Proposal for Intelligent Crew Personal Dosimeter

Ts. Dachev[1], B. Tomov[1], Pl. Dimitrov[1], Yu. Matviichuk[1], Y. Uchihori[2], O. Ploc[2]

[1]Solar-Terrestrial Influences Institute, Sofia, Bulgaria, tdachev@bas.bg
[2]National Institute of Radiological Sciences, Chiba, Japan
ploc@ujf.cas.cz, uchihori@nirs.go.jp

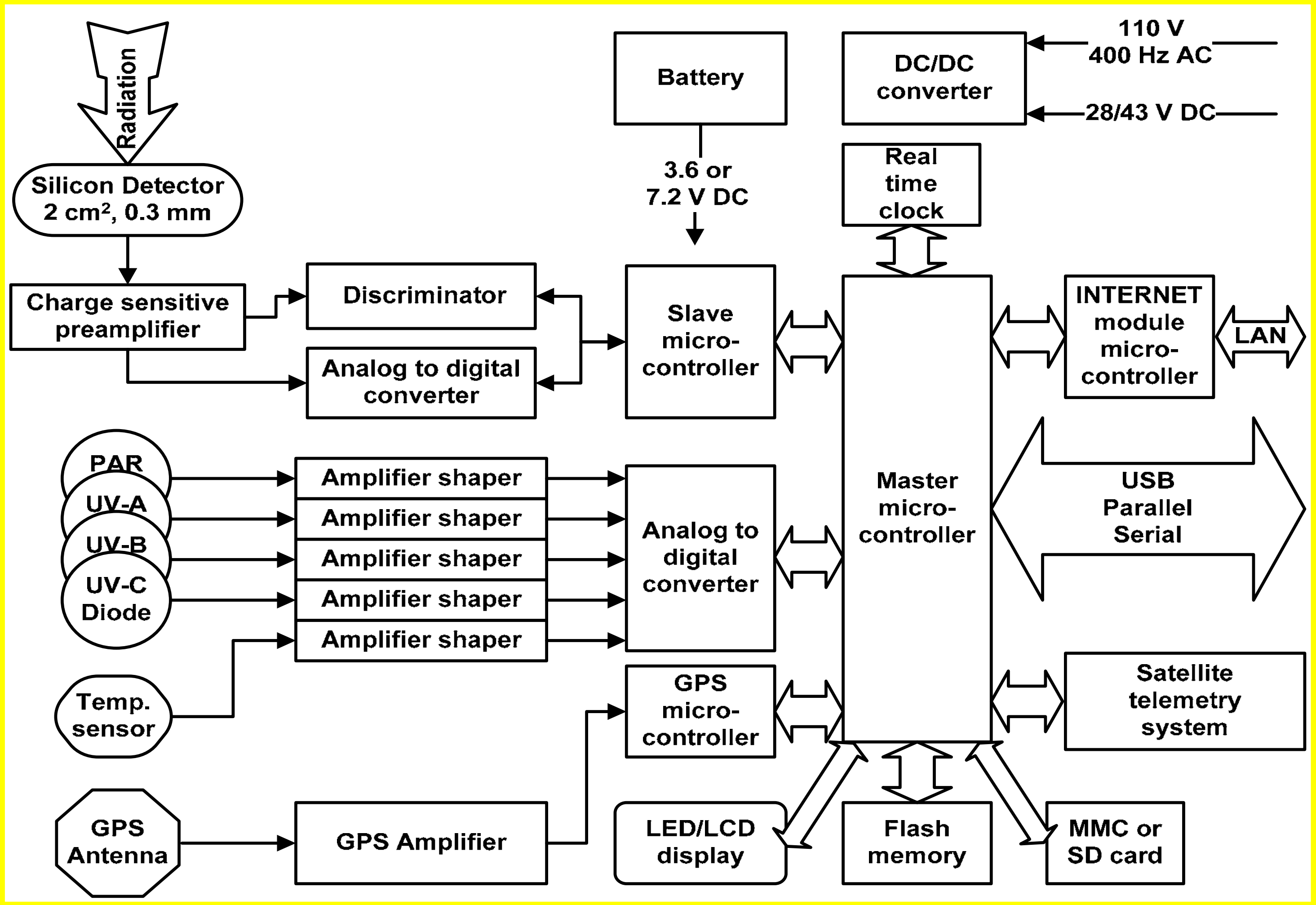
Motivation

- To present the developed Liulin personal devices and to compare their dimensions with the proposed EuCPAD;
- To compare the Liulin space and aircraft radiation data with data from other instruments and codes;
- To review the existing Liulin dose interpretation and radiation sources separation procedures;
- To obtain the advantages and disadvantages of the 1 and 2 detectors (telescope) design of the new dosimeter;
- To be proposed a new "Intelligent Crew Personal Dosimeter" on the base of the existing Liulin type devices, which can be used by astronauts in internal and external vehicle activities;
- To present the algorithm of the software, which will be able on the base of the analysis of the form of the deposited energy spectrum to distinguish the different kind of radiation sources in space as GCR, Inner radiation belt protons and outer radiation belt electrons and to calculate, store and present on display the absorbed and equivalent doses.

Presentation of the developed Liulin personal devices

Comparison with the proposed EuCPAD

Integrated Block - diagram of the Liulin type devices



The usage of fast 12 bit ADC allows Liulin devices to analyze each event in the detector and to build and store the energy deposition spectrum for each measurement cycle. The form of the spectrum characterize the predominant radiation source as Inner Radiation Belt (IRB (SAA)) protons, Outer Rad. Belt (ORB) electrons and Galactic Cosmic Rays (GCR)

History of the Liulin personal devices 1

Name (year of development)	Use (years)	Dimensions (mm)	Volume (ml)	Mass (g)	Battery type	Active time (days)
LIULIN Detector & Control unit (1988)	Mir Space Station (1988-1994)	160x100x40	640	490	4 AA size primary	2
Liulin-3 2 detectors telescope (1995)	Aircraft & accelerator (1995-1997)	150x80x50	600	450	4 AA size primary	1
Liulin-E094 4 MDU units (detectors) & Control unit (1998)	ISS (2001) & aircraft (2005-till now)	96x64x24	147	230	Li-ion 7.2 V 1350 mAh accum.	4
Liulin-ISS 4 MDU units (detectors) & Control unit (2002)	(2005-till now)	100x65x26	188	230	Li-ion 7.2 V 1350 mAh accum.	6

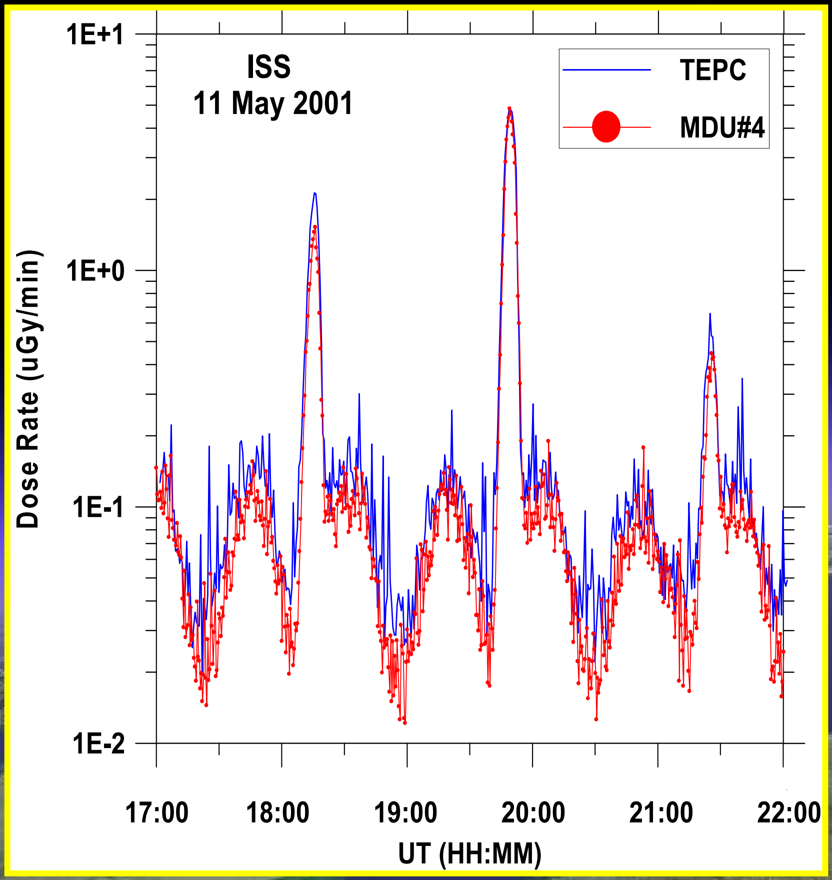
History of the Liulin personal devices 2

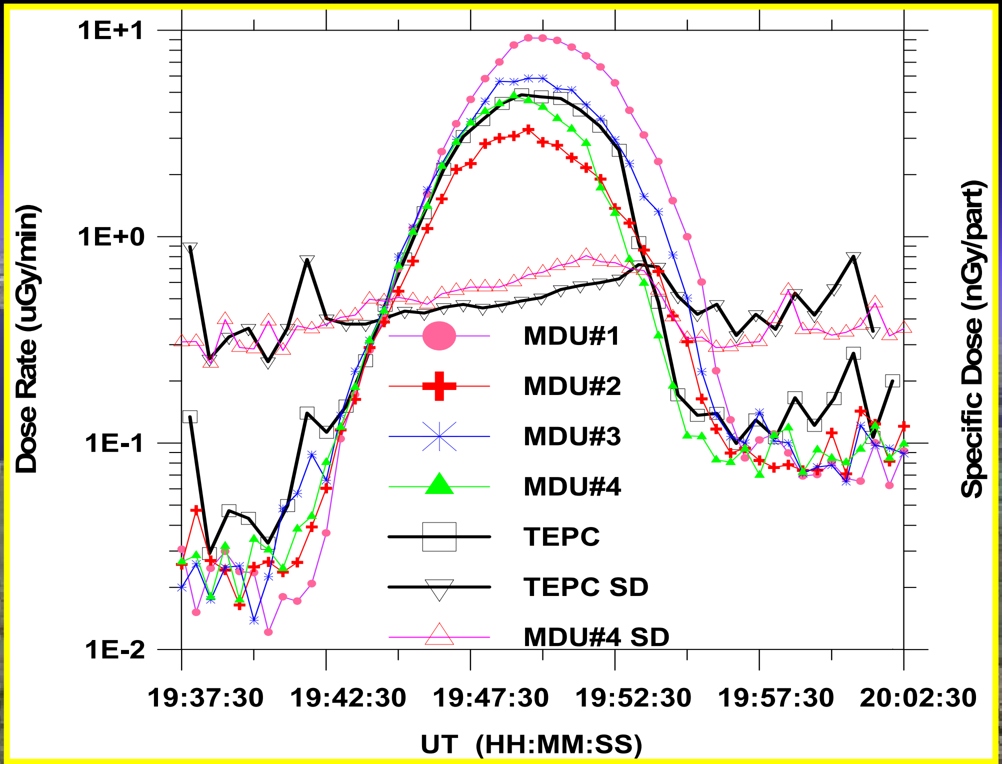
Name (year of development)	Use (years)	Dimensions (mm)	Volume (ml)	Mass (g)	Battery type	Active time (days)
Liilin-4SA Detector & GPS unit & display (2005)	Aircraft (2005-till now)	160x100x40	640	490	External 12 V accum.	2
Liulin-6S (2006)	Aircraft & accelerators (2006-till now)	100x40x20	80	100	Li-ion 3.6 V 1.8 Ah accum.	7
Liulin-6G (2008)	Aircraft (2008-till now)	120x40x20	96	125	Li-ion 3.6 V 1.8 Ah accum.	5
Portable EuCPAD instrument (2008)*	ISS	Maximum 105x67x20	Below 150	Below 250	???	???

*Reitz, G., WRMISS13, 2008.

Comparison of Liulin data with data from other instruments and codes

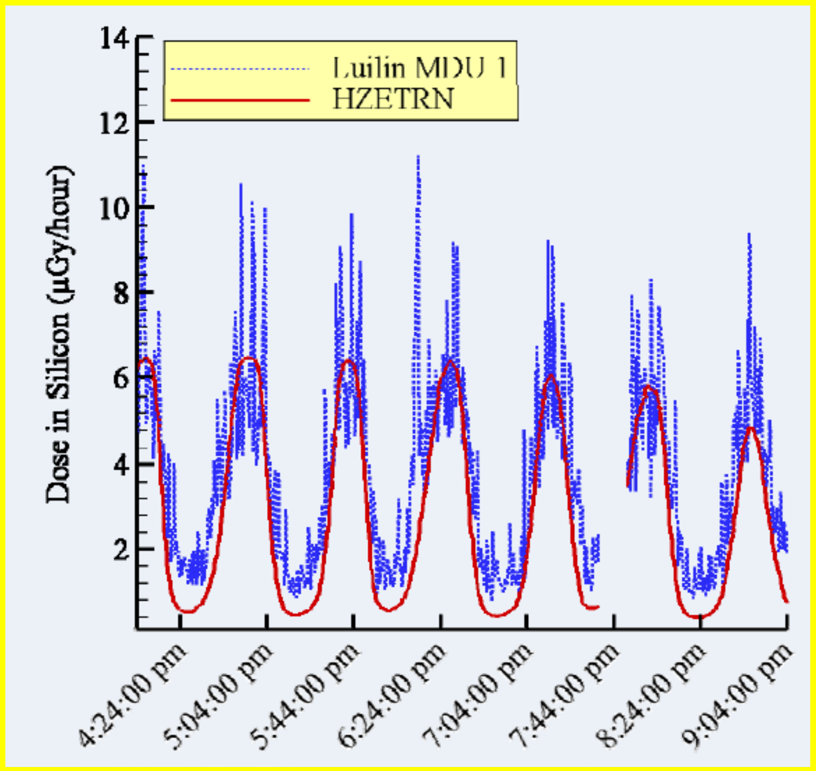
Comparison of absorbed dose data obtained by Liulin MDUs and NASA TEPC at ISS in 2001*



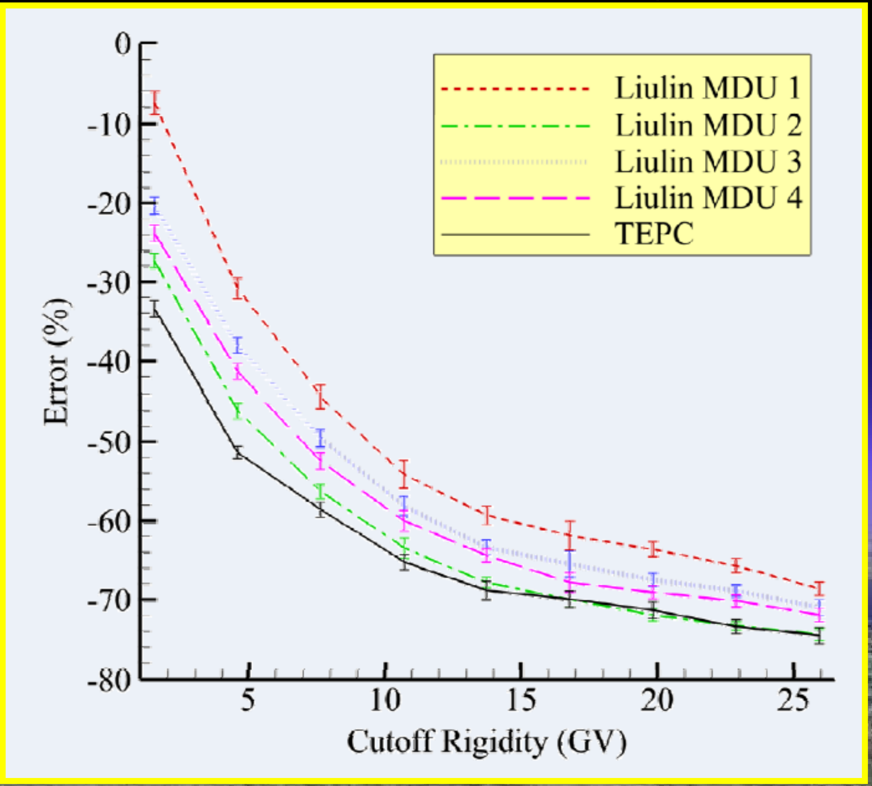


*Dachev, T., Atwell, W. Semones, E.; Tomov, B., Reddell, ISS Observations of SAA radiation distribution by Liulin-E094 instrument on ISS, Adv. Space Res., V 37, 1672-1677, 2006.

Comparison of simulated results using HZETRN and Liulin MDUs and TEPC on ISS in 2001*



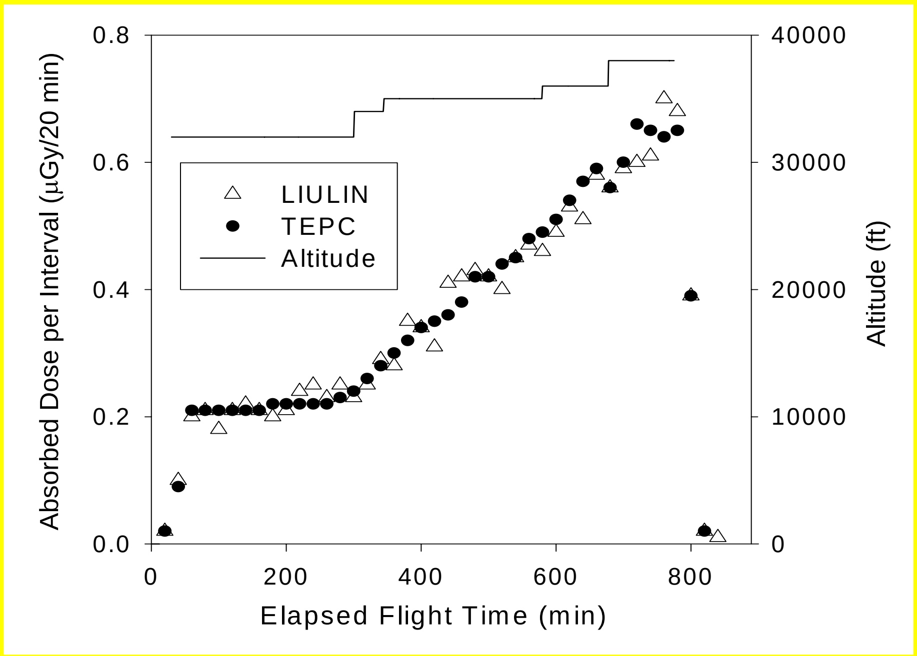
Comparison of simulated results using HZETRN and Liulin MDU1 measured data on ISS from July 6, 2001 4:00 pm to July 6, 2001 9:00 pm*

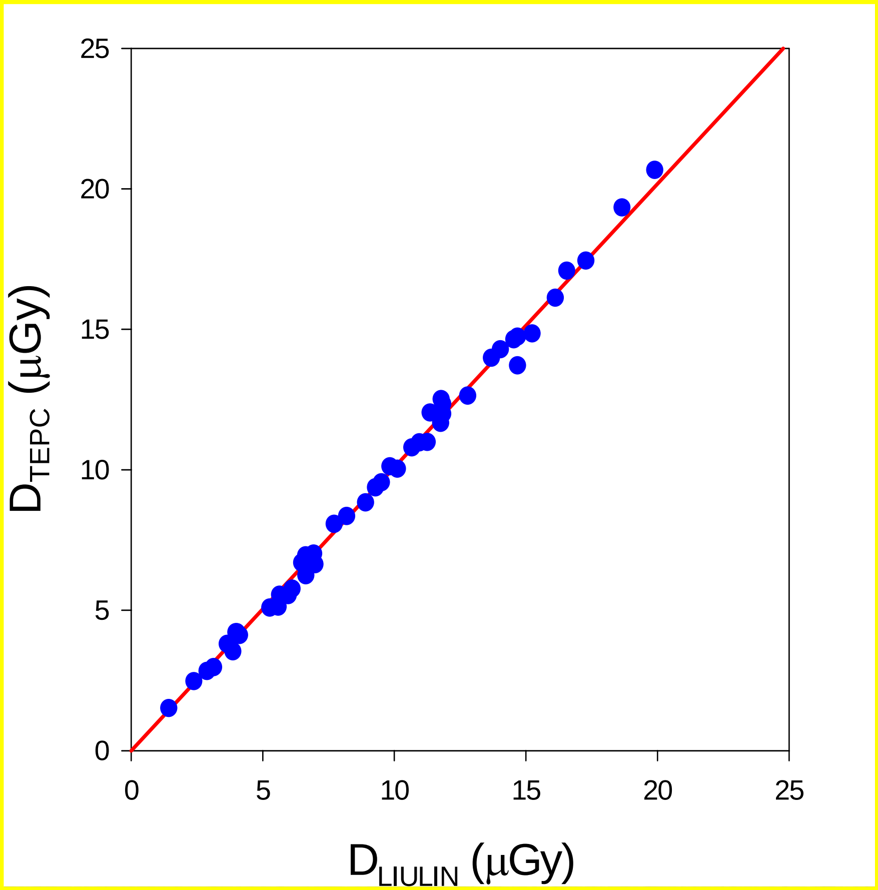


Average errors between HZETRN and the Liulin and TEPC detectors. The error bars represent the 95% confidence interval on the sample mean

*T.C.Slaba, S.R. Blattnig, F.F. Badavi et al., Statistical Validation of HZETRN as a Function of Cutoff Rigidity using ISS Measurements, Paper presented at COSPAR 2010.

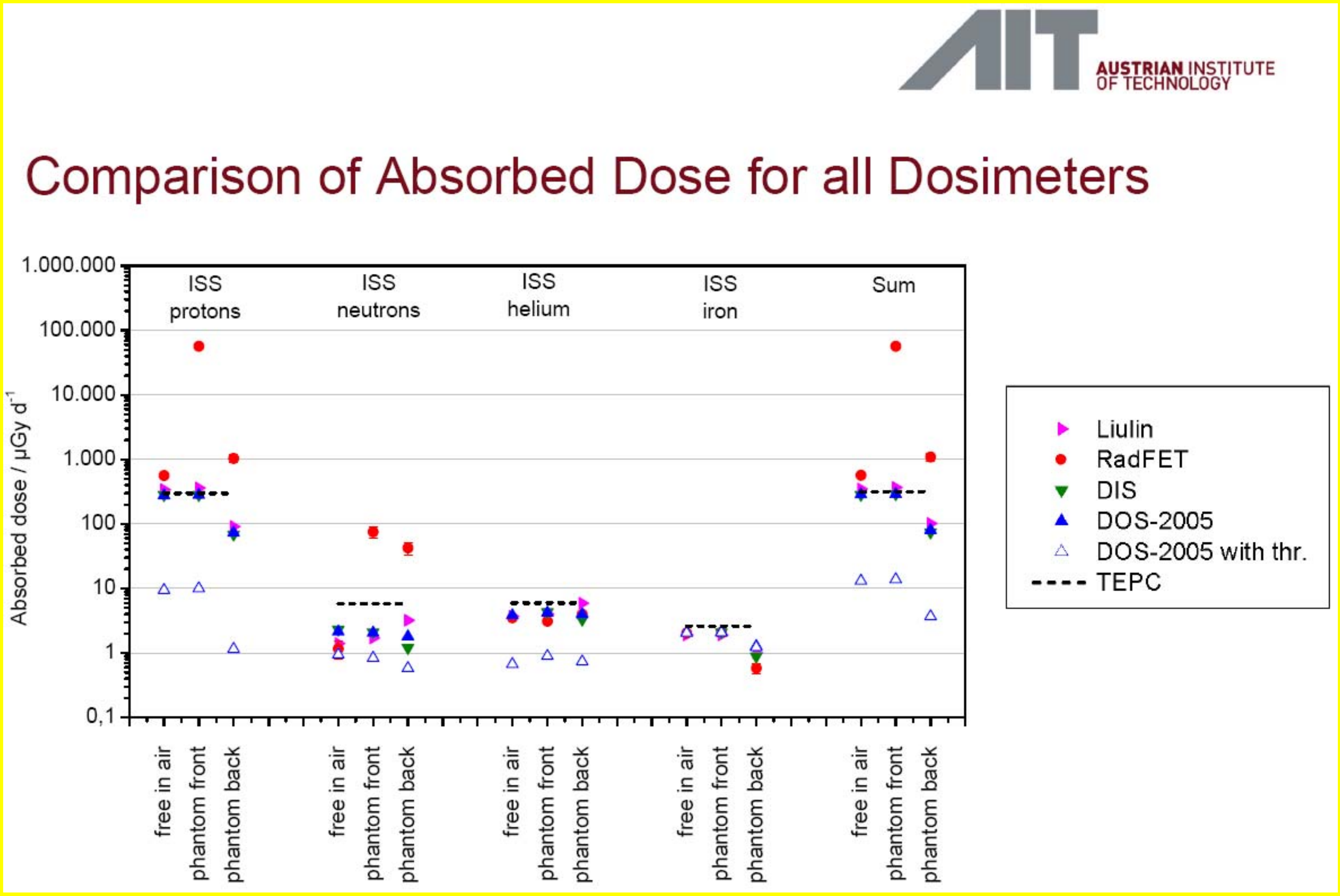
Liulin-4SN comparisons with TEPC data during aircraft experiments performed by Royal College, Canada*





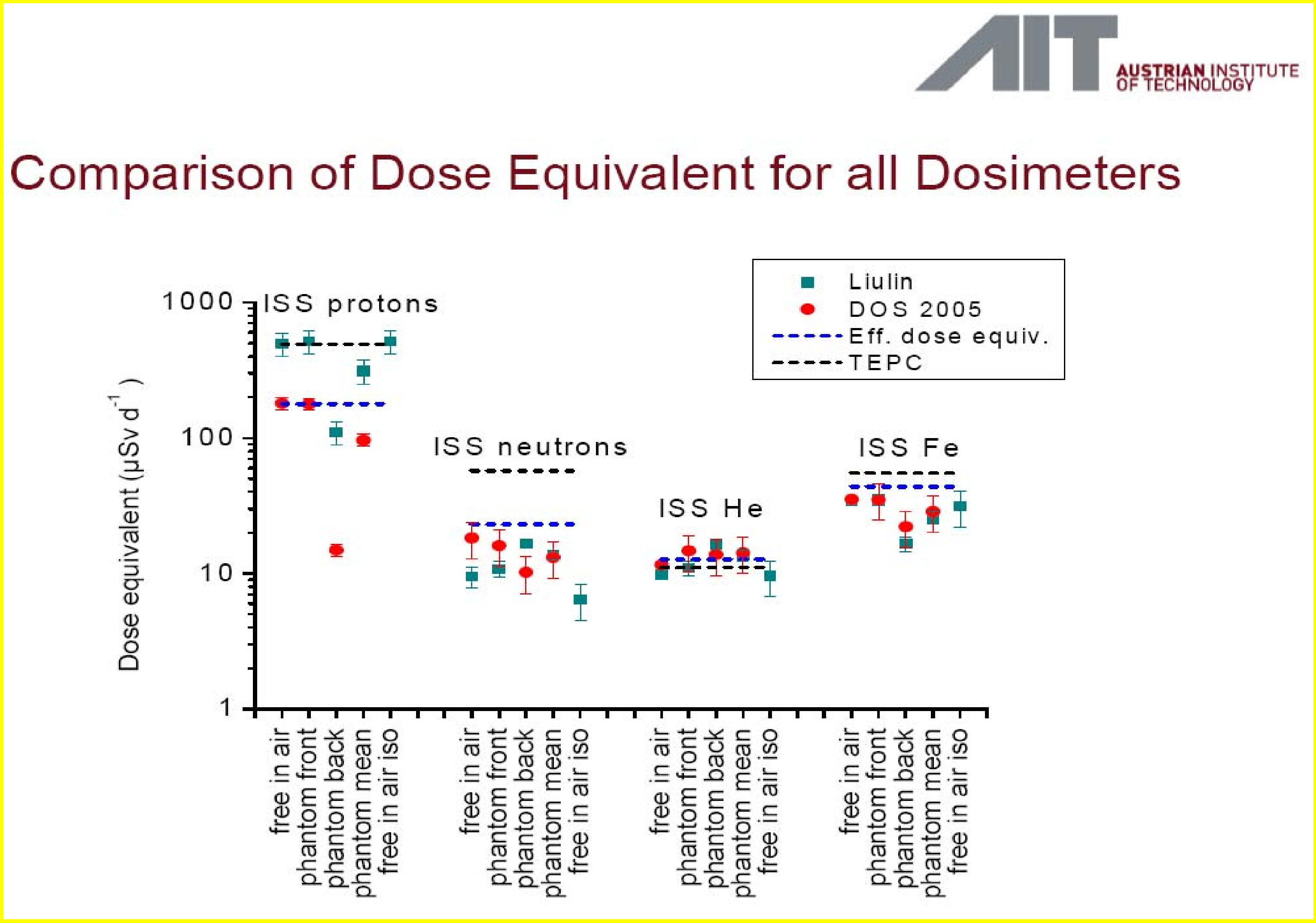
*Bennett, L.G.I; Lewis, B.J.; Kitching, F.; Green, A.R.; Butler, A., An Empirical Approach to the Measurement of the Cosmic Radiation Field at Jet Aircraft Altitudes, COSPAR04-A-01135, Presented at 35th COSPAR Assembly, Paris, July 2004.

Comparison of absorbed doses by different dosimeters as calculated by P. Beck*



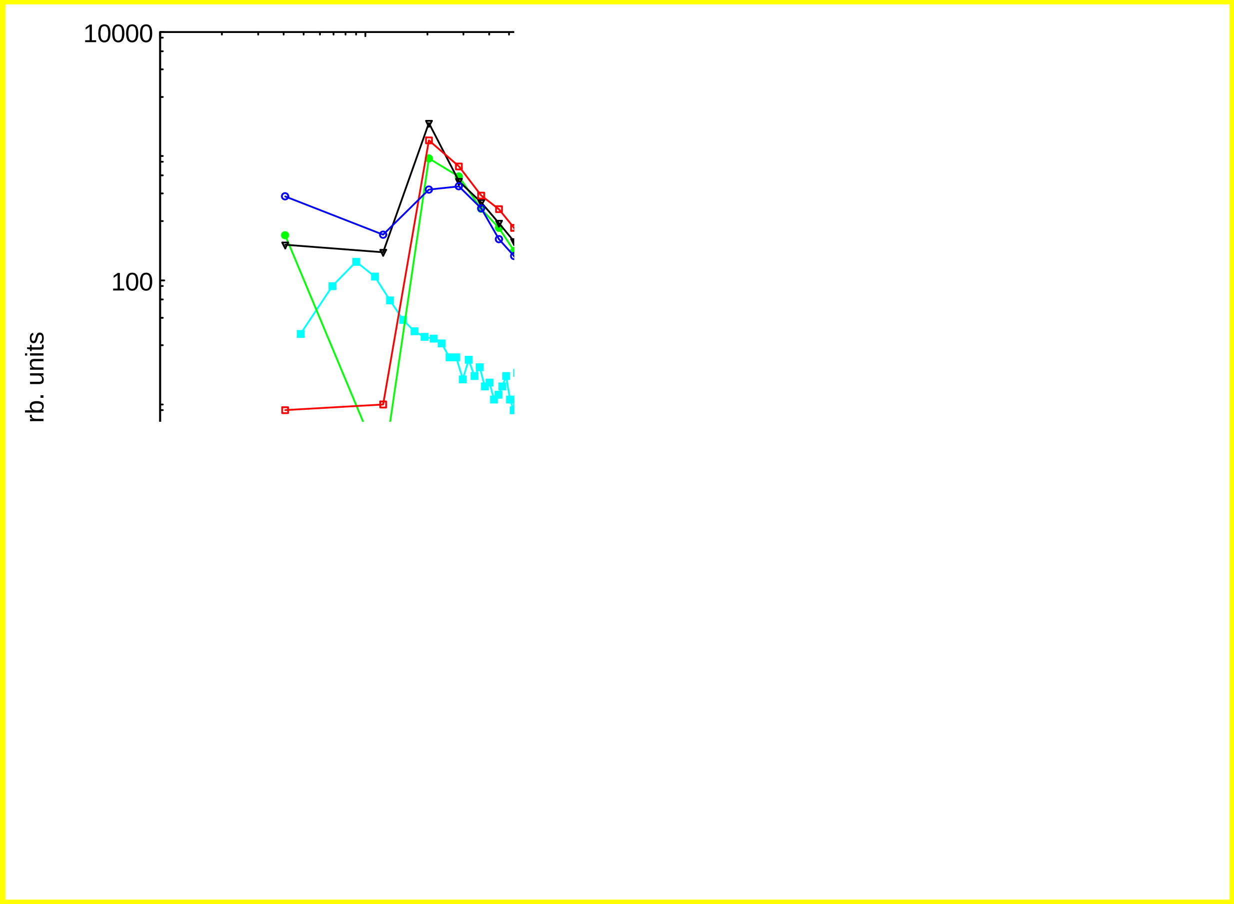
*Beck, P., Modeling Microdosimetric Spectra of Absorbed Dose and Dose Equivalent due to Exposure of Tissue and Silicon at International Space Station (EuCPADs), 14th WRMISS Workshop on Radiation Monitoring for the International Space Station, Dublin, 8-10 September 2009.

Comparison of absorbed doses by different dosimeters as calculated by P. Beck, et al, 2009.*



*Beck, P. et al., Modeling Microdosimetric Spectra of Absorbed Dose and Dose Equivalent due to Exposure of Tissue and Silicon at International Space Station (EuCPADs), 14th WRMISS Workshop on Radiation Monitoring for the International Space Station, Dublin, 8-10 September 2009.

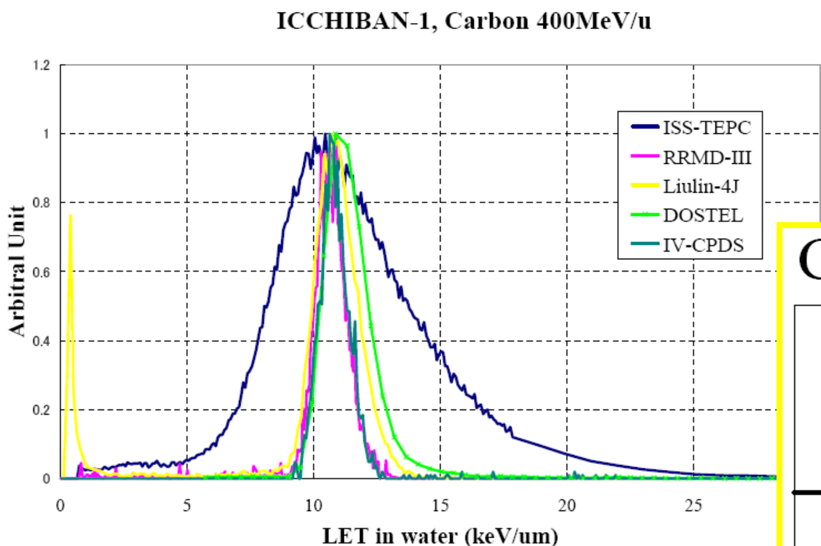
Comparison of the spectra obtained during the calibrations at Chiba, Japan (February, 2002) with 400 MeV/u Carbon ions by the 4 MDUs of Liulin-E094 and DOSTEL-1 instrument build by Kiel University, Germany*



*Burmeister, S., R. Beaujean, F. Petersen, G. Reitz, Post Flight Calibration of DOSTEL with Heavy Ions During the First and Third ICCHIBAN Run at HIMAC Chiba, 8th WRMISS, LBNL, Berkeley, USA, 3-5 September 2003

Comparison of spectra and calculated LET as published by Uchihori et al, 2002*

Comparison for Carbon Run



0 degree
Center
No Absorber

Comparison Table (C400, 0deg., Center)

	Avg. LET (keV/um- H_2O)	Avg. y_f (keV/um- H_2O)	Avg. y_d (keV/um- H_2O)	Quality Factor (ICRP-60)
RRMD-III	10.6	-----	-----	1.26
DOSTEL-2	10.7	-----	-----	1.6
DOSTEL-D	(10.7)	-----	-----	1.7
IV-CPDS	N.R.	-----	-----	N.R.
ISS-TEPC	-----	11.76	13.49	2.39
Liulin-4J	(9.8) 10.8	-----	-----	(1.29) 1.32
Calculation	10.9	-----	-----	(1.29)

*Uchihori, Y., K. Fujitaka, N. Yasuda, E. Benton, Comparison of Results from the 1stICCHIBAN Experiment and Current Status of the 3rdICCHIBAN Experiment, 8th Workshop on Radiation Monitoring for the International Space Station, Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA, USA, 3-5 September 2003.

Conclusions made by Uchihori et all, 2008*

6. Conclusions

Most of the heavy ion beams used in the ICCHIBAN-3 experiment possessed average LET values that fell above the range of LET to which the Liulin-4J MDU is sensitive. The one exception was 400 MeV/u neon at an incident angle of 0°. However, we demonstrated that the MDU can measure lower LET ions and particles from 'Fragment experiments' despite the fact that the instrument is both simple and small. In the space radiation environment, the majority of radiation fluence consists of protons and helium ions. The Luilin-4J MDU has the capability to measure radiation dose from these light ions and can be used as a personal dosimeter by astronauts and cosmonauts.

*Uchihori, Y., H. Kitamura, N. Yasuda, H. Kentaro, K. Yajima, Ts. P. Dachev, Chapter 7: Liulin-4J portable Silicon Spectrometer, Results of the ICCHIBAN-3 and ICCHIBAN-4, Experiments to Inlercompare the Response of Space Radiation Dosimeters, HIMAC-128, NIRS, Japan, pp 76-88, March, 2008.

Review the existing Liulin dose interpretation procedures

Liulin ranges

Deposited energy (Si):	0.0394-20.83 MeV
“LET(Si)”:	0.582-29.8 keV/μ
LET(H_2O):	0.722-36.95 keV/μ
LET(H_2O) (PHITS):	0.722-42.1 keV/μ

MDU - Liulin aircraft dose interpretation procedure

1) Absorbed Dose in Si is calculated as:

$D = K * \sum k_i A_i / MD$, where

MD – mass of the detector;

A_i – amplitude in volts of pulses in channel "i";

k_i – events number in the channel i;

K – coefficient based on W_e in Si

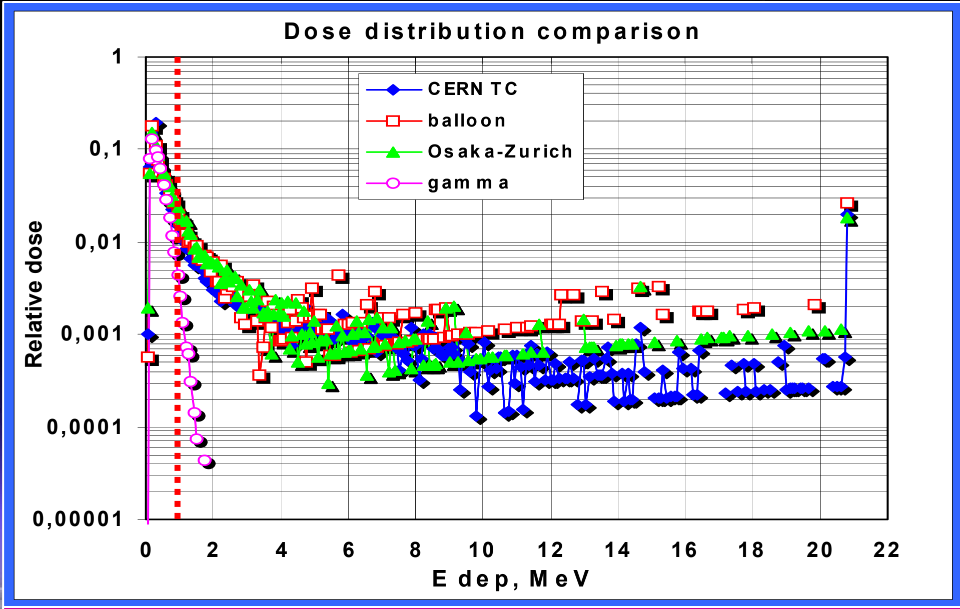
2) Apparent dose equivalent Happ (Ambient dose equivalent - H*(10)) is calculated as:

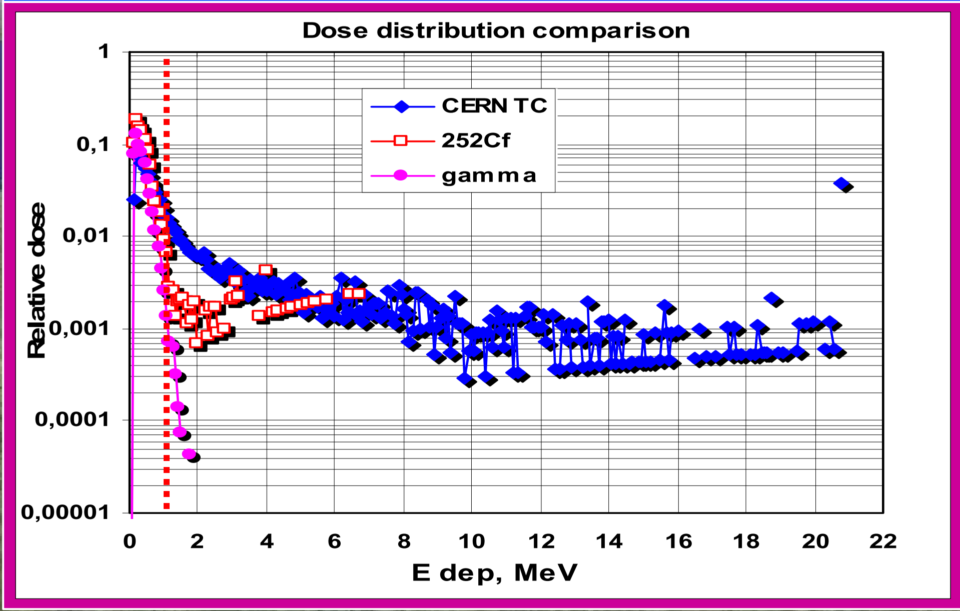
D(Si) above ~ 1 MeV (D_{high}) neutron like component

D(Si) below ~ 1 MeV - (D_{low}) non-neutron component

H*(10)= k1*Hlow + k2*Hhigh

Coefficients – established in CERF fields and/or on the base of comparison with TEPC results. All aircraft spectra (more than 6000 hours; ~ 30 mSv) summed up and regressed to get as good statistical reliability to distinguish neutron and GCR contribution - for energy deposition spectra above ~ 1 MeV





New results...

Spurny's apparent dose equivalent interpretation procedure

GCR Supposed that:

E_{dep} bellow ~ 1 MeV low LET component

E_{dep} above ~ 1 MeV high LET component composed of: neutron like component, with similar spectra as onboard aircraft, and

contribution of HECP of GCR

Interpretation:

Low LET component: (Si)→D(tissue)→"H*(10)";

High LET or Neutron like component: as onboard aircraft;

GCR component: D(Si)x5→D(tissue)="H*(10)";

$$H_{GCR}*(10) = K\{\sum_{i=1}^{14} ik_i A_i + 5\sum_{i=15}^{256} ik_i A_i\} / MD$$

GCR Selected as:

Ch2<20, ch20=0; ch21=0

SAA Supposed all events from protons

Interpretation:

D(Si)→D(tissue), and

D(tissue) x QFaverage calculated from energy distribution spectra (~1.3) = "H*(10)"

SAA Selected as:

Ch20>0; ch21>0

$$H_{SAA}*(10) = K\{1.3\sum_{i=1}^{14} ik_i A_i + 1.3\sum_{i=15}^{256} ik_i A_i\} / MD$$

Outer Radiation Belt Supposed all events from electrons

Interpretation:

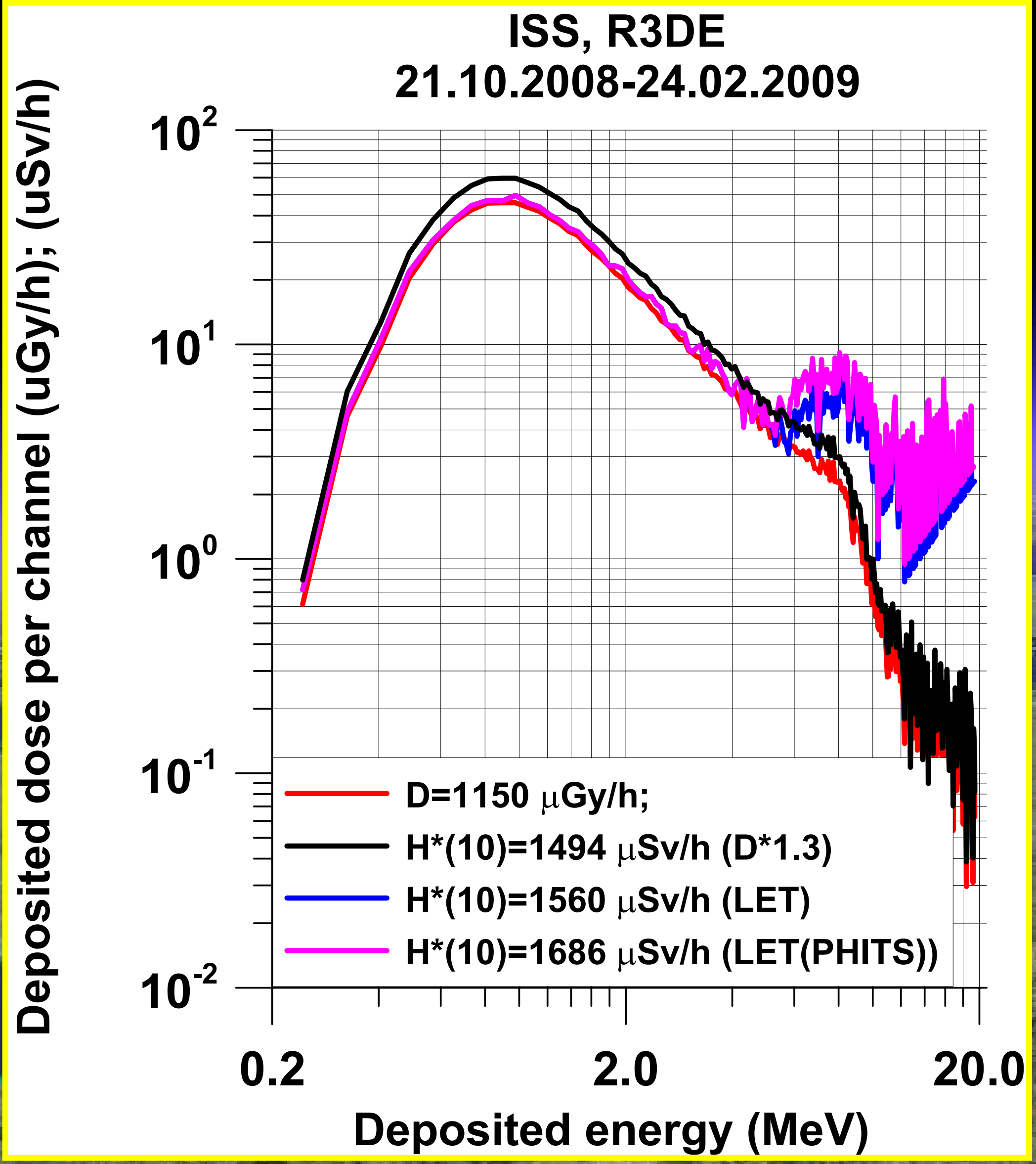
D(Si)→D(tissue), and

D(tissue) x QFaverage calculated from energy distribution spectra (~1) = "H*(10)"

ORB Selected as: Ch2>20

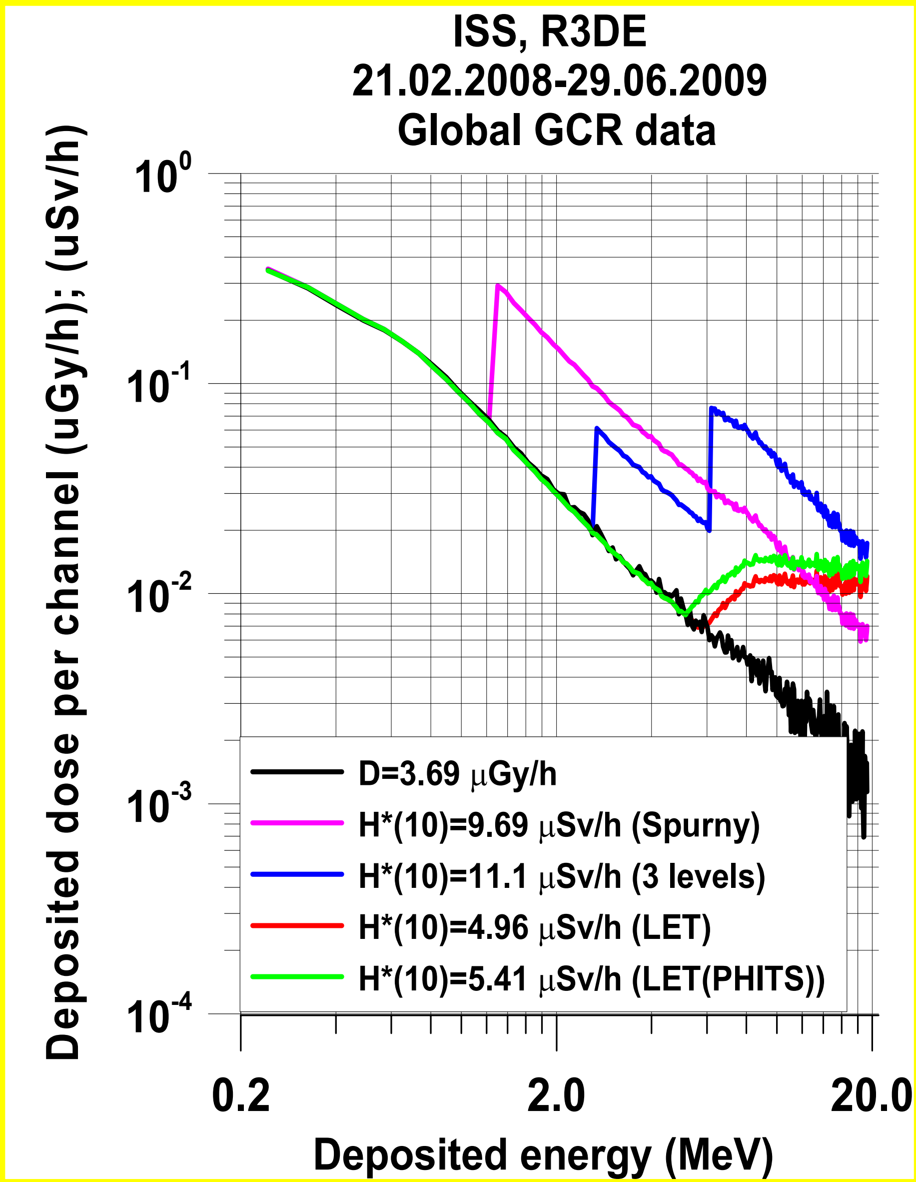
$$H_{ORB}*(10) = K\{1\sum_{i=1}^{14} ik_i A_i + 1\sum_{i=15}^{256} ik_i A_i\} / MD$$

IRB (SAA) spectra transformation at different H*(10) calculation procedures



	Dose μGy/h	Koeff.	H*(10) μSv/h	Q
Spurny	1150	1.3	1496	1.3
LET (simple)	1150	Variable	1560	1.36
LET (PHITS)	1150	Variable	1686	1.47
DOSTEL (aver.)				1.2
Liulin-5 (aver.)				1.2-1.4
TEPC (aver.)				1.8

GCR spectra transformation at different H*(10) calculation procedures

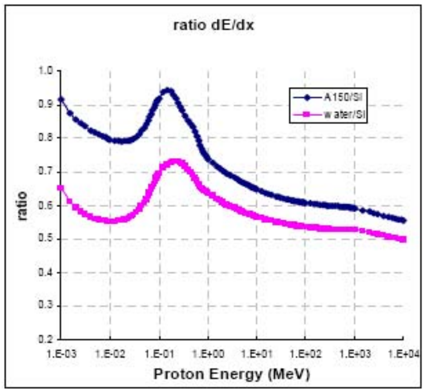


	Dose μGy/h	Coefficients	H*(10) μSv/h	Q
Spurny	3.69	1&5	9.69	2.62
3 levels		1&3.22&12.2	11.1	3.0
LET (simple)	3.69	Variable	4.96	1.34
LET (PHITS)	3.69	Variable	5.41	1.47
DOSTEL (aver.)				3,4*
Liulin-5 (aver.)				2.6-4.0
TEPC (aver.)				2.9

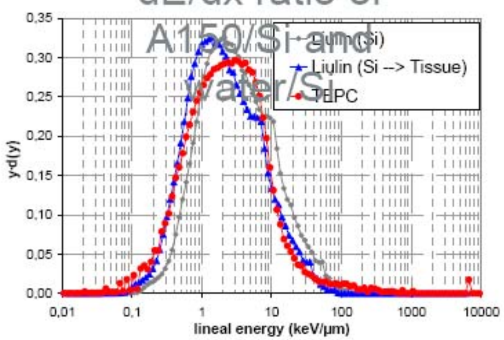
*Reitz et al., RPD, 2005.

Convert Absorbed Dose in Liulin (Si) into Liulin (Tissue)

AUSTRIAN INSTITUTE OF TECHNOLOGY



dE/dx ratio of A150/Si and water/Si



General geometry, ISS protons:

$$\overline{\eta} = \frac{\int dE \cdot \varphi(E) \cdot LET_{A150}}{\int dE \cdot \varphi(E) \cdot LET_{Si}} = 1.55$$

$H_{proton,}$ = 585 µSv d^{-1}

TEPC: H_{proton} = 490 µSv d^{-1}

Specific geometry (Liulin), ISS protons:

D_{tissue} / D_{Si} = 1.29

H_{proton} = 420 µSv d^{-1}

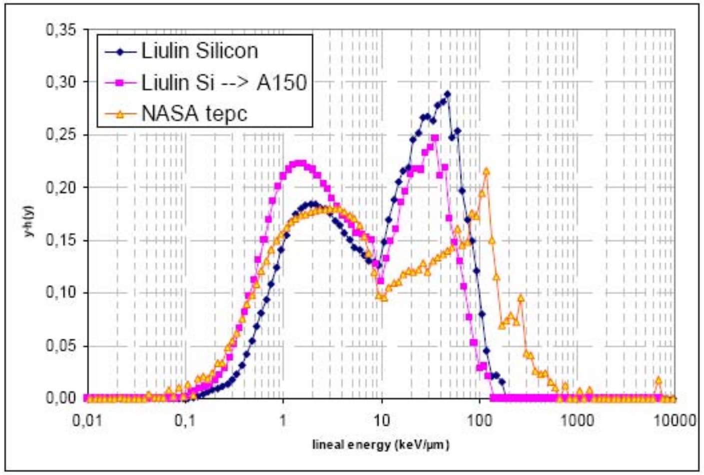
Incident proton isotropic irradiation, outside ISS, solar maximum, 400km

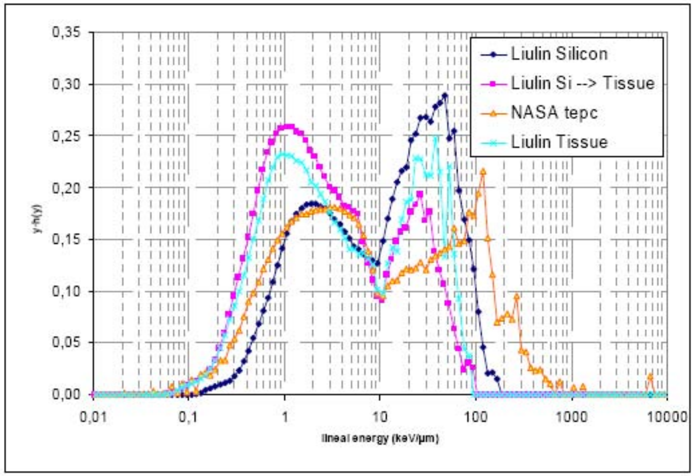
WRMISS 14th, Dublin, September 8-10, 2009 44

*Beck, P. et al., Modeling Microdosimetric Spectra of Absorbed Dose and Dose Equivalent due to Exposure of Tissue and Silicon at International Space Station (EuCPADs), 14th WRMISS Workshop on Radiation Monitoring for the International Space Station, Dublin, 8-10 September 2009.

AUSTRIAN INSTITUTE OF TECHNOLOGY

Dose Equivalent Distribution, Liulin Detector corrected for Tissue





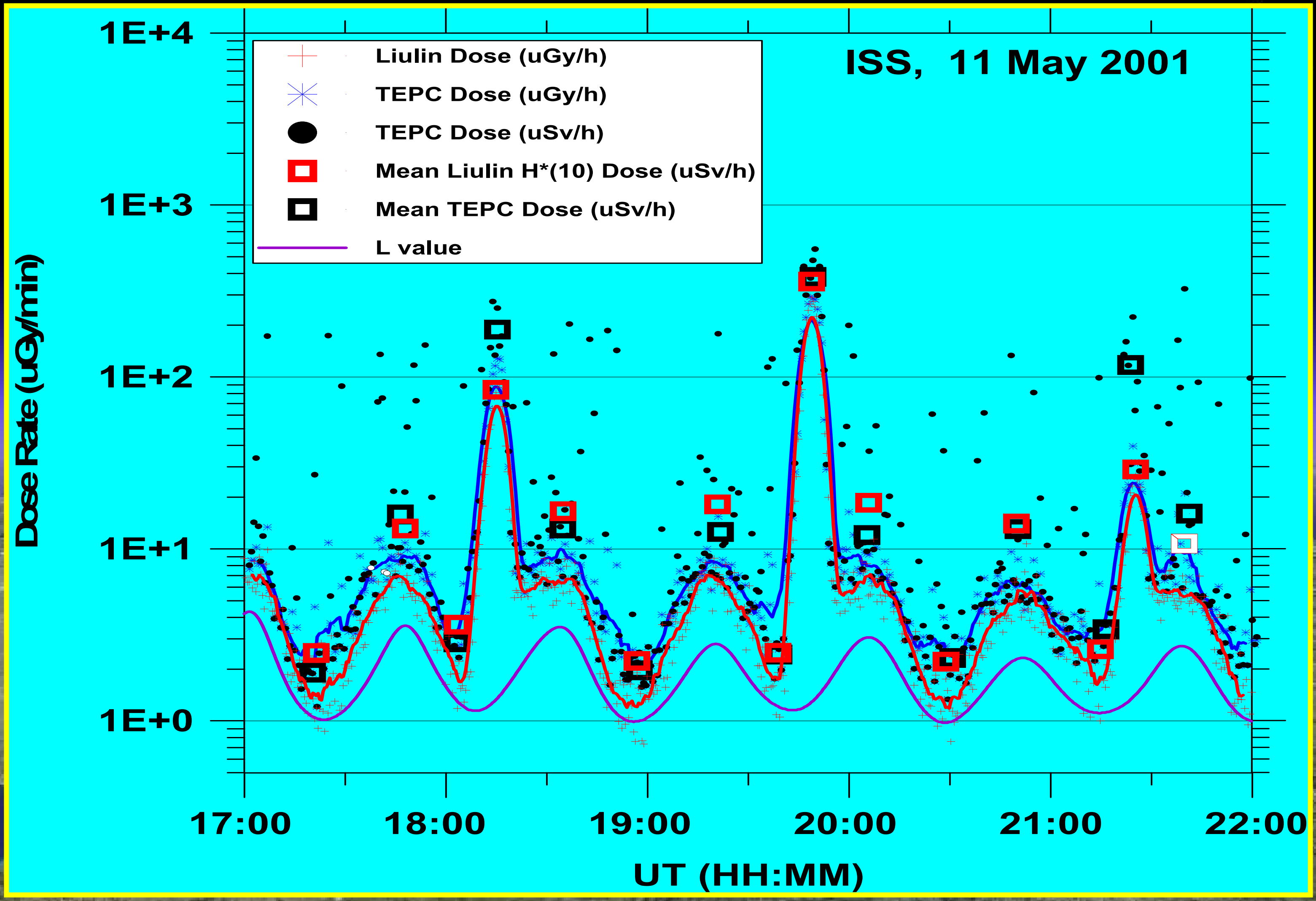
General geometry, ISS protons: 1.55 Specific geometry (Liulin), ISS proton

WRMISS 14th, Dublin, September 8-10, 2009 45

*Beck, P. et al., Modeling Microdosimetric Spectra of Absorbed Dose and Dose Equivalent due to Exposure of Tissue and Silicon at International Space Station (EuCPADs), 14th WRMISS Workshop on Radiation Monitoring for the International Space Station, Dublin, 8-10 September 2009.

Comparison of the Liulin apparent dose equivalent data obtained at ISS with TEPC data

Comparison between NASA TEPC and MDU doses. H*(10) MDU doses are calculated as shown on next slide



Authors are thankful to Dr. E. Semones for the Phantom TORSO NASA TEPC data

Tabulated results from previous slide

$$H_{GCR}*(10) = K\{\sum_{i=1}^{14} k_i A_i + 5\sum_{i=15}^{256} k_i A_i\} / MD$$

$$H_{SAA}*(10) = K\{1.3\sum_{i=1}^{14} k_i A_i + 1.3\sum_{i=15}^{256} k_i A_i\} / MD$$

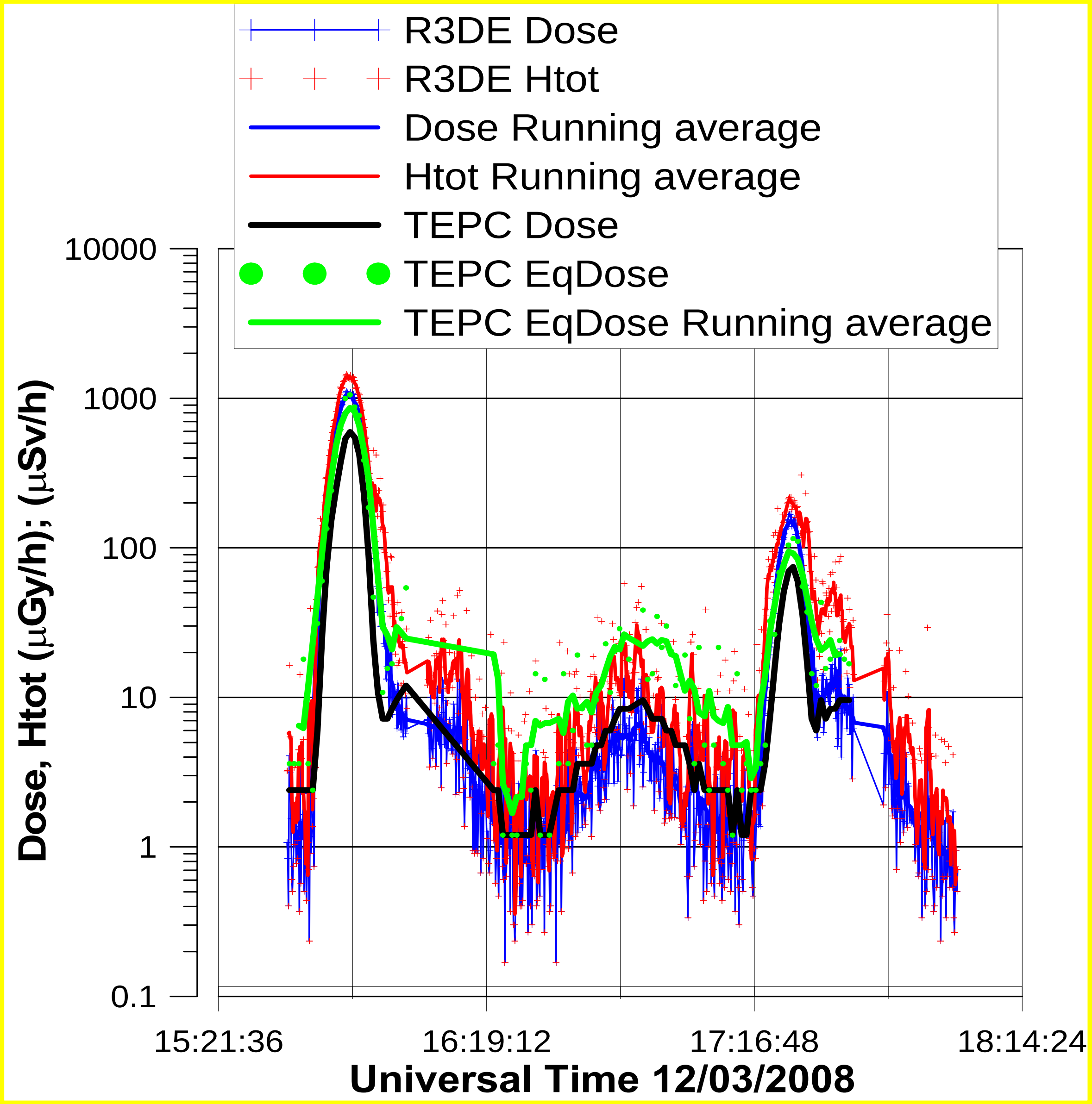
Dose/Instrument Position	H*(10)low µSv/h	H*(10)high µSv/h	H*(10)tot µSv/h	D µGy/h
Liulin MDU#4 Equator (GCR) (mean value over 81 spectra)	1.2	1.37	2.58	1.48
Liulin MDU#4 Equator (GCR) (%)	47	53		
Phantom TORSO NASA TEPC (GCR) (%)	29	71		
Liulin MDU#4 L~3 (GCR) (mean value over 63 spectra)	4.29	10.6	14.89	6.41
Liulin MDU#4 L~3 (GCR) (%)	29	71		
Phantom TORSO NASA TEPC (GCR) (%)	29	71		
Liulin MDU#4 SAA (Trapped) (mean value over 33 spectra)	85.1	53.4	138.5	106.7
Liulin MDU#4 SAA (Trapped) (%)	61	39		
Phantom TORSO NASA TEPC (Trapped) (%)	71	29		

►Best results from the comparison are obtained for GCR component at L~3;

► The results for GCR component in equatorial region are fair;

► Trapped radiation comparison is relatively good.

Comparison of data with the NASA TEPC inside of US Lab module in 2008



TEPC GCR doses are higher than R3DE doses because the smaller sensitivity of the TEPC

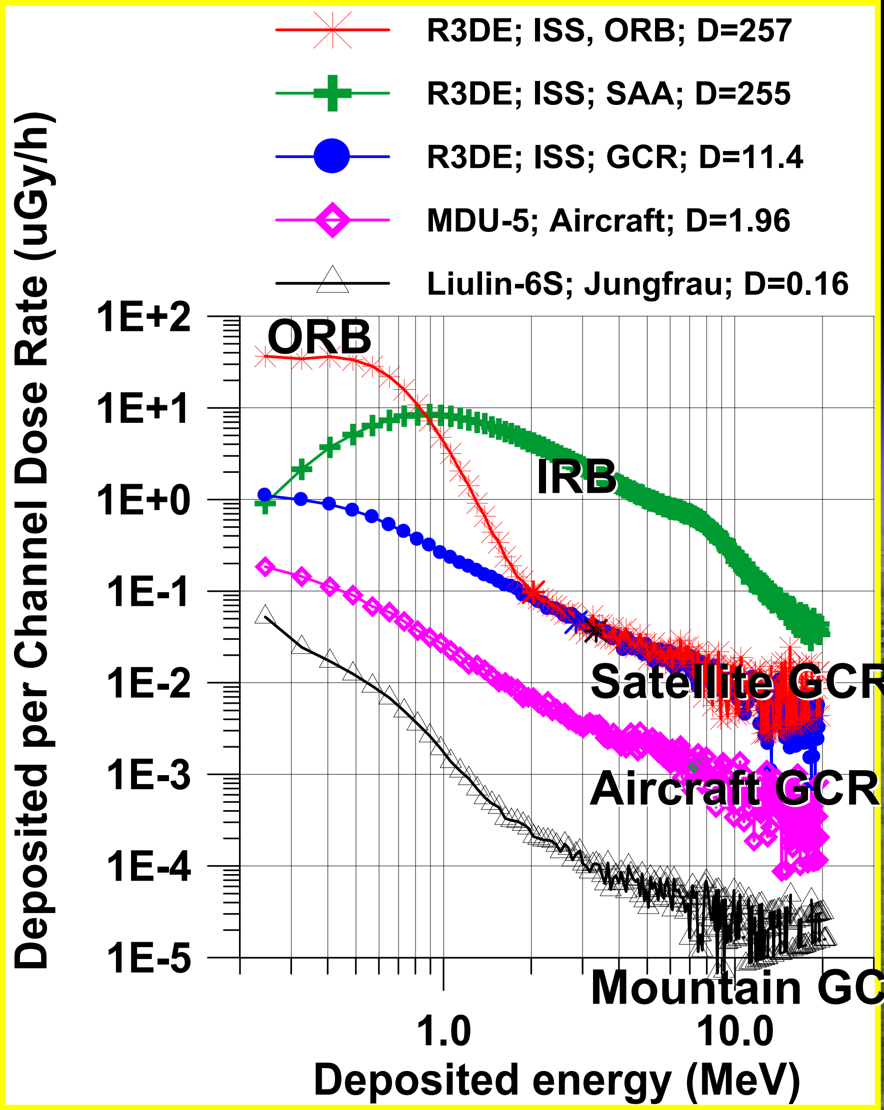
TEPC SAA doses are lower than R3DE doses because of larger shielding of TEPC

Further improvement of the calculation procedure is needed

Authors thanks to Dr. E. Semones for the TEPC data

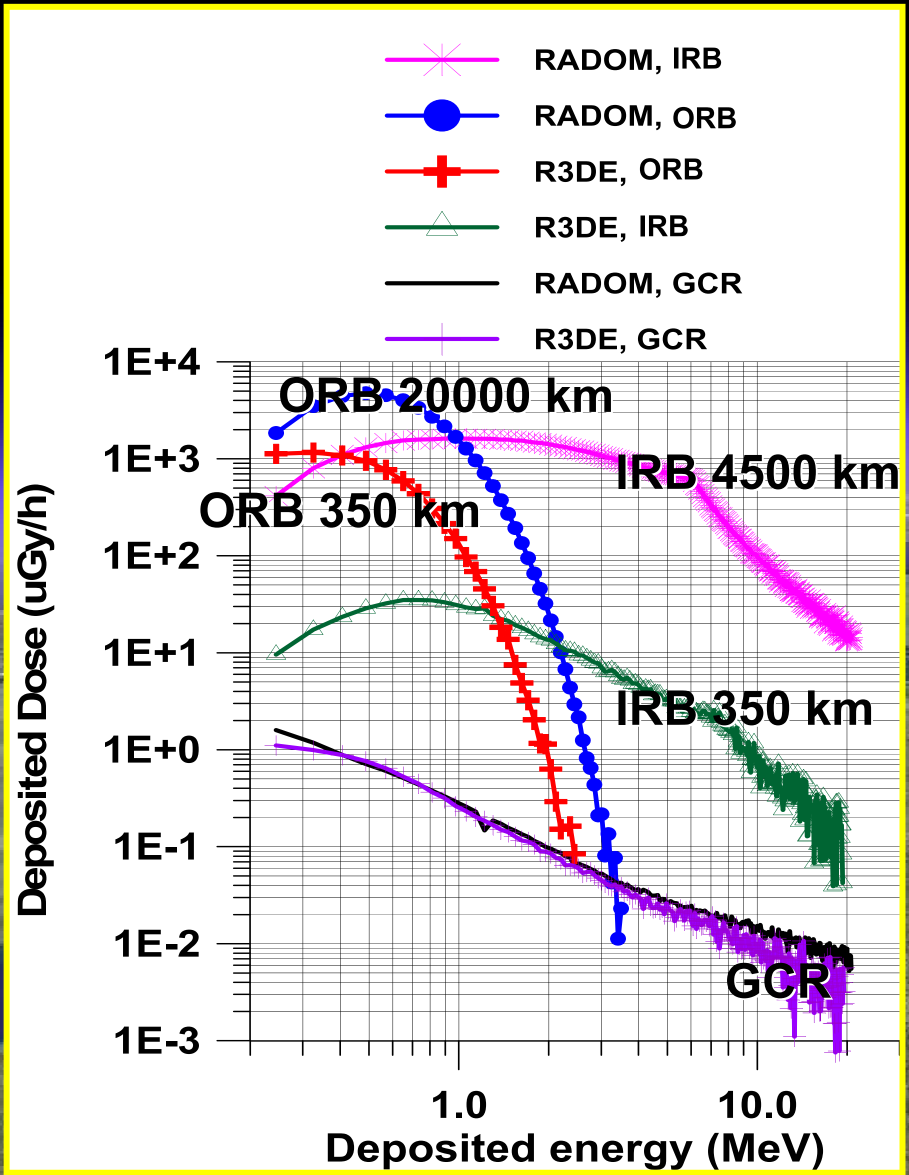
Liulin radiation sources separation procedures applicable in the battery operated devices

Separation of the space radiation sources by the form of the Liulin deposited energy spectrum*



*Dachev, Ts. P., Characterization of near Earth radiation environment by Liulin type instruments, Adv. Space Res., 1441-1449, 2009. doi:10.1016/j.asr.2009.08.007

Comparison of Chandrajaan-1 RADOM spectra with ISS - R3DE spectra



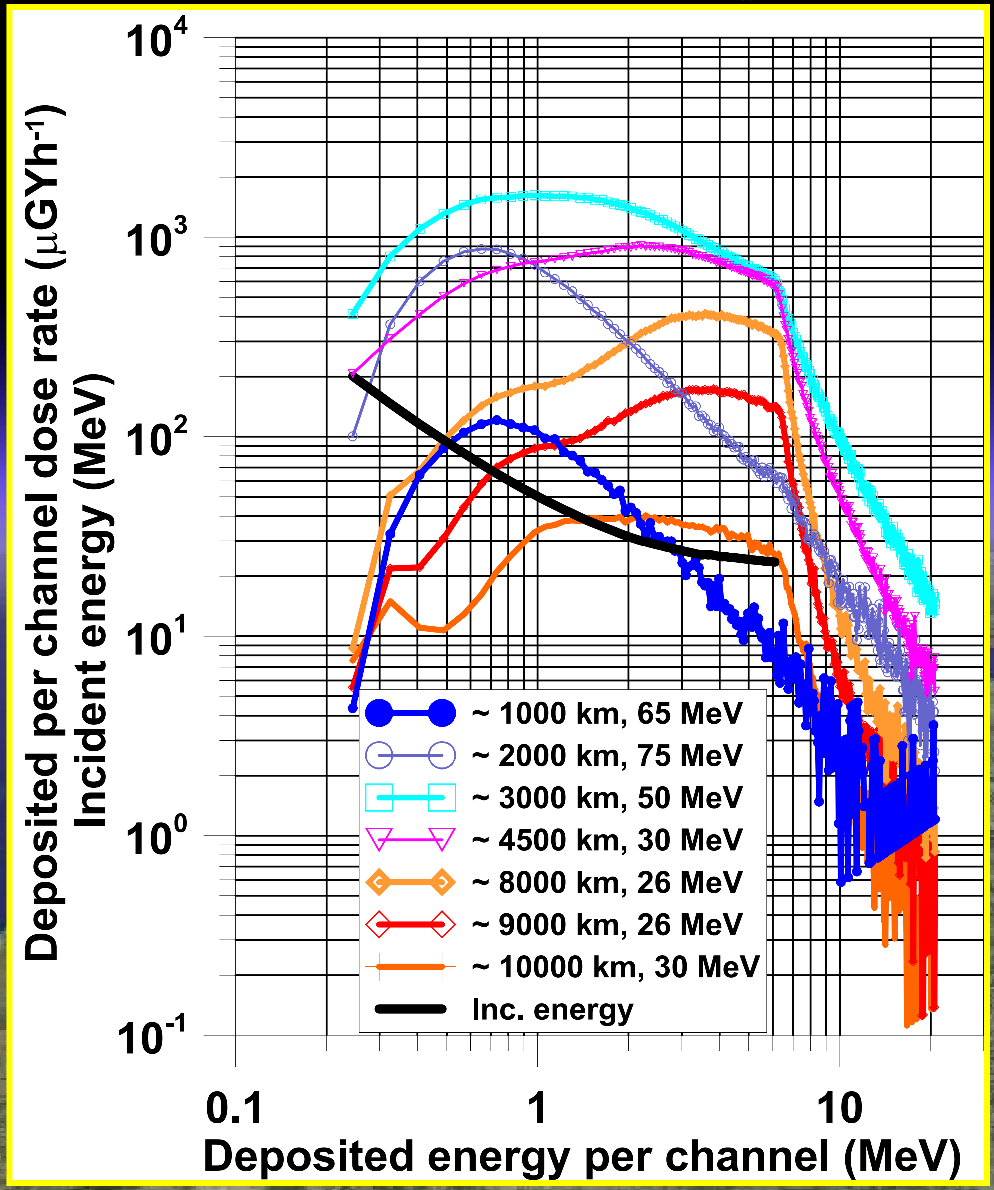
The shape of spectra obtained by RADOM are same as spectra obtained by R3DE at Int. Space Station

The RADOM proton radiation belt (IRB) spectrum is with same shape as R3DE spectrum but at about 1.5 order of magnitude higher because higher flux and respectively dose

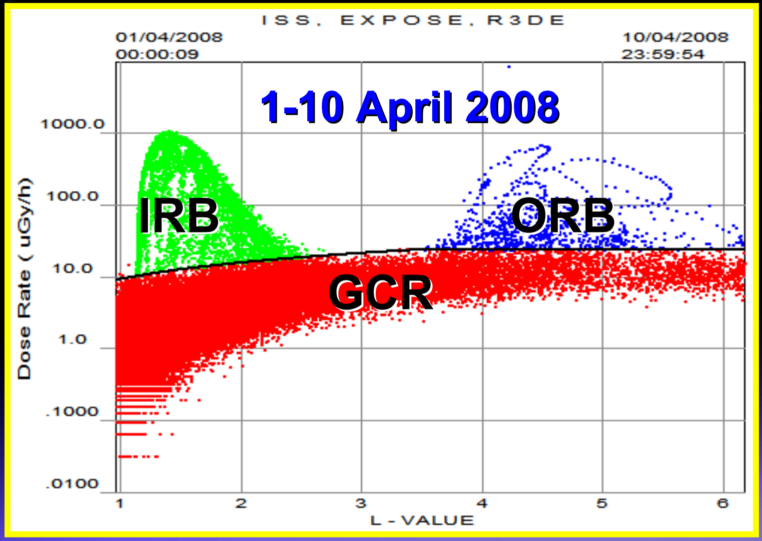
The RADOM electron radiation belt (ORB) spectrum is with same shape as R3DE spectrum but about 4 time higher lower because higher dose

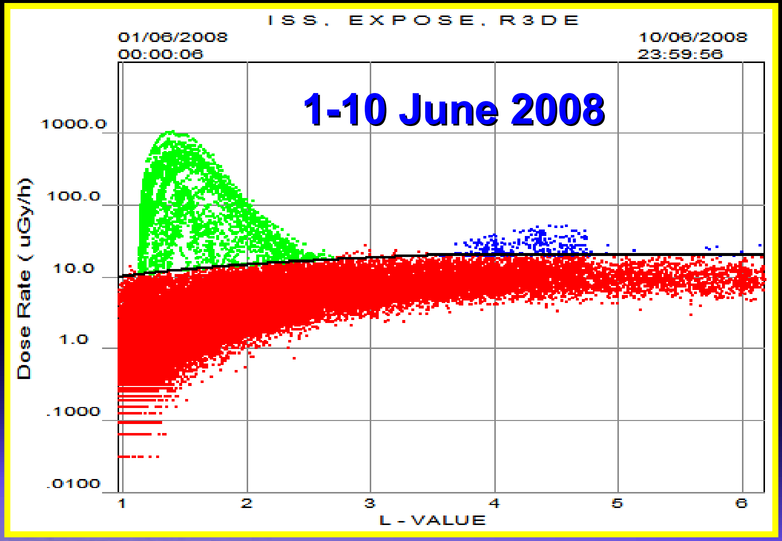
The RADOM galactic cosmic rays (GCR) spectrum practically overlap the REDE spectrum, because of same flux and respectively doses

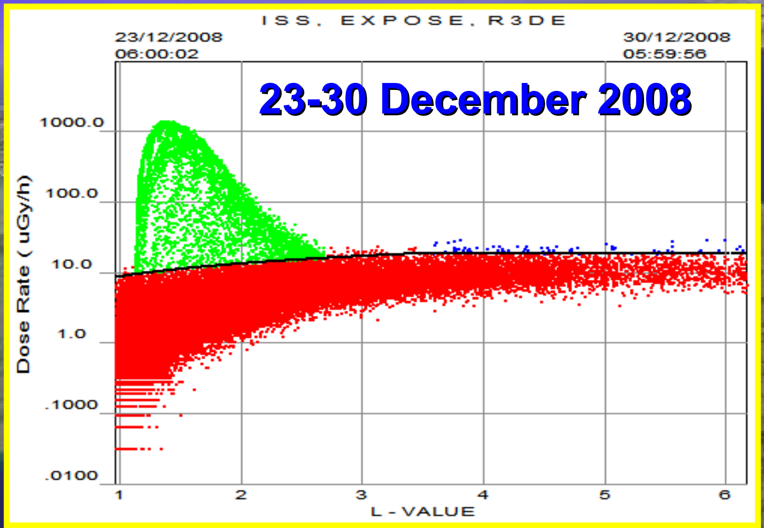
Averaged IRB spectra obtained by RADOM instrument on 22nd of October 2008 between 19:55 and 20:55 UT

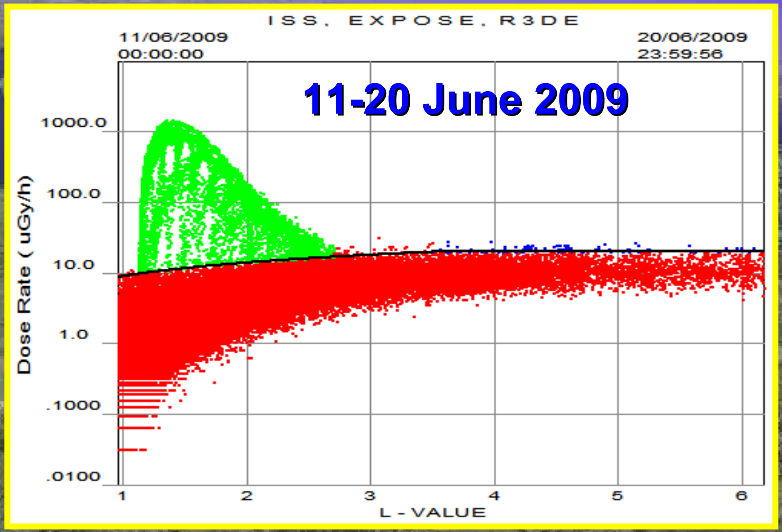


Separation of ISS radiation sources by polynomial of L value



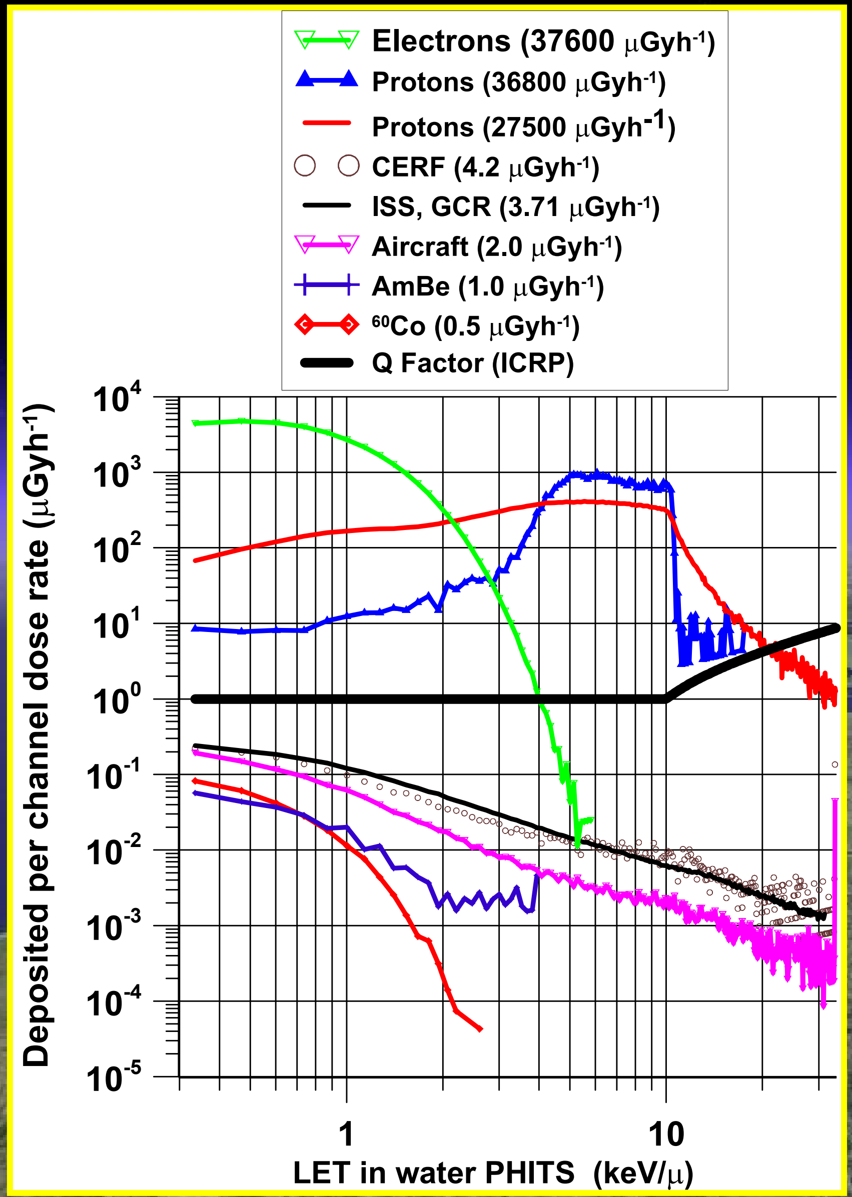






- With the decay of solar activity in 200-2009 the number of ORB events decrease;
- The increase in SAA dose rates in 200-2009 is result of ISS altitude increase;
- Global GCR visually don’t change. Small average increase from 3.7 to 3.9 mGy/h is observed.

Spectra shapes obtained by Liulin type instruments during calibrations and on aircraft and spacecraft



Methods for sources separation inside of the Intelligent personal dosimeter

1. Separation by the count rate in different channels as follows:
   - Relativistic electrons in ORB can be separated easy by observation of high count rate in first 2-3 channels (Ch2>20);
   - IRB (SAA) protons can be separated by relative high rate in all first 30 channels (Ch20,21>0);
   - GCR can be separated by observation of low count rate in first 2-3 channels (Ch2<20);
   - These values can be changed from ground after specification in first days of mission.

2. Separation with count rates exceeding a given threshold, which can be regarded as crossings of the SAA. This is usual procedure for DOSTEL, Liulin-5 and TriTel telescopes;

3. Separation by more sophisticated methods to compare the form of the observed spectrum with preliminary tabulated forms;

4. Separation of radiation sources by knowledge of L value. Applicable only in case of wireless connection between the personal dosimeter and board computer.

Preliminary proposal for the hardware and software of the Intelligent Crew Personal Dosimeter

Liulin-6G specifications

Size: 120x40x20 mm
Mass: 110 grams
Volume: 96 ml
Detector: 2 cm^2, 0.3 mm
LET Si: 0.1164- 29.8 keV/µ
LET H_2O: 0.1443- 36.9 keV/µ
Dose: 0.093 nGy – 1.56 mGy
Dose rate: $2.8.10^{-9}$ -0.19 Gy/h
Flux range: 0.01 – 1250 cm^2s
Temperature: -20°C - +40°C
Li-Ion battery: 3.6 V, 1.8 Ah
Flash memory: 2 MB (30 days in space)
Active time: 5 days

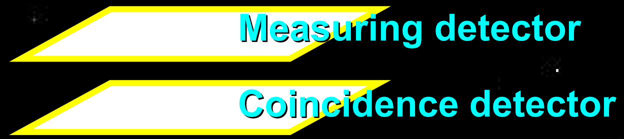
First row: Absorbed dose (µGy/h)
Second row: Calculated apparent *H*(10)* (µSv/h)
Third row: Accumulated since the beginning of the measurements absorbed dose (µGy)

Alert signal

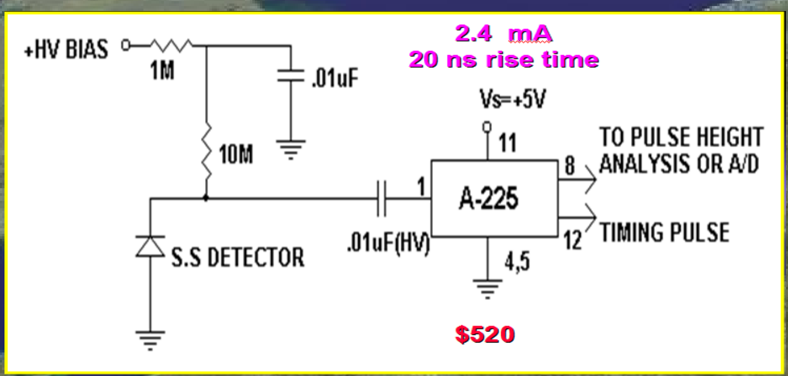
USB control

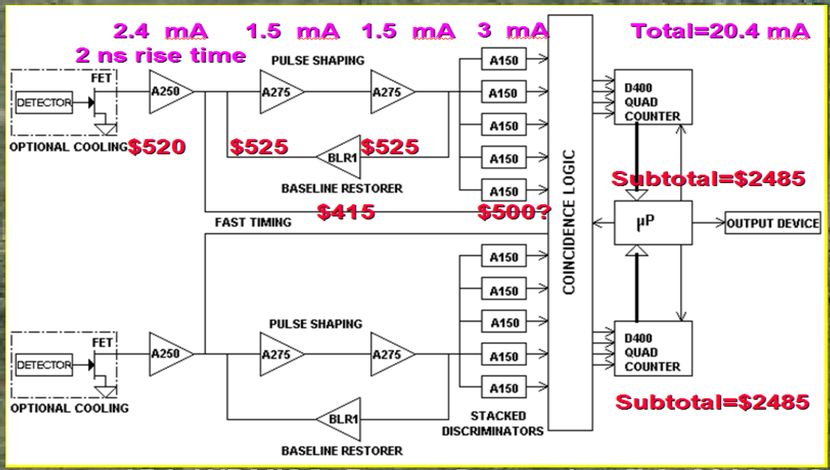
Battery charge from 5 V of USB

Advantages and disadvantages of the 1 and 2 detectors telescope design



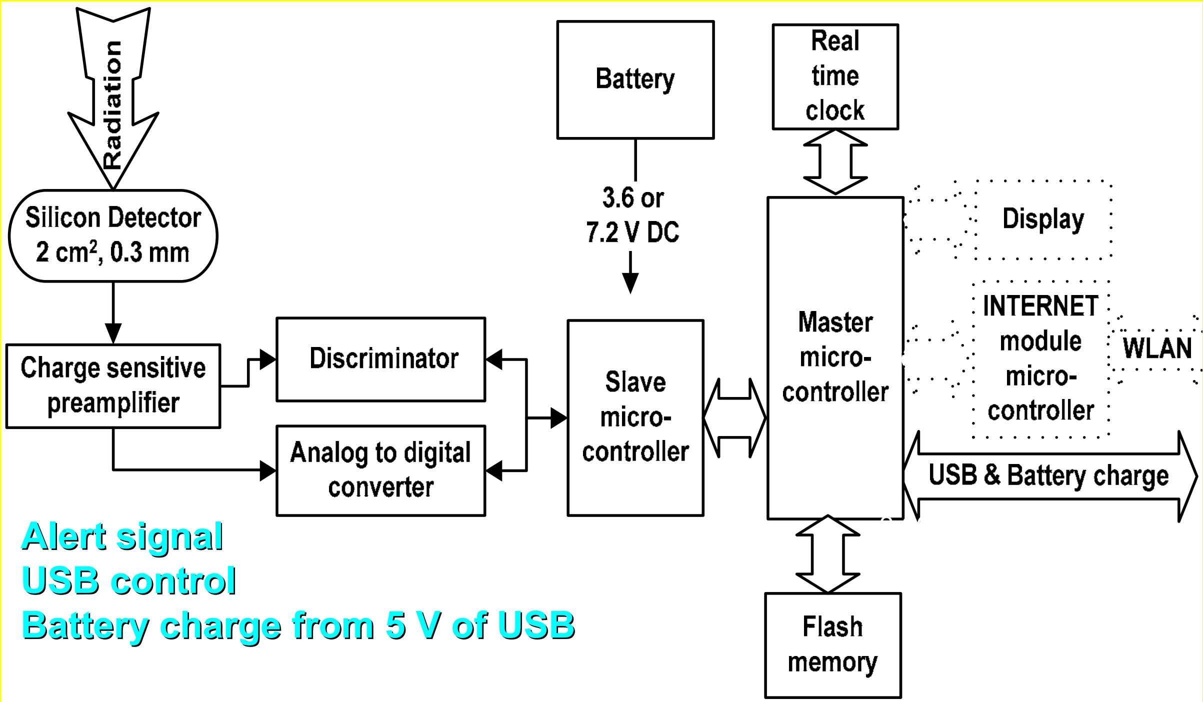
	1 Detector		2 Detectors	
	Advantage	Disadvantage	Advantage	Disadvantage
LET spectrum & Dose equivalent		No Apparent	Yes Yes	
Power consumption from 8 V DC	I < 7 mA			I >14 mA
Volume	V < 100 ml			V > 100 ml
Time of operation	T > 5 days			T < 2 days
Cost	Less			More





Proposed by AMPTEK block-schemas of one and two detector telescope system

Preliminary block-diagram of the Intelligent Crew Personal Dosimeter and specifications wit 1 and 2 ranges ADC

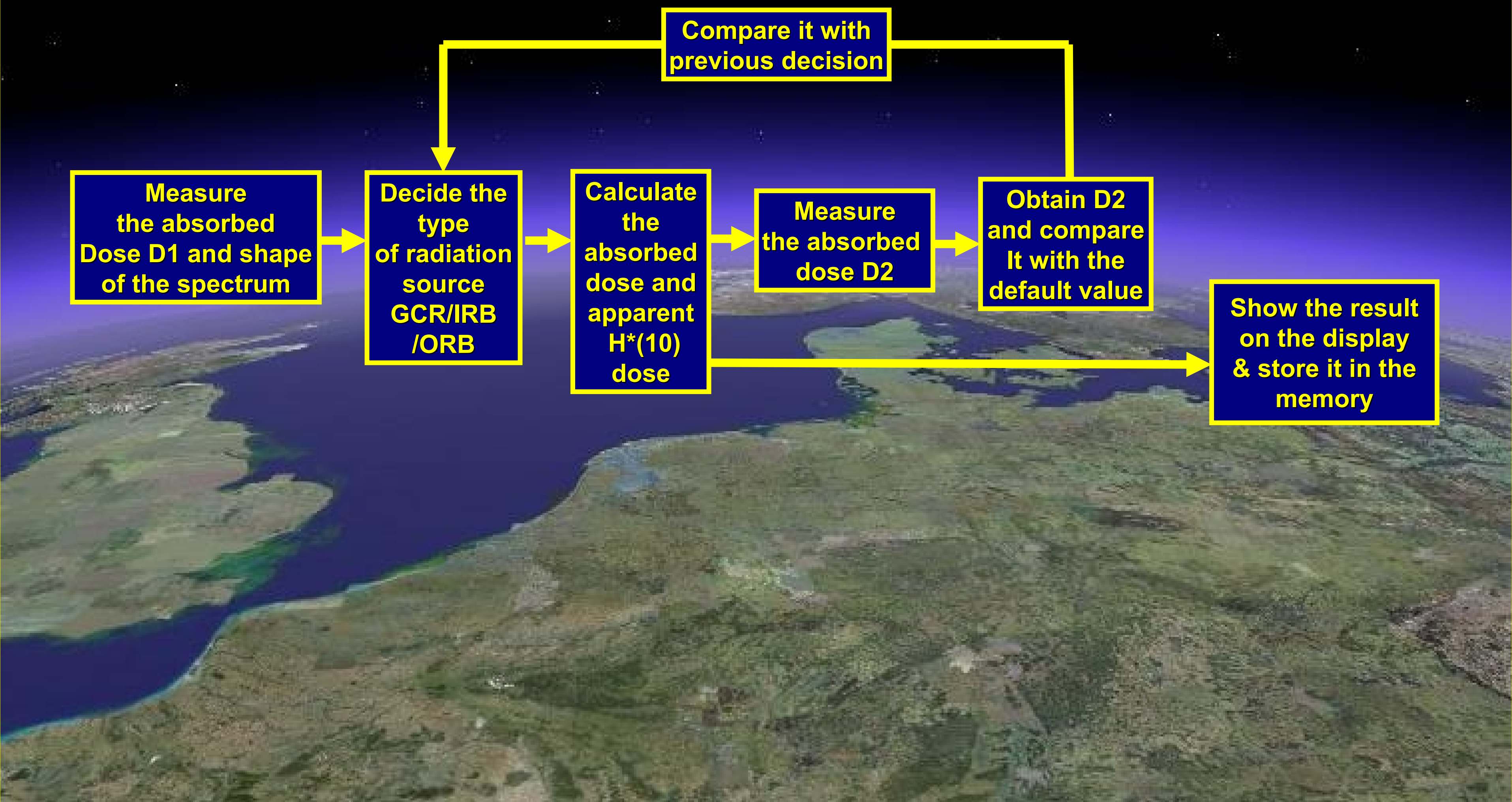


Alert signal
USB control
Battery charge from 5 V of USB

- Size: <120x40x20 mm
- Mass: <110 grams
- Volume: <96 ml
- Detector: 2 cm^2 , 0.3 mm
- LET Si: 0.1164- 29.8 keV/μ
- LET H_2O: 0.1443- 36.9 keV/μ
- Dose range: 0.093 nGy – 1.56 mGy
- Dose Rate: $2.8.10^{-9}$ -0.19 Gy/h
- Flux range: 0.01 – 1250 cm^2s
- Temperature: -20°C - +40°C
- Li-Ion battery: 3.6 or 7.2 V
- Flash memory: 2 MB
- Active time: >5 days

Maximal amplitude of AMPTEK pulse (V)	Deposited energy Range (MeV)	LET Si(0.3 mm) range (keV/μ)	LET H_2O range (keV/μ)	Q H_2O range ICRP
5	0.081-20.8	0.116-29.8	0.144-36.9	1-9.6
10	0.163-41.6	0.233-59.6	0.289-73.9	1-21.4
15	0.244-62.5	0.349-89.4	0.433-89.4	1-29.99-28.49
7.5	0.122-31.2	0.175-44.7	0.217-55.4	1-15.54
7.5-15	31.37-62.5	44.88-89.4	55.65-110.8	15.61-29.99-28.49

Preliminary algorithm for the Intelligent dosimeter internal software



Conclusions

- The mass and volume characteristics of the developed Liulin personal devices are smaller than the same of the proposed EuCPAD device;
- The existing Liulin radiation sources separation procedures are sufficient to be used in the software of proposed a new "Intelligent Crew Personal Dosimeter" ;
- Same for the dose interpretation procedures;
- The analysis of the advantages and disadvantages of the 1 and 2 detectors (telescope) design of the new dosimeter show that the 1 detector system will be better for the battery operated new dosimeter;
- Preliminary proposal of the block-schema of the new "Intelligent Crew Personal Dosimeter", which can be used by astronauts in internal and external vehicle activities is presented;
- The algorithm of the software, which will be able to distinguish the different kind of radiation sources in space and to calculate, store and present on display the absorbed and equivalent doses is presented.

Thank you

Liulin ranges

Deposited energy range (Si): 0.0394-20.83 MeV

"LET(Si)" range: 0.582-29.8 keV/μ

$LET(H_2O)$ range: 0.722-36.96 keV/μ

$LET(H_2O)$ range (PHITS): 0.722-42.1 keV/μ

$LET(H_2O)= 1.24 x LET(Si)$

Q =1 for LET < 10 keV/μm

Q =0.32LET-2.2 for 10 keV/μm < LET < 100 keV/μm

Q =300$LET^{-0.5}$ for LET > 100 keV/μm

$LET(Si)_i = \Delta E_i .\cos\alpha /(\rho.D) \sim \Delta E_i /(\rho.D)$; $\rho=2.33\ g/cm^3$; D=0.3 mm

400 MeV protons ~ 64% of speed of light or 2 cm for 0.1 ns