Dosimetric and Calibration Advances in HDR ^{192}Ir Brachytherapy for Clinical Implementation

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Disclosure

There are no conflicts of interest for the presenter on the topics discussed in this presentation.

Opinions contained are solely those of the presenter, not meant to be interpreted as societal guidance.

Specific commercial equipment, instruments, and materials are described to fully describe the necessary procedures. Such identification does not imply recommendation or endorsement by the presenter nor imply that the identified material or equipment is necessarily the best available for these purposes.

Learning Objectives

AAPM/ESTRO refinement of TG-43 protocol via:

- High-Energy Brachytherapy Dosimetry WG report
- Task Group 186 (TG-186) report

2012 AAPM/ESTRO HEBD Report

Medical Physics

Dose calculation for photon-emitting brachytherapy sources with average energy higher than 50 keV: Report of the AAPM and ESTRO

AAPM/ESTRO recommendations on dose calculations for high-energy (average energy higher than 50 keV) photon-emitting brachytherapy sources are presented, including the physical characteristics of specific ^{192}Ir, ^{137}Cs, and ^{60}Co source models. This report includes considerations in the application of the TG-43U1 formalism to high-energy photon-emitting sources with particular attention to phantom size effects, interpolation accuracy dependence on dose calculation grid size, and dosimetry parameter dependence on source active length.

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

2012 AAPM/ESTRO HEBD Report

Evaluate TG-43 formalism as used with LE brachytherapy

Review construction and dosimetry parameter data for ^{192}Ir, ^{137}Cs, and ^{60}Co sources

Develop consensus datasets for uniform TPS usage

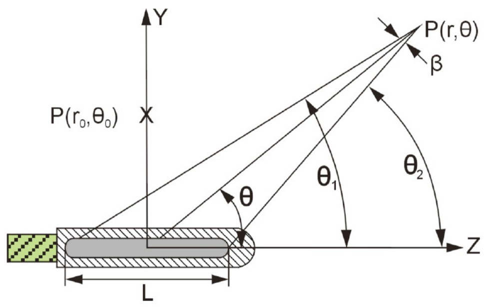
Dosimetry investigator guidelines for experimental dosimetry and MC for source dosimetry parameters

Dataset Evaluation Criteria

1. Internal geometry and description of the source
2. Review of pertinent literature for the source
3. Measurement medium to liquid water medium corrections (if applicable)
4. Experimental method used
5. Geometry function used; active length assumed for the line source approximation
6. Name and version of MC code
7. MC cross-section library
8. Variance reduction techniques used (for s_K and dose in water)
9. Electron emission inclusion
10. Photon emission spectrum
11. MC benchmarking according to the HEBD prerequisites[17]
12. Phantom shape and size used in MC and EXP
13. Agreement between MC and experimental dosimetry (if applicable, according to the HEBD prerequisites)[17]

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

Reference Coordinate System



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

Reference Radionuclide Data

TABLE I. Physical properties of radionuclides considered in this report. Data have been taken from the NNDC (Ref. 20). Mean photon energy values are calculated with a cut-off of $\delta = 10$ keV. Data on Auger and IC electrons are not included.

	^{192}Ir	^{137}Cs	^{60}Co
Half-life	73.81 days	30.07 yr	5.27 yr
Type of disintegration	β^- (95.1%), EC (4.9%)	β^- (100%)	β^- (100%)
Maximum x-ray energy (keV)	78.6	37.5	8.3
Gamma energy-range (keV)	110.4–1378.2	661.6	1173.2–1332.5
Mean x-ray and gamma energy (keV)	350.0	613.0	1252.9
Maximum β^- ray energies (keV)	81.7 (0.103%) 258.7 (5.6%) 538.8 (41.43%) 675.1 (48.0%)	514.0 (94.4%) 1175.6 (5.6%)	318.2 (99.88%) 1491.4 (0.12%)
Mean β^- ray energy (keV)	180.7	188.4	96.5
Air-kerma rate constant, $\Gamma_{\delta = 10\ \mathrm{keV}}$ (μGy m^2 h^{-1} MBq^{-1})	0.1091	0.0771	0.3059
Specific activity (GBq mg^{-1})	341.0	3.202	41.91

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

Interpolation Method

Parameter	$r_{\min} < r \leq r_{\max}$ Interpolation
$g_L(r)$	Linear (*log-linear*) using datapoints immediately adjacent to the radius of interest
$F(r, \theta)$	Bilinear (*bilinear*) interpolation method for $F(r, \theta)$ *(Ditto)*

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

Extrapolation Method (near)

Parameter	$r < r_{min}$ Extrapolation
$g_L(r)$	Nearest neighbor or zeroth-order extrapolation *(Ditto)*
$F(r, \theta)$	Nearest neighbor or zeroth-order extrapolation *(Ditto)*

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

Extrapolation Method (far)

Parameter	$r > r_{max}$ Extrapolation
$g_L(r)$	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 r-extrapolation *(Ditto)*

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

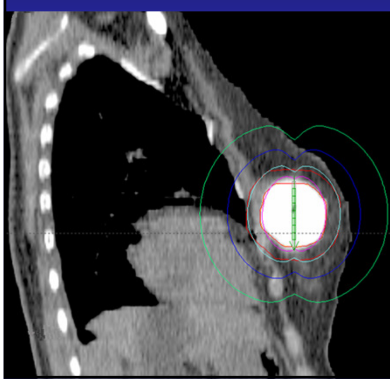
^{192}Ir Dose-Rate Constant Trend

$$\frac{\Lambda_L}{G_L(r_0,\theta_0)} = \frac{\Lambda_{L_{REF}}}{G_{L_{REF}}(r_0,\theta_0)}.$$

$$\Lambda = 1.12 \times G_L(r_0,\theta_0)\ [\mathrm{cGy\,h^{-1}\,U^{-1}}]$$

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

Conventional TPS Fails to Accurately Calculate Brachytherapy Dose



air ≠ water?

tissue ≠ water?

contrast impact?

source superposition?

source shielding?

radiation scatter?

Brachytherapy Dose Calculation Methods

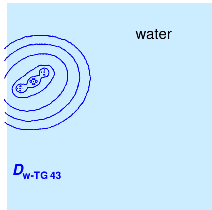
	INPUT		"CALCULATION"		OUTPUT
TG-43	source characterization	⇨	superposition of single-source data	⇨	$D_{W:TG\text{-}43}$

	INPUT		CALCULATION		OUTPUT
MBDCA	source characterization	⇨	Monte Carlo GBBS Collapsed Cone	⇨	$D_{M,M}$ $D_{W,M}$
	tissue+applicator information	⇨			

courtesy Å. Carlsson Tedgren

Dose is Calculated

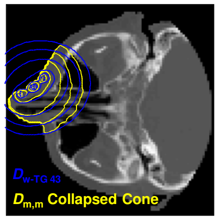
TG-43



superposition of single-source water-doses

imaging: localize dose onto anatomy

MBDCA



dose is *calculated* using

imaging: for tissue information

courtesy Å. Carlsson Tedgren

Brachytherapy Dose Calculation Methods

model based

factor based

Method	Characteristics	Remarks
Monte Carlo	explicit particle transport simulation + accurate – noisy dose distributions	standard source characterization and research tool, clinical use under development
analytic solvers	solves transport equations deterministic methods + accurate – discretization effects	standard tool in Nuc Engin, clinical implementation (GBBS) only for HDR ^{192}Ir (currently)
scatter kernel methods Collapsed Cone based on PSS data	implicit particle transport + accurate – discretization effects – small systematic errors	potential for parallel hardware, e.g. GPU, clinical use under development
TG-43 hybrid methods	+ more accurate than TG-43 + fast, available with current TPS – highest accuracy not obtained	can serve as dose engine within optimization loops, sensitive geometry assumptions
Parameterization of Primary and Scatter Separation (PSS) data	no particle transport + fast, robust radial extrapolation – neglect effects from shields, finite patient, heterogeneities	same source data as advanced algorithms
TG-43	no particle transport + fast, familiar, permits hand calcs – neglect effects from shields, finite patient, heterogeneities	current clinical workhorse

explicit physics modeling

courtesy Å. Carlsson Tedgren

2012 TG-186 Report

Medical Physics

Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation

The Task Group 186 charge is to provide guidance for early adopters of model-based dose calculation algorithms (MBDCAs) for brachytherapy dose calculations to ensure practice uniformity. Contrary to external beam radiotherapy (EBRT), heterogeneity correction algorithms have only recently been made available to the brachytherapy community. Yet, brachytherapy dose calculation accuracy is highly dependent on scatter conditions and photoelectric effect cross-sections relative to water. In specific situations, differences between the current TG-43 based dose calculation formalism and MBDCAs can lead to differences in calculated doses exceeding a factor of ten.

Beaulieu et al., Med. Phys. 39, TBD (2012) ***ACCEPTED***

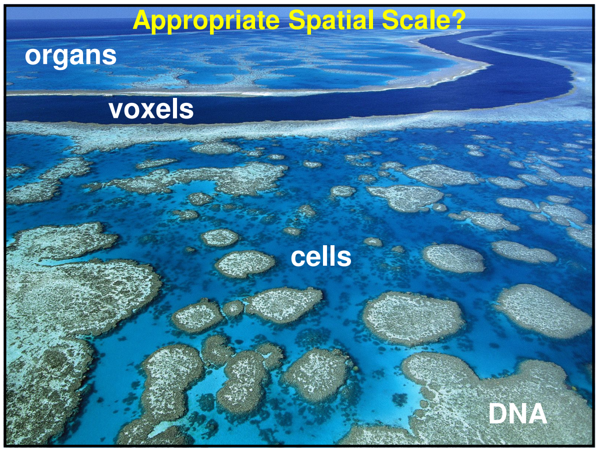
TG-186 Guidelines Address Dosimetry Hurdles

- 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
- commissioning issues, standard geometries
- patient-related input data (FOV, material assignments)
- CT/CBCT artifact removal for dose calculations
- potential clinical issue, risks, and limitations

provide recommendations to MBDCA early-adopters

TG-186 Guidelines

- maintain inter-institutional consistency
- dose accuracy is needed for:
  - source clinical comparisons
  - transfer of experience to new sources (eBx, ^{131}Cs, ^{169}Yb)
  - new applicators (Savvy, AccuBoost, Valencia)
- differences between $D_{M,M}/D_{W,W}$ and $D_{W,M}/D_{W,W}$
- unclear which approach best correlates toxicities/outcomes
- tissue (breast) composition uncertainty is 2nd order effect in comparison to advancement from TG-43 algorithm
  Landry *et al.*, Med. Phys. 37, 5188-5199 (2010).



Need Future Developments

- dual-energy CT will permit automatic tissue identification, but will still require:
  - corrections for CT-reconstruction artifacts
  - full patient geometry for scatter calculations
  - overriding of MRI/US imaging data
- international Registry to house reference data
  - standardized tissue info
  - source + applicator libraries
  - 3D treatment planning benchmarks
  - blog and repository for users' group
- develop retrospective and prospective relationships of:
  - dose-to-patient outcomes and dose-to-OAR toxicities

TG-186 Summary

- MBDCA TPS allow more accurate dose calcs than TG-43
- TG-43 Hybrid approach is also available
- dosimetric benchmarks required for safe clinical use
- Working Group develops standards and benchmarks
- incorporate dose changes cautiously (IRB clinical trial)
- Rx paradigm shift should be societally-coordinated