Determination of the Neutron Component of the Cosmic Radiation Field in Spacecraft using a PADC Neutron Personal Dosemeter

(i) Determination of the neutron component
(ii) Response to HZE
(iii) Preliminary results of STS measurements

David Bartlett, Luke Hager and Rick Tanner

National Radiological Protection Board

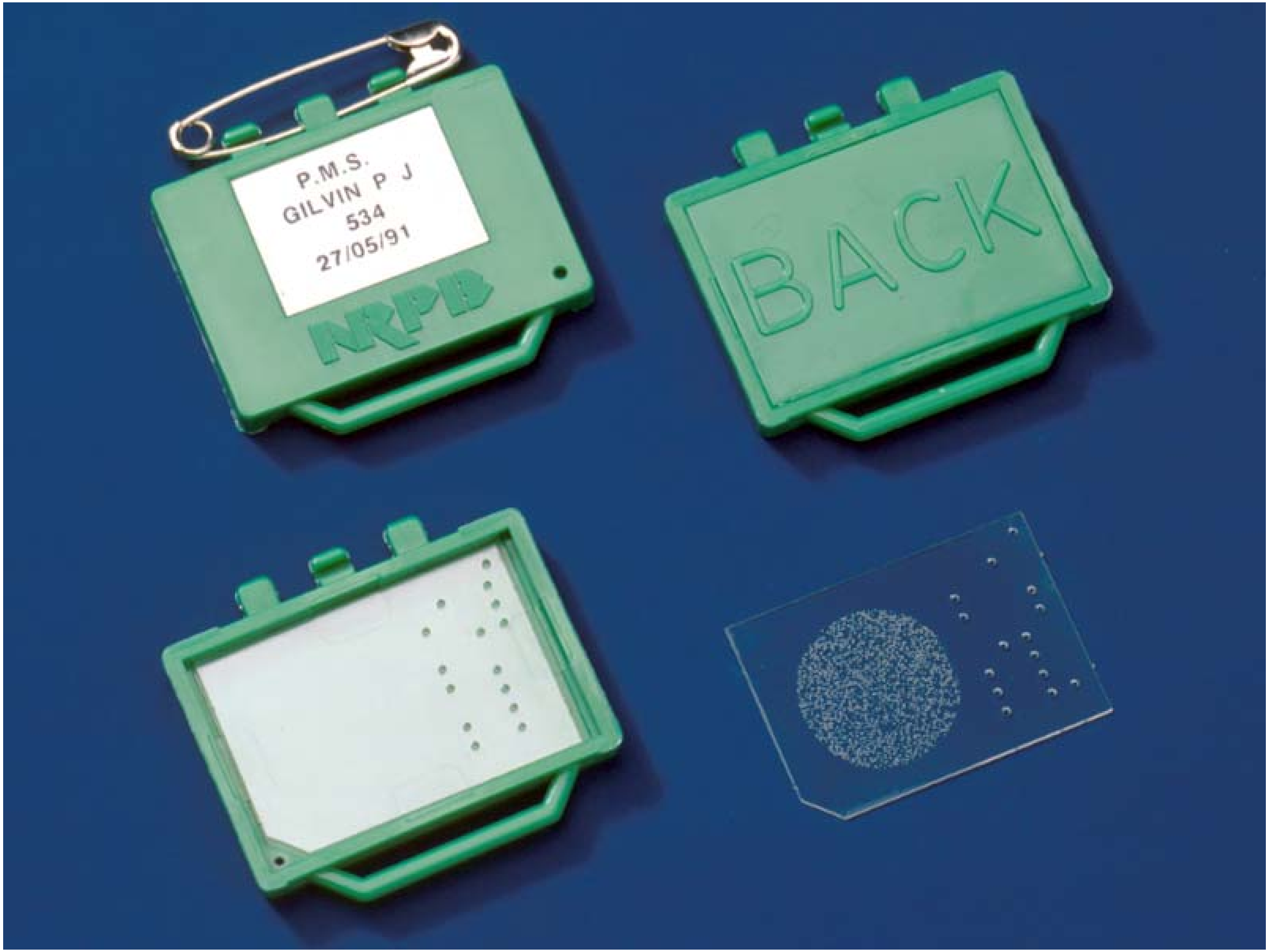
(i) Neutron component

Routine issue NRPB PADC neutron personal dosemeters, electrochemically etched, automatically read

Charged particle threshold ~ 30 keV μm^{-1}
(for protons, $E_p < 1$ MeV)

Neutrons + neutron-like interactions of protons

Calibration factor determined for the calculated neutron field in spacecraft


P.M.S.
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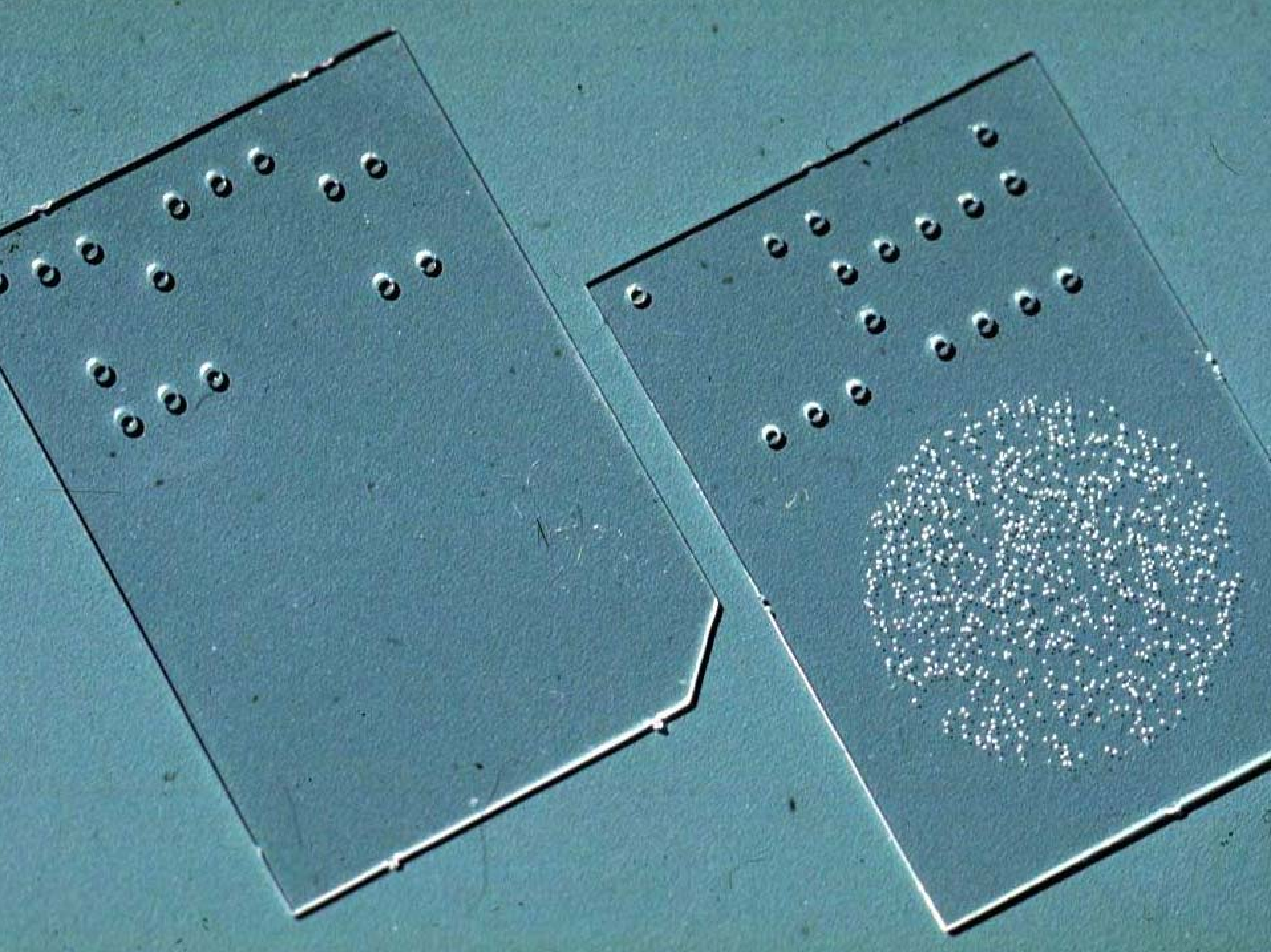
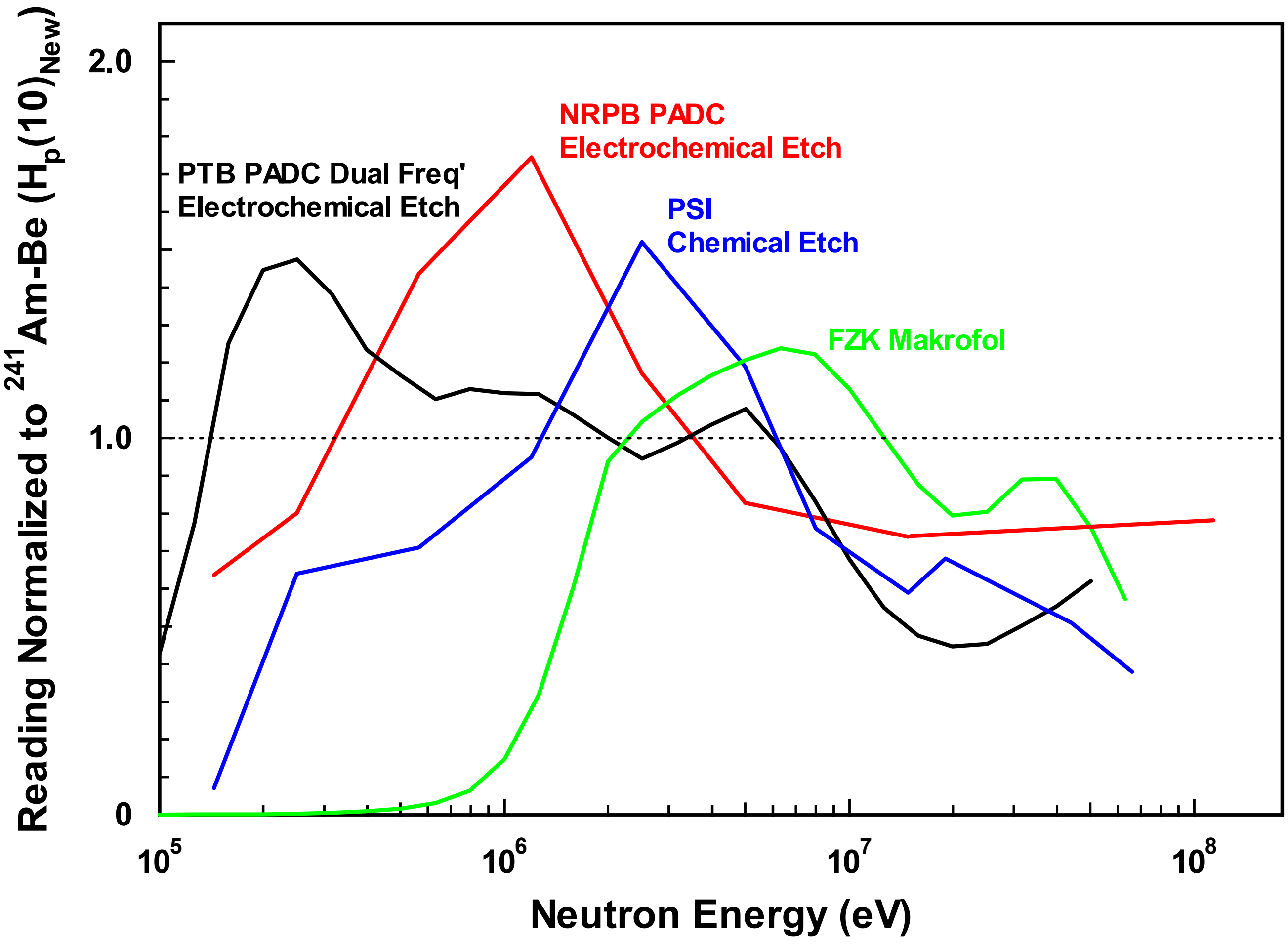


Etched Track Detector Response Characteristics

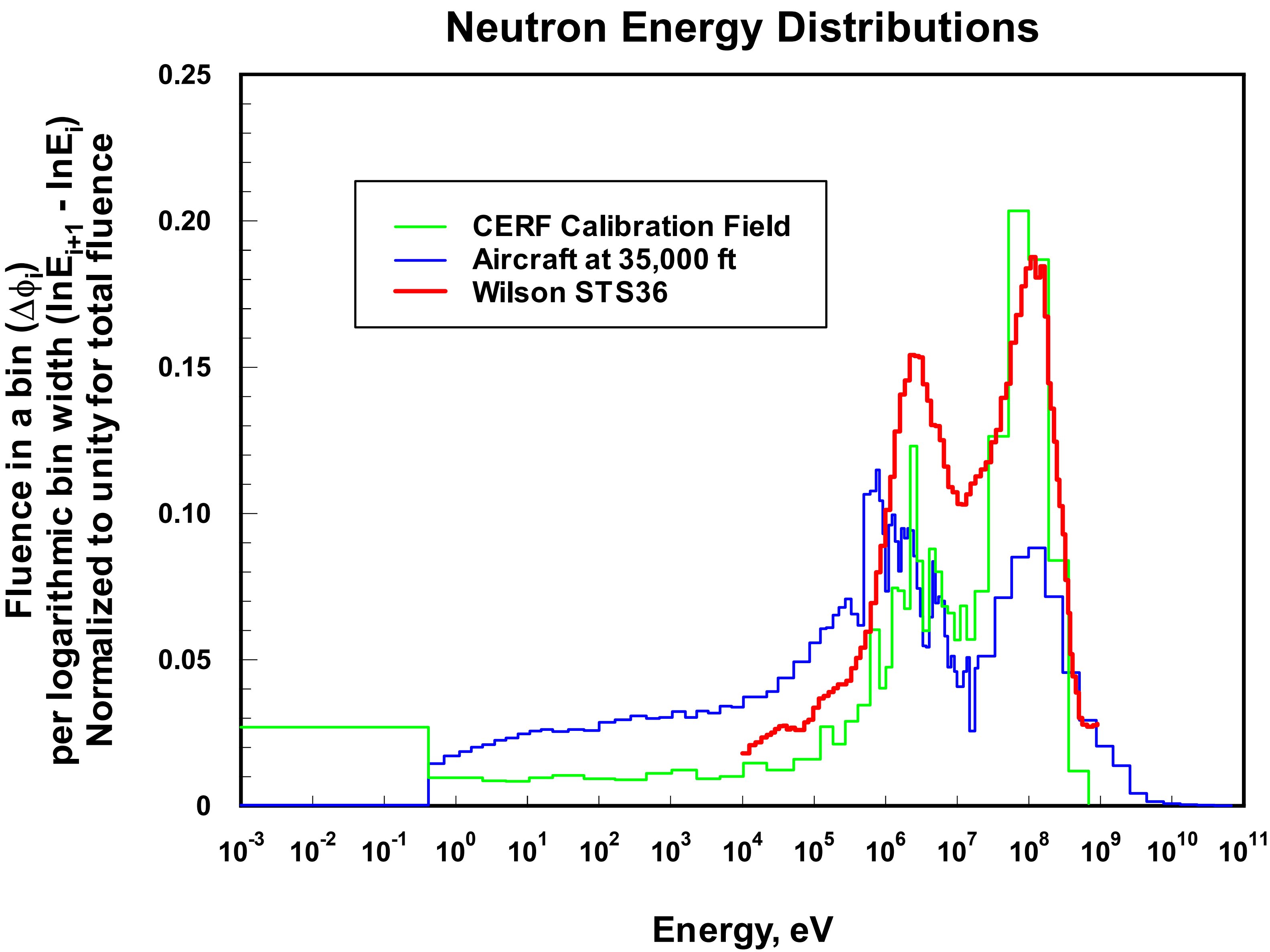


Energy Dependence of Response of the NRPB Passive Survey Instrument

Radiation Field	Net tracks[a] per unit fluence ($cm^2\ 10^{-6}$)	Net tracks per unit effective dose (ISO) (mSv^{-1})	Net tracks per unit ambient dose equivalent (mSv^{-1})
144 keV (PTB)	2.25 (0.38)[b]	66 (11)[b]	17.7 (11)[b]
542 keV (PTB)	14.4 (1.3)	182 (16)	42.9 (3.9)
1.13 MeV (PTB)	30.3 (2)	242 (16)	71.5 (4.7)
2.5 MeV (PTB)	41.8 (2.3)	208 (11)	100 (5.5)
5 MeV (PTB)	38.5 (1.7)	142 (6)	95.1 (4.2)
8 MeV (PTB)	35.3 (1.4)	119 (5)	86.3 (3.4)
14.8 MeV (PTB)	48.7 (2.4)	145 (7)	90.9 (4.5)
18.73 MeV (PTB)	In progress		
60.2 MeV (UCL)	53 (5)	148 (14)	74 (7)
68 MeV (TSL)	42 (13)	115 (36)	106 (33)
95 MeV (TSL)	30 (9)	75 (23)	83 (25)
100 MeV (iThemba)	In progress		
160 MeV (iThemba)	In progress		
173 MeV (TSL)	20 (6)	38 (11)	68 (20)

(a) Average of three angles

(b) Statistical uncertainty (s) on instrument reading added in quadrature to total standard uncertainty on fluence.



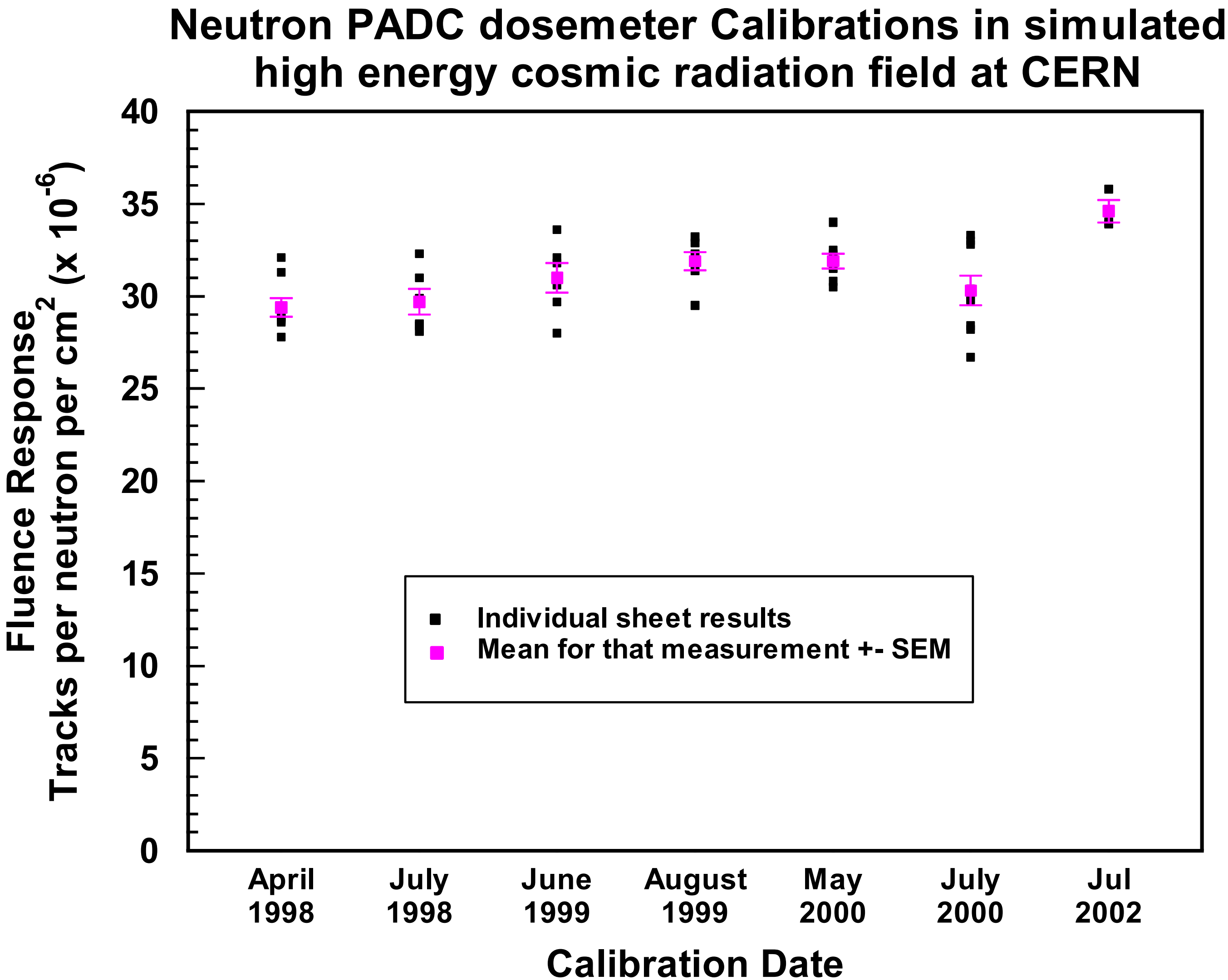
Neutron Energy Distributions
CERF Calibration Field
Aircraft at 35,000 ft
Wilson STS36
Fluence in a bin (Δφ_i)
per logarithmic bin width (lnE_{i+1} - lnE_i)
Normalized to unity for total fluence
0.25
0.20
0.15
0.10
0.05
0
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
Energy, eV

NRPB survey instrument calculated and measured responses in cosmic radiation neutron fields

Neutron Spectrum	Instrument reading[a] per unit fluence (tracks cm^2 10^{-6})	Instrument reading per unit effective dose (ISO) (mSv^{-1})	Instrument reading per unit ambient dose equivalent (mSv^{-1})
Wilson *et al.* STS 36	33.2 (3.9)[b]	109	94
Heinrich *et al.* 35,000 ft	18.9 (2.4)[b]	95	82
Rancati *et al.* CERF (calculated)	25.5 (4.2)[b]	109	98
Rancati *et al.* CERF (measured)	29.8 (2.0)[c]		

(a) Average of three angles
(b) Uncertainty by folding mean response ± s with spectrum
(c) Statistical uncertainty (1 s) on instrument reading only

CERN: top concrete position; neutron monitor, ionization chamber, SSM1, TEPCs (ARCS, ISPN, CIEMAT, SSI)


Neutron PADC dosemeter Calibrations in simulated high energy cosmic radiation field at CERN
Fluence Response
Tracks per neutron per cm2 (x 10-6)
40
35
30
25
20
15
10
5
0
Individual sheet results
Mean for that measurement +- SEM
April 1998
July 1998
June 1999
August 1999
May 2000
July 2000
Jul 2002
Calibration Date

Measured Neutron Ambient Dose Equivalent Rates at Temperate Latitudes (40 – 60^0 N)

Altitude	Investigator	Neutron H*(10) rate (μSv h^{-1})
10.6 km (35 000 ft)	DIAS	3.2 (0.3)[(a)]
	USAAR	3.5 (0.8)
	SSI	3.1 (0.3)
	NRPB	3.8 (0.5)
16 km (53 000 ft)	NRPB	7.8 (0.5)
	DIAS	7.1 (0.6)
	ANPA	6.1 (0.5)
20 km (67,000 ft)	NRPB	9.2 (0.9)
	NASA	8.0

(a) One standard deviation for repeated measurements

Conclusions from Aircraft Measurement Programme

Good agreement of measured and calculated instrument readings for CERF

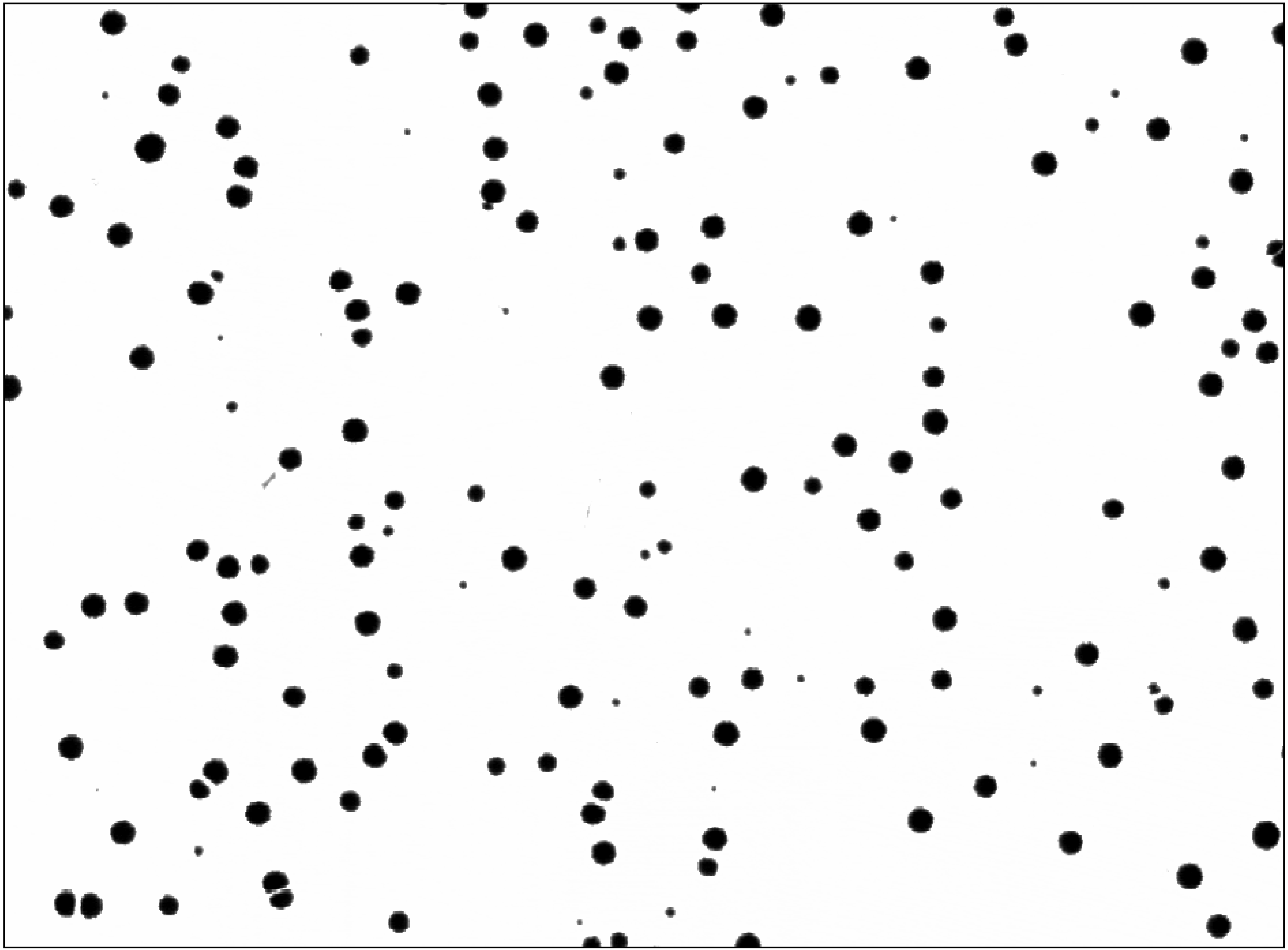
Broad agreement with results for other etched track detector systems

Good agreement of in-flight measurements with other systems

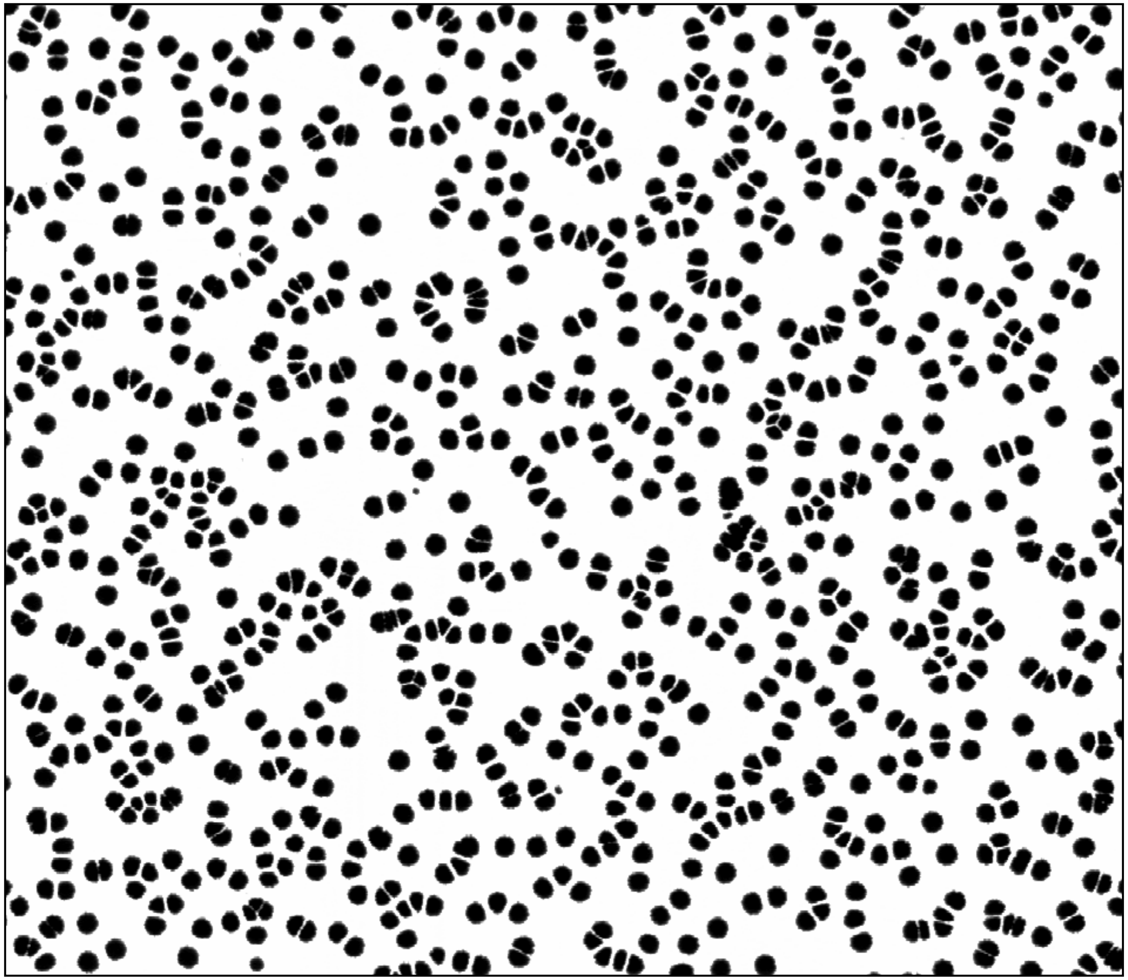
(ii) Response to charged particles

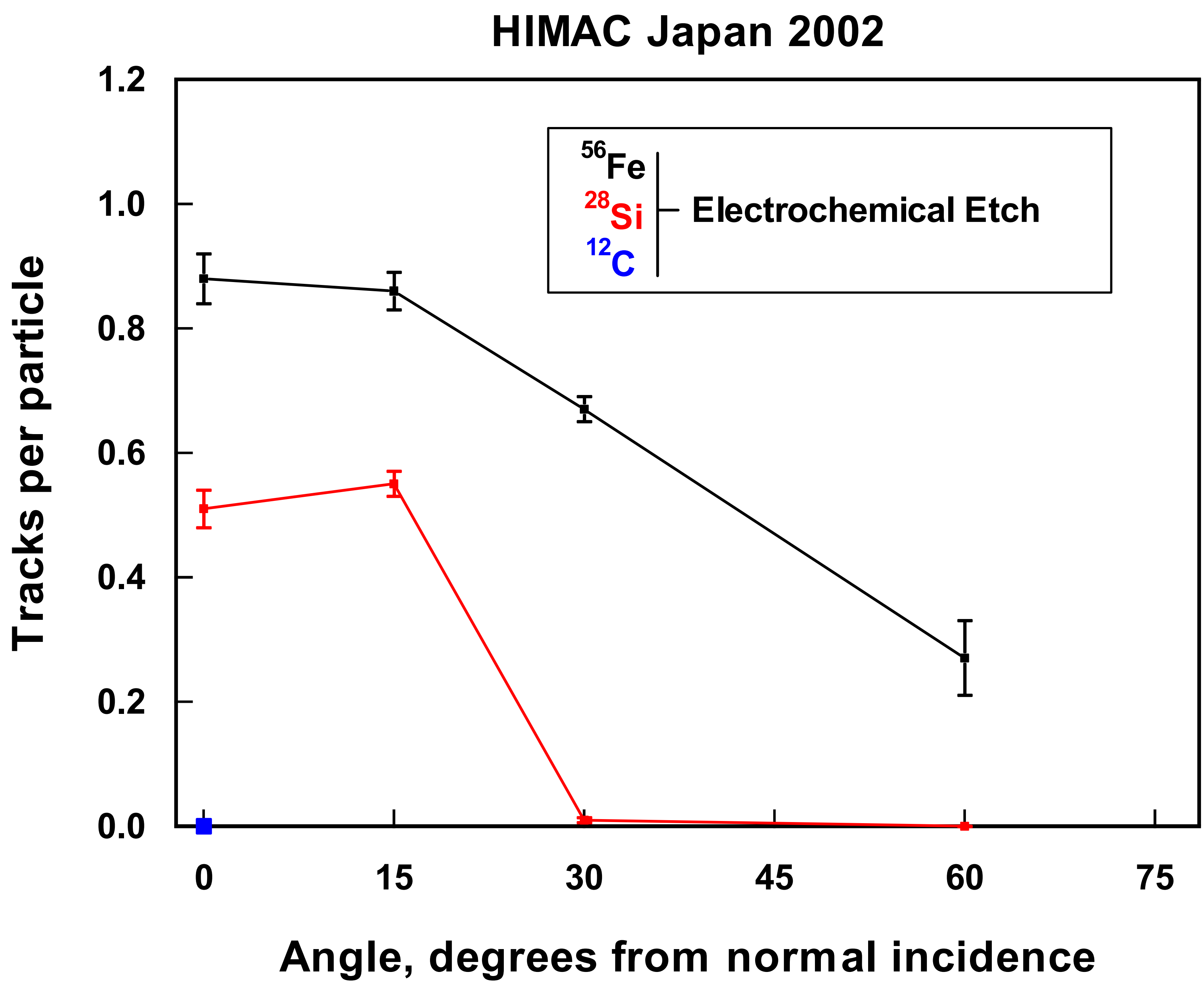
- PADC neutron personal dosemeter responds to neutrons plus neutron-like interactions of high-energy protons
- Only responds directly to protons of E_p < about 1 MeV at the surface to be etched
- Some response to heavier charged particles LET_{200} > about 30 keV μm^{-1}, depending on particle type
- Can generally distinguish HZE electrochemically etched tracks by second chemical etch

CERF Electrochemical etch



Brookhaven Fe 1000MeV per nucleon – Electrochemical etch





HIMAC Japan 2002
56Fe
28Si
12C
Electrochemical Etch
Tracks per particle
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
15
30
45
60
75
Angle, degrees from normal incidence

Charged particle angle dependence of relative response

	0º	15º	30º	60º	75º	Forward 2π (ISO free air)	ISO on body
^{56}Fe 464 MeV/n	0.90	0.85	0.70	0.30	0	30% to 40%	15% to 20%
^{28}Si 469 MeV/n	0.50	0.55	0.02	0	0	about 5%	about 2%

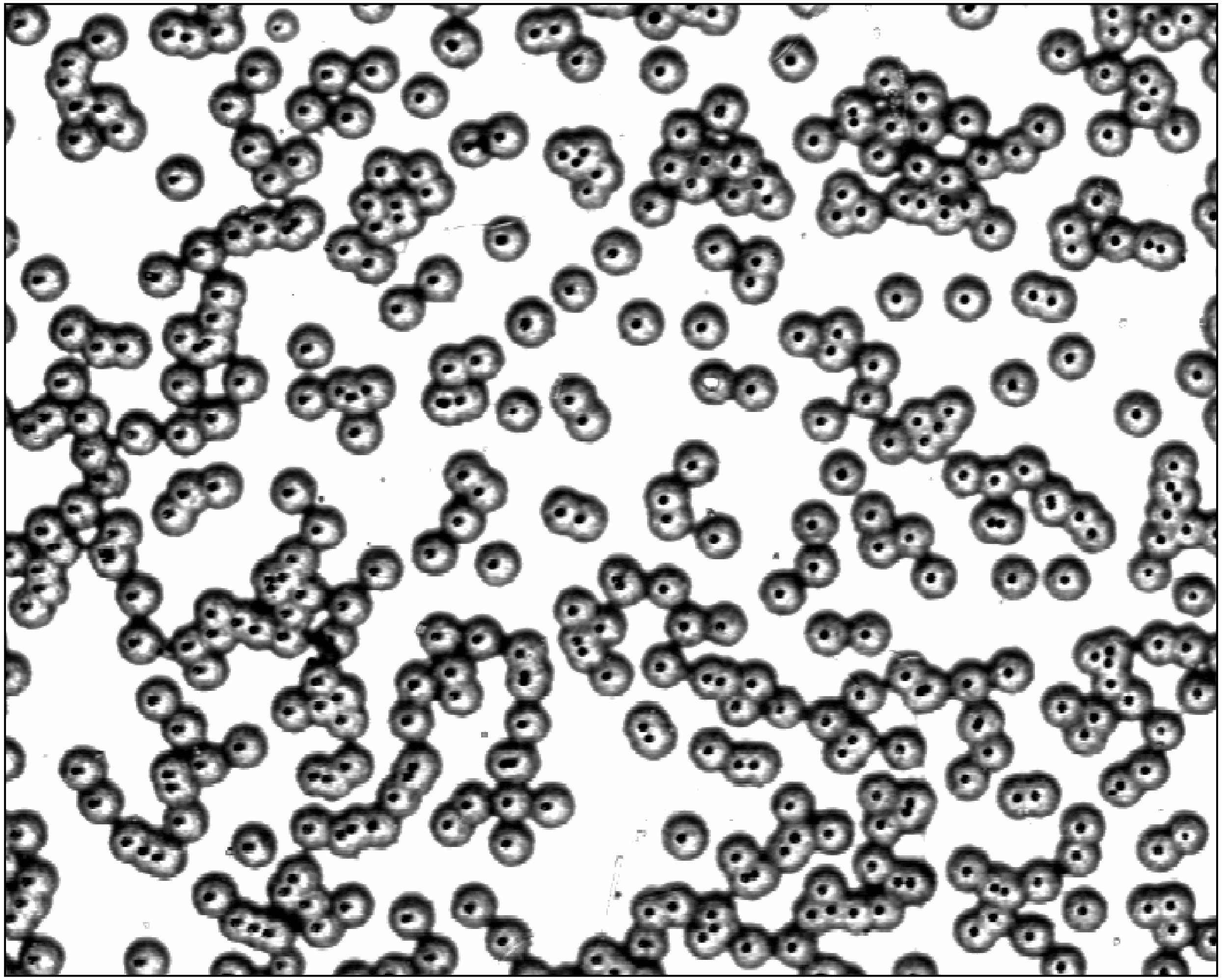
Electrochemical etch - back face

11.5 hours 20% NaOH at 40^{0}C followed contiguously
by 8 hours 20% NaOH at 40^{0}C at 23.5 kVcm^{-1}

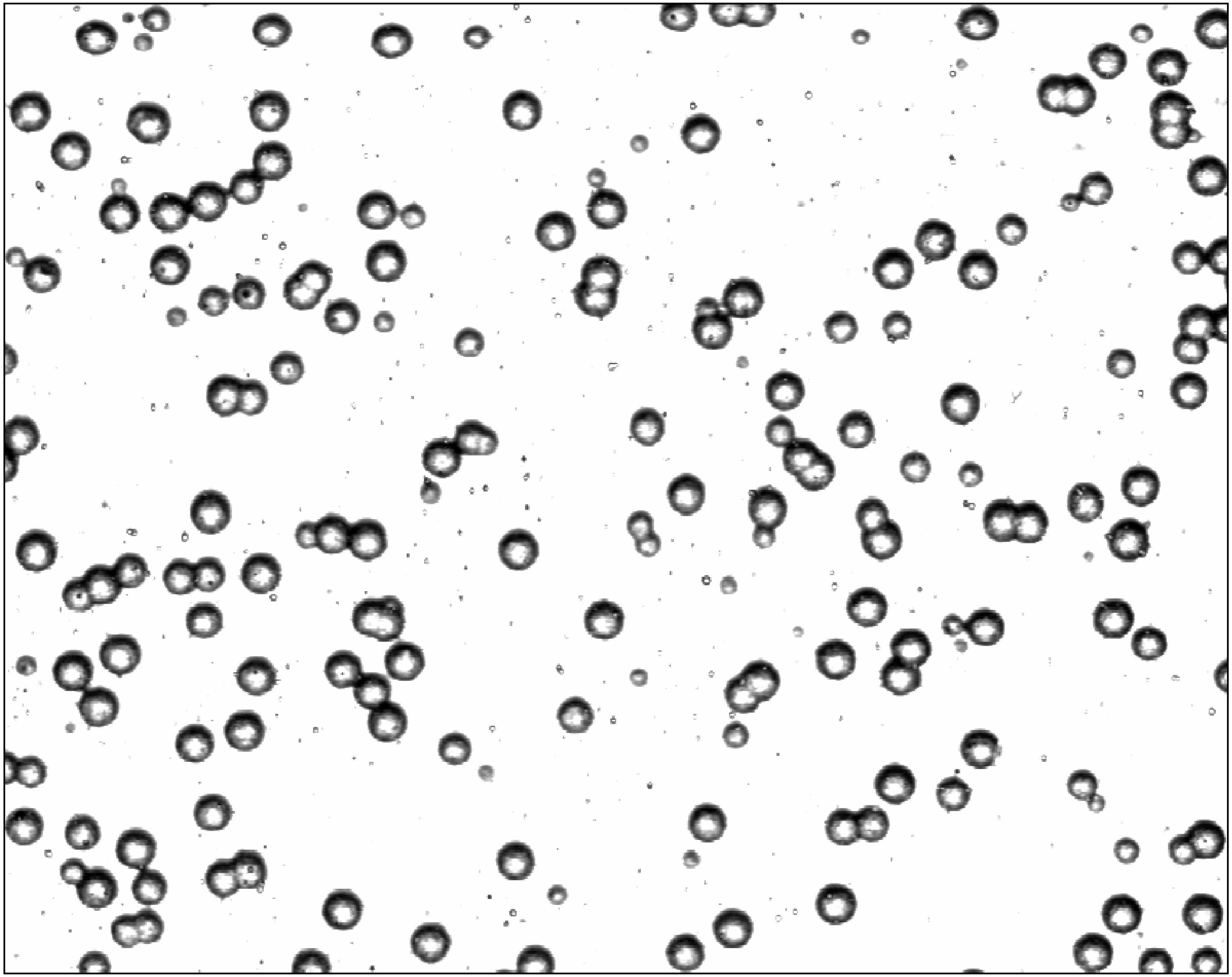
Chemical etch - both faces

18 hours 20% NaOH at 80^{0}C

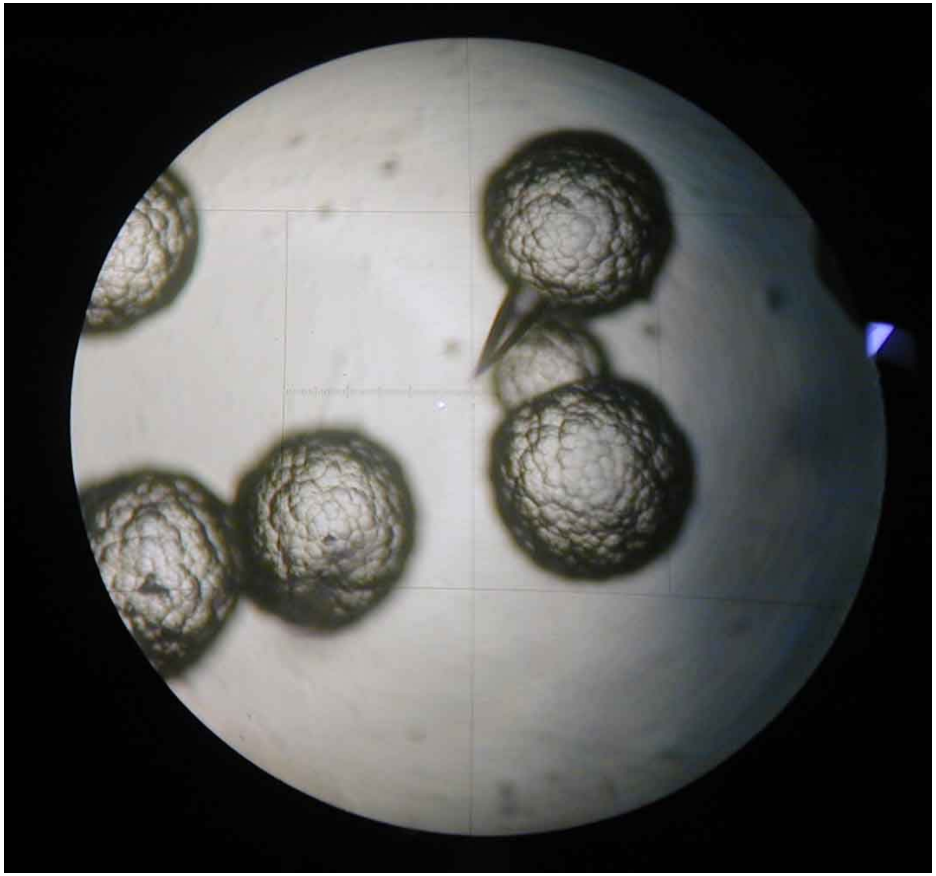
Brookhaven Fe 1000MeV per nucleon – Electrochemical etch + chemical etch

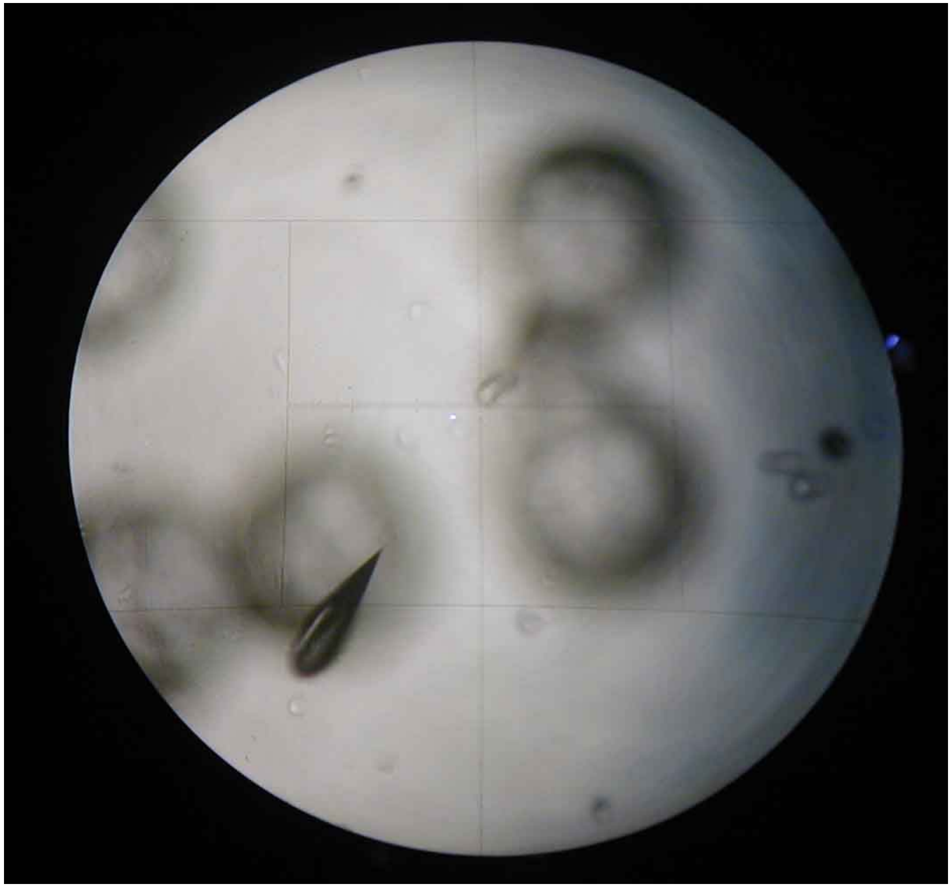


CERF Electrochemical etch + chemical etch

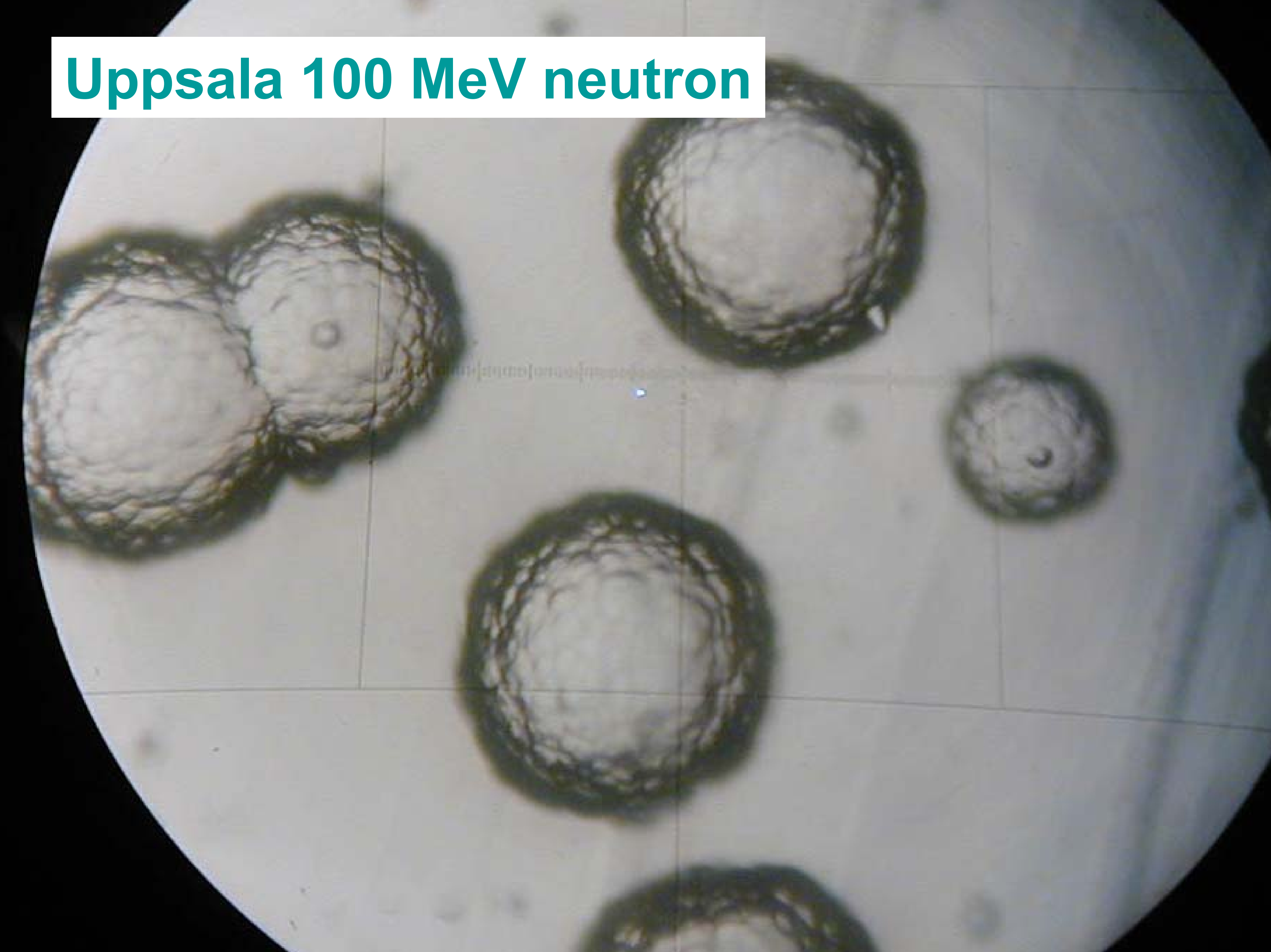


STS 105





Uppsala 100 MeV neutron



(iii) Preliminary results for STS measurements

- Use response data for NRPB passive survey instrument for area passive dosemeter measurements
- Calculate response using monoenergetic data folded with the Wilson STS 36 neutron energy distribution
- Determine net neutron tracks after chemical etch and subtraction of long range particle tracks
- Uncorrected results in good agreement with other estimates of the neutron component of dose equivalent
- Preliminary - need correction for track fading and ageing

Results of measurements of neutron component on STS flights

Flight (duration)	Detector	Tracks	Net Tracks[a]	Estimated Neutron Tracks)[c]	Neutron H*(10) (mSv)	Neutron E(ISO) (mSv)	H*(10) rate (μSv d^{-1})
STS 97 (10d 20h)	D100726 D100761	185 175	171 (14)[b] 160 (14)	130 133	1.19 1.22	1.38 1.41	110 113
STS 98 (12d 21.3h)	D100722	237	226 (16)	201	1.84	2.13	144
STS 104 (12d 18.6h)	D102042	232	219 (17)	178	1.64	1.90	127
STS 105 (11d 21h)	D102010 D102035	198 227	170(16) 201(17)	140 172	1.29 1.58	1.49 1.83	108 132
STS 108 (10d 20h)	D102070	205	177(15)	136	1.24	1.44	115
STS 112 (10d 20h)	D108124 D108126	204 201	188 (16) 185 (16)	153 152	1.41 1.39	1.63 1.62	130 130

(a)Background and transit control subtracted, linearity corrected.
(b)Standard deviation assuming Poisson distribution for observed tracks with standard deviation on background and transit controls added in quadrature.
(a)After chemical etch and subtraction of long-range tracks.

- Neutron ambient dose equivalent rate of 110 to 145 μSv d^{-1}
- Average neutron effective dose rate about 15% larger
- Consistent with the neutron component inferred from other measurements

Application as area passive dosemeter or personal dosemeter

Estimate of neutron component only of dose equivalent 200μSv to 100 mSv, but no dose rate information; robust; no power supply; contains no flammable gases; no supervision; relatively small size; well-proven reliable and simple detectors
(but full track analysis of PADC detector to get H > 10 keV μm^{-1} better option)

Use with

(i) small ionization chamber (DIS?) but absorbed dose not dose equivalent – need Q (w_R?) or correction factor to get non-neutron component of effective dose

(ii) TLD or OSL with correction for charged particle response and for Q (w_R?)

part of integrated scheme with calculated values of field quantities and effective dose

ACKNOWLEDGEMENTS

Irradiations carried out at the The Svedberg Laboratory were supported under the European Commission Research Infrastructure programme and those at the Physikalisch-Technische Bundesanstalt (PTB) and at the Université Catholique Louvain were funded by the European Commission RTD Programme: Nuclear Energy, Euratom Framework Programme V, 1998-2002, Contract N° FIGM-CT-2000-00068

The authors should like to thank Yukio Uchihori, N Yasuda, Eric Benton and their colleagues at NIRS; Frank Wissmann, Helmut Schuhmacher and Ralph Nolte at PTB; Alexander Prokofiev, Jan Blomgren, Per-Ulf Renberg and Nils Ollson at TSL; Marco Silari, Evangelia Dimovasili, Sabine Mayer and Angela Mitaroff at CERN; and Edward Semones and Mike Golightly at NASA, for their help with these investigations. One of us (DTB) should especially like to thank Graham Stevenson and Manfred Höfert of CERN for many useful discussions on these matters over several years.