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Title: Neutron Operational and Protection Quantity Conversion Coefficients Under ICRP-26, ICRP-60, and ICRP-103

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Neutron Operational and Protection Quantity Conversion Coefficients Under ICRP-26, ICRP-60, and ICRP-103

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Y-12 National Security Complex
Evolution of Recommendations

- Three major revisions to ICRP recommendations
  - 1977 – ICRP-26
  - 1991 – ICRP-60
  - 2007 – ICRP-103
- All are risk-based approaches
- All use organ/tissue risk factors
System of Radiation Protection

Physical Quantities
- Fluence, Kerma, Absorbed Dose

Operational Quantities
- Ambient Dose Equivalent
- Personal Dose Equivalent

Calculated using $Q(L)-L$ and simple phantom. Validated by measurements and calculation.

Calibration

Instrument Response

Protection Quantities
- Effective Dose Equivalent
  - Equivalent Dose
  - Effective Dose

Conservative Approximation

Calculated using $W_R, W_T$ and anthropomorphic phantoms.
ICRP-26

- “Dose Equivalent” – organs/tissues
- Organ/Tissue weighting factors ($w_T$)
- Effective Dose Equivalent ($H_E$)
- Dose modifier = quality factor ($Q$)
- $Q$ based on LET in water (keV/μm)
- $Q$ based on spectrum in organ/tissue
- Mathematical phantom
- Remainder organs
- Non-additive
ICRP-60

- “Equivalent Dose” – organs/tissues
- Organ/Tissue weighting factors ($w_T$)
- Effective Dose ($E$)
- Dose modifier = radiation weighting factor ($w_R$)
- $w_R$ based on spectrum incident on phantom
- Mathematical phantom
- Remainder organs
- Non-additive
ICRP-26 and ICRP-60 Protection Quantity Calculations

- ICRP-26 Effective Dose Equivalent, $H_E$
  \[
  H_T = \frac{\int \int Q(L) D_L dL dm}{m} \\
  H_E = \sum T \omega_T H_T
  \]

- ICRP-60 Effective Dose, $E$
  \[
  E = \omega_R \sum T D_T \omega_T
  \]

($\omega_R$ based on spectrum incident on phantom. Single value for all organs)
ICRP-103

- “Equivalent Dose” – organs/tissues
- Organ/Tissue weighting factors ($w_T$)
- Effective Dose ($E$)
- Dose modifier = radiation weighting factor ($w_R$)
- $w_R$ based on spectrum incident on phantom
- Voxel phantom (male and female) (ICRP-110)
- Remainder organs, but specified
- Sex averaging
ICRP-103 Protection Quantity Calculations

Radionuclide Intake & External Exposure

Male phantom
Absorbed doses, $D_T^M$

$w_R$

Female phantom
Absorbed doses, $D_T^F$

Equivalent doses, $H_T^M$

Equivalent doses, $H_T^F$

Sex-averaged equivalent doses, $H_T$

Effective dose, $E$

Reference Male

Reference Female

Reference Person
Calculations

• Monte Carlo
• Various geometries (AP, PA, LLAT, RLAT, ISO, ROT)
• Absorbed dose in organs
• Modifier (QF or $w_R$)
• Remainder organs
• Weighted sum
Phantom Models

• Through ICRP-60 mathematical models used. ICRP-103 uses volumized pixel (voxel) phantoms developed from high-res scans.
Protection Quantity DCFs

Neutron Energy (MeV) vs. Conversion Coefficient (pSv cm$^2$)

- ICRP-26 $H_E$
- ICRP-60 E (ICRP-74)
- ICRP-60 E (Pelliccioni 2000)
- ICRP-103 E
- Hp(10) (ICRP-60 QF)
Operational Quantities

• Defined by ICRU
• Intended to be measurable (and calculable)
• Based on simple phantom designs
• Based on standard (but unattainable conditions)
• Should conservatively approximate protection quantities
Personal Dose Equivalent

- Monitoring for individuals
- Defined in the body – multi-valued quantity
- Usually the trunk = 30 cm X 30 cm X 15 cm ICRU Slab

![Diagram showing a unidirectional field and dosimeter on a slab.](attachment:diagram.png)
Ambient Dose Equivalent

- Area monitoring
- Defined in the ICRU sphere (15 cm radius)
- Instrument calibrations

Aligned and expanded field
ICRP/ICRU DCFs

• ICRP-74
• ICRP revising ICRP-74 now (to include ICRP-103)
• Includes ICRP-103 DCFs
• ICRU to update operational quantities
• No changes to Q(L)-L, so QF same
• Higher energies
Quality and Radiation Weighting Factors

![Graph showing neutron energy vs. QF or wR for different ICRP publications: ICRP-26 QF, ICRP-60 QF, ICRP-60 wR, ICRP-103 wR. The graph indicates a peak in weighting factors at neutron energies around 1 to 10 MeV, with a gradual decrease at higher energies.](image-url)
ICRP-26 and ICRP-60 $H^*(10)$
Protection/Operational Quantity DCFs

Conversion Coefficient (pSv cm$^2$) vs Neutron Energy (MeV)

- ICRP-26 $H_E$
- ICRP-60 E (ICRP-74)
- ICRP-60 E (Pelliccioni 2000)
- ICRP-103 E
- $H_p(10)$ (ICRP-60 QF)
Conservative Approximation?

![Graph showing neutron energy distribution](image-url)

- **Conservative**
  - H*(10) ICRP-26: EDE
  - Hp(10):E (ICRP-60)
  - Hp(10):E (ICRP-103)
  - Unity

- **Non-Conservative**

The graph illustrates the ratio of prot. qty. vs. op. qty. across different neutron energy levels (MeV).
How Different are the New Dose Conversion Coefficients?

• Photons
  – The differences of effective dose conversion coefficients are lower than 10%.

• Neutrons
  – Generally lower (up to a factor of 2) than ICRU 57 / ICRP 74 due to the reduced $w_R$ differences

• Protons
  – Generally lower than ICRU 57 / ICRP 74 due to the reduced $w_R$

• For some geometries greater differences are observed due to increased value of $w_T$ for the breast

• More data available at higher energies
## ICRP-26 Vs. ICRP-60 Source DCFs

<table>
<thead>
<tr>
<th></th>
<th>$^{252}\text{Cf}$</th>
<th>$D_2\text{O}$</th>
<th>Am-Be</th>
<th>Am-B</th>
<th>Poly. Mod. $^{252}\text{Cf}$</th>
<th>Pu-F</th>
<th>Pu-Be</th>
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<tr>
<td><strong>ICRP-26 $H^*(10)$</strong></td>
<td>333</td>
<td>93</td>
<td>373</td>
<td>378</td>
<td>218</td>
<td>333</td>
<td>291</td>
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<td>(pSv-cm$^2$)</td>
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<td><strong>ICRP-60 $H^*(10)$</strong></td>
<td>380</td>
<td>107</td>
<td>394</td>
<td>410</td>
<td>242</td>
<td>384</td>
<td>317</td>
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<tr>
<td>(pSv-cm$^2$)</td>
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<tr>
<td><strong>Rem Ball Response</strong></td>
<td>333</td>
<td>133</td>
<td>334</td>
<td>384</td>
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<td>272</td>
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<td>ICRP-26 Cal. (counts)</td>
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Data from HPJ Vol. 95, suppl. 2 August 2008
Conclusions

• Quality factors same in ICRP-60 and ICRP-103 (operational quantities don’t change)
• Q(L)-L differs from ICRP-26 to ICRP-60 (DOE impact)
• Protection quantities are generally lower
• Data to higher energies