ICRU Report 95: *Operational quantities for External Radiation Exposure*
What changes for Radiation Protection?

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ICRU Report 95 (2020)
Operational Quantities for External Radiation Exposure

- Previous quantities (ICRU 39 and 51)
- Operational Quantities for external exposure
- Conversion Coefficients
- Practical Consequences
- Appendices
  - Values of Conversion coefficients
  - Computer Codes
• Short excursion to quantity definition
• What changes?
• Effect on dose values in radiation fields
• Effect on instrument calibration
• Summary
Protection vs. Operational Quantities

- ICRP defines *protection quantity* Effective Dose based on absorbed dose to express risk, constraints and limits.
- Protection quantity defined over the volume of a body, not measurable.
- ICRU proposes *operational quantities*, defined in a point and measurable.
Relation of Quantities

Physical Quantities
\( \Phi, K_a, D \)

Protection Quantity
Calculation With Phantoms

Operational Quantities
Calculation With Phantoms

Numerical value for specified radiation field

Measurement
Instrument response \( R(E, \Omega) \)

Numerical value for specified radiation field
Today

Physical Quantities
\( \Phi, K_a, D \)

Protection Quantity
Effective dose \( E \)
Calculation:
Anthropomorphic Phantoms

\[ E = \int dE_p \ \Phi_{E_p} \ h_E(E_p, \text{inc}^*) \]

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

Operational Quantities
Ambient dose equivalent \( H^*(10) \)
Personal dose equivalent \( H_p(10) \)
Calculation:
Geometric Phantoms

\[ H_p(d, \Omega) = \int \int dE_p\ d\Omega \ \Phi_{E_p} \ h_p \left( d, E_p, \Omega \right) \]

\[ H^*(d, \Omega) = \int \int dE_p\ d\Omega \ \Phi_{E_p} \ h^* \left( d, E_p, \Omega \right) \]

For photons in kerma approximation

Measurement
Instrument response \( R(E,\Omega) \)

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What changes?

- Operational quantities from present to future:
- Change to anthropomorphic phantoms

- Better approximation of $E$ by definition
- Also:
  - Definition of quantities to limit tissue effects (local dose to skin and to eye lens) as absorbed dose
  - More radiation types, e.g. positrons, protons, pions…
  - Much wider energy range
ICRU Report 95

Physical Quantities
$\Phi, K_a, D$

Protection Quantity
Effective dose $E$

Calculation: Anthropomorphic Phantoms

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

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

Definition

Operational Quantities
Ambient dose $H^*$
Personal dose $H_p$

Calculation: Anthropomorphic Phantoms

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

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

Measurement
Instrument response $R(E, \Omega)$

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What changes – Photons

Effective dose $E$ vs. Personal Dose $H_p$
What changes – Neutrons

Effective dose $E$ vs. Ambient Dose $H^*$

$h_E(\Omega), h^*$ (pSv cm$^2$) vs. Neutron Energy (MeV)
Personal dose – photons

Conversion coefficients from kerma $K_a$ to operational quantity

At energies typical for radioisotopes, $H_p = 0.86 \times H_p(10)$

At low-energy x-ray (backscatter from patient) $H_p = 0.2 \times H_p(10)$
Activation products

Activation with 3.5 GeV proton beam
Photon and electron spectra (1h decay)
$H^*(10)$ and $H^*$ overlay

<table>
<thead>
<tr>
<th>Decay Time</th>
<th>1 hour</th>
<th>1 week</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon</td>
<td>0.87</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>Electron</td>
<td>2.9</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Positron</td>
<td>0.9</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Total</td>
<td>0.87</td>
<td>0.87</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**Ratio $H^* / H^*(10)$**
- Photons dominate
- $H^* < H^*(10)$ by 15%
- Typical for radionuclides
- Attention for pure $\beta$–emitters
Low-energy x-ray spectra

High-dose rate spectrum, 20 kV tube voltage

Fluence spectrum

$H^*(10)$-weighted spectrum

$H^*$-weighted spectrum

Diagnostic x-ray calibration spectra

Upper curve: $H^*(10)$

Lower curve: $H^*$

Influence on dose of medical personnel during interventional radiology under study
Prompt radiation at a particle accelerator (160 MeV protons)

- Behind the dump: high-energy particles, $H^* \geq H^*(10)$
- In Front: multiple scattered neutrons: $H^* < H^*(10)$

- Analogue results for proton therapy accelerators
Consequences for Dose Registers

- Dose registers (should) record effective dose $E$
- New quantities: closer approximation to $E$
- For most workers, where monthly dose is (close to) zero, no difference
- Measurement uncertainty at low dose (trumpet curve)!
- Recorded value for workers with significant dose will be slightly lower
- Case of medical staff in Interventional Radiology needs to be studied in more detail
ICRU 95 – Consequences for Photon Dosimeters

Area monitoring instruments with energy cut-off > 50 keV nearly unaffected

Simple recalibration of sensitivity

Today’s personal dosimeters would show overresponse at low photon energies

Redesign of filter required (or algorithm for multi-detector types)

T. Otto 2019 *JINST* 14 P01010
ICRU 95 – Consequences for Neutron Monitors

Black lines: IEC 61005 Ed. 3.0 b:2014 recommended response interval
Re-assessment of IEC acceptance regions required

As previously, standard Rem-counter response in mono-energetic fields within a large factor

No significant change for use at $E_{\text{kin}} < 20$ MeV

Field calibration may be necessary

J S Eakins et al 2018 J. Radiol. Prot. 38 688
ICRU 95 – Conclusion

• New operational quantities are defined in a consistent manner to the protection quantities
• Numerical values and their trends with energy are coherent with protection quantities
• System of quantities is easier to understand
• Adaptation of certain dosimeter types required:
  • Personal dosimeters for $\gamma$ and $\beta$ radiation at low energy
Thank you for your Attention
Response of dosimeters

- **Response:** \( R = \frac{G}{C} \)
  - Dose Indication \( G \) / Conventional true value \( C \)
  - Change of quantity: \( C_{\text{old}} \rightarrow C_{\text{new}} \)
  - Dose indication remains the same: \( G \rightarrow G \)

- Response of dosimeter in the new quantity:
  \[
  R_{\text{new}} = \frac{G}{C_{\text{old}}} \frac{C_{\text{old}}}{C_{\text{new}}} = R_{\text{old}} \frac{C_{\text{old}}}{C_{\text{new}}} = R_{\text{old}} \frac{h_{\text{old}}}{h_{\text{new}}}
  \]
Response of Survey instrument

Recalibration at reference point
Response of Ionisation chamber

![Graph showing the response of an ionisation chamber with two curves: \( R(H^*(10)) \) (ICRP74) and \( R(H^*) \) (ICRU95). The x-axis represents energy in keV, and the y-axis represents the relative response.]
Response of personal dosimeter 1

![Image of dosimeter and graph](image)

- $R(H_p(10))$ (ICRP 74)
- $R(H_p)$ (ICRU 95)

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Response of personal dosimeter 2

![Image of dosimeter]

- $R(H_p(10))(ICRP74)$
- $R(H_p)(ICRU95)$

Graph showing the relative response ($rel.\ resp.$) as a function of $E_p$ (keV).
Due to similar phantom $H_p(0.07)$ and $D_{local \ skin}$ are numerically similar.
Response of “skin” dosimeters

- Similar calculation phantoms for the conversion coefficients to $D_{\text{local skin}}$ and $H_p(0.07)$
- Existing dosimeter elements for $H_p(0.07)$ will give very good reading of $D_{\text{local skin}}$
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 low photon energies
  - Reason: $H_p(10) > E \approx H_p$
  - Possible solutions:
    - Multi-detector dosimeters: change of algorithm
    - Single detector dosimeters: reconstruct holder

- For more details: arxiv:1809.08680v2 [physics.ins-det]