# What is New in External Radiation Dosimetry?

## An ICRP/ICRU View


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and

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# Evolution of Quantities

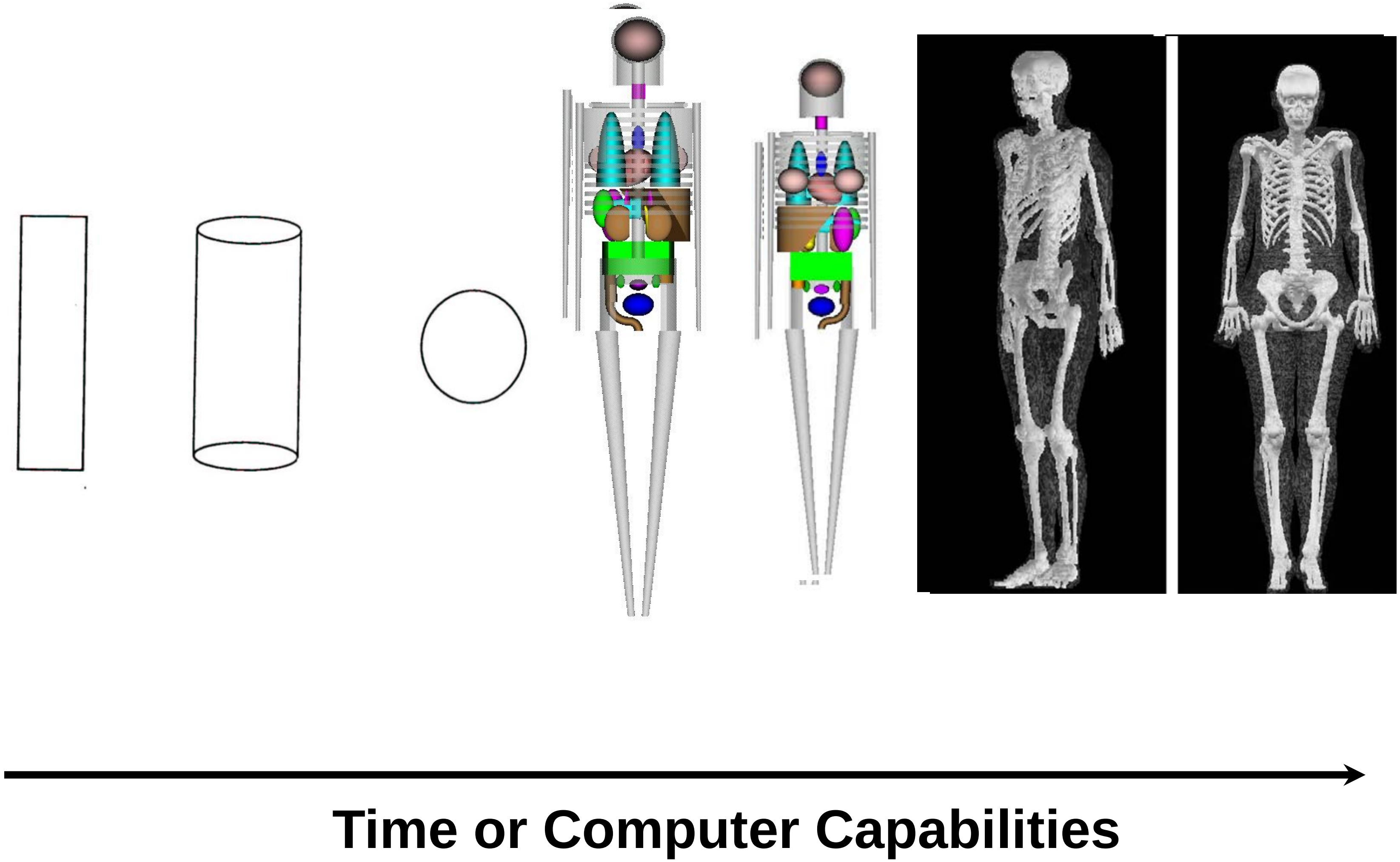
## Protection Quantities

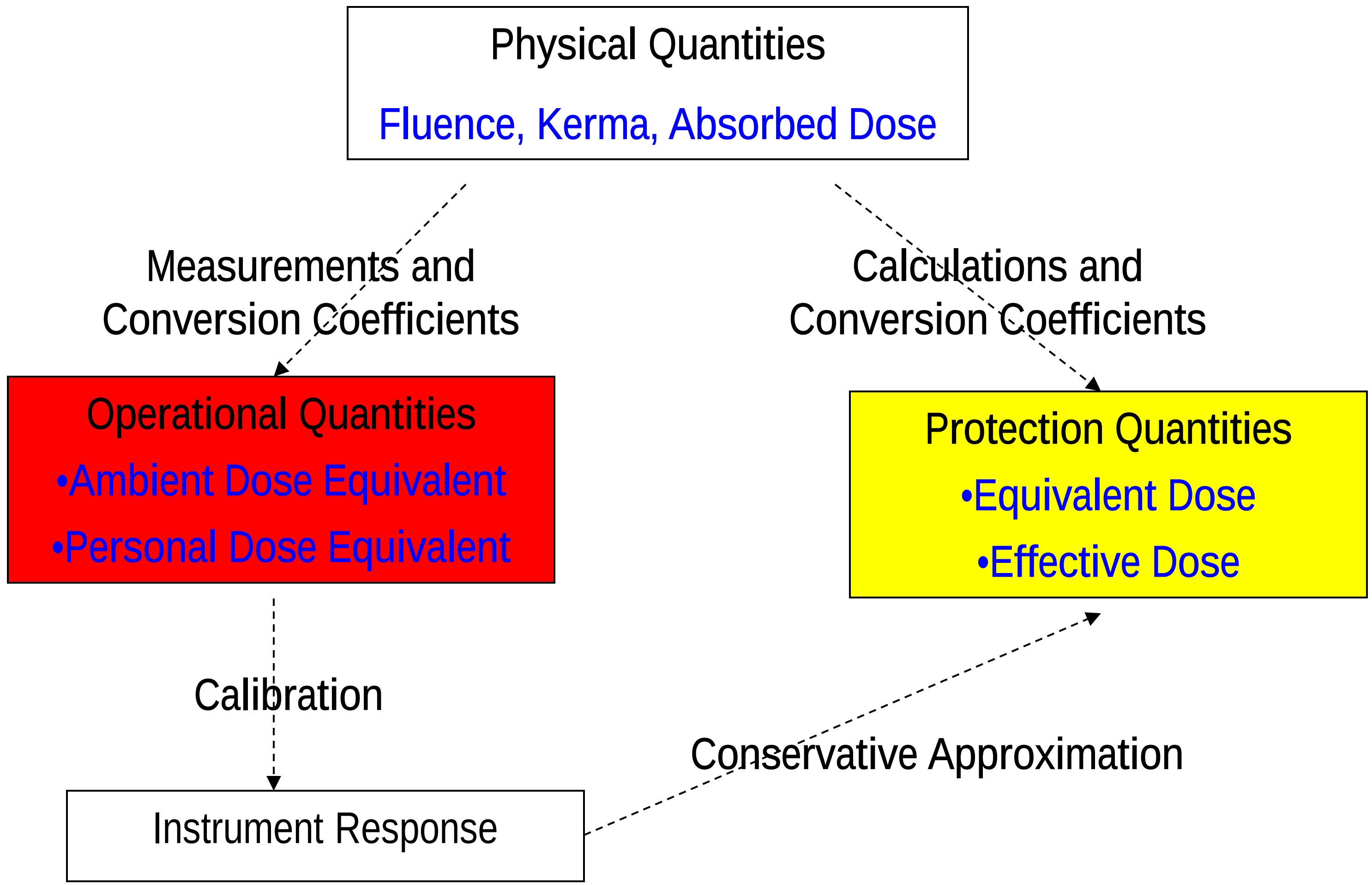
***Dose Equivalent → Effective Dose Equivalent → Effective Dose***

## Operational Quantities

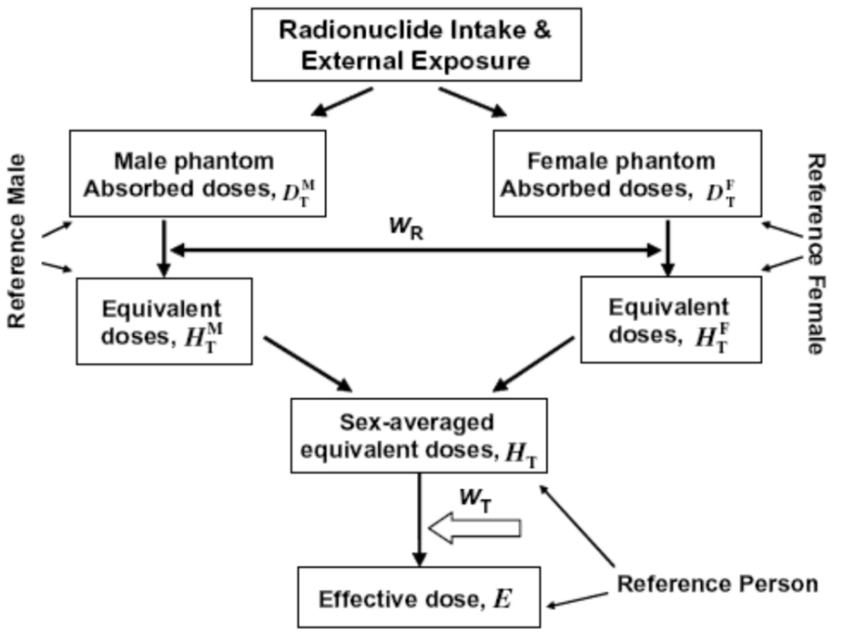
***MADE → Dose-Equivalent Indexes → Ambient, Directional and Personal Dose Equivalent***

# Your Body as a Target – Phantom Evolution




Physical Quantities
Fluence, Kerma, Absorbed Dose
Measurements and Conversion Coefficients
Calculations and Conversion Coefficients
Operational Quantities
•Ambient Dose Equivalent
•Personal Dose Equivalent
Protection Quantities
•Equivalent Dose
•Effective Dose
Calibration
Conservative Approximation
Instrument Response

# 2007 ICRP Recommendations:
# It's Changed but it's Still Effective




| Tissue/Organ | ICRP 26 | ICRP 60 | ICRP 103 |
|---|---|---|---|
| Gonads | 0.25 | 0.20 | 0.08 |
| Bone marrow (red) | 0.12 | 0.12 | 0.12 |
| Colon | | 0.12 | 0.12 |
| Lungs | 0.12 | 0.12 | 0.12 |
| Stomach | | 0.12 | 0.12 |
| Bladder | | 0.05 | 0.04 |
| Breast | 0.15 | 0.05 | 0.12 |
| Liver | | 0.05 | 0.04 |
| Esophagus | | 0.05 | 0.04 |
| Thyroid | 0.03 | 0.05 | 0.04 |
| Skin | | 0.01 | 0.01 |
| Bone surface | 0.03 | 0.01 | 0.01 |
| Remainder | 0.3 | 0.05 | 0.12 |
| Brain | | | 0.01 |
| Salivary Glands | | | 0.01 |

**Remainder tissues:** Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral Mucosa, Pancreas, Small intestine, Spleen, Thymus, Uterus/cervix or Prostate.

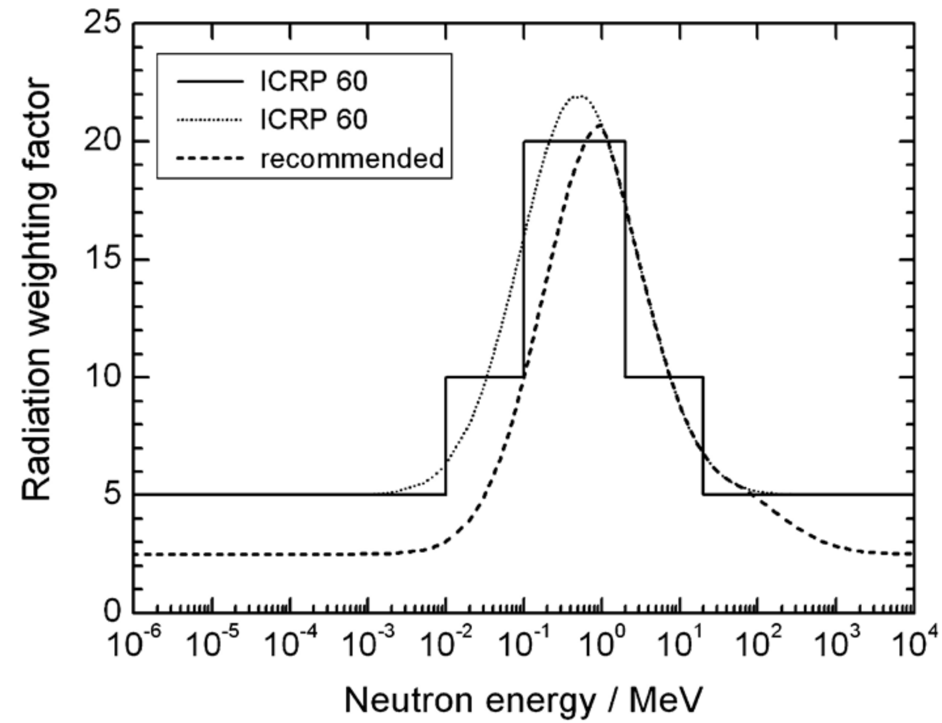
# ICRP 103

Table 2. Recommended radiation weighting factors.

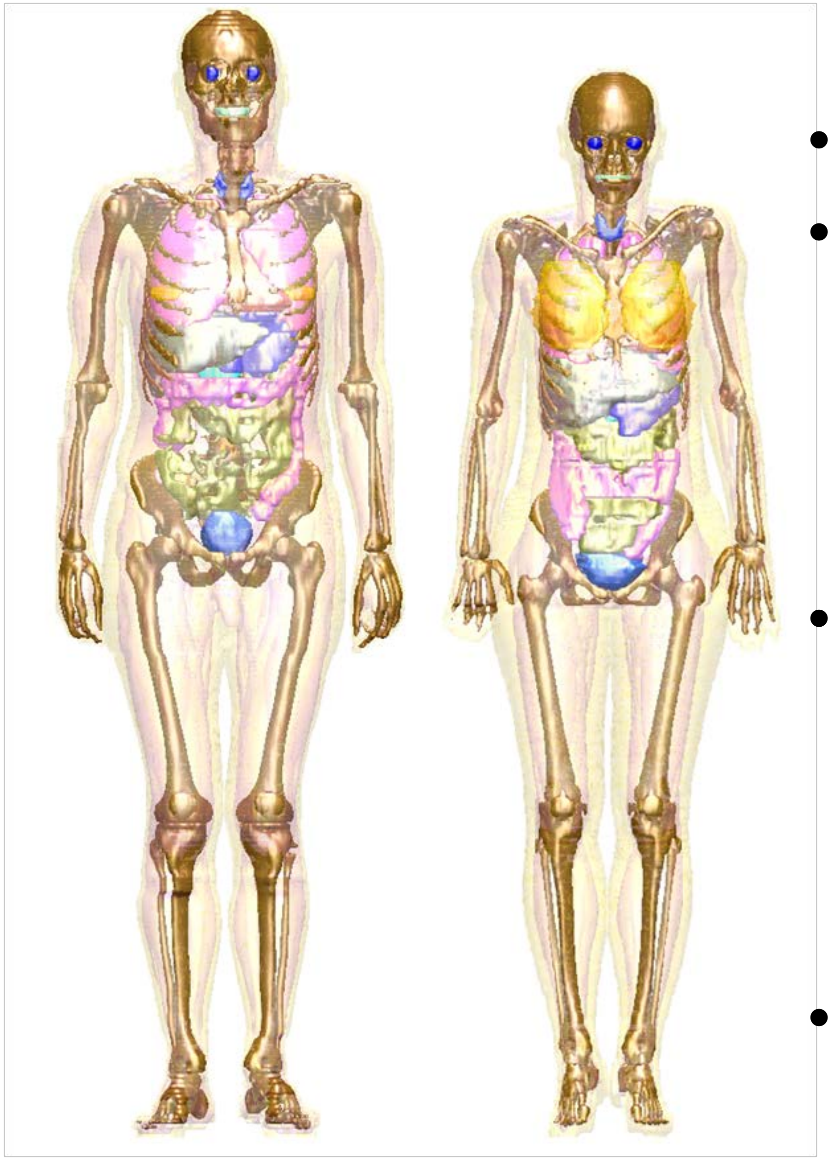
| **Radiation type** | **Radiation weighting factor, $w_R$** |
|---|---|
| Photons | 1 |
| Electrons[a] and muons | 1 |
| Protons and charged pions | 2 |
| Alpha particles, fission fragments, heavy ions | 20 |
| Neutrons | A continuous function of neutron energy (see Fig. 1 and Eq. 4.3) |

All values relate to the radiation incident on the body or, for internal radiation sources, emitted from the incorporated radionuclide(s).

[a] Note the special issue of Auger electrons discussed in paragraph 116 and in Section B.3.3 of Annex B.



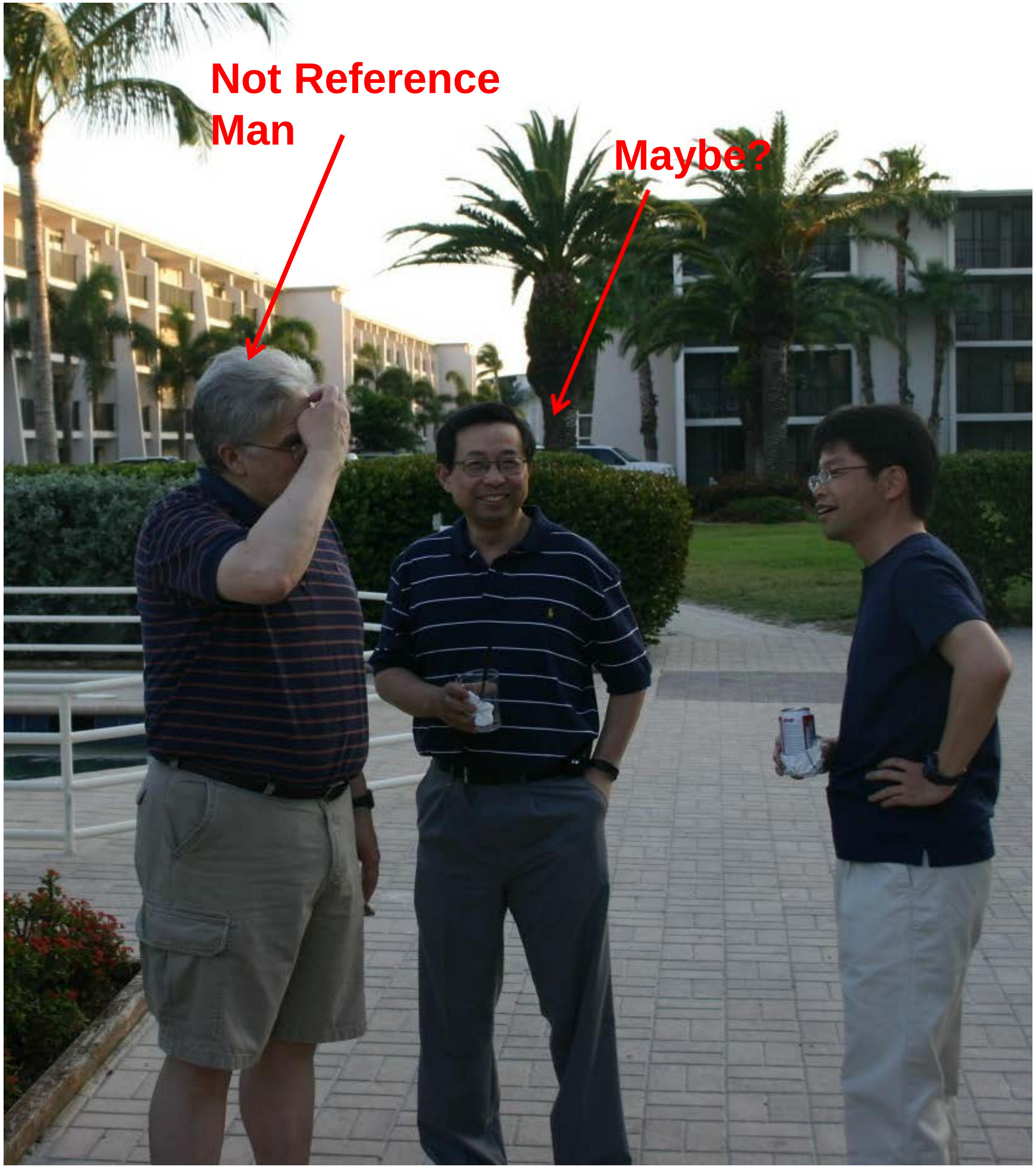
# ICRP Publication 110 Reference Phantoms



- ICRP Publication 89 (2002)
- Male – 1.95 million tissue voxels
  - slice thickness of 8.0 mm and lateral dimensions of 2.137 mm
  - 1.76 m
  - 73 kg
- Female -3.89 million tissue voxels
  - Slice thickness of 4.84 mm
  - Lateral dimensions of 1.775 mm.
  - 1.63 m
  - 60 kg
- 140 Organ identification numbers

**The problem with Reference Phantoms!**

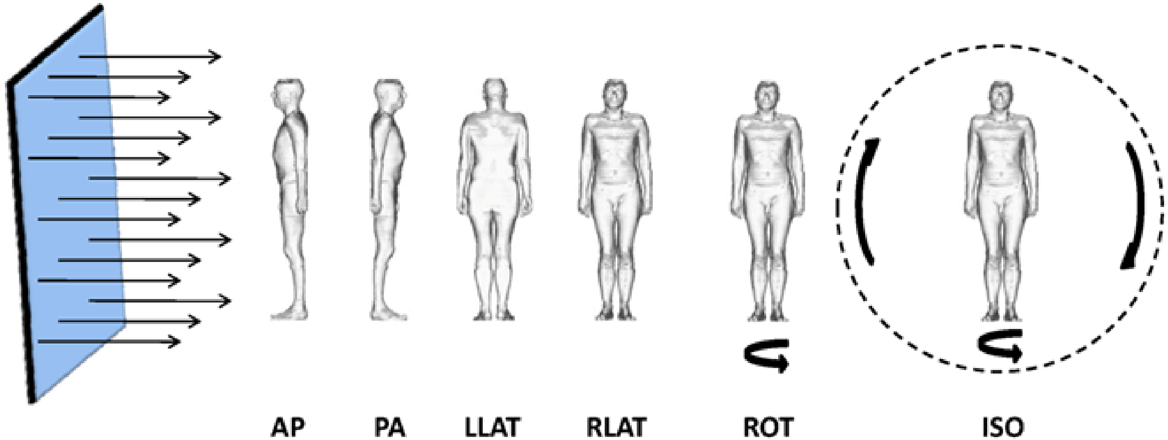
**There are some problems with voxels as well.**



# Revision of ICRP 74/ICRU 57
# ICRP Publication 116

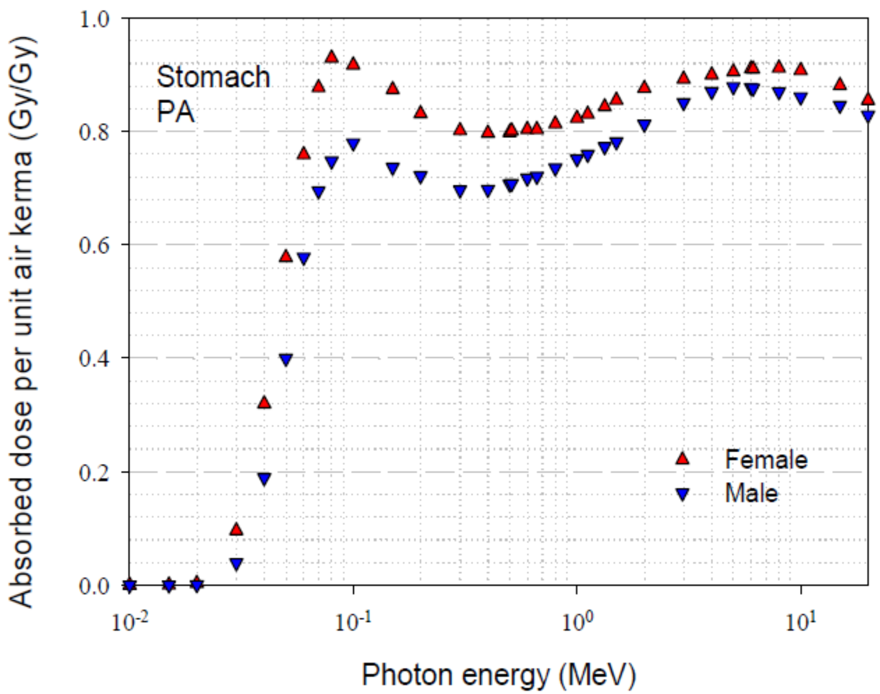
- Conversion Coefficients for use in Radiological Protection against External Radiation
- ICRP 103 recommendations
  - $W_R$ and $W_T$ changed
  - Remainder changed
  - Slightly modified definition of Effective dose
  - ICRP reference voxel phantoms (Publication 110) replace MIRD-type stylized phantoms

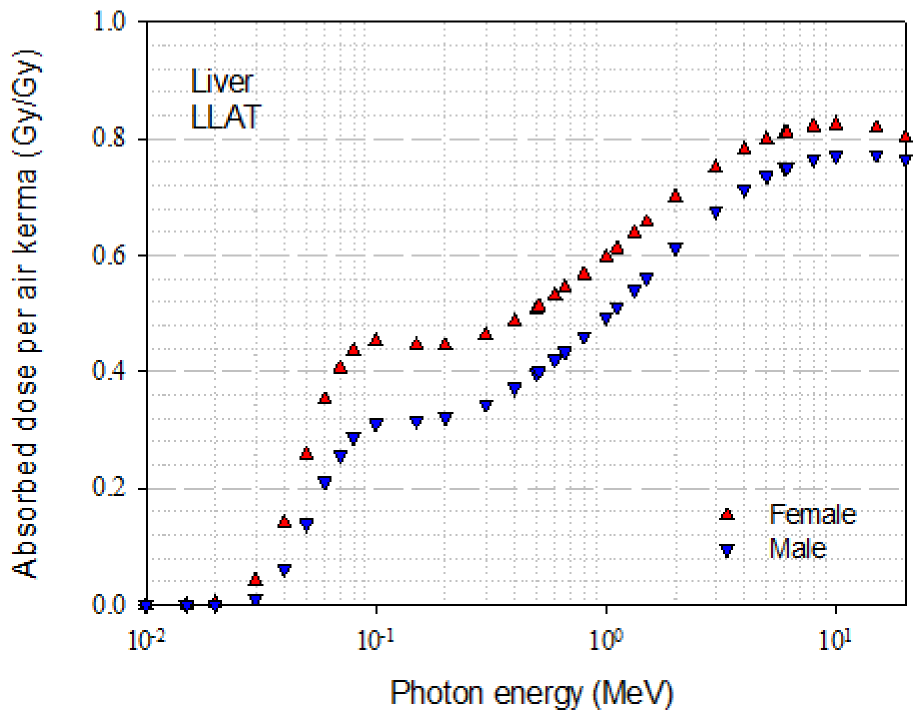
# ICRP 116



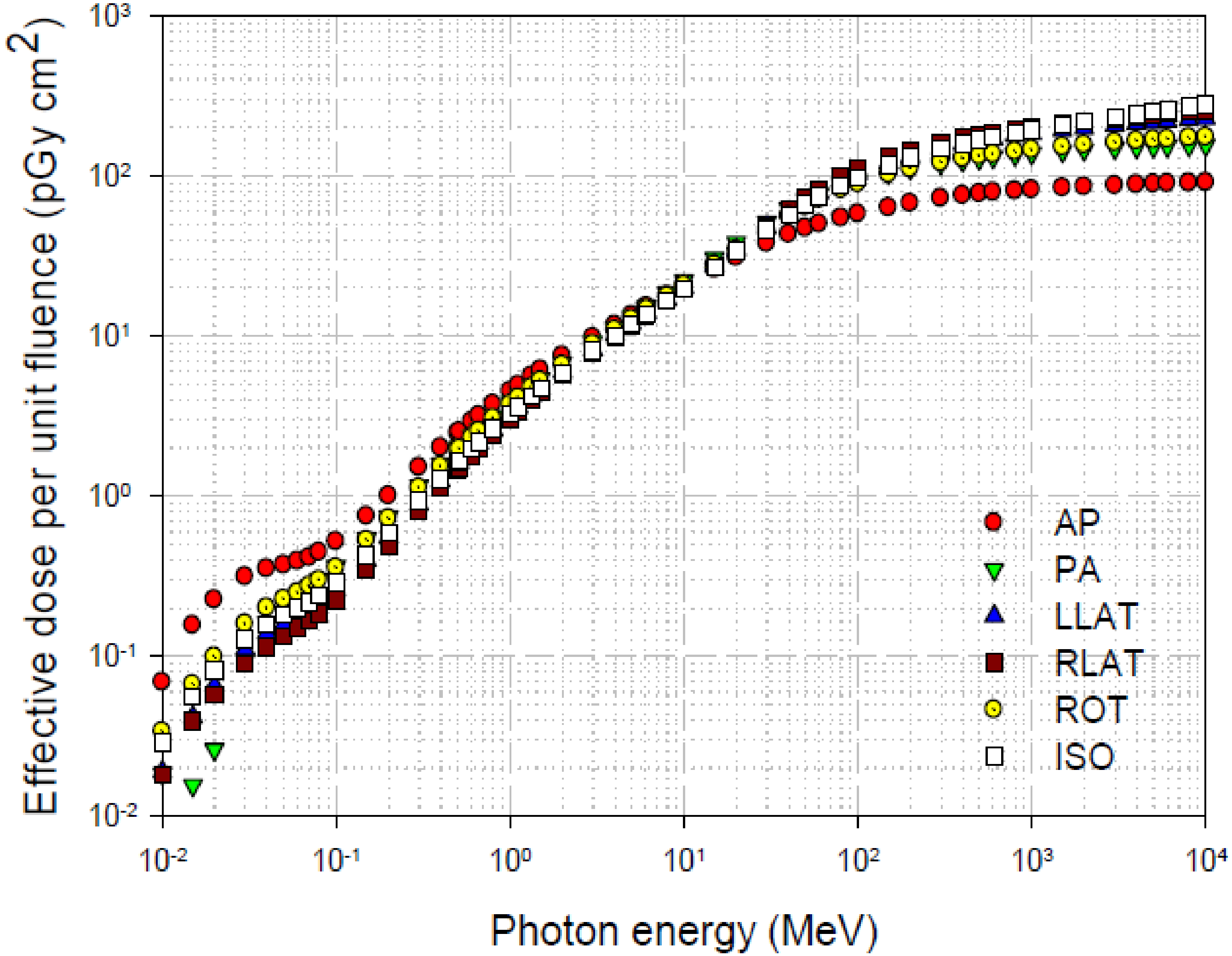

| Particles | Energies | Geometries |
|---|---|---|
| **Photons** | 10 KeV-10 GeV | AP, PA, LLAT, RLAT, ISO, ROT |
| **Neutrons** | $10^{-9}$ MeV-10 GeV | AP, PA, LLAT, RLAT, ISO, ROT |
| **Electrons and Positrons** | 50 keV – 10 GeV | AP, PA, ISO |
| **Protons** | 1 MeV – 10 GeV | AP, PA, LLAT, RLAT, ISO, ROT |
| **Positive and Negative Pions** | 1 MeV-200 GeV | AP, PA, ISO |
| **Muons** | 1 MeV-10 GeV | AP, PA, ISO |
| **He-Ions** | 1 MeV/n – 100 GeV | AP, PA, ISO |

# There are Sex Differences Besides the Obvious

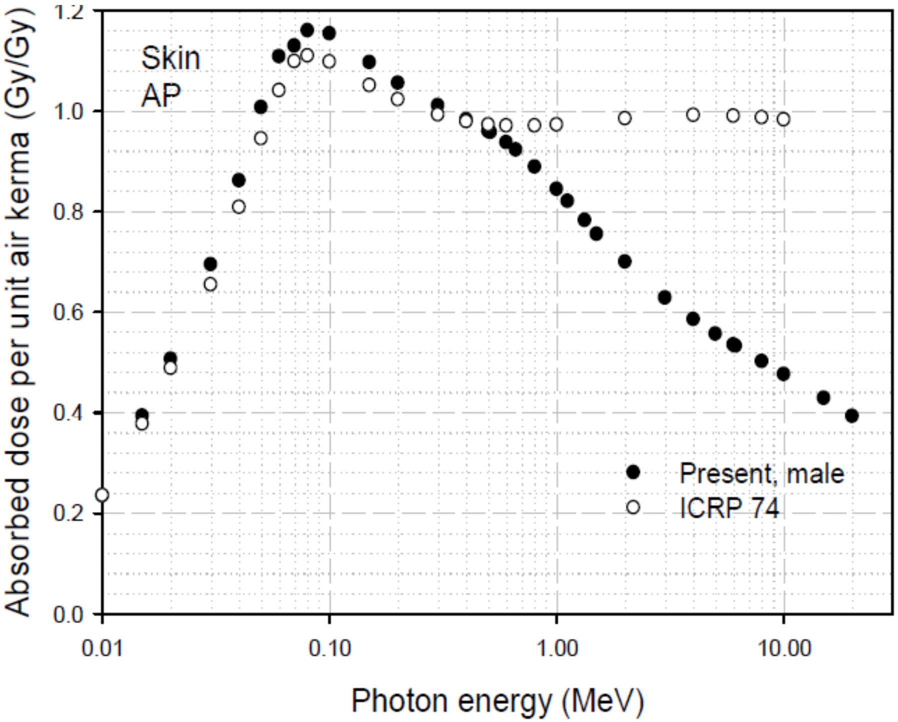


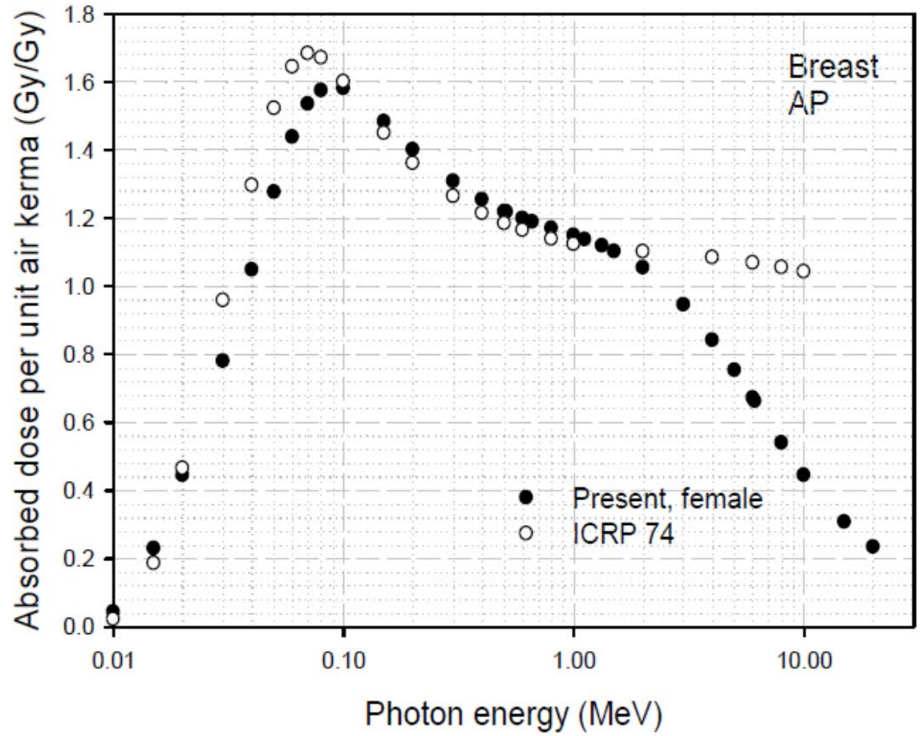



# Photon Effective Dose

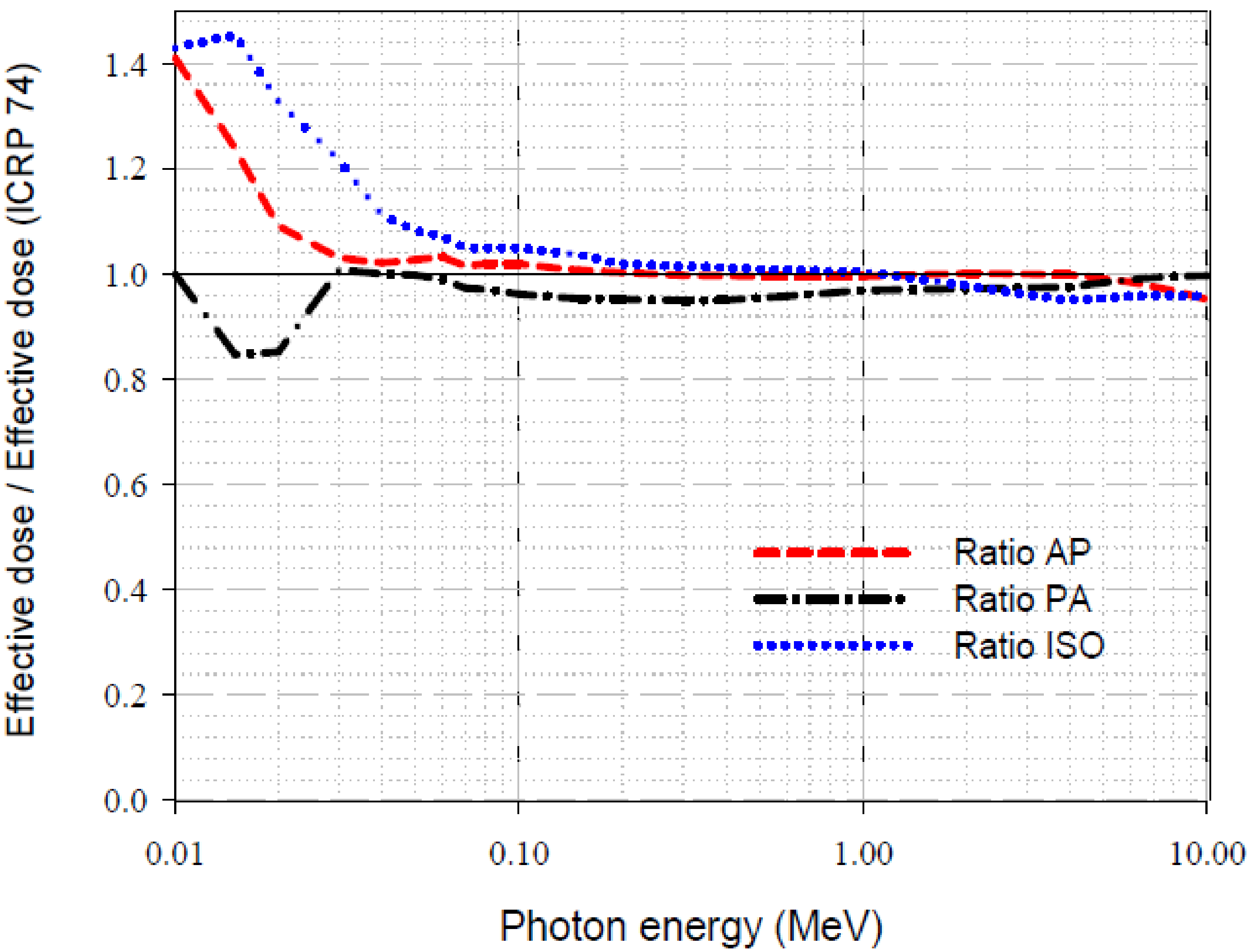


# Photons – Present vs. ICRP 74(kerma)

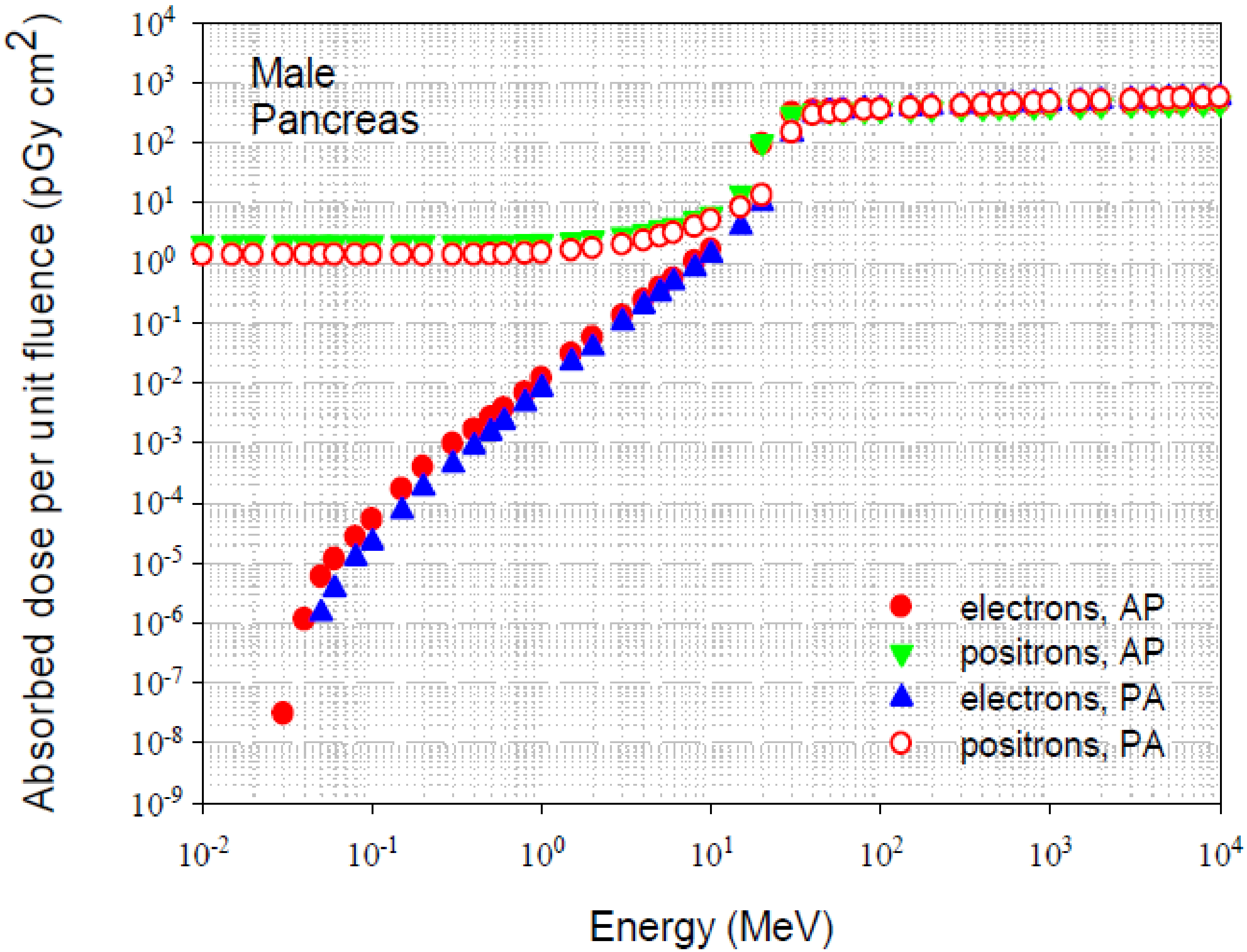


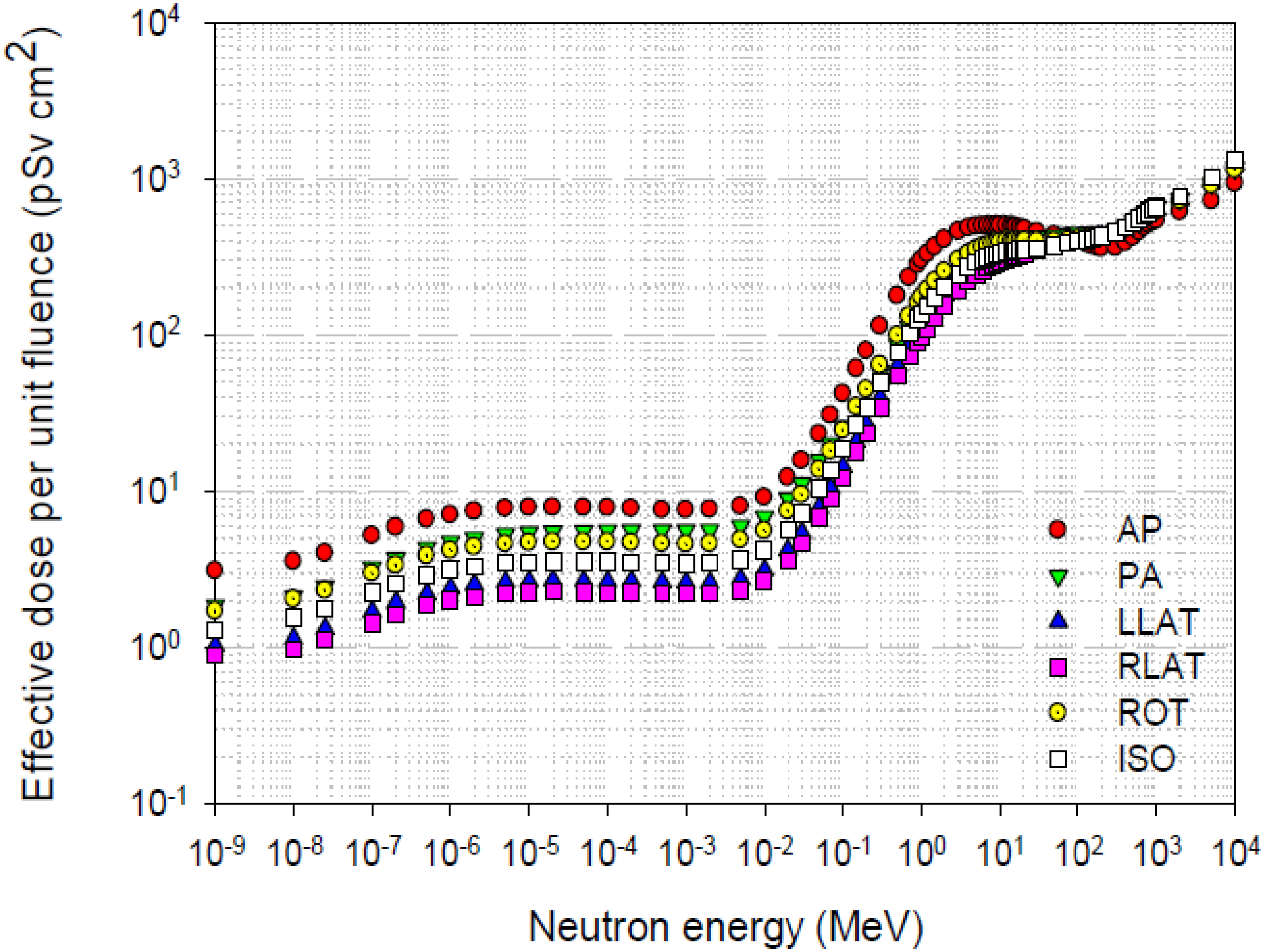
# Photon: E(new)/E(ICRP74)



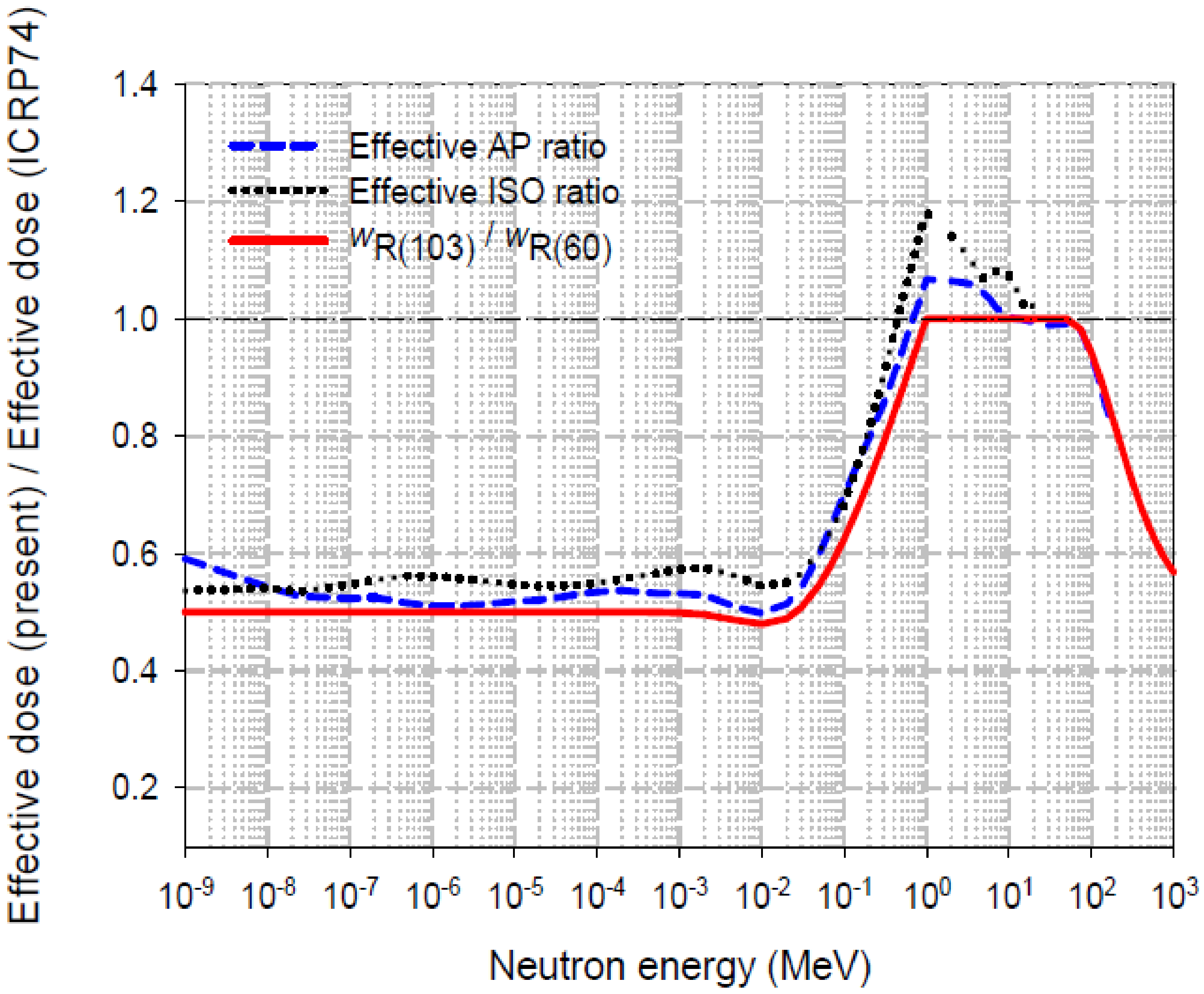
# Positrons and Electrons

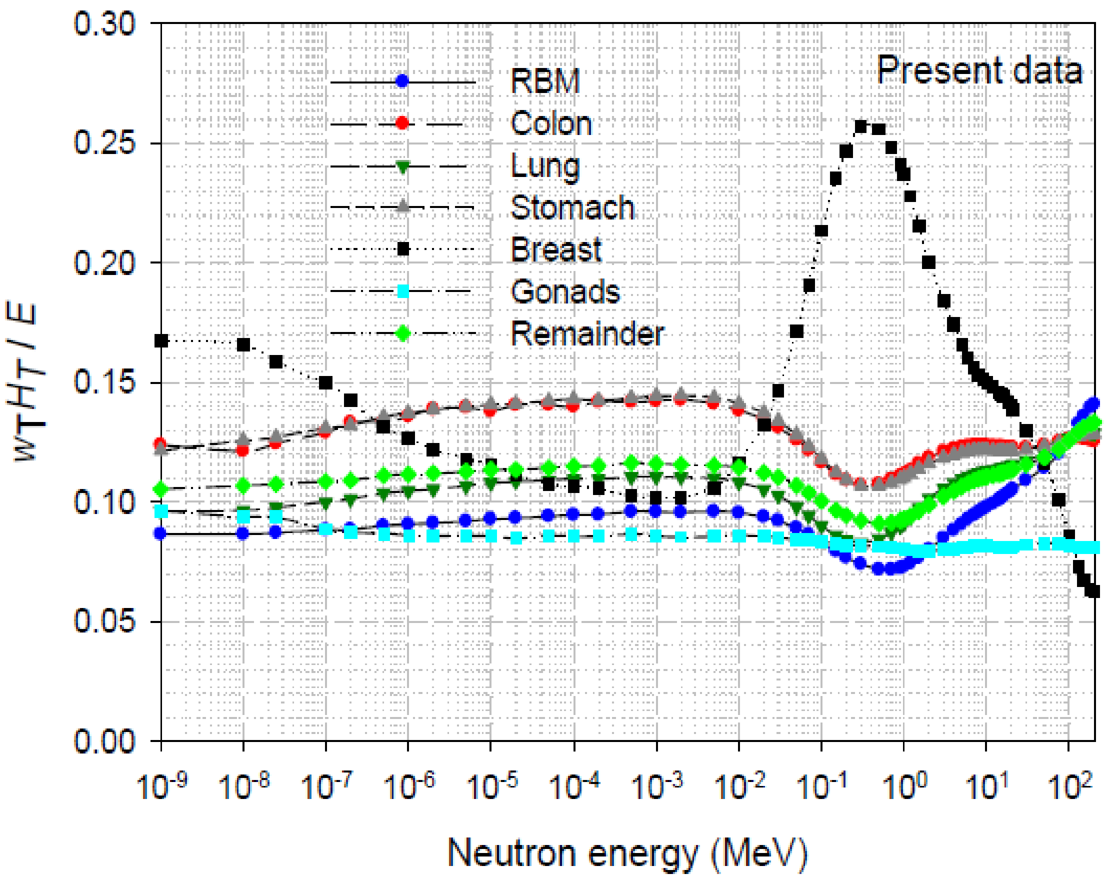


# ICRP 116 Neutron Effective Dose Conversion Coefficients



# Neutron: E(new)/E(ICRP74)





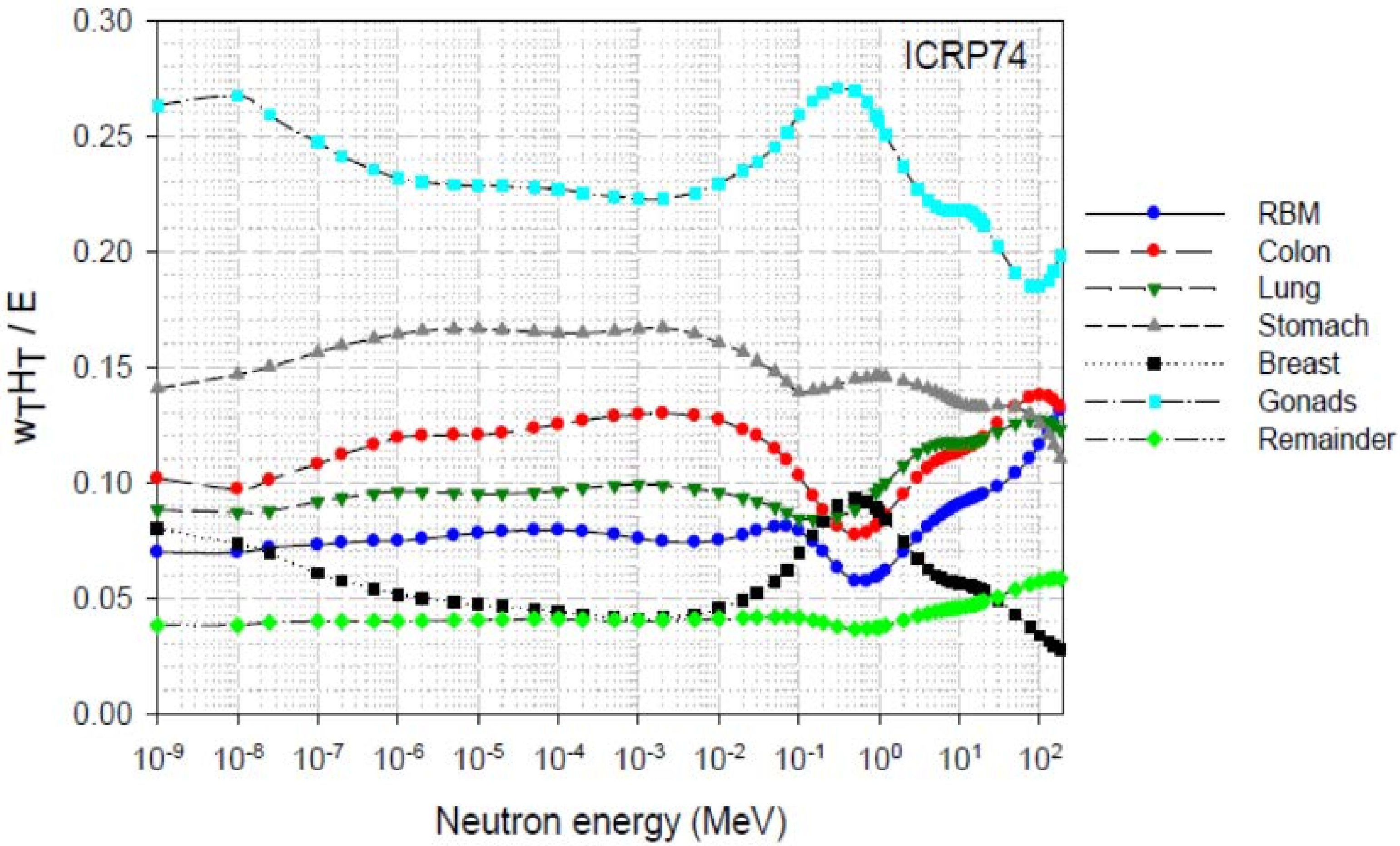

# Weighted Organ Equivalent Dose Contribution to Effective Dose

| Tissue | $w_T$ |
|---|---|
| Red bone marrow, colon, lung, stomach, breast, remainder tissues | 0.12 |
| Gonads | 0.08 |
| Bladder, oesophagus, liver, thyroid | 0.04 |
| Endosteum (bone surface), brain, salivary glands, skin | 0.01 |

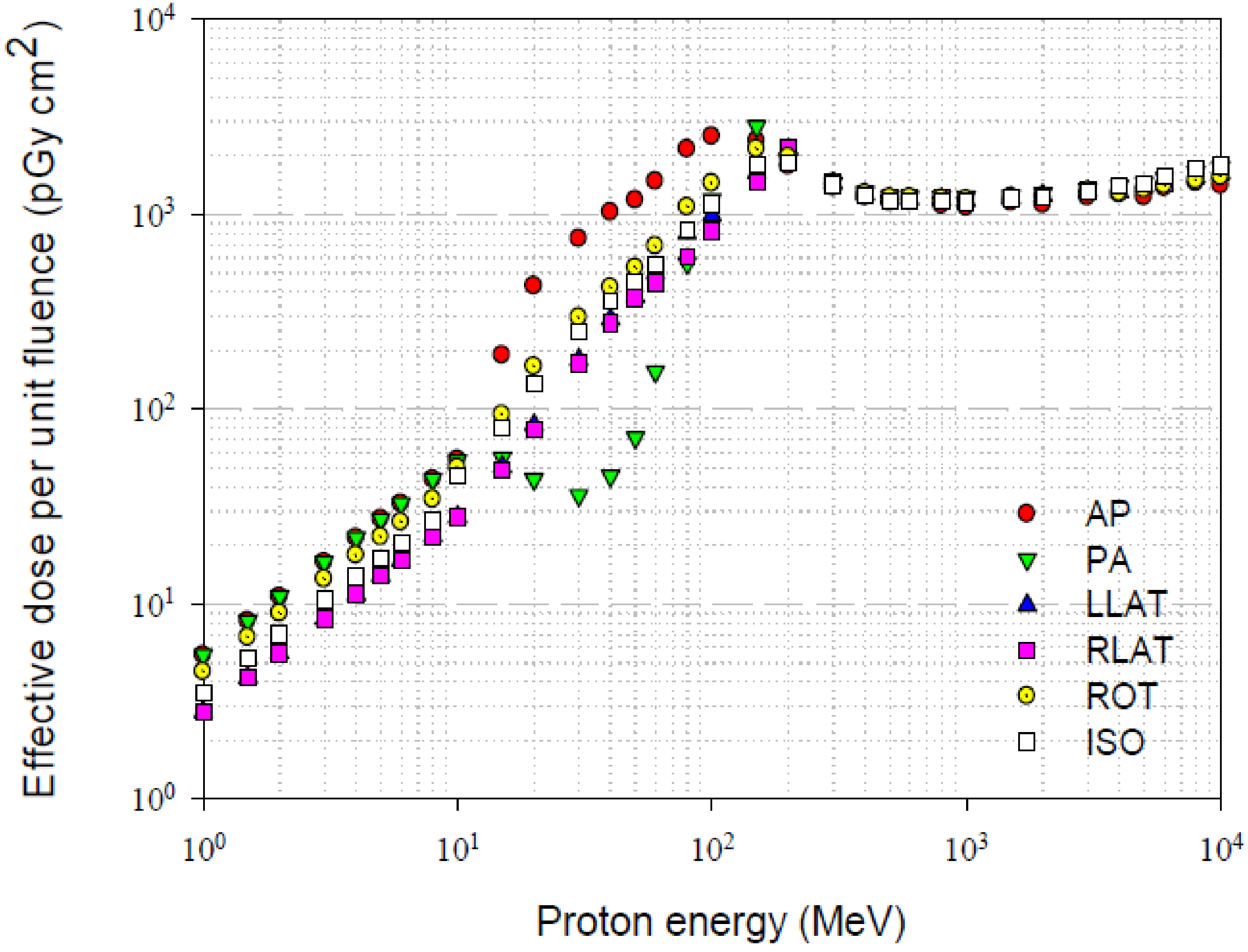
Slide I added after the talk

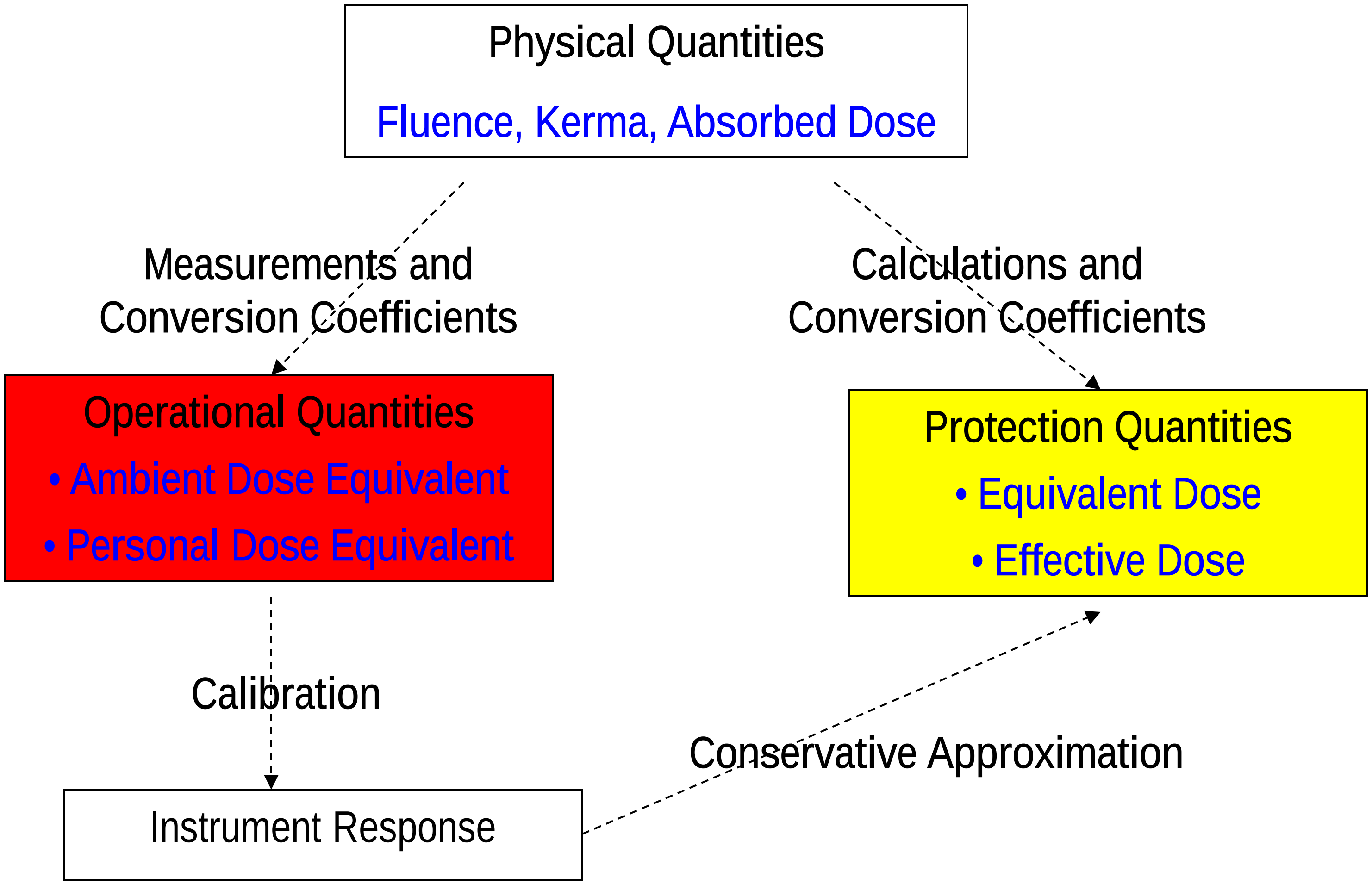
**Weighted Organ Equivalent Dose Contribution to Effective Dose for ICRP 74**

**See slide #5 for $w_T$. The gonad tissue weighting factor was 0.2 in ICRP 60 and is now 0.08.**



# Proton Effective Dose

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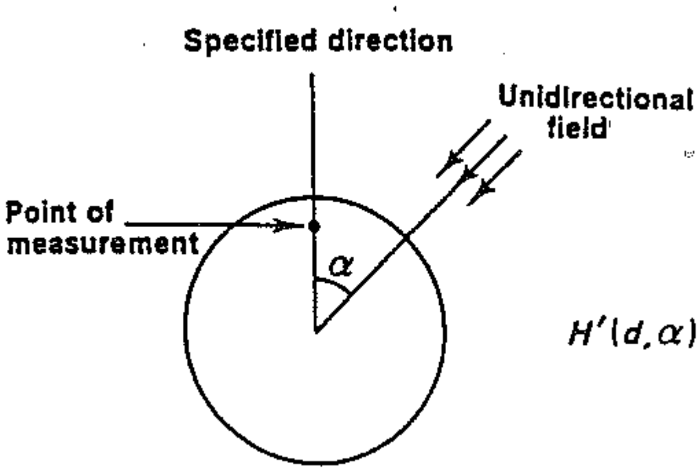
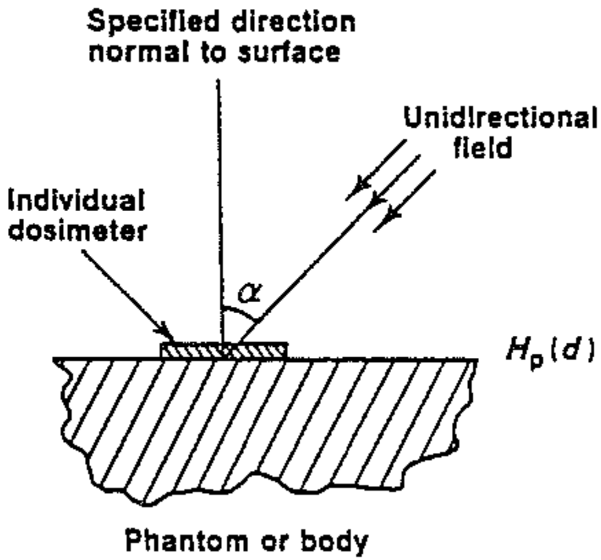
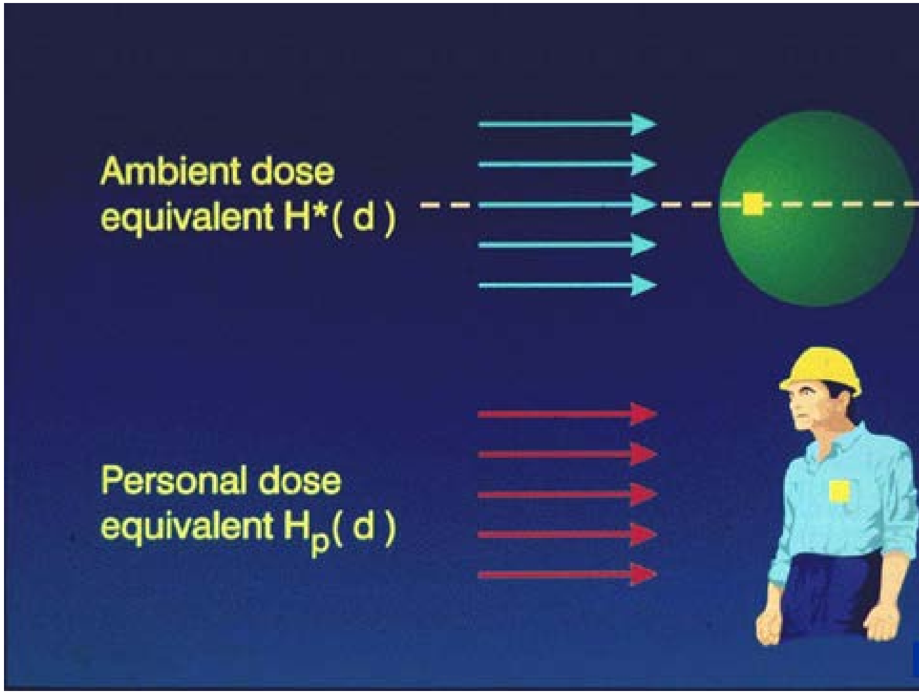
# Ambient, Directional and Personal Dose Equivalents



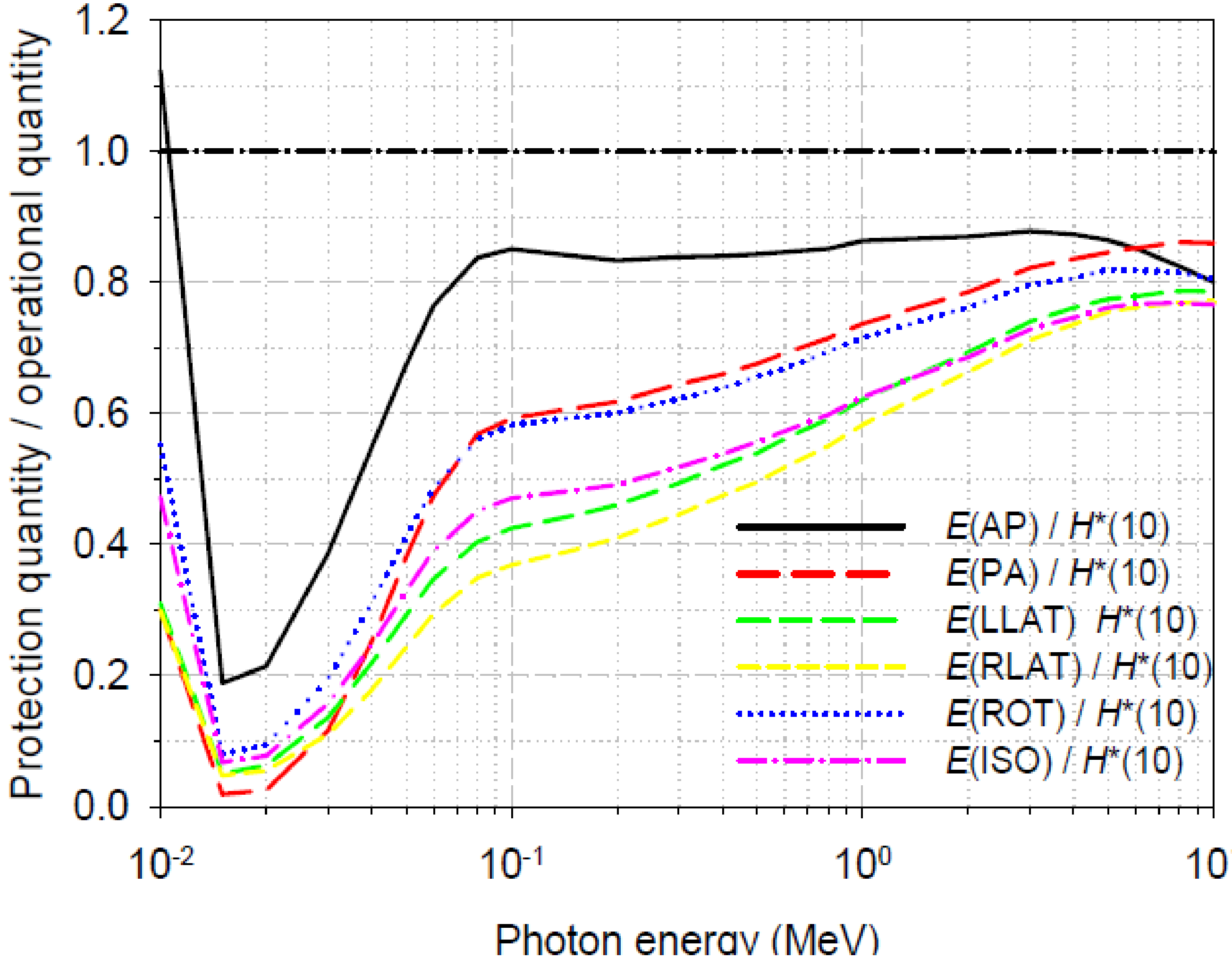
# Ambient Dose Equivalent

- **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**
  - **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
  - **Underground Definition -- Ambient dose equivalent is the dose equivalent that a 30-cm spherical person would receive, IF THEY WERE NOT THERE!**

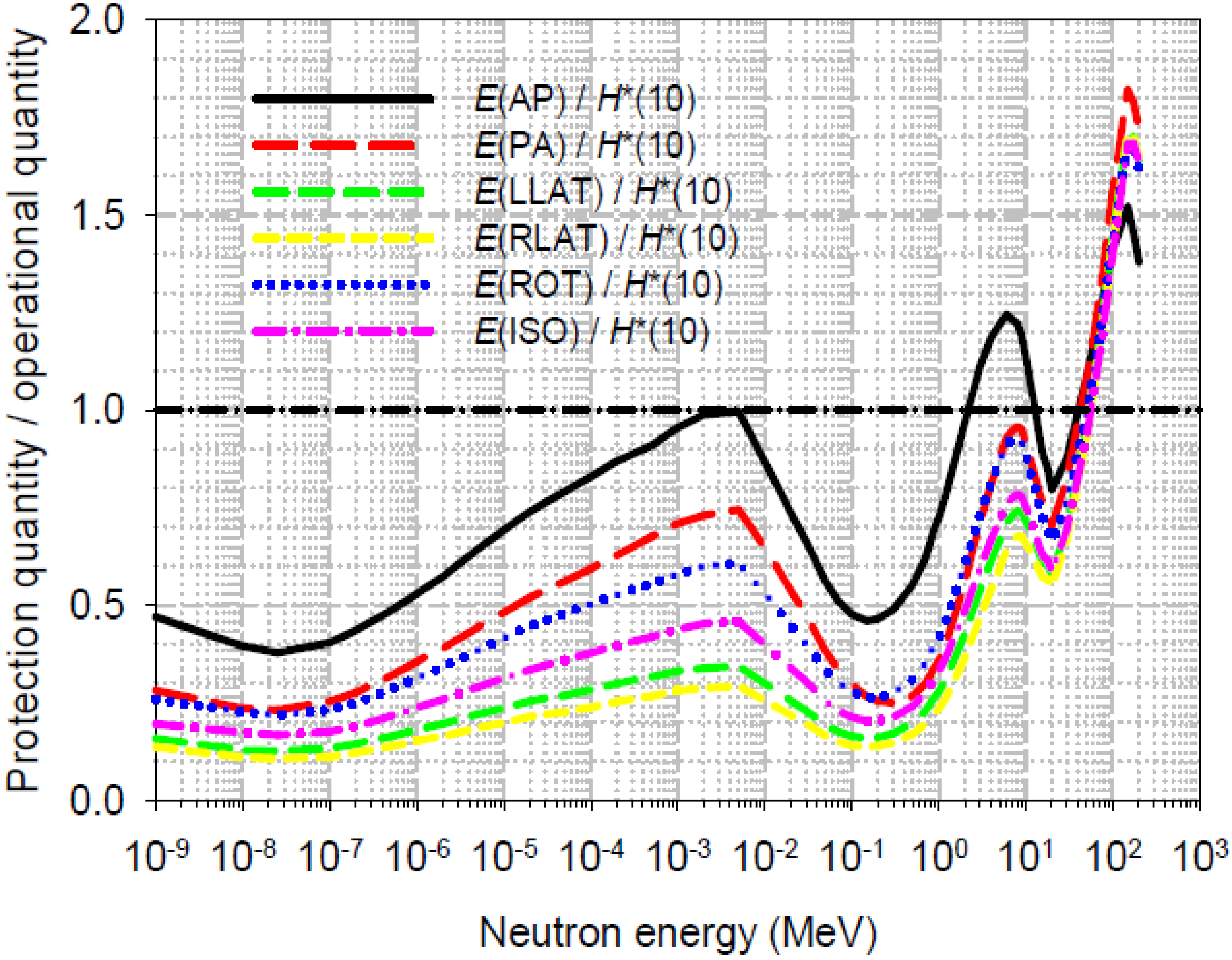
# Are the Operational Quantities Still Good Approximations?

- Ambient and Personal Dose Equivalent were not addressed in the revision
  - Being reconsidered by ICRU RC #26
- How do they compare?
- For photons, they were calculated by the "kerma approximation"
  - Implies CPE on the surface of the phantom

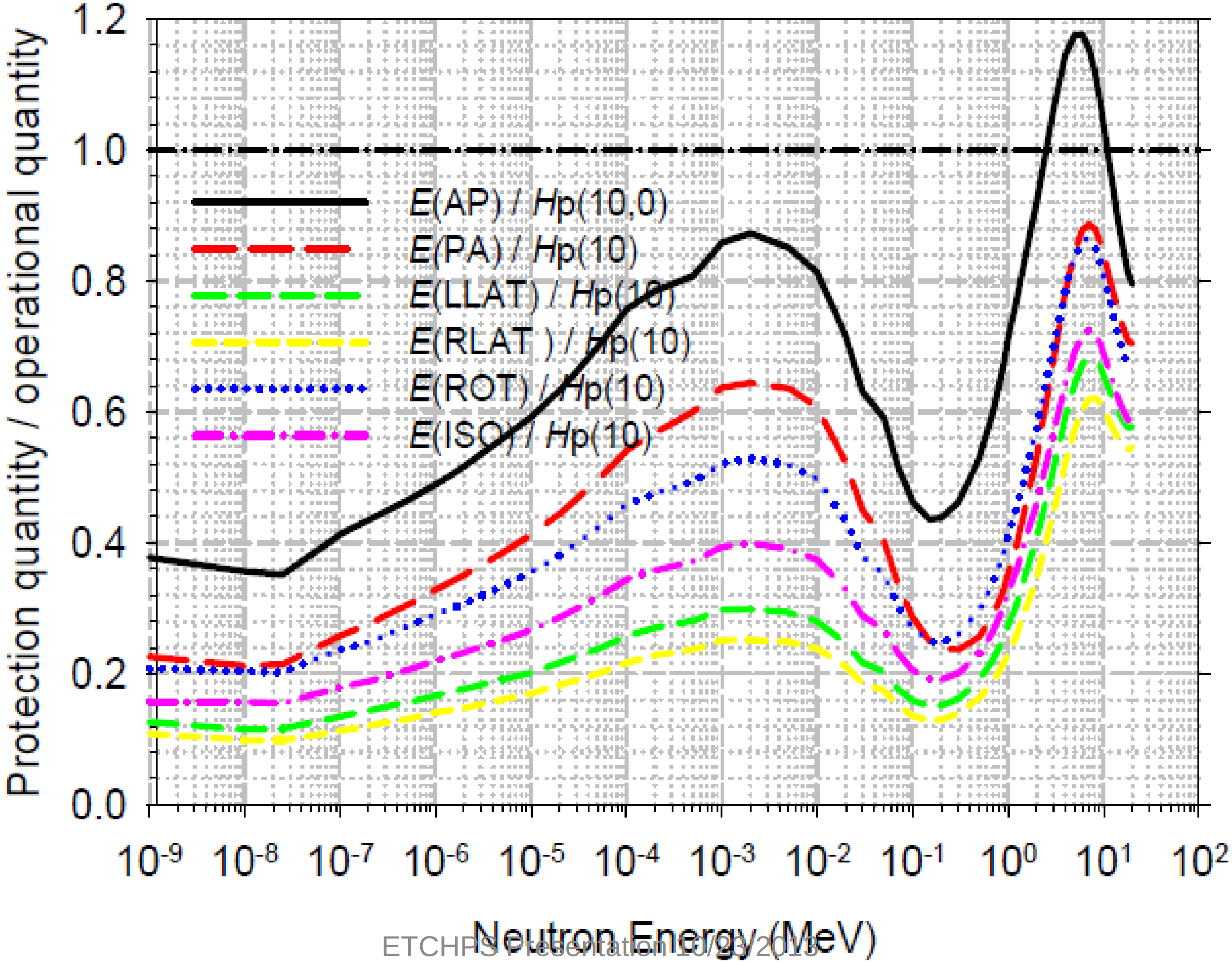
# Photons: Ratio of Recommended E to Ambient Dose Equivalent



# Neutrons: Ratio of Recommended E to Ambient Dose Equivalent



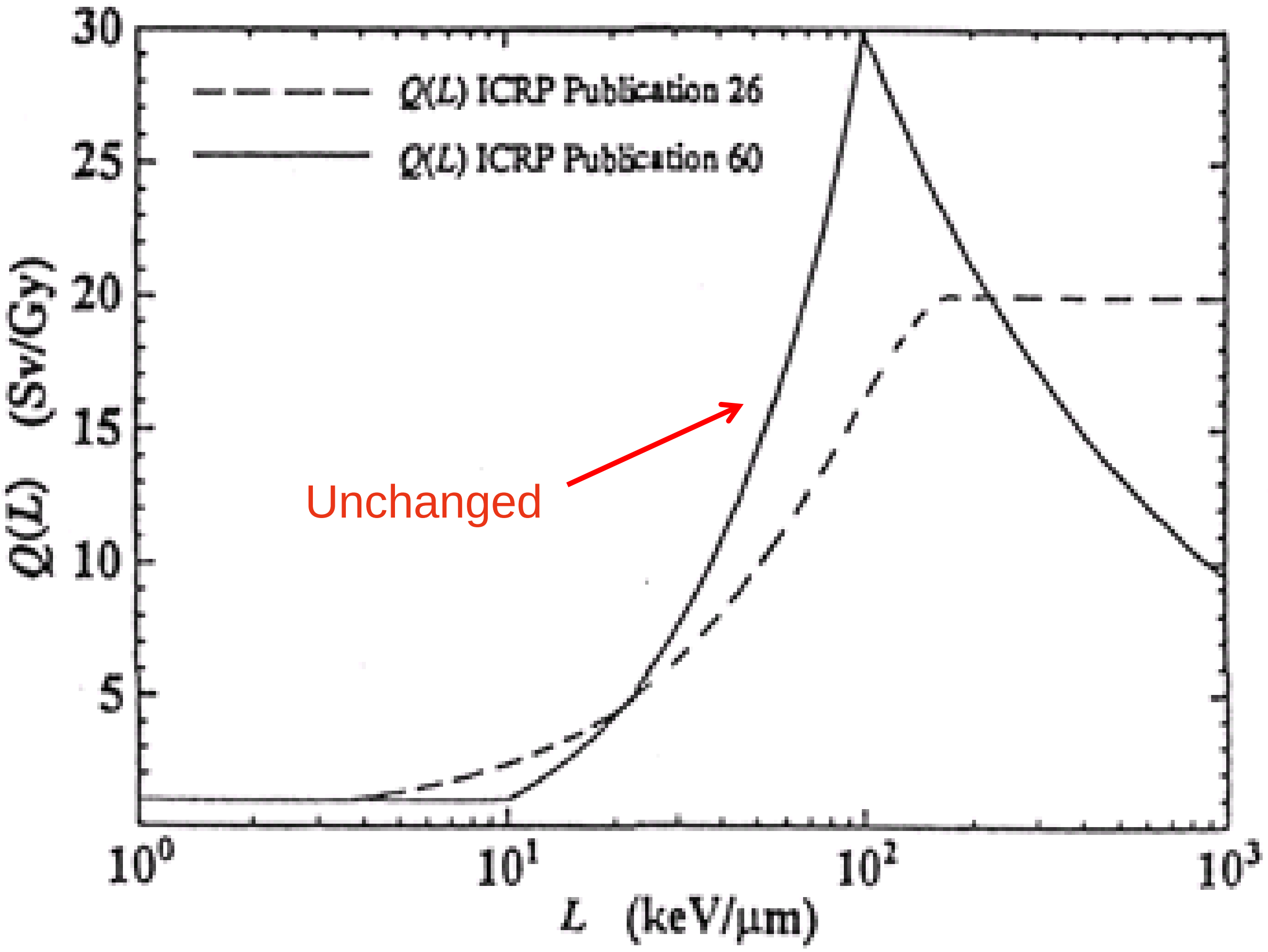
# Neutrons: Ratio of Recommended E to Personal Dose Equivalent



# Operational Quantities

- "…it can be deduced that the operational quantities for photons, neutrons, and electrons (ICRP74/ICRU57) continue to provide a good approximation for broad particle energy and direction distributions, and to be of practical application for most radiation protection practices for the range of particles energies in the radiation fields considered, but not at the higher energies considered in this publicaiton." ICRP 116

# Publication 103 had *Some* Good News for Measurers, BUT . . .



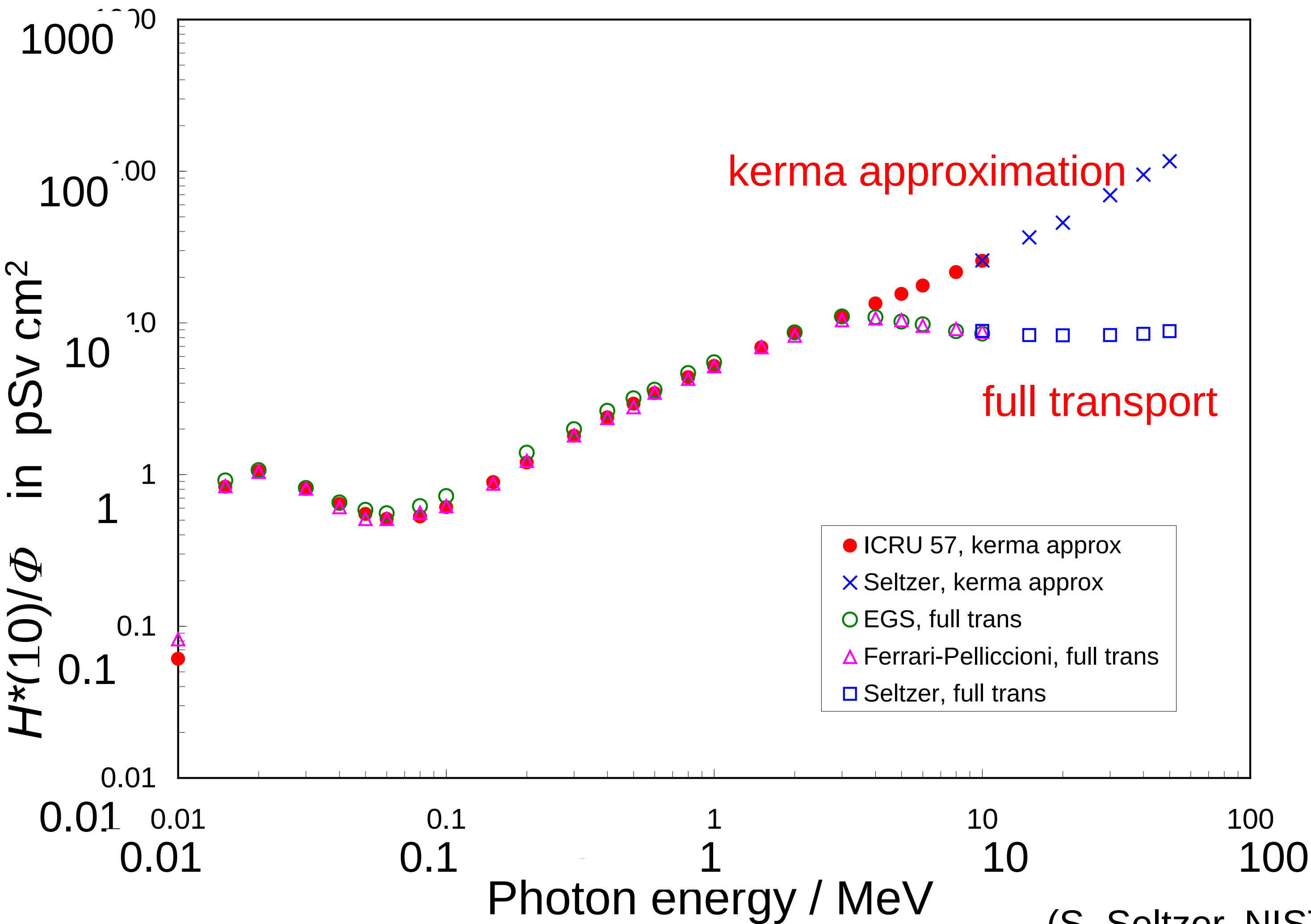
# ICRU Operational Quantities: Deficiencies and Limitations of the Current System

- Difficulties with *H*(10), H'(0.07),* and *Hp(d)*
  - Current ICRP and ICRU calculations have in general been computed *in vacuo* using the kerma approximation
    - For photons this presumes full CPE at the point of interest
    - When *d* exceeds the ranges of the secondary charged particles, such computed values diverge from the true values
      - Above 2 MeV for *H*(10)* and *Hp(10)* for photons
      - Above 70 keV for *H'(0.07)* and *Hp(0.07)* for photons
      - Without the inclusion of secondary electrons in air, H*(10) underestimates E by about a factor of 3 for photons of 10 MeV

# ICRU RC26: Operational Radiation Protection Quantities for External Radiation

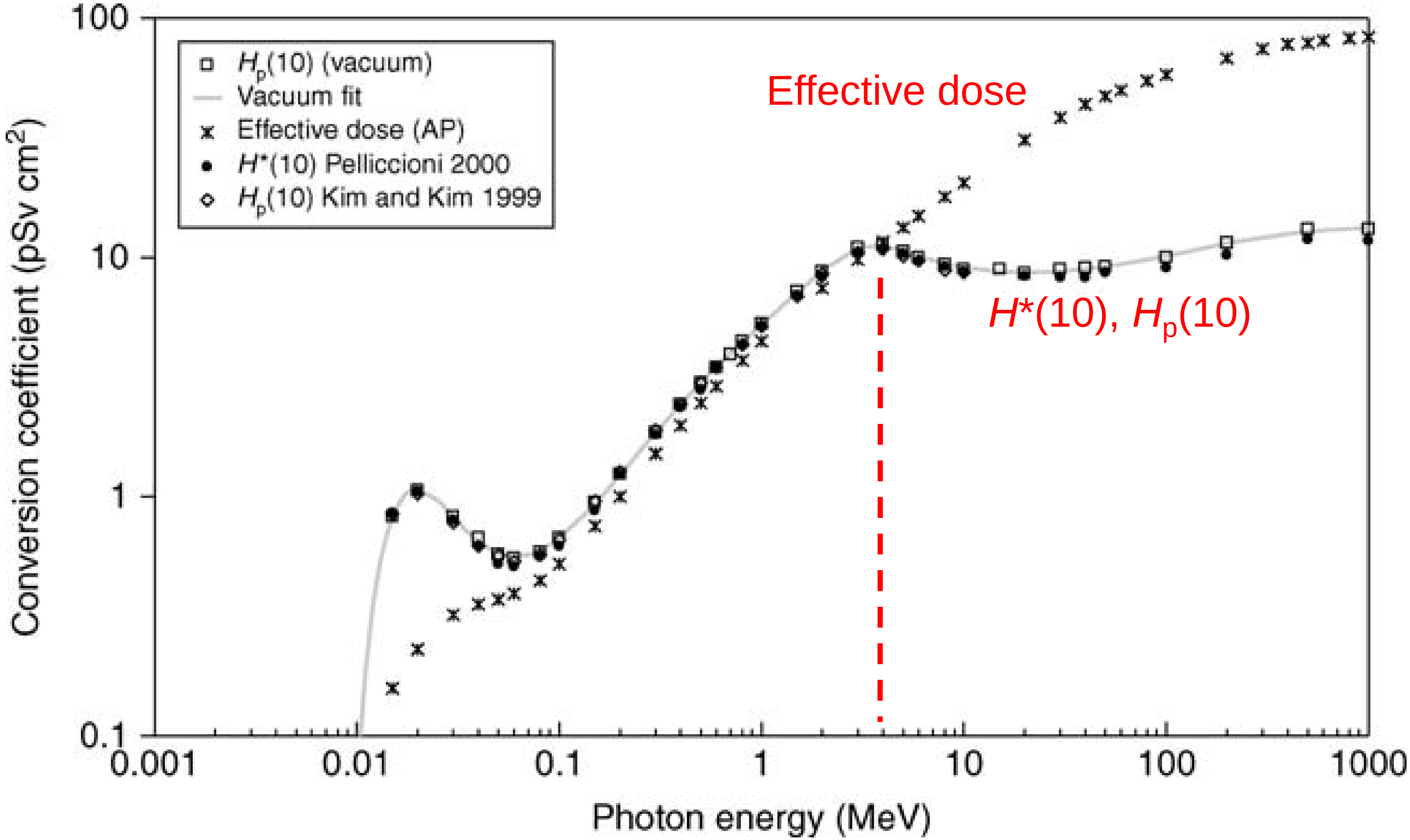
- Examine the rationale for operational quantities. Consider
  - Changes in the definitions of the protection quantities
  - Changes in the fields of application of the operational quantities and protection quantities
    - Including the range of types and energies of particles contributing to doses to workers and members of the public.
- Present
  - Relationships of the operational quantities recommended with the protection quantities
  - Impact of changes on routine measurement practice, including instrument design and calibration,
  - Conversion coefficients would be listed for all particle types and for an appropriate range of energies for practical application.

# *Calculations of conversion coefficients H*(10) / Φ for photons performed using the ICRU sphere in vacuo*




(S. Seltzer, NIST, 2011)

# Conversion coefficients for effective dose, $H^*$(10) and $H_p$(10,0). (K. G. Veinot and N. E. Hertel, RPD **145** (2011))



- The dose equivalents deposited by external secondary particles and scattered primary are not included in the definitions (sphere *in vacuo*) for $H^*(10)$ and $H'(d,\Omega)$. For $H^*(10)$ these components cannot be aligned. For photons, the energy of secondary electrons for a range equal to 10 mm is about 2 MeV; for neutrons the energy of protons is about 35 MeV.
- For higher energies, the ICRU sphere could be located in air. This requires that the distance between source and sphere needs to be defined. To achieve secondary charged particle equilibrium at the surface, this distance depends on the photon energy and is nonadditive.
- **Today, in reference photon fields used for calibration of dosimeters, secondary charged particle equilibrium is approximately realized by including tissue-equivalent material between the radiation source and the dosimeter to be calibrated.**
- **The depth of 10 mm is not adequate to assess *E* at higher photon and neutron energies. Could use $H_{max}$?**

# Option I

## Area and individual monitoring

- Stay with the existing situation for those particles and energy ranges for the limited range of particle energies where the system is well established.
- The ICRU spherical phantom and the phantoms for calibration are not changed.
- The $Q(L)$ function remains unchanged.
- **For higher radiation energies define new sets of values of the depth *d* in the ICRU sphere phantom for the calculation of coefficients of $H^*(d)$ for ranges of values of photon and neutron energies to better match values of *E*. (In fact use $H_{max}$, which might result in a non-additive quantity).**

# Option IIa
# Area monitoring

- Redefine $H^*(10)$ and $H'(d,\Omega)$, to take account of the contributions of secondary charged particles and scattered primary particles, and calculate conversion coefficients (without using the kerma approximation )for irradiation in an infinite air medium.
- Note that if an infinite air medium is not included for the calculations of coefficients ,the values will depend on the particle energy and the conditions of phantom/body exposure.
- The ICRU sphere phantom and the phantoms for calibration are not changed.
- The $Q(L)$ function remains unchanged .
- A new assessment of the relationships of the values of the operational and protection quantities will be needed.

# Option IIIa
## Area monitoring

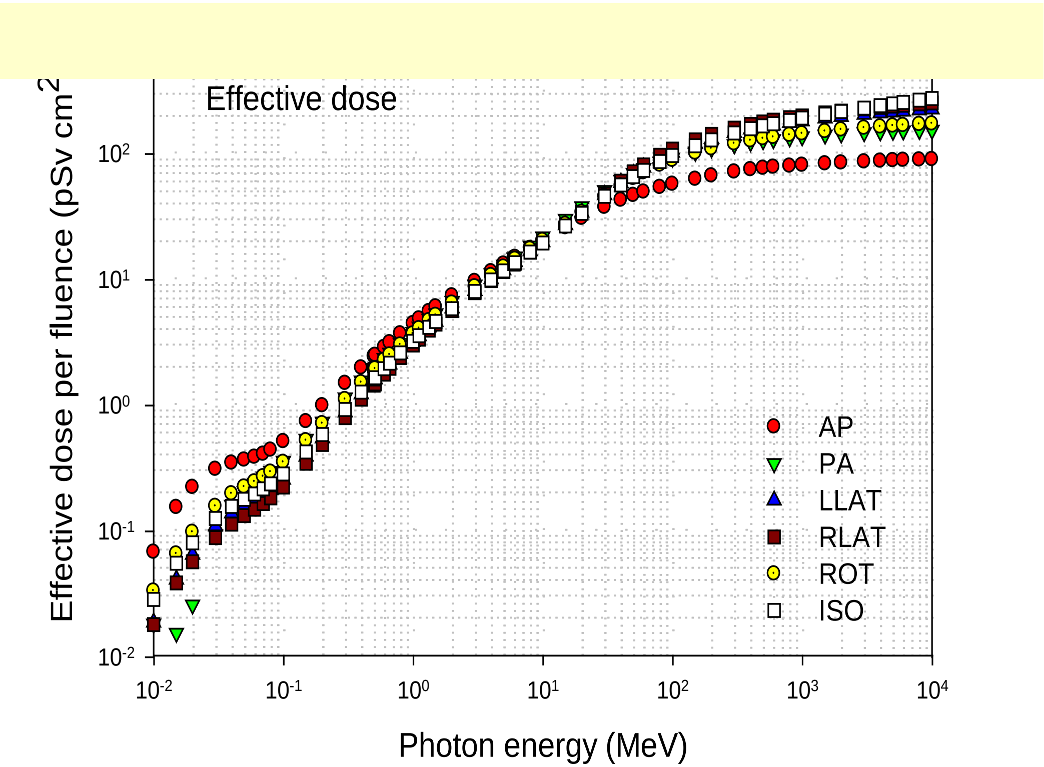
- Define the operational quantities for area monitoring without using the ICRU sphere and the quality factor $Q(L)$
- The definition of the operational quantities given by the product of fluence/air kerma/absorbed dose x conversion coefficient

$$\Phi_{\mathrm{R}}\, h_{\mathrm{quantity,R}} \quad \text{or} \quad K_{\mathrm{a}}\, h_{\mathrm{quantity,R}}$$

  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 anthropomorphic reference phantoms, on effective dose, local skin dose and dose to the lens of the eye (envelope/max functions).
- If more than one type of radiation is involved, the value of the operational quantity is given by the sum over R.

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

# Option IIb Individual monitoring

- Ensure that $H_p(d)$ includes the contributions of all of the radiation field incident on the body/phantom, including the secondary charged particles and scattered primary particles;

**or**

change $H_p(d)$ to be in terms of equivalent dose to soft tissue (at the depth $d$) (in ICRU 4-element tissue?), using $w_R$ instead of $Q(L)$.

- Conversion coefficients for calibration are calculated for the radiation field at the point of reference, including the scattered primary plus secondary particles. Note that if these values are not calculated for an infinite air medium they will depend on the particle energy and the conditions of phantom/body exposure.
- The phantoms for calibration are not changed, and the $Q(L)$ function remains unchanged .
- A new assessment of the relationships of the values of the operational and protection quantities will be needed.

# Option IIIb
## Individual monitoring

- Redefine $H_p(d)$ to assess $E_{AP}$ or $E_{max}$ for the radiation field incident on the body, including the contributions of secondary charged particles and scattered primary particles.
- The phantoms defined for calibration of personal dosimeters are the same.

# Impact of changes

- There are different options for improving the system of operational dose quantities, but it is necessary to look at the impact of the proposed changes, and carefully consider the consequences for radiation protection practice, e.g. dosimeter design, and calibration procedures.
- More to come in the very near future.

# ICRU Report Committee 26: Operational Radiation Protection Quantities for External Radiation

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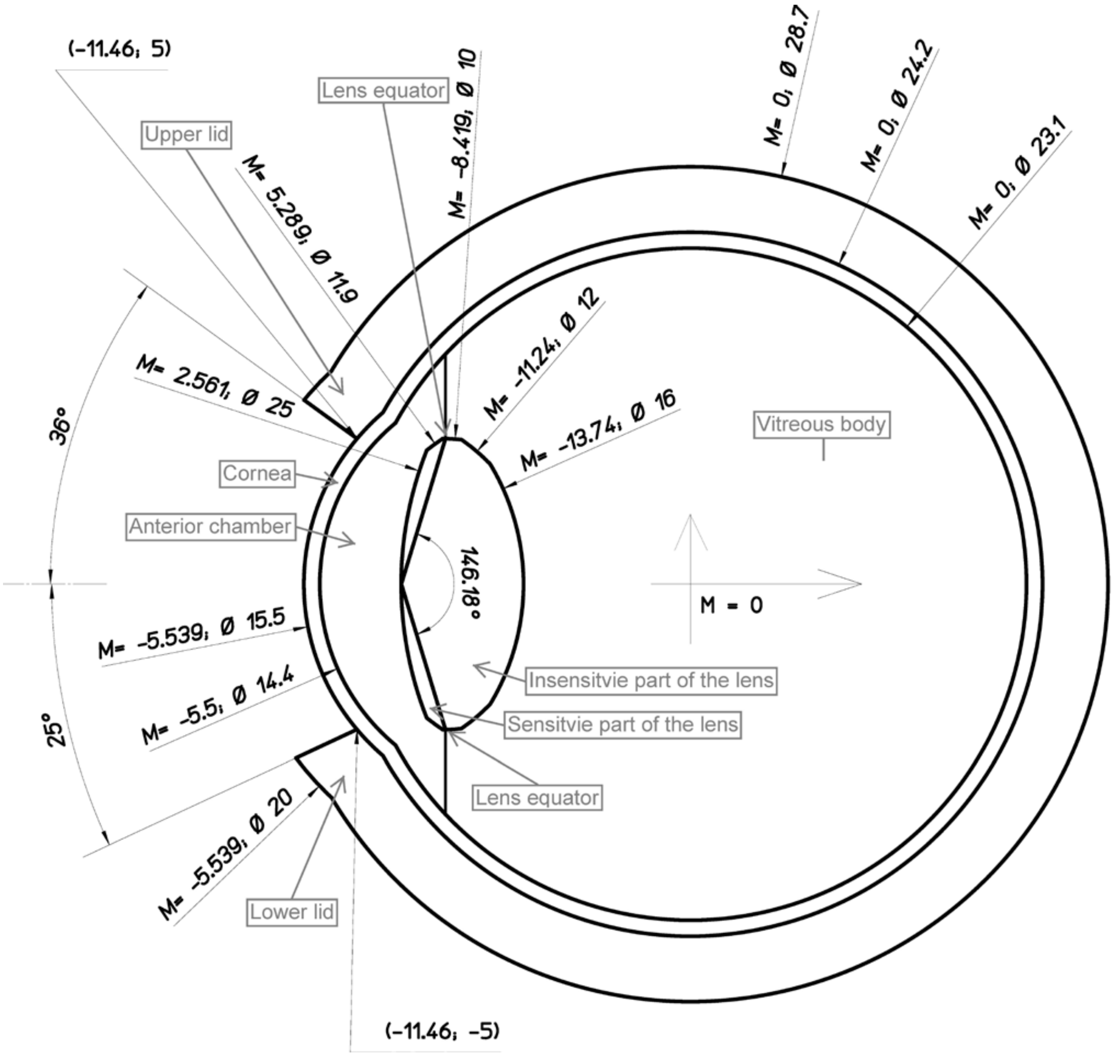
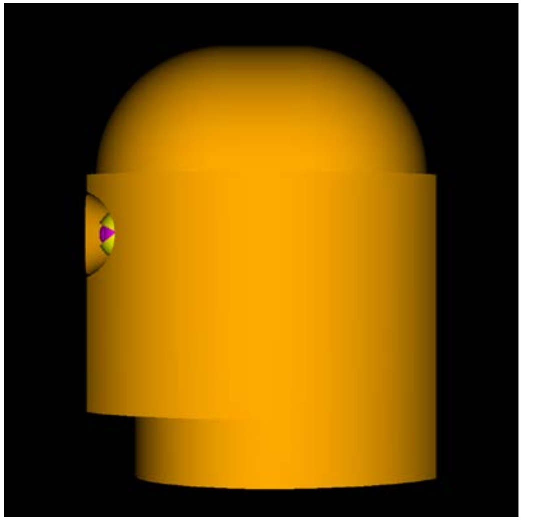
# Some Extras

Eye Dose is taking on importance

# Eye Model



(-11.46; 5)
Lens equator
Upper lid
M= -8.419; Ø 10
M= 0; Ø 28.7
M= 0; Ø 24.2
M= 0; Ø 23.1
M= 5.289; Ø 11.9
M= -11.24; Ø 12
M= 2.561; Ø 25
M= -13.74; Ø 16
Vitreous body
36°
Cornea
Anterior chamber
146.18°
M = 0
M= -5.539; Ø 15.5
M= -5.5; Ø 14.4
Insensitvie part of the lens
Sensitvie part of the lens
25°
Lens equator
M= -5.539; Ø 20
Lower lid
(-11.46; -5)

# Photon Eye Lens Dose