Operational Quantities for External Radiation Exposure
- Actual Shortcomings and Alternative Options -

G. Dietze, Braunschweig, Germany
D.T. Bartlett, Oxford, UK
N.E. Hertel, Atlanta, USA

IRPA 2012, Glasgow, Scotland, UK, 13.-18. May 2012

ICRU Report Committee: Operational Radiation Protection Quantities for External Radiation

Members:

Nolan Hertel (USA) Chairman
David Bartlett (UK)
Jean-Marc Bordy (France)
Günther Dietze (Germany)
Akira Endo (Japan)
Gianfranco Gualdrini (Italy)
Maurizio Pelliccioni (Italy)

Corresponding members:

David Burns (BIPM)
Peter Ambrosi (Germany)
Bernd Siebert (Germany)

ICRU Sponsors:

Hans Menzel, Steve Seltzer, Elena Fantuzzi

Need for Operational Dose Quantities for External Exposure Situations

Why do we need operational dose quantities for external radiation exposure ?

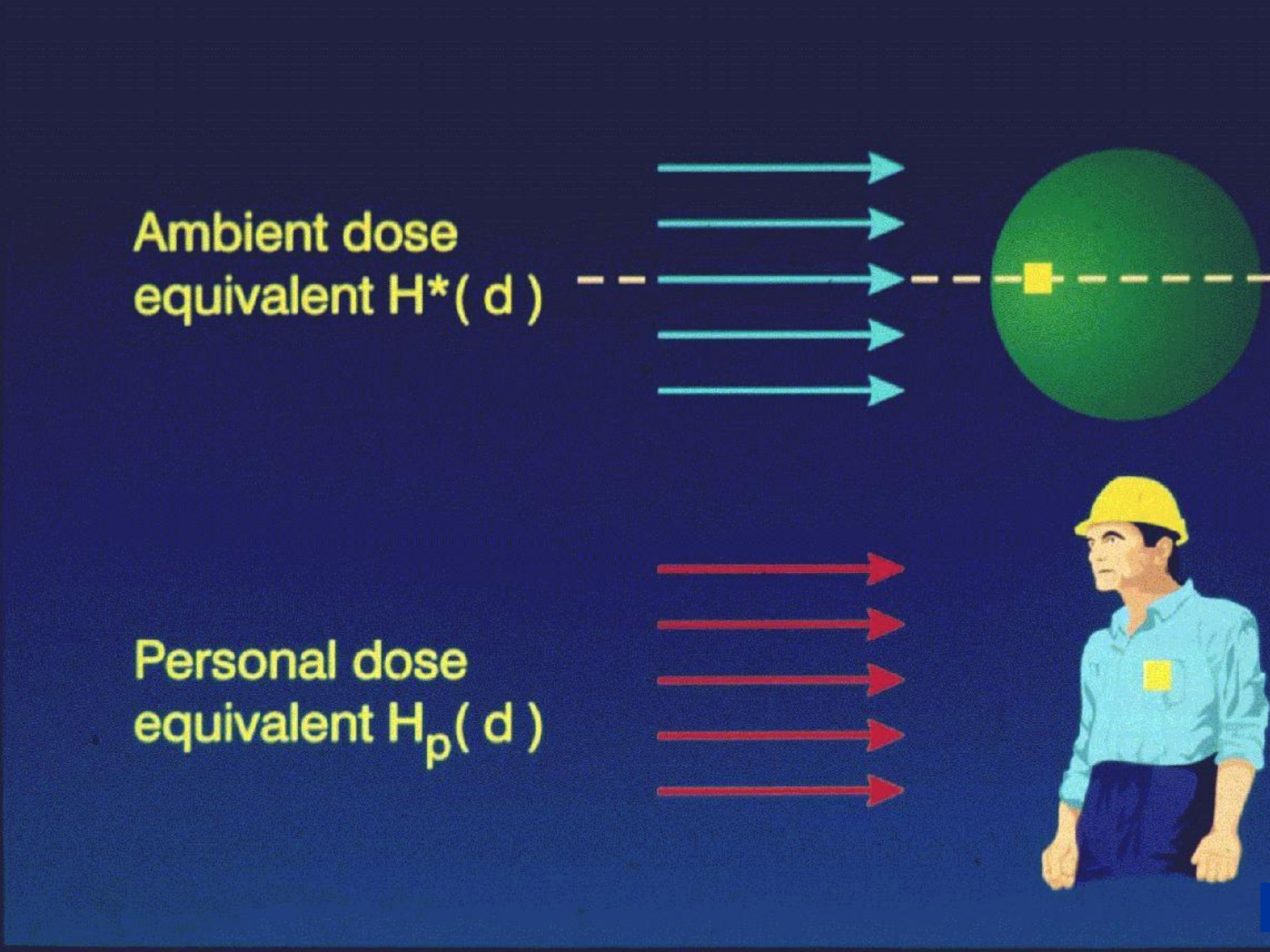
- The protection quantities equivalent dose in an organ or tissue and effective dose are generally not measurable.
- Exposure limits are given in terms of protection quantities.
- Control of dose limits needs the assessment of values of the protection quantities by measurements.
- Measurements need a calibration of instruments in terms of measurable quantities.

Operational Dose Quantities

Limits (ICRP 103) are given in terms of

- effective dose, E
- equivalent dose to the skin, H_{skin}
- equivalent dose to the lens of the eye, $H_{eye\ lens}$
- equivalent dose to the hands and feet (no conversion coefficients)

Task	**Area monitoring**	**Individual monitoring**
Monitoring of effective dose	*Ambient dose equivalent*, $H^*(10)$	*Personal dose equivalent*, $H_p(10)$
Monitoring of equivalent dose to the skin and the hands/feet	*Directional dose equivalent*, $H'(0.07,\Omega)$	*Personal dose equivalent*, $H_p(0.07)$
Monitoring of equivalent dose to the eye lens	*Directional dose equivalent*, $H'(3,\Omega)$	*Personal dose equivalent*, $H_p(3)$


Ambient dose equivalent H*(d)
Personal dose equivalent Hp(d)

More sources of high-energy radiation where operational dose quantities may be applied

- Increasing use of medical accelerators with accelerating potentials of up to 21 MV for radiotherapy with photons and electrons.
- Use of high-energy proton and heavy-ion accelerators for radiotherapy.
- Radiation fields near high-energy accelerators for research
- Natural sources of high-energy radiation (in aviation heights and in space)

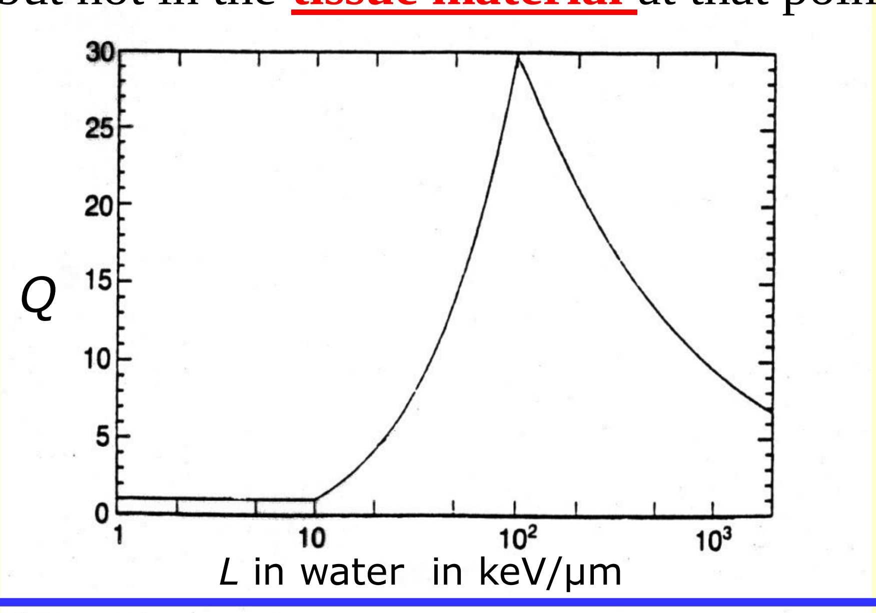
Quantities for area monitoring, $H^*(d)$ and $H'(d)$

- Primary standards for ambient and directional dose equivalent, $H^*(d)$ and $H'(d)$, do not exist.
- Reference fields for calibration of instruments are usually realised in terms of radiation fluence rate, $\dot{\Phi}$, (for neutrons) and air kerma rate, $\dot{K}_a$, (for photons) and the application of fluence-(or air kerma) to-dose equivalent conversion coefficients.
- The values of conversion coefficients are usually fixed reference values recommended by ICRU, ICRP and ISO and defined to have no uncertainty.
- The conversion coefficients are very important data in all calibration procedures.

Deficiencies and limitations of the current operational dose quantities for area monitoring

- The ICRU sphere (defined more than 30 years ago) is based on the definition of an ICRU 4-element tissue-equivalent material which does not really exist and cannot be fabricated.

- Dose equivalent, *H*, is defined as absorbed dose in tissue times the radiation quality factor, *Q*.
  Q is defined by a function *Q*(*L*), where *L* is the *unrestricted linear energy transfer*, L_∞, of the charged particle traversing the point (or small volume) of interest , but not in the **tissue material** at that point but in **water**.



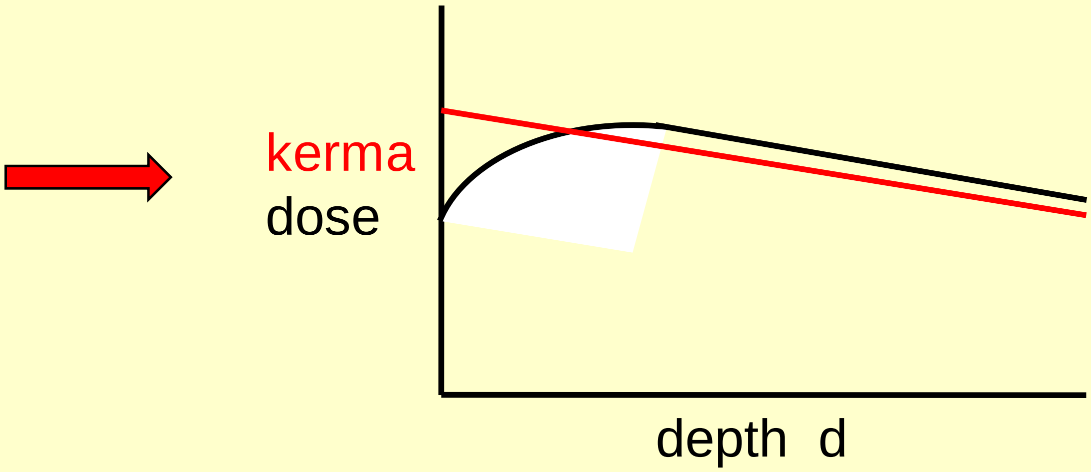
Deficiencies and limitations of the current operational dose quantities for area monitoring

- Calculations of conversion coefficients for photons and neutrons are performed using the kerma approximation *in vacuo*

Kerma approximation

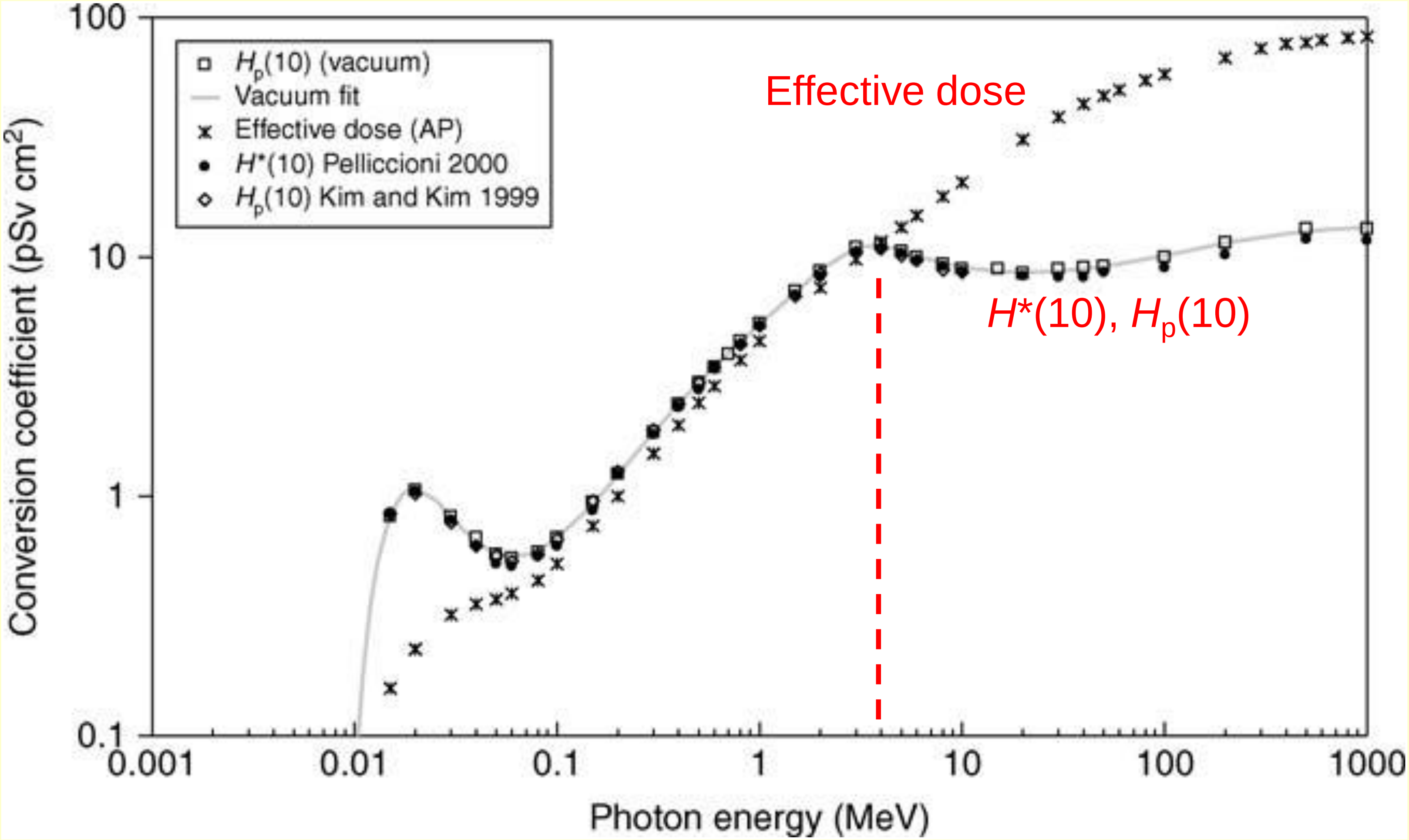
All energies of the emitted secondary charged particles are fixed to be deposited in the volume element where the reaction takes place.
If secondary charged particle equilibrium exist at that point, then kerma and absorbed dose have the same value.

Dose distribution near a surface

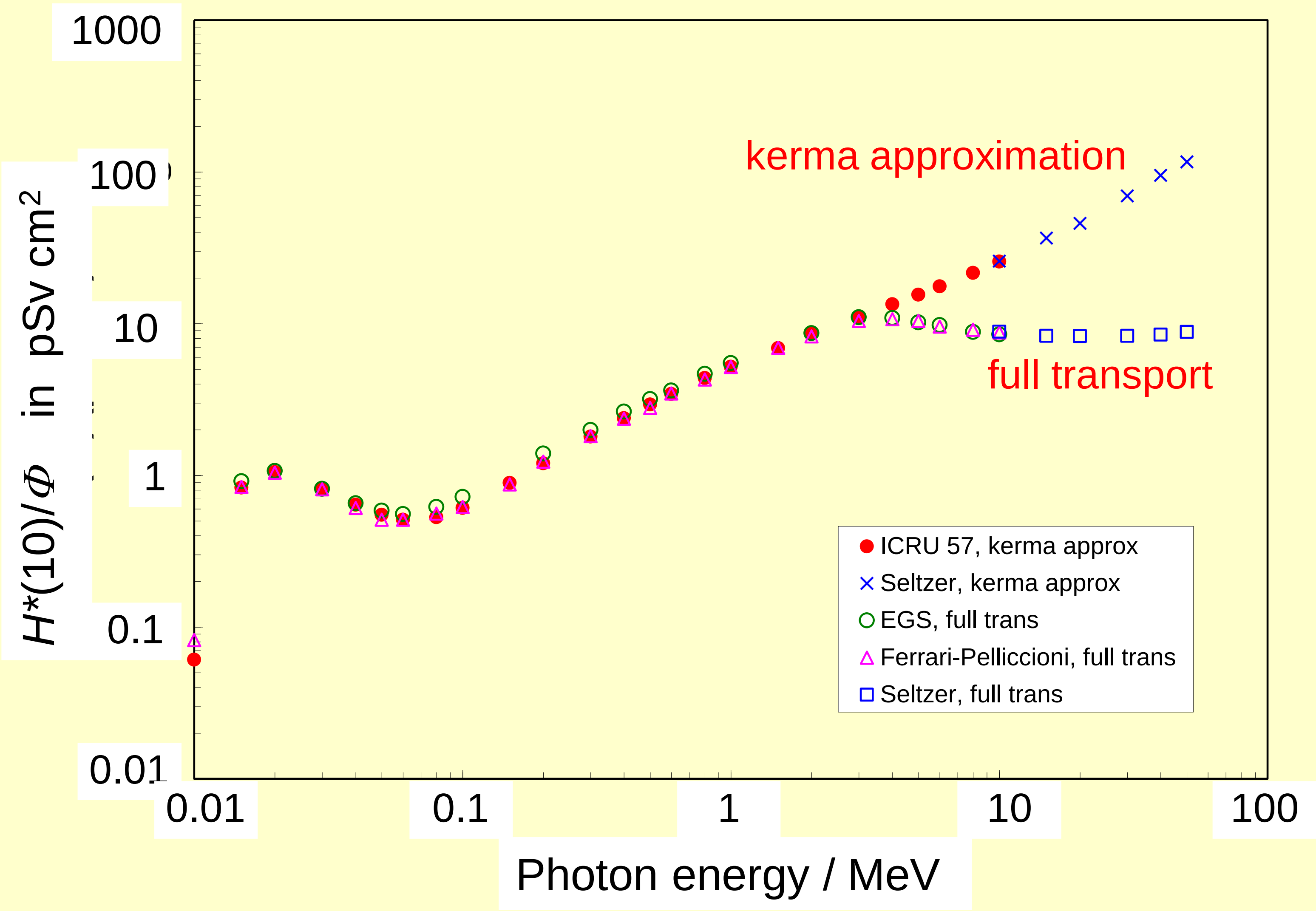


Conversion coefficients for effective dose, $H^*(10)$ and $H_p(10)$ calculated using full follow-up of secondary charged particles.

(K. G. Veino and N. E. Hertel, RPD **145** (2011))

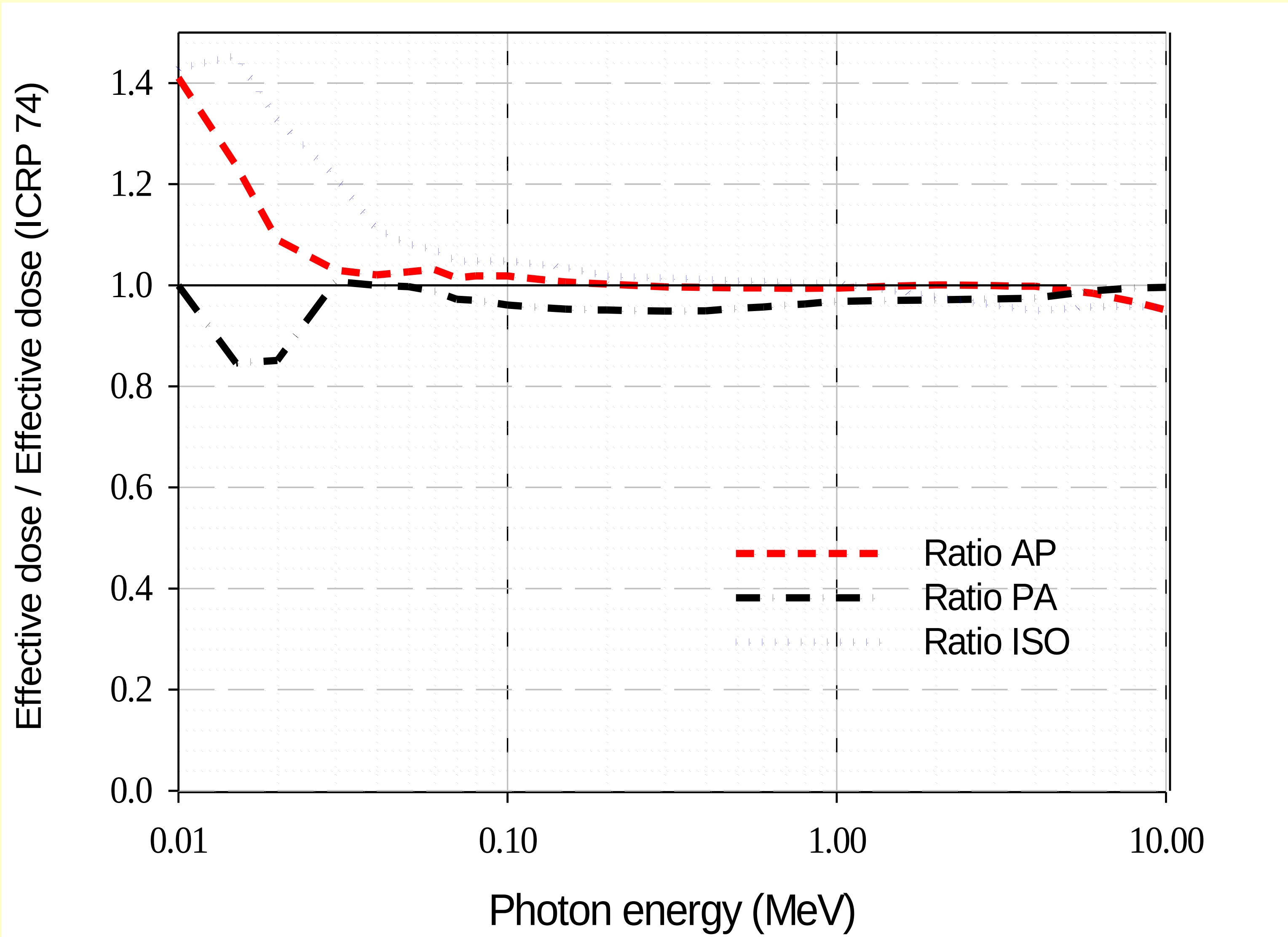


Calculations of conversion coefficients $H^*(10)/\Phi$ for photons performed using the ICRU sphere *in vacuo*



(S. Seltzer, NIST, 2011)

Ratio of E(ICRP 116) to *E*(ICRP 74)

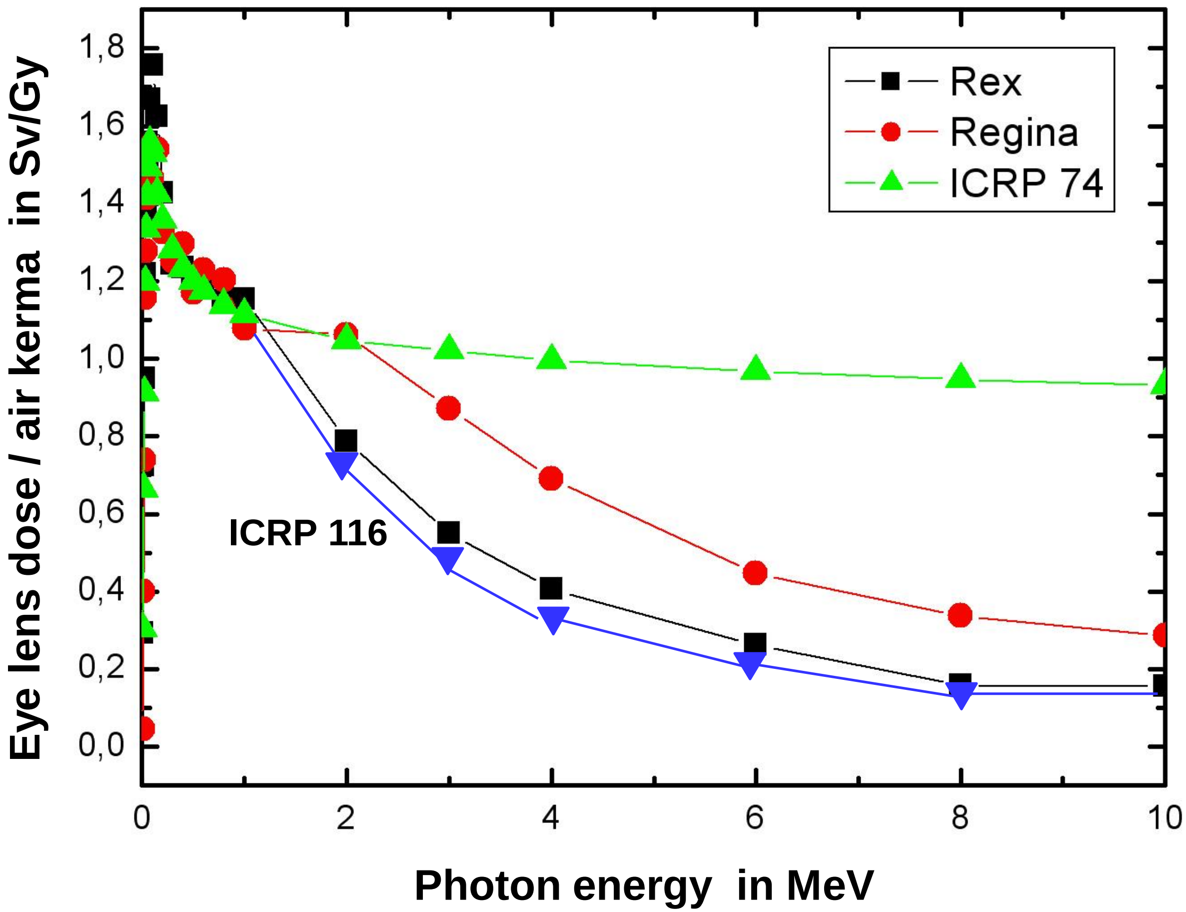


Deficiencies and limitations of the current operational dose quantities for area monitoring

- The dose equivalent deposited by external secondary particles is not included in the definitions (sphere in vacuum) and for $H^*(10)$ this component cannot be aligned. It is also not considered for $H'(d,\Omega)$.
- If the ICRU sphere would be considered to be located in air, this needs to define the distance between source and sphere. For always achieving secondary charged particle equilibrium at the surface, this distance depends e.g. on the photon energy ➡ non-additive.
- Today, in reference photon fields used for calibration of dosimeters, secondary charged particle equilibrium is approximately realised by including tissue-equivalent material between the radiation source and the dosimeter to be calibrated.

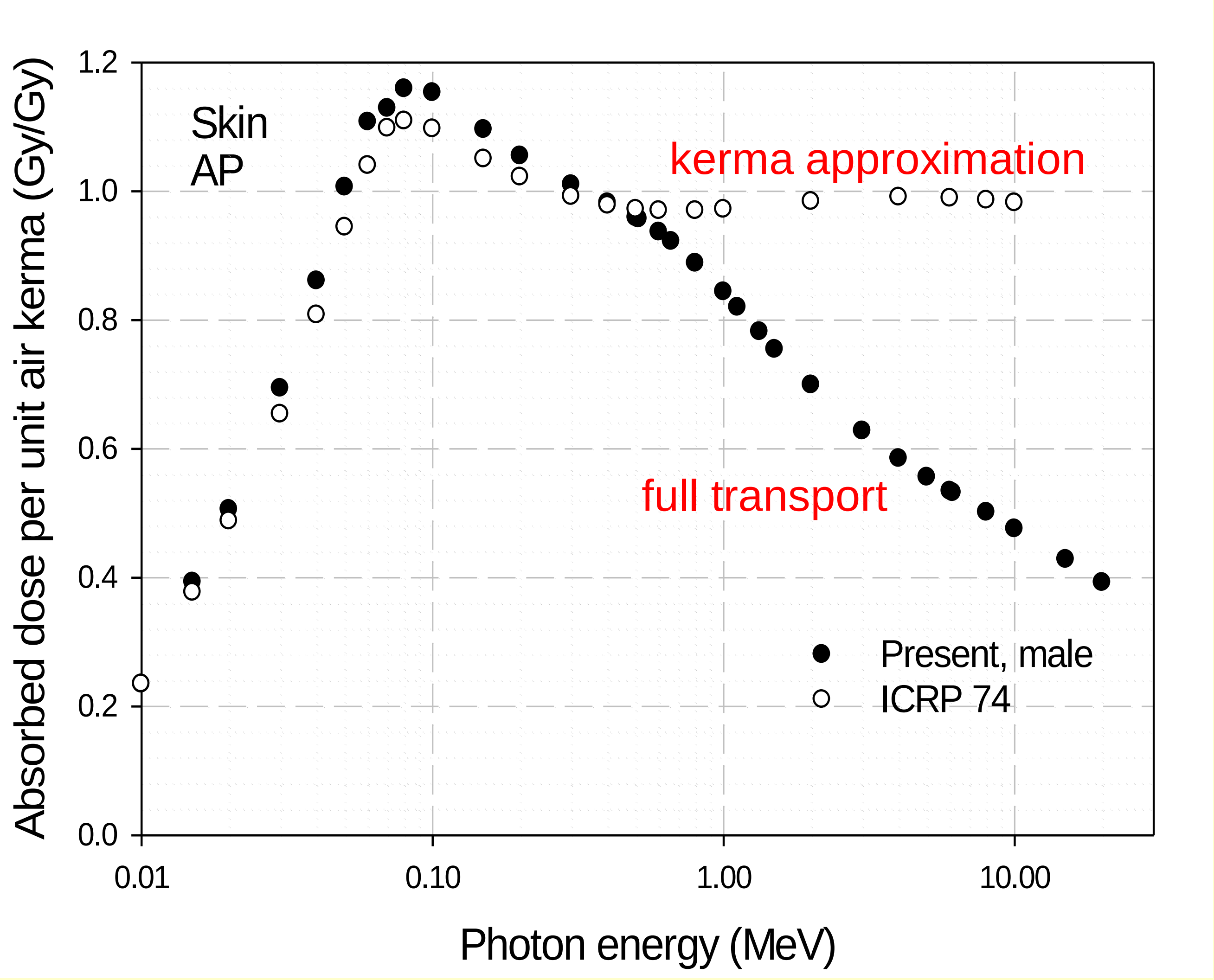
Photon exposure of the eye lens

ICRP 74 kerma approximation
Rex, Regina secondary charged particle follow-up
ICRP 116

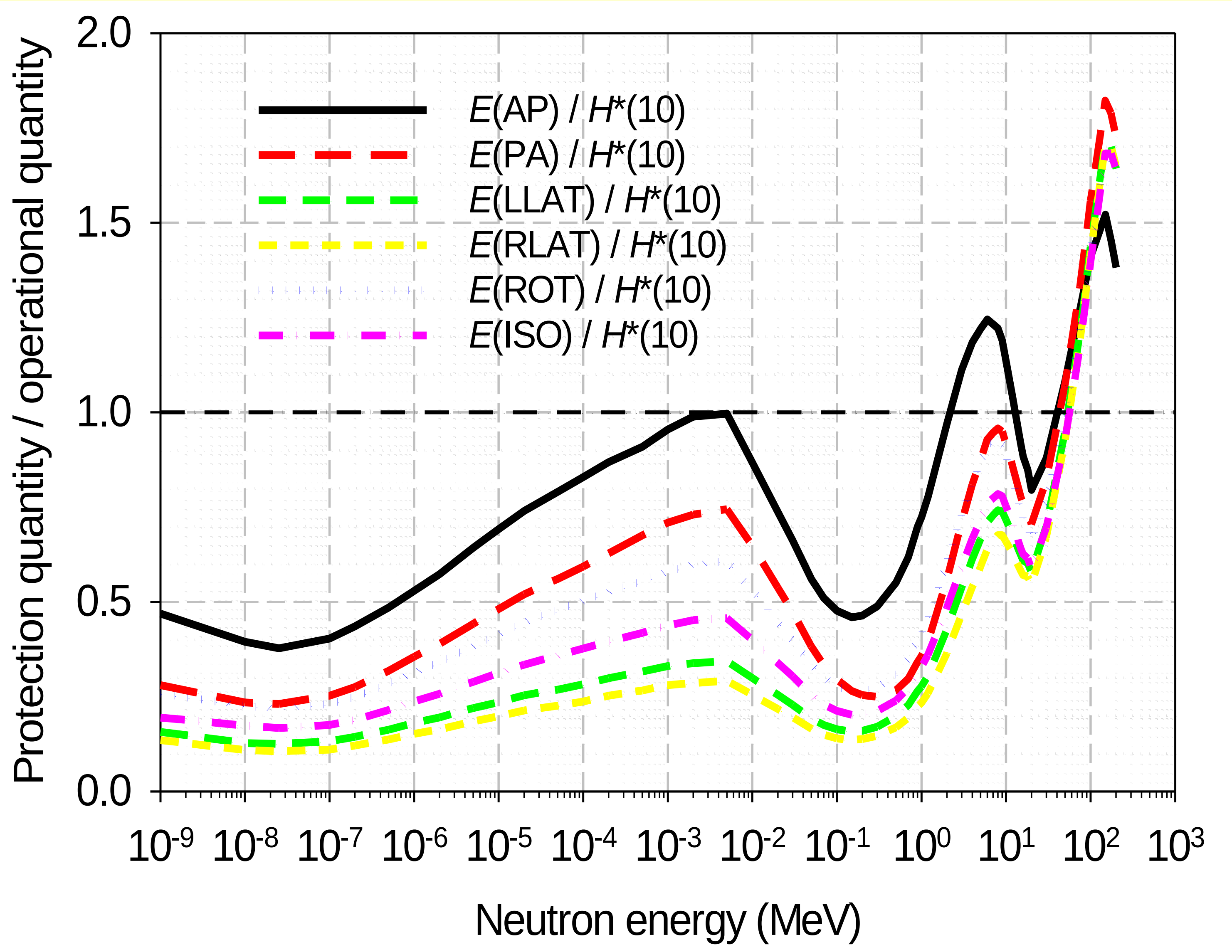


Photon exposure of the skin

ICRP 74 — kerma approximation
ICRP 116 — secondary charged particle follow-up



E(ICRP 116) / *H**(10) for neutrons



Options for future development

1. Mainly stay with the existing situation.

- The definition of the operational quantities stays as it is.
- The ICRU sphere phantom and the phantoms defined for calibration of dosimeters are not changed.
- The $Q(L)$ function remains unchanged.
- Conversion coefficients are calculated with the phantoms in vacuum and using the kerma approximation. At high energies this provides a conservative assessment of the values of protection quantities.
- Conversion coefficients need to be calculated for higher energies.

Options for future development

2. Define the operational quantities without using the ICRU sphere and the quality factor $Q(L)$.

- The definition of the operational quantities is always given by the product of

  fluence/air kerma x conversion coefficient

  $\Phi_R \, h_{quantity,R}$ **or** $K_a \, h_{quantity,R}$ (for photons)

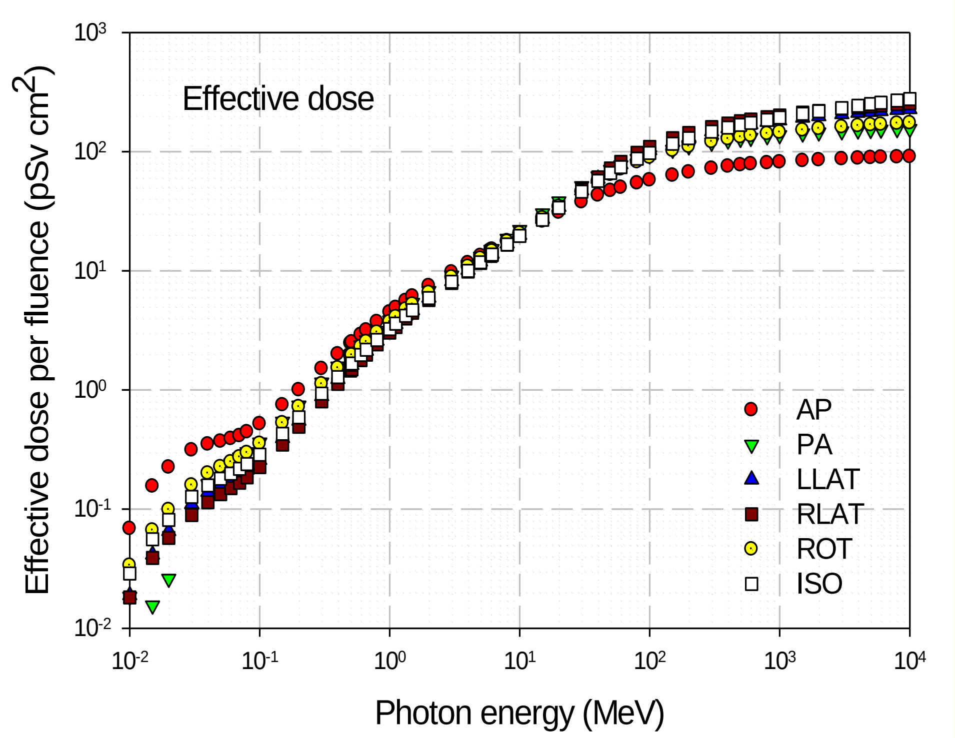
  where the value of the fluence/air kerma of radiation R is given by the value at the point of interest.

- For area monitoring the conversion coefficients are generally based on the reference voxel phantoms, hence on effective dose, local skin dose and dose to the lens of the eye.

- If more than one type of radiation is involved, the value of the operational quantity is given by the sum over R.

Options for future development

- For area monitoring and assessment of effective dose the conversion coefficient is given by E_{max}/Φ or E_{max}/K_a for photons, respectively, where E_{max} is the envelop of effective dose of the various directions of radiation incidence.



- For area monitoring and assessment of equivalent dose to the local skin or the eye lens the conversion coefficient is given by $H_{local\ skin}/\Phi$ or $E_{eye\ lens}/K_a$ for photons, respectively.

Options for future development

3. Stay with the existing situation for those particles and energy ranges where the system is well established .

- The ICRU sphere phantom and the phantoms for calibration are not changed.
- The $Q(L)$ function remains unchanged.
- For higher radiation energies define a larger depth d in the ICRU sphere phantom for the calculation of conversion coefficients for area monitoring. Similar procedure for individual monitoring.

Options for future development

4. Redefine *H**(*d*) and *H*´(*d*,Ω) to include in the definition the unaligned contributions of secondary charged particles and scattered primary particles for irradiation in an infinite air medium. Similar for $H_p(d)$.

- The ICRU sphere phantom and the phantoms for calibration are not changed.
- The *Q*(*L*) function remains unchanged
- Calculate conversion coefficients without using the kerma approximation considering all secondary particles produced in air in front of the sphere.

Conclusions

- The operational dose quantities defined for external radiation exposure are very important for radiation protection in practice. Radiation monitoring and the design of dosemeters used in practice are based in their definition.

- The actual system of operational dose quantities includes deficiencies in the definition of the sphere phantom used and the calculation of conversion coefficients.

- For high particle energies the values of the operational quantities provide not a conservative assessment of effective dose.

- There are different options for improving the system of operational dose quantities, but changes need to carefully consider the consequences for radiation protection practice, e.g. dosimeter designs and calibration procedures.

I thank you

for your attention.