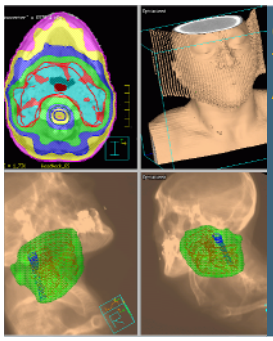
London Health Sciences Centre



Quality Assurance of Radiation Treatment Planning Systems: A Significant Challenge ?

Jake Van Dyk
London Regional Cancer Program
University of Western Ontario

University of Western Ontario

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)

Introduction

- Modern TPS
  - 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
  - IMRT
    - Step and shoot
    - Dynamic delivery

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

Benedick Fraass[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

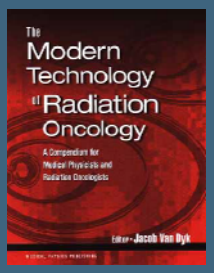
Med Phys 25:1773-829,1998

Recent References

Chapter 8

Computerized Radiation Treatment Planning Systems

Jacob Van Dyk, Robin B. Barnett, and Jerry J. Battista



1999

Recent References

- For manufacturers

NORME INTERNATIONALE — CEI IEC
INTERNATIONAL STANDARD — 62083
Première édition / First edition 2000-11

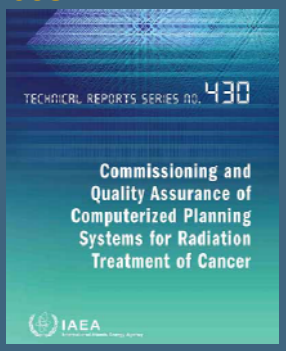
Appareils électromédicaux – Règles particulières de sécurité pour les systèmes de planification de traitement en radiothérapie

Medical electrical equipment – Requirements for the safety of radiotherapy treatment planning systems

International Electrotechnical Commission (IEC), 2000

Recent References

2004



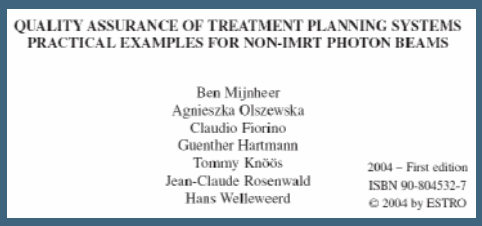
Available in pdf format from:
http://www-pub.iaea.org/MTCD/publications/PDF/TRS430_web.pdf

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

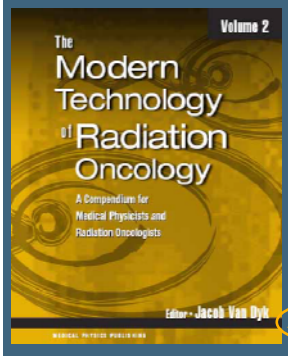

QUALITY ASSURANCE OF TREATMENT PLANNING SYSTEMS
PRACTICAL EXAMPLES FOR NON-IMRT PHOTON BEAMS

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

2004 – First edition
ISBN 90-804532-7
© 2004 by ESTRO

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

25 July 2005

Future Reference


Nederlandse Commissie voor Stralingsdosimetrie
Netherlands Commission on Radiation Dosimetry

Quality Assurance of 3-D Treatment Planning Systems
Practical guidelines for acceptance testing, commissioning and periodic quality control of radiation therapy treatment planning systems.

Members of the Task Group

I.A.D. Bruinvis, chairman
R.B. Keus
W.J.M. Langlaat
G.J. Meijer
B.J. Mijnheer
A.A. van 't Veld
J.L.M. Venselaar
J. Wellweerd
E. Wondergem

Draft

Future Reference

IAEA

Report of Consultants' Group

Protocol for Specification and Acceptance Testing of Radiation Treatment Planning Systems

Contributors: Geoffrey Ibbott, Rainer Schmidt, Jake Van Dyk
Scientific Secretary: Stanislav Vatnitsky

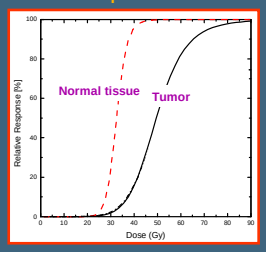
Draft 16 March 2005

2006?

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

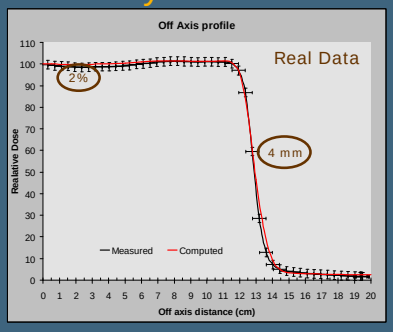
- General accuracy desired in dose delivered to patient: **5%**

	Uncertainty Type	Uncertainty Range (%)
A	Absorbed dose to reference point in water phantom	2.5
B	Determination of relative dose (Measurement away from reference point)	2.5
C	Relative dose calculations	2.5
D	Patient irradiation	2.5
E	**Overall**	**5.0**

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**

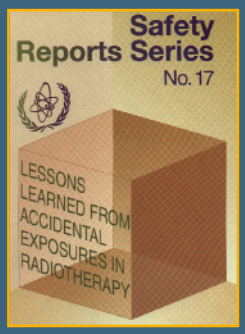


Avoidance of Treatment Errors

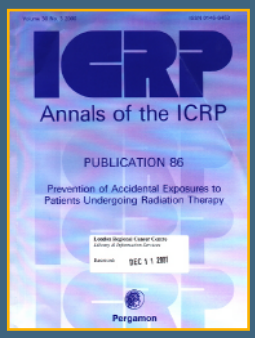
- Error
  - "The failure of planned action to be completed as intended (i.e., error of execution) or the use of a wrong plan to achieve an aim (i.e., error of planning)."

Institute of Medicine. To Err is Human: Building a Safer Health System, 2000.

Avoidance of Errors in RT



IAEA 2000



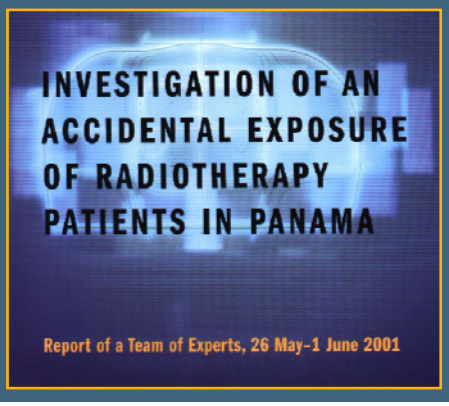
ICRP 2000

IAEA: Categories of Errors

Categories	*Number of errors*
Radiation measurement systems	5
External beam:	
Machine commissioning & calibration	15
External beam therapy:	
Treatment planning, patient setup and treatment	26
Decommissioning of teletherapy equipment	2
Mechanical and electrical malfunctions	4
Brachytherapy:	
Low dose rate sources and applicators	29
Brachytherapy: High dose rate	3
Unsealed sources	8
	92

IAEA: Lessons… Examples

Description	*Comments*
Inconsistent/incorrect data set	Lack of proper commissioning/verification
Insufficient understanding of algorithm	Lack of understanding on use of wedge factors
Incorrect calculation of treatment times	Lack of independent check
Incorrect distance correction	Lack of understanding/training Lack of independent check
Misunderstanding of complex treatment plan - verbal communication	Lack clear documentation Ineffective communication
Incorrect positioning of beams on patient	Poor implementation of instructions
Wrong source strength	Insufficient tranining/understanding No independent check
Wrong isotope	No independent check
Error in removal time	No independent check



IAEA

Discovery of Problem

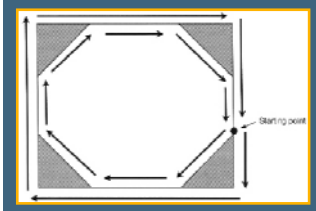
- Nov 2000, patients with prolonged diarrhoea
- Physicists reviewed plans - no anomaly
  - Double checking of plans was used
  - **No independent, manual time calc check**
- Dec 2000, similar symptoms in other patients
- Feb 2001, physicists initiated search for cause of such effects
- March 2001, physicists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

…

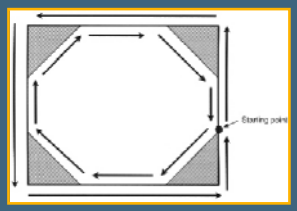
Treatment Planning Problem

- "Shortcut" method of block entry even when 4 blocks

Two approaches

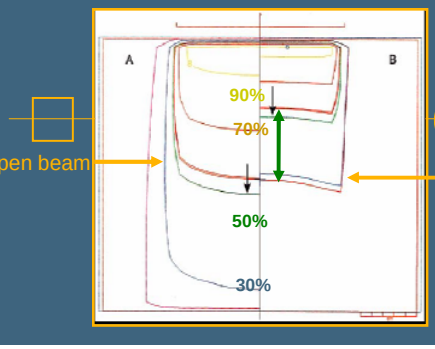


Time incorrect



Time correct

Identification of Problem



Open beam

Blocks entered together with two CW contours

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

Components of 3-D TPS

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

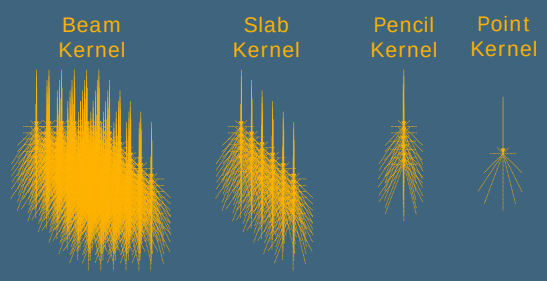
- All algorithms have two major attributes:

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

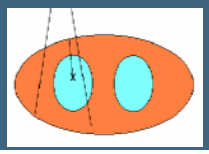
A. Scatter Integral

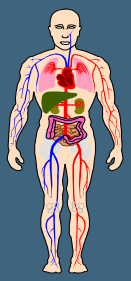
Superposition Principle



B. Use of Anatomy Data

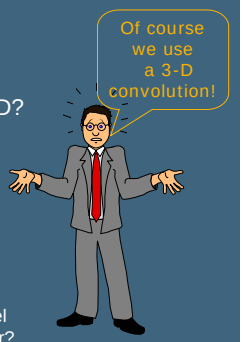
- Patient's Anatomy
  - As imaged by CT, MR, PET, etc
  - Geometry and density
    - As sensed by algorithm
  - Symmetry assumptions
- 1-D, 2-D, 2.5-D, or 3-D matrix





If you are buying...

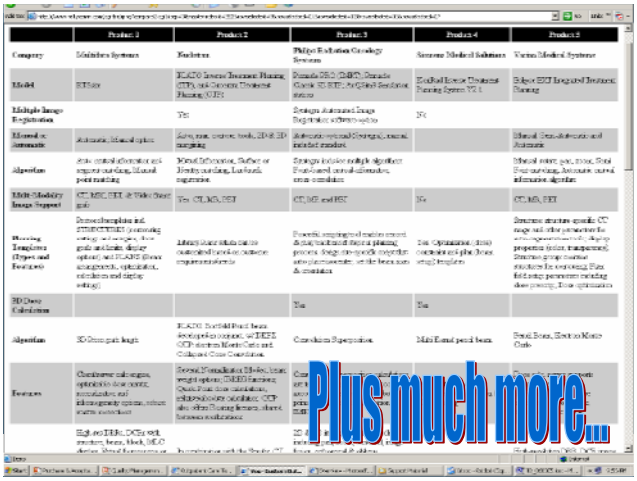
- Does the algorithm "feel" the anatomy voxels in 1-D? 2-D? 3-D?
- Is the algorithm
  - 0-D,1-D, 2-D or 3-D in its scatter integration?
  - Does the algorithm handle electron transport?
  - Does it use a point kernel or a pencil beam kernel?
  - How is the primary TERMA and kernel changed with density?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



http://www.opctonline.net/

- Interesting background information

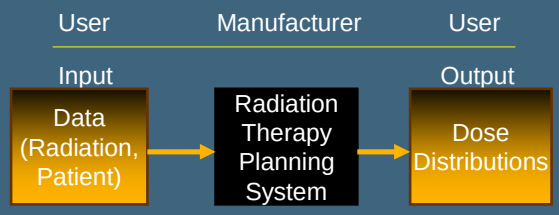
http://www.opctonline.net/



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

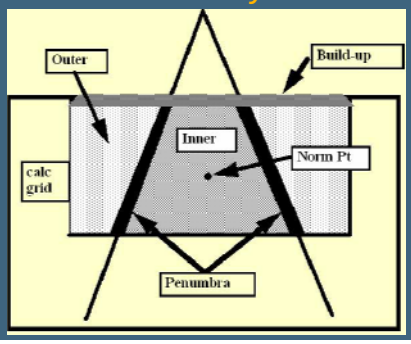
Commissioning and QA of TPS



Compare to expected results

Commissioning: Initial tests
Quality control: Reproducibility

Regions of Different Dose Calculation Accuracy



AAPM TG53

Sample Criteria of Acceptability

IAEA TRS 430

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	-

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

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

Type Tests

- Elekta
- 6, 10, 18 MV

Venselaar & Welleweerd Radioth Oncol 60: 203-213, 2001.

Table 1
Correspondence of the NCS test set and the AAPM task group 23 test set[a]

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

[a] Tests 10–12 were not included in the original set.

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

TABLE 36. STEPS IN DOSE CALCULATION COMMISSIONING

Step	Goal	Description
1	Create a commissioning plan (Section 9.4.1.3)	Identify the algorithm type Identify specific issues for special attention Define an efficient plan for data collection, dose distribution comparisons and analysis of results
2	Obtain measured data (Section 9.4.1.4)	Plan, measure, transfer, analyse and prepare data for use
3	Check input data (Section 9.4.1.5)	Verify the correctness of input data
	(a) Configuration parameters	Confirm machine–beam configuration parameters
	(b) Algorithm input data	Verify that input data have been entered correctly
	(c) Model parameters	Determine beam model fitting parameters
4	Perform calculation checks (Section 9.4.1.6)	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
	(a) Beam specific calculation checks	Compare beam specific calculations with measured data to confirm that beam specific parameters are correctly set and that calculations give good results
	(b) Algorithm specific investigations	Test algorithms to confirm the proper behaviour of the algorithm Document algorithm accuracy on a test or benchmark data set Investigate specific algorithm issues
	(c) Clinical calculation verification	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
5	Calculation comparison and analysis (Section 9.4.1.7)	Verify calculation techniques and plan comparison tools

IAEA TRS 430

Phantoms

- IMRT & 3-D QA

Med-Tec

QA of the Non-Dosimetric Components of a TPS: *QUASAR®*

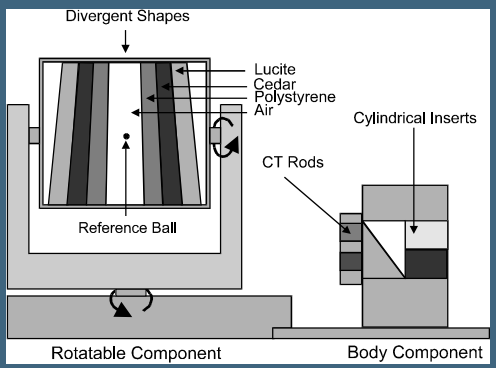
Disclosure

- 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:
  - *A Quality Assurance Phantom for Three-Dimensional Radiation Treatment Planning.* Craig, T.C., Brochu, D., Van Dyk, J. Int. J. Radiat. Oncol. Biol. Phys., 44, 955-966, 1999.
  - *A Multileaf Collimator Phantom for the Quality Assurance of Radiation Therapy Planning Systems and CT Simulators.* McNiven, A., Kron, T., Van Dyk, J. Int. J. Radiat. Oncol. Phys. Biol. 60, 994-1001, 2004.

Non-Dosimetric Issues

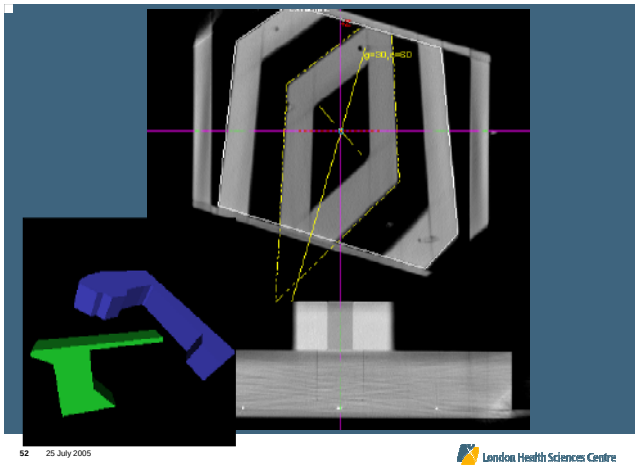
- Image acquisition and transfer
- Beam display
- CT image reconstructions
  - Multiplanar CT image reconstructions
  - Digitally reconstructed radiographs
- Anatomical volumes
  - 3-D display
  - Automatic tools - autocontouring, automargin, etc
  - Dose volume histograms
- CT numbers to electron density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

Phantom Schematic

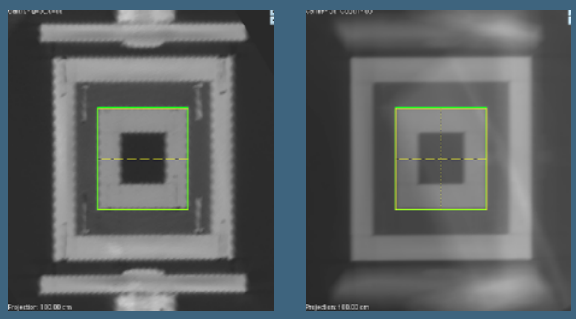


Commercial Version of QA Phantom

Modus Modus Medical Devices, London, Ontario



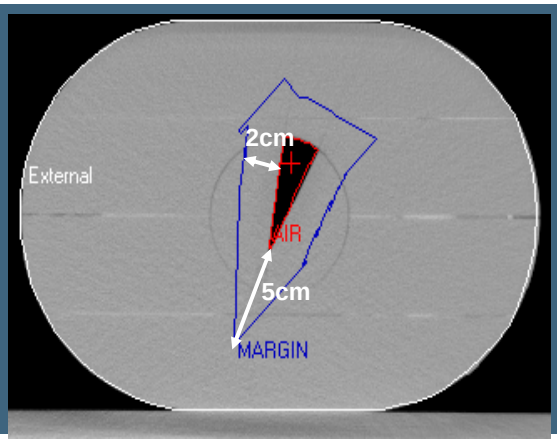
Reconstructed Image Verification

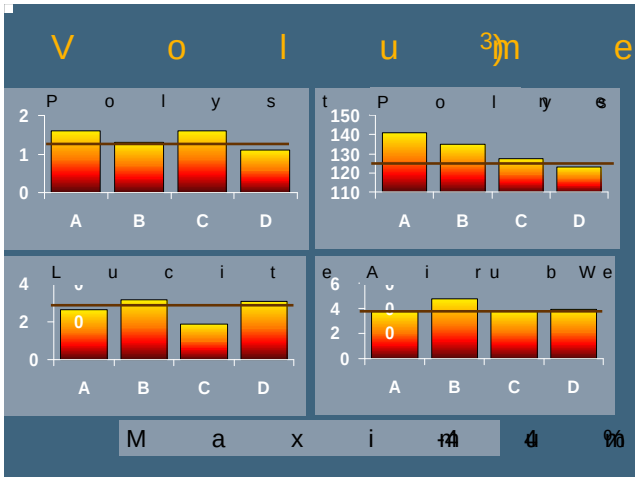


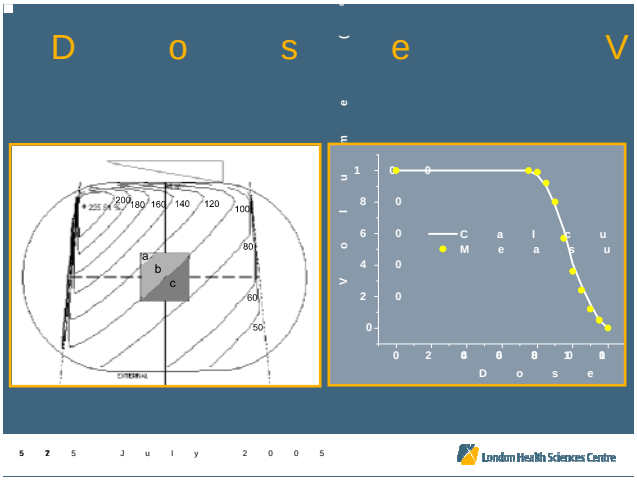
Oblique CT reconstruction | Digitally reconstructed radiograph

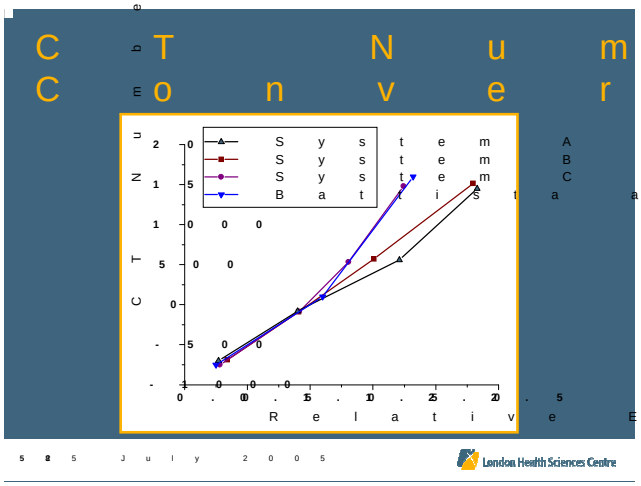
Multi-Institution Evaluation

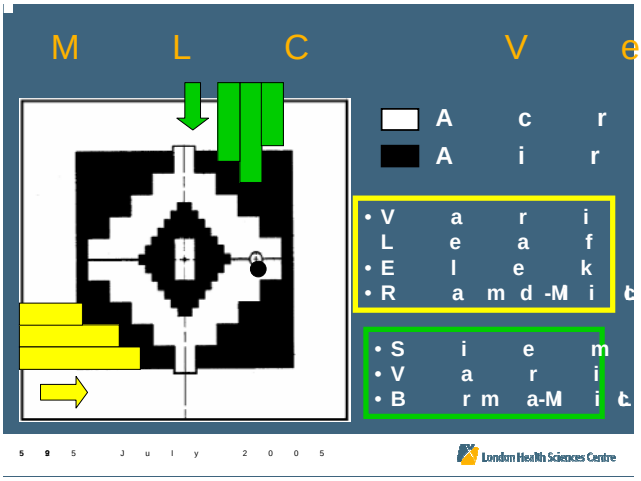
- Phantom used to evaluate 3 TPSs and 1 CT simulator
  - Picker ACQSIM
  - Varian CADPlan
  - ADAC Pinnacle
  - Theratronics TheraplanPlus




Volume
Polys
Polys
Lucite
Air
A B C D
Max


Dose
Calcu
Meas
Dose
25 July 2005
London Health Sciences Centre


CT Number
Converter
System A
System B
System C
Bath
Relative

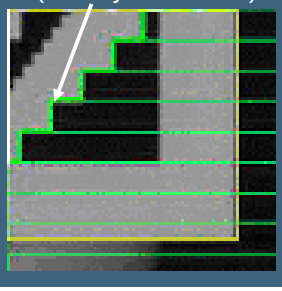

MLC
Acr
Air
• Varia
Leaf
• Elek
• Rand-Mid
• Sim
• Varia
• Brma-Mid
25 July 2005
London Health Sciences Centre

MLC Phantom

AAPM TG 66, 2003

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

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

Quality Control

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

Subject	Test	PS	W	M	Q	A	U
Hardware							
CPU	QC Test 1			*			*
Digitizer	QC Test 2		*[1]	*[2]			*
Plotter	QC Test 3				*		*
Backup recovery	QC Test 4				*		*
Anatomical information							
CT (or other) scan transfer	QC Test 5	*					*
CT geometry and density check	QC Test 6				*		*
Patient anatomy	QC Test 7	*					*
External beam software (photons and electrons)							
Revalidation (including MU)	QC Test 8	*				*	*
Monitor unit	QC Test 9	*					
Plan details	QC Test 10	*		*			
Electronic plan transfer	QC Test 11	*		*		*	*
Brachytherapy							
Revalidation	QC Test 12					*	*
Plan details	QC Test 13	*					
Independent dose/time check	QC Test 14	*					
Electronic plan transfer	QC Test 15	*		*		*	*
TPS software recommissioning	Section 10.3.2.4						

[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 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

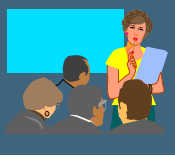
Key Issues

Education

Documentation

Verification

Communication



Summary

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