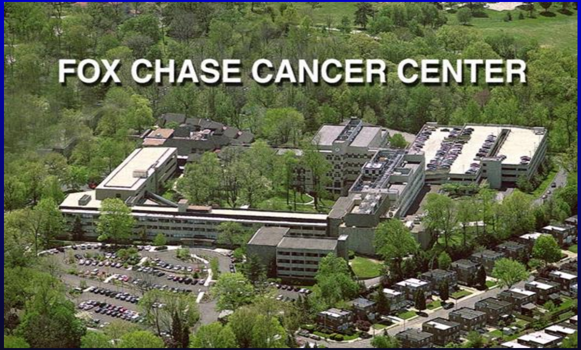
Monte Carlo Dose Calculation and Review of AAPM TG157: Part II



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Conflict Statement

I have nothing to report regarding funding support, disclosures, and conflicts of interest

AAPM Task Group 157

Beam modeling and beam model commissioning for MC dose calculation based radiation therapy treatment planning

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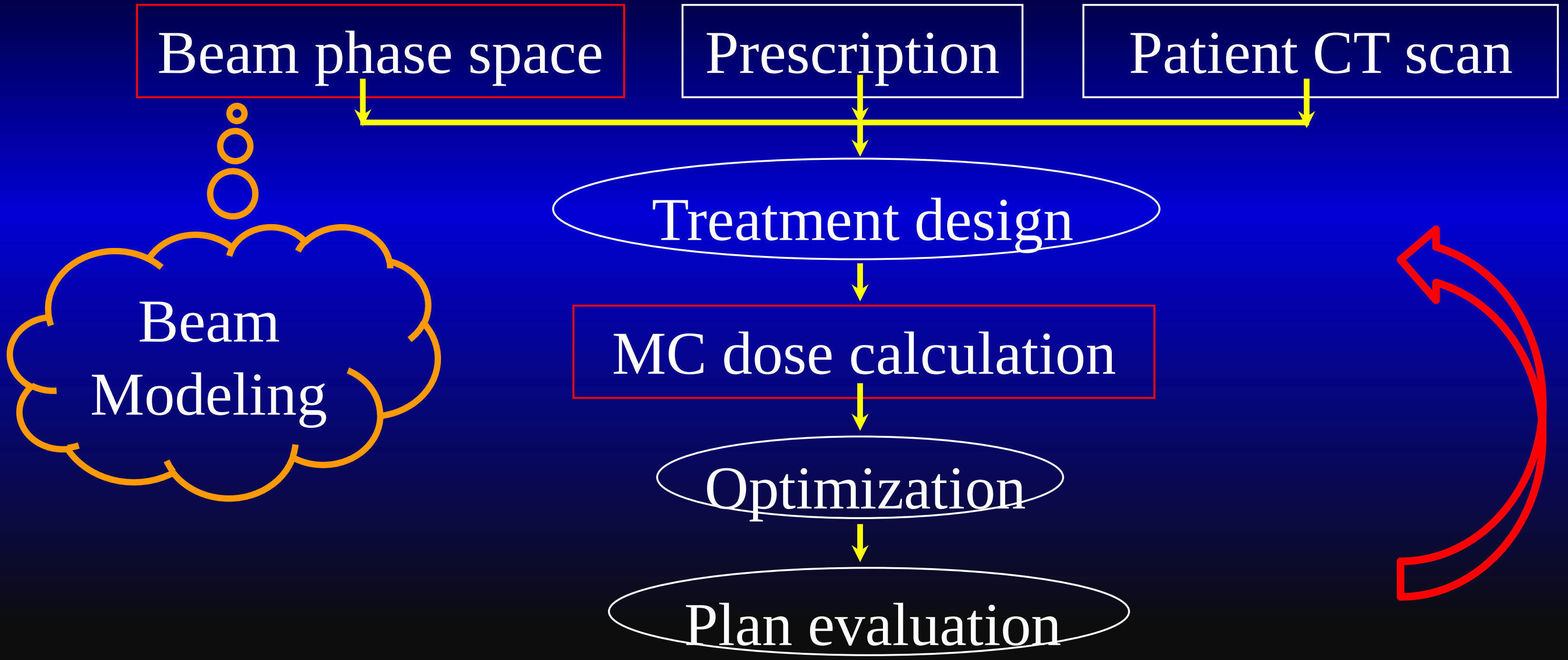
Outline (Learning Objectives)

- Objectives of the AAPM Task Group 157
- Beam modeling in MC dose calculation
- MC beam models in commercial TPS
- TG157 guidelines for acceptance testing of MC-based TPS
- TG157 recommendations on beam model commissioning

TG157 Objectives

- To assist clinical physicists with the complex task of acceptance testing and commissioning MC-based TPS
- To focus on MC beam modeling and beam model commissioning
- To provide guidelines and recommendations for photon beams and electron beams

MC-Based Treatment Planning

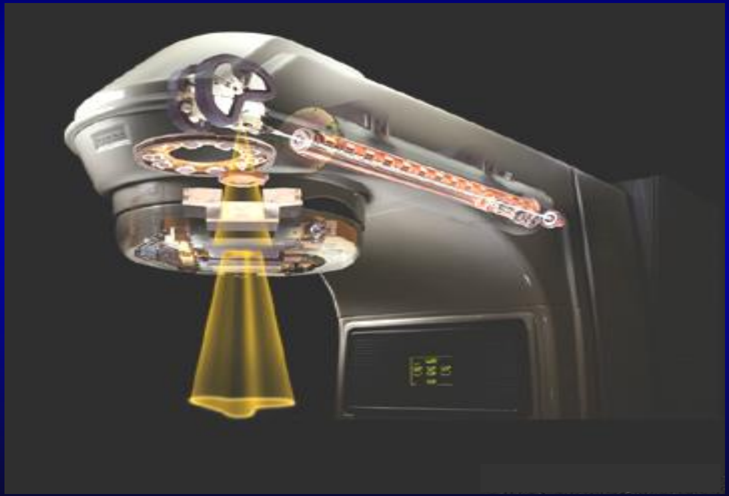


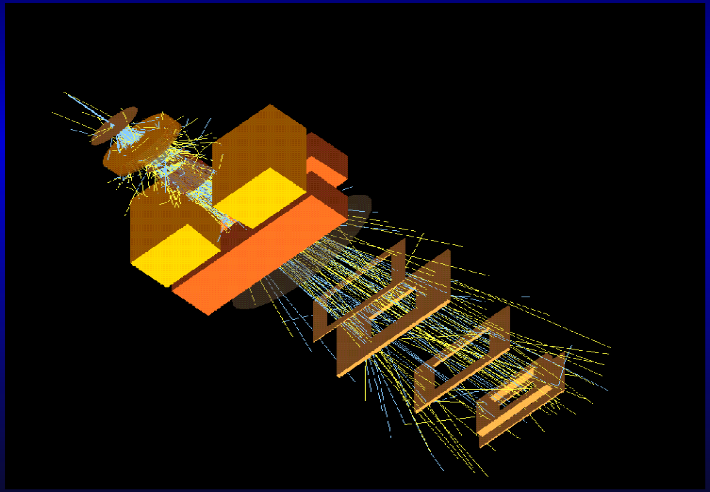
Beam Phase-Space (Ph-Sp) Data

- Particle type (photon, electron, positron, etc.)
- Particle energy (kinetic, rest mass)
- Particle position (spatial coordinates: x, y, z)
- Particle direction (direct cosines, α, β, γ)
- Other … (see IAEA 2005 recommendation for Ph-Sp format)

https://www-nds.iaea.org/phsp/phsp.htmlx

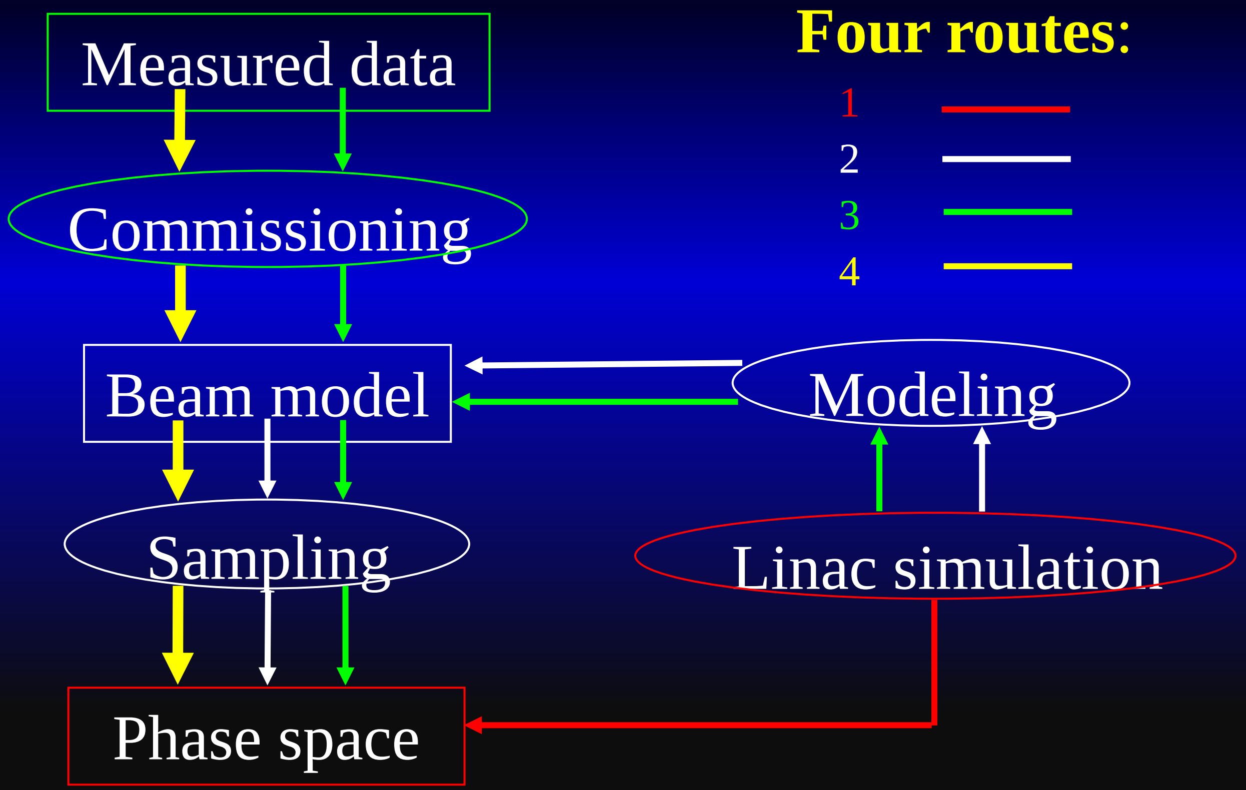
MC Simulation of Linac Beams





Linacs ⟶ Models ⟶ Beam Phase Space Data

Beam Modeling for MC Dose Calculation



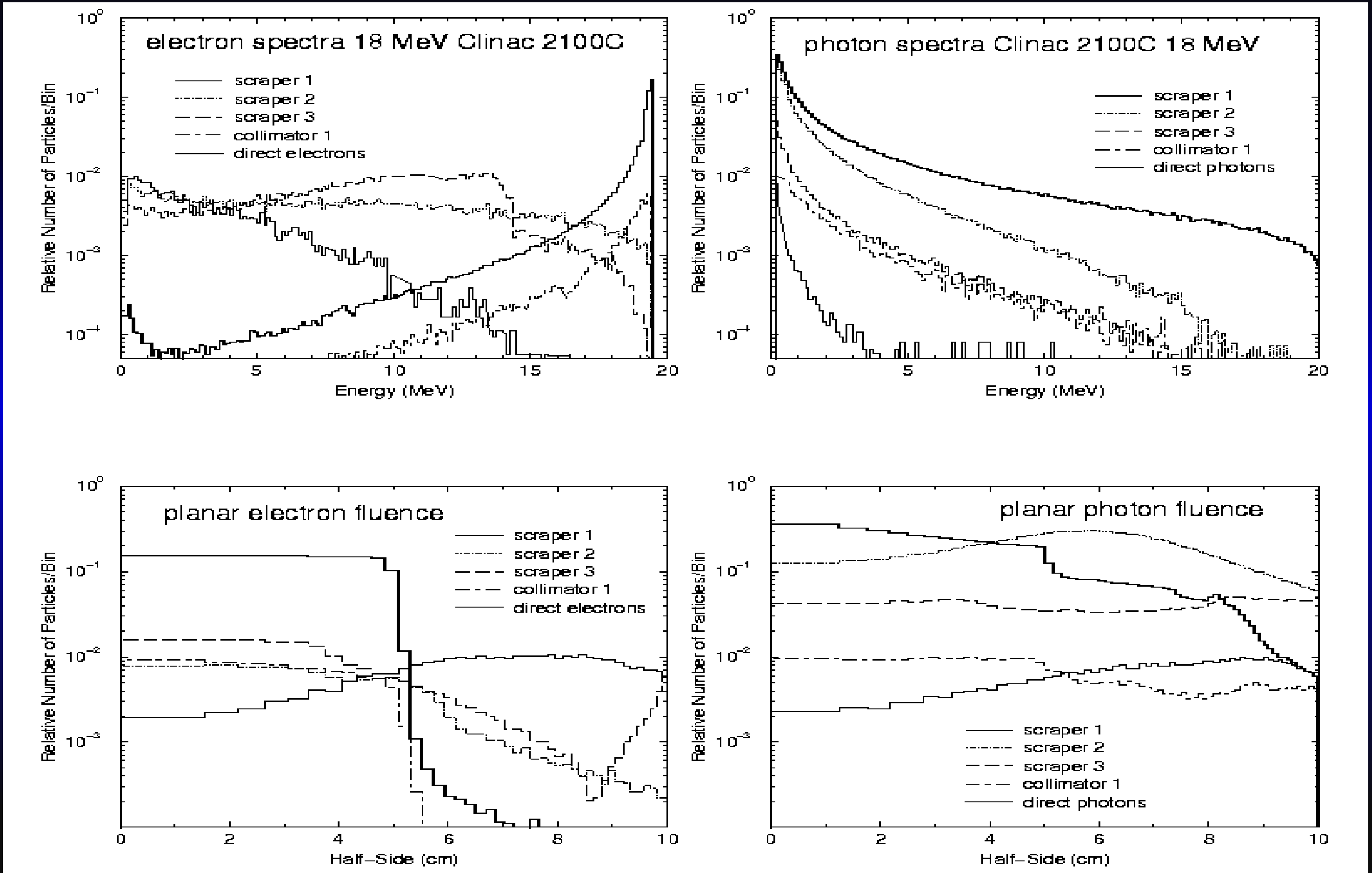
Advantages of Beam Models

- Beam models are based on good understanding of ph-sp representation and reconstruction
- Beam models are computationally efficient
- Beam models require minimal storage space
- Beam models are commonly used in commercial TPS

A Multiple Source Model

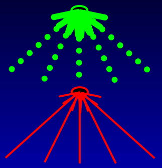
- Assumption: individual linac components are considered as sub-sources
- Each sub-source has its own energy and fluence distributions (from ph-sp data)
- Angular correlation is retained based on geometry

Ma et al *Med Phys* (1997) 24: 401-16



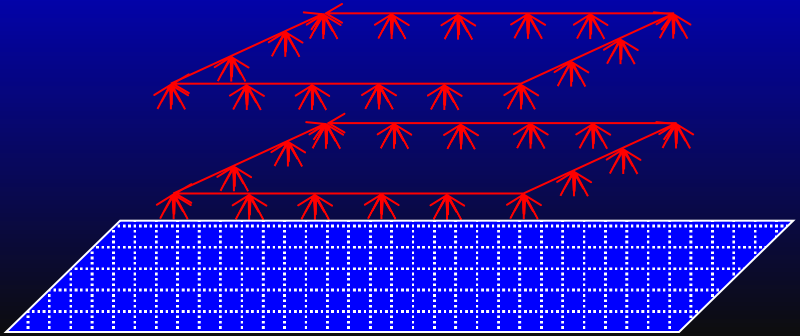
electron spectra 18 MeV Clinac 2100C
scraper 1
scraper 2
scraper 3
collimator 1
direct electrons
Relative Number of Particles/Bin
Energy (MeV)
photon spectra Clinac 2100C 18 MeV
scraper 1
scraper 2
scraper 3
collimator 1
direct photons
Relative Number of Particles/Bin
Energy (MeV)
planar electron fluence
scraper 1
scraper 2
scraper 3
collimator 1
direct electrons
Relative Number of Particles/Bin
Half-Side (cm)
planar photon fluence
scraper 1
scraper 2
scraper 3
collimator 1
direct photons
Relative Number of Particles/Bin
Half-Side (cm)

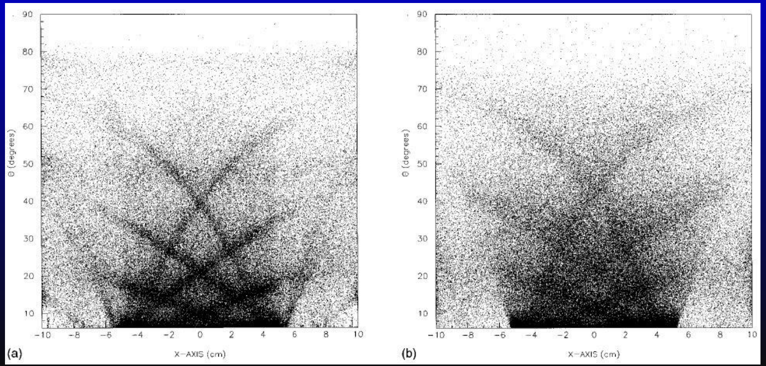
A Four-Source Model for Varian 2100C



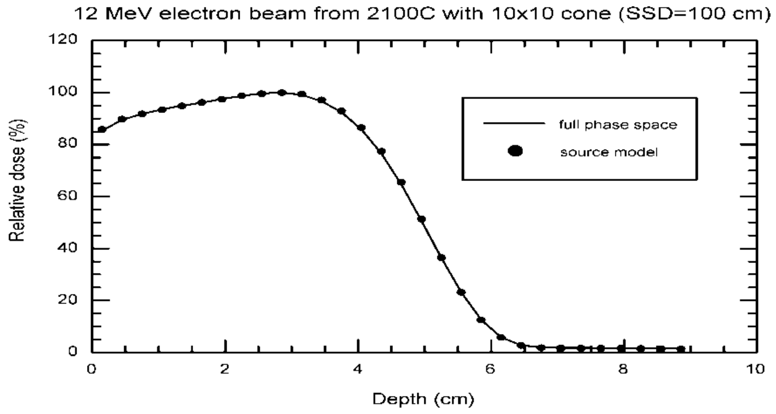
photon point source

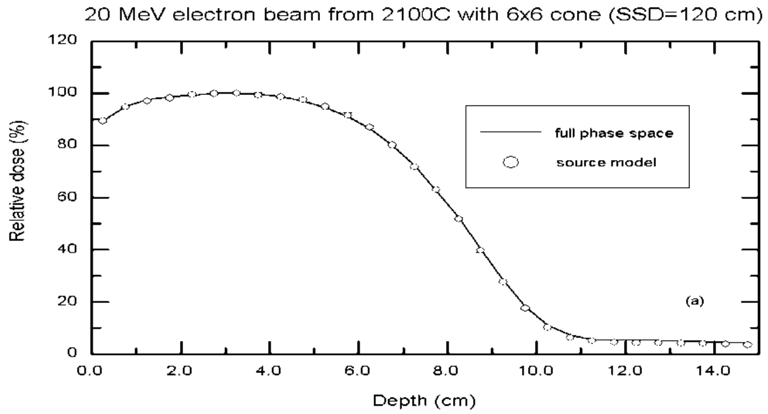
electron point source

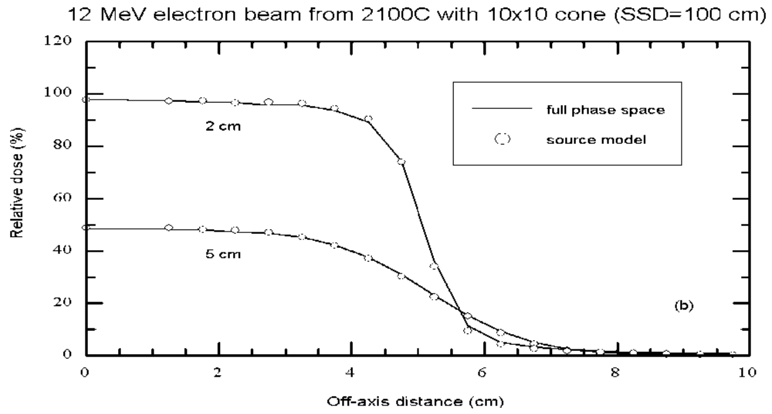


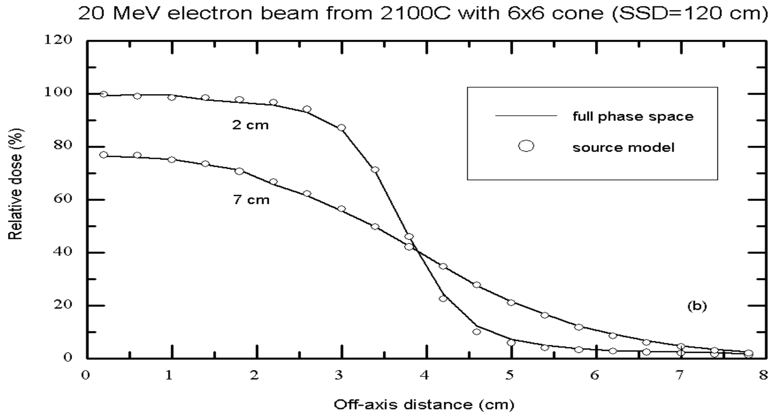


Jiang et al *Med. Phys.*(1999) 27: 180-191; Deng et al *Proc. ICCR* (2000)


12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm)
full phase space
source model
Relative dose (%)
Depth (cm)


20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm)
full phase space
source model
(a)
Relative dose (%)
Depth (cm)


12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm)
full phase space
source model
2 cm
5 cm
(b)
Relative dose (%)
Off-axis distance (cm)


20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm)
full phase space
source model
2 cm
7 cm
(b)
Relative dose (%)
Off-axis distance (cm)

Linacs of the Same Model

Ma Rad Phys Chem (1998) 53: 329-344; Jiang et al *Med. Phys.*(2000) 27: 180-191

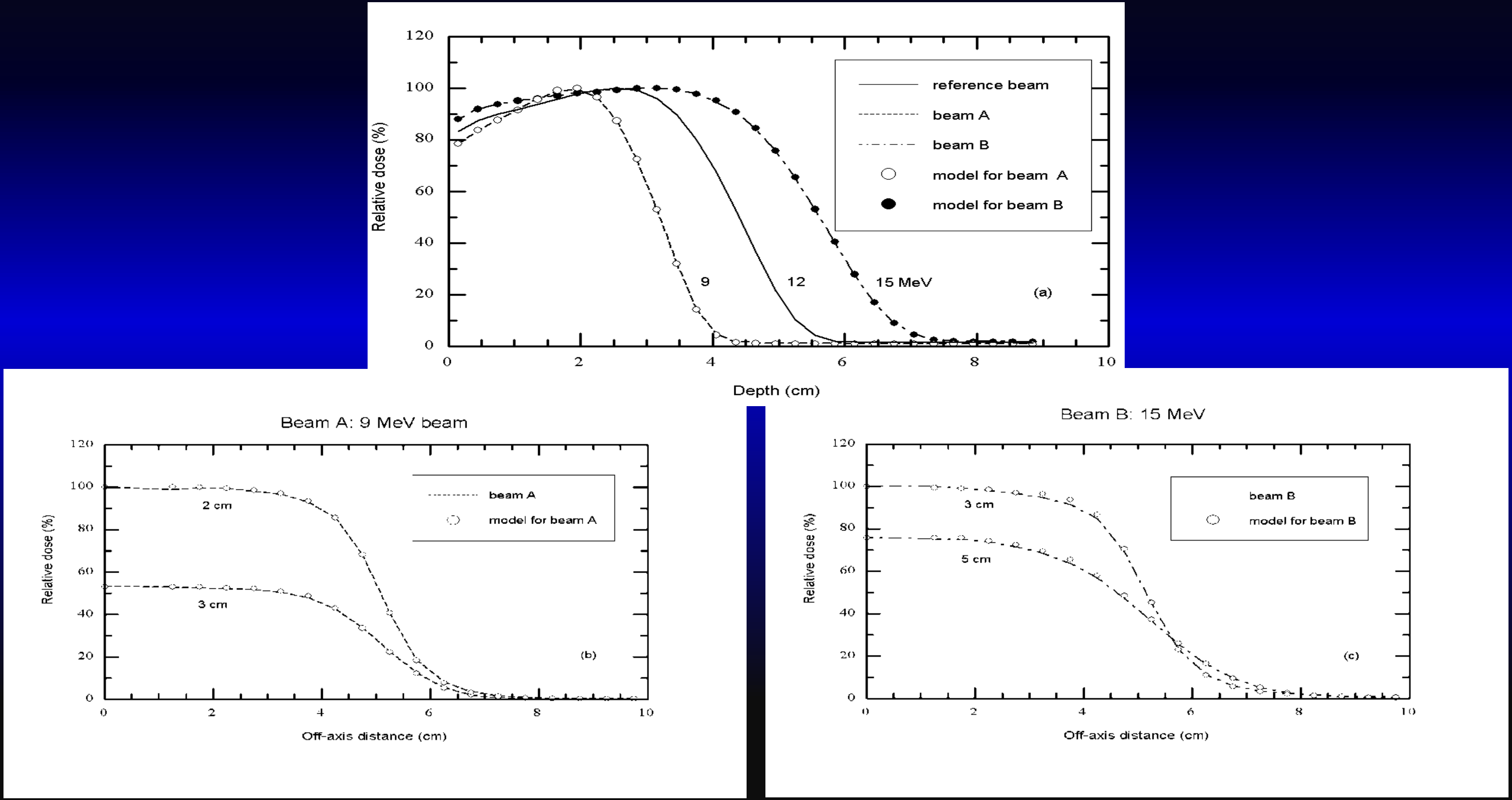
Robustness of Beam Modeling

- Reference beam: E_{in} = 12 MeV (simulated)

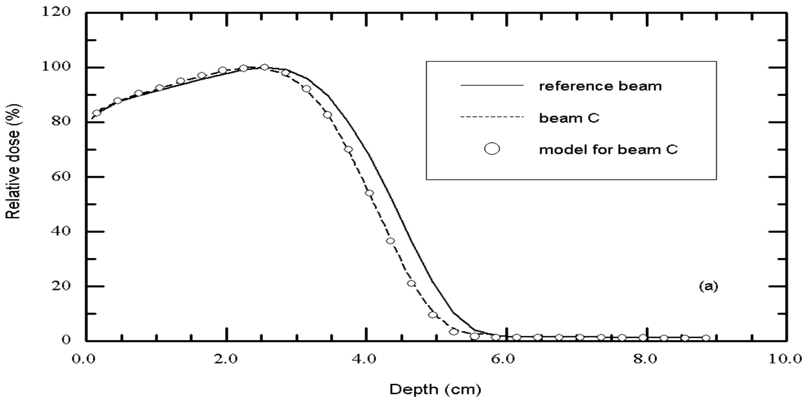
to match

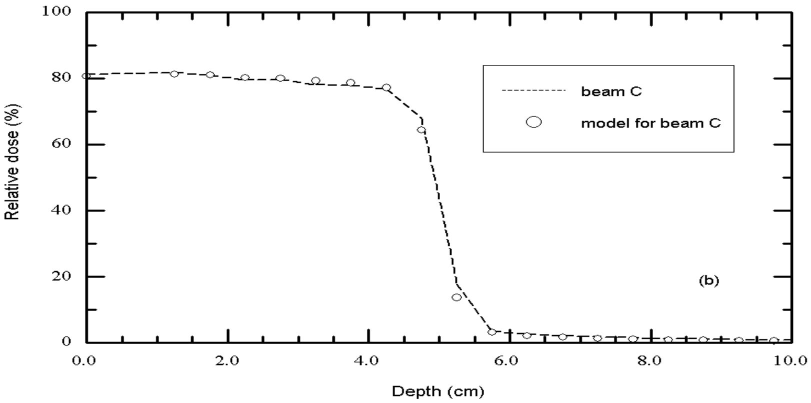
- Beam A: E_{in}=9 MeV (simulated)
- Beam B: E_{in}=15 MeV (simulated)
- Beam C: Nominal 12 MeV (published data)

Match Different Energies



Match Unknown Clinical Beams





Measurement accuracy is the key!

Advantages of Measurement-Based Models

- Fluence dist. ensured by profile measurement
- Energy spectra ensured by depth dose measurement
- Beam output ensured by direct measurement
- Angular dist. ensured by analytical/MC simulation (model)

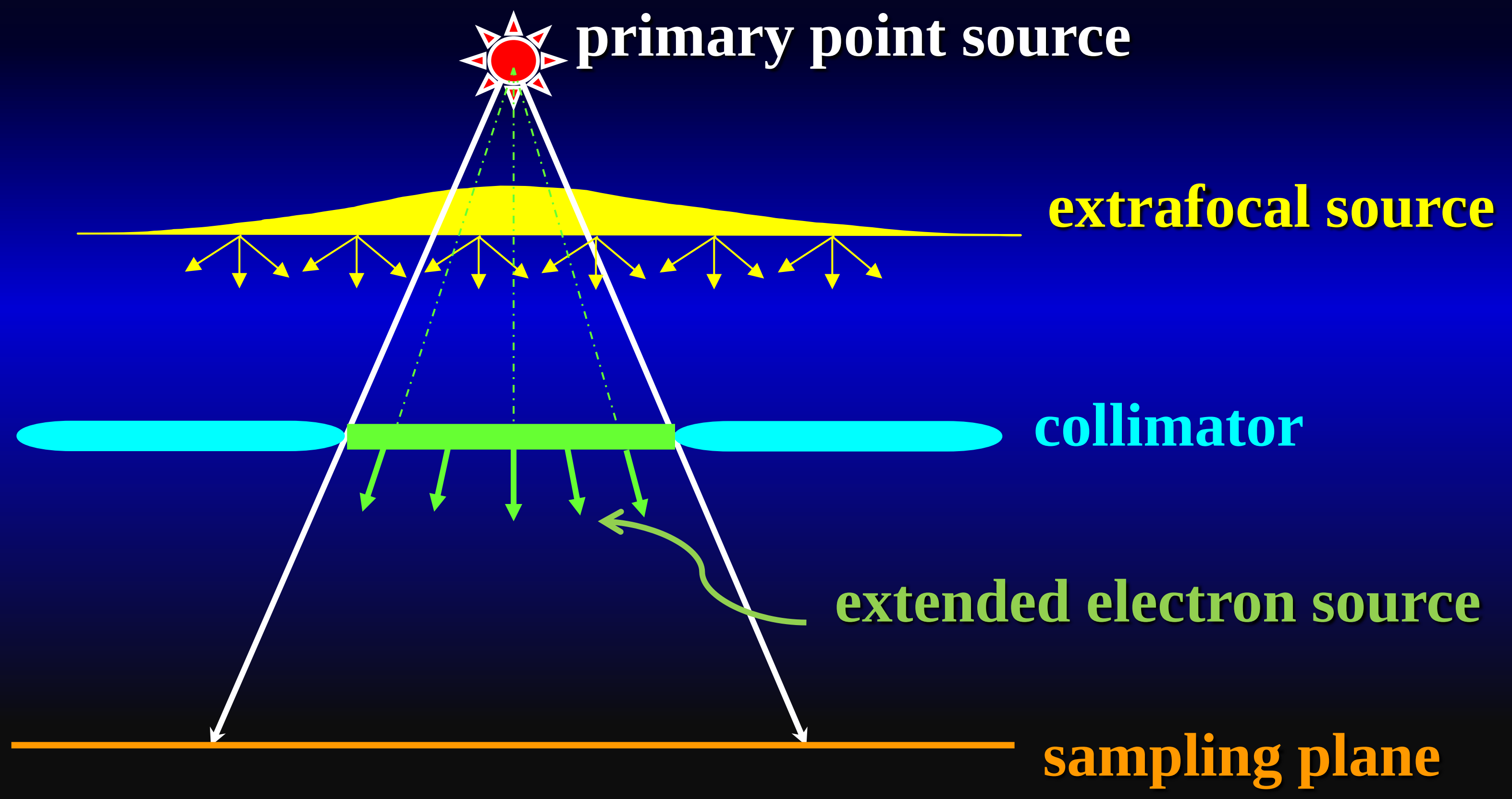
Less dependent on precise knowledge of linac geometry

A Three-Source Model for Clinical Photon Beams

- Point/extended source for primary photons
- extrafocal source for scattered photons
- extended source for contaminant electrons

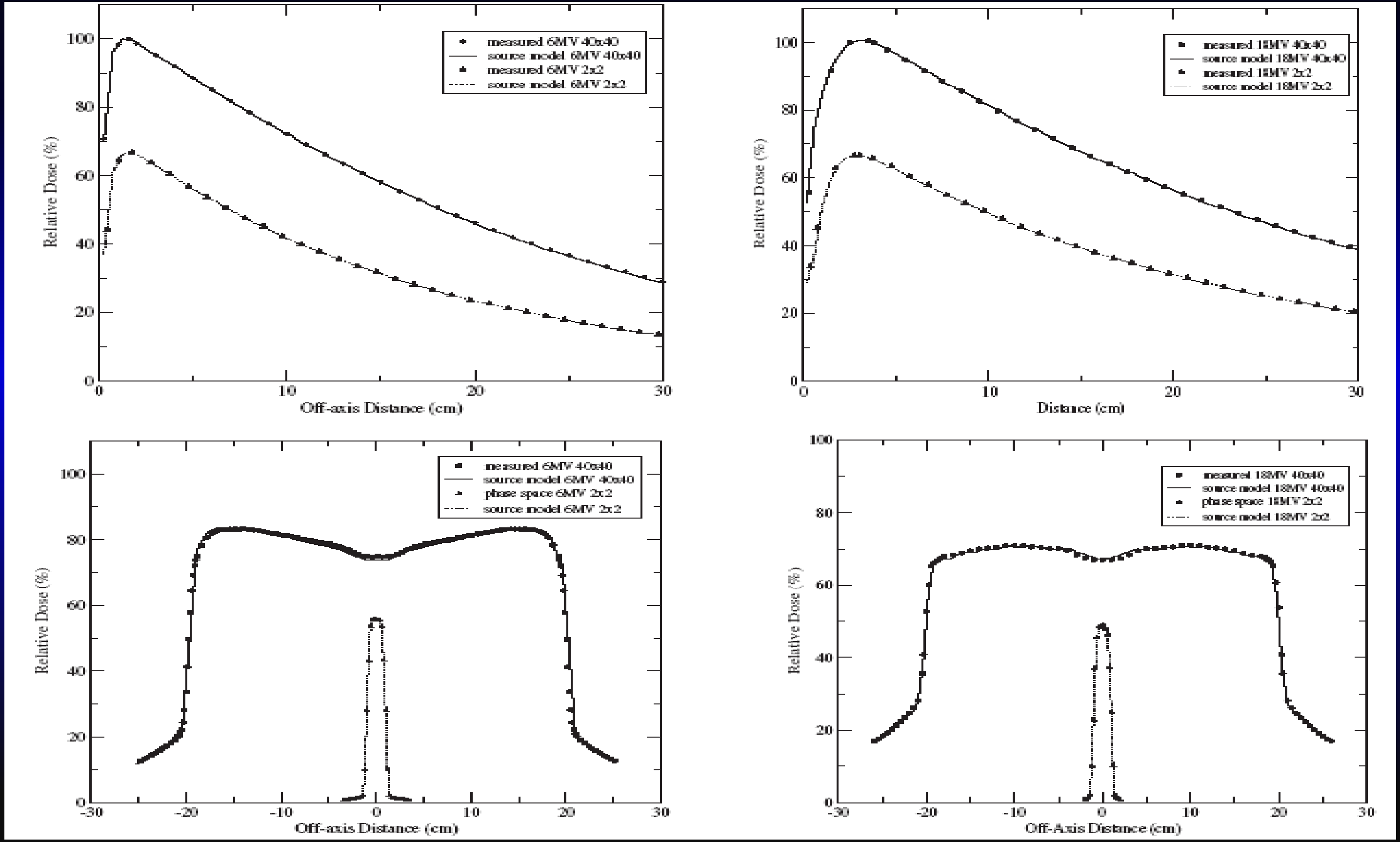
Jiang et al *Med. Phys.*(2001) 28: 55-66; Li et al (2004) 31: 1023-31

A Generic Beam Model



Comparison: Model vs Measurement

6 MV
40cmx40cm



18 MV
40cmx40cm

Yang et al, *Phys Med Biol* (2004) 49: 2657-73

Beam Models in Commercial TPS

Accuray	BrainLab	Elekta (CMS)	Elekta (Nucletron)	RaySearch	Varian
Multiplan	iPlan	Monaco	OncentraMP	RayStation	Eclipse
Photon Tx	Photon Tx	Photon Tx Electron Tx	Electron Tx	Electron Tx	Electron Tx
MCSIM	XVMC	VMC	VMC++	VMC++	MMC
Single source	Multiple sources	Multiple sources	Multiple sources	Multiple sources	Multiple sources
Photons only	Photons Electrons	Photons Electrons	Electrons only	Electrons only	Electrons Photons
Analytical	MC sim	Analytical	Analytical	MC sim	Analytical

Acceptance Testing for MC TPS

- **Purpose:** to confirm that a TPS performs according to its specifications

- Guidance documents: AAPM TG157, TG53, TG244

- IAEA reports IAEA-TRS-430, IAEA-TECDOC-1540, IAEA-TECDOC-1583

Acceptance Testing: Documentation

Verify manufacturer FDA approval	Documents are accessible for verification
Verify software design standards compliance (e.g., IEC60601-1-4 or IEC62083)	Documents are accessible for verification
Identify documents on user training, operational instructions, application procedures and limitations (e.g., TPS training certificate, accuracy statement, descriptions of required input data, beam model generation or tuning procedures, physics models for treatment head components and allowed variable ranges)	Documents are accessible for verification

Acceptance Testing: Functionality

Verify if the TPS supports the user's requirements as detailed in the specifications agreed between the vendor and user For example: Photon energies for flattened and unflattened beams, MLCs and dynamic dose delivery modes Electron beam energies and applicators, field size and SSD limitations	All functionalities demonstrated

Acceptance Testing: Dosimetry

Calculate absolute dose for the reference condition (e.g., the central-axis dose at a depth of 10 cm in water for a 10 cm x 10 cm field defined at 100 cm SSD) **Note that this should be the normalization point for MC calculated dose distributions**	**Dose difference < 0.5%**
Calculate X, Y and Z relative dose profiles in water for available clinical photon/electron beams	**< 2% / 2 mm**

Acceptance Testing: Safety Checks

Verify dose calculation not allowed for features and/or beam energies unavailable	TPS will not allow dose calculation under these conditions
Verify validation is required when treatment head parameters are changed	TPS will not work under these conditions
Verify validation is required when beam model data are changed	TPS will not work under these conditions
Verify dose calculation not allowed for non-validated beams (energies, applicators, SSDs)	TPS will not allow dose calculation under these conditions

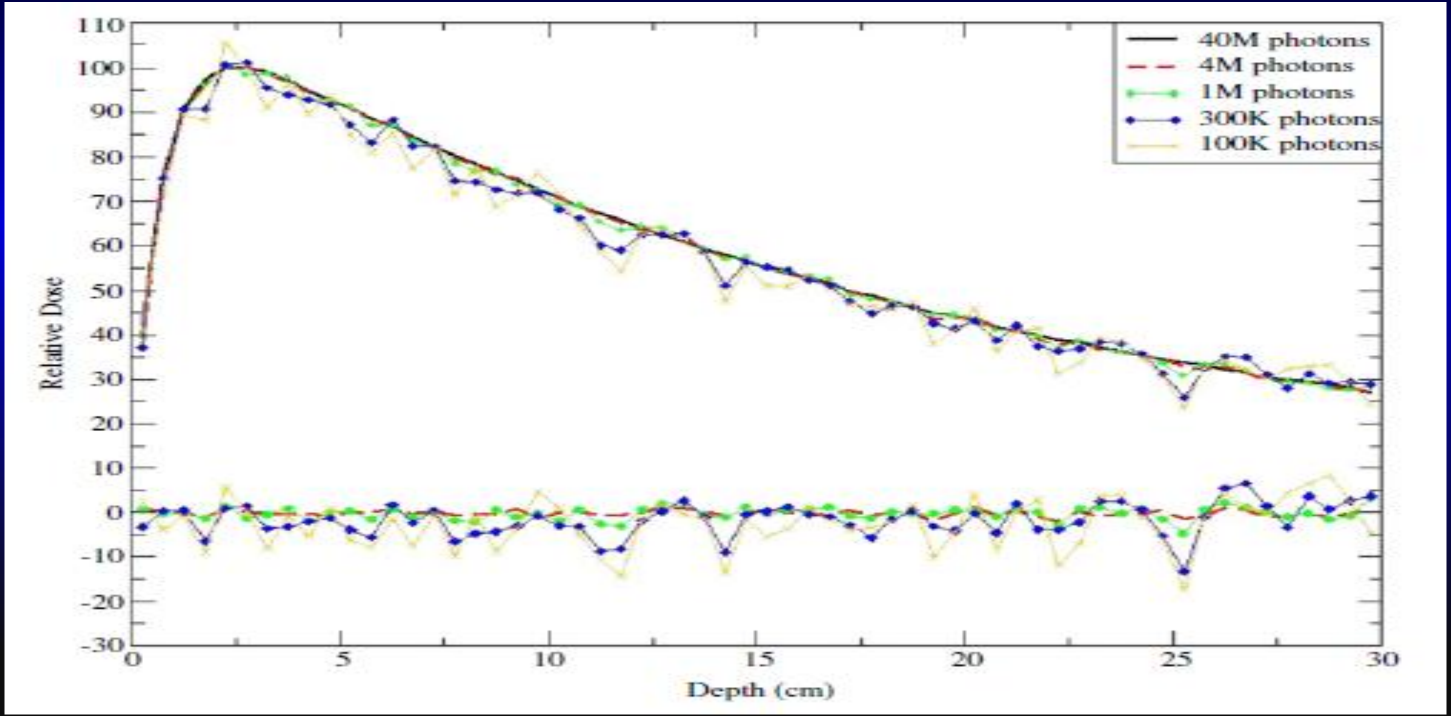
$1/\sqrt{N}$

Acceptance Testing: Statistical Uncertainty

Verify TPS allows dose calculation at different preset uncertainties (e.g., 2%, 1%, 0.5%, etc.)	Consistent with documentation
Verify the uncertainty for each preset statistical uncertainty in uniform dose regions inside and outside typical fields	Agrees within 30% of independently calculated uncertainties, or estimated uncertainties in a uniform dose region, or calculated with different seeds
Verify the uncertainty follows a $1/\sqrt{(N)}$ behavior. N is the number of histories	It is followed to within 10 %
Verify the fidelity of the denoising option in uniform dose regions for different voxel sizes (e.g., 1-2mm voxels for SRS/SBRT)	The denoising option does not cause a difference of >3-sigma from the unsmoothed distribution

$1/\sqrt{N}$

Acceptance Testing: Uncertainty Analysis



$1/\sqrt{N}$

Acceptance Testing: Denoising Technique

Recommendations for Beam Model Commissioning

- **TG157 recommends the use of procedures and tolerances in AAPM reports TG53, TG142 and TG244**
- **Basic commissioning of the beam model should be performed by comparing MC calculations with measurements in water (PDD, profiles, output factors) - same requirements as for conventional methods**
- **Tests of all beam modifying devices utilized for all treatment techniques should be performed (3DCRT, IMRT, VMAT, etc.)**

The power of MC dose calculation is for heterogeneous anatomy

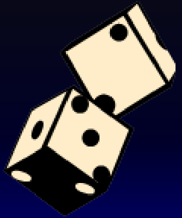
Recommendations for Beam Model Commissioning

Dose distribution	Absolute dose for the reference condition (e.g., central-axis dose at 10cm depth in water for a 10cm x 10cm field at 100cm SSD)	0.5%
	Relative dose distribution in water for all field sizes available (2cm x 2cm – 40cm x 40cm, 1cm x 1cm if needed for SBRT)	2% /2 mm
Output factor	For photon beams, open fields (2cm x 2cm – 40cm x 40cm), off-axis and blocked fields including trays and wedges for 80 – 120cm SSD	2%
	For electron beams, all applicator sizes available and arbitrarily-shaped cutouts used clinically	2%
Beam modifying device	Dose distribution for a single field in water for all beam modifiers (e.g., MLC, blocks, wedges, compensators, cutouts, bolus)	2% /2 mm
Patient calculation	Point dose measurements for composite dose distribution in homogeneous or heterogeneous phantoms	2% of prescription
	Planar/volumetric dose array for composite dose distribution in treatment plan QA phantoms	2%/2mm

Guidelines for Dose Calculation and Measurement

- Accurate dose measurements using proper detectors, correction factors and alignment techniques $D_{med} = D_{det}\ s_{w,det}\ P_u$
- The statistical precision of MC calculations should be sufficient to discern at tolerance dose differences (1-σ uncertainty < 1/3 difference)
- For dose comparison, dose voxel size ~ detector effective volume
- For patient dose calculation, dose voxels 2-5 mm for field sizes >3x3 cm^2 and 1-2 mm for field sizes < 3x3 cm^2

Recommendations for Vendors: Statistical Tests

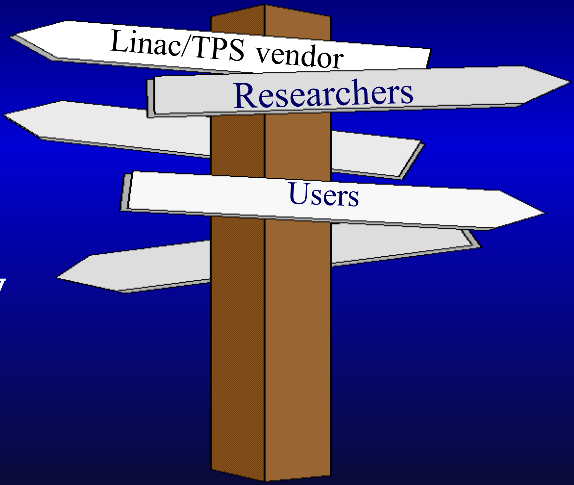


- Discern whether the code is deterministic, or determinism is present for a particular hardware or technique
- Determine if out-of-tolerance systematic deviations exist
- Determine if the reported estimated statistical uncertainty is consistent over many repeated computations with results in a voxel
- Determine if the reported estimated statistical error is consistent in a uniform dose region with the deviation from the mean

Additional Recommendations

- TG157 encourages linac vendors to provide sufficient machine information to permit full MC simulation for ph-sp generation

- TG157 encourages the medical physics community to develop benchmarks of commonly used clinical beams (e.g., standardized beam data)



Thank You