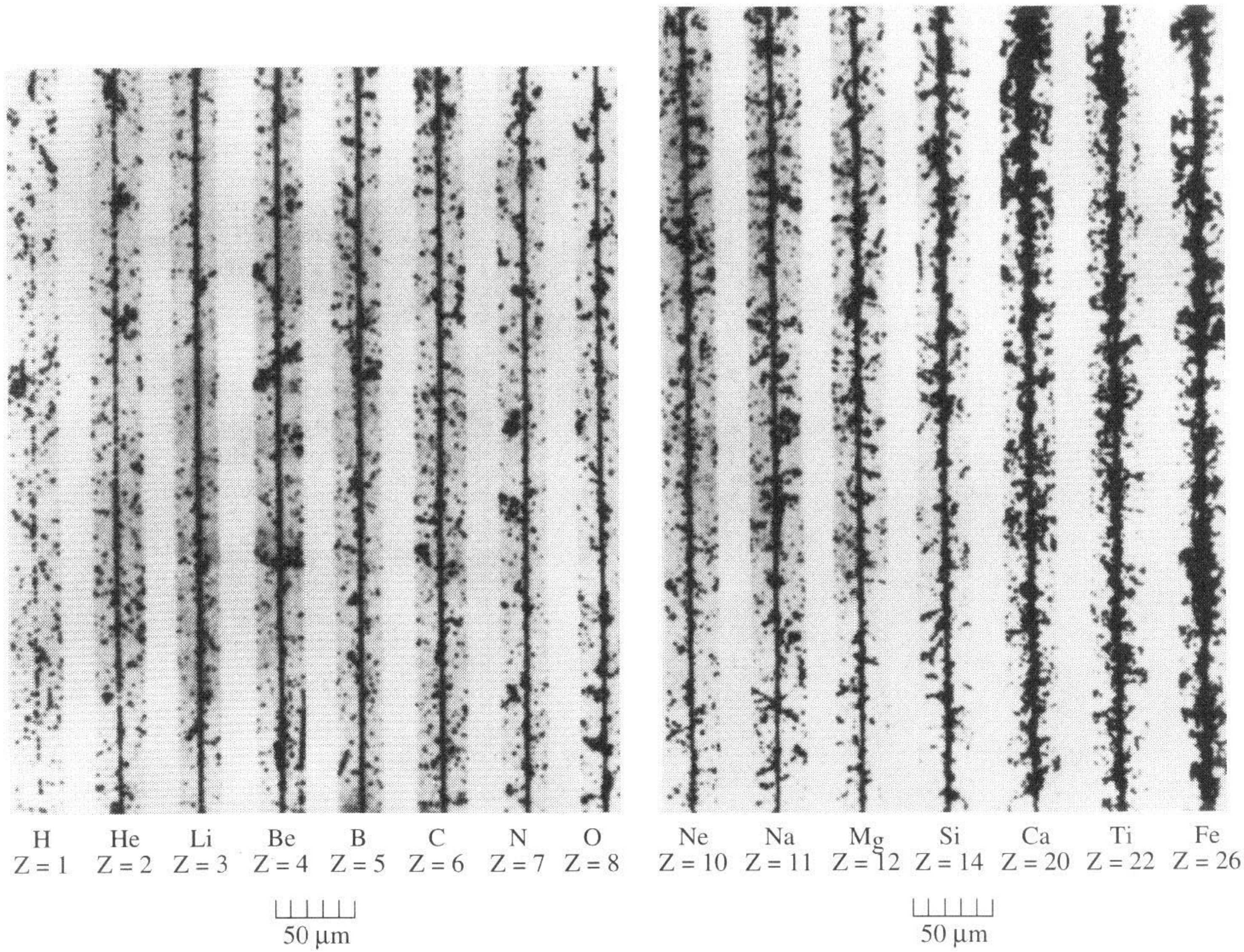
The radiation risk for later long term consequences estimated as 3%

Conclusion

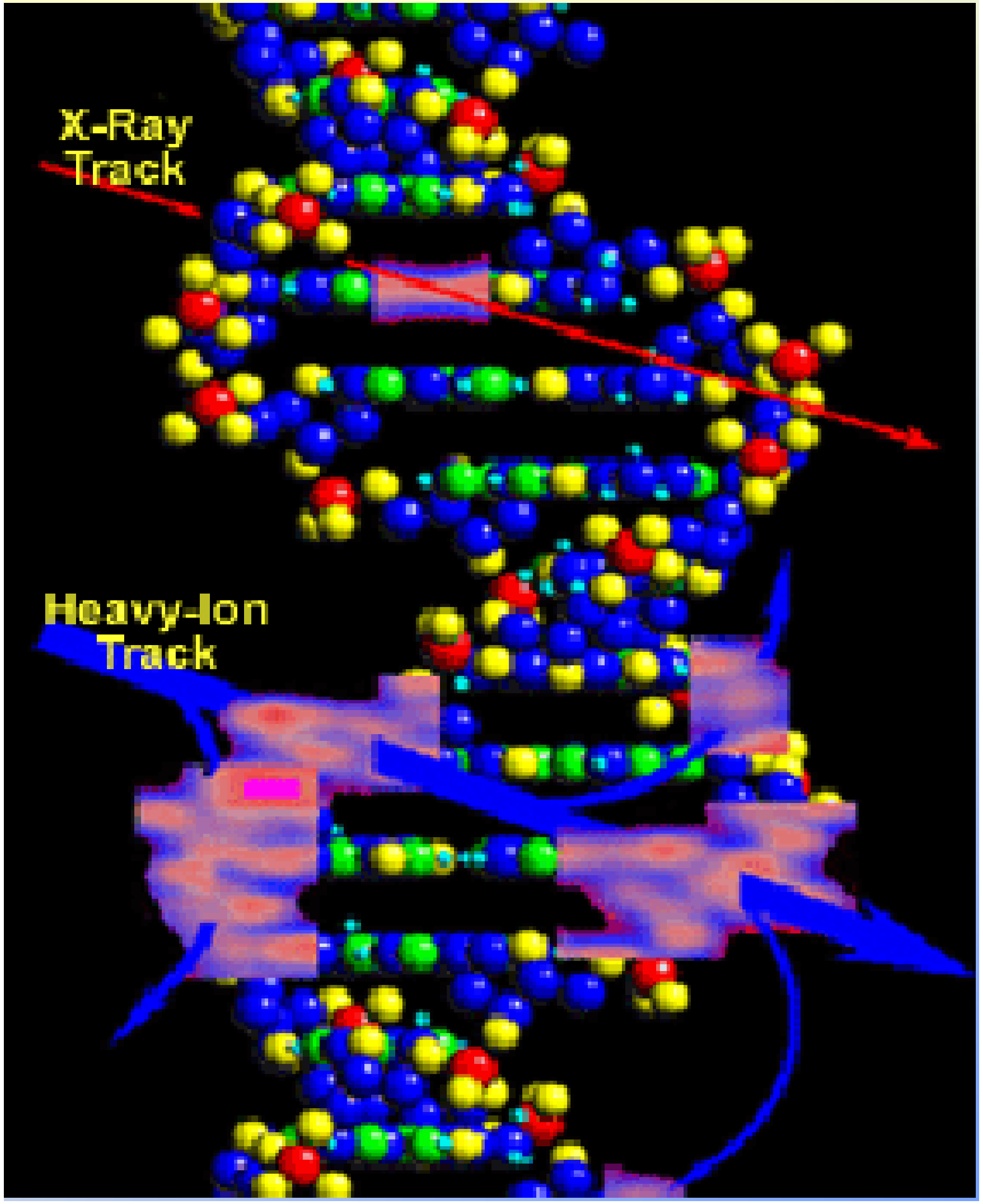
- Radiation Environment aboard the ISS is determined mostly by contribution of galactic cosmic rays and internal Earth's radiation belt
- Contribution of Solar cosmic rays to the effective dose obtained during the flight is usually negligible. Solar protons events that could cause acute radiation effects aboard the ISS have been never observed.
- Mean absorbed dose rate variations are caused mostly by changes of the ISS orbit flight altitude
- Total lifetime radiation risk estimation of cosmonaut is 3 % for one year mission. Expected averaged life time shortening is one year also.

Thank you
for your attention!

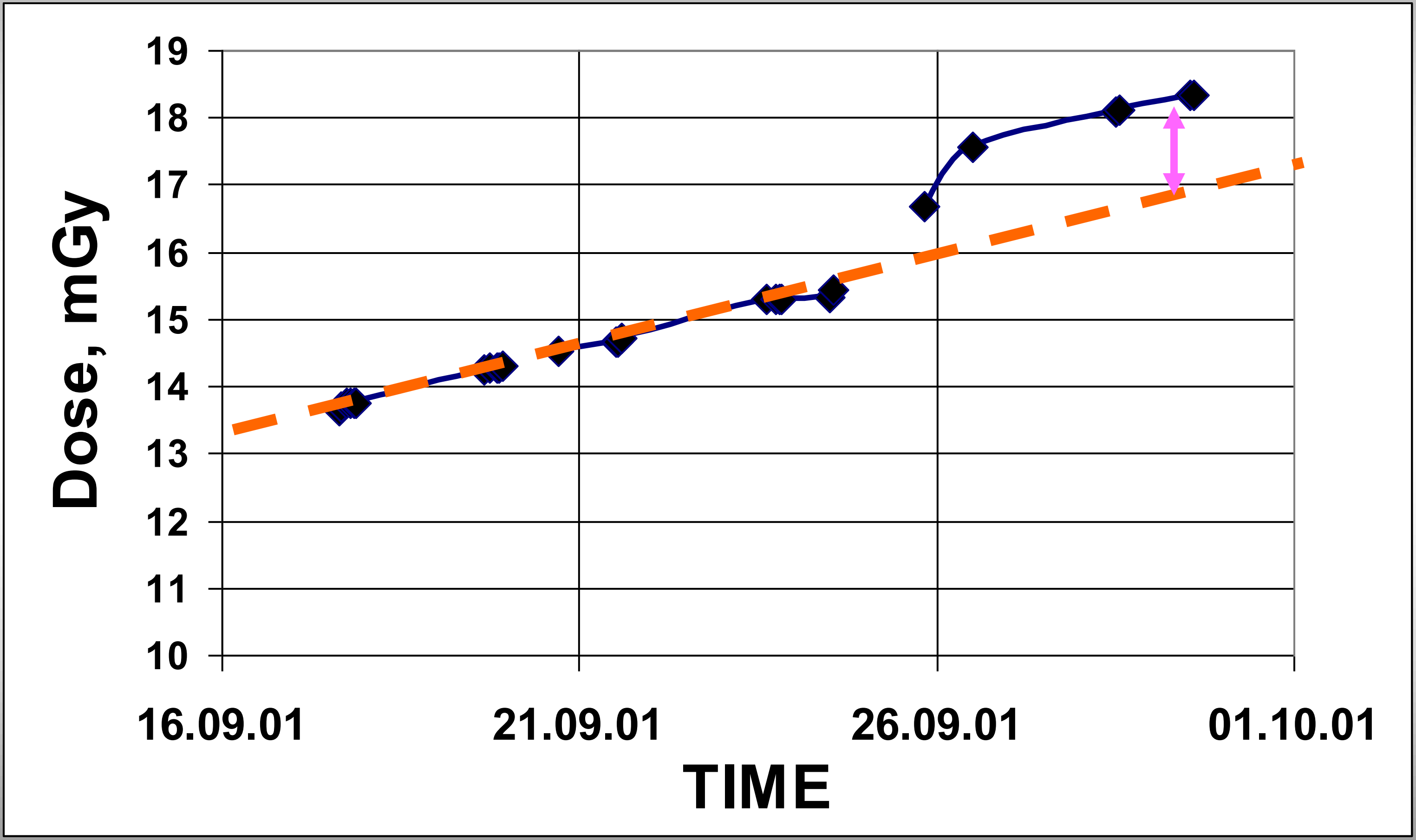
Структура трека заряженной частицы



Особенности воздействия космической радиации на биологические структуры



SPE 25.09.2001 dose estimation.
DB-8 #1 unshielded detector

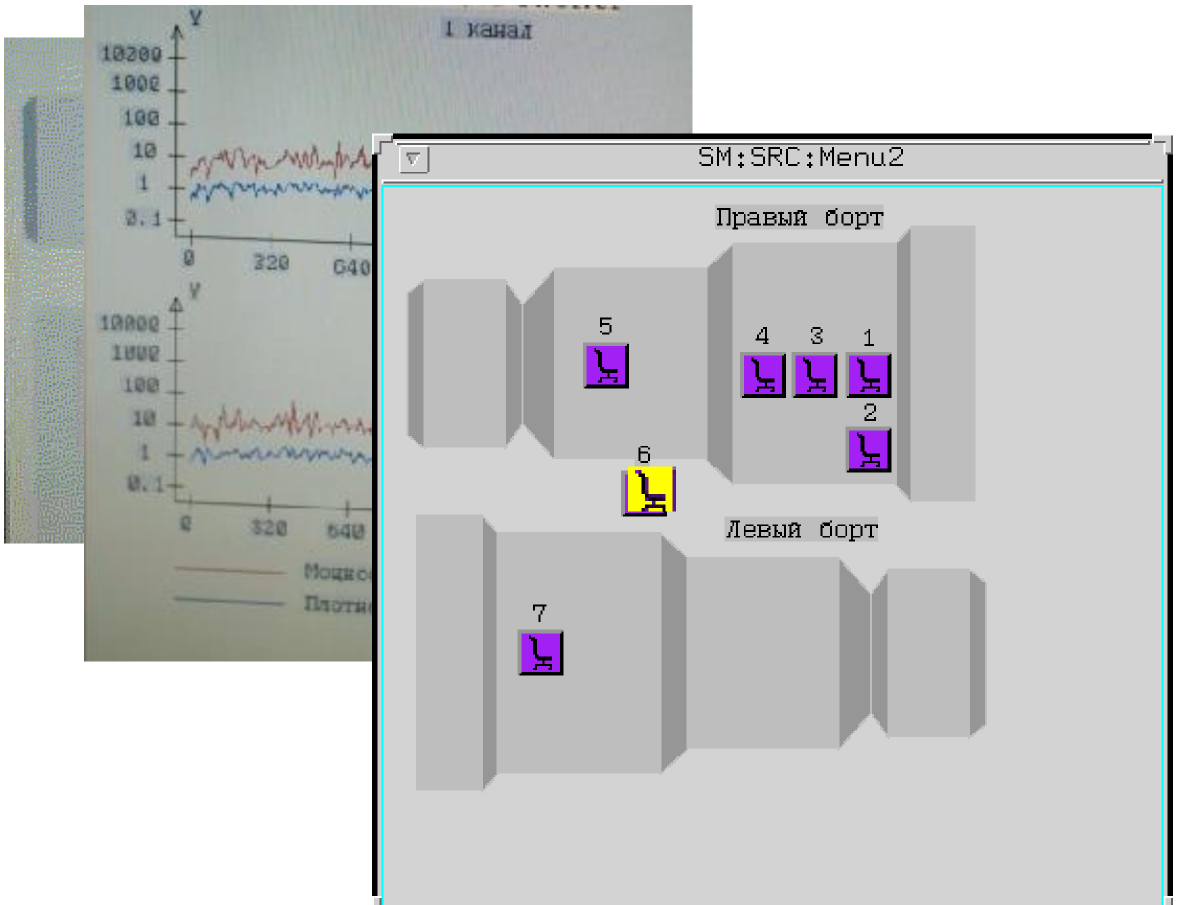


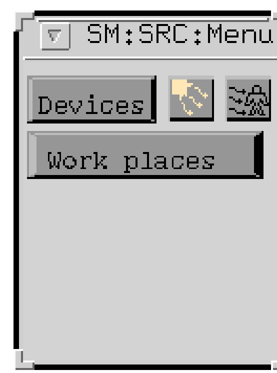
Radiation alert criteria

- If during 3 ten-second intervals not less than 2 detectors simultaneously register dose rate more then 4 mGy/hour;
- If the equivalent dose forecast for next 24 hour more then 5 mSv.

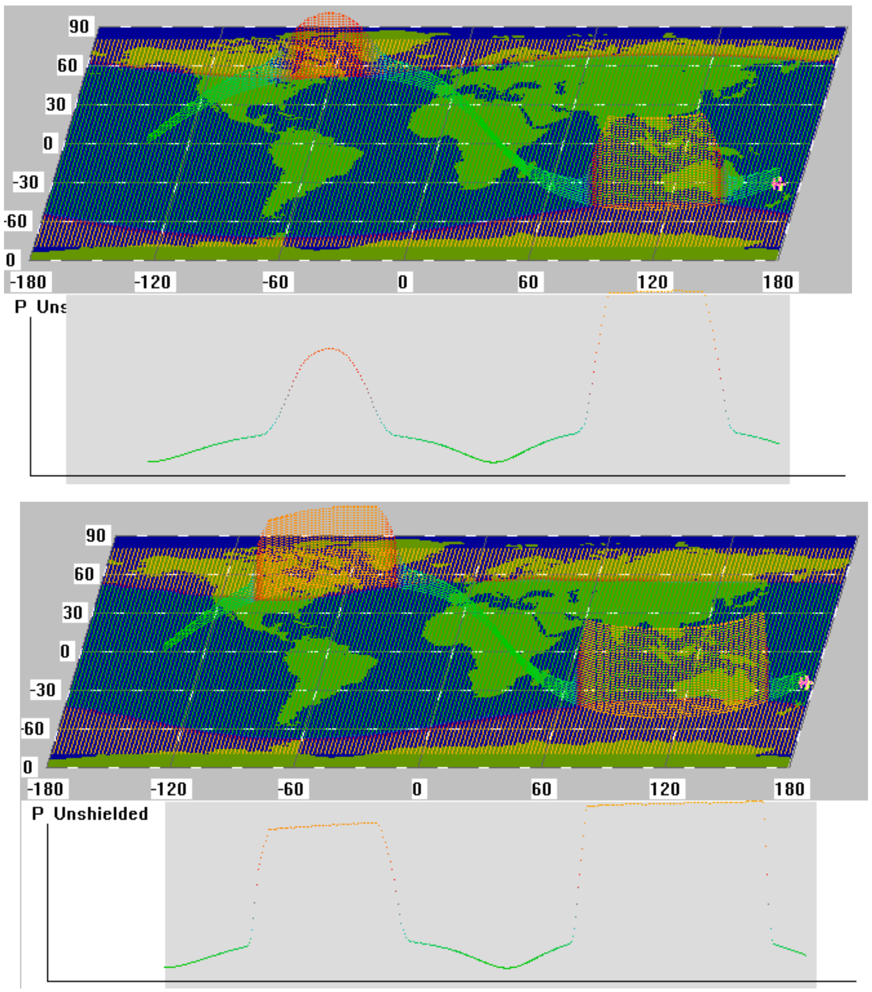
1 - Compartment No 1
2 - Racecourse
3 - Bicycle
4 - Working table
5 - Control desk place
6 - Extravehicular activity
7 - Compartment No 2

The forms of an RMS information display on a Laptop screen



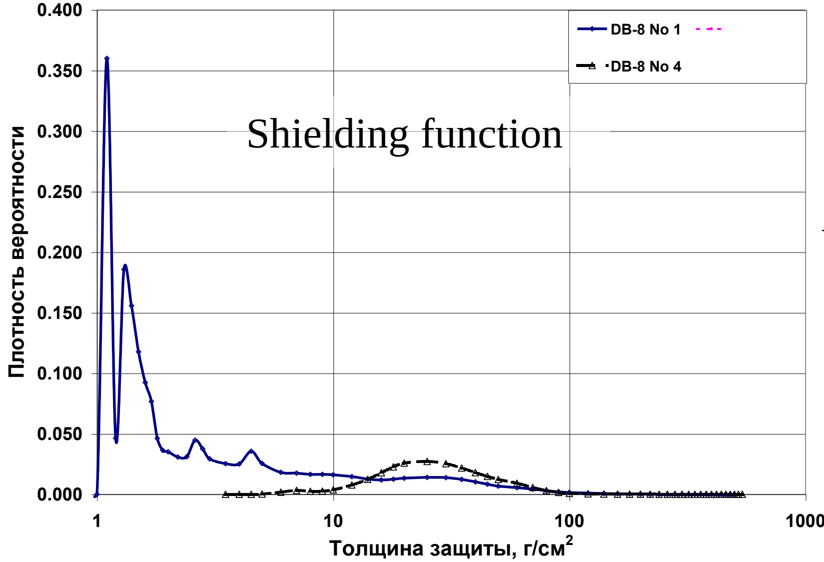


Forecasting supply techniques



- Ballistic calculations.
- Estimations of dose rate and durations of polar cusp’s crossings.
- Conversion of detector’s doses into workplaces doses.

SPE proton energy range essential for dose estimation on ISS



$\varphi(E)$

Absorbed dose in elementary volume

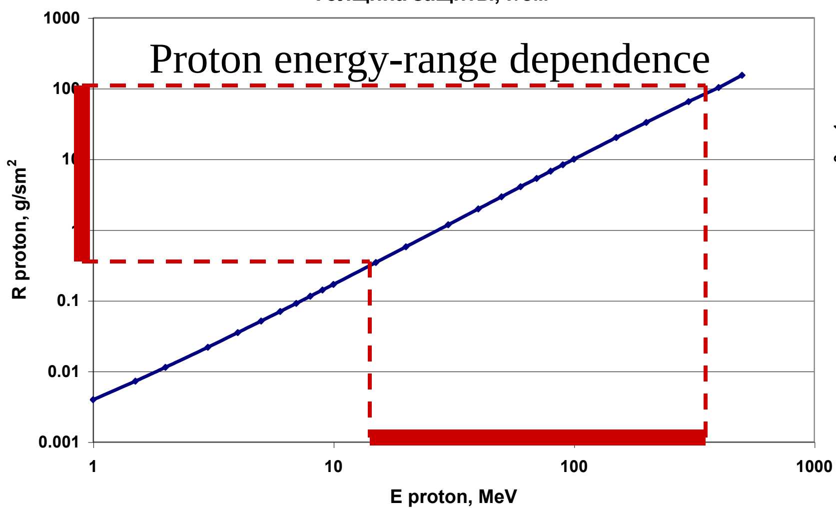
$$D = \frac{1}{\rho} \int_E \varphi(E) \frac{dE}{dx}(E) dE$$

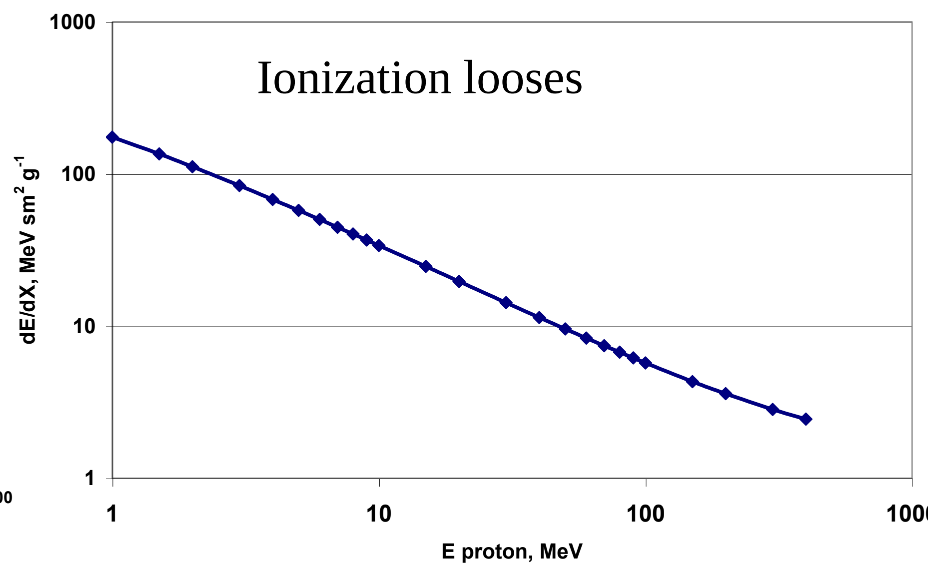
Where E – particle energy;

$\varphi(E)$ - spectrum;

$\frac{dE}{dx}(E)$ - ionization looses.

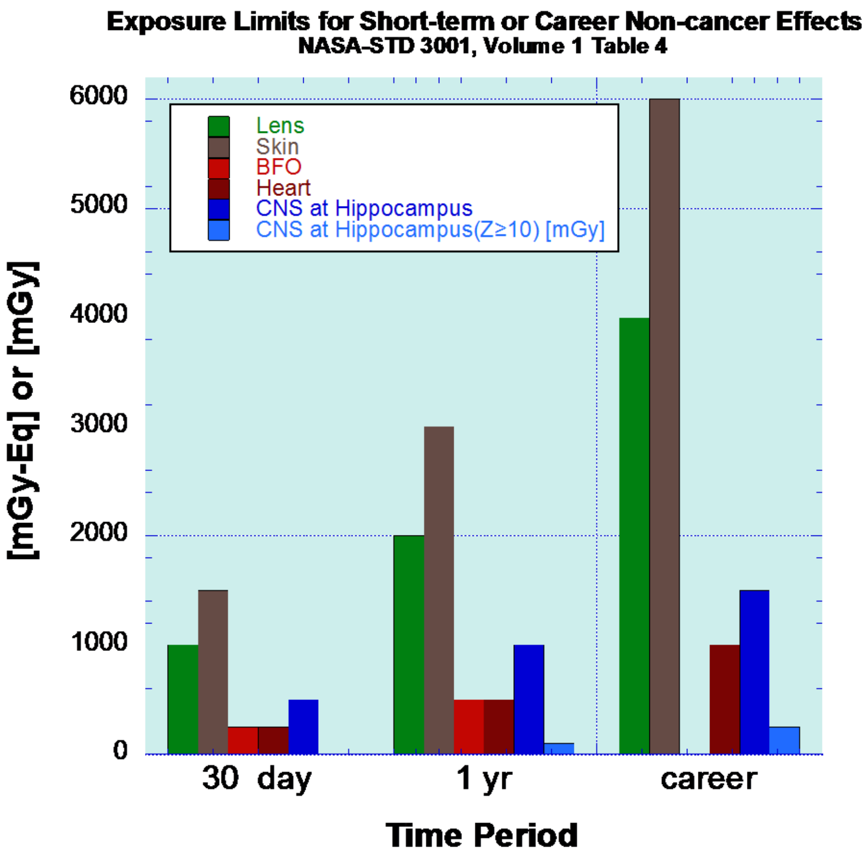
ρ - density.





Space Permissible Exposure Limits for Early or Late Non-cancer Effects

Organ	30 day limit	1 Year Limit	Career
Lens *	1000 mGy-Eq	2000 mGy-Eq	4000 mGy-Eq
Skin	1500	3000	6000
BFO	250	500	Not applicable
Heart**	250	500	1000
CNS ***	500	1000	1500
CNS*** (Z≥10)		100 mGy	250 mGy



*Lens limits are intended to prevent early (< 5 yr) severe cataracts (e.g., from a solar particle event). An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (> 5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.

**Heart doses calculated as average over heart muscle and adjacent arteries.
***CNS limits should be calculated at the hippocampus.

Limit of the equivalent doses (cZv) for different tissue of cosmonauts (astronauts) and career limit in USSR [1-3, 5] and USA [4, 6-8] before 1990 year and in current of time in Russia [3, 9], and USA [10]

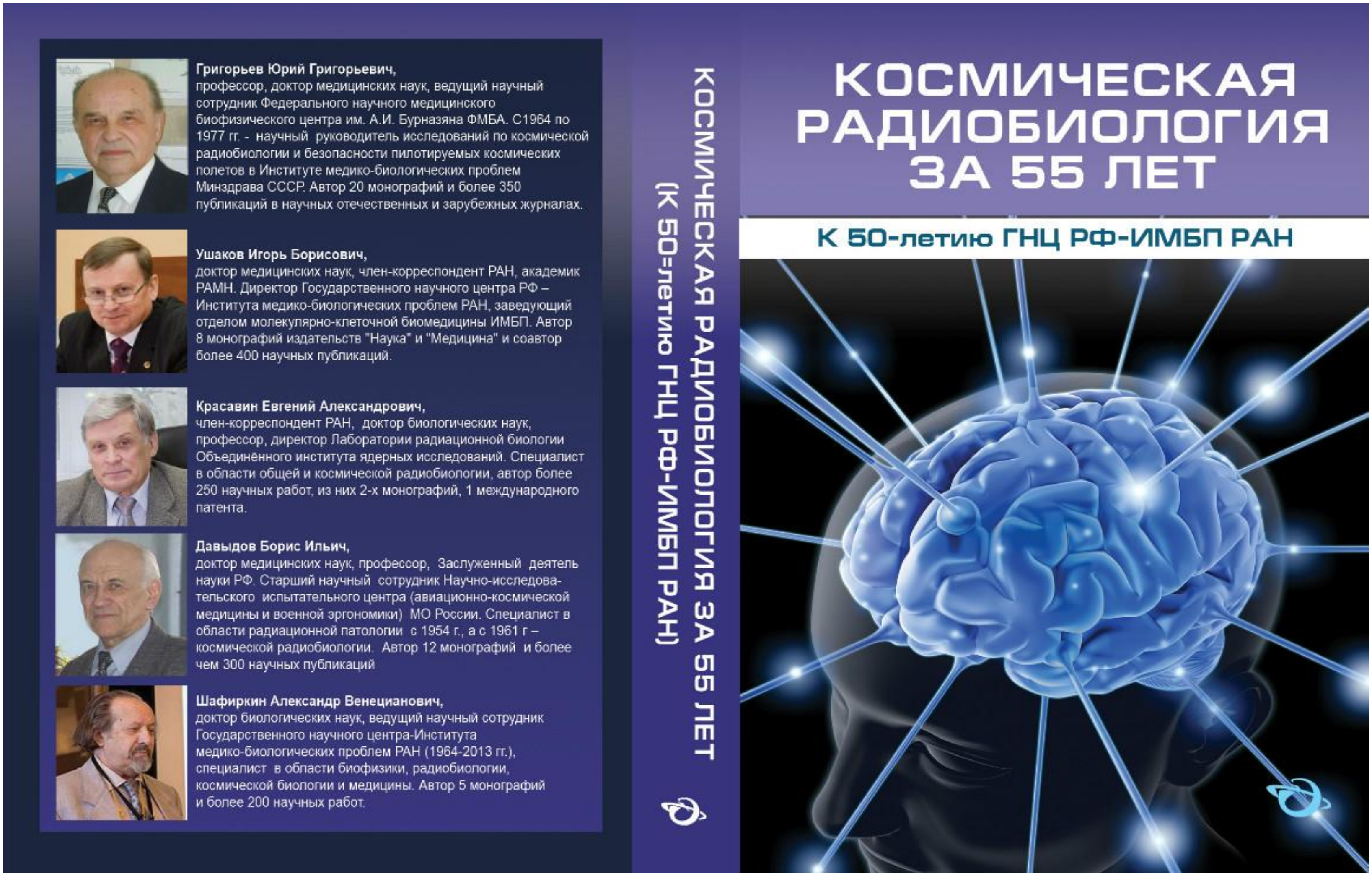
Critical organ, tissue	Duration of a flight	USSR 1965 1975 [1-3]	USA 1970 [4]	USSR 1986* [2,3, 5]	USA 1988-1990 [6-8]	RUSSIA 2004 [3, 9]	USA 2000 [10]
Doses on bone marrow in depth 5 cm (BFS)	Time of SCR (risk< 1 %)	15 15 50 50	-	15 50	-	15	-
	For 30 days	50 50	25	10,5	25	25	25
	For 90 days	80	35	21,5	-	-	-
	For year	150	75	66,5	50	50	50
	Career limit	400	400	400	150-400 D= f(T_0)*	100**	70-290 D=f (T_0)***
Doses on eye in depth 0,3 cm	For 30 days	75	37	75		50	100
	For 90 days	120	52	120	-	-	-
	For year	225	112	225	200	100	200
	Career limit	600	600	600	400	200	400
Doses on skin in depth 0,01 cm	For 30 days	150	75	150	150	150	150
	For 90 days	240	105	240	-	-	-
	For year	450	225	450	300	300	300
	Career limit	1200	1200	1200	600	600	600

* Limit of dose depended from bound value of radiation risk in flight: R = f(T,D); D = f(T, R)

** Limit of dose constant and non depended from age of cosmonauts (astronauts)

*** Limit of doses strong depended from age of cosmonauts (astronauts)

Are present result of investigations for 55 years in Institute aviacosmic medicine of military ministry USSR, Institute biophysics of health ministry USSR, Institute of medical-biological problems of health ministry USSR and join Institute of nuclear research



E. Semones (NASA)

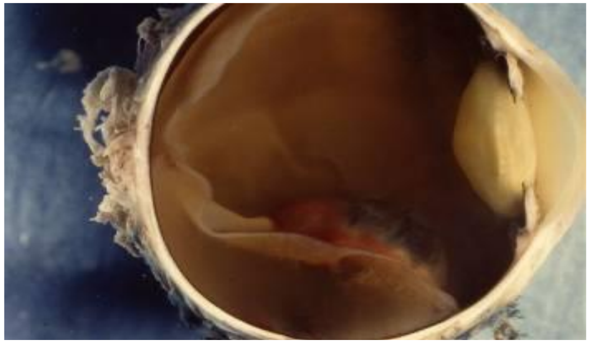
Categories of Radiation Risk

Four categories of risk of concern to NASA:

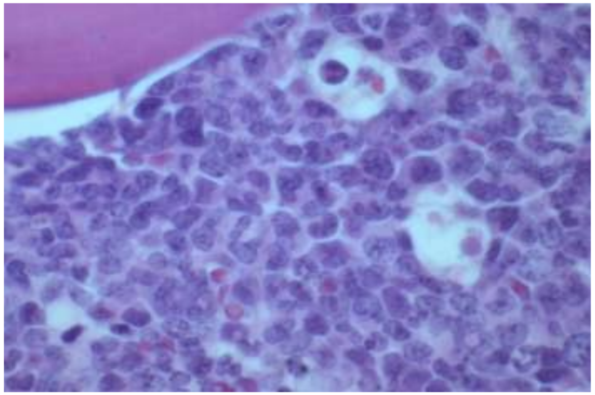
- ***Carcinogenesis (morbidity and mortality risk)***
- ***Acute and Late Central Nervous System (CNS) risks to the Brain***
- ***Chronic & Degenerative Tissue Risks***
  - ✓ cataracts, heart-disease, etc.
- ***Acute Radiation Risks***
- Nausea, vomiting, diarrhea, lethargy, cognitive effects, skin “burn”

Differences in biological damage of heavy nuclei in space with x-rays, limits Earth-based data on health effects for space applications

- **New knowledge on risks must be obtained**
- **Simplified with radiation “quality” factor**
- **Influences of space environment (temporal and qualitative characteristics of the radiation fields, μG, immunosuppression, other stressors) on biological response**



From Space Radiation Project/SK



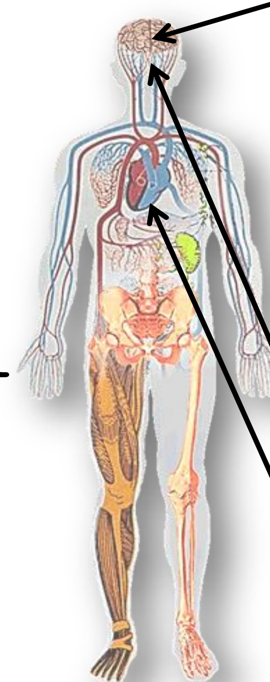
E. Semones (NASA)

Risks of Space Radiation Exposure

Carcinogenesis

Focus of NASA Radiation Risk Model

- Solid Cancers – tumors
- Leukemia
- Issues emerging from research studies of GCR solid cancer risks:
  - Earlier appearance and aggressive tumors not seen with controls, gamma-rays or proton tumors
  - GCR Heavy ions may produce more aggressive tumors compared to controls or X-ray tumors



Central Nervous System (CNS) risks to the Brain

- Retinal flashes observed by astronauts suggests single heavy nuclei can disrupt brain function.
- In-flight *cognitive and short-term memory changes* are a concern for GCR.

Chronic & Degenerative Tissue Risks

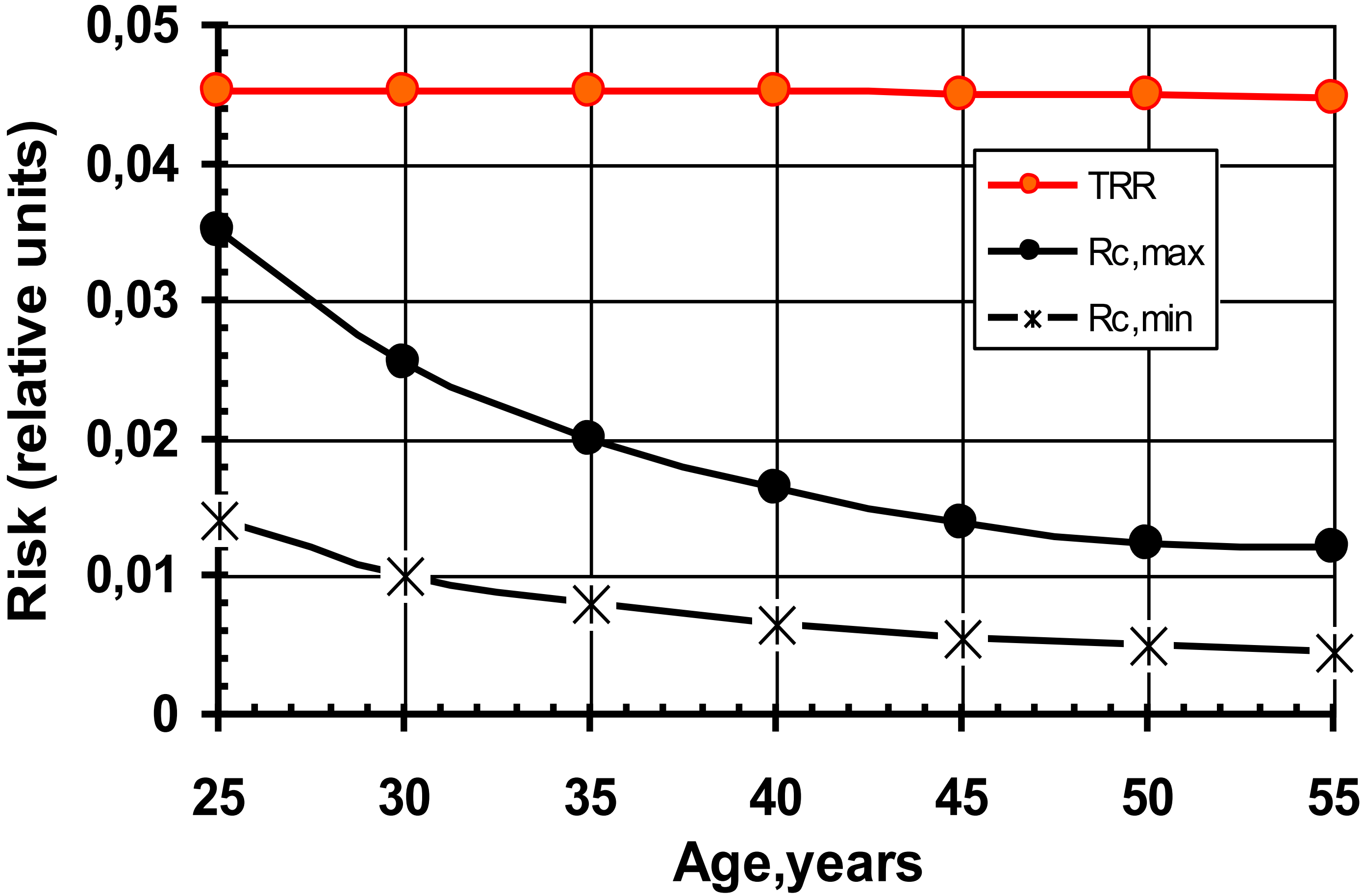
- *Cataract* incidence increased at low GCR doses (<100 mSv) shown in NASA studies.
- *Circulatory Disease* concerns include CVD, IHD, and coronary revascularization and myocardial infarction

ALARA (As Low As Reasonably Achievable)

The ALARA principle is a legal requirement intended to ensure astronaut safety. An important function of ALARA is to ensure that astronauts **do not approach radiation limits** and that such limits are not considered as "tolerance values." ALARA is especially important for space missions in view of the large uncertainties in cancer and other risk projection models. Mission programs and terrestrial occupational procedures resulting in radiation exposures to astronauts are required to find cost-effective approaches to implement ALARA.

Challenges: Uncertainties in biological response to the high-LET component of GCR make ALARA difficult to implement. ALARA is more easily performed for reducing SPE exposure using shielding and limiting exposures during EVAs

Dependences of TRR and maximum and minimum assessments of cancer risk over lifetimes of cosmonauts (relative units) on their age after 2 year-long interplanetary flight in the phase maximum SA for habitat module shielding thickness (Xhmst = 30 g/cm2).



Matching of possible values of SCR doses and thresholds values of organism responses