Summary and Insights into the TG-43U1S2 Report on brachytherapy dosimetry

Mark J. Rivard, Wayne M. Butler, and Facundo Ballester on behalf of the report authors

1Alpert Medical School of Brown University, Providence, RI
2Schiffler Cancer Center and Wheeling Jesuit University, Wheeling, WV
3Departamento de Física Atómica, Molecular y Nuclear Universitat de Valencia, Burjassot, ESPAÑA
Disclosures

This session may be interpreted as societal guidance.

Specific commercial equipment, instruments, and materials are listed to fully describe the necessary procedures. Such identification does not imply endorsement by the presenters, nor that these products are necessarily the best available for these purposes.

For work performed preceding this report, Dr. Rivard has received research support from GE Healthcare, CivaTech Oncology, and IsoRay Medical; Dr. Ballester from Elekta; Dr. DeWerd from GE Healthcare, CivaTech Oncology, andIsoRay Medical; Dr. Ibbott from IsoRay Medical; Dr. Meigooni from Intl. Brachytherapy and IsoAid; and Dr. Papagiannis from Elekta AB and BEBIG GmbH
Learning Objectives

1. understand method for deriving consensus datasets
   see 11 practical examples

2. become familiar with recommendations to vendors of BT sources and TPSs

3. identify reference data for BT dosimetry investigations:
   radionuclide source spectra and half-lives,
   reference dose scoring media, and
   TLD methodological corrections
Supplement 2 for the 2004 update of the AAPM Task Group No. 43 Report: Joint recommendations by the AAPM and GEC-ESTRO

Mark J. Rivard\textsuperscript{(a)}

\textit{Department of Radiation Oncology, Tufts University School of Medicine, Boston, MA 02111, USA}

Facundo Ballester

\textit{Unidad Mixta de Investigación en Radiofísica e Instrumentación Nuclear en Medicina (IRIMED), Instituto de Investigación Sanitaria La Fe (IIS-La Fe)-Universitat de València, Bujassot 46100, Spain}

Wayne M. Butler

\textit{Schiffler Cancer Center, Wheeling Hospital, Wheeling, WV 26003, USA}

Larry A. DeWerd

\textit{Accredited Dosimetry and Calibration Laboratory, University of Wisconsin, Madison, WI 53706, USA}

Geoffrey S. Ibbott

\textit{Department of Radiation Physics, M.D. Anderson Cancer Center, Houston, TX 77030, USA}

Ali S. Meigooni

\textit{Comprehensive Cancer Centers of Nevada, Las Vegas, NV 89169, USA}

Christopher S. Melhus

\textit{Department of Radiation Oncology, Tufts University School of Medicine, Boston, MA 02111, USA}

Michael G. Mitch

\textit{Radiation Physics Division, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA}

Ravinder Nath

\textit{Department of Therapeutic Radiology, Yale University School of Medicine, New Haven, CT 06510, USA}

Panagiotis Papagiannis

\textit{Medical Physics Laboratory, Medical School, University of Athens, Athens, Greece}
(a) $^{125}$I (0.002 mm)
  radioactive coating
  0.023 mm Ag
  0.003 mm Ni
  0.50 mm diam.
  Mo marker
  0.050 mm wall
  Ti capsule

BEBIG model I25.S17

(b) $^{125}$I (0.001 mm)
  radioactive coating
  0.003 mm Ag
  0.51 mm diam.
  Ag marker
  0.055 mm wall
  Ti capsule

BEBIG model I25.S17plus

(c) $\text{SiO}_2$ (0.002 mm)
  $\text{SiO}_2 + ^{125}$I (0.023 mm)
  radioactive coating
  0.48 mm diam.
  Pb glass marker
  0.14 mm wall
  polymer capsule

BEBIG model I25.S18

(d) $^{125}$I (0.003 mm)
  radioactive coating
  0.51 mm diam.
  Ag marker
  0.050 mm wall
  Ti capsule

Elekta model 130.002

(e) $\text{Ag}_2\text{Br}_2 + ^{125}$I (0.002 mm)
  radioactive coating
  0.30 mm diam.
  Ag marker
  0.057 mm wall
  Ti capsule

Oncura model 9011

(f) $^{125}$I (0.002 mm)
  radioactive coating
  0.59 mm diam.
  Ag marker
  0.050 mm wall
  Ti capsule

Theragenics model AgX100
Radial Dose Functions

Radial dose function $g_r(r)$

- Cs-131
- S18, I-125
- Pd-103
- I-125

$r / \text{cm}$
1D Anisotropy Functions

The graph shows 1D anisotropy functions for various materials and conditions. The function values are plotted against the radial distance in centimeters (r/cm).

Key materials and conditions include:
- S17
- S17plus
- S18
- 130.002
- 9011
- AgX100
- CS10
- 1031L
- 1032P
- IAPd-103A
- CS-1 Rev2

The graph illustrates how the anisotropy function decreases as the radial distance increases, with each material or condition showing a distinct pattern.
1D Anisotropy Functions

$\phi_{an}(r)$ vs $r$ in cm for various materials:
- S17
- S17plus
- S18
- 130.002
- 9011
- AgX100
- CS10
- 1031L
- 1032P
- IAPd-103A
- CS-1 Rev2
Summary and Insights into the TG-43U1S2 Report on brachytherapy dosimetry: Report summary, methods to formulate consensus data, and presentation of the consensus datasets

Mark J. Rivard,¹ Wayne M. Butler,² and Facundo Ballester³ on behalf of the report authors

¹Alpert Medical School of Brown University, Providence, RI
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³Departamento de Física Atómica, Molecular y Nuclear Universitat de Valencia, Burjassot, ESPAÑA
AAPM Task Group 43 formed in 1988 and published its report in 1995

Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43

Ravinder Nath  
Department of Therapeutic Radiology, Yale University School of Medicine, New Haven, Connecticut 06510

Lowell L. Anderson  
Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York 10021

Gary Luxton  
Department of Radiation Oncology, University of Southern California, Los Angeles, California 90033

Keith A. Weaver  
Department of Radiation Oncology, University of California, San Francisco, California 94143

Jeffrey F. Williamson  
Division of Radiation Oncology, Washington University School of Medicine, St. Louis, Missouri 63110

Ali S. Meigooni  
Department of Radiation Medicine, University of Kentucky, A. B. Chandler Medical Center, Lexington, Kentucky 40536

• Included data on $^{192}$Ir and 3 permanent seed LDR sources
  • $^{125}$I models 6711 and 6702 and $^{103}$Pd model 200
Subsequent TG-43 reports

• 2004, TG-43 U1
  • Updated 3 models
  • Added 5 new seed models
  • Included Bebig and Best $^{125}$I models

• 2007, TG-43 U1S1
  • Added 8 new seed models
  • Included IsoAid $^{125}$I and Best $^{103}$Pd models
Finally...!
The latest report, TG-43 U1S2

Supplement 2 for the 2004 update of the AAPM Task Group No. 43 Report:
Joint recommendations by the AAPM and GEC-ESTRO

Mark J. Rivard$^{(a)}$
\textit{Department of Radiation Oncology, Tufts University School of Medicine, Boston, MA 02111, USA}

Facundo Ballester
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Panagiotis Papagiannis
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TG-43 Update 1, Supplement 2

- Added 11 new seed models
  - Included Elekta and Theragenics $^{125}$I, CivaTech and IsoAid $^{103}$Pd and IsoRay $^{131}$Cs models
  - Data for 5 discontinued models included for retrospective analyses
- Contains 38 data tables
  - > 6,800 data points
  - 42 pages in Med Phys
  - Considerable manual labor!
in TG-43 U1S2

- Dose rate tables for each source for $r$ vs. polar angle
  - $r$ range from 0.1 cm to 10 cm
  - Angles from 0° to 90°
- Dose rate tables for each source in Cartesian coordinates (along and away)
  - $r$ from 0 to 7 cm
### TABLE XVIII. Dose rates (cGy h\(^{-1}\) U\(^{-1}\)) per unit source strength (Theragenics model AgX100 \(^{125}\)I source)

<table>
<thead>
<tr>
<th>Along (cm)</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>3.981</td>
<td>0.952</td>
<td>0.386</td>
<td>0.1950</td>
<td>0.0676</td>
<td>0.0290</td>
<td>0.01388</td>
<td>0.00718</td>
<td>0.00390</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>1.018</td>
<td>1.928</td>
<td>0.763</td>
<td>0.352</td>
<td>0.1858</td>
<td>0.0667</td>
<td>0.0287</td>
<td>0.01381</td>
<td>0.00715</td>
<td>0.00389</td>
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<tr>
<td>1.0</td>
<td>0.287</td>
<td>0.599</td>
<td>0.417</td>
<td>0.248</td>
<td>0.1481</td>
<td>0.0593</td>
<td>0.0268</td>
<td>0.01322</td>
<td>0.00694</td>
<td>0.00380</td>
</tr>
<tr>
<td>1.5</td>
<td>0.1393</td>
<td>0.241</td>
<td>0.218</td>
<td>0.1581</td>
<td>0.1073</td>
<td>0.0491</td>
<td>0.0237</td>
<td>0.01209</td>
<td>0.00649</td>
<td>0.00361</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0788</td>
<td>0.1185</td>
<td>0.1202</td>
<td>0.0986</td>
<td>0.0745</td>
<td>0.0389</td>
<td>0.0201</td>
<td>0.01074</td>
<td>0.00592</td>
<td>0.00335</td>
</tr>
<tr>
<td>2.5</td>
<td>0.0480</td>
<td>0.0657</td>
<td>0.0702</td>
<td>0.0628</td>
<td>0.0510</td>
<td>0.0300</td>
<td>0.01664</td>
<td>0.00929</td>
<td>0.00528</td>
<td>0.00306</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0316</td>
<td>0.0402</td>
<td>0.0434</td>
<td>0.0407</td>
<td>0.0349</td>
<td>0.0225</td>
<td>0.01345</td>
<td>0.00788</td>
<td>0.00462</td>
<td>0.00274</td>
</tr>
<tr>
<td>3.5</td>
<td>0.0210</td>
<td>0.0256</td>
<td>0.0279</td>
<td>0.0270</td>
<td>0.0242</td>
<td>0.01686</td>
<td>0.01070</td>
<td>0.00656</td>
<td>0.00398</td>
<td>0.00242</td>
</tr>
<tr>
<td>4.0</td>
<td>0.01455</td>
<td>0.01717</td>
<td>0.01860</td>
<td>0.01837</td>
<td>0.01693</td>
<td>0.01255</td>
<td>0.00841</td>
<td>0.00539</td>
<td>0.00338</td>
<td>0.00211</td>
</tr>
<tr>
<td>4.5</td>
<td>0.01030</td>
<td>0.01189</td>
<td>0.01274</td>
<td>0.01275</td>
<td>0.01200</td>
<td>0.00934</td>
<td>0.00658</td>
<td>0.00438</td>
<td>0.00283</td>
<td>0.00181</td>
</tr>
<tr>
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<td>0.00845</td>
<td>0.00897</td>
<td>0.00902</td>
<td>0.00861</td>
<td>0.00699</td>
<td>0.00512</td>
<td>0.00353</td>
<td>0.00236</td>
<td>0.00154</td>
</tr>
<tr>
<td>5.5</td>
<td>0.00545</td>
<td>0.00607</td>
<td>0.00640</td>
<td>0.00648</td>
<td>0.00627</td>
<td>0.00524</td>
<td>0.00397</td>
<td>0.00283</td>
<td>0.001945</td>
<td>0.001303</td>
</tr>
<tr>
<td>6.0</td>
<td>0.00404</td>
<td>0.00445</td>
<td>0.00465</td>
<td>0.00471</td>
<td>0.00459</td>
<td>0.00395</td>
<td>0.00308</td>
<td>0.00227</td>
<td>0.001593</td>
<td>0.001092</td>
</tr>
<tr>
<td>6.5</td>
<td>0.00302</td>
<td>0.00331</td>
<td>0.00343</td>
<td>0.00347</td>
<td>0.00340</td>
<td>0.00300</td>
<td>0.00239</td>
<td>0.001803</td>
<td>0.001300</td>
<td>0.000909</td>
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<tr>
<td>7.0</td>
<td>0.00229</td>
<td>0.00249</td>
<td>0.00255</td>
<td>0.00258</td>
<td>0.00255</td>
<td>0.00228</td>
<td>0.001865</td>
<td>0.001433</td>
<td>0.001058</td>
<td>0.000754</td>
</tr>
</tbody>
</table>

- Easily check your TPS (use $T_{avg}$)
There is, of course, an erratum

- Med Phys, 45:971–974, 2018
- 6 data tables republished with errors corrected
TG-43 dose equation for a line source

\[ Dose = S_K \cdot \Lambda \cdot g_L(r) \cdot F(r, \theta) \cdot T_{avg} \cdot \frac{G_L(r, \theta)}{G_L(r_0, \theta_0)} \]

- \( S_K \): air-kerma strength in cGy·cm²/h = \( U \)
- \( \Lambda \): dose rate constant in cGy / h·U
- \( g_L(r) \): radial dose function (atten & scatter)
- \( F(r, \theta) \): 2D anisotropy function
- \( T_{avg} \): average life of the radionuclide = \( t_{1/2}/ln2 \)
- \( G_L(r, \theta) \): geometry function of source distribution
Reference quality published data necessary for consensus

- Effective active length, $L_{\text{eff}}$, determined for geometry function calculations
- Two methods used to determine dosimetry parameters
  - Experimental: TLD
    - Solid to liquid corrections used
  - Monte Carlo transport is up-to-date
    - cross section library
    - scoring estimator
The consensus dose rate constant, $\Lambda$

$$\Lambda = \frac{\dot{D}(r_0, \theta_0)}{S_K}$$

- The reference position: $r_0 = 1 \text{ cm}$ and $\theta_0 = \pi/2$

- $\Lambda$ is a 50:50 average of all the valid, published TLD data and all the valid, published Monte Carlo data

  - The uncertainty for each methodology, experimental or calculational, is summed in quadrature
    
    $$\sigma = \sqrt{\sigma_\text{EXP}_a^2 + \sigma_\text{EXP}_b^2}$$

- Total uncertainty is the weighted quadrature sum of each methodology

  $$\sigma_\text{TOT} = \sqrt{\sigma_\text{EXP}^2 + \sigma_\text{MC}^2 + \left(\frac{\Lambda_\text{EXP}-\Lambda_\text{MC}}{2\sqrt{3}}\right)^2}$$
The radial dose and 2D anisotropy functions

- The functions are intermediaries to reproduce and interpolate doses found by experiment or Monte Carlo

- $g(r)$ and $F(r, \theta)$ are not measured quantities but are derived from the doses in order to separate factors contributing to dose.

$$g_L(r) = \frac{D(r, \theta_0)}{D(r_0, \theta_0)} \cdot \frac{G_L(r_0, \theta_0)}{G_L(r, \theta_0)}$$

$$F(r, \theta) = \frac{D(r, \theta)}{D(r, \theta_0)} \cdot \frac{G_L(r, \theta_0)}{G_L(r, \theta)}$$
Geometry functions

- $G(r, \theta)$ for a point source is simply the inverse square:
  \[ G_P(r, \theta) = \frac{1}{r^2} \]

- When describing the source as a line:
  \[ G_L(r, \theta) = \frac{\beta}{L_{\text{eff}} r \sin \theta} \]

- $L_{\text{eff}} = \Delta S \cdot n$ for $n$ discrete pellets of spacing $\Delta S$

- Beta, $\beta$, is the angle subtended by $L_{\text{eff}}$ at the calculation point
All candidate data was checked for consistency

- Reported $g(r)$ converted from line to point or vice versa using geometry functions

$$G_L(r, \theta) = \left( \tan^{-1} \left( \frac{L_{eff}}{2 \cdot r \cdot \sin \theta} + \frac{1}{\tan \theta} \right) + \tan^{-1} \left( \frac{L_{eff}}{2 \cdot r \cdot \sin \theta} - \frac{1}{\tan \theta} \right) \right) \Big/ (L_{eff} \cdot r \cdot \sin \theta)$$

- $F(r, \theta)$ and $\phi_{an}(r)$ values using geometry functions, dose weighting, and angular weighting
Calculated $g(r)$ were plotted to reveal outliers

(Elekta model 130.002)
$F(r,\theta)$ for $r \leq 1 \text{ cm}$  (Elekta model 130.002)
$F(r, \theta)$ for $r \geq 1$ cm  
(Elekta model 130.002)
Interpolation and extrapolation

- Interpolation of $F(r,\theta)$ uses a bi-linear approach
- Interpolation of $g(r)$ uses a log-linear approach

$$g(r_x) = g(r_i) \cdot e^{(r_x-r_i) \cdot \ln(g(r_f)) - \ln(g(r_i))) / (r_f-r_i)}$$

<table>
<thead>
<tr>
<th>$g(r)$</th>
<th>$r$</th>
<th>linear</th>
<th>log-lin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_i$</td>
<td>0.1</td>
<td>0.576</td>
<td>0.576</td>
</tr>
<tr>
<td>$r_x$</td>
<td>0.15</td>
<td>0.679</td>
<td>0.664</td>
</tr>
<tr>
<td>$r_f$</td>
<td>0.25</td>
<td>0.884</td>
<td>0.884</td>
</tr>
</tbody>
</table>
Log-linear interpolation for g(r) compared to linear interpolation
In TG-43 U1S2, interpolated data is **bold** and extrapolated is **underlined**

- Those values are not derived from numbers in the printed report but from nearby high resolution values.

<table>
<thead>
<tr>
<th>( r ) (cm)</th>
<th>BEBIG S17</th>
<th>BEBIG S17plus</th>
<th>BEBIG S18</th>
<th>Elekta 130.002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-source approximation, ( CONS1(r) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>1.072</td>
<td>1.059</td>
<td>1.169</td>
<td>1.042</td>
</tr>
<tr>
<td>0.15</td>
<td>1.090</td>
<td>1.080</td>
<td>1.152</td>
<td>1.062</td>
</tr>
<tr>
<td>0.25</td>
<td>1.100</td>
<td>1.092</td>
<td>1.121</td>
<td>1.085</td>
</tr>
<tr>
<td>0.50</td>
<td>1.077</td>
<td>1.073</td>
<td>1.070</td>
<td>1.078</td>
</tr>
<tr>
<td>0.75</td>
<td>1.042</td>
<td>1.040</td>
<td><strong>1.033</strong></td>
<td><strong>1.044</strong></td>
</tr>
<tr>
<td>1.00</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**Extrapolated from \( \theta = 6^\circ \) or from \(11^\circ \)**

**Interpolated from \( r = 0.7 \) and 0.8**

### Table AIX: \( CONF(r, \theta) \) data for the CivaTech model CS10 \( ^{103}\text{Pd} \) from the consensus \( CONF(r, \theta) \) dataset.

<table>
<thead>
<tr>
<th>Polar angle ( \theta ) ((^\circ))</th>
<th>0.1</th>
<th>0.25</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td></td>
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<tr>
<td>5</td>
<td></td>
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</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>1.266</td>
</tr>
<tr>
<td>10</td>
<td>1.287</td>
<td>1.281</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.271</td>
<td>1.274</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.252</td>
<td>1.244</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.358</td>
<td>1.229</td>
<td>1.213</td>
</tr>
</tbody>
</table>
Use the report wisely, & thank you
Summary and Insights into the TG-43U1S2 Report on brachytherapy dosimetry: Dosimetry parameter dependence on radionuclide, influence of dataset grid size, and recommendations to vendors of brachytherapy sources and treatment planning systems

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Learning objectives

- show dependence of TG-43 parameter values on radionuclide
- highlight influence of consensus dataset grid size on TPS calculations
- identify societal recommendations to vendors of brachytherapy sources and treatment planning systems
Contents

- background
- dependence of TG-43 parameter values on radionuclide
- resolution grid size influence on TPS calculations
- recommendations to seed and TPS vendors
TG-43U1S2 seeds

(a) Ag$^{125}$I (0.002 mm) radioactive coating
0.023 mm Ag
0.003 mm Ni
0.50 mm diam.
Mo marker
0.050 mm wall
Ti capsule

BEBIG model I25.S17

(c) SiO$_2$ (0.002 mm)
SiO$_2$ + Ag$^{125}$I (0.023 mm)
radioactive coating
0.48 mm diam.
Pb glass marker
0.14 mm wall
polymer capsule

BEBIG model I25.S18

(b) Ag$^{125}$I (0.001 mm) radioactive coating
0.51 mm diam.
Ag marker
0.055 mm wall
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BEBIG model I25.S17plus

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(e) Ag$^{125}$I (0.002 mm) radioactive coating
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0.050 mm wall
Ti capsule

Theragenics model AgX100
TG-43U1S2 seeds

- **Pd-103**
  - Polymer + $^{103}$Pd radioactive wells
  - 0.80 mm long
  - 0.25 mm diam.
  - Au marker

- **Cs-131**
  - Polymer capsule

- **CivaTech Oncology model CS10**
  - 0.85 mm

- **IBt model 1031L**
  - Polymer + $^{103}$Pd radioactive bands
  - Pt + Ir marker
  - 1.27 mm long
  - 0.040 mm wall
  - Ti capsule
  - 3.70 mm
  - 4.50 mm

- **IBt model 1032P**
  - Polymer + $^{103}$Pd radioactive cylinders
  - 2.00 mm long
  - 0.45 mm diam.
  - Au marker
  - 0.20 mm wall
  - Ti capsule
  - 3.80 mm
  - 5.00 mm

- **IsoAid model IAPd-103A**
  - Polymer + $^{103}$Pd radioactive spheres
  - Ag marker
  - 0.80 mm
  - 3.82 mm
  - 4.50 mm

- **IsoRay Medical model CS-1 Rev2**
  - Ceramic + $^{131}$Cs radioactive core
  - 0.25 mm diam.
  - Ag marker
  - 0.056 mm wall
  - Ti capsule
  - 4.00 mm
  - 4.50 mm

- **Cs-131**
  - 0.82 mm
Dose rate constant values: Dependence on radionuclide

For seeds of the same radionuclide, the dose rate constant is approximately constant.
Radial dose function: Dependence on radionuclide

For seeds of the same radionuclide, the radial dose functions are indistinguishable, except for \( r < 0.5 \) cm. special case: S18 \(^{125}\)I sed
2D anisotropy function values: Dependence on radionuclide

2D anisotropy function, $\text{CON}_F(r,\theta)$

For seeds of the same radionuclide, the 2D anisotropy functions are similar. Special case: S18 $^{125}$I seed

Anisotropy function for $^{125}$I seeds

$r = 0.5 \text{ cm}$
1D anisotropy function values: Dependence on radionuclide

For seeds of same radionuclide, 1D anisotropy functions exhibit specific characteristics for \( r < 0.5 \text{ cm} \)

special case: S18 \(^{125}\)I seed
1D anisotropy function functions for the 11 seed models

![Graph showing 1D anisotropy function functions for the 11 seed models.](image)
Influence of the grid size resolution on TPS calculations

Data interpolation/extrapolation method recommendations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$r &lt; r_{\min}$ Extrapolation</th>
<th>$r_{\min} &lt; r \leq r_{\max}$ Interpolation</th>
<th>$r &gt; r_{\max}$ Extrapolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_L(r)$</td>
<td>Nearest neighbor or zeroth-order extrapolation (Ditto)</td>
<td>Linear (log-linear) using datapoints immediately adjacent to the radius of interest</td>
<td>Linear using data of last two tabulated radii (single exponential function based on fitting $g_L(r)$ datapoints for the furthest three $r$ values)</td>
</tr>
<tr>
<td>$F(r,\theta)$</td>
<td>Nearest neighbor or zeroth-order extrapolation (Ditto)</td>
<td>Bilinear (bilinear) interpolation method for $F(r,\theta)$</td>
<td>Nearest neighbor or zeroth-order $r$-extrapolation (Ditto)</td>
</tr>
</tbody>
</table>

Influence of grid size resolution on TPS calculations

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Brachytherapy treatment planning commissioning: effect of the election of proper bibliography and finite size of TG-43 input data on standard treatments

Christian N. Valdés,¹a Gustavo H. Píriz,² Enriquee Lozano,³
Departamento de Física Médica,¹ Centro Oncológico de Antofagasta, Antofagasta, Chile;
Departamento de Física Médica,² Centro de Oncología ONCOSUR, Florida, Uruguay;
Departamento de Física Médica,³ Instituto Nacional del Cáncer, Santiago, Chile
cvalcort@gmail.com

The aim of this work is to evaluate performance of a commercial BT TPS with vendor TG-43 data, analyze possible discrepancies with respect to a proper reference source and its implications for standard treatments, and judge the effectiveness of certain widespread recommended quality controls to find potential errors related with interpolations of TG-43 tables.

Influence of grid size resolution on TPS calculations

Influence of grid size resolution on TPS calculations

<table>
<thead>
<tr>
<th>2D anisotropy function grids in TG-43U1S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>r (cm)</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>S17</td>
</tr>
<tr>
<td>S17Plus</td>
</tr>
<tr>
<td>S18</td>
</tr>
<tr>
<td>130,002</td>
</tr>
<tr>
<td>9011</td>
</tr>
<tr>
<td>AgX100</td>
</tr>
<tr>
<td>CS10</td>
</tr>
<tr>
<td>1031L</td>
</tr>
<tr>
<td>1032P</td>
</tr>
<tr>
<td>IAPd-103A</td>
</tr>
<tr>
<td>CS-1 Rev2</td>
</tr>
</tbody>
</table>
Consensus datasets

preferences on dosimetry datasets origin for clinical use

- societal consensus data: TG-43U1, TG-43U1S1, TG-43U1S2 reports
- data posted on the AAPM/IROC Houston Brachytherapy Source Registry
  
  [IROC](http://rpc.mdanderson.org/RPC/BrachySeeds/Source_Registry.htm)

- for a seed not posted on the Registry: the user should perform a study similar to the ones described in the TG-43U1S2 report.

- early adopters of a seed should collaborate with vendor, vendor dosimetry consultant, and TPS vendor
Consensus datasets

preferences on dosimetry datasets origin for clinical use

- seeds approved in Europe but new in North America: follow GEC-ESTRO recommendations
- dataset on ESTRO and Carleton University websites as Excel spreadsheet formats

https://www.estro.org/about/governance-organisation/committees-activities/tg43
http://www.physics.carleton.ca/clrp
Consensus datasets preferences on dosimetry datasets origin for clinical use

<table>
<thead>
<tr>
<th>x (cm)</th>
<th>(0.10)</th>
<th>(0.15)</th>
<th>(0.25)</th>
<th>(0.50)</th>
<th>(0.70)</th>
<th>(1.00)</th>
<th>(1.50)</th>
<th>(2.00)</th>
<th>(2.50)</th>
<th>(3.00)</th>
<th>(4.00)</th>
<th>(5.00)</th>
<th>(6.00)</th>
<th>(7.00)</th>
<th>(10.00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>y (cm)</td>
<td>0.547</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
<td>0.813</td>
</tr>
<tr>
<td>(d_{0})</td>
<td>1.175</td>
<td>1.353</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
<td>1.401</td>
</tr>
</tbody>
</table>

Interpolated data are highlighted in boldface while extrapolated data are underlined.

Consensus datasets

Theragenics I-125 model AgX100

\(\Lambda = 0.952 \text{ cGy/h (U)}\)

\(u(A) = 0.043 \text{ cGy/h (U)}\)

\(L = 0.35 \text{ cm}\)
Seed and TPS vendor dosimetry recommendations

Seed vendors:

- source strength must be specified in terms of $S_K$ in U units
- contained activity should only be used for regulatory purposes: NRC reported events due to the use of apparent activity instead of $S_K$

https://www.nrc.gov/docs/ML0807/ML080710054.pdf

In the manufacturer’s certificate, the date format must be specified:

- DD/MM/YY or MM/DD/YY or YY/MM/DD?
Seed and TPS vendor dosimetry recommendations

TPS vendors:

- use consensus datasets
- use of the correct $L$ (or $L_{\text{eff}}$)
- follow recommended methods for interpolation/extrapolation
- the date format must be specified: DD/MM/YY or MM/DD/YY or YY/MM/DD
- use QA tables in the report available to the user
- implement 1D approximation for dose calculation
- information on manu. certificate and TPS must be the same
Acknowledgements

TG-43U1S2 members
Mark J Rivard, chair
Facundo Ballester, vice chair
Wayne M. Butler
Larry A. DeWerd
Geoffrey S. Ibbott
Ali S. Meigooni
Christopher S. Melhus
Michael G. Mitch
Ravinder Nath
Paniagottis Papagiannis

Valencia University Group
Javier Vijande
José Pérez-Calatayud
Cristian Candela-Juan
Domingo Granero

Mark J. Rivard,¹ Wayne M. Butler,² and Facundo Ballester³ on behalf of the report authors

¹Alpert Medical School of Brown University, Providence, RI
²Schiffler Cancer Center and Wheeling Jesuit University, Wheeling, WV
³Departamento de Física Atómica, Molecular y Nuclear Universitat de Valencia, Burjassot, ESPAÑA
§ 5.B. Radionuclide Half-Lives

- Recommended source:
  National Nuclear Data Center (NNDC) of Brookhaven National Laboratory

- The NNDC collects, evaluates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies.
  De Frenne, Nuclear Data Sheets 110, 2081 (2009) 103Pd
  16.991(34) days

  Katakura, Nuclear Data Sheets 112, 495 (2011) 125I
  59.407(10) days

  Khazov et al, Nuclear Data Sheets 107, 2715 (2006) 131Cs
  9.689(16) days
choice of reference data not a simple decision based on current evaluations
NNDC is comprehensive for gamma ray tabulations (limited for x rays)
NIST is thorough for x-ray transition energies, but not intensities
NCRP Report 58 is coarse and from a 1984 evaluation
Lund University (Sweden) and Lawrence Berkeley National Lab is from 1999
Laboratoire National Henri Becquerel (France) is missing $^{103}\text{Pd}$ and $^{131}\text{Cs}$

combine evaluations for AAPM+GEC-ESTRO $^{131}\text{Cs}$ reference data

choice of reference data weakly influences dose calculations
choice of reference data weakly influences TG-43 dosimetry parameters
§ 5.A. Radionuclide Photon Spectrum: $^{131}$Cs

Table XXIV. Half-life and photon spectrum for $^{131}$Cs dosimetry. X-ray transitions are listed after the elemental symbol for the daughter nuclide (i.e., Xe). Subgroups are enumerated for the K$_{α}$ and K$_{β}$ transitions, while the mean energies and total intensities are given for the other transitions, e.g., $L_{γ} = L_{γ1} + L_{γ2} + L_{γ3}$.

$^{131}$Cs (half-life = 9.689 ± 0.016 days)

<table>
<thead>
<tr>
<th>Photon energy (keV)</th>
<th>Photons per disintegration</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.760 Xe L$_{ααα}$</td>
<td>0.0037</td>
</tr>
<tr>
<td>4.109 Xe L$_{α}$</td>
<td>0.0702</td>
</tr>
<tr>
<td>4.479 Xe L$_{β}$</td>
<td>0.06302</td>
</tr>
<tr>
<td>5.138 Xe L$_{γ}$</td>
<td>0.00844</td>
</tr>
<tr>
<td>29.112 Xe K$_{αα}$</td>
<td>0.000022</td>
</tr>
<tr>
<td>29.461 Xe K$_{αα}$</td>
<td>0.211</td>
</tr>
<tr>
<td>29.782 Xe K$_{α1}$</td>
<td>0.389</td>
</tr>
<tr>
<td>33.562 Xe K$_{β3}$</td>
<td>0.0364</td>
</tr>
<tr>
<td>33.624 Xe K$_{β1}$</td>
<td>0.0702</td>
</tr>
<tr>
<td>33.881 Xe K$_{β5}$</td>
<td>0.00071</td>
</tr>
<tr>
<td>34.419 Xe K$_{β2}$</td>
<td>0.0213</td>
</tr>
<tr>
<td>34.496 Xe K$_{β4}$</td>
<td>0.00412</td>
</tr>
<tr>
<td>30.411 mean (&gt; 10 keV photons)</td>
<td>0.8781 total photons per disintegration</td>
</tr>
<tr>
<td>30.411 mean (&gt; 10 keV photons)</td>
<td>0.7328 total (≥ 10 keV photons)</td>
</tr>
</tbody>
</table>
§ 5.C. Reference Dose Scoring Media

- density of water ($H_2O$) at 22 °C is 0.998 g/cm$^3$

- standard temperature and pressure (STP) of air depends on locale
  N. American STP is 22 °C and 101.325 kPa
  European STP is 20 °C and 101.325 kPa

- density of dry air depends on ambient conditions
  N. American $\rho_{air}$ is 1.197 mg/cm$^3$
  European $\rho_{air}$ is 1.205 mg/cm$^3$

- air composition (by mass) is fixed
  75.527% N, 23.178% O, 1.283% Ar, 0.012% C
§ 5.D. TLD Dosimetry Methodological Corrections

\[ D_{med}(Q) = M(Q) \frac{N}{D_{med}(Q)} \]  \hspace{1cm} (1)

\[ S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} \]  \hspace{1cm} (2)

\[ S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} = \frac{M(Q)}{D_{TLD}(Q)} \frac{D_{TLD}(Q)}{D_{med}(Q)} = \frac{1}{k_{bq}(Q)} \frac{1}{f(Q)} \]  \hspace{1cm} (3)

\[ S_{rel}^{AD,med} = \frac{S_{AD,med}(Q)}{S_{AD,med}(Q_0)} = \frac{1}{k_{rel,bq}} \frac{1}{f_{rel}} \]  \hspace{1cm} (4)

\[ E(r) = \frac{S_{rel}^{AD,med}(Q)}{P_{phant}} = \frac{1}{k_{rel,bq}} \frac{1}{f_{rel}} \frac{1}{P_{phant}} \]  \hspace{1cm} (5)
§ 5.D. TLD Dosimetry Methodological Corrections

• understand relationship between detector measurement, medium corrections, detector corrections, and absorbed dose to the medium as function of radiation quality \( Q \) (i.e., photon energy)

• convert detector measurement \( M(Q) \)

to absorbed dose to the medium \( D_{med}(Q) \)

via the absorbed dose calibration coefficient \( N_{D,med}(Q) \)

\[
D_{med}(Q) = M(Q) \cdot N_{D,med}(Q)
\] (1)
§ 5.D. TLD Dosimetry Methodological Corrections

- inverse of the absorbed dose calibration coefficient \( N_{D,med}(Q) \) is the absorbed dose sensitivity coefficient \( S_{AD,med}(Q) \)

\[
S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)}
\]  \( (2) \)
§ 5.D. TLD Dosimetry Methodological Corrections

- partition $S_{AD,med}(Q)$ into two components
  $$S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} = \frac{M(Q)}{D_{TLD}(Q)} \frac{D_{TLD}(Q)}{D_{med}(Q)}$$

- avg. TLD dose for radiation quality $Q$

- intrinsic $Q$ dependence $k_{bq}(Q)$
determined only by measurement of signal formation

- absorbed dose sensitivity $f(Q)$, dependent on medium and detector, may be estimated with Monte Carlo

$$S_{AD,med}(Q) = \frac{1}{k_{bq}(Q)} \frac{1}{f(Q)}$$  (3)
§ 5.D. TLD Dosimetry Methodological Corrections

- relative absorbed dose sensitivity coefficient uses ratios with $Q$ and $Q_0$

$$S_{AD,med}^{rel} = \frac{S_{AD,med}(Q)}{S_{AD,med}(Q_0)} = \frac{1}{k_{rel}^{bq}} \frac{1}{f_{rel}}$$

**ratio to calibration**

*relative intrinsic $Q$ dependence* $k_{rel}^{bq}$ of the detector

*relative absorbed dose sensitivity* $f_{rel}$ of the detector

$$S_{AD,med}^{rel} = \frac{1}{k_{rel}^{bq}} \frac{1}{f_{rel}}$$  (4)
§ 5.D. TLD Dosimetry Methodological Corrections

- account for phantom presence $P_{phant}$ different than calibration medium

\[
\frac{S_{AD,med}^{rel}(Q)}{P_{phant}} = \frac{1}{k_{rel}^{bq}} \frac{1}{f^{rel}} \frac{1}{P_{phant}}
\]

- relative energy response function $E(r)$

dosimetry investigators should specify assumptions and methods for deriving the methodological corrections to dose

\[
E(r) = \frac{1}{k_{rel}^{bq}} \frac{1}{f^{rel}} \frac{1}{P_{phant}}
\]
Summary

- 11 new sources evaluated with consensus data provided
- $\text{CON}$ for $^{103}\text{Pd}$ seeds all within 0.6% of 0.697 cGy/h/U except for plastic encapsulated model 1032P and CS10 sources
- $\text{CON}$ for $^{125}\text{I}$ seeds all within 1.2% of 0.942 cGy/h/U except for plastic encapsulated model S18 source
- $\text{CON}$ for $^{131}\text{Cs}$ (1.056) increased as expected relative to $^{103}\text{Pd}$ and $^{125}\text{I}$
- $\text{MC}/\text{EXP} = 0.961$ on avg. for all 11 source models
- $\text{CON} g(r)$ and $\text{CON} \phi_{an}(r)$ varied with energy and $r$ as expected
- QA tables (along-away, polar coordinates) were provided
- medical physicists should document their TPS commissioning
WAYNE’S SLIDES GO HERE