Revisions to ICRU Operational Quantities

Proposed Quantities of ICRU Report Committee 26

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Caveat lector: **Operational Quantity Definitions Should Be Considered "Proposed" Quantities Until the ICRU issues the Final Report with Dose Coefficients**

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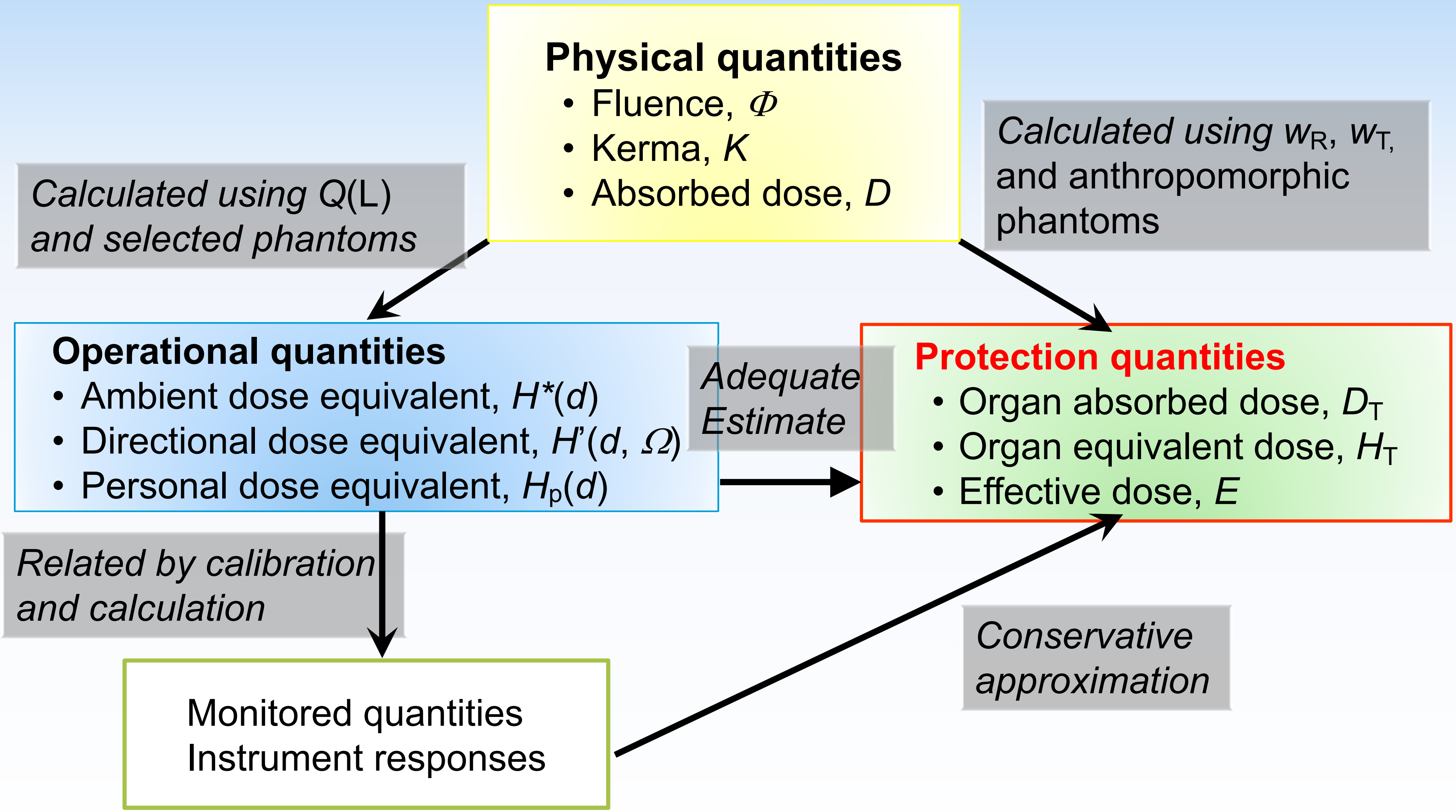
Protection and Operational Quantities

- **Protection Quantities (ICRP Publication 103)**
  - Define dose limits
  - Optimization of radiation protection
  - Not point quantities
  - Not appropriate for instrument calibration
  - Not appropriate for area and individual dose measurements
- **Operational Dose Quantities (ICRU Reports 39 and 51)**
  - Measurements of them used as reasonable estimate of protection quantities
  - Allows calibration of area and individual monitoring instruments

Dose Quantities For Radiological Protection



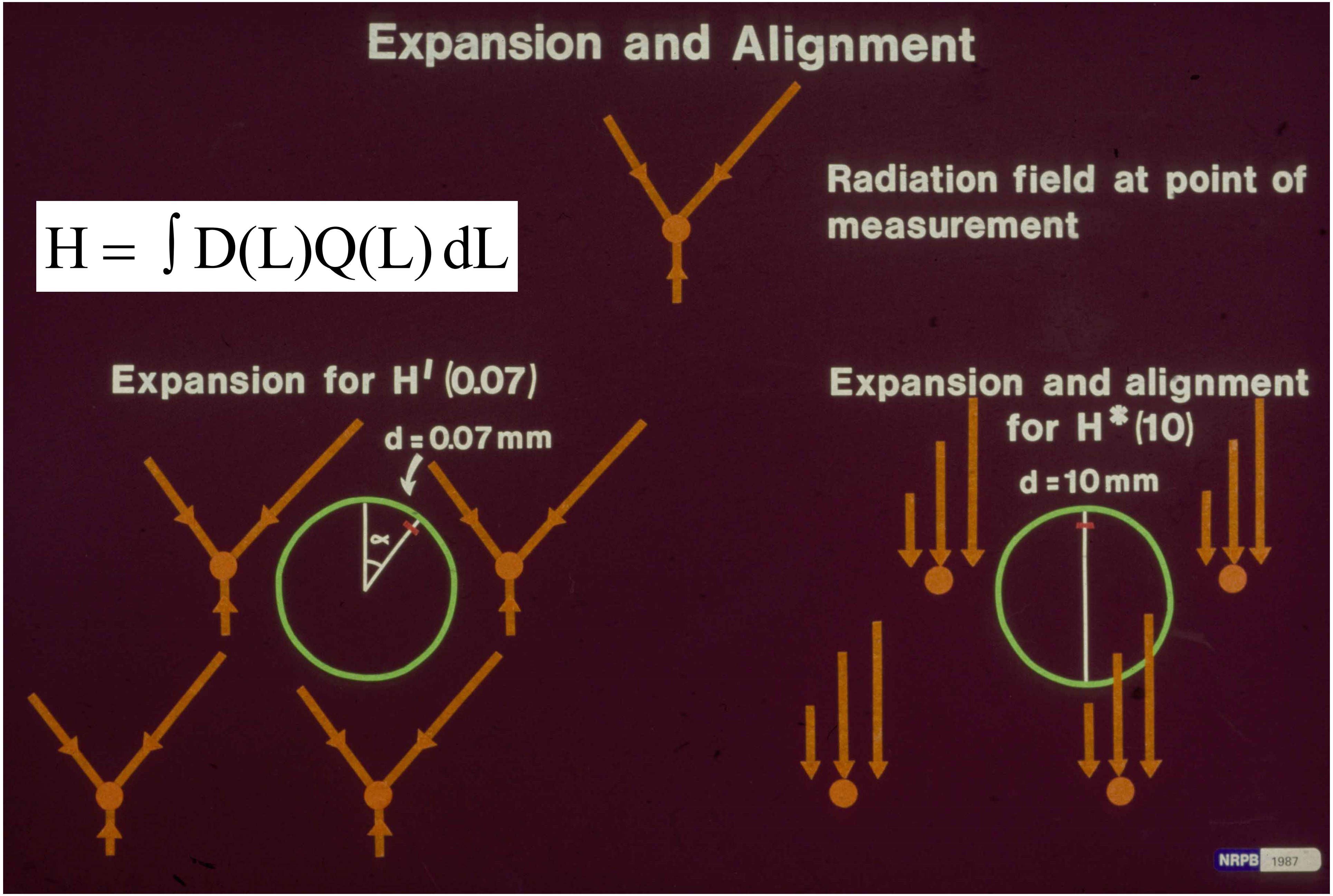
ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Operational Quantities

- **Area monitoring** generally characterizes radiation fields with respect to their relevance for radiation protection measures
- **Individual monitoring** is used for determining the individual exposure of persons
  - Particularly occupationally exposed
  - Normally monitored by a wearing a personal dosimeter

Operational Dose Quantities for External Radiation Exposure - Current

Task	Area Monitoring	Individual Monitoring
Monitoring Of Effective Dose, E	Ambient Dose Equivalent, $H^*(10)$	Personal Dose Equivalent, H_p (10)
Monitoring Of Equivalent Dose To Local Skin, H_{skin}	Directional Dose Equivalent, $H'(0.07,\Omega)$	Personal Dose Equivalent, $H_p(0.07)$
Monitoring Of Equivalent Dose To The Lens Of The Eye, H_{lens}	Directional Dose Equivalent, $H'(3,\Omega)$	Personal Dose Equivalent, $H_p(3)$

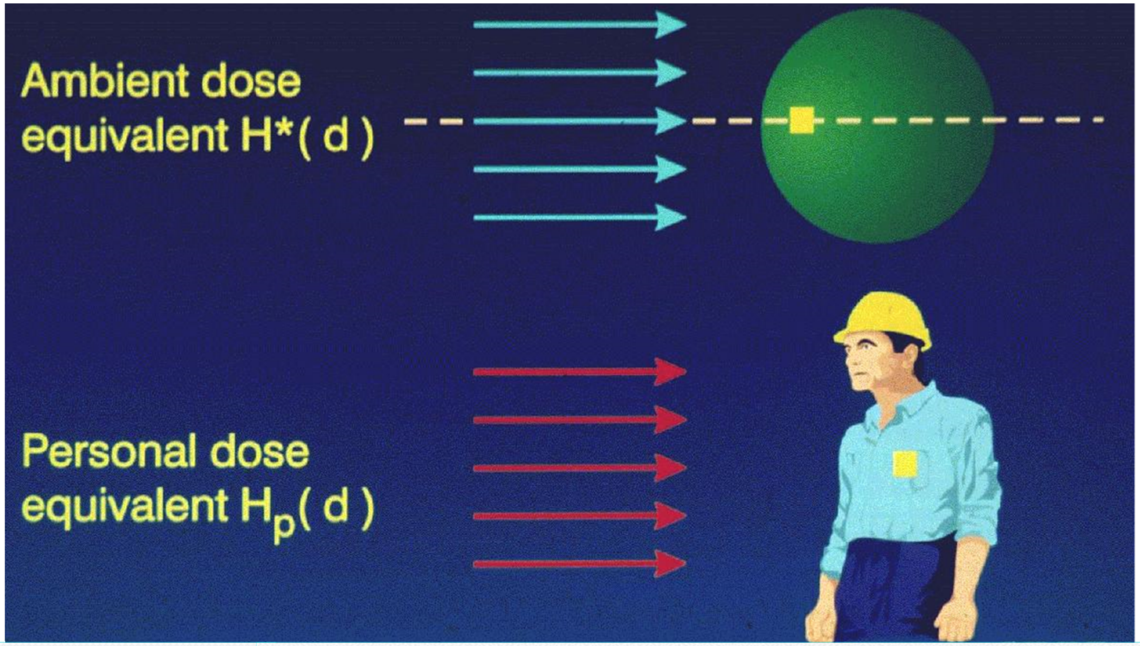

Expansion and Alignment
Radiation field at point of measurement
Expansion for H' (0.07)
d = 0.07 mm
∝
Expansion and alignment for H* (10)
d = 10 mm
NRPB 1987

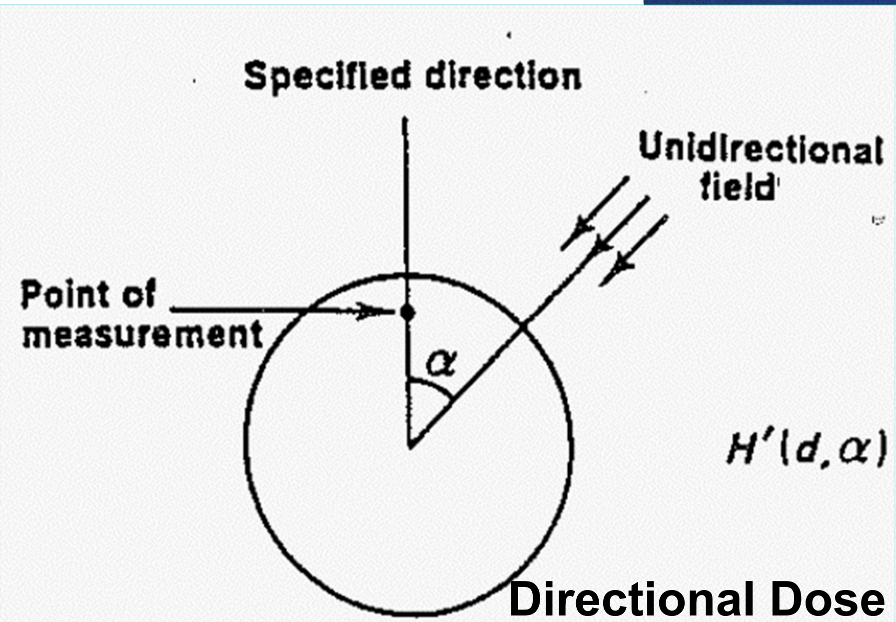
$$H = \int D(L)Q(L)\,dL$$

Expanded and Aligned Field

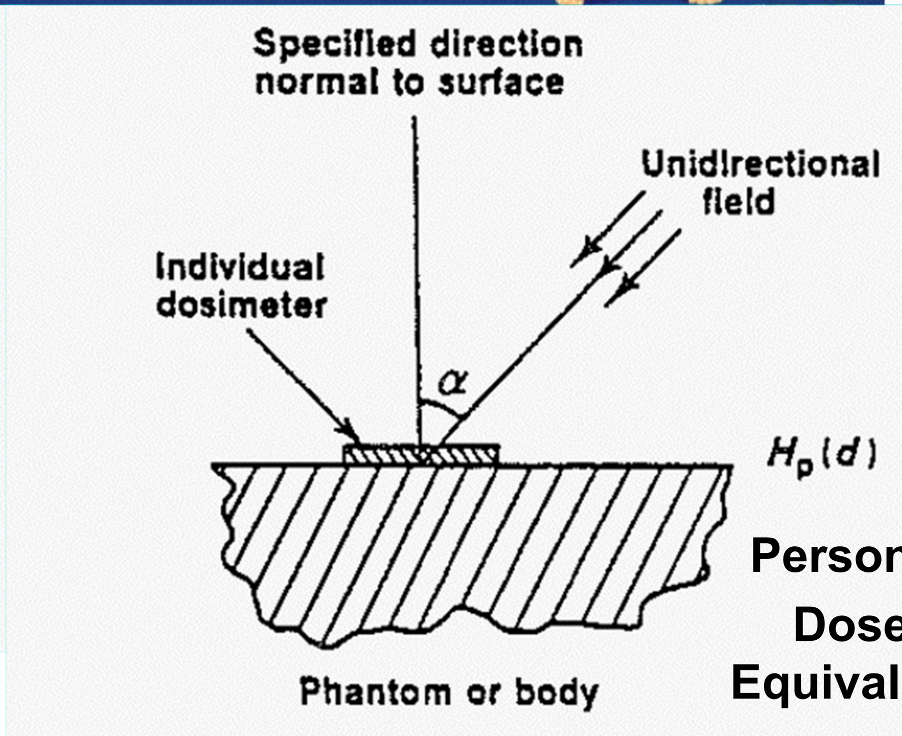
- **Expanded radiation** field is a hypothetical field
  - Fluence, and angular and energy distributions have same value in the volume of interest as in actual field at the **point** of reference
- **Expanded and aligned field** is a hypothetical field as well
  - Fluence and its energy distribution are same as in the expanded field
  - The fluence is unidirectional

Operational Quantities (ICRU 39 and 51)





Directional Dose Equivalent



Personal Dose Equivalent

Rationale for Examination of the Operational Quantities

- Changes in protection quantities
- Eye lens dose added
- Changes in the applications of dose quantities
  - Operational quantities should be defined for all particles and energies for which protection quantities exist
  - ICRP 116: γ, n, e^-, e^+, p, μ^-, μ^+ up to 10 GeV; π^- and π^+ up to 200 GeV; $^3He^+$ up to 100 GeV/nucleon
  - Recommended set (ICRP74/ICRU57) only available for n, γ and e^- in a restricted energy range

Rationale for Examination of the Operational Quantities (cont.)

- Consistency with new protection quantity dose coefficients (ICRP Publication 116)
  - Full transport of secondary charged particles in reference voxel phantoms
  - Existing operational quantities computed for photons computed using the kerma approximation (ICRU57/ICRP74)
- ICRU tissue cannot be manufactured
- $H = \int D(L)Q(L)dL$ not experimentally realized

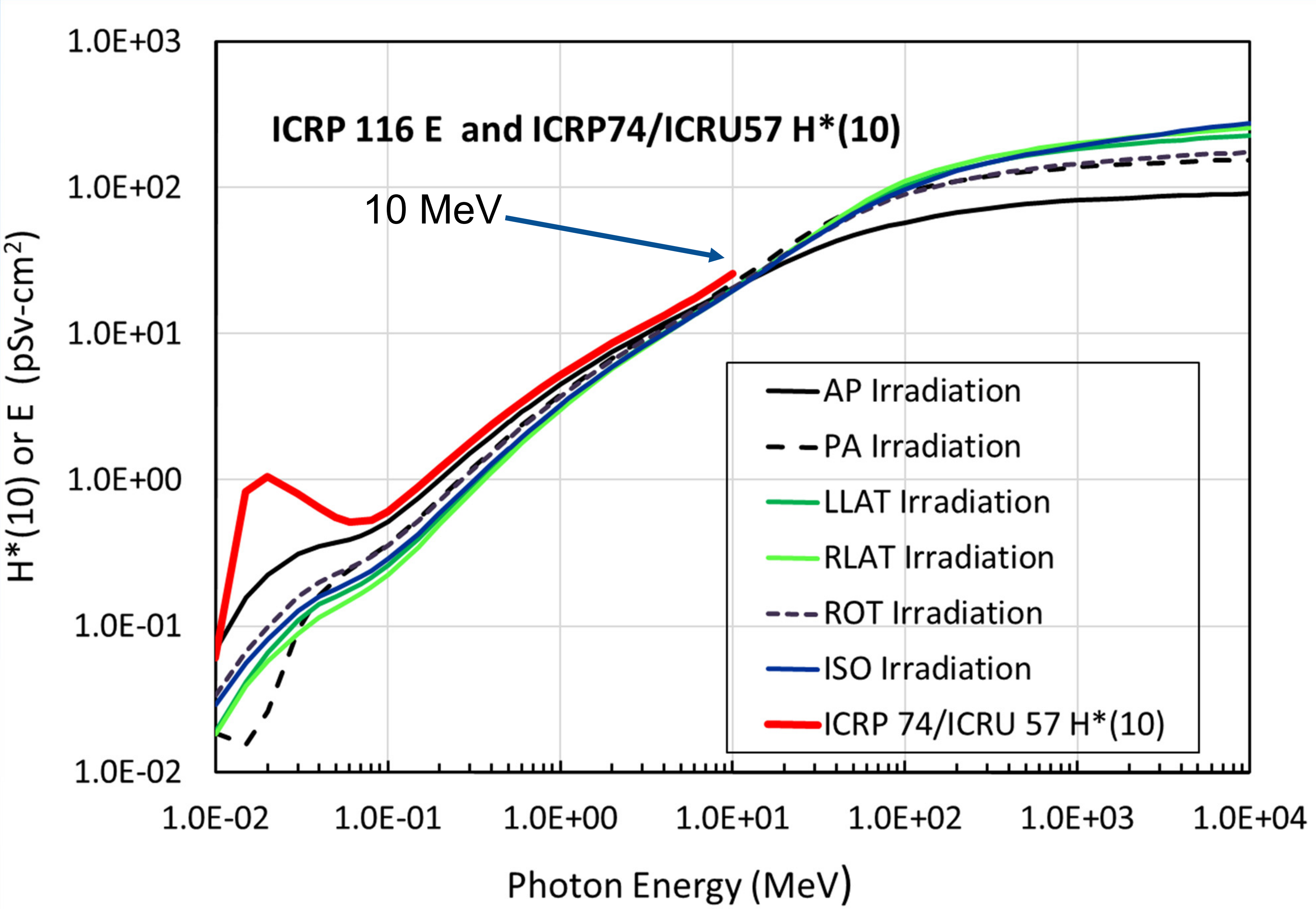
Use Ambient Dose Equivalent H*(10) as an Example

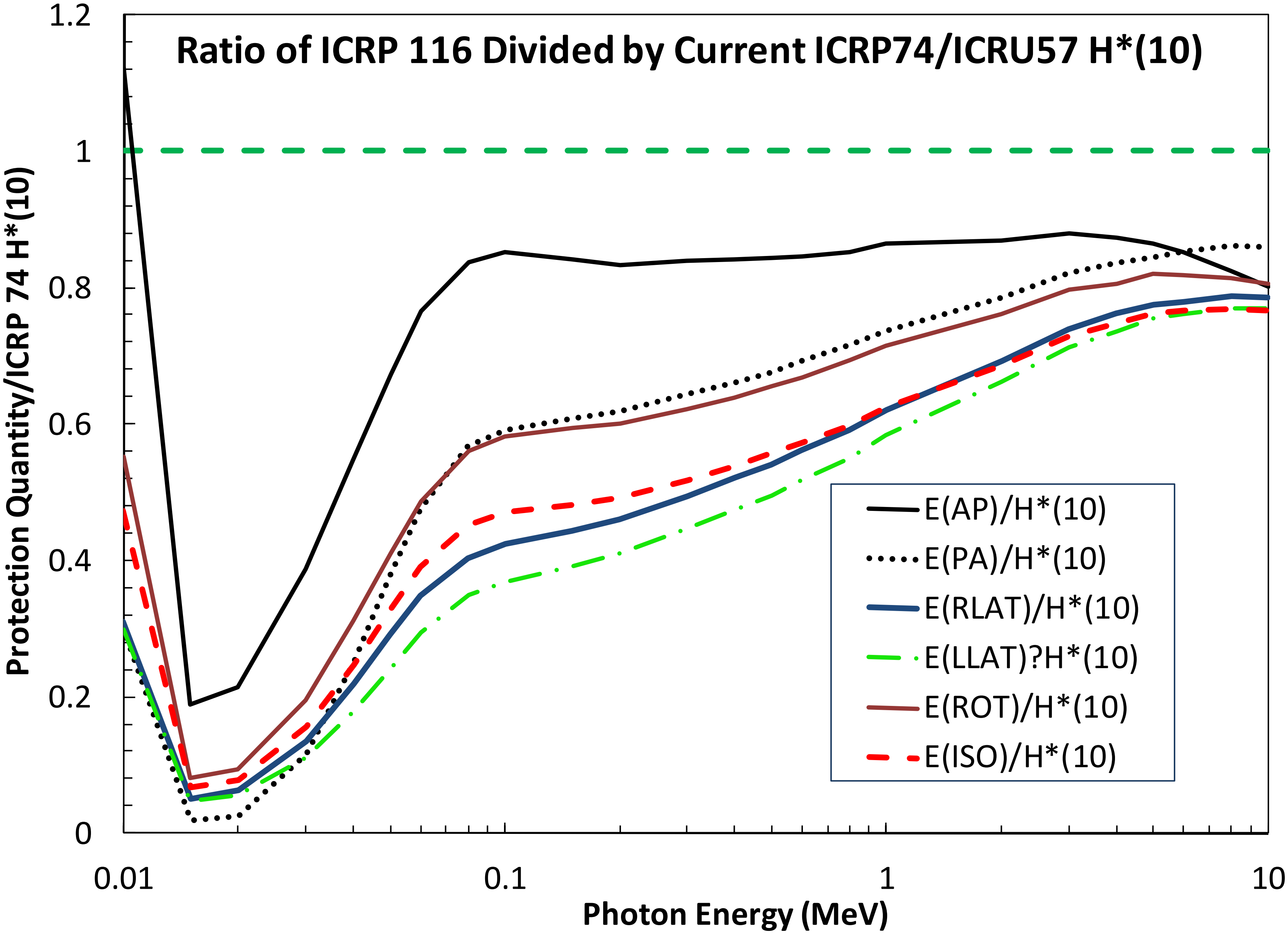
Current Definition:

Ambient dose equivalent *at a point* in a radiation field is the dose equivalent that would be produced by the corresponding ***expanded and aligned field*** in the ***ICRU sphere at a depth, d,*** on the radius opposing the direction of the aligned field.

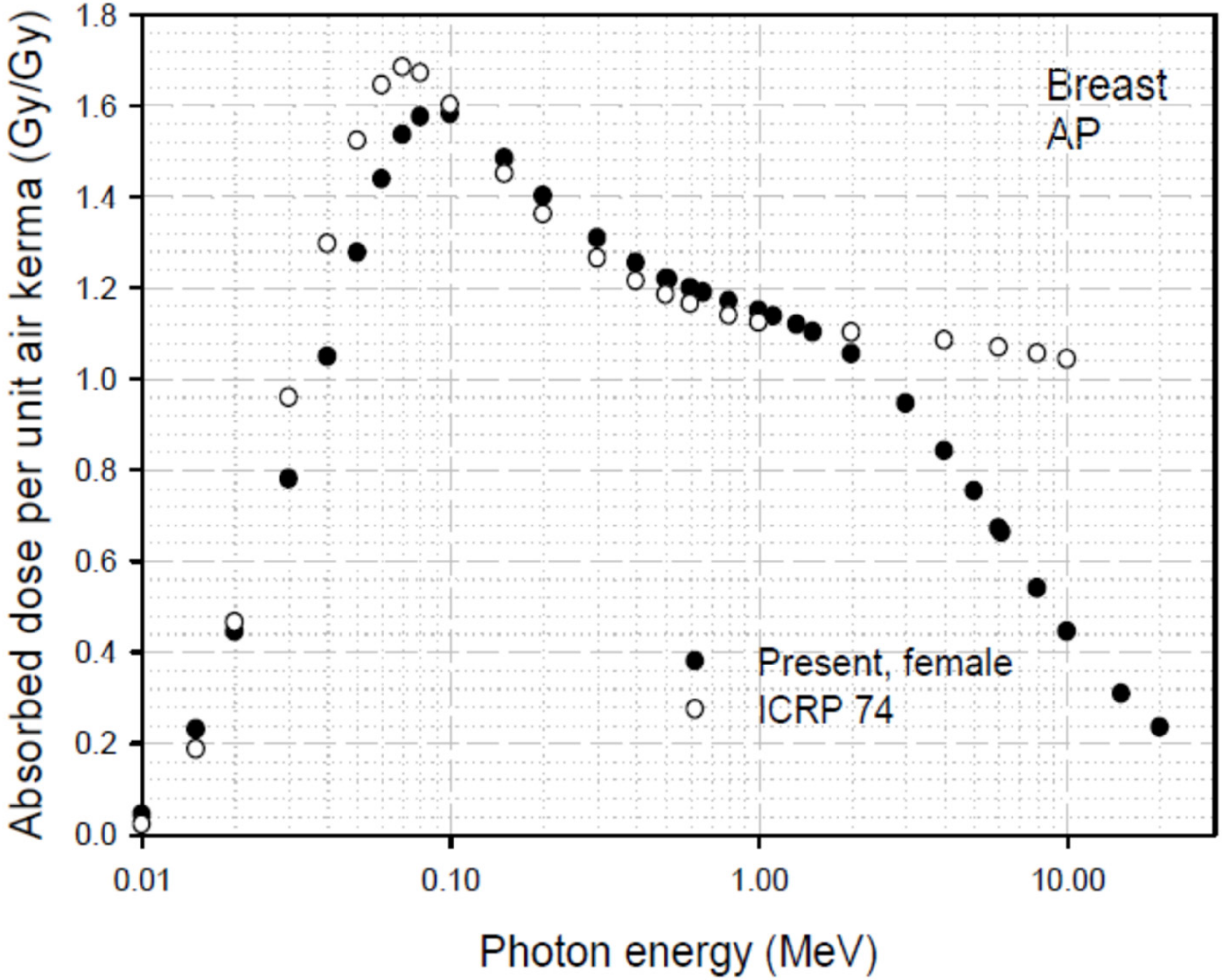
Originally computed with the Q-L relationship of ICRP 26; now with **ICRP Publication 60 revised Q-L** (ICRU Report 57/ICRP Publication 74)

- Should estimate Effective Dose regardless of irradiation geometry (E_{max})


ICRP 116 E and ICRP74/ICRU57 H*(10)
10 MeV
AP Irradiation
PA Irradiation
LLAT Irradiation
RLAT Irradiation
ROT Irradiation
ISO Irradiation
ICRP 74/ICRU 57 H*(10)
H*(10) or E (pSv-cm²)
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
Photon Energy (MeV)


Ratio of ICRP 116 Divided by Current ICRP74/ICRU57 H*(10)
1.2
1
0.8
0.6
0.4
0.2
0
0.01
0.1
1
10
Photon Energy (MeV)
Protection Quantity/ICRP 74 H*(10)
E(AP)/H*(10)
E(PA)/H*(10)
E(RLAT)/H*(10)
E(LLAT)?H*(10)
E(ROT)/H*(10)
E(ISO)/H*(10)

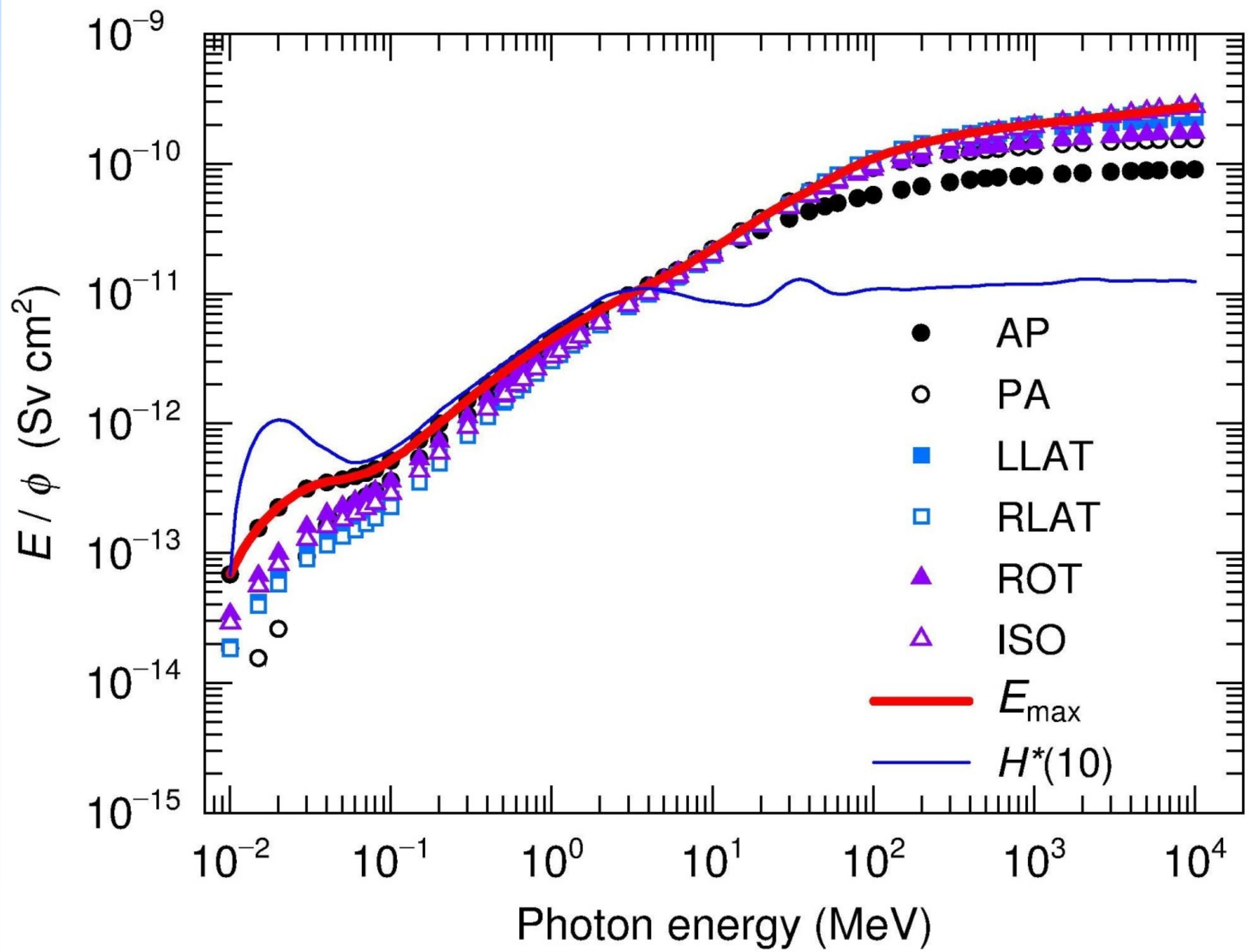
Impacts of Full Transport (ICRP 116) Compared to Kerma Approximation– Female Breast Equivalent Dose



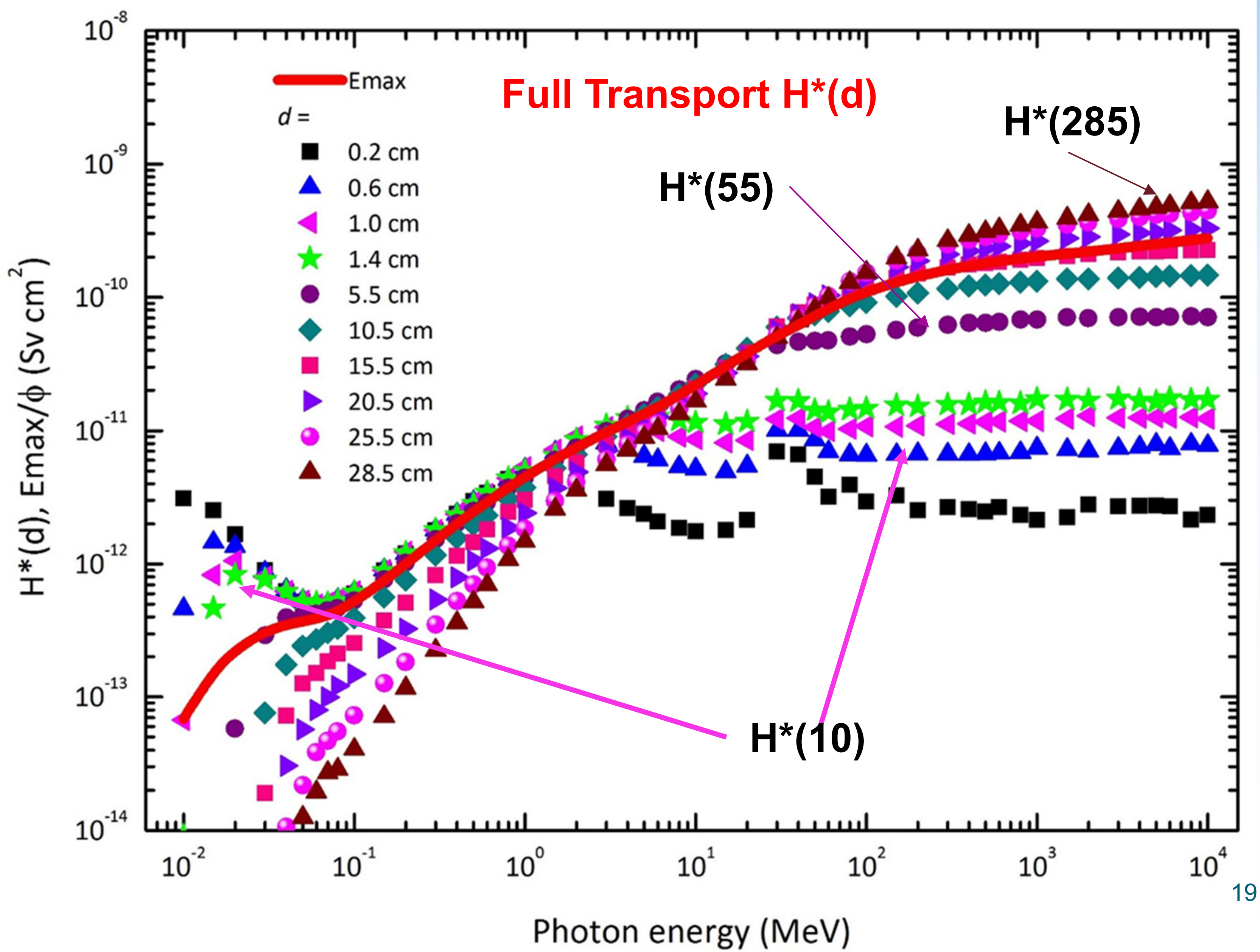
Photon Absorbed Dose Represented Acceptably By Kerma Approximation

Current Operational Quantity	Energy
$H^*(10)$ and $H_p(10)$	≤ 3 MeV
$H'(3,\Omega)$ and $H_p(3)$	≤ 700 keV
$H'(0.07,\Omega)$ and $H_p(0.07)$	≤ 70 keV

Shortcoming Of H*(10) Using Current Definition and Computed With Full Secondary Charged Particle Transport

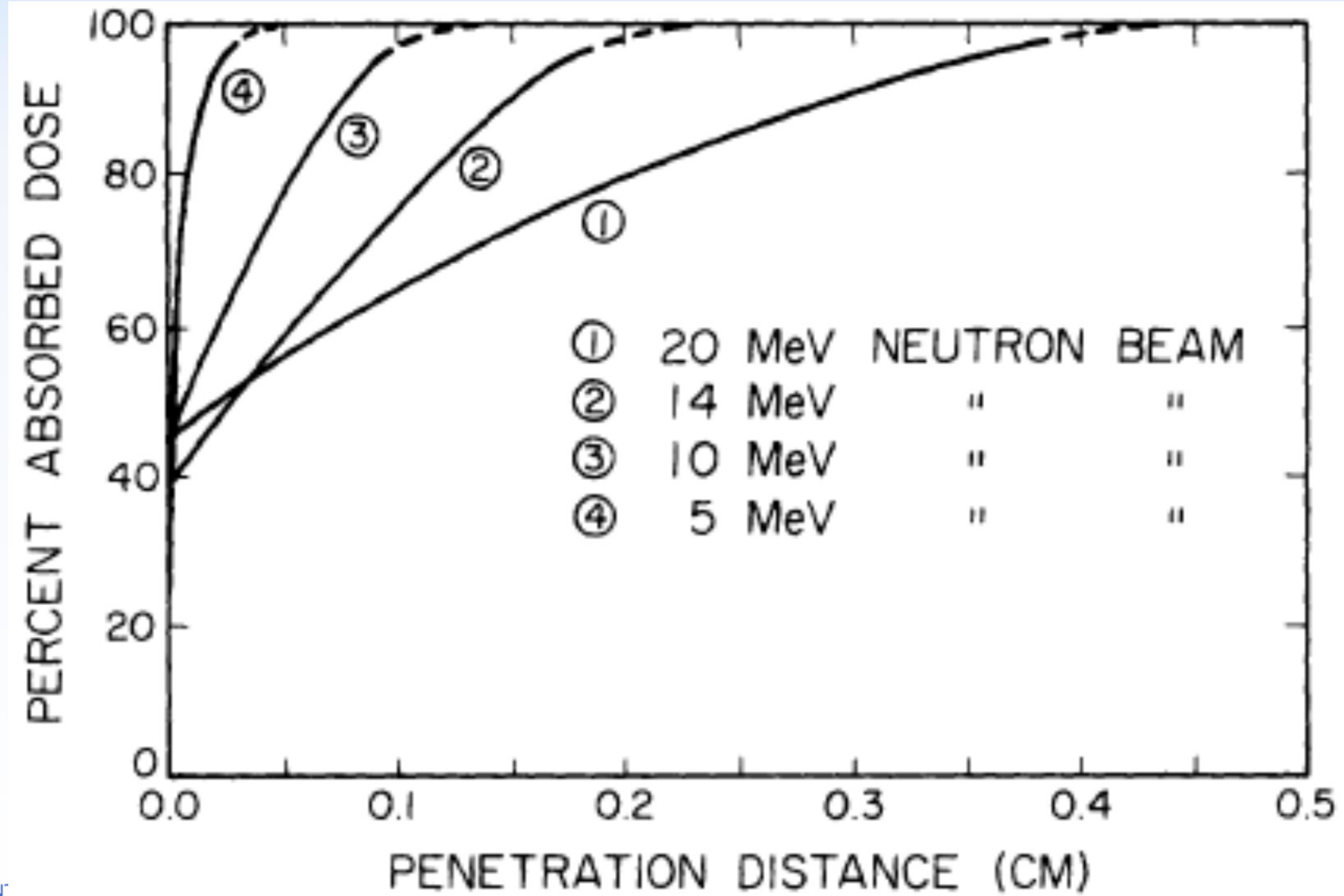


Try Different Depths in ICRU Sphere-Photons

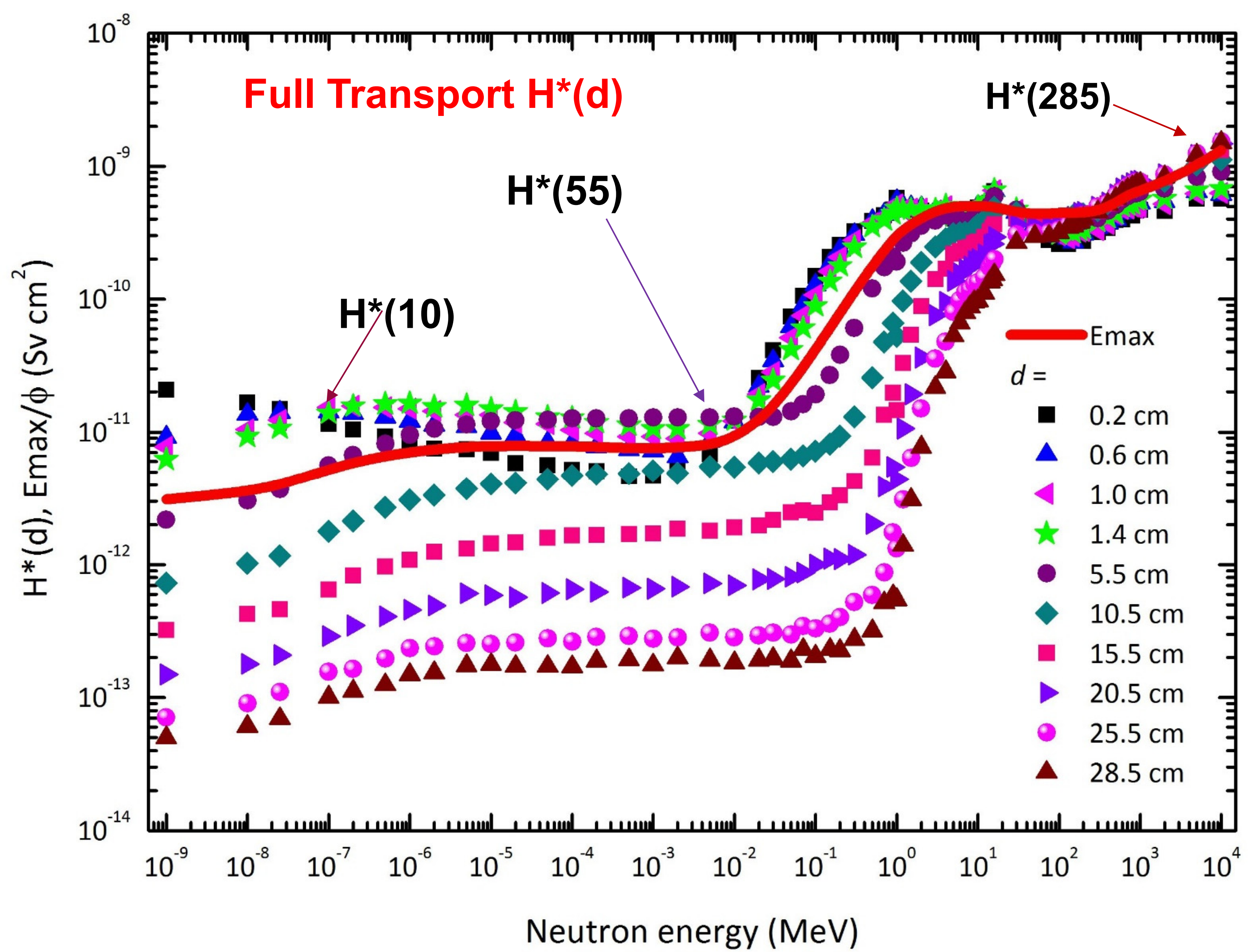


Neutron Kerma versus Full Transport

- Chen and Chilton, Rad. Res. 77, 21-33 (1979) – Tissue Slab



Try Different Depths in ICRU Sphere - Neutrons



H*(d) Current Definition Using Full Secondary Transport

- Requires different depths were used over different energy ranges for a given radiation
- The same set of depths cannot be used for each particle type
- For example to represent photon E_{max} over the needed energy range, the following would be reasonable but not very straightforward:
  - H*(55): 0.3 – 20 MeV
  - H*(155): 20 MeV – 1 GeV
  - H*(205): > 1 GeV

Operational Dose Quantities

- Requirements
  - Self evident
  - Comprehensible to the users
  - Determined by instruments
    - Without ambiguity for defining all the components of the radiation field
    - Be additive with respect to values from different radiation field components
- A single quantity cannot adequately fulfill these requirements; hence a set

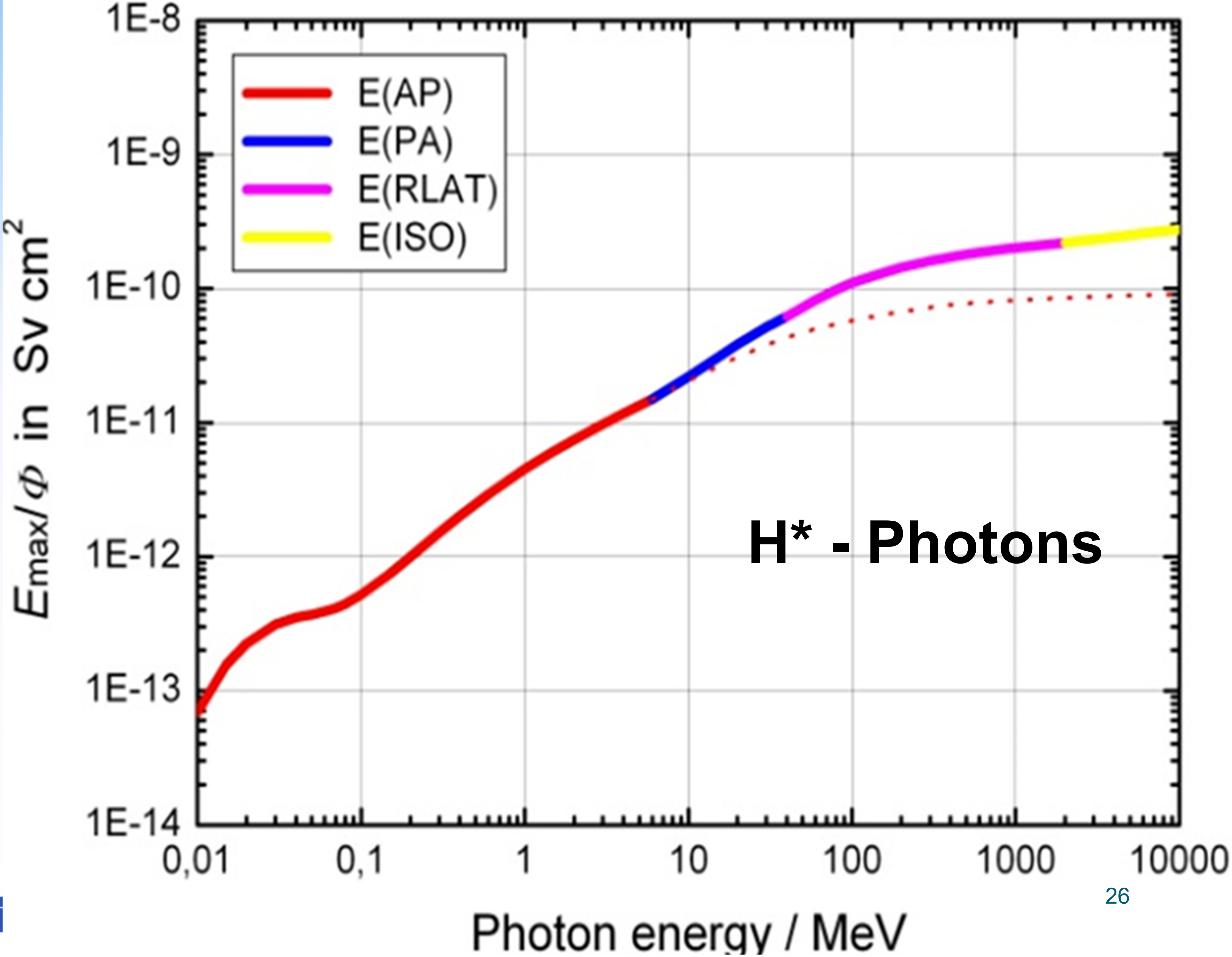
Ambient Dose Equivalent (currently proposed)

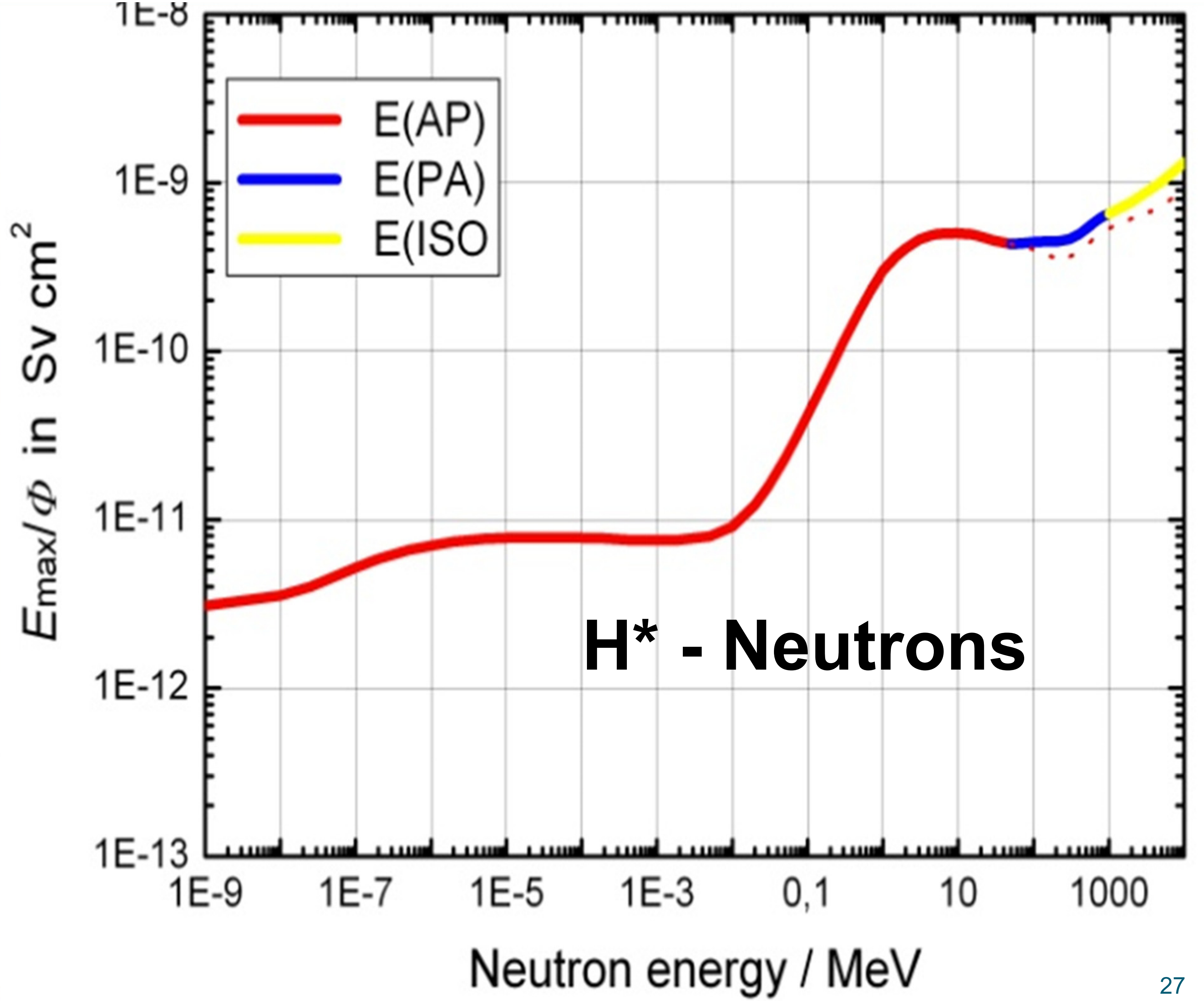
Ambient dose equivalent, ***H****** at a point in a radiation field, is the product of the particle fluence, Φ, for the radiation field at that point, and a conversion coefficient, *h*, relating the particle fluence to the maximum value of the effective dose, $E_{eff\ max}$.

$E_{eff\ max}$

Calculated for the whole-body exposure of the ICRP adult anthropomorphic phantoms irradiation geometries:

- AP, PA, LLAT, RLAT, ROT, and ISO fields, and,
- Superior-hemisphere, SS-ISO, and inferior-hemisphere, IS-ISO, isotropic fields.


1E-8
1E-9
1E-10
1E-11
1E-12
1E-13
1E-14
E(AP)
E(PA)
E(RLAT)
E(ISO)
H* - Photons
E_{max}/Φ in Sv cm^2
0,01
0,1
1
10
100
1000
10000
Photon energy / MeV


1E-8
1E-9
1E-10
1E-11
1E-12
1E-13
E(AP)
E(PA)
E(ISO
E_{max}/Φ in Sv cm^2
H* - Neutrons
1E-9
1E-7
1E-5
1E-3
0,1
10
1000
Neutron energy / MeV

Proposed Scheme of Operational Dose Quantities

Task	Area Monitoring	Individual Monitoring
Control of effective dose	Ambient Dose Equivalent, H^*	Personal Dose Equivalent, H_p
Control of doses to the the lens of the eye	Directional Absorbed Dose to the Lens of the Eye, $D'_{lens}(\boldsymbol{\Omega})$	Personal Absorbed Dose to the Lens of the Eye, $D_{p,lens}$
Control of doses to the local skin, the hands, and feet	Directional Absorbed Dose to Local Skin, $D'_{local\ skin}(\boldsymbol{\Omega})$	Personal Absorbed Dose to Local Skin, $D_{p\ local\ skin}$

Directional Absorbed Dose and Personal Dose to Local Skin - Phantoms

Local skin calculated for specific phantoms (ICRU tissue) in which the dose is averaged over a depth of 50 – 100 μm and a cross sectional area of 1 cm^2

- On the trunk: 300 x 300 x 150 mm slab (ρ=1.0 g cm^{-3})
- For the extremities: 73 mm diameter 300 mm pillar (ρ=1.11 g cm^{-3})
- For the finger: 19 mm ∅ x 300 mm rod (ρ=1.11 g cm^{-3})
- Each phantom is covered with 2 mm skin (ρ=1.09 g cm^{-3})

Individual Monitoring Quantities

- ***Using the particle fluence at a point and its angular distribution:***
  - ***H_p*** computed using a conversion coefficient for the value of the effective dose calculated for the whole-body exposure of the ICRP adult anthropomorphic phantoms to broad parallel beams
  - ***$D_{p\ lens}$*** computed using the whole-body exposure of the stylized eye model for broad parallel beams of the radiation field incident at that point
  - ***$D_{p\ local\ skin}$*** computed using a conversion coefficient calculated for exposure of the body or extremity to broad parallel beams of the radiation fields incident at that point.

Strengths Of Proposed Changes

- Strong ties to the ICRP protection quantities
- The ICRU sphere, $Q(L)$, and the definition of a hypothetical expanded and aligned radiation field are not needed.
- **Area monitoring** based on conversion coefficients for the protection quantities
  - Maximum effective dose to ICRP anthropomorphic phantoms
  - Directional dose based on equivalent dose to the lens of the eye or equivalent dose to local skin of ICRP phantoms

Strengths Of Proposed Changes

- **Individual monitoring** based on equivalent dose at a depth in the body/or on conversion coefficients for the protection quantities, determined for the particular person wearing the dosimeter.
- This would result in a simplification of the system of quantities used in radiation protection.

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