Space radiation dosimetry by PADLES in the Phase 1 and Phase 2A experiments of the MATROSHKA project

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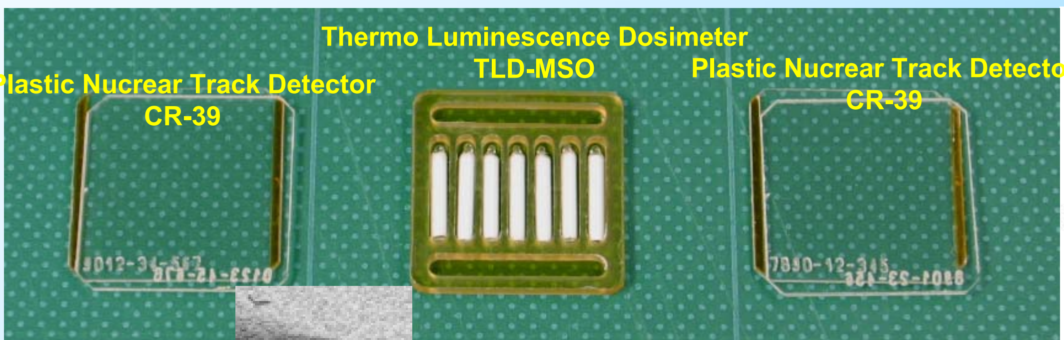
Plan of Presentation

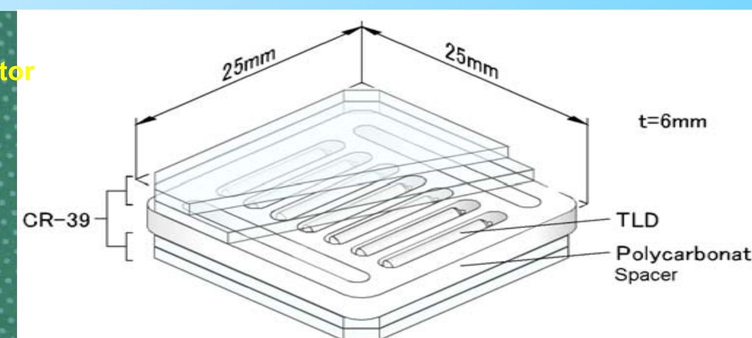
1. Introduction ~ The PADLES system ~
2. Correction for dip angle dependence to improve accuracy in LET distribution measurements
3. Reevaluated results on MATROSHKA Phase 1 using the new correction method
4. Results on MATROSHKA Phase 2

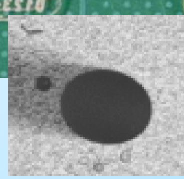
PADLES Passive Dosimeter for Life science Experiments in Space package

The PADLES package consists of two types of passive and integrating dosimeters, a CR-39 Plastic Nuclear Track Detector (PNTD) and a ThermoLuminescence Dosimeter (TLD) .

- Data reading can be done only on the ground.
- Total accumulated doses are obtained. These are not obtained at real-time.



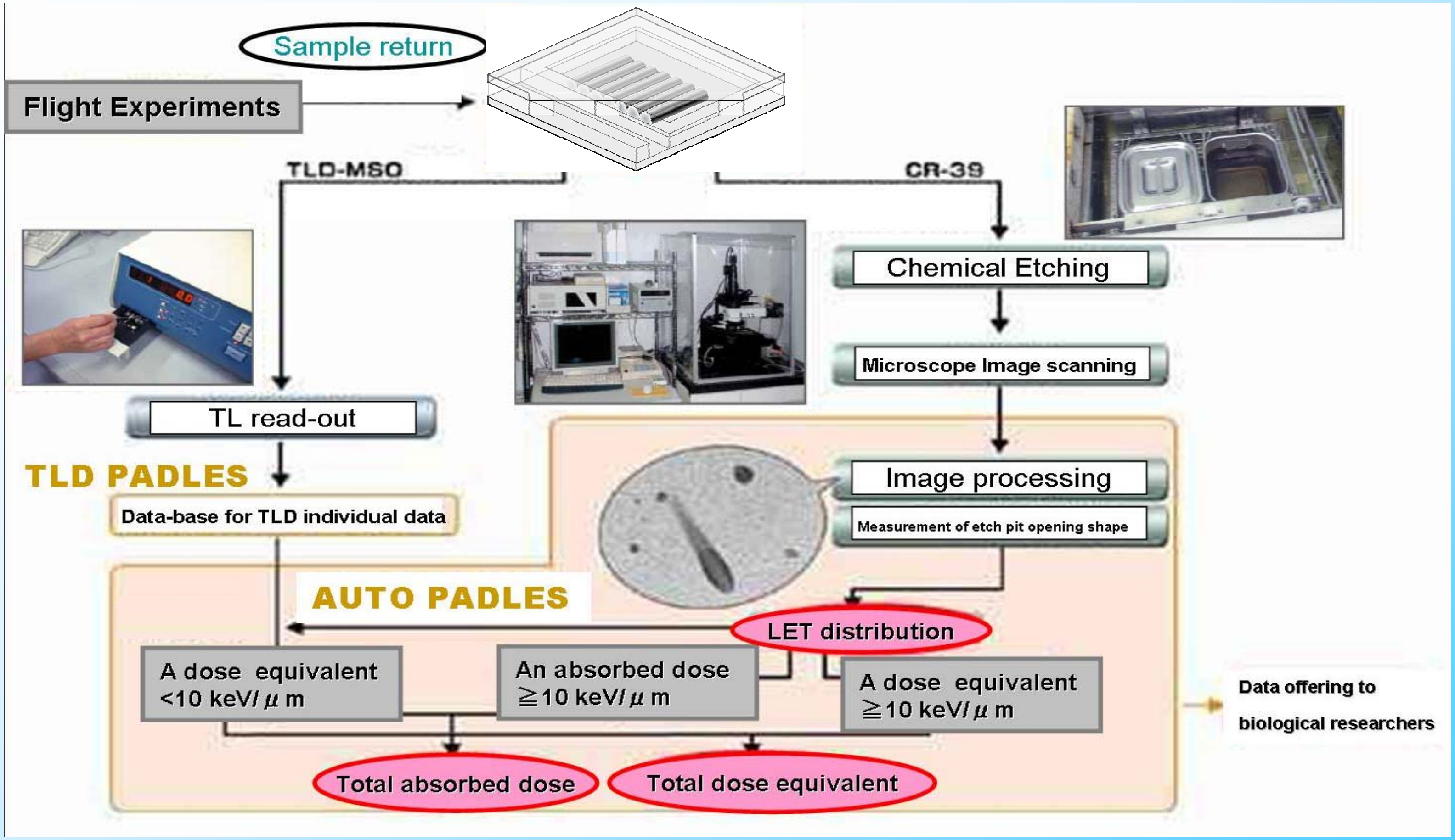




After chemical etching, we can see the track of heavy ions > 4 keV/μm.

- The PADLES is a compact passive crew dosimeter without electric power.
- less crew time required (Just wearing)
- maintenance free onboard
- easy to attach to astronaut's clothing and ExtraVehicular Activity (EVA) suits.

1. Introduction ~ PADLES System ~



□The PADLES system was developed for routine analysis of many PADLES packages recovered from ISS every increment.

□ High-speed and semi-automatic analysis of CR-39 by the AUTO PADLES

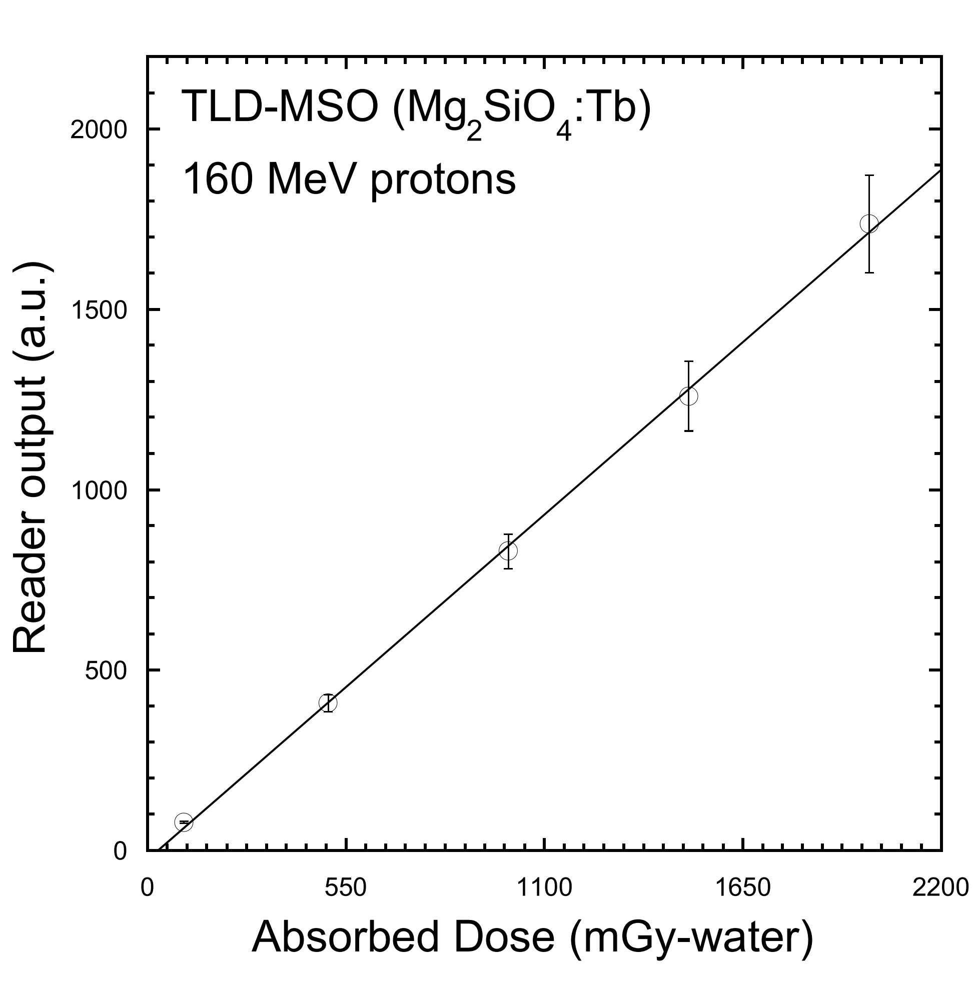
1. Introduction ~ Measurement of absorbed doses by TLD ~

$$D_{\mathrm{TLD}} = f_{\mathrm{F}} M K_{\mathrm{proton}}$$

K_{proton} Dose calibration constant
equivalent to 160 MeV/n protons

M Reader output

f_F Fading correction factor for the loading
temperature and period



Space radiation is dominated by proton above 90%. Thus, we determined the calibration constant by exposure to 160 MeV protons up to 2 Gy.

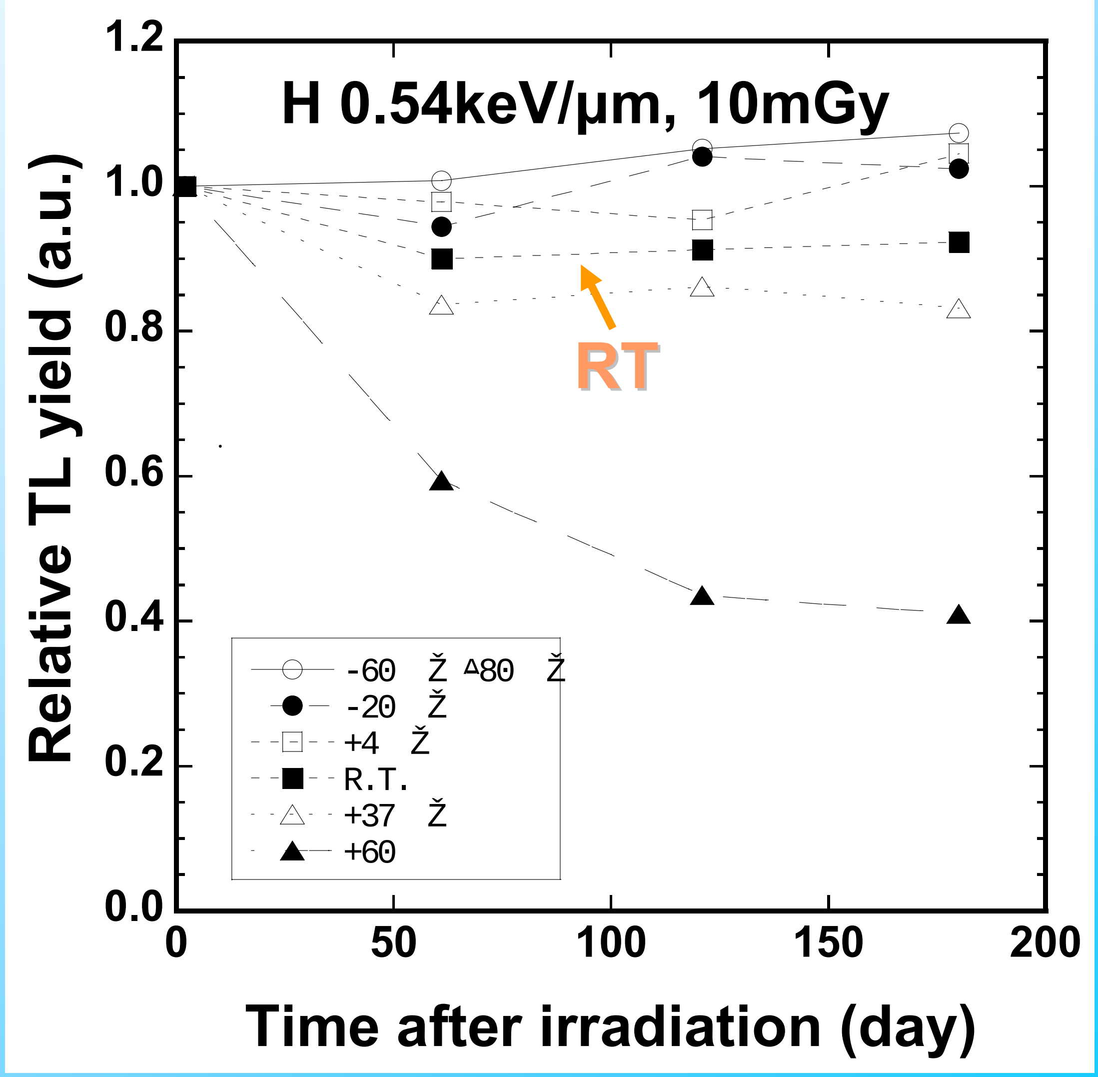
1. Introduction ~ TLD fading correction depending on the loading temperature and period~

$$D_{\mathrm{TLD}} = f_{\mathrm{F}}\, f_{\mathrm{O}}\, M K_{\mathrm{proton}}$$

Equation for fitting the fading data

$$TL(t) = \mathrm{a} + \mathrm{b} \times t + \mathrm{c} \times \log(t)$$

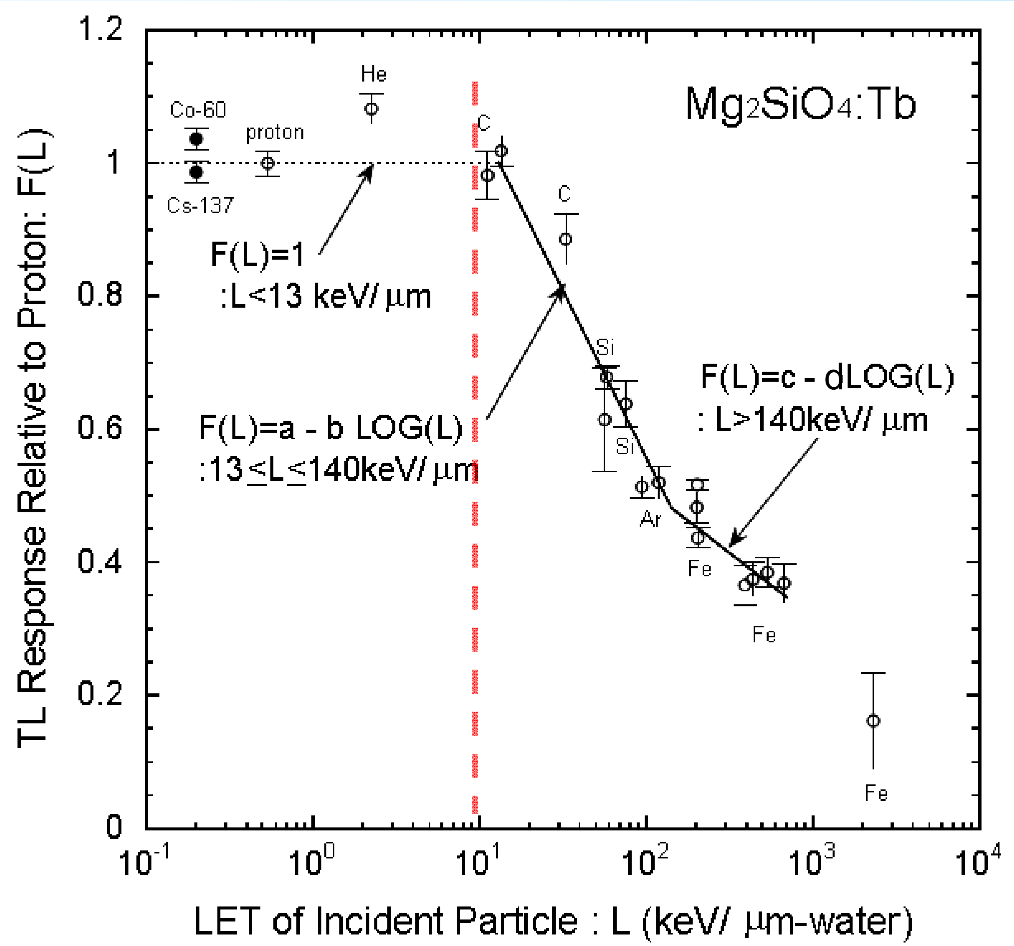
$$f_{\mathrm{F}}(T, t_{\mathrm{st}}, t_{\mathrm{ex}}) = \frac{1}{TL(T, t_{\mathrm{st}}, t_{\mathrm{ex}})}$$



1. Introduction ~ TL response as a function of LET ~

KEK Radioisotope Lab :　60Co-γ
IRM □ 60Co-γ□137Cs-γ
NIRS□HIMAC:
Proton□160 MeV
C□290 MeV/n
Si□490 MeV/n
Ar□500 MeV/n
Fe□500 MeV/n
with PMMA, AL and Cu as energy degradator to change LET.

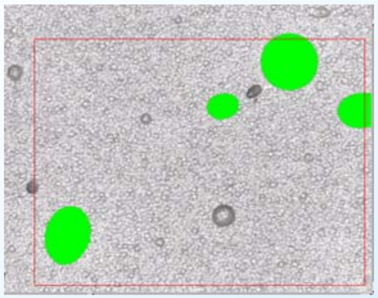
$$\kappa = \frac{\sum_{>10\mathrm{keV}/\mu\mathrm{m}} \left(f(LET)\, \Delta D(LET) \right)}{D_{\mathrm{CR-39}}}$$



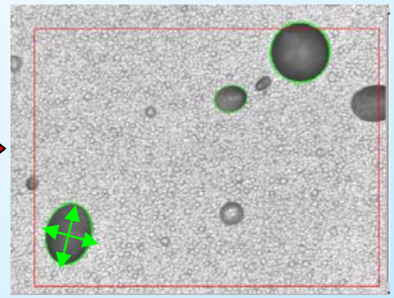
κ□mean TL effciency in the LET reagion above 10keV/μm)

1. Introduction ~ Calibration curve for CR-39 PNTDs ~

LET obtained from the measurement of the major and minor axes of heavy ions tracks. We have developed the soft ware 'AUTO PADLES' for measuring several thousand tracks.
(Elips fitting program, N. Yasuda et.al. (2005))



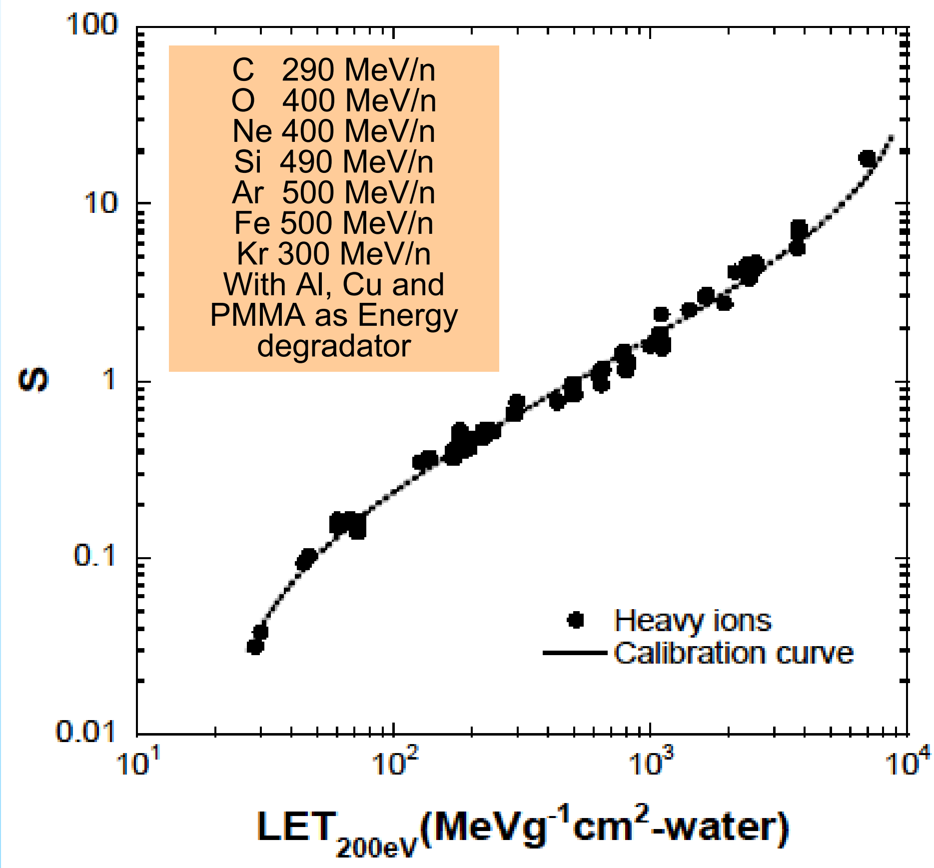
Binary images



Oval fitting

$$S \equiv V_T / V_B - 1 = \sqrt{\frac{16 D^2 B^2}{(4B^2 - d^2)^2} + 1} - 1$$

- S : Track formation Sensitivity
- V_T : Track etch rate
- V_B : Bulk etch rate
- D :Major axis
- d :Minor axis
- B : Bulk etch



Calibration curve for high-energy heavy ions of TD-1. The curve can be applied to both the 5.5 h (SRP) and 13.5 h (LRP) etched samples.

Research project with heavy Ions at NIRS-HIMAC

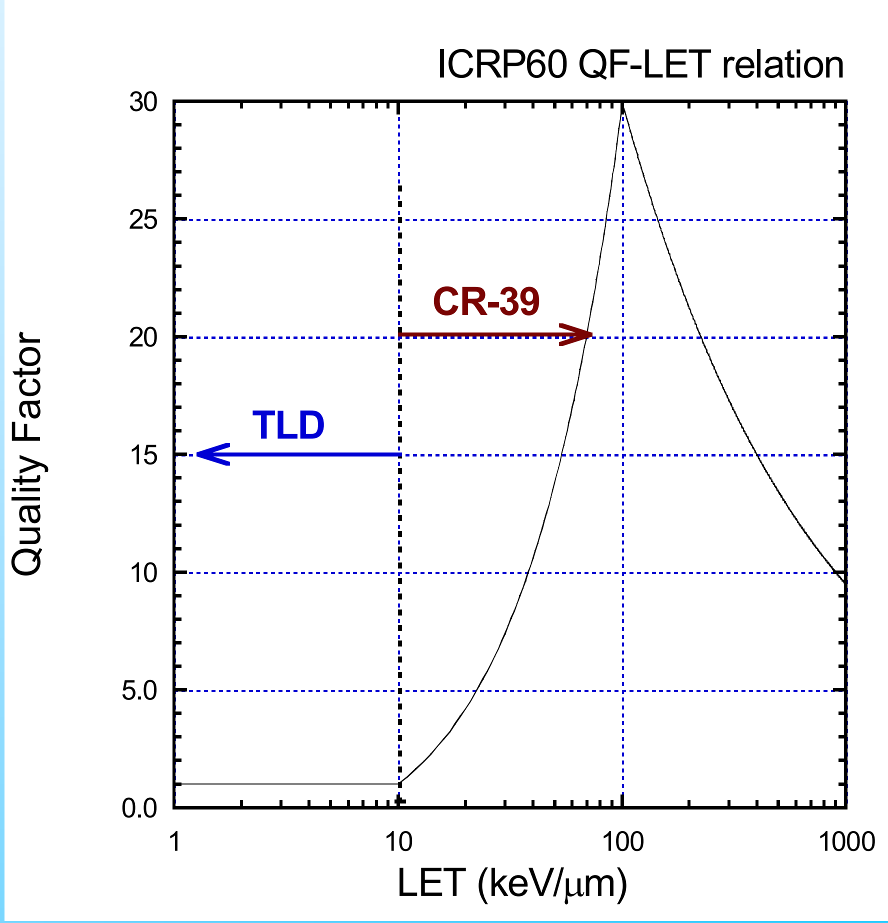
1. Introduction ~ Dosimetric quantities ~

■ Total absorbed dose : D_{TOTAL} (Gy-water□

$$
\begin{aligned}
D_{TOTAL} &= D_{\leq 10\,keV/\mu m-water} + D_{>10\,keV/\mu m-water} \\
&= (D_{TLD} - \kappa D_{CR-39}) + D_{CR-39} \\
&= D_{TLD} + (1-\kappa) D_{CR-39}
\end{aligned}
$$

■ Total dose equivalent : H $_{TOTAL}$ (Sv□

$$
\begin{aligned}
H_{TOTAL} &= D_{\leq 10keV/\mu m-water} + H_{>10keV/\mu m-water} \\
&= (D_{TLD} - \kappa D_{CR-39}) + H_{CR-39}
\end{aligned}
$$



κ□mean TL efficiency for high-LET particles

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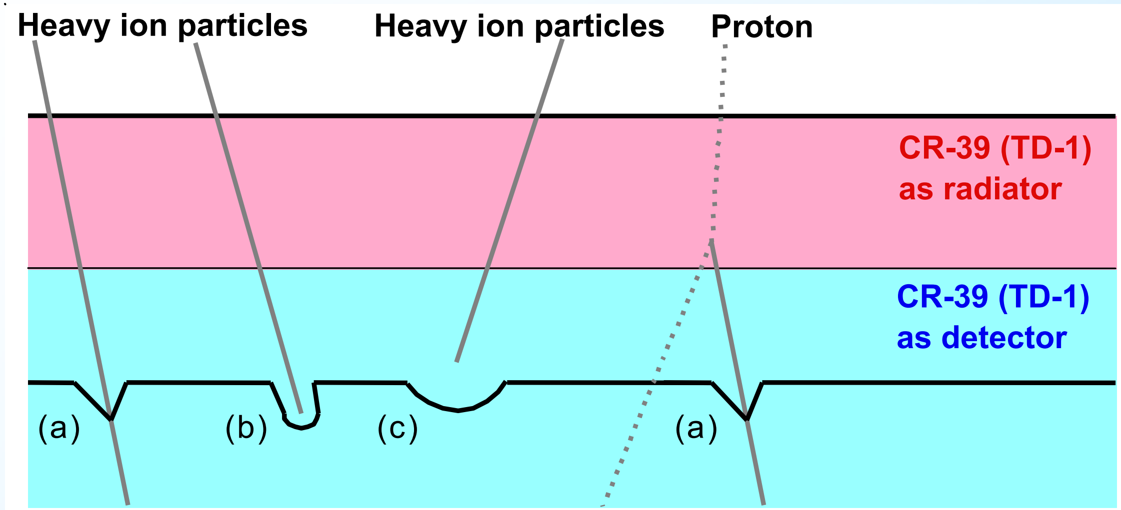
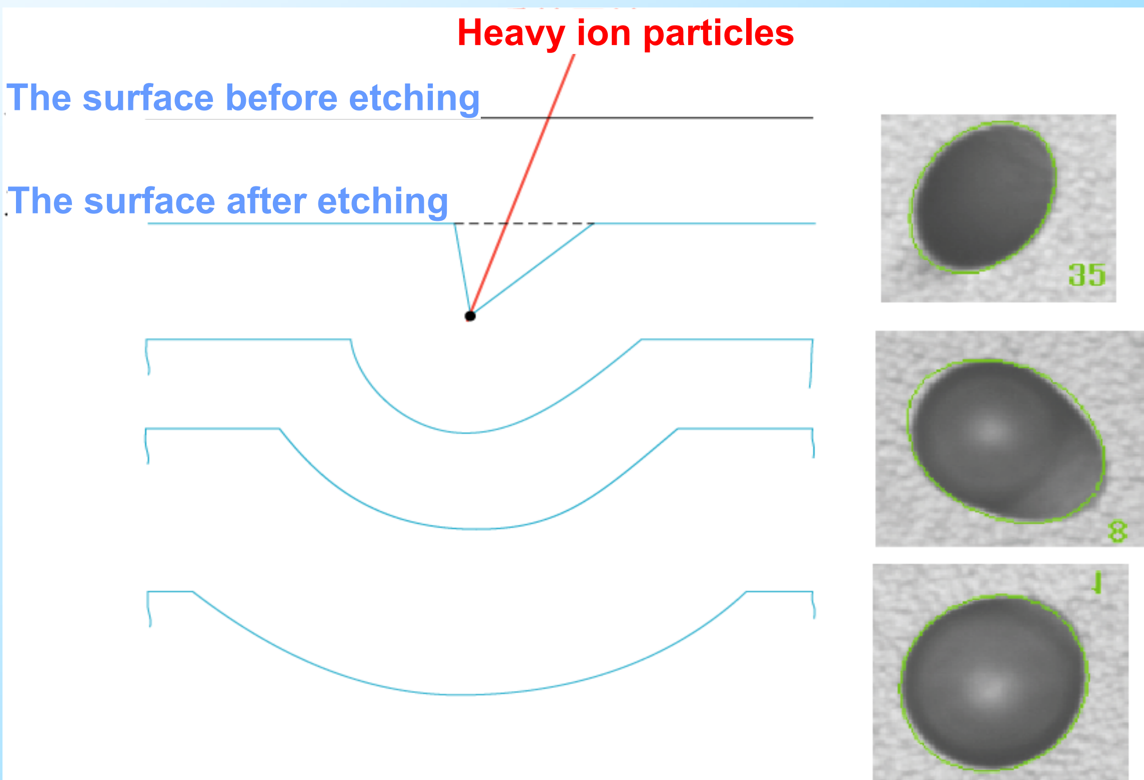
2. Measurements of LET distributions



We detect the particles passing through the surface after chemical etching.

The surface for fluence measurements



○ (a) selected

× (c) rejected

× (c) rejected

2. CR-39 correction for Dip angle dependence

Particle fluence *F* is calculated from a count factor N_{eff} and track density N_T . We must correct the Count Factor, because our CR-39 plastic has the dip angle dependences in track formation sensitivity.

F(paticles/cm2□ □

$$F = N_{\mathrm{eff}} N_{\mathrm{T}}$$

1. Without correction

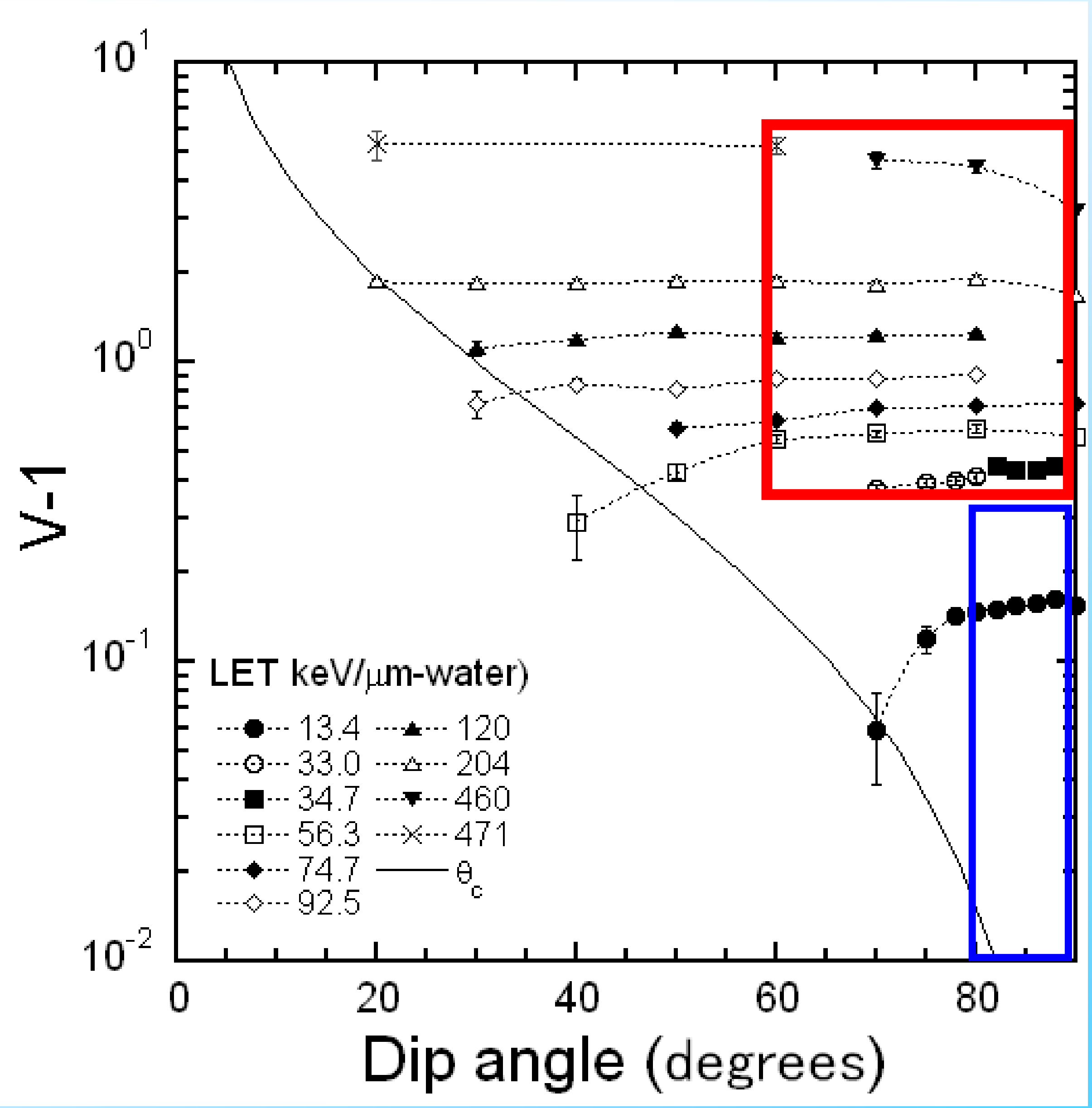
(In case that the detectable minimum dip angle is the theoretical one).

$$N_{\mathrm{eff}} = 1 - \sin^2 \theta_{th} = \frac{V^2}{V^2 - 1}$$

2□Correction method by Doke et al.1997 using η.

$$N_{\mathrm{eff}} = \square Ĺ \square @ \frac{V^2}{V^2 - 1}$$

2. New dip angle correction of CR-39 based on Ground performance test



Short range Particle (SRP) etching sample

5.5h etching for LET≥50keV/μm

θ_{min} = 60°

∴ N_{eff} = 33.1

Long range Particle (LRP) etching sample

13.5h etching for LET<50keV/mm

θ_{min} = 80°

∴ N_{eff}=4.0

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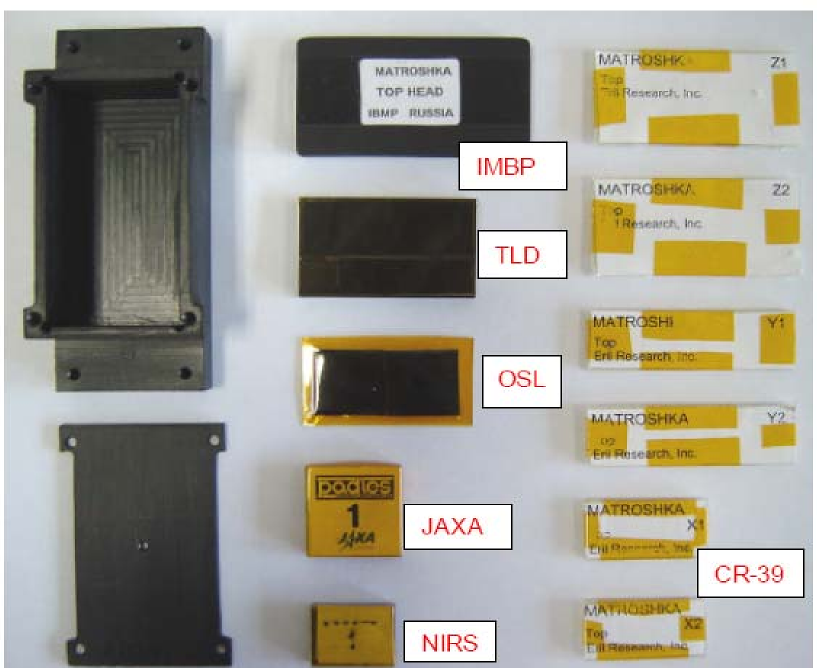
The MATROSHKA experiments : Phase 1

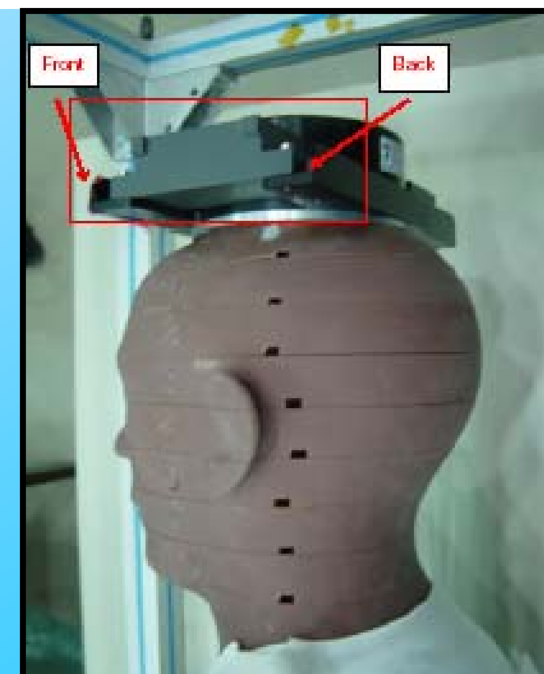
- Location of three PADLESs
  - □ Outside □ Down link temperarure, -24.6□23.8□ : the mean value -5.6□□
    : Head box on Matroshka phantom, mainly exposed area
  - □ Inside □RT□□on the wall inside ZVEZDA
  - □ Ground control □RT□□DLR
- Loaded period

From launch to return 1/29/2004 – 10/11/2005 □621 days□

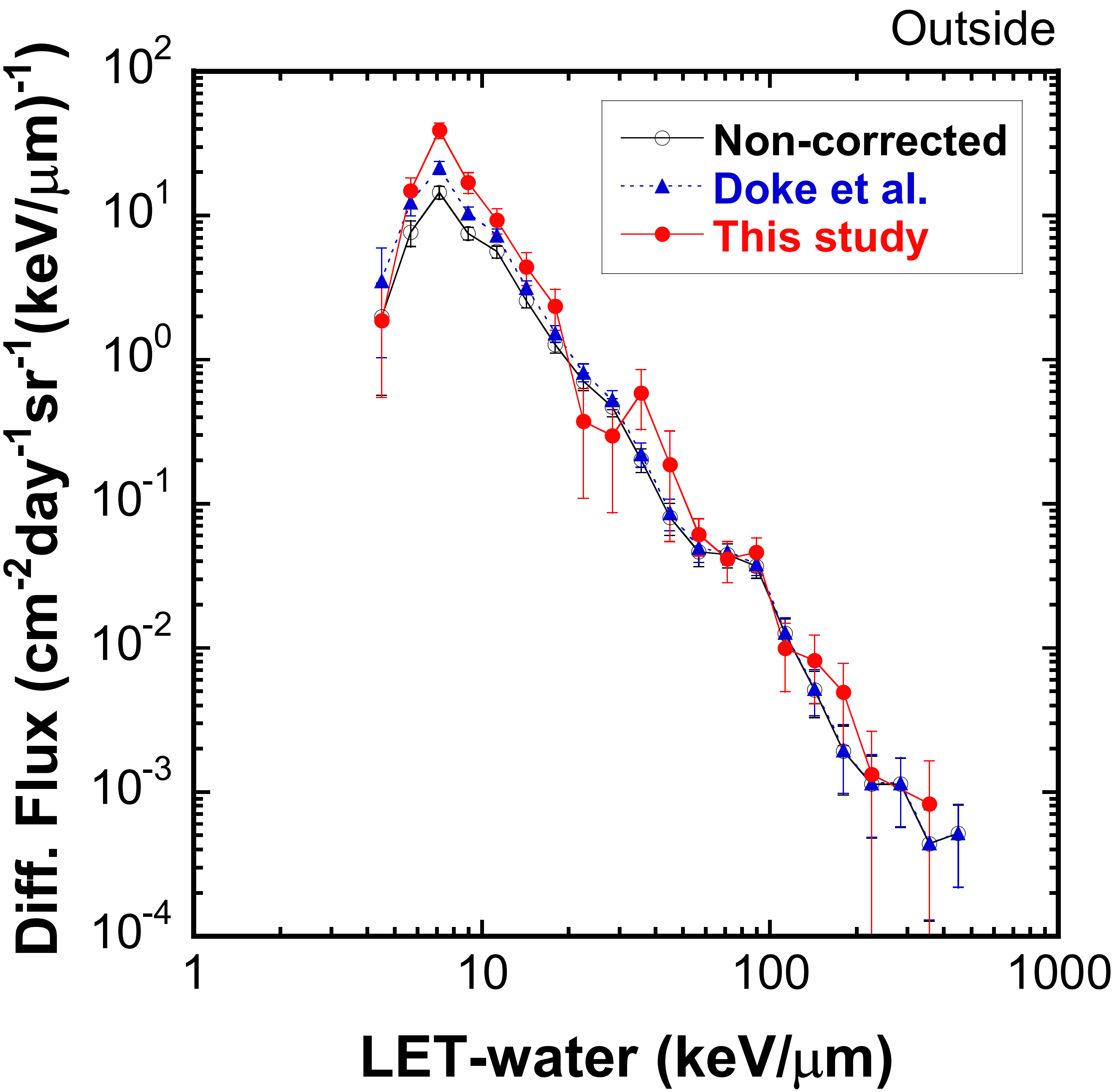
→ Exposed area 2/27/2004 –8/18/2005 <u>□538 days□</u>

→ Inside ZVEZDA 1/29/2004 – 2/26/2004, 8/19/2005 – 10/11/2005 <u>□83 days</u>

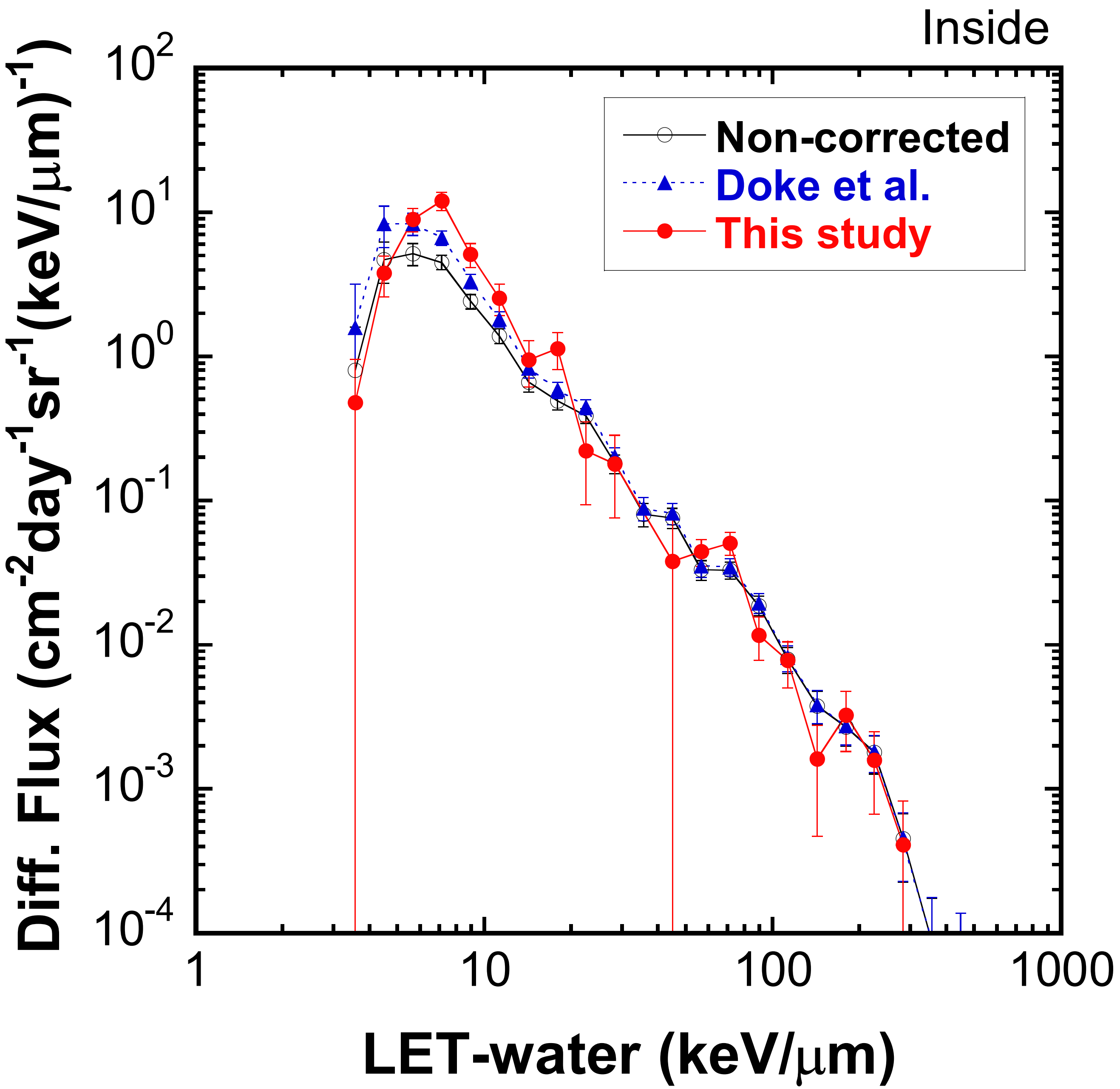




The MATROSHKA Results: Phase1 Outside

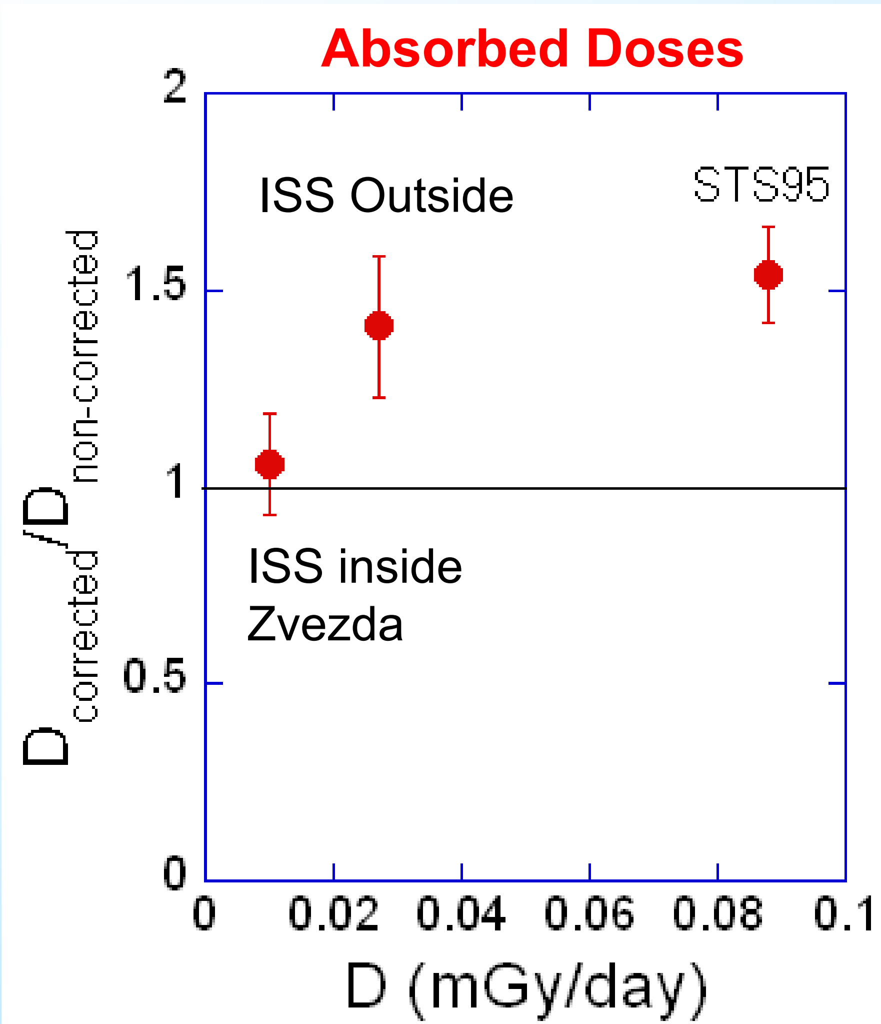


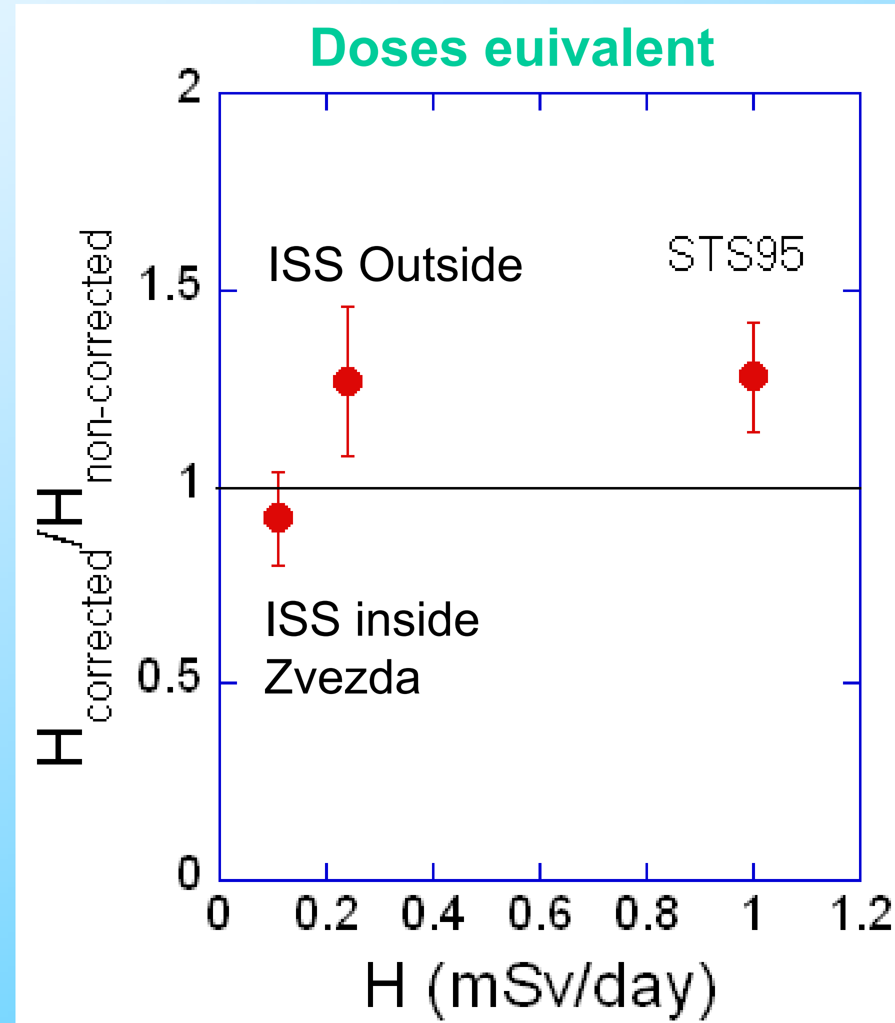
The MATROSHKA Results: Phase1 Inside Zvezda



The MATROSHKA Results: Phase1
Comparative results between with or without corrected

CR-39 LET distribution □10keV/μm





STS-95 : High altitude □□574 km□ and Low inclination mission□28.45°□, thus protons in the Earth's trapped radiation belt had great contributes to exposed doses.

Effect of correction for dip angle dependence

		Does value			Efficiency of correction
Matroshka Outside	Absorbed dose rate [mGy/day]	0.60	±	0.05	0%
	Equivalent dose rate [mSv/day]	0.81	±	0.06	6%
	Mean QF (ICRP60)	1.36	±	0.15	6%
STS-95	Absorbed dose rate [mGy/day]	1.76	±	0.09	0%
	Equivalent dose rate [mSv/day]	2.66	±	0.13	8%
	Mean QF (ICRP60)	1.52	±	0.11	7%

By dip angle correction,

1. Total absorbed doses didn’t change practically,
2. Total dose euivalent doses and mean QF showed an increase of 6~8% .

Effect of correction for dip angle dependence

When protons had great contribution to exposed Doses, it is necessary to do ‘dip angle correction’ for LET distribution measurements above10keV/μm.

In case of CR-39 measurements □10keV/μm

When efficiency is large,

- STS-95□ High altitude and Low inclination

→ The contribution of Flux from trapped proton is bigger than cosmic ray.

- Matroshka outside: Shielding is very thin.

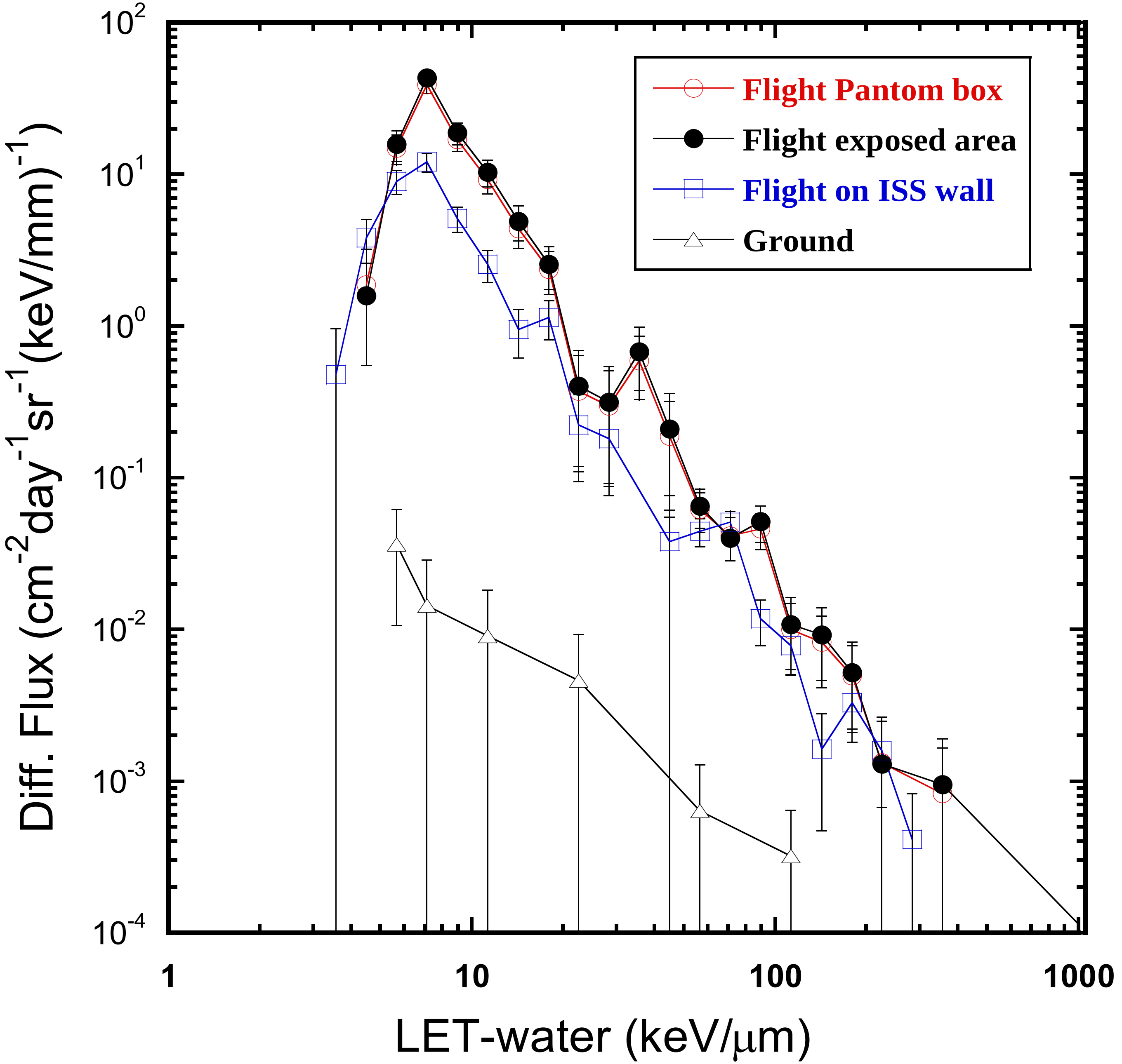
→ Low energy protons mainly contributes to exposed dose in a high LET reagion.

When efficiency is no low,

- Shielding inside ISS is thick

→ The contribution of fluence from cosmic rays is siginificant.

The MATROSHKA Results: Phase 1 LET distributions



The MATROSHKA Results: Phase1 Results

Location	Flight inside phantom ** for 621 days			Flight on exposed area *** for 538 days			Flight on ISS wall ** for 621 days			Ground for 878 days		
Total Absorbed Dose [mGy in water]	370.06	±	30.88	359.65	±	30.88	97.87	±	13.16	1.33	±	0.05
Total Dose Equivalent [mSy]*	503.10	±	36.87	472.61	±	36.14	157.79	±	15.18	1.94	±	0.49
Absorbed Dose (£10keV/mm) [mGy]	353.45	±	31.00	344.43	±	30.99	91.95	±	13.19	1.29	±	0.06
Absorbed Dose (>10keV/mm) [mGy]	16.61	±	1.92	15.21	±	1.84	5.92	±	0.64	0.04	±	0.02
Dose equivalent (>10keV/mm) [mSv]*	149.65	±	20.08	128.17	±	18.71	65.83	±	7.56	0.65	±	0.49
Absorbed Dose Rate [mGy/day]	0.60	±	0.05	0.67	±	0.06	0.16	±	0.02	0.0015	±	0.0001
Dose Equivalent Rate [mSv/day]*	0.81	±	0.06	0.88	±	0.07	0.25	±	0.02	0.0022	±	0.0006
Mean QF (ICRP60)	1.36	±	0.15	1.31	±	0.15	1.61	±	0.27			

* ICRP60
** With subtraction of the dose from the reference package on Ground control

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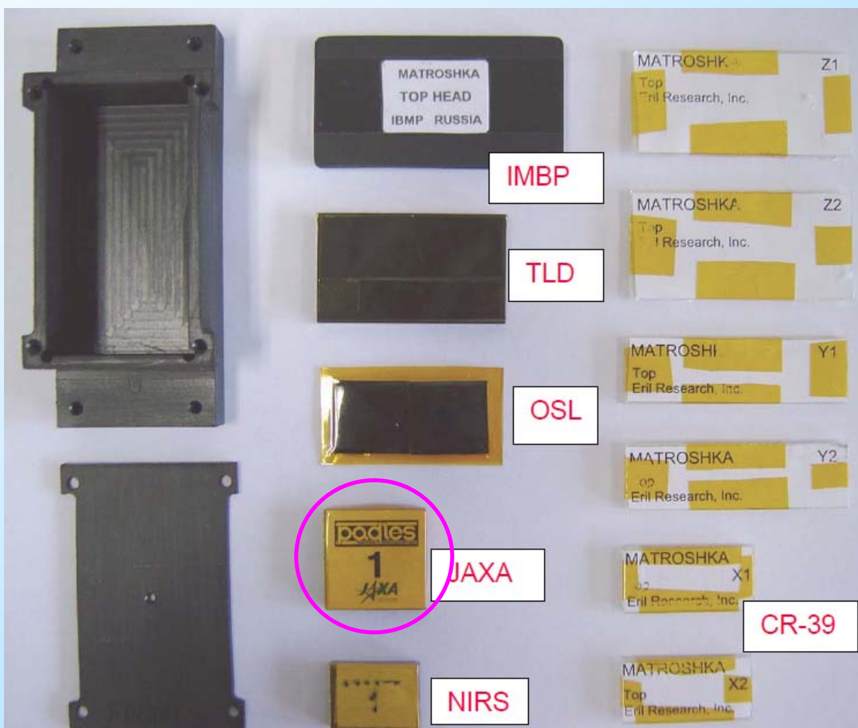
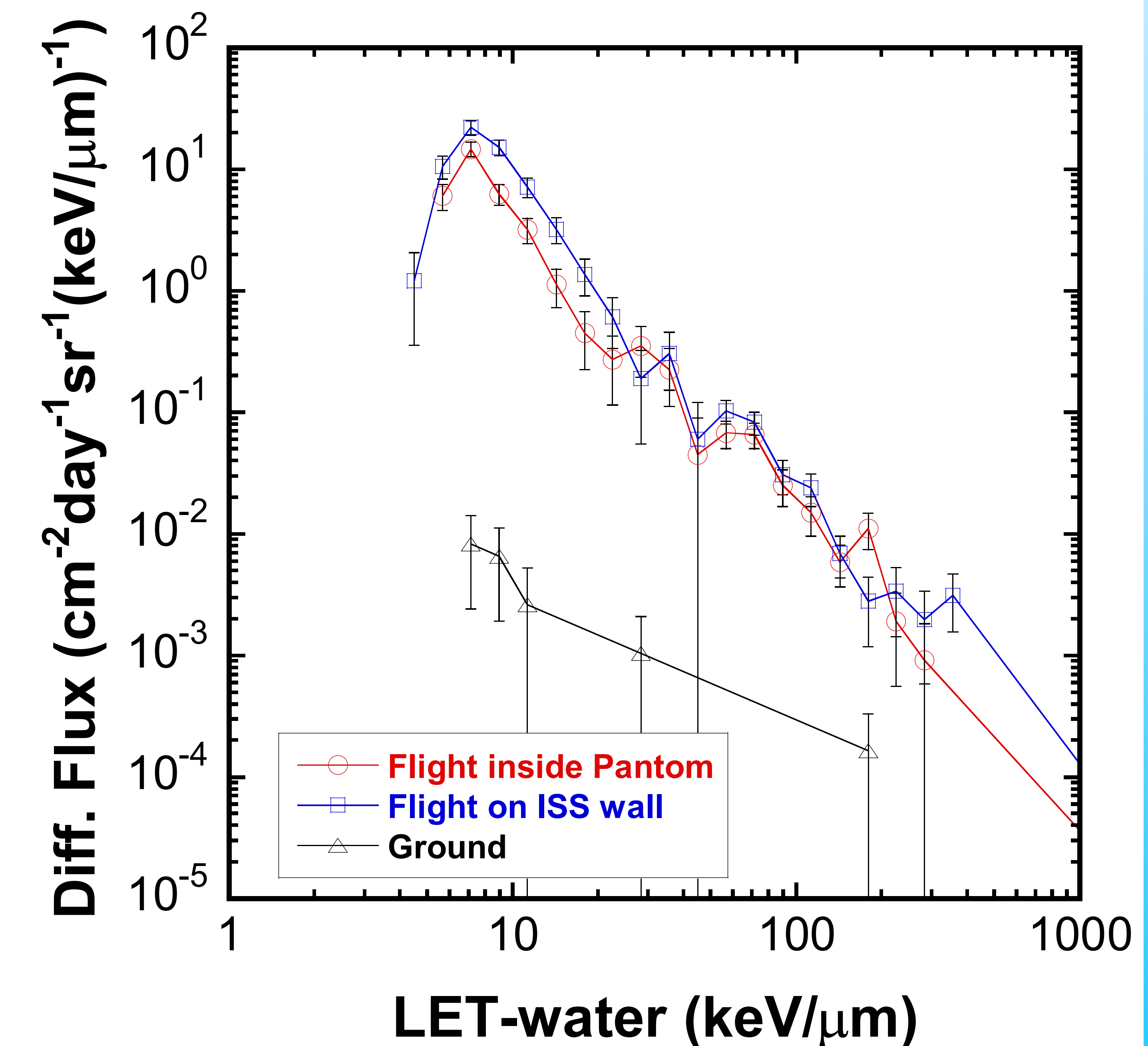
The MATROSHKA experiments : Phase 2

- Location of three PADLESs
  - □ Inside Phantom Head box □RT□
  - □ Inside □RT□□on the wall inside ZVEZDA
  - □ Ground control □RT□□DLR
- Loaded period

  From launch to return 12/22/2005 – 12/23/2006 □366 days□



The MATROSHKA Results: Phase 2 LET distributions



The MATROSHKA Results: Phase2 Results

Location	Flight inside phantom ** for 366 days			Flight on ISS wall ** for 366 days			Ground for 784days		
Total Absorbed Dose [mGy in water]	104.32	±	11.25	113.67	±	6.67	1.78	±	0.13
Total Dose Equivalent [mSy]*	171.98	±	14.18	204.83	±	13.03	12.47	±	1.46
Absorbed Dose (£10keV/mm) [mGy]	98.97	±	11.27	104.82	±	6.76	1.32	±	0.14
Absorbed Dose (>10keV/mm) [mGy]	5.34	±	0.58	8.85	±	0.85	0.46	±	0.06
Dose equivalent (>10keV/mm) [mSv]*	73.01	±	8.62	100.02	±	11.18	11.15	±	1.45
Absorbed Dose Rate [mGy/day]	0.29	±	0.03	0.31	±	0.02	0.002	±	0.0002
Dose Equivalent Rate [mSv/day]*	0.47	±	0.04	0.56	±	0.04	0.016	±	0.0019
Mean QF (ICRP60)	1.65		0.22	1.80	±	0.16			

* ICRP60
** With subtraction of the dose from the reference package on Ground control

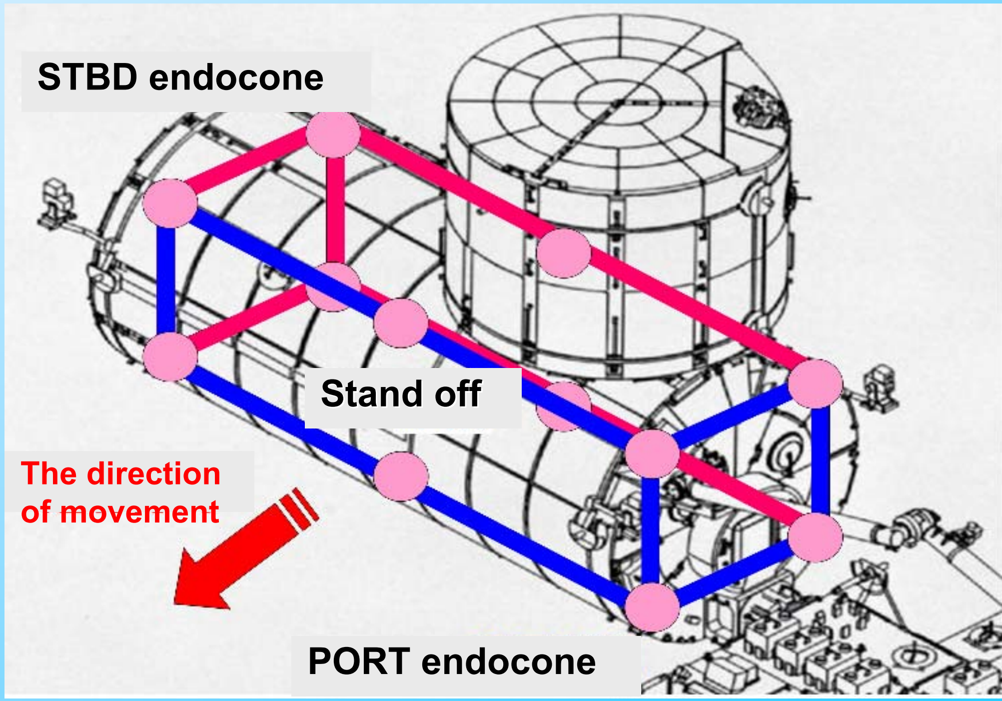
Supplement

PADLES Activity on board KIBO

Area Monitoring – Area PADLES from 1J□Inc17) –

- □ The Area monitoring aims to perform a survey of the radiation environment at 12 fixed locations inside JEM by Area PADLES.
- □ Area PADLESs is to swap out every 6 Increments throughout JEM program.

Area Dosimeter consists of cashing holder (46 x 46 x 9mm) containing dosimeter package, tether with clip and Velcro.

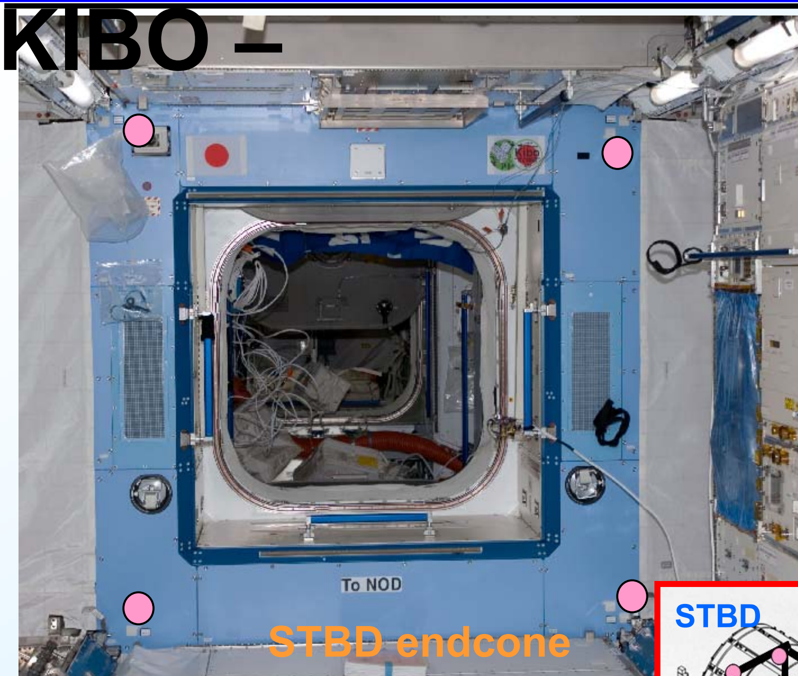


Location of Area PADLES on JEM

Area Monitoring – Area PADLES -

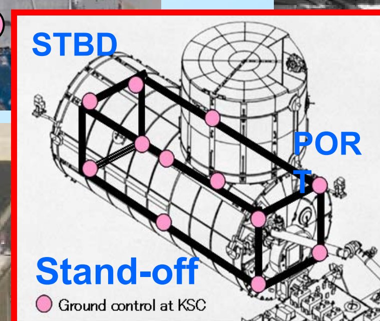
2008.06.12 Mr. Gregory E. Chamitoff astronaut onboard KIBO

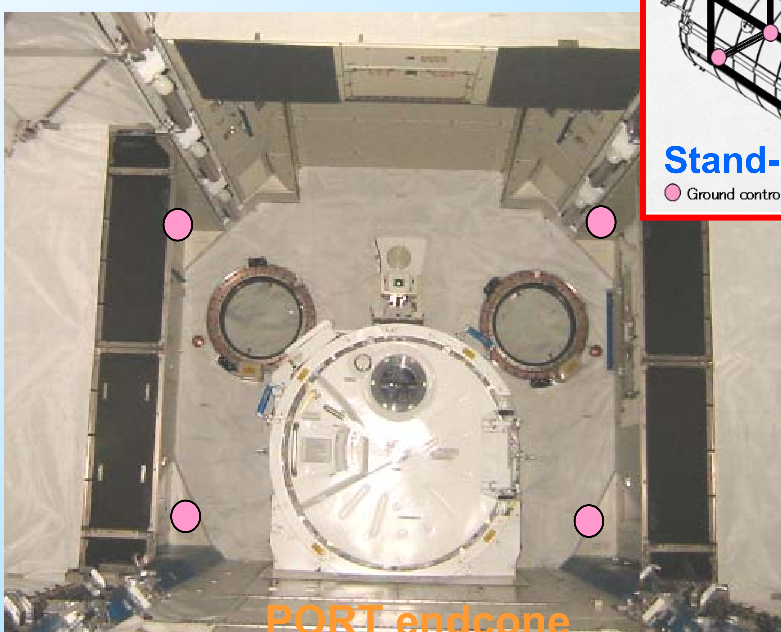
□-2 Operations – Locations in KIBO –



Stand-off DECK

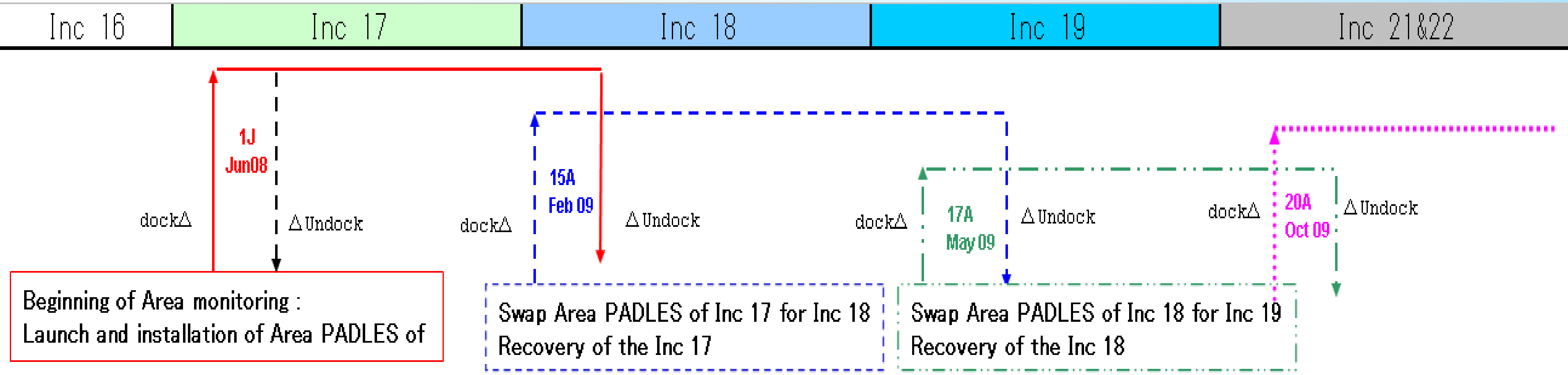
Stand-off OVHD





Stand-offs

Flight Schedules & Expectation



The results of Area PADLES are expected to:

- Support the planning of the life science experiments
- Contribute to risk assessments on space flights
- Update of the space radiation models.

Area PADLES results obtained by all Area dosimeters will be opened to JAXA Web site, PADLES database.

http://iss.sfo.jaxa.jp/kibo/kibomefc/srpds/srpds8.html

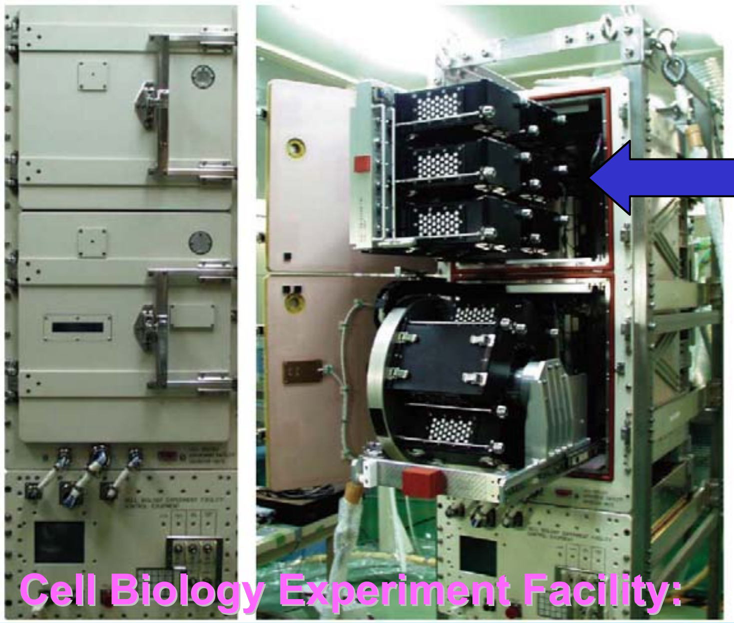
.... now under constructing.

- It’s a free access site in Japanese/English
- We also have expectation to use the control exposed dose of Japanese astronaut in future.

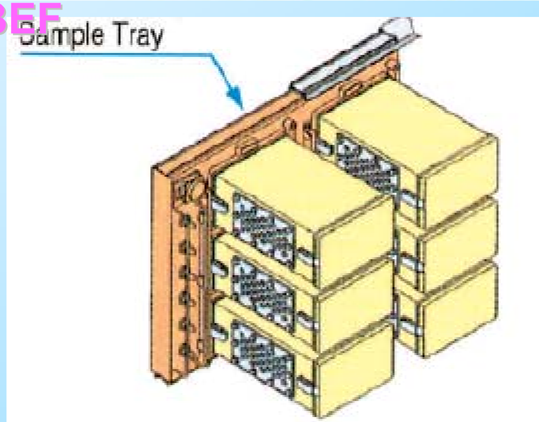
Radiation dosimetry of Biological samples – Bio PADLES -

□Radiation dosimetry of biological samples aims to investigate the correlation between the biological effects and dosimetric quantities in a space radiation environment by Bio PADLES.

□Bio PADLESs will be installed extremely close to biological samples of



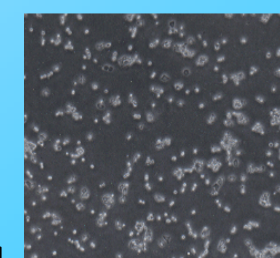
Cell Biology Experiment Facility: CBEF



Cell Experiment Unit□ CEU

Plant Experiment Unit: PEU□

Measurement Unit: MEU



2-2 Radiation dosimetry of Biological samples – User of Bio PADLES

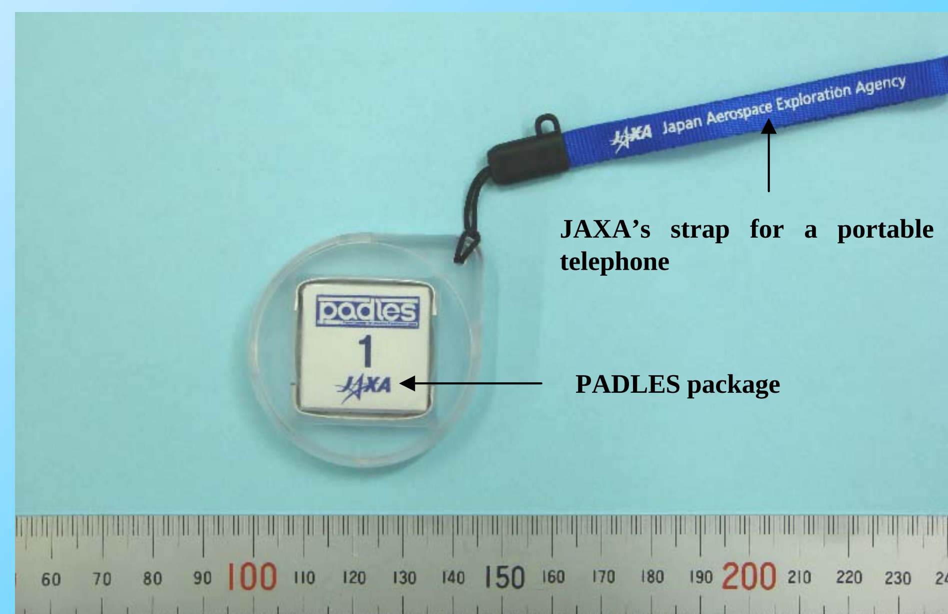
Bio PADLES used for biological research experiments proposed in the international announcements of opportunities and the first JEM utilization solicitation.

Project	Experiment Title	Investigator / Affiliation	Hardware (Agency)
Dome gene	Control of cell differentiation and morphogenesis of amphibian culture cells	Asashima, M. / Tokyo Univ.	CBEF
Myo Lab	Cbl-Mediated Protein Ubiquitination Downregulates the Response of Skeletal Muscle Cells to Growth Factors in Space	Nikawa, T. / Tokushima Univ.	CBEF
CERISE	RNA interference and protein phosphorylation in space environment using the nematode Caenorhabditis elegans	Higashitani, A. / Tohoku Univ.	CBEF
Neuro Rad	Biological effects of space radiation and microgravity on mammalian cells	Majima, H. / Kagoshima Univ.	CBEF
Rad Gene	Gene expression of p53-regulated Genes in Mammalian Cultured Cells after Exposure to Space Environment	Ohnishi, T. / Nara Medical Univ.	CBEF
Rad Silk	Integrated assessment of long-term cosmic radiation through biological responses of the silkworm, Bombyx mori, in space	Furusawa, T. / Kyoto Institute of Technology	CBEF
LOH	Detection of Changes in LOH Profile of TK mutants of Human Cultured Cells	Yatagai, F. / RIKEN	CBEF
Space Seed	Life Cycle of Higher Plants under Microgravity Conditions	Kamisaka, S. / Toyama Univ.	CBEF
Ferulate	Regulation by Gravity of Ferulate Formation in Cell Walls of Wheat Seedlings	Wakabayashi, K. / Osaka Ctiy Univ.	CBEF
Hydro Tropi	Hydrotropism and auxin-inducible gene expression in roots grown in microgravity conditions	Takahashi, H. / Tohoku Univ.	CBEF

Personal Dosimetry – Crew PADLES –

- The personal dosimetery aims at dose records of the each astronaut for the increments.
- Crew PADLESs will be provided for continuous use during their missions throughout EVA and IVA.
- Dose records are applied to asses radiation exposure limits defined to individual astronauts in future.

Crew PADLES dosimeter



Light : 14.4 g
Compact : 52.3 X 45.1 X 9 mm

JAXA Crew PADLES Cooperation

We evaluated portability and operability of Crew PADLES using four Shuttle flight opportunities participating Asian astronauts for

15S, STS-123, 16S and STS-124 flight.

2007 Oct, 15S Soyuz for Dr. Muszaphar (ANGKASA)

2008 Feb, STS-123 for Dr. Doi (JAXA)

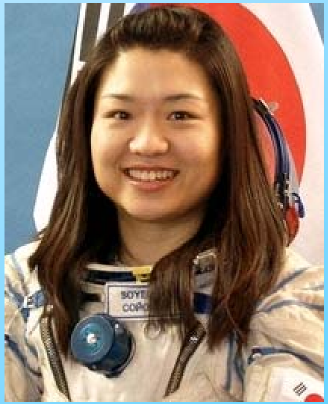
Apr, 16S Soyuz for Mr. Ko (KARI)

Apr, STS-124 for Mr. Hoshide (JAXA)

2009 Feb, 15A for Mr. Wakata (JAXA, Expedition crew)


Dr.Muszaphar


Dr. Doi


Dr. Yi

Mr. Hoshide

Mr. Wakata

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Thanks you for your attention !!

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Passive Dosimeter for Lifescience Experiments in Space