Brachytherapy Dose Calculation Formalism, Dataset Evaluation, and Treatment Planning System Implementation

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AAPM Summer School: Clinical Dosimetry Measurements in Radiotherapy
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As related to the contents of this presentation,

Rivard has received research support from:
Varian Medical Systems and IsoRay Medical

Williamson has received research support from:
Varian Medical Systems and Philips Medical Systems
Learning Objectives / Purpose

• explain current brachytherapy dose calculation formalism

• dosimetry parameter evaluation methods

• consensus data formulation

• clinical implementation

• background on AAPM advances
Low-Energy Brachytherapy Sources

- Amersham Health model 6711 source
- NASI model MED3831-A/M or MED3633 source
- Source Tech Medical STM1251 seed
- Bebig model 25.506 source
- Best Pd
- Imagyn model IS-2501 source
- Mentor Prostaseed
- Implant Sciences 3500
- IsoRay model CS-1 Rev2
- TheraGenics model 200 source
- DraxImage LS-1
- Amersham G733

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High-Energy Brachytherapy Sources

Figure 1. Schematic drawing of the Nucletron ‘Classic’ $^{192}$Ir HDR brachytherapy source.

Figure 2. Schematic drawing of the Nucletron ‘V2’ $^{192}$Ir HDR brachytherapy source.
Brachytherapy Dose Calculation Geometry

$P(r, \theta) = P(r_0, \theta_0) x$

$r_0 = 1 \text{ cm}$
\[ D(r, \theta) = S_K \cdot \Lambda \cdot \frac{G_L(r, \theta)}{G_L(r_0, \theta_0)} \cdot g_L(r) \cdot F(r, \theta) \]

- \( D(r, \theta) \): dose rate to water in water at point \( P(r, \theta) \)
- \( S_K \): air kerma strength
- \( \Lambda \): dose rate constant
- \( g_L(r) \): radial dose function
- \( G_L(r, \theta) \): geometry function (line source approximation)
- \( F(r, \theta) \): 2-D anisotropy function
\[ \dot{D}(r) = S_K \cdot \Lambda \cdot \frac{G_L(r, \theta_0)}{G_L(r_0, \theta_0)} \cdot g_L(r) \cdot \phi_{an}(r) \]

- \( \dot{D}(r) \): dose rate to water at point P(r)
- \( S_K \): air kerma strength
- \( \Lambda \): dose rate constant
- \( g_L(r) \): radial dose function
- \( G_L(r, \theta) \): geometry function (line source approximation)
- \( \phi_{an}(r) \): 1-D anisotropy function
Comparison of 1-D Formalisms

BAD
\[ \dot{D}(r) = S_K \cdot \Lambda \cdot \frac{G_L(r_0, \theta_0)}{G_L(r_0, \theta_0)} \cdot g_P(r) \cdot \phi_{an}(r) \]

BAD
\[ \dot{D}(r) = S_K \cdot \Lambda \cdot \left(\frac{r_0}{r}\right)^2 \cdot g_L(r) \cdot \phi_{an}(r) \]

GOOD
\[ \dot{D}(r) = S_K \cdot \Lambda \cdot \left(\frac{r_0}{r}\right)^2 \cdot g_P(r) \cdot \phi_{an}(r) \]

BEST
\[ \dot{D}(r) = S_K \cdot \Lambda \cdot \frac{G_L(r, \theta_0)}{G_L(r_0, \theta_0)} \cdot g_L(r) \cdot \phi_{an}(r) \]
Intent of 2004 AAPM TG-43U1

• provide a revised definition of air-kerma strength;

• eliminate *apparent activity* for specification of source strength;

• eliminate the anisotropy constant in favor of the distance dependent 1-D anisotropy function;

• provide guidance on extrapolating tabulated TG-43 parameters to longer and shorter distances; and

• eliminate minor inconsistencies and omissions in the original protocol and its implementation.
Consensus Dataset Formulation Methodology

- literature review of experimental and Monte Carlo dosimetry results for brachytherapy sources
- comparisons of all candidate datasets
- average $\text{MC} \Lambda$ and average $\text{EXP} \Lambda$ from literature
  
  $$\text{CON} \Lambda = \frac{(\text{MC} \Lambda + \text{EXP} \Lambda)}{2}$$

- $g(r)$ and $F(r, \theta)$ candidate datasets transformed using common $L$, possibly with $L_{\text{eff}} = \Delta S \times N$
- $g(r)$ and $F(r, \theta)$ typically taken from Monte Carlo
- $\phi(r)$ calculated from consensus $F(r, \theta)$ dataset
- final results tabulated with common mesh
## Example Dosimetry Parameter Dataset

<table>
<thead>
<tr>
<th></th>
<th>( r \text{ [cm]} )</th>
<th>( g_L(r) )</th>
<th>( g_P(r) )</th>
<th>( r \text{ [cm]} )</th>
<th>( \phi(r) )</th>
<th>( F(r,8) )</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
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<th>80</th>
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<td>0.25</td>
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<td>1.067</td>
<td>0.996</td>
<td>0.985</td>
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<tr>
<td>3</td>
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<tr>
<td>5</td>
<td>1.00</td>
<td>1.000</td>
<td>1.000</td>
<td>1.5</td>
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<td>0.15</td>
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<td>0.2</td>
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<td>0.975</td>
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<td>0.879</td>
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<td>0.997</td>
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<td>0.724</td>
<td>3.5</td>
<td>0.935</td>
<td>1</td>
<td>0.580</td>
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<td>0.813</td>
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<td>0.967</td>
<td>0.987</td>
<td>0.997</td>
</tr>
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<td>0.643</td>
<td>0.650</td>
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<td>0.626</td>
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<td>0.830</td>
<td>0.893</td>
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<td>0.967</td>
<td>0.987</td>
<td>0.997</td>
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<tr>
<td>11</td>
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<td>0.573</td>
<td>0.579</td>
<td>4.5</td>
<td>0.938</td>
<td>5</td>
<td>0.690</td>
<td>0.700</td>
<td>0.789</td>
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<td>0.968</td>
<td>0.986</td>
<td>0.996</td>
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<td>0.508</td>
<td>0.513</td>
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<td>0.938</td>
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<td>0.153</td>
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<td>18</td>
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<td>0.114</td>
<td>0.115</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

\( \Delta = 1.011 \)

\( L = 3.7 \text{ mm or 0.37 cm} \)

prefer AAPM-recommended datasets
otherwise use AAPM/RPC Registry data and original pubs websites (ESTRO, Univ. Carleton, etc) also post datasets
Dosimetry Parameter Data Trail Part 1

- **brachytherapy source vendor**
  - 5 sources
  - 5 dummy sources

- **NIST**
  - 3 sources
  - 2 sources
  - design specs.
  - 8-10 sources
  - 5 dummy sources

- ADCL(s)
  - model-specific $N_{D,w} \text{[U/mA]}$

- experimental dosimetry investigator
  - $\exp L$, $\exp \Lambda$, $\exp g(r)$,
  - $\exp F(r, \theta)$, $\exp \phi_{th}(r)$

- Monte Carlo dosimetry investigator
  - $\text{MC}_L$, $\text{MC}_\Lambda$, $\text{MC}_g(r)$,
  - $\text{MC}_F(r, \theta)$, $\text{MC}_\phi_{th}(r)$

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Dosimetry Parameter Data Trail Part 2

- ADCL(s)
  - model-specific $N_{D,W}$ [U/mA]
  - $\expL, \expA, \expS(r), \expF(r,\theta), \expF_{\text{in}}(r)$

- Experimental dosimetry investigator

- Monte Carlo dosimetry investigator
  - $\text{MC}_L, \text{MC}_A, \text{MC}_S(r), \text{MC}_F(r,\theta), \text{MC}_F_{\text{in}}(r)$

- AAPM RPC Source Registry
  - $\text{CON}_L, \text{CON}_A, \text{CON}_S(r), \text{CON}_F(r,\theta), \text{CON}_F_{\text{in}}(r)$

- Clinical medical physicist: QA, commissioning, documentation
Revised Air Kerma Strength Definition

$$S_K = \dot{K}_\delta(d) \ d^2$$

$S_K$ = air kerma strength

$\dot{K}_\delta(d)$ = air kerma rate *in vacuo* at specification point d with energy cutoff $\delta$, typically 5 keV

low-energy photon cutoff included

measurement conditions specified

NIST WAFAC
Seed Calibrations at NIST + ADCLs

NIST WAFAC

Bx source

HDR-1000+
Correction of Errors and Inconsistencies

• $g(r)$ presented for dimensionless units, consistency with investigator $g(r)$, and 5$^{th}$ order polynomial

• explicit *contraindication* for erroneous 1-D equation

\[
\dot{D}(r) = S_K \Lambda \cdot \frac{G_P(r, \theta_0)}{G_P(r_0, \theta_0)} \cdot g_L(r) \cdot \phi_{an}(r)
\]

• elimination of $A_{app}$ and anisotropy constant

• methodology to extrapolate dose calculations for large and small distances
# Need for Uncertainty Analyses

<table>
<thead>
<tr>
<th>Component</th>
<th>( \dot{d}(1 \text{ cm}, \theta_0) )</th>
<th>( \dot{d}(5 \text{ cm}, \theta_0) )</th>
<th>( s_K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: capsule geometry</td>
<td>0.16%</td>
<td>0.16%</td>
<td>0.16%</td>
</tr>
<tr>
<td>Dynamic internal components</td>
<td>0.02%</td>
<td>0.05%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Source radiation spectrum</td>
<td>0.1%</td>
<td>0.7%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Phantom composition</td>
<td>0.01%</td>
<td>0.02%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Physics of Monte Carlo code</td>
<td>0.3%</td>
<td>0.7%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Cross-sections in phantom</td>
<td>0.2%</td>
<td>0.9%</td>
<td>0.2%</td>
</tr>
<tr>
<td>( \mu_{en}/\rho ) for dose calculation</td>
<td>1.2%</td>
<td>1.2%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Tally volume averaging</td>
<td>0.006%</td>
<td>&lt;0.001%</td>
<td>&lt;0.001%</td>
</tr>
<tr>
<td>Tally statistics</td>
<td>0.02%</td>
<td>0.04%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Quadrature sum</td>
<td>0.02%</td>
<td>1.3%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Total ((k=1)) uncertainty</td>
<td>1.3%</td>
<td>1.8%</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

Recent Monte Carlo uncertainty analysis for Cs-131

Rivard, Med. Phys. 34, 754-762 (2007)
Removal of Antiquated Terms

**Apparent activity:** $A_{\text{app}}$

choice of $(\Gamma_\delta)_x$ may lead to dosimetric errors

AAPM specifies $S_K$ for source strength

**Anisotropy constant:** $\phi_{an}$

cannot accurately reproduce dose $r < 1$ cm

errors result under specific circumstances
Recommendations to Dosimetry Investigators

- **experimental measurement descriptors**
  - description of internal and external source geometry
  - source irradiation geometry, orientation, irradiation timeline
  - detector calib. technique & energy response function, $E(r)$
  - radiation detector and readout system
  - measurement phantom composition
  - phantom dimensions and use of backscatter
  - estimation volume averaging effect at all detector positions
  - # of repeated readings with standard deviation, # of sources
  - NIST $S_K$ value and uncertainty for measured source
  - uncertainty analysis section (statistical and systematic)
Recommendations to Dosimetry Investigators

• **Monte Carlo** calculation descriptors
  – radiation transport code, version, and major options
  – cross-section library name, version, and customizations
  – radiation spectrum of source
  – manner in which dose-to-water and air-kerma strength are calculated (*i.e.*, tally used)
  – source geometry, phantom geometry, and sampling space
  – composition and mass density of materials in the source
  – composition and mass density of materials in the phantom
  – physical distribution of radioisotope within the source
  – uncertainty analysis section (statistical and systematic)
Recommendations to Dosimetry Investigators

**Monte Carlo** recommended good practices

- primary calculations in 30 cm diameter liquid water phantom, with at least 5 cm of backscatter material
- use sufficient histories to limit statistical uncertainty
  \[ 1\sigma \leq 2\% \text{ for } r \leq 5 \text{ cm in water}; \ 1\sigma \leq 1\% \text{ for } s_K \text{ calculations} \]
- modern cross-section libraries should be used
- verify manufacturer’s source dimensions
- Volume averaging effects should be limited to < 1 %
- model \( k(d) \) as a function of polar angle for \( s_K \) simulation
- point source modeling is unacceptable
- mechanical mobility of internal source structures
NIST-specified source spectra, half-lives, $\rho$ and atomic composition for air and water

**TABLE XIII. Recommended nuclear data for $^{125}$I and $^{103}$Pd for brachytherapy dosimetry.**

<table>
<thead>
<tr>
<th>Photon energy (keV)</th>
<th>$^{125}$I (half-life = 59.40 ± 0.01 days)</th>
<th>$^{103}$Pd (half-life = 16.991 ± 0.019 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Photons per disintegration</td>
<td>Photons per disintegration</td>
</tr>
<tr>
<td>27.202</td>
<td>0.406</td>
<td>20.074</td>
</tr>
<tr>
<td>27.472</td>
<td>0.757</td>
<td>20.216</td>
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<td>30.98</td>
<td>0.202</td>
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<td>31.71</td>
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<td>35.492</td>
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<td></td>
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<td>357.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>497.1</td>
</tr>
</tbody>
</table>

Weighted mean energy = 28.37 keV  Total = 1.476

$^{125}$I $\Gamma_{5\text{keV}} = 0.0355 \mu \text{Gy} \cdot \text{m}^2 \cdot \text{h}^{-1}, \text{MBq}^{-1}$

Weighted mean energy = 20.74 keV  Total = 0.7714

$^{103}$Pd $\Gamma_{5\text{keV}} = 0.0361 \mu \text{Gy} \cdot \text{m}^2 \cdot \text{h}^{-1}, \text{MBq}^{-1}$

**TABLE XIV. Composition (percent mass) of air as a function of relative humidity at a pressure of 101.325 kPa.**

<table>
<thead>
<tr>
<th>Relative humidity (%)</th>
<th>Hydrogen</th>
<th>Carbon</th>
<th>Nitrogen</th>
<th>Oxygen</th>
<th>Argon</th>
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</thead>
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<tr>
<td>0</td>
<td>0.0000</td>
<td>0.0124</td>
<td>75.5268</td>
<td>23.1781</td>
<td>1.2827</td>
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<tr>
<td>10</td>
<td>0.0181</td>
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<td>23.2841</td>
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<td>40</td>
<td>0.0732</td>
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<td>60</td>
<td>0.1101</td>
<td>0.0123</td>
<td>74.7837</td>
<td>23.8238</td>
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<tr>
<td>100</td>
<td>0.1842</td>
<td>0.0122</td>
<td>74.2835</td>
<td>24.2585</td>
<td>1.2616</td>
</tr>
</tbody>
</table>
Second-party brachytherapy source calibrations and physicist responsibilities: Report of the AAPM Low Energy Brachytherapy Source Calibration Working Group

Compiling and clarifying recommendations established by previous AAPM Task Groups 40, 56, and 64 were among the working group’s charges, which also included the role of second-party handlers to perform loading and assay of sources. This document presents working group findings on the responsibilities of the institutional medical physicist and a clarification of the existing AAPM recommendations in the assay of brachytherapy sources. The AAPM leaves it to the discretion of the institutional medical physicist whether the manufacturer’s or institutional physicist’s measured value should be used in performing dosimetry calculations.

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# 2008 AAPM Calibration Recommendations

**TABLE I.** Quantities of brachytherapy sources to be assayed by the end-user physicist.

<table>
<thead>
<tr>
<th>Source form</th>
<th>Number to be assayed$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All loose sources, nonsterile</td>
<td>$\geq 10%$ of total or 10 seeds, whichever is larger.</td>
</tr>
<tr>
<td>Nonsterile cartridges</td>
<td>$\geq 10%$ of total via whole cartridge assay or via single sources.</td>
</tr>
<tr>
<td>Mixture of nonsterile loose sources and sterile assemblies</td>
<td>Loose sources amounting to $\geq 10%$ of the total order or ten seeds, whichever is larger.</td>
</tr>
<tr>
<td>Sterile source assemblies</td>
<td>$\geq 10%$ of assemblies via sterile well chamber inserts or quantitative image analysis. Alternatively, order and assay nonsterile loose seeds equal to 5% of the total or five seeds, whichever is fewer.</td>
</tr>
<tr>
<td>Strands</td>
<td>$\geq 10%$ of total or two strands, whichever is larger, using single-seed calibration coefficient (see Ref. 15). Alternatively, order and assay nonstranded loose seeds equal to 5% of the total or five seeds, whichever is fewer.</td>
</tr>
</tbody>
</table>

$^a$Each source-strength grouping in an order should be sampled. If the number of sources in a strength group is $<10$, the entire group should be assayed.
# 2008 AAPM Calibration Recommendations

**Table II.** Actions to be taken by the physicist at the end-using institution based on the sample size assayed and the relative difference, \( \Delta S_K \), found between the manufacturer’s source strength certificate and the assay by the physicist at the using institution.\(^a\)

<table>
<thead>
<tr>
<th>Sample size for assay of sources by end-user medical physicist</th>
<th>( \Delta S_K )</th>
<th>Action by end-user medical physicist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual source as part of an order of ( \geq 10 ) sources(^b)</td>
<td>( \Delta S_K \leq 6% )</td>
<td>Nothing further.</td>
</tr>
<tr>
<td></td>
<td>( \Delta S_K &gt; 6% )</td>
<td>Consult with the radiation oncologist regarding use of the outlier source: Dependent on the radionuclide, intended target, source packaging, and the availability of extra sources.</td>
</tr>
<tr>
<td>( \geq 10% ) but (&lt; 100% ) of order, or batch measurements of individual sterile strands, cartridges or preloaded needles</td>
<td>( \Delta S_K \leq 3% )</td>
<td>Nothing further.</td>
</tr>
<tr>
<td></td>
<td>( 5% \geq \Delta S_K &gt; 3% )</td>
<td>Investigate source of discrepancy or increase the sample size.</td>
</tr>
<tr>
<td></td>
<td>( \Delta S_K &gt; 5% )</td>
<td>Consult with manufacturer to resolve differences or increase the sample size. For assays performed in the operating room, consult with the radiation oncologist regarding whether to use the measured source strength or to average with the manufacturer’s value.</td>
</tr>
<tr>
<td>100% of order, or batch measurements of each and every individual sterile strand, cartridge or preloaded needle</td>
<td>( \Delta S_K \leq 3% )</td>
<td>Nothing further.</td>
</tr>
<tr>
<td></td>
<td>( 5% \geq \Delta S_K &gt; 3% )</td>
<td>Investigate source of discrepancy.</td>
</tr>
<tr>
<td></td>
<td>( \Delta S_K &gt; 5% )</td>
<td>Consult with manufacturer to resolve differences. For assays performed in the operating room, consult with the radiation oncologist regarding the consequences of proceeding with the implant using the measured source strength.</td>
</tr>
</tbody>
</table>

\(^{a}\)Assay results obtained at sites other than the end-user institution should not replace the source strength value on the manufacturer’s certificate. The source strength value to be used in planning may be either that stated on the manufacturer’s certificate or the value determined by institutional medical physicist when the difference is \( \geq 5\% \).

\(^{b}\)For orders consisting of \(< 10\) sources, the action threshold is \( \Delta S_K > 5\% \) for individual sources.
Systematic Approach to RTP QA

Example datasets (from TG-43UXX or published literature)

Methods for data entry (HDR & LDR)

Check RTP for list of key functions

Tests of all RTP field entries ($S_\kappa$ linearity, test of decay, dose superposition, shield attn factor for HDR, etc)

Impact of coarse data grid (interpolation technique & errors)

QA comparison of hand calc with RTP point doses

Compare printed/plotted isodose images

Documentation (use e-records)
AAPM Therapy QA Guidance Documents

TG-40: General Radiotherapy QA

TG-43: Bx Dosimetry Parameters & Dose Calc. Algorithm

TG-53: RTP QA

TG-56: Bx Code of Practice
TG-59: HDR Tx Delivery
TG-64: LDR Prostate Tx Delivery

These reports focus on treatment-related QA
AAPM TG-40 Guidance

Source strength decay of inventory

Global scaling of dose rate with $S_K$ and $\Lambda$

Test source localization tools over full range of clinical use

Accuracy and implementation of shield attenuation factor

Impact of grid size
AAPM TG-43 Guidance

Dosimetry parameters: $S_K$ and $\Lambda$, $g_L(r)$, $F(r, \theta)$, and $\phi(r)$
taken from consensus datasets

Parameter units: $r$ [cm] and $\theta$ [degrees] except for $\beta$ [radians] ensure consistency with RTP

Dosimetry algorithm:

$$D(r, \theta) = S_K \cdot \Lambda \cdot \frac{G_L(r, \theta)}{G_L(r_0, \theta_0)} \cdot g_L(r) \cdot F(r, \theta)$$
AAPM TG-53 Guidance

RTP specs and ATP

Hardcopy printout accuracy

Temporal dose rate correlation with radionuclide decay

Accuracy and consistency of parameter units

Computer systems storage and security
## AAPM Committee Structure

### Subcommittee

<table>
<thead>
<tr>
<th>Liaisons</th>
<th>BTSC</th>
<th>ABS + ESTRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Groups</td>
<td>SBM</td>
<td>HEBD</td>
</tr>
<tr>
<td>Task Groups</td>
<td>129, 143, 144, 182</td>
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### Chairs and Liaisons

- **Brachytherapy Subcommittee (BTSC), Mark Rivard**
  - Special Brachytherapy Modalities Working Group (SBM), Bruce Thomadsen
  - High-Energy Brachytherapy Source Dosimetry Working Group (HEBD), Jose Perez-Calatayud
  - Robotic Brachytherapy Working Group (RoboBx), Bruce Thomadsen and Yan Yu
  - Low-Energy Brachytherapy Source Dosimetry Working Group (LEBD), Michael Mitch
  - Brachytherapy Source Registry Working Group (BSR), Geoff Ibbott
    - TG-129 Eye Plaque Dosimetry, Sou-Tung Chiu-Tsao
    - TG-143 Dosimetry for Elongated Brachytherapy Sources, Ali Meigooni
    - TG-144 Dosimetry & QA Procedures for $^{90}$Y Microsphere Brachytherapy for Liver Cancer, Andy Dezarn
  - TG-137 Prostate Cancer Dose Prescription Recommendations, Ravinder Nath
  - TG-138 Brachytherapy Dose Evaluation Uncertainties, Larry DeWerd
  - TG-167 Investigational Brachytherapy Source Recommendations, Ravinder Nath
  - TG-182 Electronic Brachytherapy Quality Management, Bruce Thomadsen
  - TG-186 Model-Based Dose Calculation Techniques for Advanced Dosimetry, Luc Beaulieu

- **American Brachytherapy Society (ABS), Zoubir Ouhib**
- **European Society for Therapeutic Radiology & Oncology (ESTRO), Jack Venselaar**
AAPM Plan to Address Dosimetry Advances

TG-186 charged to review
  – next-generation dose calculation algorithms
  – studies evaluating advanced algorithms for
    • phantom size effect
    • inter-seed attenuation
    • material heterogeneities within the body
    • interface and shielded applicators
    • directional brachytherapy (azimuthal asymmetry)
  – commissioning issues
  – patient-related input data
  – potential clinical issue, risks, and limitations
Brachytherapy is a mature treatment modality that has benefited from technological advances. Treatment planning has advanced from simple lookup tables to complex, computer-based dose calculation algorithms. The current approach is based on the AAPM TG-43 formalism with recent advances in acquiring single-source dose distributions. However, this formalism has clinically relevant limitations for calculating patient dose. Dose-calculation algorithms are being developed based on Monte Carlo methods, collapsed cone, and the linear Boltzmann transport equation. In addition to improved dose-calculation tools, planning systems and brachytherapy treatment planning will account for material heterogeneities, scatter conditions, radiobiology, and image guidance. The AAPM, ESTRO, and other professional societies are coordinating clinical integration of these advancements. This Vision 20/20 article provides insight on these endeavors. 

## Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

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<th>shielding</th>
<th>scattering</th>
<th>beta/kerma dose</th>
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Phantom Size and $^{192}\text{Ir}$ Photon Scattering

Conventional TPS Fails to Accurately Calculate Brachytherapy Dose

- air ≠ water?
- tissue ≠ water?
- contrast impact?
- source superposition?
- source shielding?
- radiation scatter?
Is the Future Monte Carlo-based TPS?

Medical Physics

An approach to using conventional brachytherapy software for clinical treatment planning of complex, Monte Carlo-based brachytherapy dose distributions

Mark Rivard,¹ Chris Melhus,¹ Domingo Granero,² Jose Perez-Calatayud,² Facundo Ballester³

¹Department of Radiation Oncology, Tufts Medical Center, Boston, Massachusetts 02111

²Radiation Oncology Department, “La Fe” University Hospital, Valencia, Spain

³Department of Atomic, Molecular, and Nuclear Physics, University of Valencia, Spain

Summary

- current dose calculation formalism presented
- dosimetry parameter evaluation and consensus methods for uniform datasets derivation
- clinical implementation based on AAPM reports
- AAPM current status and areas for future advancement