



UK Health
Security
Agency

Metrology needs for ICRU95

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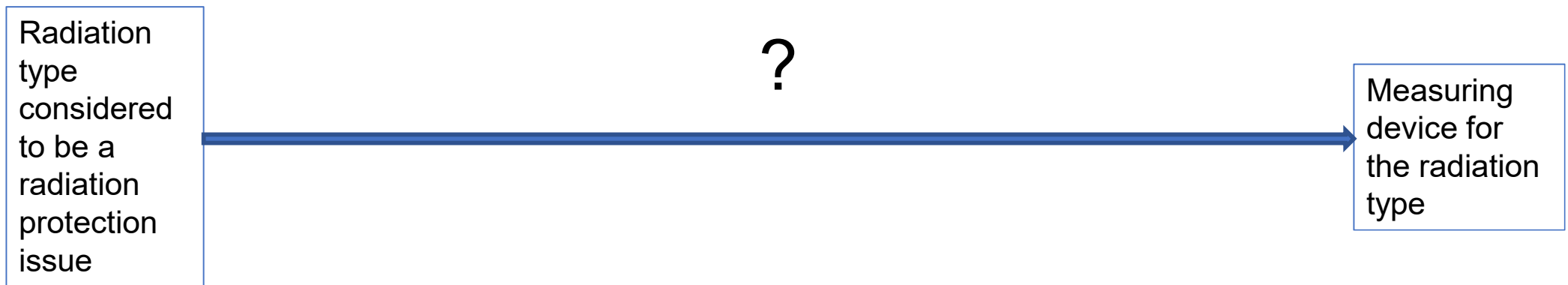
Science Group

Chilton, Oxfordshire

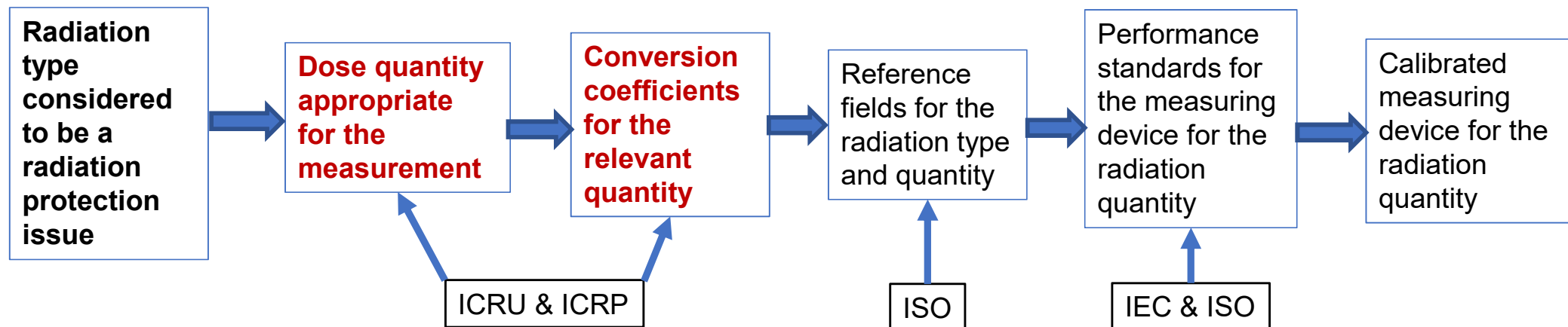
Operational dose quantities

- Designed to facilitate measurement of radiation for protection purposes: for occupational and environmental
- Based on the assumption that you can't measure the protection quantity – effective dose
- Quantities for radiation protection instruments:
 - Used to measure dose rates in a workplace or public area to determine what radiation protection measures are required
- Quantities of personal dosimeters:
 - Used to estimate the protection quantity for workers

Acceptable measurements for radiation protection

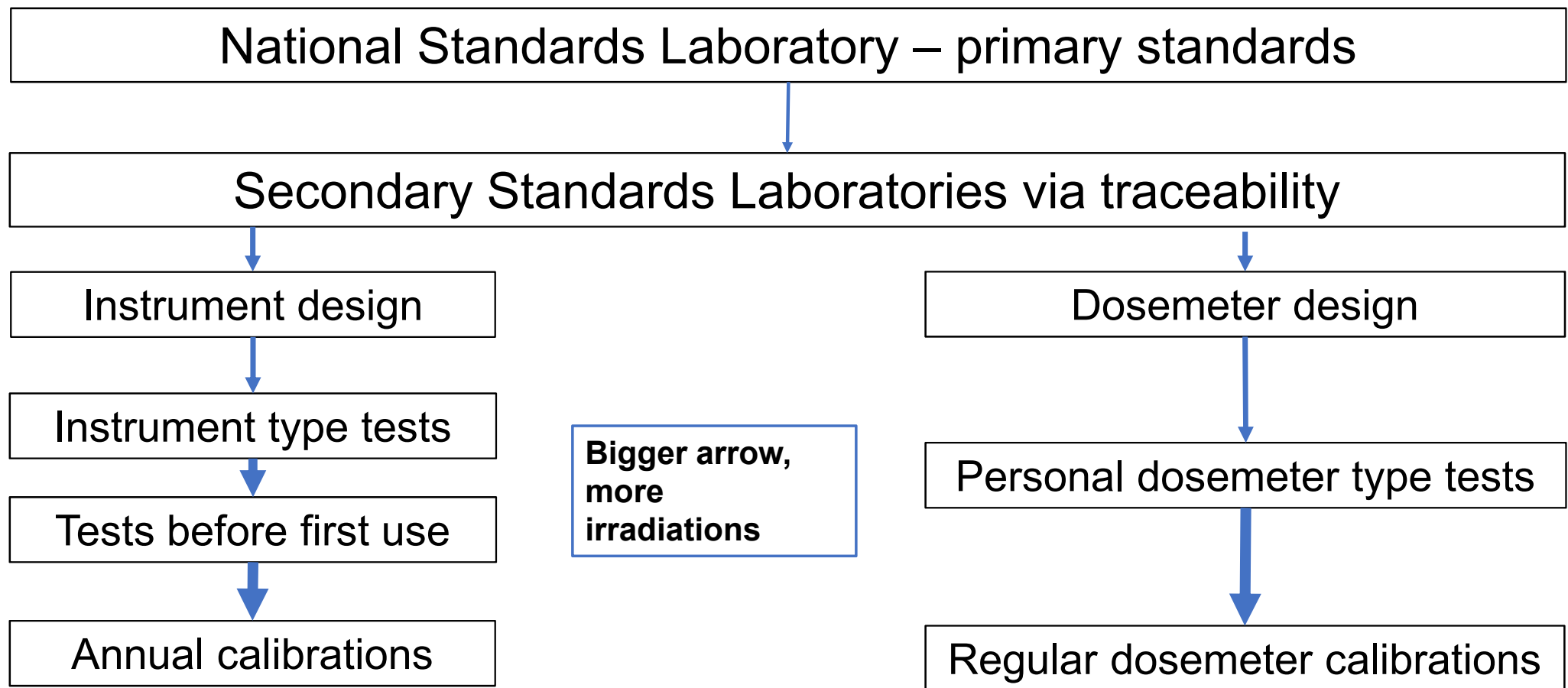


Acceptable measurements for radiation protection



- Measuring devices can be:
 - Hand-held survey meters (must be “light”)
 - Installed instruments (can be heavier)
 - Personal dosimeters (must be small & light)
 - Whole body, eye and skin
- **Measurements must be made at or be traceable to a Primary Standards lab**

System for radiation protection and calibration requirements



Three distinct types of workplace

“Normal” workplaces: nuclear power, medical, industry...

- Covered by existing quantities
- Calibration fields available
- Many instruments and dosimeters required
- Relatively **cheap** calibration fields available

Accelerators

- Better quantities required?
- Existing calibration fields not adequate and **very expensive**?
- Relatively few instruments and dosimeters required
- Radiation protection instrumentation and dosimeters not really adequate

Cosmic rays

- Better quantities required?
- Existing calibration fields not adequate?
- Few instruments required and dosimeters **not** required

ICRU Report 95 - metrology

Volume 20 • Number 1 • 2020

Journal of the ICRU

- ICRU Report 95 was published 5 years ago
 - 15 years in gestation
- There is very strong probability that the change to the new operational quantities for external radiation exposure will be included in the next ICRP Recommendations
- There has been quite a lot of discussion about the impacts on dosimeters and instruments
- There has not been a lot of discussion about the impacts on metrology
- **This presentation seeks to outline what the impacts will be and what we need to do**

ICRU REPORT 95

Operational Quantities for External Radiation Exposure



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INTERNATIONAL COMMISSION ON
RADIATION UNITS AND
MEASUREMENTS

ICRU Report 95 - motivation

Operational quantities provide a “bridge” between effective dose and measurements of risk for people exposed to ionizing radiation

- 1st revision of the Operational Quantities since ICRU Report 51 in 1993
 - “At lower and higher photon energies, the ICRU Report 39/51 defined operational quantities show significant over- and underestimates of the protection quantities...”
 - “Furthermore, the conversion coefficients given for the operational quantities have been calculated only for a limited subset of particles: photons, electrons, and neutrons.”
 - “This Report recommends alternative definitions of the operational quantities that are better estimators of the protection quantities than those previously given.”
 - “Conversion coefficients from physical field quantities—fluence and, for photons, air kerma—are given for the following particle types over **wide energy ranges**: photons, electrons, neutrons, protons, muons, pions, and helium ions.”

Background

- I am not one of the authors of ICRU Report 95
 - I am hence not speaking for ICRU (or ICRP)
- I was one of the authors of a EURADOS report*: "Evaluation of the Impact of the New ICRU Operational Quantities and Recommendations for their Practical Application"
- This presentation is intended to reflect the changes to **metrology** that will be required to fully use the huge range of new quantities and conversion coefficients that we now have for operational radiation protection

* <https://eurados.sckcen.be/sites/eurados/files/uploads/Report-Publications/Reports/2022/EURADOS%20Report%202022-02.pdf>

ICRU Report 95

- Abandons the fixed depth of d mm for external **penetrating** radiation
- Uses “realistic” models of the whole body, eye or skin to produce new operational quantities
- Quantities are calculated in vacuum, without secondary charged particle equilibrium
- This Report recommends:
 - “... that **instrument manufacturers and developers work to develop revised dosimeters and instruments** that accurately provide measurements that conform to these recommendations.”
 - “... that international and national authorities recognize the need for a gradual and prudent period of adoption to balance the costs of implementation with the benefit of a more coherent system of operational quantities, representing the protection quantity in measurement.”
 - **Has relatively little to say about the impacts on metrology**

ICRU Report 95 – Summary of changes

- **Penetrating radiation:**

- Ambient Dose Equivalent, $H^*(d)$ → Ambient Dose, H^*
- Personal Dose Equivalent, $H_p(10, \varphi)$ → Personal Dose, $H_p(\varphi)$ [φ is the direction]

- **Eye dosimetry:**

- Directional dose equivalent, $H'(3, \varphi)$ → Directional Absorbed Dose in the Lens of the Eye, $D'_{\text{lens}}(\varphi)$
- Personal dose equivalent, $H_p(3, \varphi)$ → Personal Absorbed Dose in the Lens of the Eye, $D_{p, \text{lens}}(\varphi)$
- Note: $D'_{\text{lens}}(\varphi) = D_{p, \text{lens}}(\varphi)$ so ICRU 95 only has data for $D_{\text{lens}}(\varphi)$

- **Skin dosimetry:**

- Directional Dose Equivalent $H'(0.07, \varphi)$ → Directional Absorbed Dose in Local Skin, $d'_{\text{local skin}}$
- Personal Dose Equivalent $H_p(0.07, \varphi)$ → Personal Absorbed Dose in Local Skin, $d_{p, \text{local skin}}$
- Note: $D'_{\text{local skin}}(\varphi) = D_{p, \text{local skin}}(\varphi)$ so ICRU 95 only has data for $D_{\text{local skin}}(\varphi)$

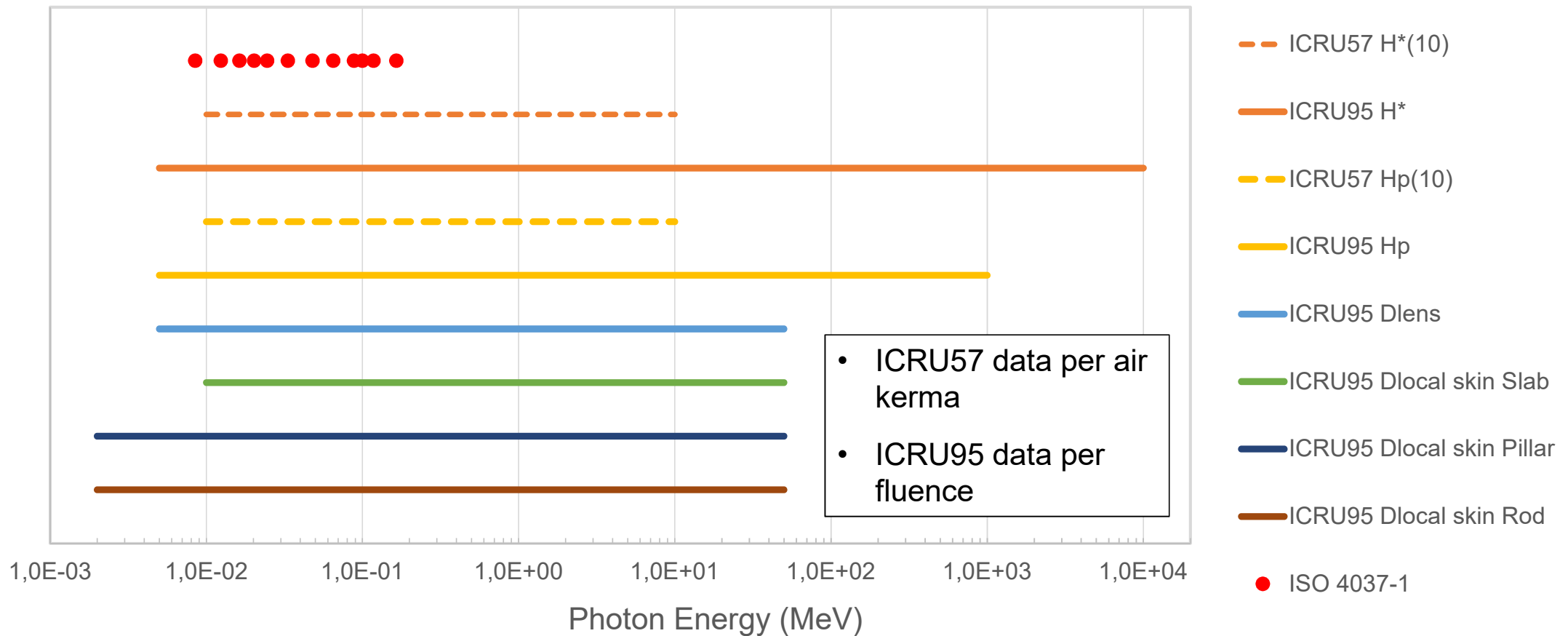
ICRU Report 95

- Ambient dose, H^*
 - Photons, neutrons, electrons, positrons, protons, μ^- , μ^+ , π^- , π^+ , helions
- Personal Dose, $H_p(\varphi)$
 - Photons, neutrons, electrons, positrons, protons, μ^- , μ^+ , π^- , π^+ , helions
- Directional and Personal Absorbed Dose in the Lens of the Eye, $D_{\text{lens}}(\varphi)$
 - Photons, neutrons, electrons, positrons
 - No RBE weighting, in Gy
- Directional and Personal Absorbed Dose in Local Skin, $d'_{\text{local skin}}$ and $d_{\text{p local skin}}$
 - Photons, neutrons, electrons, positrons, helions
 - No RBE weighting, in Gy
 - Conversion coefficients for:
 - Whole body – slab phantom
 - Fingers – rod phantom
 - Wrist/ankle – pillar phantom

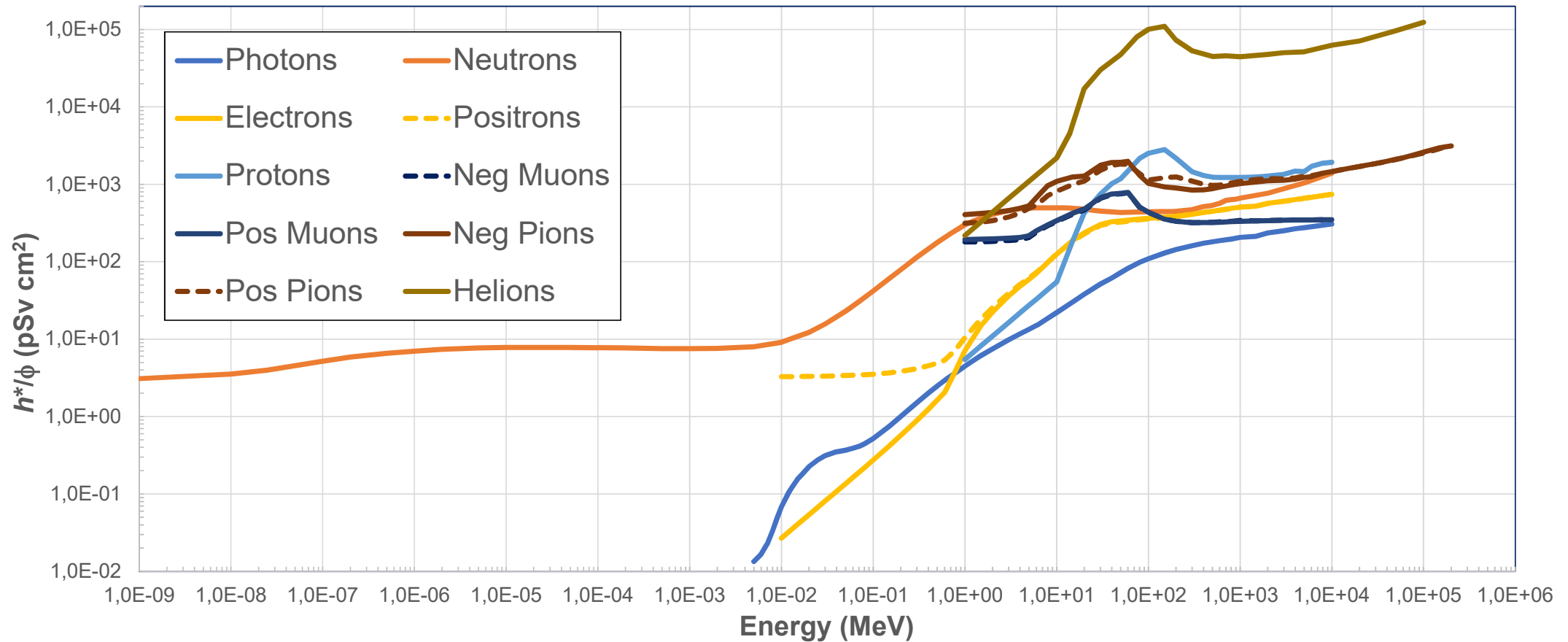
EURADOS Report on Impacts of ICRU95: general recommendations

- Free download:
<https://eurados.sckcen.be/sites/eurados/files/uploads/Report-Publications/Reports/2022/EURADOS%20Report%202022-02.pdf>
- Reviewed the impact of the new operational quantities.
- **There is considerable work that still needs doing, particularly in interpreting the practical implications.**
- Adaptation is likely to be a long process.
 - **Instrument suppliers, dosimeter suppliers, individual monitoring services and calibration laboratories, should therefore begin work soon, to evaluate and plan for the change.**
- Authorities should be aware of the potential costs involved in changing to the new quantities. These costs should be evaluated at an early stage.
- **This presentation focuses on areas not covered in detail in the EURADOS Report**

ICRU 57 & ICRU95 conversion coefficients for photons vs ISO Calibration Fields



ICRU95 conversion coefficients for h^* for all particles



Photons

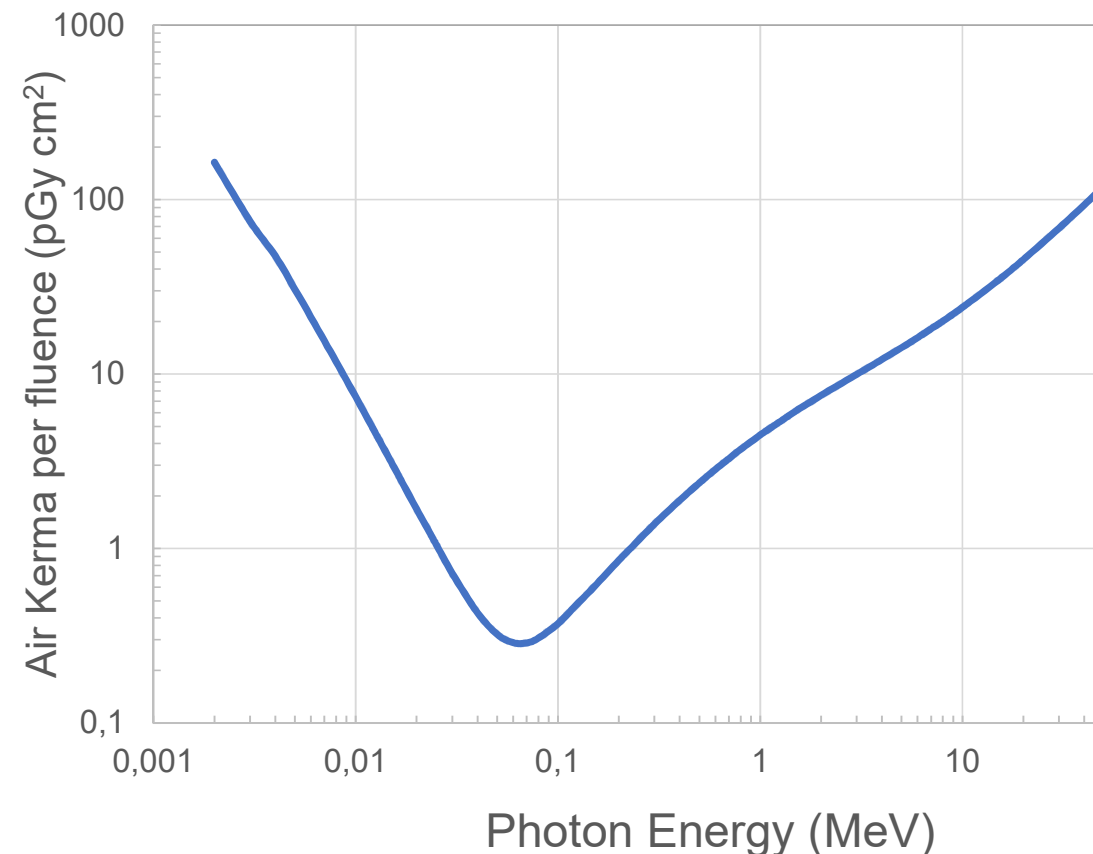
- The most significant component of dose to people in workplaces is from photons
- Photon measuring devices are well developed, as are calibration fields for the energy range for which most people are exposed
- The new conversion coefficients pose specific problems for photon calibration because of the lack of charged particle equilibrium
- The available calibration fields do not come close to covering the whole energy range of the new conversion coefficients

Air kerma vs fluence – the “kerma approximation”

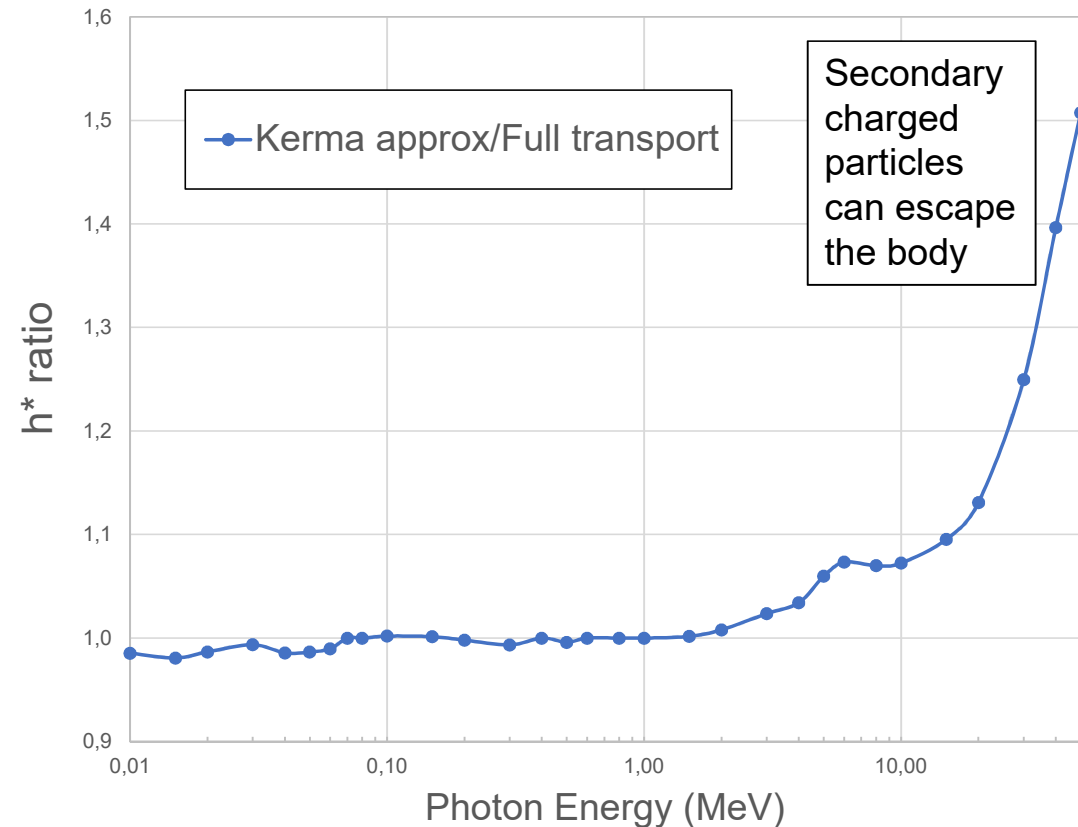
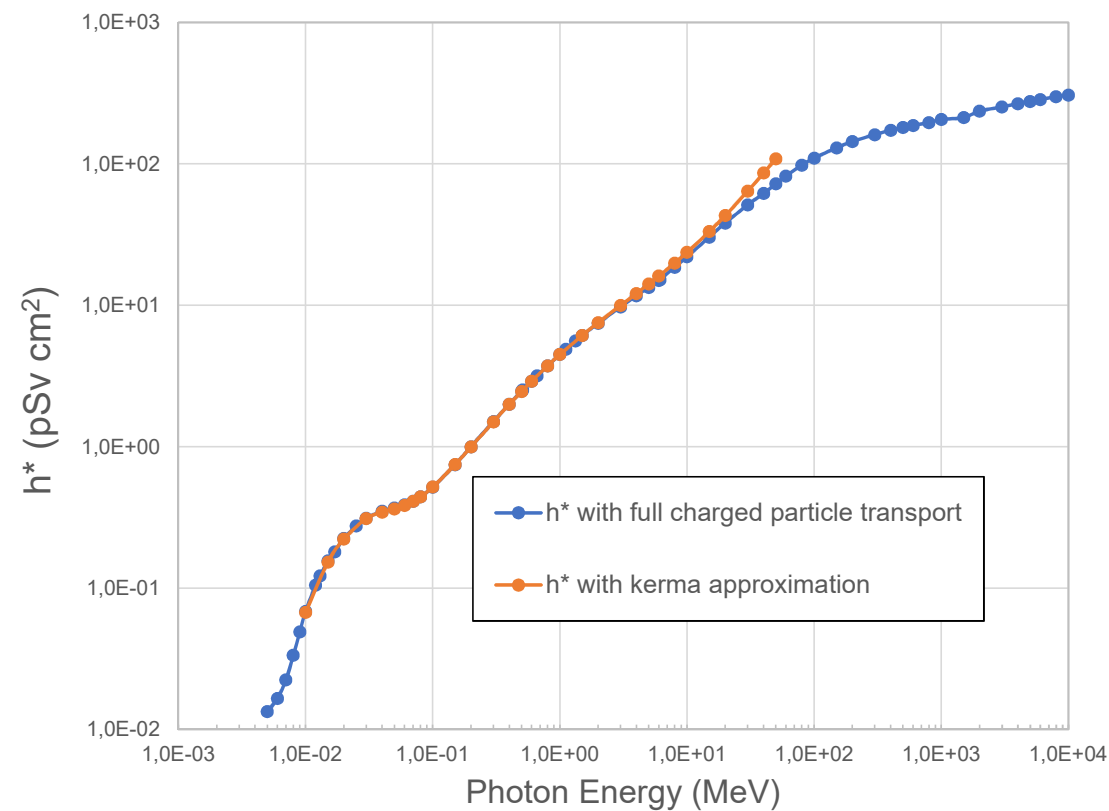
- Kerma approximation was favoured when Monte Carlo transport of secondary charged particles was problematic:
 - Relies on secondary charged particle equilibrium
 - Breaks down when secondary electrons have long ranges relative to the material boundaries, and material densities are very different
- Kerma can be estimated using an ion chamber:
 - Provides the basis for **reference dosimetry**
- Commercially available reference ion chambers go up to **50 MeV** for photons
- New quantities calculated in a vacuum with full secondary charged particle transport:
 - Per unit fluence
 - Does not include ingrowth of other particle types in the field

ICRU 95: Air Kerma per Fluence for Photons

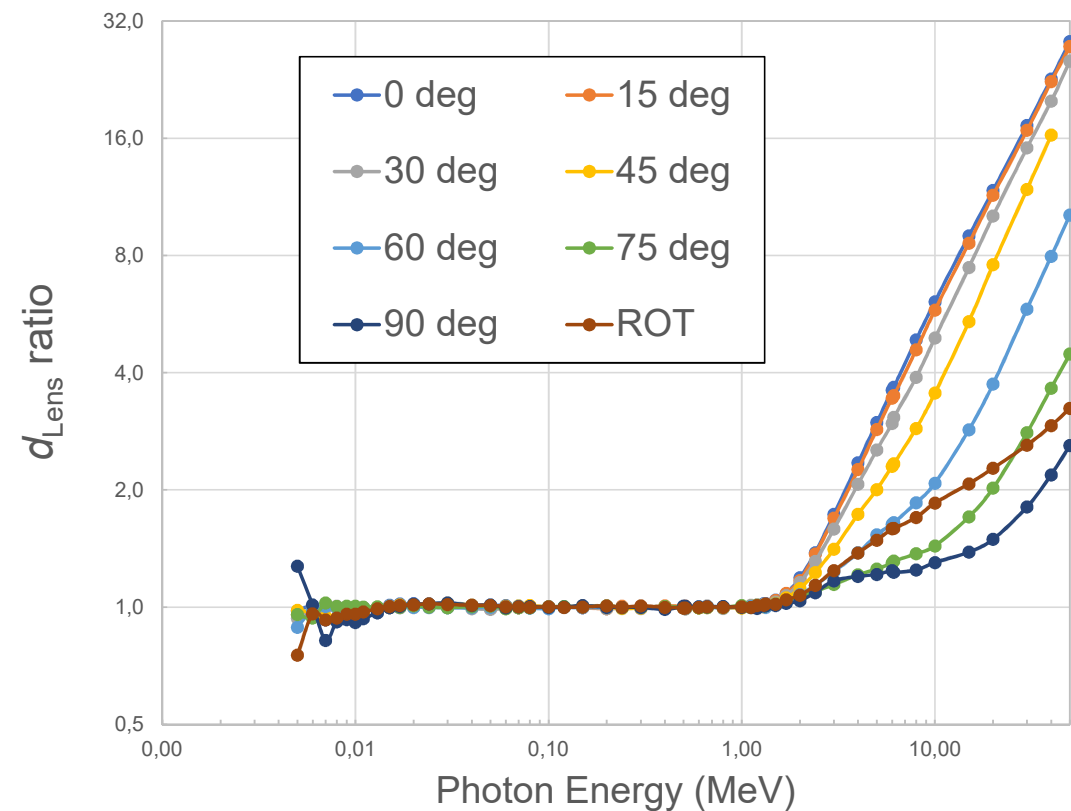
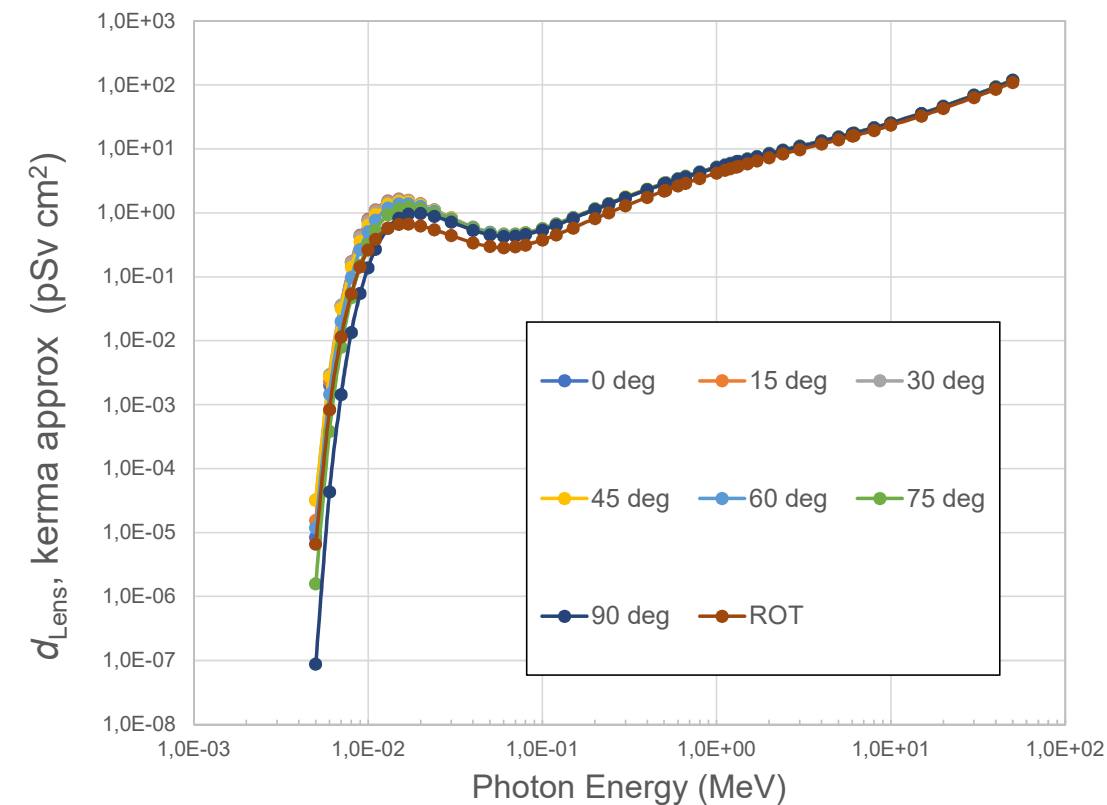
- Photon conversion coefficients were previously published with respect to air kerma **and** fluence
- ICRU95 includes photon conversion coefficients up to 50 MeV in terms of air kerma with kerma approximation
- Reference ion chambers go up to 50 MeV
- It is not clear how we would do reference dosimetry above 50 MeV



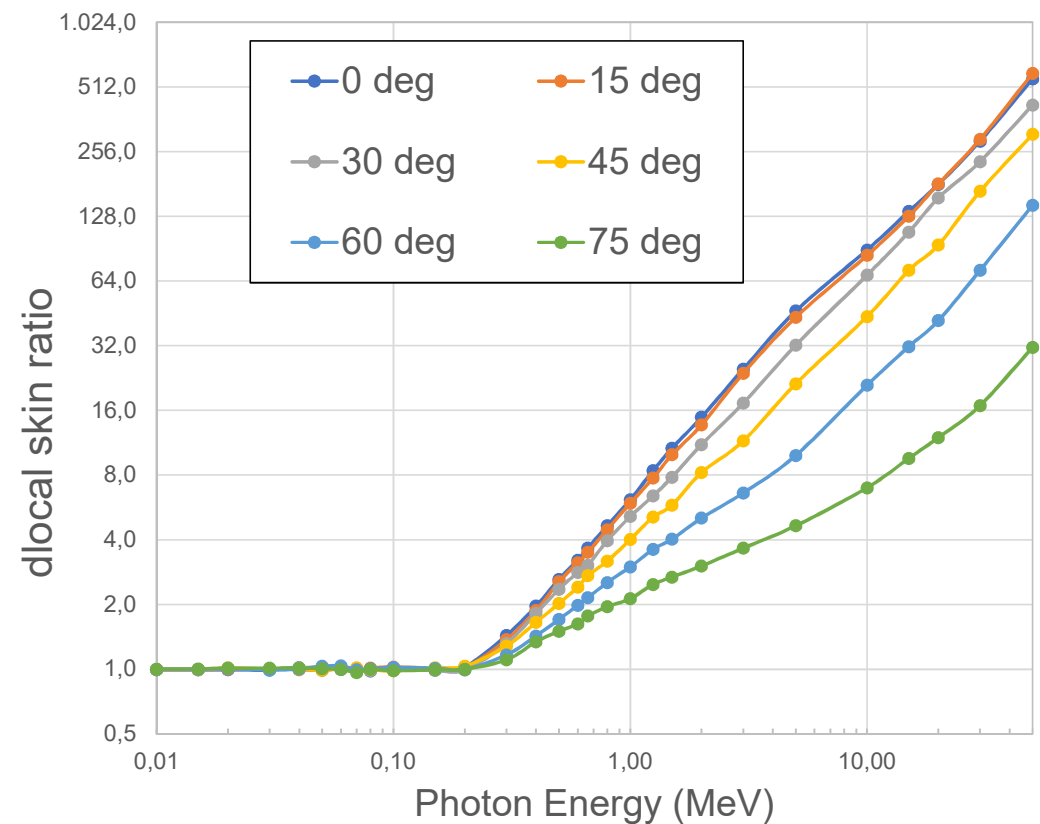
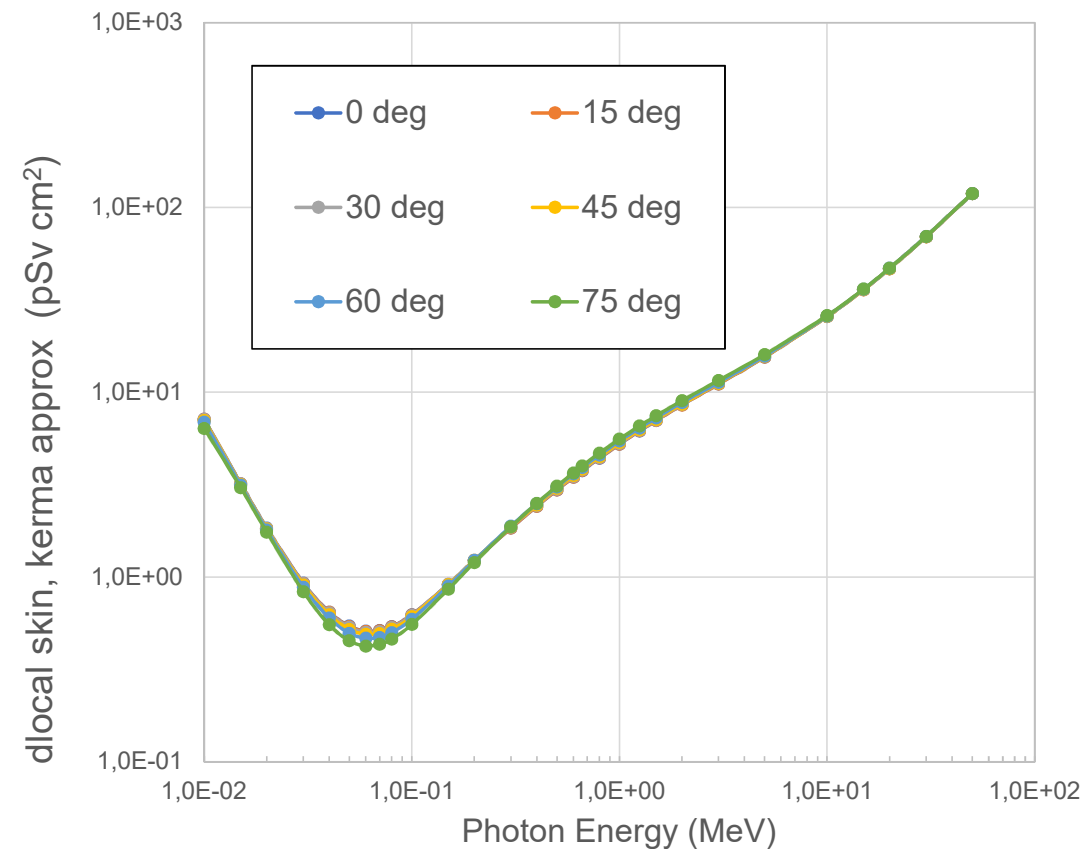
ICRU 95: h^* for Photons – kerma approximation vs full particle transport



ICRU 95: d_{Lens} for Photons – kerma approximation vs full particle transport



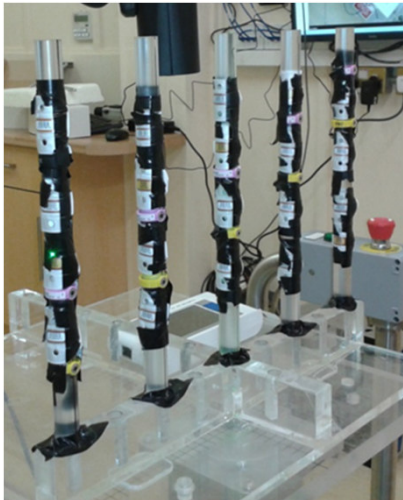
ICRU 95: $d_{\text{Local skin}}$ for Photons – kerma approximation vs full particle transport



Current devices for eye and skin dosimetry

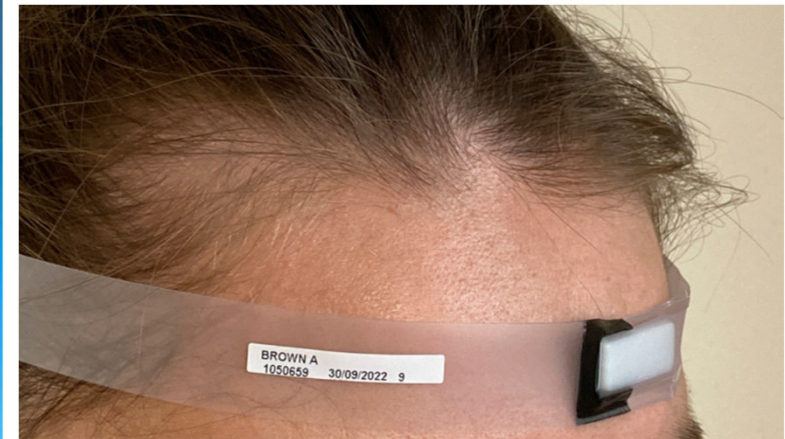
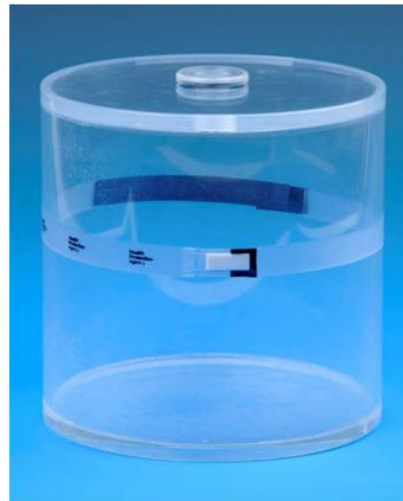
Extremity doseimeters

Need to be very **small**



Eye doseimeters

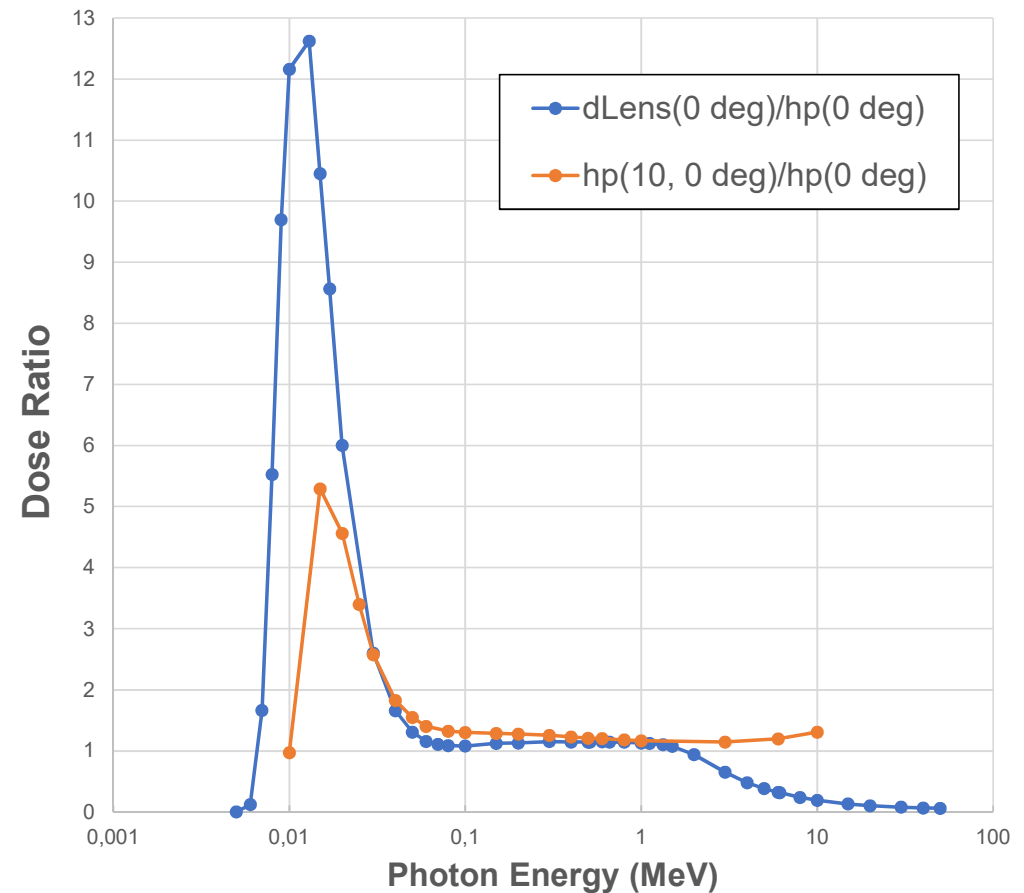
Must be wearable on headband or glasses



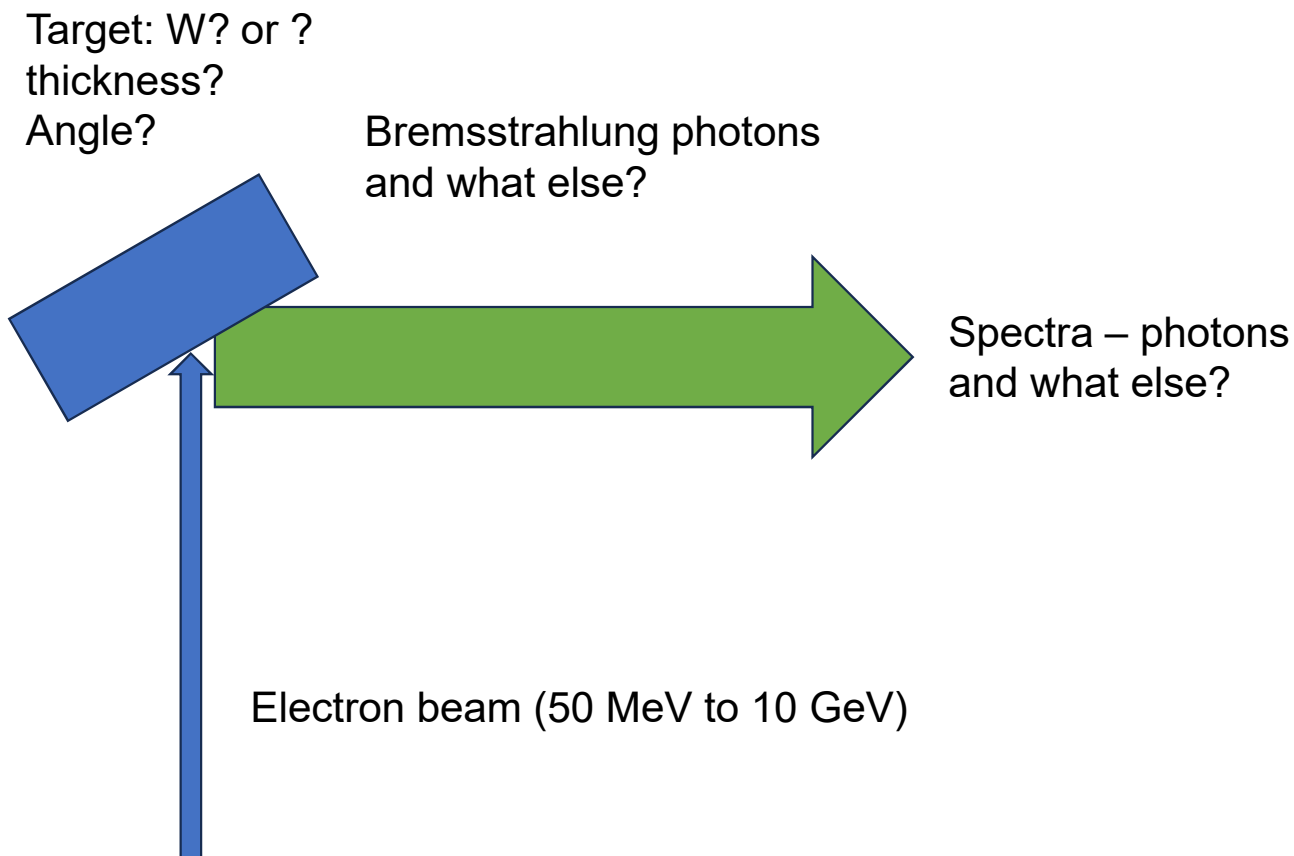
The current photon calibration fields will be able to be used with the kerma approximation if secondary charged particle build up is used, where necessary

Will eye dosimetry now dominate for low energy photon fields?

- One of the big improvements is the elimination of the big overestimates in doses of effective dose for low energy photons
- But the lens of the eye will now dominate in this energy range
- This is because the 3 mm depth is retained
- For low energy photons – eye dosimetry will be more important than whole body, **unless dose limits change**

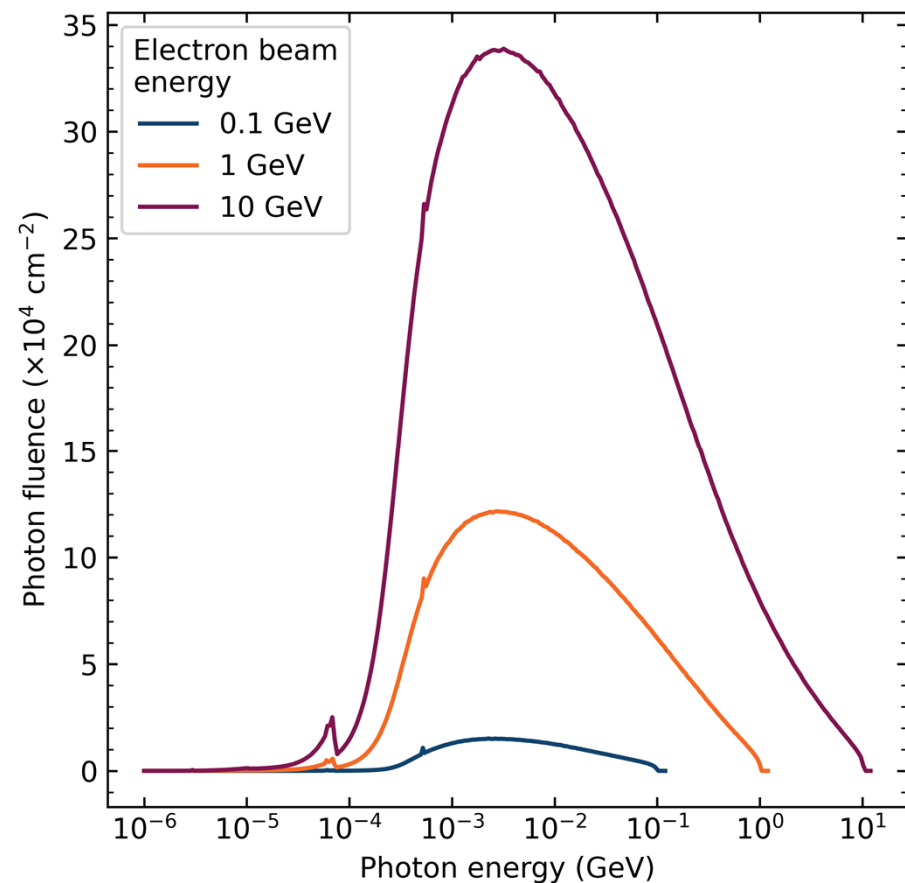


How might we generate high energy photon reference fields?

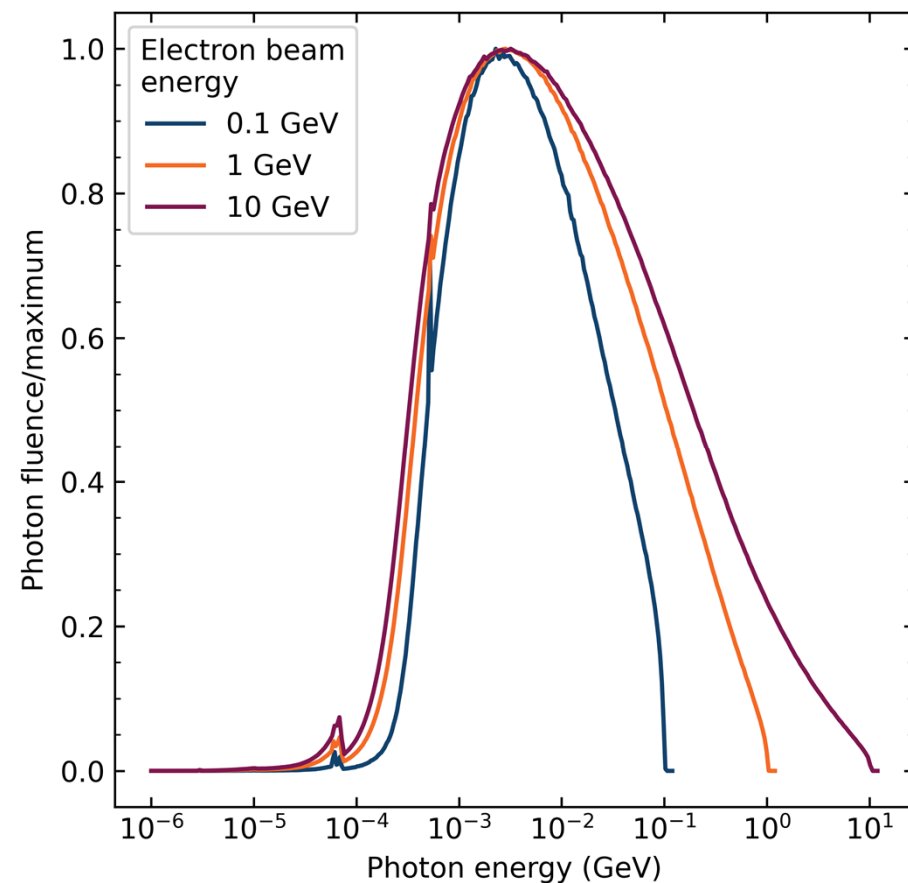


- The same principle as an X-ray tube or a linac
- High energy electrons stopping in a high Z target to generate bremsstrahlung photons
- Mean photon energy typically 1/3 of the electron energy
- Beam shaping options become quite ineffective above 100 keV

How might we generate high energy photon reference fields?



- H_p goes up to 1 GeV
- H^* goes up to 10 GeV
- Field becomes contaminated with n, p, e^- , e^+ , π , μ ...
- How are we going to calibrate devices?



Neutrons

- A significant component of dose to people in nuclear workplaces is from neutrons
- Neutron measuring devices are well developed, as are calibration fields, for the energy range for which most people are exposed
- Because of their importance for cosmic ray and accelerator dosimetry higher energy fields have been developed for neutrons
- However, the available calibration fields do not cover the whole energy range of the new conversion coefficients

Current devices for neutron radiation protection

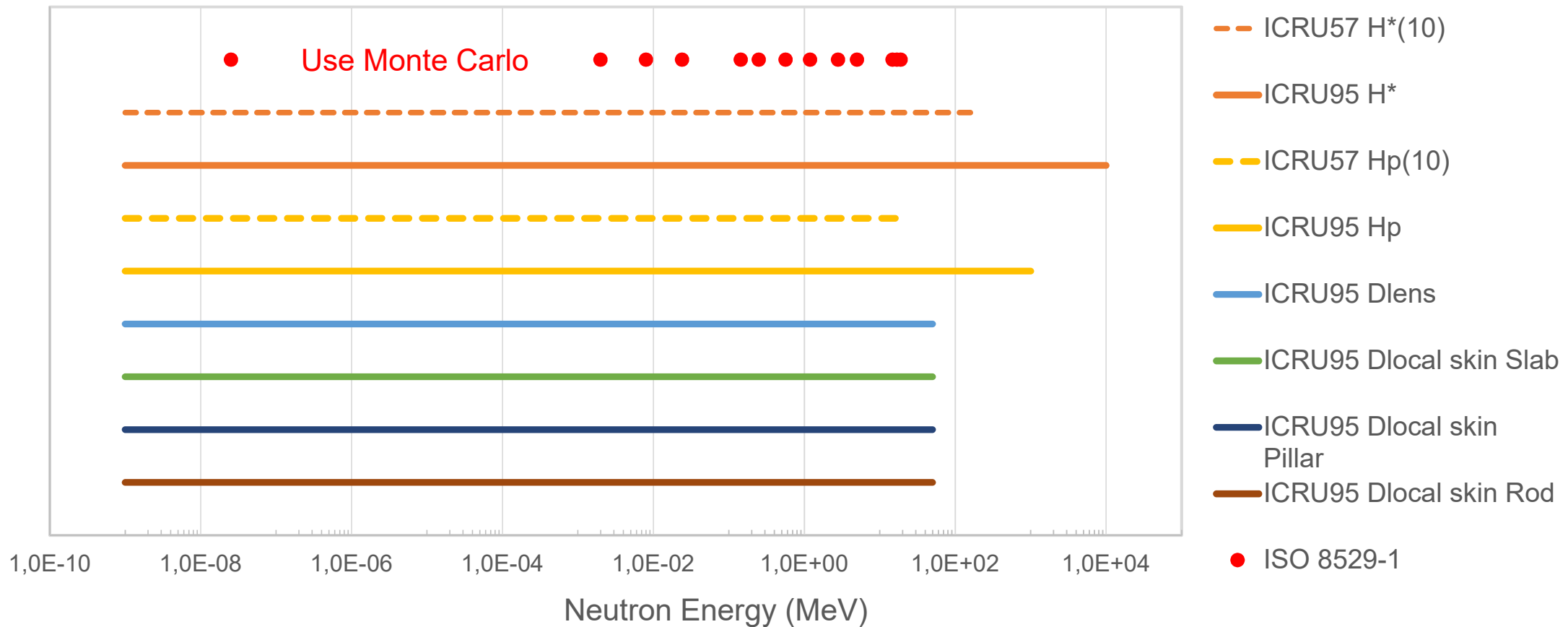
Whole body **neutron** personal dosimeters



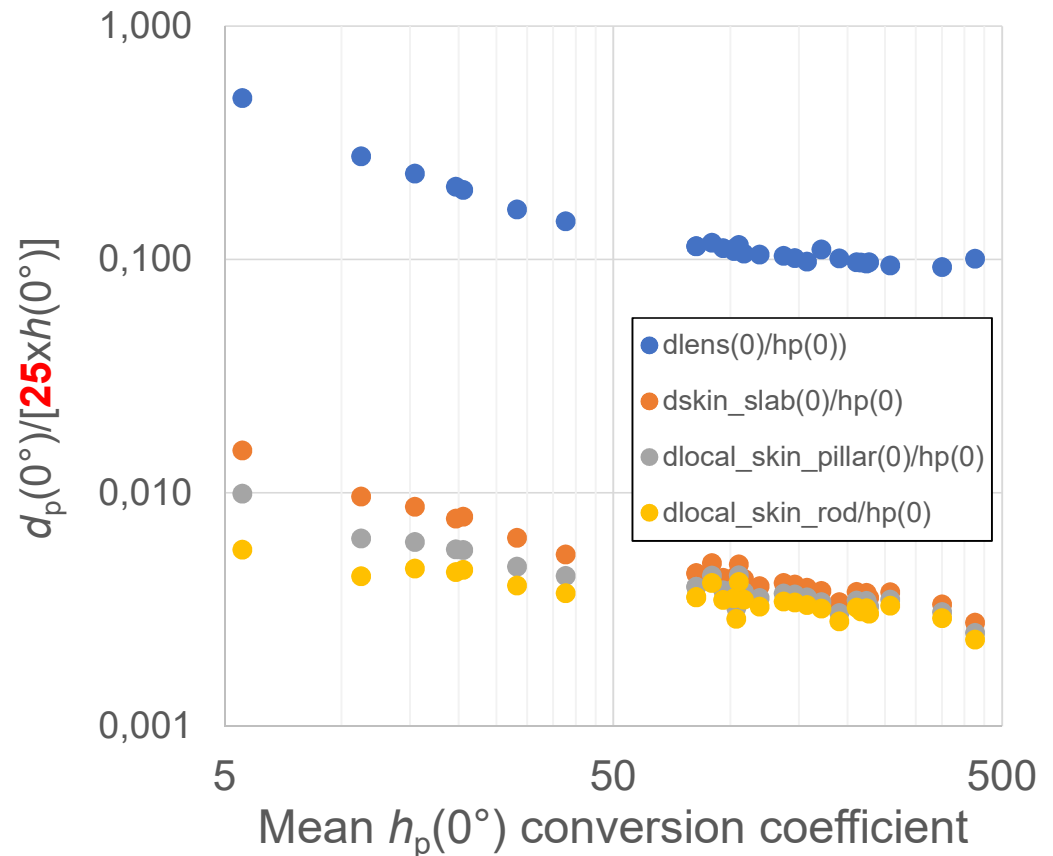
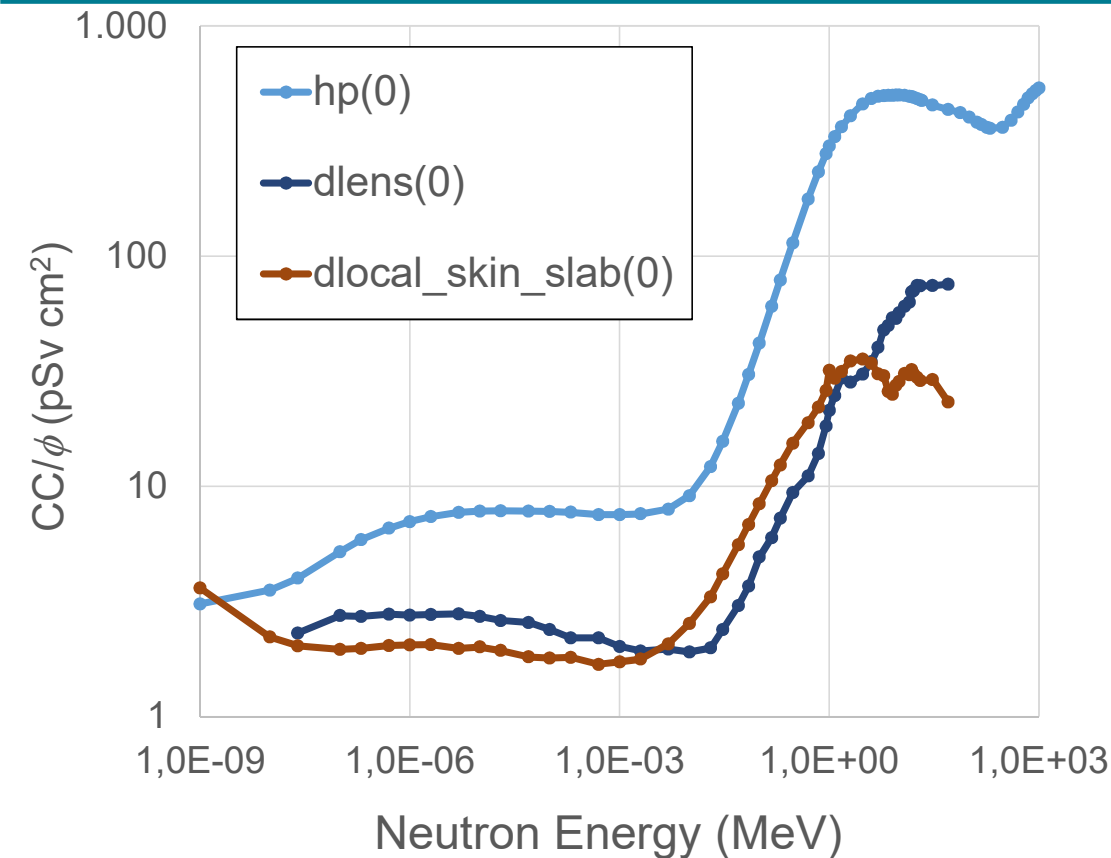
Hand-held **neutron** survey meters



ICRU 57 & ICRU95 conversion coefficients for neutrons vs ISO calibration fields



Will we need skin and eye dosimetry fields for neutrons?



Should skin and eye dose fields be added to ISO 8529-1?

- **No**
- The quantities are too small in all realistic workplace fields to warrant effort in designing skin or eye dosimeters for neutrons:
 - The lack of Relative Biological Effectiveness weighting means the doses are insignificant
 - The use of 0° for skin with full transport of all charged particles in a vacuum means that high energy neutrons deposit dose deeper than skin
 - For skin the dose limit being 25 times higher means that the doses are even less significant in terms of radiological protection.
- No need to update:
 - ISO 21909 Passive Neutron Dosimetry systems
 - IEC 61526 Direct Reading Personal Dosimeters

But what of H_p and H^* for neutrons?

- There are higher energy fields available, but often **far from monoenergetic**
 - ChipIR @STFC – up to about 500 MeV (broad distribution)
 - CERF @CERN – main peak at 100 MeV (broad distribution)
 - iThemba, Capetown – 66 MeV and 100 MeV (**quite monoenergetic**)
 - HIMAC, Japan – 100 MeV to 800 MeV (monoenergetic)
- “Need” up to **1 GeV** for H_p
- “Need” up to **10 GeV** for H^*
- Design problems for personal dosimeters greater owing to the need for low weight and compact size
- For survey instruments size issues less of a problem than weight

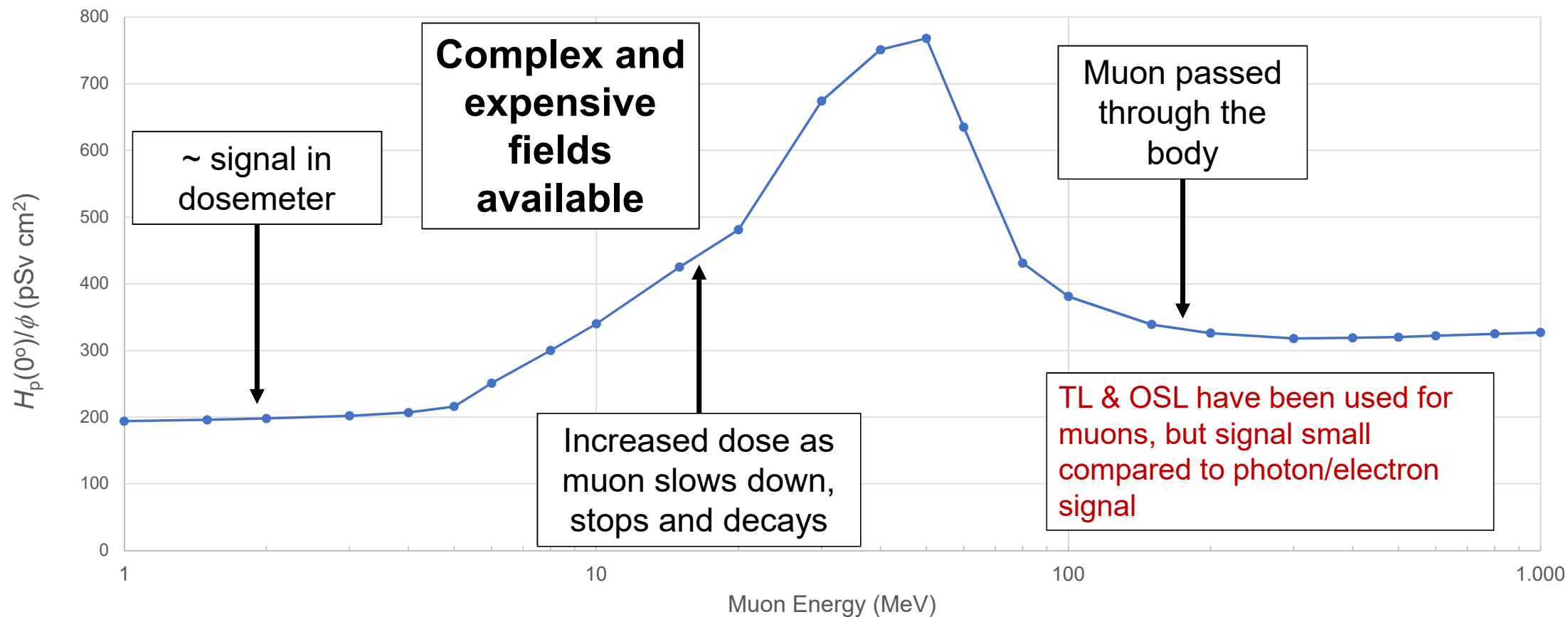
Positrons, muons, pions, kaons, protons, helions...

- The only reference fields for any of these particles are for alpha and beta particles:
 - Restricted to the energy range of radioactive decays: < 10 MeV
- Requires a reference calibration facilities to measure the response?
- Of course, measurement devices need to be developed

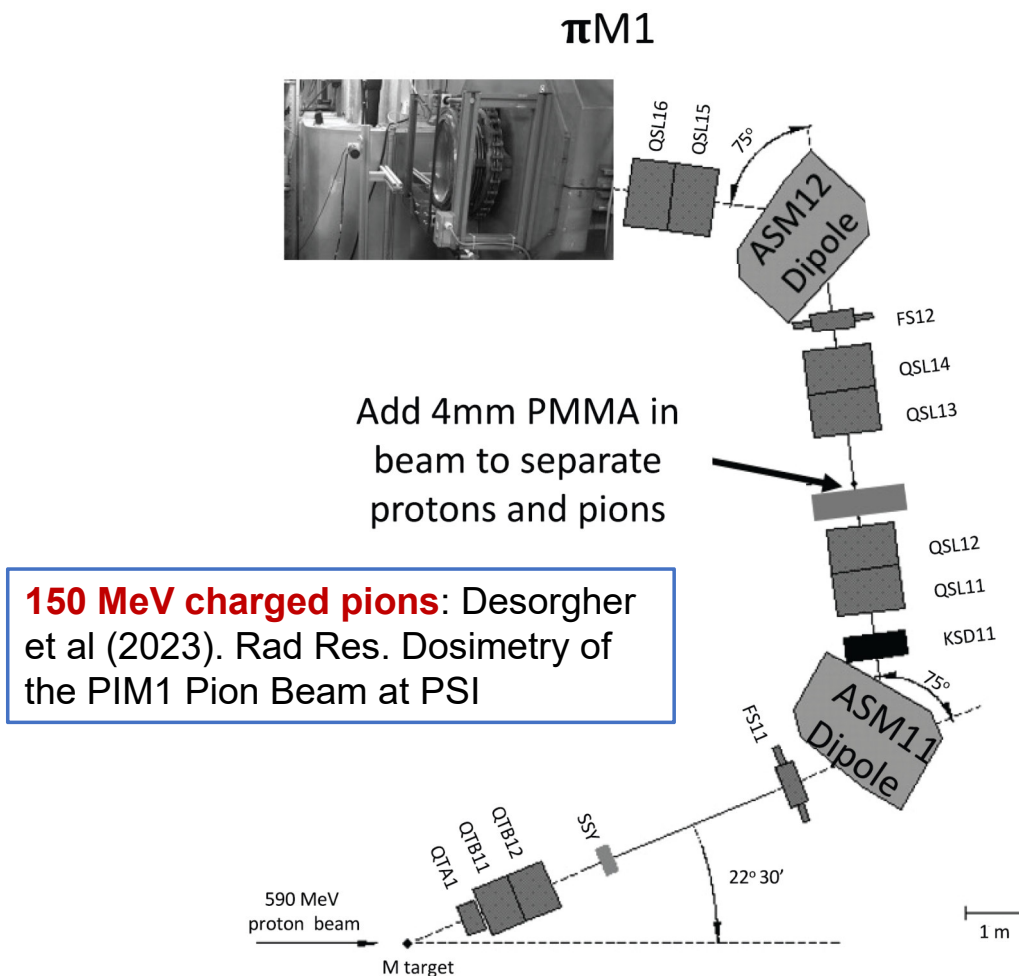
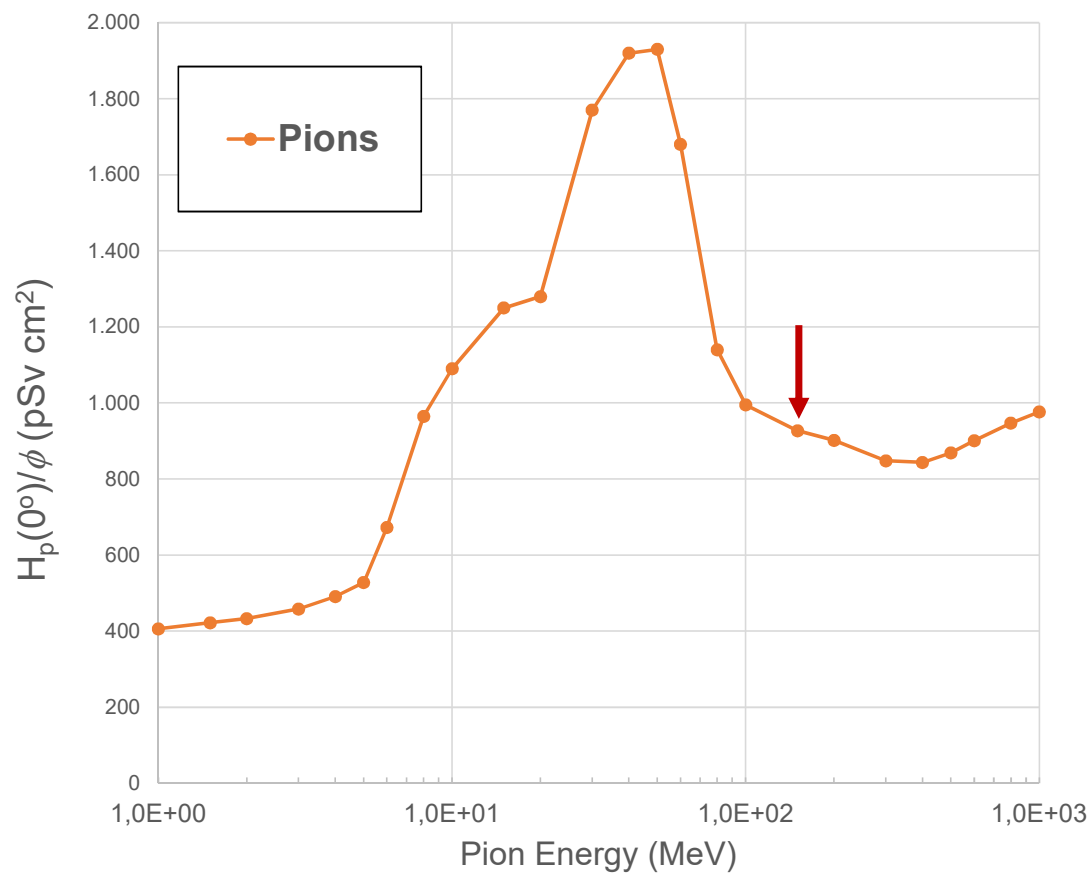
Particle	H^*	H_p	d_{lens}	$d_{\text{local skin}}$
Electron	10 GeV	1 GeV	50 MeV	50 MeV
Positron	10 GeV	1 GeV	50 MeV	50 MeV
Proton	10 GeV	1 GeV		
μ^-	10 GeV	1 GeV		
μ^+	10 GeV	1 GeV		
π^-	200 GeV	1 GeV		
π^+	200 GeV	1 GeV		
He^{2+}	100 GeV	1 GeV		50 MeV

Maximum energies of the conversion coefficients in ICRU 95 for other particles

Muons H_p – why designing a personal dosimeter is difficult



Pions: H_p and an irradiation facility



The way(s) forward?

1. We can use the kerma approximation for most photon calibrations
2. Develop a range of calibration fields to span the energy ranges for the various particles
 - i. Must accept mixed field calibrations as pure fields will be hard to attain?
 - ii. Will have to accept broad energy distributions for neutral particles
3. Develop performance standards for instruments and dosimeters
4. Manufacturers will need to design to those standards

OR

- We recognize that this cannot be done for many of the particles to cover the whole energy range
- We accept that Monte Carlo is the only method of designing and calibrating for high energies – abandon true metrology?
 - But these particles/energies span ranges of great uncertainty for Monte Carlo

Summary

- There are a vast new array of data to facilitate the design of instruments and dosimeters for operational radiation protection for planned and existing exposures
- **Using these data is far more complex than has been stated in ICRU Report 95**
- There will need to be cost-benefit analyses to determine whether a radiation type and energy range warrants this development
- A more cost-effective method may be to recognize that traditional reliance on metrology may need to be reduced
- But many of the problems identified would be better addressed by “Online Dosimetry” – direct estimates of effective dose via worker tracking