Monte Carlo Simulation and Validation of a Novel Yttrium-90 Source for Use in a Conformal Superficial Brachytherapy Device

Brent Rogers, M.S.
Overview

- Conformal Superficial Brachytherapy Device
- Radioactive Source - $^{90}\text{Y}$
- Monte Carlo Simulation - MCNP
- Gafchromic Film Measurements
- Conclusions
CONFORMAL SUPERFICIAL BRACHYTHERAPY DEVICE
Conformal Superficial Brachytherapy Device
RADIOACTIVE SOURCES

\(^{90}\text{Y}\)
Activated by Neutron Bombardment

- $\beta^-$ Decay $\rightarrow$ 99.983%
- $Q = 2.280 \text{ MeV}$
- $\bar{E}_\beta = 0.934 \text{ MeV}$
- $R_{\text{CSDA}} = 1.129 \text{ cm}$
- $t_{1/2} = 64.1 \text{ hours}$
MONTE CARLO SIMULATION
MCNP
Point Source in an Infinite Water Medium

- ICRU 56
  - $\dot{D}_{\text{mono}} \rightarrow$ Monte Carlo (EGS4, ACCEPT)
  - $\dot{D}_{\text{poly}} = \int \dot{D}_{\text{mono}} \, dE_\beta$
  - Statistical uncertainty $\rightarrow \sim 2\%$
  - Systematic uncertainty $\rightarrow 3$-$5\%$

- MCNP
  - $\beta$ spectrum $\rightarrow$ ICRU 56
  - 100 shells
  - *f8 tally (MeV)

**MCNP vs. ICRU 56 within $\bar{E}_{\text{deposited}} \sim 90\%$**

- 7.35% max difference
- 3.16% average difference
GAFCHROMIC FILM MEASUREMENTS
EBT3 Film Calibration

- 6 MeV electrons
- Rational fit function
  - $X(D) = a + b/(D-c)$
  - where $X(D)$ = red channel scanner response
- Non-Linear Least Squares Fit
- $R^2 = 0.9997$
- $R_{adj}^2 = 0.9996$

![Graph showing red channel pixel value vs dose with a fitted curve and 95% confidence interval.](image-url)
$^{90}\text{Y} \text{ Source Depth Dose Measurements}$

- Activity: $2.5 \times 10^7 \text{ Bq}$
  - $0.68 \text{ mCi}$

- $D_{\text{max}} = 4.6 \times 10^{-7} \text{ cGy/s/Bq}$

![Graph showing dose rate vs. depth](image)
Bare Source vs. Tipped Source at the Surface

Bare Source
- Slightly narrower profile
- Faster dose rate

Tipped
- Slightly wider profile
- Slower dose rate
Bare Source vs. Tipped Source at the Surface

Bare
\[ \dot{D} = 9.8 \text{ Gy/min/mCi} \]

\[ T_{\text{[min]}} = 0.11 \left[ \frac{\text{min} \cdot \text{mCi}}{\text{Gy}} \right] \cdot \frac{D_X [\text{Gy}]}{A [\text{mCi}]} \]

Tipped
\[ \dot{D} = 3.89 \text{ Gy/min/mCi} \]

\[ T_{\text{[min]}} = 0.28 \left[ \frac{\text{min} \cdot \text{mCi}}{\text{Gy}} \right] \cdot \frac{D_X [\text{Gy}]}{A [\text{mCi}]} \]

\[ \dot{D}(\text{tipped}) = 40\% \dot{D}(\text{bare}) \]
Multiple Sources Applied to the Surface with the CSBT Device

6 Sources
\[ \dot{D} = 5.27 \text{ Gy/min/mCi} \]
\[ T = 0.19 \frac{D_x}{A_{\text{per Source}}} \]

6 Sources
\[ \dot{D} = 4.66 \text{ Gy/min/mCi} \]
\[ T = 0.21 \frac{D_x}{A_{\text{per Source}}} \]

7 Sources
\[ \dot{D} = 5.05 \text{ Gy/min/mCi} \]
\[ T = 0.20 \frac{D_x}{A_{\text{per Source}}} \]

8 Sources
\[ \dot{D} = 5.10 \text{ Gy/min/mCi} \]
\[ T = 0.20 \frac{D_x}{A_{\text{per Source}}} \]

Max dose rate is weakly dependent on the number of sources.
CONCLUSIONS
Tips decrease the dose rate by 40%

Bare Source Dose Rate $\approx 10$ Gy/min/mCi

6, 7, & 8 Source Dose Rate $\approx 5$ Gy/min/mCi

Dose rate is independent of the number of sources for many sources.


THANK YOU
MCNP Simulation Benchmarking

0.1 mm, 1 cm

Dose Rate (nGy·cm²·Bq⁻¹·h⁻¹) vs. Depth (cm)

- MCNP
- ICRU 56
Rational fit function
- \( X(D) = a + \frac{b}{(D-c)} \)
- where \( X(D) \) = red channel scanner response

Non-Linear Least Squares Fit
- \( R^2 = 0.9997 \)
- \( R_{adj}^2 = 0.9996 \)
Bare Source vs. Tipped Source at the Surface

**Bare**
- Slightly narrower profile
- Faster dose administration

\[ \dot{D} = 4.30 \times 10^{-7} \text{ cGy/s/Bq} \]
\[ 5 \text{ Gy time: } 0.52 \text{ mCi*min} \]
\[ T(\text{min}) = 0.10 \]

\[ (\text{min*mcCi})*D(\text{Gy})/A(\text{mcCi}) \]

**Tipped**
- Slightly wider profile
- Slower dose administration

\[ \dot{D} = 1.82 \times 10^{-7} \text{ cGy/s/Bq} \]
\[ 5 \text{ Gy time: } 1.24 \text{ mCi*min} \]

Relative Surface Dose Profile:
Bare Source vs. Tipped Source

Source, Tip, & Rod Placed on Surface
Max dose rate is weakly dependent of the number of sources
- Relatively large distance between sources
- Relatively close proximity to surface
- One source does not contribute greatly to the area beneath neighboring sources

6 Sources
Dose Rate: **8.78 cGy/s/mCi**
Time_{5 Gy}: **0.95 mCi*min**

6 Sources
Dose Rate: **7.76 cGy/s/mCi**
Time_{5 Gy}: **1.07 mCi*min**

7 Sources
Dose Rate: **8.42 cGy/s/mCi**
Time_{5 Gy}: **0.99 mCi*min**

8 Sources
Dose Rate: **8.50 cGy/s/mCi**
Time_{5 Gy}: **0.98 mCi*min**
Bare Source vs. Tipped Source at the Surface

**Bare**

\[ \dot{D} = 9.8 \text{ Gy/min/mCi} \]

\[ T[\text{min}] = 0.11 \left( \frac{\text{min} \cdot \text{mCi}}{\text{Gy}} \right) \times \frac{D_X [\text{Gy}]}{A [\text{mCi}]} \]

**Tipped**

\[ \dot{D} = 3.89 \text{ Gy/min/mCi} \]

\[ T[\text{min}] = 0.28 \left( \frac{\text{min} \cdot \text{mCi}}{\text{Gy}} \right) \times \frac{D_X [\text{Gy}]}{A [\text{mCi}]} \]

\[ \dot{D}(\text{tipped}) = 40\% \dot{D}(\text{bare}) \]

Relative Dose

<table>
<thead>
<tr>
<th>Position (cm)</th>
<th>Measured: Bare</th>
<th>Measured: Tipped</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>-0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>-0.1</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
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<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

FWHM ≈ 0.18 cm  
FWHM ≈ 0.23 cm