AAPM 2018 JUL 29–AUG 2

BEYOND THE FUTURE!

60TH ANNUAL MEETING & EXHIBITION | NASHVILLE, TN

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

Mark J. Rivard,[1] Wayne M. Butler,[2] and Facundo Ballester[3]

on behalf of the report authors

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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, and IsoRay 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

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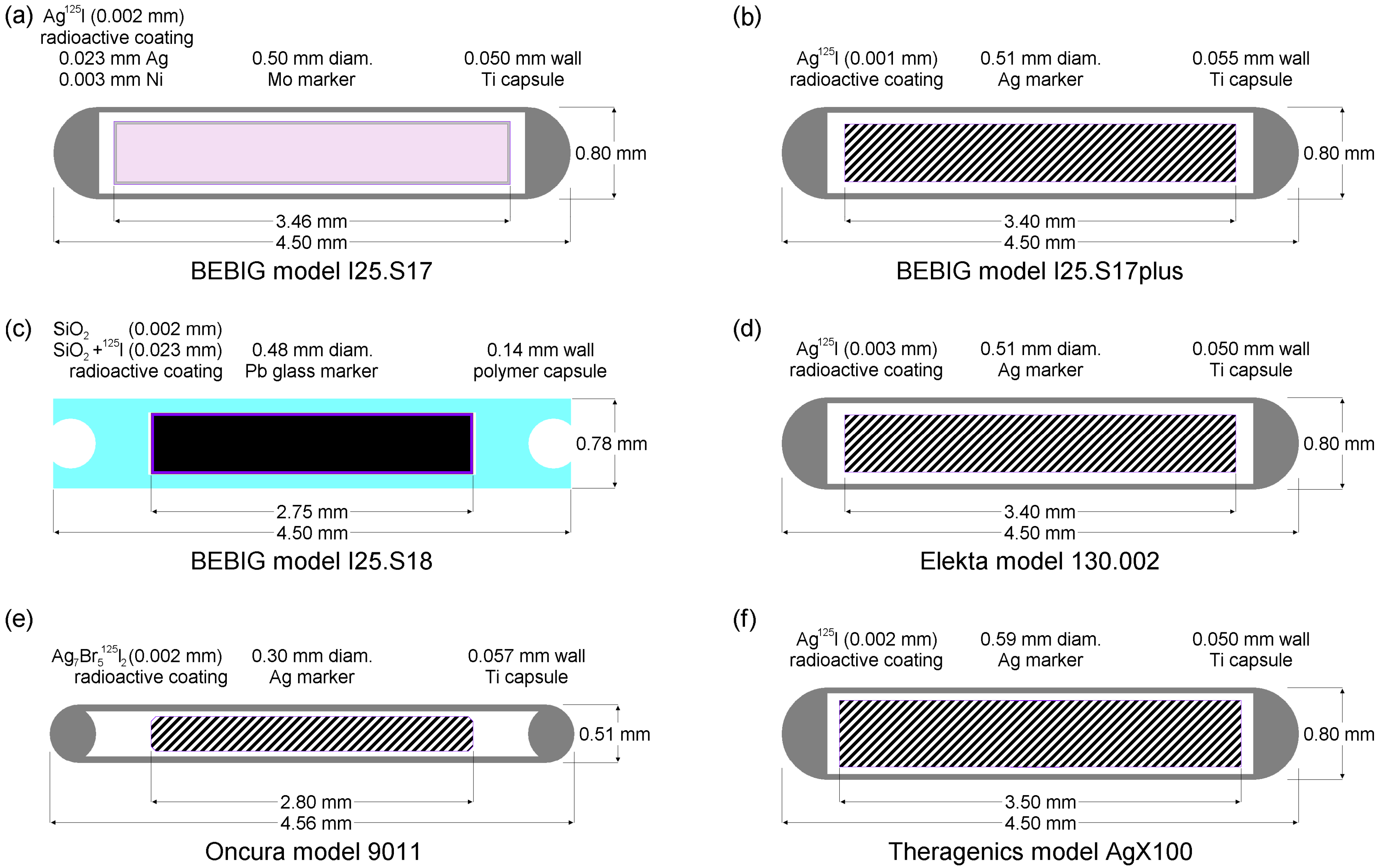
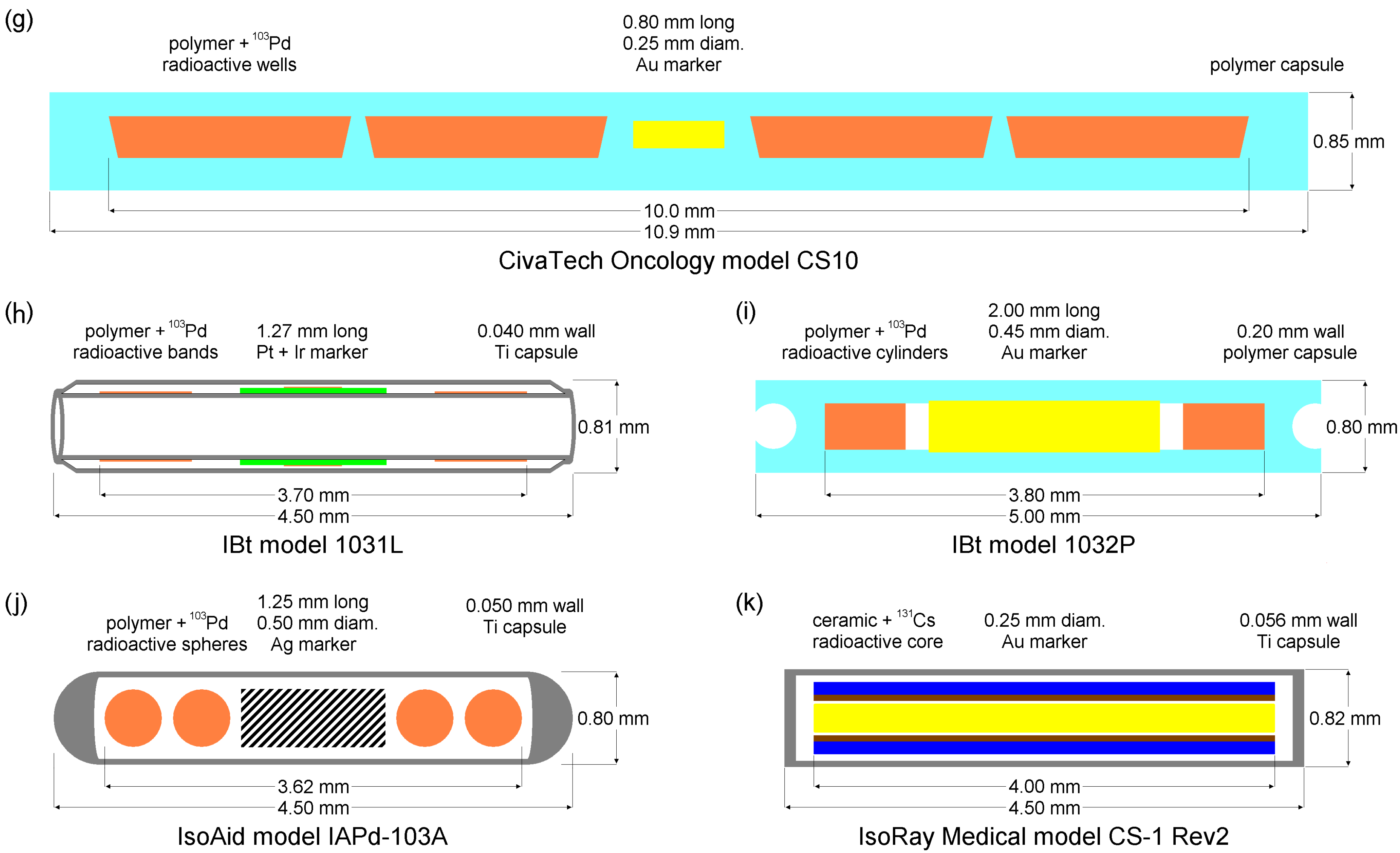
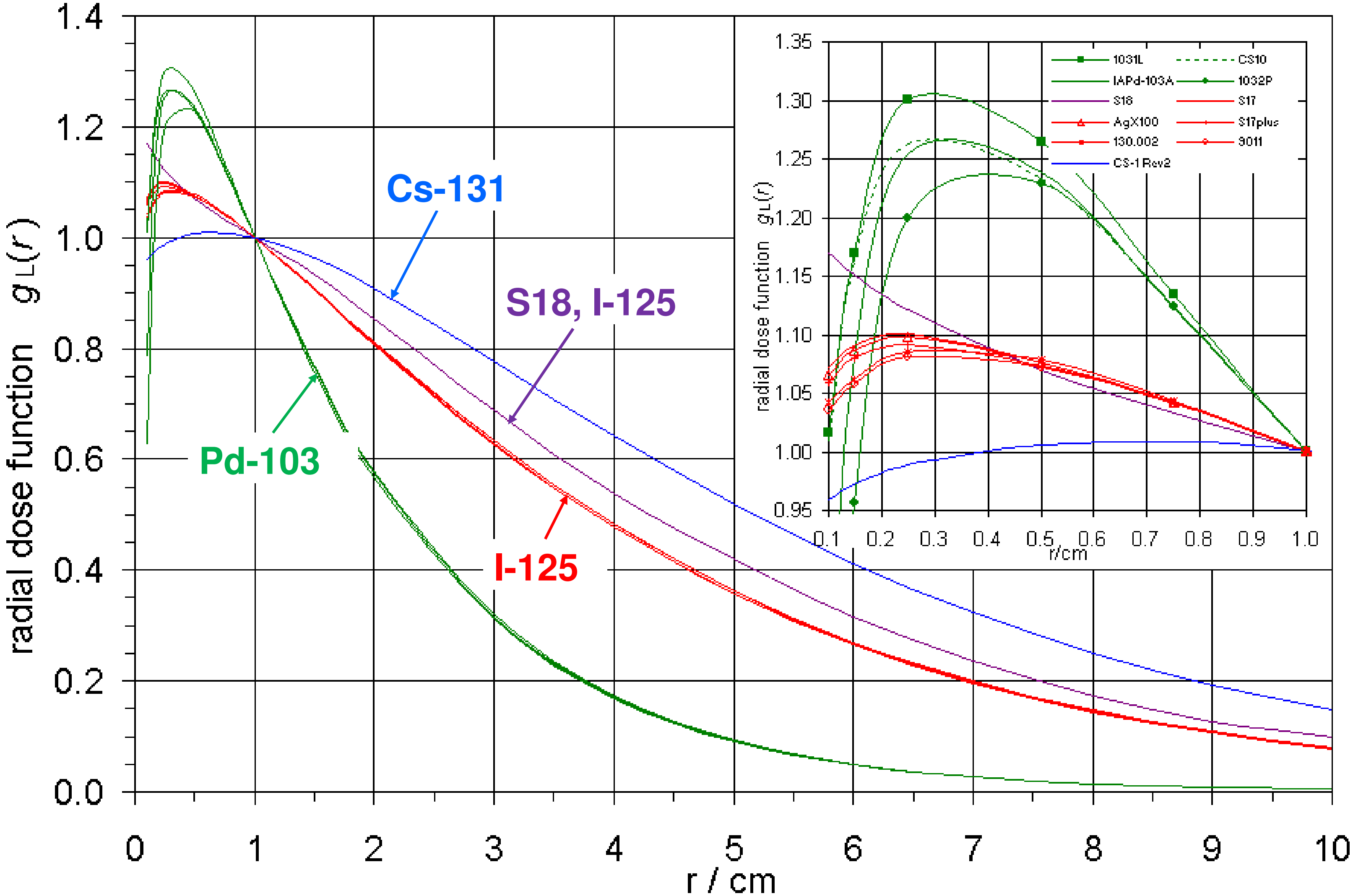


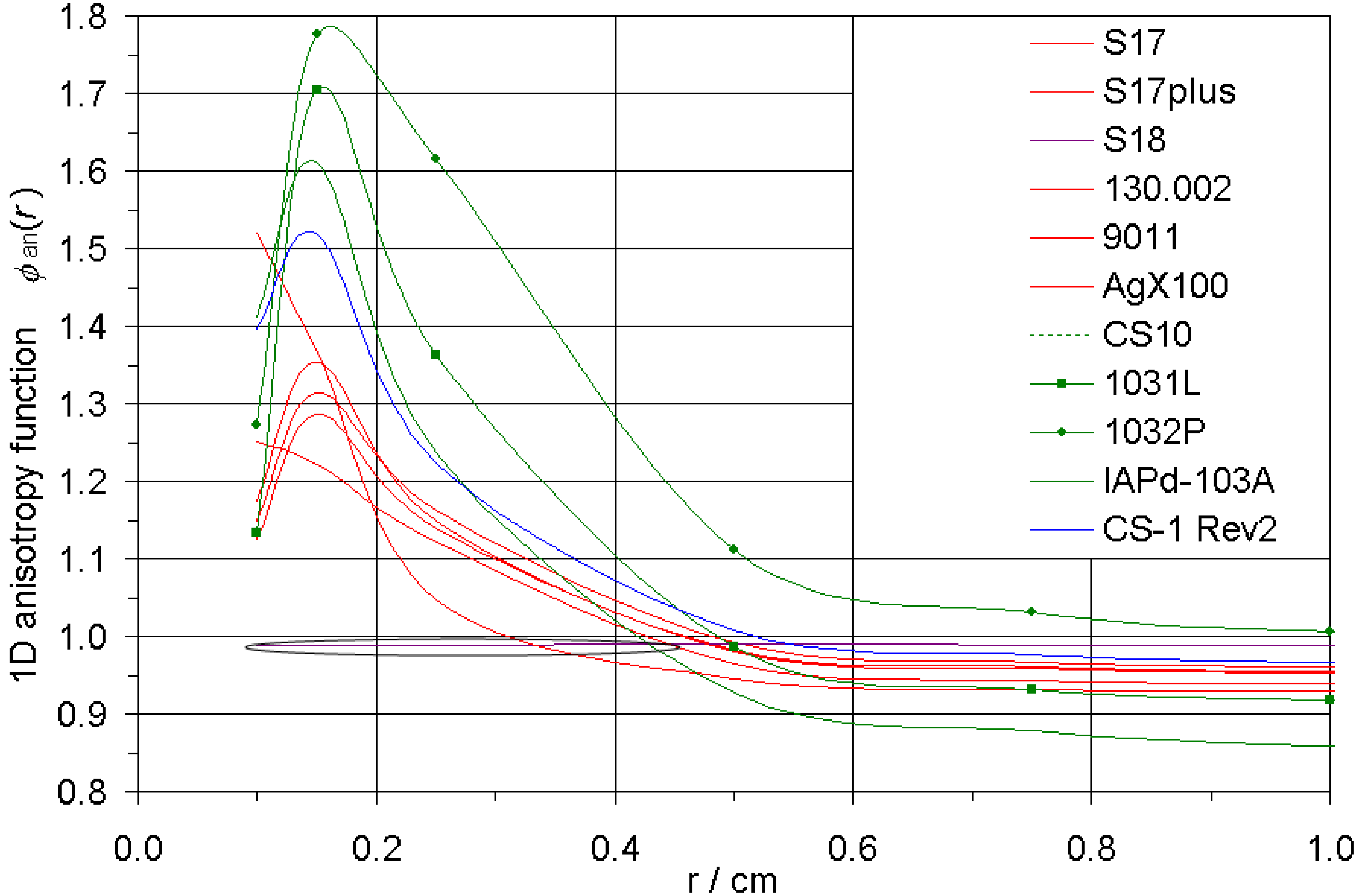
(a)
Ag125I (0.002 mm)
radioactive coating
0.023 mm Ag
0.003 mm Ni
0.50 mm diam.
Mo marker
0.050 mm wall
Ti capsule
0.80 mm
3.46 mm
4.50 mm
BEBIG model I25.S17
(b)
Ag125I (0.001 mm)
radioactive coating
0.51 mm diam.
Ag marker
0.055 mm wall
Ti capsule
0.80 mm
3.40 mm
4.50 mm
BEBIG model I25.S17plus
(c)
SiO2 (0.002 mm)
SiO2+125I (0.023 mm)
radioactive coating
0.48 mm diam.
Pb glass marker
0.14 mm wall
polymer capsule
0.78 mm
2.75 mm
4.50 mm
BEBIG model I25.S18
(d)
Ag125I (0.003 mm)
radioactive coating
0.51 mm diam.
Ag marker
0.050 mm wall
Ti capsule
0.80 mm
3.40 mm
4.50 mm
Elekta model 130.002
(e)
Ag7Br5125I2 (0.002 mm)
radioactive coating
0.30 mm diam.
Ag marker
0.057 mm wall
Ti capsule
0.51 mm
2.80 mm
4.56 mm
Oncura model 9011
(f)
Ag125I (0.002 mm)
radioactive coating
0.59 mm diam.
Ag marker
0.050 mm wall
Ti capsule
0.80 mm
3.50 mm
4.50 mm
Theragenics model AgX100


(g)
polymer + 103Pd
radioactive wells
0.80 mm long
0.25 mm diam.
Au marker
polymer capsule
0.85 mm
10.0 mm
10.9 mm
CivaTech Oncology model CS10
(h)
polymer + 103Pd
radioactive bands
1.27 mm long
Pt + Ir marker
0.040 mm wall
Ti capsule
0.81 mm
3.70 mm
4.50 mm
IBt model 1031L
(i)
polymer + 103Pd
radioactive cylinders
2.00 mm long
0.45 mm diam.
Au marker
0.20 mm wall
polymer capsule
0.80 mm
3.80 mm
5.00 mm
IBt model 1032P
(j)
polymer + 103Pd
radioactive spheres
1.25 mm long
0.50 mm diam.
Ag marker
0.050 mm wall
Ti capsule
0.80 mm
3.62 mm
4.50 mm
IsoAid model IAPd-103A
(k)
ceramic + 131Cs
radioactive core
0.25 mm diam.
Au marker
0.056 mm wall
Ti capsule
0.82 mm
4.00 mm
4.50 mm
IsoRay Medical model CS-1 Rev2

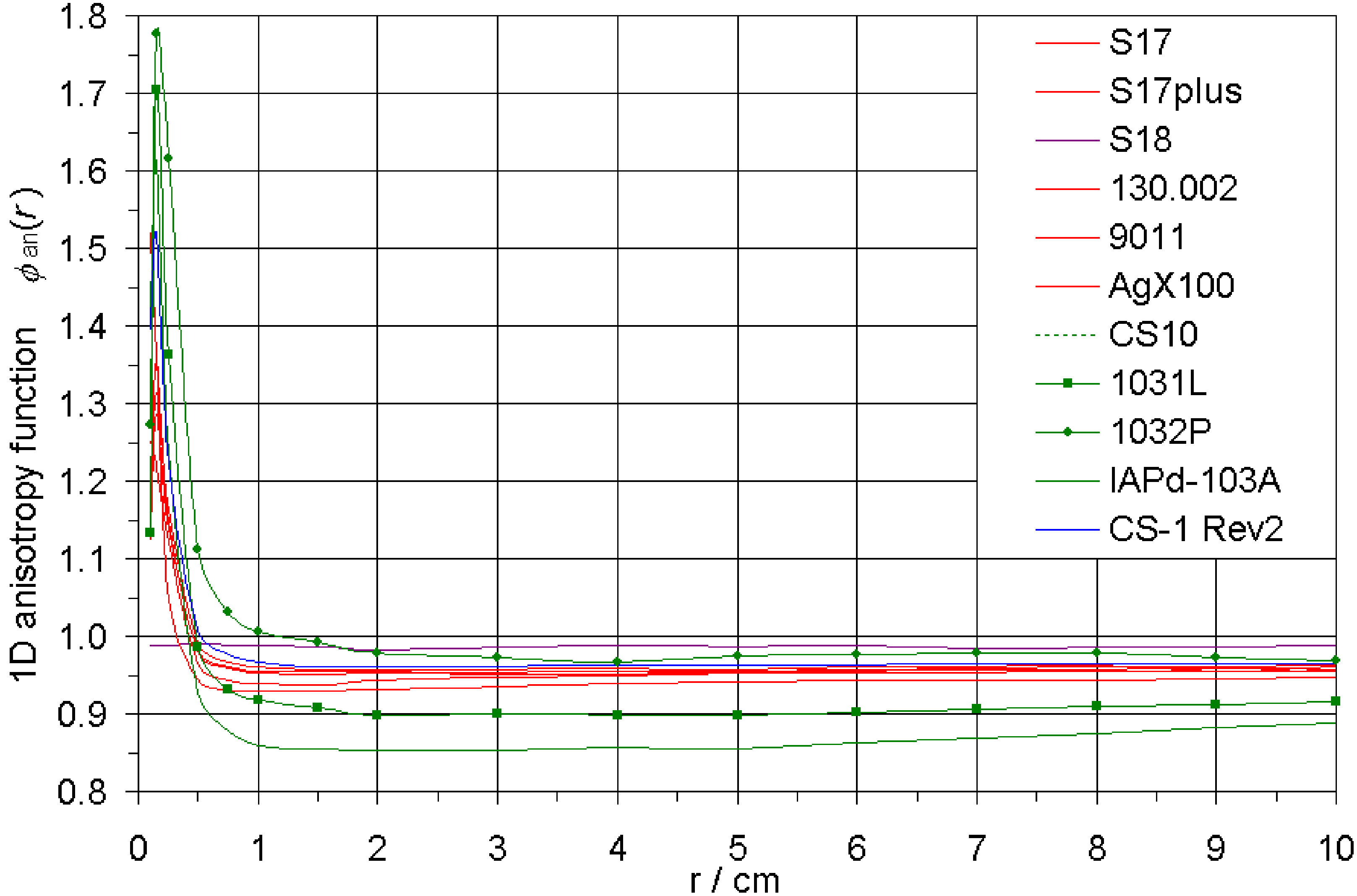
Radial Dose Functions



1D Anisotropy Functions



1D Anisotropy Functions



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

Report summary, methods to formulate consensus data, and presentation of the consensus datasets

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on behalf of the report authors

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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

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- 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

(*Med Phys*, **44**:e297–e338, 2017)

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

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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)

	Away (cm)									
Along (cm)	0	0.5	1	1.5	2	3	4	5	6	7
0.0		3.981	0.952	0.386	0.1950	0.0676	0.0290	0.01388	0.00718	0.00390
0.5	1.018	1.928	0.763	0.352	0.1858	0.0667	0.0287	0.01381	0.00715	0.00389
1.0	0.287	0.599	0.417	0.248	0.1481	0.0593	0.0268	0.01322	0.00694	0.00380
1.5	0.1393	0.241	0.218	0.1581	0.1073	0.0491	0.0237	0.01209	0.00649	0.00361
2.0	0.0788	0.1185	0.1202	0.0986	0.0745	0.0389	0.0201	0.01074	0.00592	0.00335
2.5	0.0480	0.0657	0.0702	0.0628	0.0510	0.0300	0.01664	0.00929	0.00528	0.00306
3.0	0.0316	0.0402	0.0434	0.0407	0.0349	0.0225	0.01345	0.00788	0.00462	0.00274
3.5	0.0210	0.0256	0.0279	0.0270	0.0242	0.01686	0.01070	0.00656	0.00398	0.00242
4.0	0.01455	0.01717	0.01860	0.01837	0.01693	0.01255	0.00841	0.00539	0.00338	0.00211
4.5	0.01030	0.01189	0.01274	0.01275	0.01200	0.00934	0.00658	0.00438	0.00283	0.001811
5.0	0.00747	0.00845	0.00897	0.00902	0.00861	0.00699	0.00512	0.00353	0.00236	0.001542
5.5	0.00545	0.00607	0.00640	0.00648	0.00627	0.00524	0.00397	0.00283	0.001945	0.001303
6.0	0.00404	0.00445	0.00465	0.00471	0.00459	0.00395	0.00308	0.00227	0.001593	0.001092
6.5	0.00302	0.00331	0.00343	0.00347	0.00340	0.00300	0.00239	0.001803	0.001300	0.000909
7.0	0.00229	0.00249	0.00255	0.00258	0.00255	0.00228	0.001865	0.001433	0.001058	0.000754

- 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 $cGy \cdot cm^2/h = U$

Λ = dose rate constant in $cGy / h \cdot U$

$g_L(r)$ = radial dose function (atten & scatter)

$F(r,\theta)$ = 2D anisotropy function

T_{avg} = average life of the radionuclide = $t½/ln2$

$G_L(r,\theta)$ = geometry function of source distribution

Reference quality published data necessary for consensus

- Effective active length, L_{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, Λ

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

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

$$\sigma = \sqrt{\sigma\Lambda_{\mathrm{EXPa}}{}^2 + \sigma\Lambda_{\mathrm{EXPb}}{}^2}$$

  - Total uncertainty is the weighted quadrature sum of each methodology

$$\sigma_{\mathrm{TOT}} = \sqrt{\sigma\Lambda_{\mathrm{EXP}}{}^2 + \sigma\Lambda_{\mathrm{MC}}{}^2 + \left(\frac{\Lambda_{\mathrm{EXP}} - \Lambda_{\mathrm{MC}}}{2\cdot\sqrt{3}}\right)^2}$$

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,θ) 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

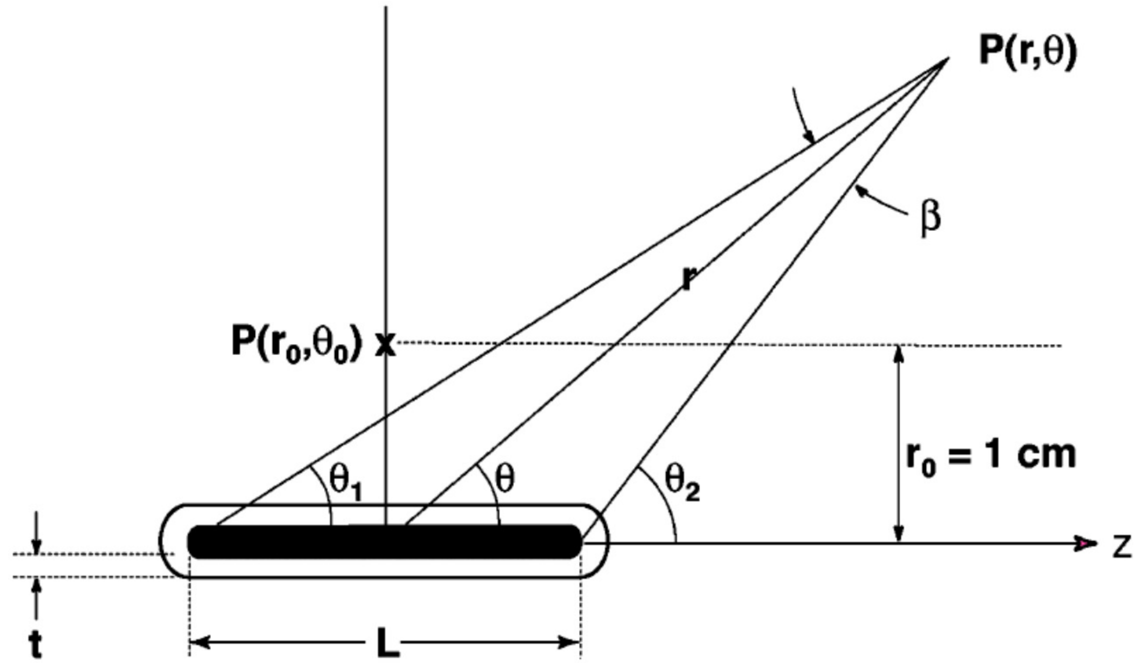
- $G(r,\theta)$ for a point source is simply the inverse square:

$$G_P(r,\theta) = \frac{1}{r^2}$$

- When describing the source as a line:

$$G_L(r,\theta) = \frac{\beta}{L_{eff} \cdot r \cdot \sin\theta}$$

  - $L_{eff} = \Delta S \cdot n$ for *n* discrete pellets of spacing ΔS
  - Beta, β, is the angle subtended by L_{eff} at the calculation point



All candidate data was checked for consistency

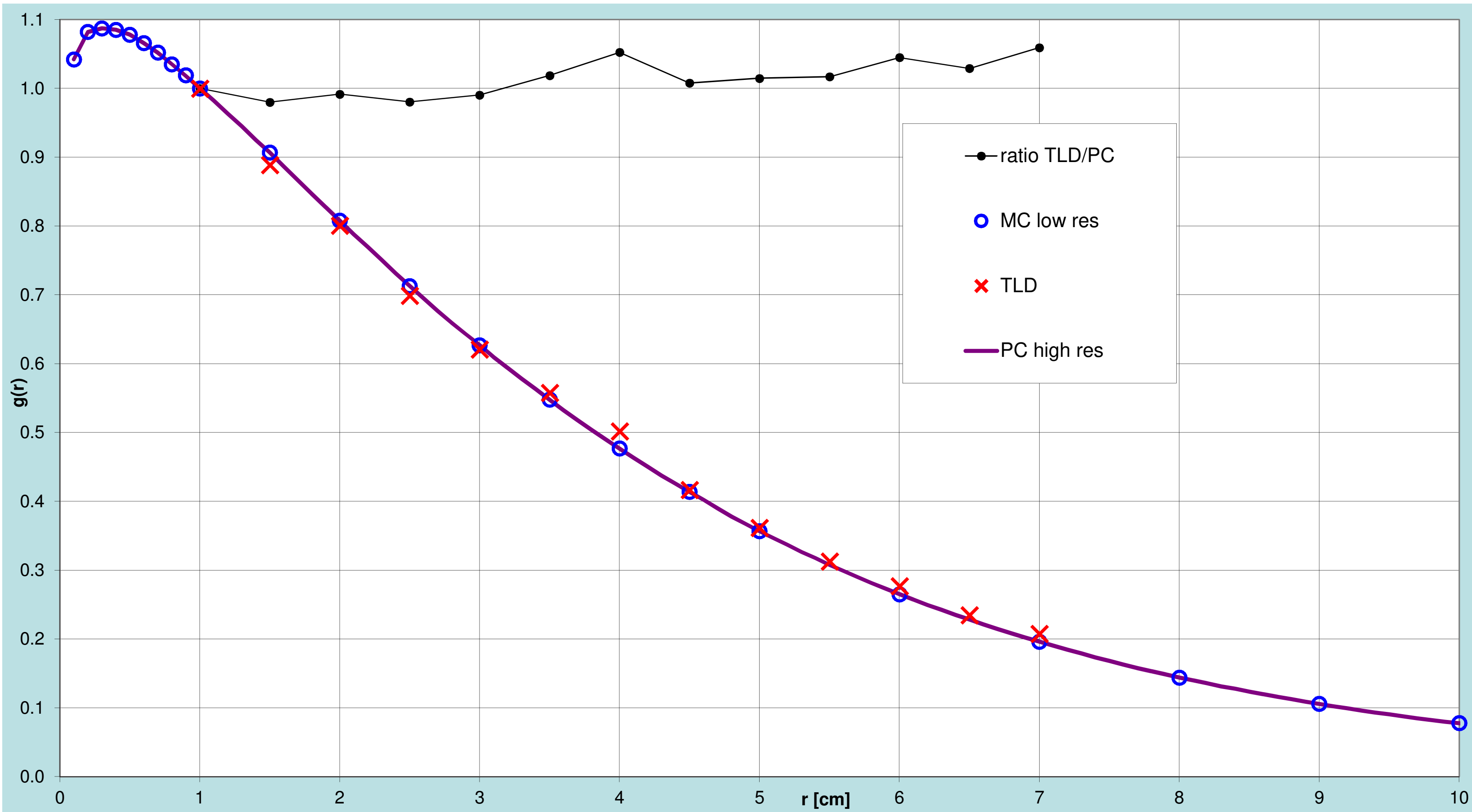
- Reported g(r) converted from line to point or vice versa using geometry functions

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

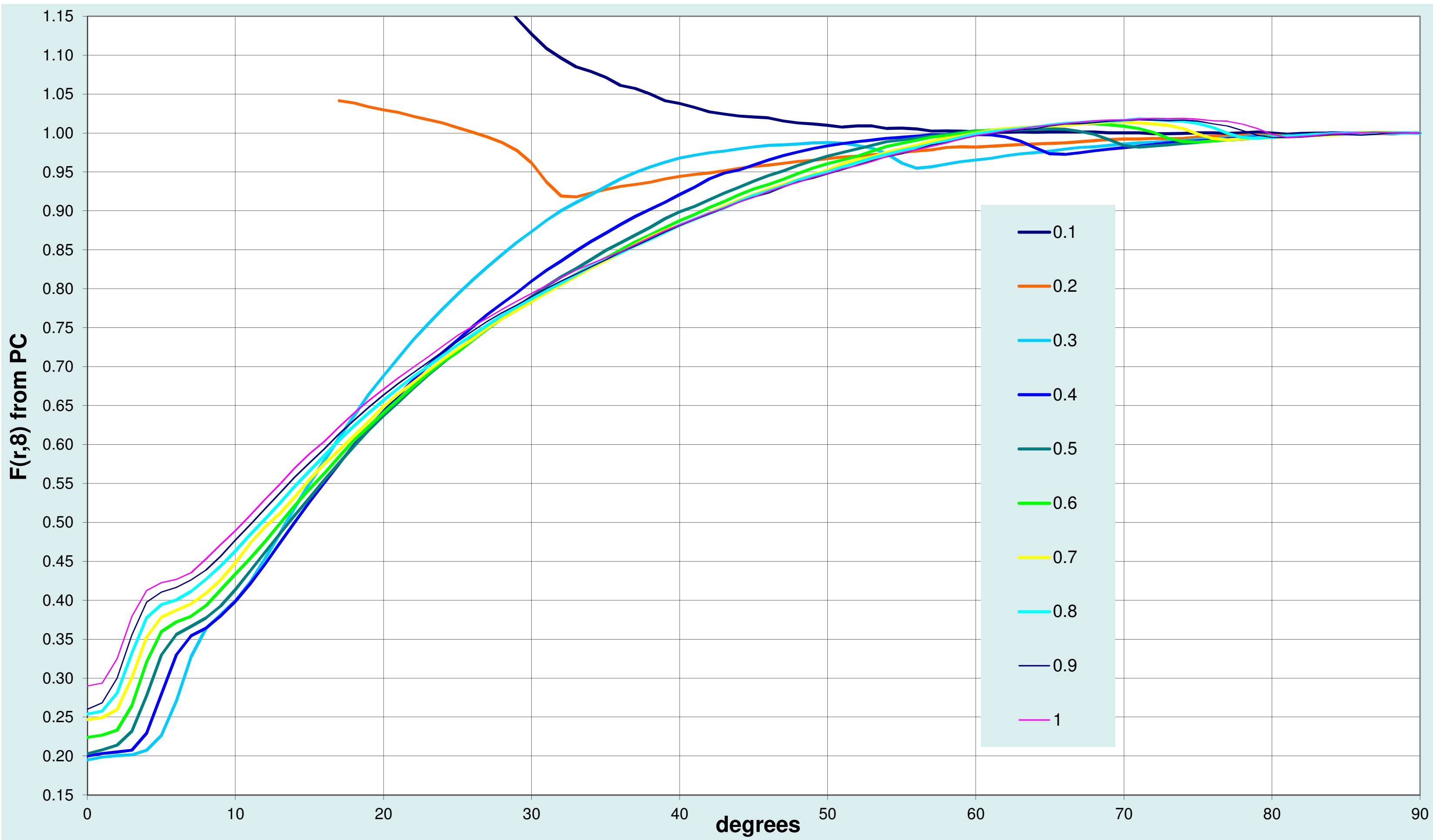
- $F(r,\theta)$ and $\phi_{an}(r)$ values using geometry functions, dose weighting, and angular weighting

Calculated g(r) were plotted to reveal outliers

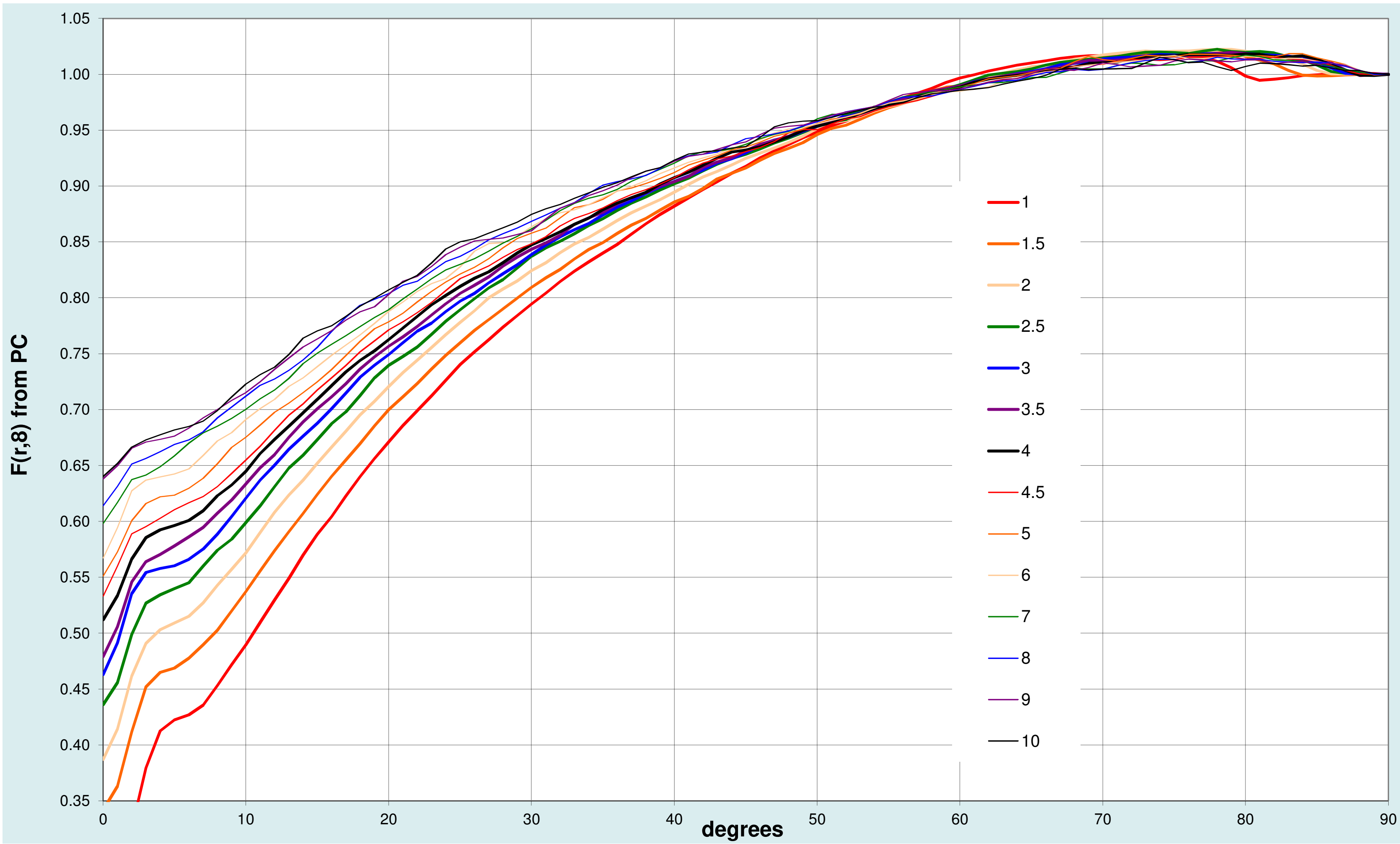
(Elekta model 130.002)



F(r,θ) for r ≤ 1 cm (Elekta model 130.002)



F(r,θ) for r ≥ 1 cm (Elekta model 130.002)



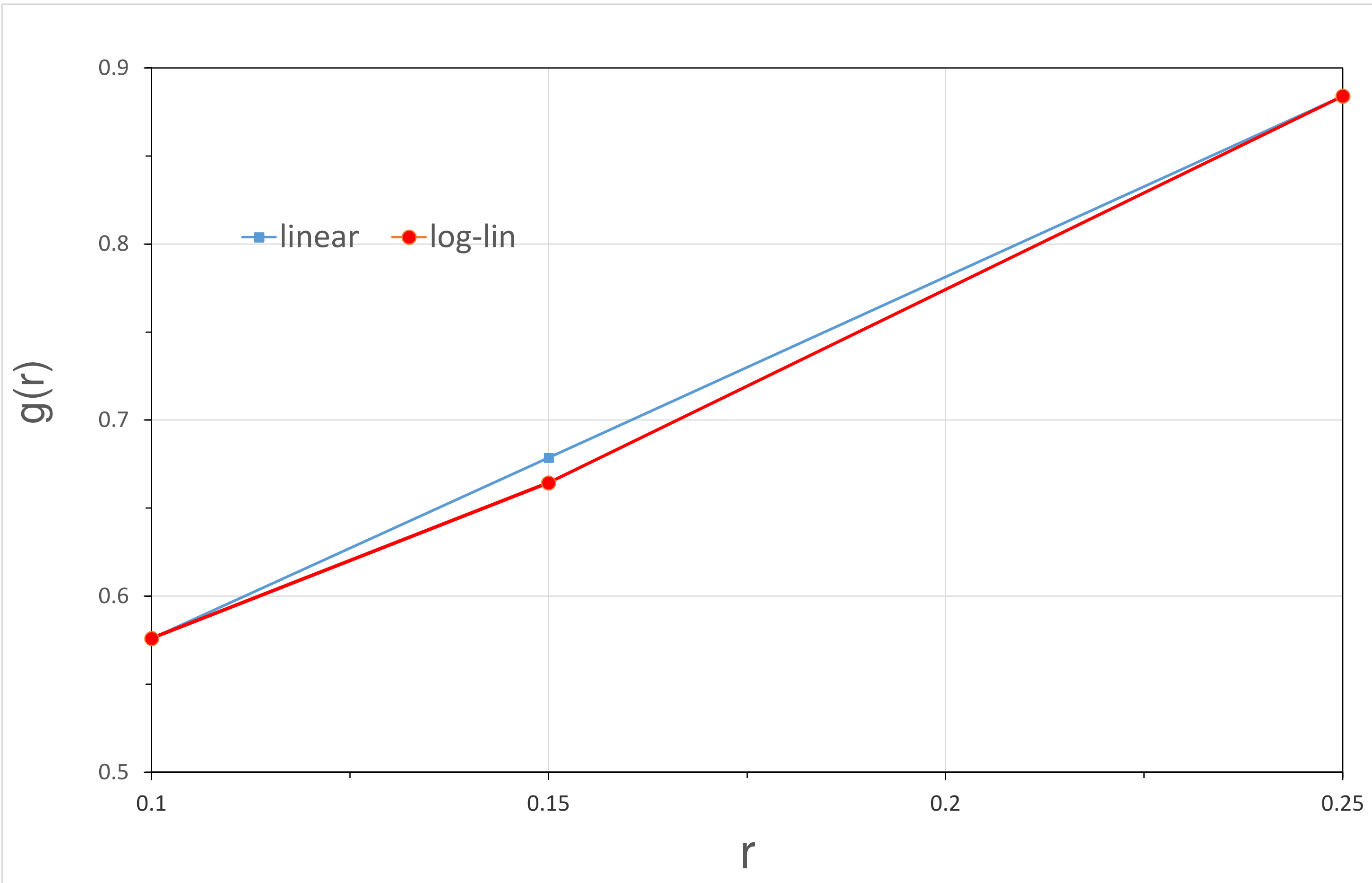
Interpolation and extrapolation

- Interpolation of F(r,θ) uses a bi-linear approach
- Interpolation of g(r) uses a log-linear approach

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

g(r)	r	linear	log-lin
r_i	0.1	0.576	0.576
r_x	***0.15***	***0.679***	***0.664***
r_f	0.25	0.884	0.884

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.

r (cm)	BEBIG S17	BEBIG S17plus	BEBIG S18	Elekta 130.002
Line-source approximation, $_{\mathrm{CON}}g_L(r)$				
0.10	1.072	1.059	1.169	1.042
0.15	1.090	1.080	**1.152**	**1.062**
0.25	1.100	1.092	**1.121**	**1.085**
0.50	1.077	1.073	1.070	1.078
0.75	1.042	1.040	**1.033**	**1.044**
1.00	1.000	1.000	1.000	1.000

Interpolated from r = 0.7 and 0.8

TABLE AIX. $_{\mathrm{CON}}F(r, \theta)$ data for the CivaTech model CS10 ^{103}Pd from the consensus $_{\mathrm{CON}}F(r, \theta)$ dataset.

Polar angle θ (°)	0.1	0.25	0.5
0			
2			
5			1.266
7			1.281
10		1.287	1.292
15		1.271	1.274
20		1.252	1.244
25	1.358	1.229	1.213

Extrapolated from θ = 6º or from 11º

Use the report wisely, & thank you

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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

Mark J. Rivard,[1] Wayne M. Butler,[2] and **Facundo Ballester**[3]

on behalf of the report authors

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[3]Departamento de Física Atómica, Molecular y Nuclear Universitat de Valencia, Burjassot, ESPAÑA

Learning objectives

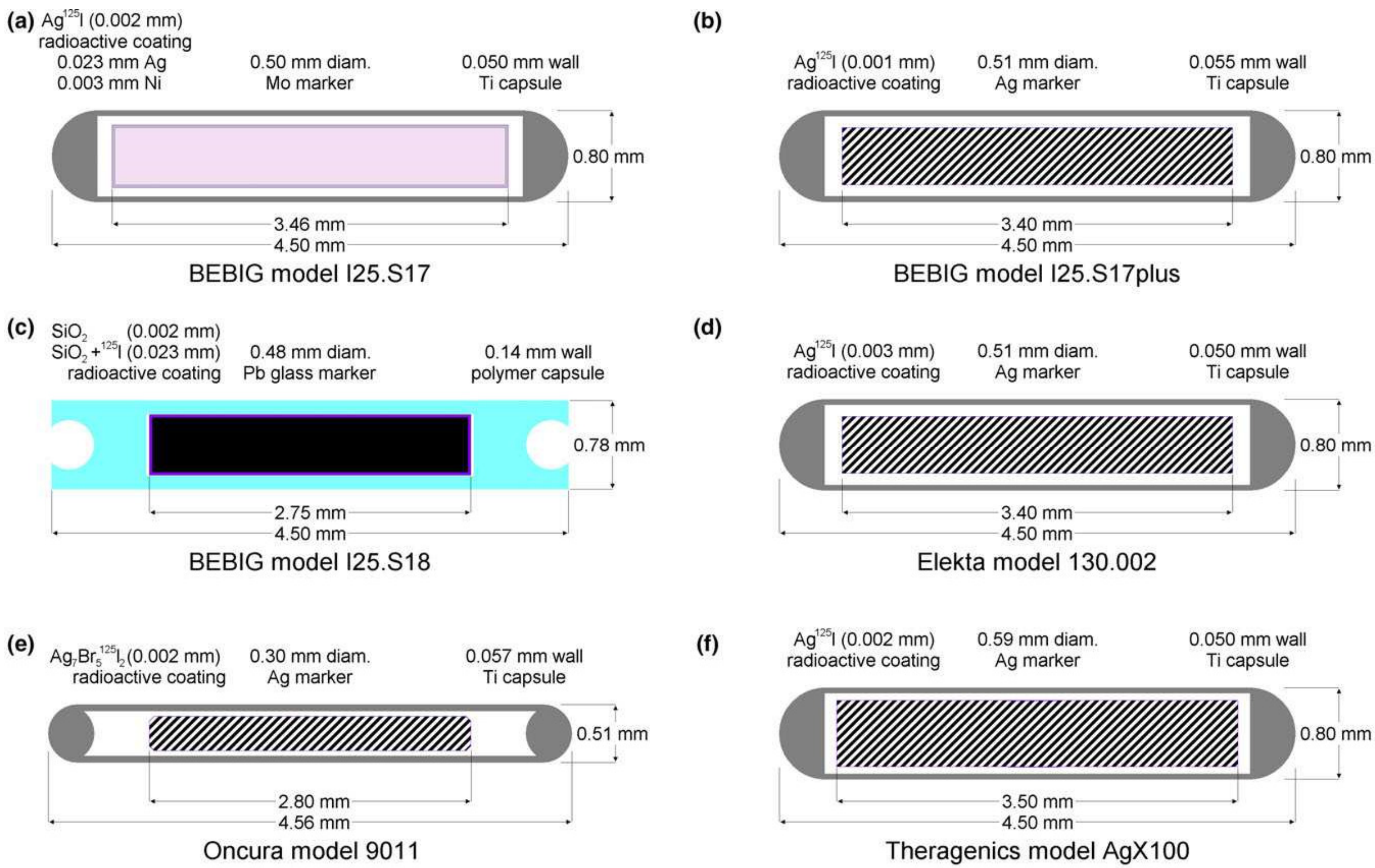
- show dependence of TG-43 parameter values on radionuclide
- highlight influence of consensus dataset grid size on TPS calculations
- identify societal recommendations to vendors of brachytherapy sources and treatment planning systems

Contents

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

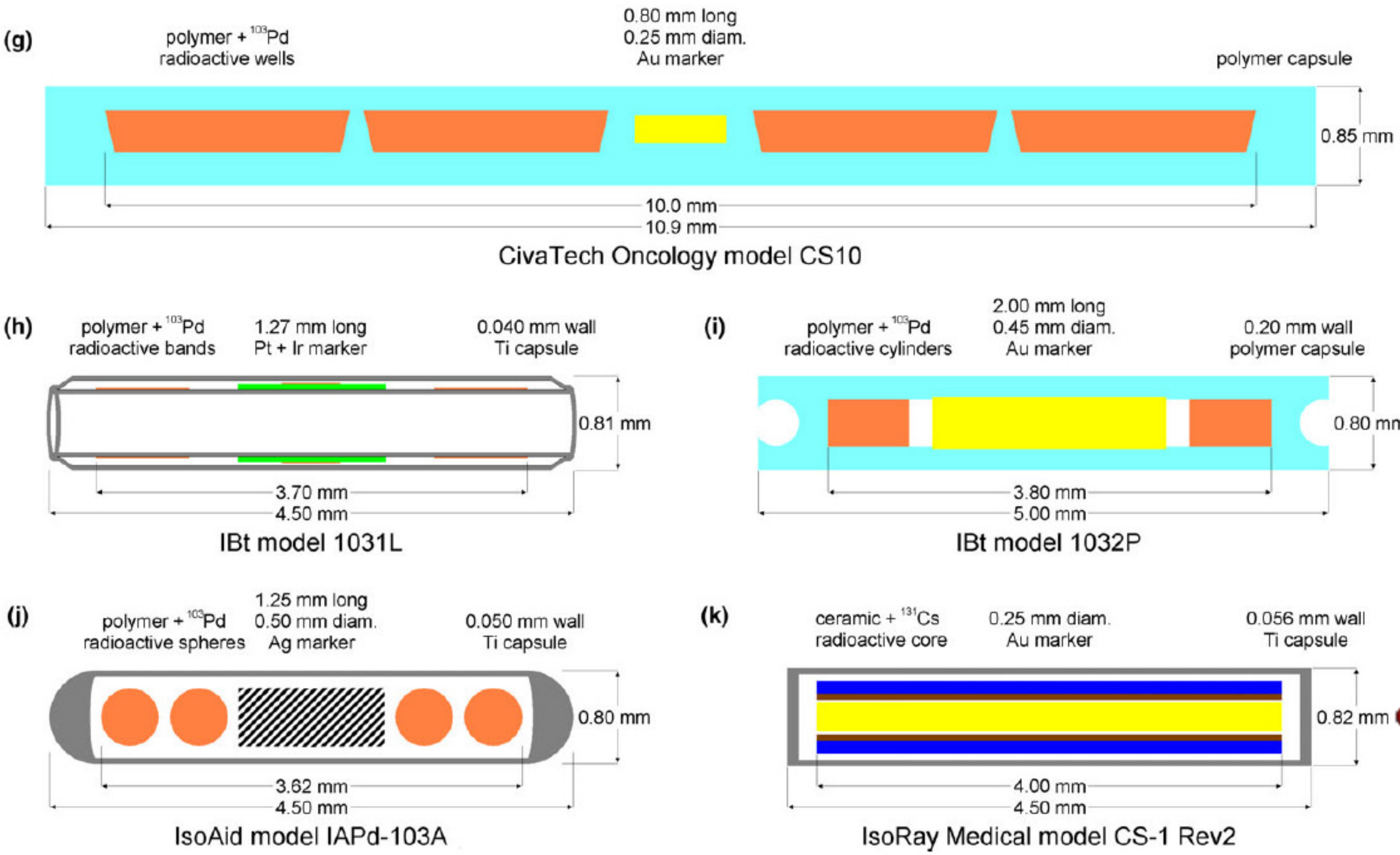
TG-43U1S2 seeds

- I-125



TG-43U1S2 seeds

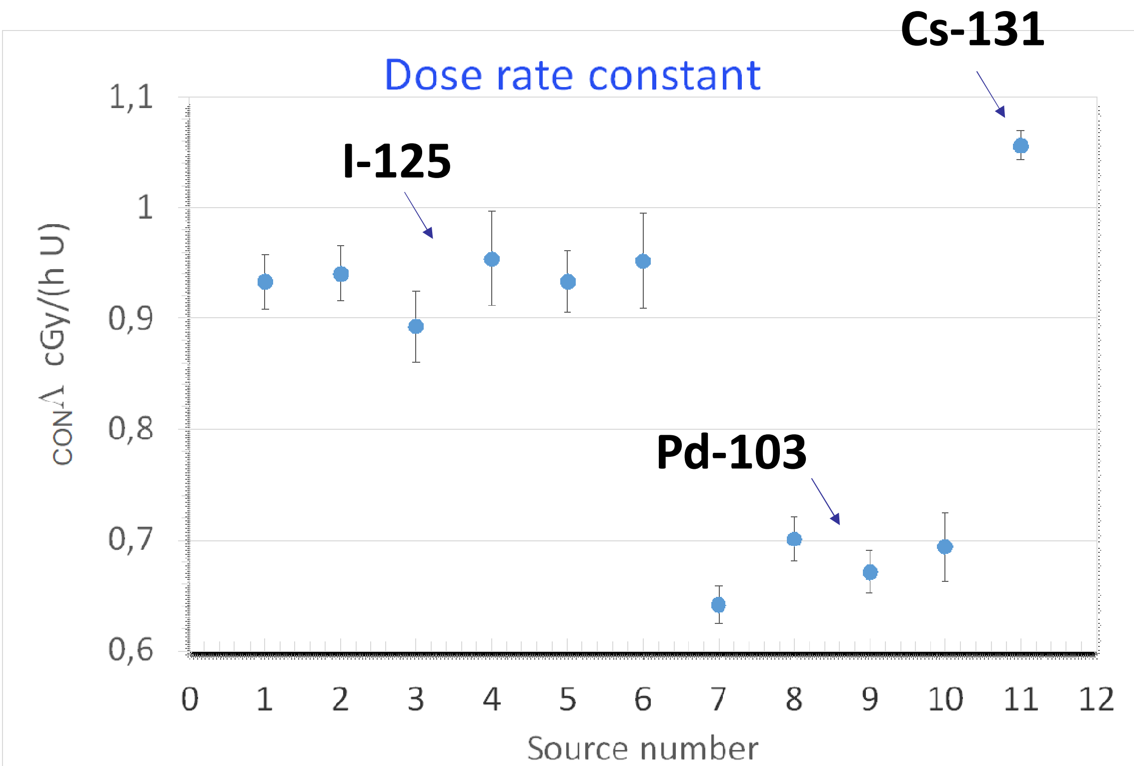
Pd-103



Cs-131

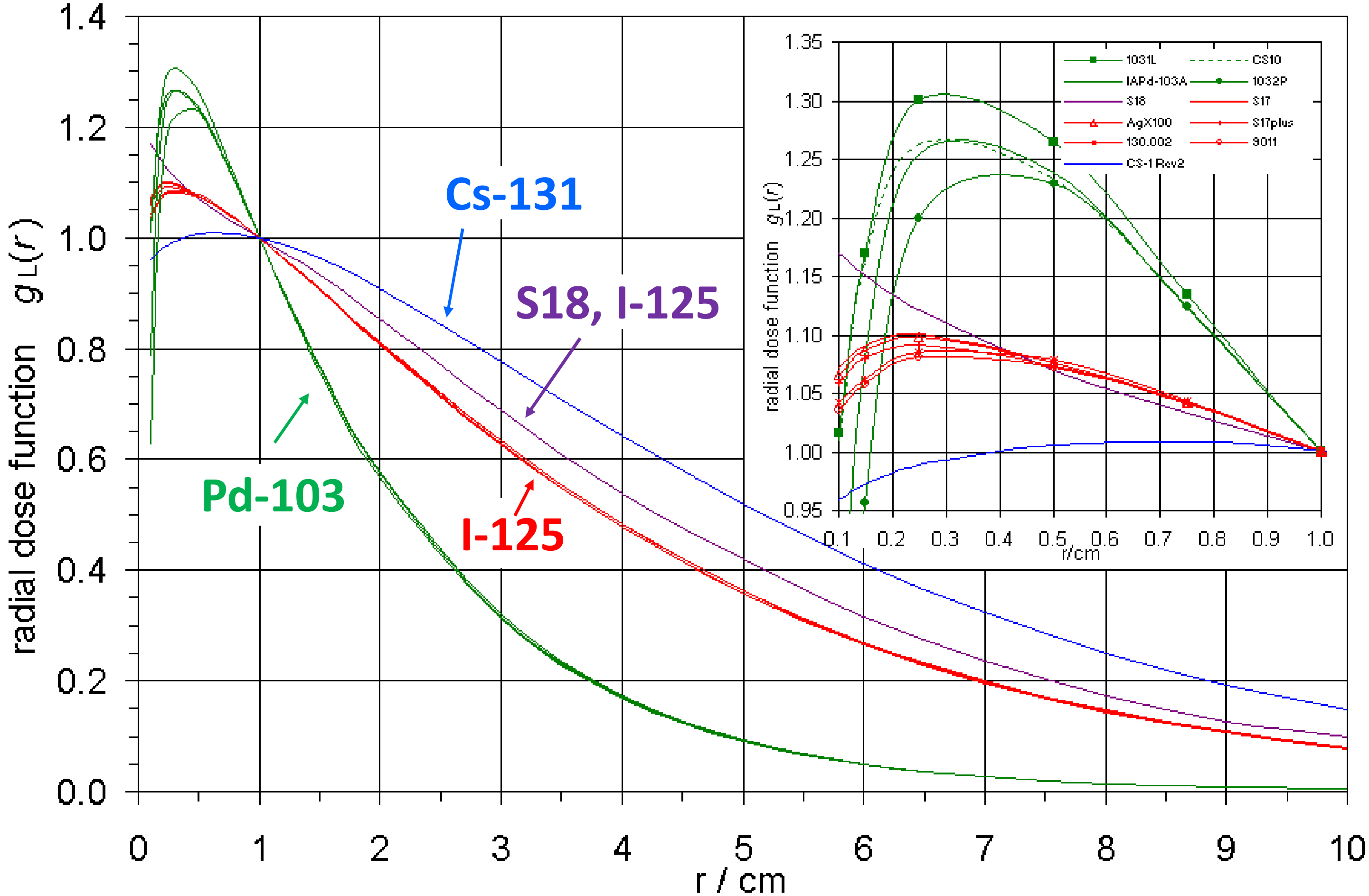
Dose rate constant values: Dependence on radionuclide

- dose rate constant, ${}_{CON}\Lambda$



For seeds of the same radionuclide,
the dose rate constant is approximately constant

Radial dose function: Dependence on radionuclide

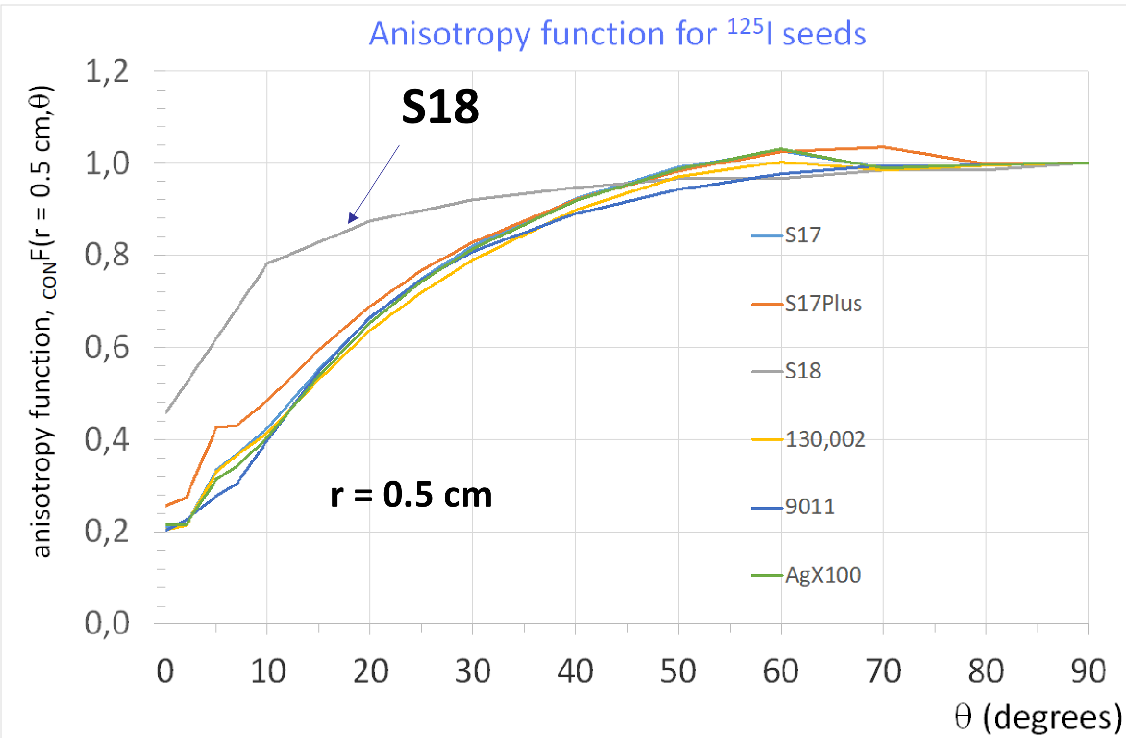


For seeds of the same radionuclide,
the radial dose functions are indistinguishable,
except for r < 0.5 cm.

special case: S18 ^{125}I sed

2D anisotropy function values: Dependence on radionuclide

- 2D anisotropy function, ${}_{CON}F(r,\theta)$

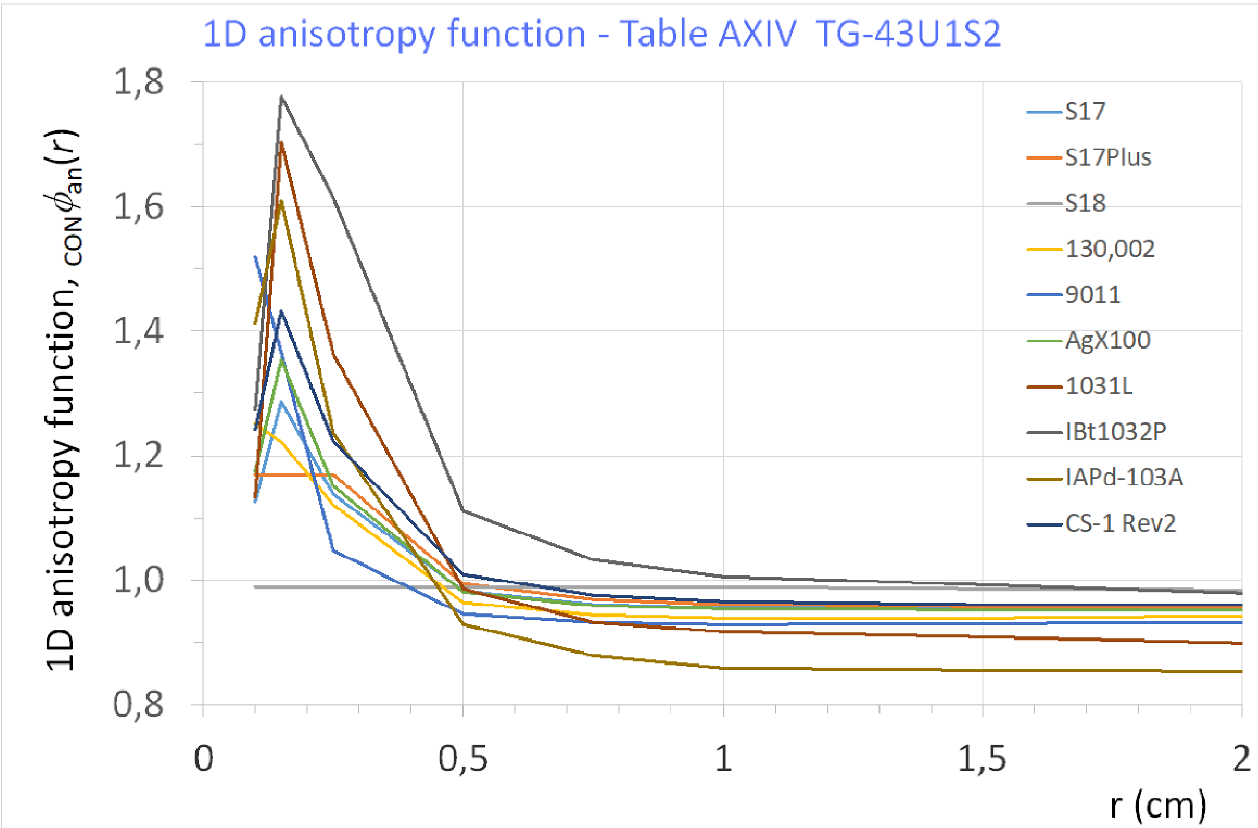


For seeds of the same radionuclide,
the 2D anisotropy functions are similar.

special case: S18 ^{125}I seed

1D anisotropy function values: Dependence on radionuclide

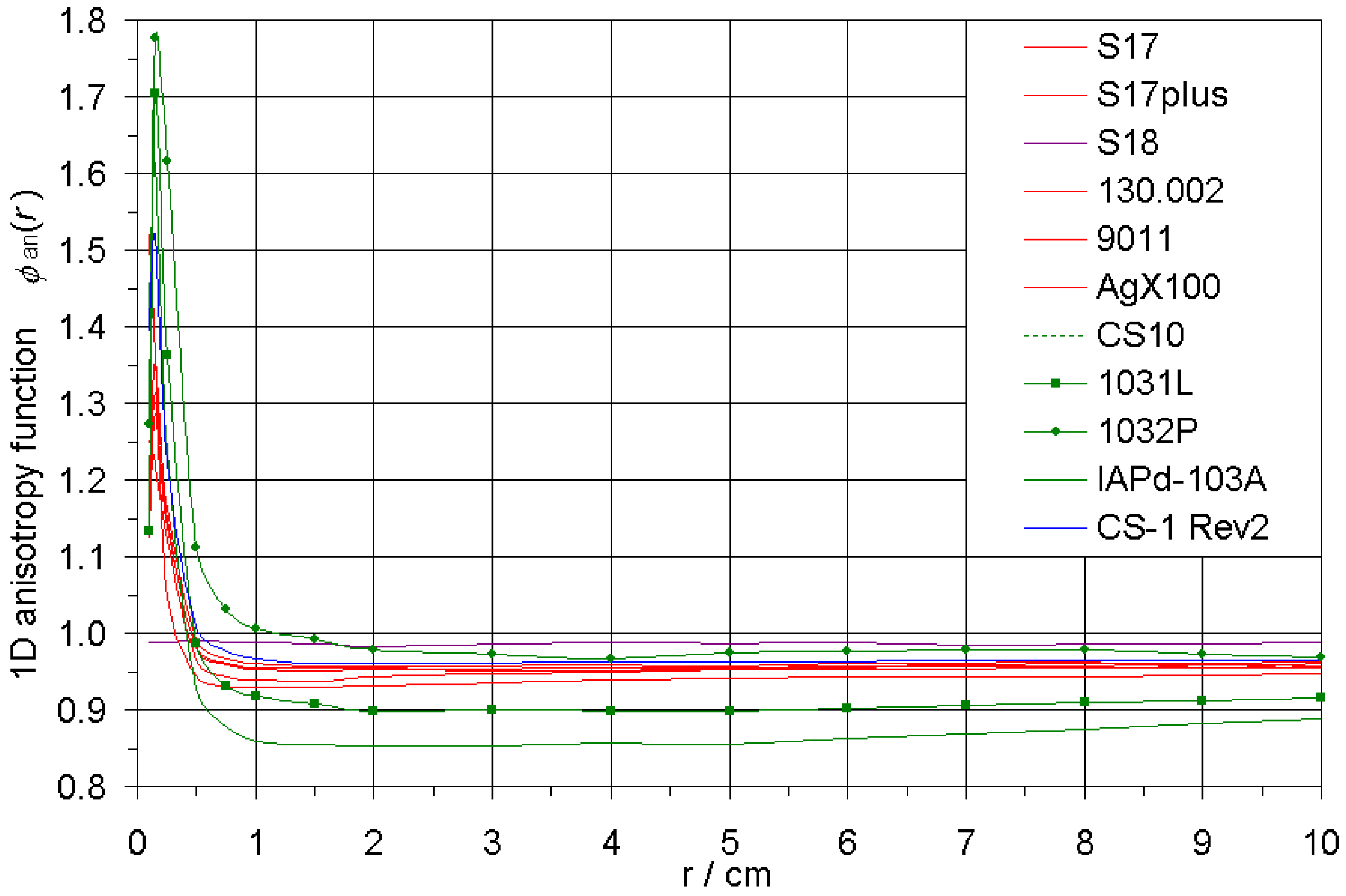
- 1D anisotropy function, ${}_{\mathrm{CON}}\phi_{\mathrm{an}}(r)$



For seeds of same radionuclide, 1D anisotropy functions exhibit specific characteristics for $r < 0.5$ cm

special case: S18 ^{125}I seed

1D anisotropy function functions for the 11 seed models



Influence of the grid size resolution on TPS calculations

- Data interpolation/extrapolation method recommendations

Table III. Interpolation and extrapolation recommendations for high-energy (*low-energy*)[3] brachytherapy sources for the line-source approximation.

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

Pérez-Calatayud, et al. *Med. Phys.* 39, 2904-2929 (2012)

Influence of grid size resolution on TPS calculations

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 4, 2015

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

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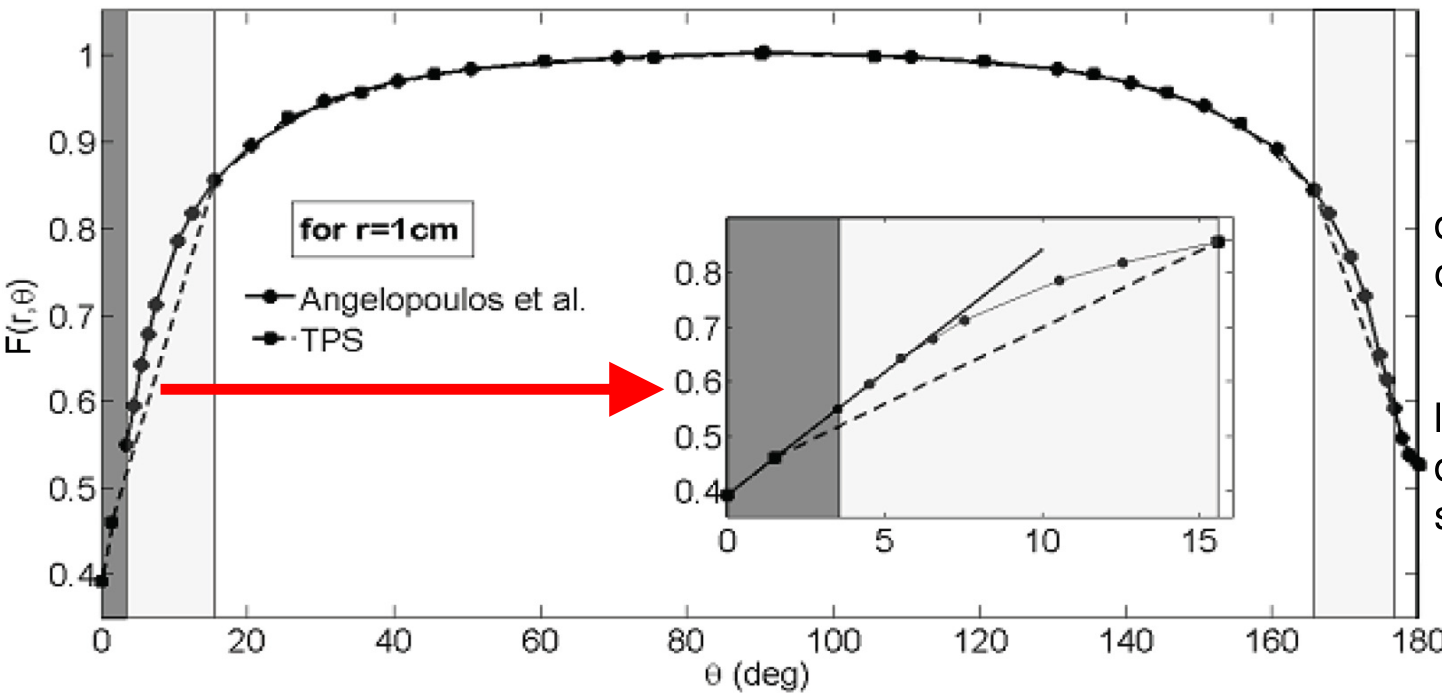
The aim of this work is to evaluate performance of a commercial BT TPS with vendor TG-43 data, analyze possible discrepancies with respect to a proper reference source and its implications for standard treatments, and judge the effectiveness of certain widespread recommended quality controls to find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

Valdés, et al., *J. Appl. Clin. Med. Phys*. 16, 3-17 (2015)

Influence of grid size resolution on TPS calculations



^{192}Ir

differences > 2% encompass ~17% of surrounding source volume

low-E LDR seeds also exhibit dose anisotropy and are equally susceptible to interpolation errors

Valdés, et al., *J. Appl. Clin. Med. Phys*. 16, 3-17 (2015)

Influence of grid size resolution on TPS calculations

- 2D anisotropy function grids in TG-43U1S2

	Anisotropy function grids												
	r (cm)								θ (degrees)				
	0	0,1	0,15	0,20	0,25	0,5	0,75	1	0	2	5	7	10
S17	o	o	o		o	o	o	o	o	o	o	o	o
S17Plus	o				o	o	o	o	o	o	o	o	o
S18	o					o		o	o				o
130,002	o	o		o		o	o	o	o	o	o	o	o
9011	o	o			o	o	o	o	o	o	o	o	o
AgX100	o	o			o	o	o	o	o	o	o	o	o
CS10	o	o			o	o	o	o	o	o	o	o	o
1031L	o	o	o		o	o	o	o	o	o	o	o	o
1032P	o	o	o		o	o	o	o	o	o	o	o	o
IAPd-103A	o	o	o		o	o	o	o	o	o	o	o	o
CS-1 Rev2	o	o	o		o	o	o	o	o		o		o

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
  - 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

ESTRO
European Society for
RADIOTHERAPY
& ONCOLOGY

Carleton
UNIVERSITY
Canada's Capital University

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

ESTRO European Society for RADIOTHERAPY & ONCOLOGY

Carleton UNIVERSITY

Canada's Capital University

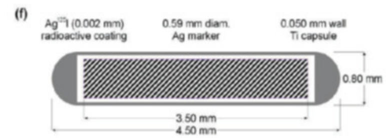
TG-43U1S2 CONSENSUS

Theragenics I-125 model AgX100

Supplement 2 for the 2004 update of the AAPM Task Group No. 43 Report: Joint
Rivard et al.
Med. Phys. 44 (9) (September 2017) e297-e338 http://dx.doi.org/10.1002/mp.12430
Erratum Med. Phys. 45(2) (February 2018) 971-974 http://dx.doi.org/10.1002/mp.12728

Λ = 0,952 cGy/(h U)
$u(\Lambda)$ = 0,043 cGy/(h U)
L = 0,35 cm

Interpolated data are highlighted in boldface while <u>extrapolated data are underlined</u>.



Theragenics model AgX100

r (cm)	$g_L(r)$ L = 0.35 cm	$g_P(r)$
0,10	1,066	0,647
0,15	1,086	0,811
0,25	1,098	0,968
0,50	1,076	1,046
0,75	1,042	1,034
1,00	1	1
1,50	0,908	0,913
2,00	0,813	0,819
3,00	0,633	0,639
4,00	0,482	0,487
5,00	0,361	0,365
6,00	0,269	0,272
7,00	0,1990	0,2010
8,00	0,1470	0,1485
9,00	0,1080	0,1091
10,00	0,0790	0,0798

r (cm)	$\phi_{an}(r)$
0,10	1,175
0,15	1,353
0,25	1,151
0,50	0,981
0,75	**0,959**
1,00	0,953
1,50	0,951
2,00	0,952
3,00	0,953
4,00	0,954
5,00	0,954
6,00	0,955
7,00	0,956
8,00	0,956
9,00	0,958
10,00	0,957

$F(r,\theta)$ Distance from Active Source Center, r (cm)

θ / deg	0,25	0,50	0,70	1,00	1,50	2,00	3,00	5,00	7,00	10,00
0	0,207	0,216	0,250	0,289	0,354	0,400	0,465	0,537	0,586	0,639
2	0,212	0,215	0,250	0,314	0,411	0,470	0,532	0,595	0,637	0,659
5	0,221	0,314	0,357	0,400	0,454	0,493	0,549	0,610	0,646	0,681
7	0,251	0,342	0,380	0,429	0,484	0,522	0,572	0,634	0,667	0,703
10	0,416	0,405	0,446	0,490	0,543	0,578	0,624	0,673	0,702	0,726
15	0,627	0,539	0,566	0,600	0,638	0,664	0,699	0,735	0,756	0,775
20	0,803	0,653	0,666	0,689	0,717	0,736	0,759	0,786	0,804	0,819
25	0,916	0,744	0,747	0,761	0,779	0,793	0,812	0,829	0,843	0,851
30	0,989	0,815	0,811	0,818	0,830	0,840	0,852	0,865	0,873	0,880
40	1,027	0,918	0,906	0,905	0,907	0,910	0,914	0,920	0,923	0,926
50	0,959	0,987	0,971	0,964	0,961	0,961	0,960	0,959	0,962	0,958
60	0,981	1,030	1,018	1,008	1,000	0,997	0,993	0,987	0,988	0,986
70	0,994	0,988	1,035	1,037	1,028	1,024	1,017	1,009	1,008	0,999
80	0,999	0,996	0,997	1,002	1,030	1,030	1,027	1,021	1,017	1,014
90	1	1	1	1	1	1	1	1	1	1

r cm	1D dose (P) $cGy\ h^{-1}\ U^{-1}$
0,10	72,4
0,15	46,4
0,25	16,96
0,50	3,91
0,75	1,679
1,00	0,908
1,50	0,367
2,00	0,1856
3,00	0,0644
4,00	0,0276
5,00	0,01324
6,00	0,00686
7,00	0,00373
8,00	0,00211
9,00	0,001228
10,00	0,000727

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_{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
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VNIVERSITAT DE VALÈNCIA

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La Fe Hospital Universitari i Politècnic

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

Radionuclide Source Spectra and Half-Lives, Reference Dose Scoring Media, and TLD Methodological Corrections

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on behalf of the report authors

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§ 5.B. Radionuclide Half-Lives

- Recommended source:
  National Nuclear Data Center (NNDC) of Brookhaven National Laboratory
  http://www.nndc.bnl.gov/chart/

- The NNDC collects, evaluates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies.

http://www.nndc.bnl.gov/chart/reCenter.jsp?z=46&n=57	**^{103}Pd**
De Frenne, Nuclear Data Sheets 110, 2081 (2009)	16.991(34) days
http://www.nndc.bnl.gov/chart/reCenter.jsp?z=53&n=72	**^{125}I**
Katakura, Nuclear Data Sheets 112, 495 (2011)	59.407(10) days
http://www.nndc.bnl.gov/chart/reCenter.jsp?z=55&n=76	**^{131}Cs**
Khazov et al, Nuclear Data Sheets 107, 2715 (2006)	9.689(16) days

§ 5.A. Radionuclide Photon Spectrum

- 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}Pd and ^{131}Cs

- combine evaluations for AAPM+GEC-ESTRO ^{131}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., $L_\gamma = L_{\gamma 1} + L_{\gamma 2} + L_{\gamma 3}$.

^{131}Cs (half-life = 9.689 ± 0.016 days)	
Photon energy (keV)	Photons per disintegration
3.760 Xe $L_{\eta+\iota}$	0.0037
4.109 Xe L_α	0.0702
4.479 Xe L_β	0.06302
5.138 Xe L_γ	0.00844
29.112 Xe $K_{\alpha 3}$	0.000022
29.461 Xe $K_{\alpha 2}$	0.211
29.782 Xe $K_{\alpha 1}$	0.389
33.562 Xe $K_{\beta 3}$	0.0364
33.624 Xe $K_{\beta 1}$	0.0702
33.881 Xe $K_{\beta 5}$	0.00071
34.419 Xe $K_{\beta 2}$	0.0213
34.496 Xe $K_{\beta 4}$	0.00412
	0.8781 total photons per disintegration
30.411 mean (> 10 keV photons)	0.7328 total (≥ 10 keV photons)

§ 5.C. Reference Dose Scoring Media

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

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

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

$$D_{med}(Q) = M(Q)\ N_{D,med}(Q) \tag{1}$$

$$S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} \tag{2}$$

$$S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} = \frac{M(Q)}{\overline{D_{TLD}}(Q)} \frac{\overline{D_{TLD}}(Q)}{D_{med}(Q)} = \frac{1}{k_{bq}(Q)} \frac{1}{f(Q)} \tag{3}$$

$$S_{AD,med}^{rel} = \frac{S_{AD,med}(Q)}{S_{AD,med}(Q_0)} = \frac{1}{k_{bq}^{rel}} \frac{1}{f^{rel}} \tag{4}$$

$$E(r) = \frac{S_{AD,med}^{rel}(Q)}{P_{phant}} = \frac{1}{k_{bq}^{rel}} \frac{1}{f^{rel}} \frac{1}{P_{phant}} \tag{5}$$

§ 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 $N_{D,med}(Q)$

$$D_{med}(Q) = M(Q)\ N_{D,med}(Q) \tag{1}$$

§ 5.D. TLD Dosimetry Methodological Corrections

- inverse of the absorbed dose calibration coefficient $N_{D,med}(Q)$

  is the absorbed dose sensitivity coefficient $S_{AD,med}(Q)$

$$S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} \tag{2}$$

§ 5.D. TLD Dosimetry Methodological Corrections

- partition $S_{AD,med}(Q)$ into two components

$$S_{AD,med}(Q) = \frac{M(Q)}{D_{med}(Q)} = \frac{M(Q)}{\boxed{\overline{D_{TLD}}(Q)}} \boxed{\frac{\overline{D_{TLD}}(Q)}{D_{med}(Q)}}$$

avg. TLD dose for radiation quality Q

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

$$\frac{M(Q)}{\overline{D_{TLD}}(Q)} \frac{\overline{D_{TLD}}(Q)}{D_{med}(Q)} = \frac{1}{k_{bq}(Q)} \frac{1}{f(Q)}$$

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

$$S_{AD,med}(Q) = \frac{1}{k_{bq}(Q)} \frac{1}{f(Q)} \qquad (3)$$

§ 5.D. TLD Dosimetry Methodological Corrections

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

$$S_{AD,med}^{rel} = \frac{S_{AD,med}(Q)}{S_{AD,med}(Q_0)} = \frac{1}{k_{bq}^{rel}} \frac{1}{f^{rel}}$$ ratio to calibration

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

relative absorbed dose sensitivity $\boxed{f^{rel}}$ of the detector

$$S_{AD,med}^{rel} = \frac{1}{k_{bq}^{rel}} \frac{1}{f^{rel}} \qquad (4)$$

§ 5.D. TLD Dosimetry Methodological Corrections

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

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

- relative energy response function $\boxed{E(r)}$

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

$$E(r) = \frac{1}{k_{bq}^{rel}} \frac{1}{f^{rel}} \frac{1}{P_{phant}} \quad (5)$$

Summary

- 11 new sources evaluated with consensus data provided
- ${}_{CON}\Lambda$ for ^{103}Pd seeds all within 0.6% of 0.697 cGy/h/U except for plastic encapsulated model 1032P and CS10 sources
- ${}_{CON}\Lambda$ for ^{125}I seeds all within 1.2% of 0.942 cGy/h/U except for plastic encapsulated model S18 source
- ${}_{CON}\Lambda$ for ^{131}Cs (1.056) increased as expected relative to ^{103}Pd and ^{125}I
- ${}_{MC}\Lambda$ / ${}_{EXP}\Lambda$ = 0.961 on avg. for all 11 source models
- ${}_{CON}g(r)$ and ${}_{CON}\phi_{an}(r)$ 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