LDR Intracavitary Brachytherapy Applicators

UT MD Anderson Cancer Center Intracavitary Brachytherapy

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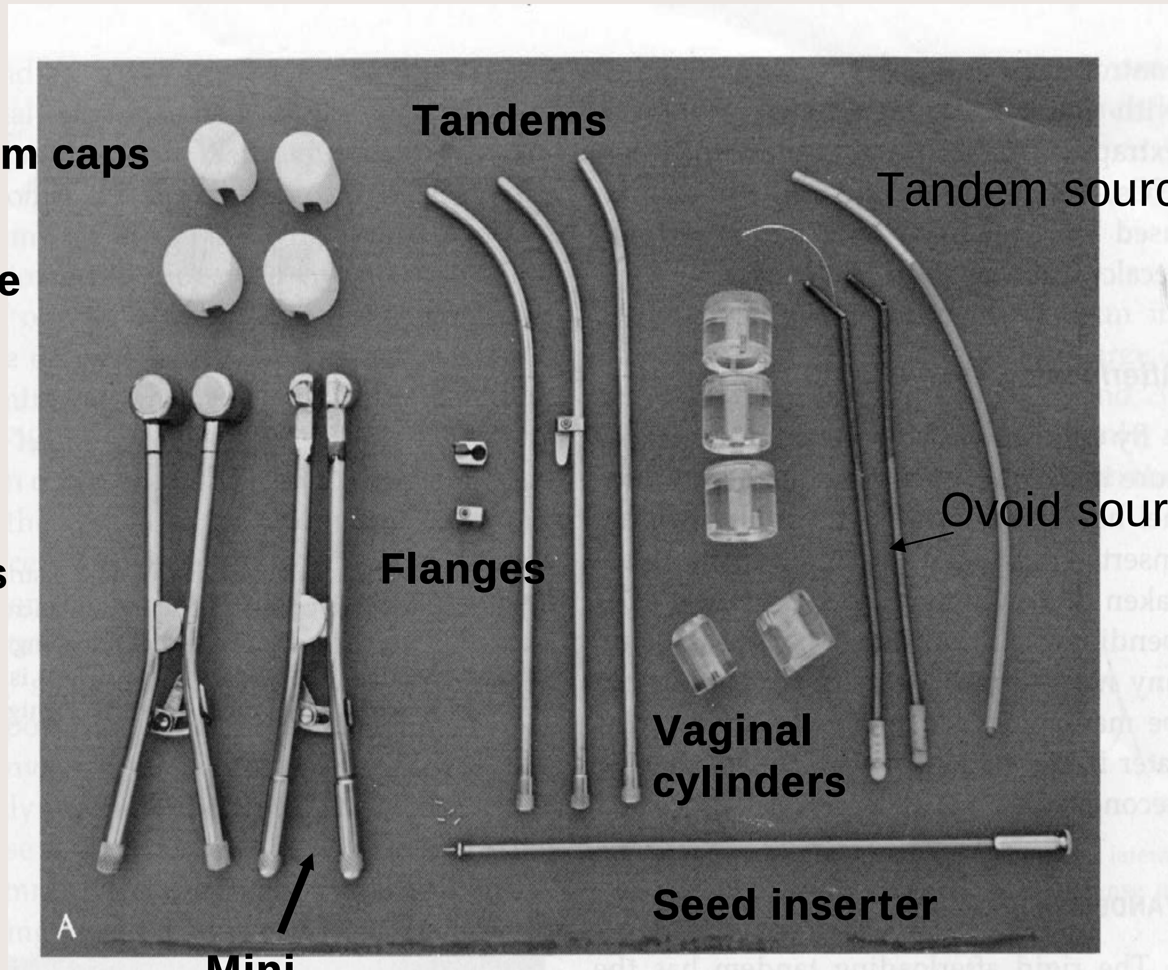
Conflict of Interest

- Nucletron sponsored research agreement supports a portion of this research
- Transpire sponsored research agreement and SBIR supports a portion of this research

Course Objectives

- Discussion
  - The most commonly used LDR intracavitary brachytherapy (ICB) applicators
  - Need for ICB applicators that permit CT & MR imaging of ICB implant
  - Importance of including applicators' attenuation effects on the 3D dose calculations for ICB implants
  - The UTMDACC system for ICB implants

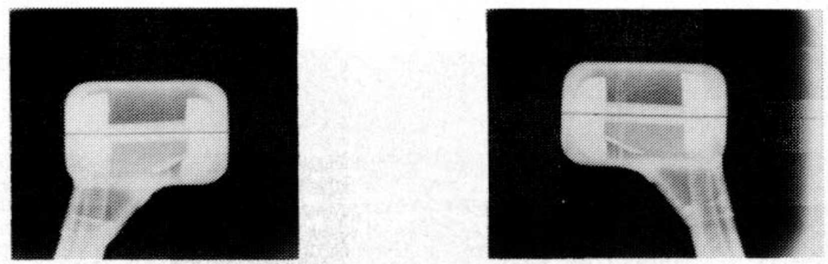
Fletcher Family of Applicators Manual Afterloaded



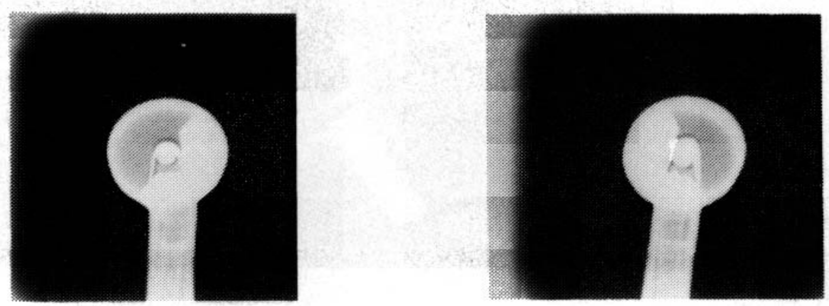
Fletcher Tandem and Ovoids

- Based on Manchester System
- Stainless steel
  - Manchester system rubber
- Cylindrical ovoid
  - Manchester ovoid, prolate spheroid, conformed to isodose surface of ^{226}Ra tube source
- Bladder and rectal shields
- Preloaded

Shields in FSD System

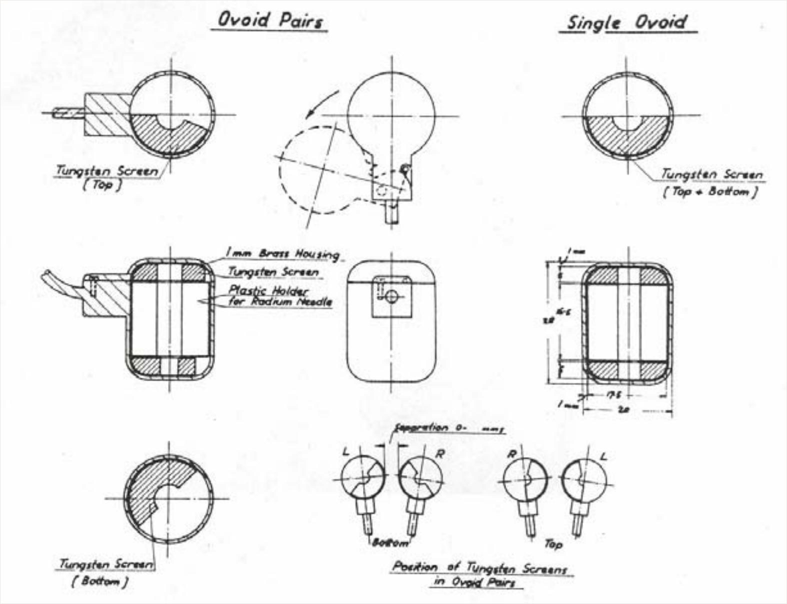


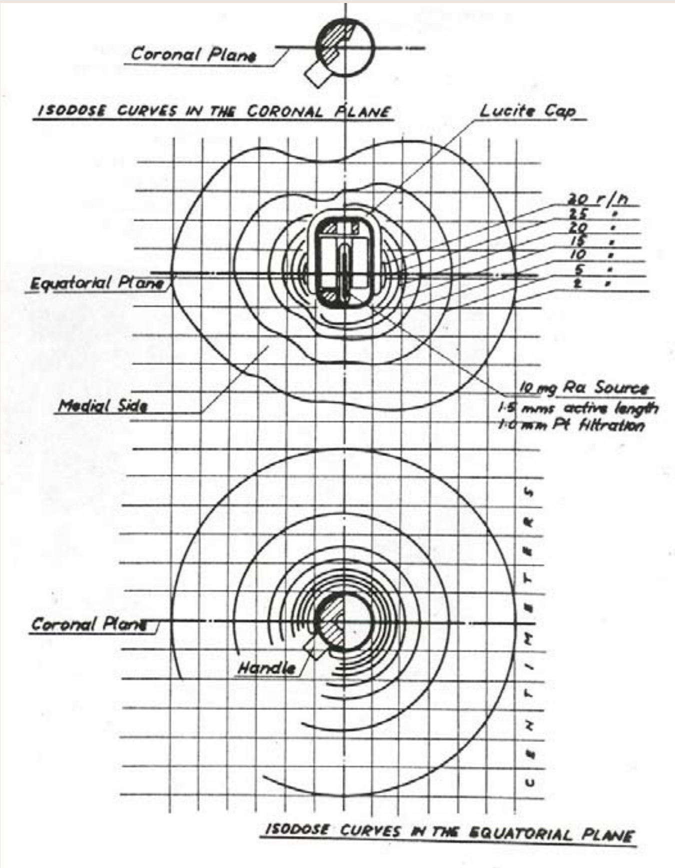
Source should be centered along axis of ovoid
Bladder and rectal shields on medial aspect of ovoid



Delclos, et al., Cancer 41, 970-979, 1978

Fletcher Preloaded Ovoids





Delclos, et al., Cancer 41, 970-979, 1978

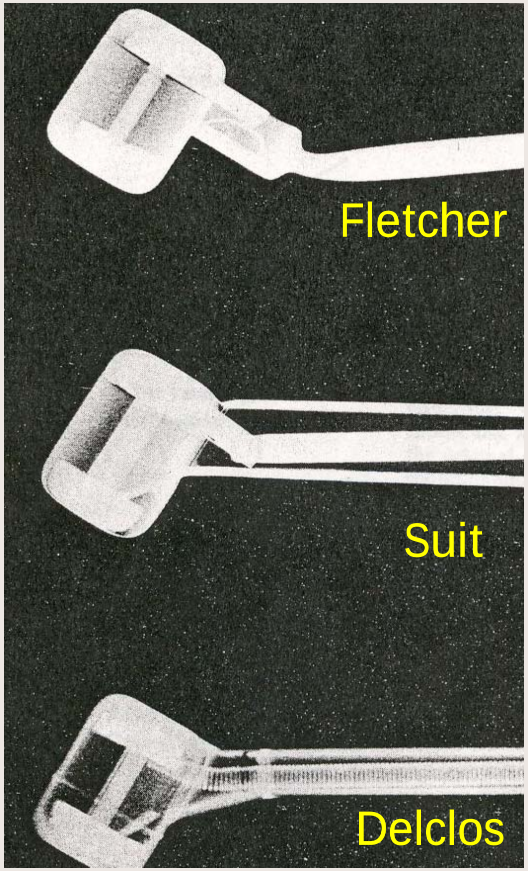
Suit Afterloading

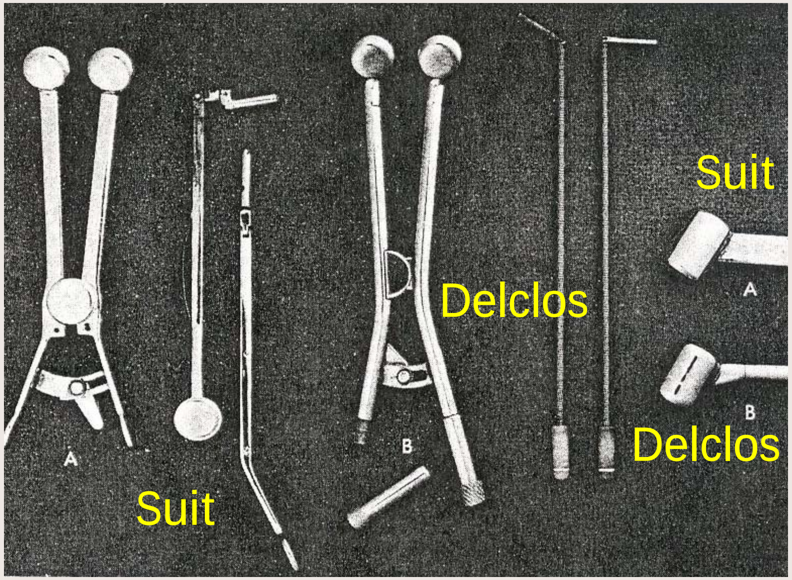
- Modified Fletcher applicators for afterloading
  - Based on Henschke afterloading idea
- Ovoid afterloading required
  - Suspending ovoid source carriers on double hinge device
  - Slight change to shield design
  - Increased length of ovoid 1 mm

Delclos Afterloading

- Improved design of ovoid source carrier
- Shields returned to original position of Fletcher design
- Ovoid same length as original Fletcher design
- Mini-ovoids
- Promoted dome and cylinder applicators

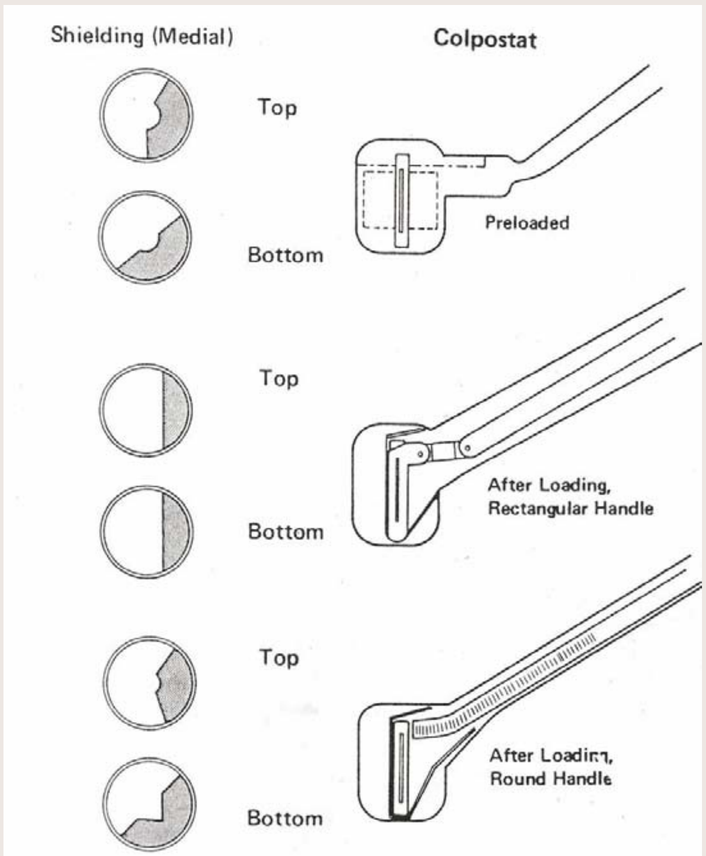
Evolution of FSD Ovoids

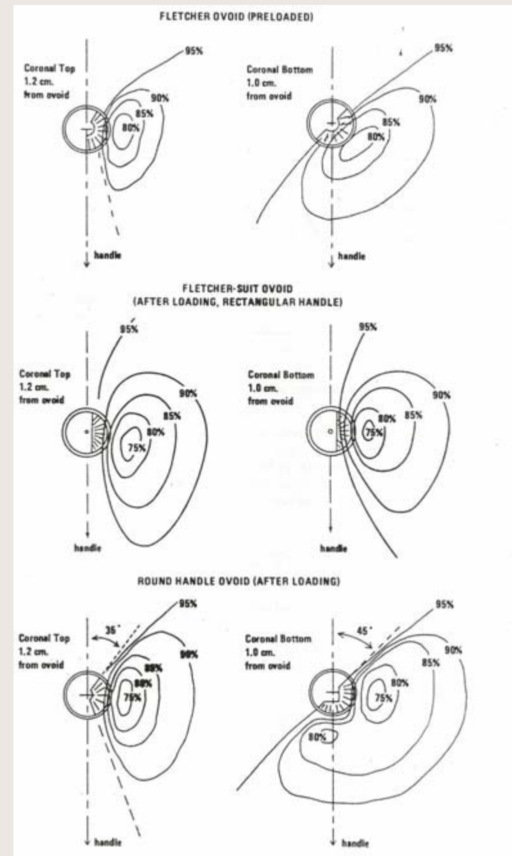




Delclos, et al., Cancer 41, 970-979, 1978

Evolution of FSD Ovoids

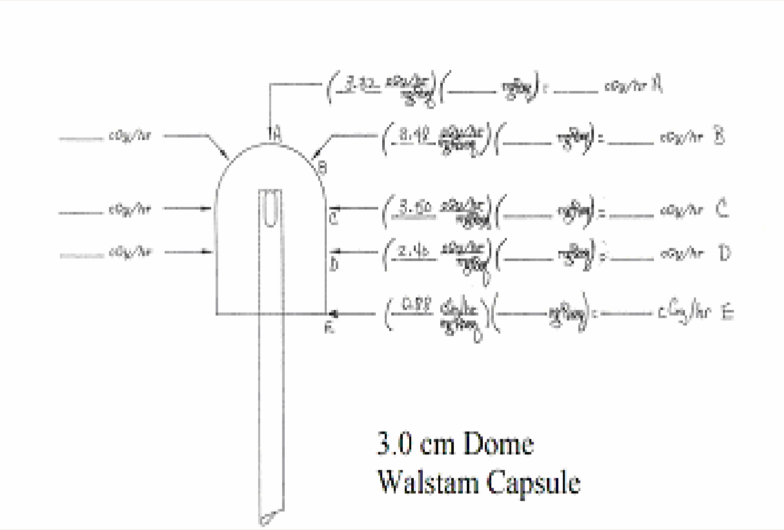




Delclos, et al., Cancer 41, 970-979, 1978

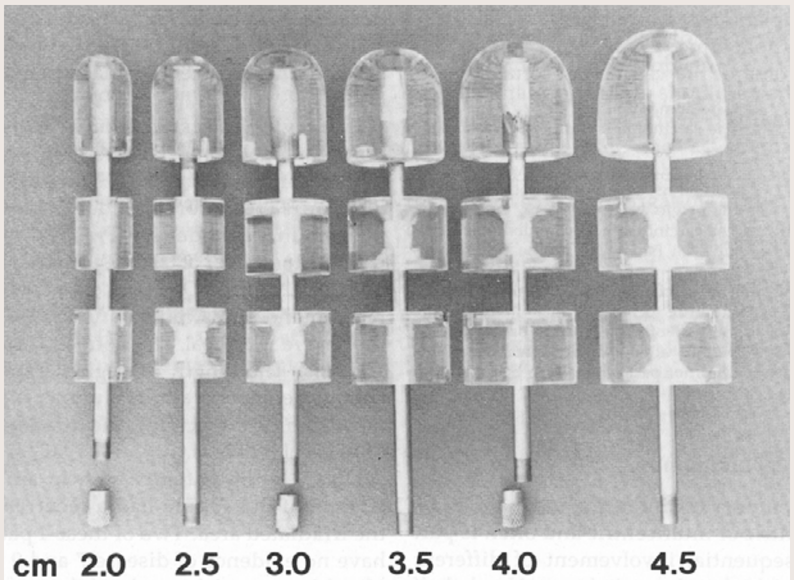
Dome

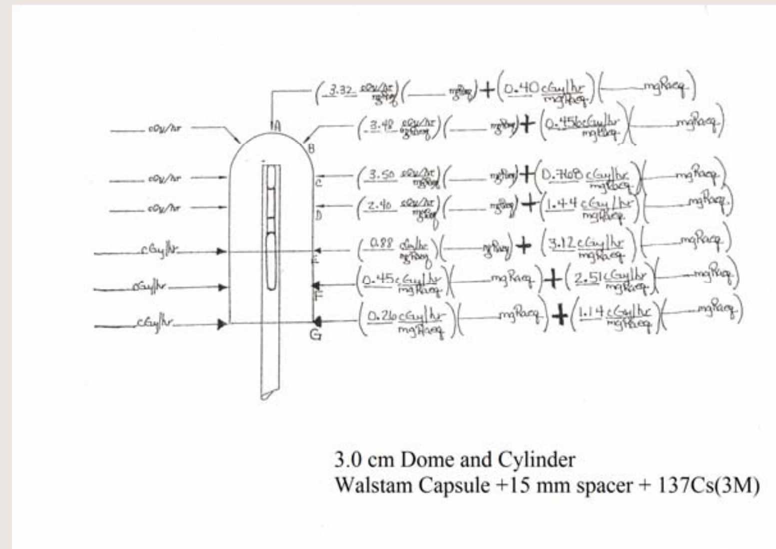
- Walstam capsule ^{137}Cs
  - 8mm PL
  - AL depends on activity
    - 2.1mm or 4.2mm



Dome and Cylinders

Walstam capsule in dome

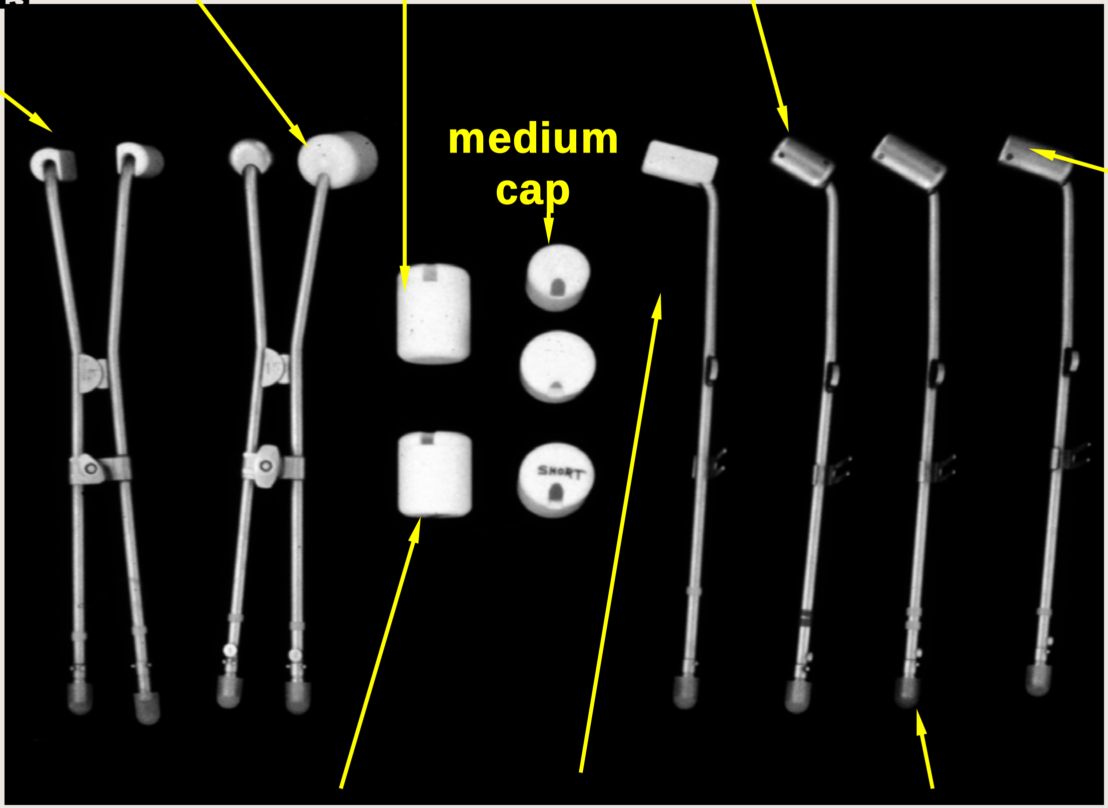




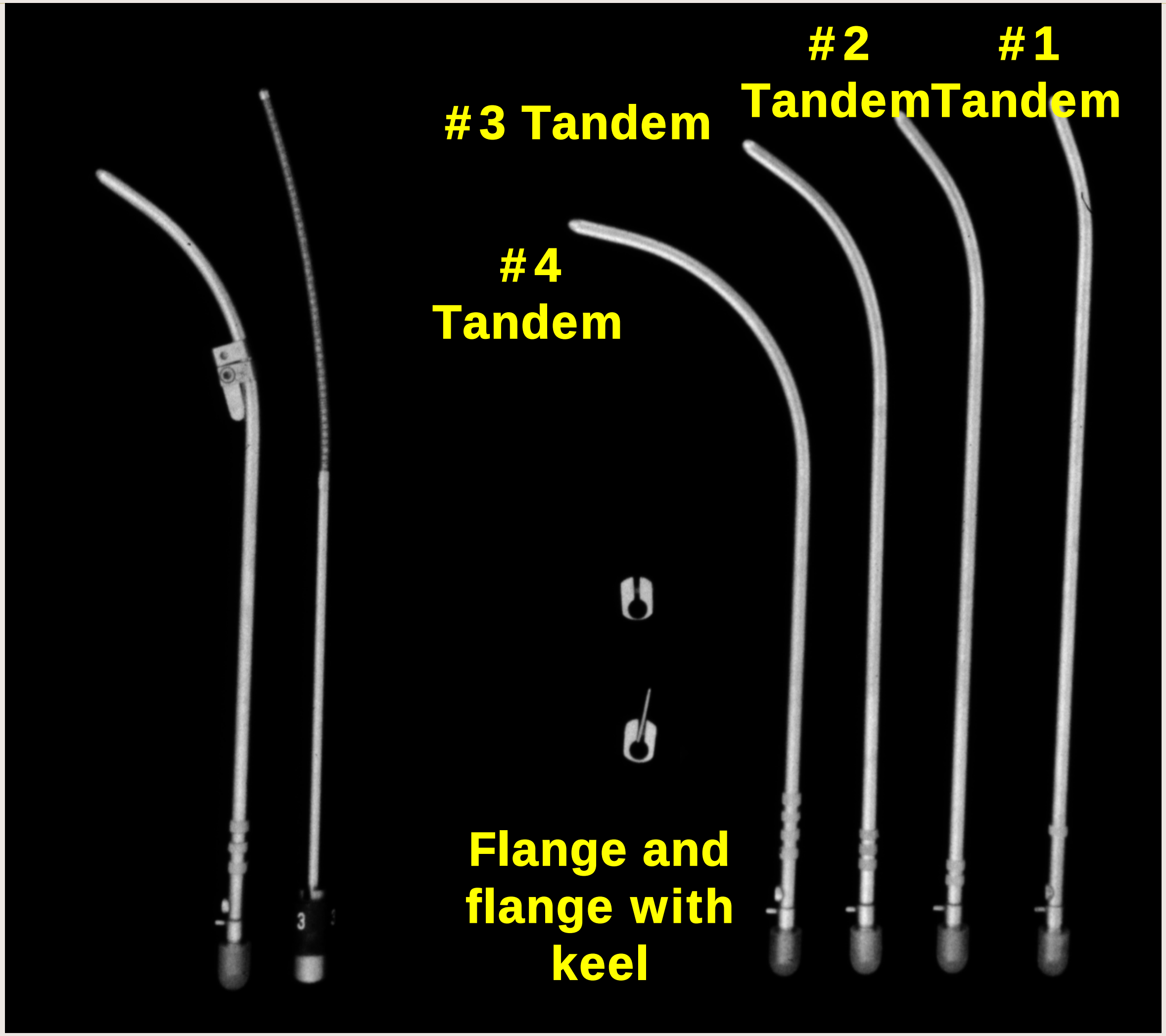
Tube source in cylinders

Spacers used to achieve desired dose distribution

Selectron LDR
Fletcher-Suit-Delclos Ovoids



Selectron LDR
Fletcher-Suit-Delclos Tandems



Henschke Applicator

- Similar to Fletcher system
- Ovoid source length along direction of handle facilitates afterloading
- Afterloading idea adapted by Suit for Fletcher system

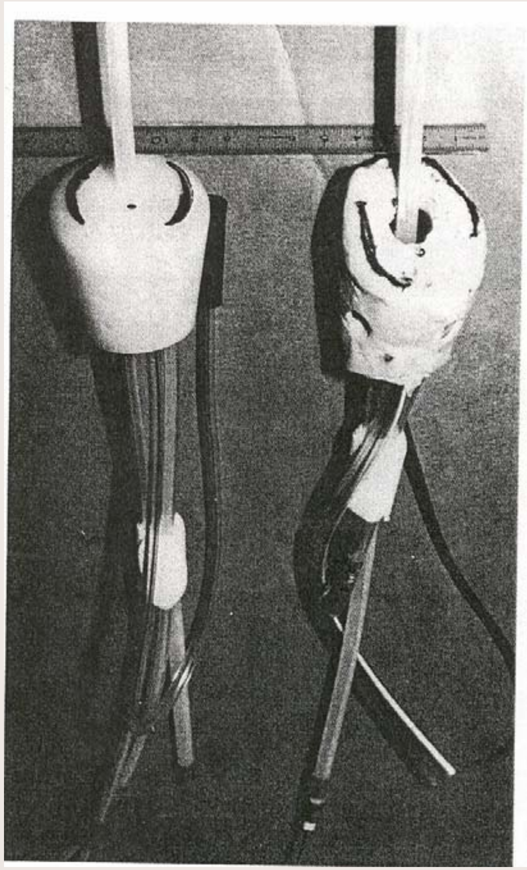
from Nucletron catalogue

Mold (Moulage) Applicators

- Mold applicators typical in France
  - Créteil
  - Insitut Gustave Roussy
  - Saint – Cloud
- Use ^{192}Ir or ^{137}Cs, depending on institution
- Different techniques and dosimetry depending on institution
- Will review Créteil technique as example
  - ^{192}Ir wire, all wire same linear intensity

Créteil Mold Applicators

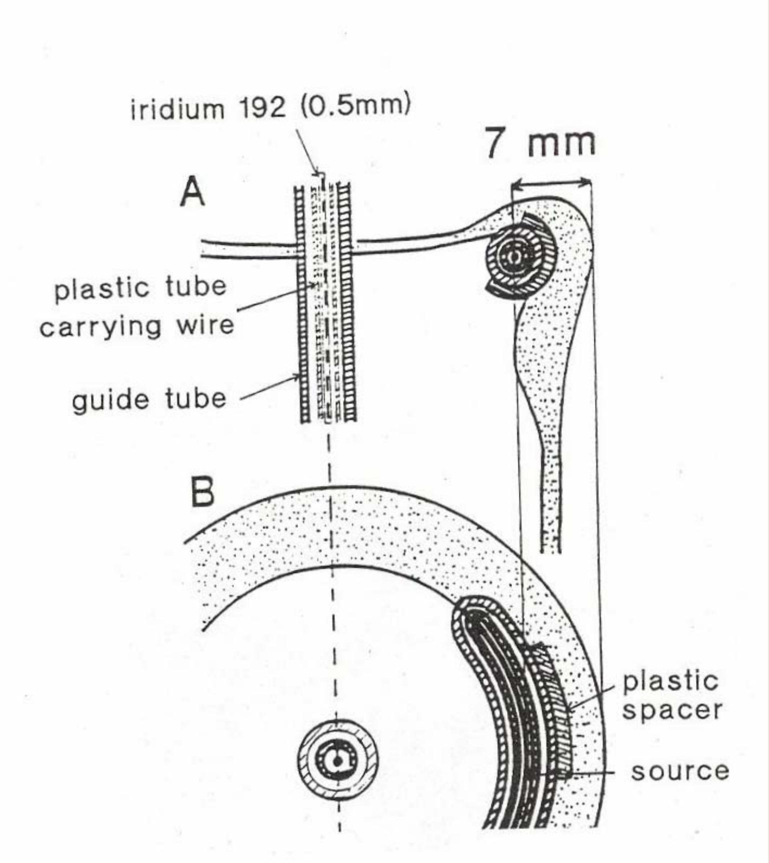
- Alginate impression of vagina
- Acrylic mold
- Custom (right) or prefabricated
  - (2.5, 3.5 or 4.5 cm)
- Plastic guide tubes
  - 2 vaginal sources
  - 1 uterine source
  - Lead shot 6 & 12 o'clock
- Tandem & ring – similar geometry



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Vaginal Sources

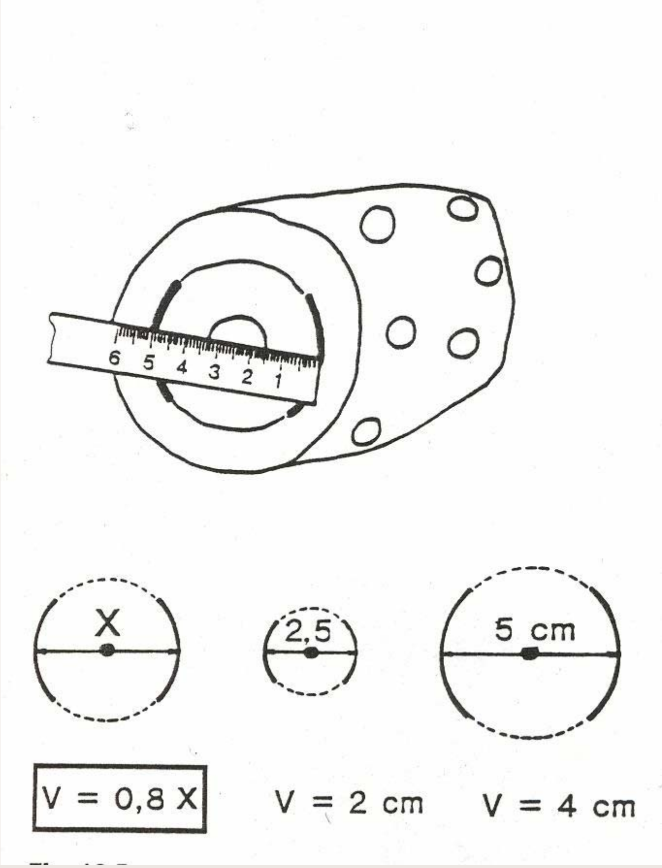
- R & L Plastic guide tubes, 7mm OD
- Centered 7mm from external lateral surfaces of mold
- ^{192}Ir wire 0.5mm diameter, placed in plastic tube 1.6mm OD, centered in plastic guide tubes



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Vaginal Sources

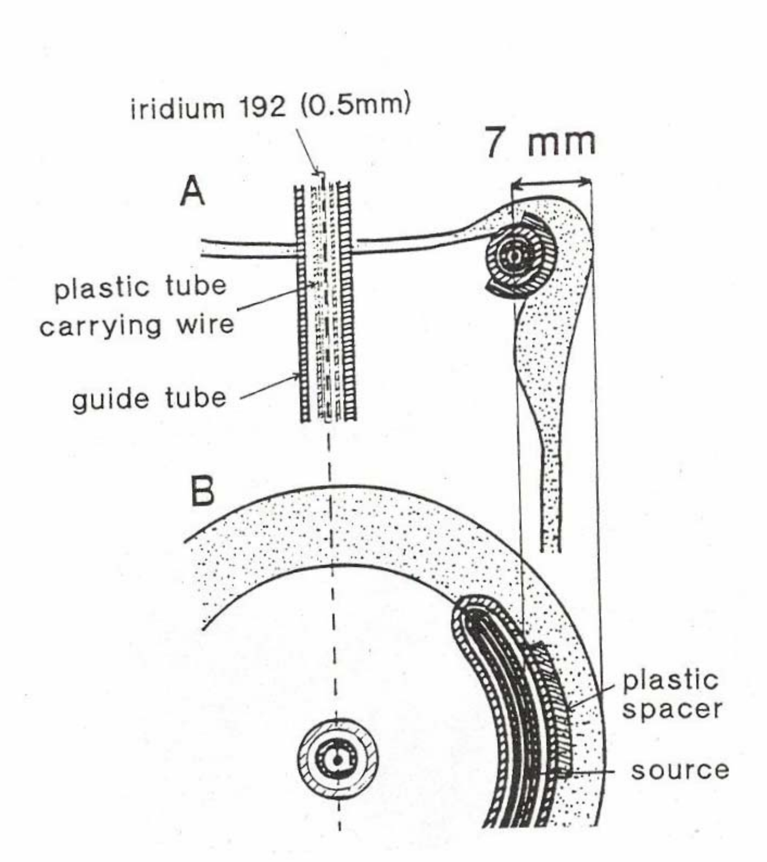
- Each source length 0.8 times the distance between sources
- Separation between ends of sources equal on bladder and rectal sides



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Uterine Source

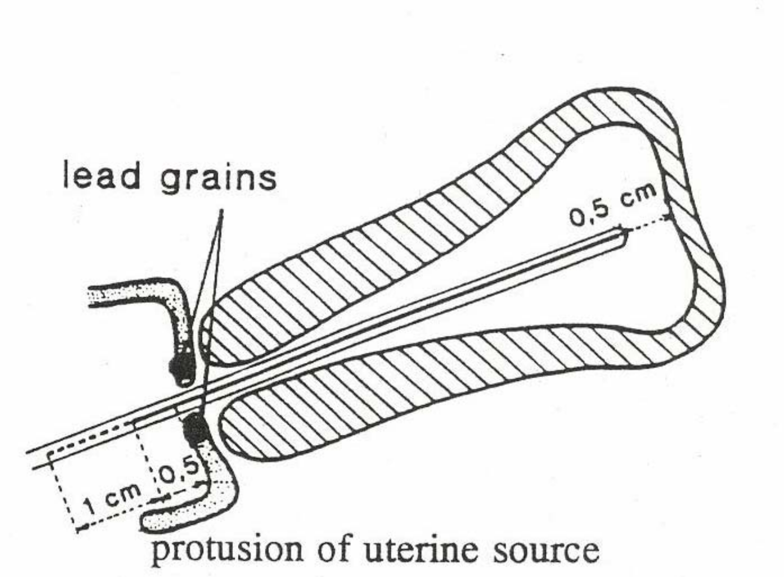
- Semi-rigid plastic guide tube, 7mm OD, 35 mm long, distal end sealed
- Centered in mold
- ^{192}Ir wire 0.5mm diameter, placed in plastic tube 1.6mm OD, centered in plastic guide tube



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Uterine Source

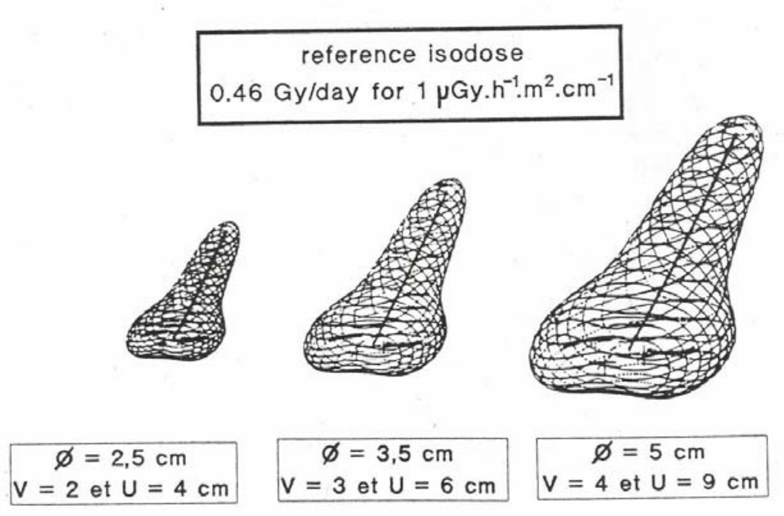
- Distal end of ^{192}Ir extends to 5mm below top of uterus
- Proximal end of ^{192}Ir extends below plane of vaginal sources, 5mm if cervix diameter less than 4cm or 15mm if larger diameter



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Dosimetry

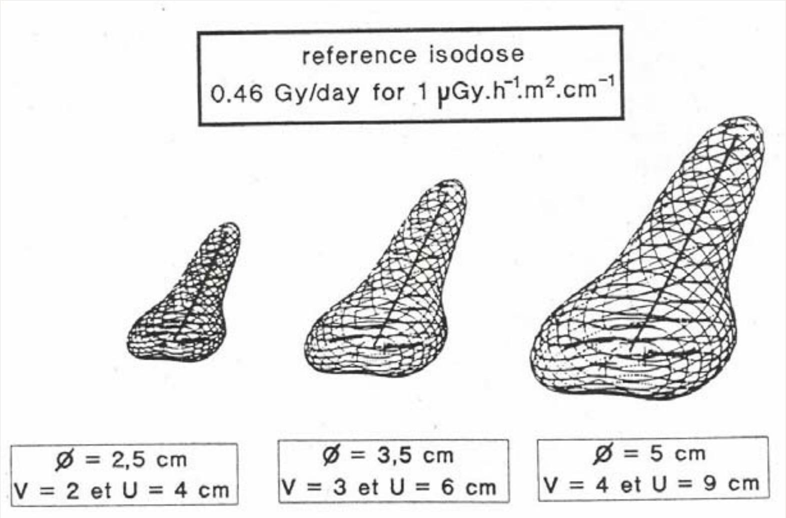
- Dosimetry – day after implant
- Well defined geometry
- Uniform and equal linear activity for vaginal and uterine sources
- Same time duration for vaginal and uterine sources



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Dosimetry

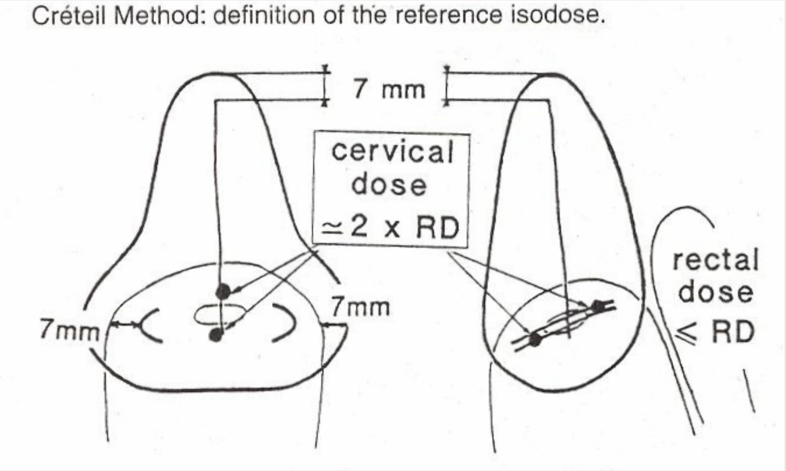
- Adherence to rules - pear shaped reference isodose (RD) surface proportional to cervix size
- RD = 0.46Gy/day per 1μGy-m^2/hr-cm linear activity
- Example – prescribe 30Gy in 2 days, requires linear activity of 32.6μGy-m^2/hr-cm w/o decay for ^{192}Ir



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

Créteil Mold Applicators Dosimetry

- Reference isodose (RD) surface - 7mm from surface of mold at level of vaginal sources, 7mm from distal end uterine source
- Cervical dose (at lead shot) approx. twice RD
- Rectal dose less than or equal to RD



From *A Practical Manual of Brachytherapy*, Pierquin & Marinello, Medical Physics Publishing, Madison WI, 1997

CT/MR Compatible Applicators

- Weeks applicators
- Adaptable applicator

Weeks Applicator "Model 1"

- CT compatible
- Shielded ovoids
- Shields afterloaded through acrylic handles
- Difficult for MD to see to position ovoids with large handles to allow afterloading shields

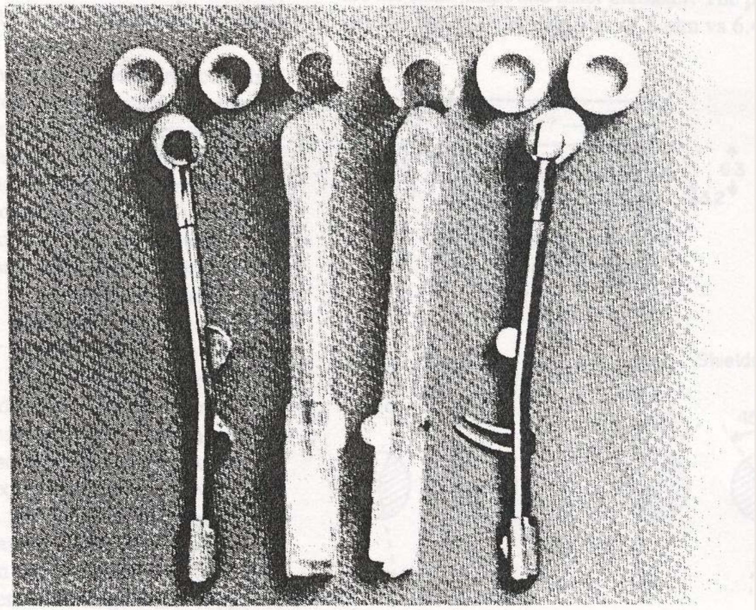
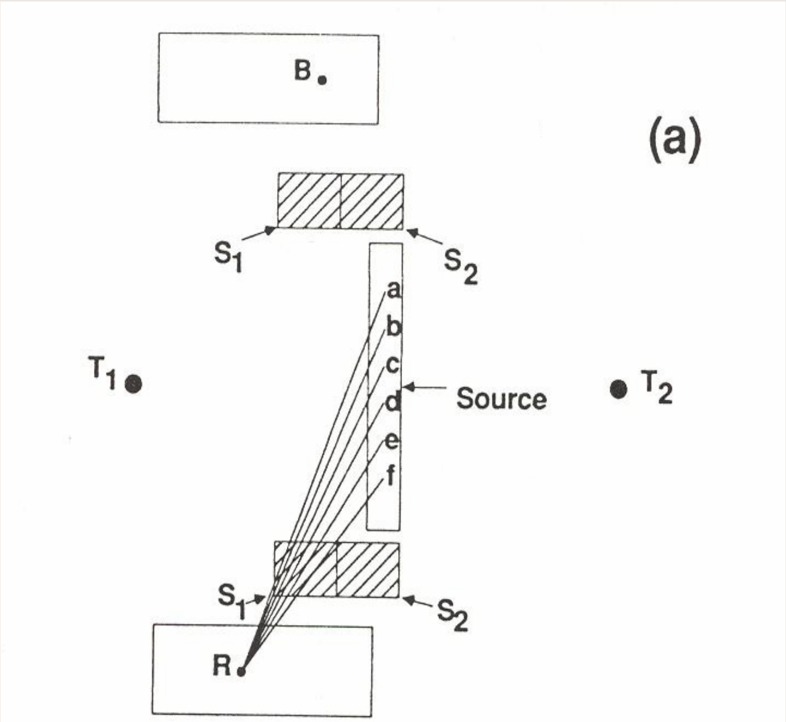


Figure 1. Metal Fletcher-Suit-Delclos (outer) and plastic (center) colpostats are compared. Medium (2.5 cm diameter) and large (3.0 cm) pairs of caps are shown above the metal colpostats. The single medium and large caps are shown above the plastic colpostats.

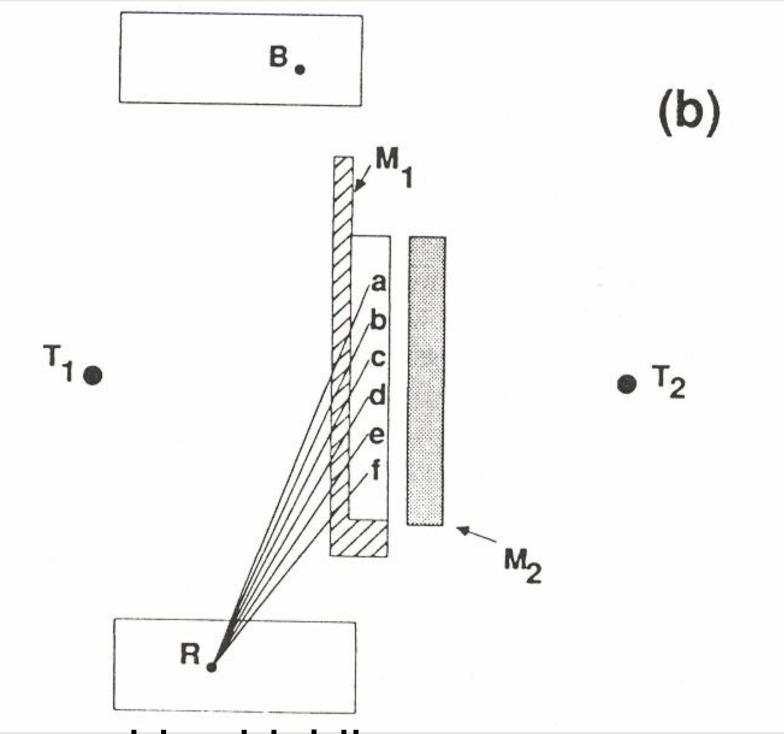
Weeks, et al., Endocurie, Hypertherm, Oncol 5, 169-174, 1989.

Weeks Applicator “Model 2”

FSD shields



Weeks shields

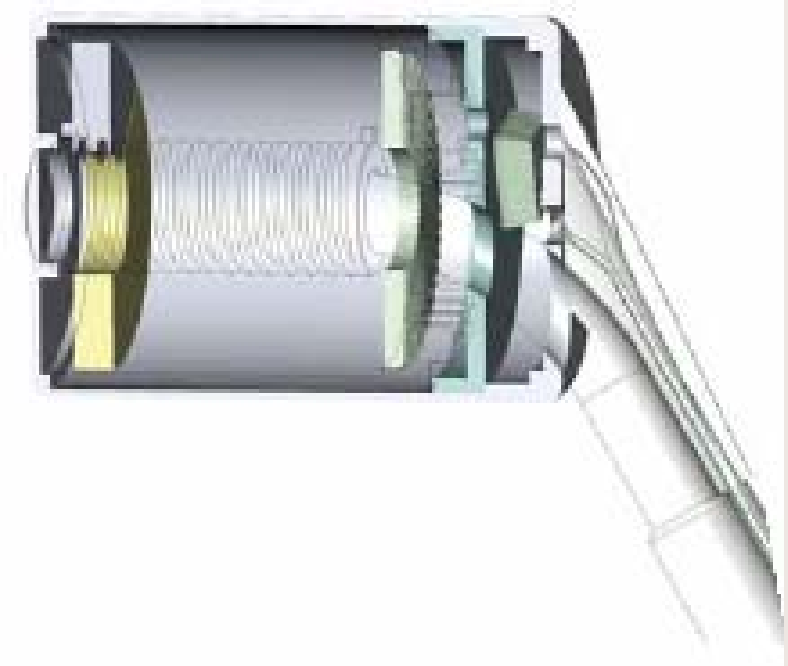


Ovoid source carriers designed to provide shielding equal to FSD ovoids, external dimensions same as FSD

Weeks and Montana, Int. J. Radiation Oncology Biol. Phys. 37, 455-463, 1997.

Adaptable Applicator

- Shield repositioned after placement in patient to
  - Reduce CT artifacts
  - Optimize shielding effects on critical structure
  - Feedback to verify correct positioning

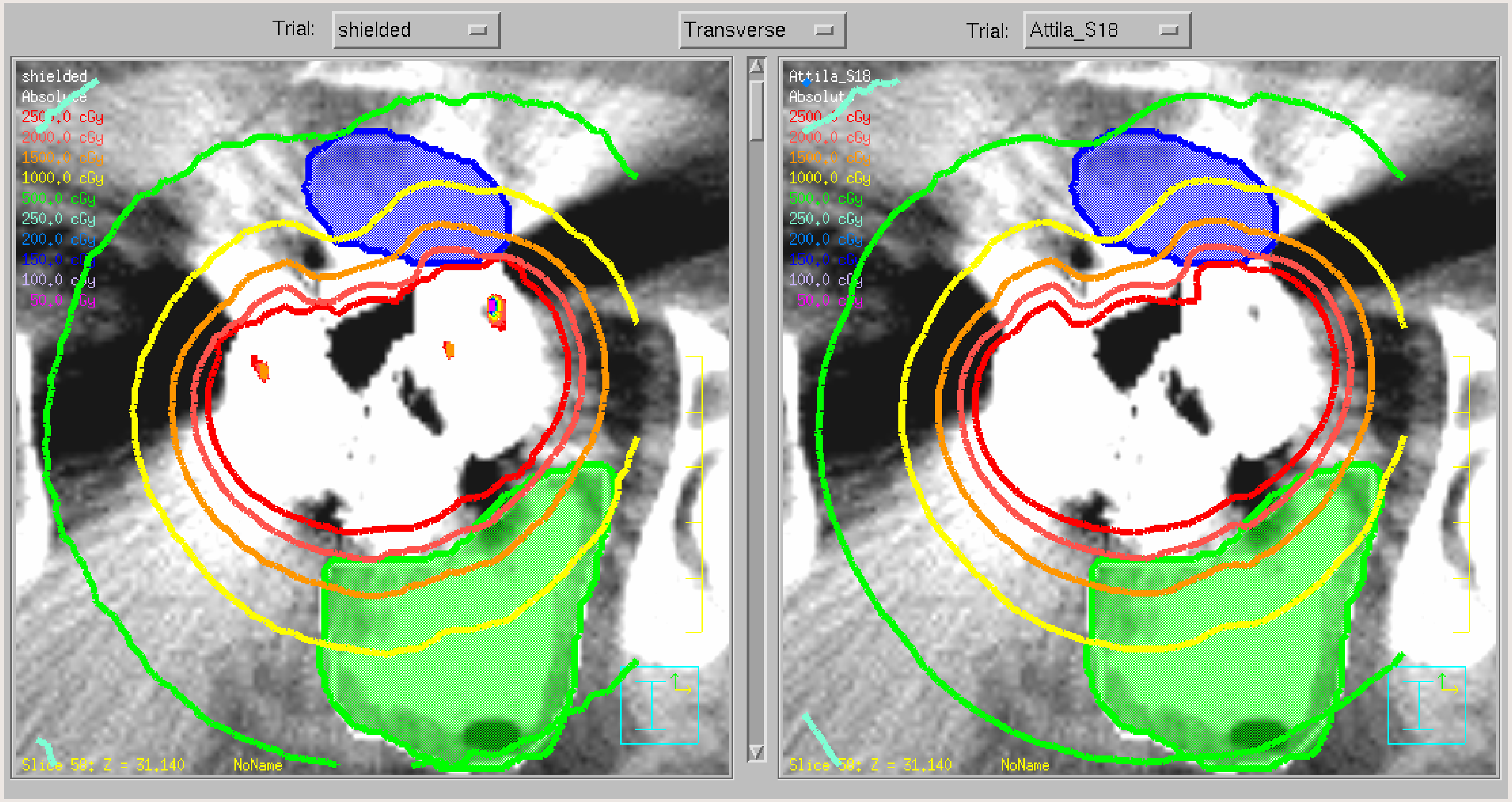


Patent pending

MCNPX2.5.c Attila

1.8 GHz Opteron CPU

18 hr 16 min 2 hr 29 min



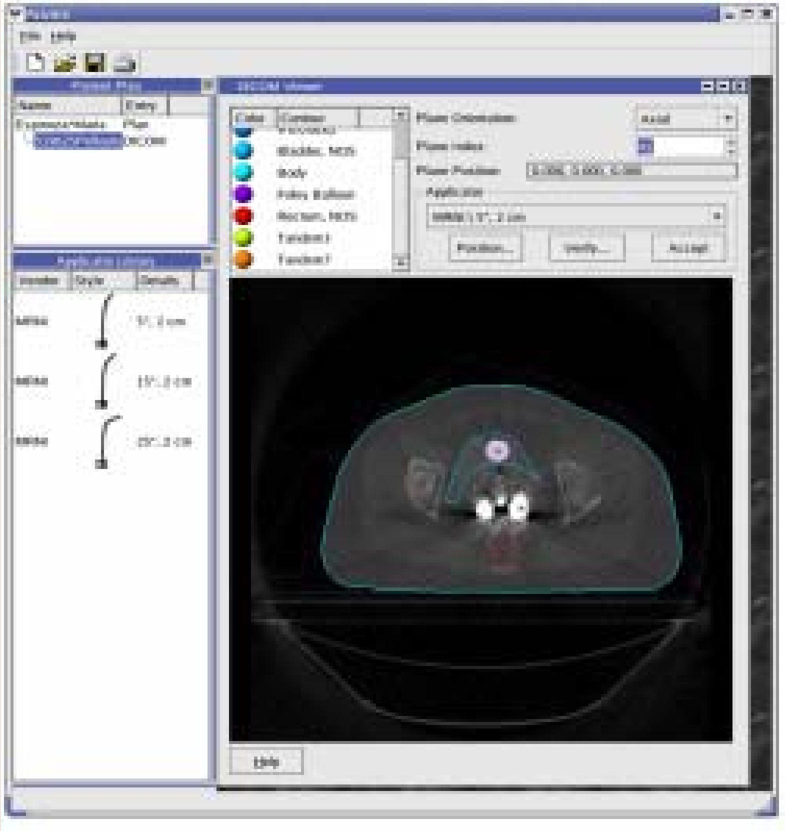
Gifford, et al., AAPM Annual Meeting 2005, SU-FF-T-2

Attila

- Deterministic transport solver including charged particles – discrete ordinates method
- Compatible with CAD programs, e.g., Solid Works, for input of geometry files

Attila

- Solid Works model of tandem and ovoids for clinical implant



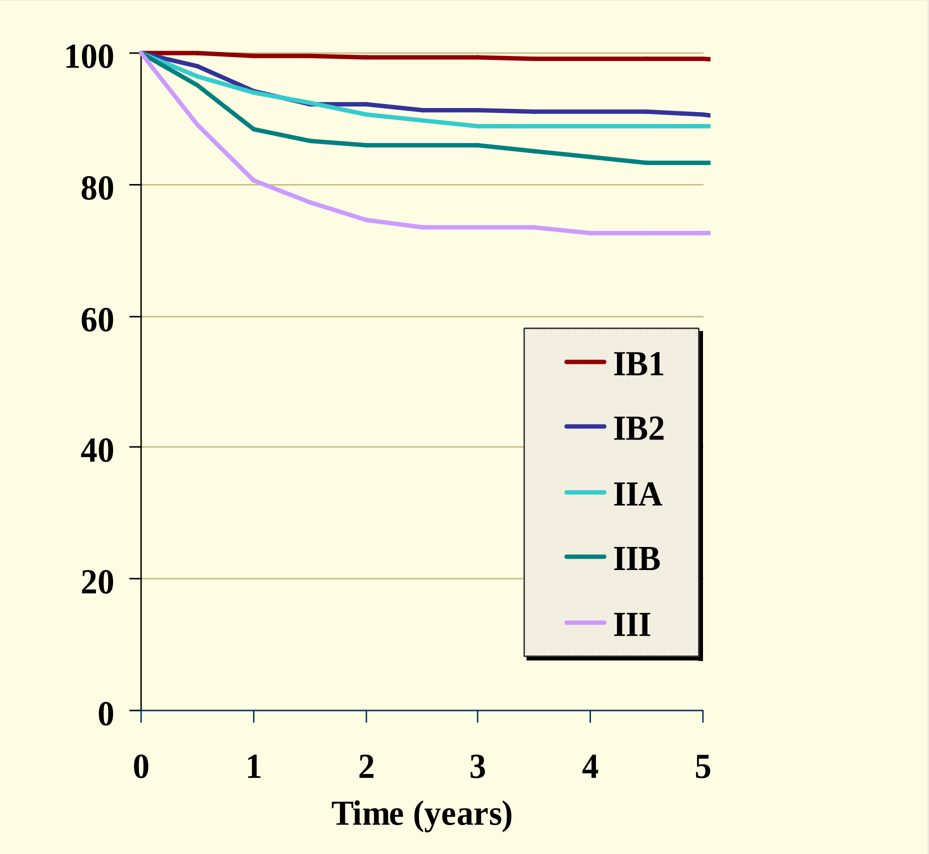
Historical Perspective UTMDACC ICBT

- UTMDACC database
  - dates to 1960
  - 7000 radiation therapy patients
    - 40 – 45 Gy external beam (typical)
    - 2 LDR ICB 48 hour treatments (typical)
- Textbook of Radiotherapy, Fletcher
  - Rules formalized
- Radium treatments
  - Tube sources, 22mm PL, 15 mm AL
  - 1 mm Pt filtration

Cervical cancer: Results of treatment with radiation at MDACC (1980 -1994)

Central recurrence:

- IB1: 1–2%
- IB2–II: 10–15%
- III: 25–30%



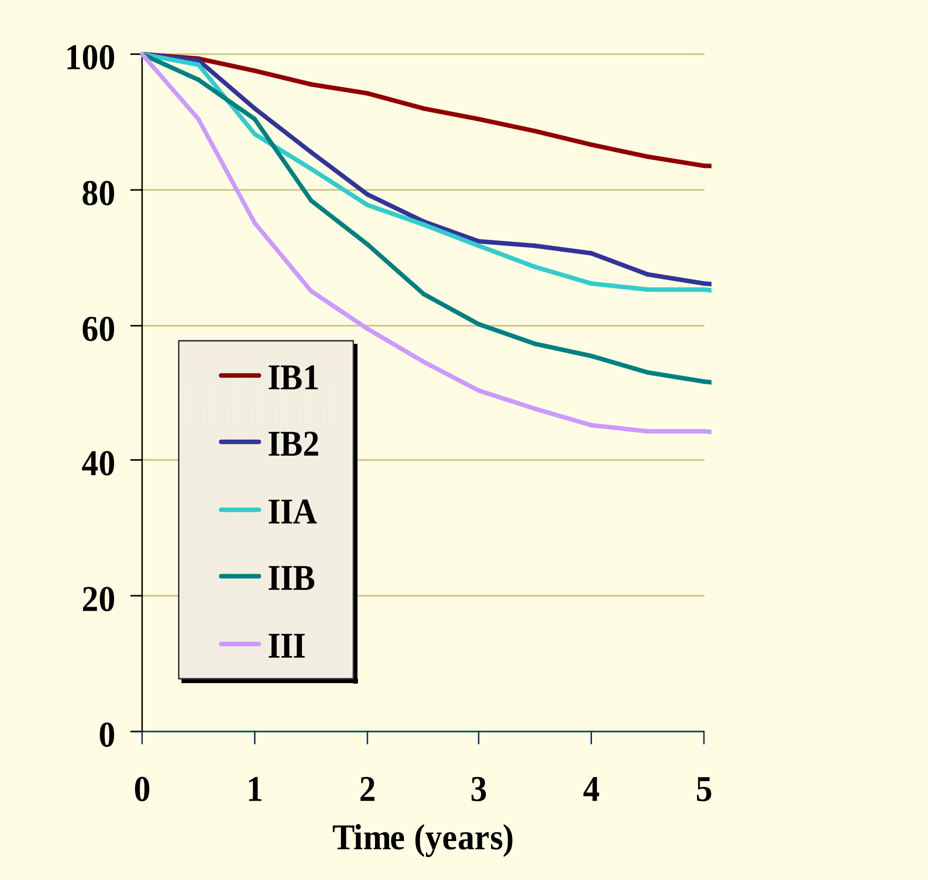
Eifel

Central disease control

Cervical cancer: Results of treatment with radiation at MDACC (1980 -1994)

Death from disease

- IB1: 10 - 15%
- IB2–II: 30 – 40%
- III: 50 – 60%



Disease Specific Survival

Eifel

Overall Major Complications (G=3 or higher) 3489 patients

At 10 Years

- Rectum 3.3%
- Sigmoid 0.2%
- Small Bowel 4.2%
- Bladder 3.0%

Eifel

Current Treatments

- ICB boost delivered with ^{137}Cs
  - Selectron ^{137}Cs LDR remote afterloaders
  - Manually afterloaded ^{137}Cs
    - 20 mm PL, 13.5 mm AL
  - Typically prescribed by geometry in mgRaeq hours (1 mgRaeq = 7.227U)
  - "sources" or "inches" or "custom"

The M. D. Anderson System for Intracavitary Implants

- First described by Fletcher in the Textbook of Radiotherapy, 1969
- Not based upon Point A dose or dose rate

The M. D. Anderson System for Intracavitary Implants

The conditions first described by Fletcher

- Tandem activity 4 to 6 mgRaeq/cm
  - Use spacers to achieve this linear intensity, if required
- Adequate dose to paracervical areas
- Respect mucosal tolerance

Fletcher System

Table 11–8. *Summary of Combination of External and Intracavitary Irradiation in Carcinoma of the Cervix with Intact Uterus*

Tumor size	Whole pelvis	Radium* hr	Radium* mg-hr	Parametrial	Comment
≤1 cm (Fig. 11–10)	None	72–2 wk–48	10,000	None	If anatomy is not good, radium is reduced and additional treatment is given with external irradiation
1–3 cm lesions of exocervix with little or no extension to parametria or fornices (Fig. 11–11)	None 2000 rads 4000 rads	72–2 wk–48 48–2 wk–72† 48–2 wk–48	≤9000 ≤7500 ≤5500	≤4000 rads§ ≤2000 rads§ None	The amount of whole pelvis and parametrial irradiation depends upon (1) extent of disease, (2) patient anatomy, and (3) geometry and location in pelvis of radium system
Endocervical tumor or disease of moderate bulk >3 cm to ≤6 cm with or without extention to medial parametrium (Fig. 11–12)	4000 rads	48–2 wk–48	5500–6500‡	None	If regression is poor and there is no parametrial involvement, one single radium insertion (72 hr or 5000 mg-hr—whichever comes first) followed by an extrafascial hysterectomy
Bulky central disease >6 cm "barrel-shaped" endocervical tumor (Fig. 11–13)	4000 rads	72	5000	None	Extrafascial hysterectomy performed 6 wk after irradiation
Bulky central disease >6 cm extending near or to pelvis wall(s) and/or lower vagina (Fig. 11–14)	4000 rads 5000 rads	48–2 wk–48 72 or 48–2 wk–24–48	5500–6600‡ 4000–5000‡	May add 1000 rads to side of major involvement	When major involvement is restricted to only one side, whole pelvis may be stopped at 4000 rads and involved side boosted through parametrial field
	6000 rads	72 or 48–2 wk–24	3000–4000‡		After 5000 rads reduce fields to ≤12 cm × ≤12 cm
Massive disease or bladder or rectal involvement (Fig. 11–15)	Up to 7000 rads	None	None	None	After 5000 rads reduce fields to ≤12 cm × ≤12 cm After 6000 rads reduce fields to ≤10 cm × ≤10 cm

* Use whichever maximum comes first, either the time or mg-hr
† May use longer time first if vault size may not permit colpostats at second application.
‡ The larger figures for radium are used if lesions have not clinically disappeared at time of second radium: the lesser figures are used if there has been excellent regression of disease.
§ Reduce parametrial irradiation by 500 rads for patients with previous pelvic surgery or pelvic inflammatory disease.

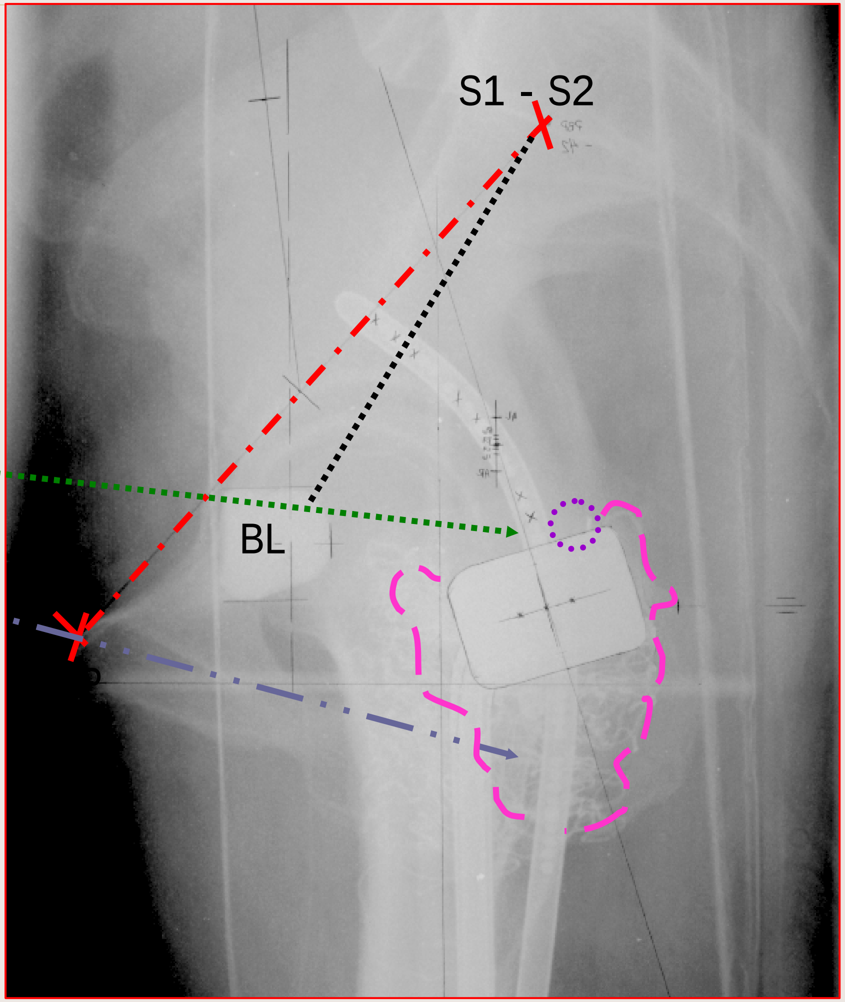
Fletcher, Textbook of Radiotherapy, 1980

Optimized System Geometry

- Optimal placement of the applicators in the uterus and vagina.
- Optimal placement of the radioactive sources in applicators
- Pear-shaped dose distribution - high dose to the cervical and paracervical tissues; reduced dose to the bladder and rectum

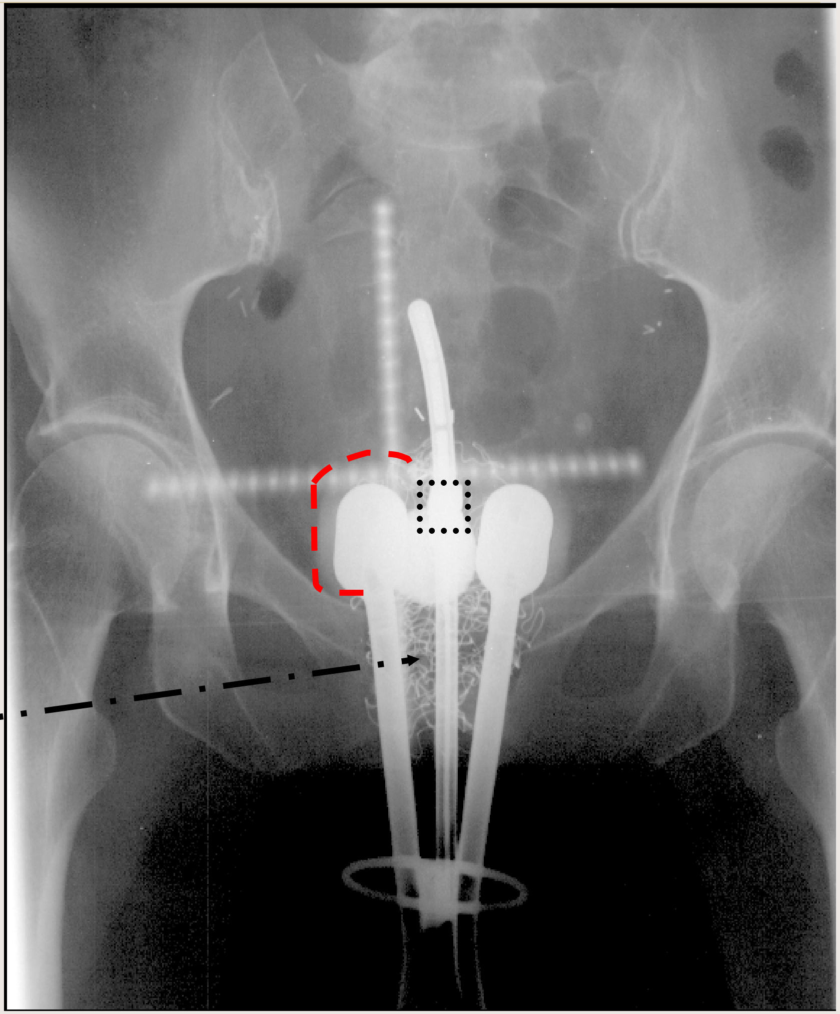
Lateral View of Optimized Applicator Placement

- Tandem - 1/3 of the way between S1 – S2 and the symphysis pubis
- The tandem - midway between the bladder and S1 - S2
- Marker seeds should be placed in the cervix
- Ovoids should be against the cervix (marker seeds)
- Tandem should bisect the ovoids
- The bladder and rectum should be packed away from the implant



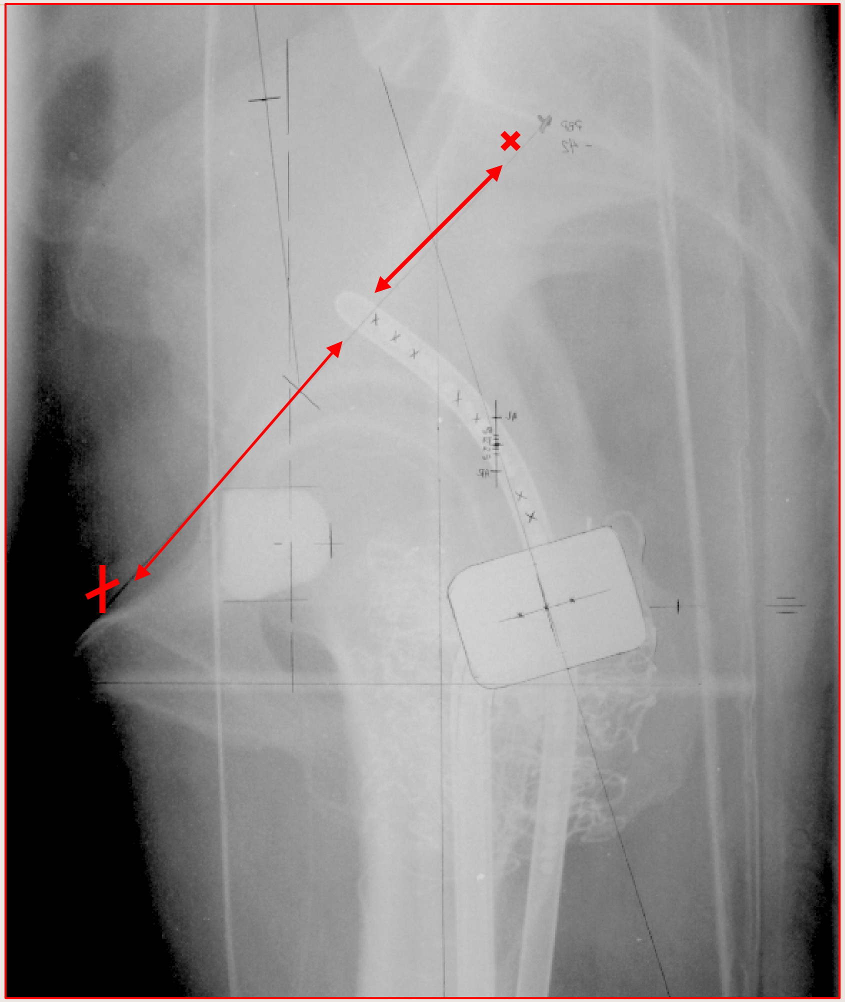
AP View of Optimized Applicator Placement

- The ovoids should fill the vaginal fornices, add caps to increase the size of the ovoids if necessary.
- The ovoids should be separated by 0.5 – 1.0 cm, admitting the flange on the tandem.
- The axis of the tandem should be central between the ovoids



Optimized System Placement In Practice

- Katz and Eifel evaluated 808 insertions of tandem and ovoids at MDACC
- Median distance between the sacrum and the tandem, 4.0 cm
- Interquartile (IQ) range, 2.2 – 4.9 cm.
- Median distance between tandem and pubis, 8.4 cm
- IQ range, 7.6 - 9.1 cm.



Tandem Loading

- 4 to 6 mgRaeq/cm
- Physical length (PL) of inferior source does not extend beyond flange, typically
- If ovoids are displaced inferior to cervix based on marker seeds, inferior end of PL of inferior source 2mm to 3 mm above superior aspect of ovoids
- Source activity in tip, typically higher than other sources, increases lateral coverage
- 30 to 45 mgRaeq over 6 to 8 cm

Ovoid Loading

- Small ovoids, 2 cm, 10 – 15 mgRaeq
- Medium ovoids, 2.5 cm, 15 – 20 mgRaeq
- Large ovoids, 3 cm, 20 mgRaeq
- Mini-ovoids, 1.6 cm, 5 mgRaeq, rarely 7.5 or 10 mgRaeq
- Selectron ovoids – 33 mm long, “short small” – 28 mm long

Treatment Planning

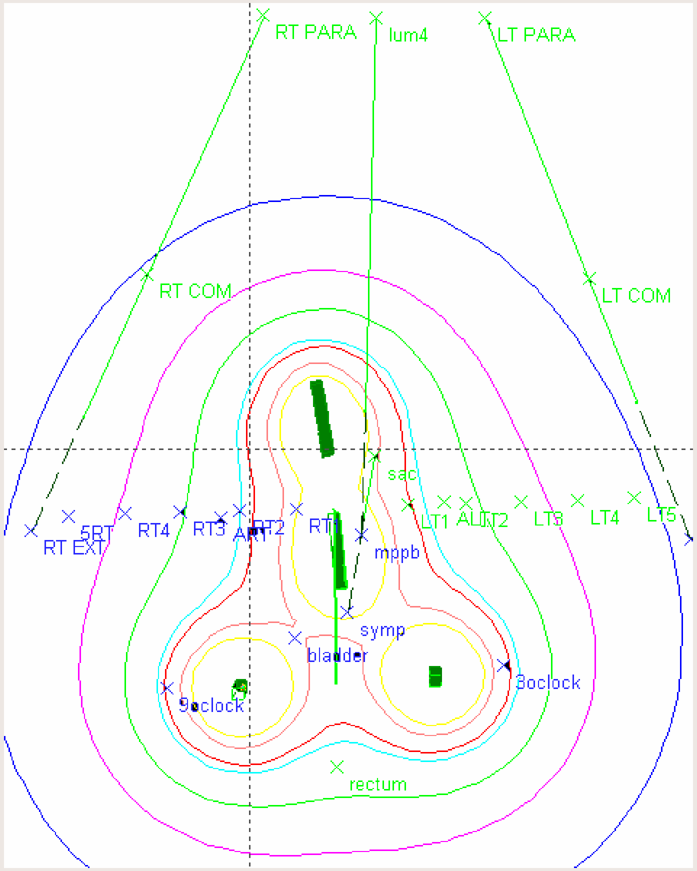
- Planes
  - Lateral throw off
  - Fletcher trapezoid
  - Pelvic brim
  - Sagittal
- Critical Structure Doses
  - Bladder
  - Rectum
  - Vaginal Mucosa, vault dose, 3 & 9 o’clock

Lateral Throw Off Plane

- Lateral throw off (LTO) plane passes through the internal os (IO) and the center of the activity in the ovoids (MO)

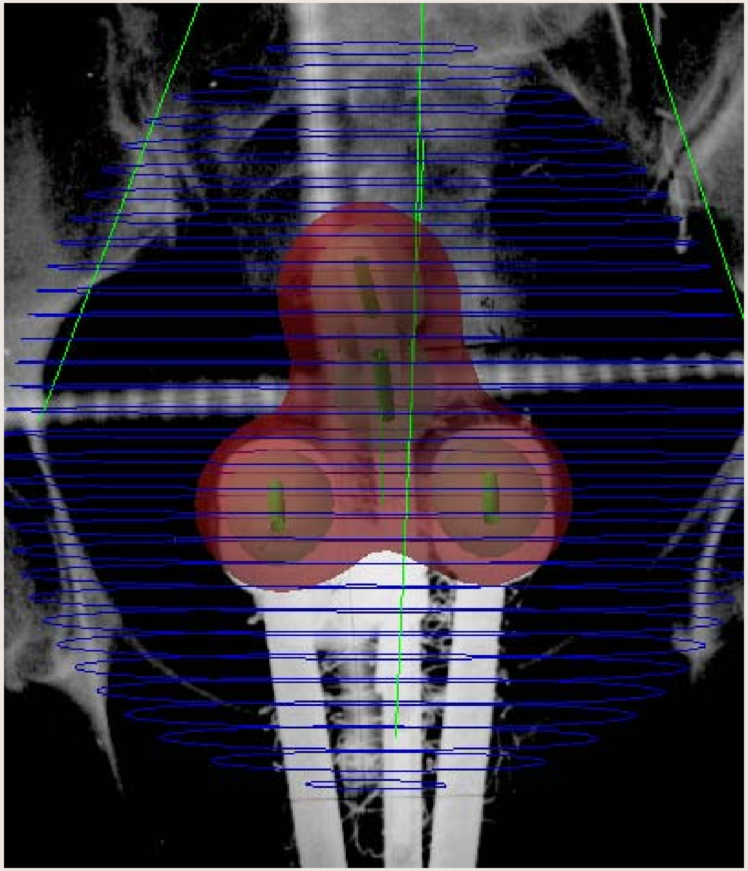
Dose Evaluation
Lateral Throw Off Plane

- 3150cGy isodose line of interest
- 3150cGy line from Manchester system typical prescription 7000R
- 7000R becomes 6300cGy Shalek & Stovall conversion
- Typically two 48 hour insertions
- 3150 cGy per insertion



Dose Evaluation
AP View

- Pear-shaped 3150 cGy volume should show
  - high dose to the cervix and paracervical tissues
  - reduced dose to the bladder and rectum
  - no high or low dose volumes



Mucosal Tolerances

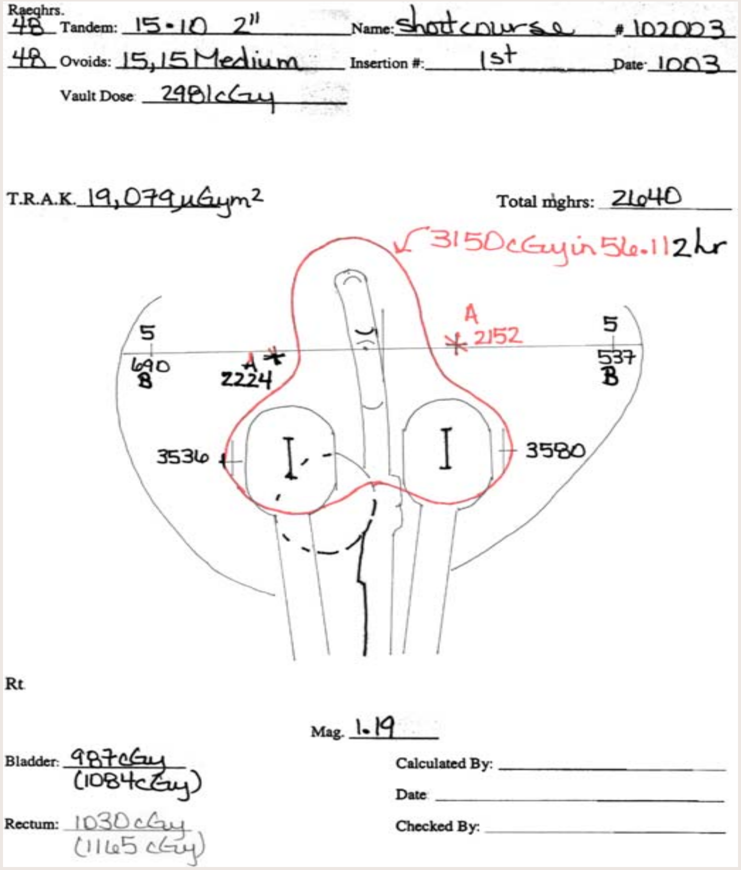
- Respect normal tissue tolerances, total external beam dose plus brachytherapy dose
  - Bladder - limit 75 to 80 Gy
  - Rectum - limit 70 to 75 Gy
  - Vaginal surface dose – limit 120 to 140 Gy
- Integral dose to the pelvis
  - 6000 to 6500 mgRaeq-hrs

Mucosal Tolerances

- Vaginal surface doses
  - Vault dose, dose to ovoid surface (vaginal mucosa) from source in that ovoid
  - 3 o'clock and 9 o'clock doses
    - Dose to ovoid surface includes vault dose plus doses from tandem sources and other ovoid source, approximate calculation
    - 3 o'clock dose at lateral surface of left ovoid
    - 9 o'clock dose at lateral surface of right ovoid

Lateral Throw Off Plane

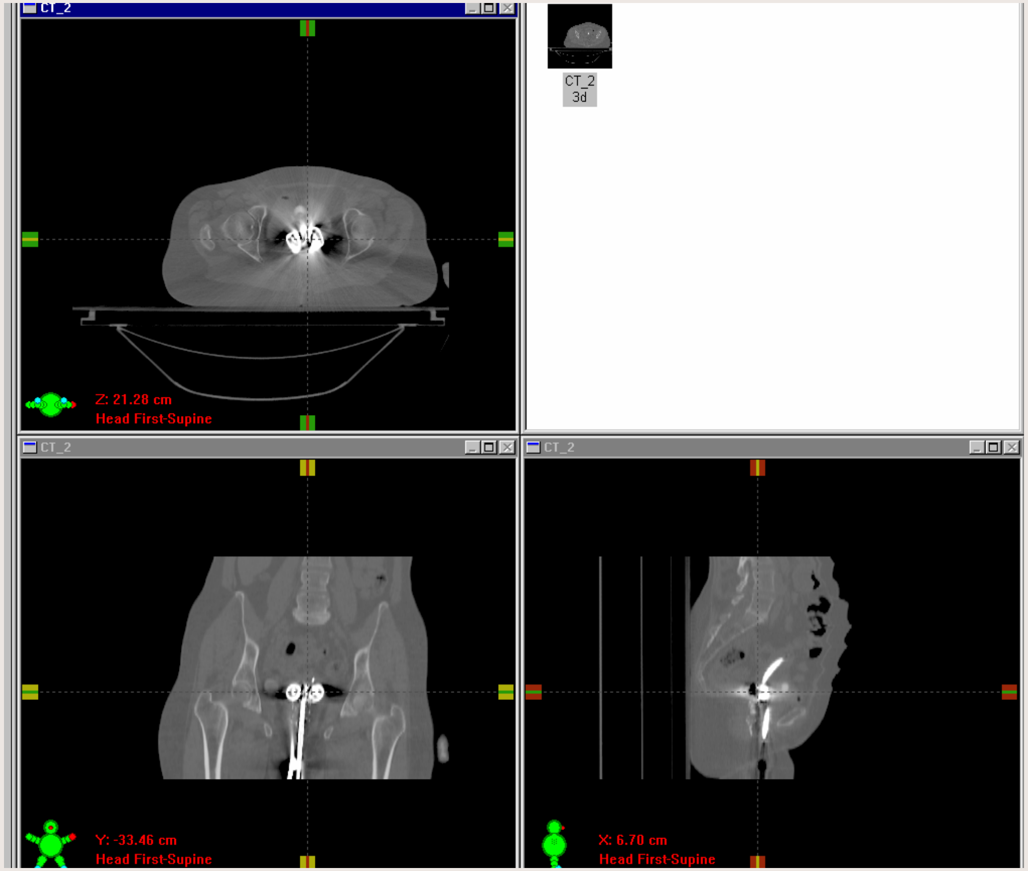
- Tandem and Ovoid loadings and hours
- mgRaeq-hour
- TRAK
- 3150 cGy line
- Doses to
  - Pelvic points A and B
  - 3 o'clock; 9 o'clock
  - Bladder
  - Rectum
  - Vault



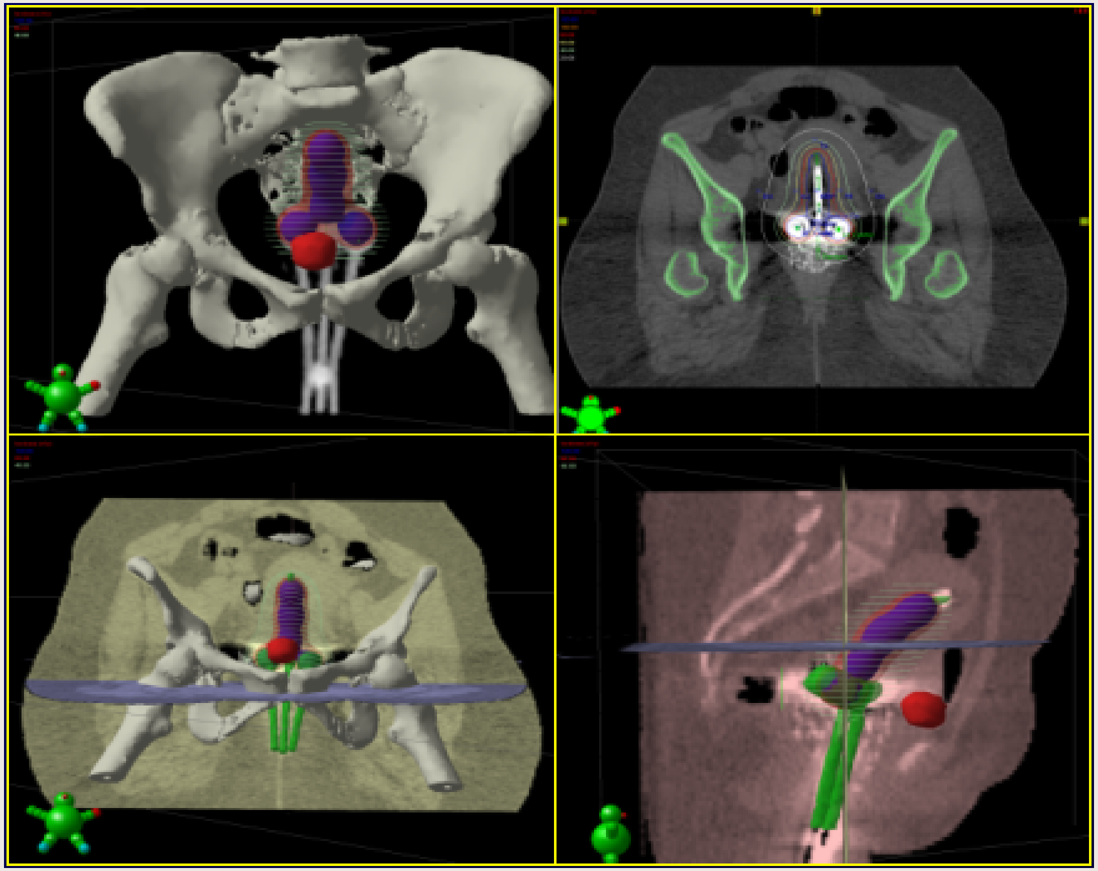
Dose to Point A

- External beam dose of 40 to 45 Gy plus brachytherapy dose from two 48 hour insertions to point A total
  - 80 to 85 Gy for small IIA and IIB tumors
  - 85 to 90 Gy for larger tumors

3D CT Treatment Planning

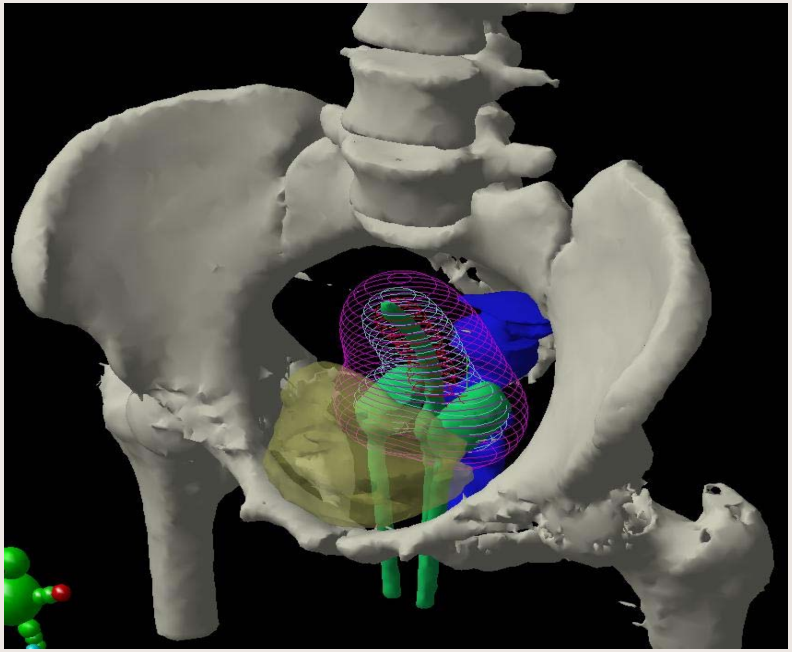


3D Treatment Planning



3D Treatment Planning

- Better knowledge of minimum tumor dose
- Better knowledge of normal tissue doses
- Improve investigation of dose responses
- Potential to improve applicator positioning



3D Treatment Planning

- 93 implants, ICRU bladder and rectal points compared 3D CT plans
- ICRU bladder point significantly lower ($p<0.001$) than 3D CT plan point D_{BV2}

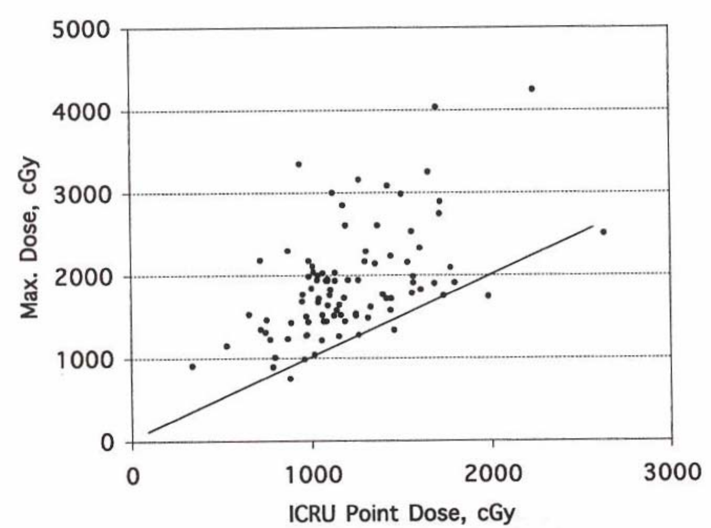


Fig. 4. Comparison of bladder dose calculated at ICRU rectal reference point and D_{BV2}.

D_{BV2} = 2cm^2 volume receiving highest dose

Pelloski, et al., Int. J Radiation Oncology Biol. Phys., 2005

3D Treatment Planning

- ICRU rectal point, surrogate for D_{RV2}, ($p=.561$)

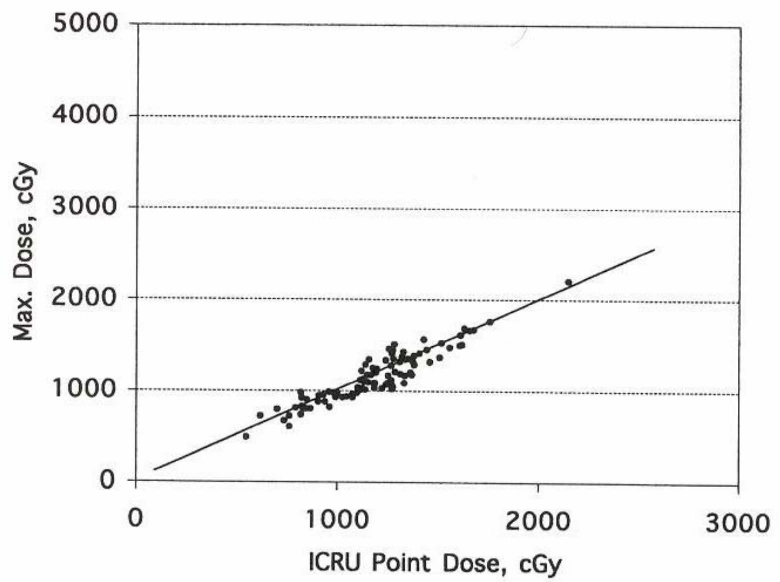


Fig. 3. Comparison of rectal dose calculated at ICRU rectal reference point and D_{RV2}.

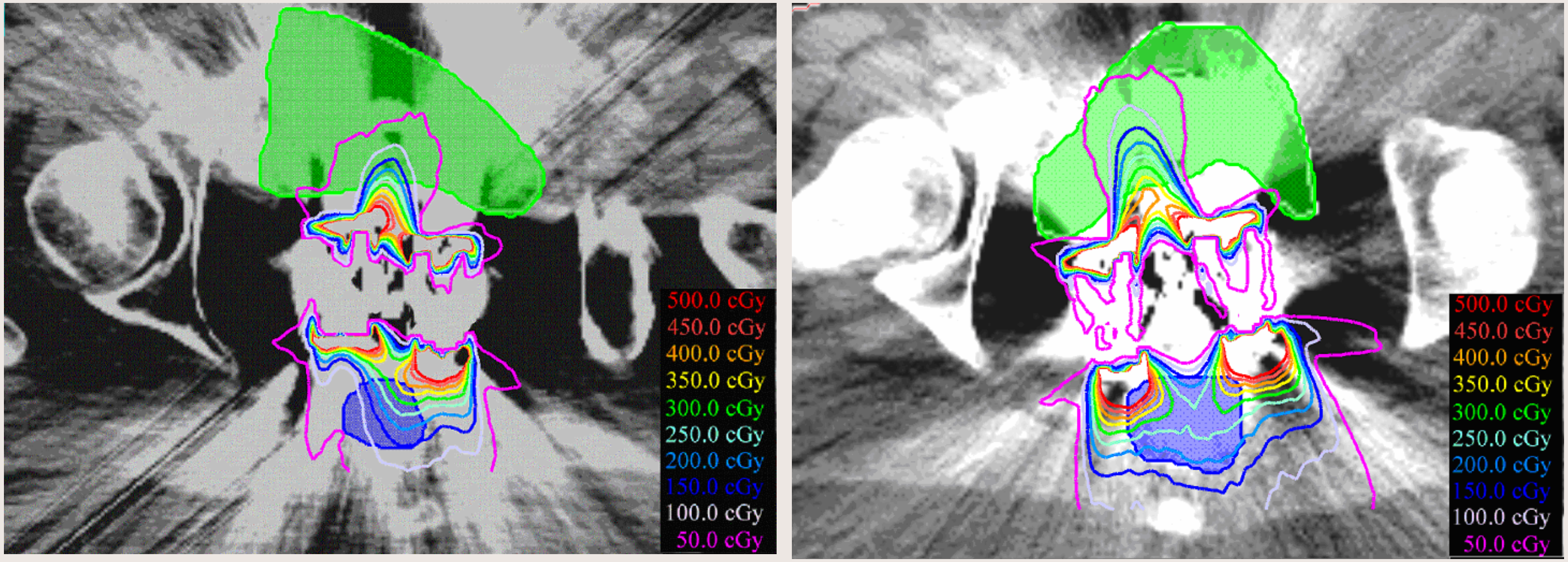
D_{RV2} = $2cm^2$ volume receiving highest dose

Pelloski, et al., Int. J Radiation Oncology Biol. Phys., 2005

3D Treatment Planning

Subset of 12 patients, Pelloski data. MCNPX2.5.c study accounted for shielding effects.

Dose difference curves comparing shields to no shields.



Gifford, et al., Int. J Radiation Oncology Biol. Phys., 2005

3D Treatment Planning

- Bladder
  - Mean dose reduction 53cGy to 5% of surface area
  - Max dose reduction 150cGy to 5% of surface area
- Rectum
  - Mean dose reduction 195cGy to 5% of surface area
  - Max dose reduction 405cGy to 5% of surface area

Gifford, et al., Int. J Radiation Oncology Biol. Phys., 2005

Dose Specification in ICB

"...universal agreement does not exist as to the superiority of any one system. The problem is perhaps with the nature of brachytherapy, no more sophisticated than gourmet cooking...as in cooking, there is a little bit of everything: art, science, technique, and taste."

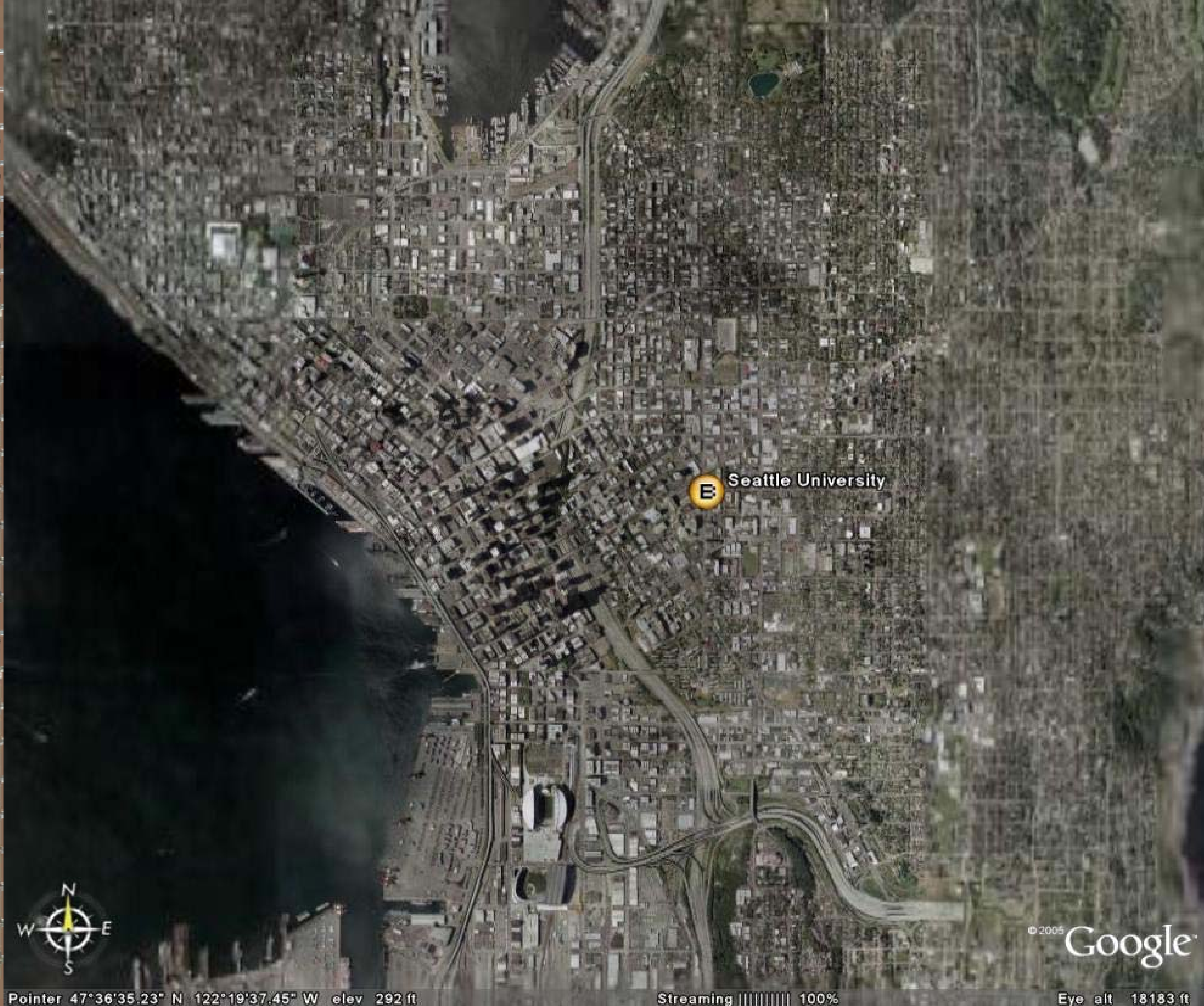
Khan, The Physics of Radiation Therapy, 3rd Edition, Brachytherapy, Chapter 15, 2003.

Dose Specification in ICB

"It is realized that the weakness of the whole system lies in the inability to visualize the target volume. Unless the target volume can be accurately determined and superimposed on the isodose pattern, one cannot determine the minimum target dose."

Khan, The Physics of Radiation Therapy, 3rd Edition, Brachytherapy, Chapter 15, 2003.

Art, Science, Technique, and Taste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