Real-time in vivo dosimetry using radioluminescence of pre-irradiated Al₂O₃:C crystals

Most of the material presented was performed during PhD project at the Technical University of Denmark, for which the clinical and primary measurements were performed at the Aarhus University Hospital, Denmark. Supervisors:
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Mentor: Sam Beddar

Brphyqs & GEC-ESTRO Seminar on Online Verification for Brachytherapy
December 5, 2014
ESTRO Office in Brussels, Belgium
1. Radioluminescence (RL) dosimetry protocol
2. Pros & cons of dosimeter system
3. Real-time *in vivo* dosimetry (IVD)
Radioluminescence dosimetry protocol

Dosimetry based on light emission from $\text{Al}_2\text{O}_3$:C crystals
Radioluminescence dosimetry protocol

Dosimetry based on light emission from $\text{Al}_2\text{O}_3$:C crystals

$\text{Al}_2\text{O}_3$:C crystal coupled to fiber-optic cable
1. RL dosimetry protocol
2. Pros & cons of system
3. Real-time IVD

Previous system: OSL (passive) + RL (real-time)

Radioluminescence dosimetry protocol

Previous system: OSL (passive) + RL (real-time)

Important Disadvantages:

Large corrections required to deduce dose rates from RL signal (RL sensitivity changes during irradiation)

Stem signal problem (30% discrepancy for BT)


Radioluminescence dosimetry protocol

New system: **RL only** (no OSL) monitoring of **stable light emission** from **pre-irradiated crystals**

1. RL dosimetry protocol
2. Pros & cons of system
3. Real-time IVD

Outline

1. Radioluminescence (RL) dosimetry protocol
2. Pros & cons of dosimeter system
3. Real-time *in vivo* dosimetry (IVD)
**Pros & cons of dosimetry system**

1. **RL dosimetry protocol**
2. **Pros & cons of system**
3. **Real-time IVD**

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**Characterization for $^{192}$Ir PDR & HDR sources**

<table>
<thead>
<tr>
<th><strong>Optimal probe characteristics</strong></th>
<th><strong>Tests; Confirm.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Small, flexible/bendable, physically robust</td>
<td>Phantom, in vivo</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Linear dose response</strong></th>
<th><strong>Phantom</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05-50 Gy</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Real-time</strong></th>
<th><strong>Phantom, in vivo</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-second data acquisition</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Radiation hard</strong></th>
<th><strong>Phantom</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity: $-0.45 \pm 0.03% / 100\text{Gy}$</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Stem signal correction</strong></th>
<th><strong>Phantom</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-dominant uncertainty component</td>
<td>1,5</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th><strong>Bright light emitter</strong></th>
<th><strong>Phantom, in vivo</strong></th>
</tr>
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<td>Large dynamic range (large S/N)</td>
<td>3</td>
</tr>
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</table>

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**References**

1. RL dosimetry protocol
2. Pros & cons of system
3. Real-time IVD

**Pros & cons of dosimetry system**

1. **Pros**
   - **Al₂O₃:C**
   - **Bright light emitter**
     - Large S/N
     - Small detector volume
     - Long transmission fiber cable (15 m)
   - **Caution:** PMT dead time correction

2. **Cons**
   - Large dynamic range (large S/N)
   - Phantom, *in vivo*

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**References**

# Pros & cons of dosimetry system

1. RL dosimetry protocol
2. Pros & cons of system
3. Real-time IVD

## Taken into account, $^{192}$Ir PDR/HDR sources

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Al}_2\text{O}_3$:C temperature dep.</td>
<td>$0.2%/K$</td>
<td>3% correction: calibration $\rightarrow$ IVD</td>
</tr>
<tr>
<td>$\text{Al}_2\text{O}_3$:C energy dep.</td>
<td>$1.3%/cm$</td>
<td>Count rate dependent correction $^3$</td>
</tr>
<tr>
<td>PMT temperature dep.</td>
<td>$-0.5%/K$</td>
<td>Uncertainty according to temp. control</td>
</tr>
<tr>
<td>PMT dead-time correction $^5$</td>
<td>$1.5e-8$ s</td>
<td>1.5% correction for $1e6$ counts/s</td>
</tr>
<tr>
<td>T-dep. $\text{Al}_2\text{O}_3$:C afterglow</td>
<td>T-dep. life time $^6$</td>
<td>Caution: source transfer time intervals</td>
</tr>
</tbody>
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1. RL dosimetry protocol
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Taken into account, $^{192}$Ir PDR/HDR sources

$\text{Al}_2\text{O}_3$:C temperature dep.

$\text{Al}_2\text{O}_3$:C energy dep.

PMT temperature variations

PMT dead-time correction

T-dep. $\text{Al}_2\text{O}_3$:C afterglow

T-dep. life time

Caution: source transfer time intervals

In vivo

Body temp.

Calibration

Room temp.

~3 s

~0.5 s

## Pros & cons of dosimetry system

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<tr>
<th>Cons</th>
<th>Requirement</th>
<th>Prior to all patient measurements:</th>
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<tr>
<td>Pre-irradiation</td>
<td>≥20 Gy</td>
<td>To assure stable RL signal</td>
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<tr>
<td>Calibration</td>
<td>One “source fly-by”</td>
<td>Since equipment setup before each treatment</td>
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*~20 min*

*~15 min*
**Pros & cons of dosimetry system**

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### Cons

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**POTENTIAL SOLUTIONS:**

**Pre-irradiation:**
Deal with sensitivity changes, however, must acquire related uncertainty

**Calibration:**
Avoid packing & unpacking equipment for each treatment

*Andersen et al., Radiat. Meas. 46, 1090-8 (2011).*
Outline

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Real-time in vivo dosimetry

20 PDR treatments between Nov 2011 and May 2012

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Real-time *in vivo* dosimetry

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- Incorporated real-time IVD during treatments:
  - 20 treatments
  - CT/MRI guided PDR (20 pulses, 1 pulse/hour)
  - Cervix cancer
  - Tandem+Ring, Tandem+Ring+Needles

- Used data driven error detection algorithm (AEDA)

- Uncertainty budget (see publications)

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Real-time *in vivo* dosimetry

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**SIGNIFICANT DEVIATION**

**AEDA $\rightarrow$ FALSE ERROR**


Real-time *in vivo* dosimetry

No significant deviation

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SUMMARY and DISCUSSION

- Real-time dosimetry protocol is based on radioluminescence **only**
- Inorganic detector volume with large light response
- Used Al\textsubscript{2}O\textsubscript{3}:C crystal, *can also use other crystals (see references)*

CONCLUSION

Al$_2$O$_3$:C radioluminescence system
Demonstrated on 20 patient measurements
• Feasible for routine based IVD
• Provides accurate dosimetry
• System is straightforward to use (with practice)