ICRU 95
OPERATIONAL QUANTITIES FOR EXTERNAL RADIATION EXPOSURE
(a joint ICRU-ICRP Publication)

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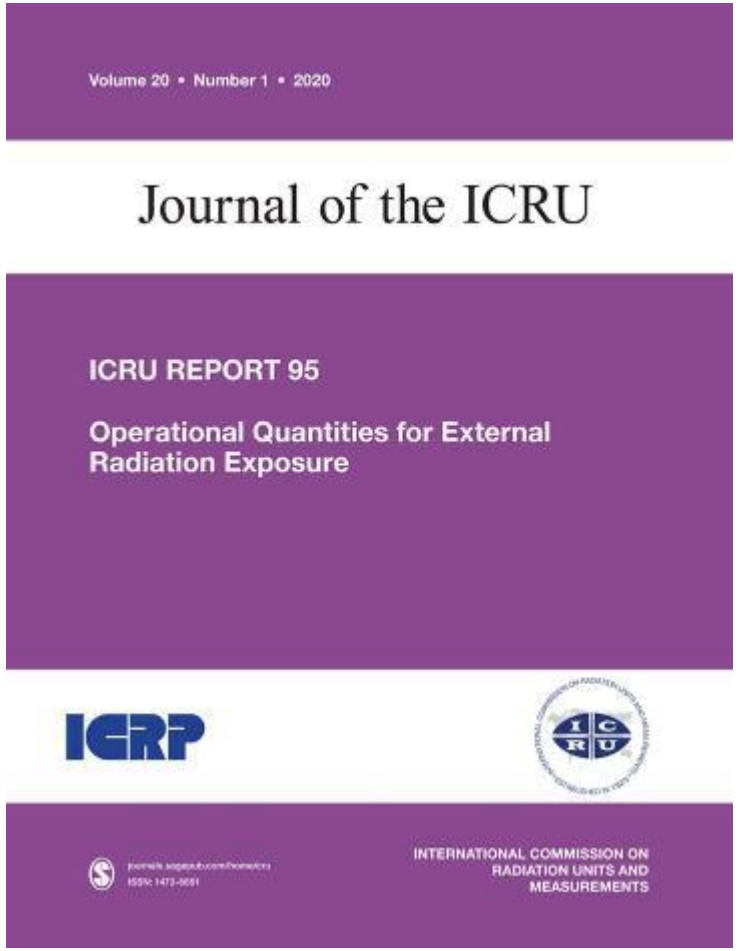
KSR Seminar, Bern, 25 March 2022

ICRU Report 95 (2020)

Operational Quantities for External Radiation Exposure



Content

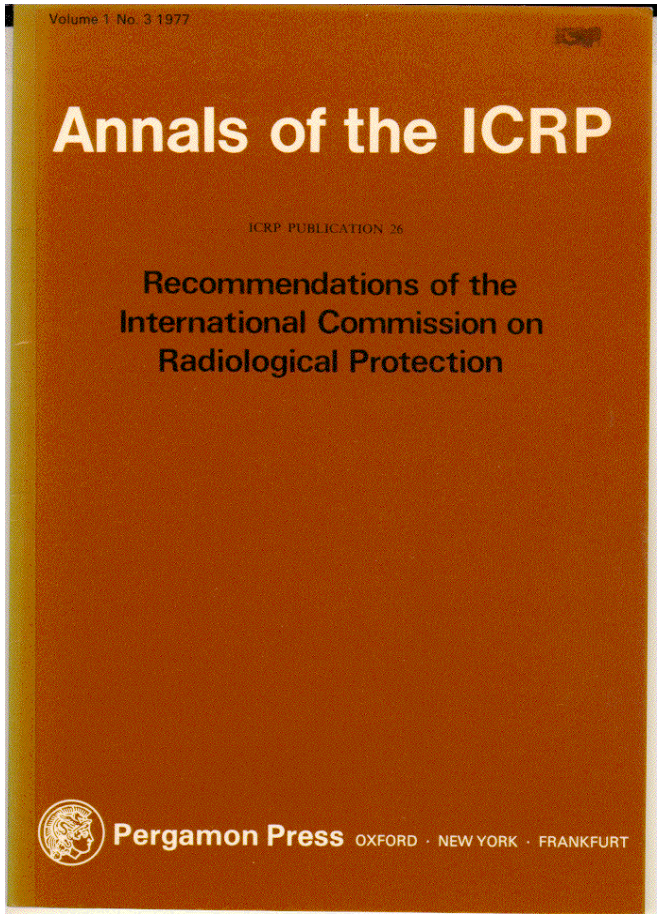
- Previous quantities (ICRU 39 and 51)
- Operational Quantities for external exposure
- Conversion Coefficients
- Practical Consequences
- Appendices
  - Values of Conversion coefficients
  - Computer Codes

A bit of History

ICRP Publication 26 (1977)

“Beginning of modern radiation protection”

- No practice shall be adopted unless it produces a net benefit (**Justification**)
- All exposures shall be As Low As Reasonably Achievable, economic and social factors taken into account (**Optimization**)
- Doses to individuals shall not exceed limits (**Limitation**)



(ICRP) Protection Quantities

The practical implementation of the

principles of limitation and optimization

requires appropriate quantification

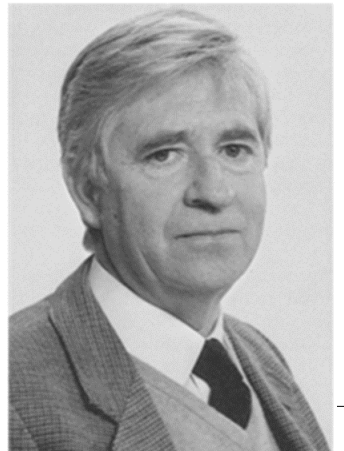
of radiation exposure.

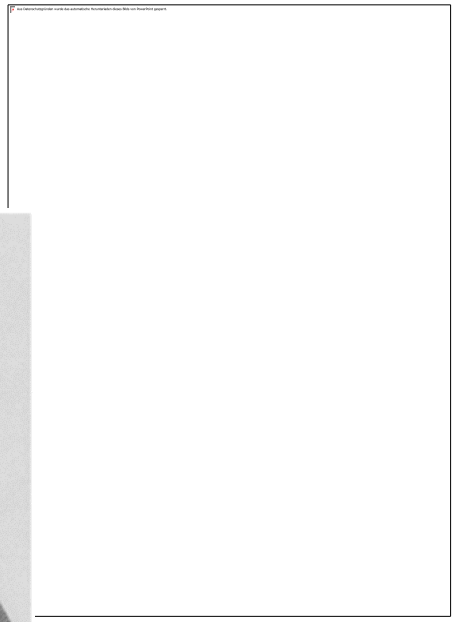
(and the availability of methods to assess these quantities in real exposure situations)

In a statement from the 1978 Stockholm Meeting the ICRP introduced the

effective dose equivalent, H_E

following a proposal by **Wolfgang Jacobi**





EffectiveDose (ICRP 60)

(averaged) organ absorbed dose

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} [Sv]$$

effective dose

Organ equivalent doses

tissue weighting

radiation (quality)weighting

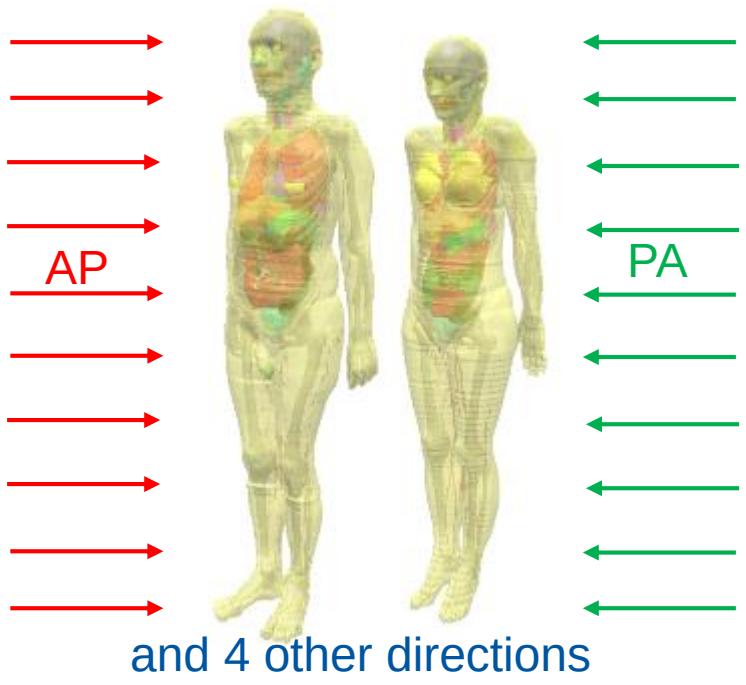
The quantity enables the summation of doses from internal emitters and from external radiation fields to provide

a single numerical value for limitation and optimization.

Calculation of Protection Quantity, E

Conversion coefficients in ICRP Report 116

Whole Body: *E*

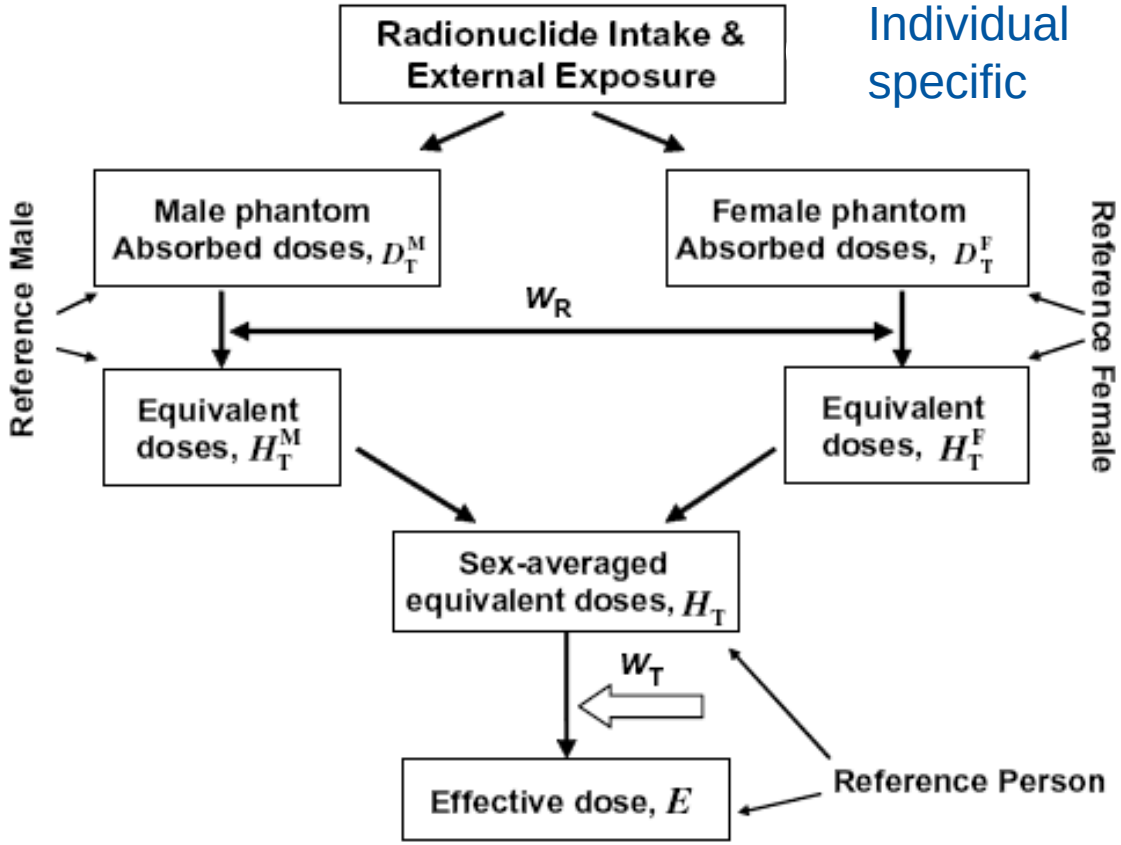


and 4 other directions

Adult ReferencePhantoms:
ICRP Report 110

Determination of Effective Dose: Reference Values

Transport Calculations or Biokinetic and Dosimetric Models



ICRU 39/51 Operational Quantities - Concept

- Effective dose, E, is defined as average over an extended volumes: organs and body and is sex-averaged, several incidence directions

→ **E cannot be measured**

- Only quantities defined in one point are measurable by an instrument
- ICRU 39: Define, in one point of a phantom, a quantity as

Dose equivalent = Absorbed dose * Quality factor

$$H(d) = D(d) * Q(L)$$

"Operational Quantity"

ICRU 39/51 Operational Quantities - Definition

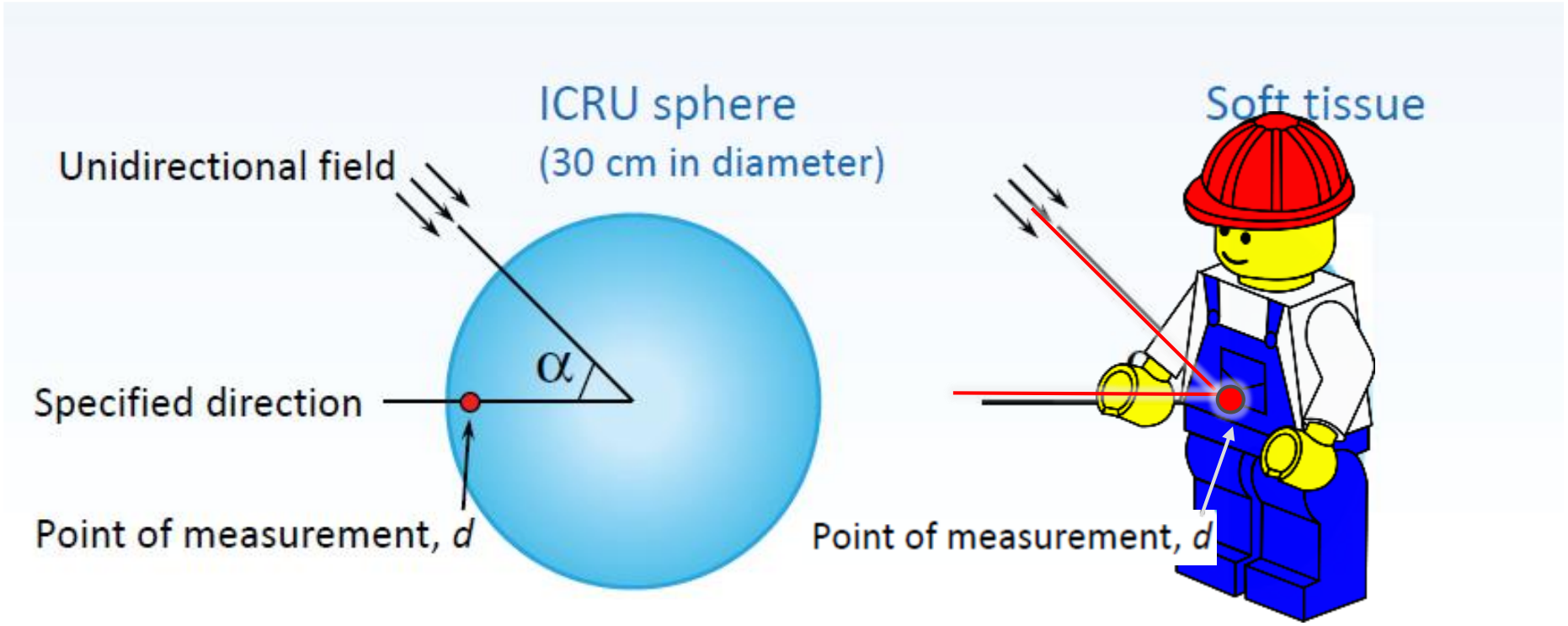
Area Monitoring

Directional dose equivalent $H'(d,\Omega)$

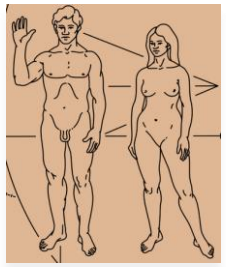
Ambient dose equivalent $H^*(d)$

Personal Monitoring

Personal dose equivalent $H_p(d,\Omega)$



Relation of quantities (whole body)

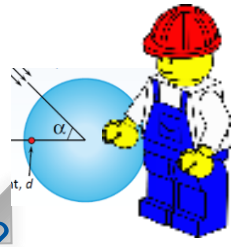


Physical Quantities

Φ, K_a, D

Definition

Definition



ICRP 103

Protection Quantities

$$E = \sum_T w_T \sum_R w_R D_T$$

ICRU 39/ 51

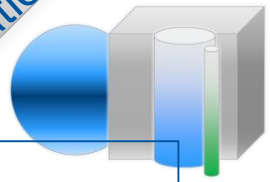
Operational Quantities

$$H(d) = D(d) * Q(L)$$

ICRP 110

Calculation

Calculation



ICRU 57/ ICRP 74
(Only Area Monitoring shown)

ICRP 116

$$E = \int dE_p \, \Phi_{E_p} h_E(E_p, \mathrm{inc}^*)$$

$\neq$

$$H'(d,\Omega) = \iint dE_p d\Omega \, \Phi_{E_p} h'_d(E_p, \Omega)$$

For photons in kerma approximation

* incident directions: AP, PA, LLAT, RLAT, ROT, ISO

Measurement

Instrument response $R(E,\Omega)$

Present Quantities - Summary

Protection quantity to account for all stochastic effects with a singlequantity.

- Defined over extended organs/body

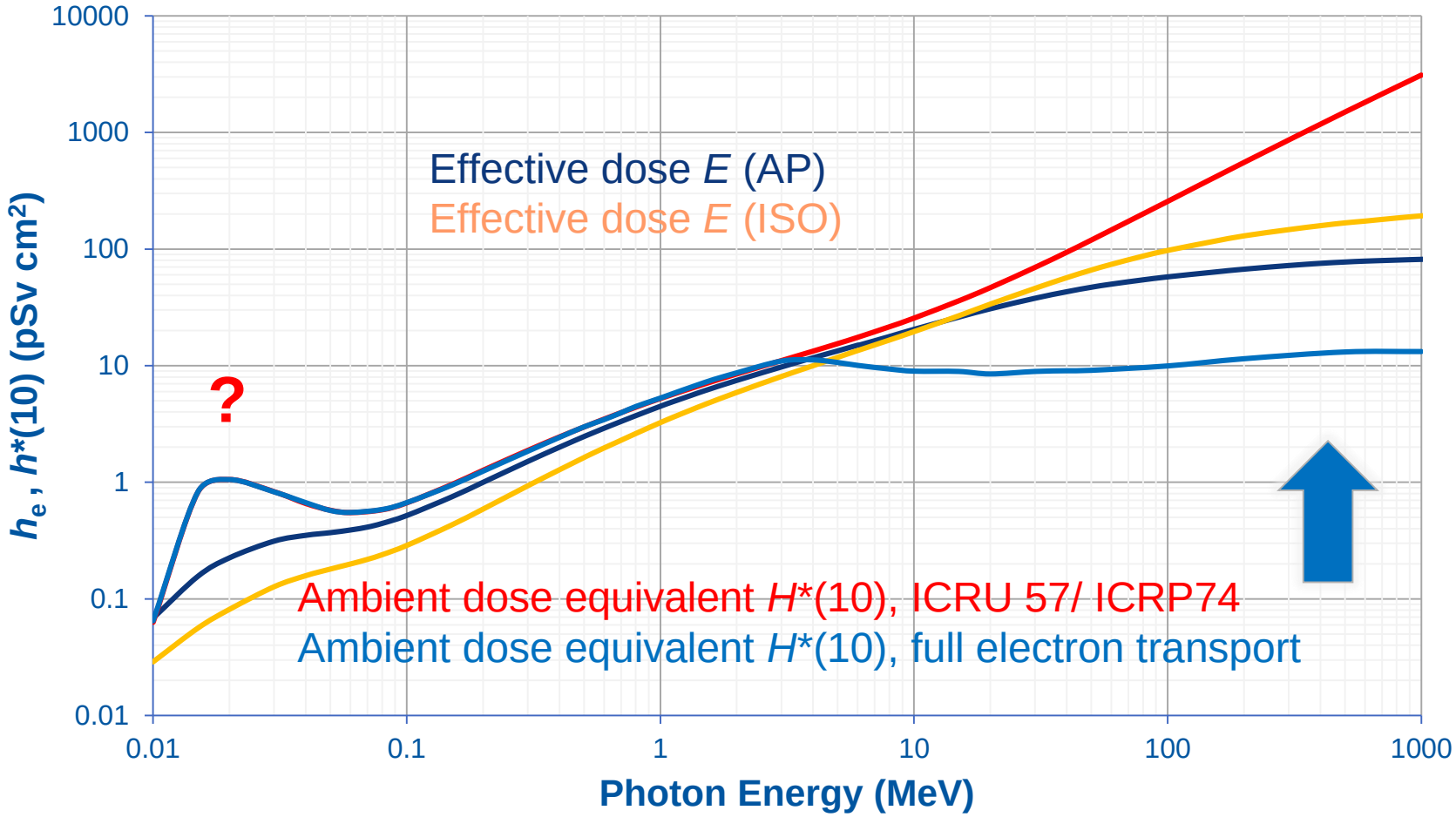
  (organs at different depths)

  - not measurable
- Calculated in anthropomorphic reference phantoms

Operational quantities (ICRU 39 / 51)

- Defined in a point – measurable
- Calculation in idealized phantoms – sphere, slab, cylinders, for a target at fixed depth.

*H**(10) vs. *E* (photons)



ICRP 116: **(248)** ***……at higher energies……. there is a need to further examine the relationship of the operational and protection quantities.***

Testes dose equivalent: D_{testes}* Q(LET)

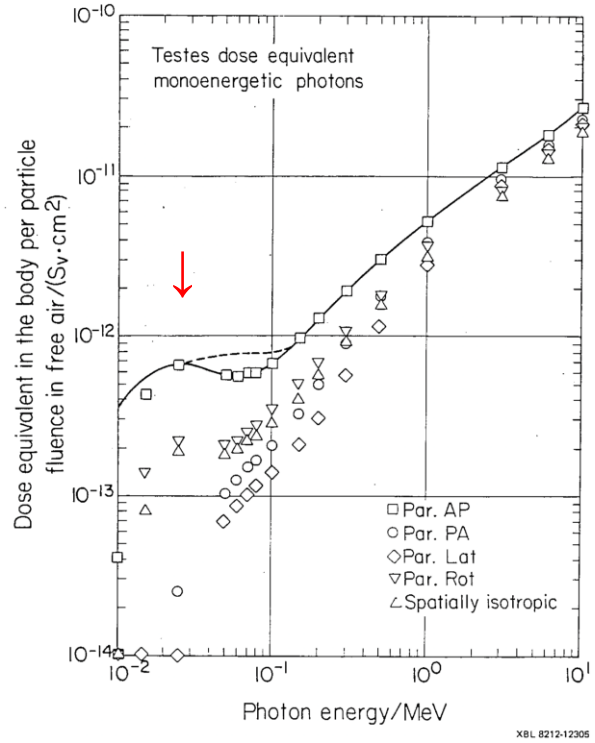


Fig. 3.8

T.E. Burlin (1985)

Shortcomings of the ICRP 74 / ICRU 57 Conversion coefficients

- No conversion coefficients for higher energies
- Only photons, neutrons, electrons published
- Overestimate of photon dose at low energies (E_p< 30 keV)
- Overestimate by legally adopted photon dose c.c.
  - for skin from E_p > 0.07 MeV
  - for eye lens from E_p > 0.2 MeV
  - for effective dose (whole body) for E_p > 3 MeV

} Calculated in kerma approximation

- Photon conversion coefficients calculated (correctly) with full electron transport lead actually to underestimates at higher photon energies

ICRU Report Committee 26

Operational Radiation Protection Quantities for External Radiation

Co- Chairs: Nolan E. Hertel, David T. Bartlett

Members: **Günther Dietze†**

Akira Endo, Thomas Otto Jean-Marc Bordy, Rolf Behrens,
Gianfranco Gualdrini,, Maurizio Pelliccioni

Consultants: P. Ambrosi, M.B. Bellamy, J.F. Bottolier-Depois, J. Daures, K. F. Eckermann, P. Ferrari, B. R. L. Siebert, K. G. Veinot

†: deceased

Change of Paradigm

- Define the operational quantities as the product of field quantity (here fluence) and a conversion coefficient

$$H = h_{\varphi} \cdot \Phi_{E_{\mathrm{p}}}$$

- $\Phi_{E_{\mathrm{p}}}$ is the unperturbed external fluence spectrum
- Derive conversion coefficient $h(E_p)$ from same phantoms as Protection quantities by:

$$h(E_p) = E / \Phi_{E_{\mathrm{p}}}$$

Kerma in air can be used as alternative to fluence

Personal monitoring: whole body

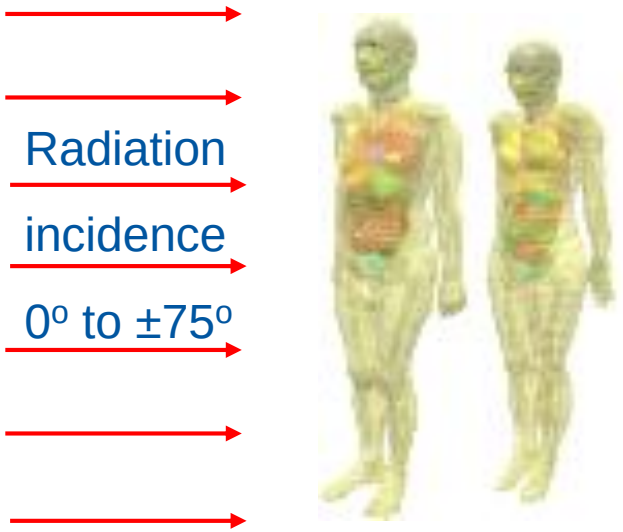
- Personal dose:

$$H_p = h_p(E_p, \Omega) \cdot \Phi(E_p)$$

- Calculation of conversion coefficients:

$$h_p(E_p, \alpha) = E(E_p, \alpha) / \Phi(E_p)$$

- Consequence
  - Numerical coherence between *E* and *H*
  - automatically good approximation



ICRP 110

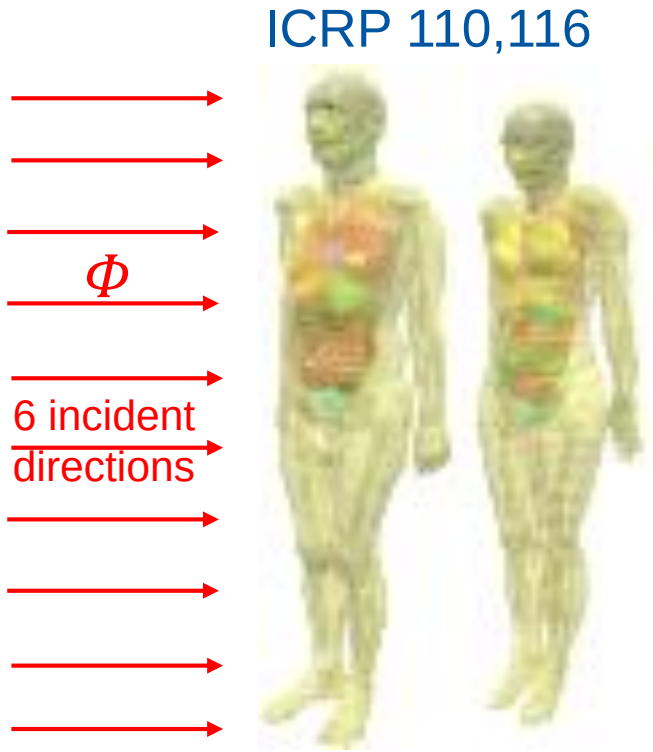
Ambient dose *H**

$$H^* = h_{E_{\max}} \cdot \Phi$$

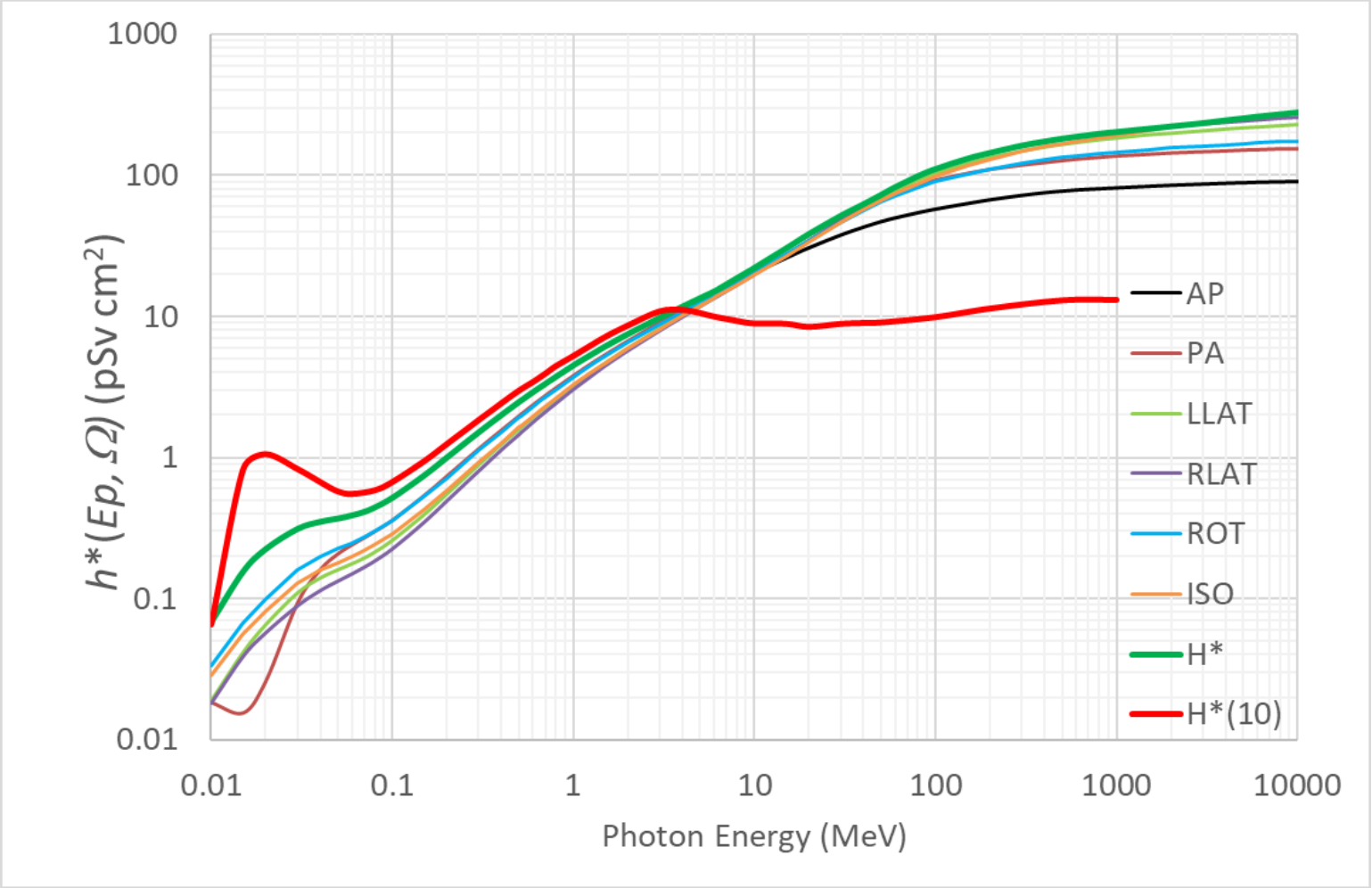
- max of *E* under the irradiation directions AP, PA, RLAT, LLAT, ROT, ISO

$$h_{E_{\max}}(E_p) = E_{\max}(E_p) / \Phi(E_p)$$

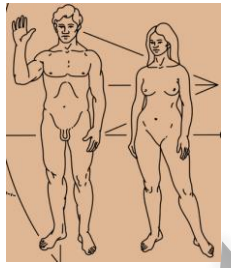
- Calculated with *the same* numerical reference phantoms as the protection quantities



*H**, *H**(10) for photons



New Relation of quantities (whole body)



Physical Quantities

Φ, K_a, D

Definition

Definition

ICRP 103

Protection Quantities

$$E = \sum_T w_T \sum_R w_R D_T$$

ICRP 110

Calculation

ICRP 116

$$E = \int dE_p \, \Phi_{E_p} h_E(E_p, \mathrm{inc}^*)$$

* incident directions: AP, PA, LLAT, RLAT, ROT, ISO

ICRP 110

ICRU Report Committee 26

Operational Quantities

$H = h * \Phi$

Calc.

ICRP 110

ICRU Report Committee 26

Operational Quantities

$$H^* = \int dE_p \, \Phi_{E_p} \cdot h_{E_{max}}(E_p)$$

$$H_p = \iint d\Omega \, dE_p \, \Phi_{E_p} \cdot h_p(E_p, \Omega)$$

Measurement

Instrument response $R(E,\Omega)$

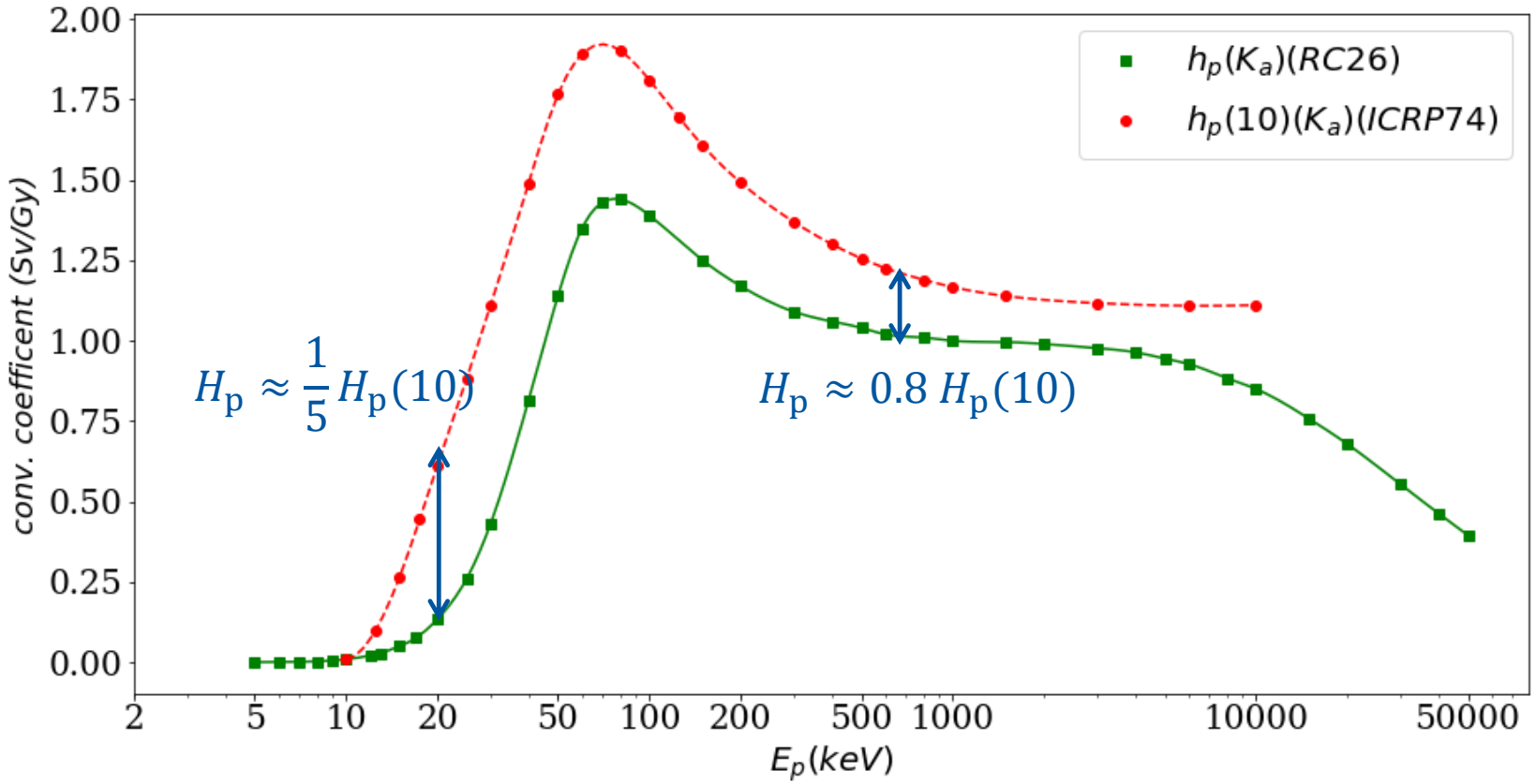
Extent of conversion coefficients

(similar to ICRP 116)

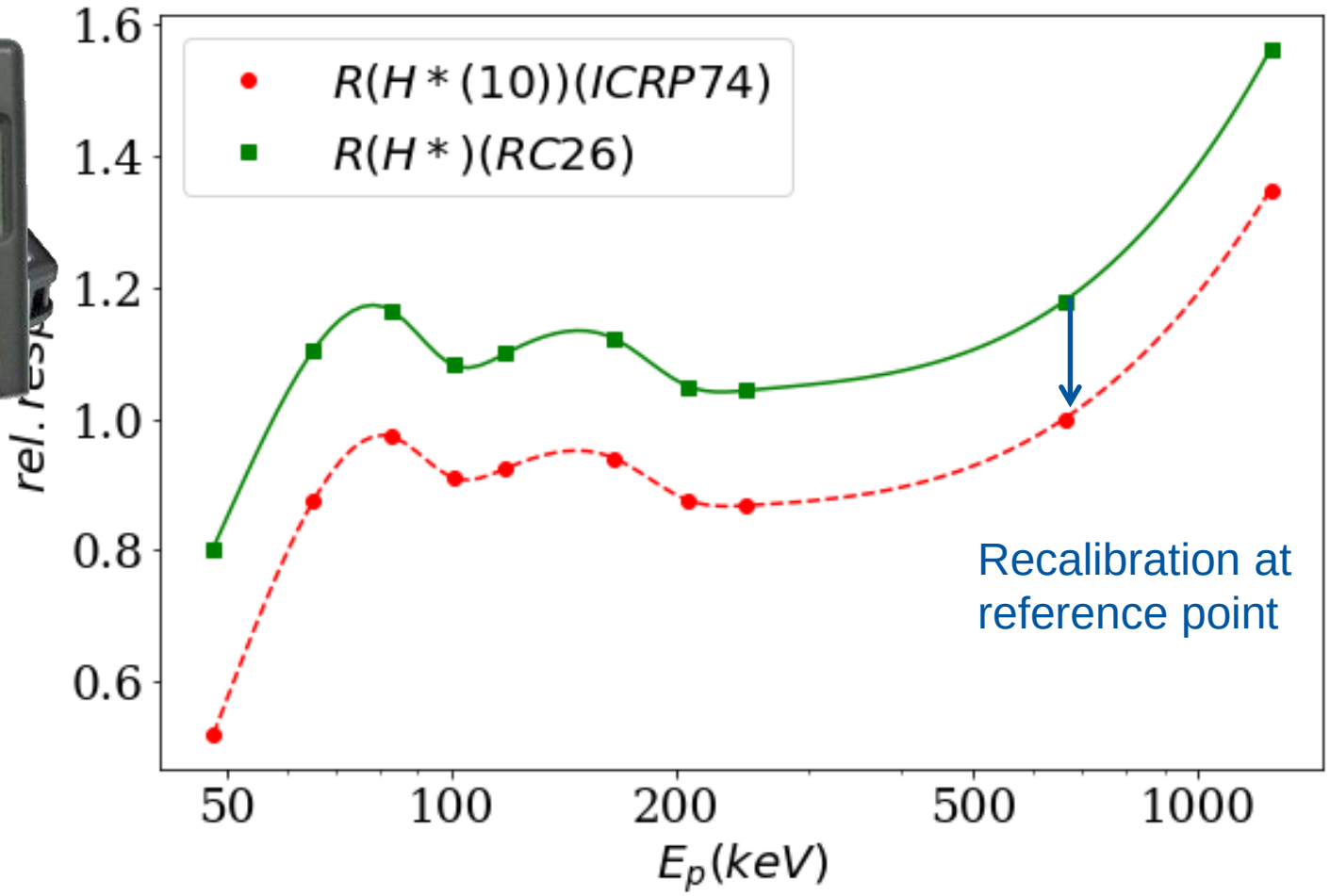
	H^*	H_p	D'_{lens} $D_{p\ lens}$	$D'_{local\ skin}$	$D_{p\ local\ skin}$		
Phantom	**Body**	**Body**	**Eye**	**Slab**	**Slab**	**Pillar**	**Rod**
Photon	x	x	x	x	x	x	x
Neutron	x	x	x	x	x	x	x
Electron	x	x	x	x	x	x	x
Positron	x	x	x	x	x	x	x
Proton	x	x					
Muon -	x	x					
Muon +	x	x					
Pion -	x	x					
Pion +	x	x					
Alpha / He	x	x		x			

Personal dose – photons

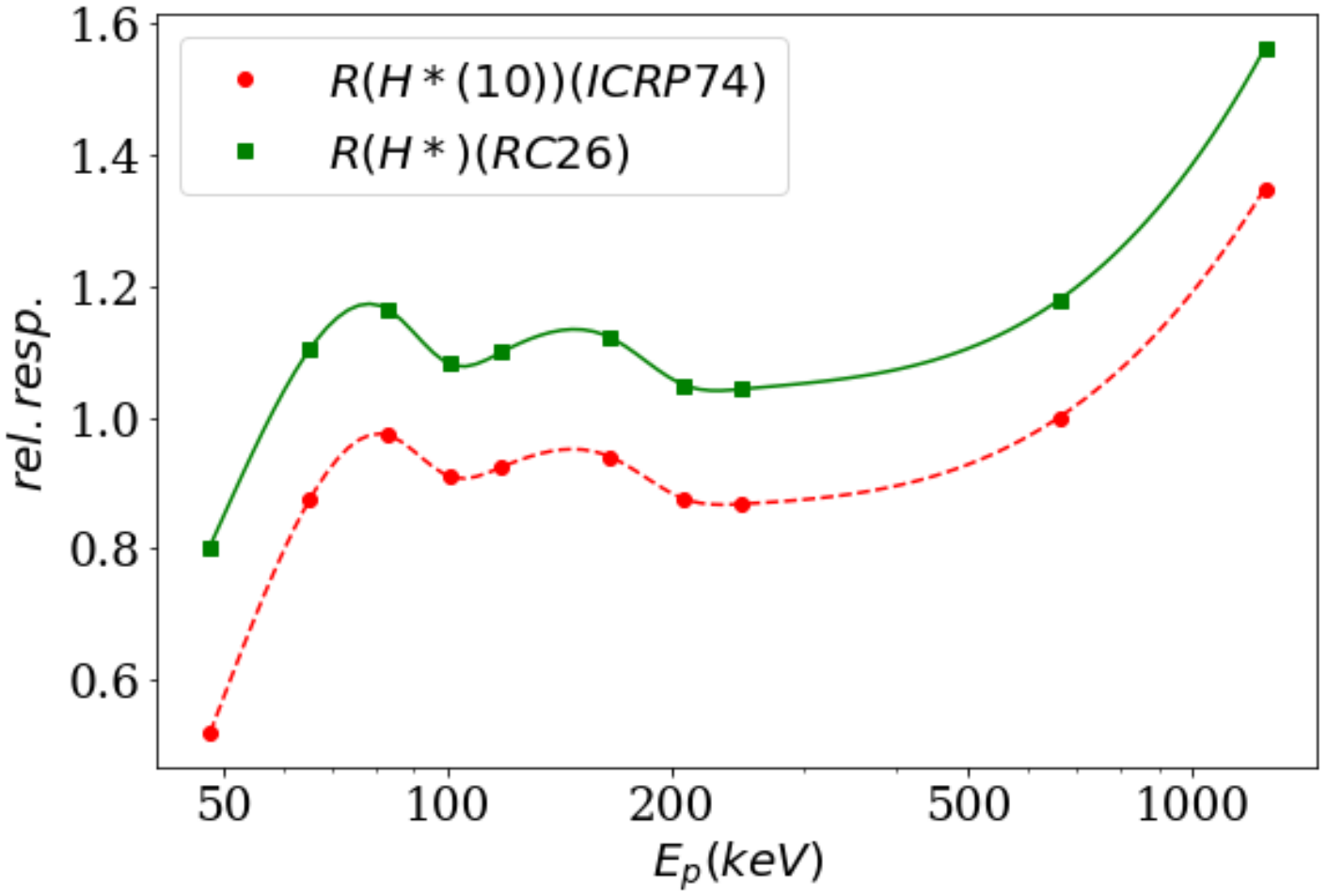
Conversion coefficients from kerma K_a to operational quantity



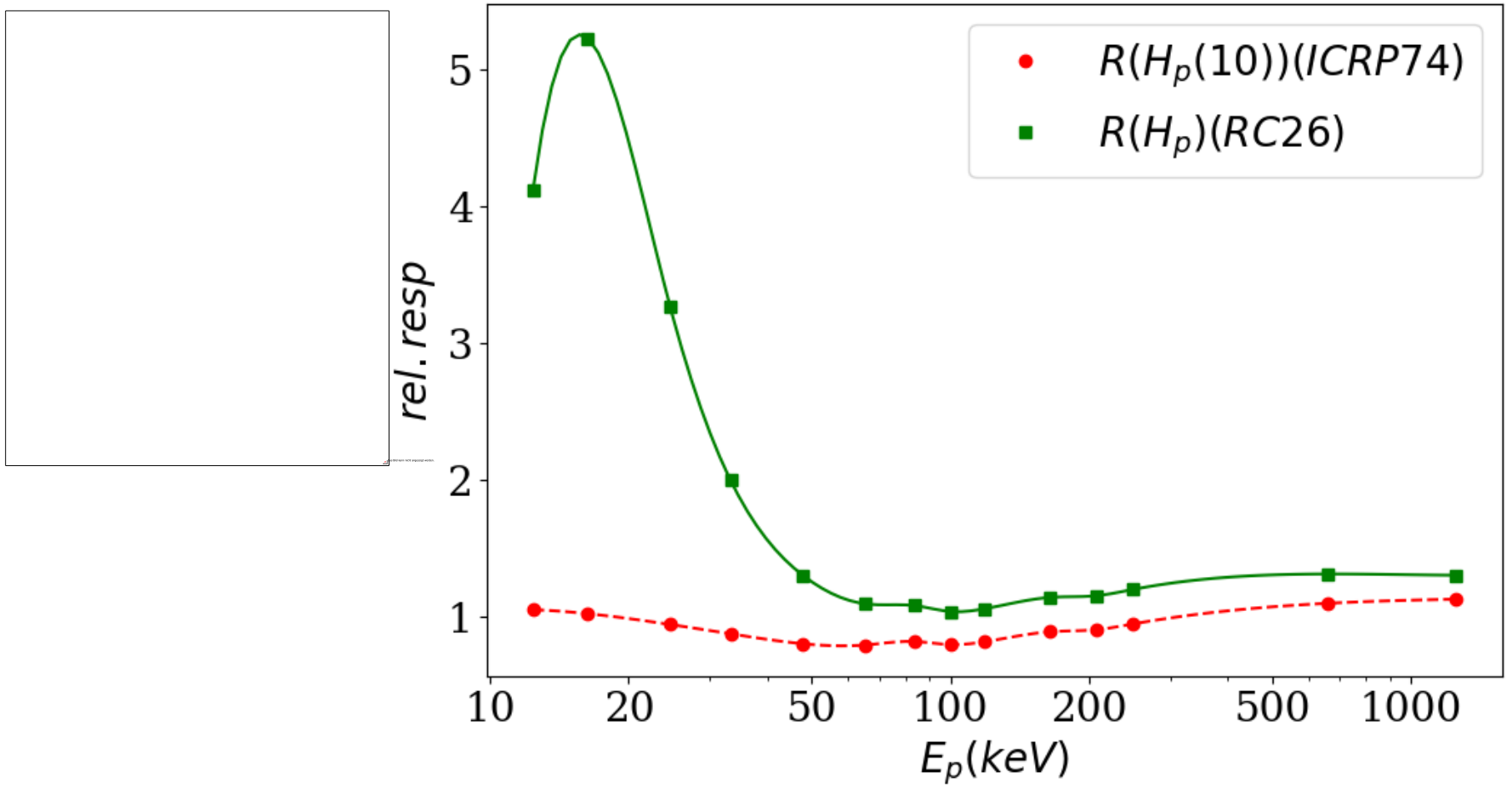
Response of Survey instrument



Response of Survey instrument



Response of personal dosimeter



Dosimeter Response - Findings

- Survey monitors can be re-calibrated in ambient dose H^* without loss of measuring capability
  - Reason: sensitivity cutoff at $E_p < 50$ keV
  - Survey meters for low energy photons must be investigated separately

- Personal dosimeters show overresponse to personal dose H_p at photon energies below 50 keV
  - Reason: $H_p(10) > E \approx H_p$
  - Possible solutions:
    - Multi-detector dosimeters: change of algorithm
    - Single detector dosimeters: reconstruct holder

Is there a need for immediate action or urgency?

Costs for implementation?

Timeline Dosim.Quantities for Radiation Protection

1977	ICRP 26 Recommendations Radiation Protection
1978	Introduction of Effective Dose Equivalent, H_E
1985	ICRU 39 Operational Quantities
I1987	ICRP 51 Conversion Coefficients (math. phantom, MIRD)
1991	ICRP 60 new Recommendations: effective dose E replaces H_E
1996	ICRP 74 (ICRU 57) Conversion Coefficients (ICRP60)(anthropomorphic phantoms)
1996	EU Council Directive (Basic Safety Standards)
2001	Implementation of EU Directive into German Law (Strahlenchutzverordnung)
2003	ICRP 103 New Recommendations
2010	New Conversion Coefficients for Protection Quantities
2013	EU Council Directive
2018	Implementation of EU Directive into German Law (Strahlenchutzverordnung),

Practical Consequences for Implementation

- **Regulatory requirement for implementation of new quantities is not likely for at least a decade**
- **New dosimeter designs will be necessary only for individual monitoring of exposure to low energy photons**
- **An increasing number of recent studies has been published confirming the appropriateness of the new approach** (see Annexe)
- **ICRU Report 95 includes a full set of conversion coefficients for operational quantities**

ICRU 95 – Conclusions

- Operational quantities and protection quantities are defined in a consistent manner, using same phantoms and radiation weighting
- System of quantities will be easier to explain, no ICRU sphere
- Change of operational quantities in real radiation fields: do not require change of RP practice and instrumentation.
- Calibration procedures will not have to change, just new conversion coefficients to be used.
- Revision of certain dosimeter types will be required:
  - Whole-body personal dosimeters for γ and β radiation <u>at low energy</u>

Thank you for your Attention

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Annexe: Additional slides

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