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* Preliminary results of water shielding effect for space radiation in ISS crew cabin by means of passive dosimeters *

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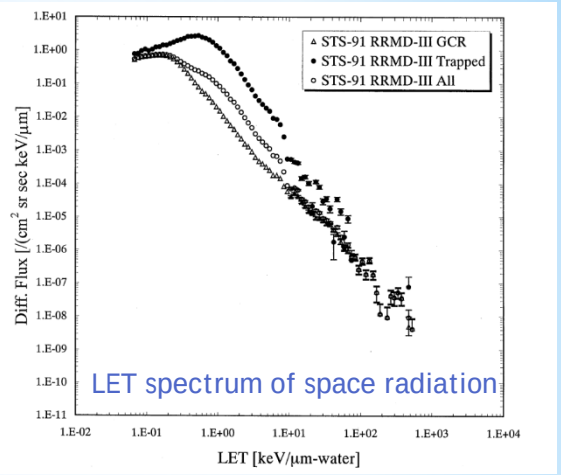
* Radiation protection on ISS *

- ISS crew is constantly exposed to space radiation
  - Daily dose: 0.5 ~ 1 mSv
  - Component: Proton, Heavy ions (~Fe)
  - Source: Galactic cosmic ray
    Solar energetic particle
    Trapped particle



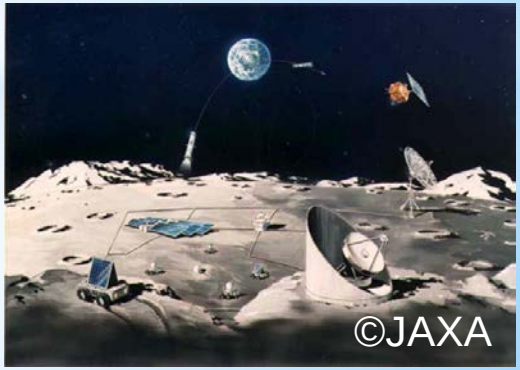
(Doke et al., 2001)

- Effective dose limits (10 yr career) for Astronauts
  - e.g.) 400 mSv (Female), 700 mSv (Male) for 25 yrs old

(NCRP No.142)

- Radiation protection in the ISS
  - Dose reduction by the vehicle wall and instruments (~a few g/cm^2)
  - Current status of radiation protection: “Passive” method

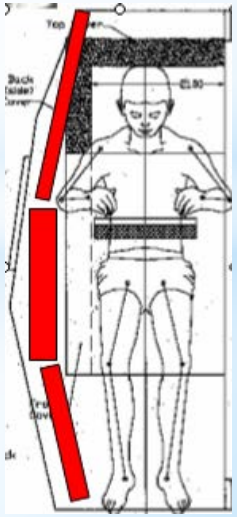
→ A possible “Active” radiation protection should be verified for not only effective dose reduction but also coming long-term missions at Lunar and Mars

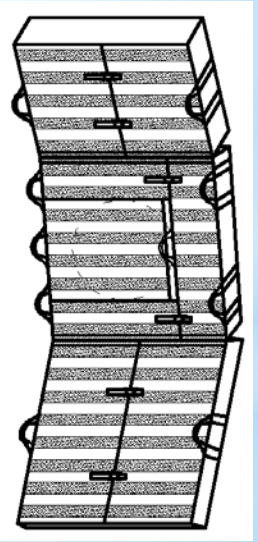


* Protective Curtain Project *

- Verification of dose reduction effect with the additional installation of “water shielding”
  - Wipes and towels containing water
  - Stack board consisting of wipes and towels is installed inside like a curtain
  - Additional shielding thickness: ~ 8 g/cm^2

	Wipe	Towel
Size	7.0 x 7.0 x 1.5 cm	13.5 x 9.0 x 2.0 cm
Mass	95 g	220 g
Density	1.3 g/cm^3	0.9 g/cm^3
Mass density of 1 layer	1.95 g/cm^2	1.80 g/cm^2
Mass density of 4 layers	7.8 g/cm^2	7.2 g/cm^2





Protective curtain design

* Radiation detector *

◆ Passive dosimeter package

- Thermo-luminescence detector (TLD)

Material	Size	Institution
LiF:Mg,Ti	3mmx3mmx0.9mmt	NIRS
LiF:Mg,Ti	5mmϕx1mmt	IBMP
$CaSO_4$:Dy	5mmϕx1mmt	NPI
Al_2O_3:C	5mmϕx1mmt	NPI

- Plastic nuclear track detectors (PNTD)

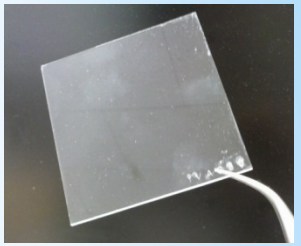
- Material: CR-39 (HARZLAS/TD-1)
- Size: 26mmx26mmx0.9mmt
- Institution: Common utilization

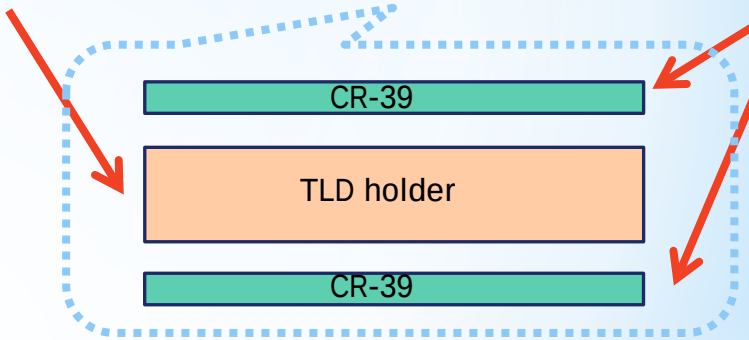
◆ Totally 12 packages were installed

TLD holder

A package

CR-39





* Dose measurement method *

Covering wide dynamic range of LET:

(1) Dose for LET<10keV/μm is obtained by TLD, while dose for LET>10keV/μm from TLD is removed by CR-39 data

(2) Dose for LET≥10keV/μm is obtained by CR-39

Absorbed dose: D_{Total} [Gy]

$$D_{Total} = D_{\le 10keV/\mu m} + D_{>10keV/\mu m}$$
$$= \left(D_{TLD} - \kappa D_{CR-39}\right) + D_{CR-39}$$
$$= D_{TLD} + \left(1-\kappa\right) D_{CR-39}$$

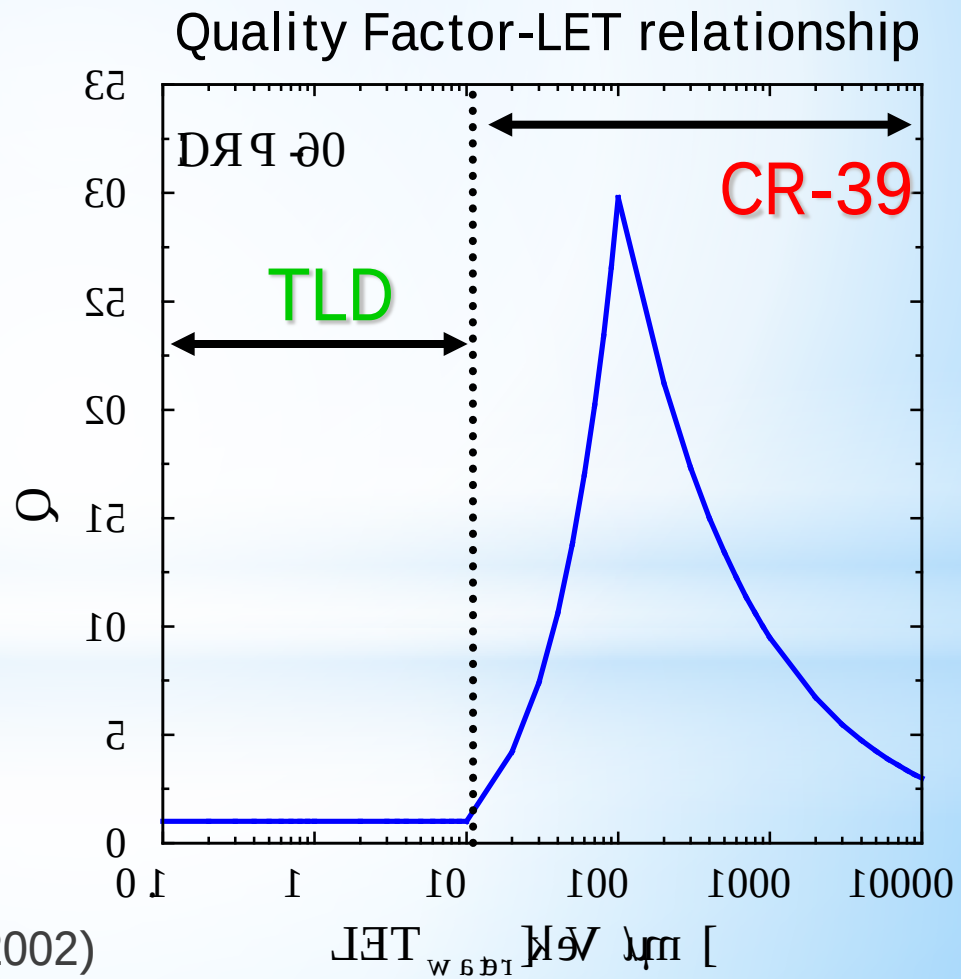
Dose equivalent: H_{Total} [Sv]

$$H_{Total} = D_{\le 10keV/\mu m} + H_{>10keV/\mu m}$$
$$= \left(D_{TLD} - \kappa D_{CR-39}\right) + H_{CR-39}$$

Mean quality factor: Q_{Mean}

$$Q_{Mean} = H_{Total} / D_{Total}$$

k: proportional constant

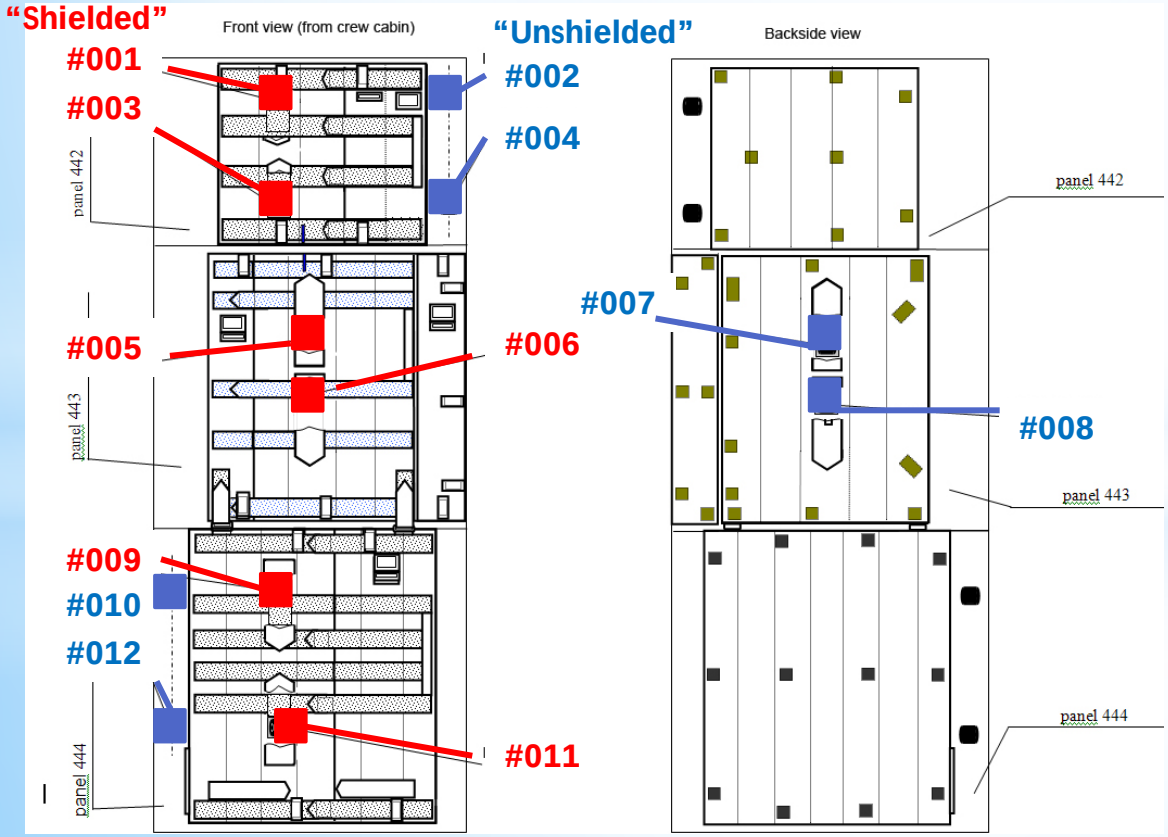


(Doke et al., 1995, Benton & Benton, 2002)

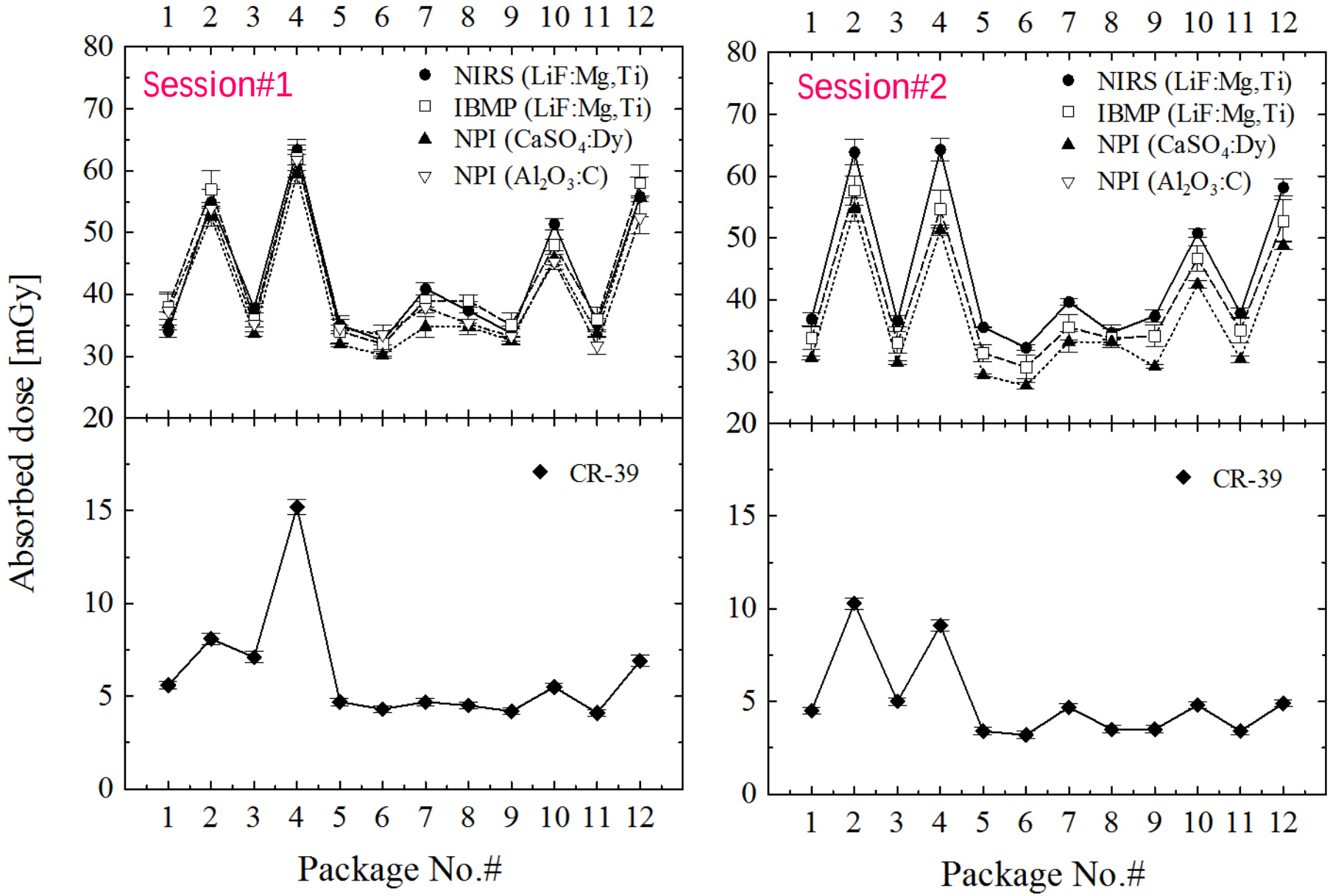
* Space radiation exposure onboard ISS *

- Session#1: Jun. 16, 2010 – Nov. 26, 2010 [163 days]
- Session#2: Dec. 15, 2010 – May 24, 2011 [160 days]
- 12 locations (#001~#012)
  - 6 locations with water shielding: "Shielded" (#001, #003, #005, #006, #009, #011)
  - 6 locations without water shielding: "Unshielded" (#002, #004, #007, #008, #010, #012)

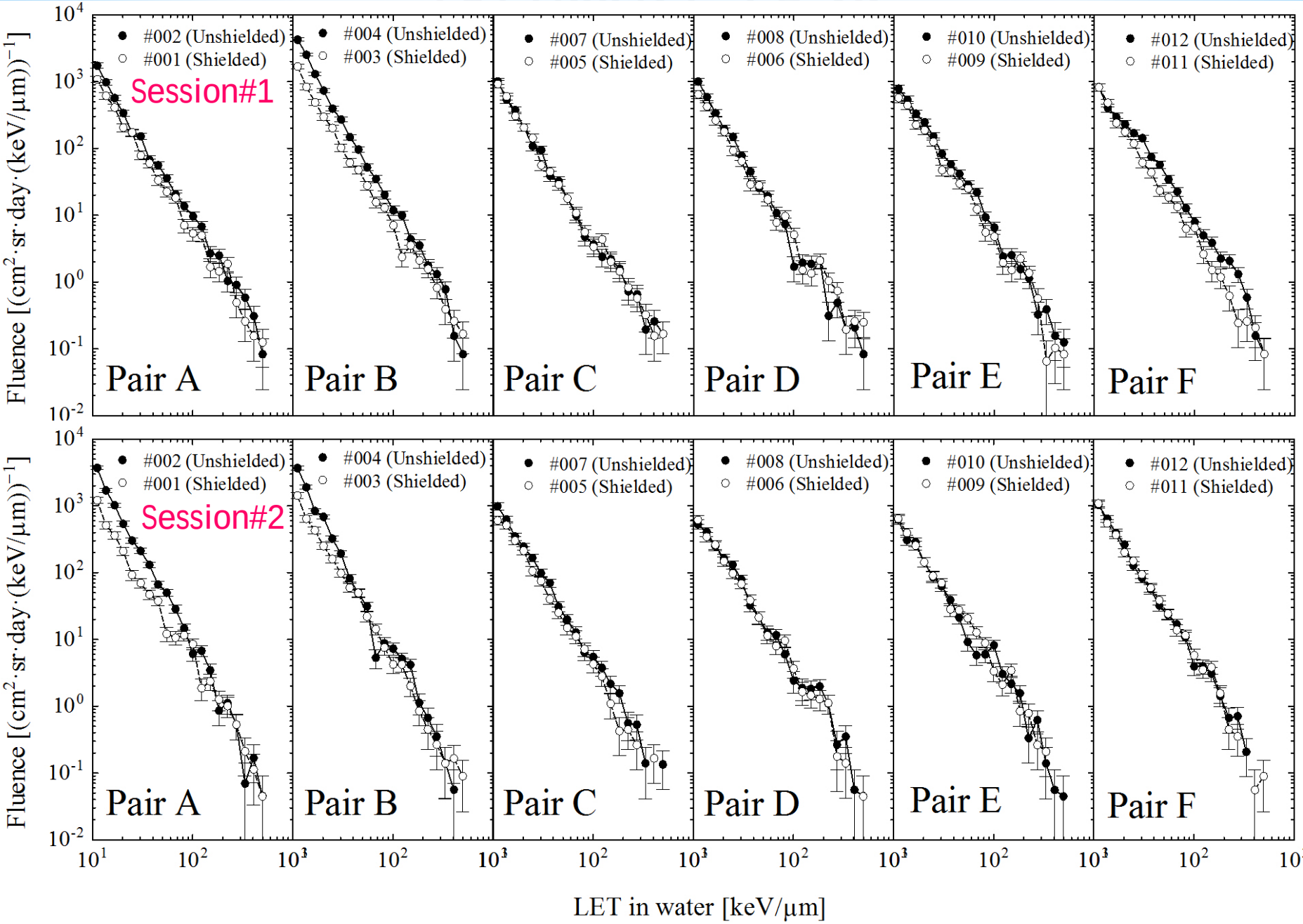
Pair	Shielded	Unshielded
A	#001	#002
B	#003	#004
C	#005	#007
D	#006	#008
E	#009	#010
F	#011	#012



* Absorbed dose at each location by TLD and CR-39 *



* LET spectra - CR-39 *

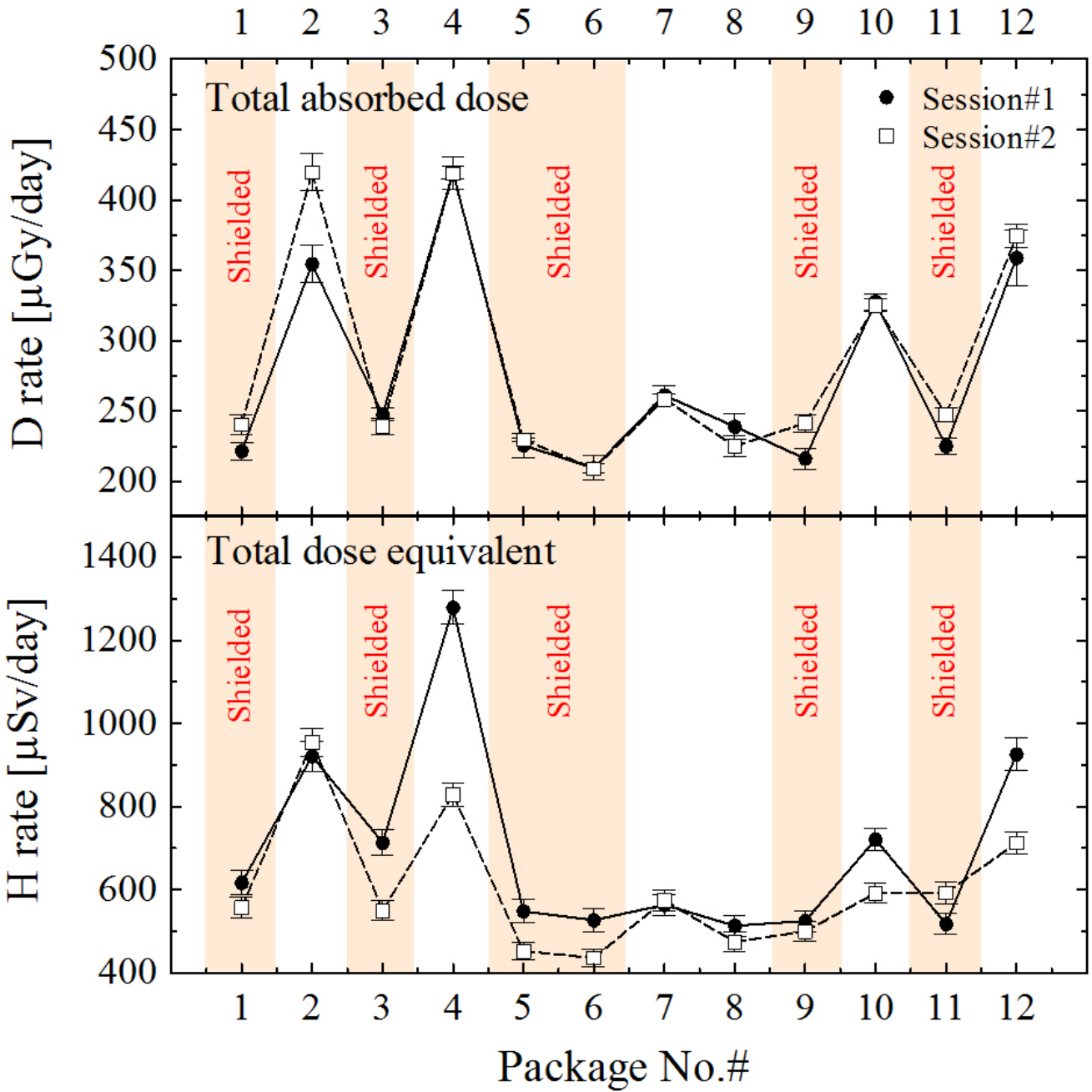


* Total dose results (LiF:Mg.Ti (NIRS) + CR-39) *

Session#1	Absorbed dose (D)		Dose equivalent (H)		Mean Q (=H/D)
	[mGy]	[μGy/day]	[mSv]	[μSv/day]	
#001 (Shielded)	36.1 ± 1.0	221.6 ± 6.3	100.5 ± 4.7	616.5 ± 28.8	2.8 ± 0.2
#002 (Unshielded)	57.8 ± 2.1	354.6 ± 13.0	150.2 ± 5.9	921.4 ± 35.9	2.6 ± 0.1
#003 (Shielded)	40.3 ± 0.7	247.5 ± 4.6	116.3 ± 4.9	713.3 ± 30.3	2.9 ± 0.1
#004 (Unshielded)	68.4 ± 0.8	419.6 ± 4.7	208.5 ± 6.5	1279.2 ± 40.1	3.0 ± 0.1
#005 (Shielded)	36.8 ± 1.4	225.7 ± 8.7	89.3 ± 4.5	548.1 ± 27.3	2.4 ± 0.2
#006 (Shielded)	34.1 ± 1.4	209.5 ± 8.7	85.8 ± 4.4	526.7 ± 27.1	2.5 ± 0.2
#007 (Unshielded)	42.6 ± 1.0	261.3 ± 6.3	91.9 ± 4.1	563.6 ± 25.4	2.2 ± 0.1
#008 (Unshielded)	39.0 ± 1.5	239.1 ± 9.3	83.7 ± 4.0	513.2 ± 24.5	2.1 ± 0.1
#009 (Shielded)	35.3 ± 1.2	216.3 ± 7.5	85.5 ± 4.1	524.8 ± 25.4	2.4 ± 0.1
#010 (Unshielded)	53.4 ± 0.9	327.7 ± 5.7	117.4 ± 4.5	720.5 ± 27.5	2.2 ± 0.1
#011 (Shielded)	36.7 ± 0.9	225.1 ± 5.6	84.4 ± 4.0	517.9 ± 24.5	2.3 ± 0.1
#012 (Unshielded)	58.5 ± 3.2	358.9 ± 19.7	150.9 ± 6.3	925.8 ± 38.8	2.6 ± 0.2

Session#2	Absorbed dose (D)		Dose equivalent (H)		Mean Q (=H/D)
	[mGy]	[μGy/day]	[mSv]	[μSv/day]	
#001 (Shielded)	38.5 ± 1.1	240.5 ± 7.0	89.1 ± 4.1	556.7 ± 25.7	2.3 ± 0.1
#002 (Unshielded)	67.1 ± 2.1	419.6 ± 13.2	152.7 ± 5.3	954.6 ± 32.9	2.3 ± 0.1
#003 (Shielded)	38.3 ± 0.9	239.4 ± 5.8	88.1 ± 3.9	550.5 ± 24.6	2.3 ± 0.1
#004 (Unshielded)	67.0 ± 1.8	418.9 ± 11.4	132.6 ± 4.6	828.6 ± 29.1	2.0 ± 0.1
#005 (Shielded)	36.8 ± 0.2	229.8 ± 1.2	72.3 ± 3.2	452.0 ± 20.1	2.0 ± 0.1
#006 (Shielded)	33.4 ± 0.5	209.0 ± 3.3	69.8 ± 3.4	436.2 ± 21.0	2.1 ± 0.1
#007 (Unshielded)	41.4 ± 0.6	258.5 ± 3.9	91.9 ± 4.0	574.2 ± 24.8	2.2 ± 0.1
#008 (Unshielded)	36.0 ± 1.2	224.9 ± 7.6	75.9 ± 3.8	474.4 ± 23.4	2.1 ± 0.1
#009 (Shielded)	38.6 ± 1.0	241.5 ± 6.3	80.0 ± 3.7	500.1 ± 22.8	2.1 ± 0.1
#010 (Unshielded)	52.0 ± 0.7	325.2 ± 4.5	94.7 ± 3.8	592.0 ± 24.0	1.8 ± 0.1
#011 (Shielded)	39.6 ± 0.8	247.5 ± 5.1	94.8 ± 4.1	592.4 ± 25.8	2.4 ± 0.1
#012 (Unshielded)	59.9 ± 1.3	374.4 ± 8.2	114.0 ± 4.3	712.8 ± 26.6	1.9 ± 0.1

* Total dose variation (LiF:Mg,Ti (NIRS) + CR-39) *



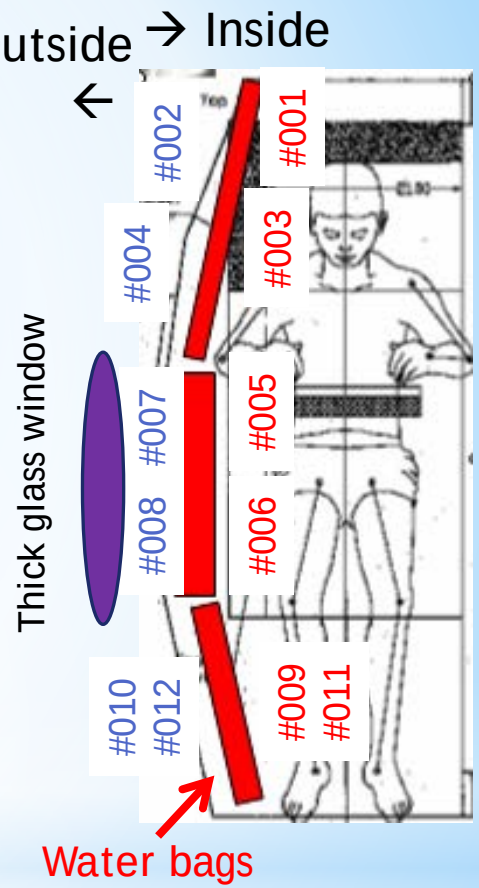
* Dose reduction rate *

Session#1

Pair	(Shielded)/(Unshielded)	D [%]	H [%]
A	#001/#002	37.5 ± 2.9	33.1 ± 4.1
B	#003/#004	41.0 ± 1.3	44.2 ± 2.9
C	#005/#007	13.6 ± 3.9	2.8 ± 6.5
D	#006/#008	12.4 ± 5.0	2.6 ± 7.2
E	#009/#010	34.0 ± 2.5	27.2 ± 4.5
F	#011/#012	37.3 ± 3.8	44.1 ± 3.5

Session#2

Pair	(Shielded)/(Unshielded)	D [%]	H [%]
A	#001/#002	42.7 ± 2.5	41.7 ± 3.4
B	#003/#004	42.8 ± 2.1	33.6 ± 3.8
C	#005/#007	11.1 ± 1.4	21.3 ± 4.9
D	#006/#008	7.1 ± 3.5	8.1 ± 6.3
E	#009/#010	25.7 ± 2.2	15.5 ± 5.2
F	#011/#012	33.9 ± 2.0	16.9 ± 4.8

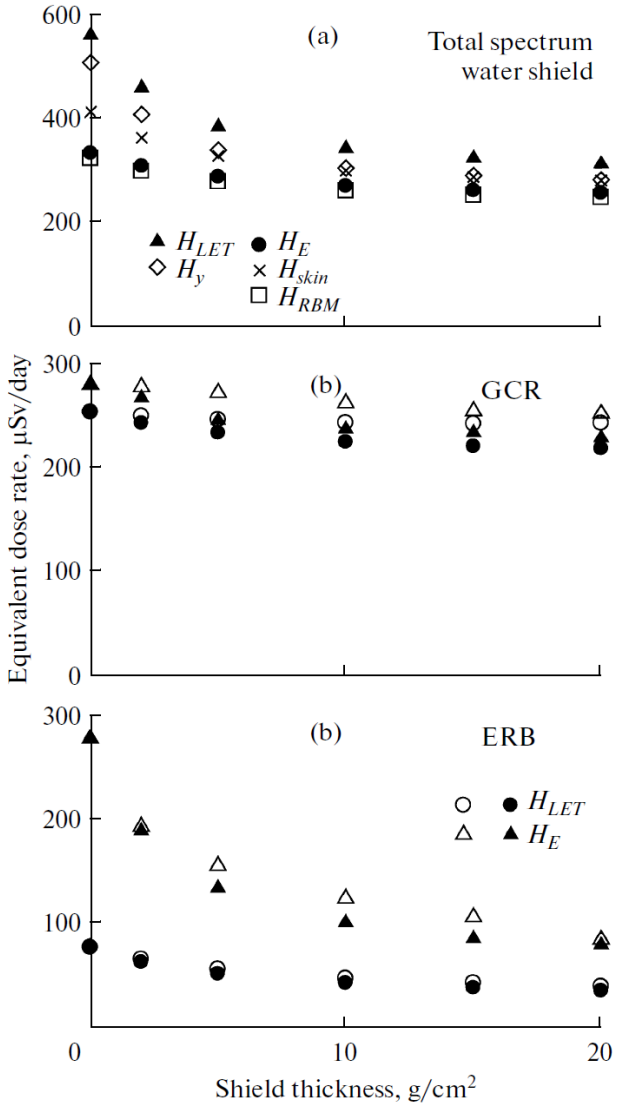


- Shielding with water bag was effective to reduce dose depending on the location
- In case of Pairs C and D, since the “Unshielded” packages (#007 and #008) are actually shielded by the another material (thick glass ~4.5 g/cm^2), the shielding effect by water bag is seemed to be relatively small compared with the other packages
- Reduction rate of dose equivalent is 15 ~ 44 % (except Pairs C and D)

* Comparison with PHITS calculation *

- T. Sato et al., Cosmic. Res., 49 (2011) 319 reports the reduction rate of dose equivalent as a function of water shielding thickness by PHITS calculation
- Water thickness used in Protective Curtain experiment is roughly ~ 8 g/cm^2
- Calculated reduction rate of H is estimated to be ~36% for the water thickness of 8 g/cm^2
- Observed reduction rate (15 ~ 44 %) is roughly consistent with the PHITS calculation

More detail and precise simulation based on the experimental condition and set-up is needed



(T. Sato et al., 2011)

* Summary *

- Dose reduction rate for space radiation by the additional installation of water shielding in ISS crew cabin was measured with the passive dosimeter packages consisting of TLD and CR-39 during two different durations (Session#1 and #2)
- Averaged water thickness is roughly ~ 8 g/cm^2
- Observed dose reduction rate is ranging from 15 to 44 % in dose equivalent depending on the thickness of shielding
- Calculated reduction rate of ~36% is roughly consistent with the observation
- Properly utilization of protective curtain will effectively reduce the radiation dose for crew living in space station and more long-term mission in the future

* Prospects *

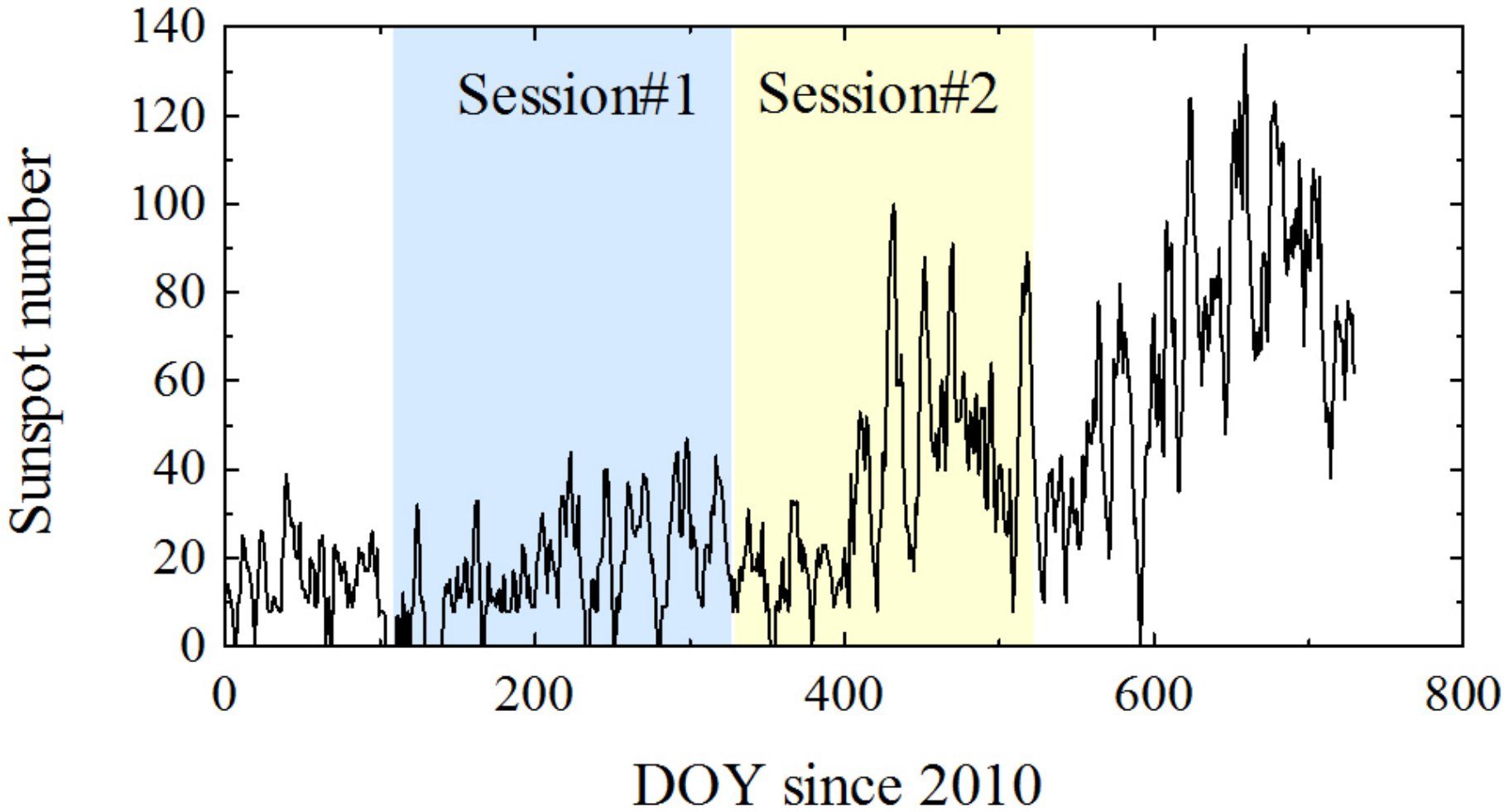
- We will analyze the recovered “Session#3 (Dec., 2011~ May, 2012)” detectors
- Session#4 (June, 2012~) is now running onboard ISS
- We will summarize the dose variation and dose reduction effect though totally four Sessions (#1~#4)
- We will compare with precise simulation based on the experimental condition and set-up

* Acknowledgements *

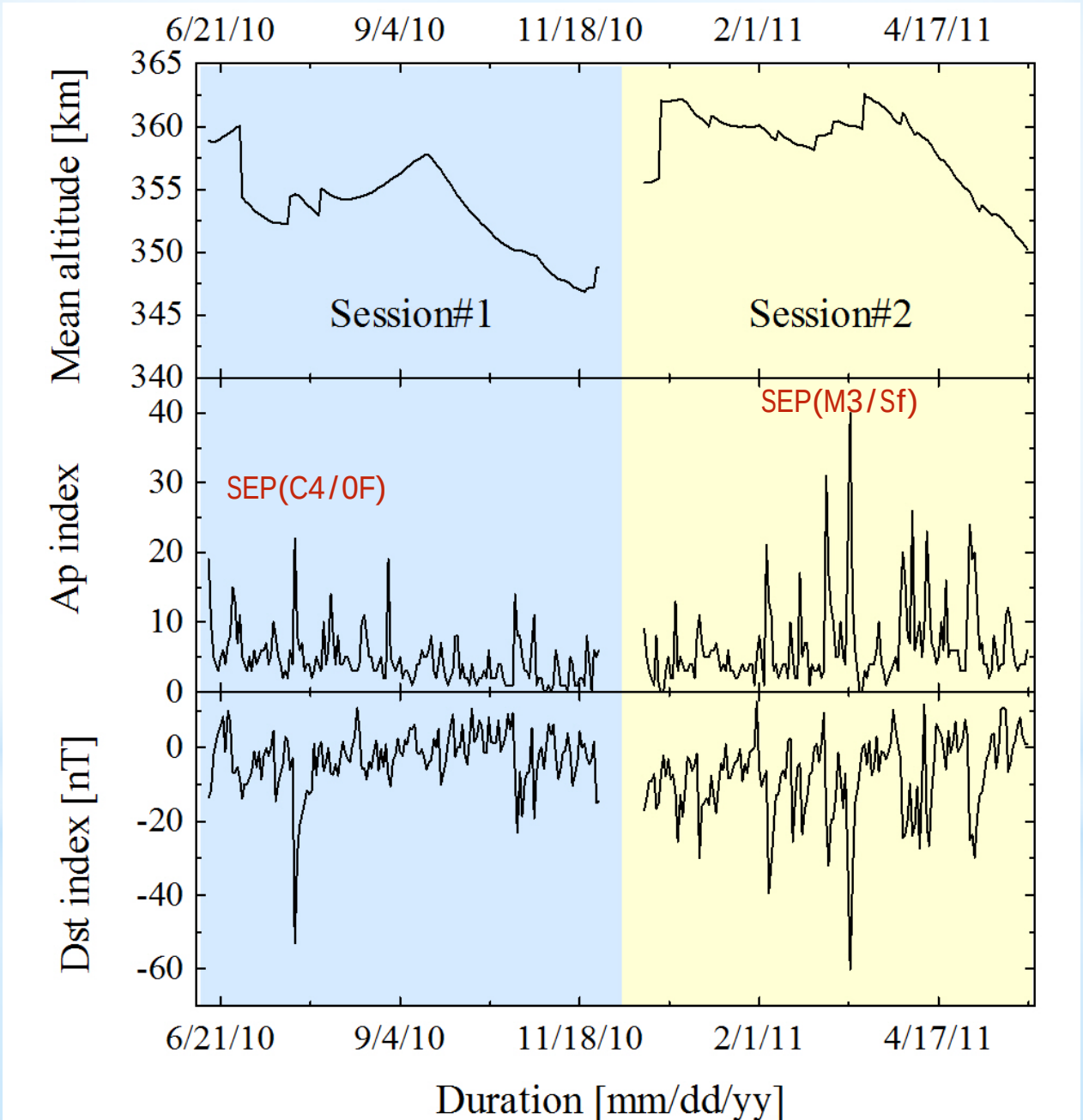
- We gratefully thank to all of staff, ISS crews and engineers of Energia and IBMP, for preparing, launching, operating and recovering our detectors
- Detector calibration was performed as a part of accelerator experiments of the Research Project at NIRS-HIMAC. We would like to express our thanks to the staff of NIRS-HIMAC for their kind supports

*Back up slides *

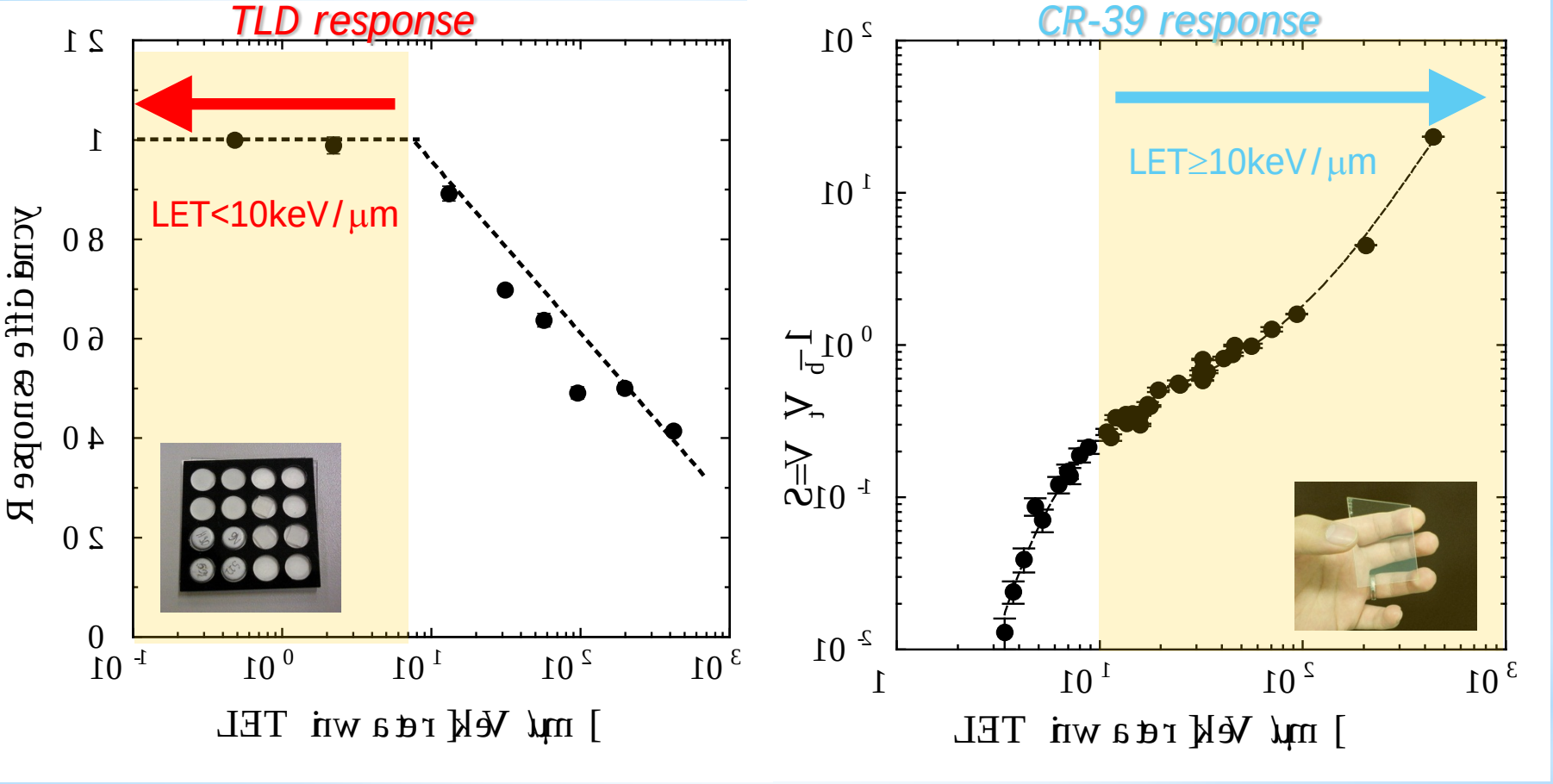
* Environmental parameters *



* Environmental parameters *



* Combination of TLD and CR-39 *



- Response of TLD for LET<10keV/μm is almost constant, while response for high LET is strongly depending on LET
- CR-39 can accurately measure high LET (≥10keV/μm) particles

→ Dose for LET<10keV/μm obtained by TLD can be estimated by deducting high LET part using CR-39 data