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Refresher Course RC-3b

External Dosimetry: Operational Quantities and their Measurement

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Short history of quantities and units

- **1928** foundation of **ICRU** and **ICRP**
- **1937** **x-ray unit “röntgen”**
- **1953** **absorbed dose D (unit: rad now Gy)**
- **1962** **dose equivalent H (rem now Sv)**
- **1977** **effective dose equivalent H_E (Sv)**
- **1985** **operational quantities H*, H’, H_p (Sv)**
- **1991** **effective dose E (Sv)**

Concept of radiation protection quantities

The international commissions ICRP and ICRU have developed a hierarchy of quantities for radiation protection applications which can be described by

- **Primary limiting dose quantities** (called "**Protection quantities**") taking account of human body properties and
- **Operational quantities** for monitoring of external exposure

Both, protection quantities and operational quantities can be related to

- **Basic physical quantities**

as specified in ICRU Report 33, which are generally used in radiation metrology and in radiation dosimetry in particular, and are defined without considering any specific aspect of radiation protection

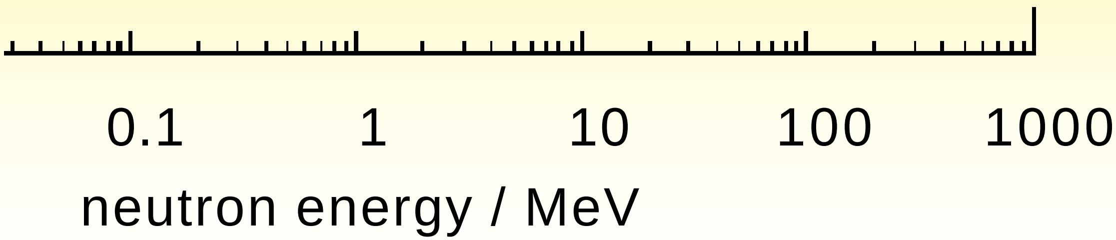
Protection quantities

- The **equivalent dose, *H_T*, in an organ or tissue** is defined by:

- $H_T = S\ w_R\ D_{T,R}$

- where $D_{T,R}$ is the mean organ dose in the organ or tissue T from radiation of type R incident on the human body and w_R are radiation weighting factors characterising the biological effectiveness of the specific radiation R relative to photons

Radiation	**Radiation weighting factor w_R**	
	ICRP 60	ICRP 92
Electrons, muons	1	1
Photons	1	1
Neutrons: $E_n < 10$ keV	5	Proposed w_R function
$E_n = 10$ keV to 100 keV	10	
$E_n > 100$ keV to 2 MeV	20	
$E_n > 2$ MeV to 20 MeV	10	
$E_n > 20$ MeV	5	
Protons (incident) ?-particles, fission fragments, heavy ions	5 20	2 20


0.1
1
10
100
1000
neutron energy / MeV

- The **effective dose, *E*,** is the weighted sum of organ equivalent doses:
- $E = \Sigma\, w_T\, H_T$ **with** $\Sigma\, w_T = 1$,
- where w_T are tissue weighting factors characterising the relative sensitivity of the various tissues with respect to cancer induction and mortality

ICRP has also defined the

- **Collective effective dose, *S***

  as product of the average dose of an exposed group by the number of individuals in the group

- Unit: **man-Sv**

Operational quantities

Due to the different tasks in radiation protection monitoring different operational quantities were defined:

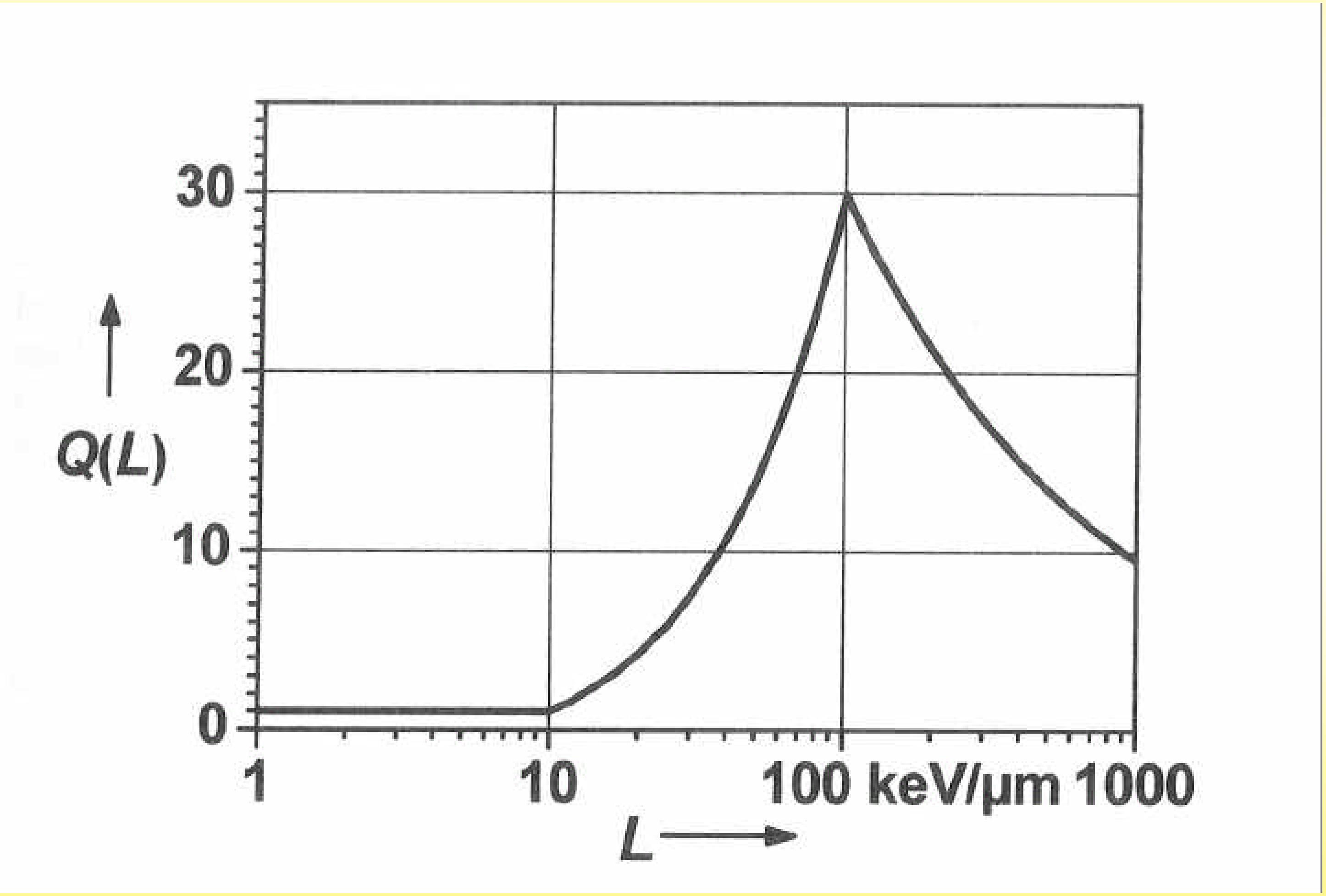
- **area monitoring** for controlling the radiation at workplaces and definition of controlled areas, or
- **individual monitoring** for the control and limitation of individual exposures

- The quantity **dose equivalent, *H***, has been defined by

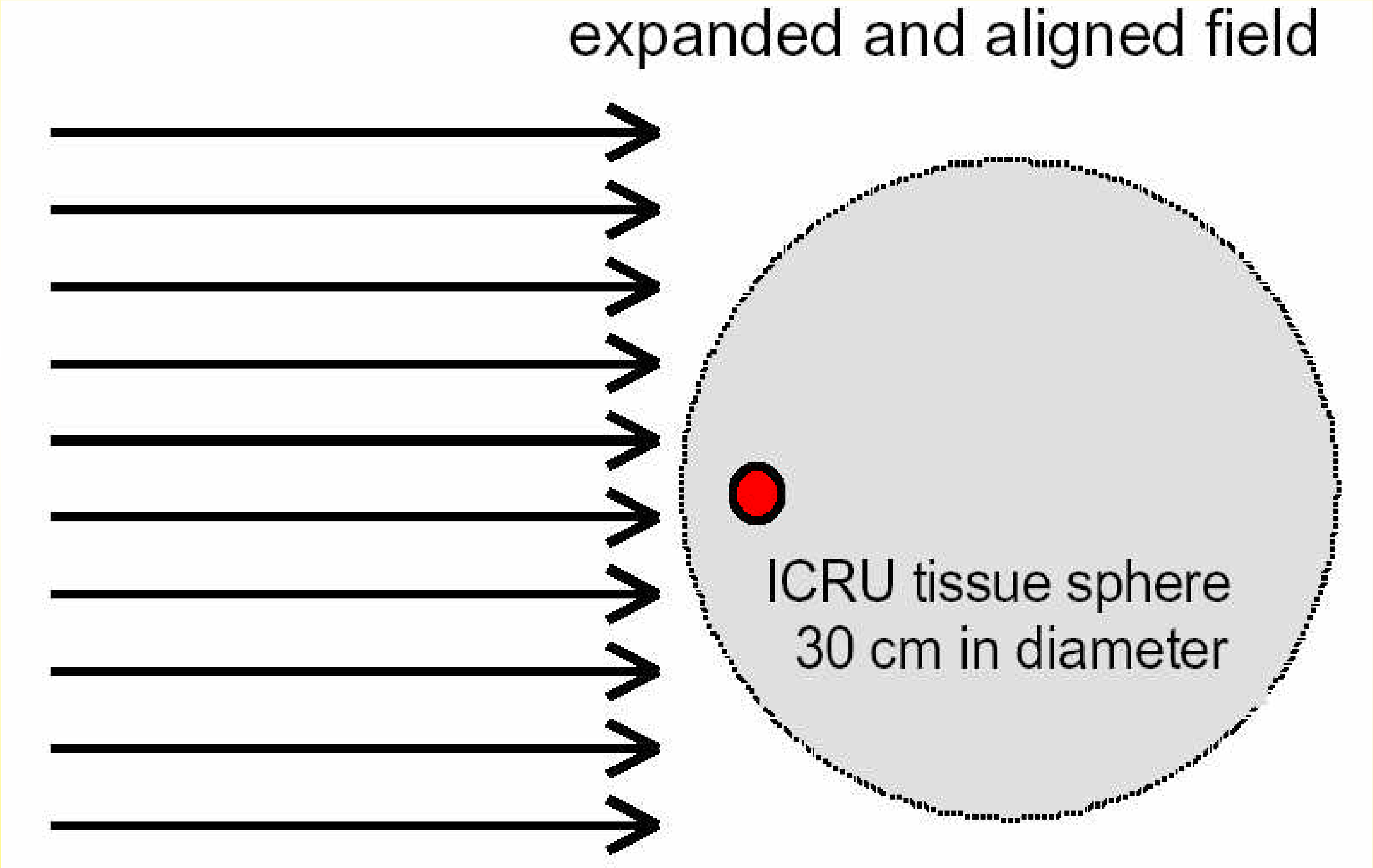
- ***H = Q(L) D***

- where ***D*** is the absorbed dose at the **point of interest** and ***Q(L)*** a quality factor weighting the relative biological effectiveness of radiation as a function of the linear energy transfer, **L**, of a charged particle in water

Quality factor, Q(L)



Concept of expanded and aligned field



Operational quantities for area monitoring

- **Ambient dose equivalent, *H**(d)**

  For area monitoring of penetrating radiation the operational quantity is the ambient dose equivalent, *H**(*d*), with d = 10 mm depth in the ICRU sphere in an expanded and aligned field

- **Directional dose equivalent, *H'*(*d,* ?)**

  For area monitoring of low-penetrating radiation the operational quantity is the directional dose equivalent, *H'*(*d,* ?) with d = 0.07 mm depth in the ICRU sphere

Operational quantity for individual monitoring

For individual monitoring the operational quantity is

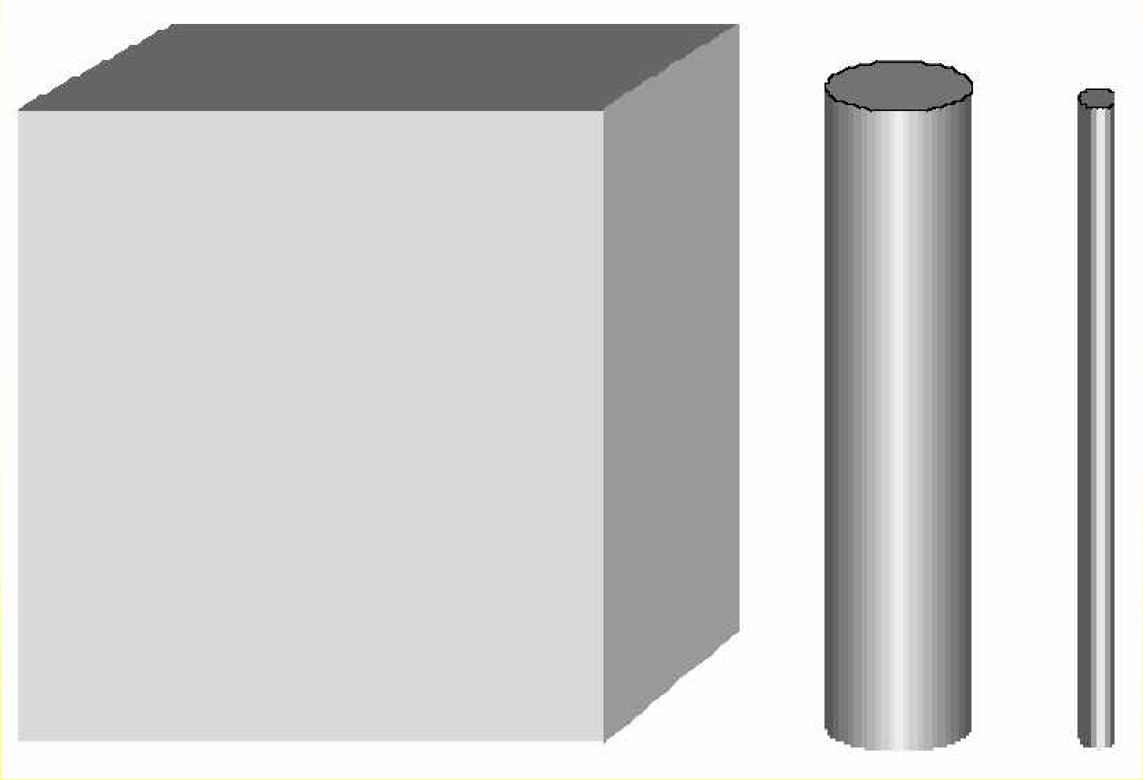
- **Personal dose equivalent, $H_p(d)$**

$H_p(d)$ is the dose equivalent in tissue at a depth d in a human body below the position where an individual dosemeter is worn

- For monitoring of effective dose it is recommended to use d = 10 mm - $H_p(10)$
  and for monitoring of skin dose
  d = 0.07 mm - $H_p(0.07)$

- For calibration purposes $\boldsymbol{H_p(d)}$ is defined as the dose equivalent in tissue at a depth ***d*** in the ICRU tissue phantom

ISO phantoms of ICRU tissue for the definition of Hp(10) and Hp(0.07)



Interrelation of quantities for external dosimetry

Physical quantities

- Particle fluence, φ
- Kerma, K
- Absorbed dose, D

Calculated using Q(L) and simple phantoms (sphere or slab) validated by measure-ments and calculations

Calculated using w_R, w_T and anthropomorphic phantoms

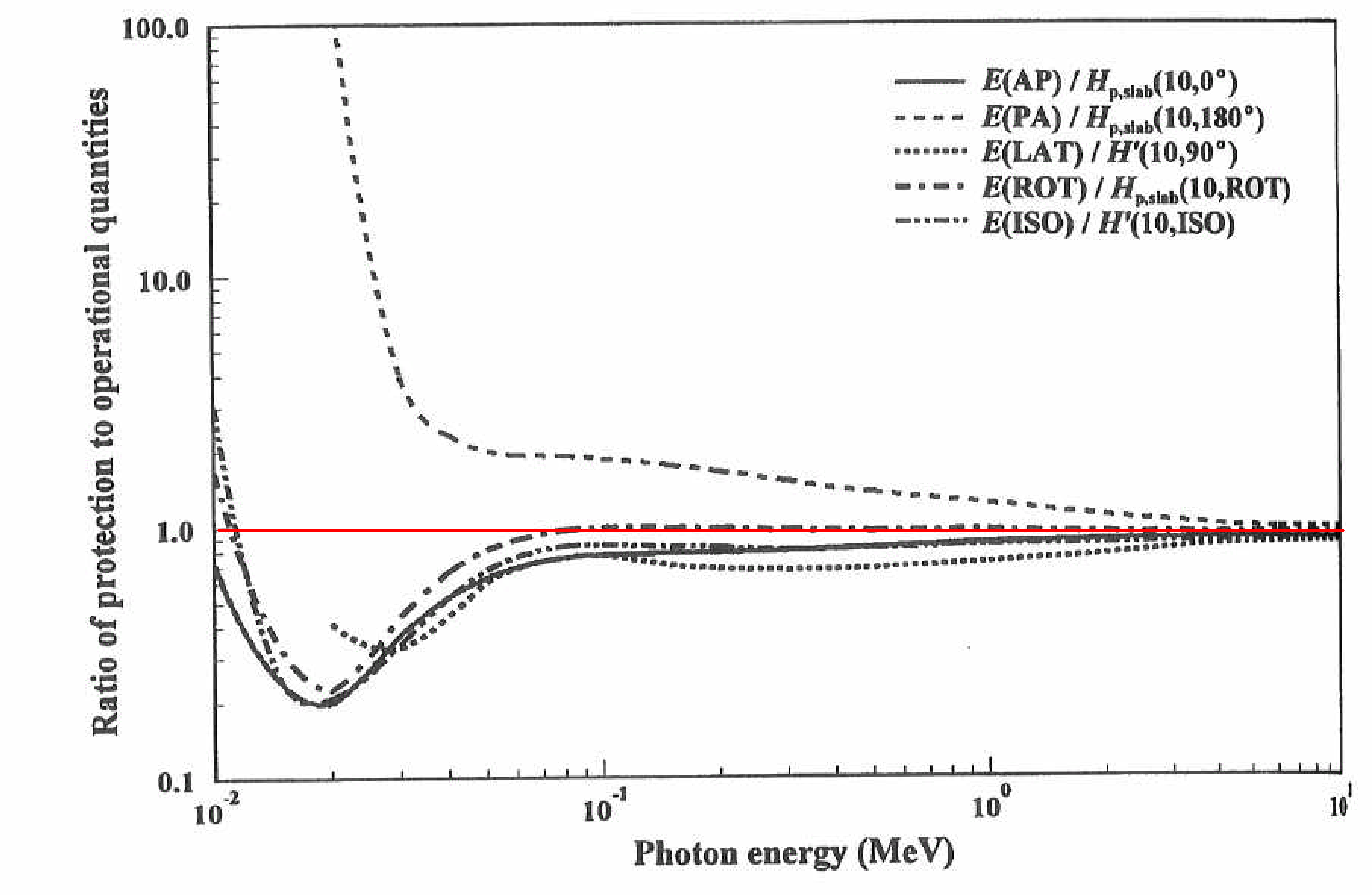
Operational quantities

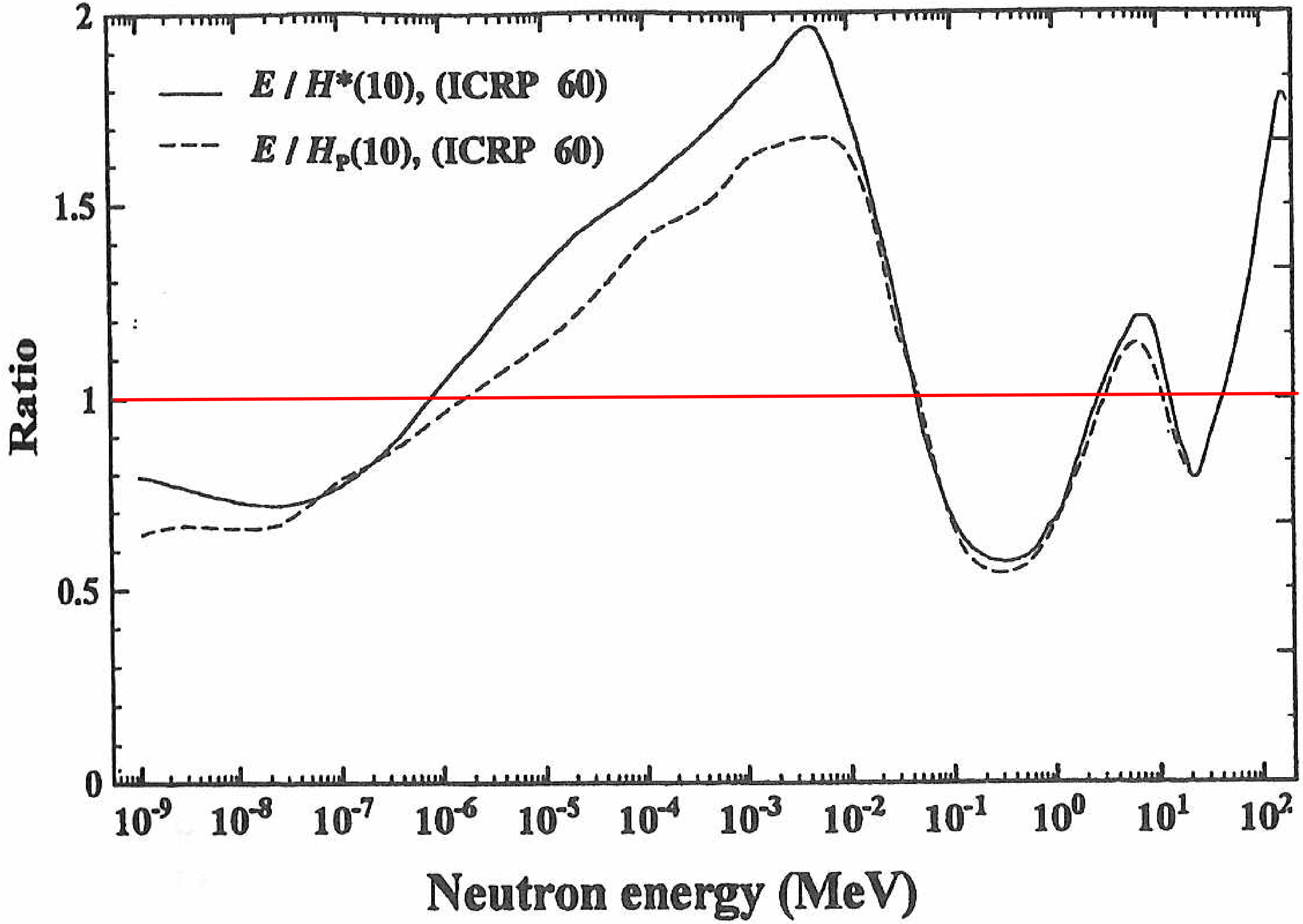
- Ambient dose equivalent, H*(d)
- Directional dose equivalent, $H'(d,\Omega)$
- Personal dose equivalent, $H_p(d)$

Compared by measurement and calculations (using w_R, w_T and anthropomorphic phantoms)

Protection quantities

- Organ absorbed dose, D_T
- Organ equivalent dose, H_T
- Effective dose, E


100.0
10.0
1.0
0.1
Ratio of protection to operational quantities
10^{-2}
10^{-1}
10^{0}
10^{1}
Photon energy (MeV)
E(AP) / $H_{p,slab}$(10,0°)
E(PA) / $H_{p,slab}$(10,180°)
E(LAT) / H'(10,90°)
E(ROT) / $H_{p,slab}$(10,ROT)
E(ISO) / H'(10,ISO)


E / H*(10), (ICRP 60)
E / Hp(10), (ICRP 60)
Ratio
2
1.5
1
0.5
0
10-9 10-8 10-7 10-6 10-5 10-4 10-3 10-2 10-1 100 101 102
Neutron energy (MeV)

Procedures for calibration

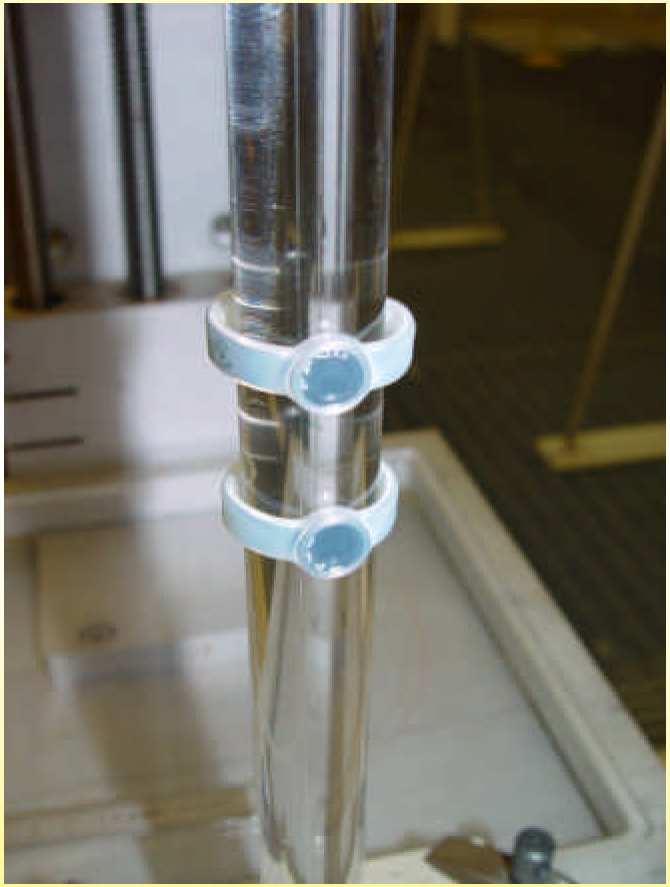
- Calibration of area monitors in terms of H*(d) is performed **free in air**. The relevant operational quantity is obtained by determining the appropriate basic physical quantity
- - **Air kerma** for photon radiation
- - **Fluence** for neutrons, or
- - **Absorbed dose** for electrons

and applying the corresponding conversion coefficient

Calibration of personal dosemeters

- Calibration of personal dosemeters is performed with the dosemeters mounted on an appropriate **phantom**
- Three phantoms have been defined by ISO for calibrations, corresponding to the positions on which personal dosemeters are worn (on the body, on the arm or on a finger)
- Their shapes are the same as those of the ICRU-tissue phantoms used for the calculation of the conversion coefficients

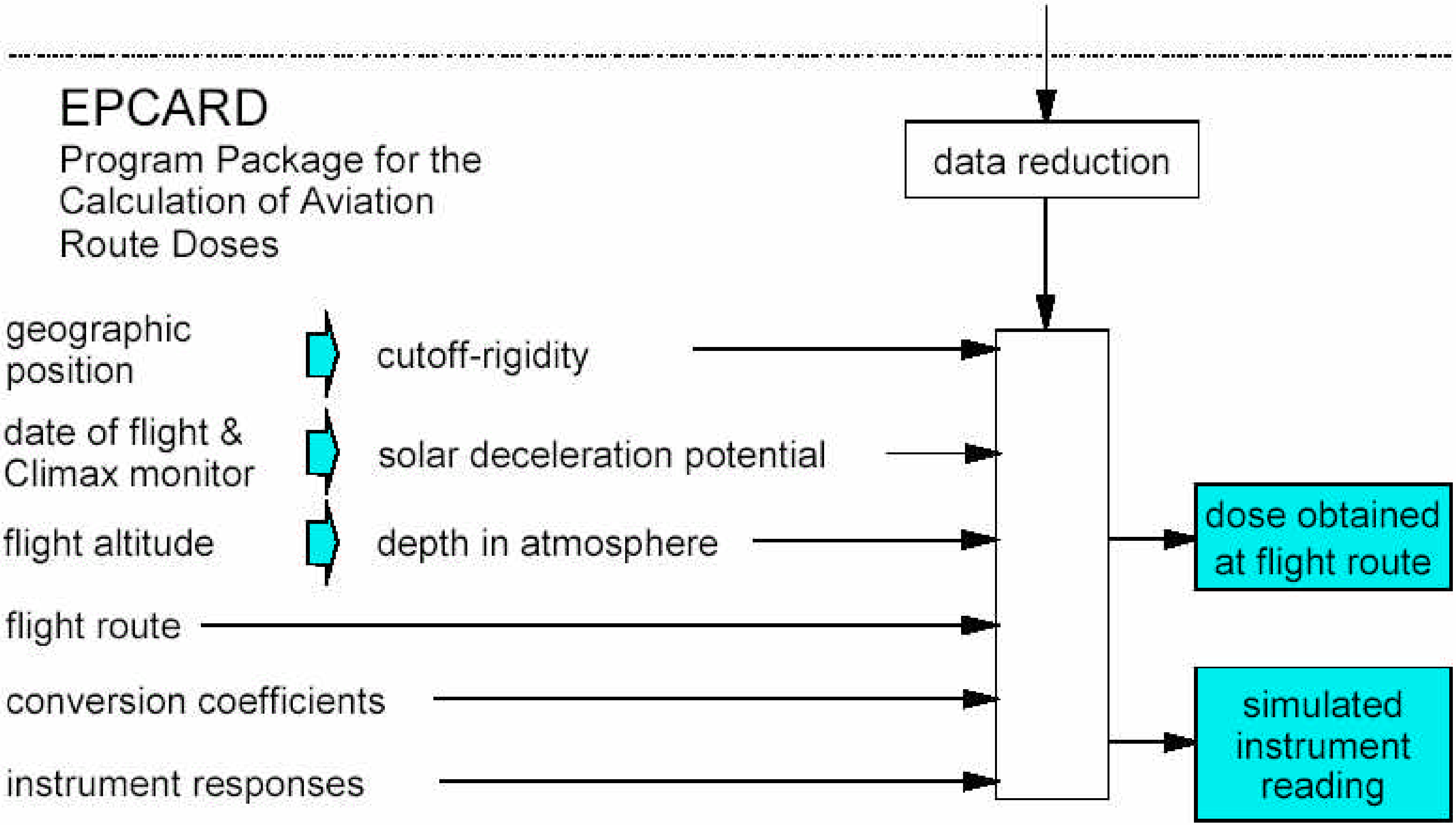
Phantoms used for calibration of dosemeters



Subject of monitoring for external radiation worldwide

- 4.6 million individually monitored persons
- 6.5 million persons occupationally exposed to enhanced natural radiation
- Individual monitoring consists mainly of dosimetry for external photon radiation
- About 20 % monitored for beta radiation
- About 6 % monitored for neutron radiation

Scheme for the calculation of aviation route dose with option of experimental verification



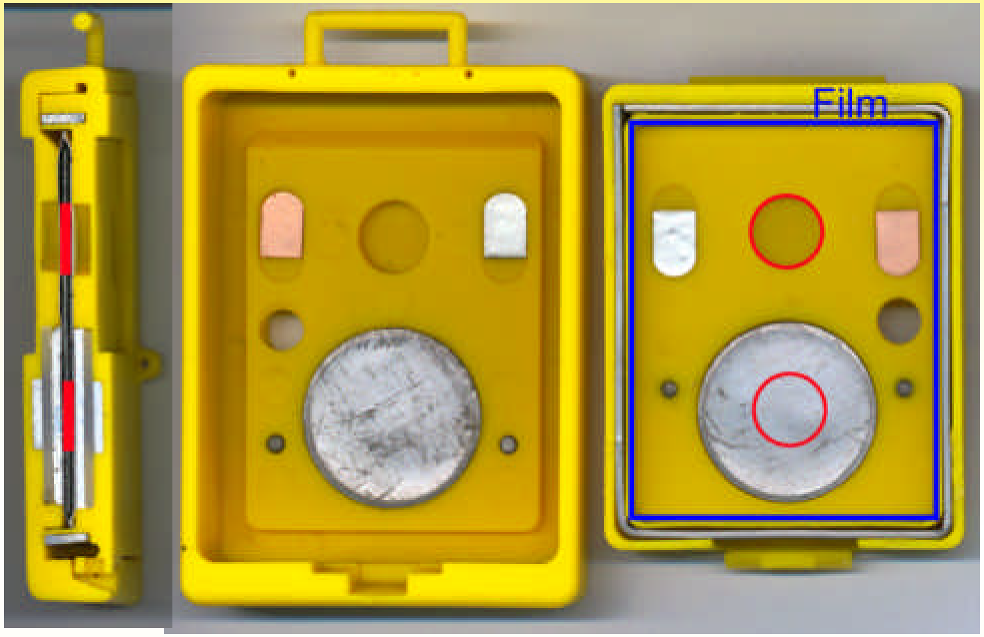
Dosimetry services

- Total number of dosimetry services in the order of 500
- Typical size of some hundred to some thousand customers per service
- Some ten very large services with up to over one million customers

Monitoring techniques for photon and beta radiation

- Photographic film
- Thermoluminescence (TLD)
- Optically stimulated luminescence (OSL)
- Radio photo luminescence (RPL)
- Electronic devices
  - Active with Si or GM detector
  - Passive with Direct Ion Storage (DIS) detector

Film dosemeters

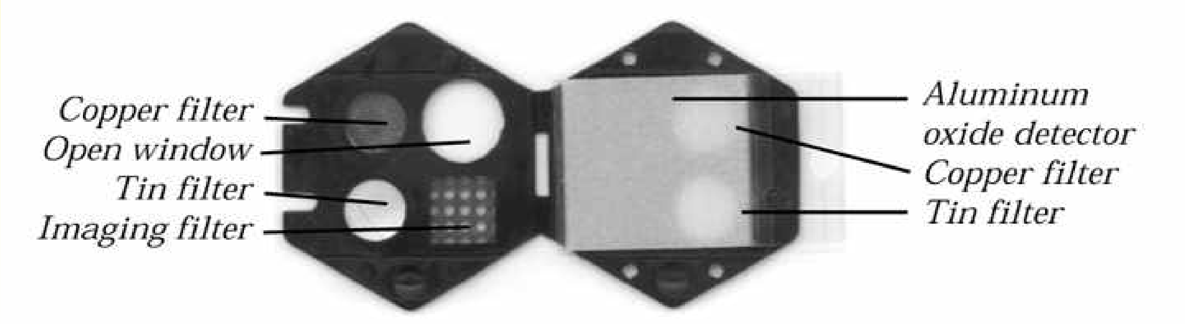


Film badge with "gliding shadow" technique

Standard film with automatic laser readout

Widely used TLD systems

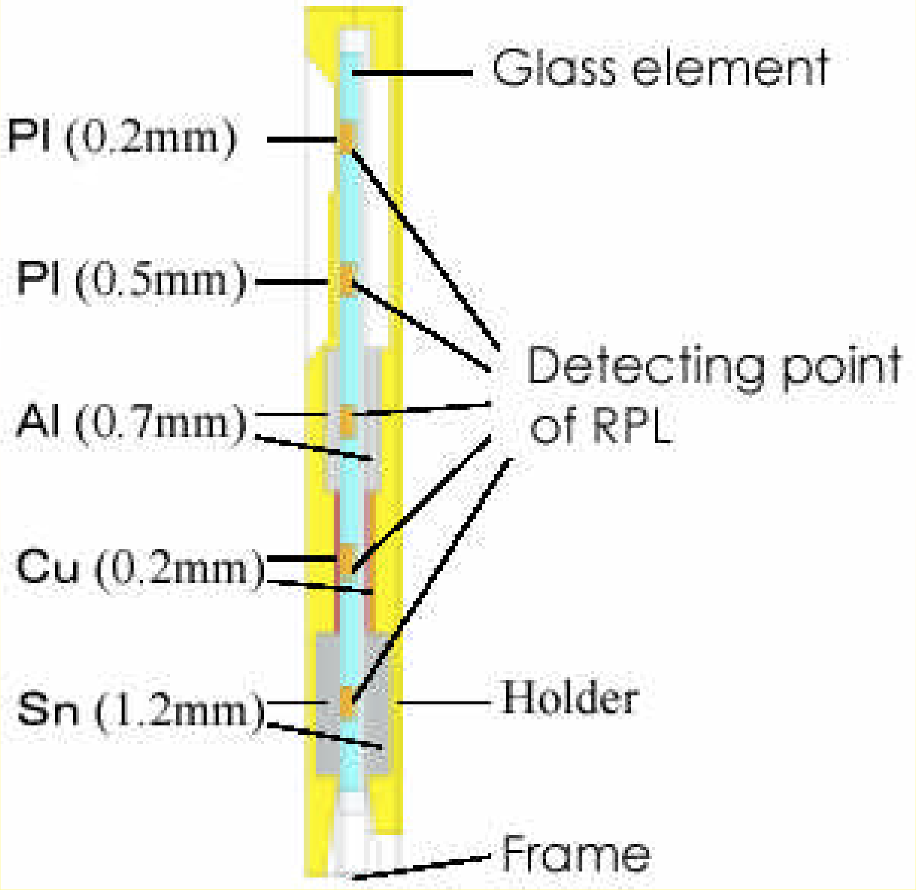
OSL systems



Inside Luxel

Combination of solid state detection principle and physical record

Example of a RPL dosemeter

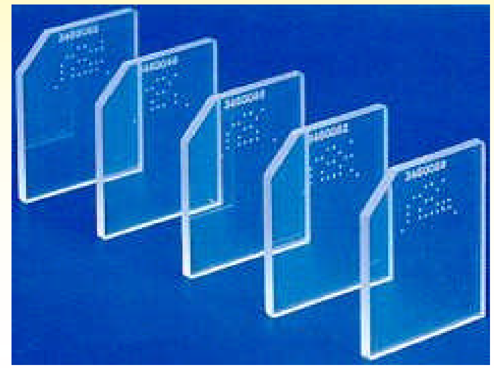


Electronic dosimeters with Si-diode detectors

Monitoring techniques for neutron radiation

- Differential TLD measurements for thermal neutrons, e.g. $^{6}LiF/^{7}LiF$ albedo dosemeters
- Track etch techniques, e.g. CR-39 for fast, and with converter also for thermal neutrons
- Bubble detectors
- Electronic devices

Readout system for CR-39 detectors



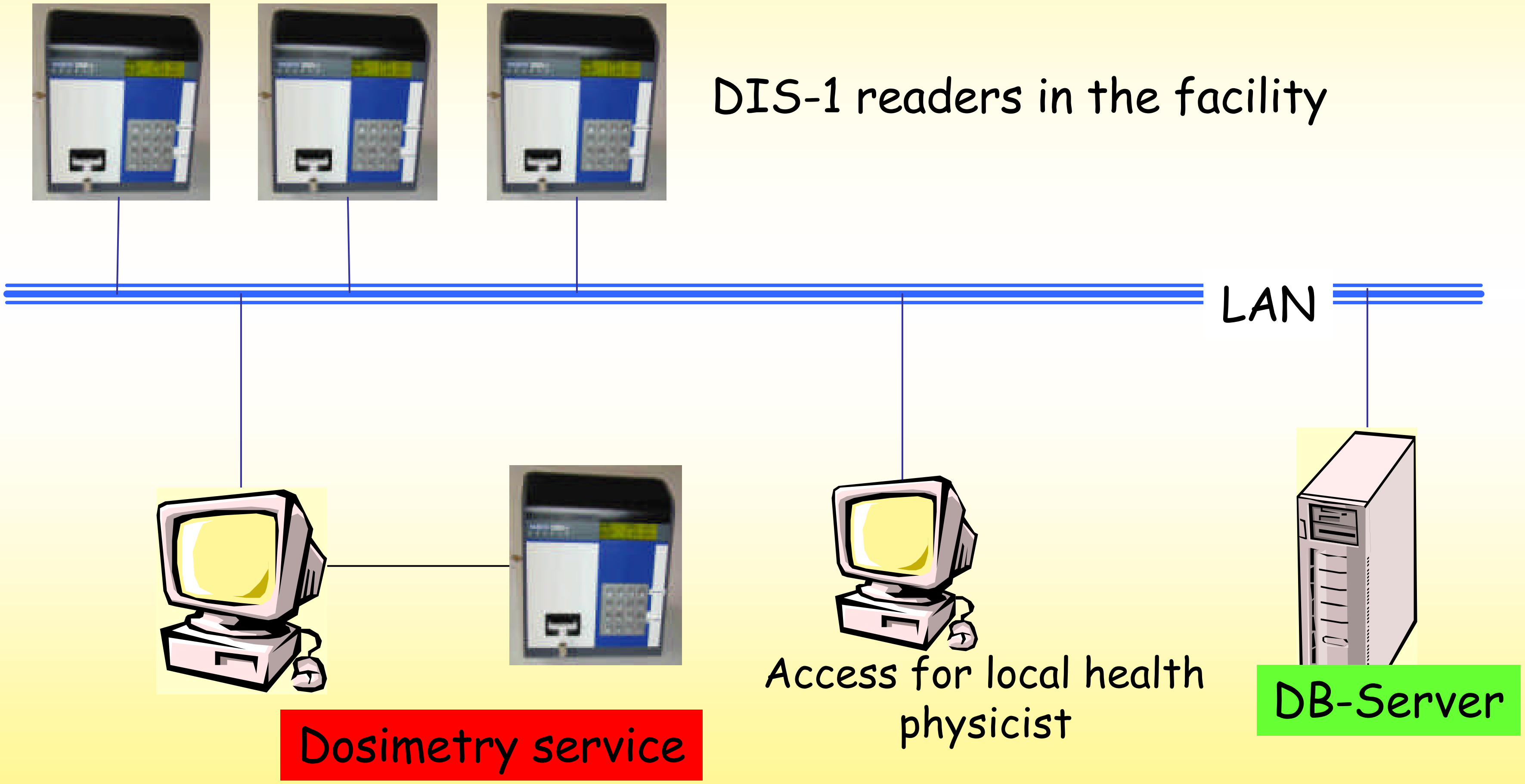
Background

3 mSv neutron dose

New development:

Combined badge with DIS-1 und CR-39 for photon, beta and neutron dosimetry

New application scheme of DIS-1



Conclusions and Outlook

- The techniques used for photon dosimetry have a high potential for significant change in the near future
- The use of passive or active electronic devices as legal dosimeters in combination with the corresponding IT networks and software may change the practice of individual monitoring

Conclusions and Outlook, cont.

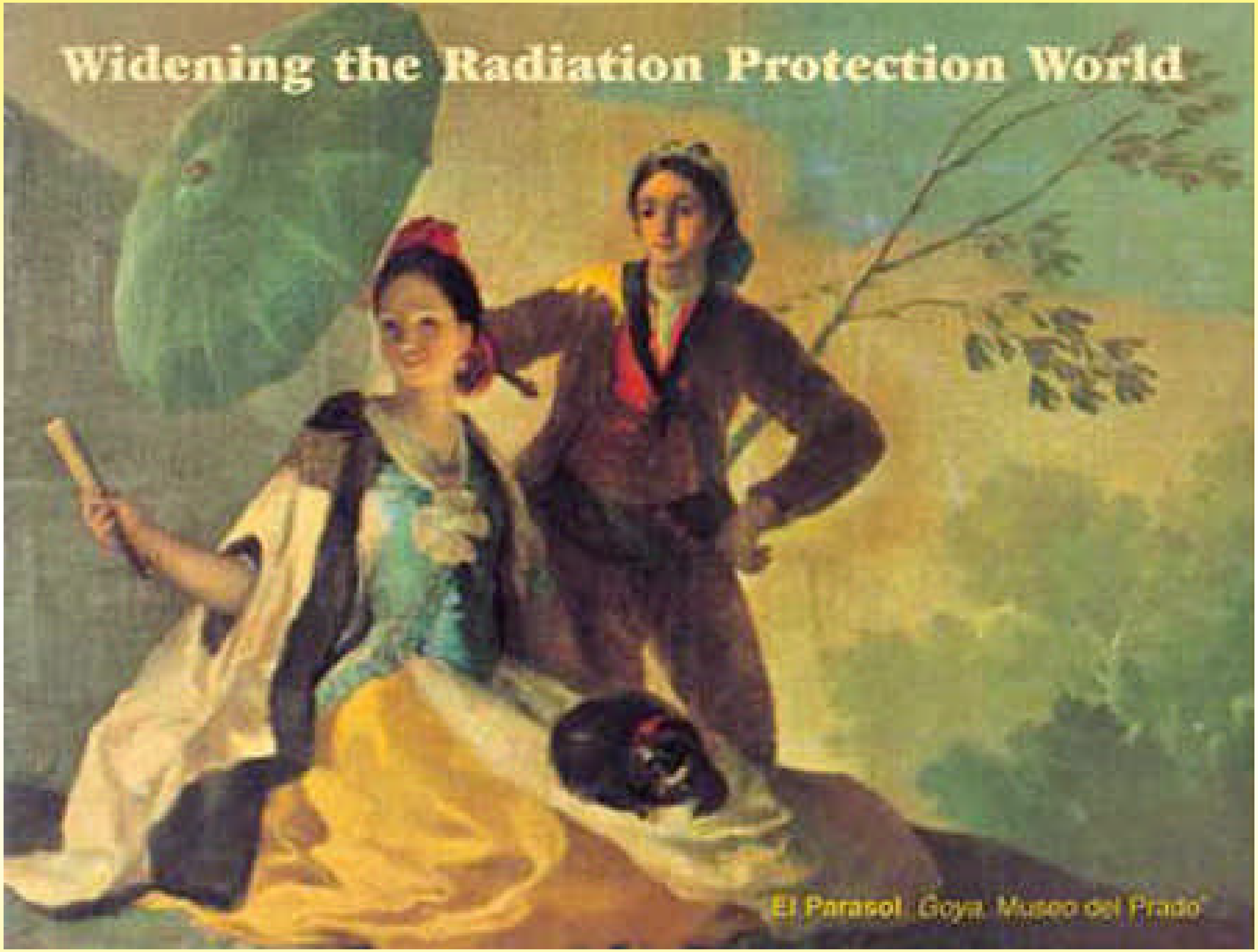
- New designs of extremity dosemeters more comfortable to wear and less energy dependent are still needed
- All passive neutron dosimetry systems have some relevant limitations and no immediate relieve is anticipated
- Electronic neutron dosimeters are emerging on the market. Their use may complement passive systems in various applications, but presumably not replace them

Conclusions and Outlook, cont.

- Data networks may become an increasingly important aspect of dose registering, reporting and record keeping
- For aircrew dosimetry the main activities are on the formal level to decide on procedures and software programs to be used. Measurements are mainly needed for verification of computed data

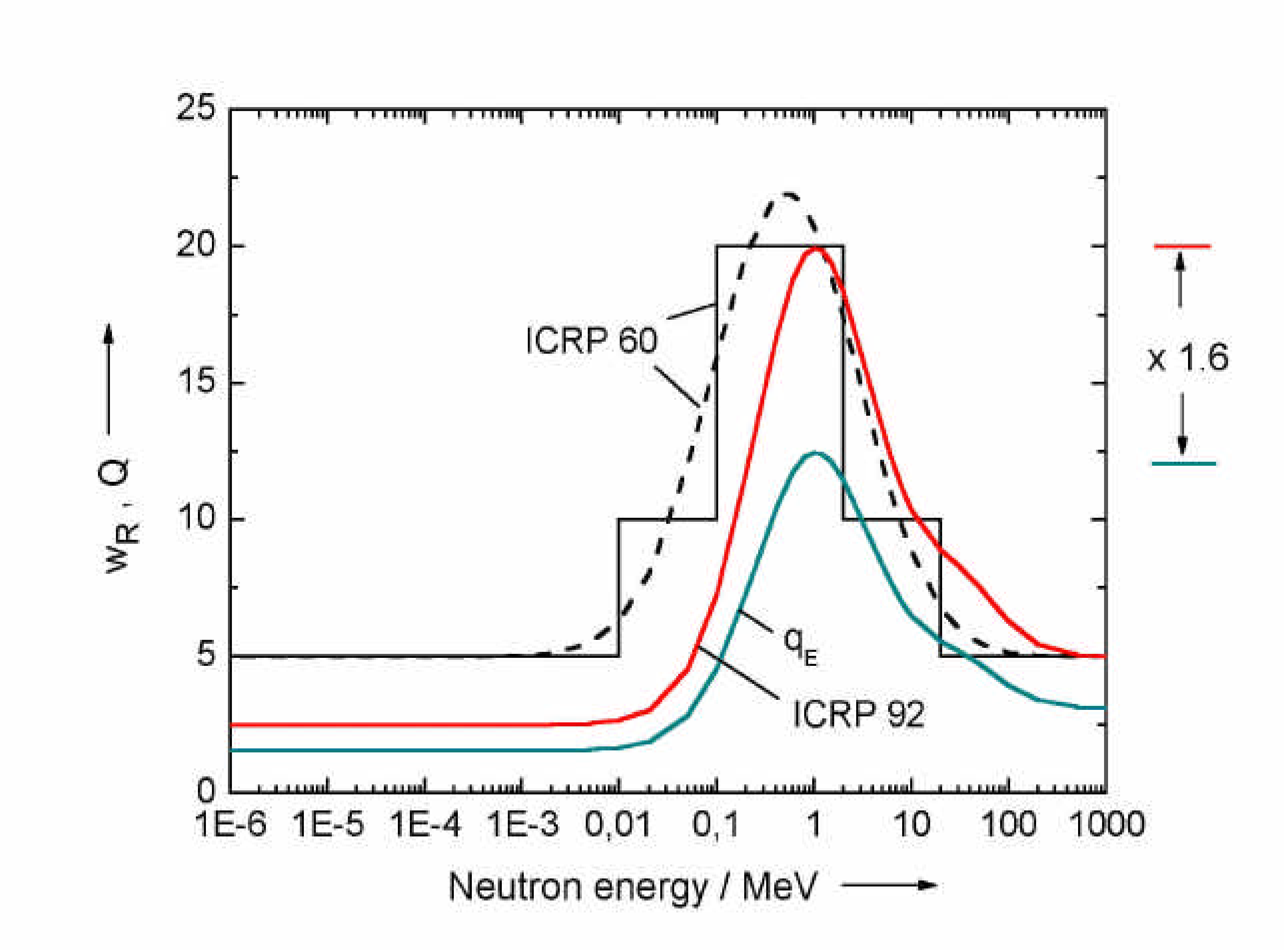
Conclusions and Outlook, cont.

- The ICRP/ICRU concept of quantities and units is an adequate basis for external dosimetry and its rigorous implementation in national legislations, regulations and work procedures is highly recommended


Widening the Radiation Protection World
El Parasol Goya Museo del Prado

Thank you

w_R and Q in ICRP 60 and ICRP 92

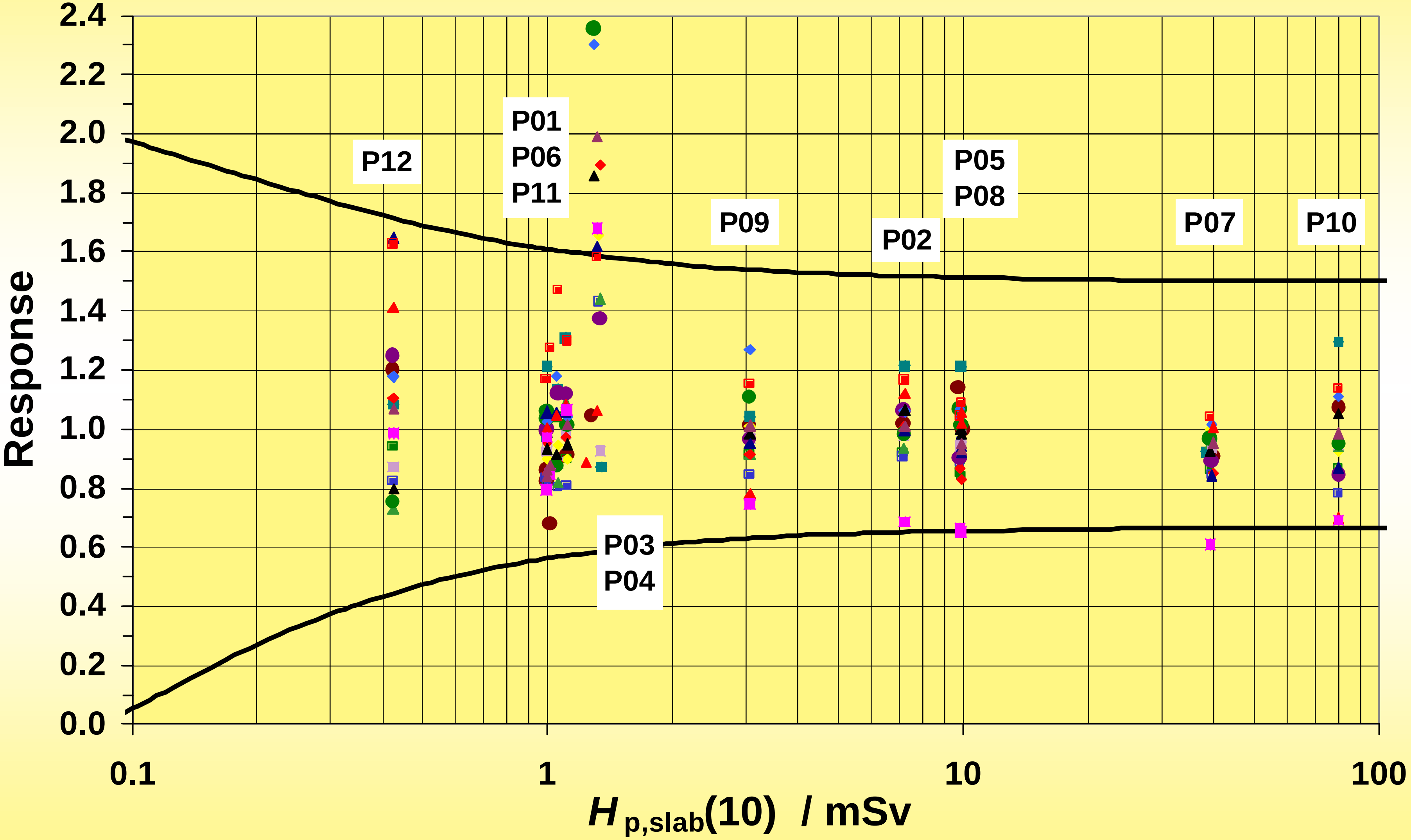


Tissue weighting factors w_T

	ICRP Publication 26 1977	Publication 60 1991
Bone surfaces	0.03	0.01
Bladder		0.05
Breast	0.15	0.05
Colon		0.12
Gonads	0.25	0.20
Liver		0.05
Lungs	0.12	0.12
Oesophagus		0.05
Red bone marrow	0.12	0.12
Skin		0.01
Stomach		0.12
Thyroid	0.03	0.05
Remainder	0.30	0.05
TOTAL	1.0	1.0

PHOTONS WB
Cogema 18
N°16
CIEHAT
Photon
CTRL- 4
11318
06.98
OPRI
MPA NRW
26752873
P-AG-18

EURADOS intercomparison: TLD systems



EURADOS intercomparison: Multielement neutron dosimeters