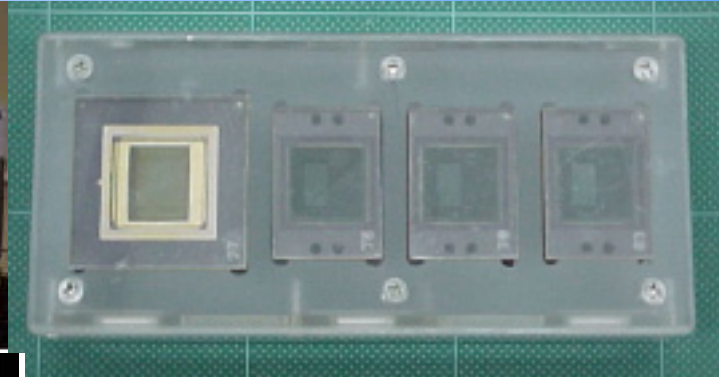


Passive Dosimeter for Lifescience Experiments in Space



Dosimetry and tracking for space radiation in a ISS Russian segment using PADLES



Co-investigators

- **Hiroko tawara** **KEK / NASDA**
- **Mitsuyo masukawa, aiko nagamatsu
takao akutsu, mitutasu kato** **NASDA**
- **Hidenori kumagai** **AES**
- **Akitoshi yokota** **JGC**
- **Junichi yamasaki, masahito yamauchi** **NHK**
- **Nakahiro yasuda** **NIRS**



Plan of Presentation



- 1. Introduction**
- 2. Flight experiments**
- 3. Dosimetric results in ISS ZVEZDA using CR-39 and TLD-MSO**
- 4. Tracking of the HZE particles on CCD elements using CR-39 stacks**
- 5. Summary & Future Work**



1. Introduction

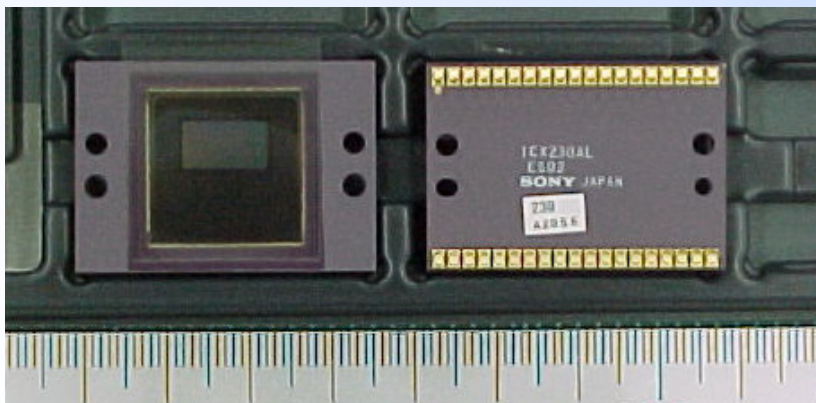


HDTV radiation damage test in space

We loaded PADLES along with the High-Definition TeleVison (HDTV) camera and its CCD elements into the ISS Russian module ZEVEZDA.

Objectives :

1. Correlation between absorbed doses of CCD elements for space radiation and the number of the white deffects
2. Correlation between the white deffect spots and the HZE-particle tracks



CCD elements



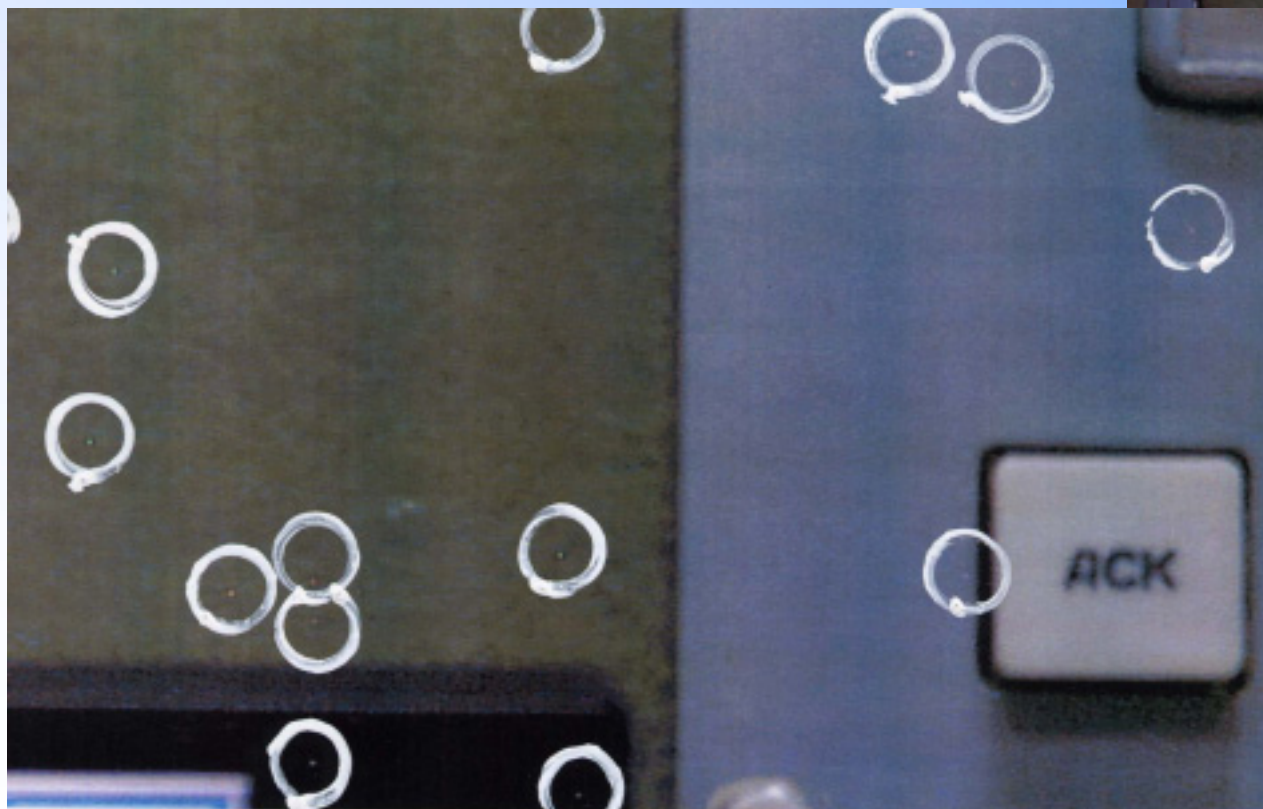
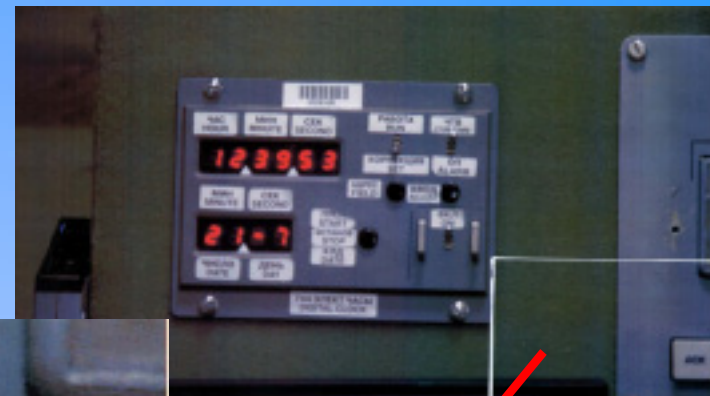
HDTV



1. Introduction



**Example for white spots
on the image getting by HDTV**



**21/10/2001
on ISS ZVEZDA**



1. Introduction



PADLES

(Passive Dosimeter for Lifescience Experiment in Space)

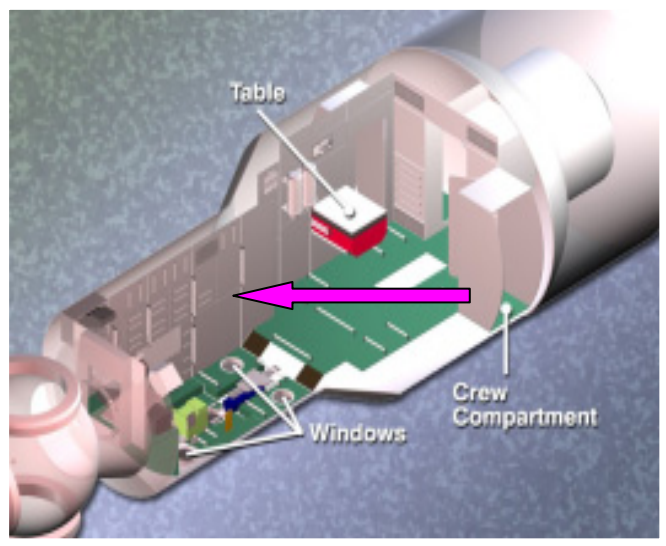
The PADLES syetem has been originally developed for biological experiments in space by NASDA.

On the basis of ground performance tests using HIMAC heavy-ion accelerator, the PADLES can also be applied for radiation resarch of electronic devices and the personal dosimetry for ISS crew members.

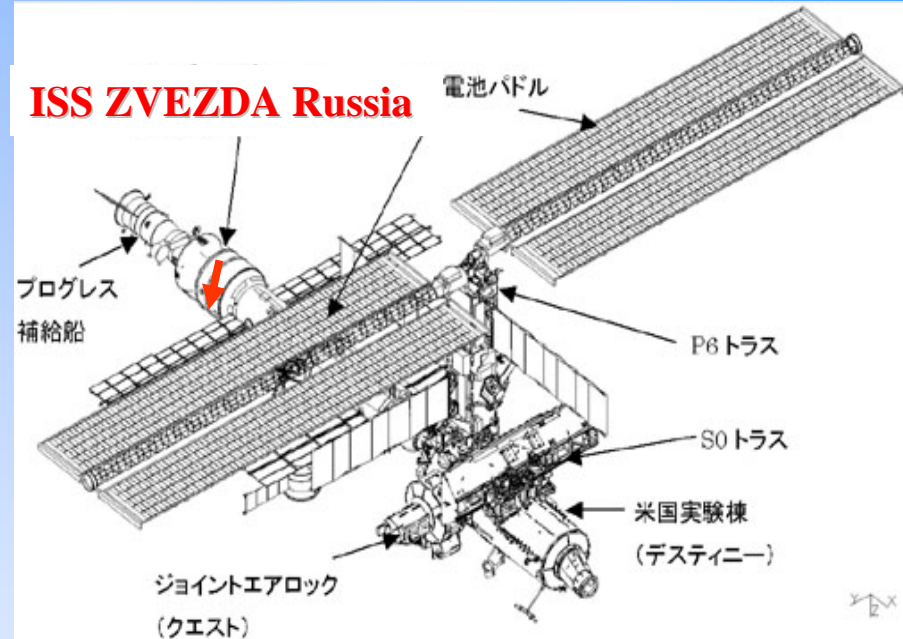
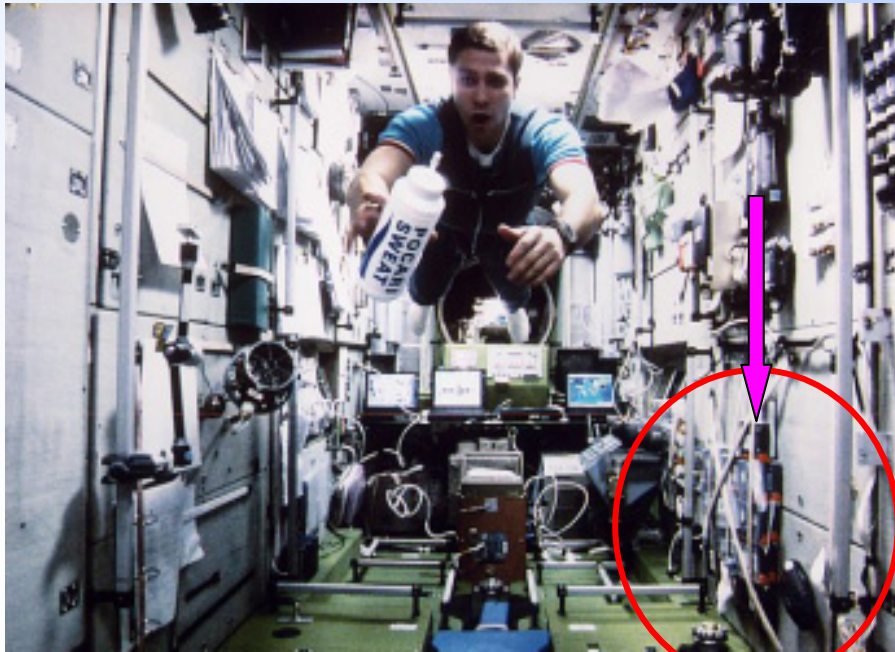
- 1. Absorbed dose (TLD-MSOs),**
- 2. LET distributions for ≥ 10 keV/ μ m-water (CR-39),**
- 3. Dose equivalent (TLD-MSO + CR-39),**
- 4. Tracking of HZE particles (CR-39 stacks).**



2. Flight Experiments



Locations of CCD/PADLES



10/26/2001

(Ohtsuka pharmaceutical company)



2. Flight Experiments



Flight conditions

Altitude : 400km, Inclination : 51.6 °

Flight durations

- **Launch 21/8/2001 18:23 (J) Russia PRGRES 5P @ Baikonur**
- **The 1st recovery 31/10/2001 71 days Soyuz-TM32**
- **The 2nd recovery 5/5/2002 257 days Soyuz-TM33**
- **The 3rd recovery 10/11/2002 446 days Soyuz-TM34**



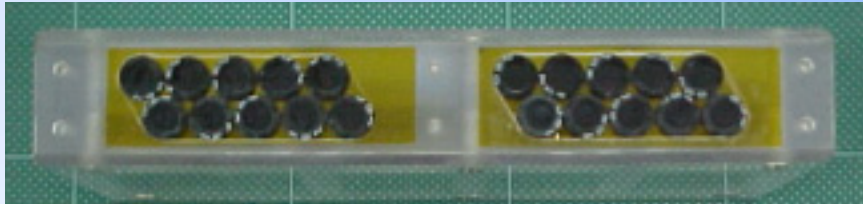
2. Flight Experiments



CCD / PADLES package

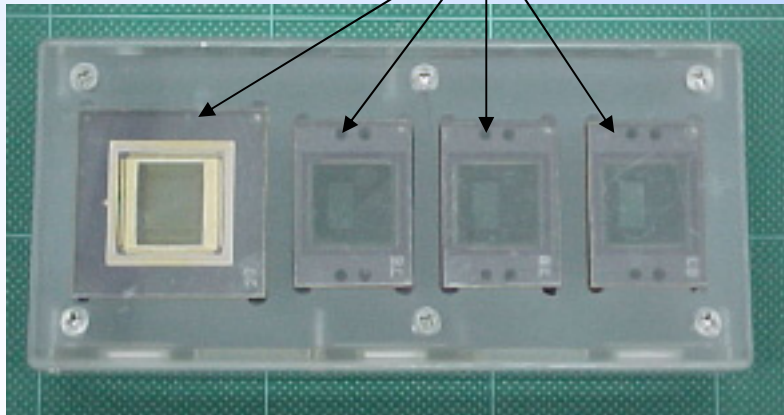


L170 × W68 × T19mm



TLB-UD807

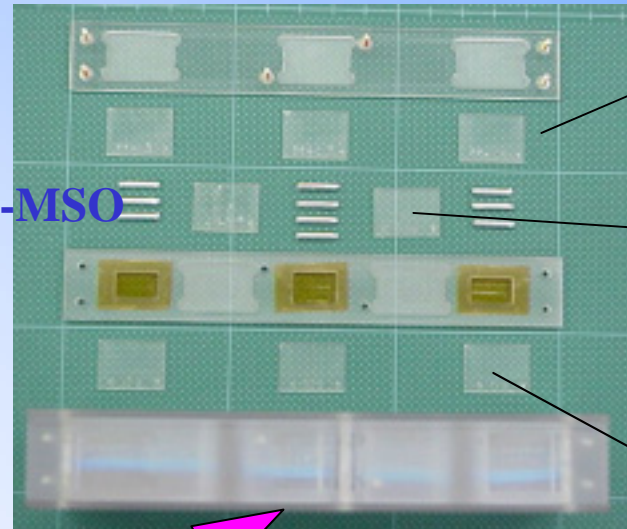
CR-39 stacks for tracking



C-MOS (1)

CCD (3)

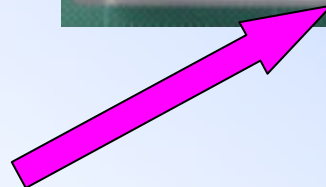
TLD-MSO



CR-39 (TNF-1) for dosimetry

Pre-exposed CR-39 (TD-1) for Calibration

CR-39 (TD-1) for dosimetry





2. Flight Experiments



Constituent Elements

Material		Type	Manufacturer	No.	Note
Dosimeters					
	TLD	TLD-MSO-S	Kasei Optonics	10	Absorbed dose
	CR-39	TD-1 (0.9mm ^ε)	Fukuv Chemical	3	LET distribution Absorbed dose Dose equivalent
		TNF-1 (0.9mm ^ε)	Fukuv Chemical	3	LET distribution Absorbed dose Dose equivalent
		TD-1 (0.9mm ^ε)	Fukuv Chemical	8	Tracking
		BARYOTRAK (0.45mm ^ε)	Fukuv Chemical	16 sheets	Tracking
		TD-1 (0.9mm ^ε)	Fukuv Chemical	2 sheets	Si, Fe irradiated, sensitivity correction of CR-39
CCD device					
CCD	ICX230AS ES02	No. 2037	SONY	3	HCCAM CAM CODE 2.2million pixel, 2/3 inch FIT type CCD
		No. 2038			
		No. 2039			
C-MOS	PB-1024	Photobit	1	1million pixel, 145pin Ceramic	

Absorbed dose : D_{TLD}

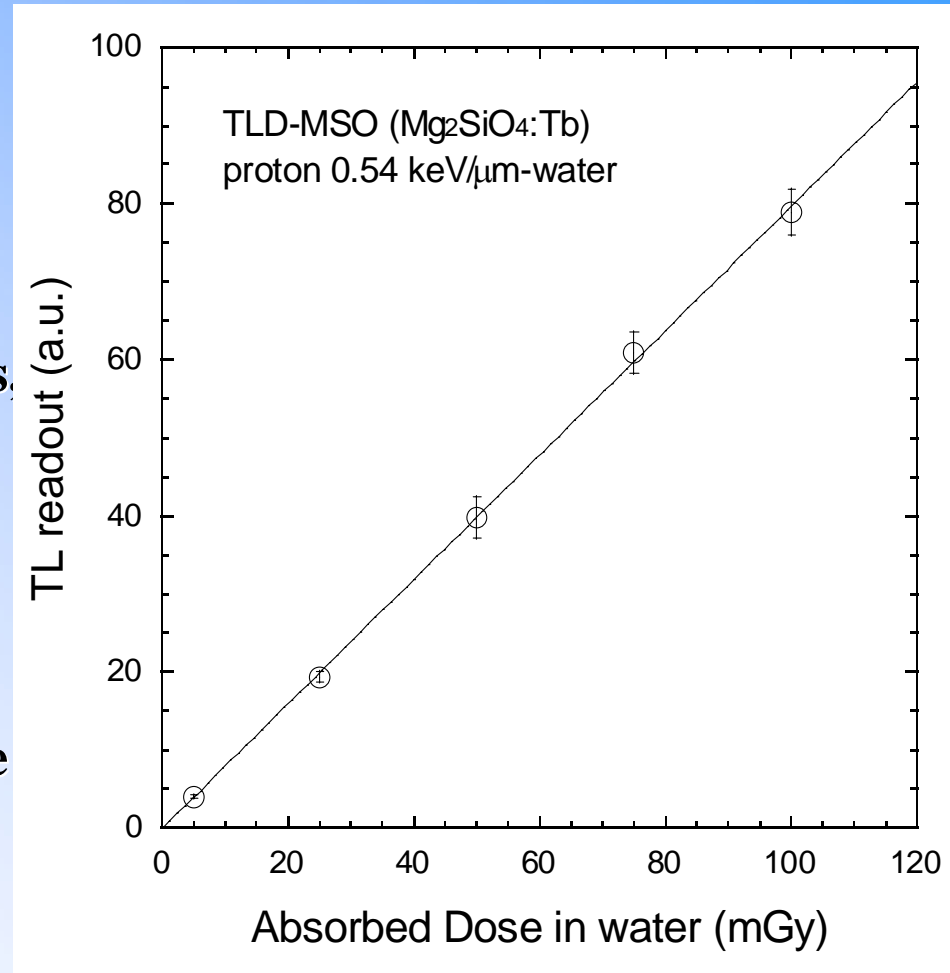
$$D_{TLD} = fMK_{\text{proton}}$$

(Gy-water)

f : Correction factor (fading effects, temperature dependence)

M : TLD reader output,

K_{proton} : the conversion factor for water-equivalent absorbed dose





3. Dosimetry - CR-39 -



LET distributions of heavy-charged particles for $\geq 10 \text{ keV}/\mu\text{m}$

$$\frac{dN}{dL} = \frac{\Delta N}{\Delta L} \frac{1}{TS \Omega}$$

(particles $\text{s}^{-1}\text{cm}^{-2}\text{sr}^{-1} (\text{keV}/\mu\text{m})^{-1}$)

ΔL : range of LET bin

($\text{keV}/\mu\text{m}$),

T : observation time (sec),

S : scan area (cm^2),

Ω : solid angle= 2π

Absorbed dose for $\geq 10 \text{ keV}/\mu\text{m}$: $D_{\text{CR-39}}$

$$D_{\text{CR-39}} = 1.602 \times 10^{-6} 4\pi T \sum_{>10\text{keV}/\mu\text{m-water}} \left(\frac{dN}{dL} L_c \Delta L \right) \text{ (mGy-water)}$$

Dose equivalent for $\geq 10 \text{ keV}/\mu\text{m}$: $H_{\text{CR-39}}$

$$H_{\text{CR-39}} = 1.602 \times 10^{-6} 4\pi T \sum_{>10\text{keV}/\mu\text{m-water}} \left(Q(L_c) \frac{dN}{dL} L_c \Delta L \right) \text{ (mSv-water)}$$

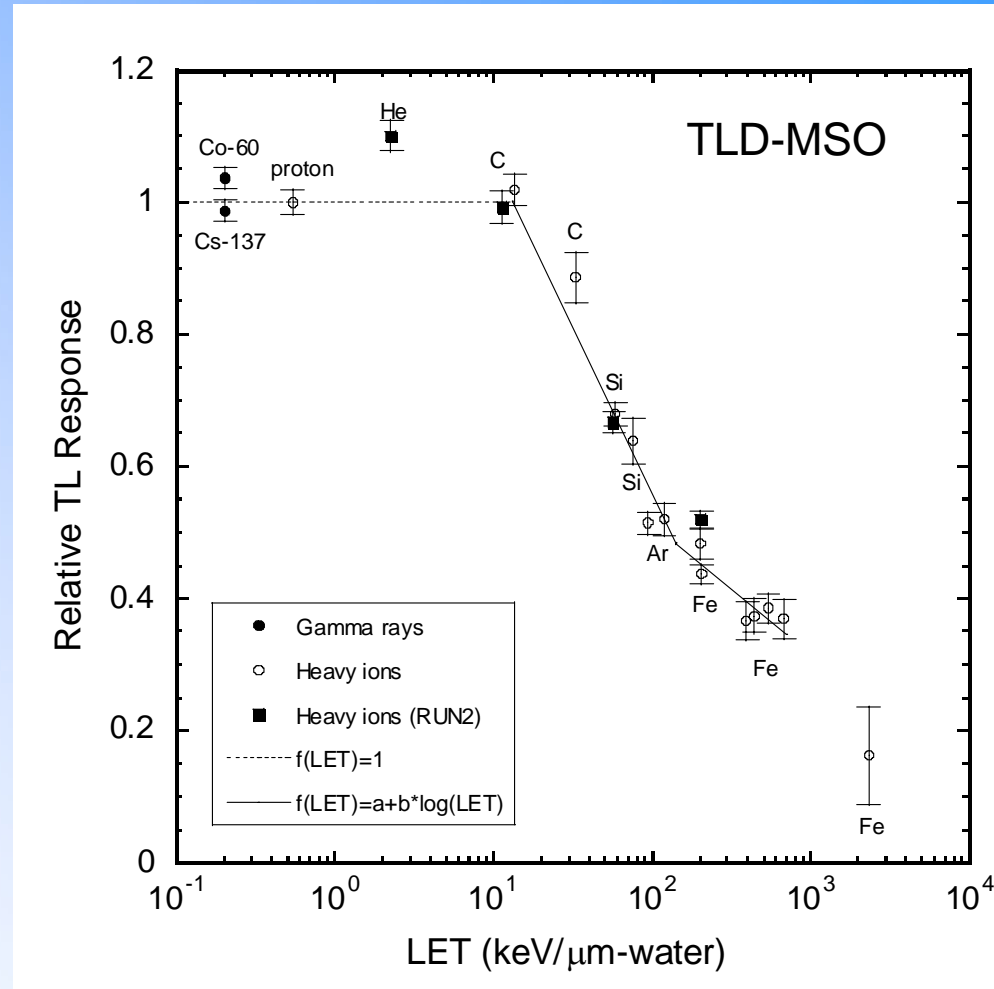
The mean TL efficiency for high-LET particles of TLD-MSO :

$$K = \frac{\sum_{>10\text{keV}/\mu\text{m}} (f(LET) \Delta D(LET))}{D_{CR-39}}$$

Where,

$$\Delta D(L_c) = 1.602 \times 10^{-6} \left(\frac{\Delta N(L_c)}{\Delta L} L_c \Delta L \right)$$

(mGy-water).



Total absorbed dose : D_{TOTAL}

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

(mGy)

Total dose equivalent : H_{TOTAL}

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

(mSv)

: mean TL efficiency for high-LET particles from TLD

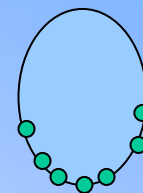
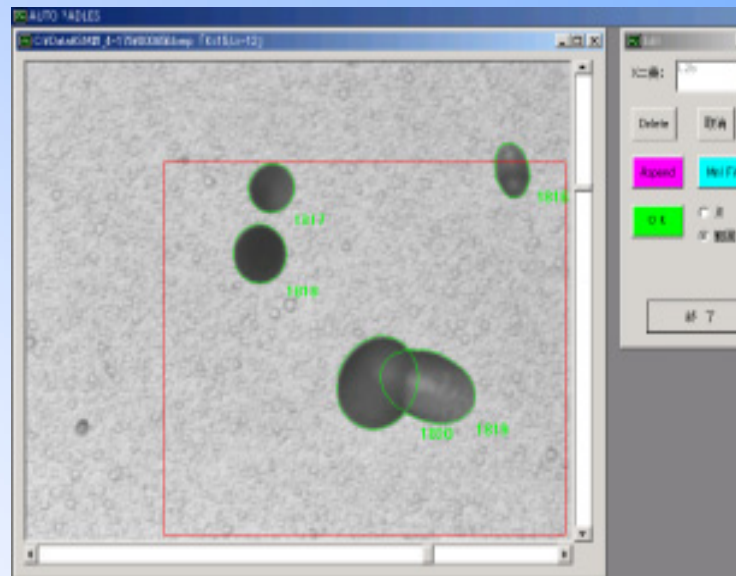
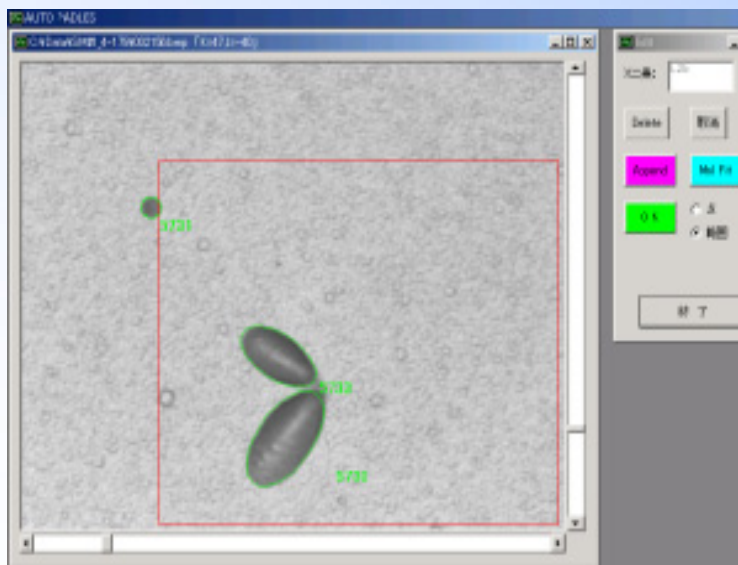


3. Dosimetry - Etch-pit analysis -



A new Auto PADLES system for CR-39 analysis

A high-speed and semi-automatic analysis system for track detectors with an ellipse fitting algorithm developed by NIRS, SEIKO precision, KEK and NASDA.



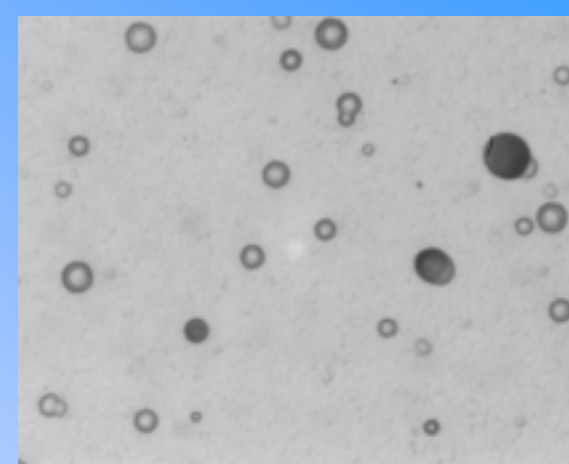
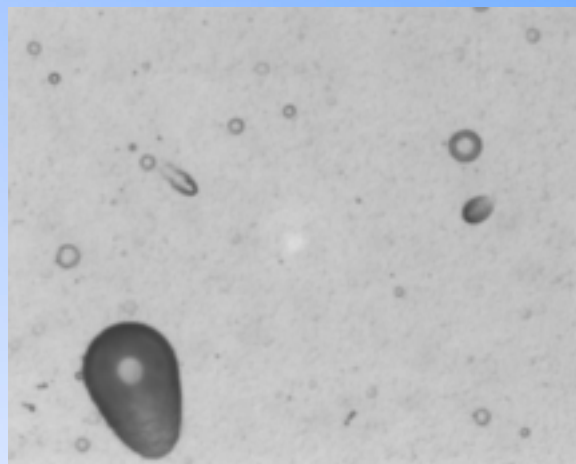


3. Dosimetry - LET distribution -

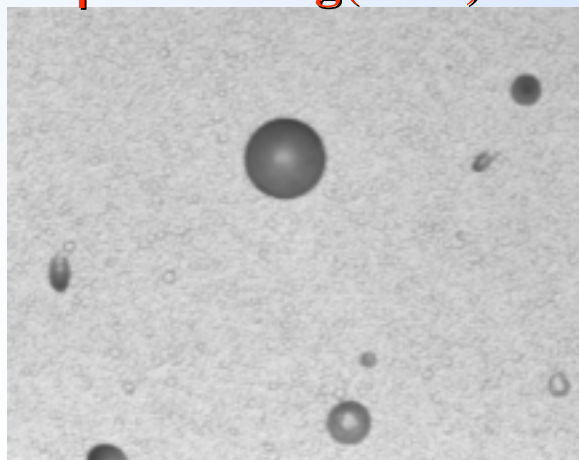


Measurements of LRP and SRP for constructing LET distributions

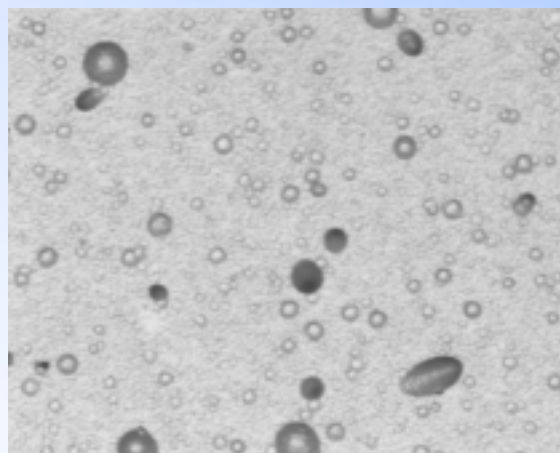
8 μ m etching (SRP) \times 500



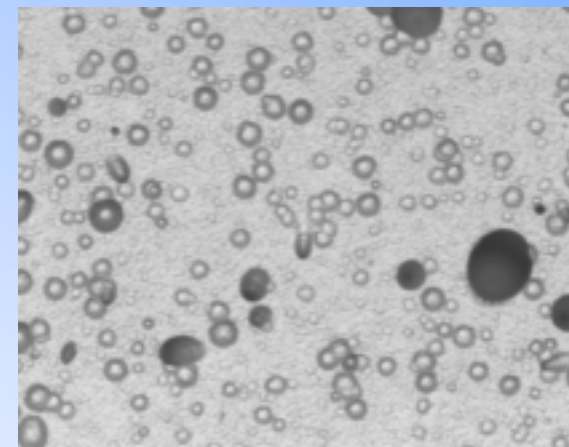
23 μ m etching(LRP) \times 200



71days



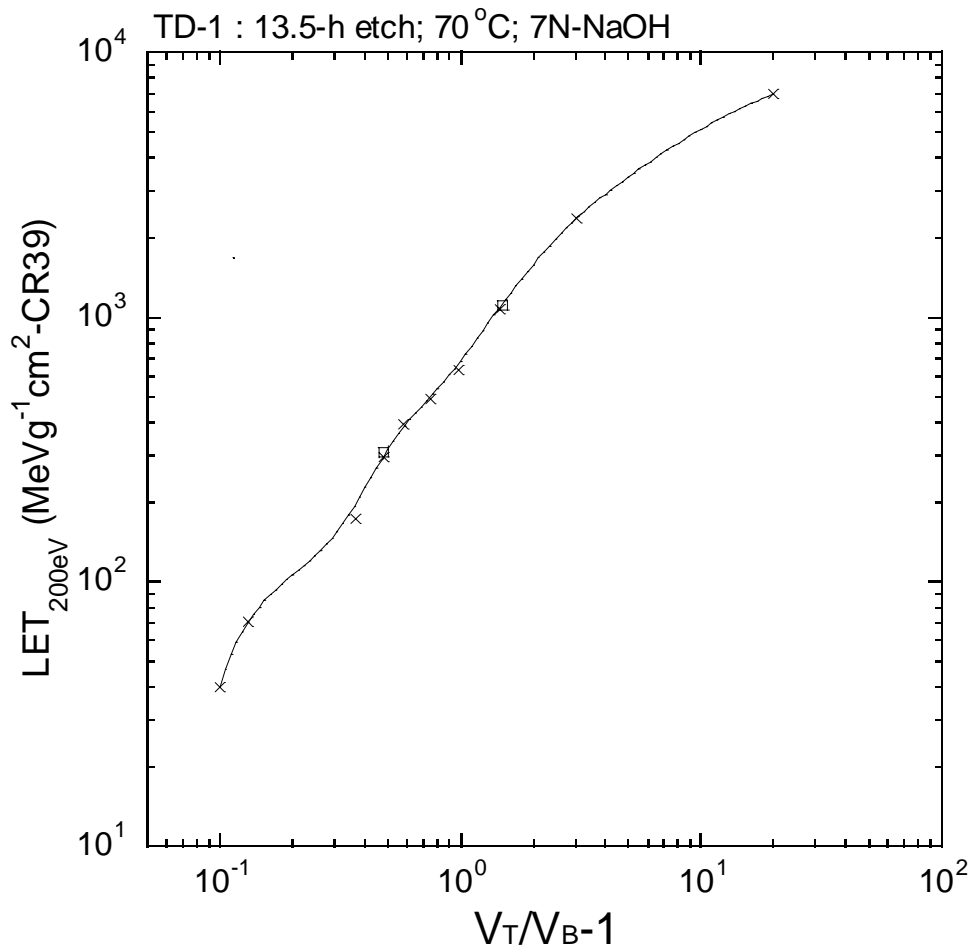
257days



446days



3. Dosimetry - calibration curve -



A calibration curve of CR-39 using flight samples pre-irradiated to Si and Fe ions from HIMAC

**× : Heavy ions from HIMAC,
□ : Flight samples (Si and Fe)**

$$\text{LET-water (keV/}\mu\text{m)} = 0.19 \times \text{LET}_{200\text{eV-CR39}} \text{ (MeVg}^{-1}\text{cm}^2\text{)}$$

* Research project with heavy Ions at NIRS-HIMAC



3. Dosimetry - results -

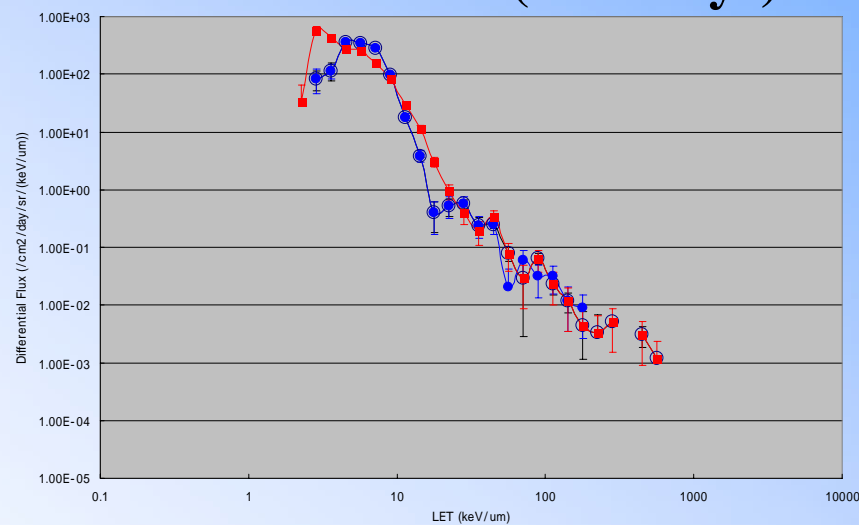
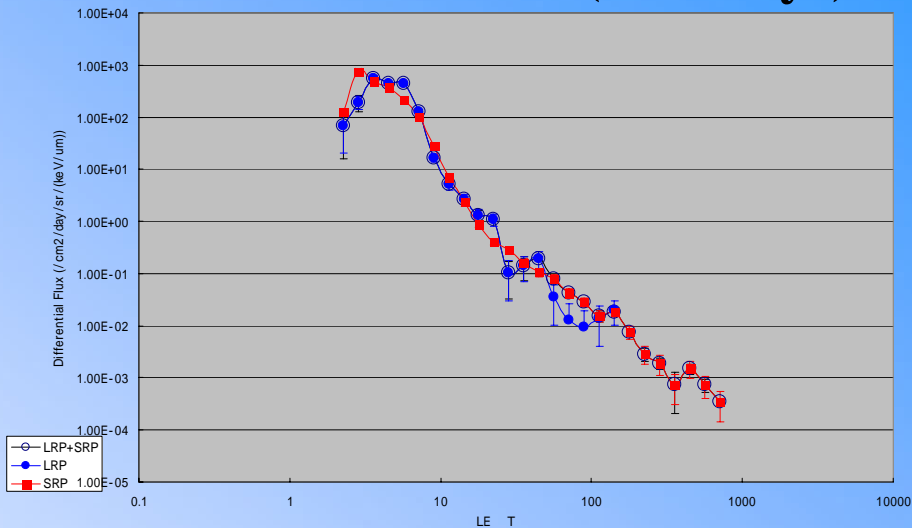
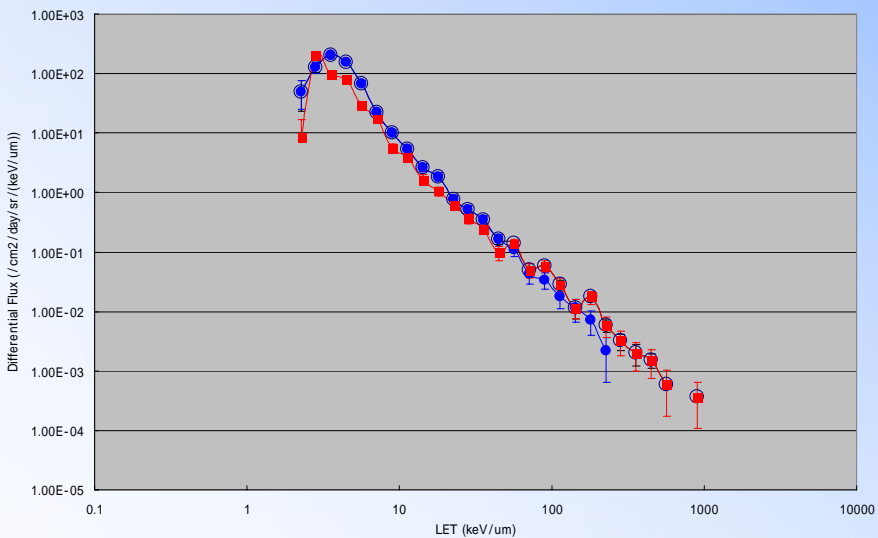


LET distributions

(71 days)

(257 days)

(446 days)



LRP+SRP
LRP
SRP

3. Dosimetry - results -

1. Duration: 31/8/2001 ~ 31/10/2001

(71 days)

LRP+SRP			
reader	15.3	±	0.7
proton equivalent absorbed dose (mGy)	19.3	±	1.0
Co-60 equivalent absorbed dose (mGy)	18.6	±	0.9
the absorbed dose 10keV/um	2.4	±	0.2
dose equivalent 10keV/um	32.4	±	2.7
	0.68	±	0.06
Dtotal (mGy)	20.1	±	1.0
Ht m	50.1	S ±	2.9
Dtotal (mGy/day)	0.283	±	0.014
Htotal (mSv/day)	0.705	±	0.040
QF(ICRP60)	2.49	±	0.19

LRP			
reader	15.3	±	0.7
proton equivalent absorbed dose (mGy)	19.3	±	1.0
Co-60 equivalent absorbed dose (mGy)	18.6	±	0.9
the absorbed dose 10keV/um	1.6	±	0.1
dose equivalent 10keV/um	18.1	±	1.9
	0.79	±	0.07
Dtotal (mGy)	19.7	±	1.0
H ₀	36.1	±	2.1
Dtotal (mGy/day)	0.277	±	0.014
Htotal (mSv/day)	0.509	±	0.030
QF(ICRP60)	1.84	±	0.14

SRP			
reader outp	15.3	±	0.7
proton equivalent absorbed dose (mGy)	19.3	±	1.0
Co-60 equivalent absorbed dose (mGy)	18.6	±	0.9
the absorbed dose 10keV/um	2.0	±	0.2
dose equivalent 10keV/um	30.6	±	2.6
	0.64	±	0.06
Dtotal (mGy)	20.0	±	1.0
H ₀	48.6	±	2.8
Dtotal (mGy/day)	0.282	±	0.014
Htotal (mSv/day)	0.684	±	0.040
QF(ICRP60)	2.42	±	0.19



3. Dosimetry - results -



2 . Duration: 31/8/2001 ~ 5/5/2002

(257 days)

LRP+SRP			
reader	46.5	±	1.3
proton equivalent absorbed dose (mGy)	58.8	±	2.1
Co-60 equivalent absorbed dose (mGy)	56.7	±	1.8
the absorbed dose 10keV/um	6.5	±	0.5
dose equivalent 10keV/um	79.8	±	6.0
	0.71	±	0.08
Dtotal (mGy)	60.7	±	2.1
Ht	134.0	±	6.4
Dtotal (mGy/day)	0.236	±	0.008
Htotal (mSv/day)	0.521	±	0.025
QF(ICRP60)	2.21	±	0.13
LRP			
reader	46.5	±	1.3
proton equivalent absorbed dose (mGy)	58.8	±	2.1
Co-60 equivalent absorbed dose (mGy)	56.7	±	1.8
the absorbed dose 10keV/um	4.4	±	0.5
dose equivalent 10keV/um	41.5	±	8.9
	0.82	±	0.13
Dtotal (mGy)	59.6	±	2.1
H ₀	96.7	±	9.2
Dtotal (mGy/day)	0.232	±	0.008
Htotal (mSv/day)	0.376	±	0.036
QF(ICRP60)	1.62	±	0.16
SRP			
reader	46.5	±	1.3
proton equivalent absorbed dose (mGy)	58.8	±	2.1
Co-60 equivalent absorbed dose (mGy)	56.7	±	1.8
the absorbed dose 10keV/um	6.2	±	0.3
dose equivalent 10keV/um	76.3	±	5.5
	0.70	±	0.05
Dtotal (mGy)	60.6	±	2.1
H ₀	130.8	±	5.9
Dtotal (mGy/day)	0.236	±	0.008
Htotal (mSv/day)	0.509	±	0.023
QF(ICRP60)	2.16	±	0.12

3. Dosimetry - results -

3 . Duration: 31/8/2001 ~ 10/11/2002

(446 days)

LRP+SRP			
reader	65.0	±	2.6
proton equivalent absorbed dose (mGy)	82.1	±	3.7
Co-60 equivalent absorbed dose (mGy)	79.2	±	3.4
the absorbed dose 10keV/um	16.3	±	1.9
dose equivalent 10keV/um	173.4	±	30.3
	0.75	±	0.11
Dtotal (mGy)	86.2	±	3.8
Ht	243.3	±	30.6
Dtotal (mGy/day)	0.193	±	0.008
Htotal (mSv/day)	0.546	±	0.069
QF(ICRP60)	2.82	±	0.38
LRP			
reader	65.0	±	2.6
proton equivalent absorbed dose (mGy)	82.1	±	3.7
Co-60 equivalent absorbed dose (mGy)	79.2	±	3.4
the absorbed dose 10keV/um	13.0	±	1.3
dose equivalent 10keV/um	120.8	±	22.1
	0.83	±	0.11
Dtotal (mGy)	84.3	±	3.7
H ₀	192.0	±	22.4
Dtotal (mGy/day)	0.189	±	0.008
Htotal (mSv/day)	0.431	±	0.050
QF(ICRP60)	2.28	±	0.28
SRP			
reader	65.0	±	2.6
proton equivalent absorbed dose (mGy)	82.1	±	3.7
Co-60 e	79.2	±	3.4
the absorbed dose 10keV/um	24.7	±	2.0
dose equivalent 10keV/um	194.6	±	30.5
	0.83	±	0.09
Dtotal (mGy)	86.4	±	3.8
H ₀	256.3	±	30.7
Dtotal (mGy/day)	0.194	±	0.008
Htotal (mSv/day)	0.575	±	0.069
QF(ICRP60)	2.96	±	0.38



3. Dosimetry - Summary -



LET distributions

LET distribution = LRP (10~45 keV/μm) + SRP (>45keV/μm).

Dose equivalents and quality factors increased.

D_{all} , H_{all} , QF

Recovery	Dates	D_{ALL} (mGy/day)	R-16 (mGy/day)	H_{ALL} (mSv/day)	QF
1	2001/8/21~2001/10/31 (71 days)	0.283 ± 0.014	0.202	0.509 ± 0.030	2.49 ± 0.19
2	2001/8/21~2002/5/5 (257 days)	0.236 ± 0.008	0.156	0.376 ± 0.036	2.21 ± 0.13
3	2001/8/21~2002/11/10 (446 days)	0.193 ± 0.008	0.179	0.431 ± 0.050	2.82 ± 0.38

* R-16: Russian ionizing chamber on ISS ZVEZDA



4 . Tracking



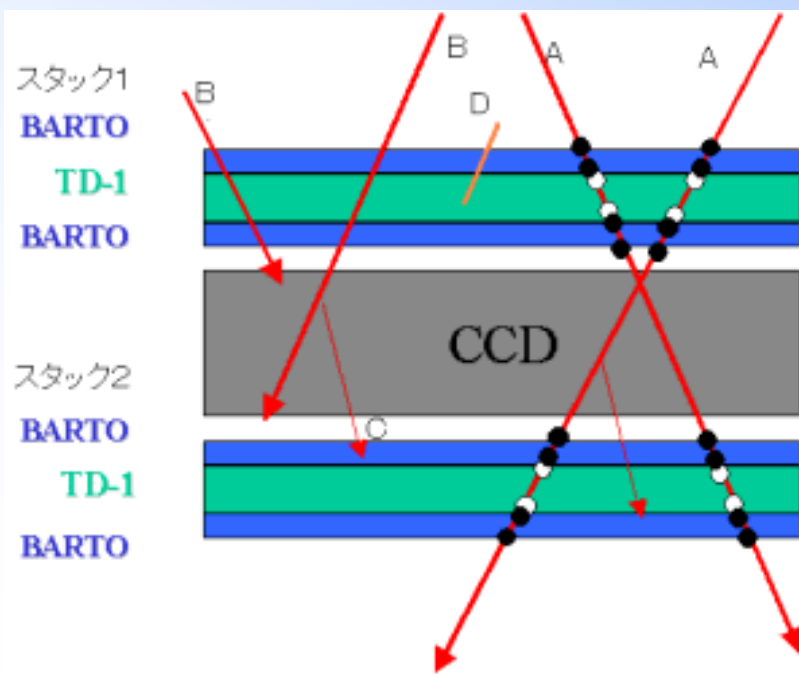
Method

(1) Analysed package :

- Package #01 CCD 2097, 2098, 2099 (71 days)

(2) Anlayzsd HZE particles:

- Relativestic and semi-relativestic particles (Si ~ Fe)



Arrangement of CCD elements and CR-39 stacks.

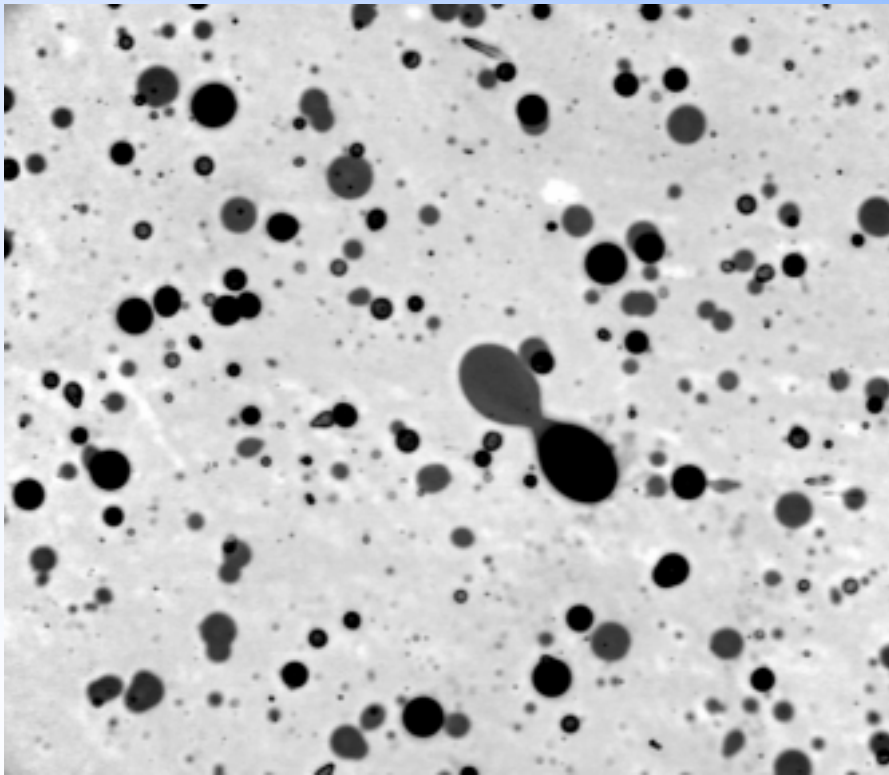
Dtect HZE particles with heavy etched BARYOTRAK sheets
Estimate the LET with TD-1



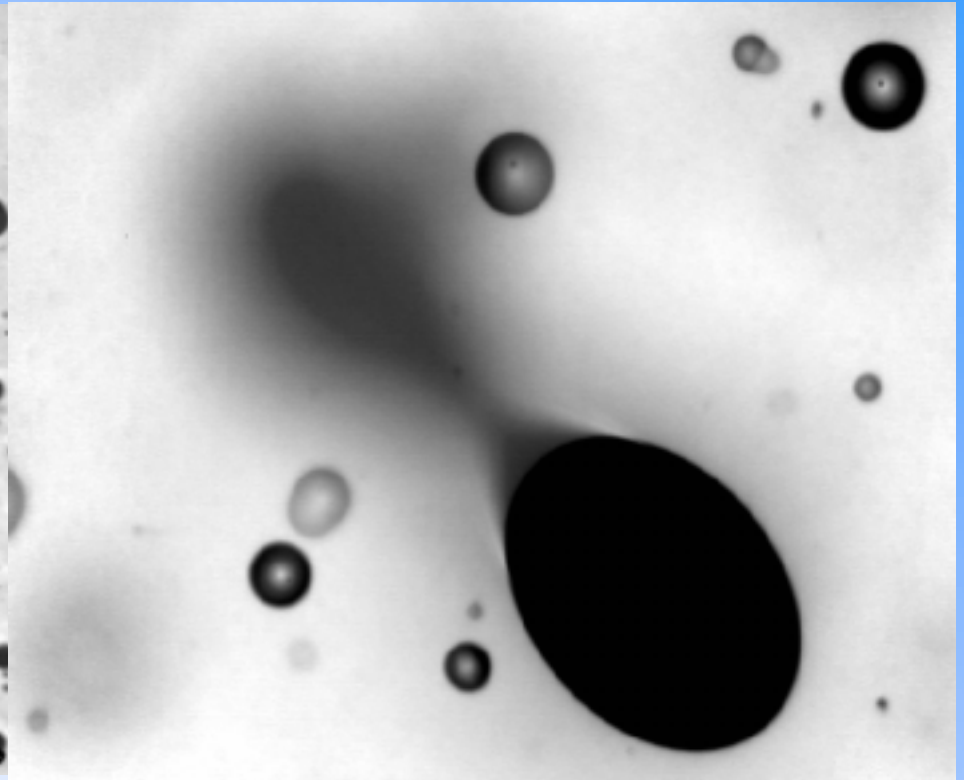
4 . Tracking



Example of the HZE-particle tracks



× 50



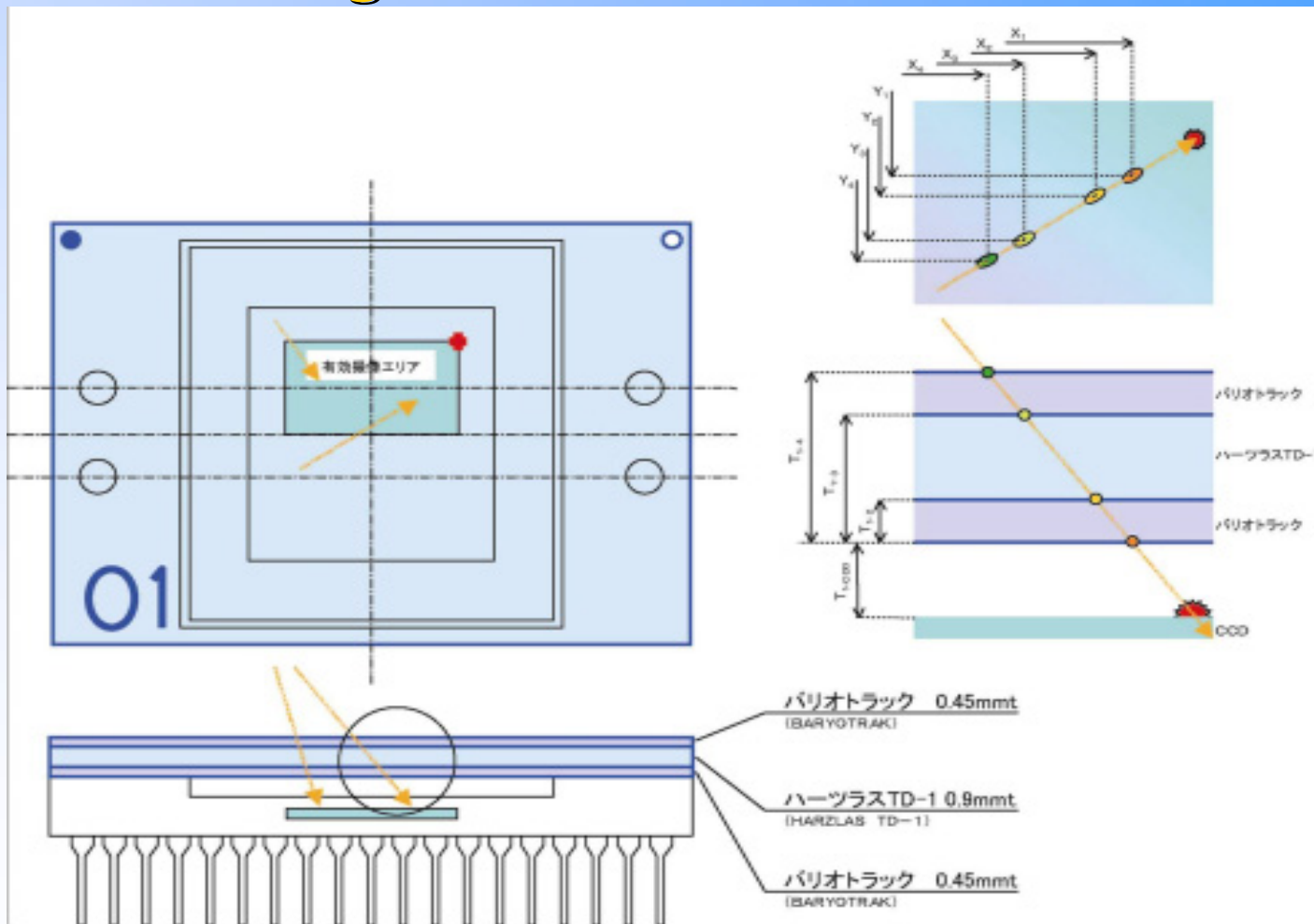
× 200

BARYOTRAK surface after 61.5h etching



4. Tracking

The arrangement of CR-39 and CCD device



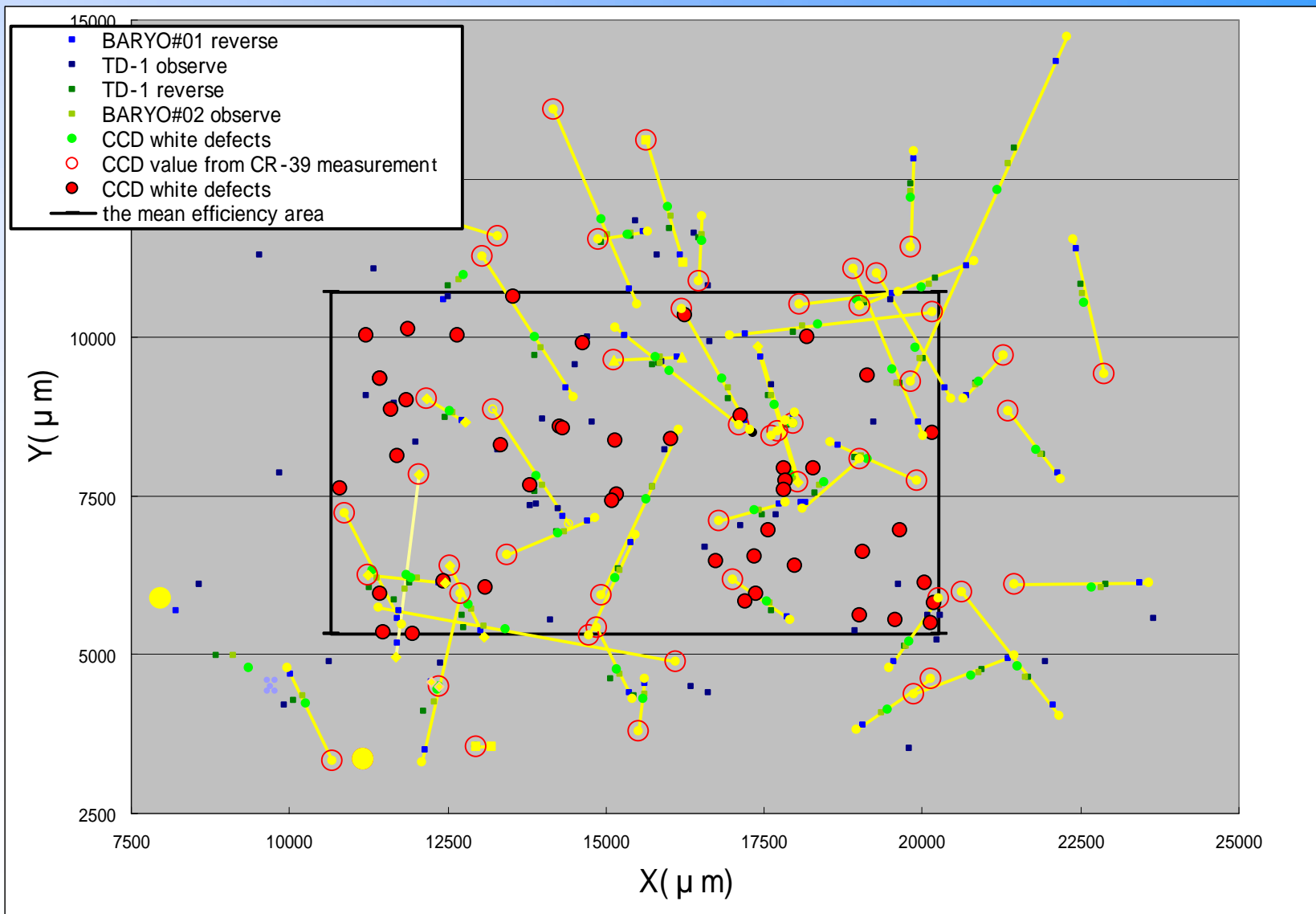
HZE particles penetrate to the effective area of CCD elements (2.2 million pixel/CCD) were analyzed.



4. Tracking



CCD 2037 [71 days]

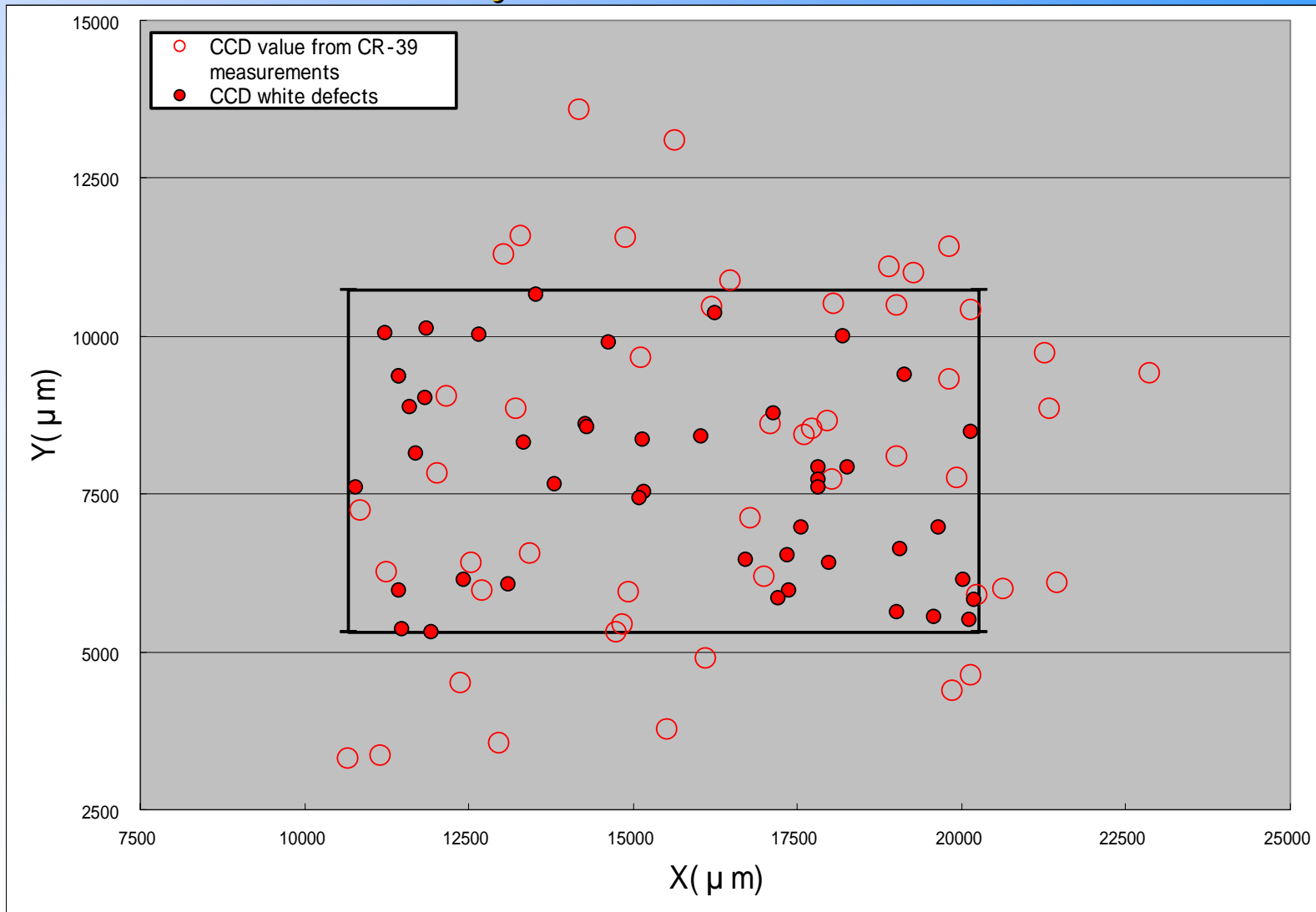




4. Tracking



CCD 2037 [71days]

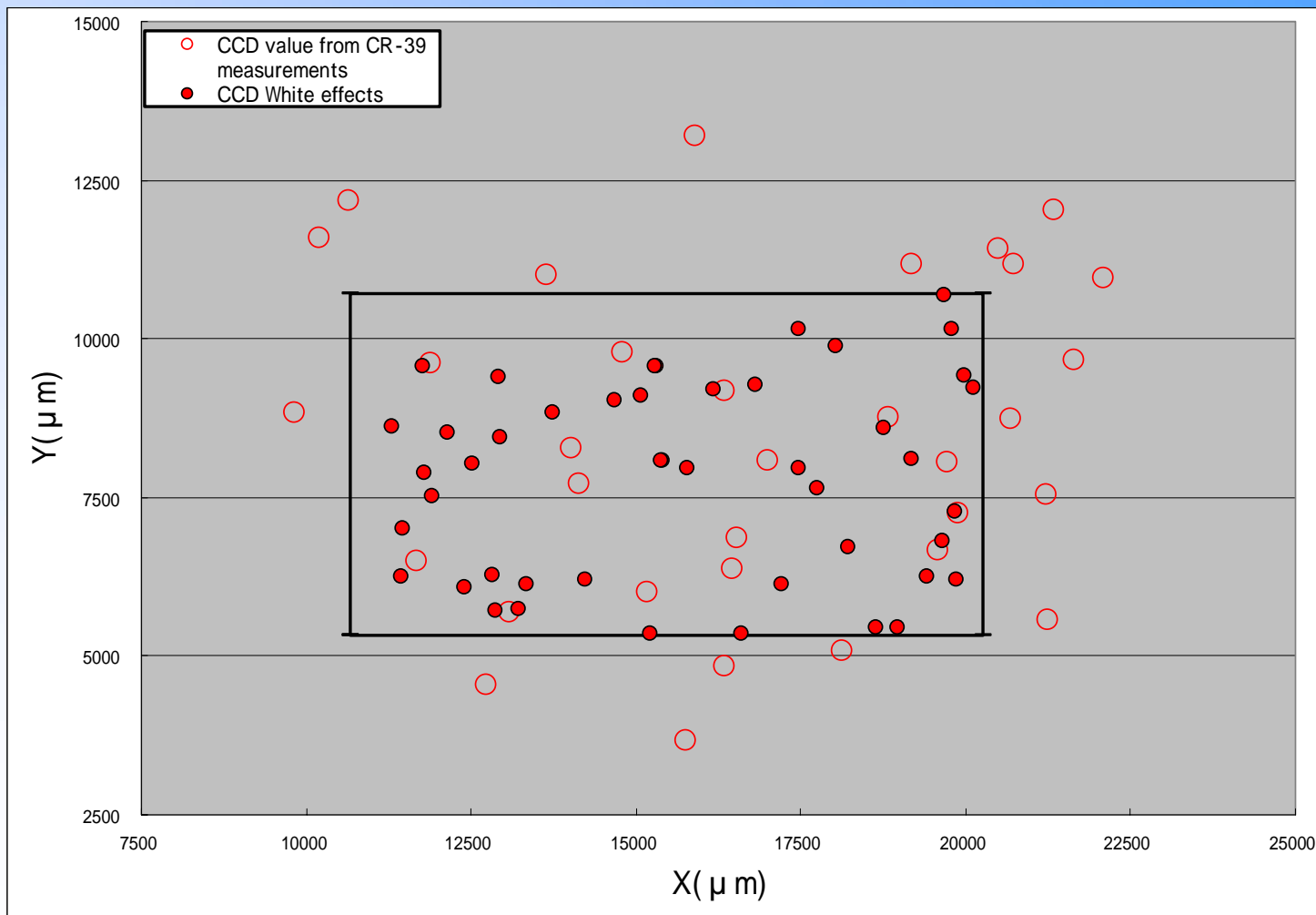




4 . Tracking



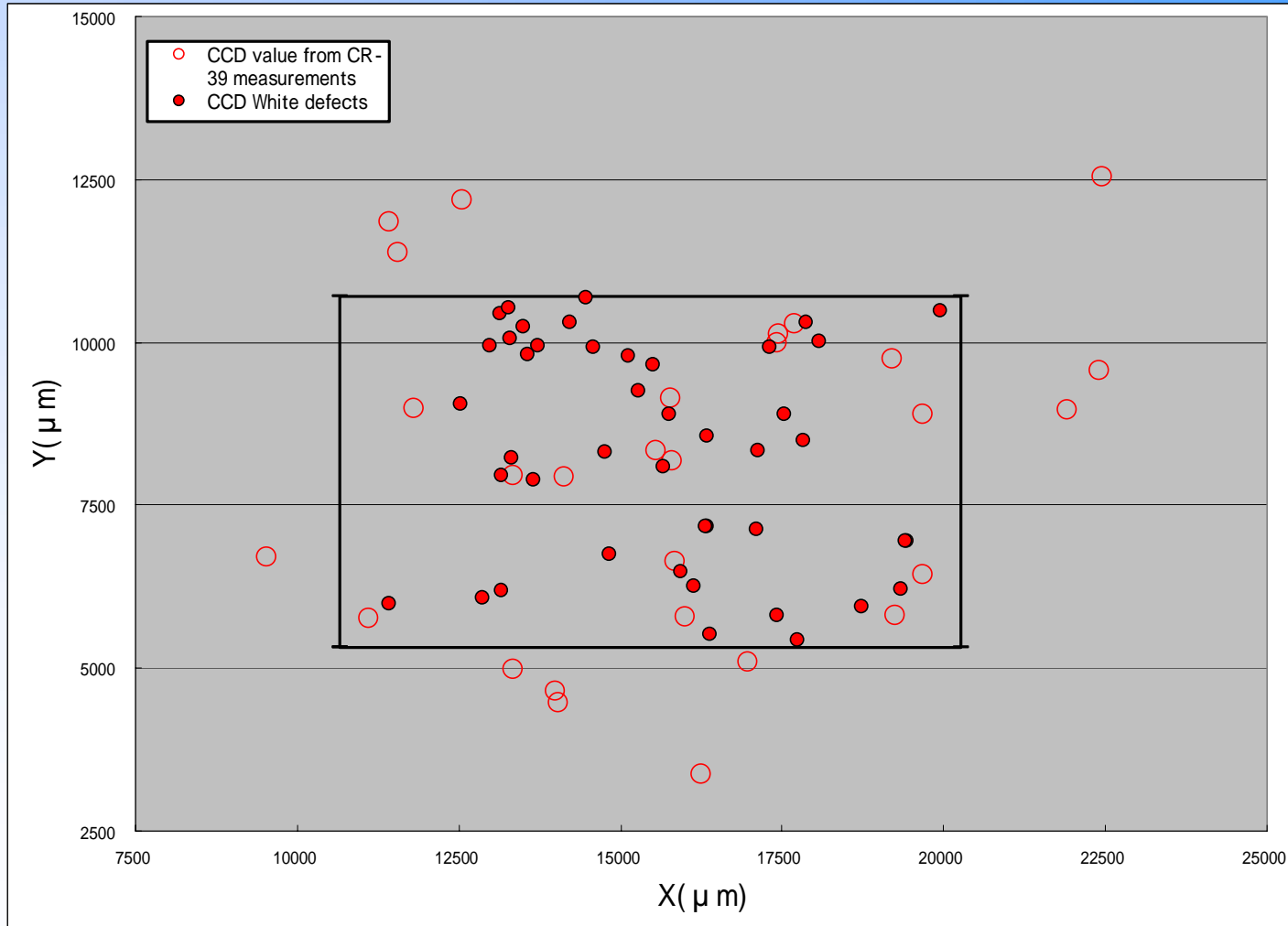
CCD 2038 [71 days]





4. Tracking

CCD 2039 [71 days]

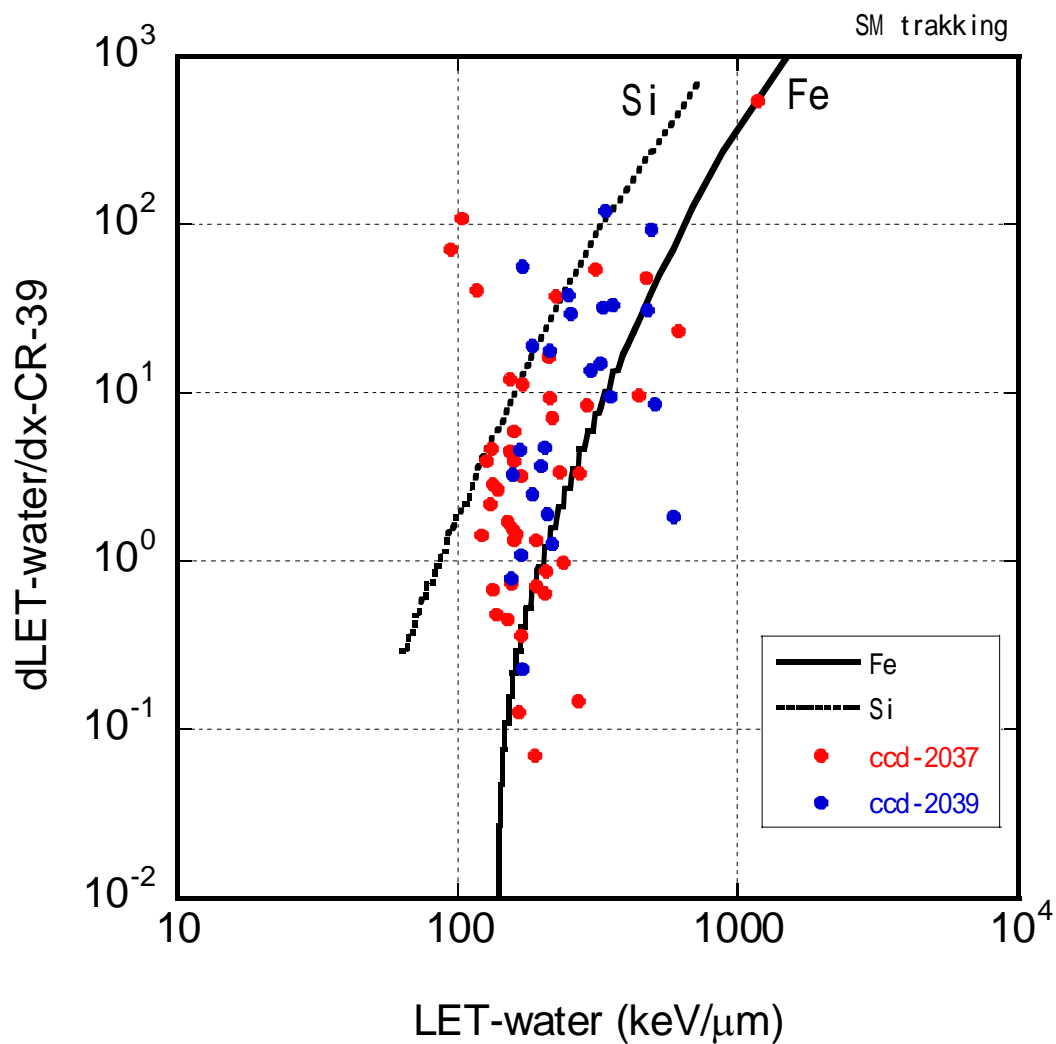




4 . Tracking - results -



LET values of measured HZE particles





4 . Tracking - results -



The number of HZE particles and their LETs measured in the CCD areas (1920×1080 pixels, 0.52 cm^2):

CCD 2037	4 9 tracks	120.7	LET	721.1 keV/ μm
CCD 2038	3 3 tracks	115.5	LET	1057 keV/ μm
CCD 2039	2 8 tracks	154.2	LET	590.2 keV/ μm

Most of these HZE particles are Si to Fe nuclei.



5. Summary & Future Work



We conducted space radiation dosimetry for the radiation damage test of HDTV CCD elements using passive detectors (PADLES) in ISS ZVEZDA, 21/8/2001 ~ 10/11/2002.

Dosimetry

We measured the absorbed doses, dose equivalents, QFs for space radiation in the entire LET region by a combination of TLD-MSO and CR-39 data.

The LET distributions were reconstructed from SRP and LRP distributions.

Tracking

We conducted tracking of the HZE particles on CCD elements using CR-39 stacks.

Future works

Development of AutoPADLES system

-high-speed and semi-automatic analysis system for track detectors -

Tracking for correlation with HZE and white spot of CCD elements.