Departments of Oncology and
Medical Biophysics

When the World was Flat:
The Two-Dimensional Radiation Therapy Era

23 July 2014

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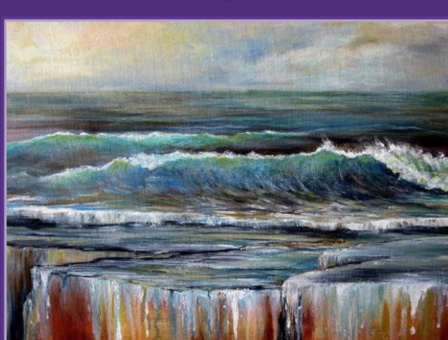
Schulich

Disclosures

- None … except I am involved with …

The Flat Earth Perspective … Artistic



The Flat Earth Perspective … Scary!

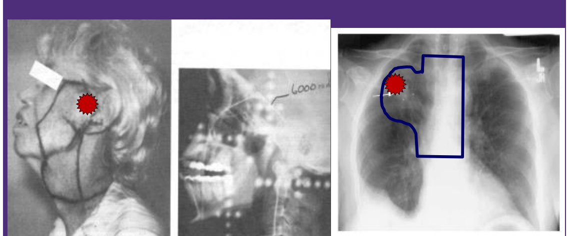
The Past and the Present in RT

Phase	Time	Technology	Issues/Benefits
1	1895-1940s	100-400 kV Brachytherapy	Non-uniform dose at depth, skin dose, bone dose Ra/Rn, systems of calculations
2	1950s	Cobalt-60 4-8 MeV linacs ≥20MeV betatrons	Skin sparing, uniform dose at depth, manual treatment planning
3	1960s-70s	Multi-energy linacs TP Systems Simulators	Isocentric machines, more physicists, detailed QA
4	1970s-80s	CT, 3D-CRT Afterloading	Improved targeting Improved dose computations LDR/HDR brachy
5	1990s-present	IMRT, IGRT, ART, MRI/MRS, PET, SPECT	MLC, on-board imaging, 4D, US, PET/CT, dose escalation, arc therapy, gating, smaller margins

2D to 3D

IVD

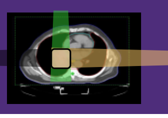
The Flat Earth Perspective: Radiation Therapy in 1960s & 1970s



- 2-D films for planning

Conventional RT

- Tumor volume and critical structures drawn on orthogonal films
- Simple setups with
  - 2, 3, or 4 fields
  - arcs/rotations
- Treatment planning on external contours
- Broad margins

Patient Data Acquisition

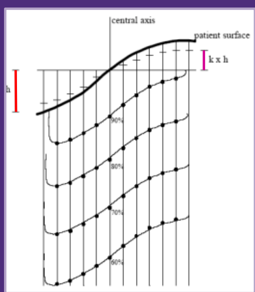
- Various methods used to obtain external contours
  - Solder wire
  - Flexi-curves
  - Contour takers
  - Simulator films

IAEA Atlases, 1965-1972

- Atlas of radiation dose distributions:
  - Vol. I, Single-field isodose charts. Webster, Tsien, 1965
  - Vol. 2, Multiple field isodose charts. Cohen, Martin, 1966
  - Vol.3, Moving field isodose charts. Tsien, Cunningham, Wright, Jones, Pfalzner, 1967
  - Vol. 4, Brachytherapy isodose charts sealed radium sources. Stovall, Lanzl, Moos, 1972

Courtesy: JR Cunningham

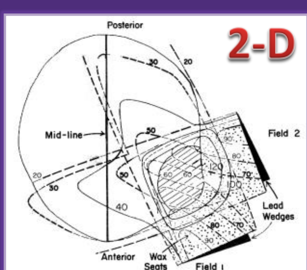
Manual Isodose Calculations



- 1960s & early 70s
- Isodose shift method
- All patients water-like

Photon energy (MV)	k (approximate)
< 1	0.8
^{60}Co – 5	0.7
5 – 15	0.6
15 – 30	0.5
30	0.4

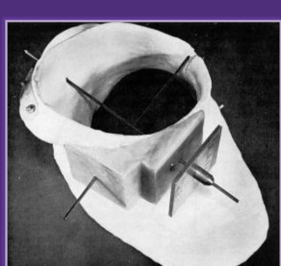
Conformal radiation therapy ~1960s



- Cobalt-60
- Wedge filters
- Wax seats for dose build-up
- Hand drawn isodose curves
- Patients made flat

Johns & Cunningham 1969

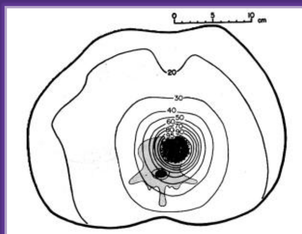
Patient positioning ~1960s



- Dose delivery system for wedge fields of previous slide
- Plaster cast with wax seats
- Fields interlocked for size and wedge orientation
- Repositioning is precise

Johns & Cunningham 1969

Conformal radiation therapy ~1959

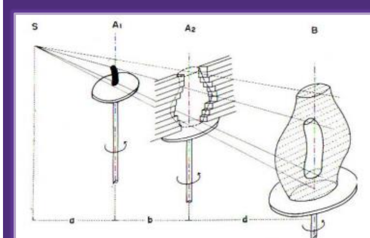


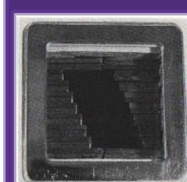
2-D

- Rotation therapy
  - 2 MV Van der Graaf generator
- An early "conformation" technique
- One contour

Johns & Cunningham 1969

Conformal Therapy and MLC ***Proposal*** by Takahashi, 1965





Not implemented in clinical practice until >30 years later!

Acta Radiol Suppl 242, 1965

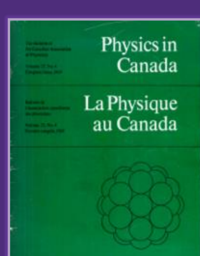
1969: Canadian Association of Physicists Annual Meeting

- Jack Cunningham
  - Chairman, Division of Medical and Biological Physics

THE PROGRAMMED CONSOLE - A SMALL SPECIAL PURPOSE COMPUTER FOR RADIOTHERAPY
J.R.Cunningham, J.Milan, D.Brinkman and Barbara Seaman
Ontario Cancer Institute, Toronto

EMPIRICAL REPRESENTATION OF BEAM PENUMBRA
J.R. Cunningham
Ontario Cancer Institute, Toronto

WORKSHOP ON COMPUTER APPLICATIONS AND METHODS IN MEDICAL PHYSICS
J.R.Cunningham, R.W.Horsley, R.G. Baker, B.Mee, J.C.F.MacDonald and K.W. Taylor
Ontario Cancer Institute, Toronto



First Computer for Radiation Therapy - 1967

The “PC”
- Programmed Console
- 12K memory

12K !!!

- Program and data storage on cards with magnetic strips
- Contour entry by a “rho-theta” tracing unit

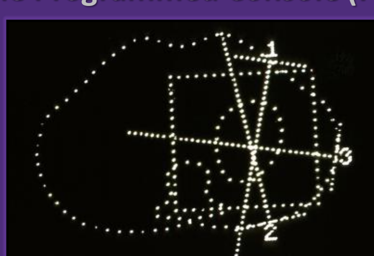
JR Cunningham

First Computer for Radiation Therapy - 1967

- Programmed Console (PC)
- 12K of memory
- 12 bit word
- Note TV camera for enlarging display

JR Cunningham

The Programmed Console (PC)



Display for treatment planning

- Display of patient’s contour & 3 beams arranged to treat target
- Isodoses are shown within the “viewing window”

JR Cunningham

The Programmed Console (PC)

- Display for treatment planning
- Plotting was also available

Display of isodose curves for a single beam

JR Cunningham

Algorithms

- Empirical
  - Measured data only – stored on grid
  - Make corrections for
    - External contours, wedges, inhomogeneities …
- Semi-empirical
  - TAR-SAR methods
    - IRREG, CBEAM, MULBEAM, ..
    - EQTAR
- Model-based
  - Convolution/superposition
- Monte Carlo

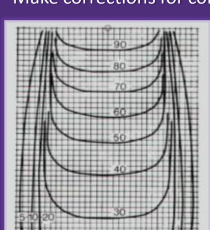
1-D

2-D – 2.5-D

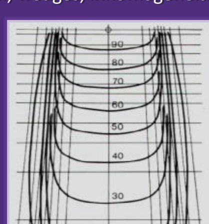
2.5 – 3-D

Matrix Representation

- Doses measured and pre-stored on grid
- For treatment planning, interpolate between points
- Make corrections for contour, wedges, inhomogeneities



X-Y Cartesian Grid



Decrement Line Grid

Scatter-Air Ratios

PHYS. MED. BIOL., 1972, VOL. 17, NO. 1, 42–51

Scatter-Air Ratios

J. R. CUNNINGHAM, PH.D.
Physics Division, Ontario Cancer Institute, Toronto, Canada

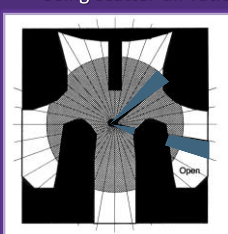
Received (revised version) 26 *April* 1971

ABSTRACT. Scatter-air ratios are empirical quantities derived from tissue-air ratios for use in calculating the dose from scattered radiation at a point in an irradiated phantom. Like tissue-air ratios, for each radiation quality, they depend only on depth and beam cross-section but are independent of the distance from the source. Their use for calculations within uniform and non-uniform radiation beams is outlined and the extension to account for tissue-heterogeneities is discussed.

PROGRAM IRREG – CALCULATION OF DOSE FROM IRREGULARLY SHAPED RADIATION BEAMS

J.R. CUNNINGHAM, P.N. SHRIVASTAVA* and J.M. WILKINSON †
Physics Division, Ontario Cancer Institute, Toronto, Canada

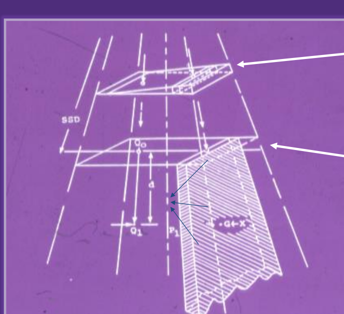
- Primary plus scatter calculations
  - Using scatter-air ratios



Radial sector integration (Clarkson)

Comput Prog Biomed 2: 192-199; 1972

CBEAM Uses Cartesian Slabs

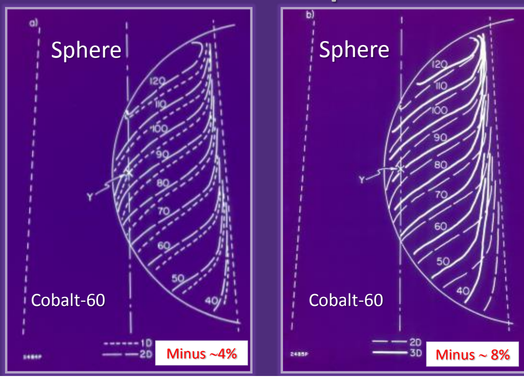


Beam intensity modulated in only one direction

Flat or symmetric contour

Cunningham's CBEAM

1-D vs 2-D vs 3-D Comparison



The Power of SARs

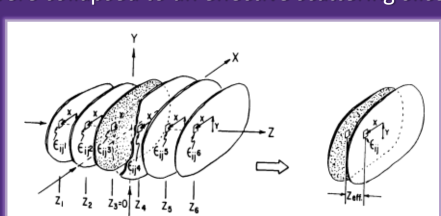
SAR	Scatter at depth from a beam
Sector SAR	Scatter from a pie-shaped 'slab'
dSAR	Scatter from a 'pencil'
d^2SAR	Scatter from a 'voxel'

Order of Canada! Nov 2005

Jack Cunningham

Original EqTAR Method is considered as "2.5-D"

- For computational speed, adjacent slice data were collapsed to an effective scattering slice



Sontag & Cunningham. Radiology 129: 787-94; 1978

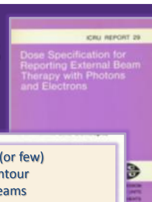
Example of Symmetry Assumptions

2-D

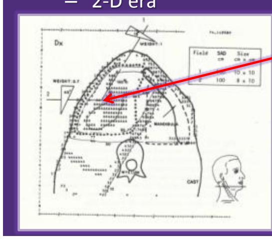
3-D

ICRU 29

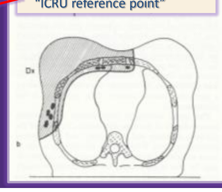
1978



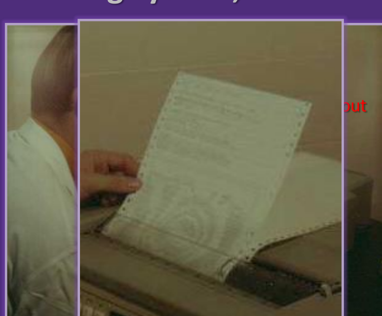
- "Target volume" & uniform prescription concepts
  - "2-D era"



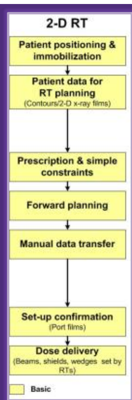
- Single slice (or few)
- External contour
- Coplanar beams
- Simple calculations
- Dose prescription to "ICRU reference point"



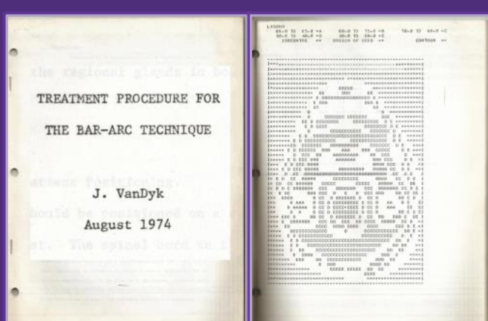
Timesharing System, ~1972



2-D RT



Bar-Arc Technique – 1974


TREATMENT PROCEDURE FOR

THE BAR-ARC TECHNIQUE

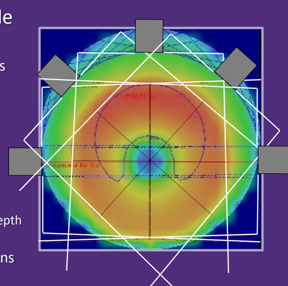
J. VanDyk

August 1974

Conventional Bar-Arc

- Bar shielding the critical organ at each gantry angle
  - Pros
    - Concave dose distributions
    - Greatest sparing of organ
  - Cons
    - Organ MUST lie along rotational axis
      - Patients adjusted
        - » On a board
        - » Feet upward
      - Patients made uniform depth
        - » Bolus
    - Rigid high dose distributions
    - Excess volume irradiated

2-D



Eugene Wong

Major Technology for 2-D RT

- Simple immobilization
- Simulator
  - Possibly access to CT (starting late 1970s)
- Treatment machine
  - Cobalt-60 or basic linear accelerator
  - Port films

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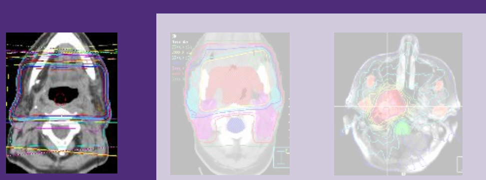
Differences between 2-D RT and 3-D CRT



2-D RT | 3-D CRT | IMRT

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Different forms of RT

2-D RT | 3-D CRT | IMRT

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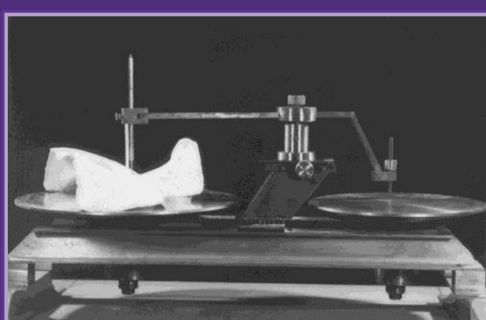
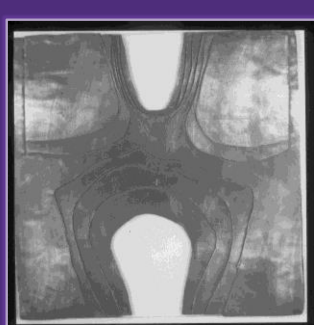
Methods of Producing Missing Tissue Compensators for High Energy Photon Beams

- Make patient flat
  - … uniform dose … for uniform H_2O density
    - Layers of lead
    - Semi-automatic compensator cutter (special purpose)
    - Milling styrofoam, low melting point alloy

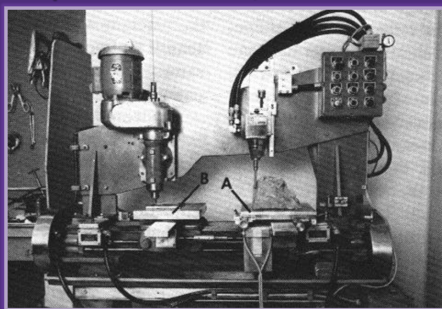
Mantle Compensator Construction



Mantle Compensator

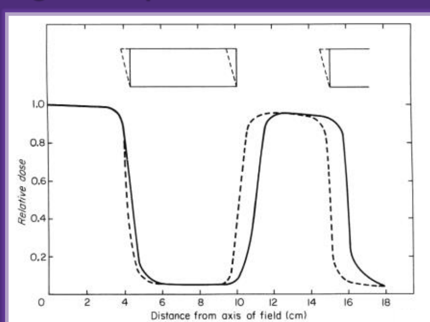


Princess Margaret Hospital, Toronto Compensator Cutter, 1960s-1990s



Cunningham et al. Radiology 82: 130-131; 1964

Dose Profiles: Straight vs Tapered Blocks



Hot Wire Technique

Something Old!

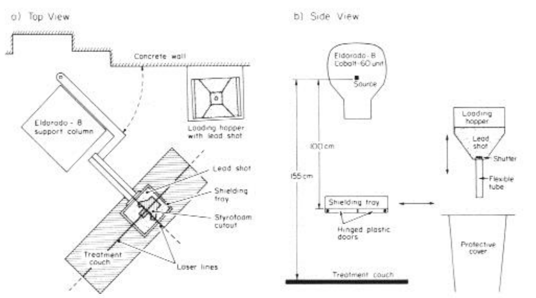


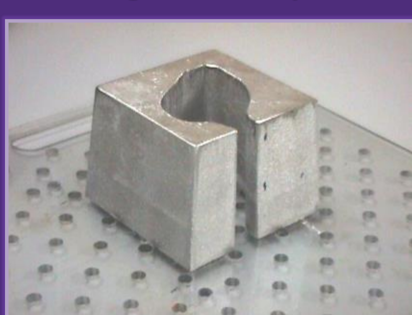
Fig. 1. Schema of the lead shot shielding system.

Lead Shot Shielding Device

Avoids carrying heavy blocks

Van Dyk et al. Radiology 134: 543-544; 1980

Low Melting Point Alloy



Boyer et al In: Modern Technology of Radiation Oncology, 1999

AECL Theraplan, 1980

- CT-based treatment planning

Summary: "When the World Was Flat"

- 2-D era
  - Anatomy defined by
    - Flexible wires
    - Special contour takers
    - X-rays
  - Dose calculations
    - Predefined atlases
    - Manual isodose summations – single planes
    - Simple beam shapes with wedges or compensators
    - Measurement based or semi-empirical calculations
    - Printed on alpha-numeric line printers or plotters

- Fortunately, we live in a world that has moved forward by several dimensions …