External Exposure to Natural Radiation

Results of some Experimental Studies

1- INRNE/NPI collaboration

Content

- Comparison of methods used to characterise the exposure due to the environmental radiation background
- Studies on the territory of the INRNE
- Studies on the high-mountain station at Moussala, comparison with Lomnický Štít (High Tatras)
- Common studies with TLDs (aircraft, HECP)

Methods used

1. **Active instruments:**

- ***Environmental radiation dose rate meter NB 3201*** **with a plastic scintillator as sensitive element; able to measure the environmental radiation background with low linear energy transfer (LET) (10 nSv to few mSv/h)**
- ***MDU-Liulin semiconductor spectrometer*** **with Si-diode as the sensitive element; able to estimate both low LET and neutron component of the natural background (10 nSv to few mSv/h)**

2. **Passive detectors:**

- ***Thermoluminescent detectors (TLD)*** $CaSO_4$***:Dy***
- ***Moderator sphere (12 inches)with TED in contact with B-radiators***

Measuring localities

1. *Territory of the INRNE BAS at Sofia:*

- Outside of the building of the Division of Cosmic Ray Physics (DCRP) and on its terrace
- Around the reactor IRT 2000 building

2. *Basic Ecological Observatory (BEO) Moussala;* altitude 2925 m, geographic coordinates 25°35’ E and 42°11’ N
3. *Lomnický Štít Observatory of the Institute of Experimental Physics SAV, High Tatras;* altitude 2634 m, geographic coordinates 20°22’ E and 49°20’ N

Results - INRNE

Measuring point	H*(10), nSv/h, as measured by		
	NB 3201	MDU-Liulin*	TLD
DCRP – in front of	106	-	-
DCRP – terrace	102	103	78-141
Reactor – 1	110	134	130-154
Reactor - 2	100	104	124

* Mean value for two MDU units

Results – BEO Moussala

Measuring point	H*(10), nSv/h, as measured by		
	NB 3201	MDU	TLD
Ground level of building	240	-	-
First floor of building	138	130*)	-
Outside of building	176	-	165-183
Terrace of building	138	140*)	-

***) Corresponding only to low LET radiation**

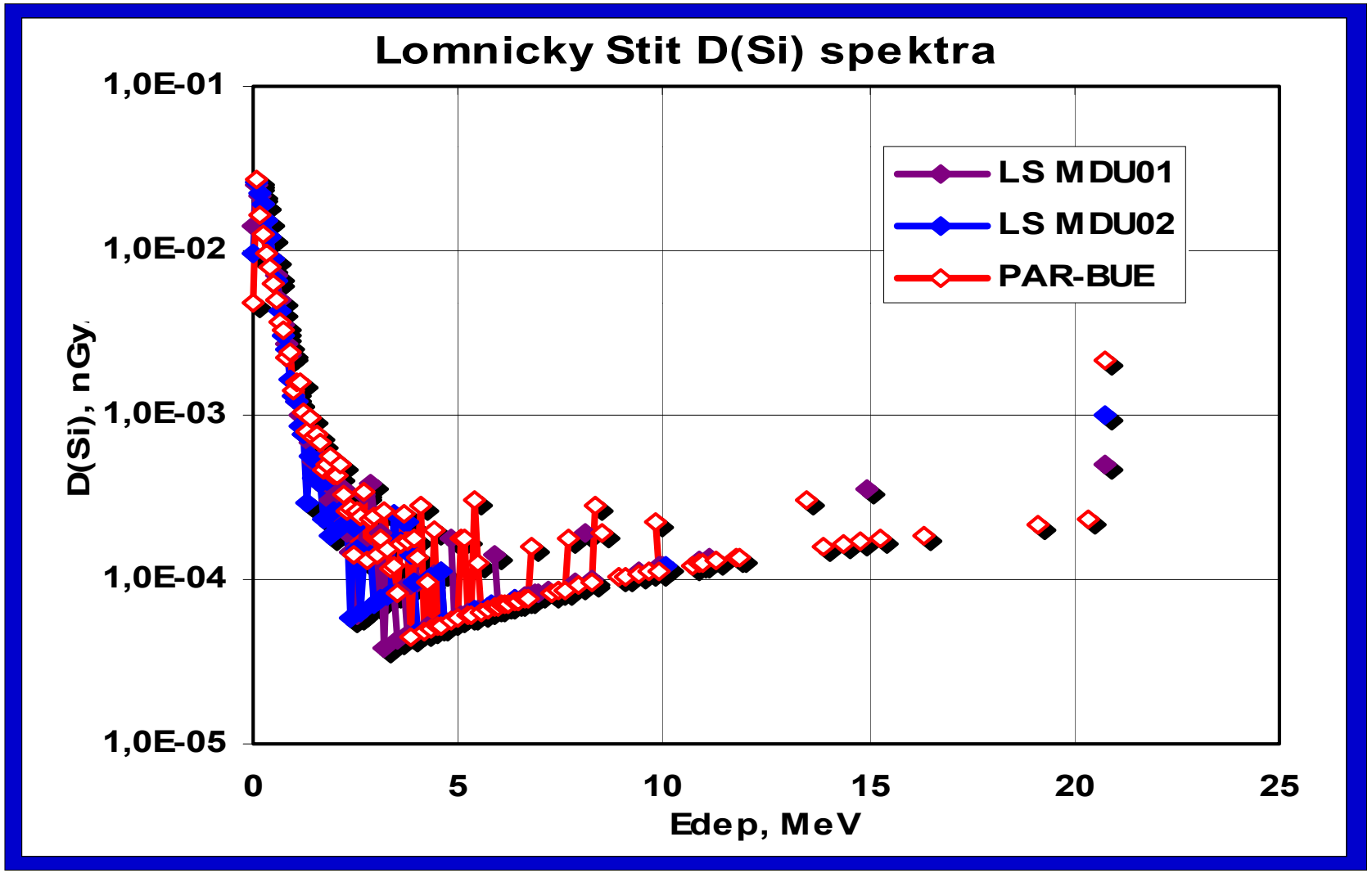
The average value of monitors of INRNE BAS110 nSv/h; minimum and maximum values 87.5 and 128.1 mSv/h

Results - neutron component of cosmic radiation at BEO Moussala – Comparison of different instruments and methods

Method (Quantity measured)	Annual value measured	Annual value corrected
Harwell 3208-1	(190 - 390) μSv[1)]	(380 – 780) μSv
Sphere with ^{10}B	(254 ± 26) μSv[2)]	(508 ± 52) μSv
MDU-Liulin	(180 ± 72) nGy[3)]	(1080 ± 380) μSv
UNSCEAR 2000	-	~ 580 μSv

[1)] Period 09/02 ÷ 05/03; [2)] Period 11/00 ÷ 02/04; [3)] November 2000

Results - neutron component of cosmic radiation at Lomnický Štít - Event spectra in MDU Si-diode instrument



Results - neutron component of cosmic radiation– Comparison of BEO Moussala and Lomnický Štít high mountain stations

Estimated from	Annual values measured at			
	Moussala[1)]		Lom. Štít[1)]	
	D(Si), µGy	H*(10), µSv	D(Si), µGy	H*(10), µSv
MDU-Fr	180 ± 72	1080 ± 380	-	-
MDU-CZ01	-	-	135±6	440 - 850
MDU-CZ02	-	-	113±7	440 - 760
UNSCEAR 2000	-	~580	-	~570

[1)] Measuring times 14 hours at Moussala, 95 hours at Lomnický Štít

Onboard aircraft exposure

- A310-300 Czech Airlines
- 05/05-31/12/05
- Together with MDU-Liulin
- All navigation data available – dose calculated
- Trach etched detectors; TLD's

TLD results:

1. Exposure dates
   - NPI's – full time
   - INRNE – since 08/09

2. Results since 08/09/05:

Al_2O_3 :C: (1.75±0.25) mSv

AlP glas: (1.66±0.09) mSv

CaSO4:Dy: (1.5-1.8) mSv

RR of TLDs to high energy charged particles HIMAC, NIRS Chiba, September 2005

Ion	Energy (MeV/n)	LET keV/μm	shield	RR		
				Al_2O_3/C	Al-P skla	$CaSO_4$
^{4}He	150	2,2	Bare Beam	0,77	0,84	1,01
^{4}He	150	3,5	Behind PMMA	1,10	1,37	1,63
^{16}O	400	19,8	Bare Beam	0,50	0,98	0,99
^{16}O	400	*23,8*	Behind PMMA	0,47	0,95	0,94
^{40}Ar	500	89,3	Bare Beam	0,34	0,68	0,62
^{40}Ar	500	*100*	Behind PMMA	0,34	0,68	0,62
^{56}Fe	200	310	Bare Beam	0,26	0,61	0,47
^{56}Fe	200	*321*	Behind PMMA	0,35	0,77	0,57

External Exposure to Natural Radiation

Results of some Experimental Studies

2 - Onboard aircraft exposure

1. International activities

2. Experimental studies 1991-2005

- Period 1991-1999 – set of dosimetry methods (TEPC, rem-meter, Bubbles, TLD, scintillator, IC, GM, APD)
- Period since 2000 – mostly MDU-Liulin results

3. Routine individual dosimetry of aircraft crew members of czech air companies, 1998-2004

ICRU&ICRP TG No. 50

- **Goal : to prepare the recommendations "Reference doses from cosmic radiation exposure of aircraft crew"**
- **Scheduled: 2001-2005; now 2006/2007**
- **Current stage: decision taken to concile different groups and prepare the data in the forme of acceptable limits for low and high „typical"solar activities periods**

WG 21 ISO TC/85 - since 2001

- **ISO 20785: "Dosimetry for exposure to cosmic radiation in civilian aircraft"**

- **Current stage: decided to prepare in 3 parts:**

- **"Conceptual basis for measurements";**
  done - 09/05
- **"Characterisation of instrument response", WD – end 2005**
- **"Standardization of measurements procedures" (≥2006)**

DG's RTD and TREN EC + EURADOS

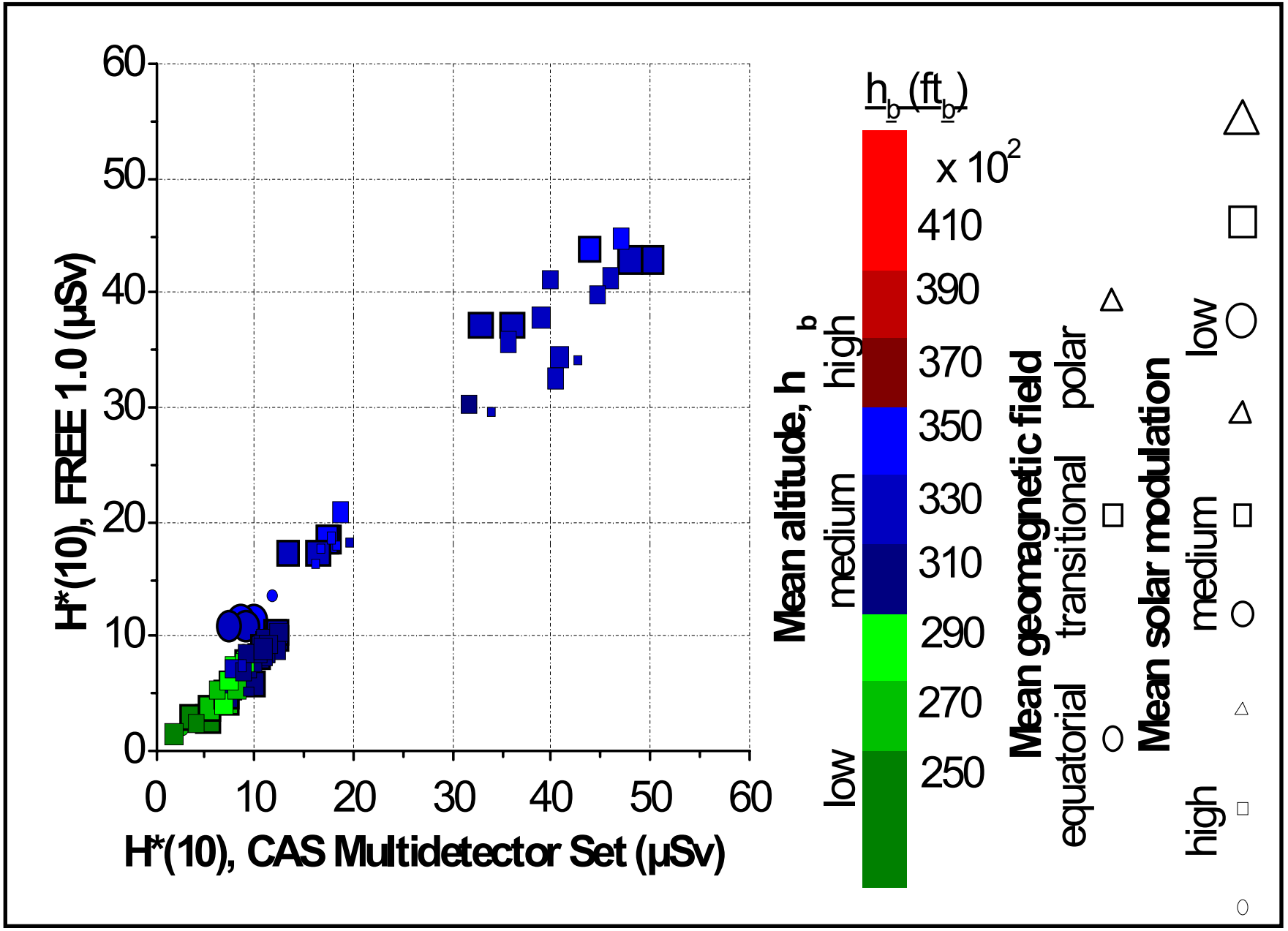
- **WG – Article 31 EURATOM**
- **DOSMAX (6thEF)**
- **CONRAD – WP 6 (7thEF)**
- **EURADOS WG 5**

WG EURADOS (Art. 31 EURATOM)

„Cosmic Radiation Exposure of Aircraft Crew: Compilation of available experimental and calculated data“

1999-2004; Eds.: I. McAulay, D. Bartlett, P. Beck, K. Schnuer, H. Schraube, F. Spurny; 280 p.

ISBN 92-894-8448-9; several ten thousands data*: **The total uncertainty of measured values is about 25% (2s). The total uncertainty in the values of effective dose calculated by different codes is estimated to be about 30%.***


H*(10), FREE 1.0 (μSv)
H*(10), CAS Multidetector Set (μSv)
0
10
20
30
40
50
60
h_b (ft_b)
x 10^2
410
390
370
350
330
310
290
270
250
Mean altitude, h_b
high
medium
low
Mean geomagnetic field
equatorial
transitional
polar
Mean solar modulation
high
medium
low

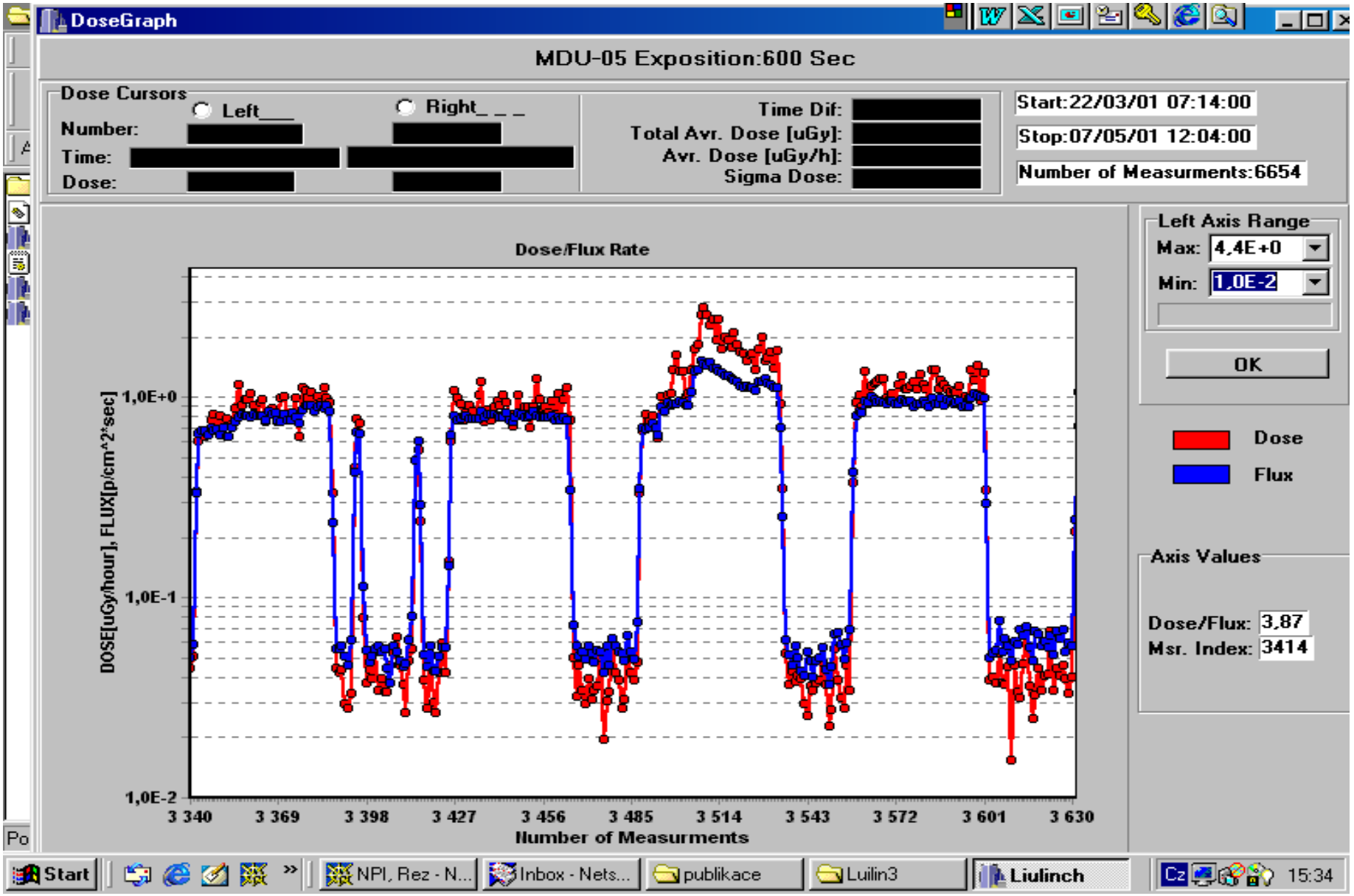
Example of results –long term monitoring-1

Period	Returned flights monitored*)	Numbers of flights
22/03-07/05/01	PRG-NY(25), PRG-TOR(13), PRG-DUB(3)	108
30/05-24/07/01	PRG-NY(41), PRG-TOR(12)	125
29/08-16/10/01	PRG-NY(26), PRG-TOR(13), PRG-DUB(2)	96
25/10-10/12/01	PRG-NY(20), PRG-TOR(7), PRG-AMS(1)	70
06/05-28/06/02	PRG-NY(22), PRG-TOR(13), PRG-DUB(8), PRG-LHR(5), PRG-MAD(5)	124
16/10-06/12/02	PRG-NY(23), PRG-TOR(10), PRG-DUB(1), PRG-DUB-CM (5), PRG-MUN(1)	110

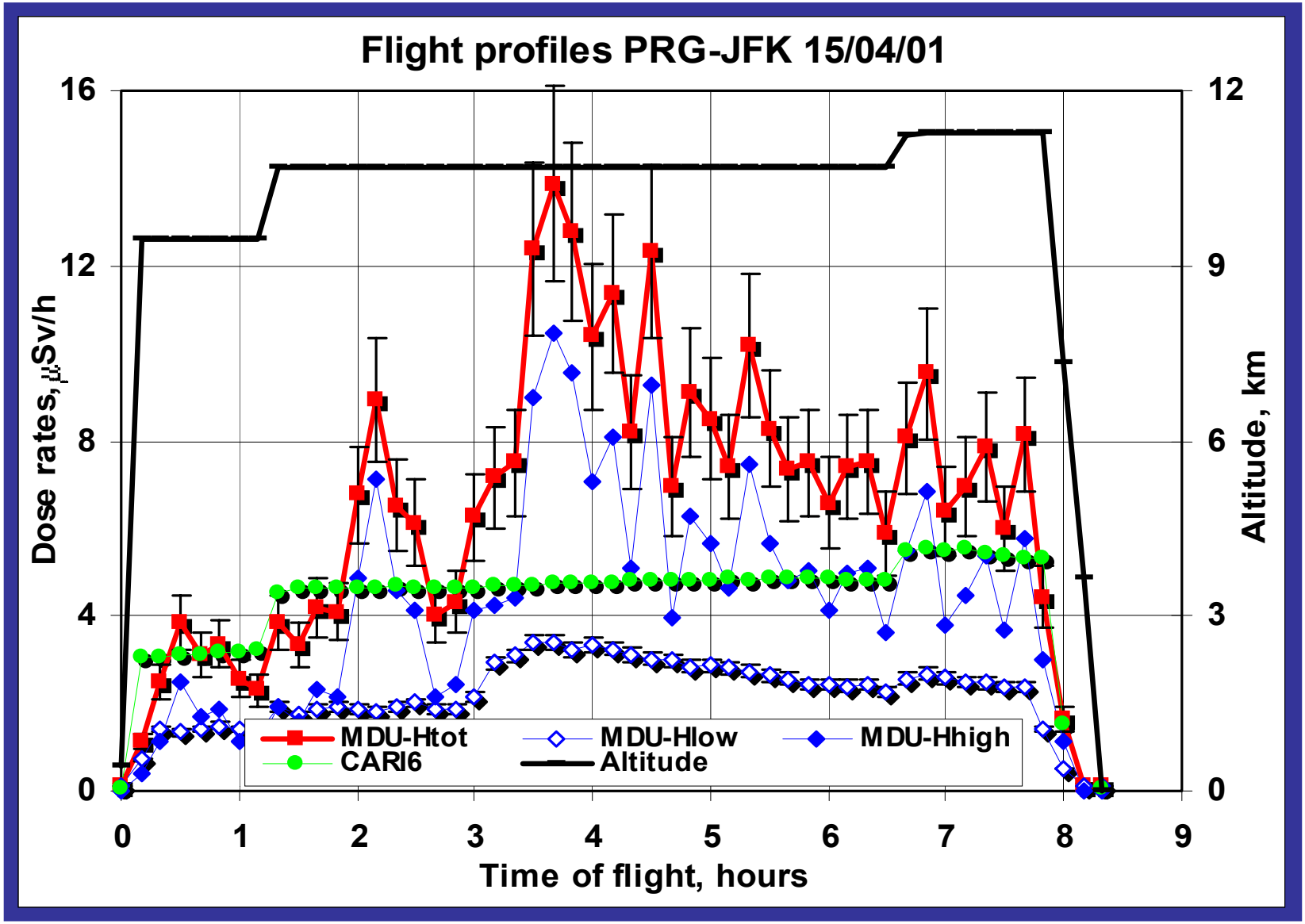
*) PRG – Prague, NY – New York, TOR – Toronto (via Montreal), DUB – Dubai, CM-Colombo, MUN – Munchen, AMS – Amsterdam, LHR-London, MAD-Madrid

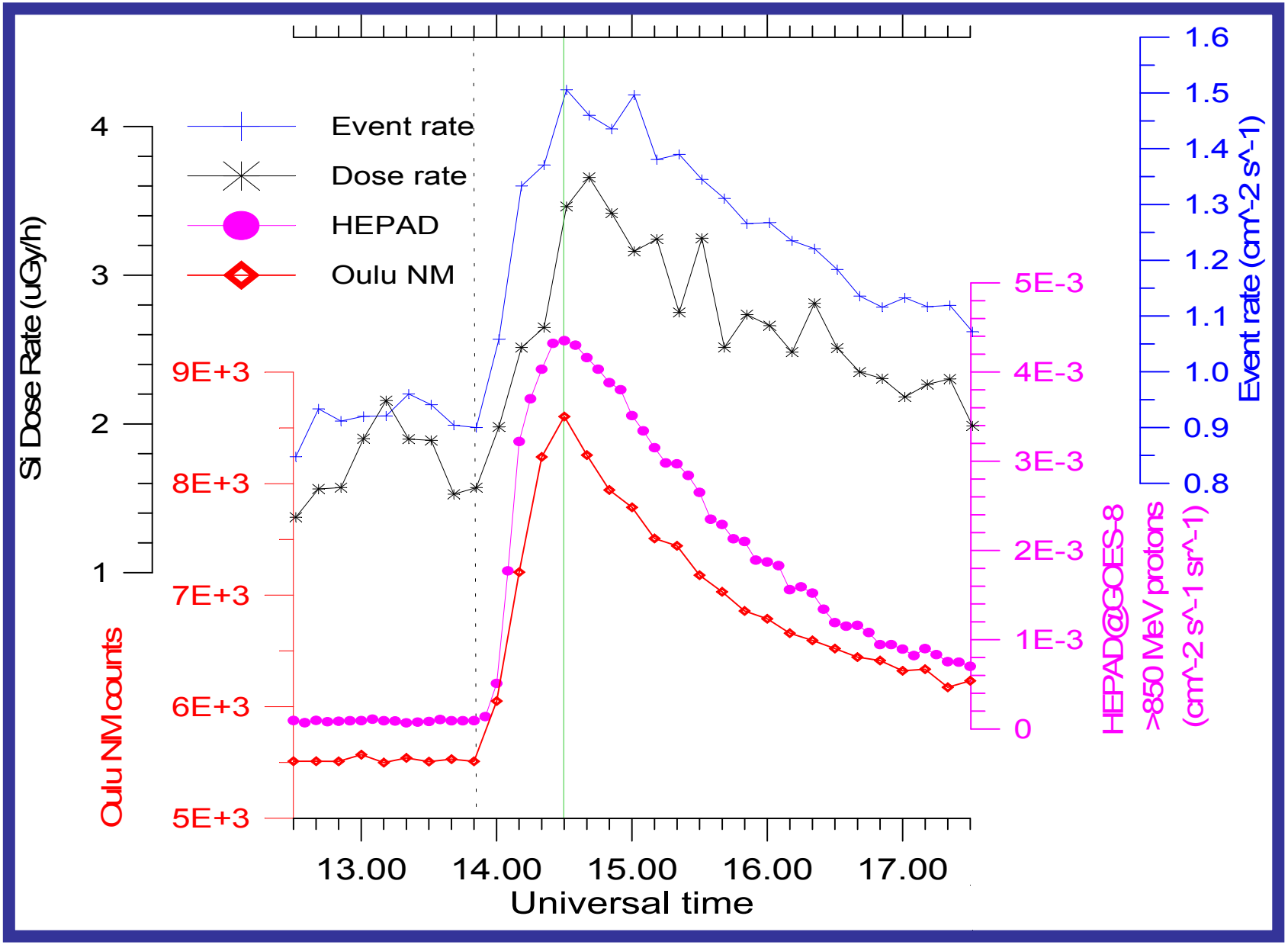
Example of results –long term monitoring-2

Route	Relative	deviation, %,	of measured	and Epcard	calculated H
Period	22/03-07/05/01	30/05-24/07/01	29/08-16/10/01	25/10-10/12/01	16/10-06/12/02
PRG - JFK	0.1±5.3	- 11.5±4.8	-5.7±3.7	-6.6±5.1	4.6±3.5
JFK - PRG	0.5±6.0	11.2±5.9	-5.6±4.0	-7.1±4.6	2.9±3.6
PRG - YYZ	-1.8	-9.1±1.5	-3.7±2.9	-	-
YYZ - PRG	9.8	-8.9±1.0	-5.2±3.6	-	-
PRG - YUL	2.6±6.9	-8.9±5.2	-5.2±3.6	-5.9±4.8	-0.4±5.3
YUL - PRG	0.6±3.8	-10.1±3.5	-0.5±5.0	-2.5±4.8	-0.8±4.8
PRG - DXB	-6.72.8	-	-13.70.1	-	9.23.3
DXB - PRG	-8.8±6.4	-	-6.8±2.7	-	13.4±4.2

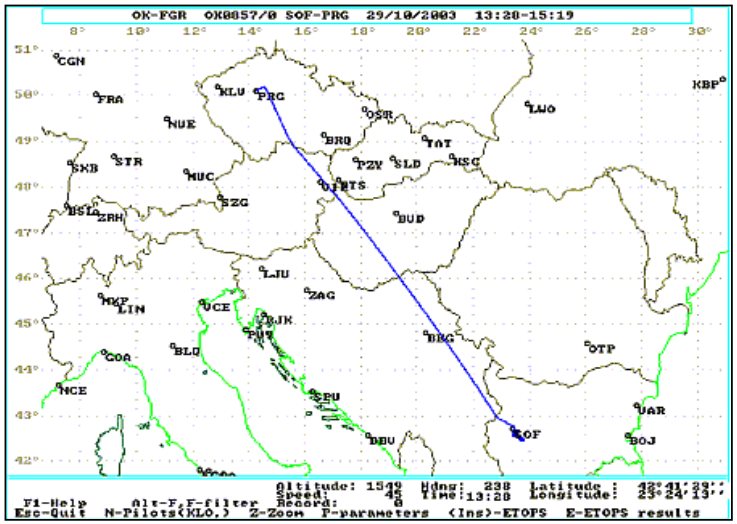

DoseGraph
MDU-05 Exposition:600 Sec
Dose Cursors
Left___
Right_ _ _
Number:
Time:
Dose:
Time Dif:
Total Avr. Dose [uGy]:
Avr. Dose [uGy/h]:
Sigma Dose:
Start:22/03/01 07:14:00
Stop:07/05/01 12:04:00
Number of Measurments:6654
Dose/Flux Rate
DOSE[uGy/hour], FLUX[p/cm^2*sec]
1,0E+0
1,0E-1
1,0E-2
3 340
3 369
3 398
3 427
3 456
3 485
3 514
3 543
3 572
3 601
3 630
Number of Measurments
Left Axis Range
Max: 4,4E+0
Min: 1,0E-2
OK
Dose
Flux
Axis Values
Dose/Flux: 3,87
Msr. Index: 3414
Start
NPI, Rez - N...
Inbox - Nets...
publikace
Luilin3
Liulinch
15:34

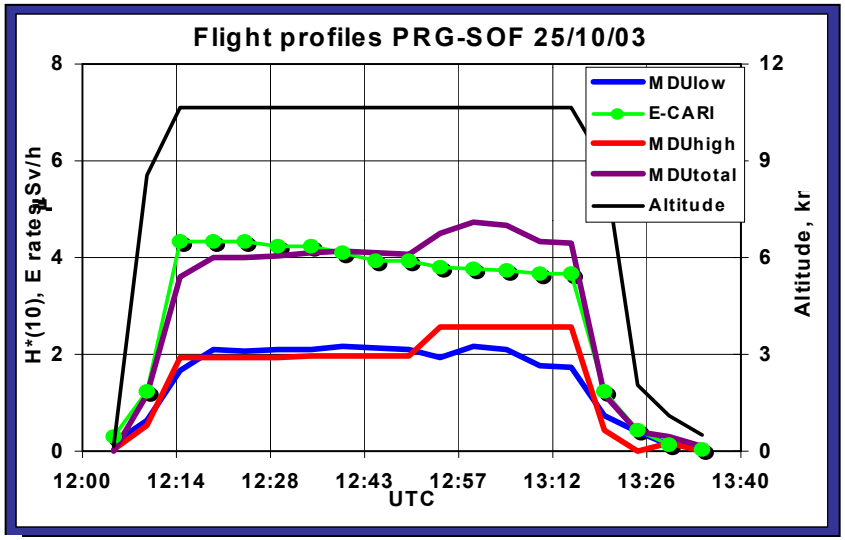
Solar flare (GLE 60) registered onboard with MDU aircraft; rate increased 3times, total E by 40%

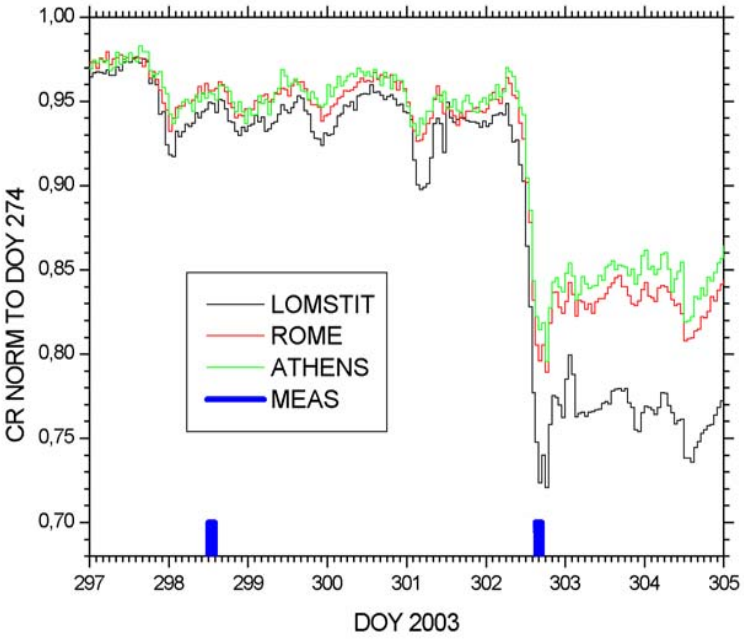


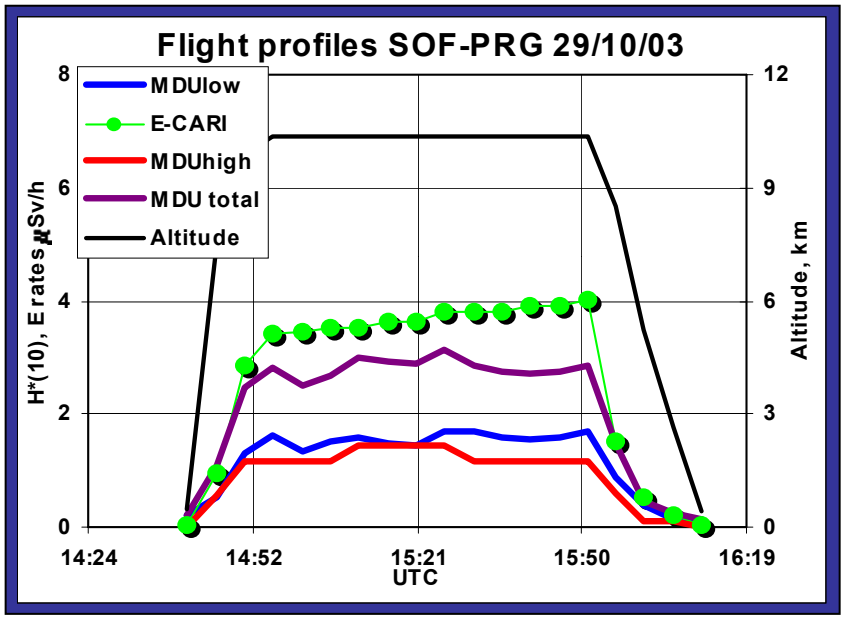

Event rate
Dose rate
HEPAD
Oulu NM
Si Dose Rate (uGy/h)
Oulu NM counts
HEPAD@GOES-8
>850 MeV protons
(cm^-2 s^-1 sr^-1)
Event rate (cm^-2 s^-1)
Universal time
13.00
14.00
15.00
16.00
17.00
1
2
3
4
5E+3
6E+3
7E+3
8E+3
9E+3
0
1E-3
2E-3
3E-3
4E-3
5E-3
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6

Registration of extreme events: Forbush decrease after GLE 65 29/10/2003









Ratios of ambient dose equivalent values for total flights estimated from MDU-Liulin measurements and calculated by means of EPCARD3.2 code

Date	Event	For low E_{dep}	For high E_{dep}	Total H
12/04/01	Forbush (LŠ: - 13 %)	0,92	0,78	0,84
15/04/01	GLE 60 (LŠ: + 10 %)	1,24	1,68	1,45
16/04/01	normal	1,01	1,00	1,01
25/10/03	normal	0,95	1,00	0,98
29/10/03	Forbush (LŠ: - 26 %)	0,88	0,62	0,74

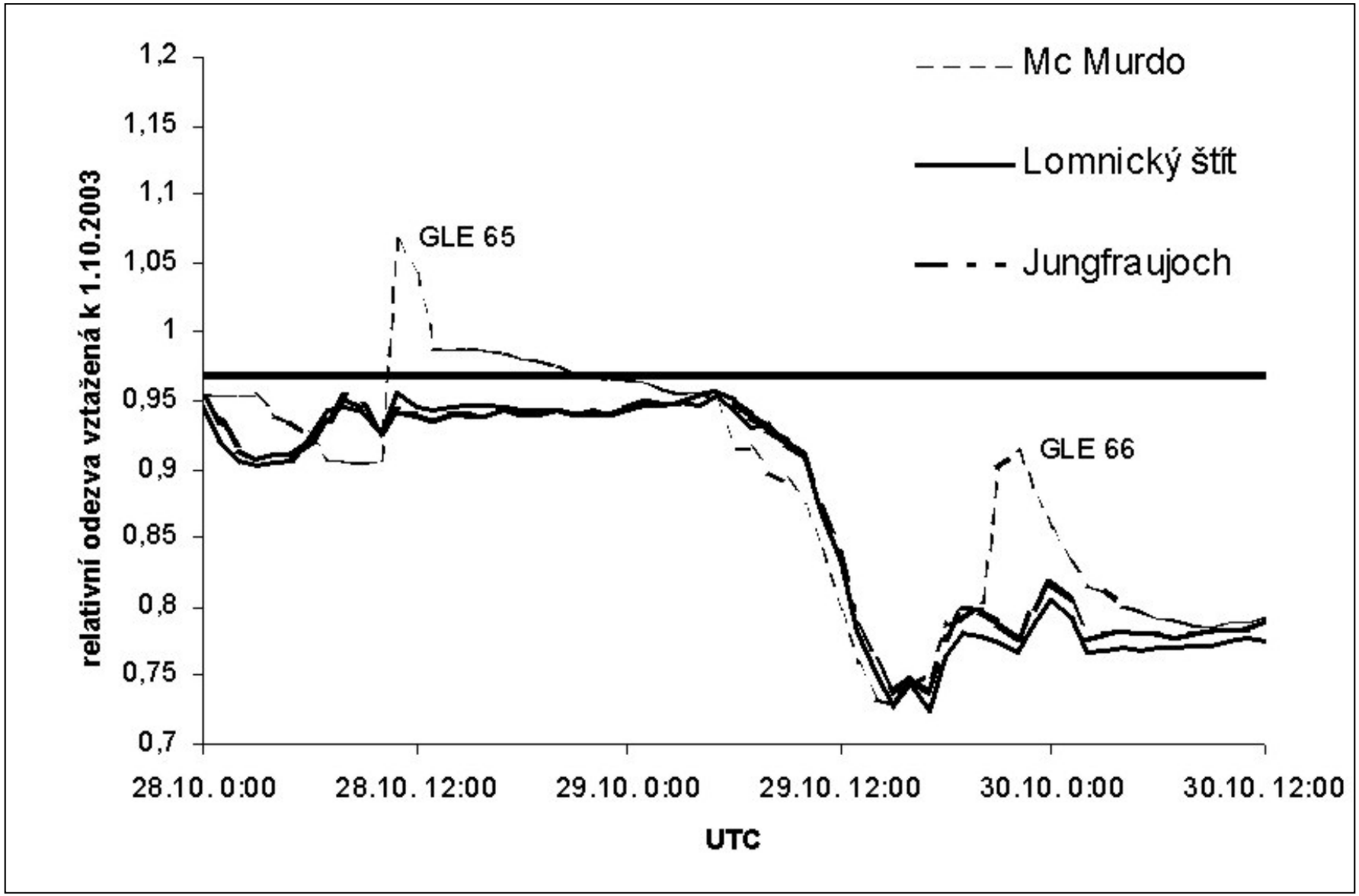
Remarks:

1) LŠ: difference of countings at Lomnický Štít cosmic ray neutron monitor

2) April 2001: PRG-JFK flights; October 2003: PRG-SOF (25/10); SOF-PRG (29/10)

Cosmic ray neutron monitor stations

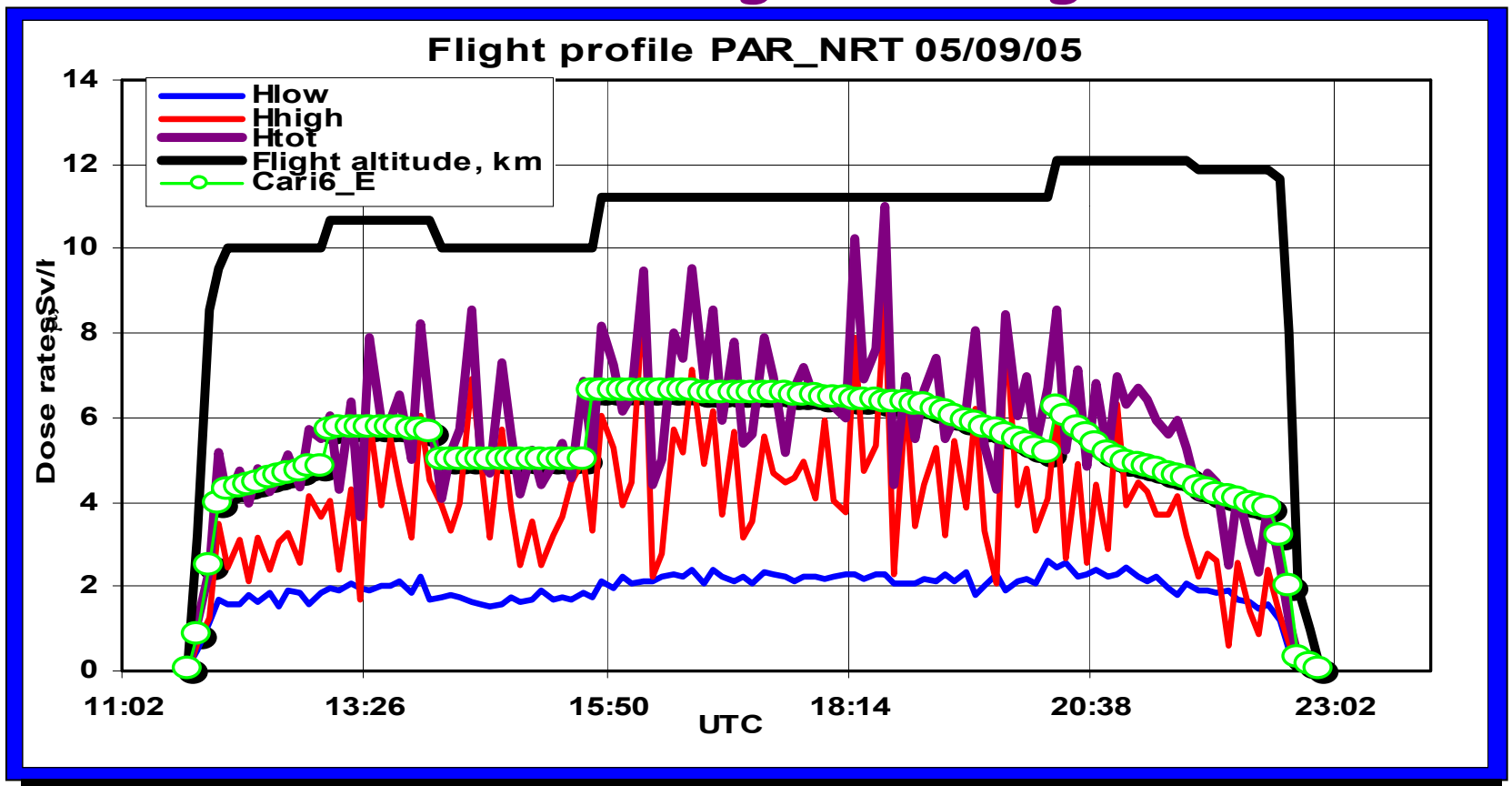
Monitor	Country	Latitude	Longitude	Altitude [m]	Rigidity [GV]
Jungfraujoch	Switzerland	46,55° N	7,98° E	3550	4,48
Lomnický štít	Slovakia	49,2° N	29,22° E	2632	3,84
McMurdo	Antarctic	77,85° S	166,72° E	48	0,01
Newark	USA	39,7° N	75,7° W	50	2,1
South Pole	Antarctic	90° S	0°	2820	0,09
Thule	Groenland	76,58° N	68,42° W	260	0


Mc Murdo
Lomnický štít
Jungfraujoch
GLE 65
GLE 66
relativní odezva vztažená k 1.10.2003
1,2
1,15
1,1
1,05
1
0,95
0,9
0,85
0,8
0,75
0,7
28.10. 0:00
28.10. 12:00
29.10. 0:00
29.10. 12:00
30.10. 0:00
30.10. 12:00
UTC

Measurements 2005

- Long-haul flights Prague Amsterdam-Beijing-Amsterdam-Prague 26/03 – 02/04;
- Long-haul flight Paris-Tokyo 05/09.
- Individual flights 2005;
- Long-term monitoring onboard a Czech Airlines aircraft

Other long-haul flight



Total exposure	MDU $H(E)_{app}$	CARI 6 E	EPCARDv.3.2 E	EPCARDv.3.2 H*(10)
µSv	63.7±8.6	59.0	56.1	47.0
relatively	1.08	1.00	0.95	0.80

Short-haul flights 2005

Flight	Date	MDU			CARI	EPC- E	EPC- H*(10)		
		Hlow	Hhigh	Htot			Htot	Hhigh	Hlow
PRG_SVO	17.II	3,52	5,51	9,03	8,73	8,5	7,5	4,2	3,3
SVO_PRG	22.II	2,84	5,95	8,79	7,38	7,5	6,5	3,7	2,8
PRG_SOF	9.III	2,12	2,21	4,33	4,41	4,5	4	2,16	1,84
SOF_PRG	15.III	1,97	3,01	4,98	4,67	4,5	4	2,16	1,84
PRG_AMS	26.III	1,28	2,36	3,64	3,56	3,48	2,48	1,42	1,06
AMS_PRG	2.IV	1,26	1,81	3,07	2,95	3,42	2,48	1,4	1,1
PRG_SOF	7.VII	1,76	2,67	4,43	4,37	5	4,5	2,43	2,17
SOF_PRG	13.VII	1,81	3,16	4,97	4,62	5	4,5	2,43	2,17
PRG_SVO	11.VIII	3,61	6,5	10,11	9,86	11,5	9,5	5,32	4,18
SVO_PRG	17.VIII	3,78	7,41	11,19	11,35	11,5	9,5	5,32	4,18
total		57,66	96,7	152,36	149,84	144,9	122,96	69,04	54,14

Average total value : (142 ± 13) μSv

Long-term monitoring onboard a CSA aircraft state-of-art 05/05/-31/12/05

- Total number of flights : ~ 400;
- More than 70 % - above North Atlantic;
- Interesting events:

➢ Forbush decreases:

✓ 8.-9.5.; **(PRG-JFK)**

✓ 15.-16.5.; **(2 x PRG-YYZ; PRG-DXB-CMB)**

✓ 17.-18.7. (small SPE ?) (**PRG–TUN (MAD)–PRG**)

✓ 10.- 16.9. (**PRG-SVO; PRG–MAD; 2x PRG-JFK; AR)**

Onboard aircraft exposure

- A310-300 Czech Airlines
- 05/05-31/12/05
- Together with MDU-Liulin
- All navigation data available – dose calculated
- Trach etched detectors; TLD's

TLD results:

1. Exposure dates
   - NPI's – full time
   - INRNE – since 08/09

2. Results since 08/09/05:

Al_2O_3 :C: (1.75±0.25) mSv

AlP glas: (1.66±0.09) mSv

CaSO4:Dy: (1.5-1.8) mSv

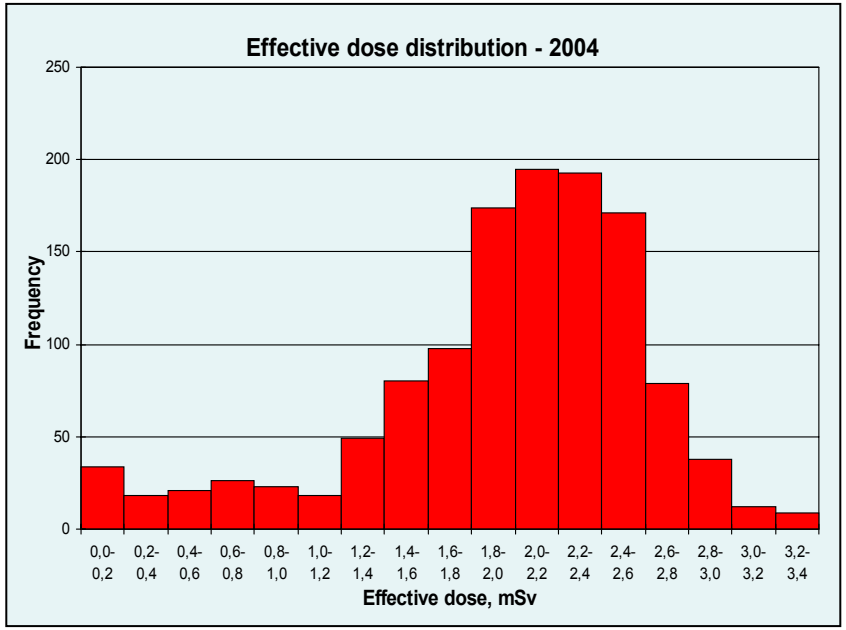
ROUTINE INDIVIDUAL DOSIMETRY PROCEDURE

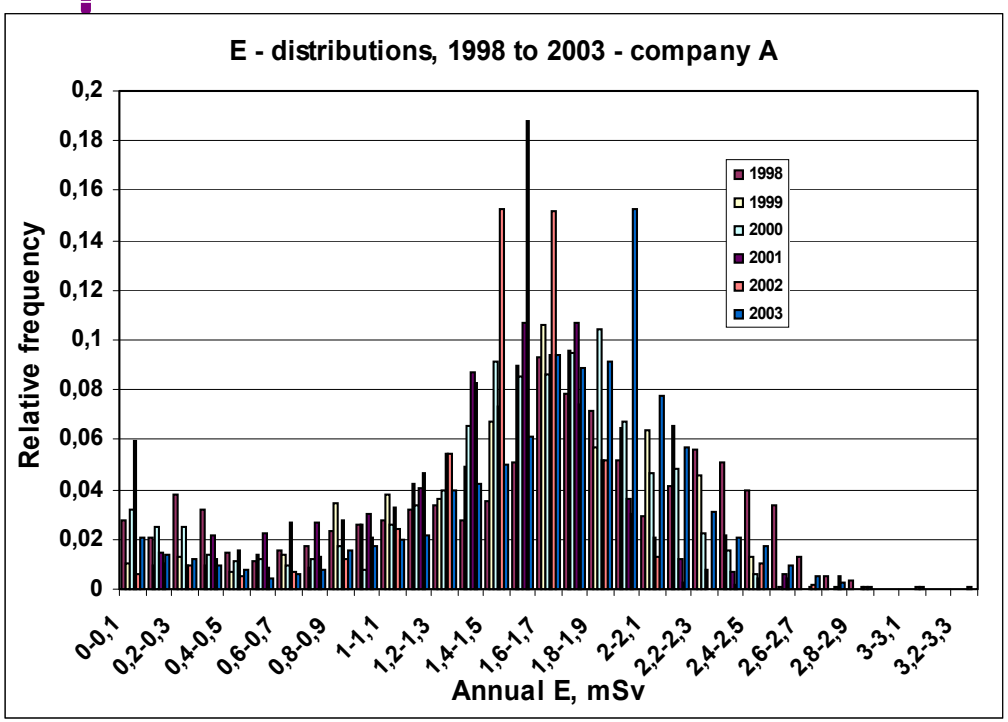
1. Air company representative prepares the data sets characterising the aircraft and persons traffic for a period
2. Sets are used to create an input set for the CARI code
3. The calculation of individual effective dosis for each flight performed, simplified flight profile:
   - only actual parameter: flight time
   - calculated for the model routes parameters, i.e.
   - flight altitude ; and the time of the rise and the falling down
4. The effective dose of each aircrew member are calculated and transmitted to an air company

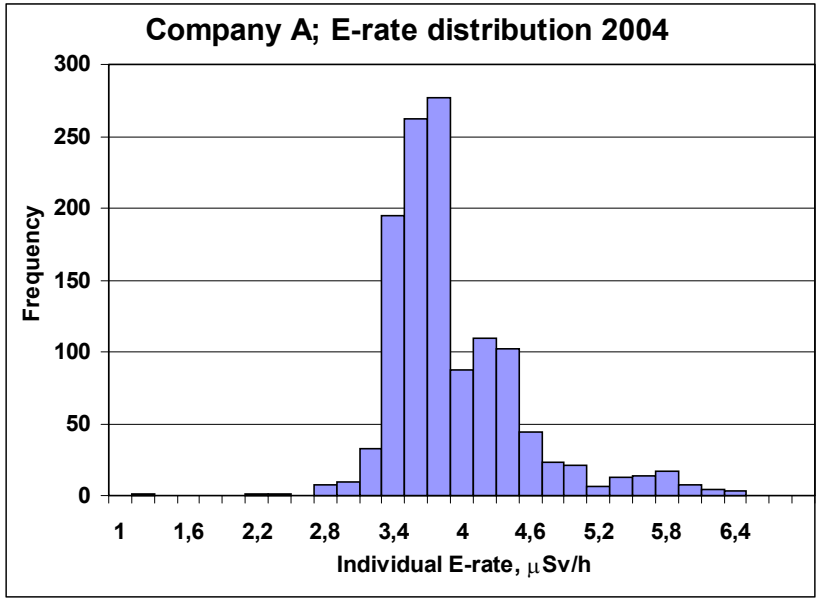
REMARKS: All data since 1998 now recalculated by CARI 6

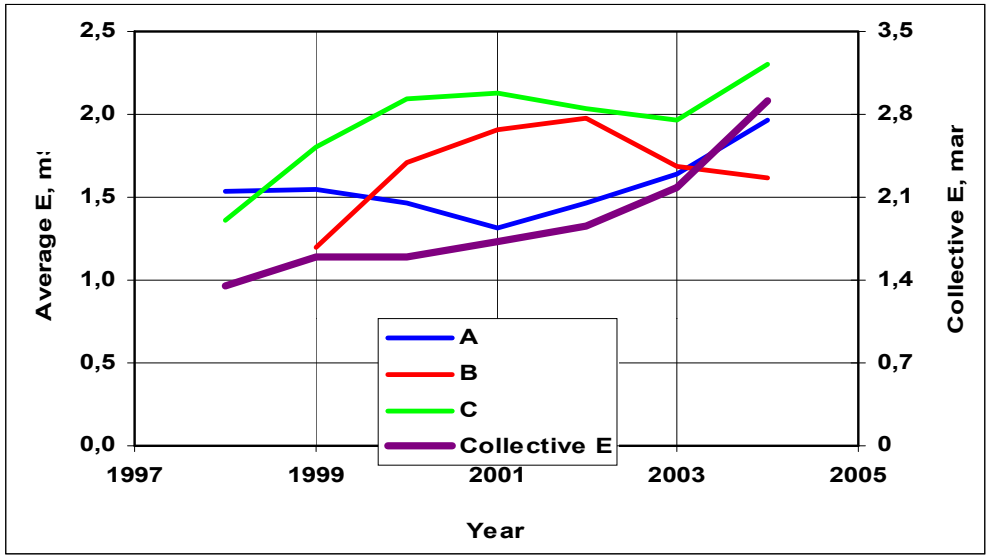
Generally – more than 90 % above 1 mSv

Individuel dosimetry of aircraft crew – czech air companies









External Exposure to Natural Radiation

Results of some Experimental Studies

2 - Onboard spacecraft exposure

Dosimetry and microdosimetry methods

- **Thermoluminescent detectors (TLD's)**
  - **Al_2O_3:C; LiF:Mg,Cu,P; $CaSO_4$:Dy; > 1 μGy**
  - **AlP glass; LiF:Mg,Ti; > 10 μGy**

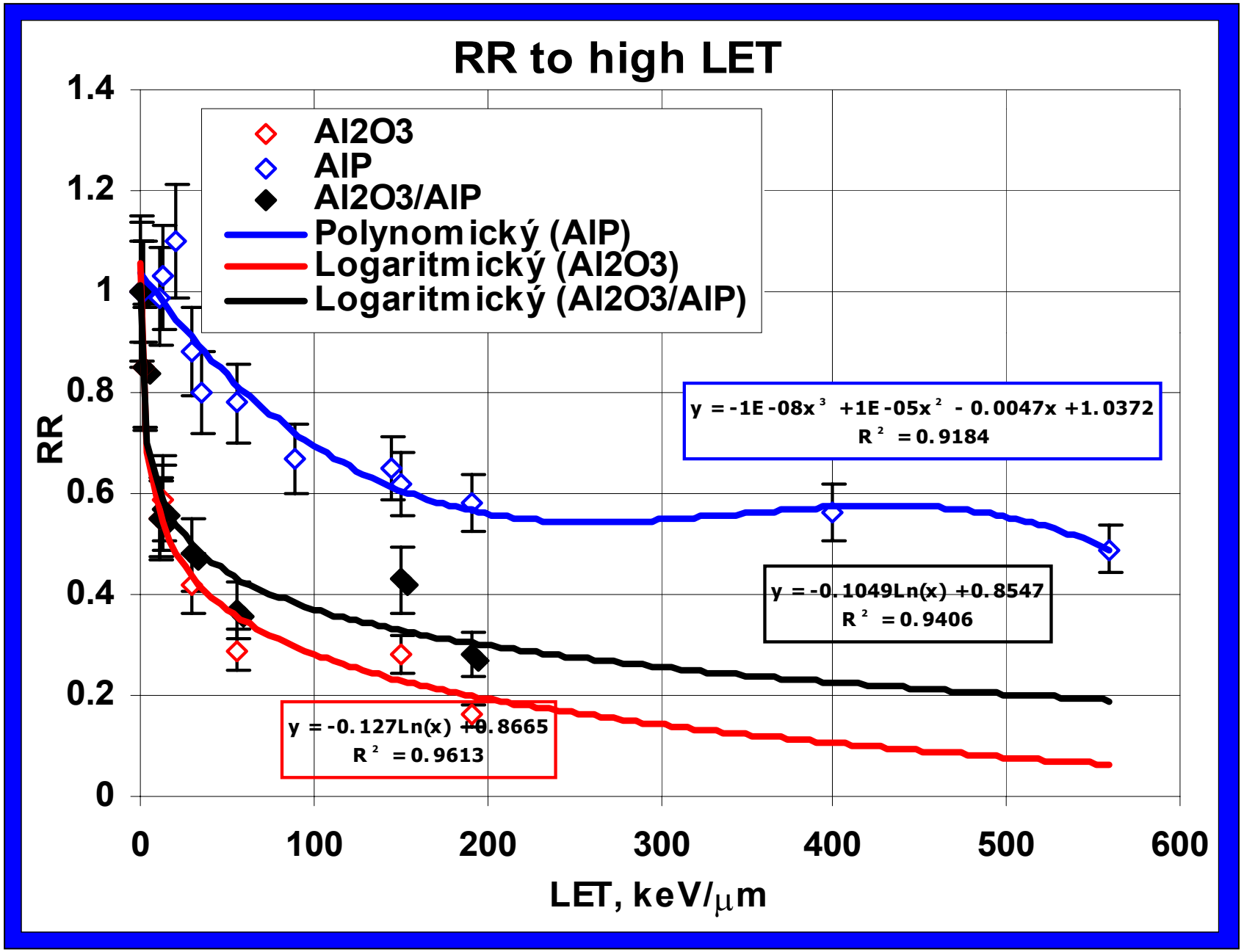
    Different RR=f(LET)

- **Spectrometer of the LET - H and D distributions in LET ∈ (≈10;700) keV/μm in tissue; 1 to 100 mSv**

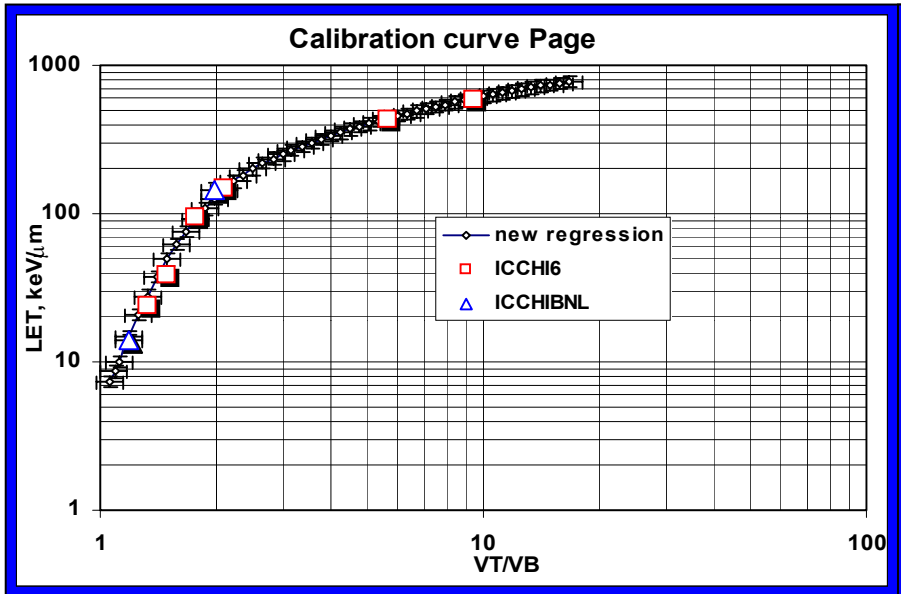
Experiments and analysis 2004-2005

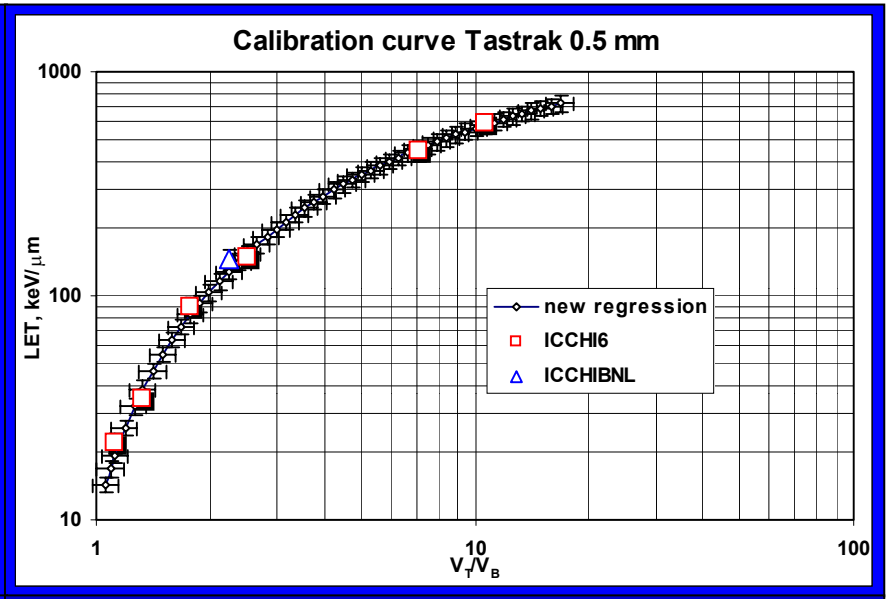
On-Earth's calibrations

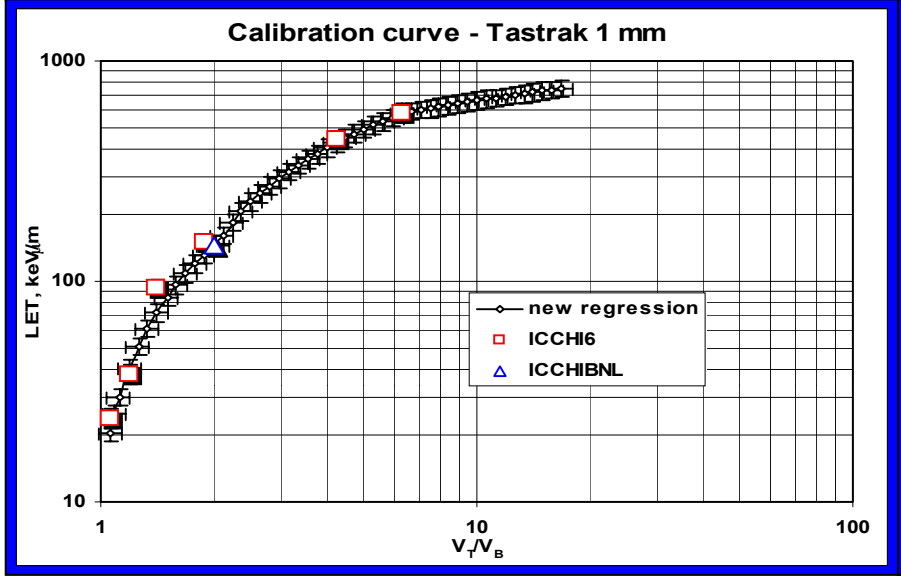
- **ICCHIBAN 6** (C, Ar, Kr; 24 - 600 keV/μm)
- **ICCHIBAN-NSRL** (H, O, Fe; 0.2 – 150 keV/μm)
- **ICCHIBAN 8** (He, O, Ar, Fe; 2.2 – 320 keV/μm)
- **Dubna Nuclotron** (C, Mg, Fe; 8 – 200 keV/μm)

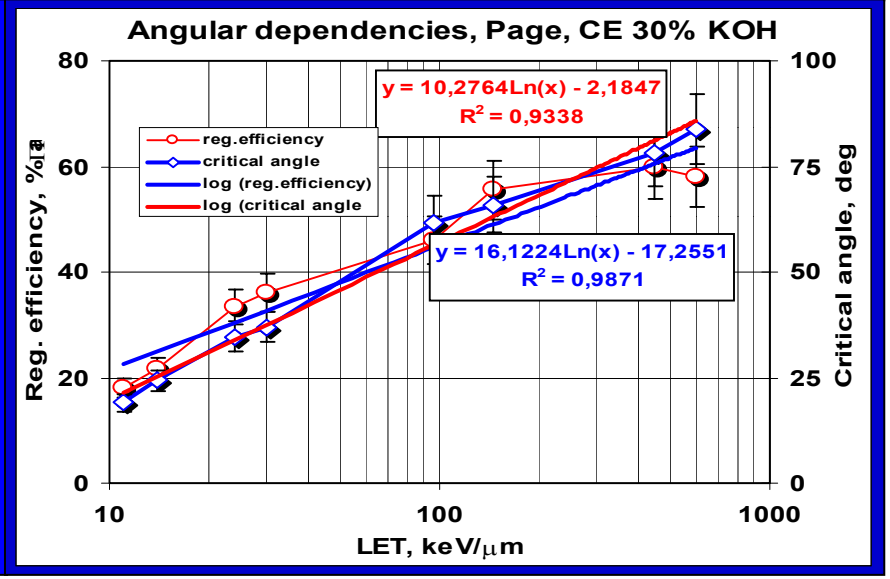

RR to high LET
Al2O3
AlP
Al2O3/AlP
Polynomický (AlP)
Logaritmický (Al2O3)
Logaritmický (Al2O3/AlP)
y = -1E-08x³ +1E-05x² - 0.0047x +1.0372
R² = 0.9184
y = -0.1049Ln(x) +0.8547
R² = 0.9406
y = -0.127Ln(x) +0.8665
R² = 0.9613
RR
LET, keV/μm
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
100
200
300
400
500
600

Calibration of TED for LET spectrometry; angular dependence of the response









Some more recent onboard SS measurements

Mission	Period	Shield $g.cm^{-2}$	Altitude km	TLD μGy/day	D-TED μGy/day	H-LET μGy/day
MIR 28	6/04/–16/06/00	~ 15	330–350	140 ± 10	13 ± 1	85 ± 5
ISS-1	30/11/01–3/11/02	~ 20	380–420	212 ± 15	22 ± 2	202 ± 12
MESSAGE	17/10/–28/10/03	~ 15	380–420	166 ± 8	16 ± 2	223 ± 22
ISS-2	31/01/–31/10/04	~ 15	340-360	150 ± 8	15 ± 1	98 ± 5

Interpretation of measured data

Made supposing that:

- **TLD's data characterize mostly of radiation with LET below few keV per μm (primary protons);**
- **the ratio of high LET secondary particle dose and primary proton collision dose is equal to (0.025 ± 0.003);**
- **the contribution of primary long range cosmic heavier charged particles represents about 22% of total LET spectrometer established dose, resp. 34% of LET spectrometer established dose equivalent value.**

Full dosimetric characteristics onboard of space stations

Mission	D, μGy/day		Neutrons in % of D	H, μSv/day		Neutrons in % of H
	>10 keV/μm	total		>10 keV/μm	total	
MIR 28	17[1)]	157	6.0	129	269	22
ISS-1	28	240	7.0	306	518	27
MESSAGE	21	186	6.4	338	504	34
ISS-2	19	191	5.6	148	322	22

[1)] 1 S.D. estimated to 15-20%

Comparison

MDU-Liulin spectra

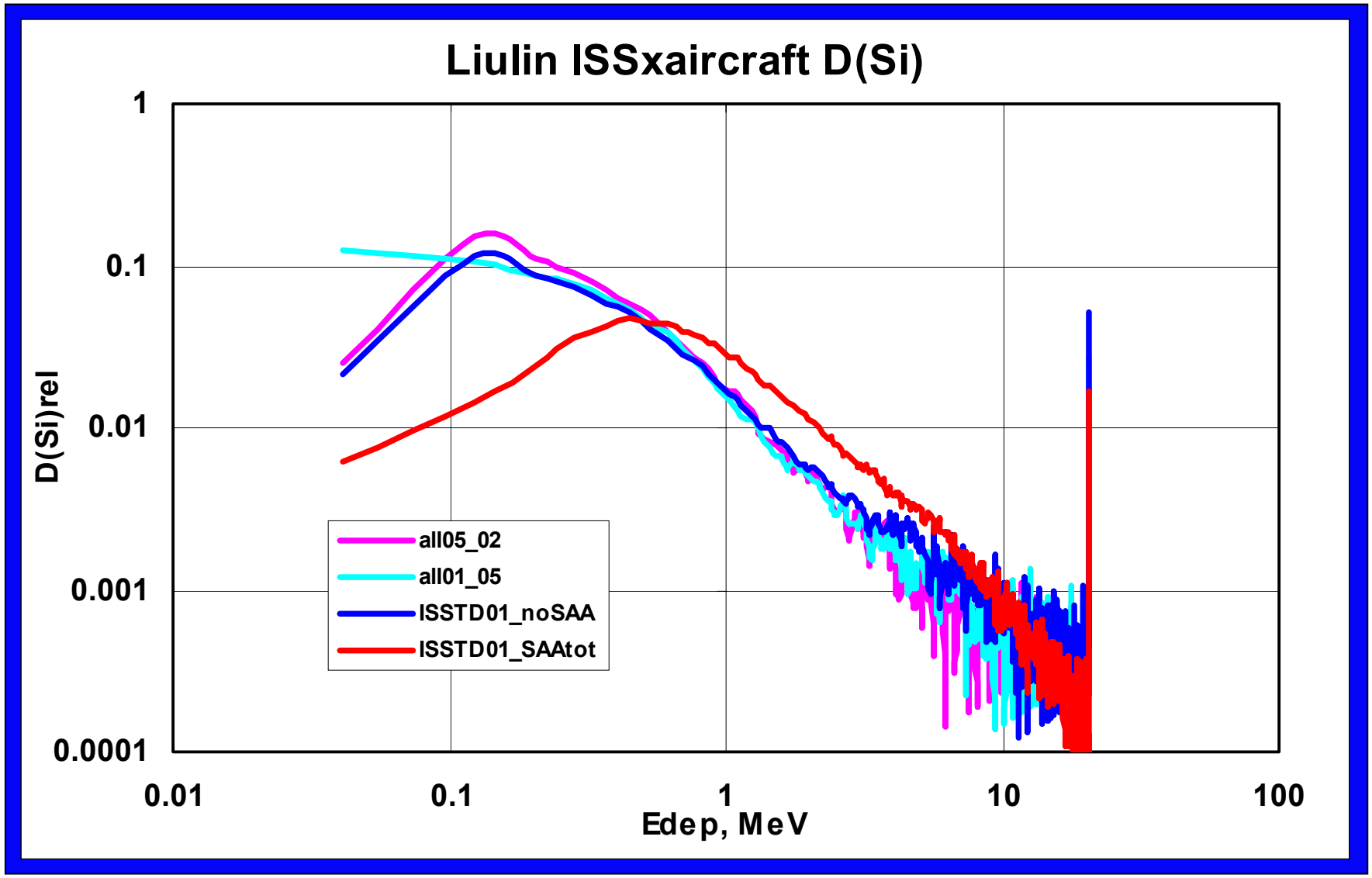
onboard aircraft

(2001, 2005 –in total ~ 200μSv);

and onboard ISS

(2001 – no SAA ~ 70 μGy; in SAA ~ 360 μGy)

Comparison of Si-energy deposition spectra



Comparison

MDU-Liulin spectra onboard aircraft (2001, 2005 ~ 200μSv); and onboard ISS (2001 – no SAA ~68.6 μGy; in SAA ~ 360 μGy)

When supposed that:

- **neutron spectra onboard ISS and aircraft are similar;**
- **relative excess above 1 MeV onboard ISS is due to HECP of GCR with QF ~ 5; and**
- **the correction factors for non-neutron and neutron-like component are the same onboard ISS as onboard aircraft;**

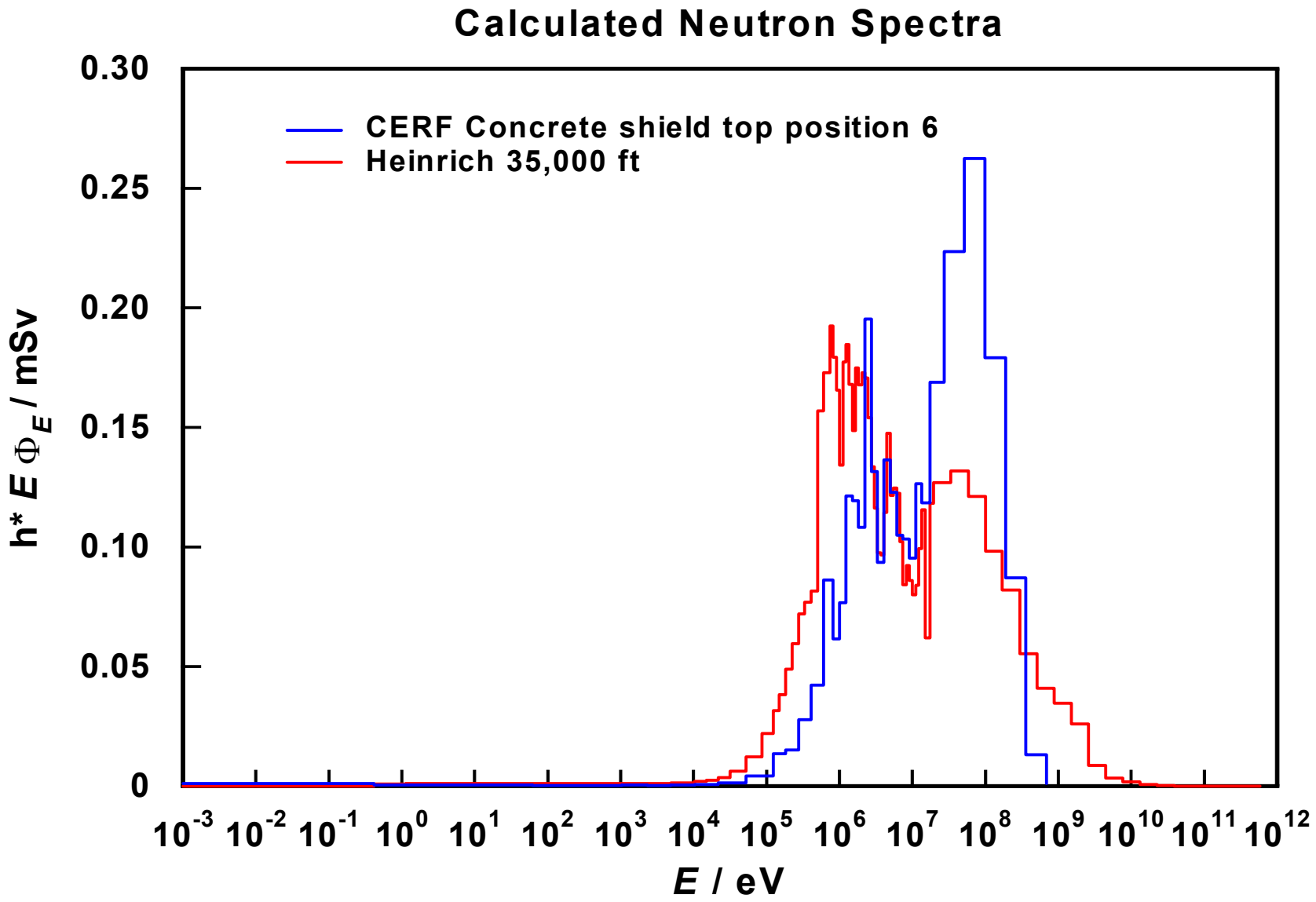
Than outside SAA the daily values of "H*(10)" are:

- **non-neutron component: 72.3 μSv;**
- **neutron-like component: 119.3 μSv;**
- **HECP component: 64.6 μSv; and**
- **Total: 256 μSv**
- **Average QF ~ 2.8**

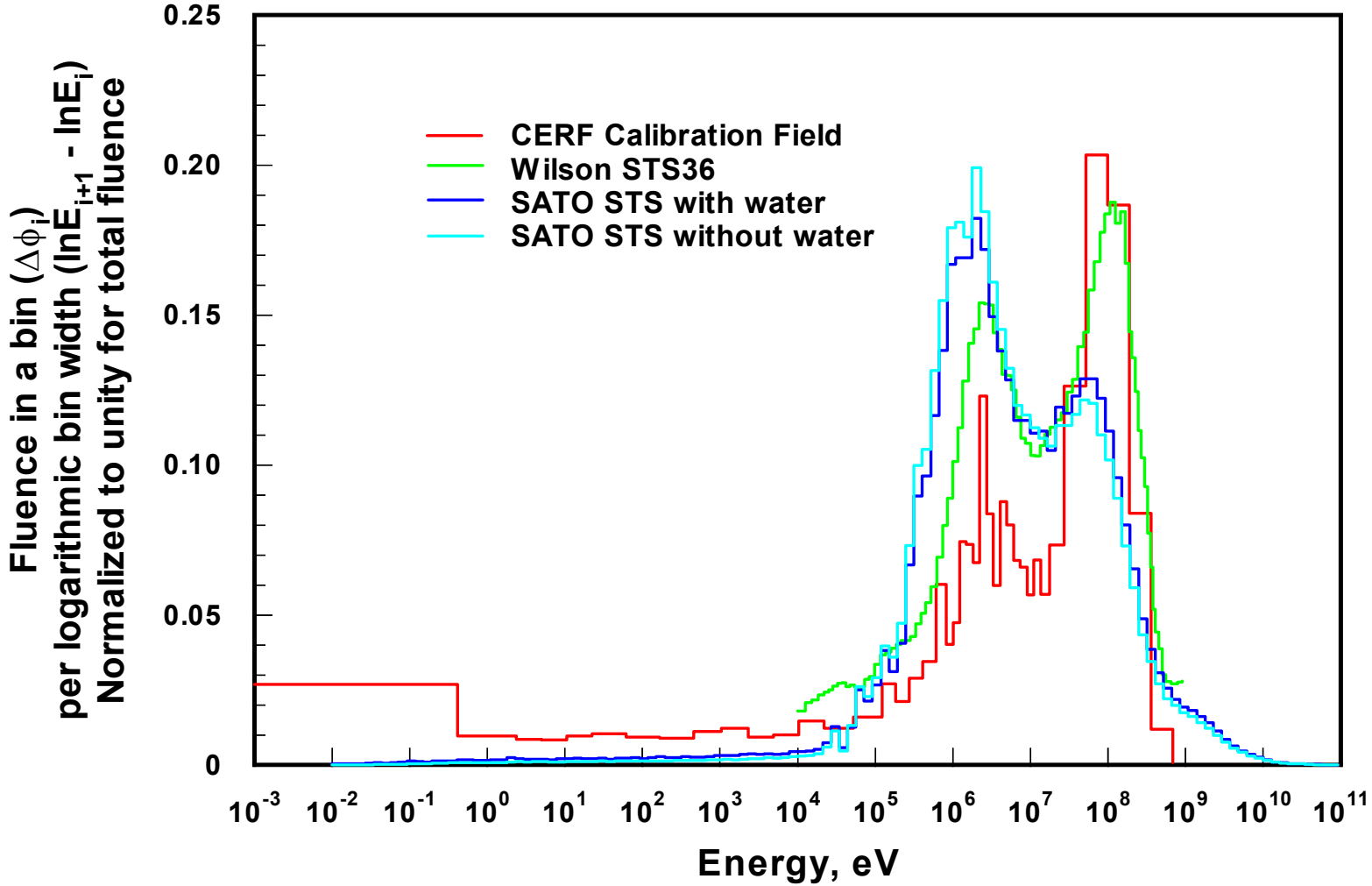
When in SAA mostly protons with QF ~ 1.5 than

Total ~ 610 μSv; QF ~ 2.0

Comparison of CERF and at 35kfeet calculated spectra



Further comparison of neutron spectra



Experiments going on; future – also with TLDs INRNE

- **Long term exposure (>3 years) – ISS;**
- **Further on-Earth calibrations**
- **Onboard ISS dosimetry and LET spectrometry:**

➢ **Interior of a phantom (russian Matrjoshka);**

➢ **In-area distribution of dosimetry characteristics**

➢ **Further comparison MDU on ISS/aircraft**

- **DOBIES project (ESA); since 2006**

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Thank you for your attention !