QA for Treatment Planning Systems (TPS)

No Conflicts of Interest

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QA for TPS in an Era of Change?

• Quality Assurance in RT?
  – Broad cooperative approach,
  – Procedures to ensure consistent and safe delivery of the prescription ...

• For TPS –
  • High quality treatment plans
  • Accurate treatment plans
High Quality Treatment Plan?

- Technique ...

- Target coverage

- Organ sparing

- Prescribed dose

High Quality?

Technique ... Technique ... Technique!
Accurate Treatment Plan?

Calculation ... Machine QA ... Verification!
Key Sources

American Association of Physicists in Medicine
Radiation Therapy Committee Task Group 53:
Quality assurance for clinical radiotherapy treatment planning

Benedick Fraass
University of Michigan Medical Center, Ann Arbor, MI

Karen Doppke
Massachusetts General Hospital, Boston, Massachusetts

Margie Hunt
Fox Chase Cancer Center, Philadelphia, Pennsylvania, and Memorial Sloan Kettering Cancer Center, New York, NY

Gerald Kutcher
Memorial Sloan Kettering Cancer Center, New York, NY

George Starkschall
M. D. Anderson Cancer Center, Houston, Texas

Robin Stern
University of California, Davis Medical Center, Sacramento, CA

Jake Van Dyke
London Regional Cancer Center, London, Ontario

(Received 15 December 1997; accepted for publication 28 December 1997)
AAPM TG 53 and IAEA TRS 430

- Similar philosophy
- Summarize issues
- A framework to design comprehensive and practical QA
- Tailor to each clinic
- No specific QA tests
Quality Plan

Technique
- Planner Skill
- Conformal (MLC)
- Imaging volume definition
- Margins
- Beam Parameters

Accurate Plan

Dose Calculation
- Pencil Beam
- DVH, gamma
- Heterogeneity
- Biological modeling

TG 53, TRS 430
Quality Plan

IMRT
VMAT
Tomotherapy
Cyber-knife

Image guidance
Imaging volume definition
Gating

Accurate Plan

Dose Calculation

Pencil Beam
Deformed dose modeling
DVH, gamma
Biological modeling

Superpos’n convolu’n M-Carlo
Heterogeneity

Current status ?...
TG53 – Components of a QA Program

• Acceptance testing
• Commissioning
  – Non-dosimetric
  – Dosimetric
• Routine QA
• QA of clinical use
• Computer systems
• Vendor responsibilities

General
• Resources
• Users ‘band together’
• A ‘responsible physicist’
QA Concepts

• System Specifications
  – Defined by vendor

• System Performance
  – Acceptance
  – Commissioning

• Clinical performance
  – Plan quality
  – Incidents

Reference data

Specifications
Measured data (beam/phantoms)
Physician feedback
QA results (# replans)
Timeliness
TG53 – Acceptance Testing

- Performed prior to clinical use
- Check system meets specifications
  - Needs quality specifications!
- Problem:
  - Not enough time for comprehensive acceptance
  - Reduced to simple check-box tests
## TG-53 Acceptance Tests

### Golden beam data
- Shui A et al., MedPhys 1992

<table>
<thead>
<tr>
<th>Topic</th>
<th>Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT input</td>
<td>Create an anatomical description based on a standard set of CT scans provided by the vendor, in the format which will be employed by the user.</td>
</tr>
<tr>
<td>Anatomical description</td>
<td>Create a patient model based on the standard CT data discussed above. Contour the external surface, internal anatomy, etc. Create 3-D objects and display.</td>
</tr>
<tr>
<td>Beam description</td>
<td>Verify that all beam technique functions work, using a standard beam description provided by the vendor.</td>
</tr>
<tr>
<td>Photon beam dose calculations</td>
<td>Perform dose calculations for a standard photon beam dataset. Tests should include various open fields, different SSDs, blocked fields, MLC-shaped fields, inhomogeneity test cases, multi-beam plans, asymmetric jaw fields, wedged fields, and others.</td>
</tr>
<tr>
<td>Electron beam dose calculations</td>
<td>Perform a set of dose calculations for a standard electron beam dataset. Include open fields, different SSDs, shaped fields, inhomogeneity test cases, surface irregularity test cases, and others.</td>
</tr>
<tr>
<td>Brachytherapy dose calculations</td>
<td>Perform dose calculations for single sources of each type, as well as several multi-source implant calculations, including standard implant techniques such as a GYN insertion with tandem and ovoids, two-plane breast implant, etc.</td>
</tr>
<tr>
<td>Dose display, dose volume histograms</td>
<td>Display dose calculation results. Use a standard dose distribution provided by the vendor to verify that the DVH code works as described. User-created dose distributions may also be used for additional tests.</td>
</tr>
<tr>
<td>Hardcopy output</td>
<td>Print out all hardcopy documentation for a given series of plans, and confirm that all textual and graphical information is output correctly.</td>
</tr>
</tbody>
</table>
Recommendations for specific tests:
- ‘type’ tests, by manufacturer
- ‘site’ tests by the user’s institution

Dose calculation tests expand on TG23 (1995):
- 6,10,18MV – Venselaar, 2001 (GreenJ)
- Input data and test cases on CD from IAEA

Software upgrades?
- Perform subset of type tests
Sample Type Test : Test 5

- AAPM Report 55
- Therac 20 (18MV)
- Central axis block test case
- SSD=SAD=100cm
- Field size 16x16
- 1x4x7 cm (w,l,t) block at the block tray
- Profile comparison
- 3cm depth
- Measured vs Pencil beam
- ± 4 mm
- ± 2%
Accepting TPC in an era of change?

- Key to acceptance – specifications
- Tendering process encouraged
  - Forces user to be organised, think through specs
  - Forces vendor to answer specifics about system capabilities and limitations
  - Legally binding contract
  - Encourages competition and low prices!
  - Get answers in writing!
- Need more gold-standard data sets
  - Deformable modeling, etc
TG-53 Commissioning

- Non-dosimetric
  - Modern complexity here!
- Dosimetric
  - Historically the main focus

Commissioning: benchmark data
Routine QA: reproducibility
Task Group No. 100 Evaluate QA Needs in RT

- MRI in planning  
- MRI functional  
- MRS in Brain  
- DCE-MRI  
- Quantitative PET  
- PET Volumes,  
- PET Monitoring  
- Image Registration  
- IMRT Commissioning  
- IMRT Metrology  
- Small Field Dosimetry  
- MU Calculations  
- Monte Carlo Clinical  
- Monte Carlo Commission  
- Accelerator commissioning  

Non-Dosimetric
- Image acquisition  
- Anatomical Description  
- Beams  
- Operation of Dose calc  
- Plan Evaluation  
- Plan verification  

Dosimetric
- Measurement consistency  
- Data input to TPS  
- Calculation Parameters  
- Methods for verification  
- Calculation verification  
- Plan normalization  
- Clinical verification
Imaging for RT Planning

• Image quality and handling
  – Multi-modal imaging
  – Registration
  – 3D target delineation
  – Volume rendering

• Tests ….
  – Image quality, transfer, orientation, slice location, registration, beam display, DRR, auto-margining, 3D reconstruction ….
Phantom for Data Transfer, Image Display, MLC

QUASAR

Craig, Brochu Van Dyk, IJROBP, 1999. Modus Medical Devices Inc, Canada
Reconstructed Image Verification

Oblique CT reconstruction

Digitally reconstructed radiograph
• Dose, volume, relative electron densities

Volume Measurements (cm³)

Polystyrene Cylinder

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<td>2</td>
<td>blue</td>
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Polystyrene Cube

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<th>D</th>
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<td>130</td>
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</table>

Lucite Cube

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<thead>
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<th>B</th>
<th>C</th>
<th>D</th>
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<td>20</td>
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</tr>
<tr>
<td>40</td>
<td>blue</td>
<td>blue</td>
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</table>

Air Wedge

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
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<td>20</td>
<td>red</td>
<td>red</td>
<td>red</td>
<td>red</td>
</tr>
<tr>
<td>60</td>
<td>blue</td>
<td>blue</td>
<td>blue</td>
<td>blue</td>
</tr>
</tbody>
</table>

Maximum variation +42% to -44%

Craig, Brochu Van Dyk, IJROBP, 1999. Modus Medical Devices Inc
Dose Volume Histograms
CT Number to Electron Density Conversion

- System A
- System B
- System C
- Battista and Bronskill
Dose calculation algorithms

- Correction Based
  - measured dose distributions in a water phantom.
- Model based
  - Convolution/superposition, pencil beam, Monte Carlo
  - Compute the dose directly in a patient representation.
  - MU calculations based on energy fluence
  - Recommended in ICRU 83, 2010
Model Based Methods?

- Finite source size.
- Angular distribution of photons.
- Primary transmission.
- Extrafocal radiation mainly from the primary collimation and the field flattening filter.
- Differential hardening of the beam by the field flattening filter.
- Curved leaf ends.
- Leaf configuration.
- Tongue and groove effect.
- Leaf transmission.
- Electron contamination.
- Tissue heterogeneities.
<table>
<thead>
<tr>
<th>Step</th>
<th>Goal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Create a commissioning plan (Section 9.4.1.3)</td>
<td>Identify the algorithm type. Identity specific issues for special attention. Define an efficient plan for data collection, dose distribution comparisons and analysis of results.</td>
</tr>
<tr>
<td>2</td>
<td>Obtain measured data (Section 9.4.1.4)</td>
<td>Plan, measure, transfer, analyse and prepare data for use.</td>
</tr>
<tr>
<td>3</td>
<td>Check input data (Section 9.4.1.5)</td>
<td>Verify the correctness of input data.</td>
</tr>
<tr>
<td></td>
<td>(a) Configuration parameters</td>
<td>Confirm machine–beam configuration parameters.</td>
</tr>
<tr>
<td></td>
<td>(b) Algorithm input data</td>
<td>Verify that input data have been entered correctly.</td>
</tr>
<tr>
<td></td>
<td>(c) Model parameters</td>
<td>Determine beam model fitting parameters.</td>
</tr>
<tr>
<td>4</td>
<td>Perform calculation checks (Section 9.4.1.6)</td>
<td>Compare beam specific calculations with measured data. The design of the specific tests and analysis of the comparisons is a combination of the three types of check listed below.</td>
</tr>
<tr>
<td></td>
<td>(a) Beam specific calculation checks</td>
<td>Compare beam specific calculations with measured data to confirm that beam specific parameters are correctly set and that calculations give good results.</td>
</tr>
<tr>
<td></td>
<td>(b) Algorithm specific investigations</td>
<td>Test algorithms to confirm the proper behaviour of the algorithm. Document algorithm accuracy on a test or benchmark data set. Investigate specific algorithm issues.</td>
</tr>
<tr>
<td></td>
<td>(c) Clinical calculation verification</td>
<td>Verify that the calculations perform as expected in the user's hands. Verify behaviour over the range of expected clinical usage and at the limits set for clinical use.</td>
</tr>
<tr>
<td>5</td>
<td>Calculation comparison and analysis (Section 9.4.1.7)</td>
<td>Verify calculation techniques and plan comparison tools.</td>
</tr>
</tbody>
</table>
Dose Calculation Accuracy Requirements

Fig. 4-1. Regions for photon dose calculation agreement analysis.
### Sample Criteria of Acceptability

**IAEA TRS 430**

<table>
<thead>
<tr>
<th>Situation</th>
<th>Absolute Dose (%)</th>
<th>Central Ray (%)</th>
<th>Inner Beam (%)</th>
<th>Penumbra (mm)</th>
<th>Outer Beam (%)</th>
<th>Build-up Region (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Square fields</strong></td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td><strong>Rectangular fields</strong></td>
<td>0.5</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td><strong>Asymmetric fields</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td><strong>Blocked fields</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td><strong>MLC-shaped fields</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td><strong>Wedged fields</strong></td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td><strong>External surface variations</strong></td>
<td>0.5</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td><strong>SSD variations</strong></td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>40</td>
</tr>
</tbody>
</table>

**A. Homogeneous Phantoms**

**B. Inhomogeneous Phantoms**

- Slab inhomogeneities
  - 3
  - 5
  - 5
  - 5
  - 5
- 3-D inhomogeneities
  - 5
  - 5
  - 7
  - 7
  - 7

* Absolute dose values at the normalization point are relative to a standard beam calibration point.
* ** Excluding regions of electronic disequilibrium.
Accuracy Requirements for IMRT

Proposed Confidence Limits and Action levels

<table>
<thead>
<tr>
<th>Region</th>
<th>Confidence Limit (P=0.05)</th>
<th>Action Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>high dose, low gradient</td>
<td>±3%</td>
<td>±5%</td>
</tr>
<tr>
<td>high dose, high gradient</td>
<td>10% or 2 mm DTA</td>
<td>15% or 3 mm DTA</td>
</tr>
<tr>
<td>low dose, low gradient</td>
<td>4%</td>
<td>7%</td>
</tr>
<tr>
<td>$\delta_{90-50%}$ (dose fall off)</td>
<td>2 mm DTA</td>
<td>3 mm DTA</td>
</tr>
</tbody>
</table>

$\delta_i = 100\% \times \frac{D_{\text{calc}} - D_{\text{meas}}}{D_{\text{prescribed}}}$

DTA = Distance to agreement

Palta, J. 2003 AAPM Summer School
Accuracy Requirements for IMRT, RPC
IMRT Inhomogeneity Corrections

- Convolution/Superposition Algorithm (CSA)
  - Average = 1.01 ± 0.08
  - ±5%/3 mm : 85% pixels
- Pencil Beam Algorithm (PBA)
  - Average = 1.07 ± 0.02
  - ±5%/3 mm : 50% pixels

CSA better than PBA!

Davidson et al. Med Phys 35: 5434-5439; 2008
Pencil-Beam Profile
AAA Profile

![Graph showing dose distribution for AAA profile with different markers and legends: Blue diamonds for RPC Film, purple line for Primary PTV, and black line for Prim PTV.]

- **Distance (cm):**
- **Dose (Gy):**
- **Legend:**
  - Blue diamonds: RPC Film
  - Purple line: Primary PTV
  - Black line: Prim PTV
  - Black circle: TLD

**Abbreviations:**
- **PTV:** Planning Target Volume
- **AAA:** Abdominal Aortic Aneurysm
Change algorithm – change isodoses!

Low isodoses expand

High isodoses retreat
• Special emphasis on the needs of the developing world
Phantoms Assessed by IAEA

Gammex RMI
Euromechanics Medical GmbH
Modus Medical Devices Inc.
Standard Imaging Inc.
CIRS Inc.
RPC Phantoms

Pelvis (10)

Thorax (15)

H&N IMRT (31)

SRS Head (4)

Liver (2)
# Phantom Results

Comparison between institution’s plan and delivered dose.

<table>
<thead>
<tr>
<th>Phantom</th>
<th>H&amp;N</th>
<th>Prostate</th>
<th>Spine</th>
<th>Lung</th>
<th>Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiations</td>
<td>752</td>
<td>174</td>
<td>19</td>
<td>174</td>
<td>23</td>
</tr>
<tr>
<td>Pass</td>
<td>585</td>
<td>143</td>
<td>13</td>
<td>124</td>
<td>12</td>
</tr>
<tr>
<td>Pass %</td>
<td>78%</td>
<td>82%</td>
<td>68%</td>
<td>71%</td>
<td>52%</td>
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<tr>
<td>Criteria</td>
<td>7%/4mm</td>
<td>7%/4mm</td>
<td>5%/3mm</td>
<td>5%/5mm</td>
<td>7%/4mm</td>
</tr>
<tr>
<td>Year introduced</td>
<td>2001</td>
<td>2004</td>
<td>2009</td>
<td>2004</td>
<td>2005</td>
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</tbody>
</table>

G Ibbott, IC3DDose 2010
# HN results grouped by TPS

<table>
<thead>
<tr>
<th>Treatment planning system</th>
<th>Pass Rate (%)</th>
<th>Attempts</th>
<th>Criteria Failed</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dose</td>
<td>DTA</td>
</tr>
<tr>
<td>Corvus</td>
<td>75</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Eclipse</td>
<td>85</td>
<td>114</td>
<td>10</td>
</tr>
<tr>
<td>Pinnacle</td>
<td>73</td>
<td>168</td>
<td>33</td>
</tr>
<tr>
<td>TomoTherapy</td>
<td>73</td>
<td>22</td>
<td>5</td>
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<td>XiO</td>
<td>73</td>
<td>59</td>
<td>7</td>
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<td>Other</td>
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<td>24</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>419</td>
<td>65</td>
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## Reasons?

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Minimum # of occurrences</th>
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<tr>
<td>Incorrect Output Factors in TPS</td>
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</tr>
<tr>
<td>Incorrect PDD in TPS</td>
<td>1</td>
</tr>
<tr>
<td>IMRT Technique</td>
<td>3</td>
</tr>
<tr>
<td>Software Error</td>
<td>1</td>
</tr>
<tr>
<td>Inadequate Account of Leaf Ends (Cadman, et al; PMB 2002)</td>
<td>14</td>
</tr>
<tr>
<td>QA Procedures</td>
<td>3</td>
</tr>
<tr>
<td>Errors in Couch Indexing (Peacock)</td>
<td>3</td>
</tr>
<tr>
<td>Equipment Performance</td>
<td>2</td>
</tr>
<tr>
<td>Setup Errors</td>
<td>7</td>
</tr>
</tbody>
</table>
Duke/RPC collaboration (NIH R01 support)

Can we make credentialing 3D?

Point dose: TLDs
Planar dose - film

RPC IMRT Phantom
DLOS/Presage 3D dosimetry system

- Accurate:
- Tissue equivalent
- Economical

$\lambda_{\text{max}} = 633 \text{ nm}$

5 Beam Tx
DLOS: Duke Large Field-of-View Optical-CT Scanner

**Design Specifications**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tr>
<td>FOV</td>
<td>24 cm</td>
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<tr>
<td>voxel size</td>
<td>0.175 mm</td>
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</tr>
<tr>
<td>scan time</td>
<td>10 minutes</td>
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</tr>
</tbody>
</table>
Benchmarking DLOS/Presage

A. PDD Side
   - 6x6 cm²
   - 16 cm

B. PDD Top
   - 10 cm

C. Dose Plateaus
   - 4 Gy
   - 12 Gy
   - 8 Gy
   - 16 cm
   - 10 cm

D. 4 Field Box
   - 4x4 cm²
   - 4 Gy

E. Small Field Output Factors
   - 1 cm
   - 0.5 cm
   - 2 cm
   - 3 cm
   - 0.5 cm
   - 16 cm

F. Linear Output
   - 80 Gy
   - 40 Gy
   - 20 Gy
   - 10 Gy
   - 10 cm
   - 16 cm
### Benchmark Results:

<table>
<thead>
<tr>
<th>NDD Pass Rate</th>
<th>PDD Top</th>
<th>PDD Side</th>
<th>Dose Plateaus</th>
<th>4-Field Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (cm)</td>
<td>10</td>
<td>16</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Noise (cGy)</td>
<td>9.8</td>
<td>10.2</td>
<td>5.2</td>
<td>7.0</td>
</tr>
<tr>
<td>5%, 3mm</td>
<td>99.5%</td>
<td>99.1%</td>
<td>98.9%</td>
<td>99.9%</td>
</tr>
<tr>
<td>5%, 2mm</td>
<td>99.3%</td>
<td>97.3%</td>
<td>97.1%</td>
<td>99.5%</td>
</tr>
<tr>
<td>3%, 3mm</td>
<td>97.3%</td>
<td>96.5%</td>
<td>97.7%</td>
<td>97.9%</td>
</tr>
<tr>
<td>3%, 2mm</td>
<td>96.3%</td>
<td>93.6%</td>
<td>95.3%</td>
<td>96.2%</td>
</tr>
<tr>
<td>2%, 2mm</td>
<td>94.0%</td>
<td>84.5%</td>
<td>90.9%</td>
<td>86.0%</td>
</tr>
</tbody>
</table>
Benchmark Data Set #1: PDD from side

A. TPS Coronal

B. Measured Coronal

C. Coronal Isodose Plot

D. TPS Transverse

E. Measured Transverse

F. Transverse Isodose Plot

--- TPS --- Measured

NDD Pass Rate

96.5%
Benchmarking results

- 2mm³ resolution 15 min
- Accurate <2% relative
- Noise <2%
- QA report <40 minutes

Clinical application:
- 6 base-of-skull IMRT,
- Presage in RPC H&N credentialing phantom
Treatments delivered to Presage in RPC phantom
Case 1
Case #1: illustrative comparisons

Eclipse
Presage

NDD Pass Rate
= 97.6%
Best Case 4
99.4%

Measured

Isodose

--- Measured

--- Calculated

NDD Map
Worst Case 6
95.2%
A clinical presentation of QA data?

**Eclipse**

**Measurement**

Patient

Phantom

DVH etc

3D Gamma or NDD
Case 2 DVH in patient

Dose volume histograms

- PTV (Transformed Presage)
- Brainstem (Transformed Presage)
- Medulla Oblongat (Transformed Presage)
- Optic Nerve, Lef (Transformed Presage)
- Eye, Right (Transformed Presage)
- Menigioma (Transformed Presage)
- Phanto-Brainstem (Transformed Presage)
- PTV (SRT:Prim)
- Brainstem (SRT:Prim)
- Medulla Oblongat (SRT:Prim)
- Optic Nerve, Lef (SRT:Prim)
- Eye, Right (SRT:Prim)
- Meningioma (SRT:Prim)
- Phanto-Brainstem (SRT:Prim)
98% pass Gamma Map (3%, 3mm, 5% threshold)

Eclipse Dose Map

- Medula Oblongata
- PTV
- Brainstem
Conclusions for an Era of change …. 

• Basics of TG53 and IAEA 430 apply, amplified
  – More resources and training!
  – Responsible physicist – a resource
  – Vendors
    • Manuals, Training courses, User-groups
  – Literature
  – Measurements
    • Gold standard data sets
    • Anthropomorphic phantoms
    • In-vivo dosimetry
    • Clinically meaningful and comprehensive QA
QA Administration

• One “qualified medical physicist” responsible
• Documentation
• Communication re:
  – Software changes on RTPS
  – New/altered data files
  – CT imager software/hardware changes
  – Machine output changes
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THE END – THANK-YOU!

Education

Verification

Documentation

Communication