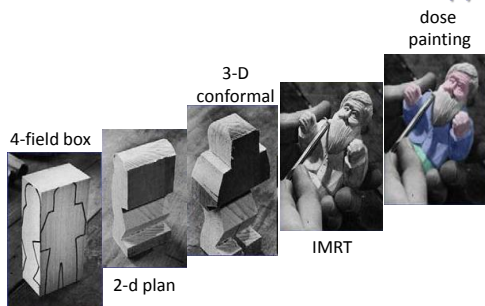


## IMRT and Inverse Planning: From the Art to the State-of-the-Art

Thomas Bortfeld

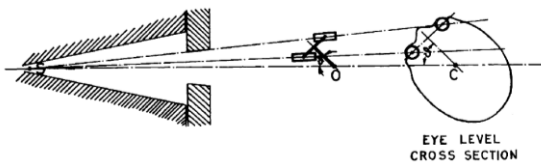
Massachusetts General Hospital  
Department of Radiation Oncology  
TBortfeld@mgh.harvard.edu

### Evolution of the art of radiation therapy

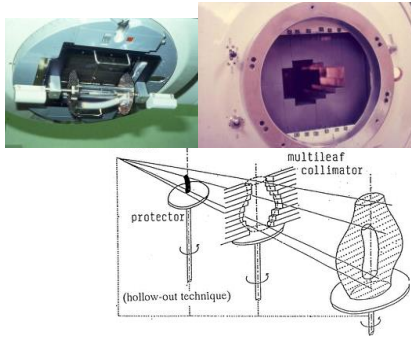


courtesy of John Schreiner, Kingston, Ontario, CA

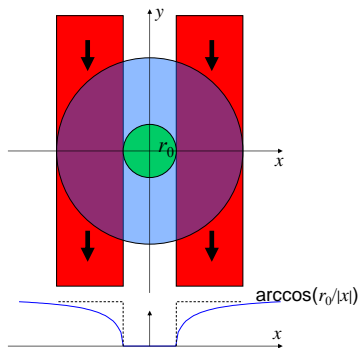
### IMRT forerunners: Synchronous shielding, Proimos 1961



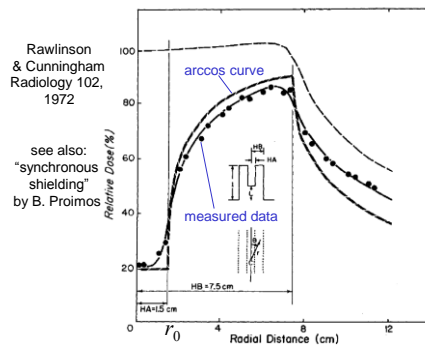
## IMRT forerunners: Conformation therapy, Takahashi 1965



## Problem with synchronous shielding

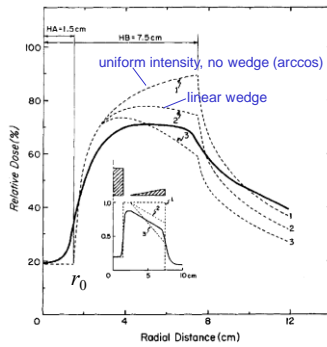


## Problem with synchronous shielding



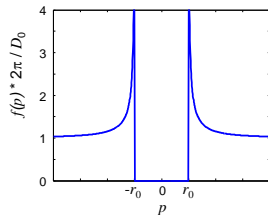
## This calls for intensity modulation!

Rawlinson  
& Cunningham  
Radiology 102,  
1972



## The idea of inverse planning was born

$$f(p) = \begin{cases} \frac{D_0}{2\pi} \frac{|p|}{\sqrt{p^2 - r_0^2}} & \text{if } |p| \geq r_0 \\ 0 & \text{otherwise.} \end{cases}$$



## Birth of IMRT: 1982

Phys. Med. Biol., 1982, Vol. 27, No. 10, 1221-1229. Printed in Great Britain

### Solution of an integral equation encountered in rotation therapy

A Brahme†, J-E Roos† and I Lax†

† Department of Hospital Physics, Karolinska Sjukhuset, Box 60204, S-104 01 Stockholm, Sweden

‡ Department of Mathematics, University of Stockholm, Box 6701, S-113 85 Stockholm, Sweden

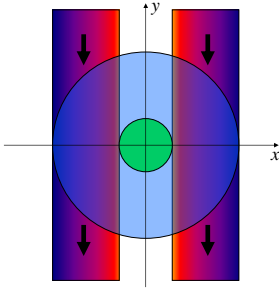
§ Department of Hospital Physics, Karolinska Sjukhuset, Box 60204, S-104 01 Stockholm, Sweden

Received 30 March 1981, in final form 4 December 1981

**Abstract.** An integral equation relating the lateral absorbed dose profile of a photon beam to the resultant absorbed dose distribution during single-turn rotating-beam therapy has been set up and solved for the case of a cylindrical phantom with the axis of rotation coinciding with the axis of symmetry of the cylinder. In the first approximation the results obtained are also valid when the axis of rotation is somewhat off-centred, even in a phantom that deviates from circular symmetry, provided the rotation is performed in both clockwise and counter clockwise directions. The calculated dose profiles indicate that improved dose uniformity can be achieved using a new type of non-linear wedge-shaped filter, which can easily be designed using the derived general analytic solution to the integral equation.



### Intensity modulation for the “donut” case




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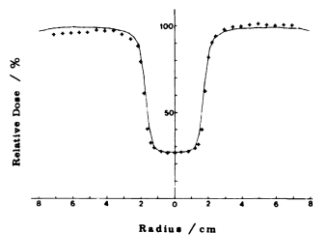
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### Birth of IMRT: 1982

Lax, Brahme  
Radiology 145  
1982



The line gives the calculated dose profile for a rotation irradiation. The crosses are the result of radiographic measurements in a spherical phantom.

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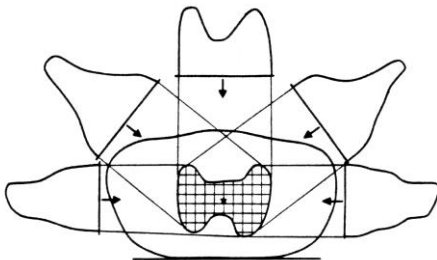
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### Key idea: Applicable to arbitrary cases with concave targets



Brahme et al, 1988

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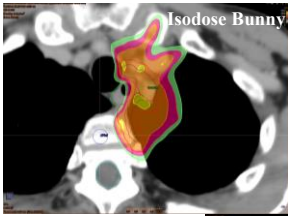
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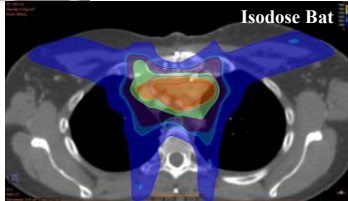
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IMRT = I aM aRT

idea of dose painting

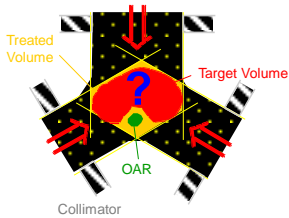
© Henning Willers, MGH



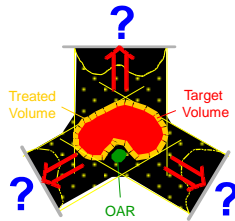
## IMRT "palette"

### 1. "Inverse" treatment planning

"Conventional" Planning



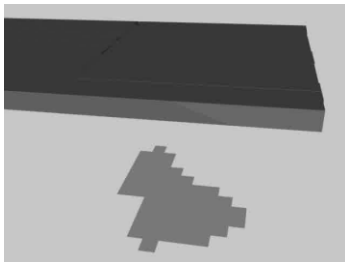
Inverse Planning



## IMRT "palette"

### 2. Delivery with MLC

Convery/Rosenbloom  
Svensson/Källman  
Spirou/Chui  
Stein et al.  
Bortfeld/Boyer  
...



© W. Schlegel, A. Marr

### Clinical translation of the IMRT idea early 1990's

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### Clinical translation of the IMRT idea early 1990's, MD Anderson CC

Art Boyer  
Thomas Bortfeld  
Darren Kahler  
Tim Waldron  
...



Art and Thomas @ AAPM Austin, 2014

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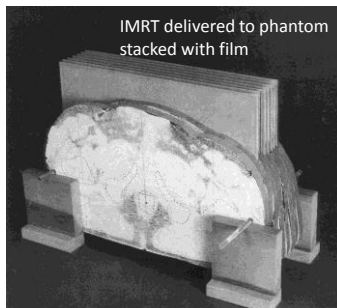
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### IMRT proof of concept in 1993



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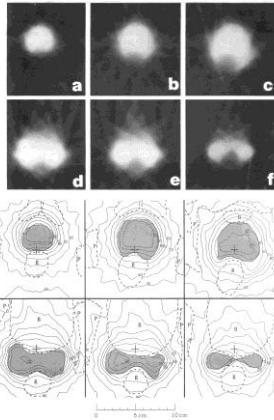
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### proof of concept (1993)

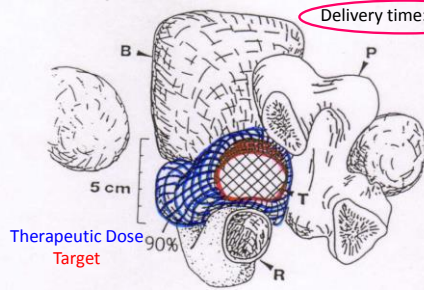
- 6 films in different slices showing concave dose distributions



- Overlay on anatomy

### IMRT proof of concept in 1993 Prostate phantom dose distribution in 3D

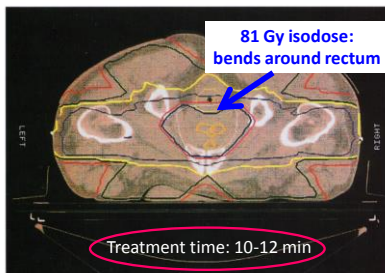
Delivery time: 3 hours



(c) A. Boyer, 1993

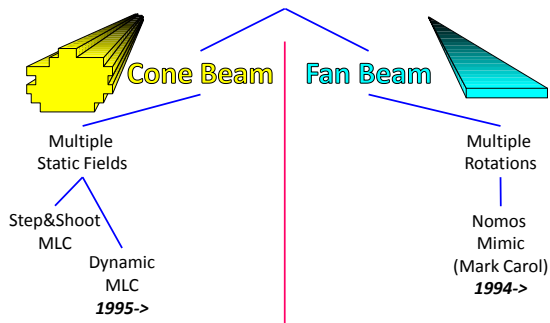
### Translation into clinical use: 1995 MSKCC, New York

Radhe Mohan  
Clifton Ling  
Zvi Fuks  
Sam Hellman  
et al.

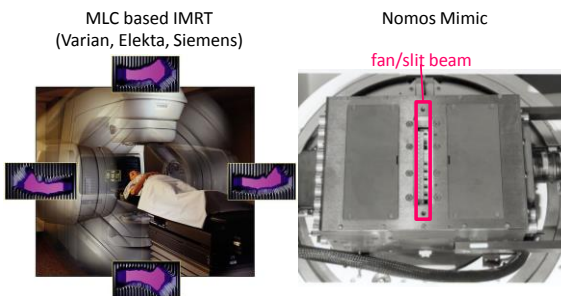


Ling et al., IJROBP 35(4): 721-730, 1996

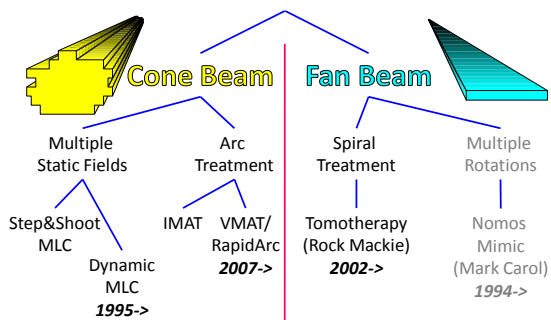
### IMRT delivery technology 1990s



### Cone beam IMRT vs. fan-beam IMRT 1990s



### IMRT delivery technology today





## IMRT: A success story of INNOVATION in Medical Physics

- Millions of patients treated
- Clear dosimetric advantage established
- Clinical benefit demonstrated through (few) randomized clinical trials

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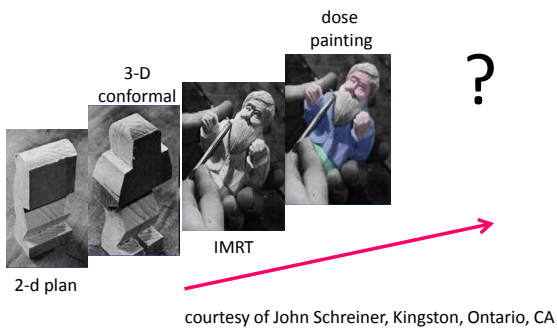
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## What comes next?




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## What comes next?

- Make IMRT simpler, faster, less of an Art
  - Multi-Criteria optimization
  - Automation
- Make IMRT truly optimal
  - What do we really want to accomplish: use biologically/clinically motivated objectives
- IMRT for particles - IMPT
- Smarter ways to deal with uncertainties
  - Robust optimization
- Optimize dynamics of multi-modality therapy over the treatment course

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**CLINICAL REALIZATION OF 3D CONFORMAL  
INTENSITY MODULATED RADIOTHERAPY: REGARDING  
BORTFELD *ET AL.*, *IJROBP* 30:899–908; 1994**

If intensity modulated therapy does improve patient outcome, it is clear that the systems of the future will be different from these used today. Manufacturers may elect to make the sort of modifications suggested by Bortfeld and the co-authors or support a dedicated machine such as described by Mackie *et al.* (12). More likely, a system would evolve that is not linked to what is familiar to us all at this time. We believe that the clinical experience we gain today with this type of technology will enable radiotherapy community to obtain the most practical system.

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SHIAO Y. WOO, M.D.  
WALTER GRANT III, PH. D.  
PAUL S. NIZIN, PH.D.  
Baylor College of Medicine  
The Methodist Hospital  
Houston, TX 77030

- Conflict of interest

**No conflict of interest** with any of the material presented here.

- Disclaimer

While trying to be **as objective as possible**, there will be some **personal bias**.

## IMRT “palette”

### 1. “Inverse” treatment planning

- **Deconvolution** approach:

Lind/Brahme, Holmes/Mackie, et al.

- **Optimization** approach

- **Simulated Annealing:**

Webb, Mohan/Mageras, et al.

- **Gradient Descent:**

Censor, Bortfeld, et al.

### IMRT optimization algorithms

- First developed by Physicists (they can do everything)
- Further developed by optimization experts (Operations Research)

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- Who came up with the IMRT = Intensity-Modulated Radiation Therapy acronym, and when?
- IMRT is a misnomer. We do not modulated the intensity – but the fluence.

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