EVALUATION OF SSNTD STACKS EXPOSED ON THE ISS

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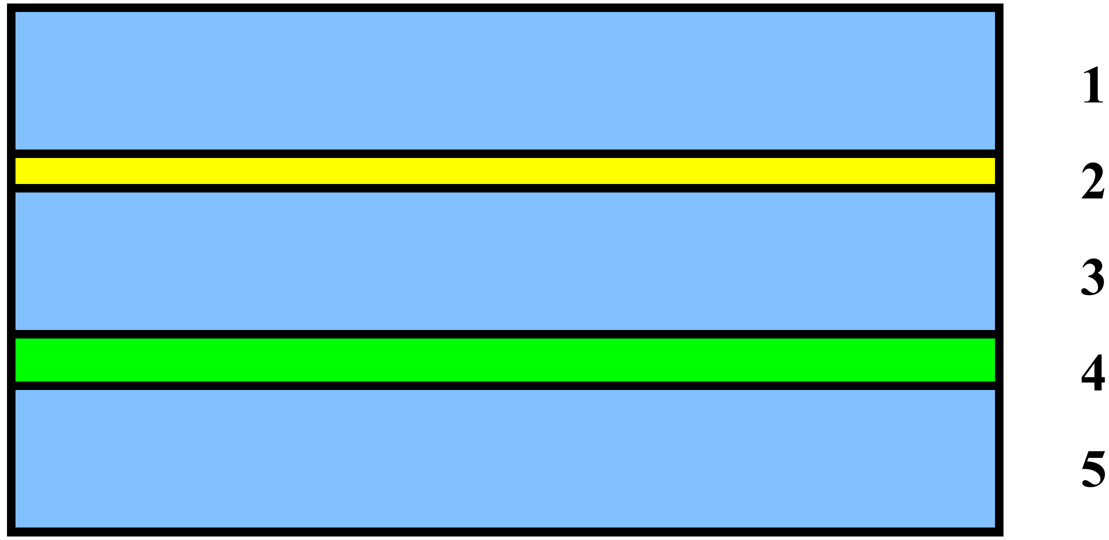
Bradoz-1 stack composition



Layer No.	*Material*	*Density, g/cm³*	*Thickness, µm*	*Thickness, mg/cm²*
1,3,5	CR-39	1.3	1180	153.4
2	Ti	4.52	50	22.6
4	Macrofol	1.28	195	24.5

Total thickness: 507.3 mg/cm²

Area of 1 sheet: 10 cm²

7 of them were placed at different positions of the Russian segment 'Zvezda'

The effective shielding thickness of the panel, where the box was placed, was not provided.

Assumptions: (after Armstrong, 1998) the proton flux inside the ISS is low below 1 MeV, constant between 1 and 200 MeV (~ 3 p/cm^2/s), then rapidly decreases. It is one order of magnitude below the neutron flux.

The stack position and orientation inside the box was not documented!

Assumptions: 1 mm thick Fe box filters out protons below 22 MeV. Maximum proton energy entering the box and will be detectable by the stack (on rear surface of 3rd CR-39) is ~50 MeV. Each surface has different upper energy limit.

Primary proton tracks can be separated from neutron induced proton tracks by multiple etching method.

What kind of particles can we expect and detect by CR-39 SSNTD inside the ISS?

Primary protons - limited detection ability, slightly disturbs neutron detection

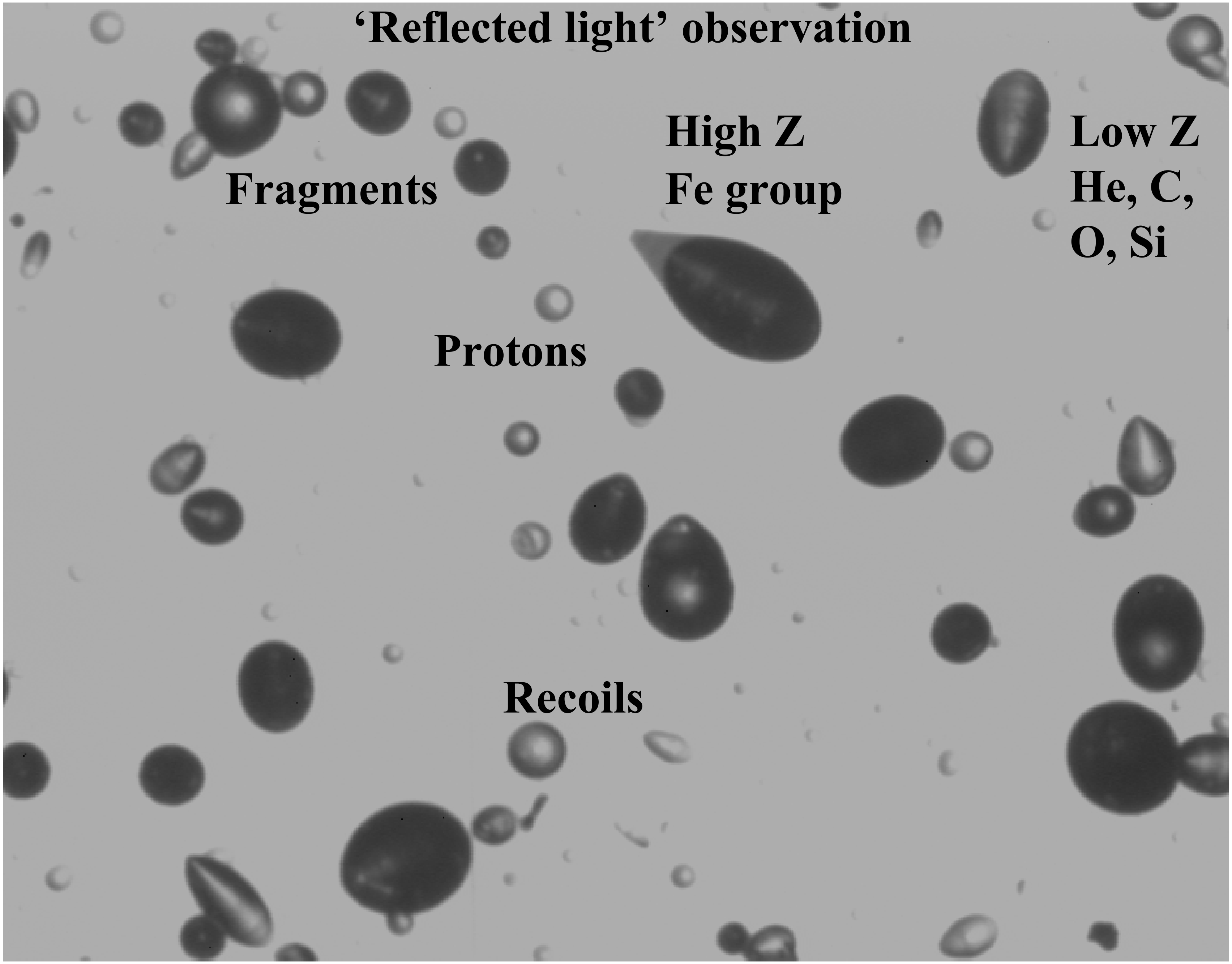
Neutrons - by p, C and O recoils, interactions producing α and p, D and T together with scattering ions (Be), fragmentation (spallation)

Short range target fragments - mostly induced by high energy protons within the detector

Low Z particles (C, O, Ne, Mg, Si) - external origin, relatively short tracks, mostly stopping within one detector sheet, limited Z resolution because of the wall effect

Fe group and UHZE particles - external origin, may penetrate more detector sheets, high LET, bigger track diameter

Projectile fragmentation, - high LET, nearly cylindrical shape with spherical end



'Reflected light' observation
High Z
Fe group
Low Z
He, C,
O, Si
Fragments
Protons
Recoils

-Assessment of neutron dose-

-GCR particle tracks are distinguishable from any other ones by our pattern recognizing software and the multiple etching method. The GCR dose was not included in this discussion and would be presented later.

-The proton flux reaching the stack with energy below 20 MeV is negligible, the estimated flux above it is ~ 6 cm^{-2} s^{-1} resulting in a high energy proton fluence of 1.3 x 10^8 cm^{-2} for the total flight time. There were few, no significant, SPE flashes. Considering the low reaction cross section (average <50 mb) for the $^{12}C(p,pn')^{11}C$ and $^{16}O(p,\alpha)^{13}N$ reactions within the CR-39 detector we estimated <250 such events per cm^2 after 6 h etching (~8 μm layer removal). Even if all the particles produced were registered by the image analyzer they would be in minority comparing to the total track density of around 10^4 per cm^2 measured on the detector surfaces. So, we conclude that protons do not disturb the neutron detection significantly (<3% overestimation of neutron dose).

-The neutron induced charge particle production with ^{12}C and ^{16}O have thresholds, the cross sections become significant above 8 MeV for $^{12}C(n,\alpha)^{9}Be$ (~50 mb) and 15 MeV for $^{12}C(n,n'3\alpha)$ (~360 mb) reactions, respectively. In the case of $^{16}O(n,\alpha)^{13}C$ reaction the threshold is at ~ 10 MeV with ~ 1000 mb. The resulting particles have short range and high LET, after few hours etching their tracks become over etched (ring shaped) and well distinguishable from other tracks. Thus the neutron fraction above the thresholds can be estimated and the dose calculated. The upper detection limit is not well defined, the reaction cross sections rapidly decrease above 20 MeV, but the fraction of tracks above and below this energy cannot be estimated. If we select 20 MeV as upper detection limit, then certainly, the dose is slightly overestimated below this limit.

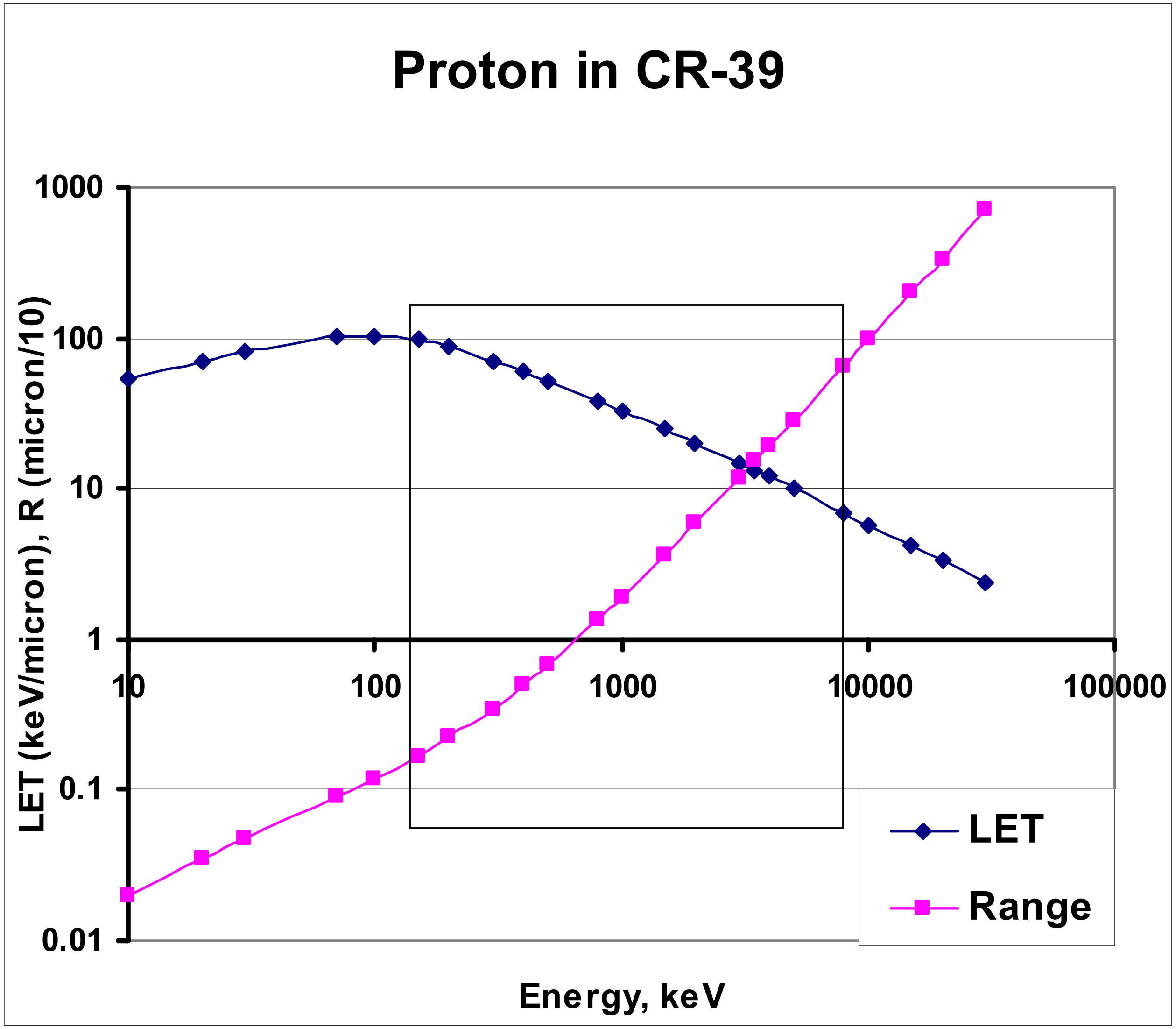
-Also all the other reaction (mostly producing protons) with these elements have high threshold but with lower cross section. Particles are partly detected as recoil protons causing some dose overestimation below 20 MeV.

-Direct C and O recoils tracks (from elastic collision) are detectable if the neutron energy is higher than 5 MeV. However, for both nuclea the cross section is rapidly decreasing above 20 MeV. These recoil tracks cannot be practically distinguished from the tracks of residual nuclei of (n,α) reactions.

-The neutron detection between ~100 keV and 8 MeV incident neutron energy is based on the neutron elastic scattering on Hydrogen atoms of the detector material. The reaction cross section is quite high, decreasing from ~15.000 mb at 0.1 MeV down to 1000 mb at 8 MeV. The high H content (50%) of the material and the high cross section make this reaction the most significant one. The tracks are well observable after 6 h etching and can be separated from recoils and other tracks. The detection window is between 0.12 and 8 MeV, determined by the LET and range of protons.

-The Lexan detector, which detects HZE particle only, has one more role within the stack: it works as a proton converter increasing the detection efficiency of CR-39 sheet No. 3.

-The role of the Ti foil is twofold: degrades the energy of the high energy recoiled protons coming from sheet No. 2 to fall into the detectable energy range and it works as a threshold detector utilizing the Ti(n,p)Sc reaction. The effective threshold is at ~2 MeV, extending the detectable neutron energy range up to ~20 MeV.



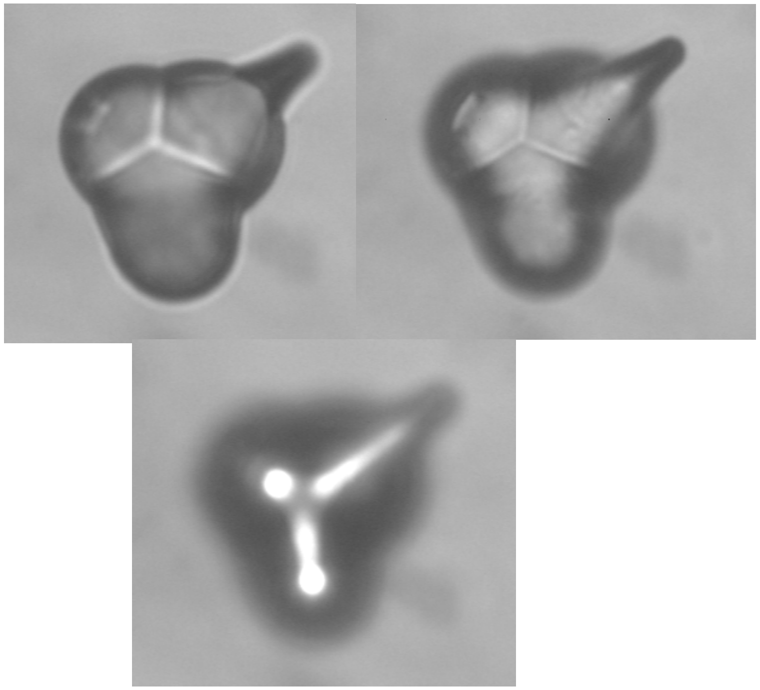
Etching: 6 h in 6N NaOH at 70 °C

Bulk etch rate: 1.34 µm/h

Detecting thresholds:

- **Diamater**: 2 µm
- **Range**: 1.5 µm,
- **LET**: 6 keV/µm,
- **Energy**: 120 keV

Maximum detectable energy without converter: 8 MeV

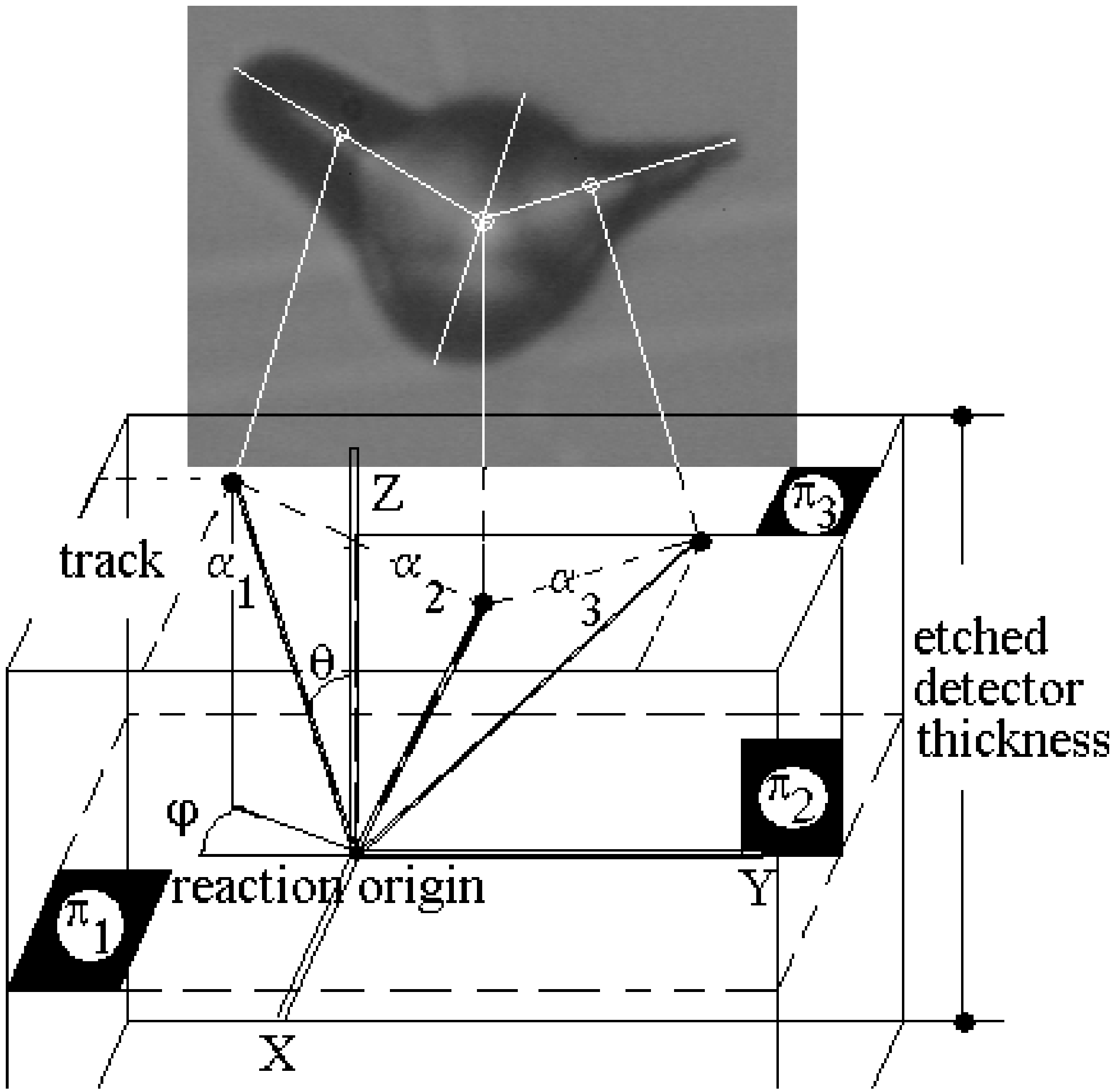


Three-focal presentation of tracks originated from $^{12}C(n,n',3\alpha)$ interaction

in CR-39, exposed at CERF in CR position

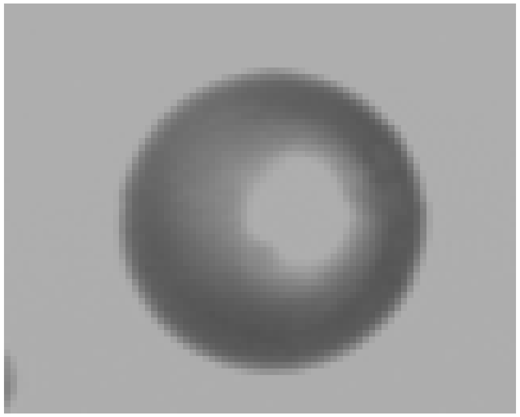
(TASTRAK, 6n NaOH, 70 ^{o}C, 12 h etching)

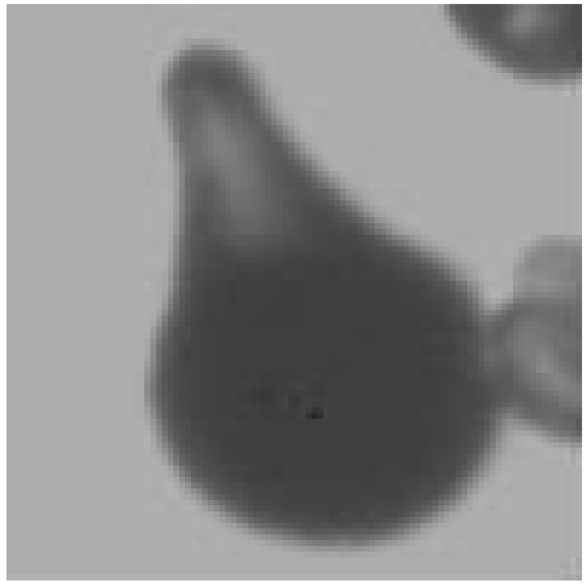
REACTION	THRESHOLD ENERGY
$^{12}C(n,3\alpha)$	15 MeV
$^{12}C(n,T)$	10 MeV
$^{12}C(n,D)$	8 MeV
$^{12}C(n,p)$	5 MeV

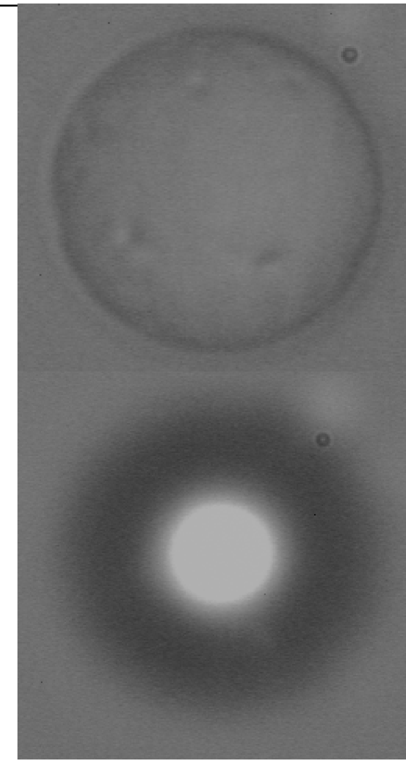


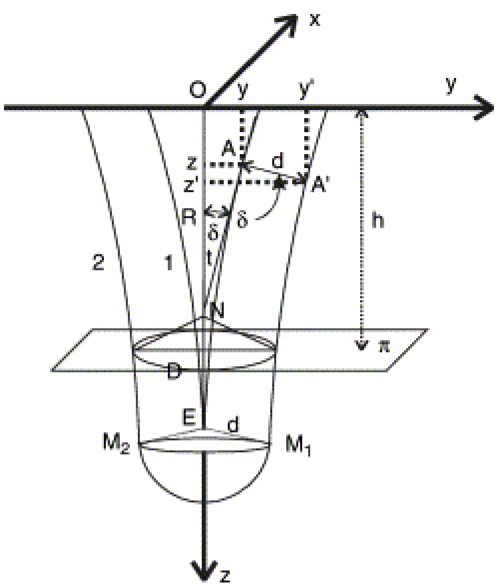
In plane π_3 we estimate the position of the latent track and from the digitalized image we deduce the geometry of the track mouth. The shape usually is the superposition of three ellipses having different eccentricity. The measured parameters allow us to determine, in principle, the direction and the range (energy) of the particles.

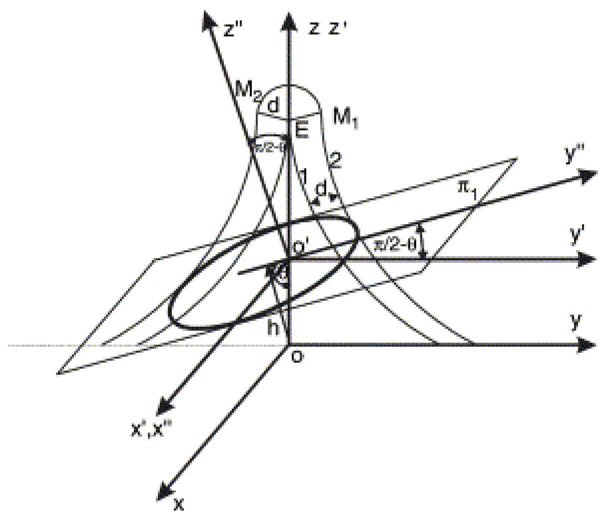
3DTrack formation dynamics, after Nikezic, 2003.

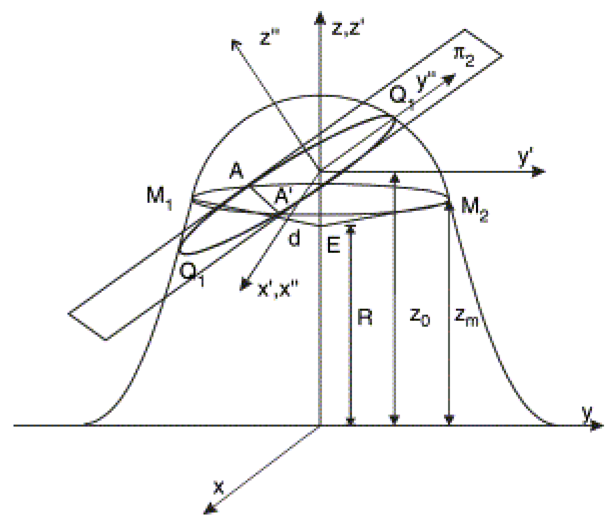






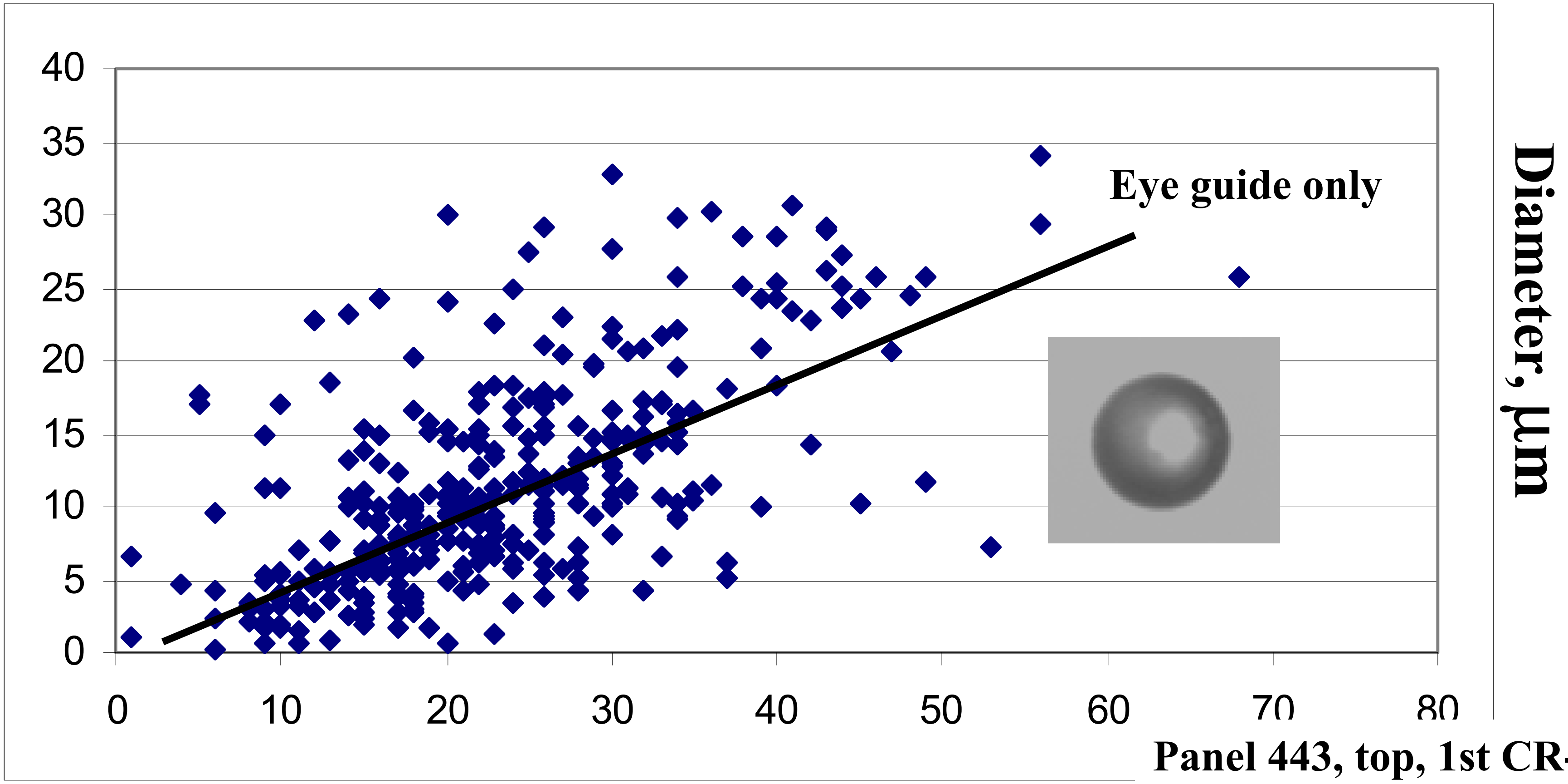






Reduced track diameter vs. Residual Path length

C or O recoils or target fragments, circular tracks



Residual Path length, µm

Removed layer: 26.8 µm

Panel 443, top, 1st CR-39 sheet

Tracks were randomly selected from the total population for illustration only

8 calibration detector stacks were exposed at CERF in the so called “concrete roof” position. Since the exposure at CERF is considered to be 2π, cosine distribution and on the ISS an isotropic field was assumed these lopsided stacks were exposed from both directions. The calibration detectors were treated together with those exposed onboard the ISS. For the dose estimate it was assumed that the neutrons reaching the detector stacks exposed both on ISS and at CERF have the same averaged fluence-to dose conversion factor.

The VIRGINIA [Palfalvi, 1997] software was taught to recognize only such type of tracks which were found on the calibration detectors. The sample tracks and their parameters were classified and stored in galleries separately for each side and each etching time (2 and 6 h). The track density measured on a given surface of the calibration detector was related to the known dose.

Stacks exposed on the ISS were investigated in the same way. Only those tracks were considered in track density and the dose calculations which were recognized by the software when compared to the learnt patterns. For each stack 6 dose values were obtained and averaged. See the results in next Table. The statistical error was always less than 10 %.

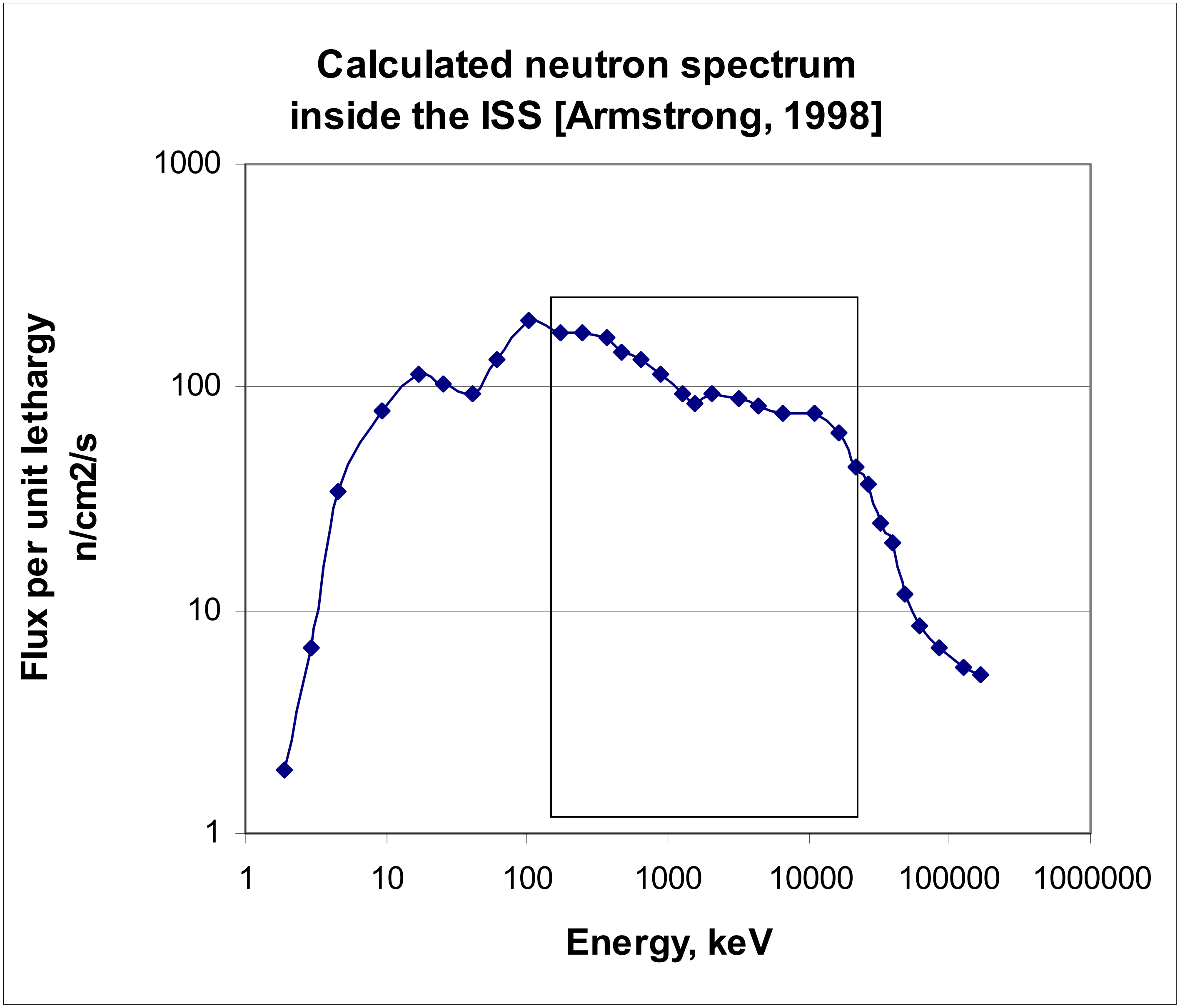
Neutron ambient dose equivalent, H*, rate at different positions of the ISS, measured in 2001

Location within the ISS

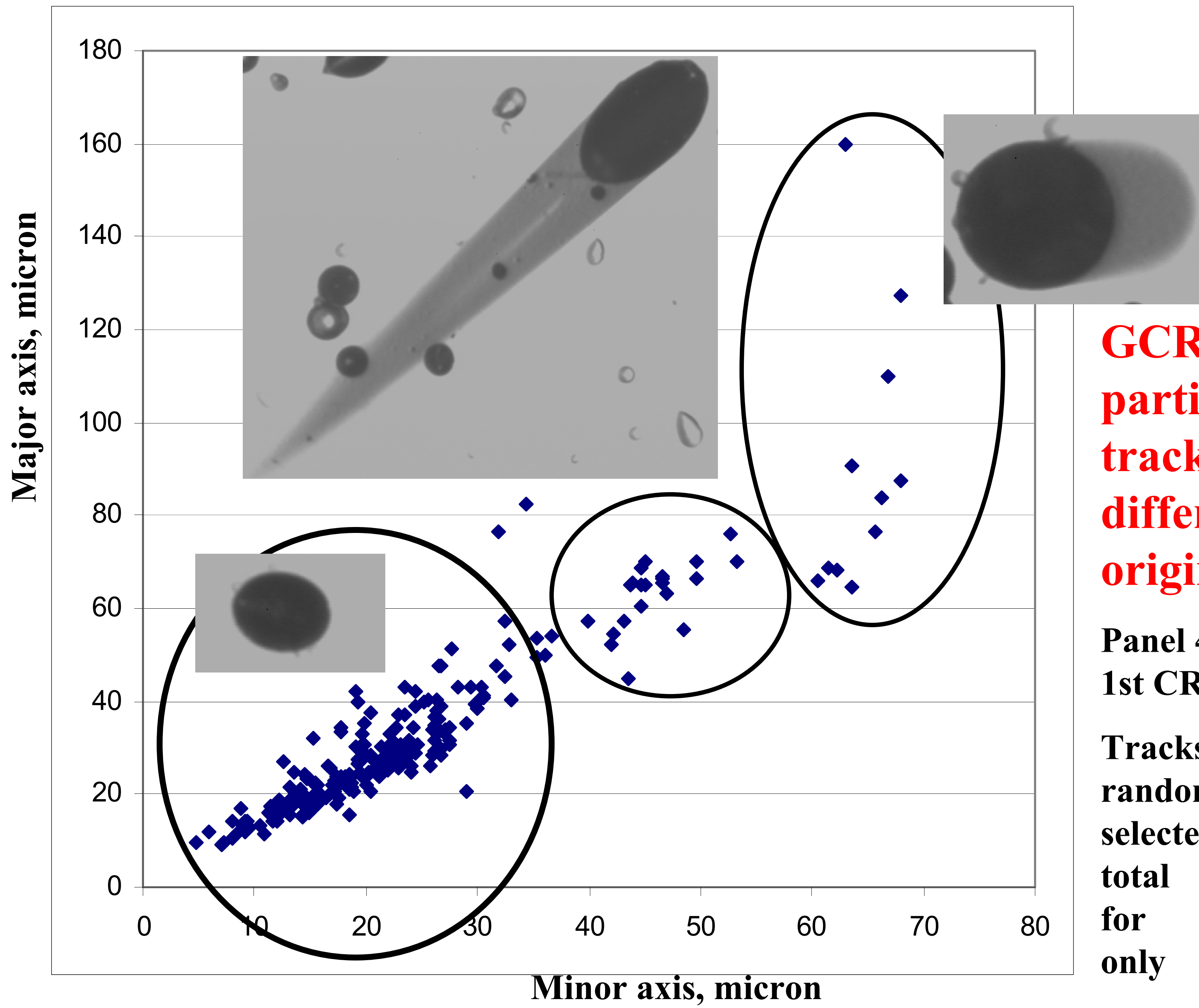
assembly, stack and panel numbers

	A11 Stack 1	A12 Stack 2	A13 Stack 3	A16 Stack 6	A16 Stack 7	A14 Stack 4	A15 Stack 5	
				orthogonal	orthogonal			
	443 starboard crew cabin window	240 port side window	110 ...floor, beside window 6...	110	110	457 starboard lavatory	318 ceiling	Average
	……………………..light shield				……………………..	….heavier shield….		
H* μSv/d	52	39	47	68	63	54	73	56.6 ± 21%

Energy range: 200 keV - 20 MeV, Overall uncertainty: < 30%


Calculated neutron spectrum
inside the ISS [Armstrong, 1998]
1000
100
10
1
1
10
100
1000
10000
100000
1000000
Energy, keV
Flux per unit lethargy
n/cm2/s

- Since the CERF calibration spectrum (concrete roof) is somewhat different from the spectra at different positions inside the ISS, the overall uncertainty of the averaged dose rate at a given position has been estimated by sensitivity analysis and found to be below ± 30 % for each location.
- The dose in 0.2 – 20 MeV range can be 60 % of the total neutron dose as calculable from the predicted neutron spectrum shown here. This would result in an averaged total neutron ambient dose equivalent of about 94 μSv/d.
- Since the standard deviation of the averaged dose value is 21% and the overall uncertainty of each measurement is ± 30%, it can be said, that the doses are not significantly different on the different places. Similar conclusion was obtained from the DOSMAP Experiment carried out in other segments of the ISS in 2001.

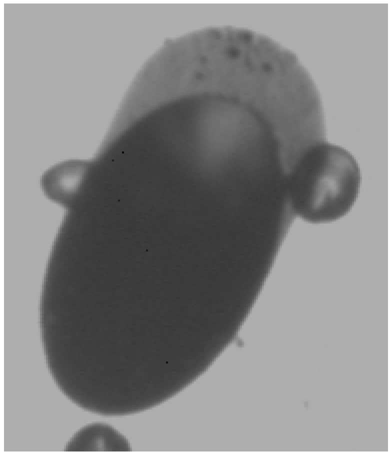


GCR particle tracks of different origin

Panel 443, top, 1st CR-39 sheet

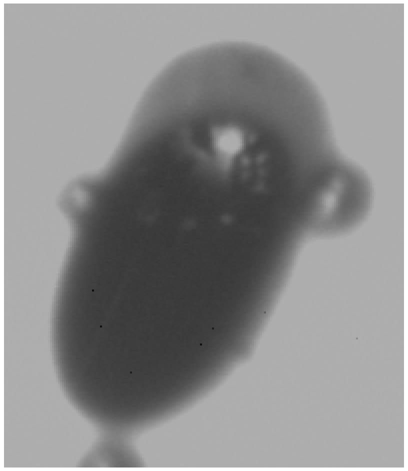
Tracks were randomly selected from the total population for illustration only

Special attention was devoted to study cylindrical like tracks



Focusing onto upper surface

Focusing onto track end

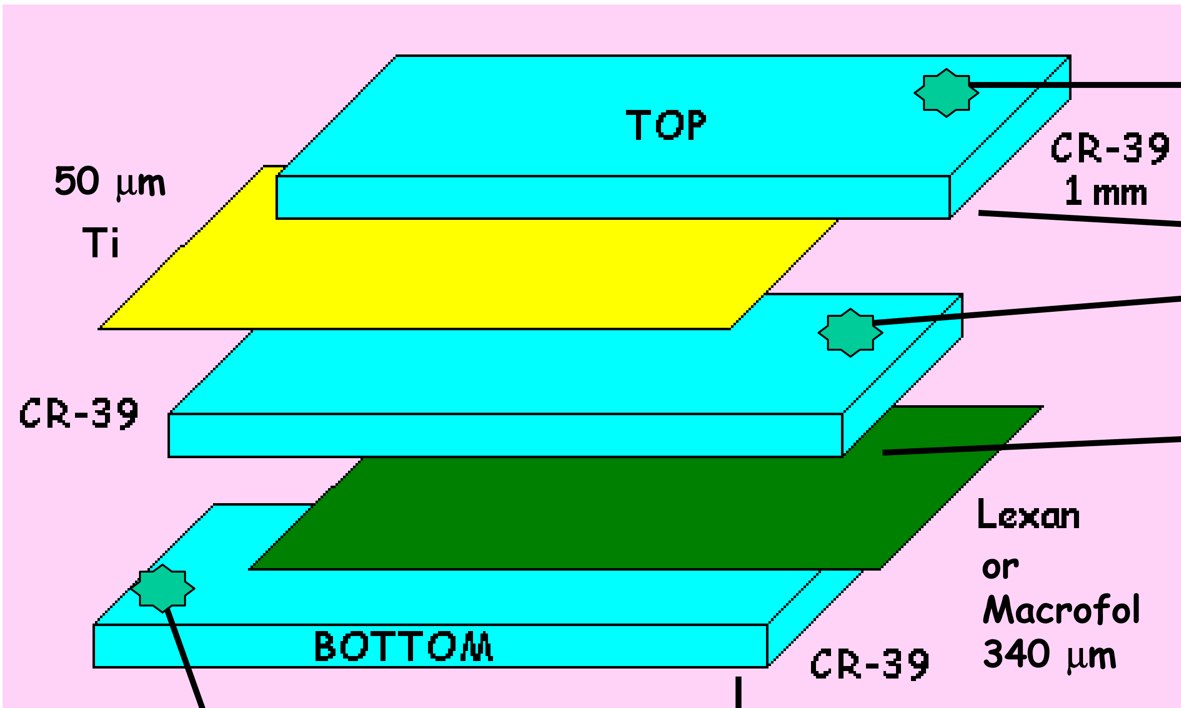


The origin of such tracks has not been clarified yet.

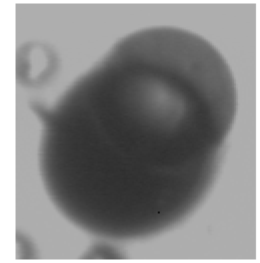
Properties:

- No matching tracks were localized on other surfaces
- Tracks are nearly cylindrical and have spherical end
- The length of the minor axes are very similar and the biggest among other measured ones

More details on next 3 pages

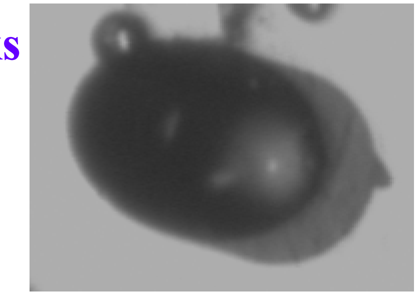


2 tracks



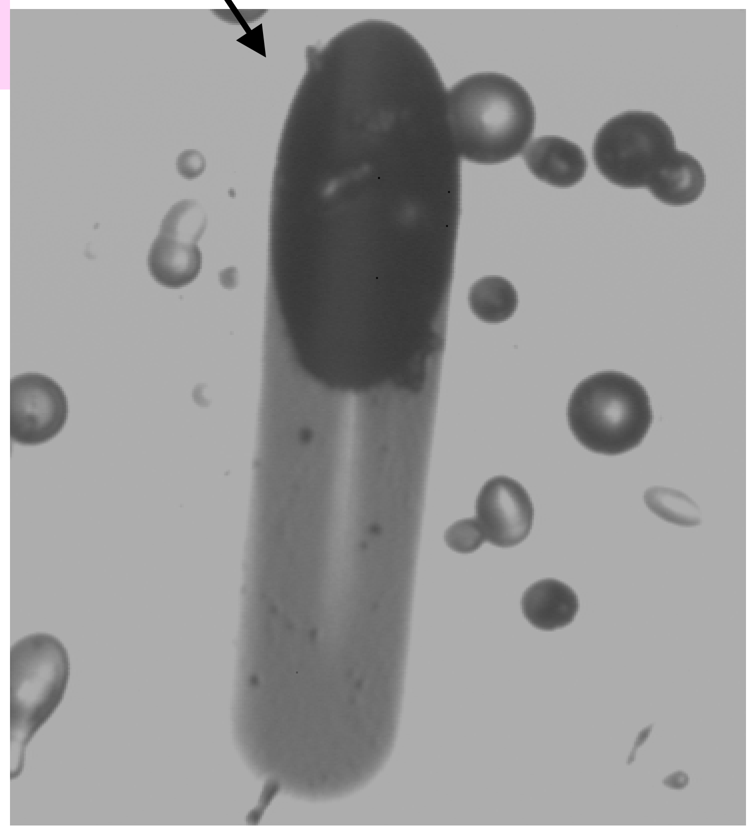
9 tracks

2 tracks

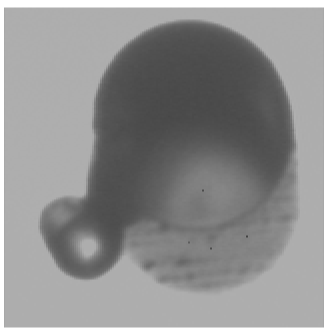


6 tracks

like this



5 tracks



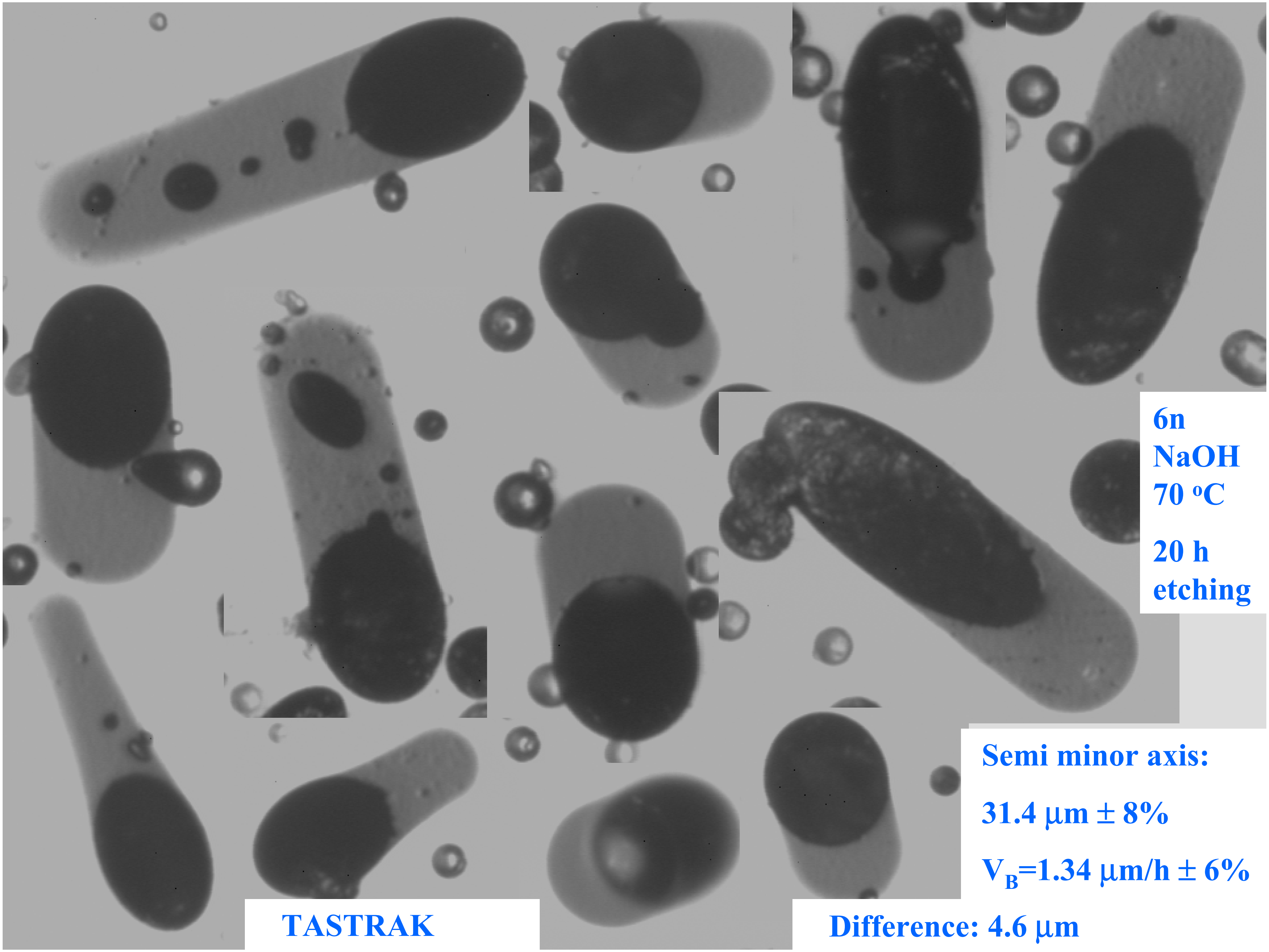
13 tracks

see next 2 pages

Thin shielding, stack No.1

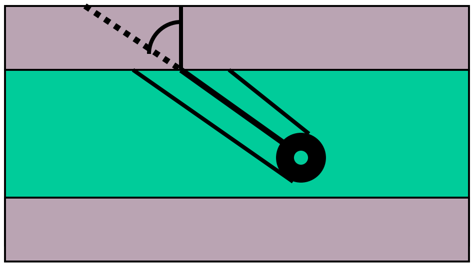
37 tracks on 60 cm^2,

246 days flight time


6n
NaOH
70 ºC
20 h
etching
Semi minor axis:
31.4 µm ± 8%
V_B=1.34 µm/h ± 6%
TASTRAK
Difference: 4.6 µm

Track Number	Reconstructed path length in detector µm	Minor axis on etched surface µm	Incident angle degree	Diameter of spherical track end µm
1	**261.1**	63.6	47.3	54.8
2	158.4	66.8	50.6	63.8
3	121.8	65.6	35.6	66.0
5	178.7	63.0	**65.3**	63.0
6	159.5	67.9	58.0	66.0
8	**74.4**	62.3	36.1	60.2
9	99.3	60.5	26.7	53.7
10	162.8	61.4	**17.7**	57.5
11	138.0	68.0	43.2	62.7
13	211.8	66.3	40.3	57.4
14	137.2	63.5	26.3	56.0
Average (11)	-	**64.4 ± 2.6 (4.1%)**	-	**60.1 ± 4.45 (7.4%)**
7	157.7	53.3	32.9	36.4
12	204.6	52.7	48.4	26.1
Average (13)	-	**62.7 ± 4.9 (7.8%)**	-	-

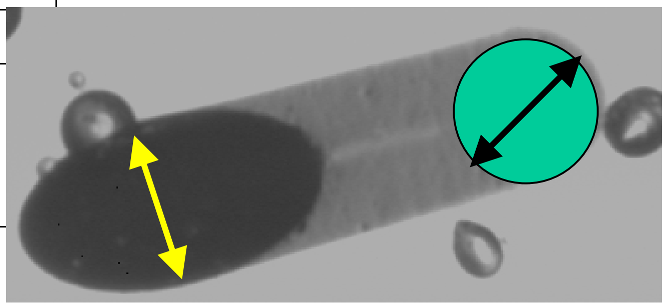
Etched off layer, 26.8 µm



V_B=1.34 µm/h

t=20 h

Uncertainty of length measurements < 1,1 µm at 96% confidence level, based on α track diameter measurements, at overall magnification = 400



References

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D. Nikezic, K. N. Yu, 2000 & 2003, Rad Meas. **32**, 277-282 & **37**, 39-45 & **37**, 595-601

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

Acknowledgement

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MISSION INFORMATION

Stacks launched on 26-02-2001 by Progress 244

Returned to Earth on 31-10-2001 by Sayuz TM-32

Received by AEKI on 28. 03. 2002.

Some results presented on WRMISS in Paris, Sept. 2002

Evaluation is still in progress (2003-2004)