Review TG-186 and WG-MBDCA guidelines, commissioning process, and dosimetry benchmarks

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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 equipment, instruments, and materials are mentioned to fully describe the necessary procedures. Such identification does not imply endorsement by the presenter nor imply that the items identified are necessarily the best available for these purposes.

Learning Objectives

- Background on advanced BT dose calculations
- Review TG-186 report and guidelines
- Introduction to WG-MBDCA guidelines
- Explain recommended process for advanced TPS clinical commissioning and practice integration
- Examine infrastructure and dosimetry benchmarks


Humans *are not* water equivalent!

Vision 20/20 Paper: 2009

Medical Physics

The evolution of brachytherapy treatment planning

Mark Rivard,[1] Jack L. M. Venselaar,[2] and Luc Beaulieu[3]
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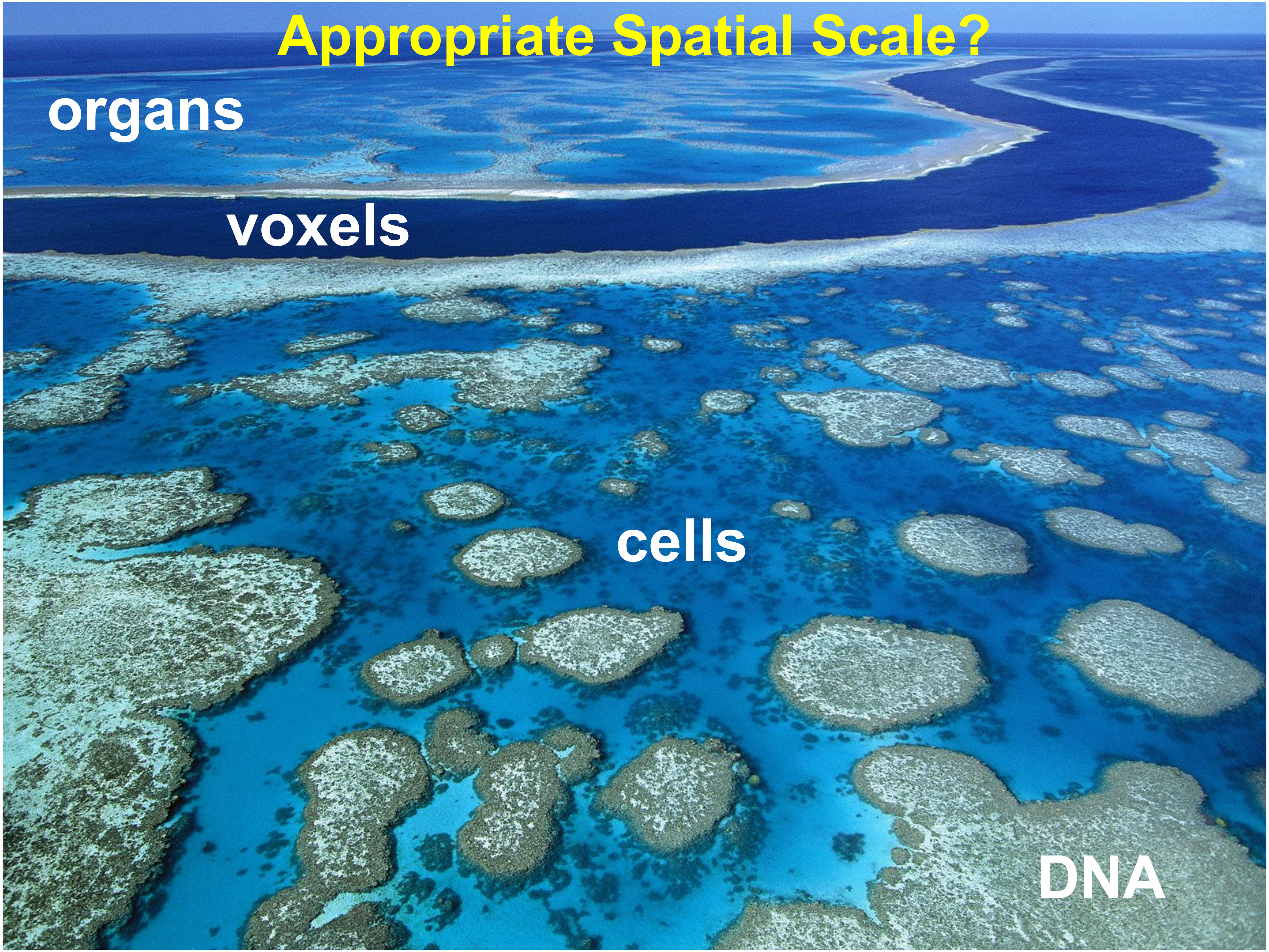
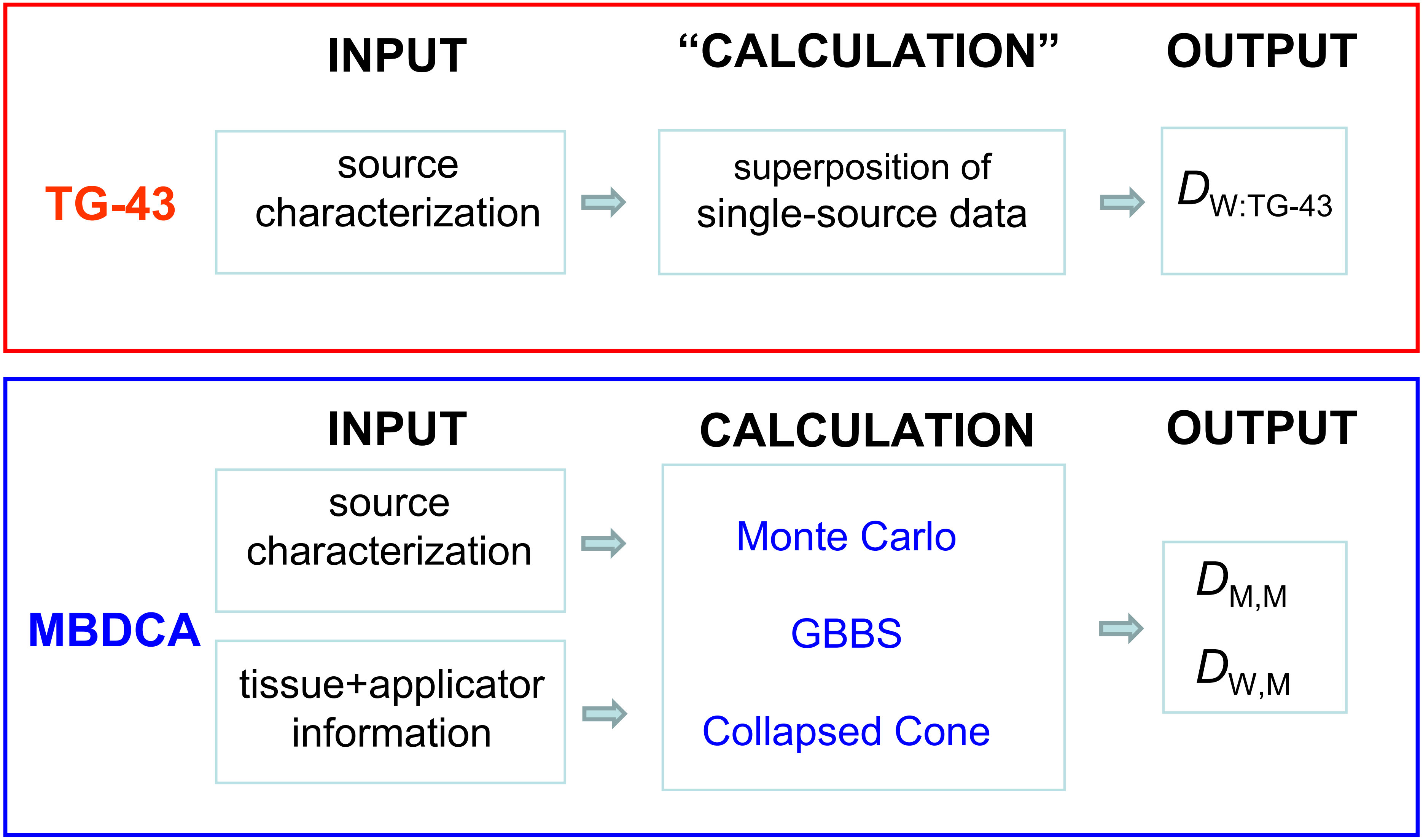
[2]*Department of Medical Physics, Instituut Verbeeten, P.O. Box 90120, 5000 LA Tilburg, The Netherlands*
[3]*Departement de Radio-Oncologie et Centre de Recherche en Cancerologie de l'Universite Laval, Quebec*

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.

Rivard, Venselaar, Beaulieu, *Med. Phys.* 36, 2136-2153 (2009)


Appropriate Spatial Scale?
organs
voxels
cells
DNA

Brachytherapy Dose Calculation Methods



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

Vision 20/20 Paper: 2010

- next-generation dose calculation algorithms
- commissioning issues
- TPS QA recommendations
- societal infrastructure
- dosimetric benchmarking
  - reference dataset and dosimetric tolerances
- clinical paradigm shift
  - dose specification, tissue segmentation, RBE

Medical Physics

Enhancements to commissioning techniques and QA of brachytherapy treatment planning systems that use model-based dose calculation algorithms

Mark Rivard,[1] Luc Beaulieu,[2] and Firas Mourtada[3]
[1]Tufts University, Boston [2]Centre Hospitalier Universitaire de Québec [3]MD Anderson Cancer Center

Med. Phys. 37, 2645-2658 (2010)

Vision 20/20 Paper: 2010

TABLE I. Status of MBDCAs that can account for radiation scatter conditions and/or material heterogeneities and were useable in brachytherapy treatment planning systems as of 12 May 2010.

MBDCA system	Sponsor(s)	Radiation type	Clinical use	FDA/CE mark status	Release date
PLAQUE SIMULATOR	Astrahan	$^{125}I + ^{103}Pd$ photons	Y	N	1990
Collapsed cone	Ahnesjö, Russell, and Carlsson	^{192}Ir photons	N	N	1996
BRACHYDOSE	Yegin, Taylor, and Rogers	0.01–10 MeV photons	N	N	2004
MCPI	Chibani and Williamson	$^{125}I + ^{103}Pd$ photons	N	N	2005
GEANT4/DICOM-RT	Carrier *et al.*	Any	N	N	2007
Scatter correction	Poon and Verhaegen	^{192}Ir photons	N	N	2008
Hybrid TG-43:MC	Price and Mourtada, and Rivard *et al.*	Any	Y	Y	2009
ACUROS	Transpire/Varian	^{192}Ir photons	Y	Y	2009

V. NEEDED INFRASTRUCTURE

While MBDCAs are expected to produce more accurate dosimetric results than the current TG-43 formalism, the authors feel that the medical community should not immediately replace the current approach without careful consideration for widespread integration. Assessment of the current infrastructure is needed before assigning new resources, with opportunity for further cooperation of national and international professional societies.

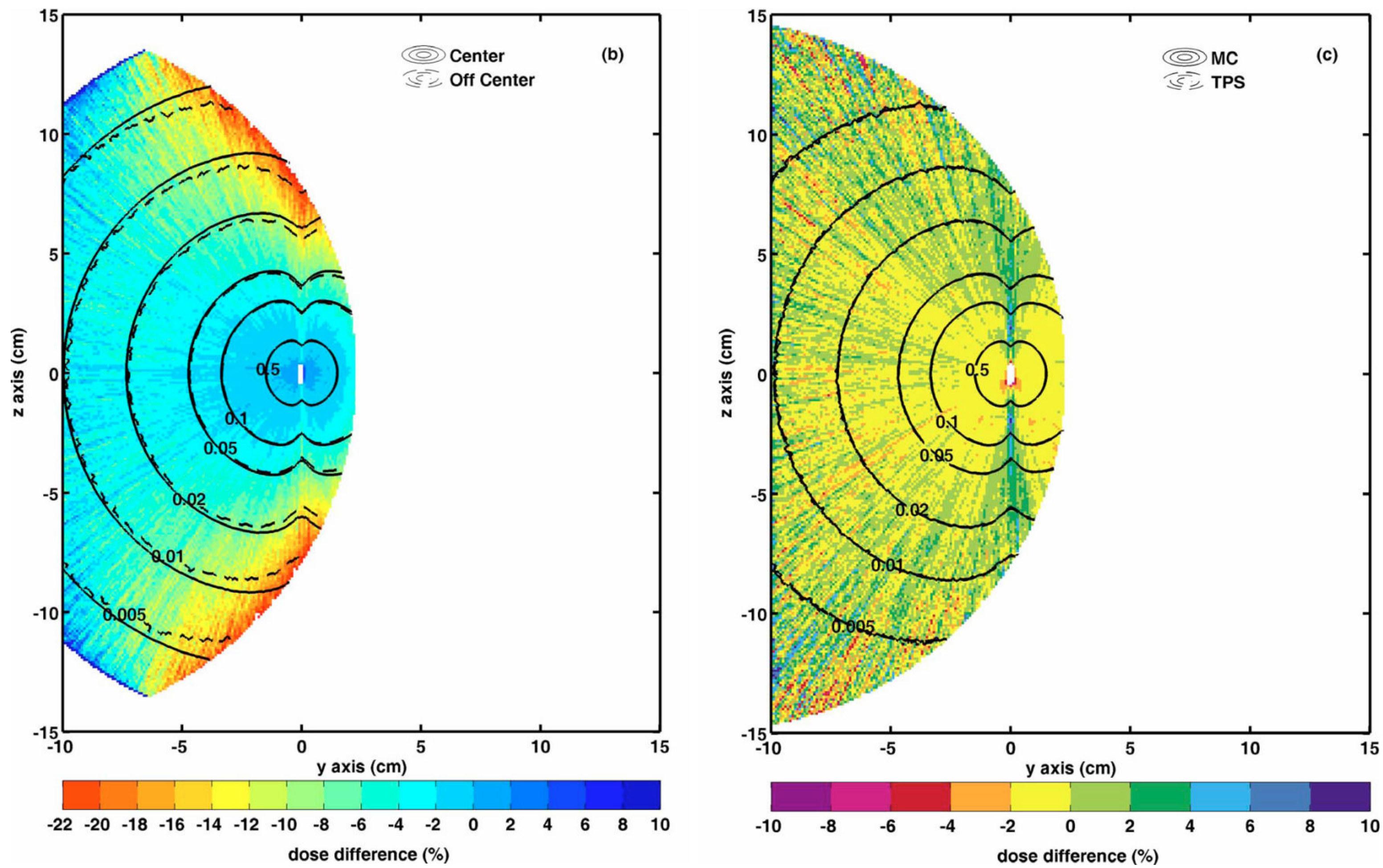
V.A. Centralized dataset management

Societal recommendations and reference data do the clinical physicist no good if they cannot be readily implemented. Having quantitative data available beyond the scientific, peer-reviewed literature may be accomplished through expansion of the joint AAPM/RPC Brachytherapy Source Registry. An independent repository such as the Registry to house the reference data would facilitate this process–especially with international accessibility.

Rivard, Beaulieu, Mourtada, *Med. Phys.* 37, 2645-2658 (2010)

Need Standardized MBDCA Benchmarks

- excellent reference HDR ^{192}Ir benchmark
  - –Acuros BrachyVision



Zourari *et al*., *Med. Phys*. 37, 649-661 (2010)

Need Standardized MBDCA Benchmarks

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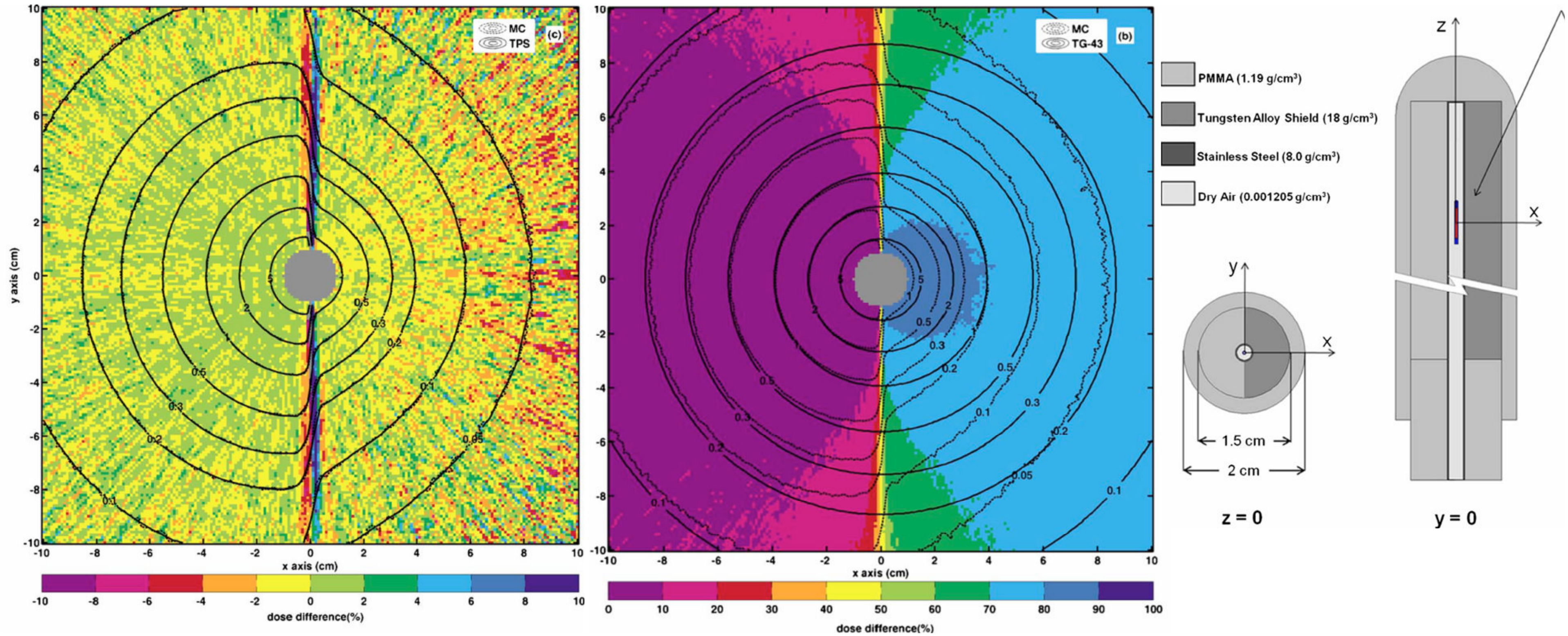
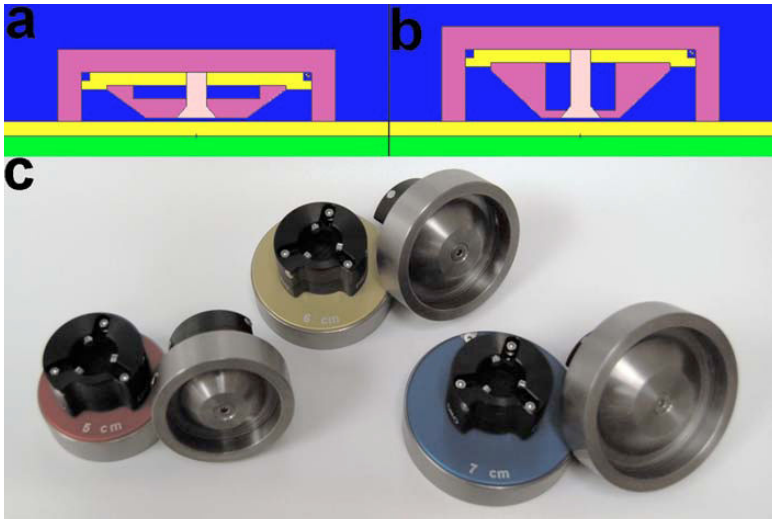
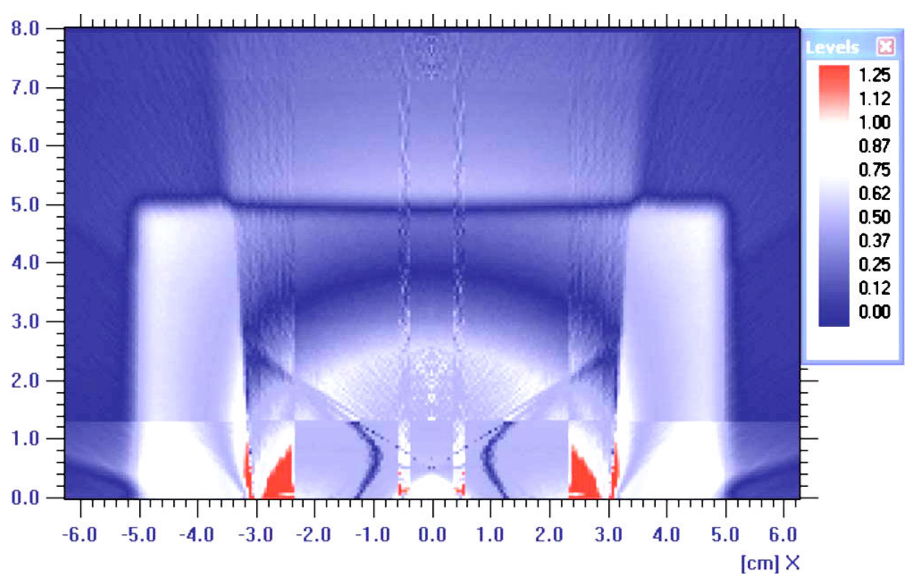


Petrokokkinos *et al.*, *Med. Phys.* 38, 1981-1992 (2011)

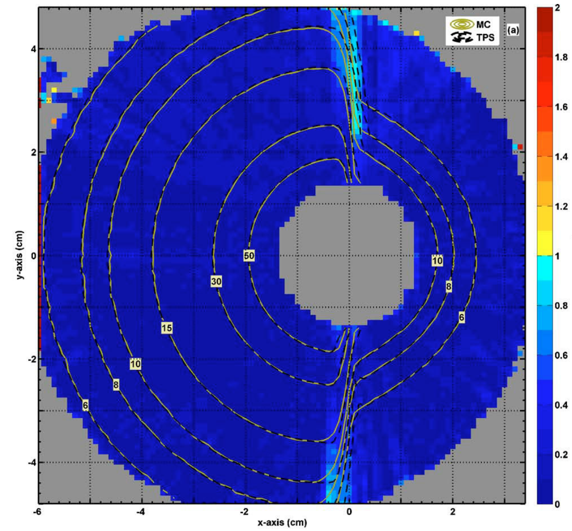
Need New TPS Evaluation Criteria

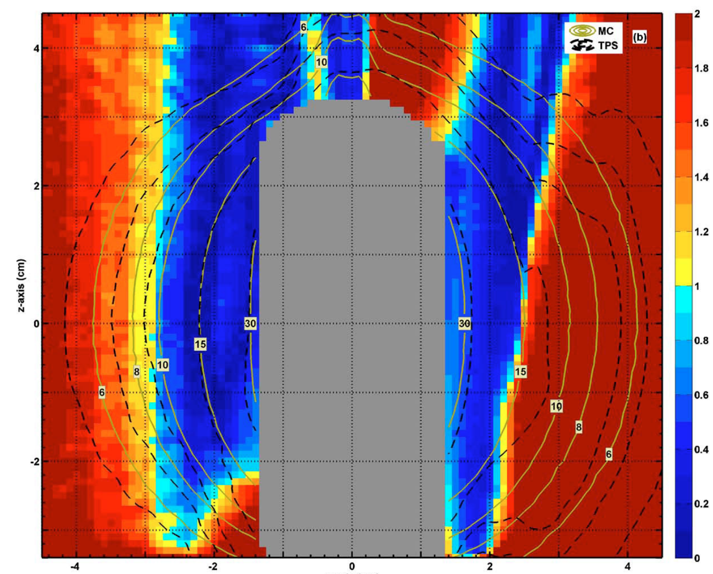




1% and 1 mm

Yang *et al*., *Med. Phys*. (2011)





5% and 2 mm

Petrokokkinos *et al*., *Med. Phys*. (2011)

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

L. Beaulieu, Å. Carlsson Tedgren, J-F. Carrier, S. D. Davis, F. Mourtada, M. J. Rivard,
R. M. Thomson, F. Verhaegen, T. A. Wareing, and J. F. Williamson

The Task Group 186 charge is to provide guidance for early adopters of model-based dose calculation algorithms (MBDCAs) for BT dose calculations to ensure practice uniformity. Contrary to external beam radiotherapy (EBRT), heterogeneity correction algorithms have only recently been made available to the BT community. Yet, BT 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, 6208-6236 (2012)

TG-186 Report

Endorsed by:

AAPM

ESTRO

American Brachytherapy Society

Australasian Brachytherapy Group

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 for Prescription Standards

- Perform dose calculations according to the TG-43 formalism *and* the more accurate heterogeneous calculations.
- File these dose estimates for clinical evaluation in anticipation of sufficient heterogeneity-enabled TPS.
- Radiation oncologist should assess clinical practice of BT using MBDCA, accounting for material heterogeneities, patient scatter conditions, and high-*Z* attenuation.
- Prescriptions should be based on TG-43 dose calculations until sufficient clinical data and societal recommendations.

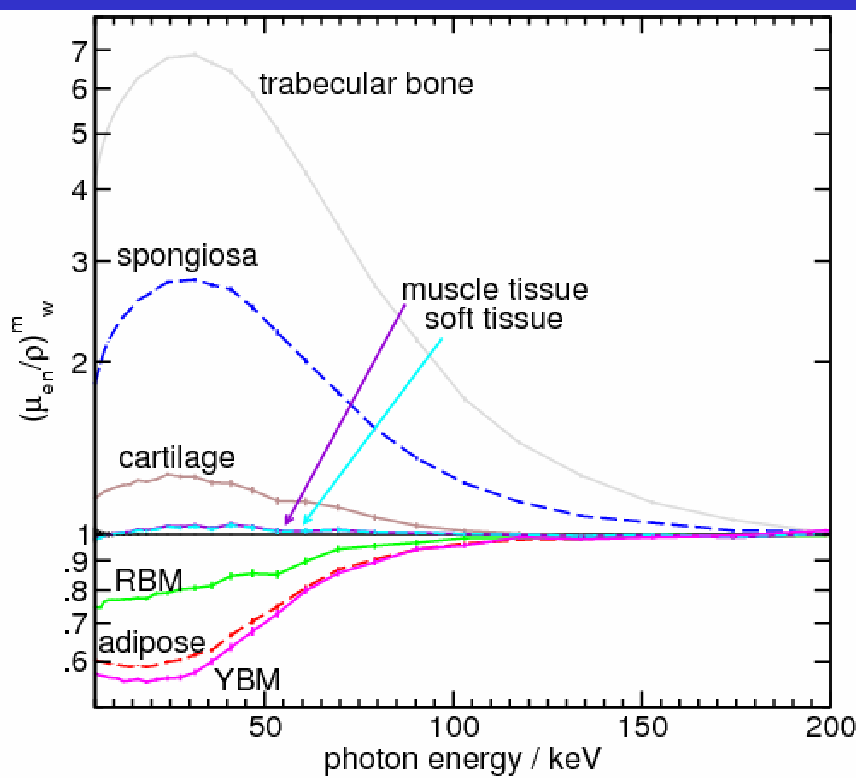
TG-186 Guidelines

- maintain inter-institutional consistency like TG-43 approach
- note 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 <u>2nd order effect</u> in comparison to advancement from TG-43 algorithm

  Landry *et al*., Med. Phys. 37, 5188-5199 (2010).

TG-186 Guidelines

- recommended standardized tissues
  - inter-institutional consistency for uniform evaluation/Tx
- define at each location within the patient:
  - scoring method ($D_{M,M}$, $D_{M,W}$, $D_{W,W}$)
  - material composition, mass density

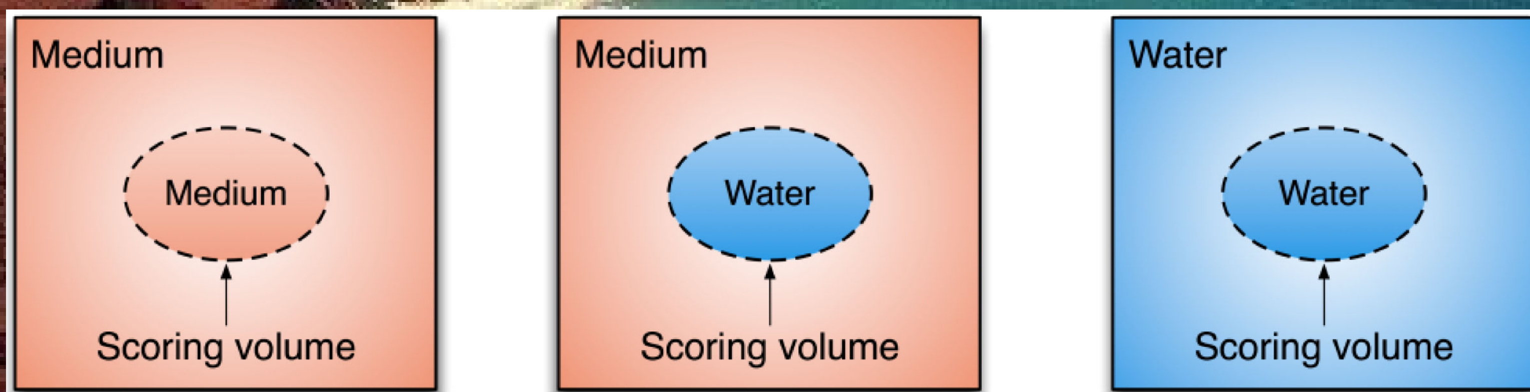


dose absorption sensitivity

as a function of photon energy

courtesy L. Beaulieu

Dose Scoring Possibilities



MBDCA TPS Acceptance Testing

- evaluate product performance within specs
- training on proper system function
- test all equipment components and features
  - validate dimensions (TPS applicator library)
- update P&P to ensure system compatibility
- results set baseline for clinical use
- re-perform annually to ensure TPS stability
- independent check calculation
  - hybrid plan of MBDCA positions into TG-43 / water geometry

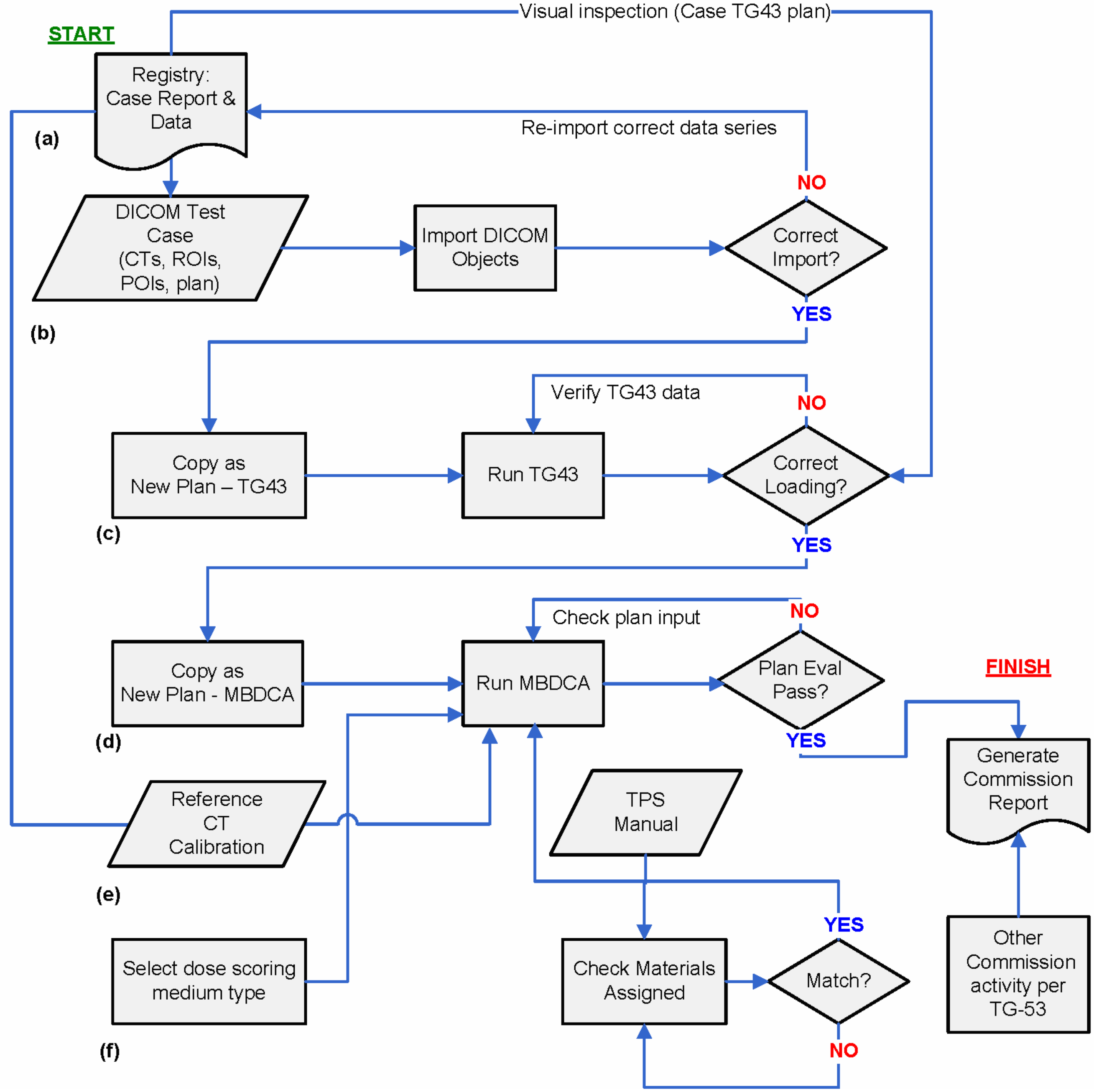
MBDCA TPS Commissioning Guidelines

- TPS commissioning levels: (1) TG-43, and (2) advanced
- update Quality Management societal standards
- consider AAPM Task Group Reports and Guidance
  - TG-56 Code of Practice for Brachytherapy (1997)
  - TG-59 High Dose Rate Tx Delivery (1998)
- consider AAPM Summer School texts
  - 1994 Chapters 28, 30, 31, 32
  - 2005 Chapters 6, 7, 11, 22, 32, 48
- consider Bruce Thomadsen’s 1999 text
  “Achieving Quality in Brachytherapy”

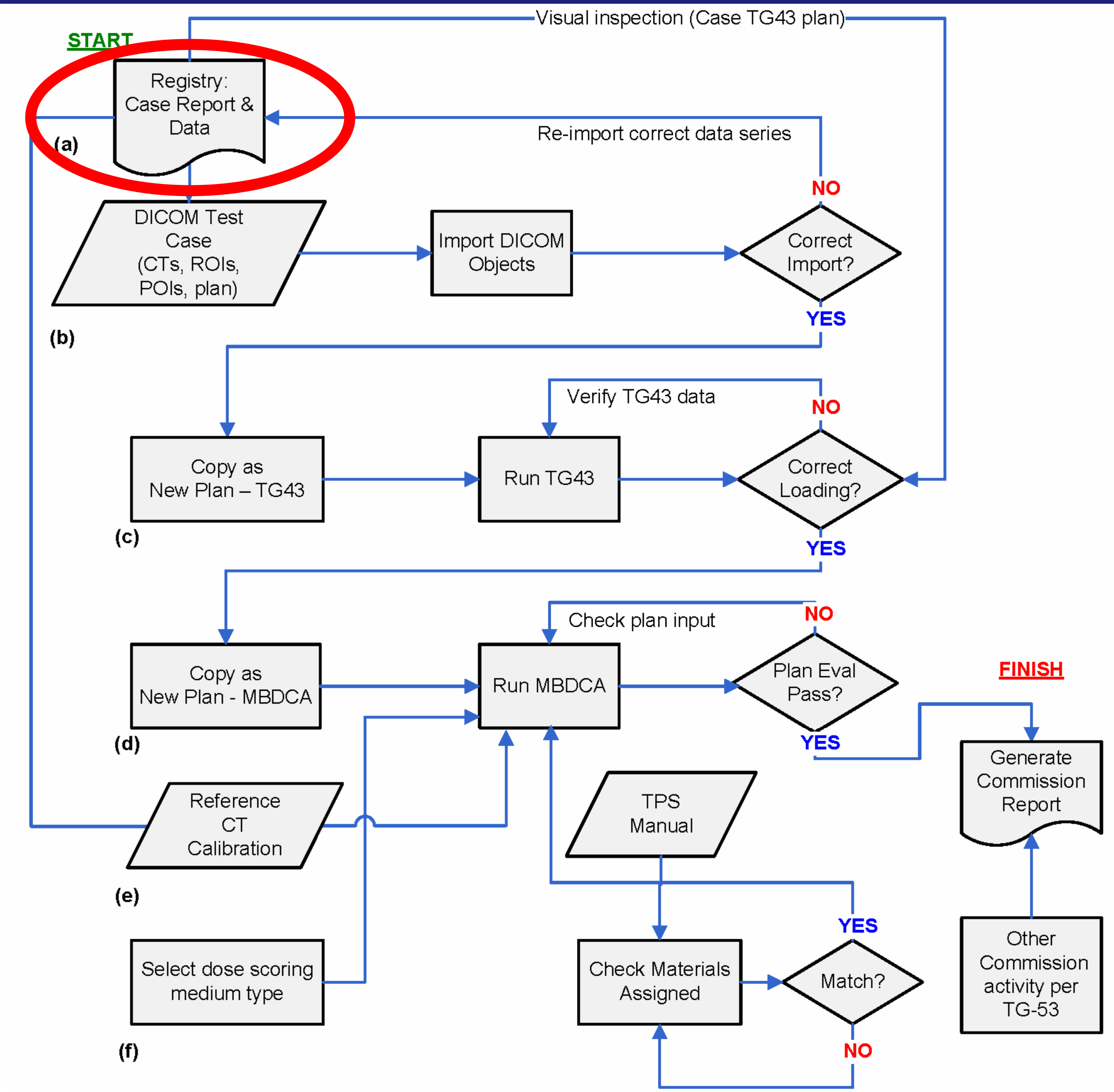
Need Future Developments

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

TG-186 TPS Commissioning Flowchart



TG-186 TPS Commissioning Flowchart



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Model Based Dose calculations

- Reference Data
- Elekta Database
- Varian Database

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Reference Data

- This folder contains the reference datasets. The reference datasets are based on MCNP6 simulations.
- User Guide
- Case 1
- Case 2
- Case 3

TestCase-1-Ref.zip

Level 1 Dosimetry Benchmark

Medical Physics

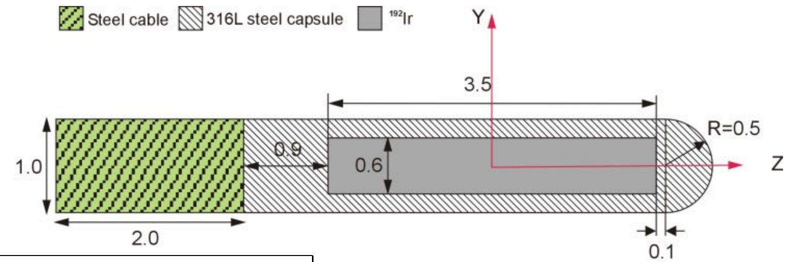
A generic high-dose-rate ^{192}Ir brachytherapy source for evaluation of model-based dose calculations beyond the TG-43 formalism

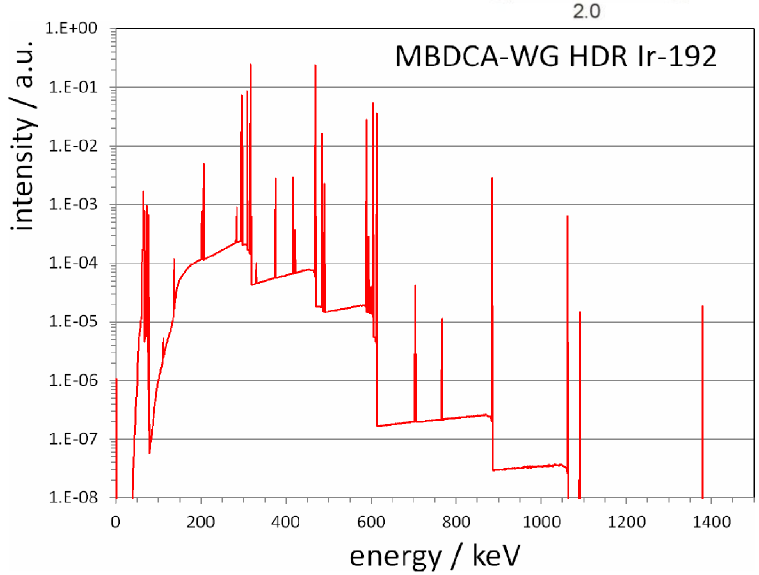
Ballester, Carlsson Tedgren, Granero, Haworth, Mourtada, Paiva Fonseca, Zourari, Papagiannis, Rivard, Siebert, Sloboda, Smith, Thomson, Verhaegen, Vijande, Ma, and Beaulieu

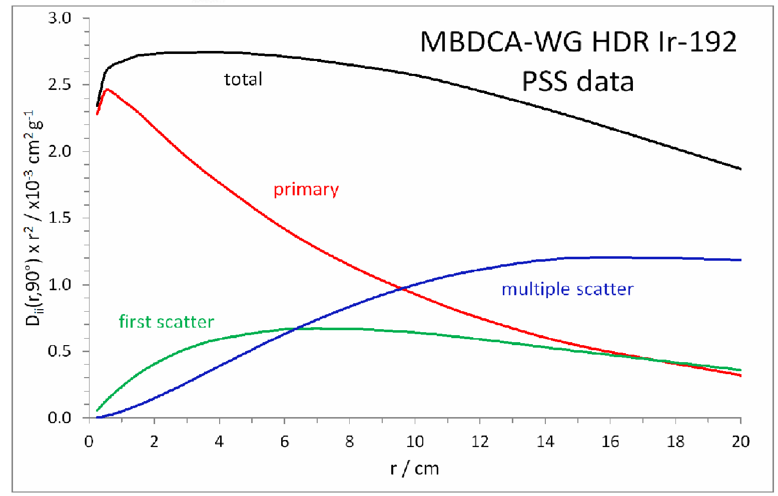
Conclusions: A hypothetical, generic HDR ^{192}Ir source was designed and implemented in two commercially available TPSs employing different MBDCAs. Reference dose distributions for this source were benchmarked and used for evaluation of MBDCA calculations employing a virtual, cubic water phantom in the form of a CT DICOM image series. Implementation of a generic source of identical design in all TPSs using MBDCAs is an important step toward supporting univocal commissioning procedures and direct comparisons between TPSs.

Ballester *et al*., *Med. Phys.* 42, XXXX-XXXX (2015)

Level 1 Dosimetry Benchmark







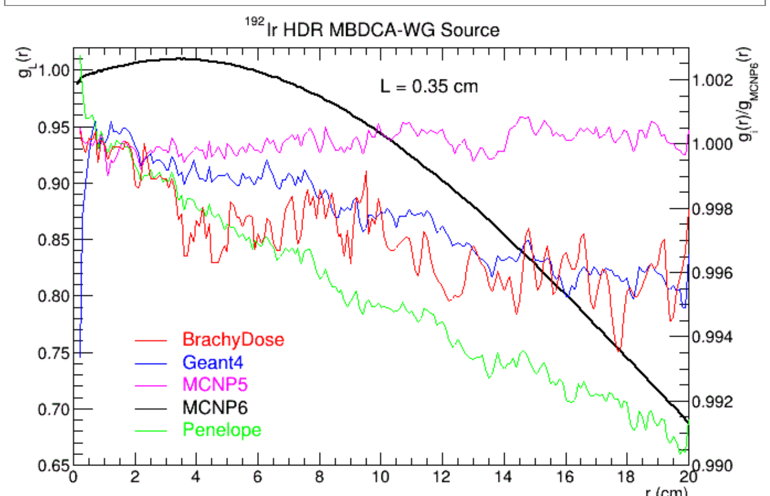
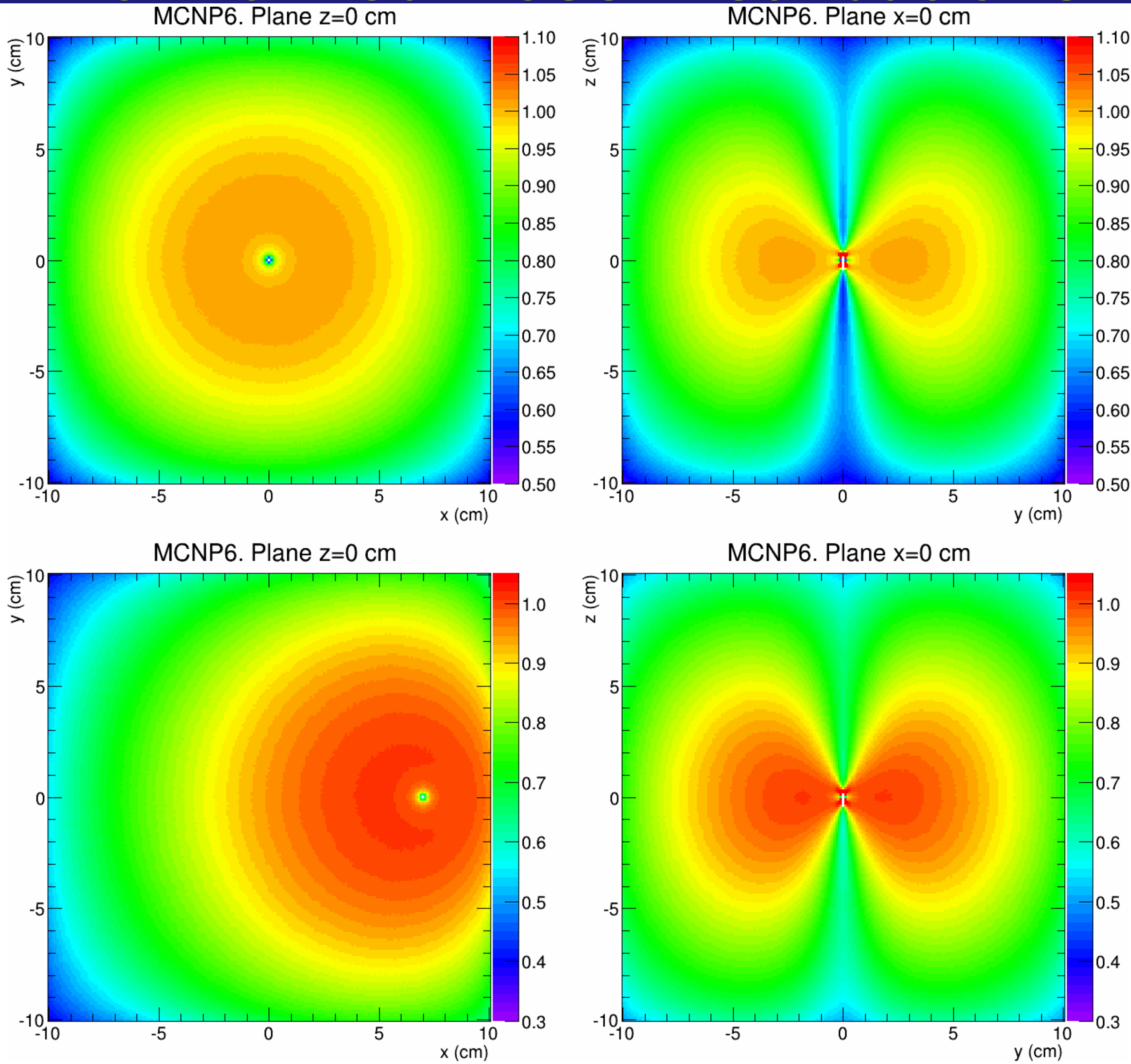


TABLE III. Air-kerma strength s_K and dose-rate constant Λ for the generic HDR ^{192}Ir source obtained with several MC methods. Reported uncertainties (absolute uncertainties in columns 2 and 4 and relative ones in columns 3 and 5) are Type A (statistical) with a coverage factor $k = 1$.

MC code	s_K ($\times 10^{-8}$ U/Bq)		Λ [cGy/(h U)]	
ALGEBRA	9.798 ± 0.006	0.06%	1.1113 ± 0.0006	0.04%
BrachyDose	9.804 ± 0.001	0.01%	1.1100 ± 0.0010	0.04%
GEANT4	9.799 ± 0.012	0.18%	1.1104 ± 0.0020	0.18%
MCNP5 v.1.60	9.797 ± 0.001	0.01%	1.1110 ± 0.0004	0.04%
MCNP5 v.1.60[a]	9.812 ± 0.006	0.06%	1.1107 ± 0.0006	0.06%
MCNP6 v.1	9.813 ± 0.006	0.06%	1.1106 ± 0.0006	0.06%
PENELOPE2008	9.784 ± 0.006	0.06%	1.1113 ± 0.0006	0.05%

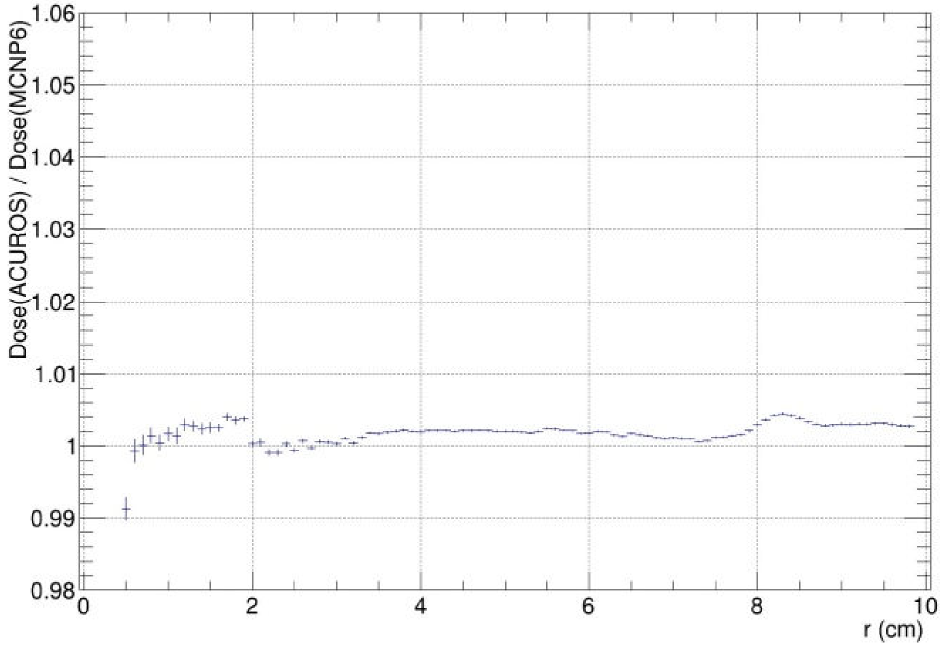
Ballester *et al.*, *Med. Phys.* 42, XXXX-XXXX (2015)

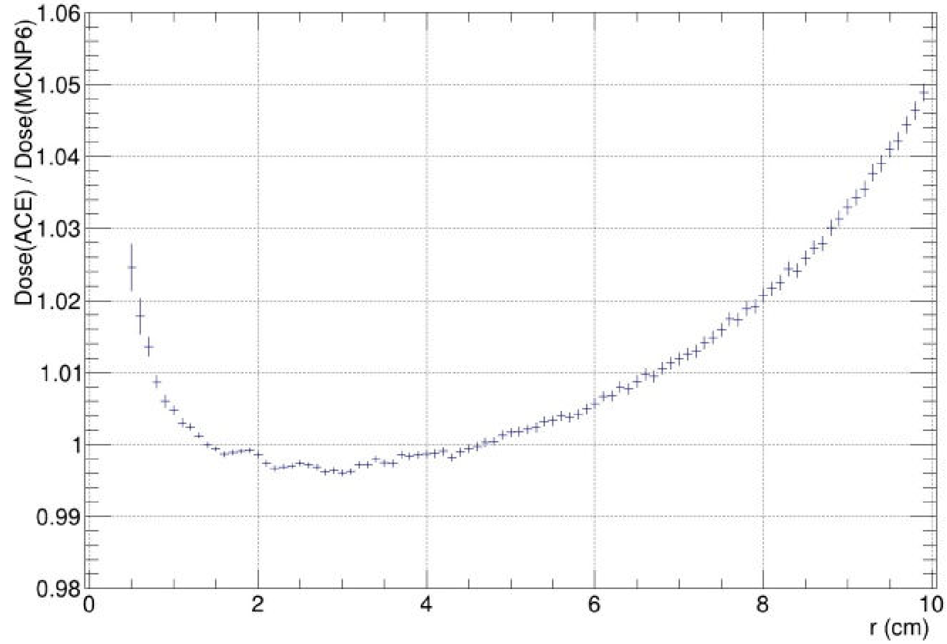
Normalized Dose Distributions



Ballester *et al.*, *Med. Phys.* 42, XXXX-XXXX (2015)

Level 1 Benchmark Results





Ballester *et al.*, *Med. Phys.* 42, XXXX-XXXX (2015)

Level 2 Benchmarks and Process Map

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Generation of 3D Dosimetric Reference Datasets for Commissioning and Validation of ^{192}Ir Brachytherapy Model-Based Dose Calculation Software


Y Ma

Y Ma[1*], J Vijande[2], F Ballester[3], Asa Carlsson Tedgren[4], D Granero[5], A Haworth[6], F Mourtada[7], G Fonseca[8], K Zourari[9], P Papagiannis[10], M Rivard[11], F Siebert[12], R Sloboda[13], R Smith[14], R Thomson[15], F Verhaegen[16], L Beaulieu[17], (1) CHU de Quebec, Quebec, QC, (2) University of Valencia, Burjassot, (3) University of Valencia, Burjassot, (4) Linkoping Univ, Linkoping, (5) ERESA-Hospital General Universitario, Mislata, (6) Peter MacCallum Cancer Centre, Vic Australia, (7) Christiana Care Hospital, Newark, DE, (8) Instituto de Pesquisas Energeticas e Nucleares IPEN-CNEN/SP, Sao Paulo, Maastricht, (9) Medical Physics Laboratory, Medical School, University of Athens, Athens, Athens, (10) Univ Athens, Athens, (11) ,Tufts Univ. School Med., Boston, MA, (12) Clinic of Radiotherapy (Radiooncology), Kiel, (13) Cross Cancer Institute, Edmonton, AB, (14) St. Thomas Hospital, Nashville, TN, (15) Carleton Univ, Ottawa, ON, (16) Maastro Clinic, Maastricht, (17) Centre Hospitalier Univ de Quebec, Quebec, QC

TH-AB-BRA-2 (Thursday, July 16, 2015) 7:30 AM - 9:30 AM Room: Ballroom A

Infrastructure and Process for Model-Based Dose Calculation Software Commissioning in Brachytherapy


R Sloboda

R Sloboda[1*], F Ballester[2], A Carlsson Tedgren[3], W Culberson[4], J Esthappan[5], A Haworth[6], J Lowenstein[7], Y Ma[8], F Mourtada[9], P Papagiannis[10], T Pike[11], M Rivard[12], F Siebert[13], R Smith[14], I Spadinger[15], P Taylor[16], F Verhaegen[17], J Vijande[18], L Beaulieu[19], (1) Cross Cancer Institute, Edmonton, AB, (2) University of Valencia, Burjassot, Spain,(3) Linkoping Univ, Linkoping, Sweden,(4) Univ of Wisc Madison, Madison, WI, (5) Washington University School of Medicine, St. Louis, MO, (6) Peter MacCallum Cancer Centre, Vic Australia, ,(7) UT MD Anderson Cancer Center, Houston, TX, (8) CHU de Quebec, Quebec, QC, (9) Christiana Care Hospital, Newark, DE, (10) Univ Athens, Athens, Greece,(11) Affinity Health System, Appleton, WI, (12) Tufts Univ. School Med.,Boston, MA, (13) Clinic of Radiotherapy (Radiooncology), Kiel, Germany,(14) The Alfred Hospital, Melbourne, Australia, (15) B.C. Cancer Agency, Vancouver, BC, (16) UT MD Anderson Cancer Center, Houston, TX, (17) Maastro Clinic, Maastricht, Netherlands,(18) University of Valencia, Burjassot, Spain,(19) Centre Hospitalier Univ de Quebec, Quebec, QC

TH-AB-BRA-5 (Thursday, July 16, 2015) 7:30 AM - 9:30 AM Room: Ballroom A

Summary

- MBDCA TPS allow more accurate dose calcs than TG-43
- MBDCA TPS are available (turnkey) for HDR ^{192}Ir
- societal recommendations / infrastructure forthcoming
- dosimetric benchmarks required for safe clinical use
- forthcoming Working Group standards and benchmarks
- Rx paradigm shift should be societally-coordinated
- incorporate dose changes cautiously (IRB clinical trial)


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