Introduction

- Technological revolution in radiation oncology
  - Enhanced use of imaging
  - Computer-controlled dose delivery
  - Tighter margins
  - Higher doses
  - Dynamic delivery
- Central to this is the treatment planning system (TPS)

Educational Objectives

1. To demonstrate the importance of QA of TPSs by reviewing significant treatment errors associated with their use.
2. To review the major functionality of a modern TPS.
3. To highlight and summarize various reports that have made recommendations regarding commissioning and QA of TPSs.
4. To discuss accuracy requirements and criteria of acceptability of the modern TPS.
5. To summarize acceptance testing procedures as proposed by the IAEA for a modern TPS.
6. To provide an overview of commissioning a modern RTPS.
7. To provide an overview of the QA associated with a modern TPS.
Recent References

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


Recent References

• For manufacturers

NORME INTERNATIONALE
INTERNATIONAL STANDARD

Downloaded from: http://www-pub.iaea.org/MTCD/publications/PDF/TRS430_web.pdf

Available in pdf format from:
IAEA TRS 430 Contents

1. Introduction
2. Clinical treatment planning process
3. Description of radiation treatment planning systems
4. Algorithms used in radiation treatment planning
5. Quality assessment
6. Quality assurance management
7. Purchase process
8. Acceptance testing
9. Commissioning
10. Periodic quality assurance
11. Patient-specific quality assurance
12. Summary

Recent References

• ESTRO 2004

QUALITY ASSURANCE OF TREATMENT PLANNING SYSTEMS
PRACTICAL EXAMPLES FOR NON-IMRT PHOTON BEAMS

Ben Mighees, Agnieszka Olszewski, Claudiu Popa, Guido Hafemann, Tomasz Rokos
Jean-Claude Rosensweig, Hans Wachter

Available from ESTRO website: http://www.estroweb.org/estro/index.cfm

Very Recent Reference

• Includes chapters on:
  - Imaging for treatment planning
  - Inverse planning
  - Monte Carlo for treatment planning
  - IMRT
  - Radiobiological modeling
  - Breathing control in radiation therapy
  - Prostate brachytherapy

Future Reference

Future Reference

IAEA
Report of Consultants’ Group
Protocol for Specification and Acceptance Testing of Radiation Treatment Planning Systems
Contributors: Geoffrey Ebbe, Rainer Schmidt, Jake Van Dyk
Scientific Secretary: Stanislav Vastavsky
Draft 16 March 2005

QA in Radiation Therapy (RT)

- Two considerations in RT
  - Need for accuracy in RT process
  - Avoidance of treatment errors

Need for Accuracy in Dose Calculations

- General accuracy desired in dose delivered to patient: 5%

<table>
<thead>
<tr>
<th>Uncertainty Type</th>
<th>Uncertainty Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Absorbed dose to reference point in water phantom</td>
<td>2.5</td>
</tr>
<tr>
<td>B Determination of relative dose (Measurement away from reference point)</td>
<td>2.5</td>
</tr>
<tr>
<td>C Relative dose calculations</td>
<td>2.5</td>
</tr>
<tr>
<td>D Patient irradiation</td>
<td>2.5</td>
</tr>
<tr>
<td>E Overall</td>
<td>5.0</td>
</tr>
</tbody>
</table>

ICRU Goal in Dose Calculation and Spatial Accuracy

ICRU 42, 1987

- Relative dose accuracy in uniform dose region: 2%
- Spatial accuracy in high dose gradient: 2 mm
Avoidance of Treatment Errors

- Error
  - “The failure of planned action to be completed as intended (i.e., error of execution) or the use of a wrong plan to achieve an aim (i.e., error of planning).”


Avoidance of Errors in RT

IAEA 2000

ICRP 2000

IAEA: Categories of Errors

<table>
<thead>
<tr>
<th>Categories</th>
<th>Number of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation measurement systems</td>
<td>5</td>
</tr>
<tr>
<td>External beam:</td>
<td></td>
</tr>
<tr>
<td>Machine commissioning &amp; calibration</td>
<td>15</td>
</tr>
<tr>
<td>External beam therapy:</td>
<td></td>
</tr>
<tr>
<td>Treatment planning, patient setup and treatment</td>
<td>26</td>
</tr>
<tr>
<td>Decommissioning of teletherapy equipment</td>
<td>2</td>
</tr>
<tr>
<td>Mechanical and electrical malfunctions</td>
<td>4</td>
</tr>
<tr>
<td>Brachytherapy:</td>
<td></td>
</tr>
<tr>
<td>Low dose rate sources and applicators</td>
<td>29</td>
</tr>
<tr>
<td>Brachytherapy: High dose rate</td>
<td>3</td>
</tr>
<tr>
<td>Unsealed sources</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>92</td>
</tr>
</tbody>
</table>

IAEA: Lessons… Examples

<table>
<thead>
<tr>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconsistent/incorrect data set</td>
<td>Lack of proper commissioning/verification</td>
</tr>
<tr>
<td>Insufficient understanding of algorithm</td>
<td>Lack of understanding on use of wedge factors</td>
</tr>
<tr>
<td>Incorrect calculation of treatment times</td>
<td>Lack of independent check</td>
</tr>
<tr>
<td>Incorrect distance correction</td>
<td>Lack of understanding/training</td>
</tr>
<tr>
<td>Lack of independent check</td>
<td>Lack of independent check</td>
</tr>
<tr>
<td>Misunderstanding of complex treatment plan</td>
<td>Lack clear documentation</td>
</tr>
<tr>
<td>Poor implementation of instructions</td>
<td></td>
</tr>
<tr>
<td>Incorrect positioning of beams on patient</td>
<td></td>
</tr>
<tr>
<td>Wrong source strength</td>
<td>Insufficient training/understanding</td>
</tr>
<tr>
<td>No independent check</td>
<td></td>
</tr>
<tr>
<td>Wrong isotope</td>
<td>No independent check</td>
</tr>
<tr>
<td>Error in removal time</td>
<td>No independent check</td>
</tr>
</tbody>
</table>
### Discovery of Problem

- Nov 2000, patients with prolonged diarrhoea
- Physicists reviewed plans - no anomaly
  - Double checking of plans was used
  - **No independent, manual time calc check**
- Dec 2000, similar symptoms in other patients
- Feb 2001, physicists initiated search for cause of such effects
- March 2001, physicists discovered problem with the calculation of treatment times
  
### Treatment Planning Problem

- "Shortcut" method of block entry even when 4 blocks
  
### Two approaches

<table>
<thead>
<tr>
<th>Time incorrect</th>
<th>Time correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Problem Summary

- “These factors, together with an apparent omission of manual checking of computer calculations, resulted in the patients concerned being exposed at radiation levels that were set too high.”

Clinical Summary - March 2002

- 28 patients treated with incorrect doses
  - 17 have since died
  - 13 had rectal complications

Physicists Jailed

November 2004
- Two physicists
  - Condemned to 4 years in prison
  - Barred to practice their profession for 7 years
  - Third physicist is acquitted

Errors in RT: Contributing Factors

- Insufficient education
- Lack of procedures/protocols as part of comprehensive QA program
- Lack of supervision of compliance with QA program
- Lack of training for “unusual” situations
- Lack of a “safety culture”
Components of 3-D TPS

Hardware
- CPU
- High resolution graphics
- Mass storage (hard disc)
- Floppy disk/CD ROM
- Keyboard & mouse
- High resolution monitor
- Digitizer
- Laser/color printer
- Backup storage facility
- Network connections

Software
- Input routines
- Anatomy modeling
- Beam geometry (virtual simulation)
- Dose calculations
- Dose volume histograms/evaluation tools
- Digitally reconstructed radiographs
- Output [hardcopies, network, web connection (RTOG)]

Components of 3-D TPS

Software utilities for...
- Treatment unit data/dose data
- Brachytherapy isotope data
- Output of treatment unit/source data
- Organization of patient data
- Contouring software – targets, organs
- Video display for interactive beam placement, shaping, sizing
- Dose calculation initialization – grid, type of dose algorithm
- Dose calculation software
- Isodose display software incl. normalization, beam weights
- Hardcopy software
- Archiving software
- Backup software

Algorithm Classification

- All algorithms have two major attributes:
  A. Scatter Integral
     - Release and Spread of Energy
     - Primary and scatter
     - Level of summation or integration
  B. Patient Anatomy
     - Use of Patient Anatomical Data
     - Imaging geometry and density data
     - Assumptions of symmetry
A. Scatter Integral
Superposition Principle

- Beam Kernel
- Slab Kernel
- Pencil Kernel
- Point Kernel

B. Use of Anatomy Data

- Patient’s Anatomy
  - As imaged by CT, MR, PET, etc
  - Geometry and density
  - As sensed by algorithm
  - Symmetry assumptions
  - 1-D, 2-D, 2.5-D, or 3-D matrix

If you are buying...

- Does the algorithm “feel” the anatomy voxels in 1-D? 2-D? 3-D?
- Is the algorithm
  - 0-D, 1-D, 2-D or 3-D in its scatter integration?
  - Does the algorithm handle electron transport?
  - Does it use a point kernel or a pencil beam kernel?
  - How is the primary TERMA and kernel changed with density? Atomic number?

http://www.opctonline.net/
- Interesting background information
Components of QA Program

- Program & system documentation
- User training
- Sources of uncertainties
- Suggested tolerances
- Initial system checks (commissioning)
- QC - repeated system checks
- QC - “manual” checks (patient specific)
- QC - in vivo dosimetry
- QA - administration

Commissioning and QA of TPS

User | Manufacturer | User
--- | --- | ---
Input | Radiation Therapy Planning System | Output
Data (Radiation, Patient) | Dose Distributions

Commissioning: Initial tests
Quality control: Reproducibility
Compare to expected results
Acceptance Testing

- **What happens in reality!**
- Catalogue delivered components
  - Hardware
  - Software
- Test components for functionality
  - Sign acceptance document

- **What should happen!**
  - Based on IAEA consultants meeting 14–18 March 2005
  - Manufacture to perform series of type tests (e.g., TG23/Report 55)
  - Type test results should be documented and made available to user
  - Site (acceptance) tests should be a subset of type tests performed at the time of TPS installation
  - Results compared to results of type tests

Sample Criteria of Acceptability

<table>
<thead>
<tr>
<th>Situation</th>
<th>Absolute Dose (%)</th>
<th>Central Ray (%)</th>
<th>Inner Beam (%)</th>
<th>Phantom Thickness (mm)</th>
<th>Outer Beam (%)</th>
<th>Build-up Region (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Homogeneous Phantoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square fields</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Rectangular fields</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Asymmetric fields</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Slotted fields</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>MLC-shaped fields</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Wedge fields</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>External surface variations</td>
<td>0.5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>SSD variations</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>40</td>
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<tr>
<td>B. Inhomogeneous Phantoms</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Slab inhomogeneities</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>S4 inhomogeneities</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

*Absolute dose values at the normalization point are relative to a specified lower calibration point.

Type Tests

- **Elekta**
  - 6, 10, 18 MV

**Venselaar & Weltevreden**

Commissioning

- Prepare system for clinical use
  - Provides experience/training for users
- Enter appropriate measured data
  - D0, TAR, TPR, beam profiles, wedge profiles, attenuation data, output factors, etc
- Perform series of commissioning tests
- Tests algorithms
  - Provides capabilities & limitations
- Assess results to see if they comply with specifications
- Provides documentation of system performance
- Results of commissioning tests used later for QC tests

IAEA TRS 430

Phantoms

- IMRT & 3-D QA
**Disclosure**

- The QUASAR® QA phantoms about to be described are commercial products
- Invented by J. Van Dyk, T. Craig, D. Brochu, A. McNiven, T. Kron
- Marketed by Modus Medical Devices, London, Ontario
  - www.modusmed.com
- References:

**Non-Dosimetric Issues**

- Image acquisition and transfer
- Beam display
- CT image reconstructions
  - Multiplanar CT image reconstructions
  - Digitally reconstructed radiographs
- Anatomical volumes
  - 3-D display
  - Automatic tools - autocontouring, automargin, etc
- Dose volume histograms
- CT numbers to electron density conversion

**Phantom Schematic**

**Commercial Version of QA Phantom**
Multi-Institution Evaluation

- Phantom used to evaluate 3 TPSs and 1 CT simulator
  - Picker ACQSIM
  - Varian CADPlan
  - ADAC Pinnacle
  - Theratronics TheraplanPlus

Reconstructed Image Verification

Oblique CT reconstruction
Digitally reconstructed radiograph
Non-Dosimetric Components

- Non-dosimetric components require QC
- Phantom is a unique tool for QC
  - 3-D TPS
  - CT-simulator
- Allows assessment of errors, limitations and uncertainties of 3-D TPS
- Several problems discovered in various commercial 3-D TPS software

Multi-Observer Test

Does leaf end align with phantom geometry (air/acrylic interface)?

- Errors ≥ 2 mm, identified 100% of the time
- 1 mm errors were identified 80% of the time

Quality Control

PS = Patient specific, W = Weekly, M = Monthly, Q = Quarterly, A = Annually, U = After software or hardware update

<table>
<thead>
<tr>
<th>Subject</th>
<th>Test</th>
<th>PS</th>
<th>W</th>
<th>M</th>
<th>Q</th>
<th>A</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CPU | OC Test 1 | | | | | |
| Digitizer | OC Test 2 | | | | | |
| Plotter | OC Test 3 | | | | | |
| Dosimetry recovery | OC Test 4 | | | | | |
| Anatomical information | OC Test 5 | | | | | |
| CT for other scan transfer | OC Test 6 | | | | | |
| CT geometry and density check | OC Test 7 | | | | | |
| Patient anatomy | OC Test 8 | | | | | |
| External beam software (voltages and electron) | OC Test 9 | | | | | |
| Reproduction (including MUs) | OC Test 10 | | | | | |
| Monitor unit | OC Test 11 | | | | | |
| Plan details | OC Test 12 | | | | | |
| Electronic plan transfer | OC Test 13 | | | | | |
| Brachytherapy | OC Test 14 | | | | | |
| Reproduction | OC Test 15 | | | | | |
| Plan details | OC Test 16 | | | | | |
| Independent dose filtration check | OC Test 17 | | | | | |
| Electronic plan transfer | OC Test 18 | | | | | |
| TPS software reconfiguration and testing | OC Test 19 | | | | | |

\[ JAE TRS-430 Table 61 \]
QA Administration

- One “qualified medical physicist” responsible
- Documentation of QA process
- Record results
- Clear channels of communication re:
  - Software changes on TPS
  - New/ altered data files
  - CT imager software/hardware changes
  - Machine output changes

Summary

- Formal QC program includes:
  - User training
  - Well- defined (re)commissioning tests
  - Well-defined repeatability checks
  - Appropriate actions as needed
  - Documentation of results
  - Patient specific QC
- Process QA
  - Incident/error rate
  - Number of replans
  - Timeliness
  - Physician satisfaction

Take Home Message

- TPS consists many components
  - Hardware
  - Software
- Acceptance and commissioning will take time and effort
  - Usually considers dose calculation issues
  - Should also includes imaging issues
- QA of non-dose components is also important

Key Issues

- Education
- Documentation
- Verification
- Communication
Summary

- Quality assurance of radiation treatment planning systems is a significant challenge
  - but not insurmountable!