Commissioning and Quality Assurance of Modern Radiation Treatment Planning Systems

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Outline

- Motivation
- General process of development of treatment planning programs
- Commissioning/QA concepts
- Components of QA program
  - Dose calculation issues
  - Non-dosimetric issues
- Summary/Conclusions

IAEA Website June 2001

The team found that it was possible to enter data in one batch for several shielding blocks in different ways; and that for some ways of entering the data, which were accepted by the treatment planning system, the output values were calculated incorrectly. However, whichever way was used, the computer produced a printout drawing that showed the treatment field and the shielding blocks as if the data had been entered correctly. The isodose curves for a single treatment field are somewhat different, but for multiple treatment fields the differences are not so obvious. (It should be noted that, for irradiation treatments in the pelvic region, which was the region of treatment for all the patients concerned, multiple treatment fields are always used in the Institute .) 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.

The IAEA team was informed that, of the 28 patients concerned, eight have since died; and the team confirmed that five of these deaths are probably attributable to the patients' overexposure to radiation.

Of the surviving 20 patients, most injuries are related to the bowel, with a number of patients suffering persistent bloody diarrhoea, necrosis (tissue death), ulceration and anaemia. About three-quarters of the surviving 20 patients may be expected to develop serious complications, which in some cases may ultimately prove fatal.

Quality Assurance in Radiotherapy

- WHO, 1988

  "all those procedures that ensure consistency ... and ... safe fulfillment of the medical prescription … re ... target volume, ... minimal dose to normal tissue, minimal exposure of personnel, and adequate patient monitoring aimed at determining the end result of treatment."

Quality Control

ISO 9000, 1994. "… the regulatory process through which the actual quality performance is measured, compared to existing standards and finally the actions necessary to keep or regain conformance with the standards"

Components
- Specifications
- Measurement → **Reference data**
- Inspection of result
- Feedback/Action

Reference Data for Quality Assurance Generic

- System specifications
  - Defined by vendor
  - Defined by user - tender document
- System performance
  - Acceptance
  - Commissioning
- User performance
  - Quality of plans
    - Number of replans
  - Assessment of incidents/errors

Reference Data for Quality Assurance Specific

Procedure	Standard
Acceptance	Specifications
Quality control	
• RTPS output	Input data Commisioning data Phantom/image data
• Staff performance	Timeliness Number of replans Physician satisfaction Incidents/errors

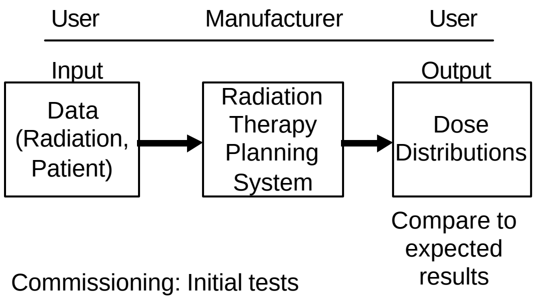
Components of 3-D Radiation Therapy Planning System

- Hardware
- Input [digitizer, image data (networked)]
- Image manipulation and display
- Target volume/normal tissue delineation
- Volume rendering

Components of 3-D Radiation Therapy Planning System

- Beam geometry (virtual simulation)
- Dose calculations
- Dose volume histograms/evaluation tools
- Digitally reconstructed radiographs
- Output [hardcopies, network (RTOG)]

Commissioning and QA of RTPS



Commissioning: Initial tests
Quality control: Reproducibility

Commissioning

- Implementation of RTPS into clinical use
- Process
  - Enter appropriate measured data
    - %DD, TAR, TPR, beam profiles, wedge profiles, attenuation data, output factors, etc.
  - Perform series of commissioning tests
  - Assess results to see if they comply with *specifications*

Components of QA Program

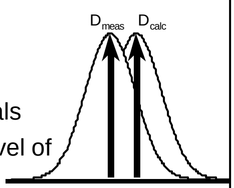
- Program & system documentation
- User training
- Sources of uncertainties
- Suggested tolerances
- Initial system checks (commissioning)
- QC - repeated system checks
- QC - "manual" checks (patient specific)
- QC - *in vivo* dosimetry
- QA - administration

User Training

- Manufacturer's training course
- Staff training
  – Special time set aside
  – Predefined projects
  – On-the-job training - closely monitored
  – Document limitations of algorithms
  – Document special procedures
  – On-going review & in-service training

Criteria of Acceptability

- Dependent on
  – Sources of uncertainties
  – Practically achievable
    • Algorithm capabilities
  – Do ***not*** represent *ideal* goals
  – Should Indicate at what level of probability
    • 1SD, 2SD, etc.



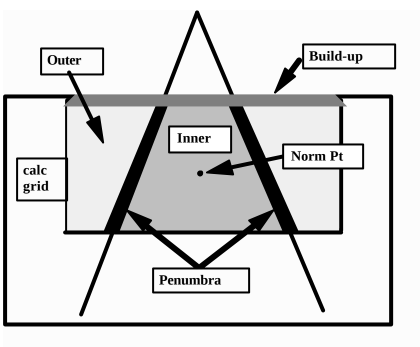
Criteria of Acceptability

- RTPS uncertainties tend to be systematic
  – Can be dependent on user parameters
    • # grid points, # pencils, etc.

Sources of Uncertainty

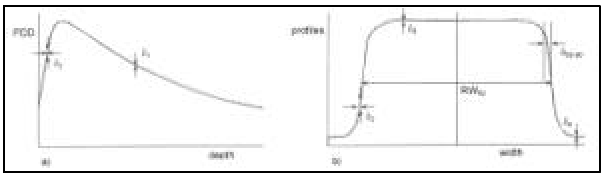
- Measured radiation data
- Measured patient data
- Data input, e.g., digitizer
- Algorithms
- Calculation parameters, e.g., grid spacing
- Data output, display/hardcopy

Regions of Different Dose Calculation Accuracy



AAPM TG53

Example Criteria of Acceptability External Photon Beams



Venselaar *et al* 2001

Example Criteria of Acceptability External Photon Beams

Tolerance	Homogeneous Simple	Complex Wedge, inhom, Asymmetry	More complex Combinations
δ_1 (central ray)	2%	3%	4%
δ_2 (build-up, pen)	2mm or 10%	3mm or 15%	3mm or 15%
δ_3 (off central ray)	3%	3%	4%
δ_4 (outside beam)			
wrt central ray	3%	4%	5%
local dose	30%	40%	50%
RW_{50} (radiol width)	2mm or 1%	2mm or 1%	2mm or 1%
δ_{50-90}	2mm	3mm	3mm

Venselaar *et al* 2001

Example Criteria of Acceptability External Beam

	Photon	Electron
Anthropomorhic phantom		
• Hi dose, lo dose gradient	4%	7%
• Hi gradient	4 mm	5 mm
• Lo dose, lo gradient	3%	5%

Van Dyk *et al* 1993

Goal		
• Hi dose, lo gradient	2%	2%
• Hi gradient	2 mm	2 mm
• Lo dose, lo gradient	2%	2%

ICRU 42, 1987

Treatment Planning System Quality Control Reference Data

Feature	*Reference*
Input	Known contours Phantom images
Image usage	Phantom images
Target/tissue volumes	Phantom images
Volume rendering	Phantom images
Beam geometry	Phantom images
Dose calculations	Measurements Calculations Published data
DVH	Phantoms/calculations
DRR	Phantom images
Output	Input/known geometry

Measured Data

- Basic data required for commissioning
  - Defined by vendor
- Data for assessing algorithms
  - Defined by user
- Anthropomorphic phantom data
  - Defined by user

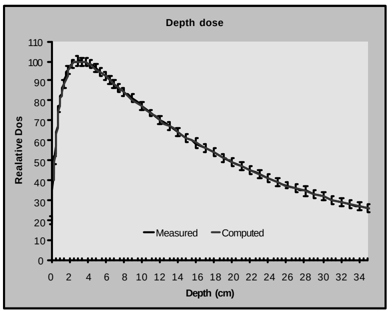
Initial Tests

Point Doses

- Compare calculated and experimental data
  - Examples
  - All available energies
  - TAR, TPR, %DD (5x5, 10x10, 35X35)
  - TAR, TPR, %DD (5x10, 5x20, 5x30)
  - TAR, TPR, %DD (Irregular fields)
  - Inverse-square correction
  - Effects of attenuators (wedge, compensator, etc.)

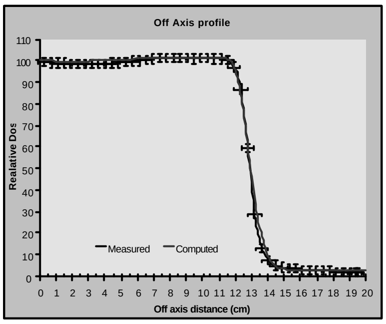
Commissioning Data Example

- **AAPM Report 55**
- Therac 20 (18MV)
- Square field test
- Field size 5x5
- SSD=SAD=100 cm
- Central Axis Comparison
- Measured vs. Pencil beam
- +/- 2%



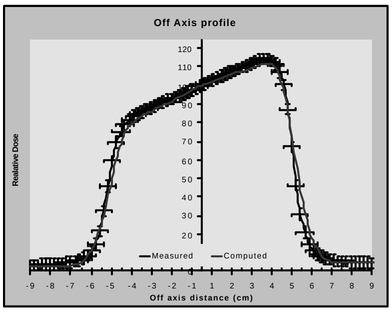
Commissioning Data Example

- **AAPM Report 55**
- Therac 20 (18MV)
- Rectangular field test
- SSD=SAD=100 cm
- Field size 25x5
- Profile Comparison
- Depth 3 cm
- Measured vs. Pencil beam
- +/- 4 mm.
- +/- 2%



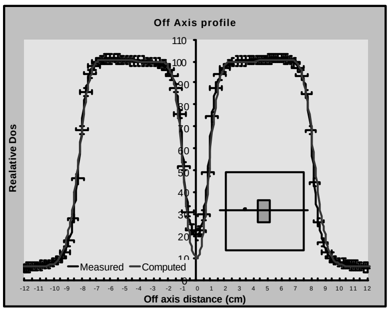
Commissioning Data Example

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



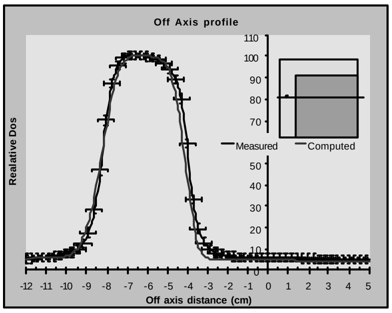
Commissioning Data Example

- **AAPM Report 55**
- Therac 20 (18MV)
- Central axis block test case
- SSD=SAD=100cm
- Field size16x16
- 1x4x7 cm (w,l,t) block at the block tray
- Profile comparison
- 3cm depth
- Measured vs. Pencil beam
- +/- 4 mm
- +/- 2%



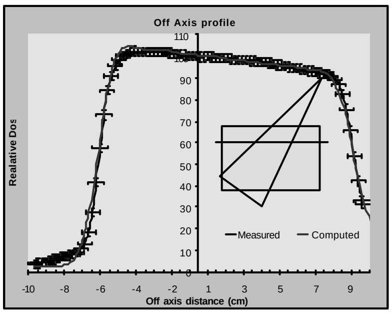
Commissioning Data Example

- **AAPM Report 55**
- Therac 20 (18MV)
- Irregular field test case
- SSD=SAD=100cm
- Field size16x16
- 12x12 (w,l) block at the block tray
- Profile Comparison
- 3 cm depth
- Measured vs. Pencil beam
- +/- 4 mm
- +/- 2%



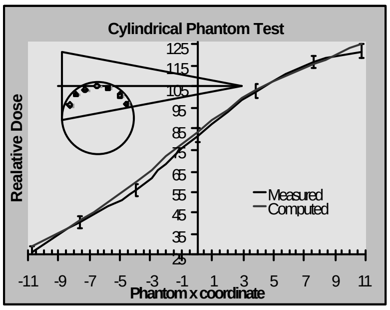
Commissioning Data Example

- **AAPM Report 55**
- Therac 20 (18MV)
- Oblique Incidence test
- SSD=SAD=100c m
- Field size10x10
- Gantry 45º
- Profile Comparison
- Depth 3 cm
- Measured vs. Pencil beam
- +/- 4mm
- +/- 2%



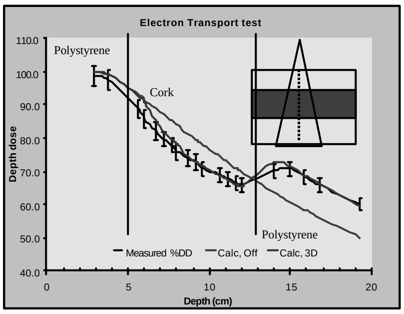
Commissioning Data Example

- **Cobalt test**
- 780C Cobalt 60
- Cylindrical Phantom
- SAD=80cm
- Field size10x10
- Scatter Comparison
- Measured vs. Pencil beam
- +/- 3%



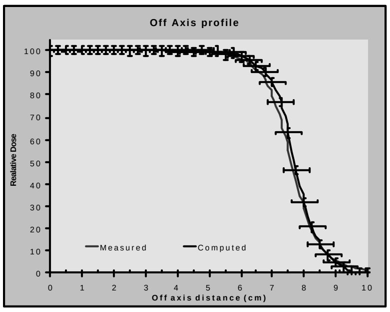
Commissioning Data Example

- Electron transport test
- 18 MV
- Field size 5x5
- 8 cm slab of cork
- Starting at 5 cm deep
- Measured vs. Pencil beam and EQTAR
- +/- 3%



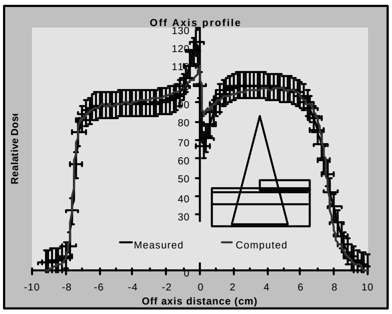
Commissioning Data Example

- **ECWG test**
- 9 MeV electron
- Field size 15x15
- SSD=100
- Profile comparison
- Depth 2.25 cm
- Measured v.s. Pencil beam
- +/- 4 mm
- +/-2%



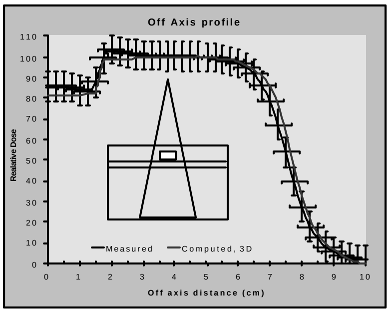
Commissioning Data Example

- **ECWG test**
- 9 MeV electron
- 90º step (Expt. #8) Field size 15x15
- SSD=100
- Profile comparison
- Depth 0.5 cm
- Measured vs. Pencil beam
- +/- 4 mm
- +/-7%



Commissioning Data Example

- **ECWG test**
- 9 MeV electron
- 2D bone (Expt. #12)
- Field size 15x15
- SSD=100
- 3x18x1cm (w,l,t) air cavity 1 cm deep
- Profile comparison
- Depth 2.3 cm
- Measured v.s. Pencil beam
- +/- 4 mm
- +/-7%



Largest Discrepancies

- Venselaar *et al* (Radioth Oncol 60: 203-213; 2001)
  - Irregular field geometry
  - Missing tissue geometry in build-up
  - Asymmetrical wedged fields
- Declich *et al* (Radioth Oncol 52: 69-77; 1999)
  - Under long narrow block
  - Long rectangular fields, outside of field

Sample Reproducibility Tests

Test	*Occasion*	*Wkly*	*Mnthly*	*Qurtrly*	*½ Yrly*
Hardware					
• Memory	Power on		*		
• Digitizer		*			
• Plotter		*			
• Video display				*	
CT (other) scan transfer	*			*	
External beam software					
(Photons & electrons)					*
• Data set					*
• Reference field size plan					*
• Non-reference field plan					*
• Beam parameters					*
• Interactive beam options					*
• Monitor units	Each patient				

- Or whenever there are software upgrades
- Develop complex plan(s) to check for reproducibility

Van Dyk *et al* 1993, IPEMB 1994

Quality Assurance of the Non-Dosimetric Components of a Treatment Planning System

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Disclosure

- The QA phantom about to be described is now a commercial product
  - Invented by the authors
  - Produced by Modus Medical Devices, London, Ontario

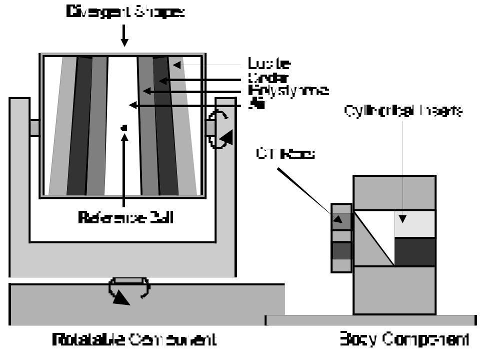
Motivation

- QA of RTPS
  - Previous emphasis
    - Dose calculation algorithms
  - Little on quality of other features of 3-D TPS
    - Images
    - Geometries
    - Automatic tools
- Will describe
  - Phantom to assess non-dose parameters

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



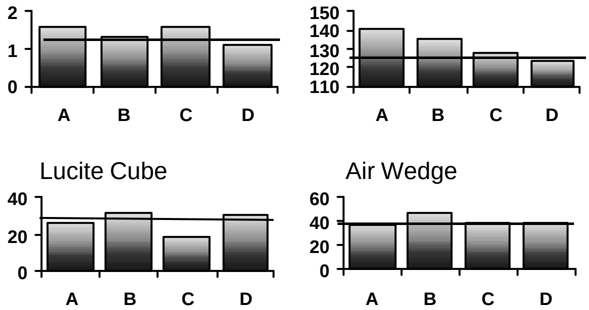
Commercial Version of QA Phantom

Modus Medical Devices Inc., London, Ontario, Canada

Multi-Institution Evaluation

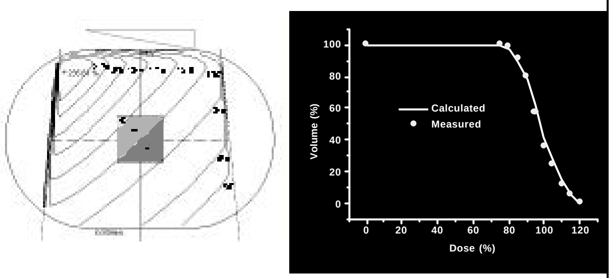
- Phantom used to evaluate 3 TPSs and 1 CT simulator
  - Picker ACQSIM
  - Varian CADPlan
  - ADAC Pinnacle
  - Theratronics TheraplanPlus

Volume Measurements (cm^3)



Maximum variation +42% to -44%

Dose Volume Histograms



Conclusions 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

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

Summary

- Therapy machine QC is standard practice
- RTPS QC not nearly as well-defined
  - Difficult to define *uniquely*
- RTPS QC is ***necessary*** & important to ensure safe and accurate patient treatments

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

Conclusions

- **RTPS QA difficult to define *uniquely***
  - Different features
  - Different input data
  - Therefore, different reference data

Conclusions

- **Reference data required for QA**
  - Data entry (basic radiation data)
  - Patient data entry
    - Contour (standard)
    - Image (phantom)
  - Data transfer (CT scan of phantom)
  - Dose calculations
    - Photons, electrons, brachytherapy

Conclusions

- **Reference data required for QA (cont'd)**
  - Volume/DVH
    - Phantoms/calculations
  - DRR (phantom images)
  - Output (known geometries)
- **Process QA**
  - Incident/error rate
  - Number of replans
  - Timeliness
  - Physician satisfaction

Conclusions

QA: Education & Training
- crucial and pervasive

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AAPM Refresher Course TU-A-BRA-1, July 24 2001
Jake Van Dyk

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