Air-Kerma Strength Measurements and Monte Carlo based Dosimetric Characterization of a directional Pd-103 planar source array.

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Outline

- Introduction
- Project Aims
- Air-Kerma Strength Measurements
- Monte Carlo Simulations
- Conclusions and Future Work
Introduction

- “Directional Pd-103 planar source array”
  - CivaSheet (CivaTech Oncology Inc.)
  - Array of Pd-103 sources, each having a Gold shield on one side, defining a hot and a cold side.
  - Variable Array Sizes: E.g. 15cmx5cm, 10cmx5cm, 5cmx5cm.
  - Possible use for treatment of Non-small cell lung carcinoma.
Introduction

A 15cm x 5cm CivaSheet having 108 “CivaDots”.

*Source Courtesy: CivaTech Oncology Inc.*
Project Aims

- **Establishing a NIST-traceable calibration procedure:**
  - Air-Kerma Strength Measurements using the UW-VAFAC and a Well Chamber.

- **Data for treatment planning purposes using Monte Carlo:**
  - Generation of a nomogram/look up table.
  - Percent Depth Dose, Dose profiles.
Air-Kerma Strength Measurements

- We have a new brachytherapy source – CivaSheet and want to formulate a calibration procedure for clinical use. Say we want to calibrate the 15 cm x 5 cm Sheet.

  - **First Thought:** Get NIST calibration for the Sheet based on Wide Angle Free Air Chamber. But the Sheet is too big in size for calibration using the NIST WAFAC used as an Air-Kerma Strength primary standard. As it is mostly used for point sources and not planar sources. Also, if it had been possible then each Sheet would have to individually calibrated.
Air-Kerma Strength Measurements

- **Second Thought:** Build a large enough parallel plate ionization chamber!

*Fig:* Custom Chamber built by Standard Imaging for UWMRRC
Air-Kerma Strength Measurements

- Spatial response mapped with ~4U Theragenics $^{103}$Pd seed.
- Non-uniform response, so reproducible positioning is important.
- We can see the presence of struts in spatial response.
- Establishing a calibration based off the chamber is hence tough!

Fig: Weier et al
Third Thought: Lets just cut the sheet into smaller sized segments!

- Now we can measure the AKS of each segment using the UW-VAFAC.
Air-Kerma Strength Measurements

- **UW – VAFAC (Variable Aperture Free Air Chamber):**

  - Similar in design to the NIST WAFAC primary standard but with the added feature of variable aperture sizes.

  ![VAFAC Setup Diagram](image)

  **Fig:** VAFAC-Setup [Culberson -2006]
Air-Kerma Strength Measurements

\[
S_K = \left( \frac{\bar{W}}{e} \right) \frac{d^2}{\rho_{\text{air}} A_{\text{eff}}(1 - g_{\text{air}})} \left( \frac{d(kl)}{ds} \right) \prod_i k_i
\]

- Constants
- VAFAC measurement
- CivaDot Correction factors.

**Fig:** Custom Holder for the VAFAC [A. Weier]
Air-Kerma Strength Measurements

Fig: Weier et al
Air-Kerma Strength Measurements

Air Kerma Strength of CivaDots

Fig: Weier et al
Air-Kerma Strength Measurements

**Figure:** Anisotropy test of a CivaDot at 0 degree and 90 transverse source rotation for a 360 degree detector sweep.
Air-Kerma Strength Measurements

- If we have a Sheet of a given size, and take a CivaDot from the same batch.
  - Then the CivaDot is a good representative of the Air-Kerma Strength of the Sheet.

- With just one CivaDot, we can measure the Air-Kerma Strength of that dot using the NIST VAFAC/ UW-WAFAC and transfer it to a Well-Chamber. This can be easily used in a Clinical setup!
Air-Kerma Strength Measurements

**Fig:** Well Chamber-Holder [SI]

**Fig:** Well-Chamber HDR 1000 plus [SI]
Air-Kerma Strength Measurements

- **Preliminary Data – Well Chamber to AKS coefficient:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Coefficient (U/pA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-Kerma Strength (Sk)</td>
<td></td>
<td>0.945</td>
</tr>
<tr>
<td>Well-chamber Current (I)</td>
<td></td>
<td>1.245</td>
</tr>
<tr>
<td>AKS-Current Ratio Sk/I</td>
<td></td>
<td>0.759</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Coefficient (U/pA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Imaging HDR 1000 Plus - A011927</td>
<td></td>
</tr>
<tr>
<td>TheraSeed</td>
<td>0.4501</td>
</tr>
<tr>
<td>Best Medical Pd-103</td>
<td>0.4423</td>
</tr>
<tr>
<td>IsoAid Pd-103</td>
<td>0.46</td>
</tr>
</tbody>
</table>

**Difference:** ~40%
Monte Carlo Simulations

- **Dosimetric Characterization:**
  - TG-43 use is not appropriate for this source: Point source approximation would not be accurate for a planar source.
  - Use of Monte Carlo based dose calculation algorithms.
  - Nomogram/Look up tables.
  - PDD’s for Lung/Tissue and Water.
  - Dose Profile for a given plane.
Monte Carlo Simulations

a. 5cmx5cm CivaSheet

b. CivaDot

Courtesy: CivaTech Oncology Inc.
Monte Carlo Simulations

Figure: Air-Kerma Strength Measurement of a single CivaDot.

Figure: CivaSheet in a Water Phantom with tally cell setup at 5mm.
Monte Carlo Simulations

- MCNP5 – “*f4” tally was used and modified using the mass energy-absorption cross-section.

- Units equivalence was done for a Pd-103 source using infinite decay approximation.

- Two setup types as shown:
  - Air Kerma Strength Setup
  - Dose Setup – Water Phantoms and Lung Tissue
Monte Carlo Simulations

- **CivaSheet Nomogram (Dot to Sheet Link!):**
  
  - Get a modified *f4 tally in a dose calculation simulation at the prescription point (5 mm hot side) using different CivaSheet Sizes.
    - Find Dose per Activity (Gy/mCi) for a given CivaSheet size using units equivalence.
  
  - Calculate the *f4 tally in an Air-Kerma strength simulation setup for a single CivaDot.
    - Find the $S_k$ per Activity (U/mCi) for a single dot using units equivalence.
  
  - Calculate the AKS required per CivaDot to deliver a given dose to the prescription point assuming all dots have equal activity:

  \[
  AKS\ required\ per\ dot = \left(\frac{S_k}{A}\right)_{Single\ CivaDot} \times \frac{Dose\ required}{Number\ of\ Dots} \times \frac{Dose}{Activity}_{CivaSheet}
  \]
Monte Carlo Simulations

### Results – AKS required per CivaDot:

<table>
<thead>
<tr>
<th>Sheet Size</th>
<th>Calculated Constant (U per Dot)</th>
<th>*f4 tallies ratio</th>
<th>AKS required per CivaDot (U/CivaDot)</th>
<th>Rel. Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 cm x 5 cm</td>
<td>509.928</td>
<td>5.220E-03</td>
<td>2.662</td>
<td>0.14</td>
</tr>
<tr>
<td>10 cm x 5 cm</td>
<td>254.964</td>
<td>1.004E-02</td>
<td>2.559</td>
<td>0.19</td>
</tr>
<tr>
<td>15 cm x 5 cm</td>
<td>169.976</td>
<td>1.505E-02</td>
<td>2.558</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Table: Air Kerma Strength Required Per CivaDot to deliver **120 Gy @ 5 mm (hot side)** from CivaSheet center.

<table>
<thead>
<tr>
<th>Difference (%)</th>
<th>15x5</th>
<th>10x5</th>
<th>5x5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>0.05</td>
<td>4.06</td>
</tr>
</tbody>
</table>

Table: Difference as compared to the 15 cmx5 cm AKS required per CivaDot.
Conclusions

- Establishment of a possible calibration procedure for the CivaSheet.

- Monte Carlo based simulations can be used to characterize the dosimetry of a planar source array.

**Future Work: A lot of work!**
- In-depth analysis of the energy spectra of the CivaDot.
- Film Measurements.
- Determine the AKS/Well Chamber coefficient.
- Further Monte Carlo Analysis and their verification.
Acknowledgements

- Prof. Larry DeWerd and all the UWMRRC lab members.
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- Jeff Radtke and Wendy Kennan.
- CivaTech Oncology Inc.
- Customers of the UW-ADCL.
Thank You

Questions?