Departments of Oncology and
Medical Biophysics

Introduction and Overview: Determination, Minimization and Communication of Uncertainties in Radiation Therapy

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Disclosures

- None ... except I am involved with ...

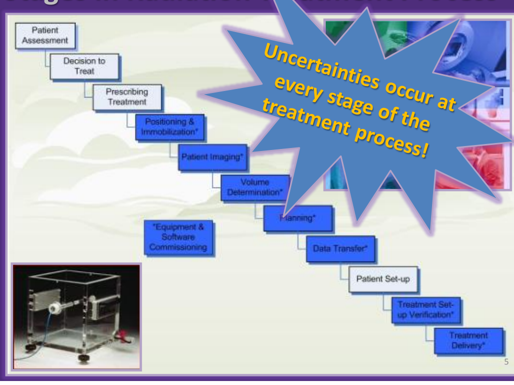
Adapted from: http://www.vbpm.org/resilience-efficiency/risk-uncertainty/

"Uncertainty": Wikipedia

- "A term used in subtly different ways in a number of fields including philosophy, physics, statistics, economics, finance, insurance, psychology, sociology, engineering, and information science."
- "It applies to predictions of future events, to physical measurements that are already made, or to the unknown."
- "Uncertainty arises in partially observable and/or stochastic environments, as well as due to ignorance and/or indolence."

http://en.wikipedia.org/wiki/Uncertainty

Stages in Radiation Treatment Process



Uncertainties in Radiation Therapy

- Scientific Uncertainty

- Human Uncertainty

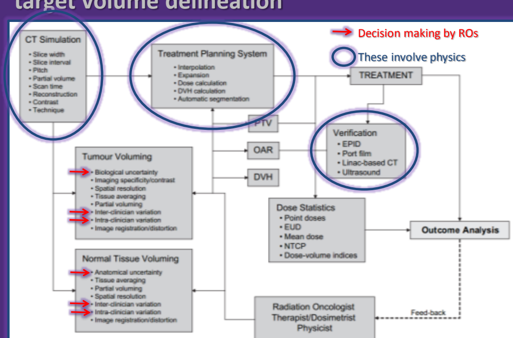
Scientific Uncertainty

- Medical Physicists' task
  - Minimize uncertainties in radiation treatment
    - Dose uncertainties
      - Calibration
      - Machine commissioning
      - Treatment planning computer commissioning
      - Dose delivery
    - Geometric uncertainties
      - Imaging uncertainties
      - Determination of patient anatomy
      - Determination of patient-beam geometry

Human Uncertainty

- Decision making
  - Diagnosis
  - Patient staging
- Target volume definition
- Normal tissue definition

Factors involved in volumetric uncertainty in target volume delineation

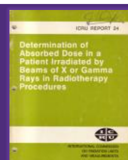


Hamilton & Ebert, Clin. Oncol 17: 456-464; 2005

Uncertainties

- New technologies … IMRT, IGRT, 4-D
  - Purpose
    - Minimize toxicity and maximize tumor dose
      - … allows for dose escalation
      - … allows for increases in dose/fraction
- Further clinical gain with new technologies
  - May be limited by ***uncertainties*** in various stages of treatment process

History … Accuracy



- 1970s-1980s: 2-D RT era
  - ICRU Report 24
  - "… need for an accuracy of ±5% the in the delivery of an absorbed dose to a target volume …"
- 1980s-1990s: 3-D CRT era
  - 3.5% (1 σ) at specification point and 5% at other points in PTV for combined Type A and B uncertainties … this required accuracy cannot always be achieved even for simple geometries.
    - Dutreix, Brahme, Mijnheer, Wambersie

Issues

- Reports on accuracy requirements mostly written in 2-D to 3-D CRT era
- Emphasis on dose to reference point in the target volume
- Technology has evolved
  - 2-D RT to 3-D CRT to IMRT, IGRT, 4-D & motion management

Uncertainty Modeling – 1985

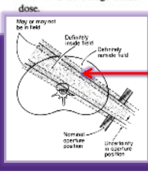
Calculation of the uncertainty in the dose delivered during radiation therapy[a)]

Michael Goitein
Division of Radiation Biophysics, Department of Radiation Medicine, Massachusetts General Hospital Cancer Center, Boston, Massachusetts 02114 and Harvard Medical School

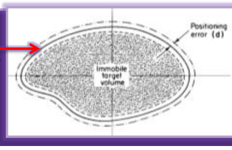
(Received 4 February 1985; accepted for publication 10 May 1985)

There is, inevitably, uncertainty in our knowledge of the dose at any point within an irradiated patient. A technique is presented for estimating this uncertainty by performing three parallel calculations, one using nominal values and the others extreme values of the parameters upon which the dose depends. Such calculations can be made with almost any algorithm for calculating dose. They result in an estimate, at some specified confidence level which is determined by the data used, of the range of dose likely at any point. Such calculations should help therapists to avert over- or underdosage which might not be evident in conventional calculations of the nominal dose.

Medical Physics 12: 608-612; 1985



"Zone of Uncertainty"



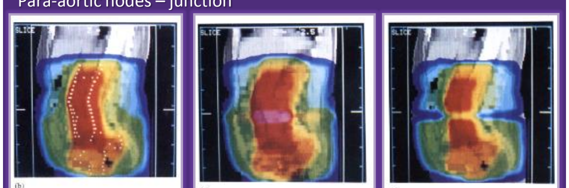
THE ROLE OF UNCERTAINTY ANALYSIS IN TREATMENT PLANNING

M. M. Urie, Ph.D.,[4] M. Goitein, Ph.D.,[4] K. Doppke, M.S.,[2] J. G. Kutcher, Ph.D.,[2] T. LoSasso, Ph.D.,[2] R. Mohan, Ph.D.,[2] J. E. Munzenrider, M.D.,[4] M. Sontag, Ph.D.[1] and J. W. Wong, Ph.D.[3]

[1]University of Pennsylvania School of Medicine and the Fox Chase Cancer Center, Philadelphia, PA 19111; [2]Memorial Sloan-Kettering Cancer Center, New York, NY 10021; [3]Mallinckrodt Institute of Radiology, Washington University School of Medicine, St. Louis, MO 63110; and [4]Massachusetts General Hospital, Department of Radiation Medicine, Boston, MA 02114 and Harvard Medical School

Photon Treatment Planning Collaborative Working Group. IJROBP 21:91-107; 1991

Para-aortic nodes – junction



Nominal | "Upper bound" Misregistered by 1 cm | "Lower bound" Misregistered by 1 cm

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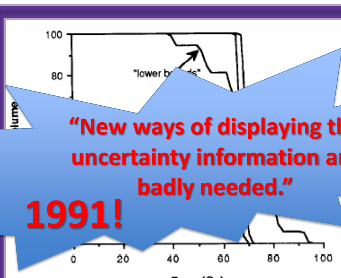
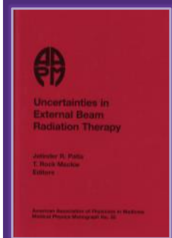
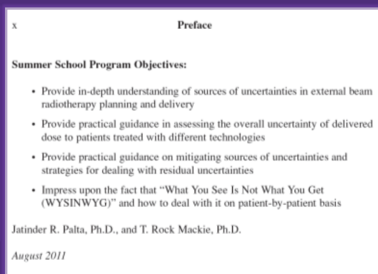


"New ways of displaying the uncertainty information are badly needed."

1991!

2011 AAPM Summer School




x Preface

Summer School Program Objectives:

- Provide in-depth understanding of sources of uncertainties in external beam radiotherapy planning and delivery
- Provide practical guidance in assessing the overall uncertainty of delivered dose to patients treated with different technologies
- Provide practical guidance on mitigating sources of uncertainties and strategies for dealing with residual uncertainties
- Impress upon the fact that "What You See Is Not What You Get (WYSINWYG)" and how to deal with it on patient-by-patient basis

Jatinder R. Palta, Ph.D., and T. Rock Mackie, Ph.D.

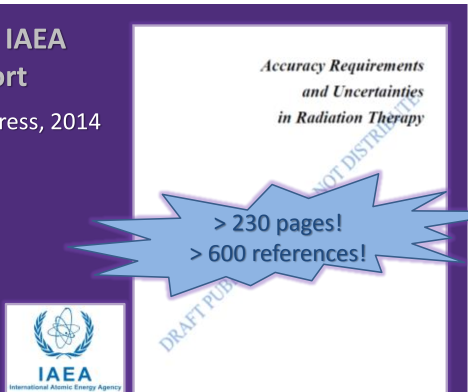
August 2011

2011 AAPM Summer School Summary

- 27 Chapters
- Considers all aspects of dosimetric uncertainties
  - Each stage of treatment process
  - In individual chapters
- No grand summary
- No specific consensus recommendations other than what is in individual chapters

New IAEA Report

- In press, 2014



Objective of IAEA Report

- To provide an "*international guidance document on accuracy requirements and uncertainties in radiation therapy in order to reduce these uncertainties to provide safer and more effective patient treatments*".

IAEA Draft Report

Nine recommendations:

1. Accuracy statement … AAARA, technical & biological …
2. Implement ICRU reports and/or other recognized consensus group recommendations
3. Sample guide of uncertainty estimates for both external beam & brachytherapy
4. Independent dosimetry audit
5. Implement comprehensive QA program
6. Appropriate education and training
7. Uncertainty estimates should be reported in publications
8. Training by vendors on use of technologies
9. Areas for further research

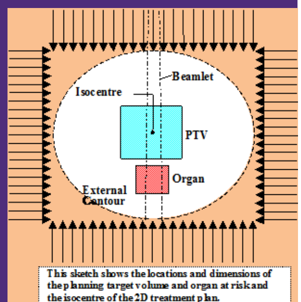
Areas for Further Research …

- *Display of uncertainties as part of the treatment planning process*
  - "… Further research is required into practical methods of displaying and using treatment uncertainties as an aid to decision making and as a means of developing robust treatment plans that minimize the impact of uncertainties and provide a maximum therapeutic benefit for the patient."

Impact of Uncertainties on Plan Optimization

Eugene Wong, 12th ICCR, 1997

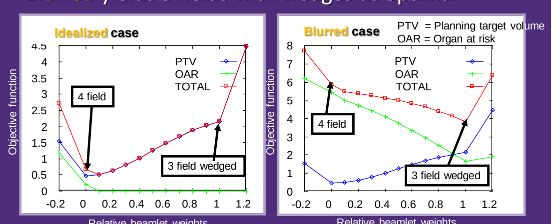
- Schematic PTV and critical organ
- Four 6 MV fields with 17 beamlets each
- 68 beamlet weights are varied between 0 and 1 for optimization



Impact of Uncertainties on Plan Optimization

Eugene Wong, 12th ICCR, 1997

- Objective function plotted for "ideal" and "blurred"
- Ideal yields 4 field technique as optimal
- Blurred yields 3 fields with wedges as optimal



Impact of Uncertainties on Plan Optimization

Eugene Wong, 12th ICCR, 1997

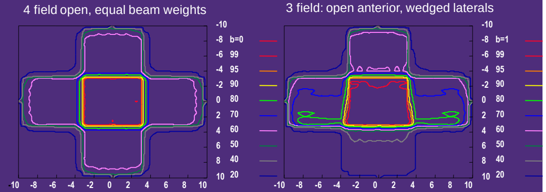
- Dose distributions for ideal and blurred optimized techniques

Optimized: No uncertainties

4 field open, equal beam weights

Optimized: With uncertainties

3 field: open anterior, wedged laterals



Impact of Uncertainties on Plan Optimization

Eugene Wong, 12th ICCR, 1997

- Conclusions - Technique Optimization
  - Predicted outcome is strongly dependent on uncertainties propagated through treatment process.
  - Optimized plans are affected by uncertainties.
  - Proper optimization requires uncertainty information.

Communicating Uncertainties

- **"It's more than just error bars"**
- How do radiation oncologists know about levels of uncertainty in their treatment plans?
  - We tell them … usually "guestimates"
  - We show them data
    - Commissioning data
    - Published data
      - E.g., Inter- & intra-physician target volume delineation
      - Audit data of calibrations, TPSs, QA center end-to-end tests
    - In planning process, we ask physician's preferences
      - If there is a significant uncertainty, do you prefer a higher dose or a lower dose to …?

This Symposium

- Learning Objectives
  - To review uncertainty determination in the overall radiation treatment process.
  - To consider uncertainty modeling and uncertainty propagation.
  - To highlight the basic ideas and clinical potential of robust optimization procedures to generate optimal treatment plans that are not severely affected by uncertainties.
  - To describe methods of uncertainty communication and display.

This Symposium …

- Introduction & Overview
  - Jake Van Dyk, Professor Emeritus, Western University, London, Canada
- Dose Uncertainty Modeling
  - Jatinder Palta, Professor & Chairman Medical Physics, Radiation Oncology Virginia Commonwealth University, Richmond, VA.
- Robust Optimization Accounting for Uncertainties
  - Thomas Bortfeld, Professor, Francis H Burr Proton Therapy Center, Massachusetts General Hospital, Boston, MA
- Communication of Uncertainties in Radiation Therapy
  - Ben Mijnheer, Dept of Radiation Oncology, Netherlands Cancer Institute, Amsterdam, Netherlands




http://www.barbroose.com/wp-content/uploads/2014/03/Uncertain-times.jpg