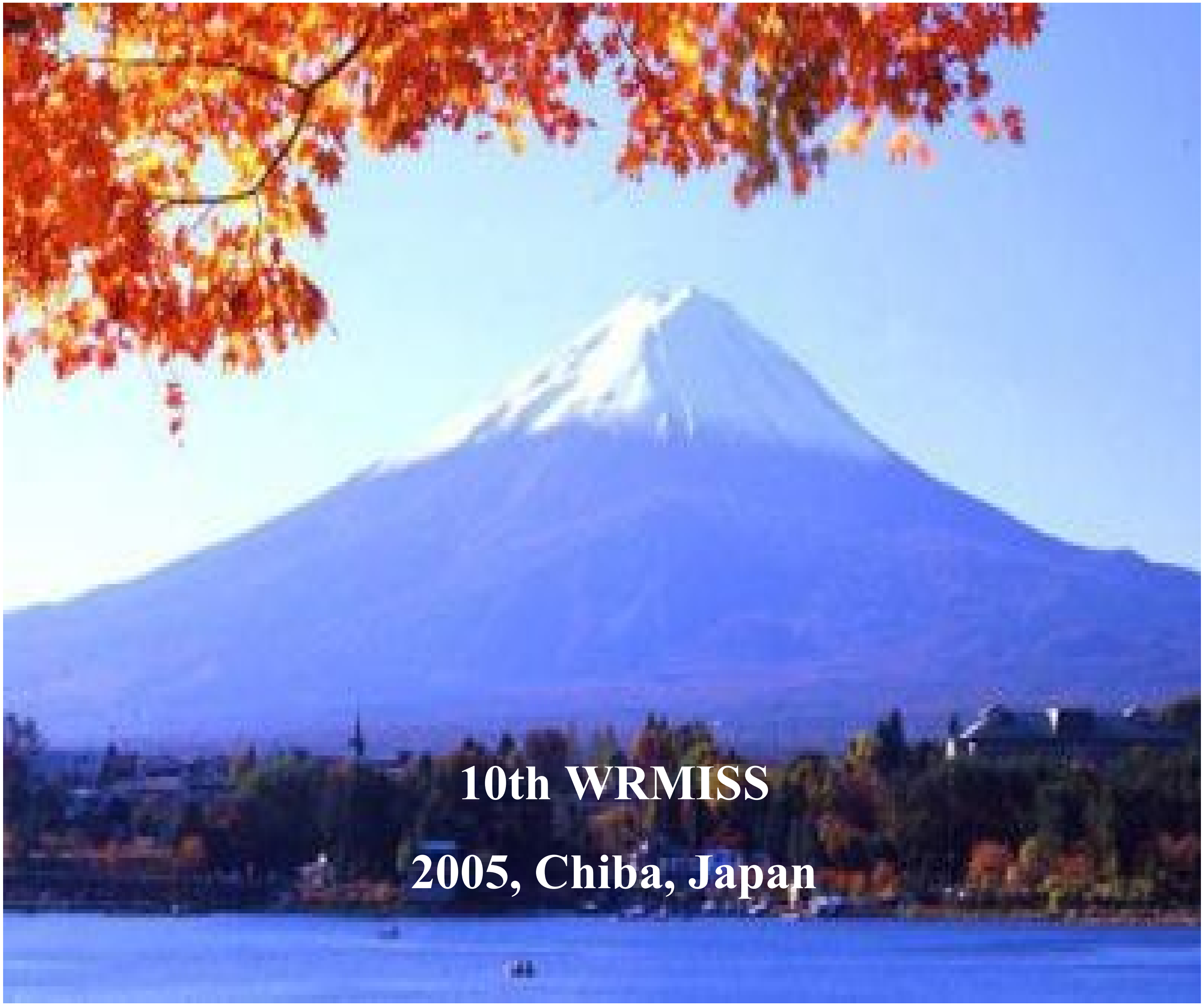
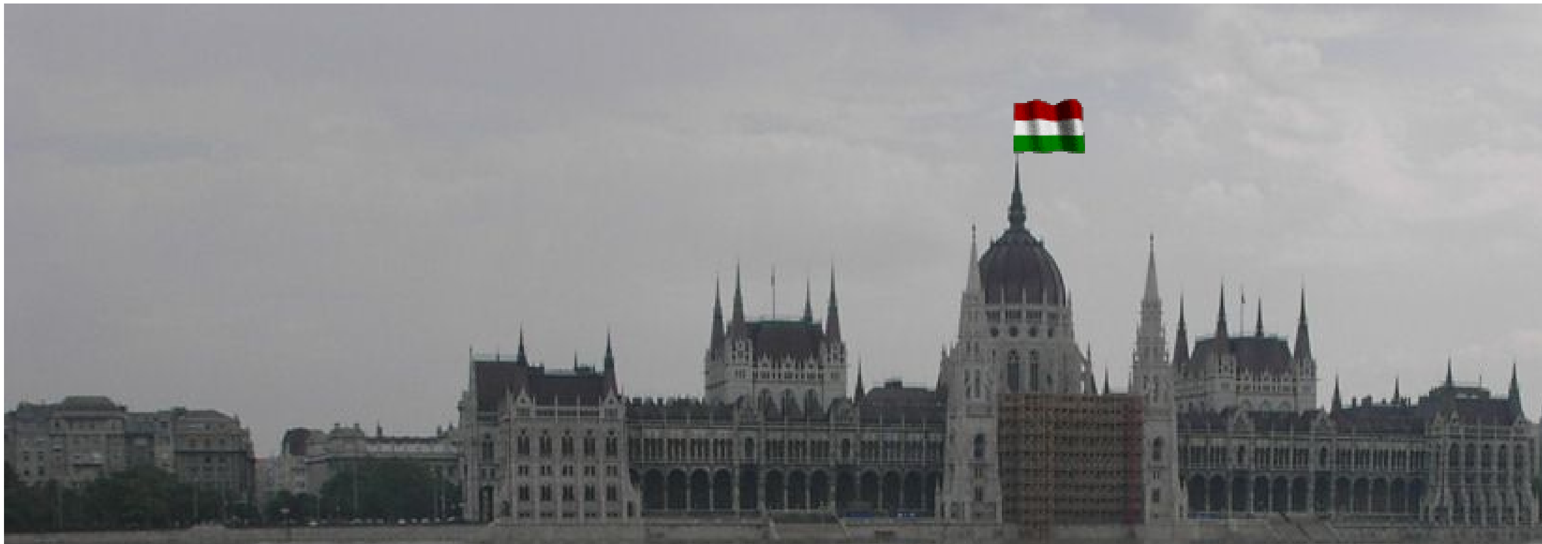

10th WRMISS
2005, Chiba, Japan



ICCHIBAN calibrations and intercomparisons: ICCHIBAN-6 and NSRL-BNL

J. K. Pálfalvi[1], J. Szabó[1], B. Dudás[1], and I. Eördögh[2]

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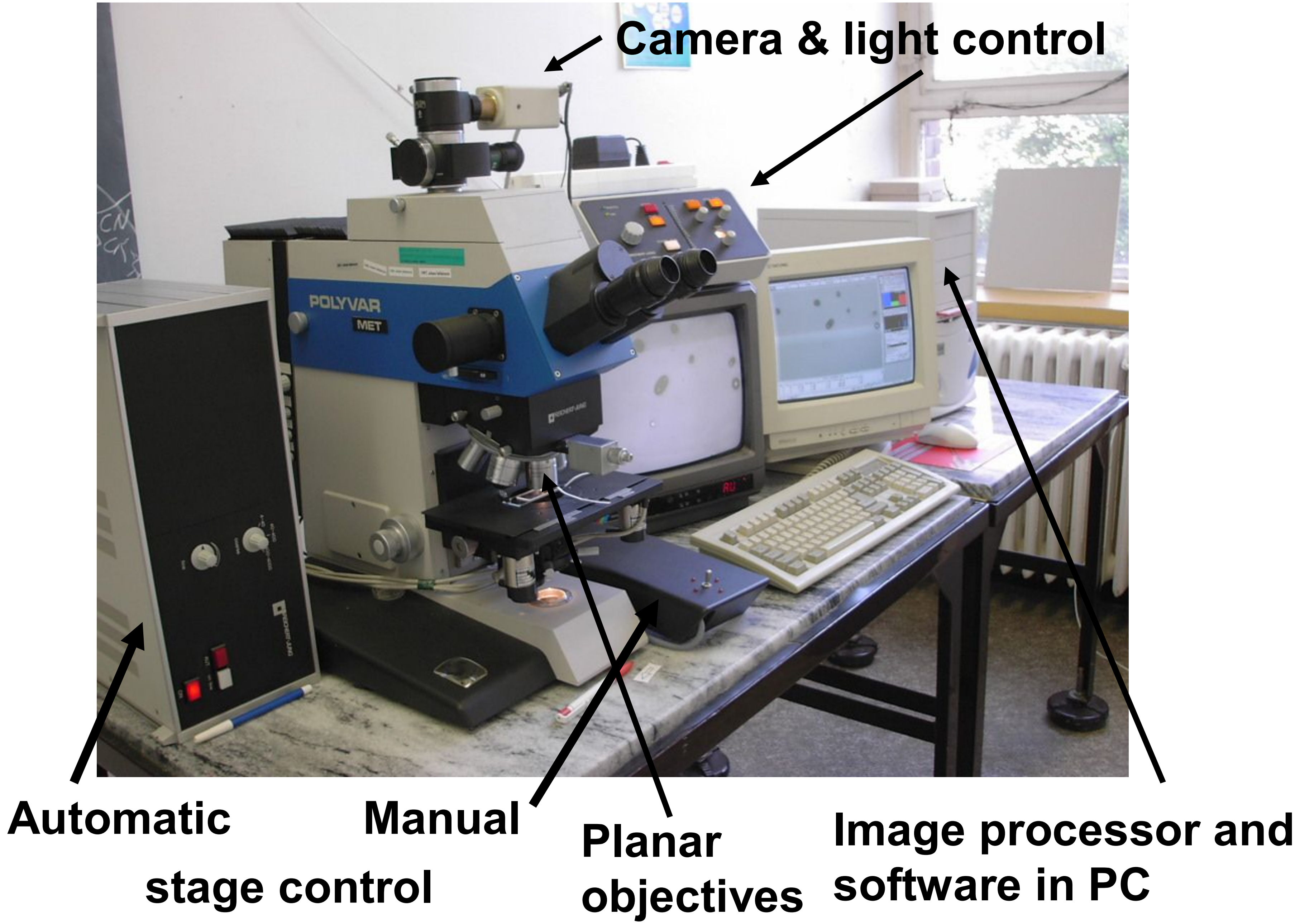
CONTENTS

This work was partly supported by the Hungarian Space Office, 2001-2005, Contract No. TP-174.



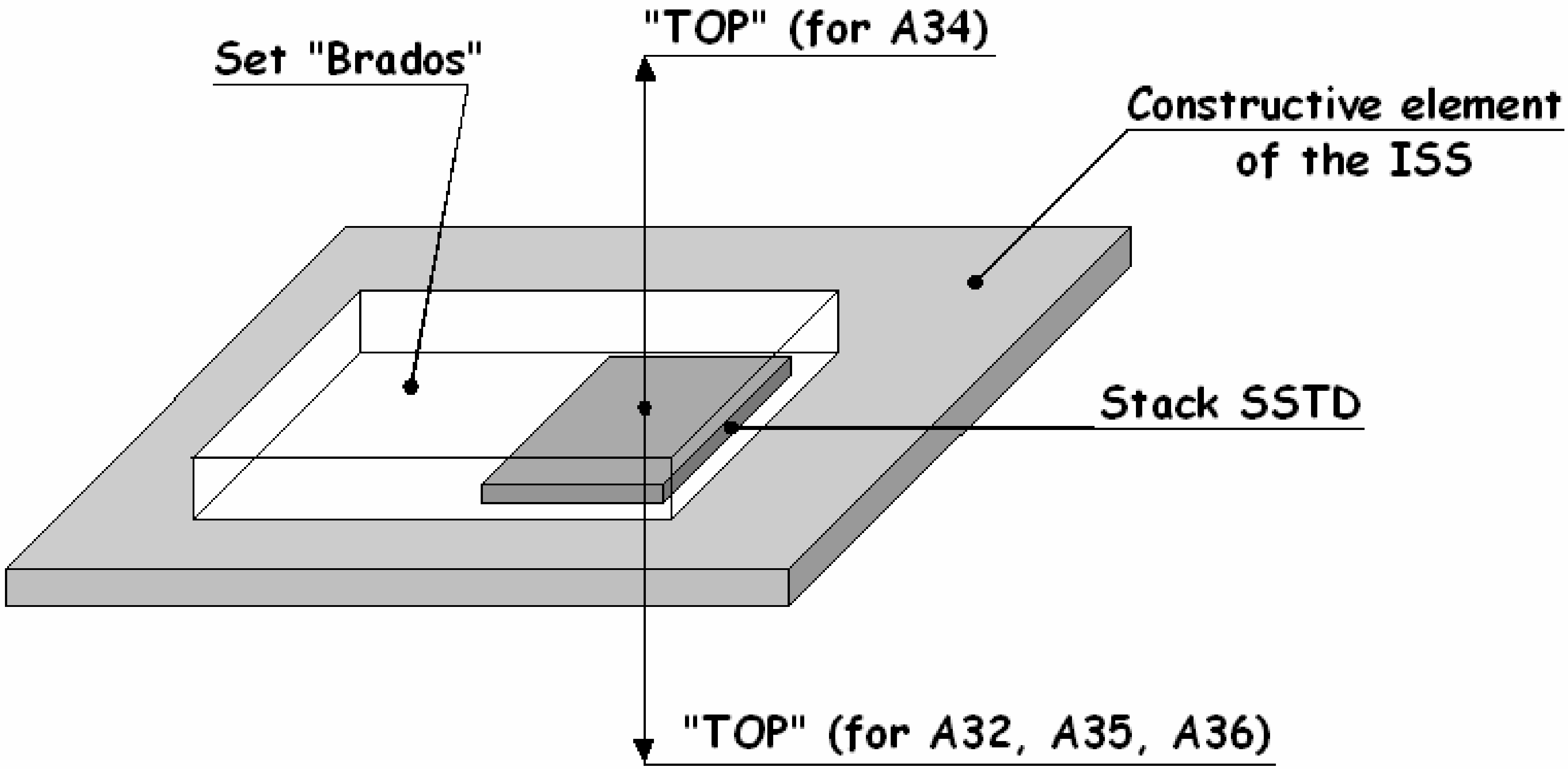
VIRGINIA© system, Ver. 4/2005

VIRGINIA image analyser: few modifications since 2000, see Refs. 1-4.

The purpose of participating in ICCHIBAN inter calibrations was to facilitate the evaluation of track etch detector stacks exposed on the ISS during the BRADOS 1, 3 and 5 projects, 2001-2005, and MATROSHKA I and II projects 2003-2007, see Refs. 2-5.

ICCHIBAN stacks were developed to simulate the BRADOS box made of aluminium and fixed to different panels of the ISS with different effective shielding thickness.

The stacks were covered on both sides by 1.5 mm thick Al layers, below the Al, 2 to 4 layers of 1 mm thick PADC layers (TASTRAK) were places, followed by few polycarbonate (Makrofol-E or Lexan) sheets of 0.475 mm thick.

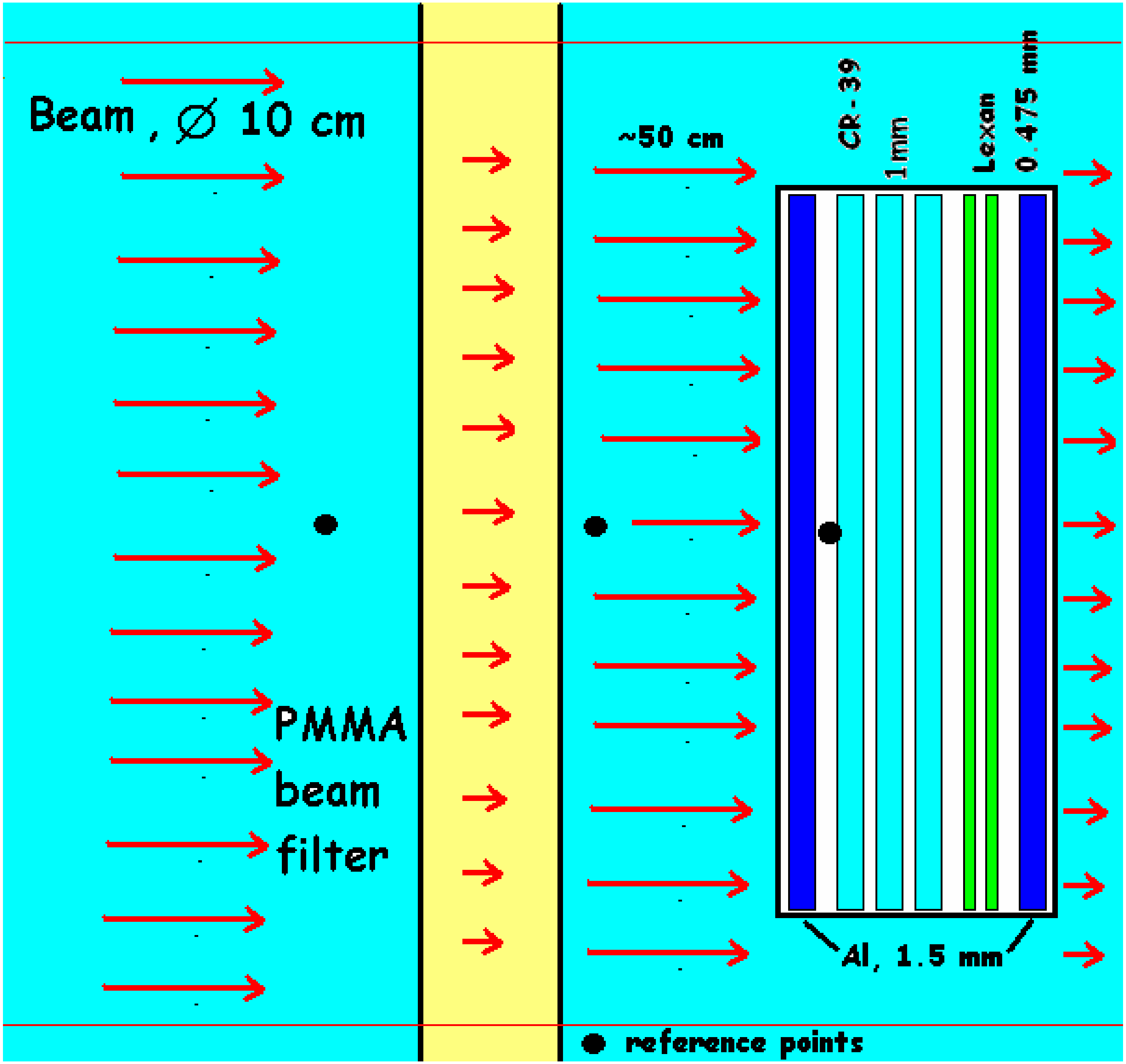


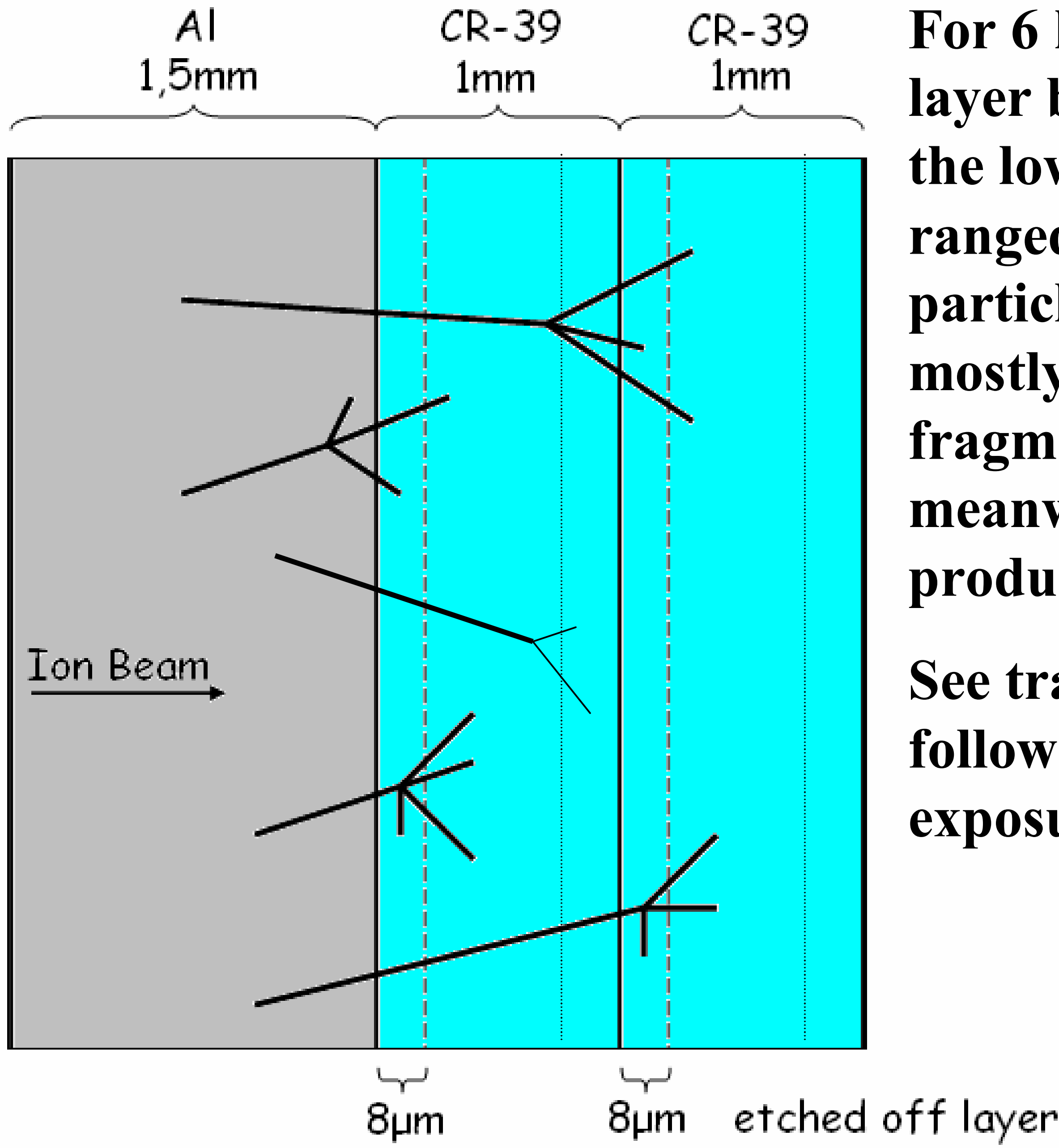
Schematic view of the BRADOS box with the location and orientation of the PADC stacks during BRADOS-3 experiment in 2003.

The ICCHIBAN exposures were carried out with or without filters made of different materials and thickness.

The schematic view of the experimental arrangement of the ICCHIBAN-6 exposures at the HIMAC facility of the NIRS (Chiba, Japan) with PMMA filters is shown on next page.

During the NSRL-BNL (USA) exposures, Al filters were used, the stacks were directly fixed to the filters.


Beam , ∅ 10 cm
PMMA
beam
filter
~50 cm
CR-39
1 mm
Lexan
0.475 mm
Al, 1.5 mm
reference points



For 6 h, etchig, (8 μm removed layer by 6 n NaOH at 70 °C) the low LET, high energy, long ranged (< 15 keV/ μm) particles can be detected mostly via target fragmentation and recoils, meanwhile high LET particles produce also tracks directly.

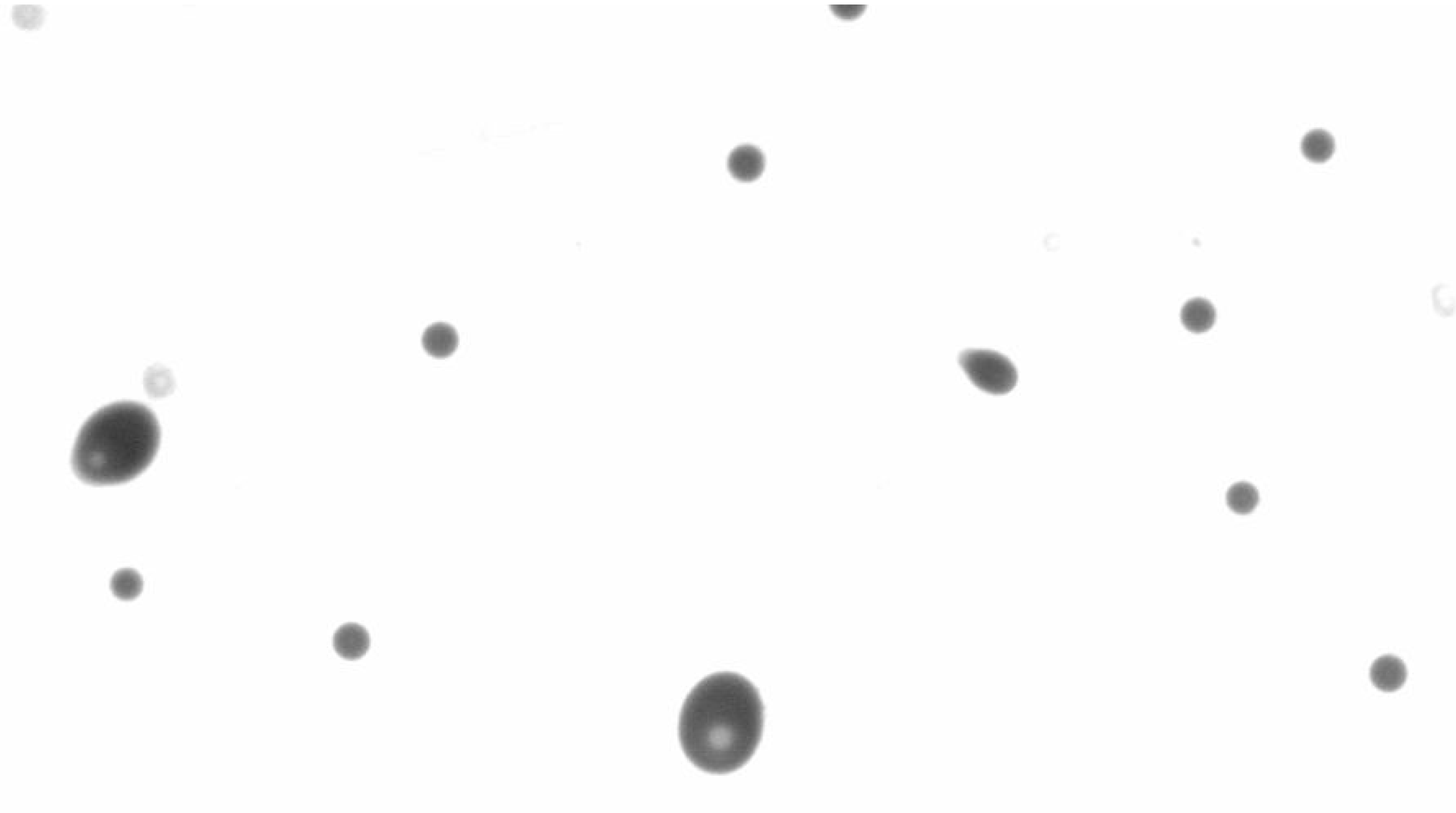
See track pictures in the followings and details of exposures in Tables.

ICCHIBAN-6

Exposures at HIMAC of NIRS

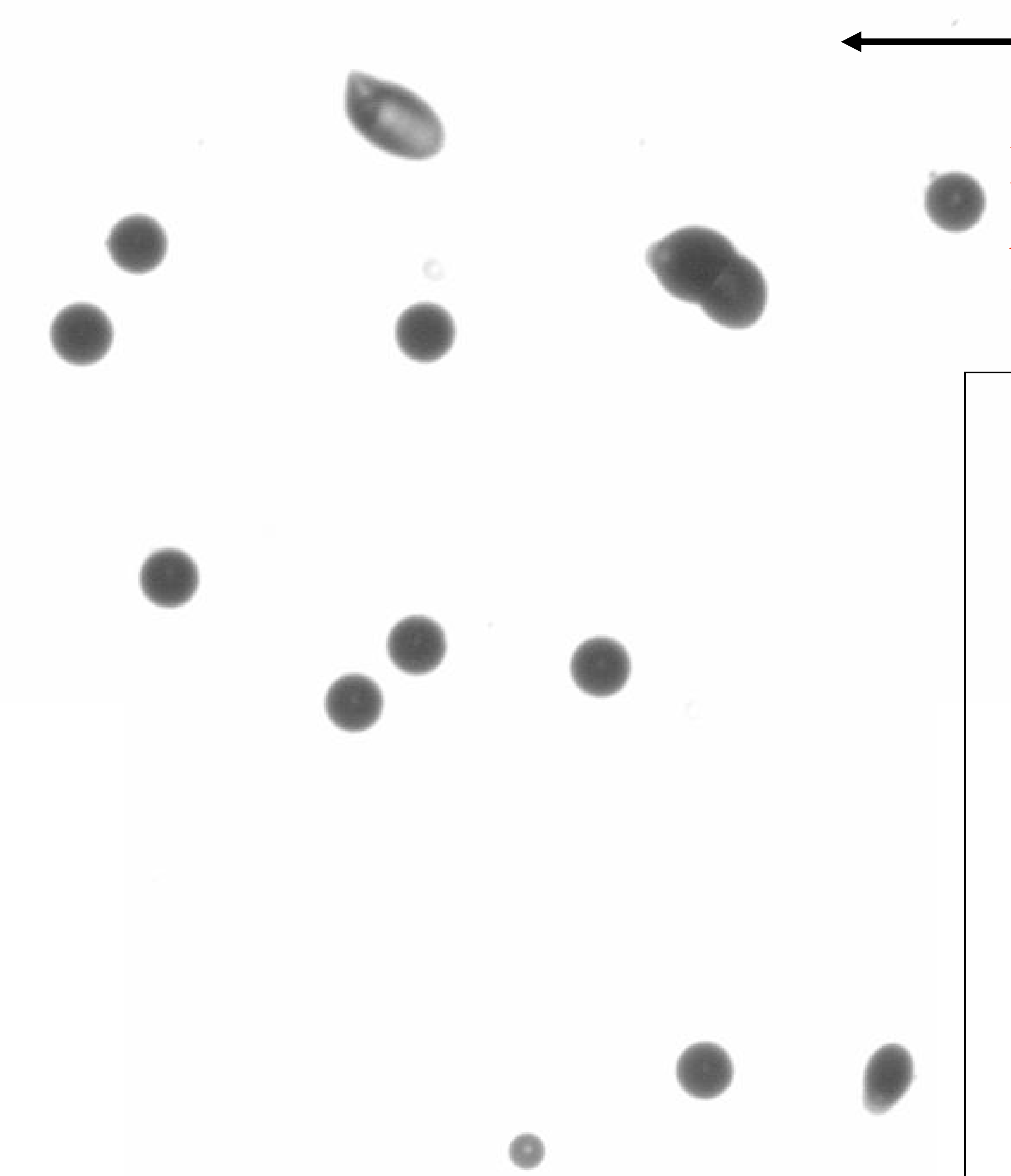
Chiba, Japan

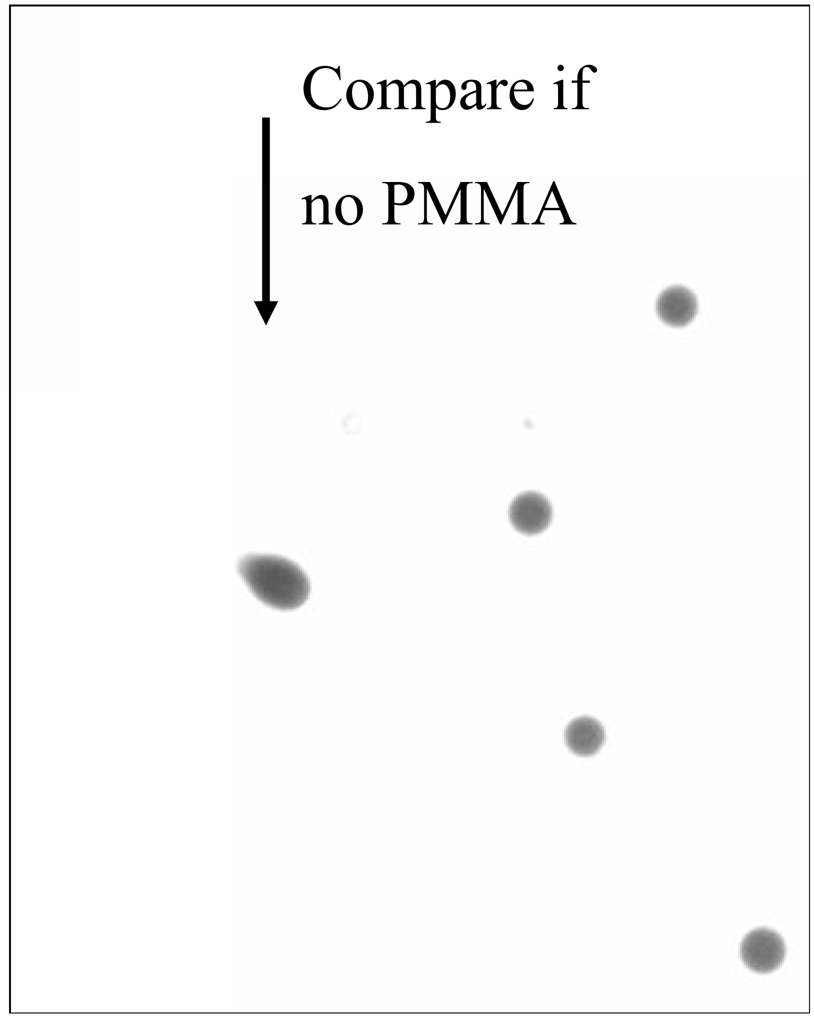
June, 2004

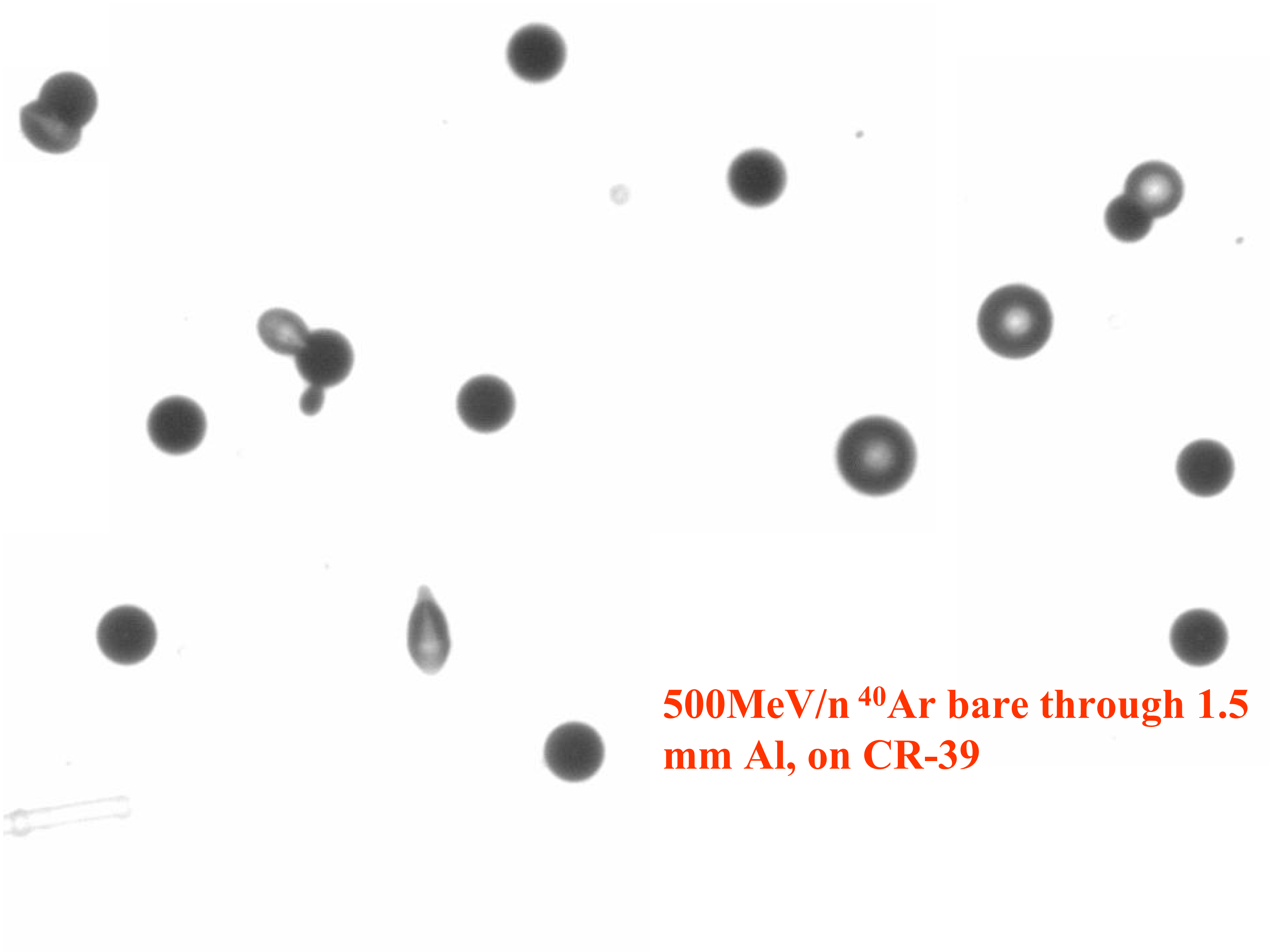


135 MeV/n ^{12}C through 1.5 mm Al & on CR-39, 6n NaOH, 70 ^{o}C, 6h

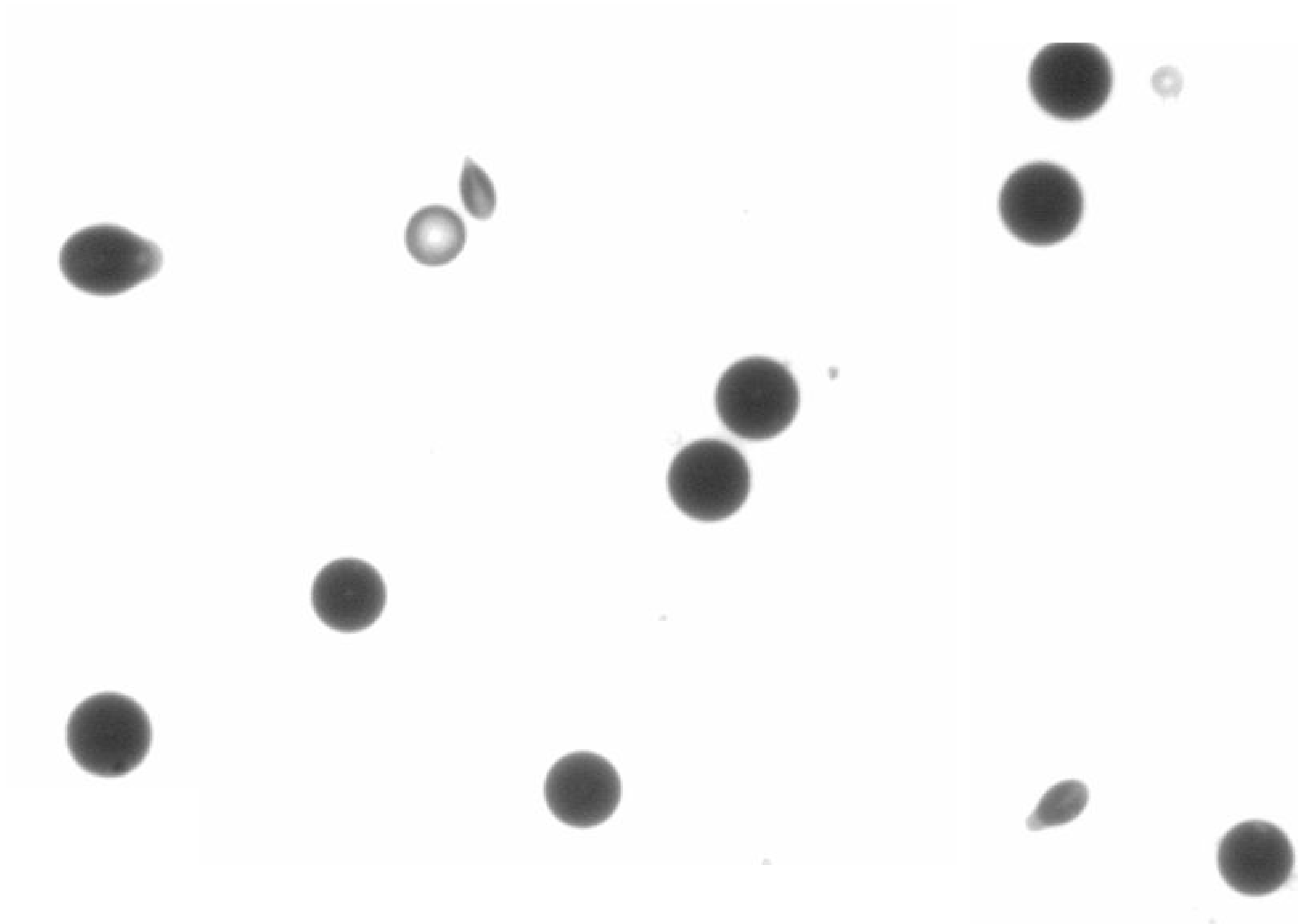
135 MeV/n ^{12}C + 16.6 mm PMMA through 1.5 mm Al & on CR-39, 6n NaOH, 70 ^{o}C, 6h



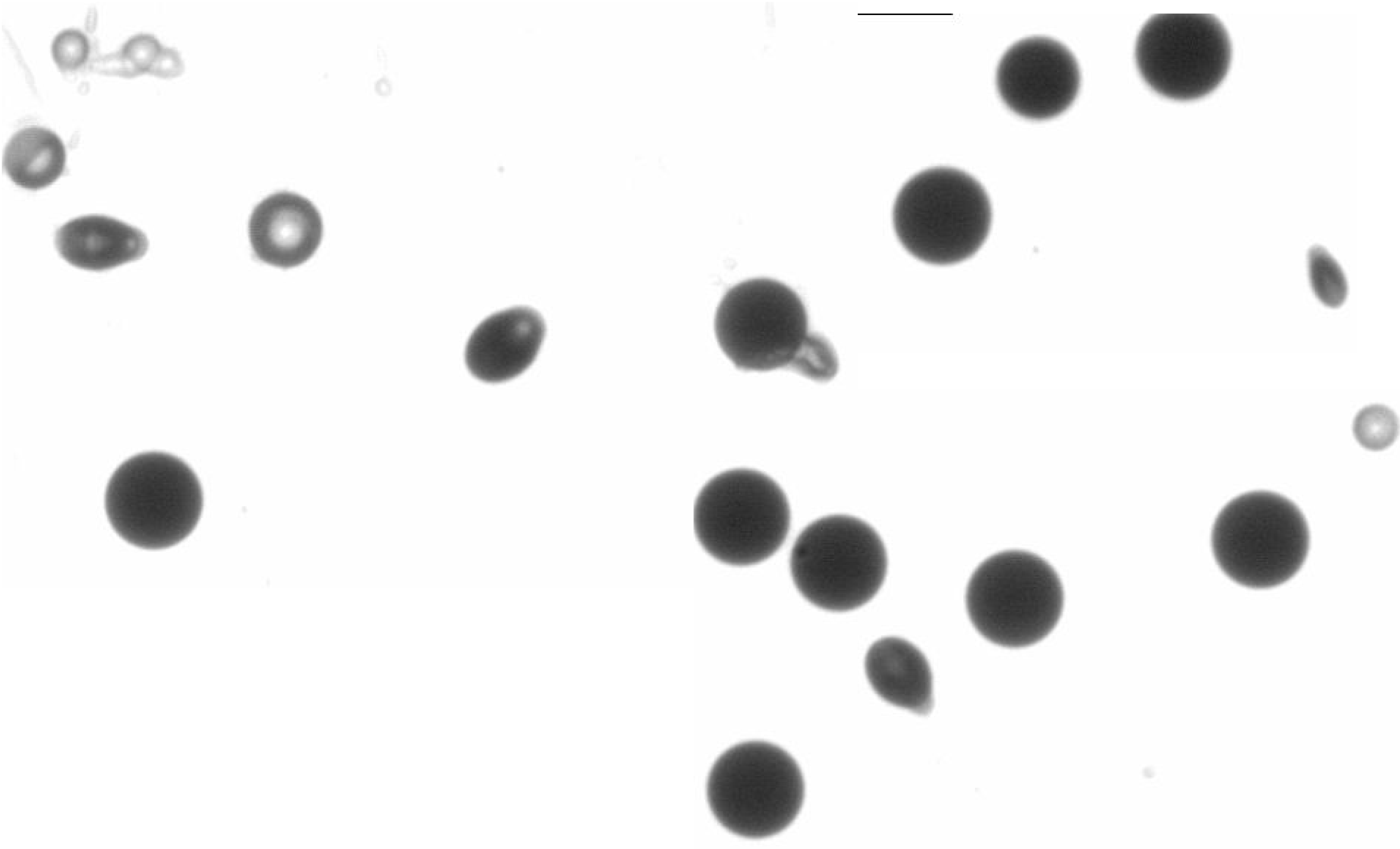




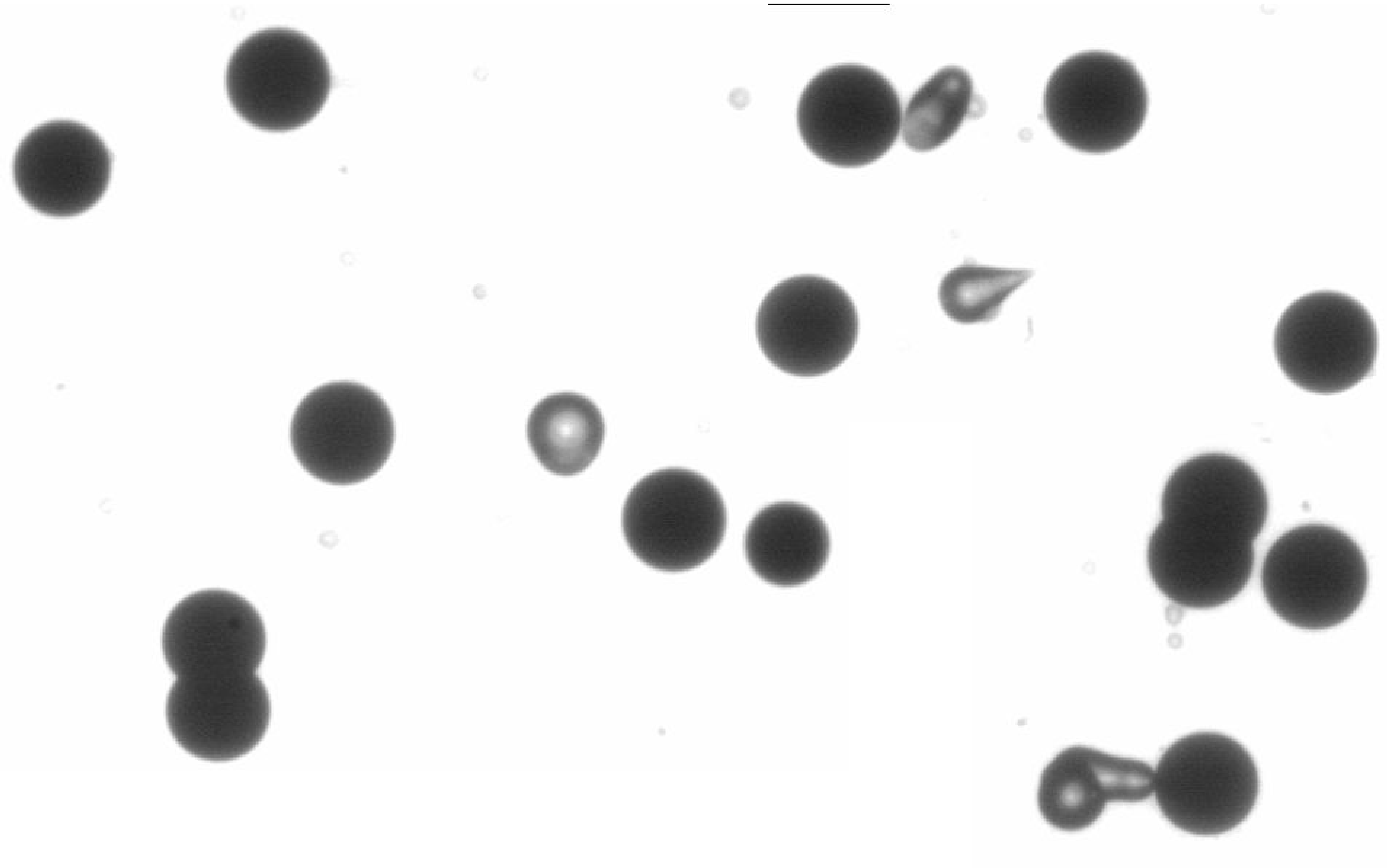
500MeV/n ^{40}Ar bare through 1.5 mm Al, on CR-39



500MeV/n ^{40}Ar + 75.7 mm PMMA through 1.5 mm Al, on CR-39



400 MeV/n Kr-84 bare, through 1.5 mm Al, on CR-39



400 MeV/n Kr-84 & 16.6 mm PMMA, through 1.5 mm Al, on CR-39

	Ar-40, 19.2 GeV*, 93.92 keV/μm **			
Depth in	Al***		PMMA^ +Al***	
CR-39	Energy	LET in Water	Energy	LET in Water
mm	GeV	keV/μm	GeV	keV/μm
0	18.9	94.56	9.14	139.2
1	18.8	94.78	8.96	141
2	18.7	95	8.79	142.8
3	18.6	95.2	8.61	144.7
4	18.5	95.43		

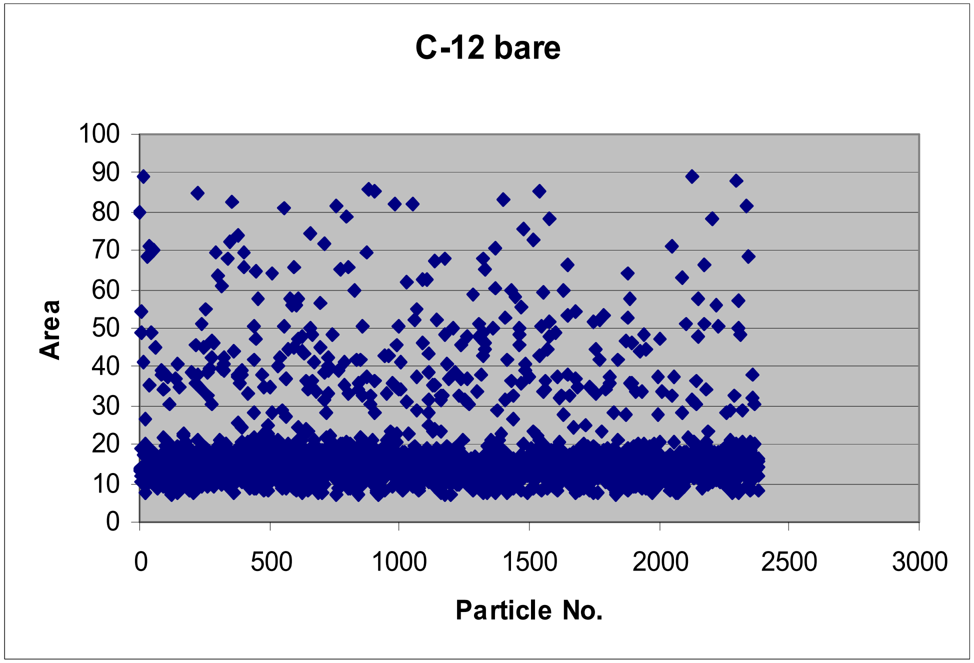
Kr-84, 25.95 GeV*, 450.8 keV/μm **			
Al***		PMMA^^ +Al***	
Energy	LET in Water	Energy	LET in Water
GeV	keV/μm	GeV	keV/μm
24.5	465.2	14	655.1
23.9	471.9	13.1	684.4
23.3	478.6	12.3	714
22.7	485.8	11.4	752

C-12, 1.3 GeV*, 24.43 keV/μm **			
Al***		PMMA^^ +Al***	
Energy	LET in Water	Energy	LET in Water
GeV	keV/μm	GeV	keV/μm
1.22	25.6	0.591	45.1
1.19	26.08	0.533	49.1
1.16	26.59	0.468	54.5
1.13	27.1	0.396	62.4
1.1	27.68	0.31	74.8

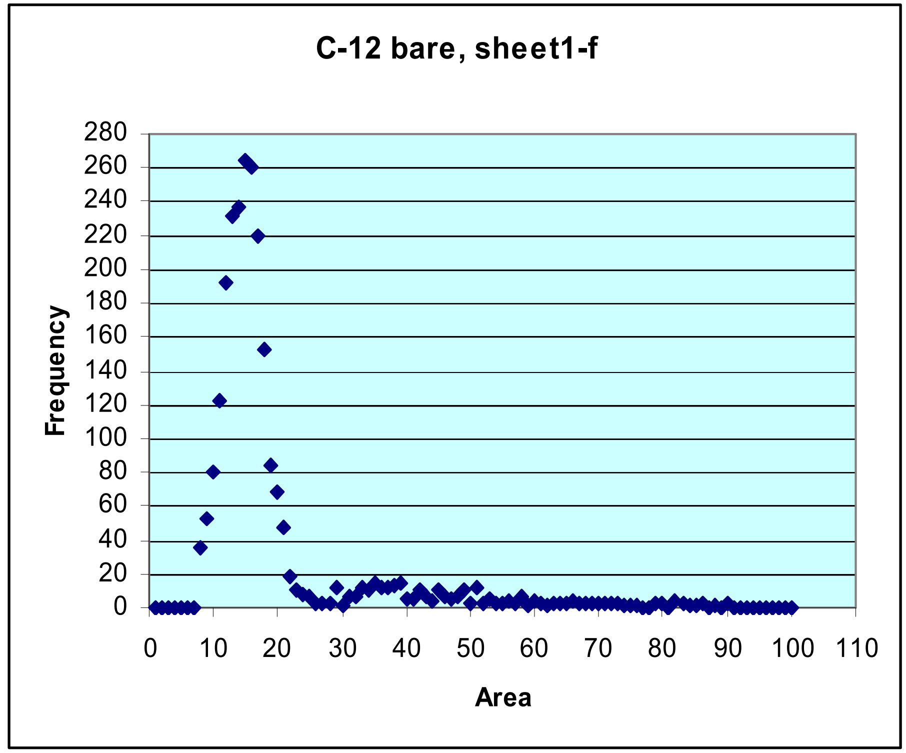
* Calculated by SRIM2003 from LET given by HIMAC staff			
** LET given by HIMAC staff			
*** Al cover thickness =1.5 mm			
^ PMMA thickness =75.66 mm, 90.04 mm water equivalent			
^^ PMMA thickness =16.6 mm, 19.8 mm water equivalent			

DETERMINATION OF THE CALIBRATION FUNCTION USING PARTICLES $Z_i > 1$

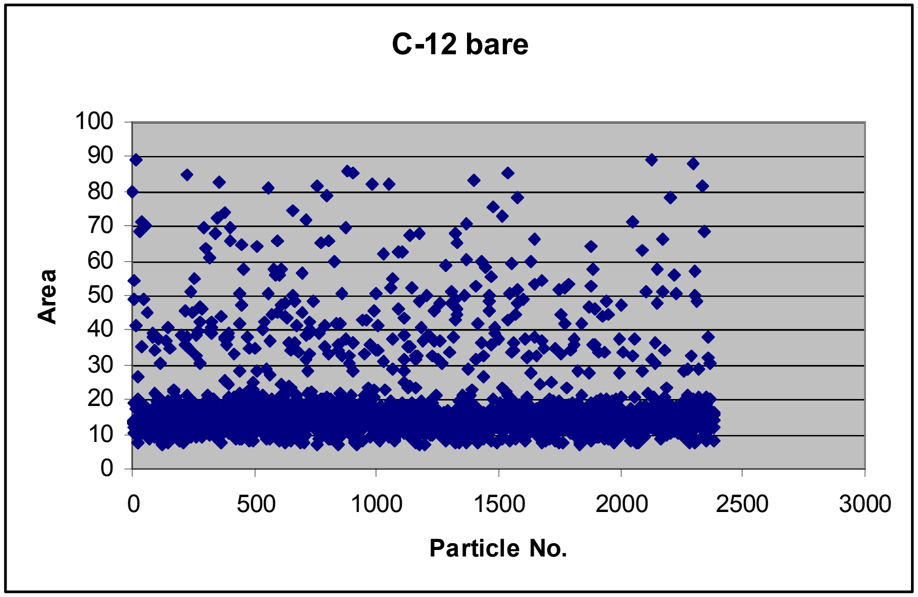
1) Obtain circular track AREA distribution and lower & upper limits for Z_i. Tracks out of limits are due to recoils and fragmentation not to be considered when obtaining the calibration curve.

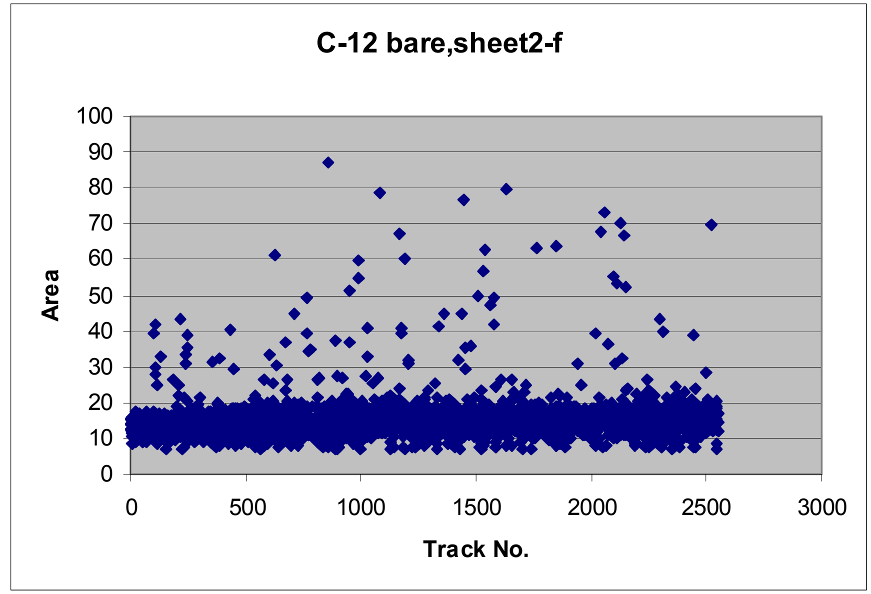


Here the limits are: 5 & 25 μm^2

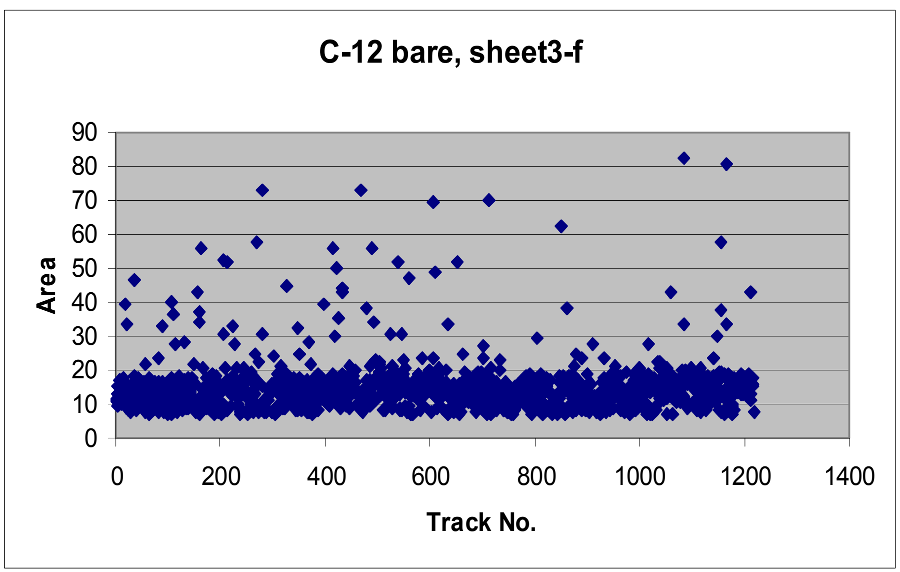


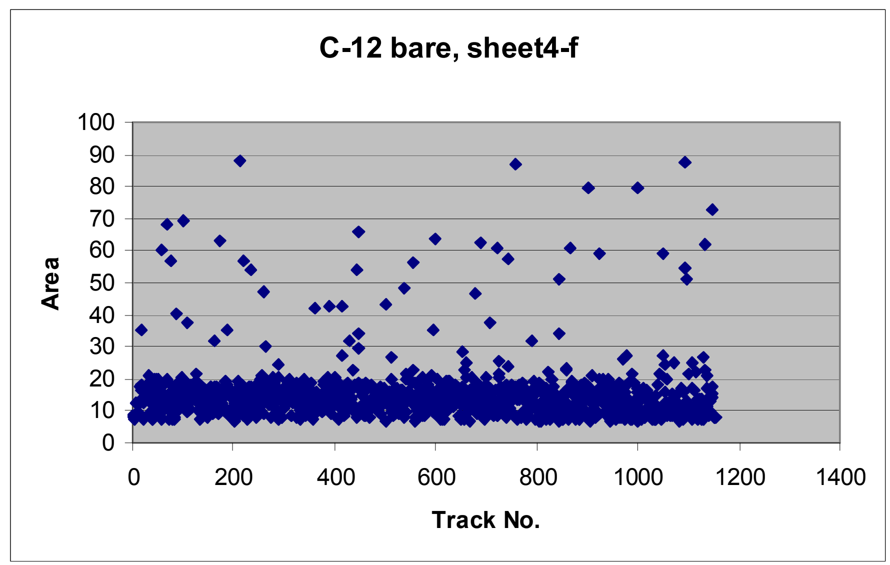
2) From minor & major axes, calculate the track etch rate ratio, V_i, assuming constant V. Then, V_i isrelated to LET_i known from some source or calculated by SRIM 2003 as shown in previous Tables.

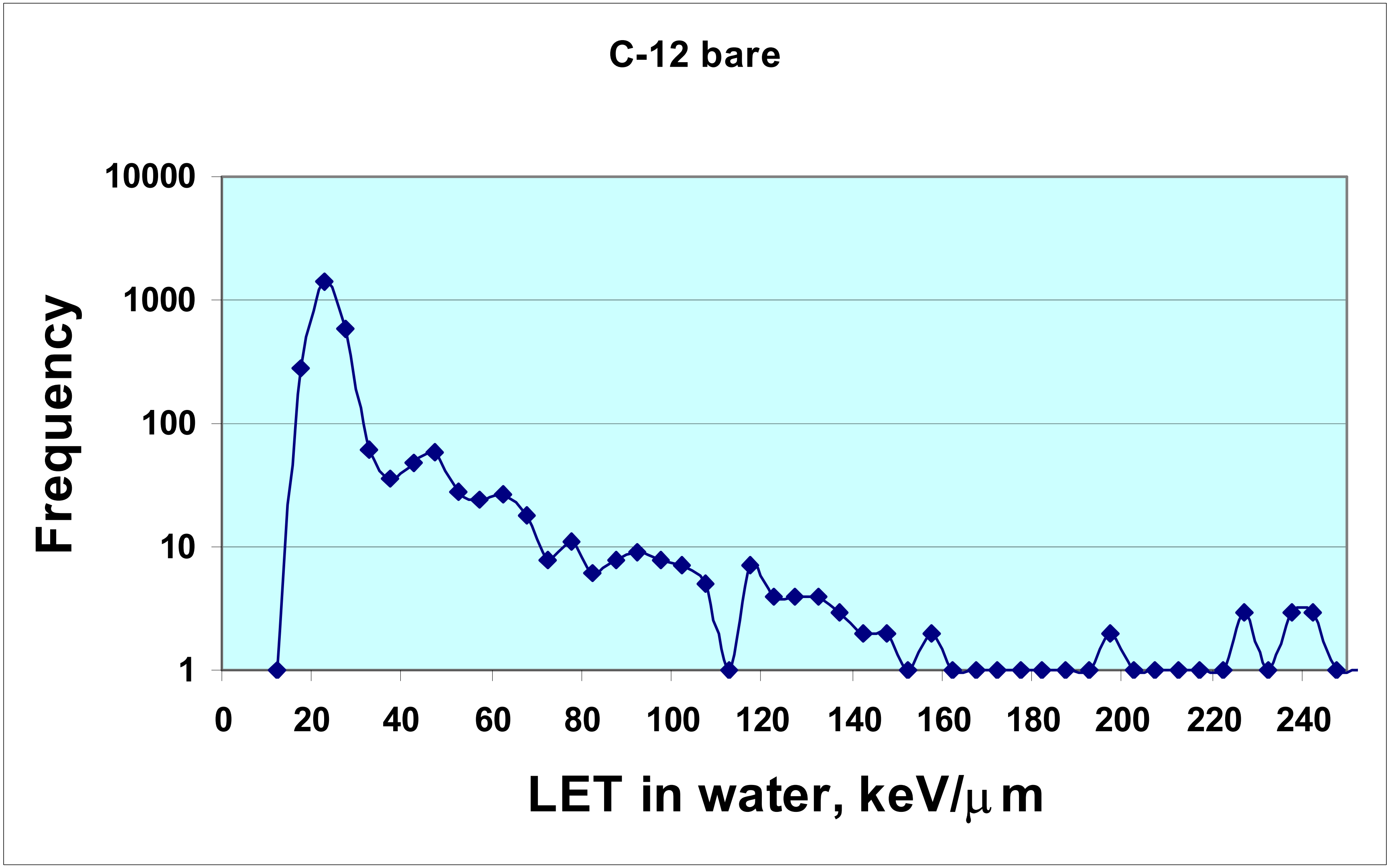




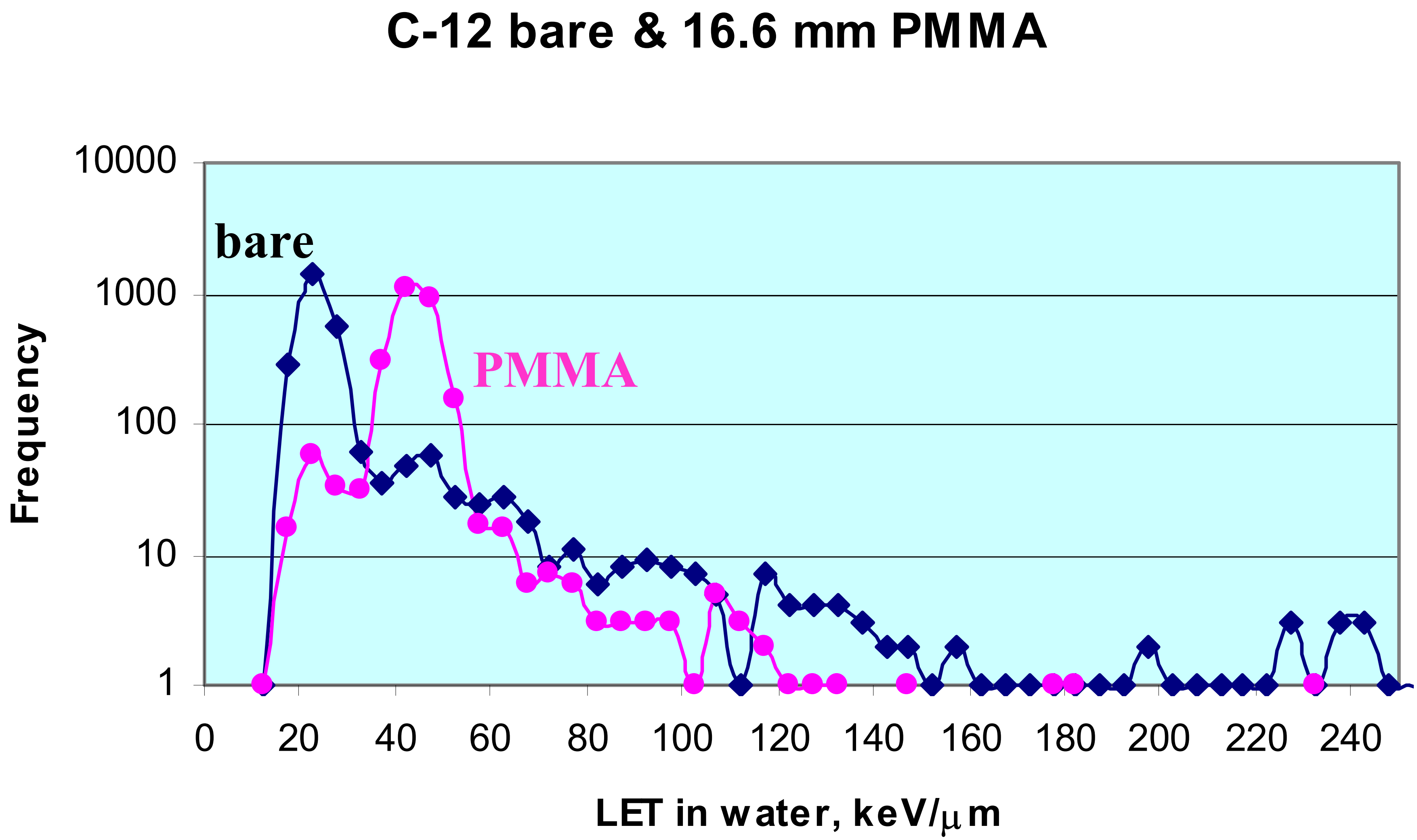
Direct, recoiled and fragmented particle tracks in a stack of 4 sheets after 8 μm removed layer.







Re-calculated LET distribution using the final calibration function, no angular correction was applied.



Re-calculated LET distributions using the final calibration function. The PMMA, composed of low Z atoms, shifts the LET peak in the distribution towards the high LET wing.

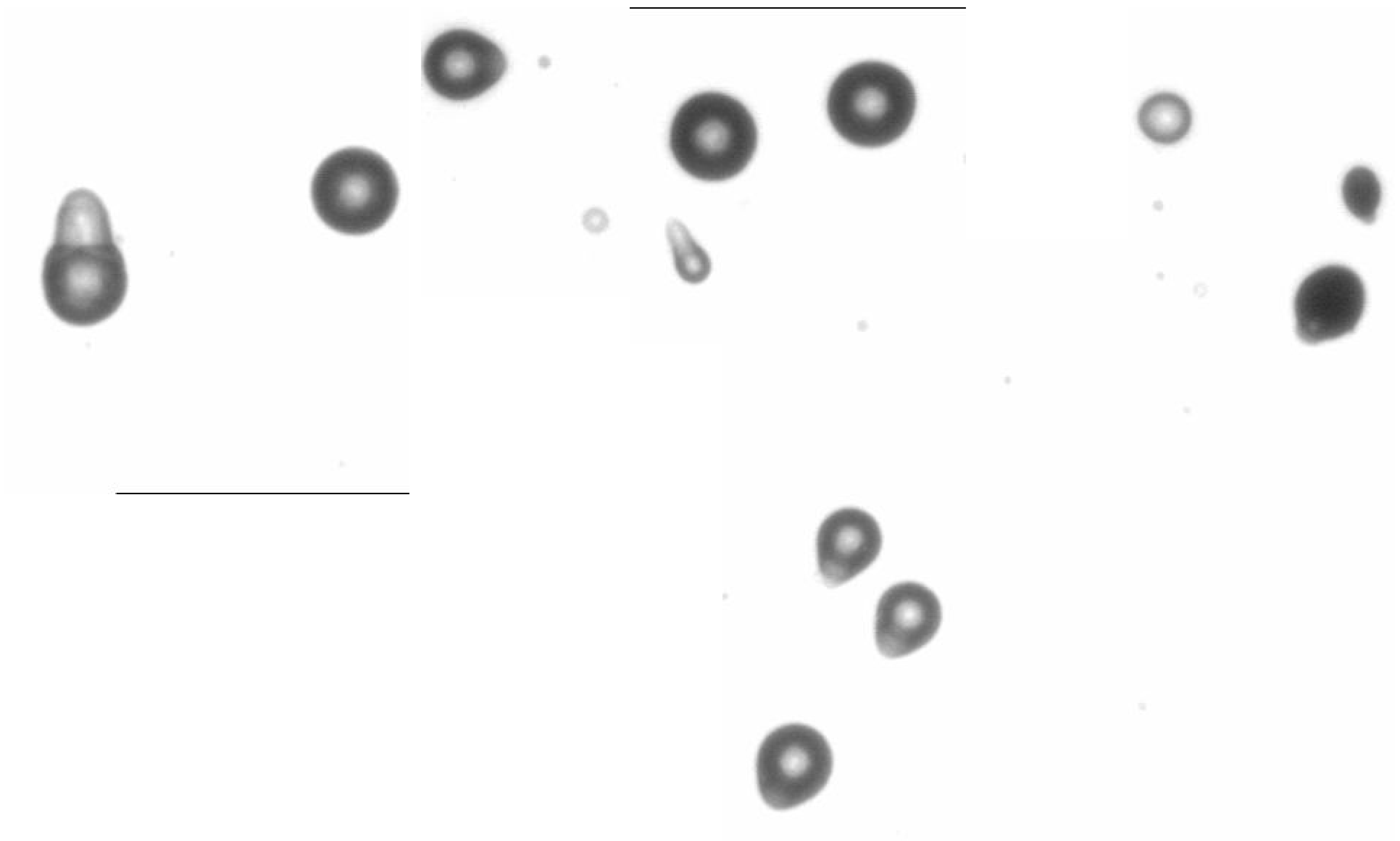
NSRL ICCHIBAN

exposures at

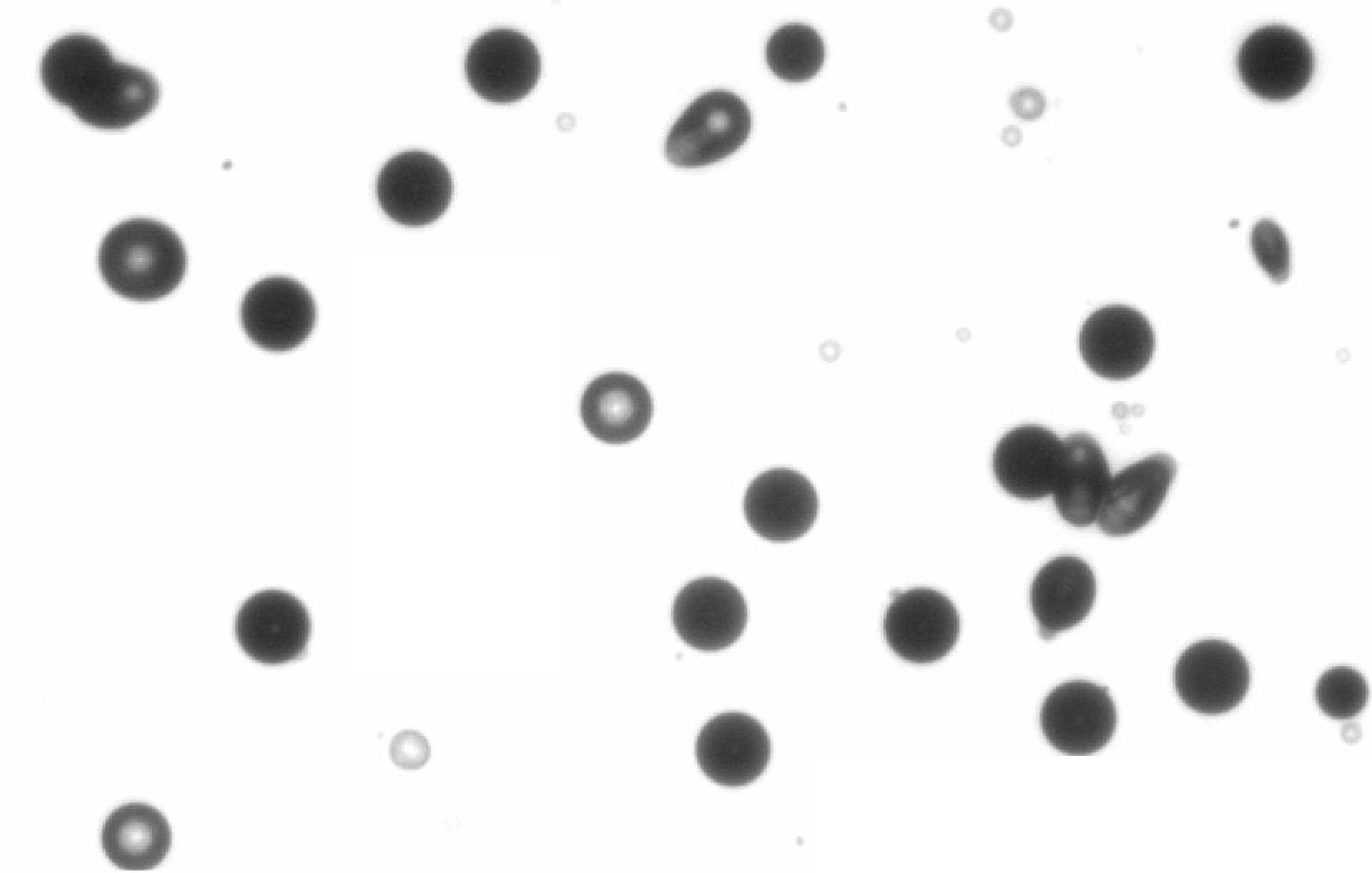
Brookhaven National Laboratory

USA

September, 2004

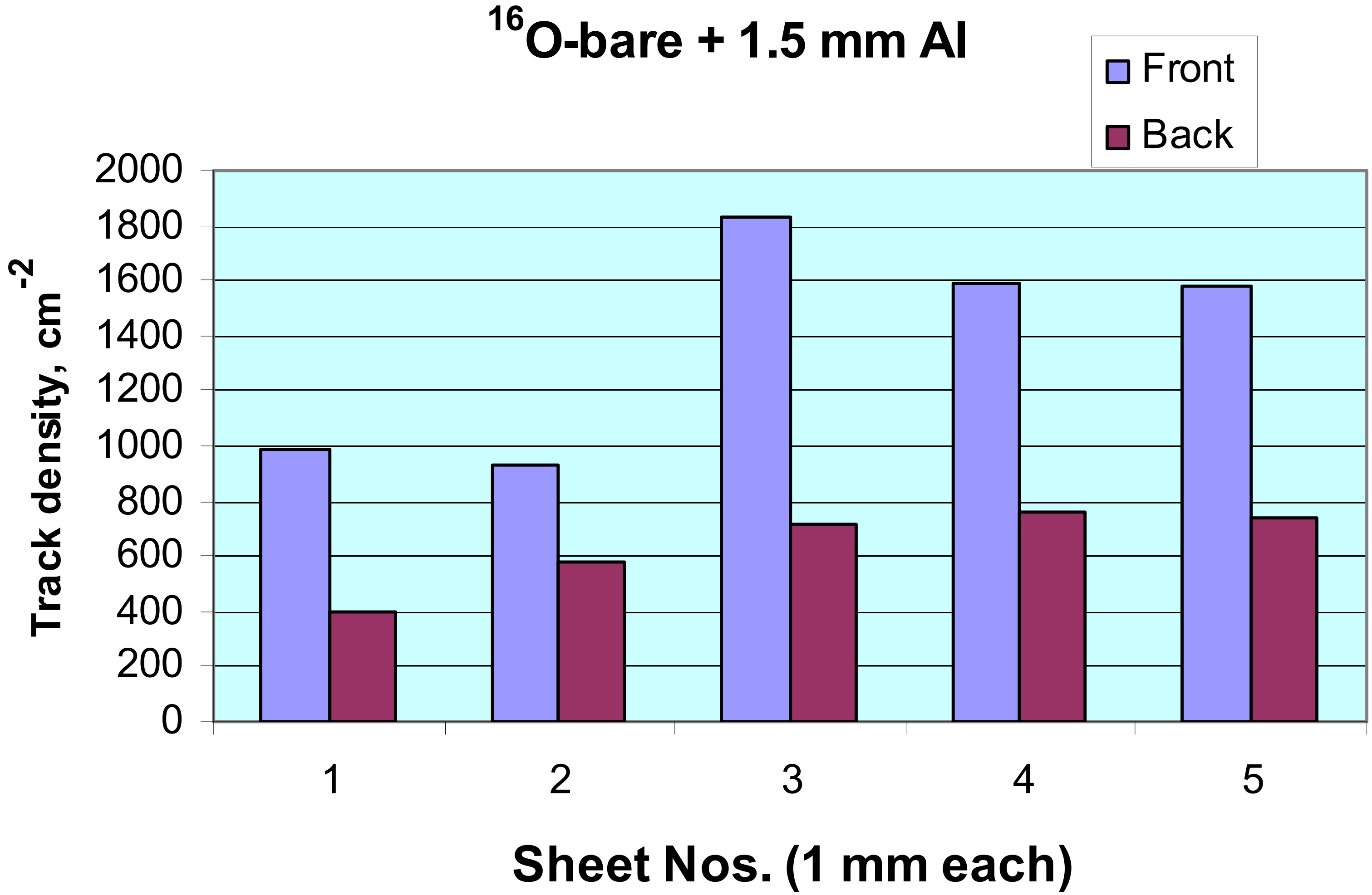


1 GeV/n O-16 bare, through 1.5 mm Al, on CR-39

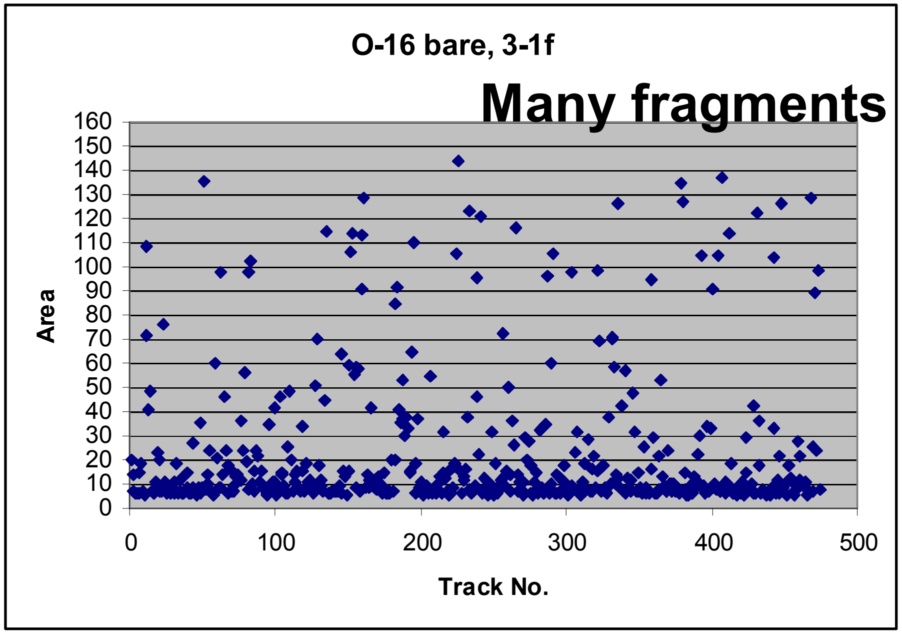


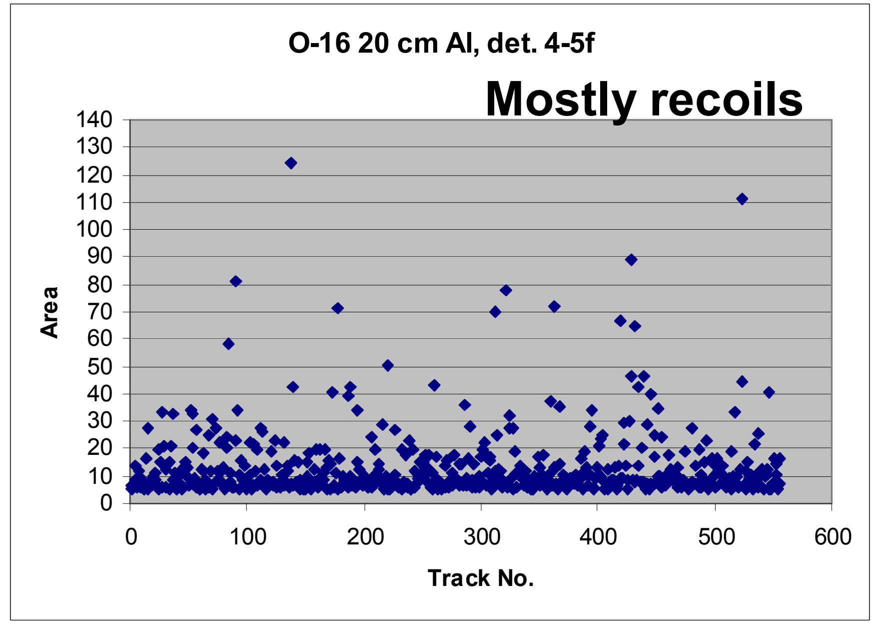
1 GeV/n Fe-56 bare, through 1.5 mm Al, on CR-39

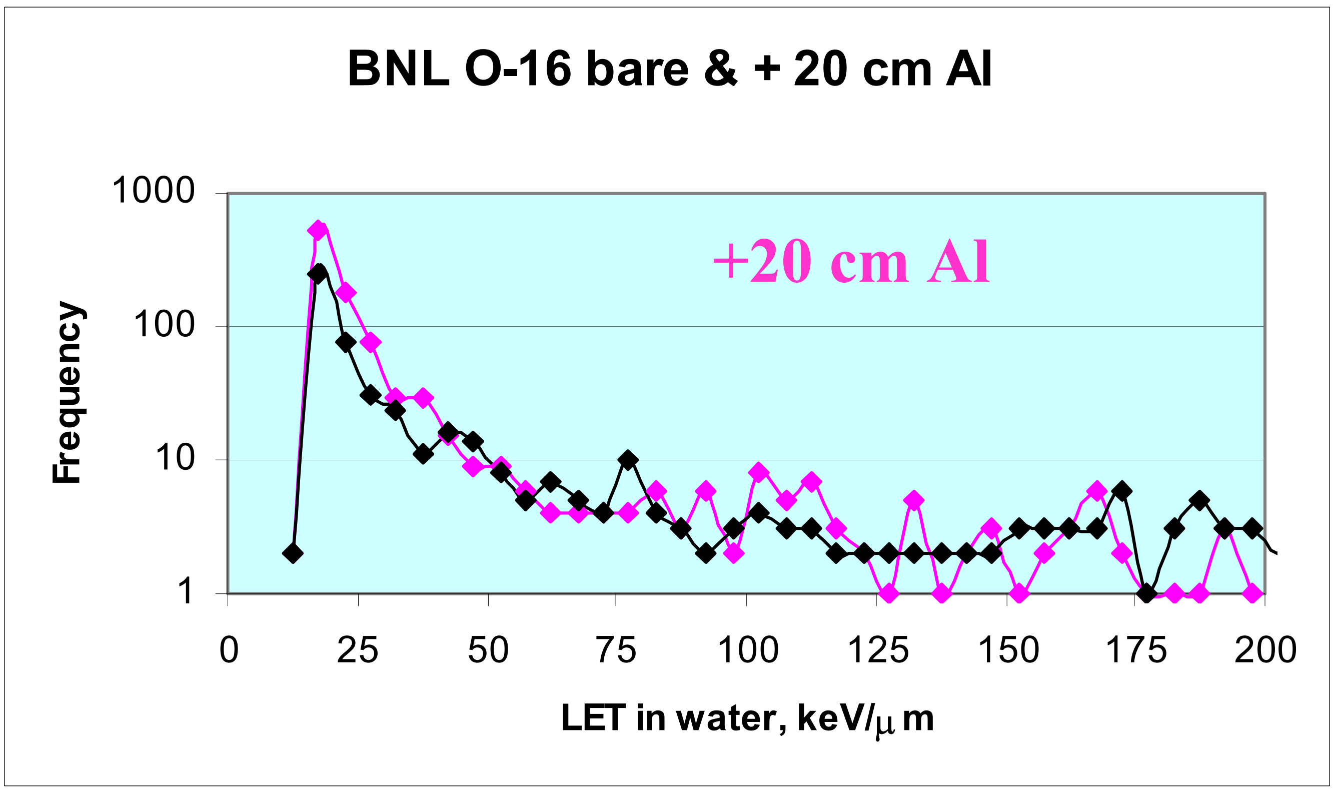
	Filter	Energy (GeV)	LET (keV/micron) in water	
O-16	bare*	16	14.09	
	1,5 mm Al ***	15.95	14.1	
	20 cm Al ***	9.63	16.28	
	+1,5 mm Al ***	9.58	16.31	
Fe-56	bare	56*	147***	
	bare	54.2** / 49***	151.4 **	
	1,5 mm Al^	48.5	151.8	
	3,7 cm Al^	36.6	164.8	
	+1,5 mm Al^	36.1	165.6	
* Nominal values				
** Provided by organizers				
*** Calculated by SRIM 2003 from nominal values				
^ Calculated by SRIM 2003 from LET given by organizers				



For this low LET radiation a "build-up" effect, combined with the appearance of fragmentation can be recognised as shown also later.

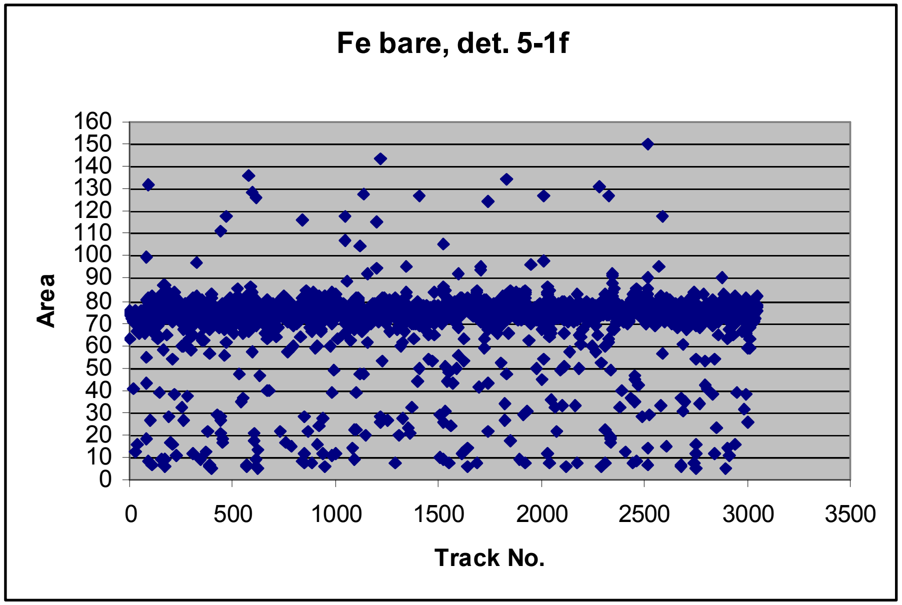


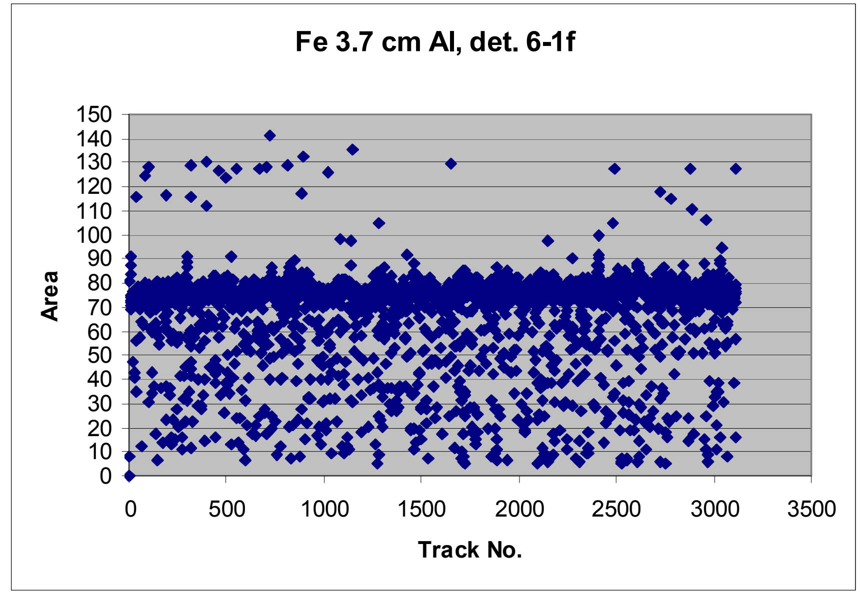


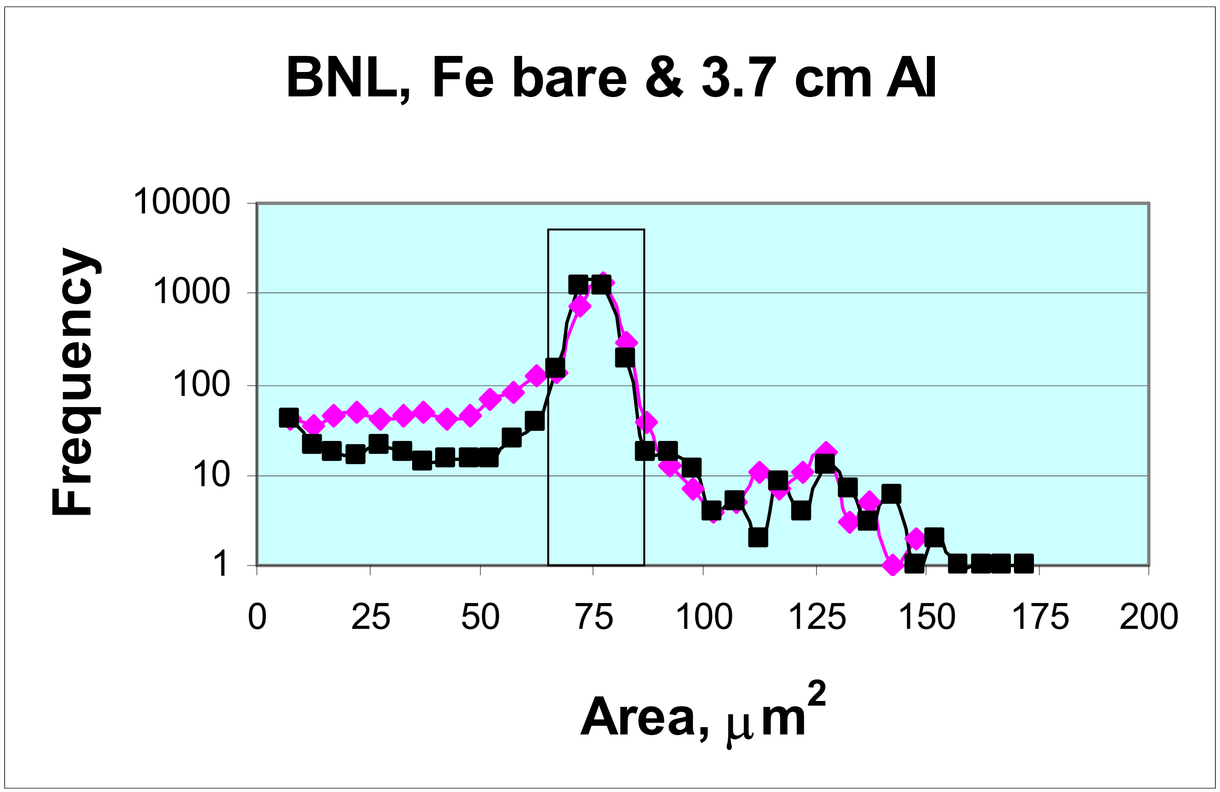


Reconstructed LET distribution using the final calibration.

The 20 cm Al does not change drastically the LET distribution for low LET radiation







The importance of area filtration to calculate the V-LET relationship in the case of the HZE iron particle seems to be evident.

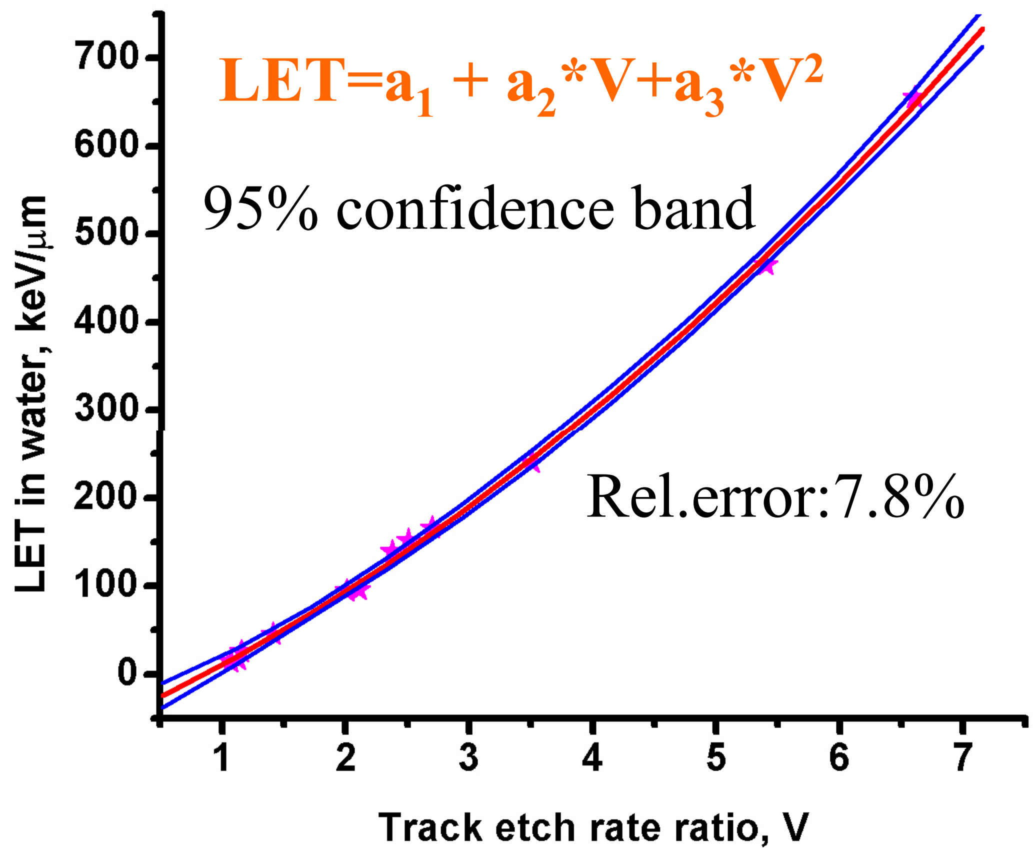
The limits of the area filtration is shown by the rectangle.

The calibration curve

Beside the ICCHIBAN-6 and NSRL-BNL exposures also proton and alpha particle exposures were taken into consideration to obtain the relationship between the track etch rate ratio and the LET of the incident particle. See the list of exposures on next page.

It was found that a polynomial fit can well describe the relationship, valid when etching off 8 μm thick layer from the TASTRAK PADC detector in 6n NaOH at 70 ^{o}C for 6 h.

The methods used to calculate the track etch rate ratio ($V=V_T/V_B$) are detailed in Ref. 4.



a_1 = -58.729 ± 9%

a_2 = 63.372 ± 6%

a_3 = 6.622 ± 1%

r^2 = 0.998 ± 8%

TASTRAK PADC

standard, 1 mm

6 n NaOH, 70 °C

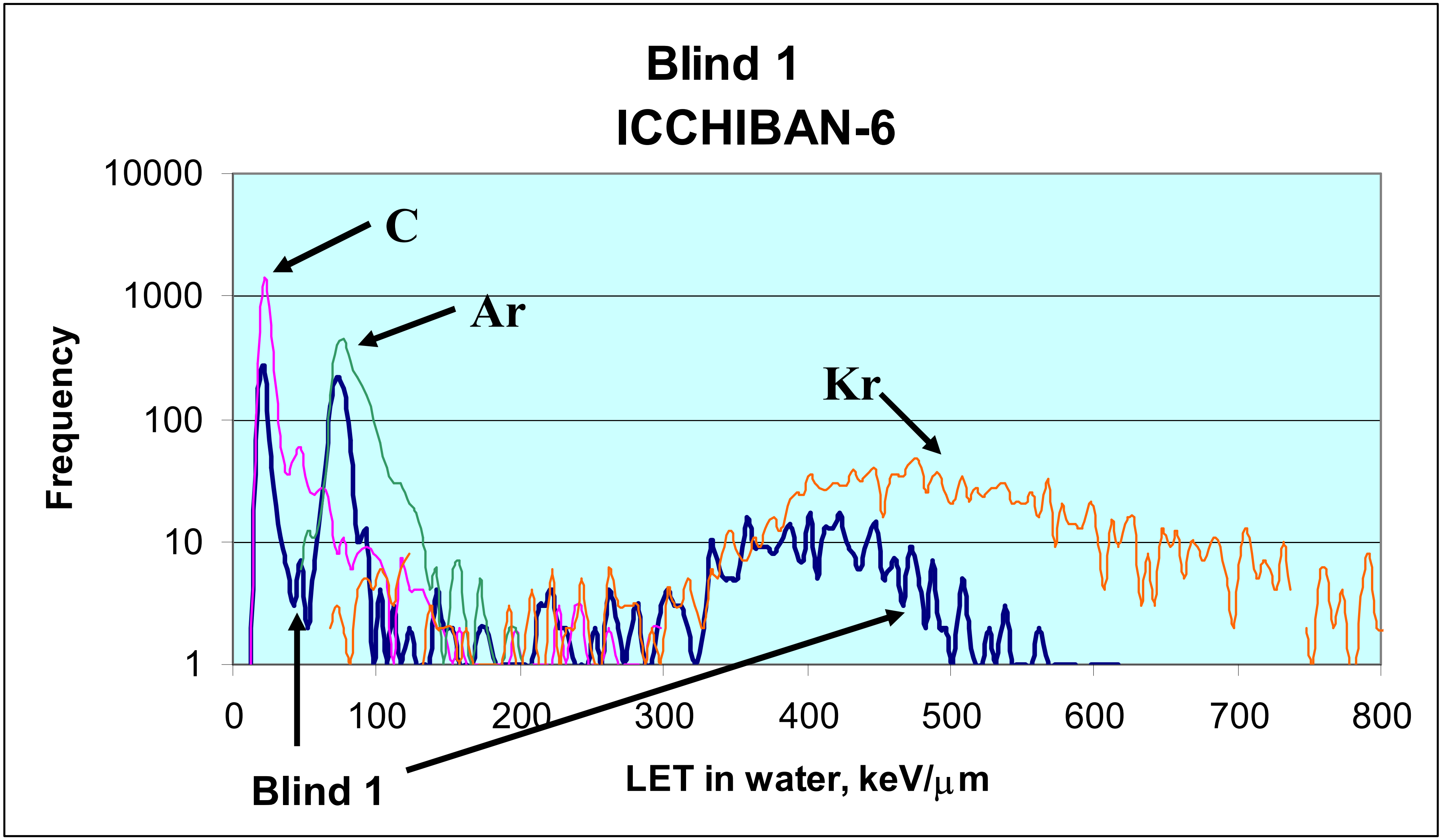
6 hours, 8μm off

Data in increasing order of V

- * 16 GeV ^{16}O, bare
- * 16 GeV ^{16}O, 20cm Al
- ** 1.3 GeV,^{12}C, bare
- ** 1.3 GeV,^{12}C, 16.6 mm PMMA
- ** 19.2 GeV ^{40}Ar, bare
- 4.65 MeV α (collimated, ^{210}Po)
- ** 19.2 GeV ^{40}Ar, 75.66 mm PMMA
- * 56 GeV ^{56}Fe, bare
- * 56 GeV ^{56}Fe, 3.7 cm Al
- 1 MeV proton (Van de Graaf)
- ** 25.96 GeV ^{84}Kr, bare
- ** 25.96 GeV ^{84}Kr, 16.6 mm PMMA

* NSRL-BNL

** ICCHIBAN-6, HIMAC



The super positioning the reconstructed LET distribution of the 3 known (bare) and the Blind 1 exposures clearly shows how the exposure Blind 1 was composed.

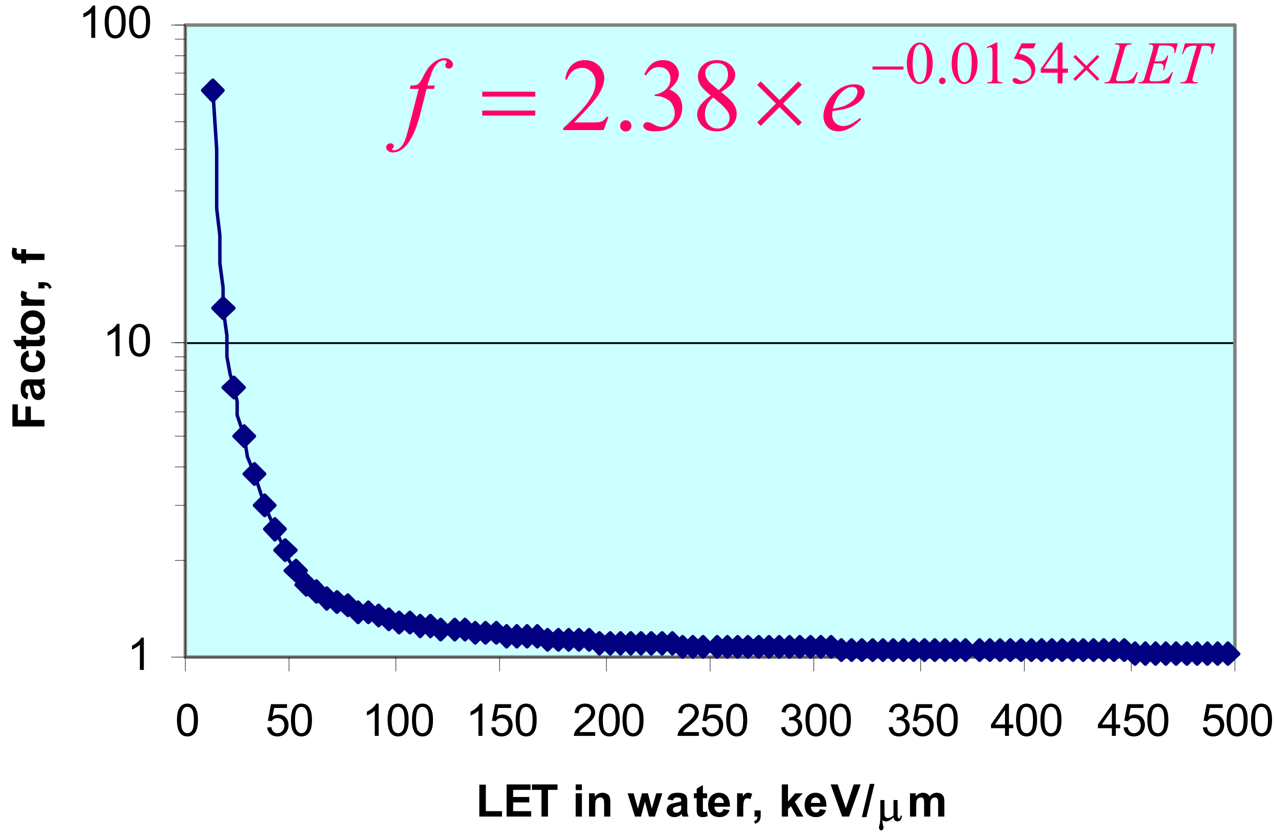
Evaluation of Blind exposures exposed during the ICCHIBAN-6 and NSRL-BNL exposures

All the detected tracks on the top surface of the stacks were considered.

The detection efficiency dependence on the incident angle and on LET was considered, the combined correction factor is shown on next page.

The absorbed dose in water, D, the equivalent dose, H, and the quality factor, Q, were calculated according to NCRP No. 137 and 142 (based on ICRP 60)

Combined correction factor



The curve below 100 keV/μm was obtained from track density measurements on detectors exposed to alpha and proton particles at different incident angles and with known LET. The high LET values were obtained from the fitted exponential curve. (6n NaOH, 70 ^{o}C, 6h, 8 μm off)

Method after Tawara et al. Rad. Meas. V. 35, 119-126, 2002.

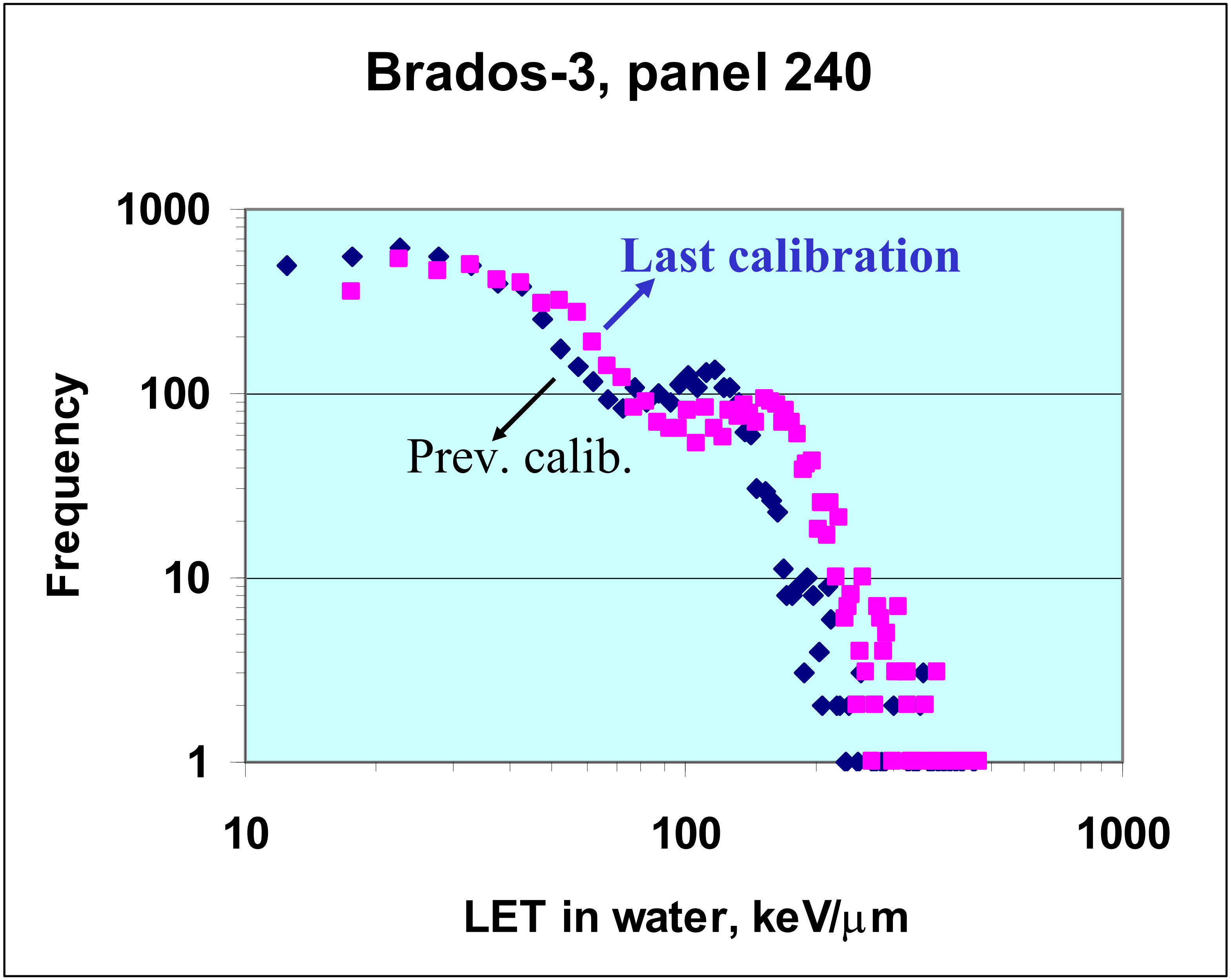
ICCHIBAN-6			
	D, mGy	H, mSv	Q
Blind	LET > 15 keV/μm		
1	0.171	2.81	16.43
2	0.13	2.28	17.54
3	0.183	3.6	19.66
4	0.305	5.91	19.4
5	0.107	2.26	21.08
6	0.39	7.23	18.52

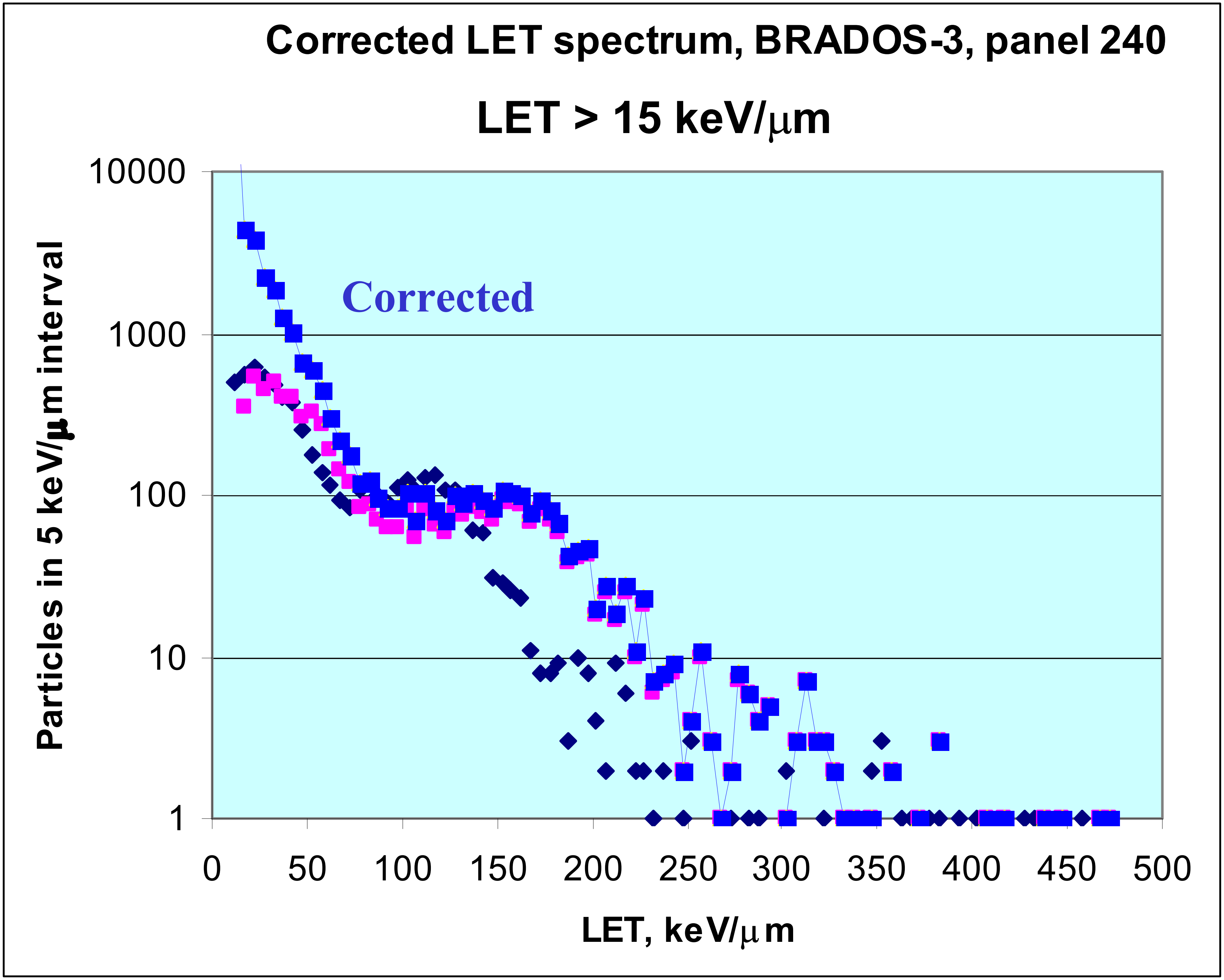
NSRL - BNL			
	D, mGy	H, mSv	Q
Blind	LET > 15 keV/μm		
1	0.722	14.1	19.54
2	0.668	12.63	18.9
3	0.636	13.38	21
4	0.97	0.924	11.78

LET spectrum and dose on the ISS

an example

We conclude that using the previous calibration curve (given in Ref. 4.) and the new curve presented here the LET distribution on the ISS does not change too much, more important is the angular correction at the low LET region, see next pages.


Brados-3, panel 240
Last calibration
Prev. calib.
Frequency
1000
100
10
1
10
100
1000
LET in water, keV/μm



Corrected LET spectrum, BRADOS-3, panel 240
LET > 15 keV/μm
Corrected
10000
1000
100
10
1
Particles in 5 keV/μm interval
0
50
100
150
200
250
300
350
400
450
500
LET, keV/μ m

	This work	ERIL Res.	DIAS
	2003, ISS	2001, ISS	2001, STS-108
	Panel 240		
	LET > 15 keV/μm	LET > 10 keV/μm	LET > 20 keV/μm
D, μGy/d	2.93	29.8	2.05
H, μSv/d	**46**	214	32.35
Q	15.8	7.18	15.75

It is worthwhile to mention that the neutron dose for the energy interval 200 keV - 20 MeV was found to be 44 μSv/d, for the exposure on Panel 240 in 2003, based on the calibration at the CERF facility as detailed in Refs. 2 & 3.

It means that the short range charged particles above ~15 keV/μm may have their origin from secondary neutrons interacting with the holders and materials of the detector and their tracks are detected on the surface of stacks after a short etching (8 μm removal). Similar results were found for all the other exposures on the ISS

Ref. 1

Pálfalvi, J., Eördögh, I., Szász, K. and Sajó-Bohus L., 1997, New Generation Image Analyser for Evaluating SSNTDs. Radiat. Meas. **28**, 849-852.

Ref. 2

Pálfalvi, J. K., Akatov, Yu., Szabó, J., Sajó-Bohus, L. and Eördögh I. *Evaluation of SSNTD Stacks on the ISS.* Rad. Prot. Dos. **110** (1-4), 393-397 (2004).

Ref. 3.

Presented on the 22nd ICNTS meeting in Barcelona, September, 2004.

Cosmic Ray Studies on the ISS using SSNTD, BRADOS Projects, 2001-2003

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[2]*Inst. for Biomedical Problems, Moscow 123007, Russia*
[3]*Univ. Simon Bolivar, Caracas 89000, Venezuela*
[4]*Res. Inst. for Technical Phys. & Material Sci. P.O.B.49, H-1525 Budapest, Hungary*

In Radiation Measurements, 2005, in print

Ref. 4.

Contribution to: 14th International Conference on Solid State Dosimetry. June, 2004, New Haven, USA

Detection of primary and secondary cosmic ray particles aboard the ISS using SSNTD stacks

J. K. Pálfalvi[1] ,Yu. Akatov[2], J. Szabó[1], L. Sajó-Bohus[3] and I. Eördögh[4]

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[2]Institute for Biomedical Problems, Moscow 123007, Russia
[3]Univ. Simon Bolivar, Caracas 89000, Venezuela
[4]Res. Inst. for Technical Physics and Material Sci. POB-49, H-1525 Budapest, Hungary

In Radiation Protection Dosimetry, 2005, in print.

Ref. 5

Summary of BRADOS 1 and 3 experiments on the ISS

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[1]KFKI-Atomic Energy Res. Institute, POB-49, H-1525 Budapest, Hungary
[2]Institute for Biomedical Problems, Moscow 123007, Russia

Under compilation for the Radiation Measurements