Safe Use of $^{223}$Ra Radium Dichloride

A Radiation Safety Perspective

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APRIL 4, 2019
**223RaCl₂ THERAPY**

- Therapeutic treatment for metastatic bone cancer
- Approximately 3.5 MBq of 223Ra is administered
- Delivers a large dose to the bone while sparing healthy tissues
- Treated on an outpatient basis
$^{223}\text{Ra}$ DECAY

Thorium-227 $\xrightarrow{18.7 \text{ d}}$ Radium-223 $\xrightarrow{11.4 \text{ d}}$ Radon-219 $\xrightarrow{3.9 \text{ s}}$ Polonium-215

1. $^{223}\text{Ra} \rightarrow ^{219}\text{Po} + ^{4}\text{He}$, $Q_{\alpha} = 18.7 \text{ MeV}$
2. $^{219}\text{Po} \rightarrow ^{215}\text{Pb} + ^{4}\text{He}$, $Q_{\alpha} = 11.4 \text{ MeV}$
3. $^{215}\text{Pb} \rightarrow ^{211}\text{Bi} + ^{4}\text{He}$, $Q_{\alpha} = 3.9 \text{ MeV}$

Lead-207 $\xrightarrow{4.8 \text{ m}}$ Thallium-207 $\xrightarrow{2.1 \text{ m}}$ Bismuth- 211 $\xrightarrow{36.1 \text{ m}}$ Lead-211

1. $^{207}\text{Pb} \rightarrow ^{207}\text{Bi} + ^{4}\text{He}$, $Q_{\alpha} = 4.8 \text{ MeV}$
2. $^{207}\text{Bi} \rightarrow ^{207}\text{Tl} + ^{4}\text{He}$, $Q_{\alpha} = 2.1 \text{ MeV}$
3. $^{207}\text{Tl} \rightarrow ^{207}\text{Bi} + ^{4}\text{He}$, $Q_{\alpha} = 36.1 \text{ MeV}$

The Ottawa Hospital
L'Hôpital d'Ottawa

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## GAMMA PHOTONS

<table>
<thead>
<tr>
<th>Photon Energies</th>
<th>$^{223}\text{Ra}$</th>
<th>$^{219}\text{Rn}$</th>
<th>$^{215}\text{Po}$</th>
<th>$^{211}\text{Pb}$</th>
<th>$^{211}\text{Bi}$</th>
<th>$^{201}\text{Tl}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>144 keV</td>
<td>130 keV</td>
<td>-</td>
<td>404 keV</td>
<td>351 keV</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>269 keV</td>
<td>271 keV</td>
<td></td>
<td>427 keV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>154 keV</td>
<td>401 keV</td>
<td></td>
<td>832 keV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abundance</td>
<td>14 %</td>
<td>11%</td>
<td>-</td>
<td>4%</td>
<td>13%</td>
<td>-</td>
</tr>
</tbody>
</table>
RADIATION ATTENUATION
HIGH LET RADIATION

Gamma Radiation (Low LET IR)

Alpha Particle Radiation (High LET IR)

DNA Backbone Break

ROS Production

https://www.sciencedirect.com
## Internal Exposures

<table>
<thead>
<tr>
<th>Ingestion Coefficient (Sv/Bq)</th>
<th>Effective dose for 3.5 MBq (mSv)</th>
<th>ALI* (MBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>223Ra</td>
<td>1.0x10^{-7}</td>
<td>3.5x10^2</td>
</tr>
<tr>
<td>131I</td>
<td>8.7x10^{-11}</td>
<td>3.0x10^{-1}</td>
</tr>
</tbody>
</table>

*Ingested Activity required to receive a dose equal to the occupational dose limit (20 mSv)
Alexander Litvinenko

- Poisoned with 2GB (50 mCi) of $^{210}$Po
- Organ doses of 20 Gy-100 Gy
- Irreversible damage to bone marrow, kidneys and liver
- 9 MBq (240 uCi) of $^{210}$Po is considered lethal
# EXTERNAL GAMMA DOSE RATE

<table>
<thead>
<tr>
<th></th>
<th>$^{223}$Ra</th>
<th>$^{219}$Rn</th>
<th>$^{215}$Po</th>
<th>$^{211}$Pb</th>
<th>$^{211}$Bi</th>
<th>$^{201}$Tl</th>
<th>Total (mGy/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra-223* @ 1 m</td>
<td>7.0E-05</td>
<td>3.0E-05</td>
<td>0.0</td>
<td>3.3E-05</td>
<td>2.4E-05</td>
<td>0.0</td>
<td>1.6E-04</td>
</tr>
<tr>
<td>I-131* @ 1 m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.0E-03</td>
</tr>
</tbody>
</table>

*assuming an activity of 3.5 Mbq

## STAFF EXPOSURES

<table>
<thead>
<tr>
<th></th>
<th>Dose Rate (uSv/hr)</th>
<th>Time (min)</th>
<th>Dose (uSv)</th>
<th>Body Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vial/Syringe (1 cm)</td>
<td>$1.5 \times 10^3$*</td>
<td>2</td>
<td>50</td>
<td>Extremity</td>
</tr>
<tr>
<td>Vial (30 cm)</td>
<td>$1.7^*$</td>
<td>10</td>
<td>0.29</td>
<td>Whole Body</td>
</tr>
<tr>
<td>Patient (1m)</td>
<td>0.07**</td>
<td>15</td>
<td>0.02</td>
<td>Whole Body</td>
</tr>
</tbody>
</table>

*David S. Smith & Michael G. Stabin (Health Physics 2012; 102:271-291)
MINIMIZING STAFF EXPOSURES

▶ Proper PPE
  • Lab coat
  • Double gloves
▶ Good work practices
▶ Frequent radiation monitoring
FAMILY MEMBER EXPOSURES

- Majority of the family member exposure comes from co-sleeping in the same bed.
- Assume 8 hours per night at a distance of 0.3 cm.
- Total dose to the family member is 100 uSv.
- This is the exposure received in 15 hours of flying.
- Exposure from living in Ottawa for 20 days due to background radiation.
RADIATION DETECTION
# Radiation Detection

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Background (cpm)</th>
<th>Efficiency (cpm/dpm)</th>
<th>Minimum detectable activity (dpm)</th>
<th>(Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Probe (Zinc Sulfide)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0</td>
<td>0.08</td>
<td>71</td>
<td>1.2</td>
</tr>
<tr>
<td>Thin Window Beta/Gamma Probe (GM)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28</td>
<td>0.13</td>
<td>350</td>
<td>5.8</td>
</tr>
<tr>
<td>Low Energy Gamma Probe (Sodium Iodide)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94</td>
<td>0.29</td>
<td>1296</td>
<td>21.6</td>
</tr>
<tr>
<td>Liquid Scintillation Counter</td>
<td>49</td>
<td>0.97</td>
<td>64</td>
<td>1.1</td>
</tr>
<tr>
<td>Gamma Counter</td>
<td>210</td>
<td>0.40</td>
<td>333</td>
<td>5.6</td>
</tr>
</tbody>
</table>

<sup>a</sup>For wipe test evaluations in a fixed geometry at a distance of 0.32 cm.
85% of the activity absorbed
- 61% absorption in 4 hrs
- 1.1% remaining in blood after 24 hours

15% of the activity is excreted
- 2.2% of the activity is in the urine after 48 hrs (cumulatively)
- 13% of activity voided in the feces
Clinics Experience – Patient Requiring Hip Surgery

- Patient underwent emergency hip replacement surgery 4 days following treatment with $^{223}\text{RaCl}_2$
- The surgical team met with Radiation Safety to discuss precautions for the case
  - Potential for equipment to be contaminated
  - Identification of hot and cold zones
  - Identification of specific bins to collect items for radiation surveys
  - All staff would be monitored prior to leaving OR
CLINICAL EXPERIENCE – PATIENT REQUIRING HIP SURGERY
Prior to surgery a calibration factor was obtained for our contamination meter.

A sample of activity was dispensed onto a 2 cm x 2 cm square of absorbent material and calibration factor was determined.

Used to estimate the activity contained on bone specimens in the OR.
CLINICAL EXPERIENCE – PATIENT REQUIRING HIP SURGERY

- No activity was measured in blood removed from the patient during surgery
- No contamination was measured on the gloved hands of the OR staff
- Activity was measured on the femoral head and on two smaller bone fragments
- Approximately 10 kBq was measured on the femoral head
CLINICAL EXPERIENCE – PATIENT REQUIRING HIP SURGERY

- Radioactive bone fragments were placed in formalin
- Container was sealed and labelled with the isotope, and activity and was stored for decay
- After 10 half-lives (114 days) it was disposed as biohazardous waste
DEATH OF RADIOACTIVE PATIENT

- No external exposure concerns if an autopsy is required
- Usual PPE able to prevent contamination
- For autopsy, radiation safety personnel should be on site to monitor equipment and work surfaces
- No precautions required after 3 months
## CNSC REGDOC-2.7.3 – SAFE HANDLING OF DECEDEANTS

<table>
<thead>
<tr>
<th>Autopsy</th>
<th>Time frame: 3 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• In addition to the appropriate personal protective equipment, use a double layer of disposable gloves when handling the body to avoid the presence and spread of contamination.</td>
</tr>
<tr>
<td></td>
<td>• Wear safety glasses or goggles.</td>
</tr>
<tr>
<td></td>
<td>• Avoid handling tissues directly. Use tools and tongs.</td>
</tr>
<tr>
<td></td>
<td>• Minimize time spent in the vicinity of the body.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Embalmment</th>
<th>Time frame: 2 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Minimize direct contact with the venous drainage tube and use handling tools to manipulate it.</td>
</tr>
<tr>
<td>Cremation</td>
<td>Time frame: 3 months</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------</td>
</tr>
<tr>
<td><strong>Precautions for death-care professionals:</strong></td>
<td></td>
</tr>
<tr>
<td>• Clean the cremation chamber as thoroughly as possible to avoid contamination of future cremations.</td>
<td></td>
</tr>
<tr>
<td>• Leave the exhaust fan on at all times until the cremated remains are placed in their final container and the area has been cleaned.</td>
<td></td>
</tr>
<tr>
<td>• Avoid pulverizing the cremated remains to prevent the contamination of equipment.</td>
<td></td>
</tr>
</tbody>
</table>
| Cremation | Time frame: 3 months  
Precautions for handling cremated remains:  
• Store the cremated remains in a closed container, preferably one made of stainless steel. Keep cremated remains in a low-occupancy area for two weeks.  
• Do not scatter the cremated remains. Label the container with the date on which cremated remains may be scattered.  
• Do not make memorial keepsake jewelry or tattoos with the cremated remains.  
• Do not directly handle/touch the cremated remains. |
Exposures to staff and family members are significantly lower than other Nuclear Medicine Therapy Procedures

Regular PPE effective at preventing ingestion or absorption

Despite the negligible external dose rates, there are still hazards that need to be considered.
THANKS & DISCLOSURE

Thanks
Dr. Lionel Zuckier
Dr. Eugene Leung
Dr. Stephen Dinning

Disclosure
I have no actual or potential conflict of interest in relation to this presentation