The use of passive personal neutron dosemeters to determine the neutron component of cosmic radiation fields in spacecraft- an update

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Secondary neutrons are a major contributor to dose equivalent and effective dose inside a spacecraft for the altitude range and inclination of the International Space Station.

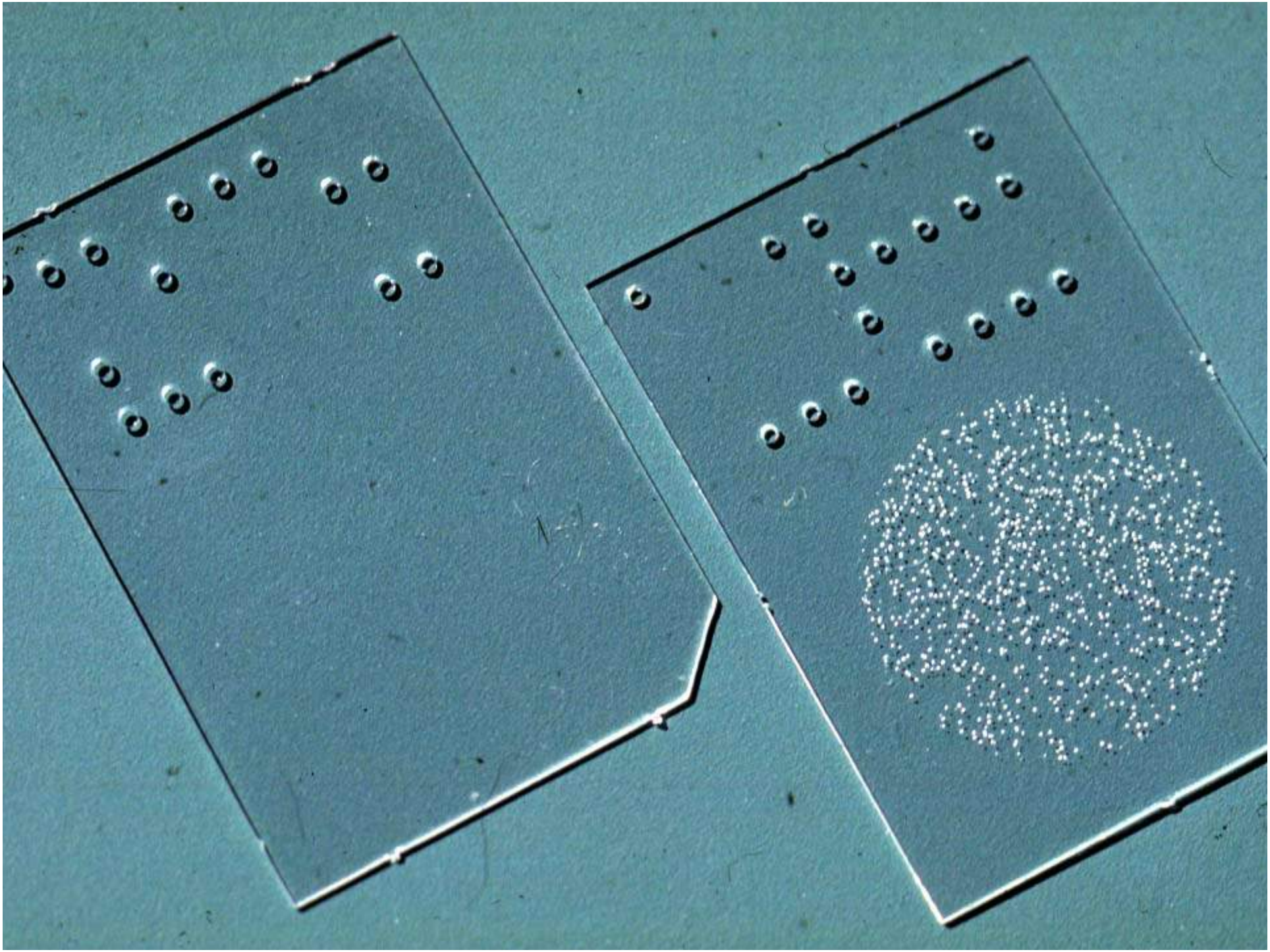
Exact proportion very dependent on amount of shielding, but perhaps 10% to 60%.

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

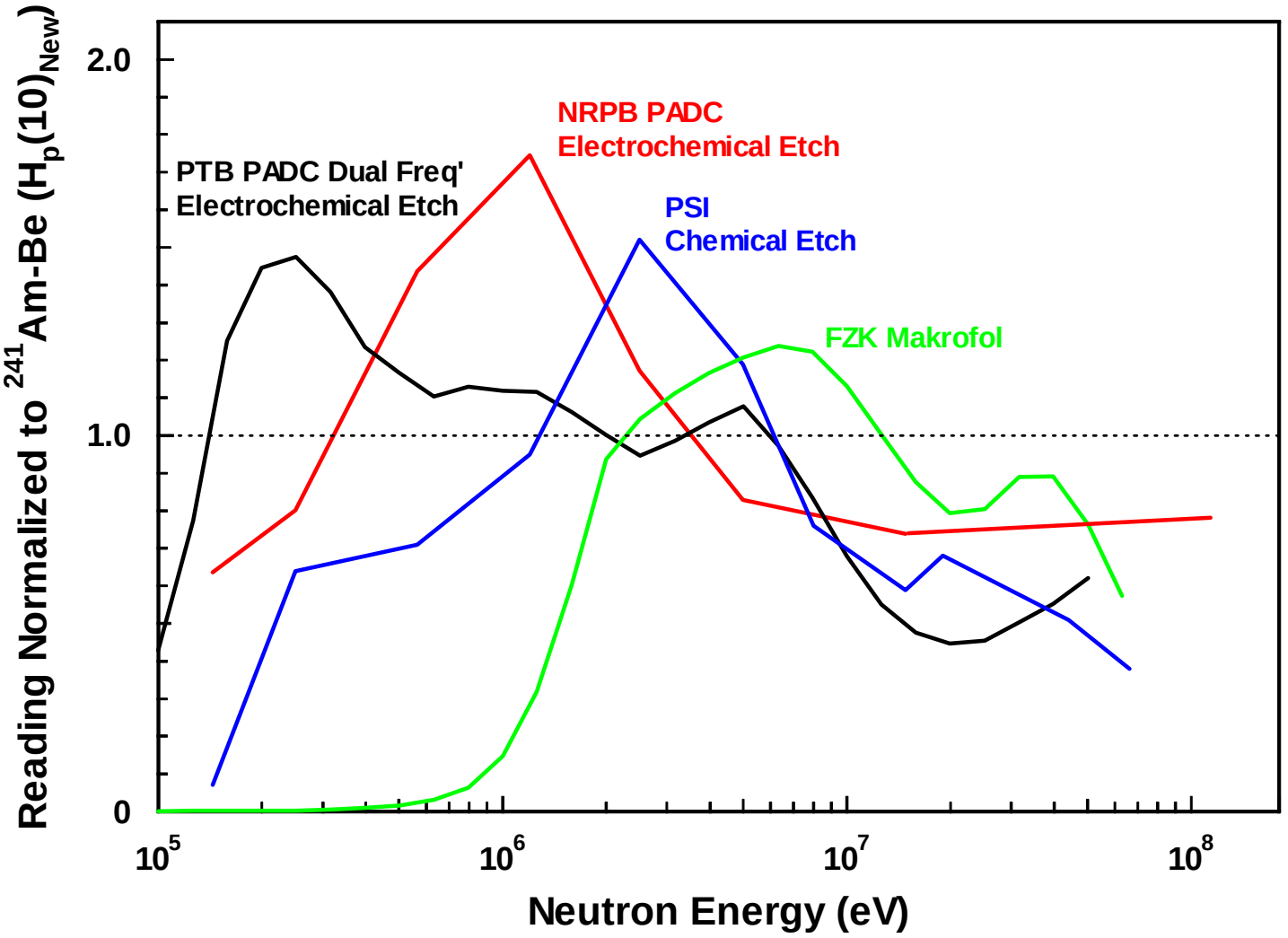
Charged particle threshold 30 to 40 keV μm^{-1}
(e.g. $E_p < 1$ MeV)

Neutrons + neutron-like interactions of protons

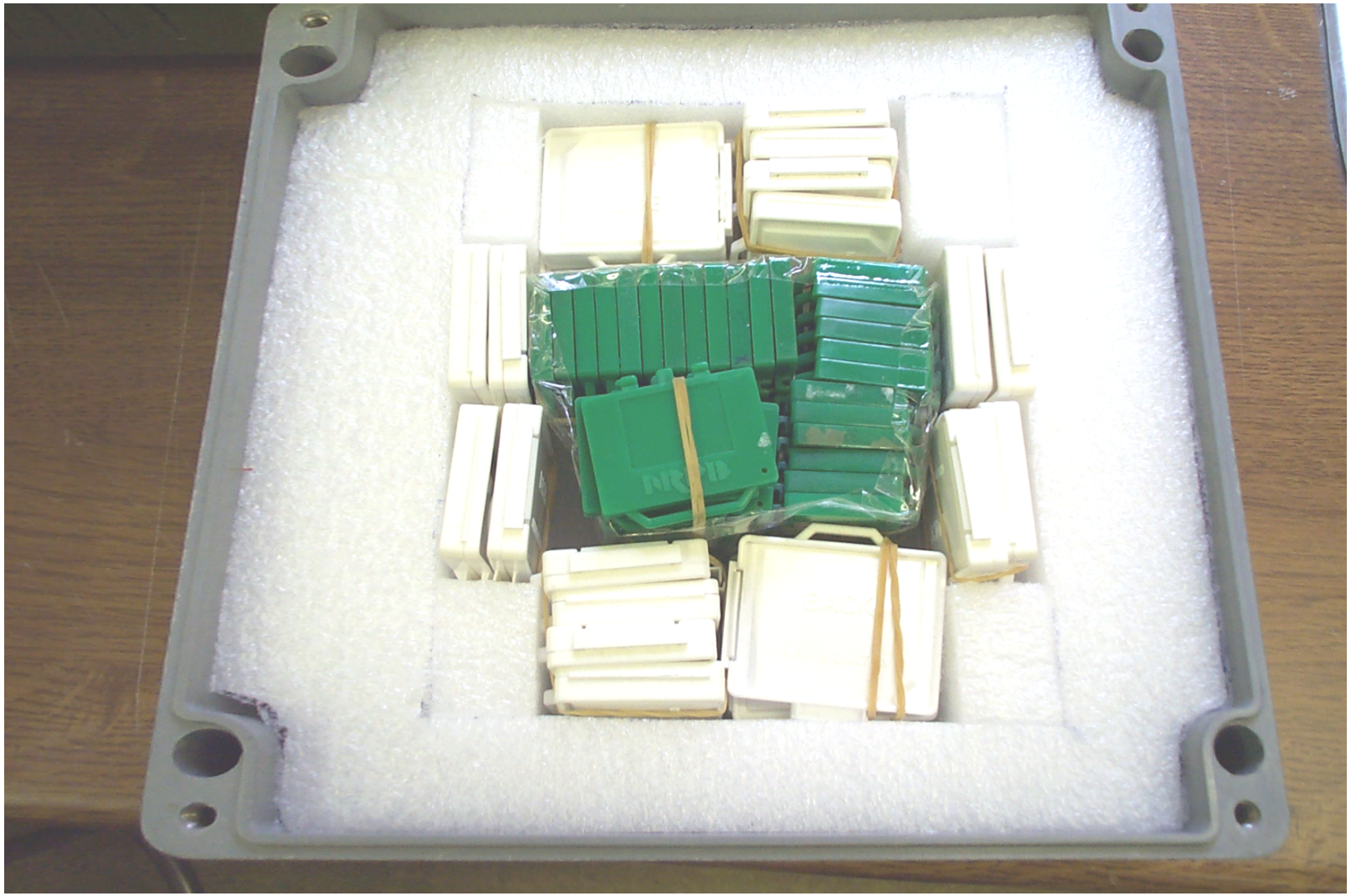
Calibration factor determined for the calculated neutron field in spacecraft



Etched Track Detector Response Characteristics

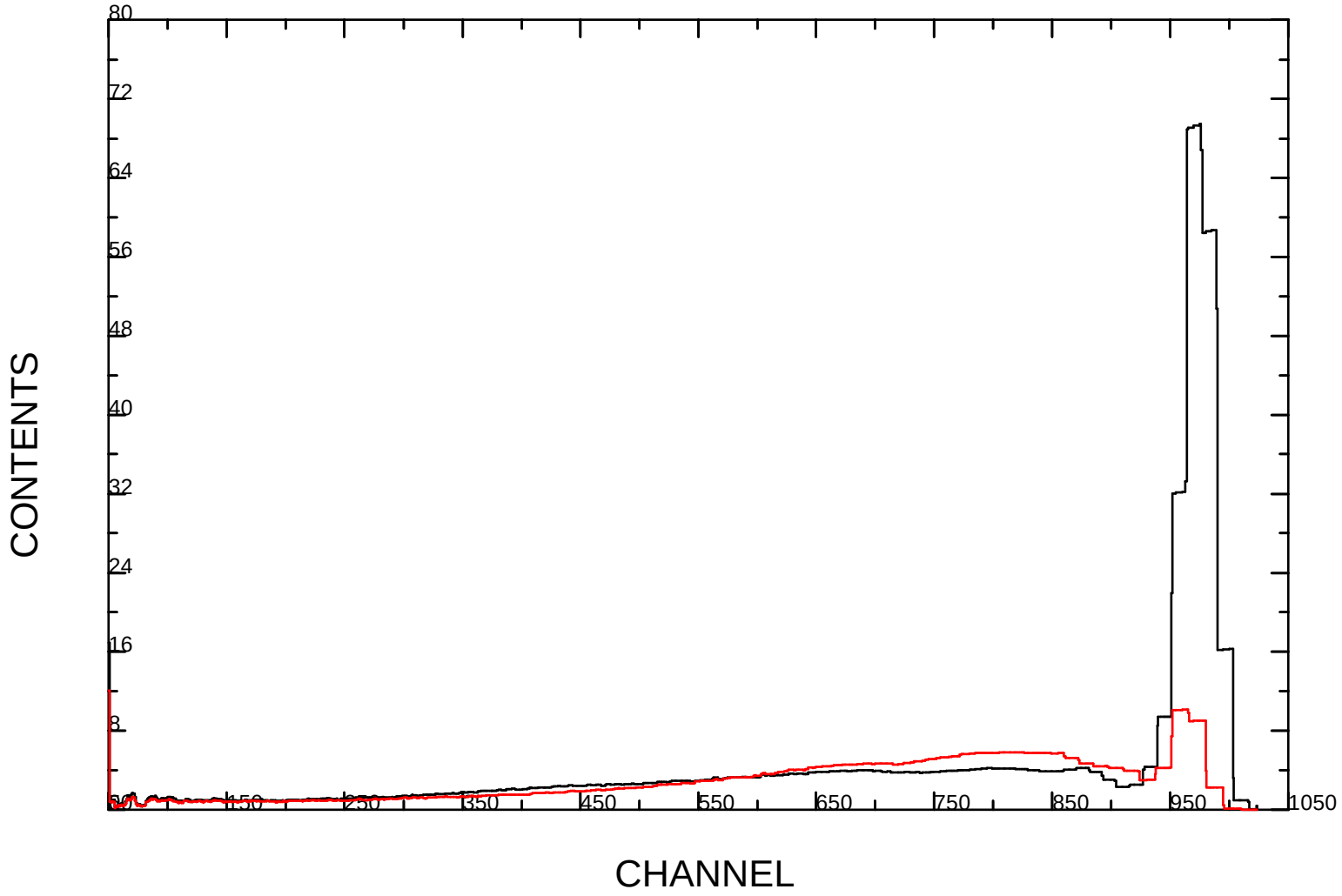


Area passive dosimetry- HPA passive survey instrument



iThemba 1103: 100 MeV

comparison 0°-16°: spectra norm. to same monitor reading and distance



Energy Dependence of Response of the HPA Passive Survey Instrument

Radiation Field	Net tracks[(a)] per fluence ($cm^2\ 10^{-6}$)	Net tracks per ambient dose equivalent (mSv^{-1})
144 keV (PTB)	2.25 (0.38)[(b)]	17.7 (3)[(b)]
542 keV (PTB)	14.1 (1.3)	42.0 (3.9)
1.13 MeV (PTB)	29.9 (2)	70.5 (4.7)
2.5 MeV (PTB)	41.3 (2.3)	99.4 (5.5)
5 MeV (PTB)	38.1 (1.7)	94.1 (4.2)
8 MeV (PTB)	34.8 (1.4)	85.1 (3.4)
14.8 MeV (PTB)	48.0 (2.3)	89.5 (4.3)
19 MeV (PTB)	54.7 (8.2)	93.6 (14)
60.2 MeV (UCL)	51 (5.5)	139 (15)
68 MeV (TSL)	42 (13)	121 (38)
95 MeV (TSL)	30 (9)	103 (33)
97 MeV (iThemba)[(c)]	39 (4)	135 (19)
173 MeV (TSL)	20 (6)	80 (25)
200 MeV (iThemba)	In progress	

(a)Averaged over 3 orientations
(b)Total uncertainty
(c) New Data

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

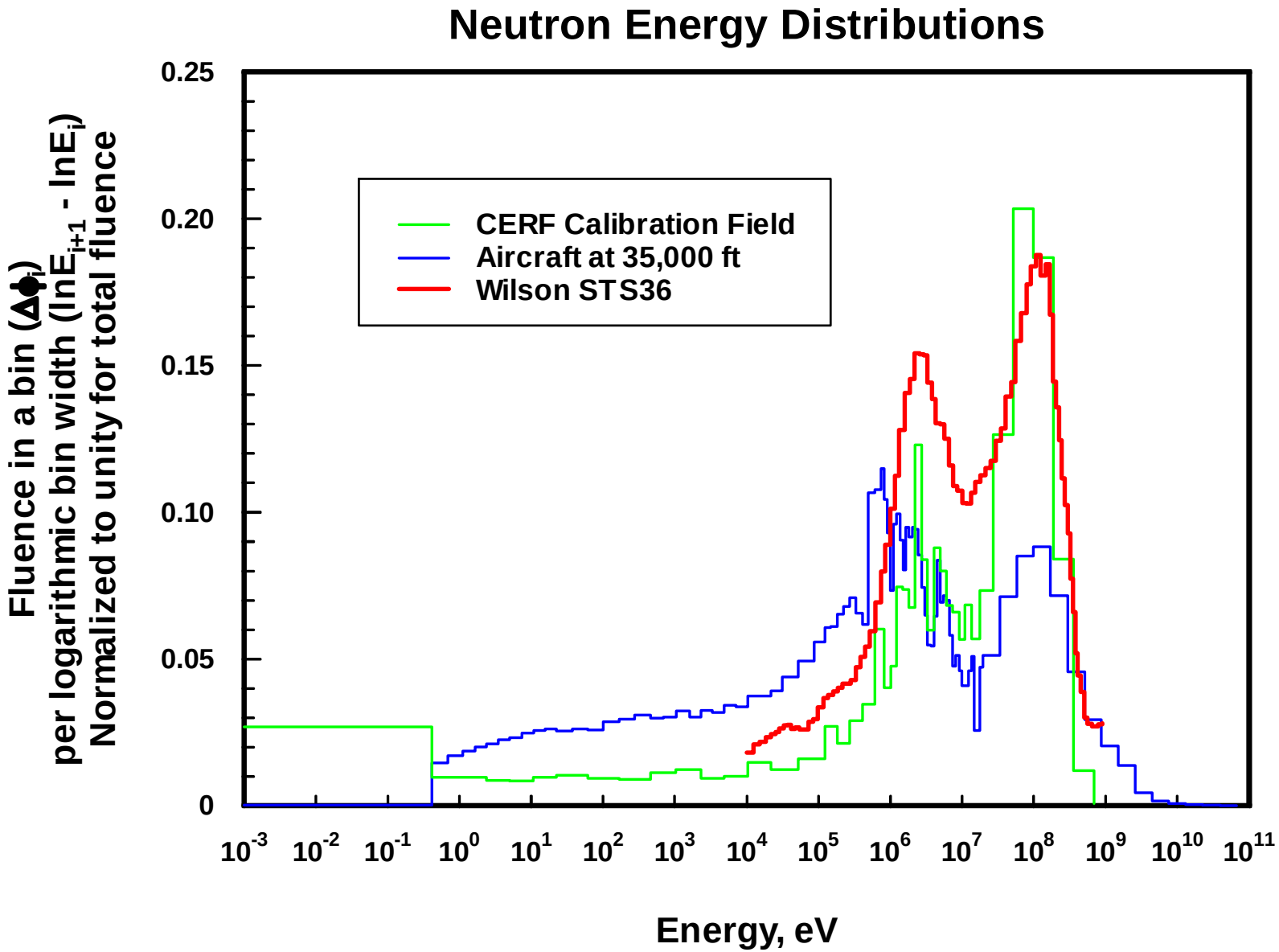
(results averaged over three orientations)

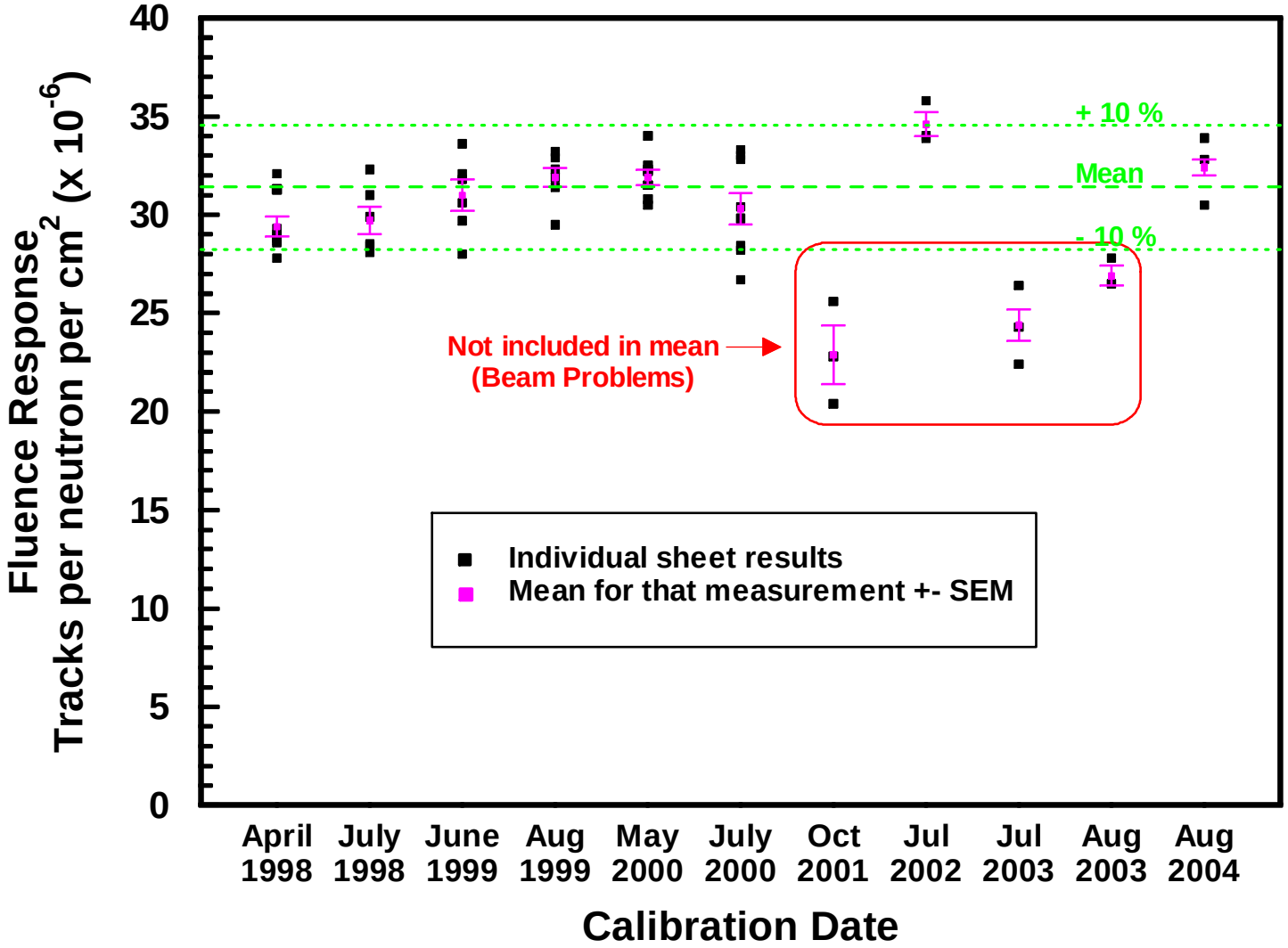
Neutron field	R_Φ (cm^2 10^{-6})	$H^*(10)/\Phi$ (pSv/cm^2)	$H^*(10)$ integral response characteristics $R_{H^*(10)}$ (mSv^{-1})	
			New	Old
Wilson STS 36 calculated	33.0 (4.2)[a]	354	93 (12)[a]	90 (12)[a
Lyagushin 20 g/cm^2 calculated	19.6	275	71	
Lyagushin 30 g/cm^2 calculated	24.2	325	74	
CERF calculated	26.0 (2.9)	262	99 (11)	94 (16)
CERF measured	30.9 (2.0)[b]			
Roesler 246 g/cm^2 calculated	18.7 (2.6)	230	81 (11)	79(11)

(a) Uncertainty by folding mean response ± s with spectrum

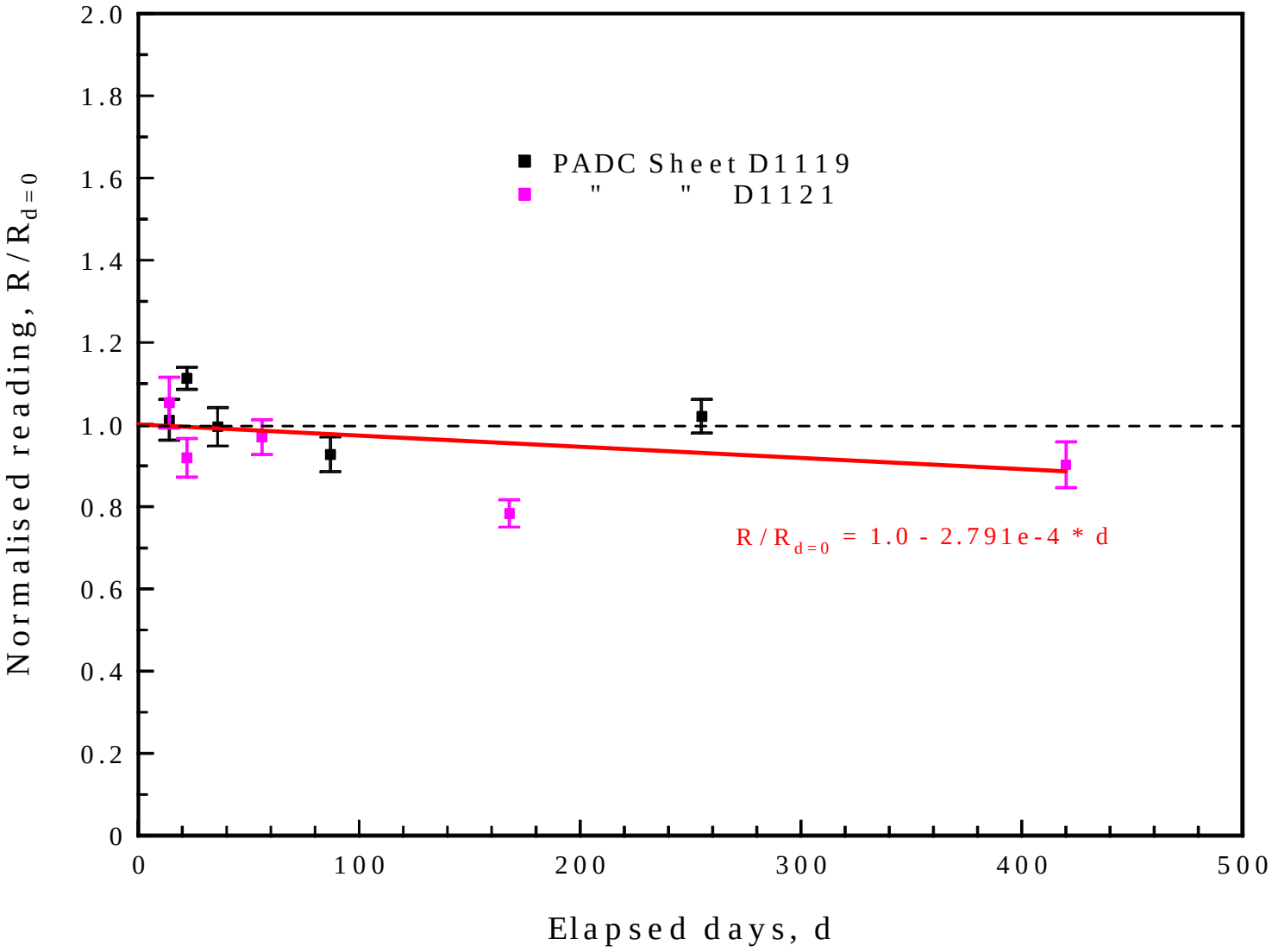
(b) Statistical uncertainty (1 s) on instrument reading only

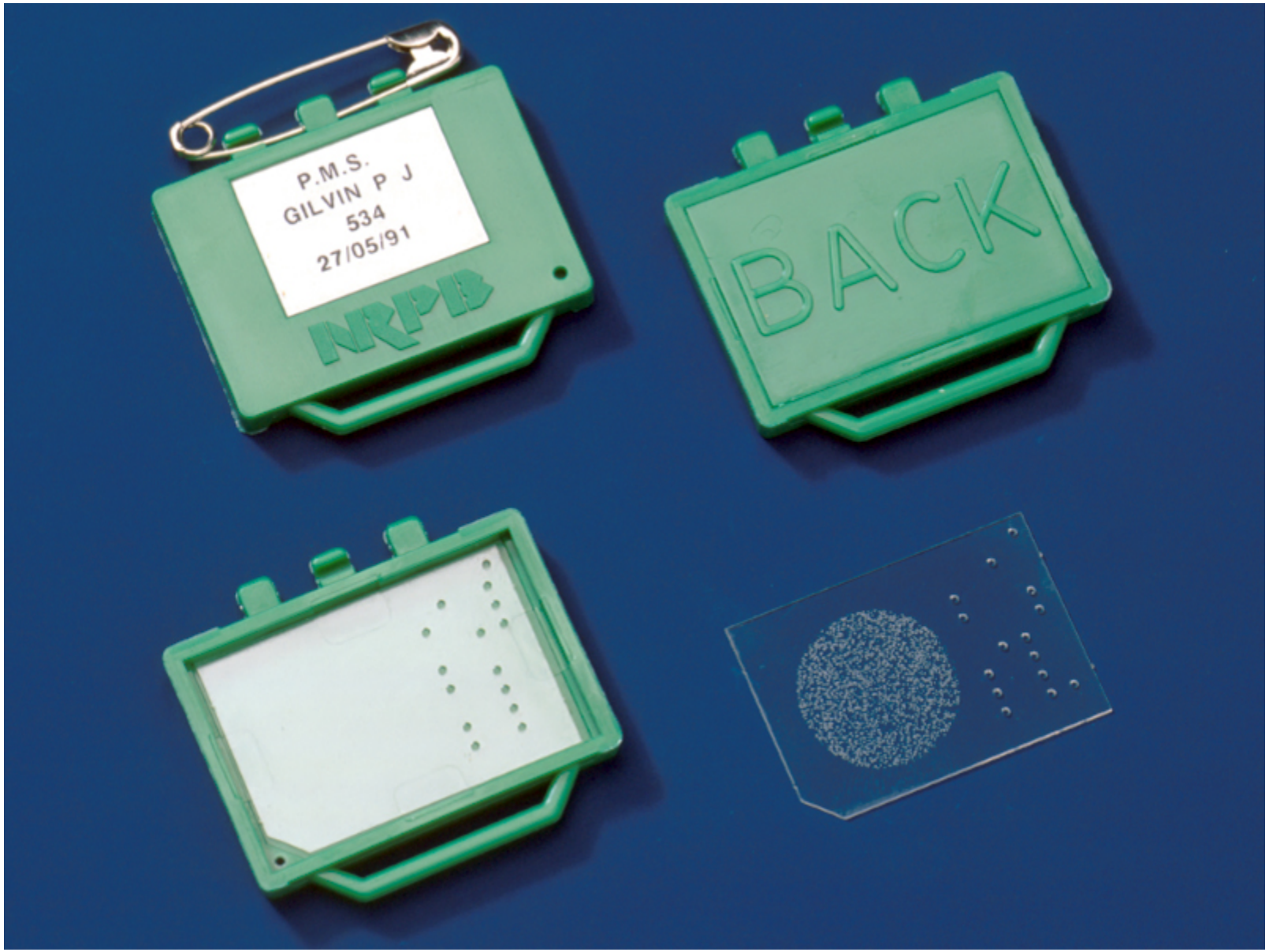
CERN: top concrete position; neutron monitor, ionization chamber, SSM1, TEPCs (ARCS, ISPN, CIEMAT, SSI)


Neutron Energy Distributions
Fluence in a bin (ΔΦi)
per logarithmic bin width (lnEi+1 - lnEi)
Normalized to unity for total fluence
0.25
0.20
0.15
0.10
0.05
0
CERF Calibration Field
Aircraft at 35,000 ft
Wilson STS36
10-3
10-2
10-1
100
101
102
103
104
105
106
107
108
109
1010
1011
Energy, eV


Fluence Response
Tracks per neutron per cm^2 (x 10^{-6})
40
35
30
25
20
15
10
5
0
+ 10 %
Mean
- 10 %
Not included in mean
(Beam Problems)
Individual sheet results
Mean for that measurement +- SEM
April 1998
July 1998
June 1999
Aug 1999
May 2000
July 2000
Oct 2001
Jul 2002
Jul 2003
Aug 2003
Aug 2004
Calibration Date

Fading data: CERF irradiated PADC

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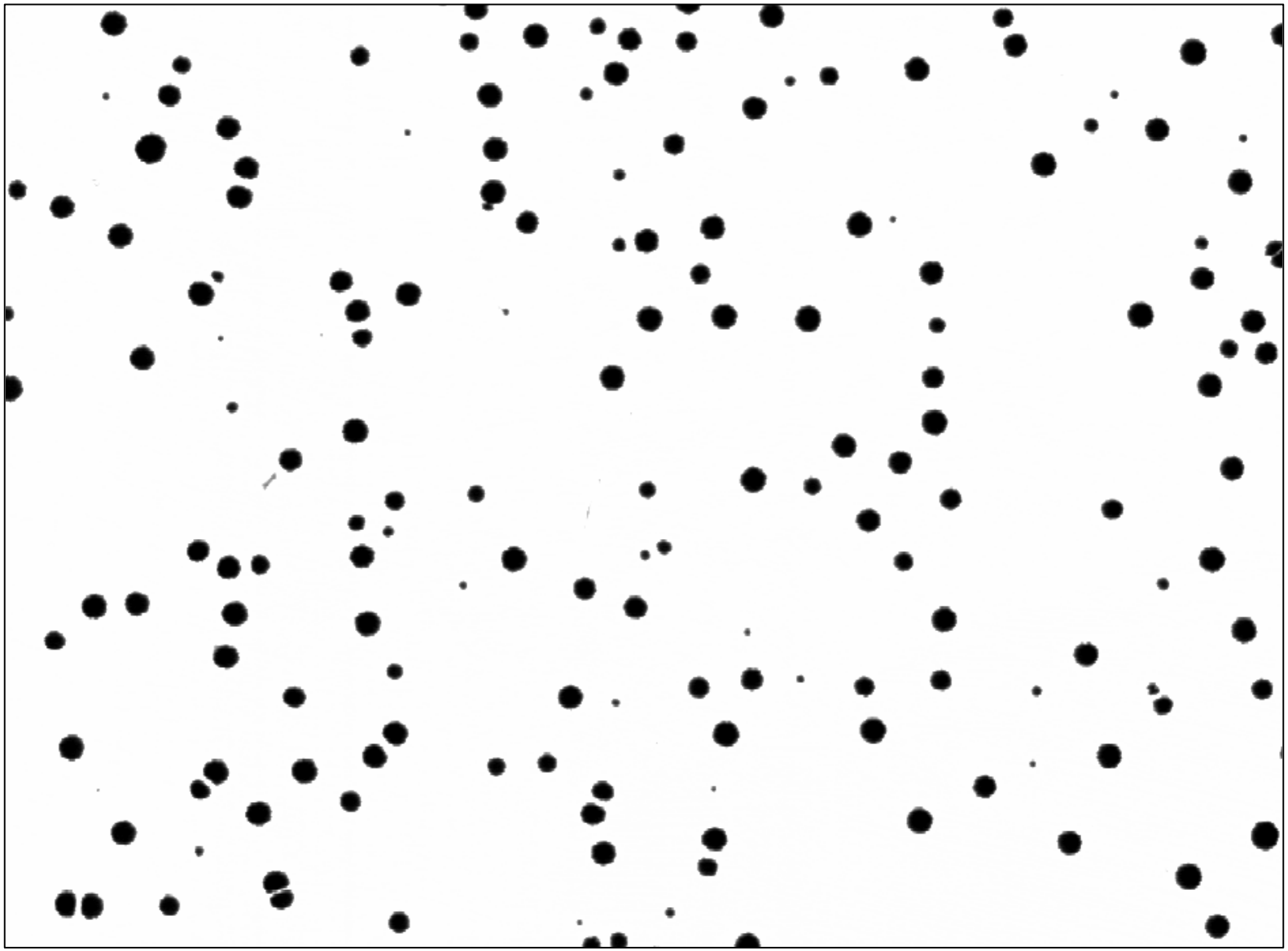
NRPB
BACK

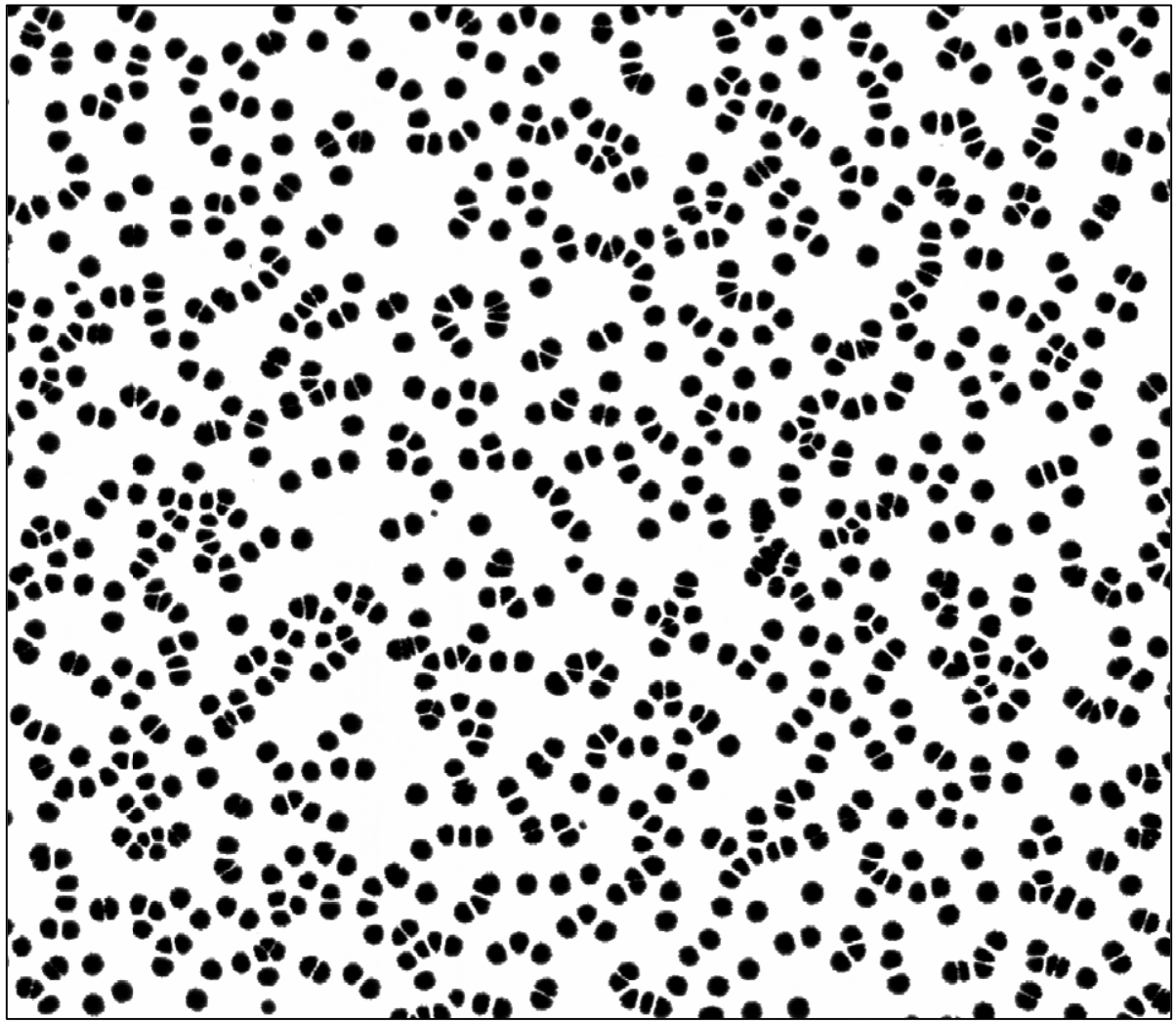
Response to charged particles

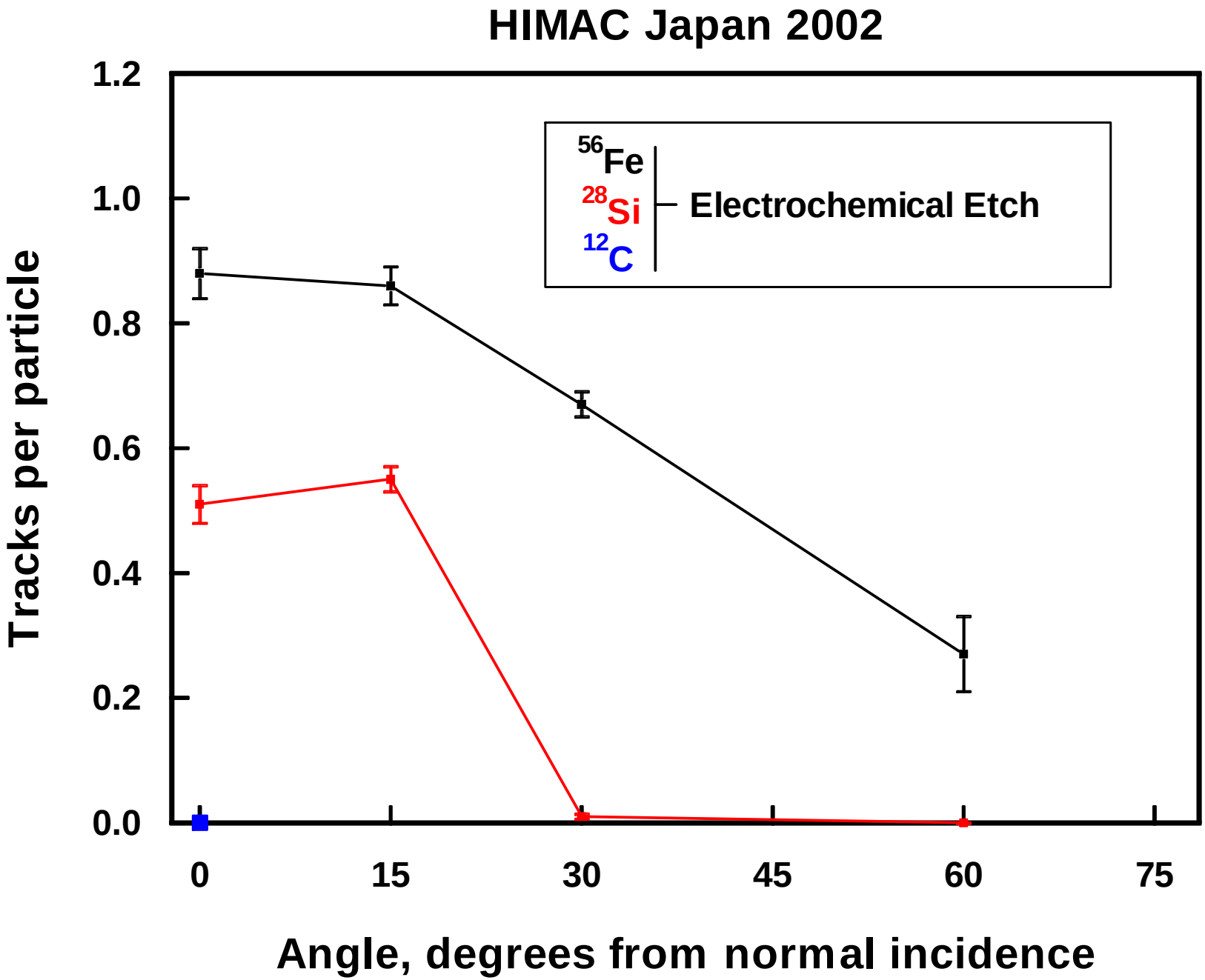
- PADC neutron personal dosemeter responds to neutrons plus neutron-like interactions of high-energy protons
- Only responds directly to protons of E_p < about 1 MeV at the surface to be etched
- Some response to heavier charged particles LET_{200} > about 30 keV μm^{-1}, depending on particle type
-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

CERF Electrochemical etch



Brookhaven Fe 1000MeV per nucleon – Electrochemical etch




HIMAC Japan 2002
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
56Fe
28Si
12C
Electrochemical Etch

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%

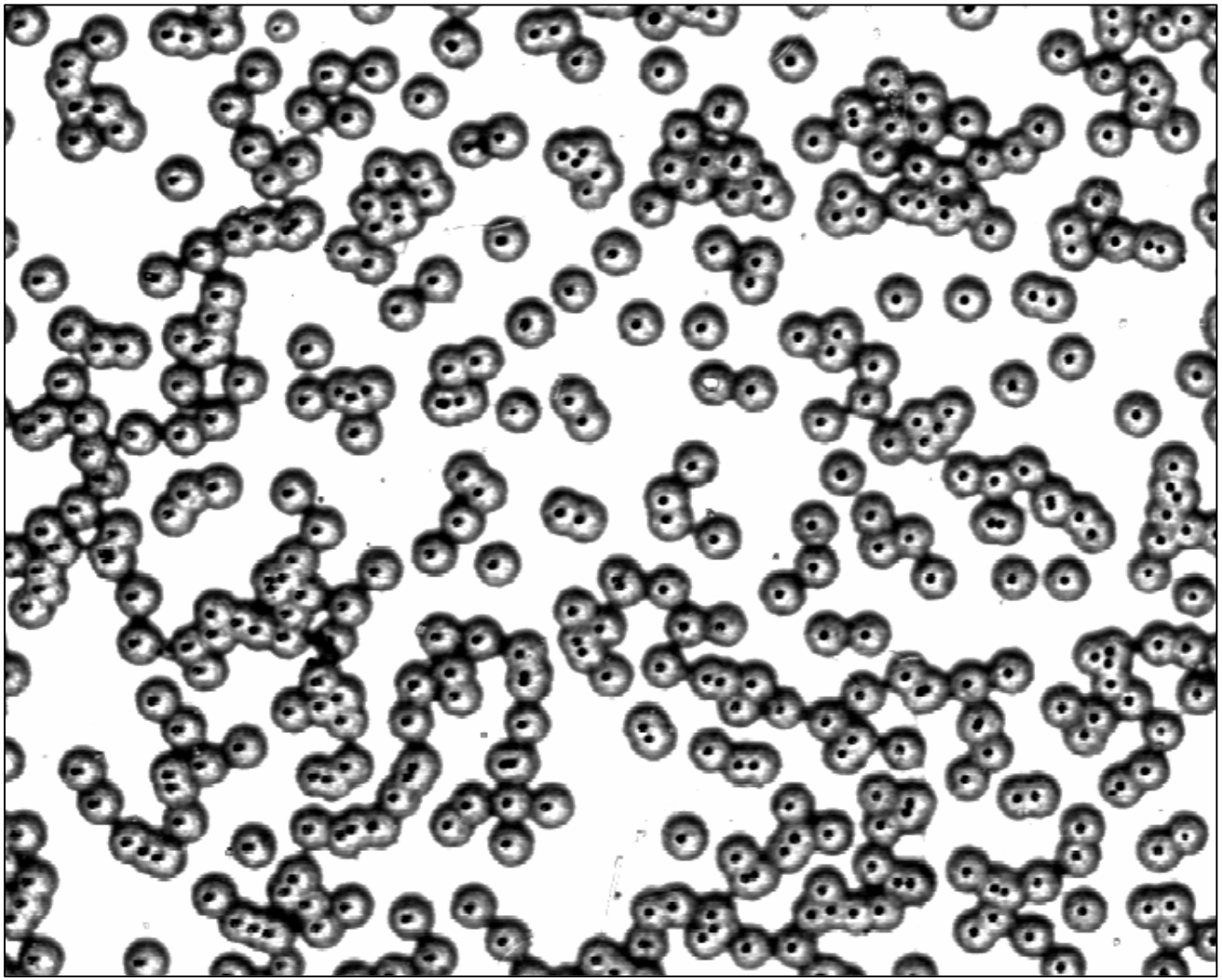
Electrochemical etch - back face

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

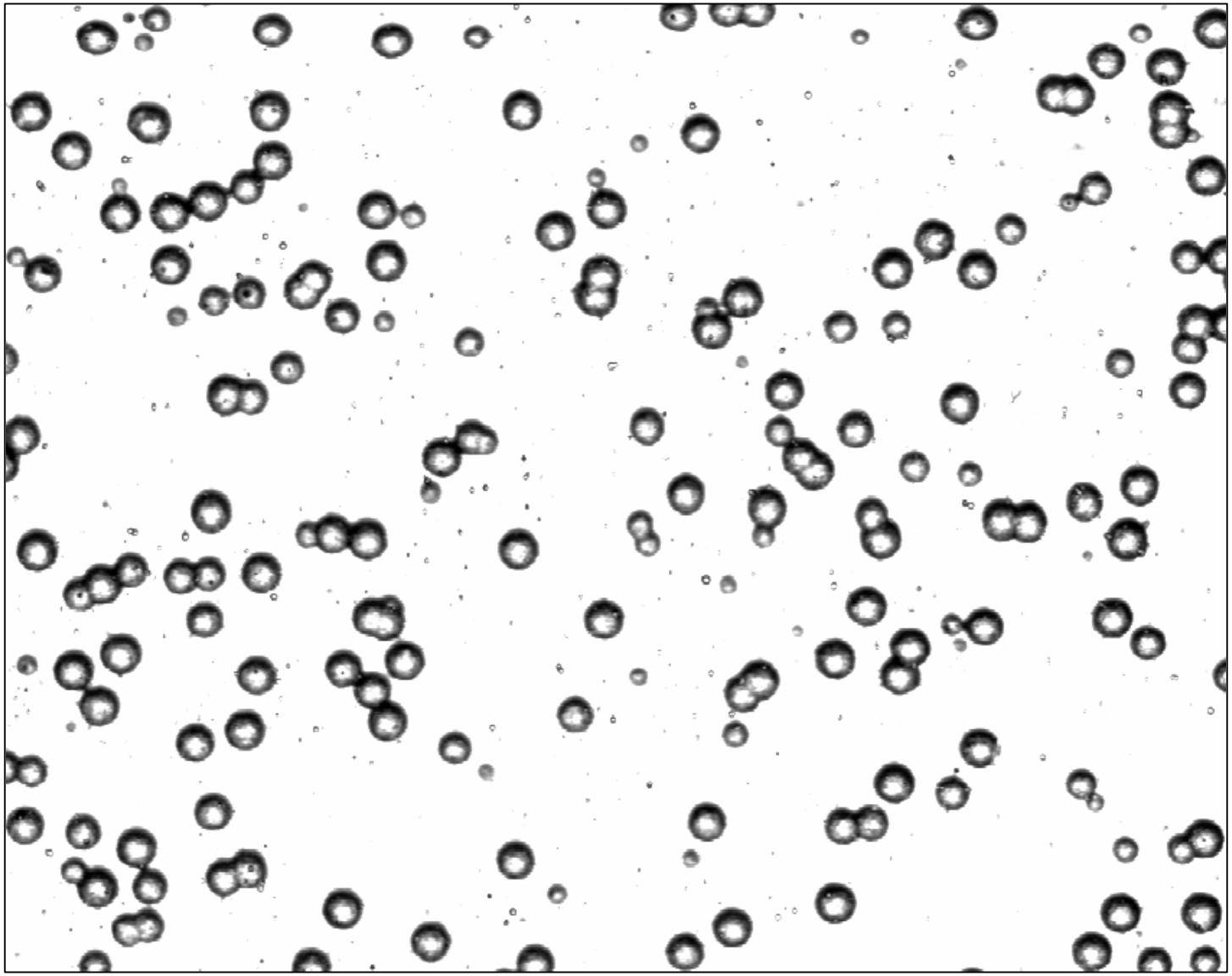
Chemical etch - both faces

18 hours 20% NaOH at 80^0C

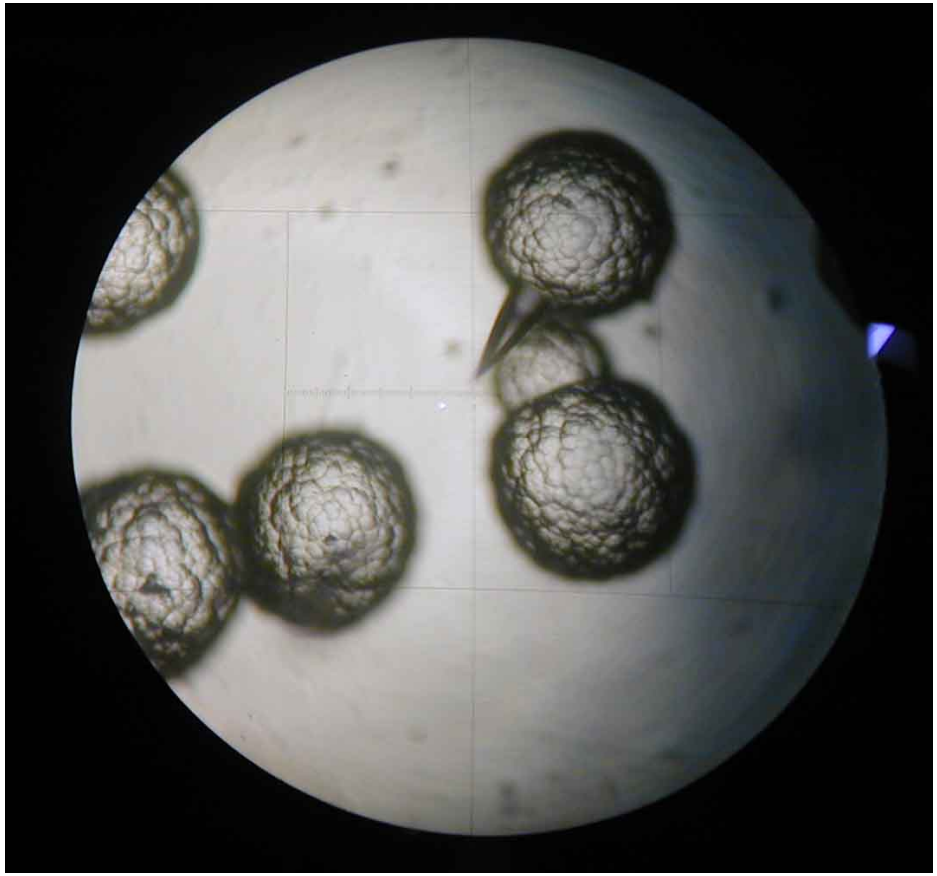
Brookhaven Fe 1000MeV per nucleon – Electrochemical etch + chemical etch

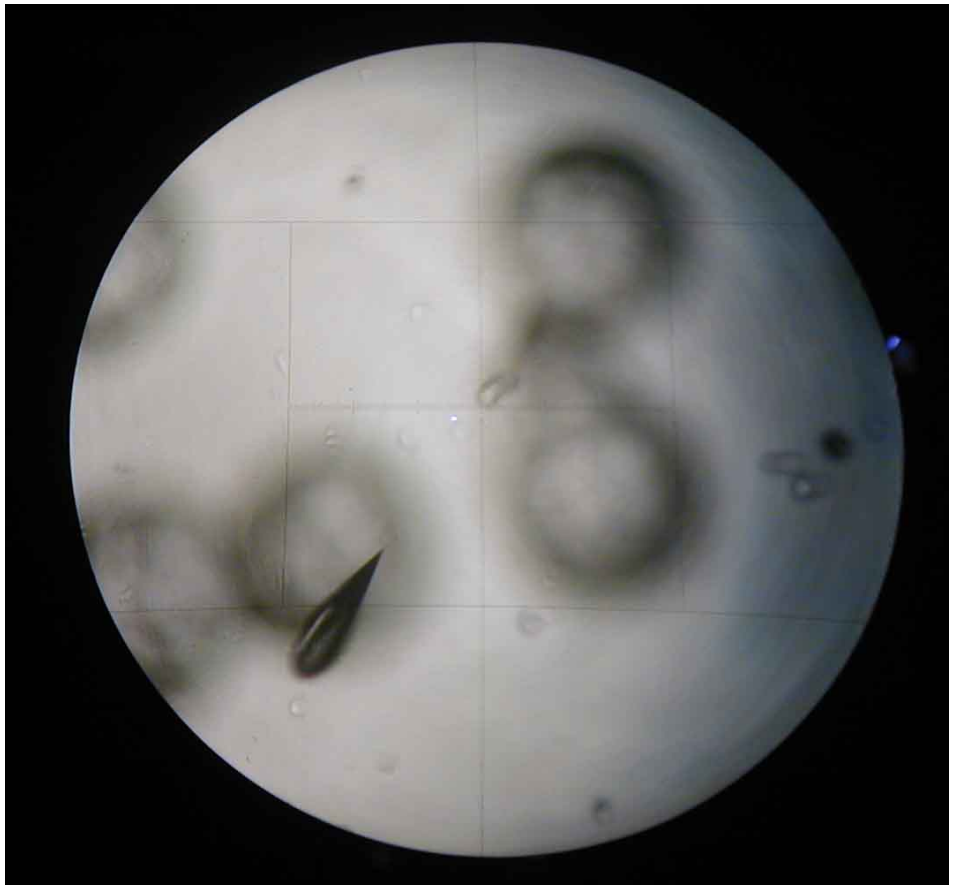


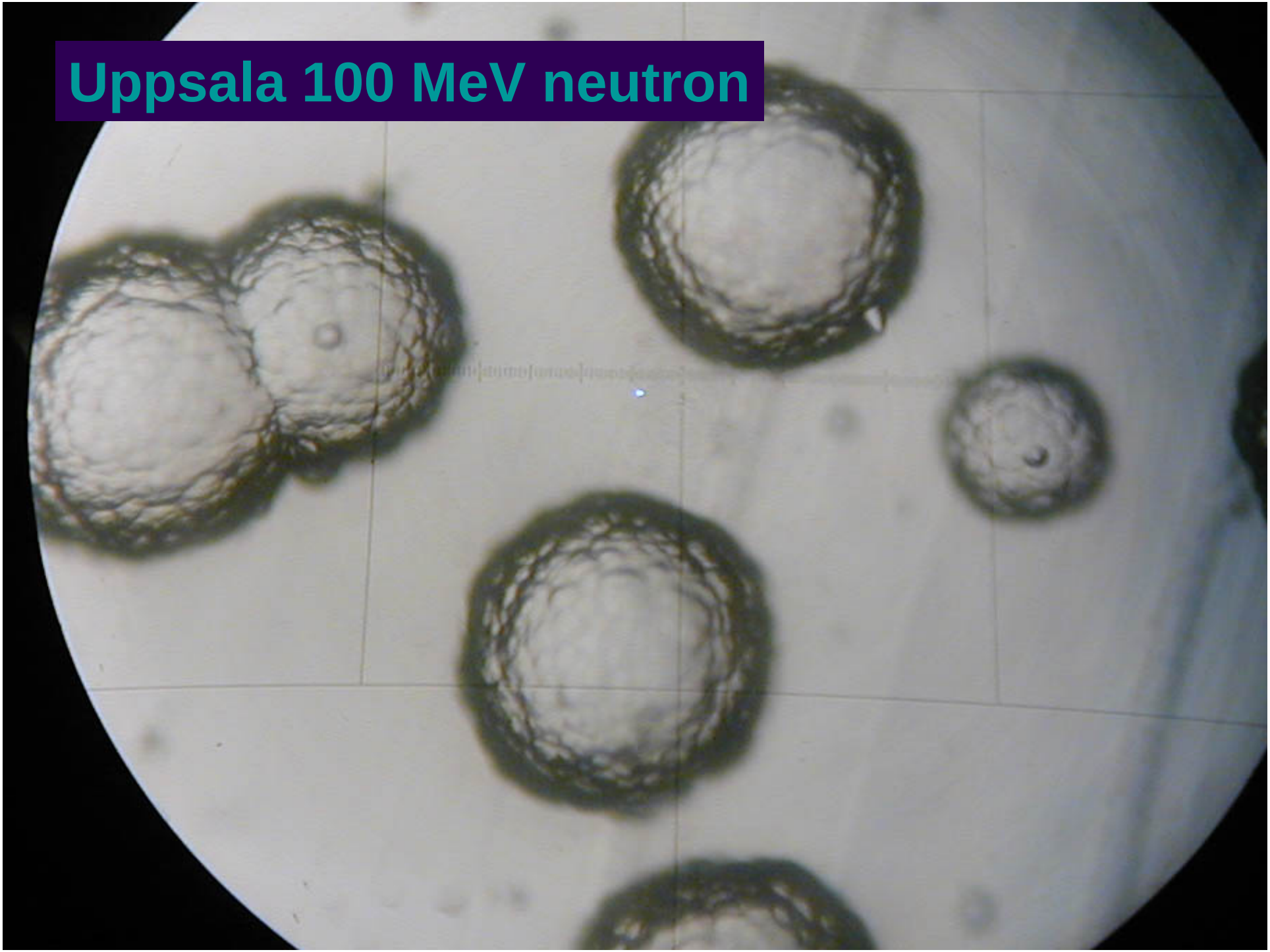
CERF Electrochemical etch + chemical etch



STS 105






Uppsala 100 MeV neutron

- 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
- Need correction for track fading and ageing

STS RESULTS

- Neutron ambient dose equivalent rate of 130 to 170 µSv d^{-1}
- Average neutron effective dose rate about 15% smaller
- Consistent with the neutron component inferred from other measurements
- Correction for ageing and fading

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