

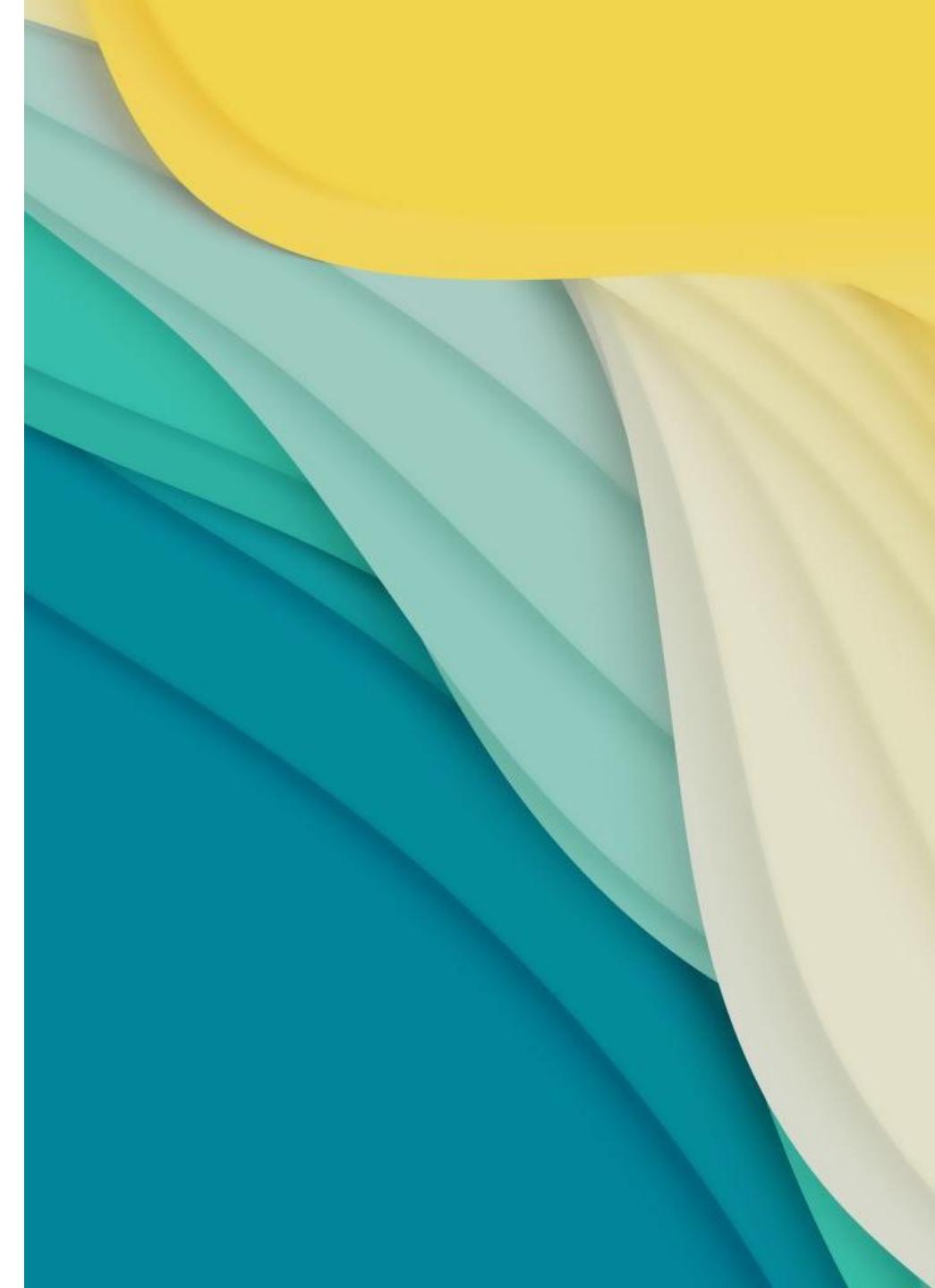
Brachytherapy Calculations

RT4220 – Lecture #16

Kedree Proffitt

WSU

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ADDITIONAL INTRO TO BRACHY STUFF

Have even more brachy!

Effective Half life

$$\lambda_{eff} = \lambda_P + \lambda_b$$

$$\frac{1}{T_{eff}} = \frac{1}{T_P} + \frac{1}{T_b}$$

$$T_{eff} = \frac{T_P \times T_b}{T_P + T_b}$$

Historical Perspective

- Initially most treatment techniques were developed with radium
- Modern dosimetry is still associated with radium
- Safety concerns about radium
 - Radium decays to radon (a gas)
 - In a sealed chamber (seed), gas builds up
 - Gas leak
 - Radioactive material dissemination
- Artificial radionuclides are now used
 - Useful energies for therapy treatments
 - Convenient half-life's

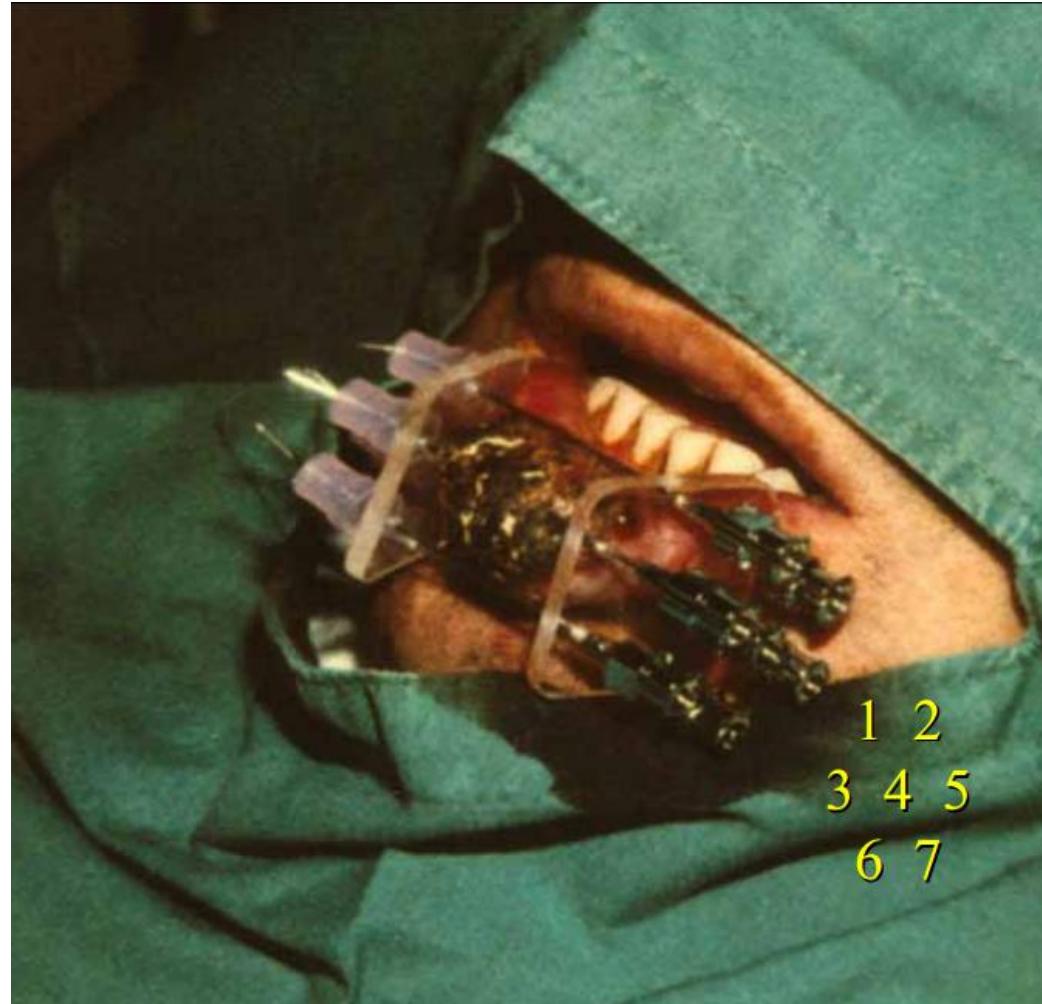
Lower Lip Tumor (example)

- 53 year old patient
- Surgery could remove tumor but the patient would lose partial function of the lip



7 Iridium-192 Needles

- Custom plaque for inserting sources
- Local anesthetic
- 6 day treatment



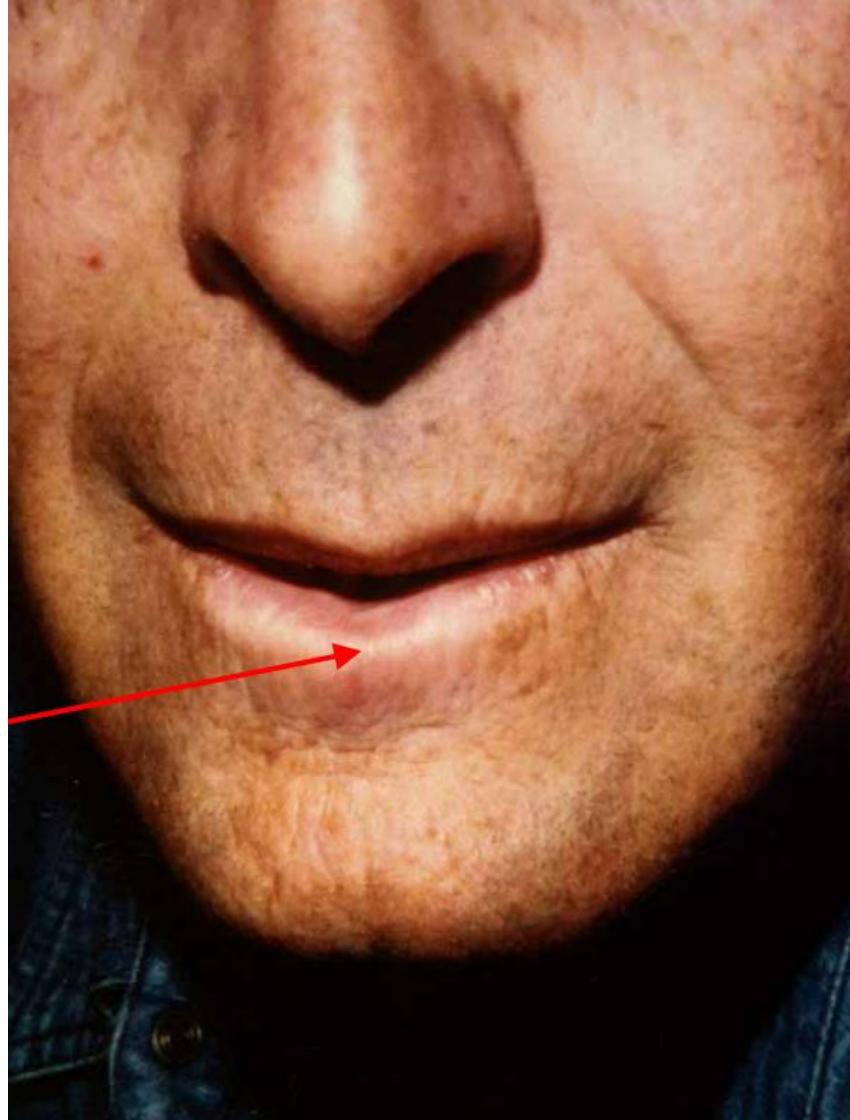
One Month Later...



Two Months Later...



Four Months Later

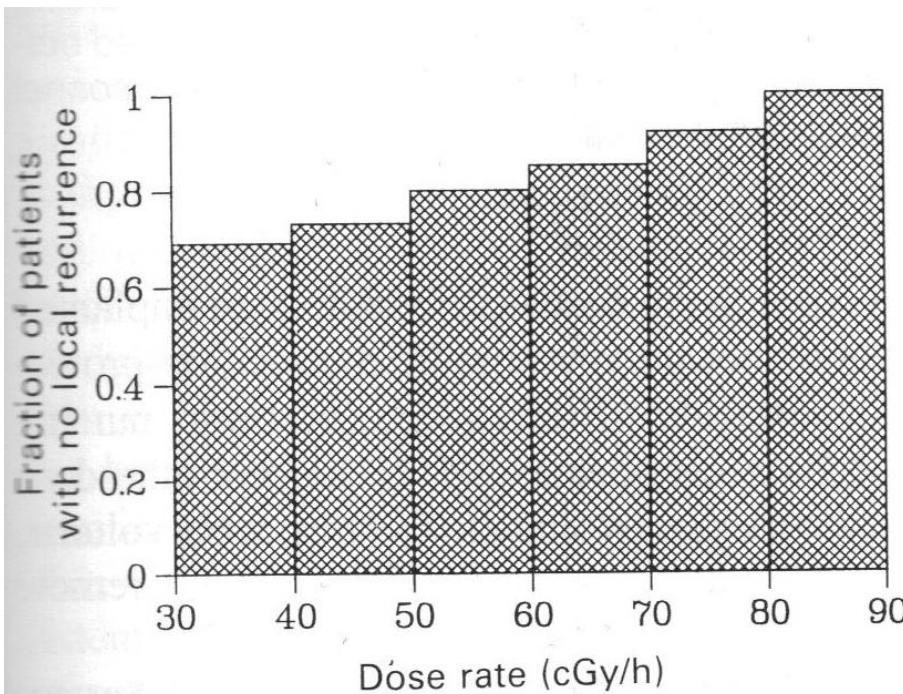


Dose Rate

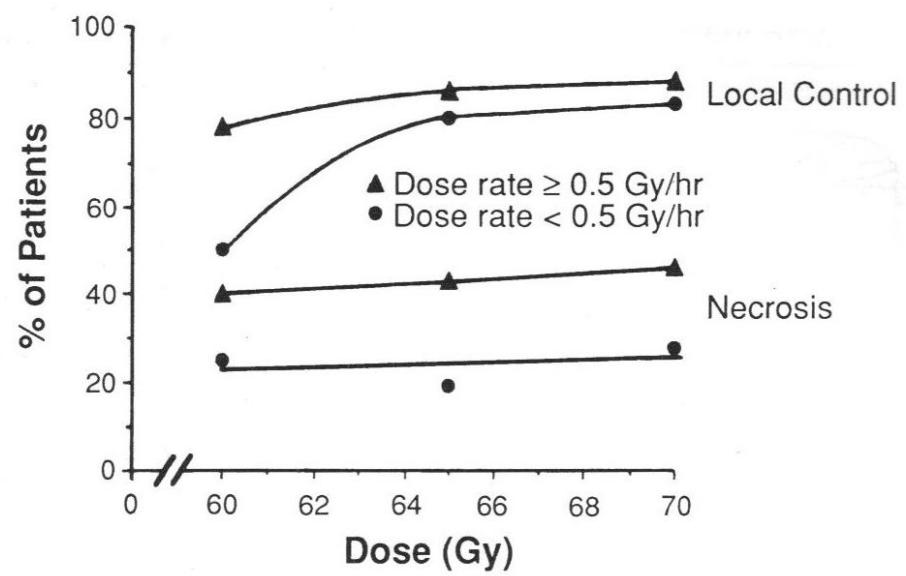
- Want to achieve maximum dose to tumor and keep acceptable toxicity to surrounding normal tissue
- Depends upon:
 - Number of sources
 - Geometric distribution
 - Volume of target tissue
 - Radiobiology of tumor vs. normal tissues

Dose Rate

- The biological effectiveness depends upon dose rate
- Long term effects (toxicities) also depend upon dose rate



REPAIR OF RADIATION DAMAGE

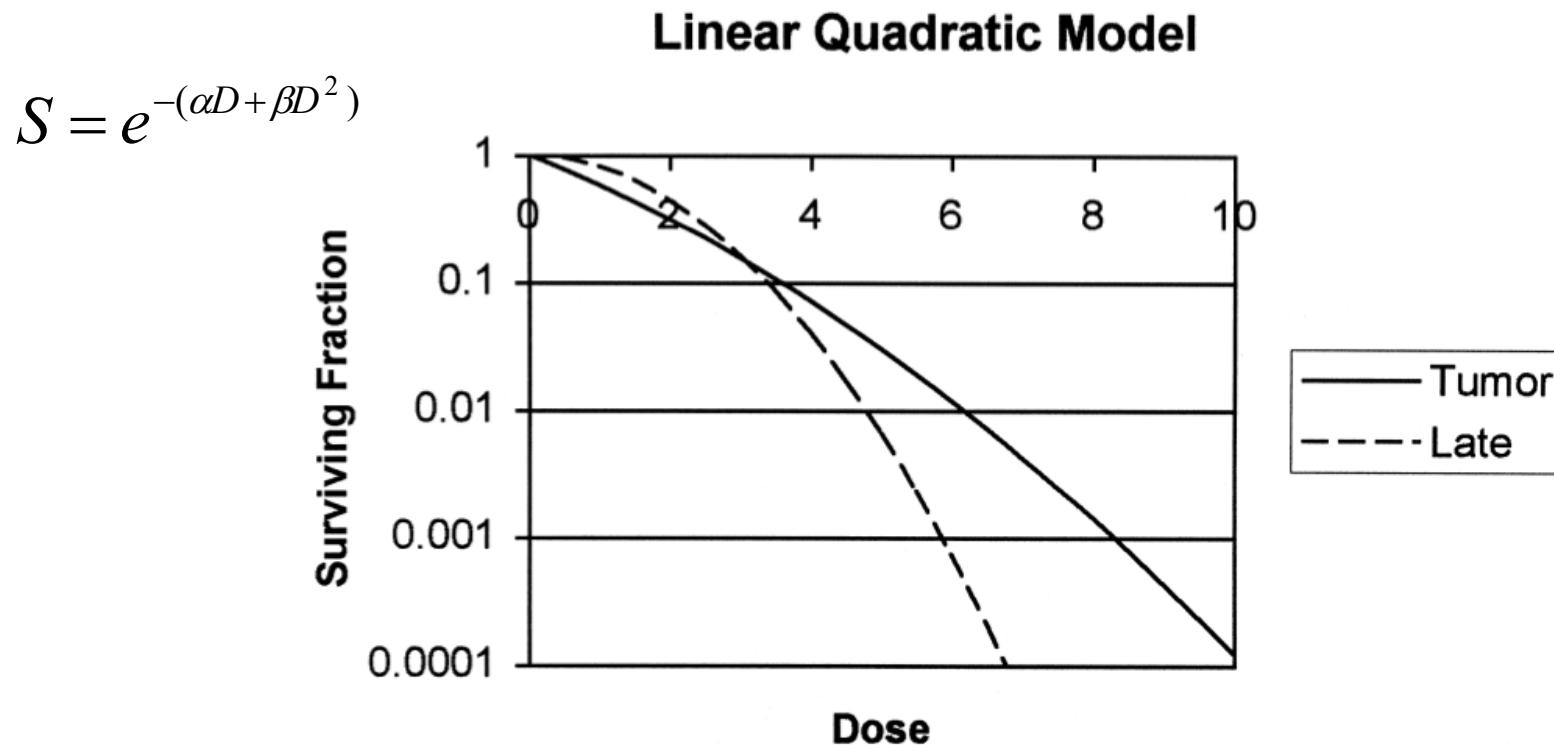


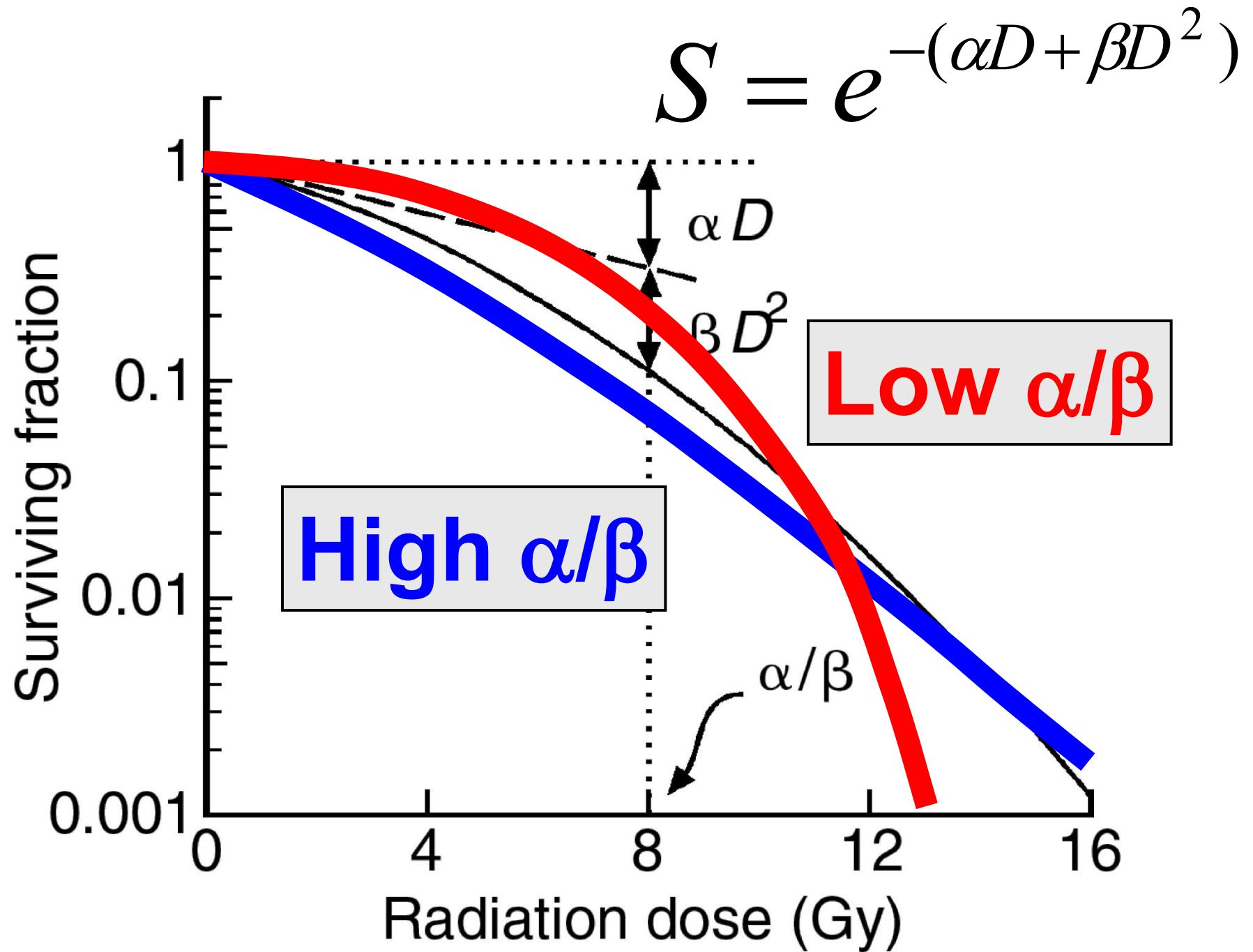
Radiobiology of Dose Rate

- To increase the survivability of healthy cells one should try to:
 - Reduce dose rate or
 - Extend treatment
 - This allows repopulation of healthy cells
 - This is why HDR is fractionated

Radiobiology of LDR vs. HDR

- α = unrepairable damage; β = repairable damage
- α/β ratios determine the “bendiness” of the cell survival curve for a particular tissue under radiation





Radiobiology of LDR vs. HDR

- If the α/β of normal tissue is **less** than the α/β of a tumor, LDR is better
 - Early responding tissues have a **high** alpha beta ratio
 - Skin, bone-marrow, intestinal epithelium
 - Rapidly dividing cells
 - Late responding tissues have a **low** alpha beta ratio
 - Spinal Cord, lung, kidney
 - Most tumors have a **high** alpha beta ratio
 - Some tumors have a **low** alpha beta ratio
 - Melanoma, sarcoma, prostate, breast

HDR vs. LDR

- Comparing HDR to LDR
 - Clinical outcome
 - Toxicities
 - Radiobiological effectiveness depends on tumor repair vs. normal tissue repair
- Target for HDR
 - Just be equal to LDR (does not have to be better) because of other benefits
 - Increased patient numbers
 - Outpatient treatment
- Trend is moving toward HDR

LDR Brachytherapy

- Advantages
 - Biological advantage for normal tissues vs. tumor tissues
 - Does not require large amounts of shielding
- Disadvantages
 - Requires long time to deliver therapeutic dose
 - Often requires hospitalization
 - Limited number of patients can be treated

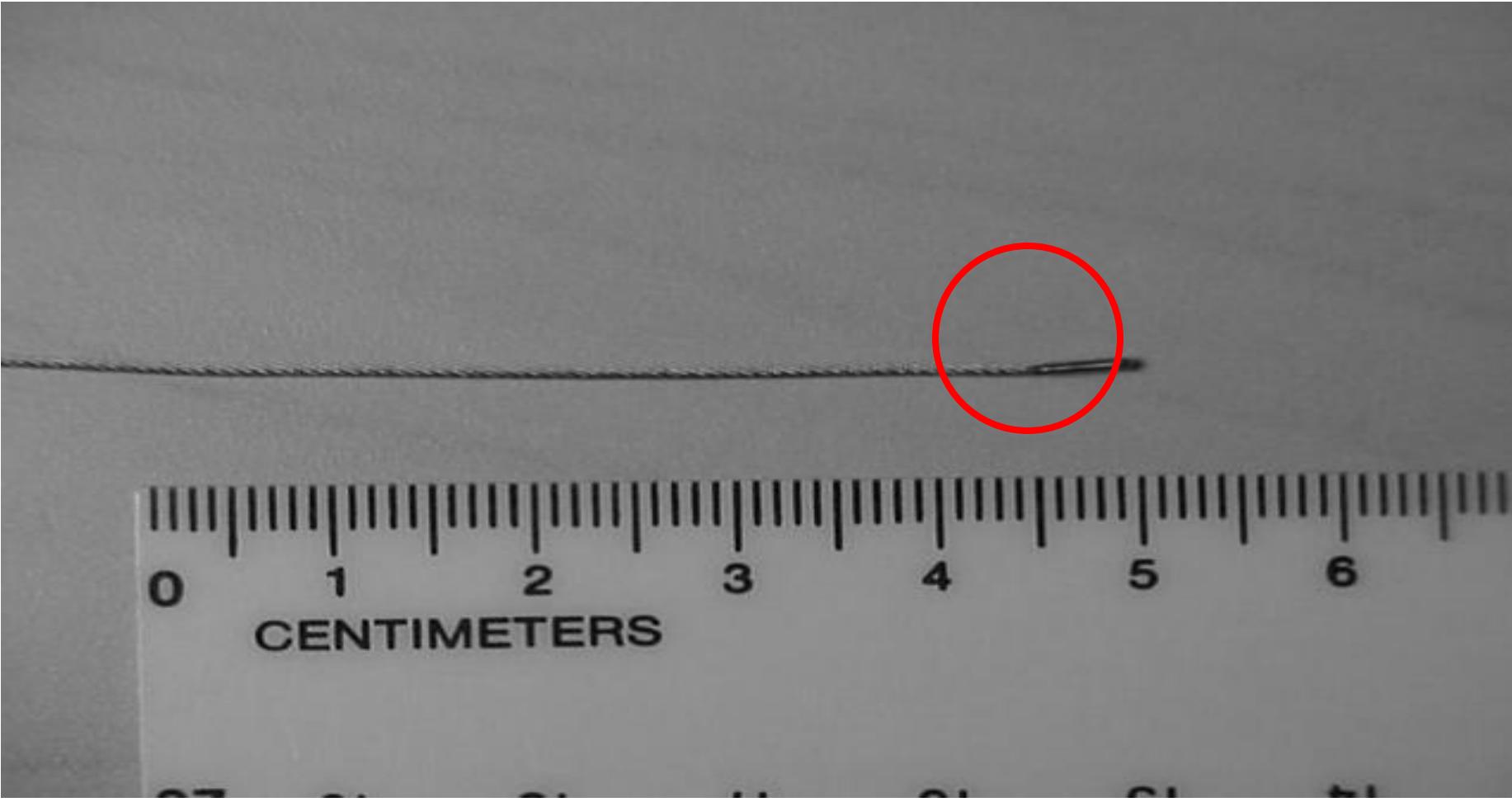
HDR Brachytherapy

- Advantages
 - Short duration treatment time
 - Increase patient population
 - More precise dose distribution than LDR
 - HDR often used as a boost or even primary treatment for prostate cancer
- Disadvantages
 - Dose to staff more of a concern
 - Must use a remote afterloader
 - Radiobiology can be an issue

HDR Source

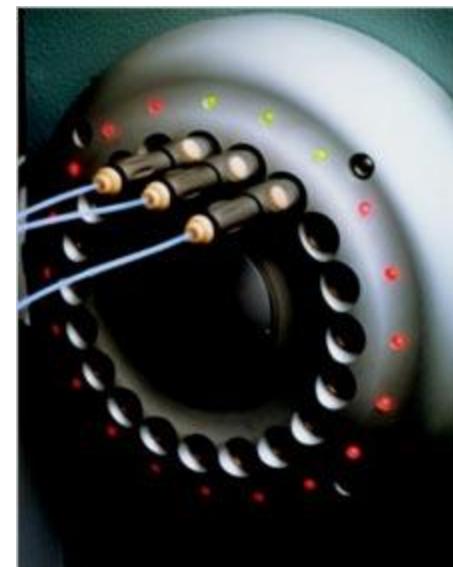
- Iridium-192
 - Small line source welded to end of a flexible drive cable
 - Ir-192 source of 5-10 Ci provides a dose rate of 7Gy/min at 1cm from the source.
- Source dimensions
 - 0.3 to 0.6 mm diameter
 - 3.5 to 10 mm long
- Storage of source wire (when not in use)
 - In shielded safe or vault (Tungsten or depleted uranium)
 - 1 mR/h at 10 cm

Radioactive Source



HDR Channels

- HDR has several channels
- Indexer system delivers sources from vault to channel
- Applicators or catheters connected to channels
 - Transfer tubes / guides
- Dummy source wires used as QA to verify path is clear of obstructions



BRACHYTHERAPY CALCULATIONS

Meat and... nay, but potatoes!

Quantities For Source Specification

- A_{app} (Apparent Activity)
 - Activity of an un-encapsulated source delivering the same activity as the encapsulated source
- Exposure Rate
 - Exposure rate constant “ Γ ”
 - Milligrams Radium equivalent ($MgRa_{eq}$)
- S_k : Air Kerma Strength (U, or $\mu\text{Gy}^*\text{m}^2 / \text{hr}$)
 - Kerma = Kinetic Energy Released in MATter
 - Reference energy transfer / dose rate currently used for source calibration and brachytherapy dosimetry
 - Reference Air kerma rate measured at 1 meter in air

Apparent Activity

- Actual activity not particularly useful quantity because the source is encapsulated
- Apparent activity
 - Activity of an un-encapsulated source producing the same exposure as the encapsulated source
- Allows the use of activity for dose calculation without explicit knowledge of source encapsulation

Exposure Rate Constant (Γ)

- Tabulated constant
 - Assigned to source based on ionization measured in air
- Typical Γ units:
 - $R^*cm^2/(mg^*hr)$, when working in “mg Radium”
 - $R^*cm^2/(mCi^*hr)$

Exposure Rate Constant (Γ)

$$\dot{X} = \frac{A\Gamma}{r^2}$$

- \dot{X} Exposure rate (R/hr, R/s, etc)
- A = Apparent activity (Ci, mCi, Bq, etc)
- Γ = Exposure rate constant
- r = distance from source

Radium-226

- The curie is the historical unit for activity
 - 1 Ci = decays per second in 1g of radium
 - 1g radium \approx 1 Ci = 3.7×10^{10} Bq (we now know that 1g of Radium measures closer to 0.98Ci)
 - This is why we can have different units for Γ_{Ra} :
 - $\Gamma_{Ra} = 8.25 \text{ R} \cdot \text{cm}^2 / \underline{\text{mCi}} \cdot \text{hr}$ or
 - $\Gamma_{Ra} = 8.25 \text{ R} \cdot \text{cm}^2 / \underline{\text{mg}} \cdot \text{hr}$

Radium Equivalence

- Older treatment protocols may call for a mass of Radium instead of exposure rate or dose
- Other radionuclides may be substituted for Radium using exposure rate constants (Γ)

Common Exposure Rate Constants (Γ)

Radionuclide Γ (R*cm²/mCi*hr)

- | | |
|----------|-------|
| • Ra-226 | 8.25 |
| • Co-60 | 13.07 |
| • Cs-137 | 3.28 |
| • Au-198 | 2.327 |
| • Ir-192 | 4.62 |
| • Pd-103 | 1.48 |

Radium Equivalence Ratios

$$\text{mgRa}_{\text{eq}} = A(\text{mCi}) \frac{\Gamma_{\text{isotope}}}{8.25 \frac{\text{R} \cdot \text{cm}^2}{\text{mg} \cdot \text{h}}}$$

↓ ↓
Apparent Activity Exposure Rate
of isotope Constant of isotope

\nwarrow

Exposure Rate Constant
for Radium (Γ_{ra})

$$\text{mgRa}_{\text{eq}} = A_{\text{app}} * \Gamma_x / \Gamma_{\text{ra}}$$

$$\text{mgRa}_{\text{eq}} = * r^2 / \Gamma_{\text{ra}}$$

\dot{X}

Exposure to Dose Rate: Air Kerma Strength

- Now relate exposure in air (X) to dose
 - Can get Exposure from Activity, Distance, Time and the Exposure rate constant
- KERMA
 - Kinetic Energy Released per unit Mass
 - All KE given to charged particles from uncharged particles
 - Proportional to Dose

Kerma

- Indirectly ionizing radiation (photons and neutrons) deposit energy:
 - Kinetic energy imparted to electrons/nuclei is then deposited as dose downstream

Exposure to Dose Rate: Air Kerma Strength

- Air Kerma:

$$K = X (W/e)$$

X = exposure [R]

(W/e) = average energy to create ion pair [J/C or eV/i.p.]

- Air Kerma Strength: $S_k = dK(r)/dt * r^2$

- *Change in Air Kerma per unit time * area*
- **Units of “U” [$\mu\text{Gy} \cdot \text{m}^2/\text{hr}$] or [$\text{cGy} \cdot \text{cm}^2/\text{hr}$]**
- Source with 1U produces:

- 1cGy/h at 1 cm from source

- 1 $\mu\text{Gy}/\text{h}$ at 1 m from source

Common Air Kerma Strength Conversions @ 1m

1U (μ Gy m²/h)

= 0.348 mCi for ^{137}Cs

= 0.243 mCi for ^{192}Ir

= 0.486 mCi for ^{198}Au

= 0.787 mCi for ^{125}I

= 0.773 mCi for ^{103}Pd

Air Kerma Strength – Why?

- Source specification
- TG-43:

Accounts for variations due to dose distribution, drop off, absorption, scatter, filtration, geometric effects for any point.

Dose rate Air Kerma Dose rate
at a point Strength constant

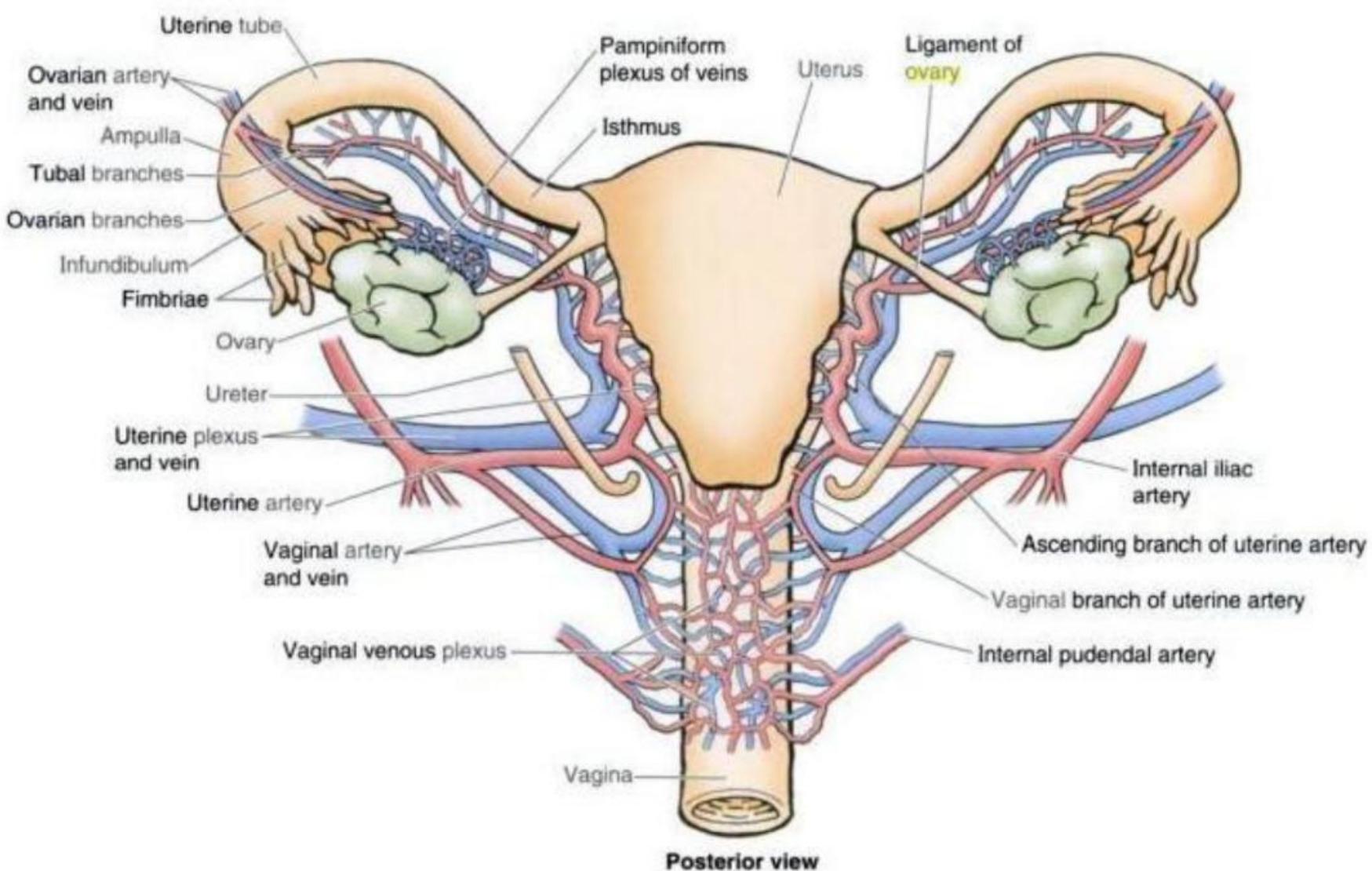
$$\dot{D}(r) = S_K \cdot \Lambda \cdot \frac{G_L(r, \theta_0)}{G_L(r_0, \theta_0)} \cdot g_L(r) \cdot \phi_{an}(r)$$

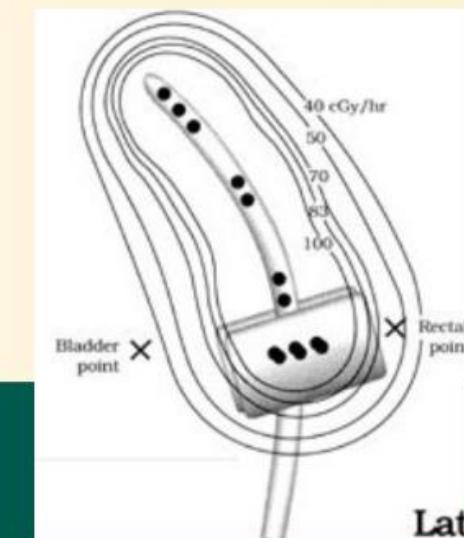
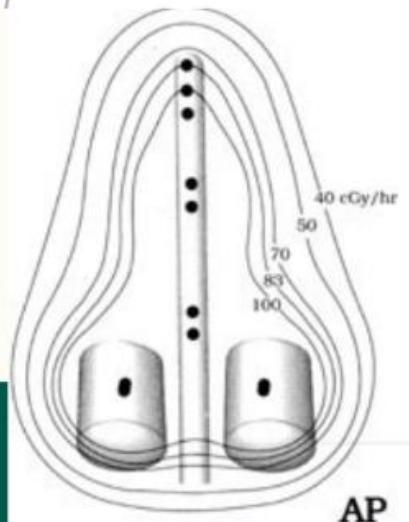
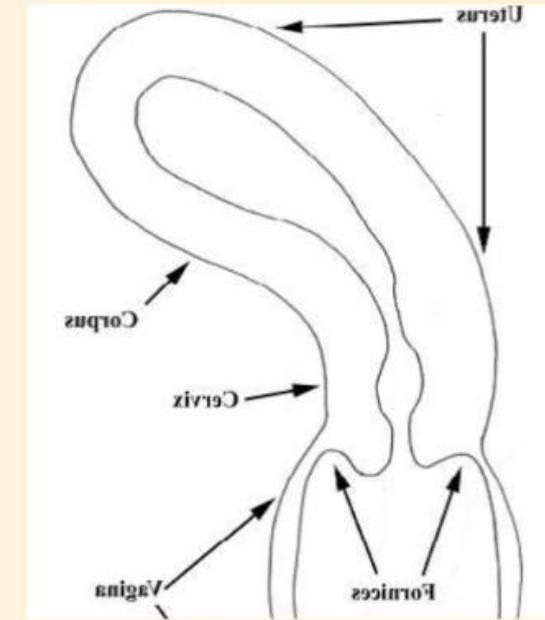
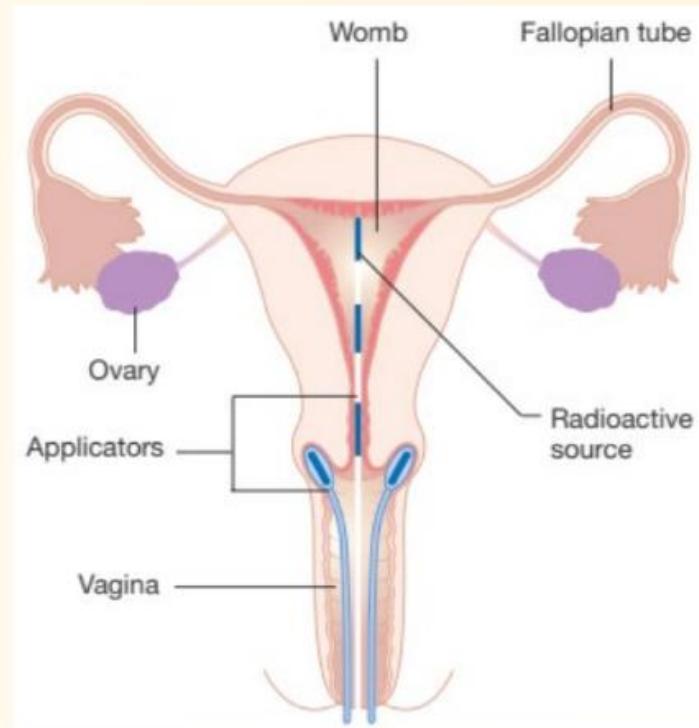
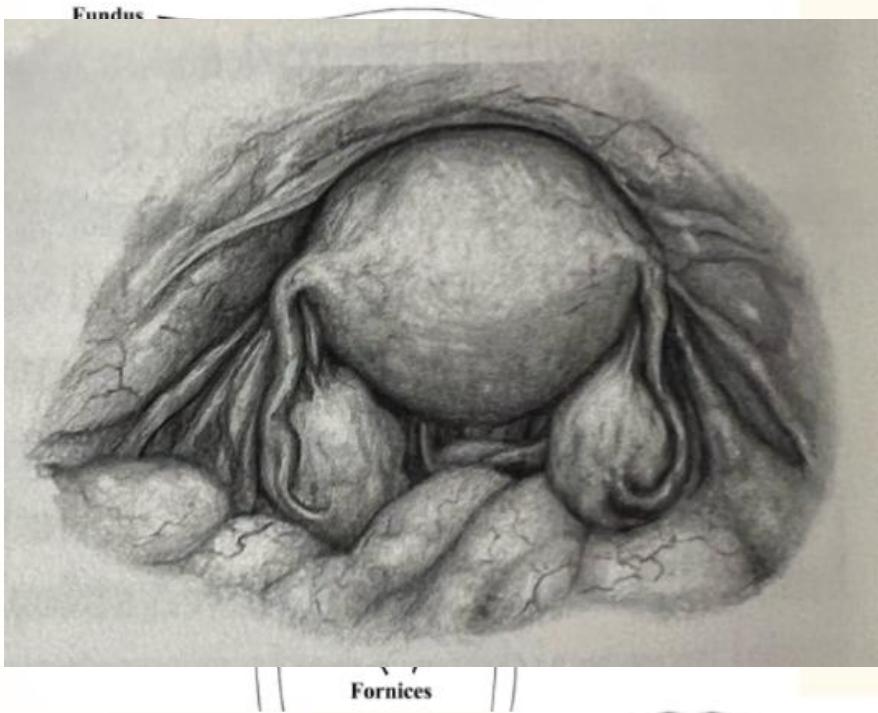
Don't panic I won't test you **too** hard on this...

IMPORTANT CALCULATION DEFINITIONS

Poke ya prostate, Yank ya Uterus

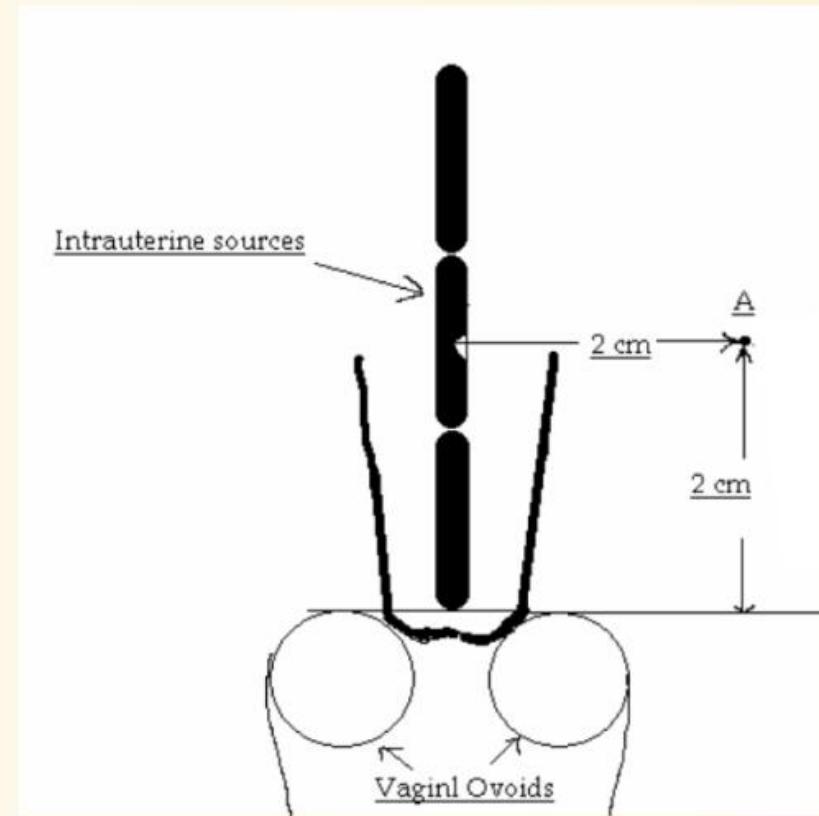
Paracervical Triangle





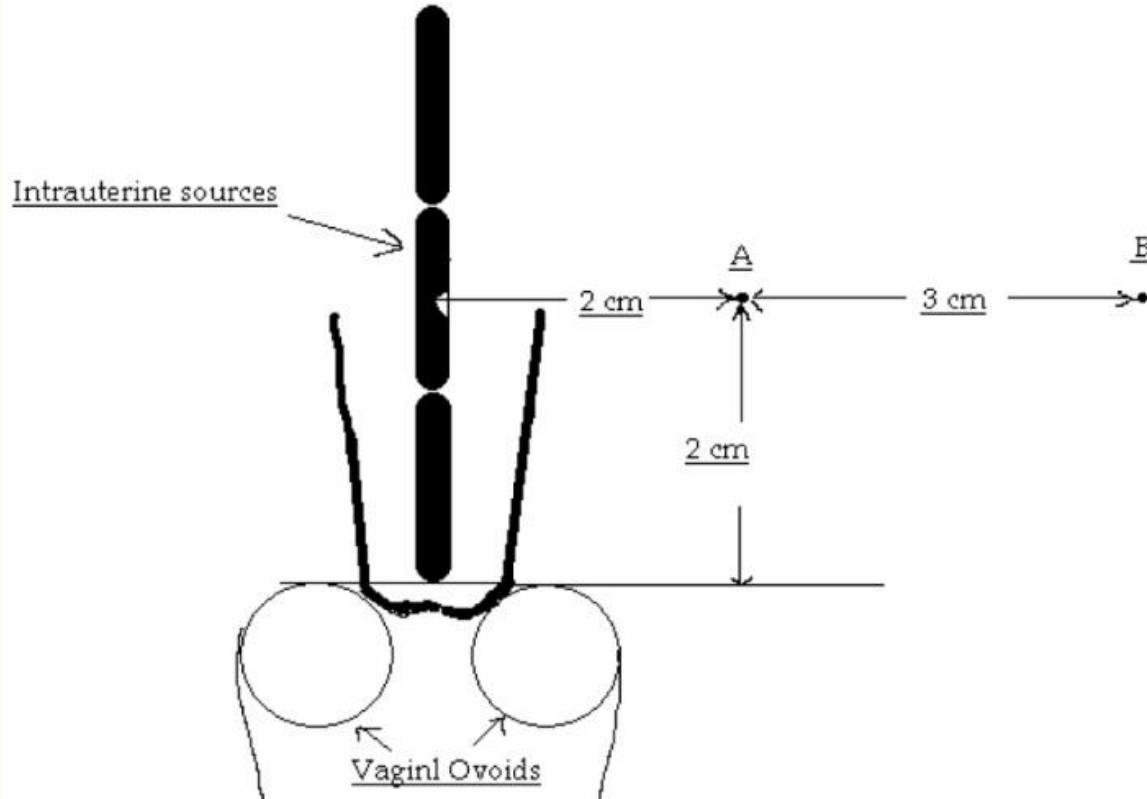
Manchester System - Point A

- 2 cm lateral to the uterine canal and 2 cm superior from a line connecting the tops of the ovoid caps



Manchester System - Point B

- 5 cm lateral to the uterine canal and 2 cm superior from a line connecting the tops of the ovoid caps
- Location of Obturator Lymph nodes



Manchester Prescription

- Optimal total dose to point ‘A’:
 - 80-85 Gy for early stage
 - 90-95 Gy for advanced stage
- Expected dose at point ‘B’ ~20-35% of point ‘A’
- Point ‘B’ dose now delivered using external beam boost



Other Dose Limitations

- Bladder - limit 75 to 80 Gy
 - Goal is <80% of Point A
- Rectum - limit 70 to 75 Gy
 - Goal is <70% of Point A
- Vaginal surface dose – limit 120 to 140 Gy
 - Not more than 40% of the total dose at point ‘A’ delivered from the vaginal ovoids.



ICRU Rectal and Bladder Points

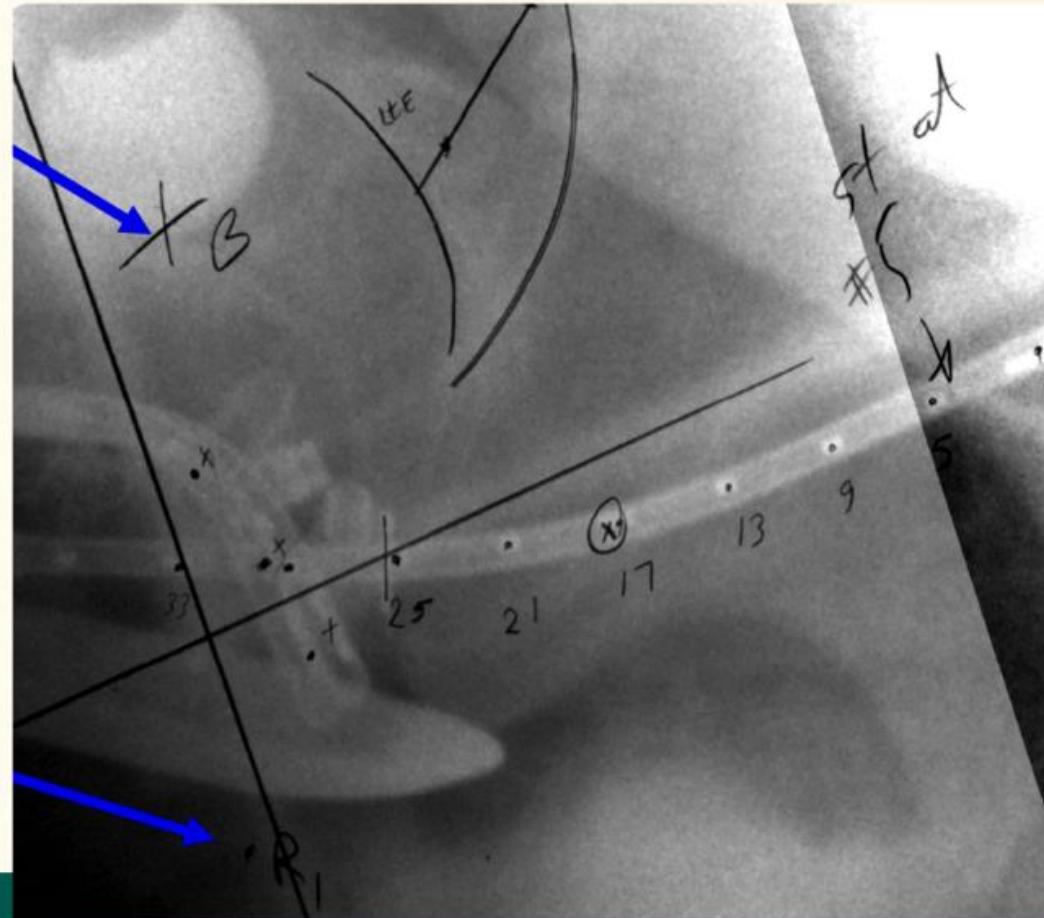
Bladder

point:

Bottom of the
Foley bulb

Rectal point:

0.5 cm below
the posterior
vaginal wall at
mid-ovoid



Anatomy Schematic

