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

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nrpb

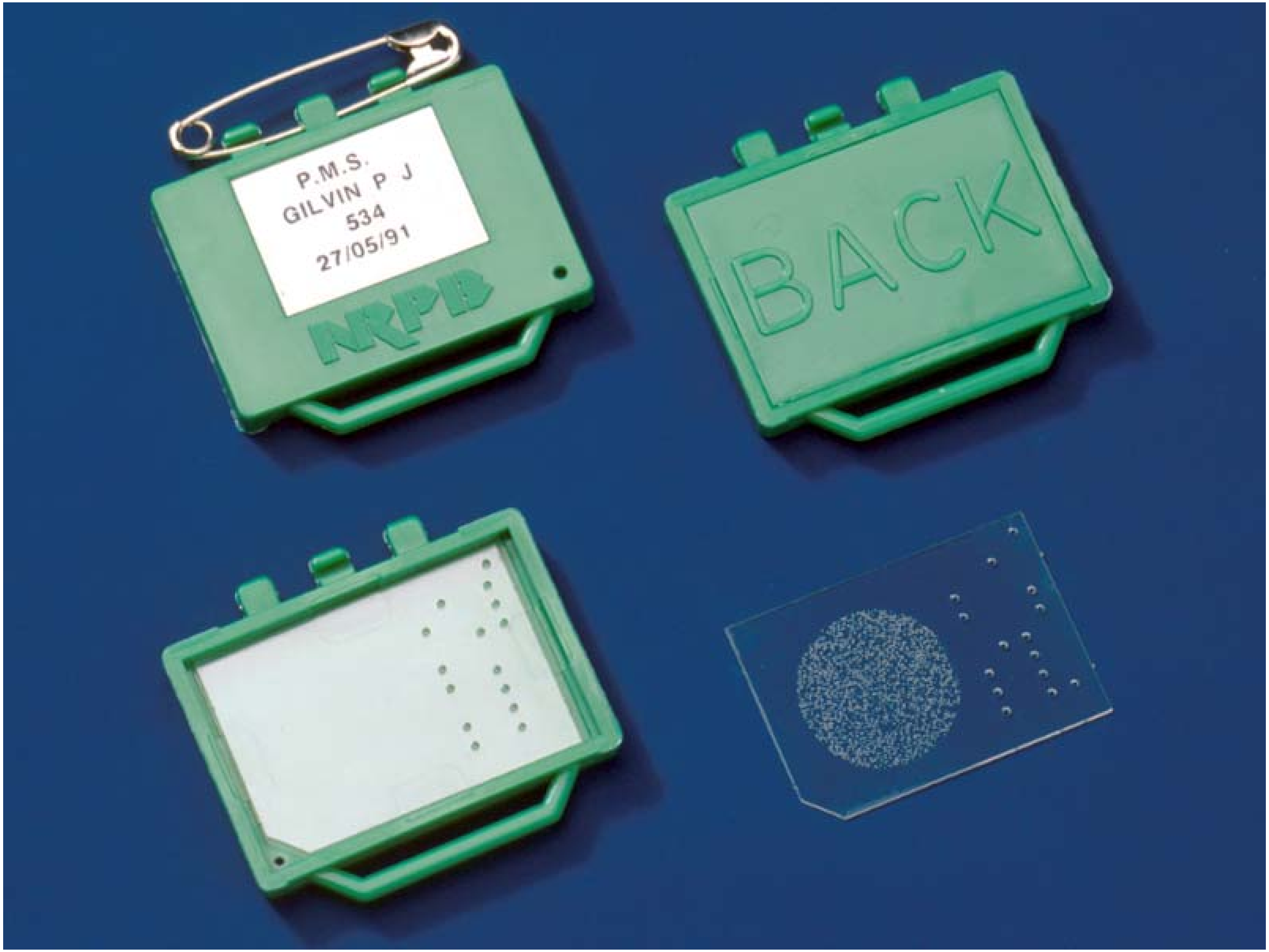
(i) Neutron component

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

Proton threshold ~ 20 keV μm^{-1} (E_p < ~ 1.5 MeV)

Neutrons + neutron-like interactions of protons

Calibration factor determined for the simulated cosmic radiation neutron field (CERF) at CERN
(corrected for difference to field in spacecraft)


P.M.S.
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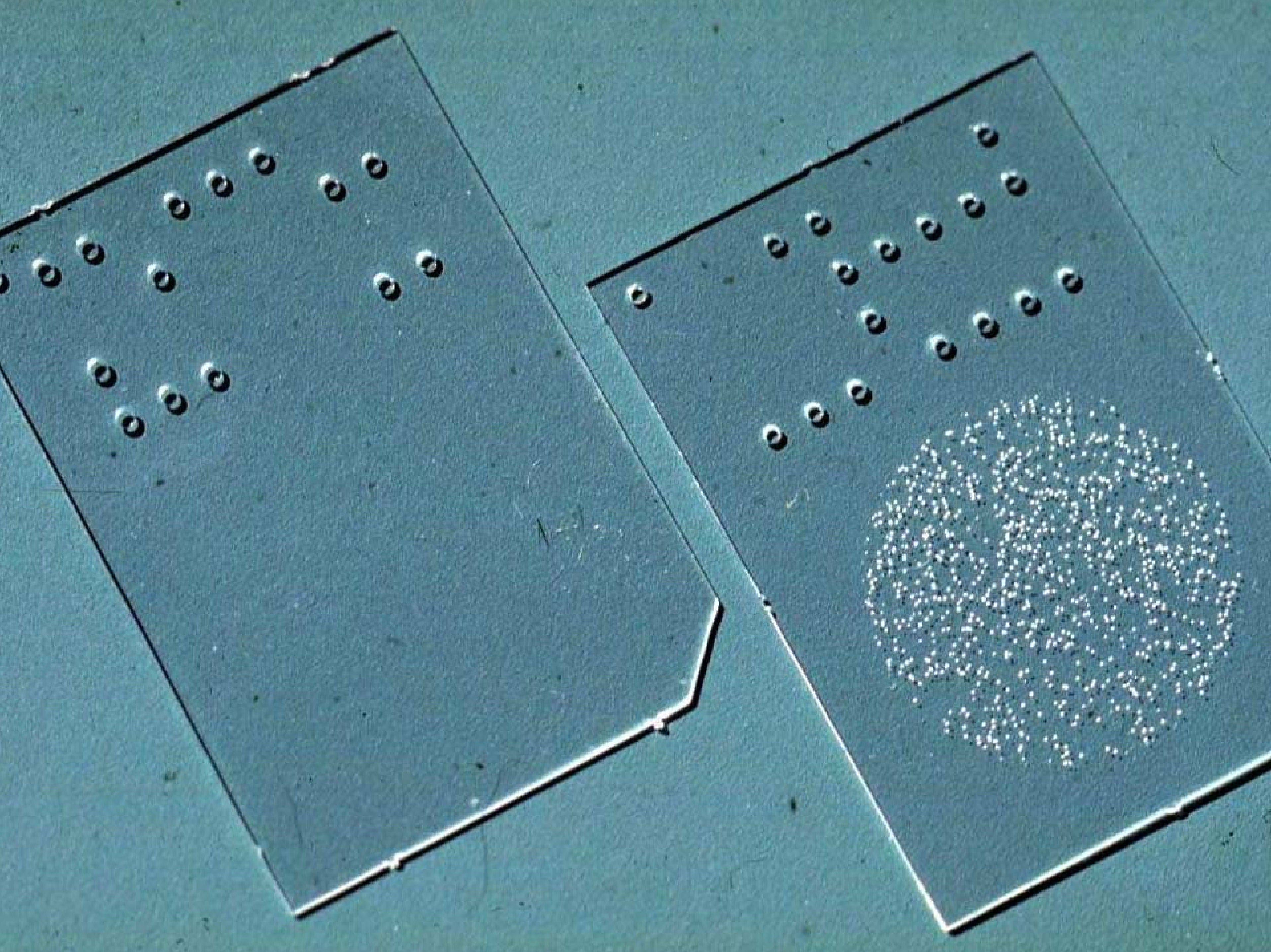
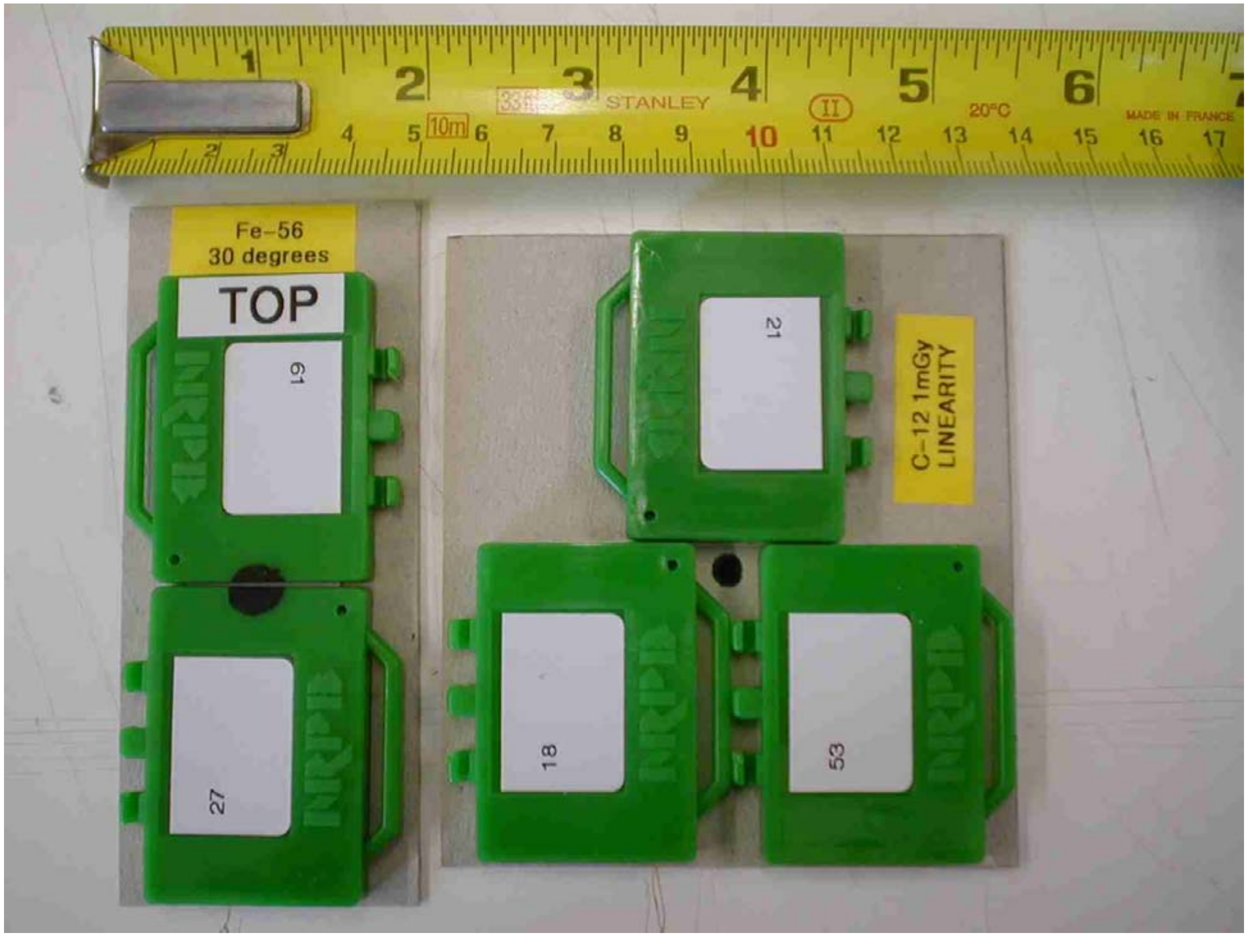
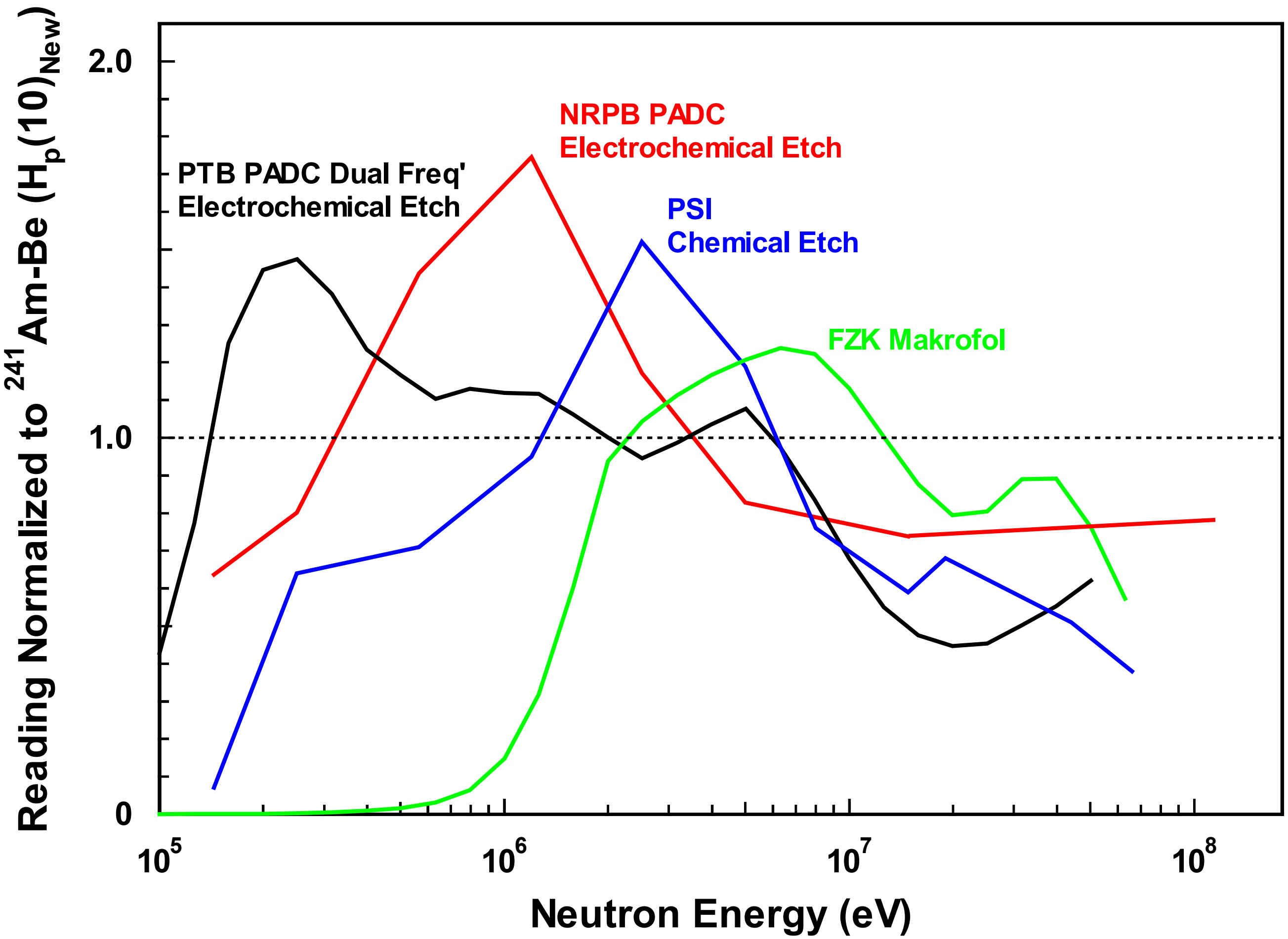


Measurements at HIMAC with the NRPB PADC Dosemeter



Etched Track Detector Response Characteristics

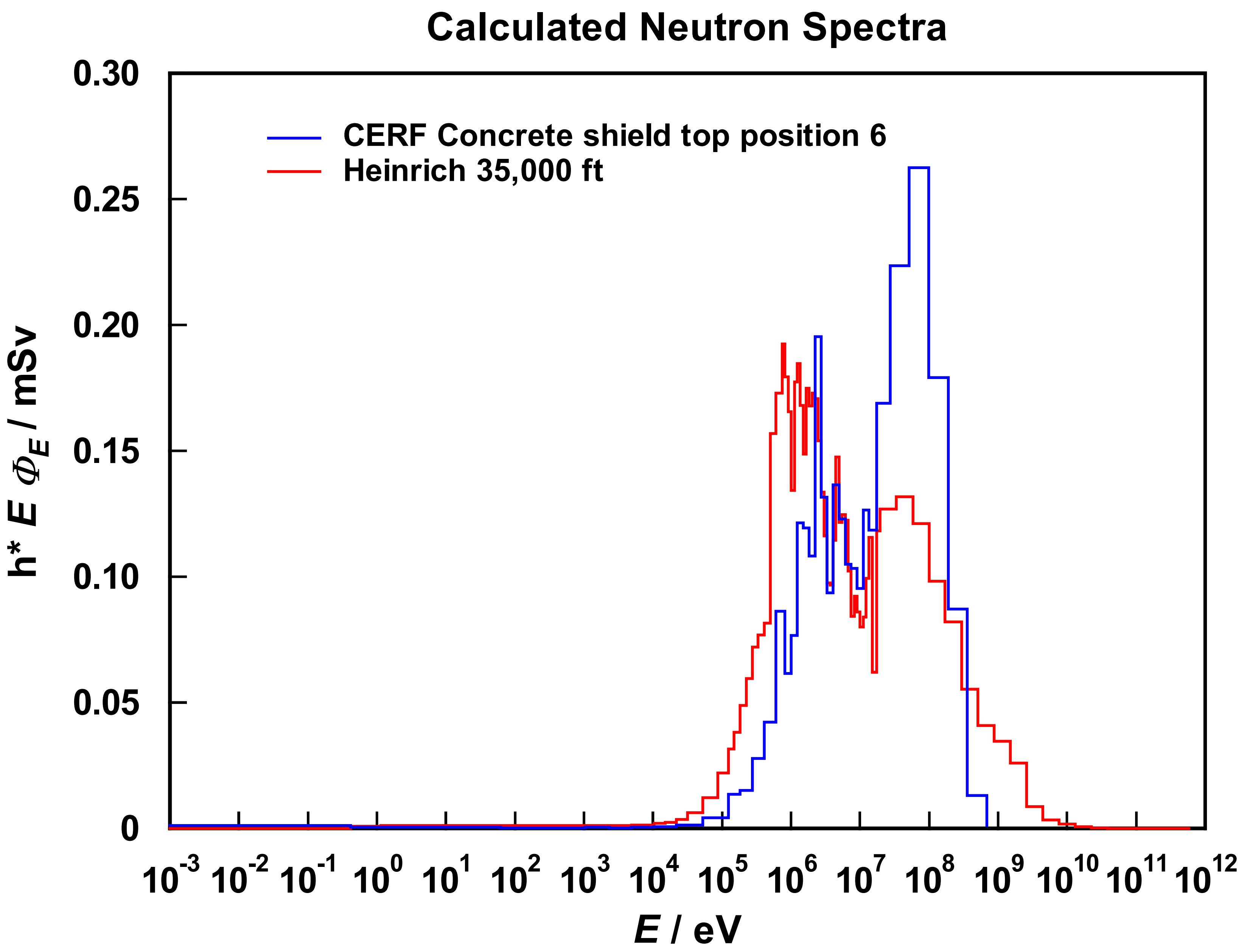


Energy Dependence of Response of the NRPB Passive Survey Instrument

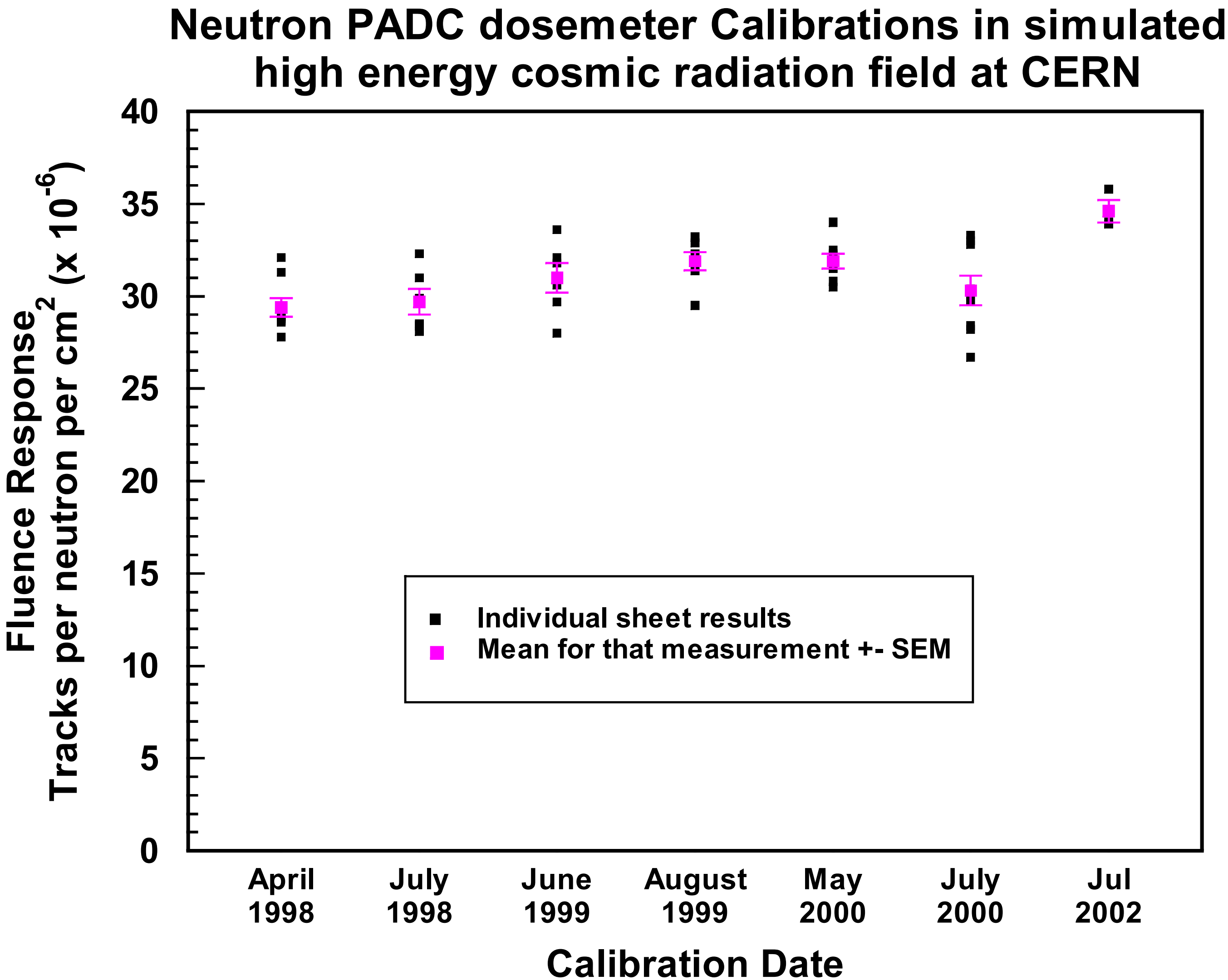
Radiation Field	Net tracks per unit fluence (cm^2 10^{-6})	Net tracks per unit effective dose (ISO) (mSv^{-1})
144 keV (PTB)	2.25±0.38[a]	66±11[a]
542 keV (PTB)	14.4±1.3	182±16
1.13 MeV (PTB)	30.3±2	242±16
2.5 MeV (PTB)	41.8±2.3	208±11
5 MeV (PTB)	38.5±1.7	142±6
8 MeV (PTB)	35.3±1.4	119±5
14.8 MeV (PTB)	48.7±2.4	145±7
60.2 MeV (UCL)	53±5	148±14
68 MeV (TSL)	42±13	115±36
95 MeV (TSL)	30±9	75±23
173 MeV (TSL)	20±6	38±11

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

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



Calculated Neutron Spectra
CERF Concrete shield top position 6
Heinrich 35,000 ft
h* E Φ_E / mSv
0.30
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} 10^{12}
E / eV



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

Comparison of observed and calculated instrument reading for CERF

Neutron Spectrum	Instrument reading per unit fluence (tracks cm^2 10^{-6})		Spectrum weighted conversion coefficient (pSv cm^2)		Reading per unit effective dose ISO (tracks mSv^{-1})
	Calculated	Measured	H*(10)	E_{ISO}	
Ferrari and Rancati CERF	24.5	27.5 ±0.4[a]	260	238	116

(a) Statistical uncertainty (1 σ) on instrument reading

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 USAAR SSI NRPB	3.2 (0.3) 3.5 (0.8) 3.1 (0.3) 3.8 (0.5)
16 km (53 000 ft)	NRPB DIAS ANPA	6.7 (0.4) 7.1 (0.6) 6.1 (0.5)
20 km (67,000 ft)	NRPB NASA	8.3 (0.8) 8.5

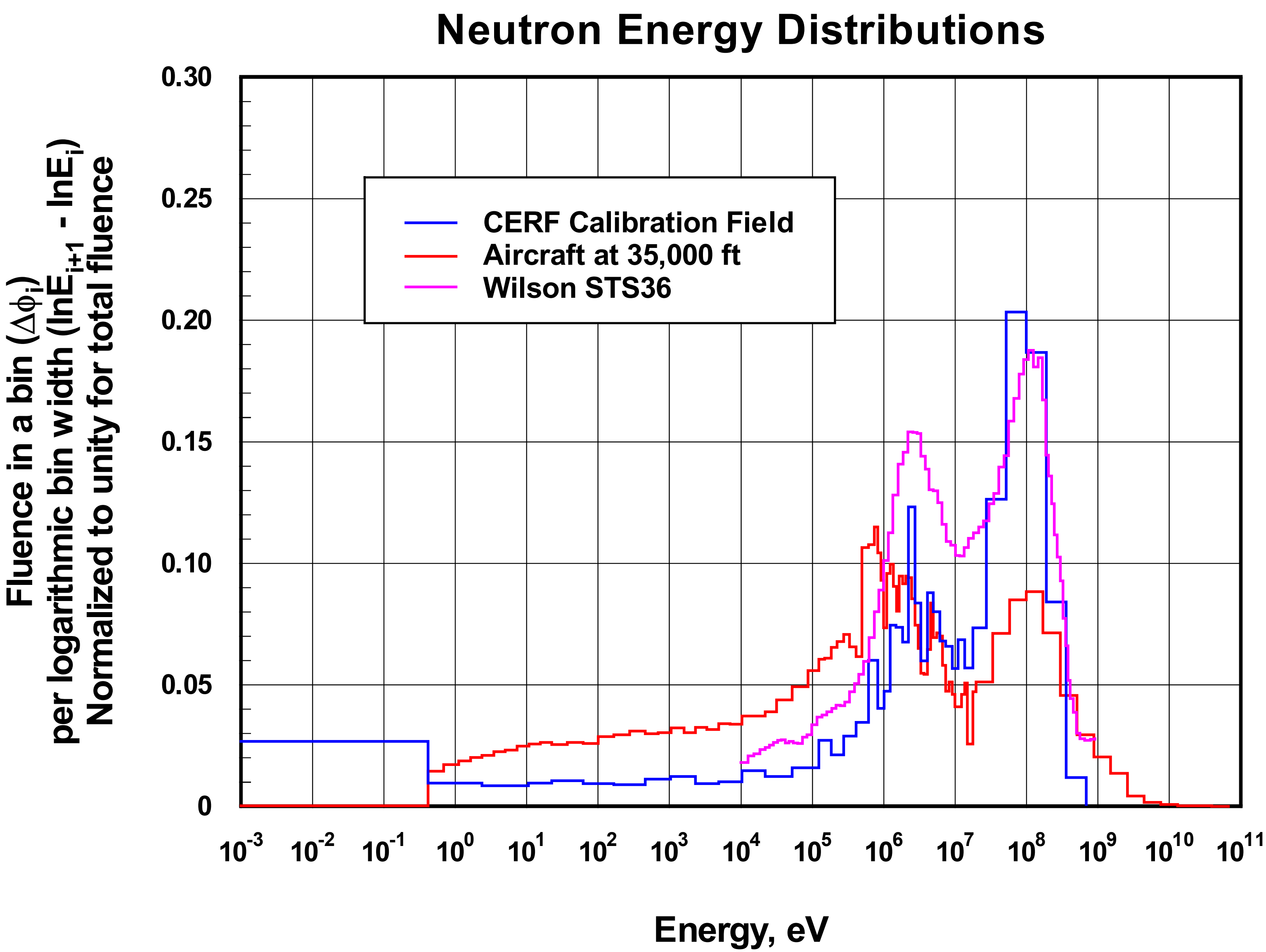
One standard deviation for repeated measurements

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


Neutron Energy Distributions
CERF Calibration Field
Aircraft at 35,000 ft
Wilson STS36
Fluence in a bin ($\Delta\phi_i$)
per logarithmic bin width ($\ln E_{i+1} - \ln E_i$)
Normalized to unity for total fluence
0.30
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

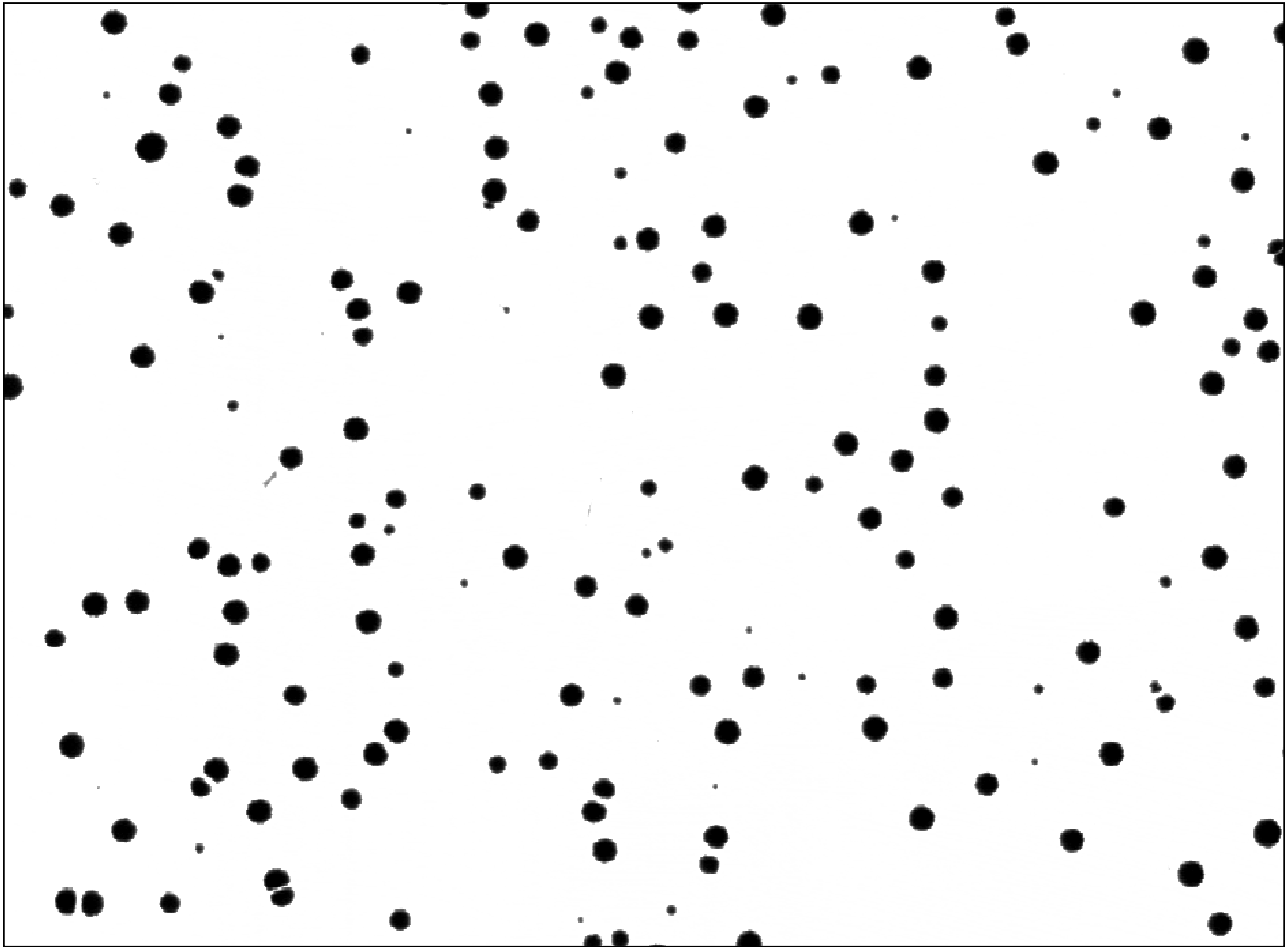
NRPB neutron survey instrument calculated E_{ISO} response in cosmic radiation neutron fields

	$R_{\Phi ISO}$ (cm^2 10^{-6})	E_{ISO} / Φ (pSv cm^2)	R_{Eiso} (mSv^{-1})
STS-36 (Wilson et al)	31.8	304	105
CERF(Rancati and Ferrari)	24.5	238	103

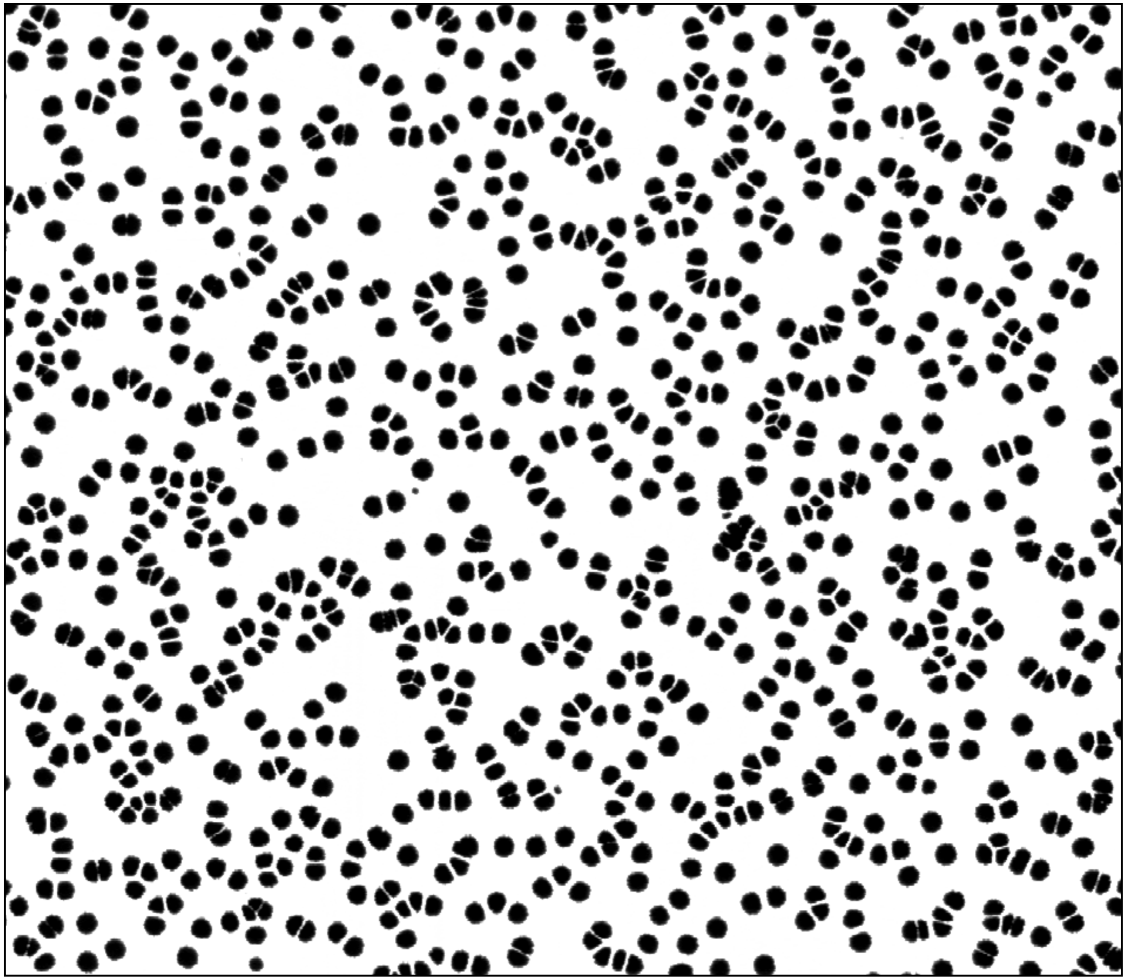
(ii) Response to charged particles

- PADC neutron personal dosemeter responds to neutrons plus neutron-like interactions of high-energy protons
- Only responds directly to protons of E_p < about 2 MeV
- Some response to heavier charged particles LET_{200} > about 30 keV μm^{-1}, depending on particle type
- Can, in many cases, distinguish HZE electrochemically etched tracks by second chemical etch

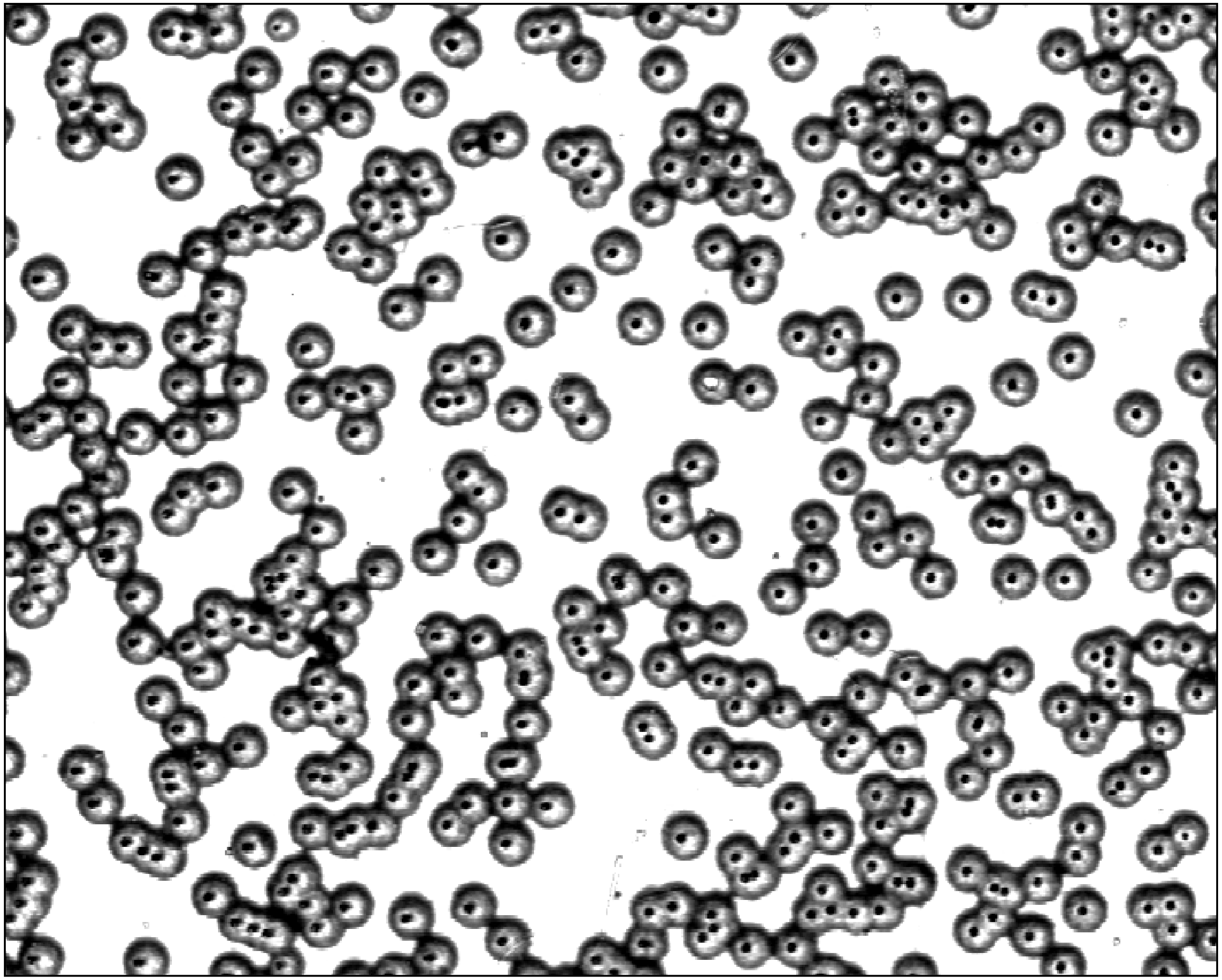
CERF Electrochemical etch



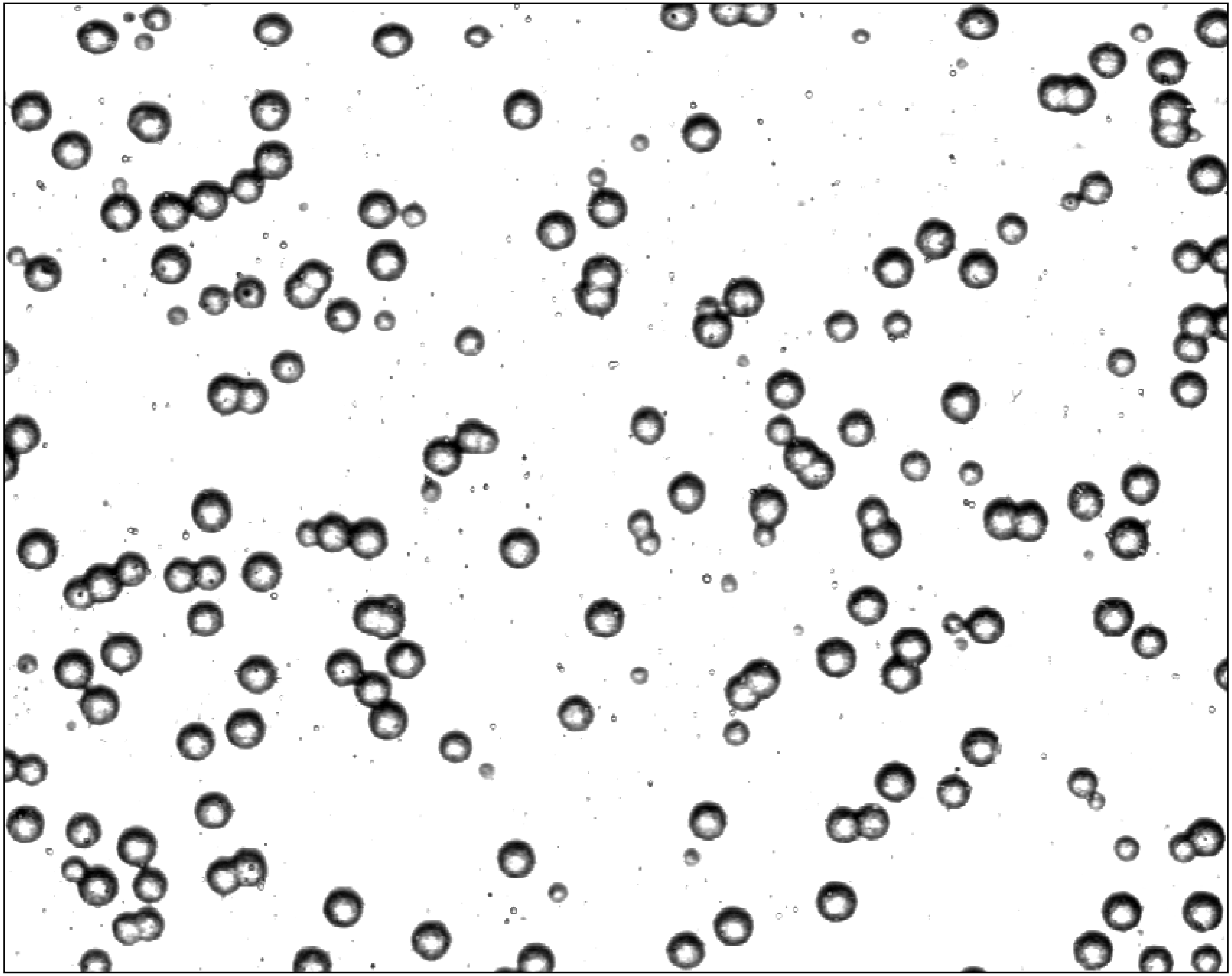
Brookhaven Fe 1000MeV per nucleon – Electrochemical etch



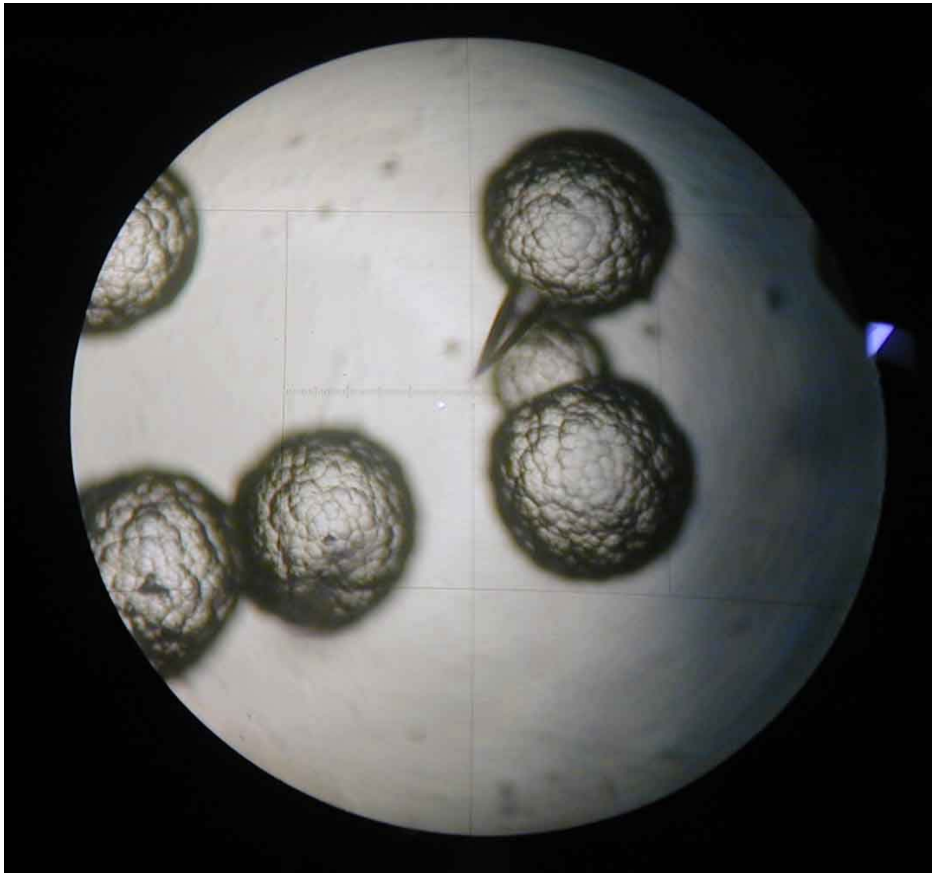
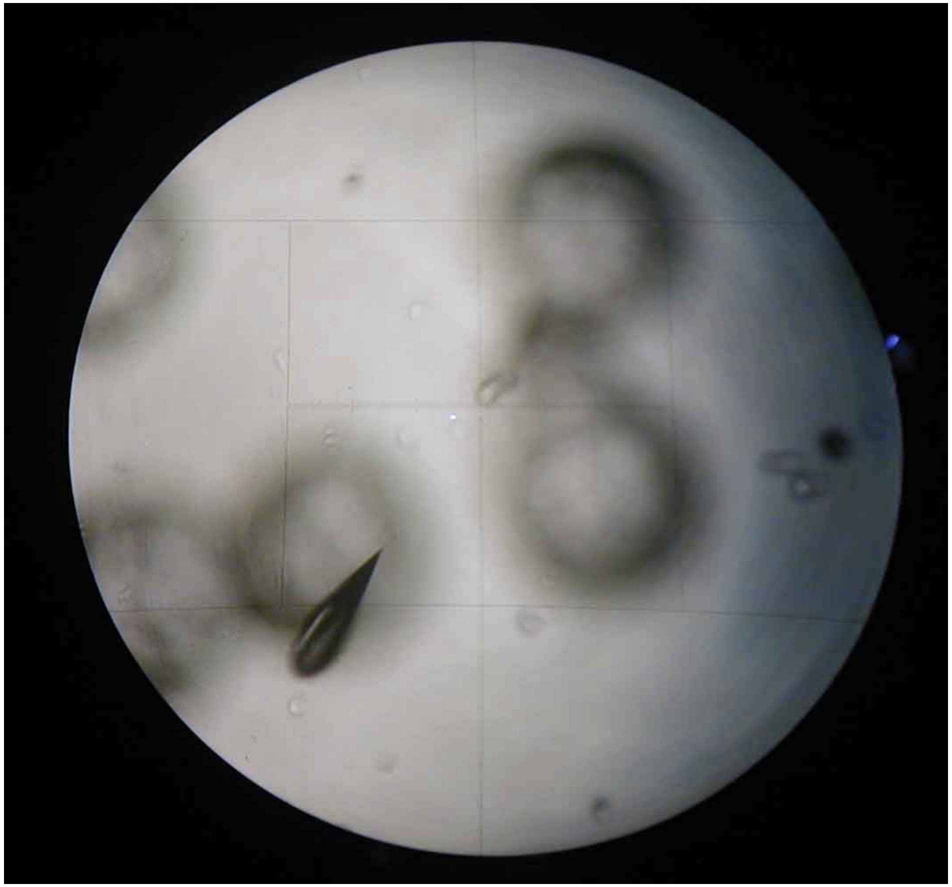
Brookhaven Fe 1000MeV per nucleon – Electrochemical etch + chemical etch

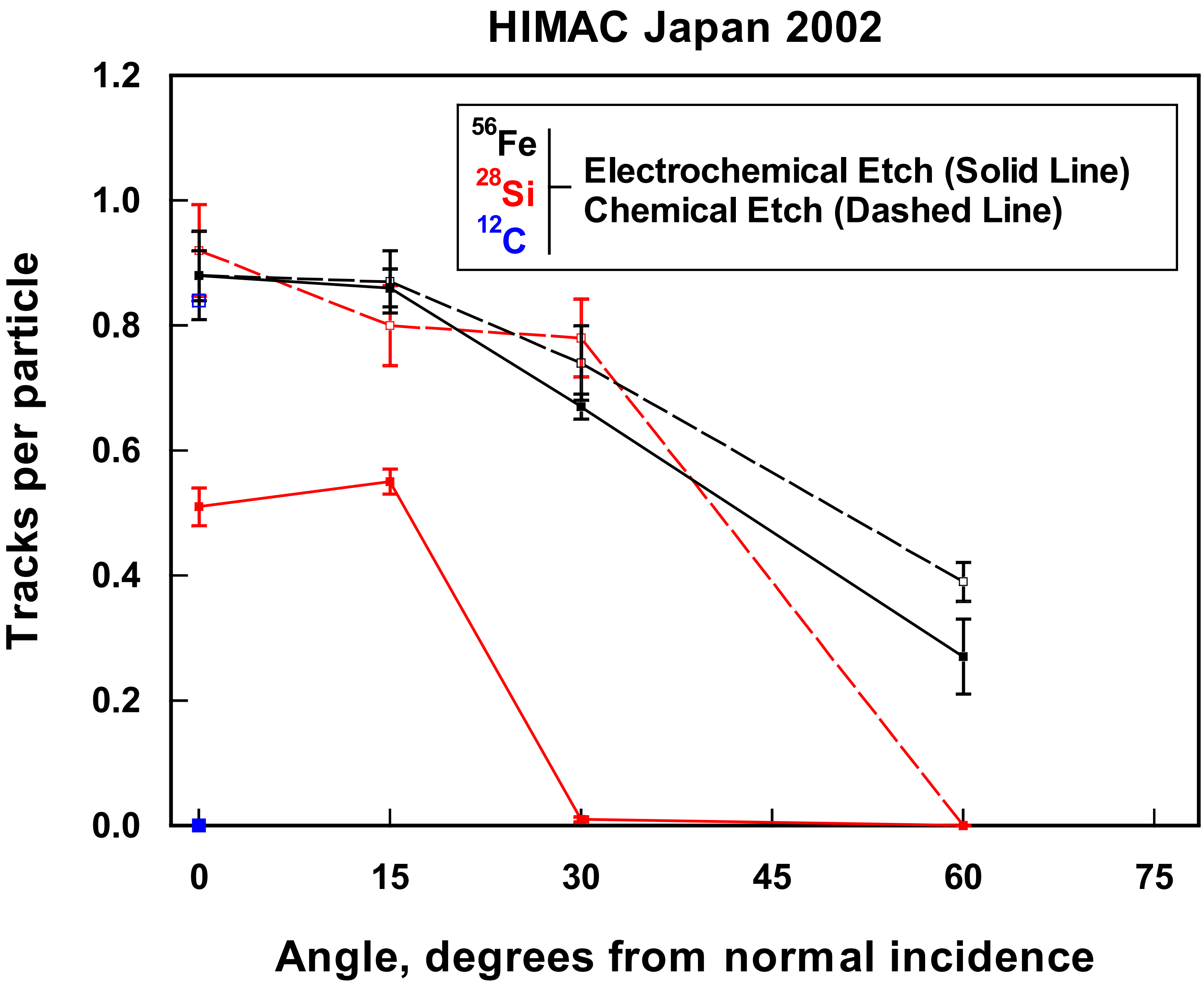


CERF Electrochemical etch + chemical etch



STS 105


HIMAC Japan 2002
56Fe
28Si
12C
Electrochemical Etch (Solid Line)
Chemical Etch (Dashed Line)
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%

(iii) Preliminary results for STS measurements

- Use response data for NRPB passive survey instrument for area passive dosemeter measurements
- Correct for difference in neutron energy distribution using Wilson STS 36 data
- Uncorrected results in good agreement with DIAS dose equivalent measurements
- Preliminary - need correction for track fading and ageing

Results of measurements of neutron component on STS-105 and STS-108

STS 105

Detector	Tracks	Linearity Corrected Tracks	Linearity Corrected Net Tracks	Estimated Neutron Tracks[a]	Neutron E_{ISO}[b] (mSv)
D102035	227	234	201	191	1.6
D102072	228	235	202	191	1.6
D102010	198	203	170	162	1.4
D102036	218	224	191	181	1.5

STS 108

Detector	Tracks	Linearity Corrected Tracks	Linearity Corrected Net Tracks	Estimated Neutron Tracks[a]	Neutron E_{ISO}[b] (mSv)
D102070	205	210	177	168	1.4
D102057	219	225	192	182	1.5
D102065	243	250	217	206	1.8

(a) There is a large uncertainty at present on the subtraction of the tracks produced by the HZE component, research is in progress. Here 5% of tracks (after linearity correction) has been subtracted.
(b) The dosemeters were issued for about a year. The long-term ageing and fading is being studied.

Application as area passive dosemeter or personal dosemeter

Estimate of neutron component of effective dose 100μSv 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

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