HDR Applicators and Dosimetry*

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*with a ‘too much’ radiobiology

Objectives

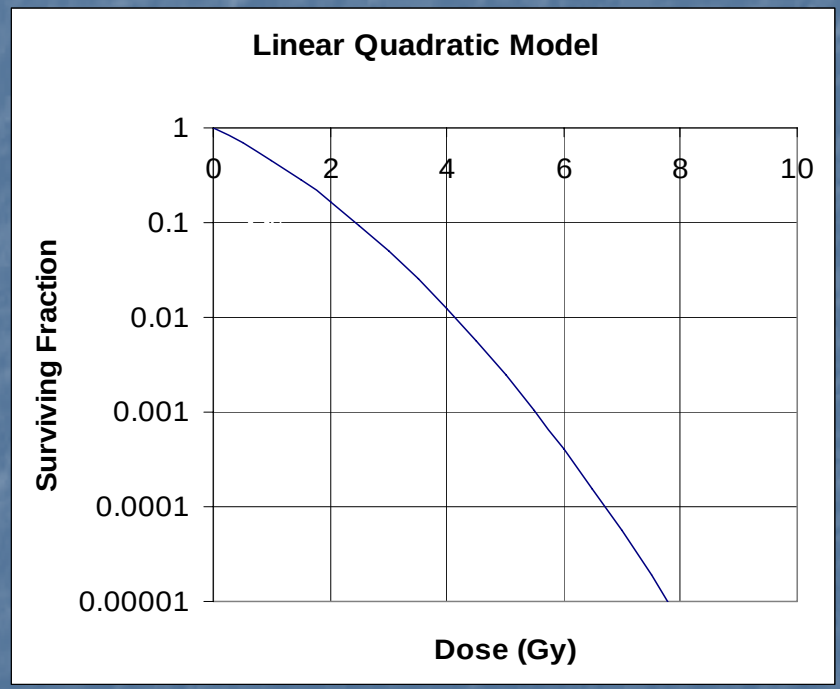
- Review the radiobiology of brachytherapy-linear quadratic model.
- Understand how to convert LDR dose prescriptions to HDR treatments.
- Understand some of the differences between LDR and HDR planning and treatment methods.

Radiobiology of Cell Death

- Single Strand Breaks (SSB)
  - easily repaired DNA damage
- Double Strand Breaks (DSB)
  - less frequent and less easily repaired DNA damage
- Hypothesis
  - unrepaired DSB lead to cell death-inactivation

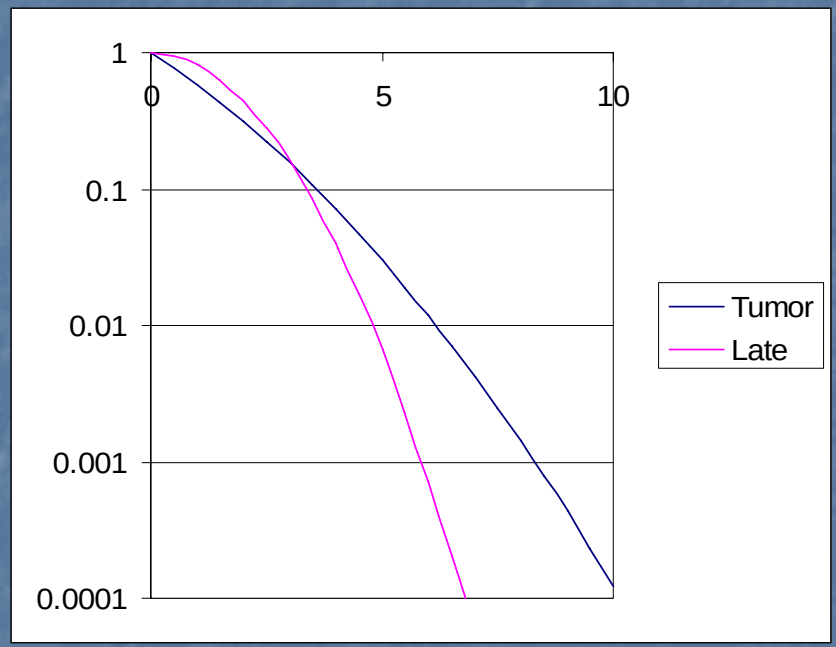
Radiobiology-LQ Model

- $S = \exp-(\alpha D+\beta D^2)$
  - α single event coefficient of a DSB
  - β double event coefficient of a DSB
  - S is the surviving fraction or overall probability of survival
  - High dose rate delivery with respect to repair



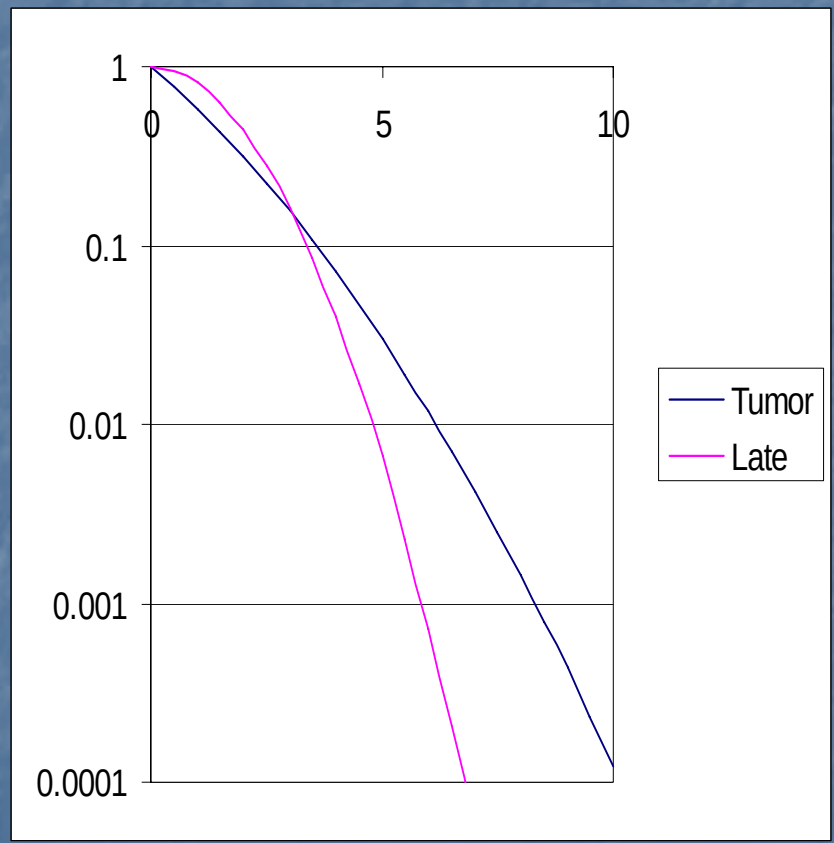
Radiobiology-Fractionation

- Late responding normal tissue cells versus tumor cells
  - shallower initial slope
  - steeper final slope
- Crossover point
  - $\alpha D = \beta D^2$
- Dose/fraction below the crossover point
  - higher survival of late responding tissues



Radiobiology-Dose Rate

- Low Dose Rate (LDR)
  - similar in effect to low dose per fraction below crossover point
- High Dose Rate (HDR)
  - possible to be above crossover point in effect
- Equivalence?



Radiobiology-the effect

- Biological Effect-E
  - single acute dose = $\alpha D+\beta D^2$
  - n well separate fractions = $n(\alpha D+\beta D^2)$
- $E = (nD)*(\alpha+\beta D)$
- $E/\alpha = \alpha*(nD)*(1 + D/(\alpha/\beta))$
- Biological Effective Dose (BED)
  - Extrapolated Response Dose (ERD)
  - BED=E/α =Total Dose*Relative Effectiveness

Prescriptions-Equivalence

↓ total dose, ↓ fraction size, ↑ fraction number to minimize complications

To determine a reasonable dose for HDR treatments, based upon a continuous LDR treatment, the BED's or ERD's are assumed to be equal.

HDR: $ERD\text{-}Nd\left(1+\frac{d}{\alpha/\beta}\right)$ [1]

LDR: $ERD\text{-}NRt\left[1+\frac{2R}{\mu(\alpha/\beta)}\left(1-\frac{1-e^{-\mu t}}{\mu t}\right)\right]$ [2]

where:

N = number of fractions (for HDR or LDR);

d = dose/fraction (for HDR) in Gy;

R = dose rate (for LDR) in Gy/hour;

t = time for each fraction (for LDR) in hours;

and α/β (in Gy) and μ (in h^{-1}) are tissue-specific parameters.

Prescription-Equivalence

Equate and solve for HDR dose, spreadsheet math…

	ERD Calculation for SOMEBODY		4/21/03			
	"Variable" (V)	Value of V	ERD LDR			
N_LDR	# 0f LDR fxs	1	54.25			
Rate	**LDR Rate (cGy/hr)**	**60**		R	0.60	Gy/hr
t	time in hrs (LDR Dose/Rate)	83.3		T	83.33	hours
mu	1.4 hr for tumors	1.4		N	5	fractions
alphabeta	alpha/beta=10 for tumors	10		d	6.55	Gy/HDR fraction
d	**dose given by LDR (cGy)**	**5000**				
N_HDR	**# of HDR Fractions**	**5**				
			ERD HDR			
		Dose	**6.55**	**Gy**		

Treatment Goals

- Deliver the dose to the target
  - LDR limited source strengths, limited variability
  - HDR can ‘tune’ the dose distribution
- Spare normal tissues
  - LDR: pull applicator or sources early as needed
  - HDR: adjust position and optimization points pre treatment

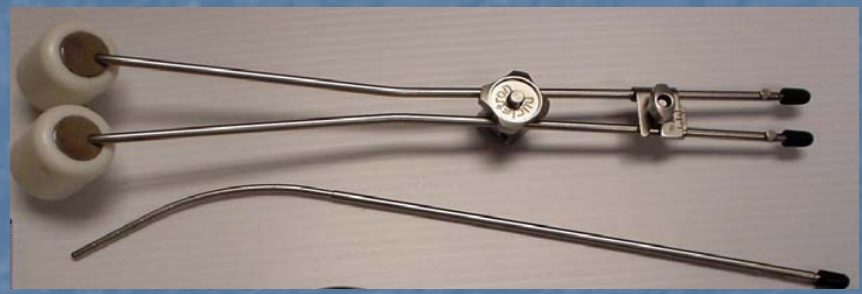
HDR Planning-Matching

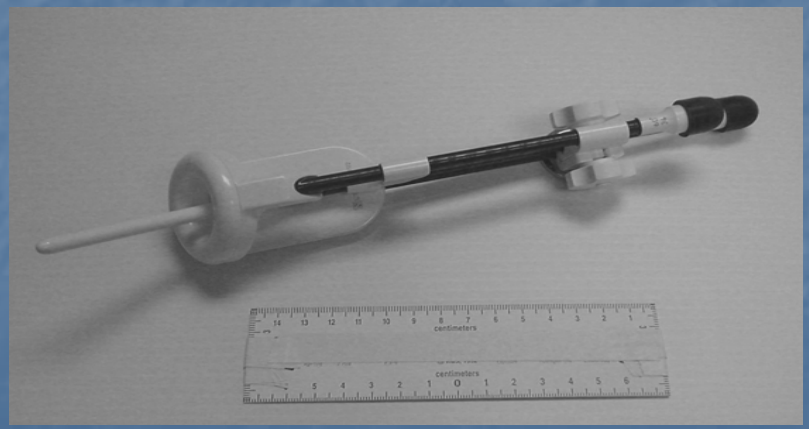
- Exact matching of an individual isodose is possible, but …
  - You may not always want a perfect match
  - Using BED, the DOSE relationship is NOT linear between HDR and LDR isodoses

HDR Planning-Considerations

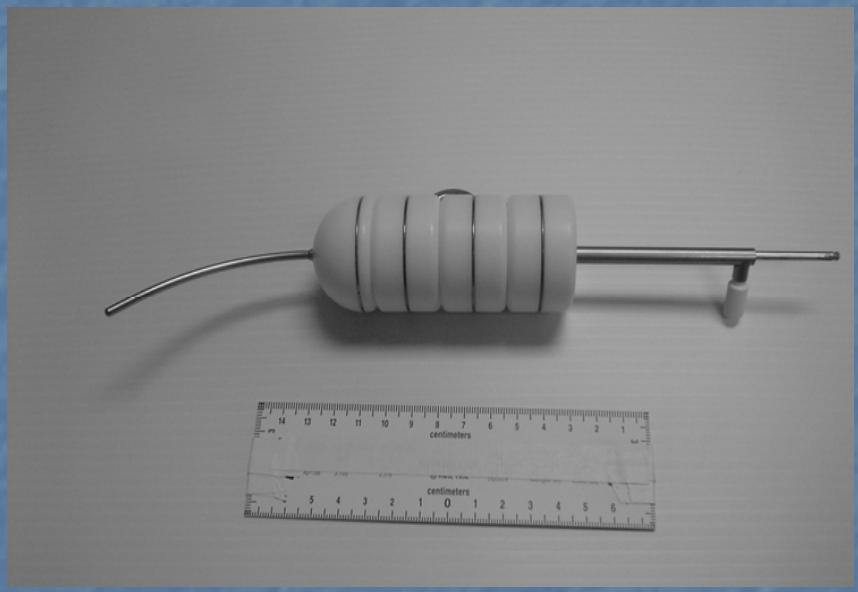
- LDR classic pear shape
  - tapered near tip of tandem because of source placement
  - clinical outcome based upon cervix target
- HDR mimic classic pear shape
  - tapered near tip via optimization
  - planned outcome to mimic LDR shape
- How is this done...

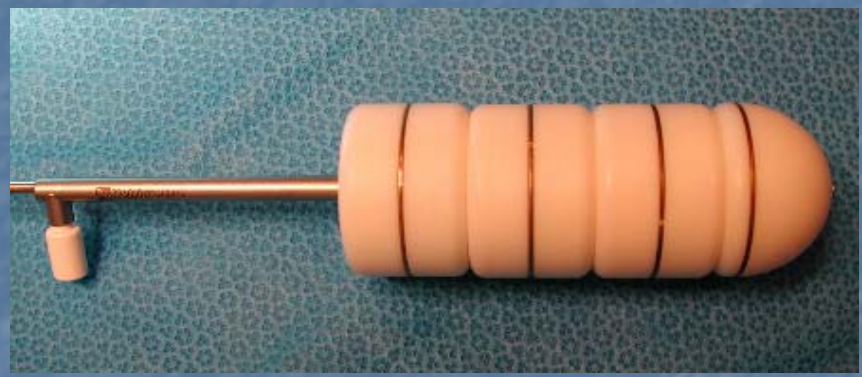
Various HDR Applicators





Various HDR Applicators



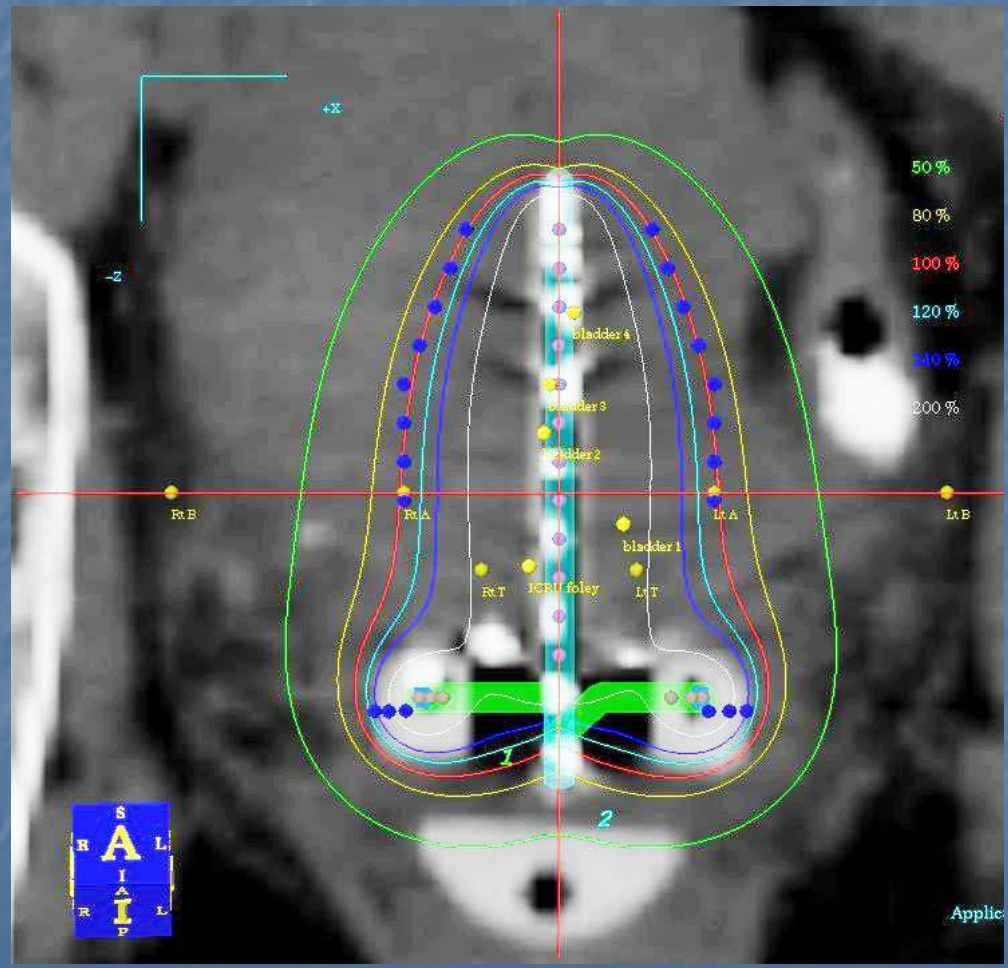


Prescription Points Vs Dose Optimization Points (Vs DVH?)

- Dose Optimization Points
  - control the shape of the isodose distribution
  - assign relative weights to the points
  - e.g 140% to ring surface
- Prescription Points
  - define the absolute value of the isodose lines
  - scale the entire dose distribution
- Equivalence
  - dose is prescribed to a ‘Point’
  - isodose shape is described by optimization
  - dose is delivered to a ‘Volume’

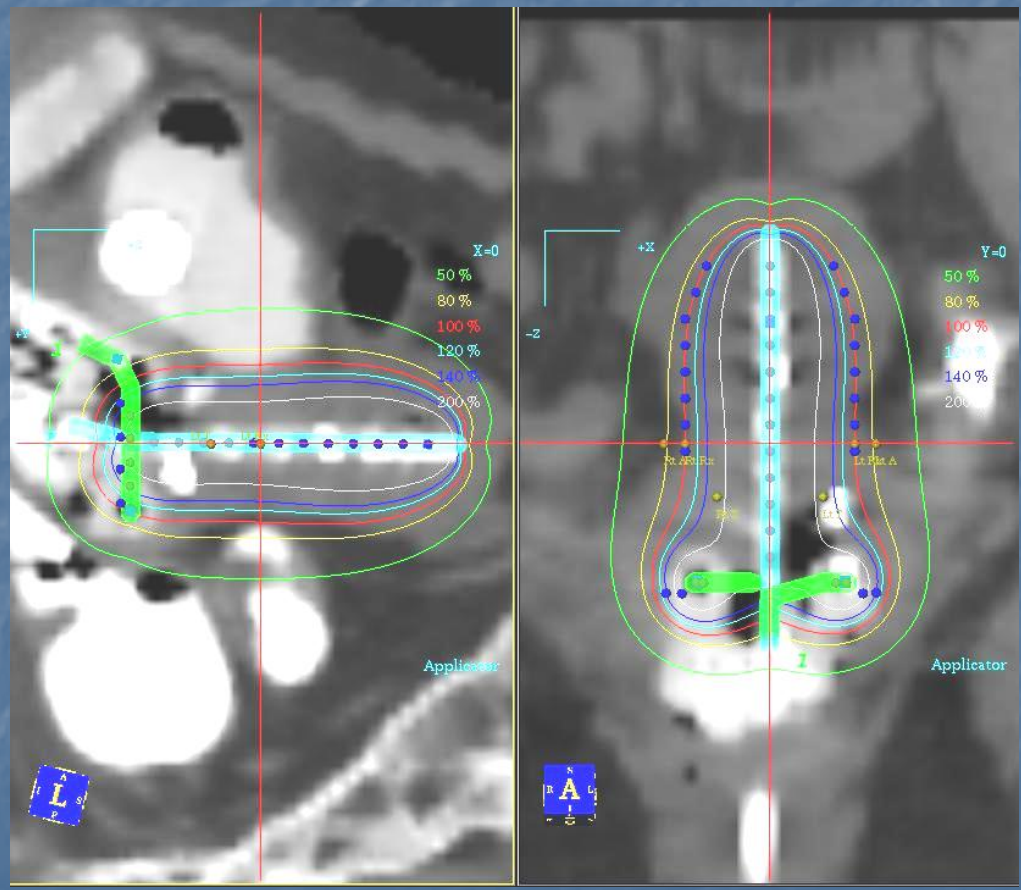
Dosimetry Methods-Tandem and Ring

- Dose optimization points are tapered along the tandem axis
- Applicator points entered based on classic distances
- Dwell locations down to ring, but not past



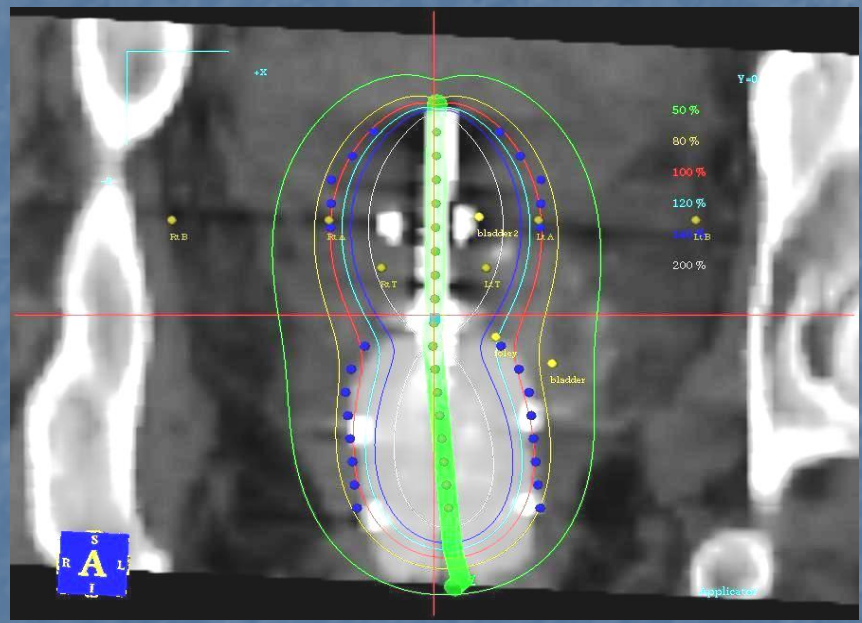
Dosimetry Methods-Tandem and Ring

- Dose optimization points can also be used to modify the classic location of dose specification (Point A)
- 1.8 cm, 1.5 cm, 1.2 cm
- Use CT scan information to get uterine wall thickness



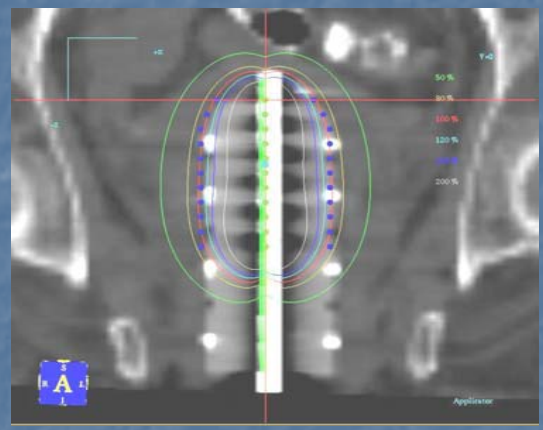
Dosimetry Methods-Tandem and Cylinder

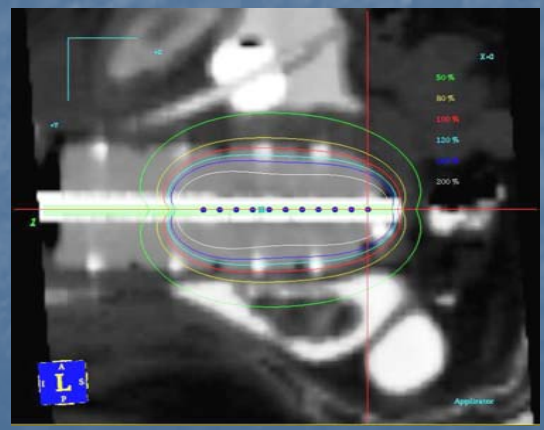
- Dose optimization points along the tandem
- Dose optimization points along the cylinder surface
- When vaginal vault will not accept ovoids or ring geometry



Dosimetry Methods-Cylinders

- Simplest geometry
- Vaginal surface target
  - or depth
- follow the shape of the cylinder
- decide upon a treatment length





Conclusion

There are lots of details to keep track of during brachytherapy.

Document your thoughts and rationales for any planning decisions

Communicate…

HDR PLANNING SHORTCUTS

Tandem and Ring: (step size 2.5 mm, dummies spaced 1.0 cm)

Digitizing Catheter 1 (Ring):1, 5, 9,..,37, 41, 45
Digitizing Catheter 2 (Tandem): 1, 5, 9, 13, 17, 21, 25

(If using film, try tracking OR describing, whichever works. If using CT/MR use tracking)

Tandem Table: (tandem dwells active every 5.0 mm up to level of ring plane but not protruding into ring) DOSE POINTS@100%

Tandem Dwell Position along +/- X axis	4 cm tandem	6 cm tandem	8 cm tandem
1	12 mm	12 mm	12 mm
3	16 mm	14 mm	14 mm
5	20 mm	16 mm	14 mm
7	20 mm	18 mm	16 mm
9	20 mm	20 mm	18 mm
11+	20 mm	20 mm	20 mm

Ring Table: (adjust for symmetry or prescription)

Active Dwells	36 mm Ring (4 dwells each side)	40 mm Ring (5 dwells each side)	44 mm Ring (6 dwells each side)
Right Side Dwells	5,7,9,11	5,7,9,11,13	5,7,9,11,13,15
Left Side Dwells	21,23,25,27	25,27,29,31,33	27,29,31,33,35,37

Ring optimization points placed relative to catheter axis @ 6 mm in the – U axis all active dwells in ring with DOSE POINTS@140%

Cylinder: (step size 5.0 mm, dummies spaced 1.0 cm) DOSE POINTS@100%

Digitize using tracking for easiest method.

Dwell Position along +/- X axis	2 cm diameter	2.5 cm diameter	3 cm diameter	3.5 cm diameter	4 cm diameter
1	9	11	12	13	15
2	10	12.5	14	16	18
3	10	12.5	15	17.5	20
4	10	12.5	15	17.5	20
5+	10	12.5	15	17.5	20

Tip Dwell along +Z axis	2 cm diameter	2.5 cm diameter	3 cm diameter	3.5 cm diameter	4 cm diameter
1	5.1 mm	4.9 mm	4.7 mm	4.3 mm	3.9 mm