RC 422: Acceptance Testing and QA of Treatment Planning Systems

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Radiological Physics Center
University of Texas
Learning Objectives

1. To demonstrate the importance of the quality assurance (QA) of radiation treatment planning systems (RTPS) by reviewing significant treatment errors associated with their use.
2. To review the major functionality of a modern RTPS.
3. To highlight and summarize various reports that have made recommendations regarding acceptance, commissioning and QA of RTPSs with special emphasis on IEC-62083 and IAEA TRS-430.
4. To discuss accuracy requirements and criteria of acceptability of the modern RTPS.
5. To summarize acceptance testing procedures as proposed by the IAEA for a modern RTPS.
6. To provide an overview of commissioning a modern RTPS.
7. To provide an overview of the quality control associated with a modern RTPS.
Disclosures

• J. Van Dyk
  • License agreement, Modus Medical Devices Inc
• G. Ibbott
  • Consultant, IsoRay Inc, Richland, WA
  • Spouse, Employee, Accuray Incorporated, Sunnyvale, CA
Overview

- Scope of problem
- Complexity of modern RTPS
- Recent reports & recommendations
- Accuracy & criteria of acceptability
- IAEA proposal for acceptance testing
- IAEA report on commissioning
- Issues not addressed in current reports
Introduction

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

- Modern RTPS
  - Increased use of patient images
    - Possibly from various imaging modalities
  - Enhanced 3-D displays
  - More sophisticated dose calculation algorithms
  - More complex treatment plan evaluation tools
  - Generation of images used for treatment verification
  - Dynamic delivery
    - Wedges
    - IMRT

IAEA TRS-430
Radiation Therapy Process

- Diagnosis & 3-D Imaging
- Dose calculation & beam optimization
- Virtual Simulation
- Biological modeling & prescription
- Beam shaping
- Beam selection
- Target volume and organ localization
- Treatment verification & delivery

Adapted from S Webb
QA in Radiation Therapy (RT)

- Two considerations in radiation therapy

Need for accuracy in RT process

Avoidance of treatment errors

![Diagram showing the relationship between dose and relative response of normal tissue and tumor.](image-url)
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><strong>A</strong> Absorbed dose to reference point in water phantom</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>B</strong> Determination of relative dose (Measurement away from reference point)</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>C</strong> Relative dose calculations</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>D</strong> Patient irradiation</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>E</strong> Overall</td>
<td>5.0</td>
</tr>
</tbody>
</table>
ICRU Goal in Dose Calculation and Spatial Accuracy

- **ICRU 42, 1987 Recommends**
  - Relative dose accuracy in uniform dose region: 2%
  - Spatial accuracy in high dose gradient: 2 mm

### Off Axis profile

- **Real Data 1990s**
- **2%**
- **4 mm**

**Graph Details:**
- **Measured** and **Computed** curves are plotted.
- The graph illustrates the relative dose variation with off-axis distance (cm).
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).”

_Institute of Medicine. To Err is Human: Building a Safer Health System, 2000._
Euphemisms for “Errors”

- Accidents
- Incidents
- Misadministrations
- Unusual occurrences
- Discrepancies
- Adverse events
Medical Errors - General

• In United States…

• Annual errors
  • 44K-98K people die from medical errors
  • More than motor vehicle accidents, breast cancer or AIDS
  • Total annual cost $37.6 to $50 billion

• Most common types
  • Technical (44%)
  • Diagnosis (17%)
  • Failure to prevent injury (12%)
  • Use of drugs (10%)

Medical Error Analysis

Recently, more public & acceptable practice

- **Sample references - medicine in general**
  - *Institute of Medicine. To Err is Human: Building a Safer Health System, 2000.*

- **Sample references - RT**
Avoidance of Errors in RT

IAEA 2000

ICRP 2000

IAEA 2001
IAEA: Lessons Learned from Accidental...

- Describes 92 accidental exposures
  - 26 relate to radiation treatment planning
    - 16 external beam therapy
    - 10 brachytherapy
<table>
<thead>
<tr>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation measurement systems</td>
</tr>
<tr>
<td><strong>External beam:</strong></td>
</tr>
<tr>
<td>Machine commissioning &amp; calibration</td>
</tr>
<tr>
<td><strong>External beam therapy:</strong></td>
</tr>
<tr>
<td>Treatment planning, patient setup and treatment</td>
</tr>
<tr>
<td>Decommissioning of teletherapy equipment</td>
</tr>
<tr>
<td>Mechanical and electrical malfunctions</td>
</tr>
<tr>
<td><strong>Brachytherapy:</strong></td>
</tr>
<tr>
<td>Low dose rate sources and applicators</td>
</tr>
<tr>
<td>Brachytherapy: High dose rate</td>
</tr>
<tr>
<td>Unsealed sources</td>
</tr>
<tr>
<td>Total</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>Misunderstanding of complex treatment plan - verbal communication</td>
<td>Lack of independent check</td>
</tr>
<tr>
<td>Incorrect positioning of beams on patient</td>
<td>Lack clear documentation</td>
</tr>
<tr>
<td>Wrong source strength</td>
<td>Ineffective communication</td>
</tr>
<tr>
<td>Wrong isotope</td>
<td>Poor implementation of instructions</td>
</tr>
<tr>
<td>Error in removal time</td>
<td>Insufficient training/understanding</td>
</tr>
<tr>
<td></td>
<td>No independent check</td>
</tr>
</tbody>
</table>

---

2007-11-27

RSNA

London Health Sciences Centre
London Regional Cancer Program
Panama Incident

• Error due to digitizer entry of shielding blocks
• Dose error up to ~2 times
• Affected 28 patients
  • 17 died, 13 rectal complications
Factors Contributing to Errors

- Inadequate instructions in the RTPS manual
- Insufficient QA in treatment planning process
  - No manual checks
  - No written procedure of changes when entering the blocks
- Work organization
- Excessive workload
- Lack of coordination between members of radiation therapy team
Errors Related to Modern Technology

- Sample errors
  - 2004-2005. Epinal, France. 23 patients overdosed by 7-34%. Error in interpretation of dynamic vs physical wedge
  - 2006. Glasgow, Scotland. Error associated with a change in process due to update of a record and verify system (Varis 7). ~60% overdose to brain. Patient died.
  - 2007. Detroit, MI. Gamma Knife
    - Reported 29 Oct 2007. Wrong side of brain treated – coordinates were reversed – related to how patient was scanned with MRI – feet first vs head first.
  - RPC IMRT phantom data
    - Later…
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”
Complexity of Modern RTPS

• Many issues to address
  • Hardware
  • Software
    • Use of images, 3-D, IMRT, optimization, plan evaluation
  • Networking
    • Dosimetry devices
    • Imaging devices
    • Treatment machines
    • Oncology information system
    • Physicians’/physicists’ offices/homes

• Some capabilities not easy to test
Components of 3-D RTPS

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
Components of 3-D RTPS

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)]
Dose Calculation Algorithms

A. Scatter Integration

Superposition Principle

Beam Kernel

Slab Kernel

Pencil Kernel

Point Kernel
Dose Calculation Algorithms

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
Example Symmetry Assumptions

From Nick Linton - Elekta
National/International Reports re RTPS

- Geoff Ibbott...
National/International Reports re RTPS

• ICRU 42
  • *Use of Computers in External Beam Radiotherapy Procedures with High Energy Photons and Electrons*
  • 70 pages, 1987

• AAPM Report No. 55 (TG 23)
  • *Radiation Treatment Planning Dosimetry Verification*
  • 271 pages, 1995
National/International Protocols

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

Benedick Fraass\textsuperscript{a)}
University of Michigan Medical Center, Ann Arbor, Michigan

Karen Doppke
Massachusetts General Hospital, Boston, Massachusetts

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

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

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

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

Jake Van Dyk
London Regional Cancer Center, London, Ontario, Canada

The IEC came into being on 26-27 June 1906 in London, UK, and ever since has been giving the very best global standards to the world's electrotechnical industries. The IEC thanks industry, government, academia, end-users, and everyone else who has been involved from around the world for 100 years of commitment and partnership.
The International Electrotechnical Commission

- 68 member nations (including associate members)
- Produces standards addressing the design of electrotechnical equipment.
- Safety and performance standards apply to manufacturer’s design and construction
- Compliance tests can be *type tests*, or *site tests*
- Site tests sometimes incorporated into acceptance testing procedures
Adoption of IEC Standards

In US:

- IEC standards (or sections) incorporated into ANSI standards, FDA regulations, NEMA guidelines, etc.
- IEC standards can be used as written; FDA requires vendor to report compliance
Publications from WG-1

• Equipment for Radiation Therapy
  - Linear Accelerators
  - Cobalt Units (including Gammaknife)
  - Orthovoltage Treatment Units
  - Simulators
  - Brachytherapy Remote Afterloaders
  - Treatment Planning Systems
  - Record & Verify Systems
National/International Protocols

• For manufacturers

International Electrotechnical Commission (IEC), 2000
IEC 62083 - Safe Operation of Treatment Planning Systems

- Format of displays, units, date & time
- Data limits, transfer
- Saving and archiving data
- Equipment and source model
- Patient model
- Treatment planning
- Dose calculation
- Treatment plan report
National/International Protocols

• ESTRO 2004

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

Ben Mijnheer
Agnieszka Olszewska
Claudio Fiorino
Guenther Hartmann
Tommy Knöös
Jean-Claude Rosenwald
Hans Welleweerd

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

• Netherlands Commission on Radiation Dosimetry 2006
National/International Protocols

• IAEA TRS-430, 2004

Available in pdf format from:
New Protocol

• IAEA-TECDOC-1540
  • April 2007
• Contributors:
  • Geoffrey Ibbott
  • Rainer Schmidt
  • Jake Van Dyk
• Scientific Secretary:
  • Stanislav Vatnitsky
Upcoming Protocol

• IAEA Protocol for Commissioning of Radiation Treatment Planning Systems
  • Specific guidelines for IAEA supported systems
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
Quality Assessment
Accuracy Requirements

AAPM TG53
Sample Criteria of Acceptability

<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>A. Homogeneous Phantoms</strong></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>1.5</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>Blocked fields</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>MLC-shaped fields</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Wedged 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>2</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>SSD variations</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td><strong>B. Inhomogeneous Phantoms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab inhomogeneities</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>3-D inhomogeneities</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
</tbody>
</table>

*Absolute dose values at the normalization point are relative to a standard beam calibration point.

**Excluding regions of electronic disequilibrium.
Accuracy Requirements for IMRT

• Palta, J. 2003 AAPM Summer School Proceedings

Proposed Values of the Confidence Limits and Action levels for IMRT Planning

<table>
<thead>
<tr>
<th>Region</th>
<th>Confidence Limit* (P=0.05)</th>
<th>Action Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_1$ (high dose, small dose gradient)</td>
<td>$\pm3%$</td>
<td>$\pm5%$</td>
</tr>
<tr>
<td>$\delta_2$ (high dose, large dose gradient)</td>
<td>10% or 2 mm DTA$^\oplus$</td>
<td>15% or 3 mm DTA$^\oplus$</td>
</tr>
<tr>
<td>$\delta_3$ (low dose, small dose 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>

* Mean deviation used in the calculation of confidence limit is $\delta_1 = 100\% \times \frac{(D_{\text{calc.}} - D_{\text{meas.}})}{D_{\text{prescribed}}}$

$^\oplus$ DTA = Distance to agreement
Accuracy Requirements for IMRT

± 7%

4 mm
Accuracy Requirements for Brachytherapy

- AAPM recommends ± 2% calculation accuracy, and grid spacing 1mm x 1mm x 1mm (TG-43 update 2004)
- RPC requires agreement with benchmark plans within 5%, and 5% or 0.5 mm for single source calculations
IAEA TRS 430 Dose Calculations & Acceptance Testing

• Jake Van Dyk…
### Table 11. External Beam Dose Calculation Algorithm: Dose in Water-Like Medium Without a Beam Modifier

<table>
<thead>
<tr>
<th>Question</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>General principle of relative dose calculation</td>
<td>From interpolation in tables?</td>
</tr>
<tr>
<td></td>
<td>From analytical functions?</td>
</tr>
<tr>
<td></td>
<td>By addition of primary and scatter components?</td>
</tr>
<tr>
<td></td>
<td>By superposition of pencil beam kernels?</td>
</tr>
<tr>
<td></td>
<td>By superposition of point dose kernels?</td>
</tr>
<tr>
<td></td>
<td>By Monte Carlo calculation?</td>
</tr>
<tr>
<td></td>
<td>From a combination of the above possibilities?</td>
</tr>
<tr>
<td>If an integration (or superposition or convolution) algorithm takes place</td>
<td>What are the shape and dimensions of the volume elements?</td>
</tr>
<tr>
<td></td>
<td>What are the limits of the integration volume?</td>
</tr>
<tr>
<td></td>
<td>Is it applied differently for each of the dose components (i.e.</td>
</tr>
<tr>
<td></td>
<td>primary, scatter, etc.)?</td>
</tr>
<tr>
<td></td>
<td>Is there any correction for spectral modifications with depth?</td>
</tr>
<tr>
<td>Influence of flattening filter</td>
<td>Is there a correction for intensity and quality variation across the</td>
</tr>
<tr>
<td></td>
<td>beam (horns)?</td>
</tr>
<tr>
<td>Influence of main collimator (photons) and/or applicator (electrons)</td>
<td>Is there a correction for scatter radiation from the head and flattening filter (extrafocal)?</td>
</tr>
<tr>
<td>Dose in the buildup region</td>
<td>What is the model used to describe the profile in the penumbra region?</td>
</tr>
<tr>
<td></td>
<td>How is it adjusted to match the actual measurements?</td>
</tr>
<tr>
<td></td>
<td>Is there a difference between the x and y collimator pairs?</td>
</tr>
<tr>
<td></td>
<td>Is there any specific model to describe the dose in the buildup region?</td>
</tr>
<tr>
<td></td>
<td>Is it sensitive to patient surface obliquity? How?</td>
</tr>
<tr>
<td></td>
<td>Is it sensitive to beam modifiers, including block trays? How?</td>
</tr>
</tbody>
</table>

• Questions users should ask
Acceptance Testing

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

That is how acceptance should **not** be done!

![Old Acceptance Process]

Customer Summation:

<table>
<thead>
<tr>
<th>Site Name:</th>
<th>London Regional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address:</td>
<td>790 Commissioners Road E</td>
</tr>
<tr>
<td>City / State:</td>
<td>Radiation Oncology, London, ON N5A 6L6</td>
</tr>
<tr>
<td>Order Number:</td>
<td>92314R</td>
</tr>
<tr>
<td>Customer Site Code:</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Pinnacle Software Options Installed**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes</th>
<th>No</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicom Print</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicom Scaler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brainscan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Wedge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicom RT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicom Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinnacle Proprietary</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**System(s) setup and configured per the PRCS Installation Procedure**

- Yes
- No
- N/A

**Standard hardware and software options installed and tested**

- Yes
- No
- N/A

**Customer operation performed, including test cycle**

- Yes
- No
- N/A

**Customer shown where all documentation was stored**

- Yes
- No
- N/A

**All images import / export devices operational**

- Yes
- No
- N/A

**Exceptions**

**Order(s)**

1) 5390-5007

**Root Cause**

1) On Backorder will be installed upon arrival
How Should Acceptance Be Done?

- IAEA Protocol
  - Developed 14-18 March 2005 – Published April 2007
    - Consultants
      - Geoff Ibbott, RPC/MD Anderson CC, Texas, USA
      - Rainer Schmidt, Hanover, Germany
      - Jake Van Dyk, London, Ontario, Canada
      - Stan Vatnitsky, Scientific Secretary, IAEA

- Reference material
  - IEC 62083
  - IAEA TRS-430
  - Standard radiation data set
Appareils électromédicaux – Règles particulières de sécurité pour les systèmes de planification de traitement en radiothérapie

Medical electrical equipment – Requirements for the safety of radiotherapy treatment planning systems
From IEC 62083 (2000)

• “… This standard defines requirements to be complied with by MANUFACTURERS in the design and construction of an RTPS in order to provide protection against the occurrence of such HAZARDS.”

This has not been demonstrated for the past ~7 years!!
Tests Defined by IEC

- **Type test:** “For a particular design of device or equipment, a test by the manufacturer to establish compliance with specified criteria.”

- **Site test:** “After installation, test of an individual device or equipment to establish compliance with specified criteria.” “Note: The recommended replacement is ACCEPTANCE TEST.”

- Site test = Acceptance test
Testing Process Recommended by IAEA

- Manufacture to perform series of type tests
- 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
Examples of Type Tests in IEC 62083

<table>
<thead>
<tr>
<th>Clause</th>
<th>Requirement</th>
<th>Compliance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td><strong>General requirements for operational safety</strong></td>
<td></td>
</tr>
<tr>
<td>7.1</td>
<td>Distances and linear dimensions</td>
<td>Yes</td>
</tr>
<tr>
<td>7.2</td>
<td>RADIATION quantities</td>
<td></td>
</tr>
<tr>
<td>7.3</td>
<td>Date and time format</td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td>Protection against unauthorized use</td>
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<tr>
<td>7.5</td>
<td>Data limits</td>
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<td>7.6</td>
<td>Protection against unauthorized modification</td>
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<tr>
<td>7.7</td>
<td>Correctness of data transfer</td>
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<tr>
<td>7.8</td>
<td>Coordinate systems and scales</td>
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</tr>
<tr>
<td>7.9</td>
<td>Saving and archiving data</td>
<td></td>
</tr>
</tbody>
</table>

Next slide
Type Test Example

• 7.1 Distances and linear dimensions
  • Distance measurements and linear dimensions shall be indicated in centimetres or in millimetres but not both.

• All values of linear measurements requested, DISPLAYED, or printed shall include their units.

• Compliance is checked by inspection of the DISPLAY and output information.
## Equipment and Dosimetric Modelling

<table>
<thead>
<tr>
<th>Clause</th>
<th>Requirement</th>
<th>Compliance?</th>
</tr>
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<tbody>
<tr>
<td>8</td>
<td><strong>RADIOTHERAPY TREATMENT EQUIPMENT and BRACHYTHERAPY SOURCE MODELLING</strong></td>
<td>Yes</td>
</tr>
<tr>
<td>8.1</td>
<td>General</td>
<td></td>
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<td>8.2</td>
<td>Dosimetric information</td>
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<tr>
<td>8.3</td>
<td><strong>EQUIPMENT MODEL, BRACHYTHERAPY SOURCE MODEL acceptance</strong></td>
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<td>8.4</td>
<td><strong>EQUIPMENT MODEL, BRACHYTHERAPY SOURCE MODEL deletion</strong></td>
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</table>
### Anatomy Modelling

<table>
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<th>Requirement</th>
<th>Compliance?</th>
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<tr>
<td>9</td>
<td>ANATOMY MODELLING</td>
<td>Yes</td>
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<td>9.1</td>
<td>Data acquisition</td>
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</tr>
<tr>
<td>9.2</td>
<td>Coordinate systems and scales</td>
<td></td>
</tr>
<tr>
<td>9.3</td>
<td>Contouring of regions of interest</td>
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</tr>
<tr>
<td>9.4</td>
<td>PATIENT ANATOMY MODEL acceptance</td>
<td></td>
</tr>
<tr>
<td>9.5</td>
<td>PATIENT ANATOMY MODEL deletion</td>
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</tbody>
</table>
# Absorbed Dose Distribution Calculation

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<th>Requirement</th>
<th>Compliance?</th>
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</thead>
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<tr>
<td>11</td>
<td>ABSORBED DOSE distribution calculation</td>
<td>Yes</td>
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<tr>
<td>11.1</td>
<td>Algorithms used</td>
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</tr>
<tr>
<td>11.2</td>
<td>Accuracy of algorithms</td>
<td>No</td>
</tr>
</tbody>
</table>

- **AAPM Report 55, TG23, 1995**

- **Netherlands Commission on Radiation Dosimetry**
## Type Tests

- **Elekta**
  - 6, 10, 18 MV
- **Venselaar & Welleweerd**
- **Co-60**
- **AKH, Vienna**

### Venselaar & Welleweerd


### Table 1

Correspondence of the NCS test set and the AAPM task group 23 test set

<table>
<thead>
<tr>
<th>NCS</th>
<th>Short description of the test (dimensions in cm)</th>
<th>AAPM TG 23</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Square field, 5 × 5</td>
<td>1</td>
</tr>
<tr>
<td>1b</td>
<td>Square field, 10 × 10</td>
<td>1</td>
</tr>
<tr>
<td>1c</td>
<td>Square field, 25 × 25</td>
<td>1</td>
</tr>
<tr>
<td>2a</td>
<td>Rectangular field, 5 × 25</td>
<td>2</td>
</tr>
<tr>
<td>2b</td>
<td>Rectangular field, 25 × 5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Square field, 10 × 10, SSD = 85</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Square field, 9 × 9, wedge</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Square field, 16 × 16, central block</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Square field, 10 × 10, off-axis</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Square field, 16 × 16, blocked to L-shaped field (irregular)</td>
<td>7</td>
</tr>
<tr>
<td>8a</td>
<td>Square field, 6 × 6, lung inhomogeneity</td>
<td>8</td>
</tr>
<tr>
<td>8b</td>
<td>Square field, 16 × 16, lung inhomogeneity</td>
<td>8</td>
</tr>
<tr>
<td>8c</td>
<td>Square field, 16 × 16, bone inhomogeneity</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Square field, 10 × 10, oblique incidence</td>
<td>9</td>
</tr>
<tr>
<td>10a</td>
<td>Square field, 10 × 10, half phantom (‘missing tissue’)</td>
<td>–</td>
</tr>
<tr>
<td>10b</td>
<td>Square field, 20 × 20, half phantom (‘missing tissue’)</td>
<td>–</td>
</tr>
<tr>
<td>11</td>
<td>Asymmetrical field, 15 × 15; geometric radiation field centre at: 7.5,0; 0,7.5; 7.5,7.5</td>
<td>–</td>
</tr>
<tr>
<td>12</td>
<td>Asymmetrically wedged field, 15 × 15; geometric radiation field centre at: 17.5,0; 0,7.5; 7.5,7.5</td>
<td>–</td>
</tr>
</tbody>
</table>

*a Tests 10–12 were not included in the original set.*
Sample Type Test

- AAPM Report 55
- Therac 20 (18MV)
- SSD test case
- SSD=85 cm
  SAD=100 cm
- Field size 10x10
- Central Axis Comparison
- Measured vs Pencil beam
- +/- 2%
Sample Type Test

- AAPM Report 55
- Therac 20 (18MV)
- SSD test case
- SSD=85 cm  
  SAD=100 cm
- Field size 10x10
- Profile Comparison
- Depth 3 cm
- Measured vs Pencil beam
  - +/- 4 mm.
  - +/- 2%

![Off Axis profile graph](image)
Sample Type Test : Test 4

- AAPM Report 55
- Therac 20 (18MV)
- Wedge test case
- SSD=SAD=100cm
- Field size 9x9
- 45° wedge
- Profile Comparison
- Depth 3 cm
- Measured vs Pencil beam
- +/- 4 mm.
- +/- 2%
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%
Sample Type Test : Test 7

- AAPM Report 55
- Therac 20 (18MV)
- Irregular field test case
- SSD=SAD=100cm
- Field size 16x16
- 12x12 (w,l) block at the block tray
- Depth dose Comparison -6 cm form the central axis
- Measured vs Pencil beam
- +/- 2%
Sample Type Test: Test 4

- AAPM Report 55
- Therac 20 (18MV)
- Irregular field test case
- SSD=SAD=100cm
- Field size 16x16
- 12x12 (w,l) block at the block tray
- Profile Comparison
- 3 cm depth
- Measured vs Pencil beam
- +/- 4 mm
- +/- 2%
Sample Type Test : Test 8b

- AAPM Report 55
- Therac 20 (18MV)
- Lung Inhomogeneity test
- SSD=SAD=100cm
- Field size 16x16
- 6x12cm (w,l) lung cylinder at 8 cm deep, 0.29g/cc
- Profile Comparison
- Depth 12 cm
- Measured vs Pencil beam with EQTAR
  - +/- 4mm
  - +/- 2%
Summary: Testing Process Recommended by IAEA

- Manufacturer to perform series of “type tests”
- 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 RTPS installation
  - Results compared to results of type tests
- **Software upgrades**
  - Type tests to be repeated and document by vendor
  - Some site tests to be repeated by user
  - Depends on nature of upgrade
Acceptance Sign Off: Based on IAEA Acceptance Protocol

This is to certify that version _____________________ of the RTPS software
produced by _____________________________________________________
Name of manufacturer
is compliant with the standards described in Section 5 of this IAEA protocol.
Company representative

Name  Signature  Date  City

The type tests described above were explained to my satisfaction:

User/purchaser representative

Name  Signature  Date  City
Commissioning

• Prepare system for clinical use
  • Provides experience/training for users
  • Enter appropriate measured data
    • %DD, 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
Commissioning

- IAEA TRS-430 provides sample tests
  - System set-up/machine configuration
  - Patient anatomical representation
  - External beam commissioning
  - Brachytherapy commissioning
  - Plan evaluation tools
  - Plan output and data transfer
  - Overall clinical tests
Phantoms Assessed by IAEA

Gammex RMI

Euromechanics Medical GmbH

Standard Imaging Inc.

CIRS Inc.

Modus Medical Devices Inc.
Other Phantoms

• 3-D & IMRT QA

Med-Tec
MLC Phantom

AAPM TG 66, 2003

Modus Medical Devices Inc
MLC Phantom

- Varian 52, 80 and 120 Leaf MLCs
- Elekta
- Radionics micro-MLC

- Siemens
- Varian 120 Leaf
- Brainlab micro-MLC
Multi-Observer Test

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

- Errors $\geq 2$ mm, identified 100% of the time
- 1 mm errors identified 80% of the time
RPC Phantoms

- Geoff Ibbott...
RPC Phantoms

Pelvis (4)

Thorax (9)

H&N IMRT (25)

SRS Head (4)

Liver (2)
IMRT H&N phantom results

- 419 irradiations were analyzed
- 322 irradiations passed the criteria
  - 68 institutions irradiated multiple times
- 97 irradiations did not pass the criteria
- 322 institutions are represented

Only 76% of institutions passed the criteria on the first irradiation.
Examples of Failures
Comparison: Planned vs. Delivered Distribution
## Explanations for Failures

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Minimum # of occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>incorrect output factors in TPS</td>
<td>1</td>
</tr>
<tr>
<td>incorrect PDD in TPS</td>
<td>1</td>
</tr>
<tr>
<td>inadequacies in beam modeling at leaf ends (Cadman, et al; PMB 2002)</td>
<td>14</td>
</tr>
<tr>
<td>not adjusting MU to account for dose differences measured with ion chamber</td>
<td>3</td>
</tr>
<tr>
<td>errors in couch indexing with Peacock system</td>
<td>2</td>
</tr>
<tr>
<td>2 mm tolerance on MLC leaf position</td>
<td>1</td>
</tr>
<tr>
<td>setup errors</td>
<td>7</td>
</tr>
<tr>
<td>target malfunction</td>
<td>1</td>
</tr>
</tbody>
</table>
# Lung Phantom Irradiations

<table>
<thead>
<tr>
<th>TPS</th>
<th>Dose Calc. Algor correction on</th>
<th>Number of irradiations</th>
<th>$D_{\text{hetero}}/D_{\text{homo}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise v 2.01</td>
<td>Scatter Integ. Clarkson Type</td>
<td>2</td>
<td>1.19 ± 2.6%</td>
</tr>
<tr>
<td>BrainLab</td>
<td>Clarkson &amp; Pencil Beam</td>
<td>5</td>
<td>1.22 ± 2.2%</td>
</tr>
<tr>
<td>Eclipse</td>
<td>Pencil Beam</td>
<td>5</td>
<td>1.18 ± 4.3%</td>
</tr>
<tr>
<td>Ergo</td>
<td>3D Convolution</td>
<td>5</td>
<td>1.19 ± 0.1%</td>
</tr>
<tr>
<td>Render plan</td>
<td>Change in primary attenuation</td>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td>Pinnacle v 6.2, 6.4, 7.0g, 7.4f</td>
<td>Adaptative Convolve</td>
<td>10</td>
<td>1.13 ± 2.1%</td>
</tr>
<tr>
<td>XiO</td>
<td>Superposition/Convolution</td>
<td>5</td>
<td>1.11 ± 2.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>33</strong></td>
<td></td>
</tr>
</tbody>
</table>
# TLD Dose vs. Hetero Corrected Plan

<table>
<thead>
<tr>
<th>TPS</th>
<th>Dose Calc. Algor correction on</th>
<th>Number of irradiations</th>
<th>$D_{\text{TLD}}/D_{\text{hetero}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise v 2.01</td>
<td>Scatter Integ. Clarkson Type Clarkson &amp; Pencil Beam</td>
<td>2</td>
<td>0.99 ± 3.1%</td>
</tr>
<tr>
<td>BrainLab</td>
<td>Clarkson Type</td>
<td>5</td>
<td>0.96 ± 2.4%</td>
</tr>
<tr>
<td>Eclipse</td>
<td>Pencil Beam</td>
<td>5</td>
<td>0.96 ± 1.8%</td>
</tr>
<tr>
<td>Ergo</td>
<td>3D Convolution Pencil Beam</td>
<td>2</td>
<td>0.98 ± 3.2%</td>
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<tr>
<td>Render plan</td>
<td>Change in primary attenuation</td>
<td>1</td>
<td>0.92</td>
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<td>Pinnacle v 6.2, 6.4, 7.0g, 7.4f</td>
<td>Adaptative Convolve</td>
<td>10</td>
<td>0.99 ± 2.1%</td>
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<tr>
<td>XiO</td>
<td>Superposition/ Convolution</td>
<td>5</td>
<td>0.96 ± 2.0%</td>
</tr>
</tbody>
</table>

**Total:** 33
Convolution R-L Profile
Pencil-Beam Profile
Errors, Inconsistencies, and Misunderstandings Discovered Through Credentialing

- RTPS used incorrect grid size, displayed isodoses in error
- RTPS truncated dose value; isodose incorrect
- Errors applying NIST 1999 correction
- Misunderstandings about TG-43
- Misunderstanding of protocol, volumes
- Poor brachytherapy technique
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>
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<td><strong>Hardware</strong></td>
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<td>CPU</td>
<td>QC Test 1</td>
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<td>Digitizer</td>
<td>QC Test 2</td>
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<td>*</td>
<td>*</td>
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<td>Plotter</td>
<td>QC Test 3</td>
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<td>Backup recovery</td>
<td>QC Test 4</td>
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<td><strong>Anatomical information</strong></td>
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<td>CT (or other) scan transfer</td>
<td>QC Test 5</td>
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<td>CT geometry and density check</td>
<td>QC Test 6</td>
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<td>Patient anatomy</td>
<td>QC Test 7</td>
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<td>(photons and electrons)</td>
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<td>Revalidation (including MU)</td>
<td>QC Test 8</td>
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<td>Monitor unit</td>
<td>QC Test 9</td>
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<td>QC Test 10</td>
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<td>Electronic plan transfer</td>
<td>QC Test 11</td>
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<td>Revalidation</td>
<td>QC Test 12</td>
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<tr>
<td>Independent dosetime check</td>
<td>QC Test 14</td>
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<td>QC Test 15</td>
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<tr>
<td>TPS software recommissioning</td>
<td>Section 10.3.2.4</td>
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<td></td>
</tr>
</tbody>
</table>

1 Sonic digitizer, 2 Electromagnetic digitizer

IAEA 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 RTPS
  - New/altered data files
  - CT imager software/hardware changes
  - Machine output changes
Issues Not Addressed in Current Reports

• Issues related to IMRT, gated therapy, image guidance (tomotherapy, cone beam CT), daily dose reconstruction
• TG 100 – Methods for Evaluating QA Needs in Radiation Therapy
  • Problems with the “old approach” to QA
  • Recommended risk-assessment approach
    • Systemic approach to processes rather than “human failure”
    • Failure modes and effects analysis (FMEA)
    • Identification and prioritization of failure pathways
    • Determination of achievable QM program based on risk analysis
• Examples of application to IMRT, HDR brachytherapy
• Suggestions for applying FMEA in radiation therapy
Summary

- Formal QC program includes:
  - User training
  - Well-defined acceptance tests
  - 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
RTPS QA - Key Issues

**Education**

**Verification**

**Documentation**

**Communication**