DEVELOPMENT OF A PRIMARY STANDARD IN TERMS OF $D_w$ FOR $^{125}$I BRACHYTHERAPY SEEDS

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• JRP6 objective

• The LNE-LNHB approach to develop a primary standard in $D_w$

• The LNE-LNHB experimental set-up
  – Design and characterization in current and volume
  – Correction factors
Primary standards for LDR brachytherapy

Use of the AAPM protocol, following the TG43 formalism

\[ \dot{K}_R(1\,m) \quad \text{Dose-rate constant, } \Lambda \quad \dot{D}_{\text{water}}(1\,cm) \quad @ \quad 10\% \]

at patient level

**JRP6** “Increasing cancer treatment efficacy using 3D brachytherapy”

\[ \dot{D}_{\text{water}}(1\,cm) \quad @ \quad 5\% \quad \rightarrow \quad \dot{D}_{\text{water}}(1\,cm) \quad @ \quad 2\% \]

at patient level within reference conditions

JRP6 partners involved in developing a primary standard for LDR BT sources:

PTB, ENEA-INMRI, LNE-LNHB
Primary standards in $D_w$ for LDR brachytherapy

The LNE-LNHB approach

Objective: Determination of $D_w(1\text{cm}, 90^\circ)$ around a single LDR source
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The LNE-LNHB approach

Primary standards in $D_w$ for LDR brachytherapy

Back scattering correction factor needed!

$$\dot{D}_w(1\,\text{cm}, 90^\circ) = \dot{K}_{col,w}(1\,\text{cm}, 90^\circ) \cdot F_{bscatt}$$
Objective: Determination of $\dot{K}_{col,w}(1\text{cm}, 90^\circ)$ around a single LDR source
Primary standards in $D_W$ for LDR brachytherapy

The LNE-LNHB approach

\[ \frac{\mu_{en}}{\rho}_{PMMA} \approx 0.63 \]

\[ \approx \frac{r_{p'}}{r_p} \quad (\approx 1600) \]

\[ \dot{\mathcal{K}}_{col,phant} = \dot{\mathcal{K}}_{col,ref} \cdot F_{med\_geo} \]
Primary standards in $D_W$ for LDR brachytherapy

**The LNE-LNHB approach**

**Objective:** Determination of $\hat{\mathcal{K}}_{\text{col,ref}}$ around a single LDR source

Two difficulties to overcome:
- the equatorial anisotropy of emission of the LDR brachytherapy seeds
- the small subtended solid angle that causes a poor S/N ratio
Primary standards in $D_w$ for LDR brachytherapy

The LNE-LNHB approach

Objective: Determination of $\dot{K}_{\text{col,ref}}$ around a single LDR source

\[
\dot{K}_{\text{col,air}} = \prod_i k_i \cdot \left(\frac{w}{e}\right)_{\text{air}} \cdot \frac{1}{\rho_{\text{air}}} \cdot \frac{1}{(1-g)} \cdot \frac{I}{V}
\]

\[
\dot{K}_{\text{col,ref}} = \dot{K}_{\text{col,air}} \cdot F_{\text{ref}}
\]

\[d_{\text{air}}, \quad d_{\text{vacuum}}\]
Primary standards in $D_w$ for LDR brachytherapy

The LNE-LNHB approach

$$\dot{D}_w(1cm, 90^\circ) = F_{bscat} \cdot F_{phant} \cdot F_{med geo} \cdot F_{ref} \cdot \prod_{i} k_i \cdot \left( \frac{w}{e} \right)_{air} \cdot \frac{1}{\rho_{air}} \cdot \frac{1}{(1-g)} \cdot \frac{I}{V}$$
Primary standards in $D_w$ for LDR brachytherapy

Signal to noise and volume characterization

\[ \frac{S}{B} \approx 100, \quad \frac{u(I)}{I} \approx 0.2\% \]

Electrodes have been added to straighten up the field lines and homogenize the electric field within the collection volume (Quickfield 5)

Interaction volume $V = (2331 \pm 22) \text{ cm}^3 (0.93\%)$
Primary standards in $D_w$ for LDR brachytherapy

Correction factors assessed by MC calculations for I25.S16 Bebig seed

Bebig I25.S16 photon emission spectrum (Ag vs. I/Te)

Characteristic x rays originating from the silver (AgI) were considered as initial emission within the source:

$$\frac{(K_{\alpha_1,Ag} + K_{\alpha_2,Ag})}{(K_{\alpha_1,Te} + K_{\alpha_2,Te})} = 5.10^{-2} \quad (5\%)$$

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td></td>
</tr>
<tr>
<td>21.9903</td>
<td>1.255 10^{-2}</td>
</tr>
<tr>
<td>22.1629</td>
<td>2.363 10^{-2}</td>
</tr>
<tr>
<td>24.9115</td>
<td>2.167 10^{-3}</td>
</tr>
<tr>
<td>24.9424</td>
<td>4.219 10^{-3}</td>
</tr>
<tr>
<td>25.4567</td>
<td>1.575 10^{-3}</td>
</tr>
<tr>
<td>Te</td>
<td></td>
</tr>
<tr>
<td>4.14</td>
<td>9.25 10^{-2}</td>
</tr>
<tr>
<td>27.202</td>
<td>2.46 10^{-1}</td>
</tr>
<tr>
<td>27.4726</td>
<td>4.59 10^{-1}</td>
</tr>
<tr>
<td>31.1</td>
<td>1.32 10^{-1}</td>
</tr>
<tr>
<td>31.76</td>
<td>2.85 10^{-2}</td>
</tr>
<tr>
<td>I</td>
<td></td>
</tr>
<tr>
<td>35.4919</td>
<td>4.14 10^{-2}</td>
</tr>
</tbody>
</table>

Numerical modeling using the PENELOPE code of the experimental set-up
Primary standards in $D_w$ for LDR brachytherapy

Correction factors – Recapitulation and first estimate

$$\dot{D}_w = F_{\text{bscat}} \cdot F_{\text{phant}} \cdot F_{\text{med\_geo}} \cdot F_{\text{ref}} \cdot \prod_i k_i \cdot \left(\frac{w}{e}\right)_{\text{air}} \cdot \frac{1}{\rho_{\text{air}}} \cdot \frac{1}{1 - g} \cdot \frac{I}{V}$$

<table>
<thead>
<tr>
<th>Correction</th>
<th>Mean value</th>
<th>$u_{\text{rel}}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{\text{ref}}$</td>
<td>1.079</td>
<td>0.2</td>
</tr>
<tr>
<td>$F_{\text{med_geo}}$</td>
<td>1.054.0</td>
<td>0.6</td>
</tr>
<tr>
<td>$F_{\text{phant}}$</td>
<td>1.522</td>
<td>0.1</td>
</tr>
<tr>
<td>$F_{\text{bscat}}$</td>
<td>1.162</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Note: Statistical uncertainties, do not include uncertainties in cross section or geometry.
Primary standards in $D_w$ for LDR brachytherapy

**Correction factors - Recapitulation**

$$
\dot{D}_w = F_{global} \cdot I \cdot \frac{w}{e} \cdot \frac{1}{\rho_{air}} \cdot \frac{1}{(1 - g)} \cdot \frac{1}{V} \cdot \prod_{i} k_i
$$

$$
F_{global} = 2019 \pm 3 \ (0.1\%) \ \text{(only statistical uncertainty)}
$$
Primary standards in $D_w$ for LDR brachytherapy

First estimate of the uncertainty budget

$$\dot{D}_w = F_{global} \cdot I \cdot \left( \frac{w}{e} \right)_{air} \cdot \frac{1}{\rho_{air}} \cdot \frac{1}{1-g} \cdot \frac{1}{V} \cdot \prod_i k_i$$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Relative uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{global}$</td>
<td>0.1 (only statistical uncertainty)</td>
</tr>
<tr>
<td>$I$</td>
<td>0.2</td>
</tr>
<tr>
<td>$(W/e)_{air}$</td>
<td>0.004</td>
</tr>
<tr>
<td>$\rho_{air}$</td>
<td>0.008</td>
</tr>
<tr>
<td>$V$</td>
<td>0.93</td>
</tr>
<tr>
<td>$k_{pol}$</td>
<td>0.10</td>
</tr>
<tr>
<td>$k_{rec}$</td>
<td>0.13</td>
</tr>
<tr>
<td>$k_{trans}$</td>
<td>0.35</td>
</tr>
</tbody>
</table>

$$\frac{u(\dot{D}_w)}{\dot{D}_w} = 1.0 \%$$

$$\frac{u(\dot{D}_w)}{(\dot{D}_w)} = \sqrt{1^2 + \left( \frac{u_{B\ type\ (F_{global})}}{F_{global}} \right)^2}$$
Conclusion

- LNE-LNHB : free-in-air ionization chamber
- PTB and ENEA-INMIRI : extrapolation chambers

Those devices and methods are different.

This will enhance the quality of the knowledge of the final dose-to-water estimate by providing different ways of identifying possible biases introduced by the different methods studied.
Thank you for your attention.