Acceptance Testing and Commissioning of Monte Carlo Dose Calculation Systems

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Disclosure

Some of the work discussed in this talk was supported by NOMOS Corporation

Acknowledgements

- UCSF
  - Cynthia Chuang, Bruce Faddegon, Lynn Verhey
- McGill University
  - Emily Heath, Jan Seuntjens
- Chiba Medical Center
  - Yuichiro Narita
- Mayo Scottsdale
  - Gary Ezzell

Acceptance Testing

- Performing an agreed set of tests to establish that the delivered product meets specifications
  - Tests often pre-packaged by manufacturer
  - Scope of tests is often limited
    - Does the calculation run?
    - Often, there is no statement of accuracy in dose algorithms
  - Most of the work is in commissioning

Acceptance Testing

- What Acceptance Testing does do
  - Verifies that hardware / software is installed correctly
  - Gives user some training in operation of software
- What Acceptance Testing does NOT do
  - Verify accuracy of algorithm over a range of clinical situations
  - Verify accuracy of your specific beam data entry
  - Provide complete training on operation and evaluation of the dose calculation

Special Issues for Acceptance Testing for Monte Carlo Dose Calculation Systems

- In general, treatment planning systems only specify accuracy in implementing an algorithm
  - No direct ties to measurements
  - No requirement to compare with actual data during acceptance testing
- Monte Carlo systems may specify dose accuracy, not just algorithmic accuracy

Sample Criteria for Dose Algorithm Accuracy

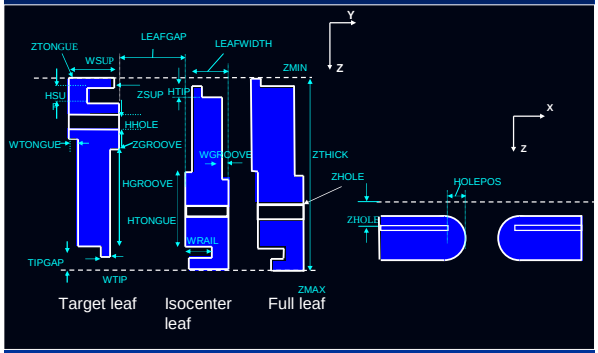
Situation	Absolute Dose (%)*	Central Ray (%)	Inner Beam (%)	Penumbra (mm)	Outer Beam (%)	Build-up Region (%)
A. Homogeneous Phantoms						
Square fields	0.5	1	1.5	2	2	20
Rectanguiar fields	0.5	1.5	2	2	2	20
Asymmetric fields	1	2	3	2	3	20
Blocked fields	1	2	3	2	5	50
MLC-shaped fields	1	2	3	3	5	20
Wedged fields	2	2	5	3	5	50
External surface variations	0.5	1	3	2	5	20
SSD variations	1	1	1.5	2	2	40
*B. Inhomogeneous Phantoms***						
Slab inhomogeneities	3	3	5	5	5	-
3-D inhomogeneities	5	5	7	7	7	-

From Van Dyk Presentation (AAPM-2004) [adopted from IAEA TRS430 and AAPM TG-53]

Special Issues for Acceptance Testing for Monte Carlo Dose Calculation Systems

- Head Models
  - Often compartmentalized (e.g. hidden) from user
    - Do they have the correct information for your machine?
    - Proprietary information
  - Often simplified
    - What details are necessary to accurately model your treatment delivery system?
  - May be beyond the scope of a user to define
    - Complex geometries / materials: Should each user be required to define the same class of delivery device?

DYNVMLC Component Module



As a result acceptance testing and commissioning cannot truly be separated for Monte Carlo Dose Calculation Systems

What can we expect today?

- References to Geometric Models
  - May include proprietary documents
- Sample data showing clinically relevant results
  - Same beam energy, …
  - Data should include heterogeneous materials
  - Most useful if comparable measurements shown for accuracy

Monte Carlo Systems: Raising the Bar?

Most medical physicists expect (?require?) Monte Carlo based dose calculations to be

- more accurate
- more precise
- more reliable

Measurements for Monte Carlo verification are

- affected more strongly by detector characteristics
- significantly subject to variations in protocol (TG-21, TG-51)

Monte Carlo Dose Accuracy?

- Dose Accuracy
  - 2% under all conditions?
    - (or just high dose / low gradient areas?)
  - 2 mm in high gradient regions
    - Is that good enough in build-up regions?
  - ?? in low dose / low gradient regions
    - under MLCs, jaws, blocks

Issues in verifying MC Dose Accuracy

- CT Issues
  - Mass Density, Material Calibration
  - Electron Density Errors
  - Edge Effects
- Dose Specification
  - to water or to media?
- Accelerator Characteristics
  - Class variations
- Measurement Equipment
- Training

Edge Effects
(Ideal Phantom)

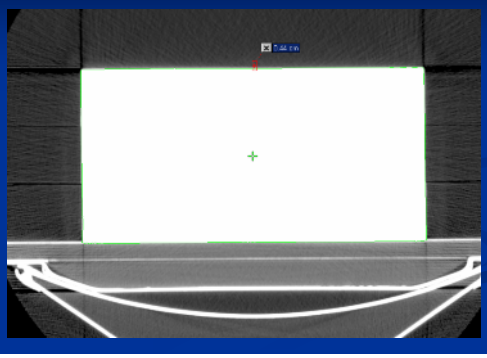
-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Edge Effects
(Scanned Phantom)

-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
-400	-400	-400	-400	-400	-400	-400	-400	-400	-400
-200	-200	-200	-200	-200	-200	-200	-200	-200	-200
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

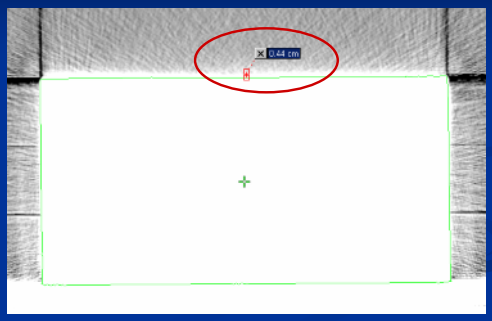
Edge Effects

Imported Solid Water CT Scan



Edge Effects

Imported Solid Water CT Scan



Edge Effects

- Caused by sudden, sharp edges in scanned volume
- Not just interpolation effect
- Can result in 'extending' the phantom several mm beyond its actual boundary
- Can offset depth dose, build-up regions

Electron Density

(Actual Phantom)

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1150	1150	1150	1150	1150	1150	1150	1150	1150	1150
1150	1150	1150	1150	1150	1150	1150	1150	1150	1150
1150	1150	1150	1150	1150	1150	1150	1150	1150	1150
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Electron Density
(Scanned Phantom)

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1150	1150	1000	900	650	650	900	1000	1150	1150
1150	1150	1000	900	650	650	900	1000	1150	1150
1150	1150	1000	900	650	650	900	1000	1150	1150
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Electron Density

- Caused by Beam Hardening Correction of CT Scanner
- 'Corrects' for higher attenuation in center of patient
- Primarily affects non-patient geometries, e.g. rectangular solids, slab heterogeneities

Dose Specification

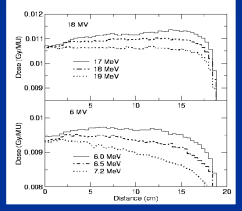
- Most centers calibrate dose to water
- MC calculations often specify dose according to media of voxel
  - CT to Material Calibration Curve
- Can result in differences of 1-3% depending upon region being measured

Accelerator Characteristics
(Lots of Questions)

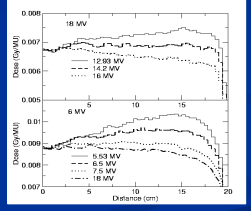
- What physical parameters vary from machine to machine within an accelerator class?
  - Energy
  - Spectrum
  - Beam spot size
    - Energy / Intensity Distribution
- How can we handle manufacturing variations?
- How does a manufacturer compensate for measurement variations?

Effect of electron energy

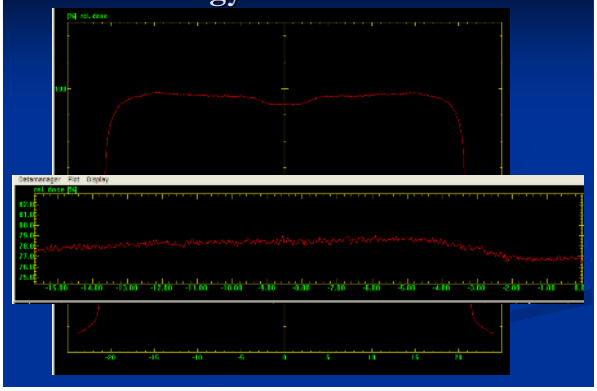
38x38 cm² profiles (Varian)



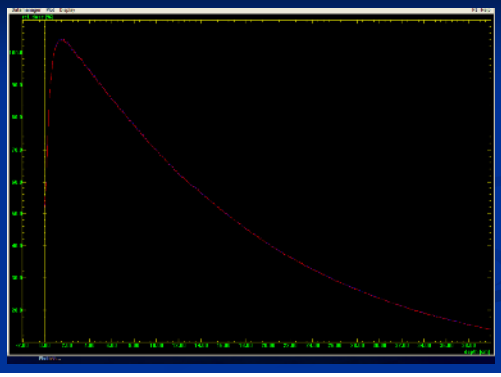
40x40 cm² profiles (Siemens)



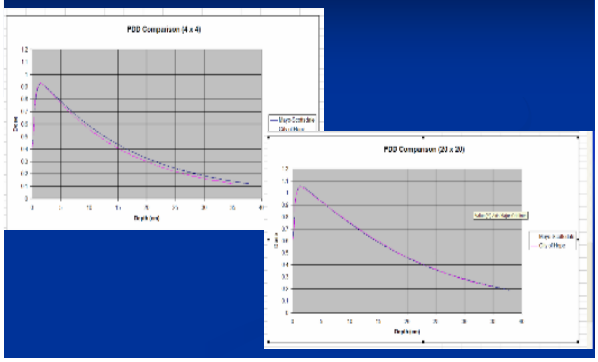
Energy Determination



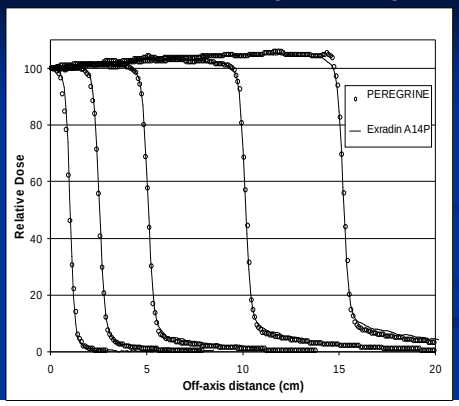
Energy Extraction



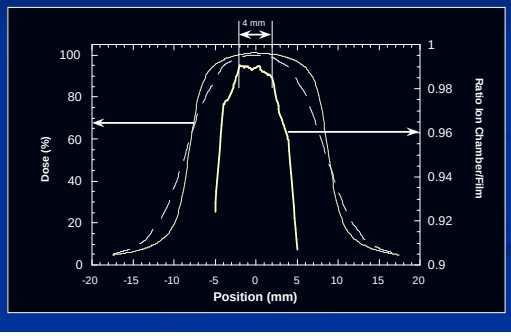
Measurement Variations



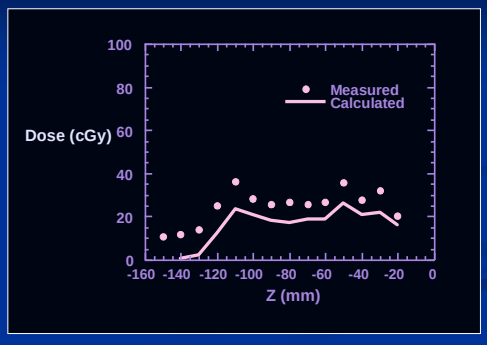
Off-axis Profiles (d=1.5 cm)



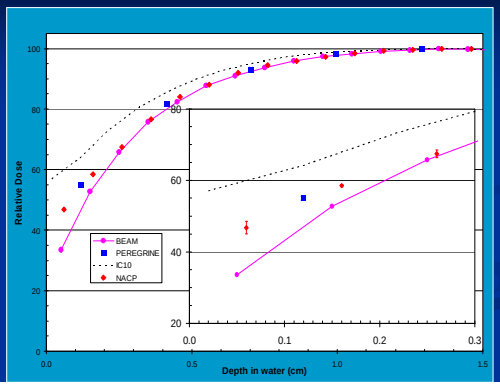
Ionization Chamber Volume Averaging



Low-Dose Results



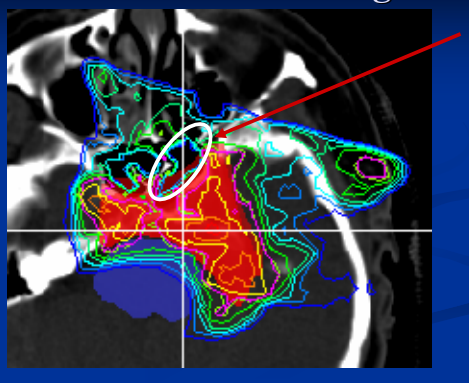
Buildup region (10x10 cm²)



Training

- Proper Measurement Techniques
  - Ion Chamber
  - Film
- Isodose Interpretation
  - Statistical Variation vs Imprecision

What are we drawing?



Summary

- Acceptance Testing of Monte Carlo Dose Calculation Systems can require significantly more effort than traditional dose algorithms
- Imperfections in both CT and Measuring Systems can result in imperfect data for use in Monte Carlo System commissioning
- MC Dose Calculation System Commissioning will require efforts by both manufacturer and user
- There will need to be some re-thinking of our traditional planning processes in order to fully utilize Monte Carlo techniques.