Achievements in workplace neutron dosimetry in the last decade: lessons learned from the EVIDOS project

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C Molinos, M Reginatto and F Vanhavere

Workplace neutron dosimetry: ANDO

- "Advanced methods of active neutron dosimetry for individual monitoring and radiation field analysis": Wolfgang Alberts and Helmut Schuhmacher, PTB-N-32 (1998)
- European Commission Nuclear Fission Safety RTD Programme funded
- Designs of active neutron personal dosemeter being developed within Europe
- Project to develop and test designs in calibration facilities

Workplace neutron dosimetry: Post-ANDO

- Some designs had shown real promise
- The demands on active neutron personal dosemeters in the workplace are severe:
  - Electromagnetic interference
  - Photon dose rate
  - Microphonics - vibrations
- Need to test designs in the workplace
- Need to determine **reference quantities** in the workplace

EValuation of **I**ndividual **Dos**imetry in mixed neutron and photon fields: EVIDOS

Health Protection Agency

Workplace neutron dosimetry: EVIDOS Consortium

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Workplace neutron dosimetry: EVIDOS

PTB: $\Phi(E,\Omega)$, active dosemeters, reference photons, BWR access, reference photon dosimetry

IRSN: $\Phi(E)$, active dosemeters, calibration fields

HPA: survey instruments, passive detectors, workplace access

PSI: active dosemeters, passive dosemeter

SCK-CEN: bubble detectors, workplace access, Monte Carlo calculations

DIMNP: $\Phi(E,\Omega)$, $H_p(10)$ reference, environmental factors

SSI: TEPC, workplace access, reference photon dosimetry

Workplace neutron dosimetry: EVIDOS - scope

- Determine how well (then) current designs of active dosemeters perform in the workplace
- Make measurements with active and passive dosemeters in workplaces where the neutron dose rate is significant
- Determine the reference quantities at those locations:
  - $\Phi(E)$ via multispheres
  - **$\Phi(E, \Omega)$ via novel means** $\rightarrow H_p(10)$, E
  - $H_p(10)$ by direct measurement
- Use survey instruments at the measurement locations

Campaign 1: Krümmel BWR and spent fuel flask

← Control rod room

Reactor top →

← Spent fuel flask

Campaign 2: Belgonucleaire and VENUS

BN 1 →

← VENUS

BN2a →

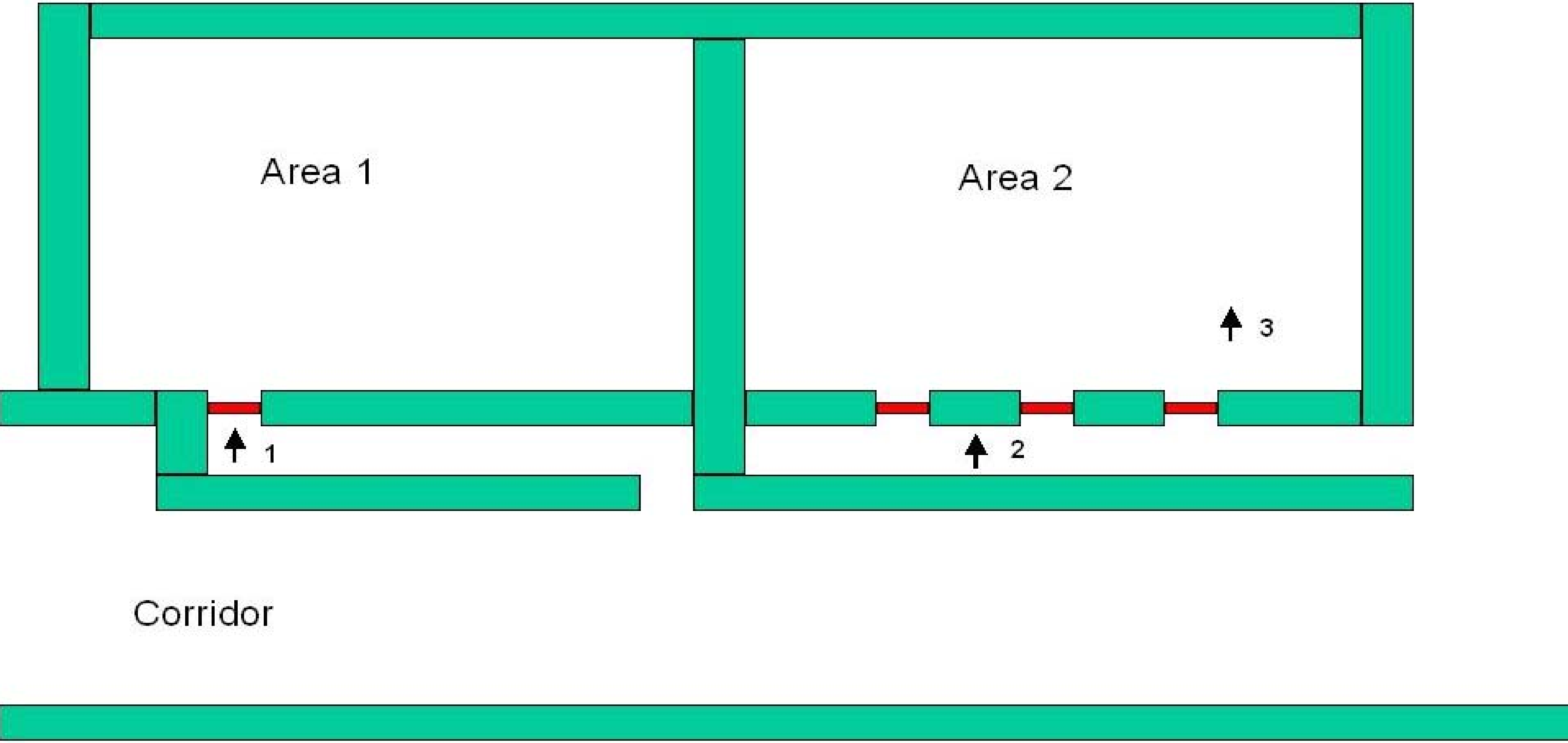
Campaign 3: Ringhals PWR and spent fuel flask

Inside containment

Spent fuel flask

← Air Lock

Campaign 4: European nuclear facility



"special nuclear material" contained within areas 1 & 2

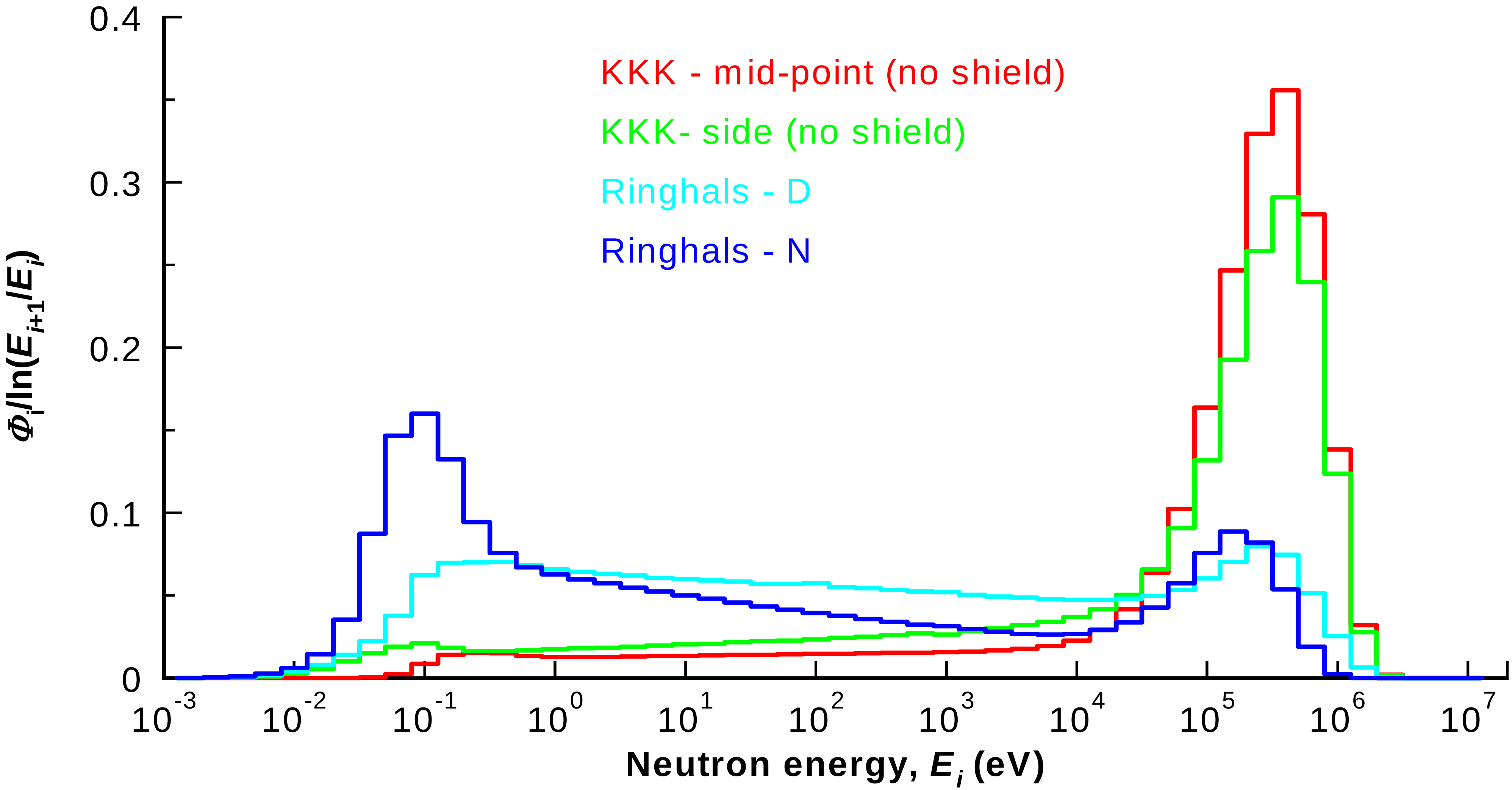
EVIDOS: $\Phi(E)$

V Lacoste, B Asselineau and H Muller, IRSN

Reference $\Phi(E)$ measurements

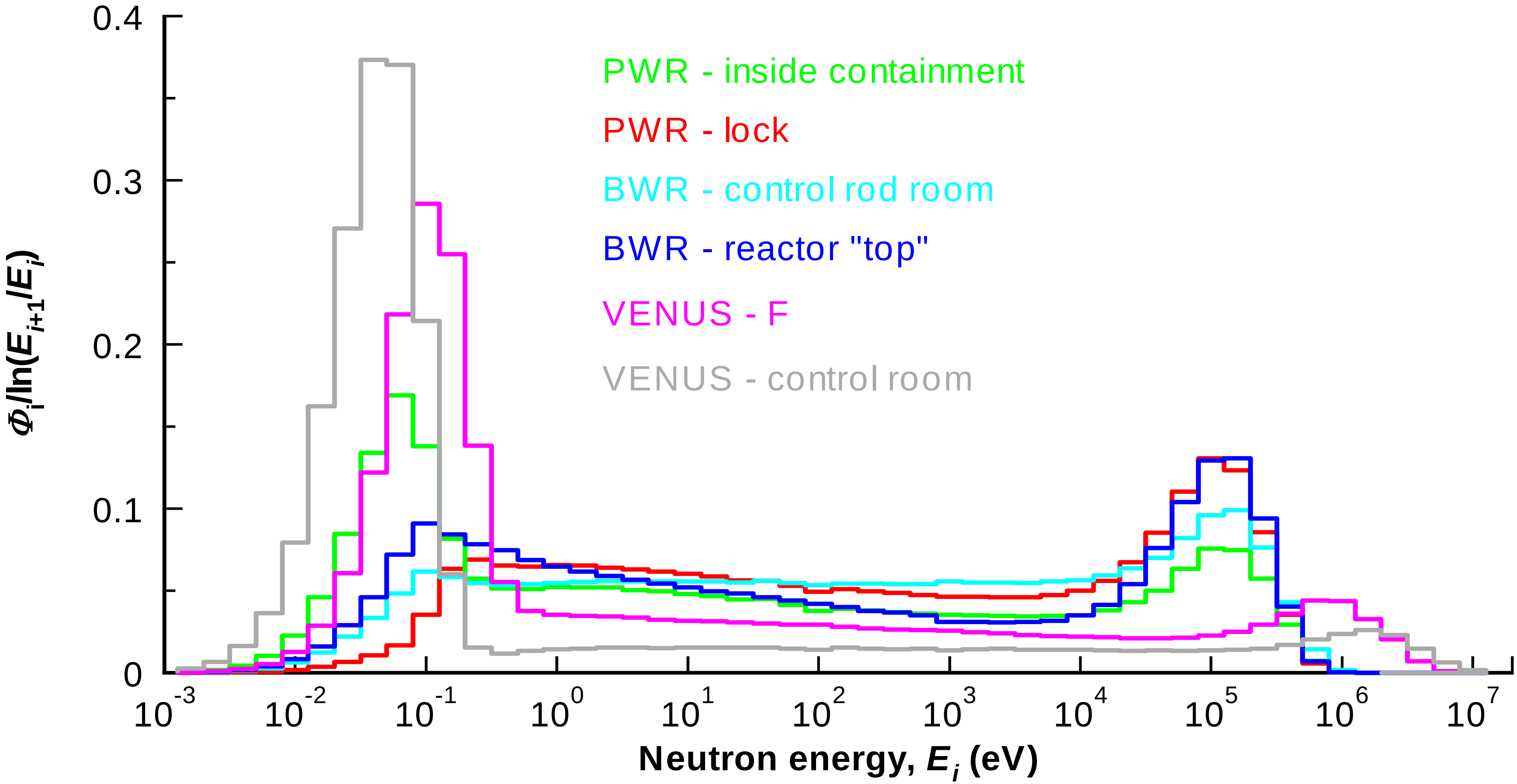
- IRSN multispheres:
  - 12 diameter polyethylene moderators,
  - 5 smallest spheres bare and with Cd cover
- Unfolding via NUBAY - 3 component energy distribution
- NUBAY solution one of the guess energy distributions for GRAVEL
  - GRAVEL used for sensitivity studies with respect to the guess energy distribution
- ROSPEC available, but developed a fault at the start of the contract - no recoil counter measurements

Fuel flasks



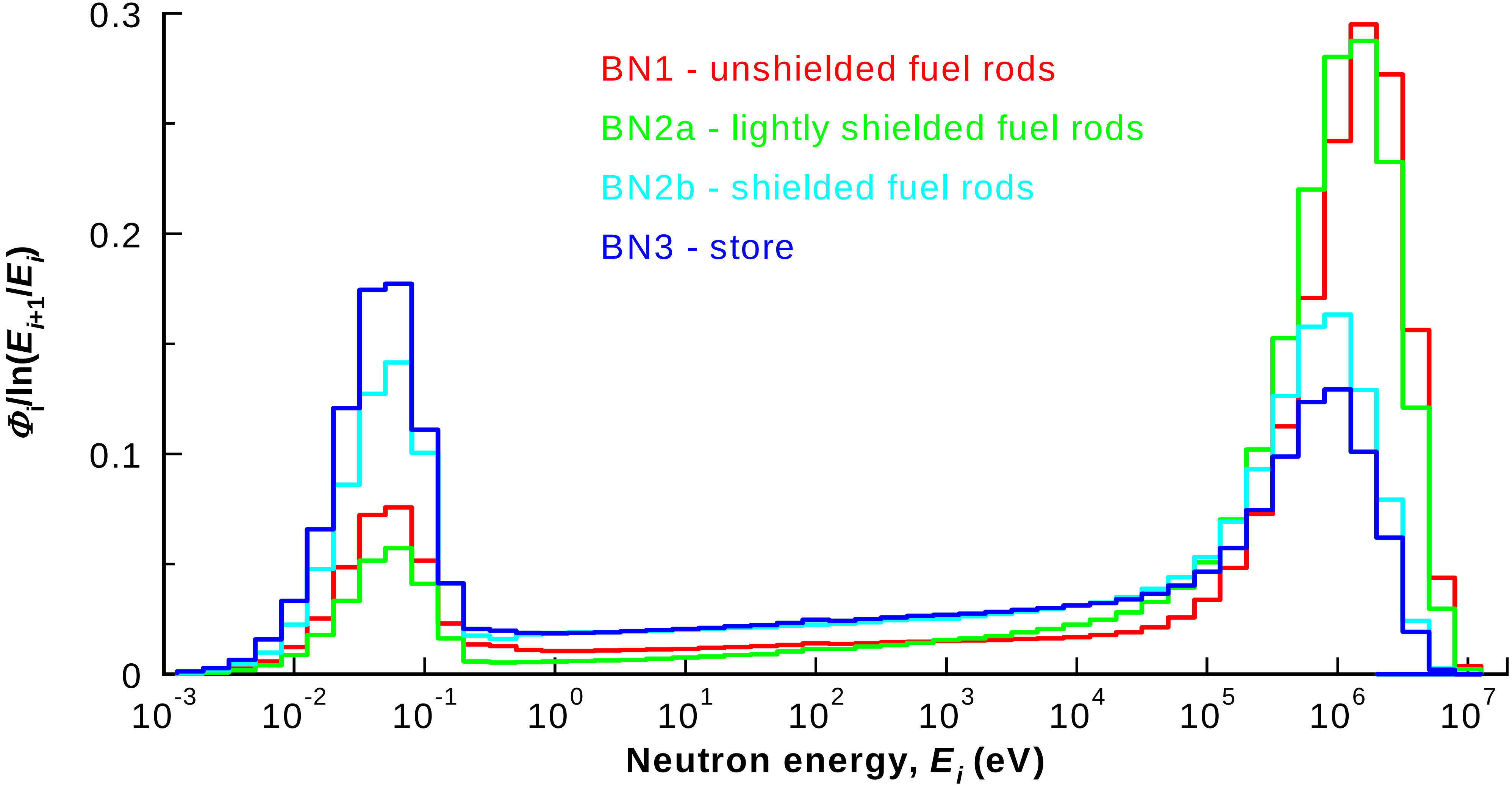
KKK - mid-point (no shield)
KKK- side (no shield)
Ringhals - D
Ringhals - N
0.4
0.3
0.2
0.1
0
$\Phi_i/\ln(E_{i+1}/E_i)$
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
Neutron energy, E_i (eV)

Reactors

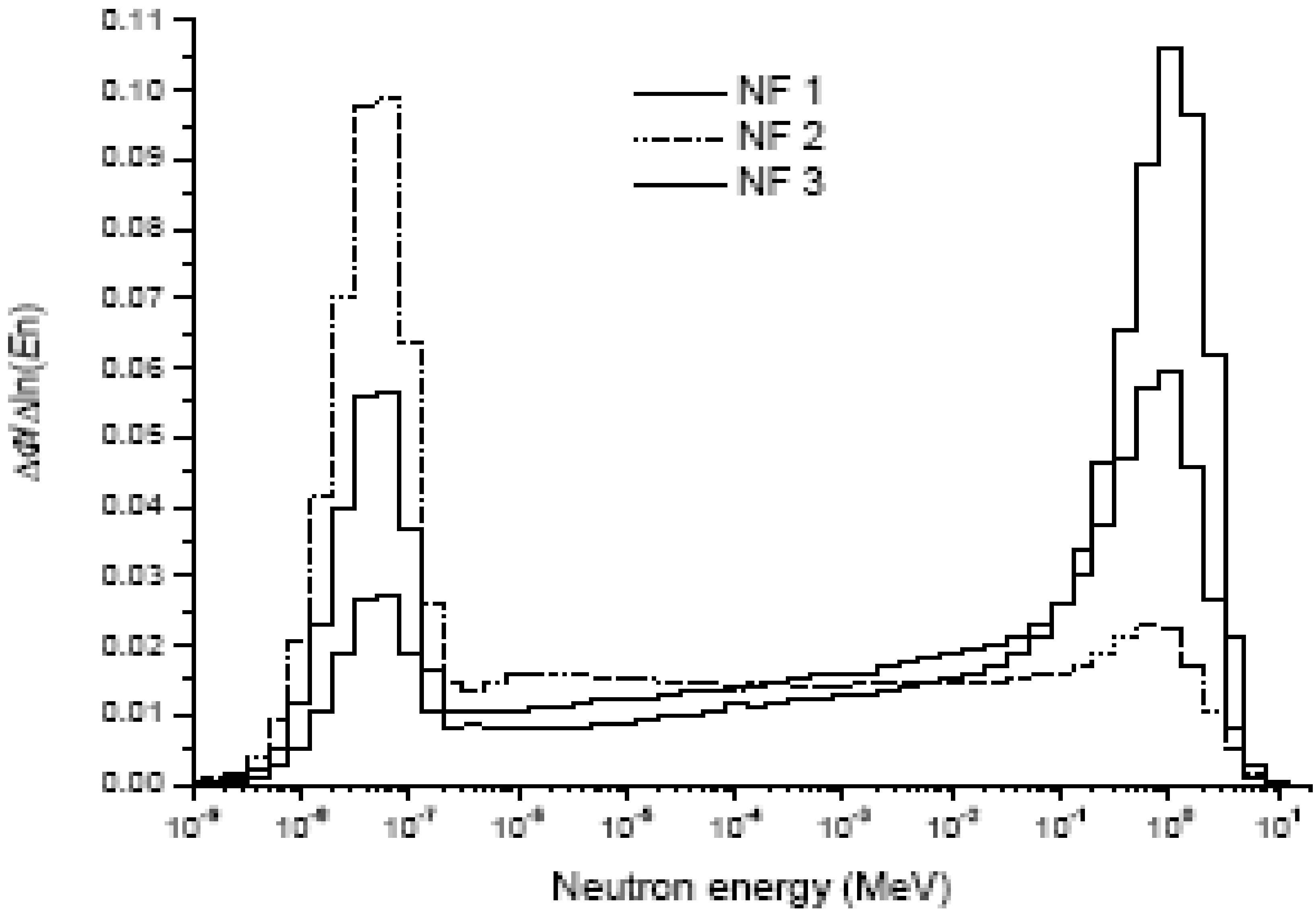


PWR - inside containment
PWR - lock
BWR - control rod room
BWR - reactor "top"
VENUS - F
VENUS - control room
Φi/ln(Ei+1/Ei)
0.4
0.3
0.2
0.1
0
10-3
10-2
10-1
100
101
102
103
104
105
106
107
Neutron energy, Ei (eV)

Fuel assembly



Special nuclear material facility



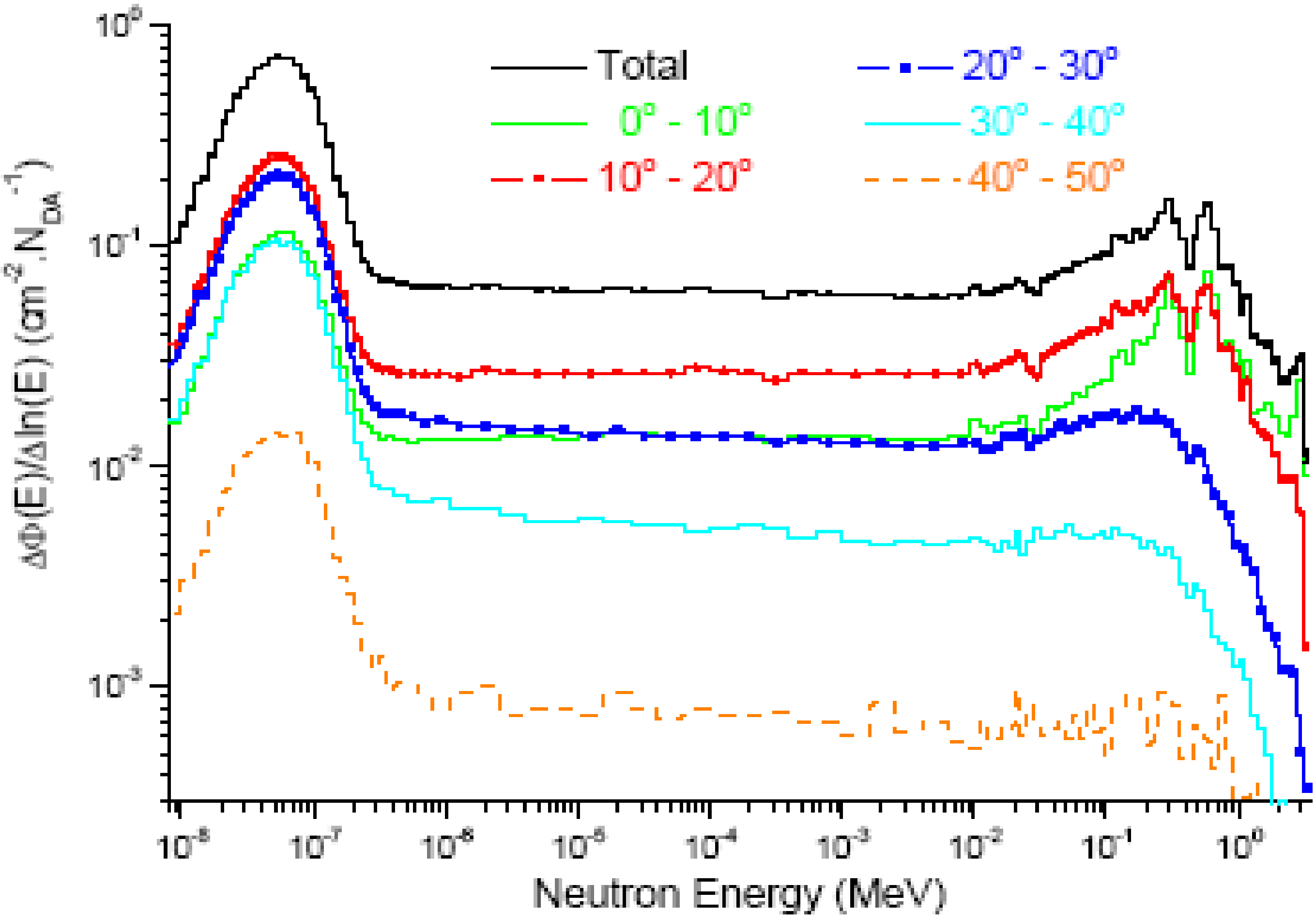
EVIDOS: $\Phi(E)$ and $\Phi(E, \Omega)$ calculations

V Lacoste, IRSN
and
M Coeck, SCK-CEN

$\Phi(E)$ and $\Phi(E, \Omega)$ calculations

- Feasible for more than a decade...
- Large geometries more feasible owing to greater computing power available
- Very difficult to specify the problem exactly
- The solution is physically realistic
- Direction bins easy
- Used for the two “realistic fields” (SIGMA and CANEL) and the research reactor (VENUS)
- Can calculate the reference quantities directly

CANEL - MCNP
(also SIGMA - not pictured)

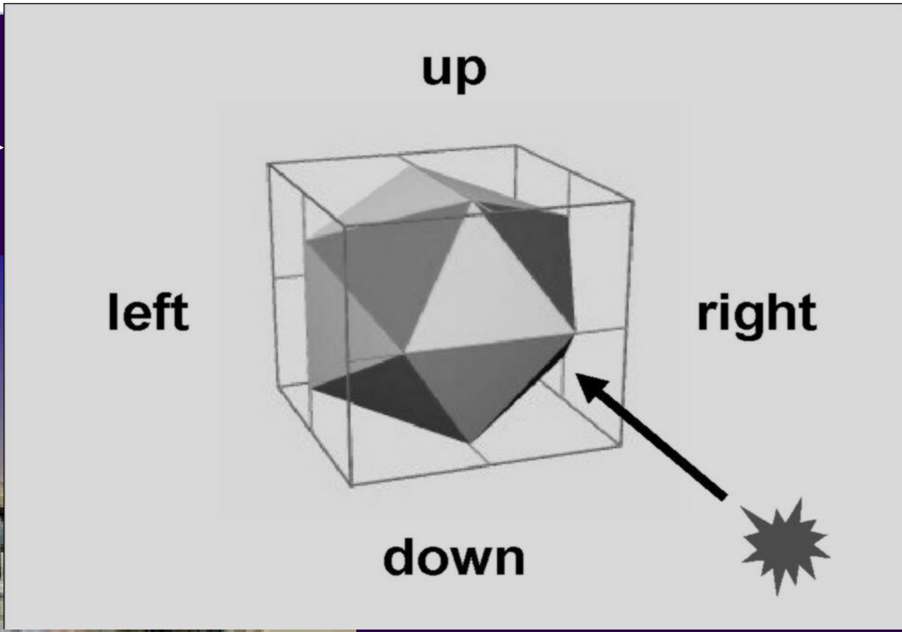


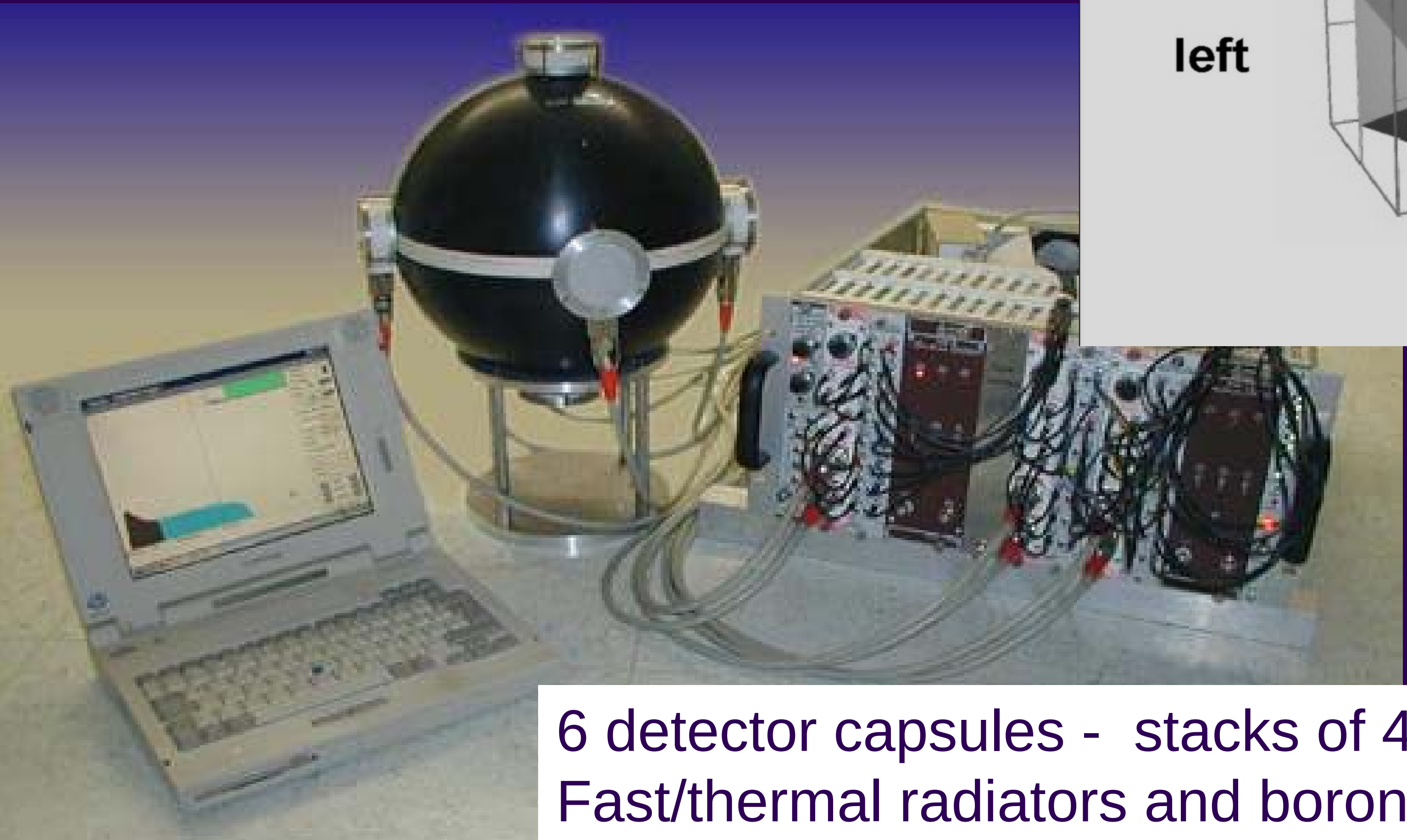
EVIDOS: $\Phi(E, \Omega)$ measurements

M Luszik-Bhadra and M Reginatto, PTB
F d'Errico, DIMNP

PTB direction spectrometer

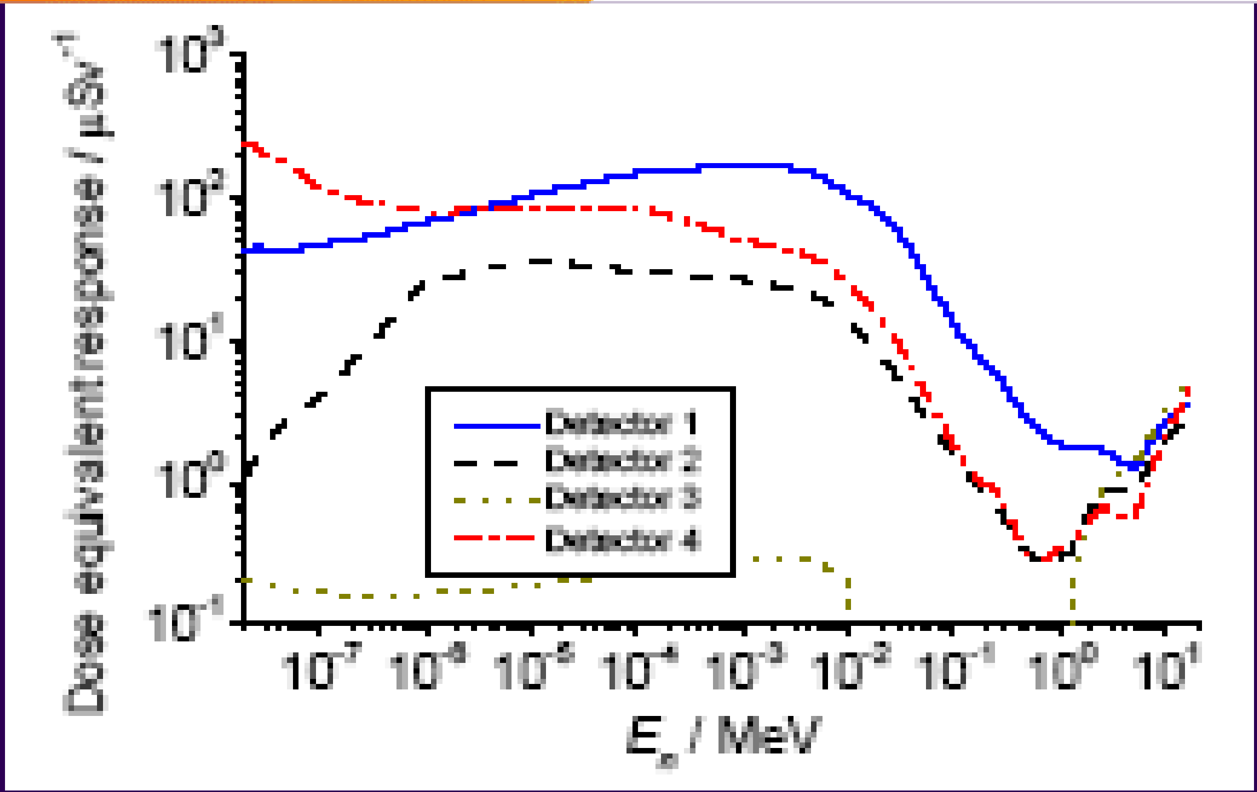
Unfolding into 20 equal solid angles: faces of an icosahedron





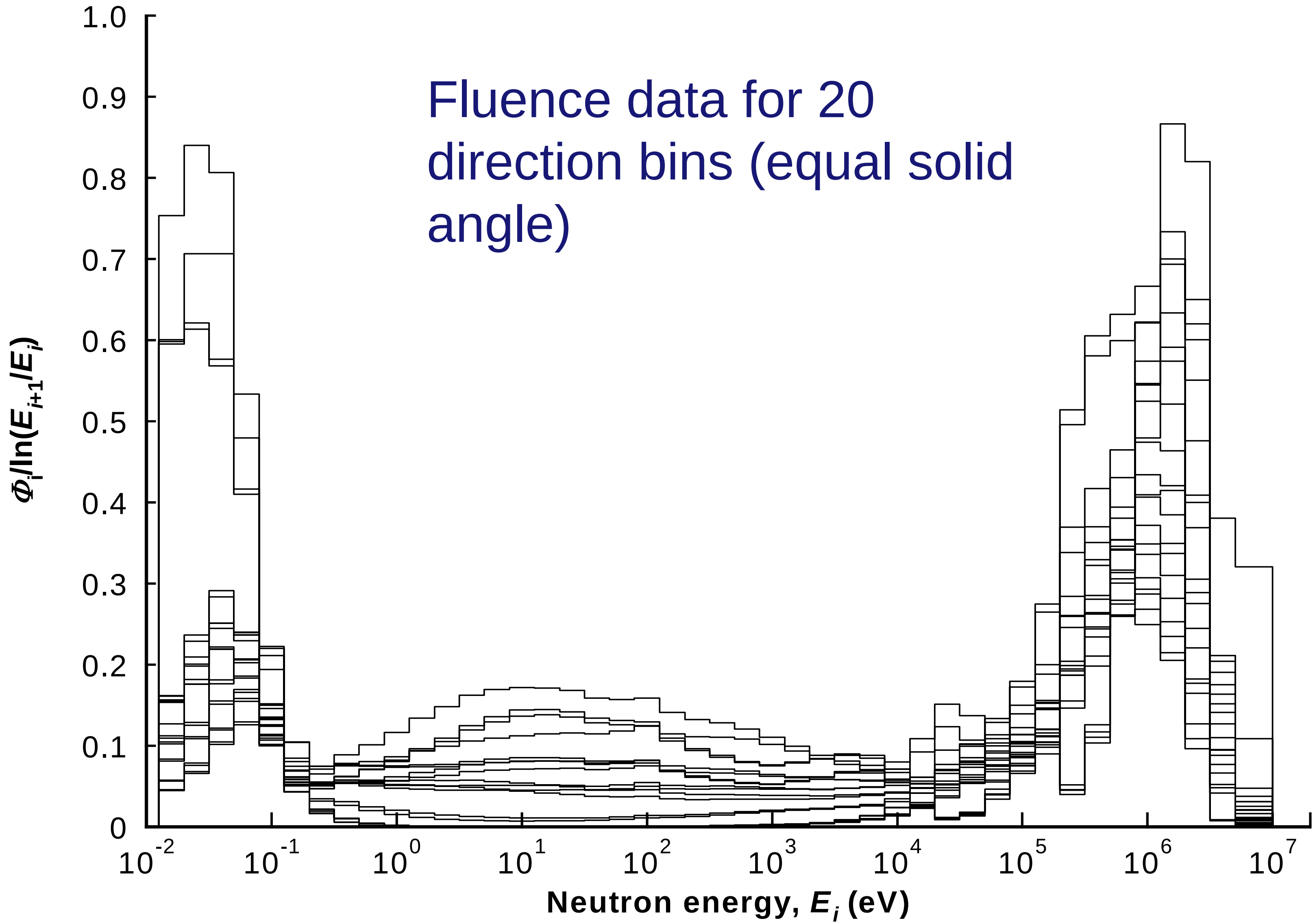
6 detector capsules - stacks of 4 Si detectors: Fast/thermal radiators and boron shielding

PTB direction spectrometer

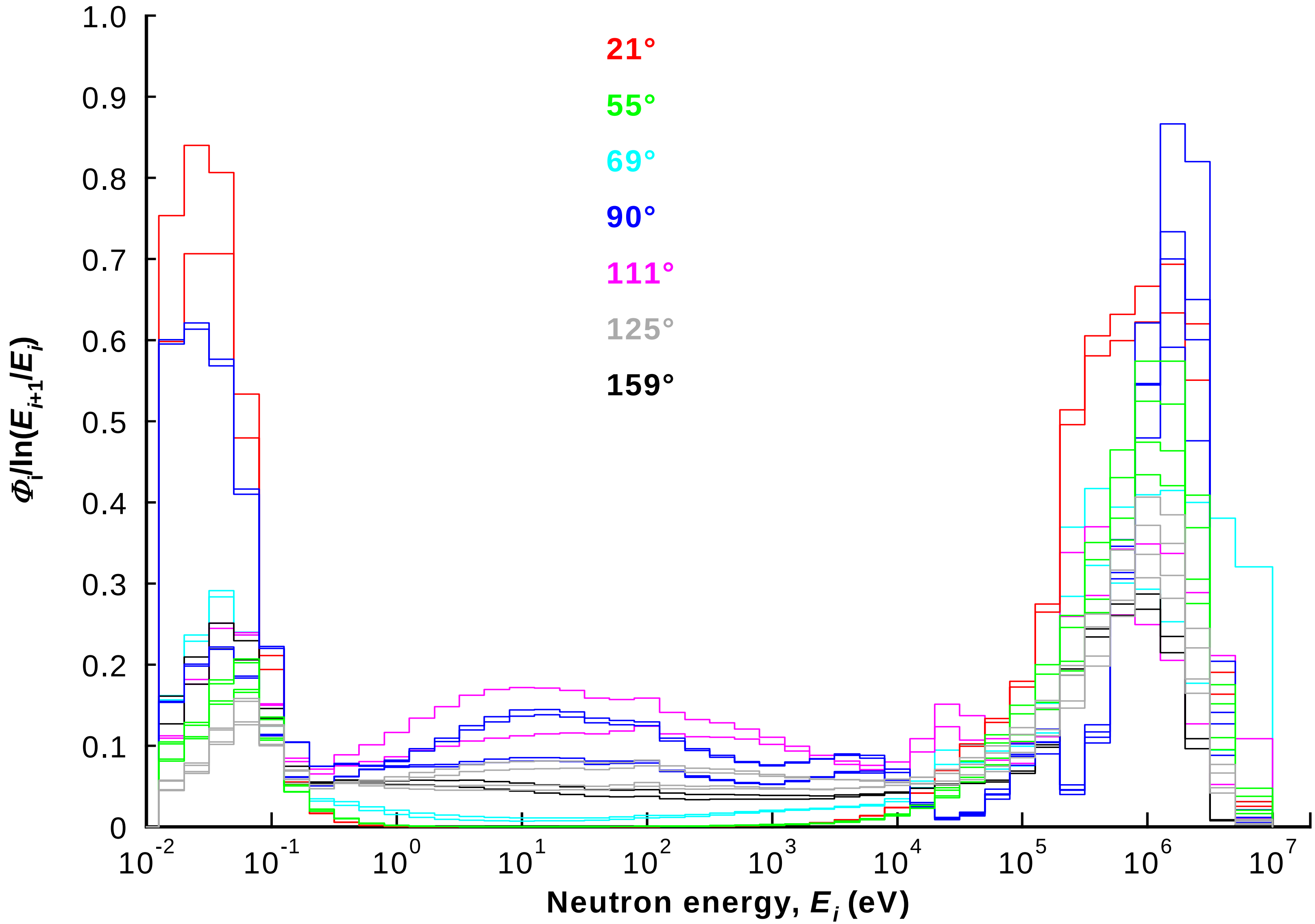


- Detectors 1, 2 and 4 have CH_2 and ^{6}LiF radiators, plus different boron shielding
- Detector 3 has CH_2 only
- Unfolding via MAXED and MIEKE

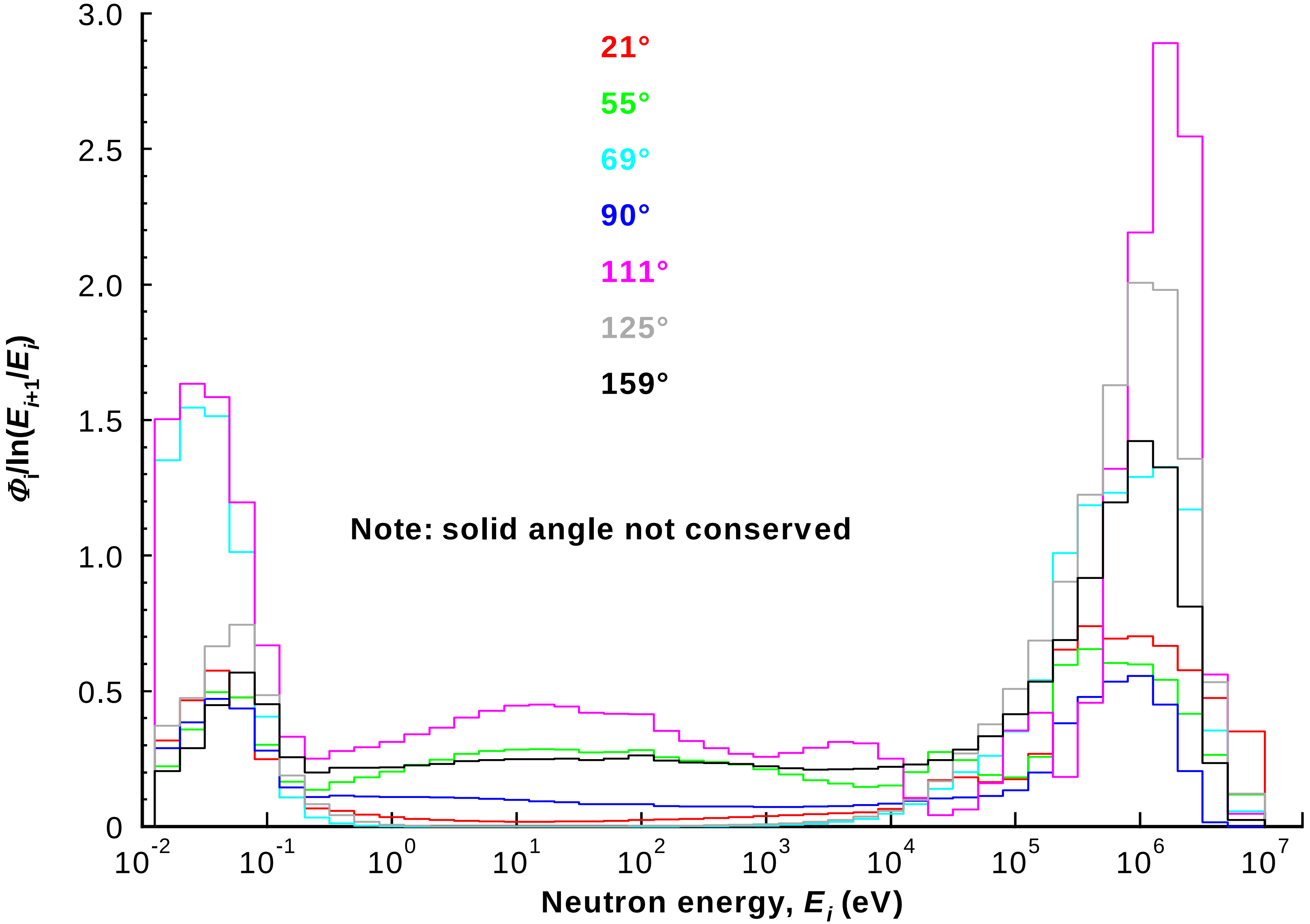
PTB direction spectrometer
C4-P3 European nuclear facility



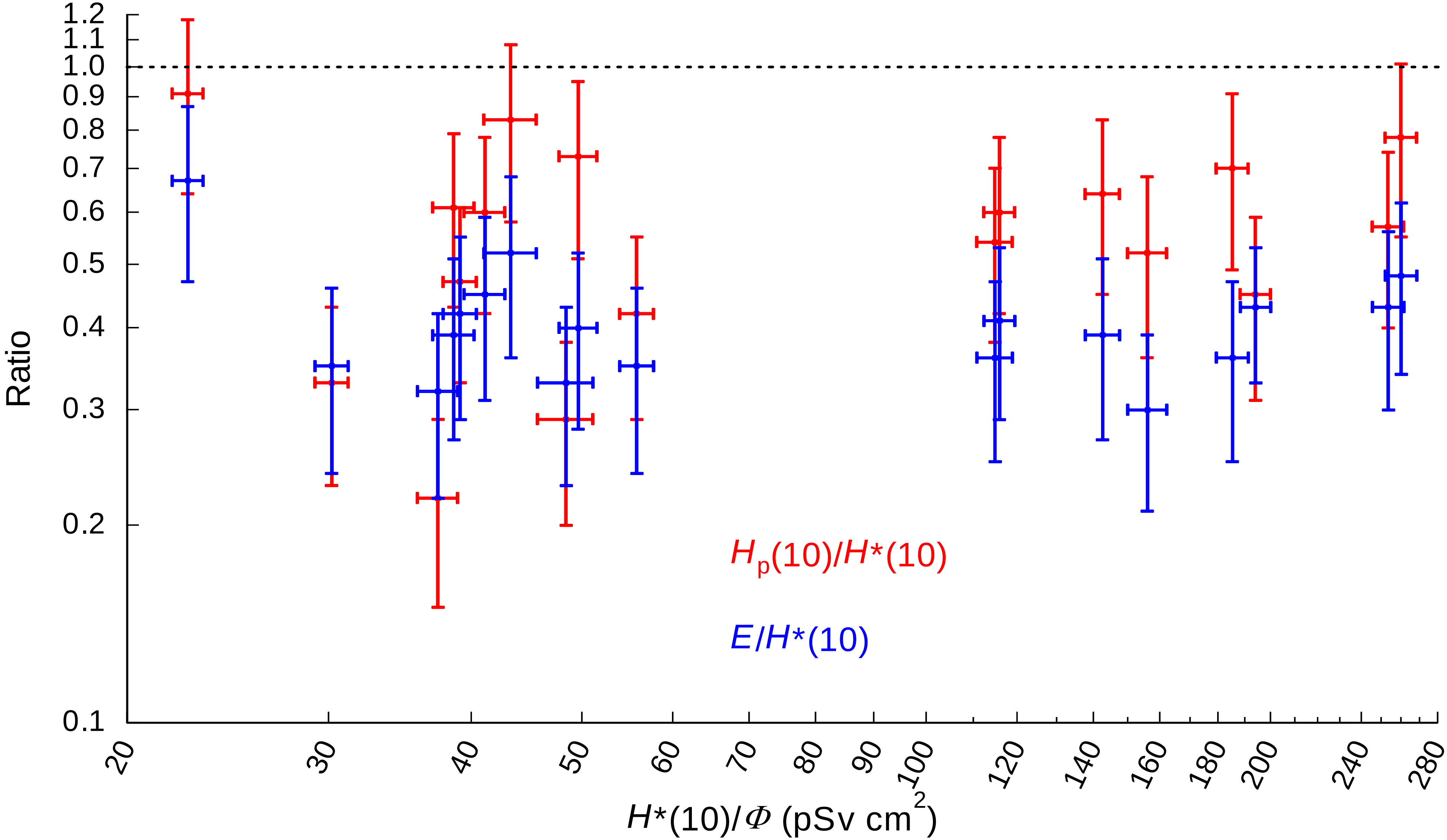
PTB direction spectrometer
C4-P3 European nuclear facility



PTB direction spectrometer
C4-P3 European nuclear facility



PTB direction spectrometer
All fields (except VENUS C)

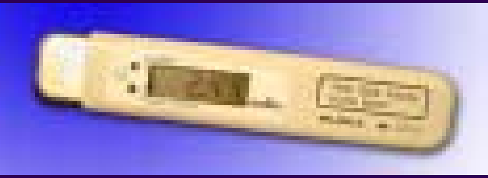


Personal dosemeters and survey instruments: results

Electronic neutron personal dosemeters

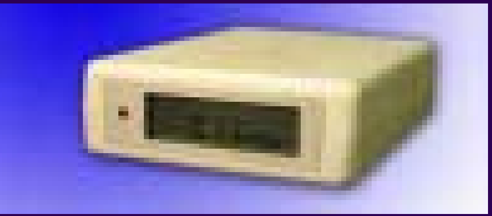
Saphydose n

PSI DIS-N



Aloka
PDM-313

Thermo Electron
EPD-N



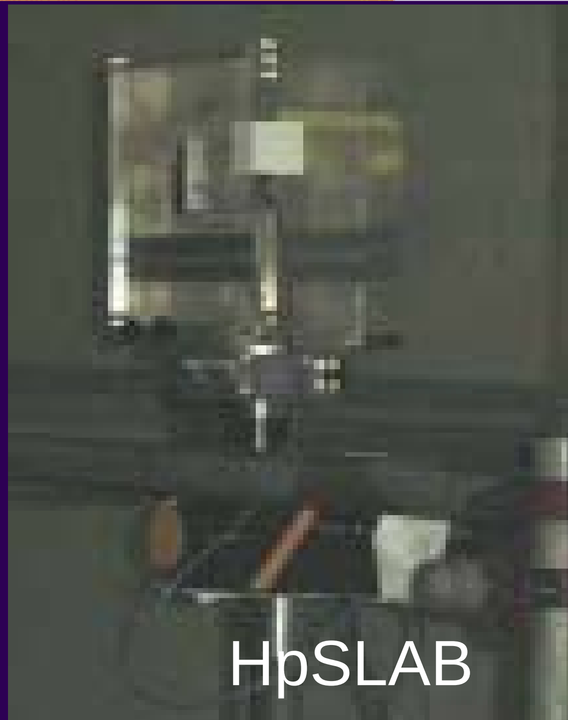
PTB
DOS-2002

Synodys
DMC 2000

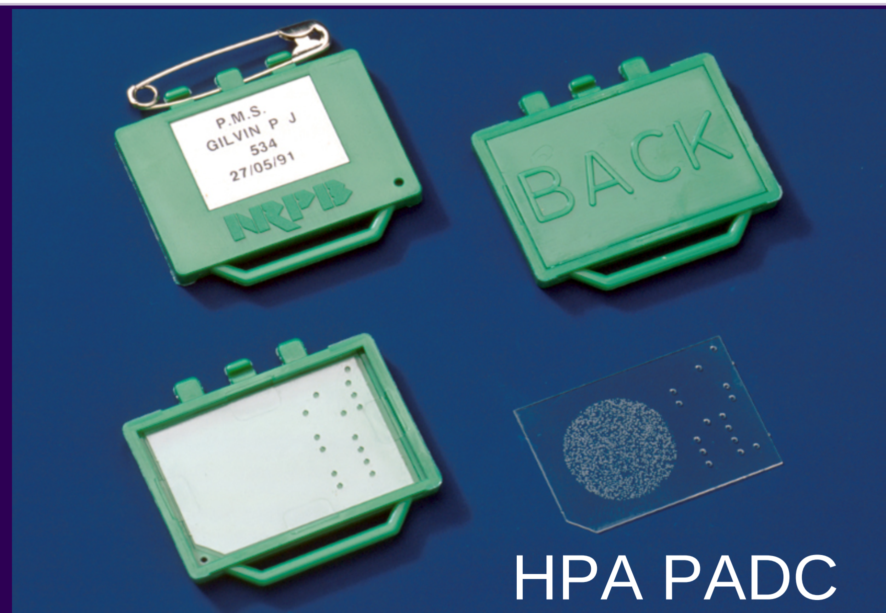
Thermo Electron
EPD-N2

Other neutron "personal" dosemeters

BTI PND and BDT



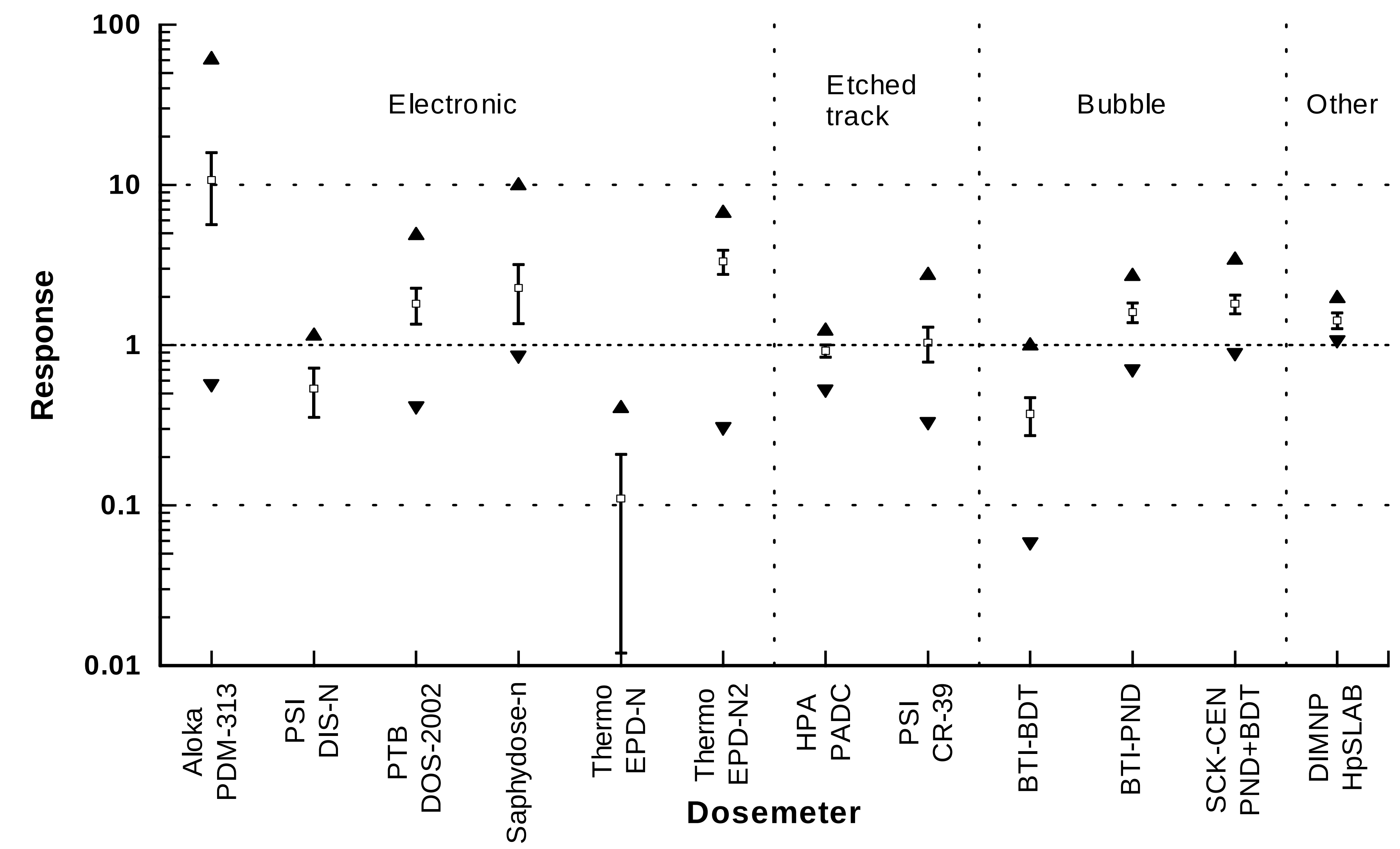
HpSLAB



HPA PADC

PSI PADC

Personal dosemeters: results



Neutron survey instruments

Health Protection Agency

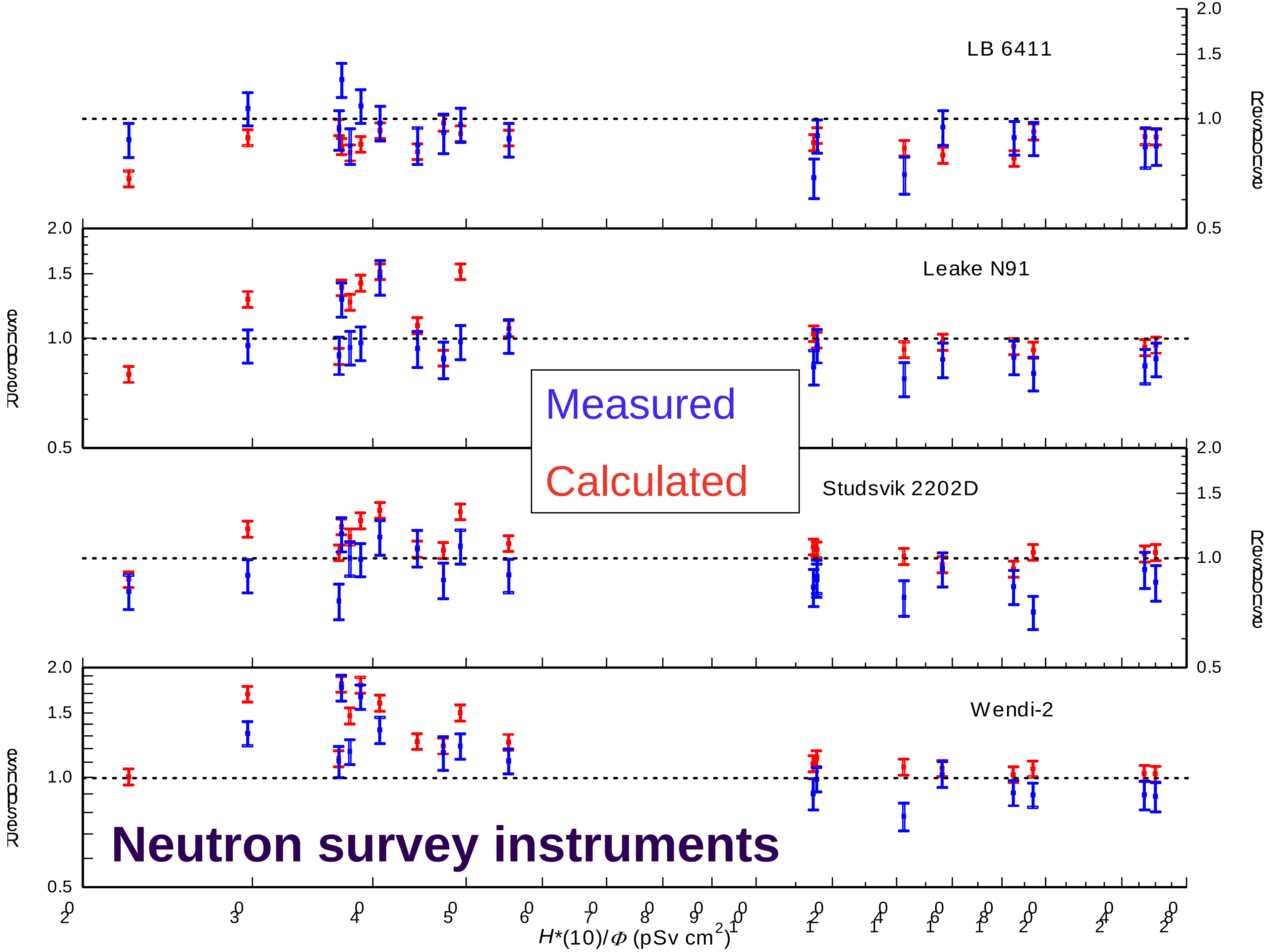
2202D

N91

Sievert instrument (TEPC)

WENDI

LB6411


LB 6411
Leake N91
Studsvik 2202D
Wendi-2
Measured
Calculated
Neutron survey instruments
Response
2.0
1.5
1.0
0.5
H*(10)/Φ (pSv cm²)

Conclusions I

- Improved workplace field characterization
- Direction distribution measurements have yielded values for *personal dose equivalent* and *effective dose* that allow the performance of personal dosemeters to be assessed in the workplace
- Folding with instrument and personal dosemeter responses demonstrates that the $\Phi(E,\Omega)$ are more useful than the $\Phi(E)$ data
- Some disagreement still between the predicted and measured responses

Conclusions IIa

- Active neutron personal dosemeters are becoming widely available
- Some newer designs are showing significantly better performance
- Some of the workplaces would not be adequately served by the alarm capability on an active photon dosemeter
- Some dosemeters produce very poor performance in the workplace - large over and under estimates
- Despite the advantages of active dosimetry, the passive systems perform well by comparison
- **The response data and reference values are all available in database format**

Conclusions IIa
$H^*(10)_n/H^*(10)_\gamma$

Campaign Site	Position or Field	$H^*(10)_n/H^*(10)_\gamma$	s
C1 - Krümmel	KKK Cask side	27.40	1.00
C1 - Krümmel	KKK Cask midline	26.95	0.84
C0 - Cadarache	IRSN Sigma	10.26	0.36
C2 - Mol	BN Pos 2A - unshielded rack	6.56	0.21
C3 - Ringhals	VF Pos A Containment	6.32	0.19
C3 - Ringhals	VF Pos L Entrance lock	5.21	0.17
C2 - Mol	BN Pos 2B - shielded rack	5.19	0.17
C1 - Krümmel	KKK Top	5.06	0.19
C2 - Mol	SCK-CEN Venus reactor side	4.55	0.15
C2 - Mol	BN Pos 3 - stockroom	2.66	0.09
C2 - Mol	SCK-CEN Venus control room	1.37	0.05
C2 - Mol	BN Pos 1 - bare rods	1.03	0.03
C3 - Ringhals	VF Pos N Cask end	0.60	0.02
C3 - Ringhals	VF Pos D Cask midline	0.60	0.02
C1 - Krümmel	KKK SAR	0.29	0.01

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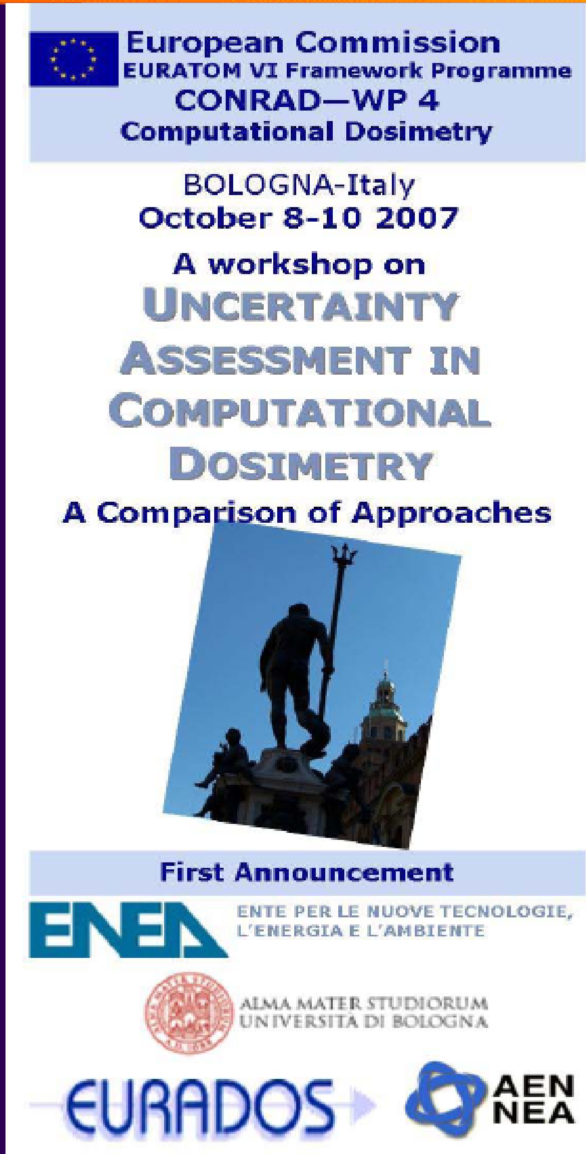
- Bernd Siebert (PTB) for calculating additional conversion coefficients for $H_p(10)$
- Other members of staff at the participating laboratories not explicitly acknowledged in the authorship

Miscellaneous



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N J Roberts, D T Bartlett,
L G Hager, L N Jones,
G C Taylor and D J Thomas
Practical Implications of Neutron Survey Instrument Performance
HPA-RPD-016 (2006).
On HPA website imminently…**