Dosimetric Calculations

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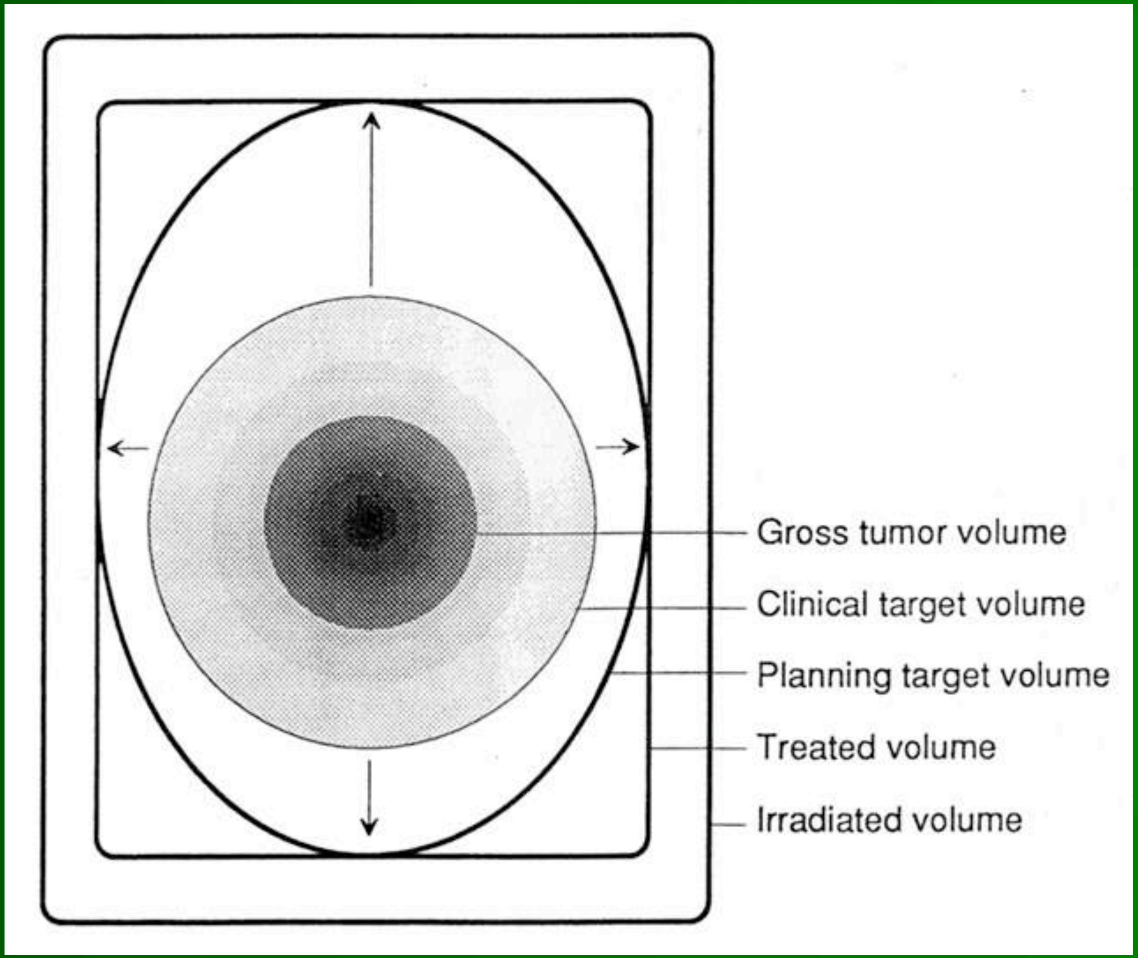
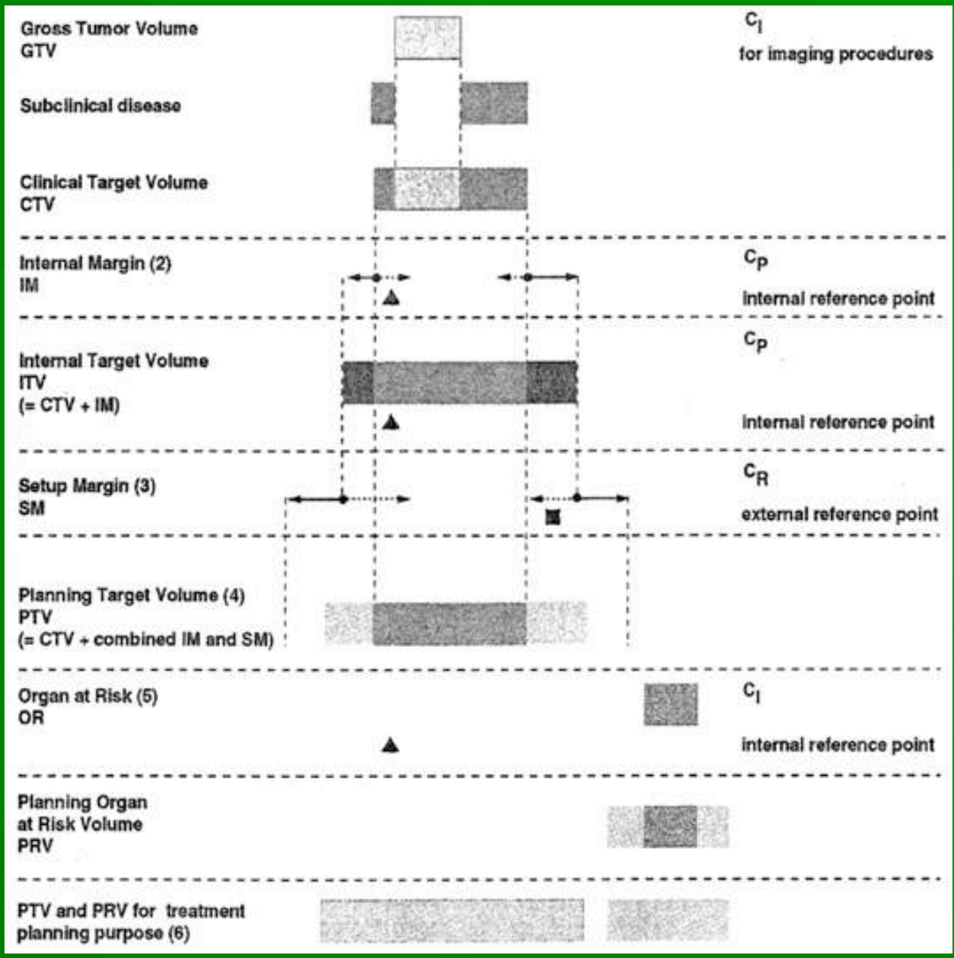
Objectives

- Dose Distribution Measurements
  - PDD, OCR
  - TAR, SAR, TPR, TMR, SPR, SMR
- Arc or Rotational Therapy
- Isodose Curves
- Point Dose Calculations
- Wedged Fields
- Photon Beam Models

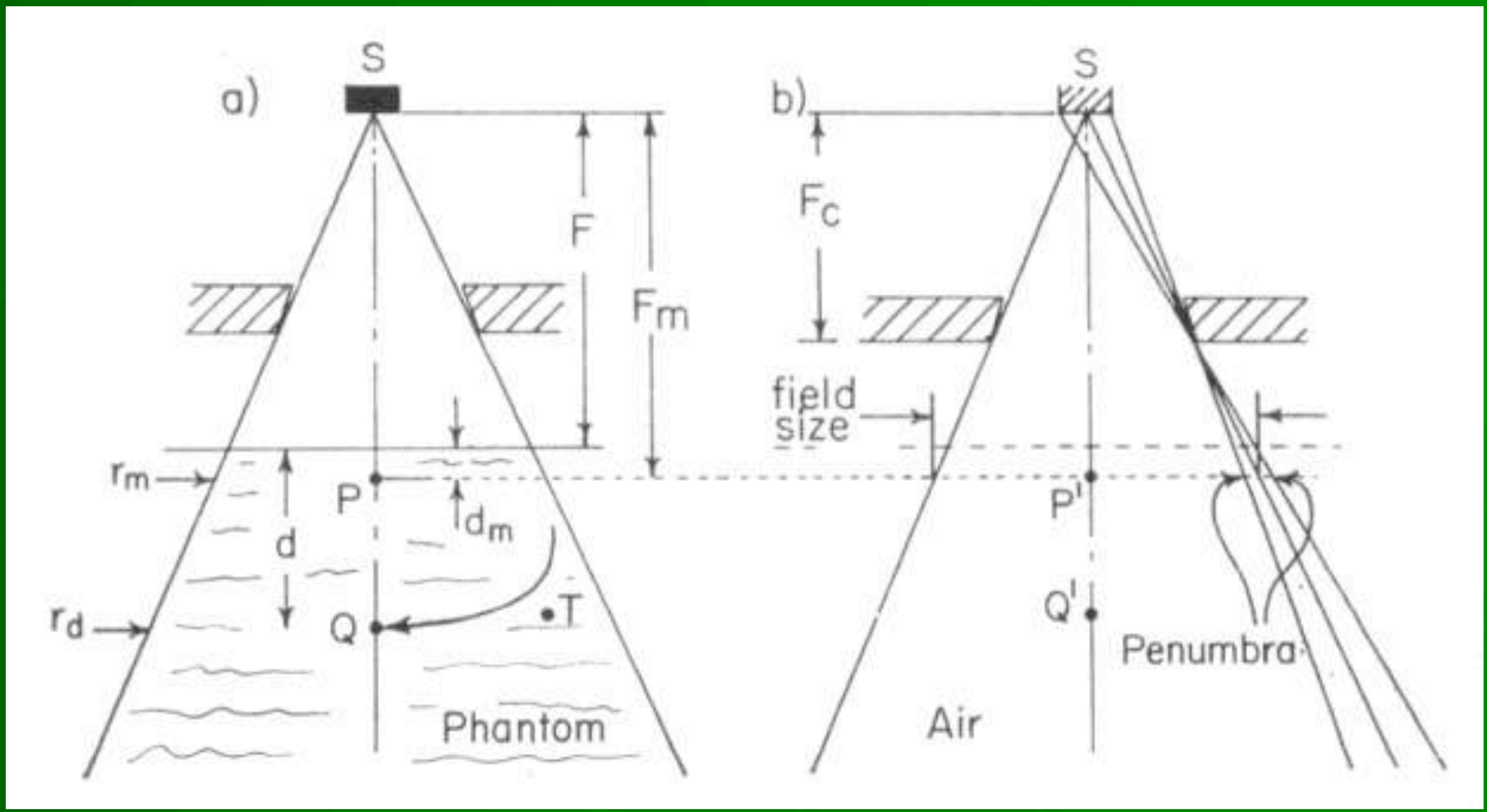
Definition of Tumor Volumes





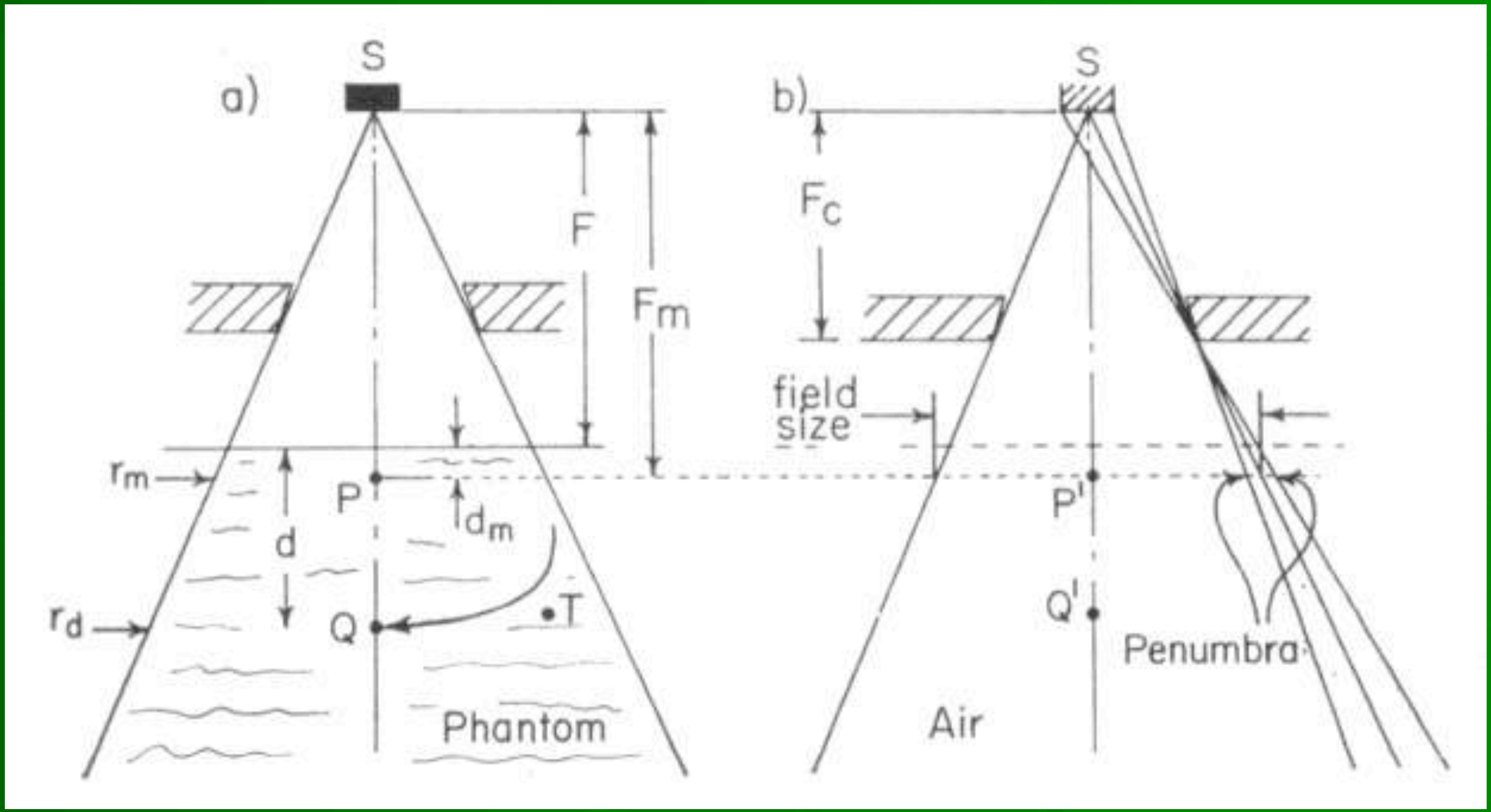
Definition of Terms

- SSD – Source Skin Distance (F)
- SAD – Source Axis Distance (Fm)



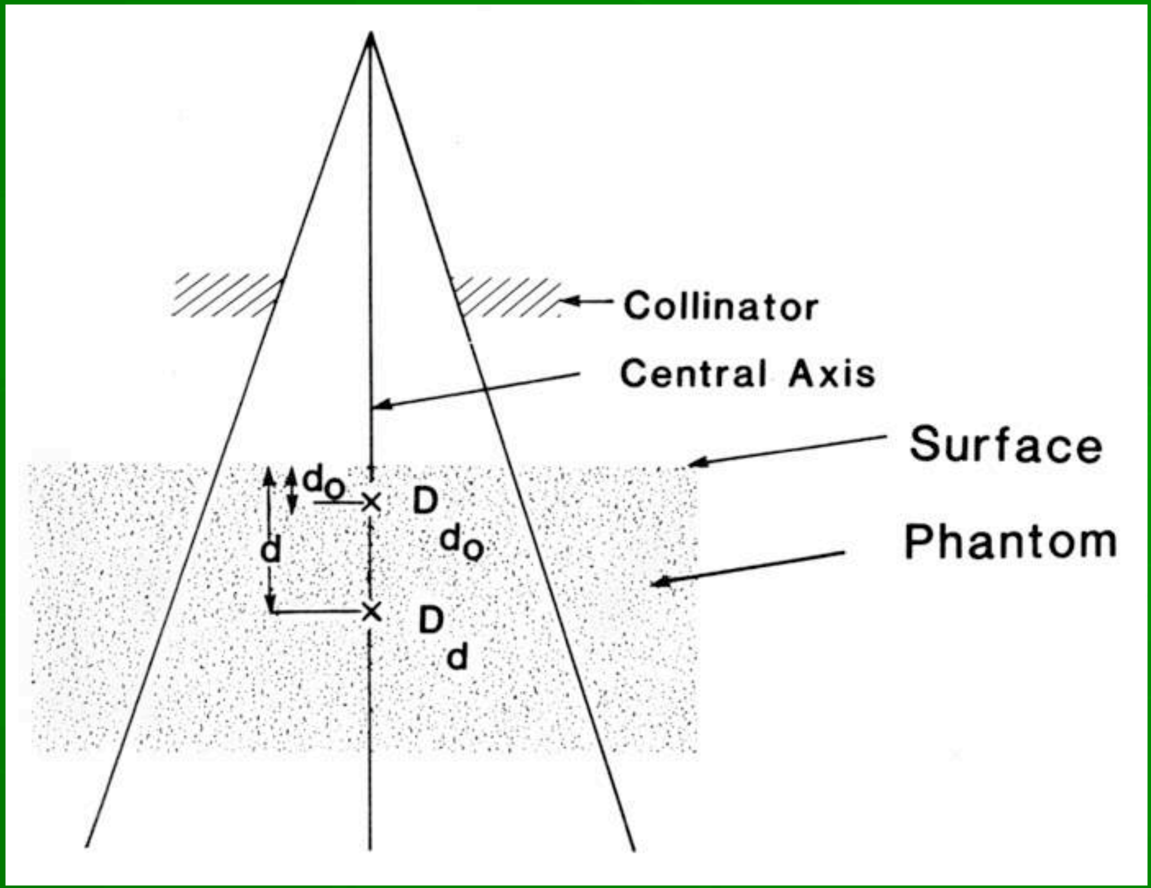
Definition of Terms

- CAX – Central Axis
- Isocenter

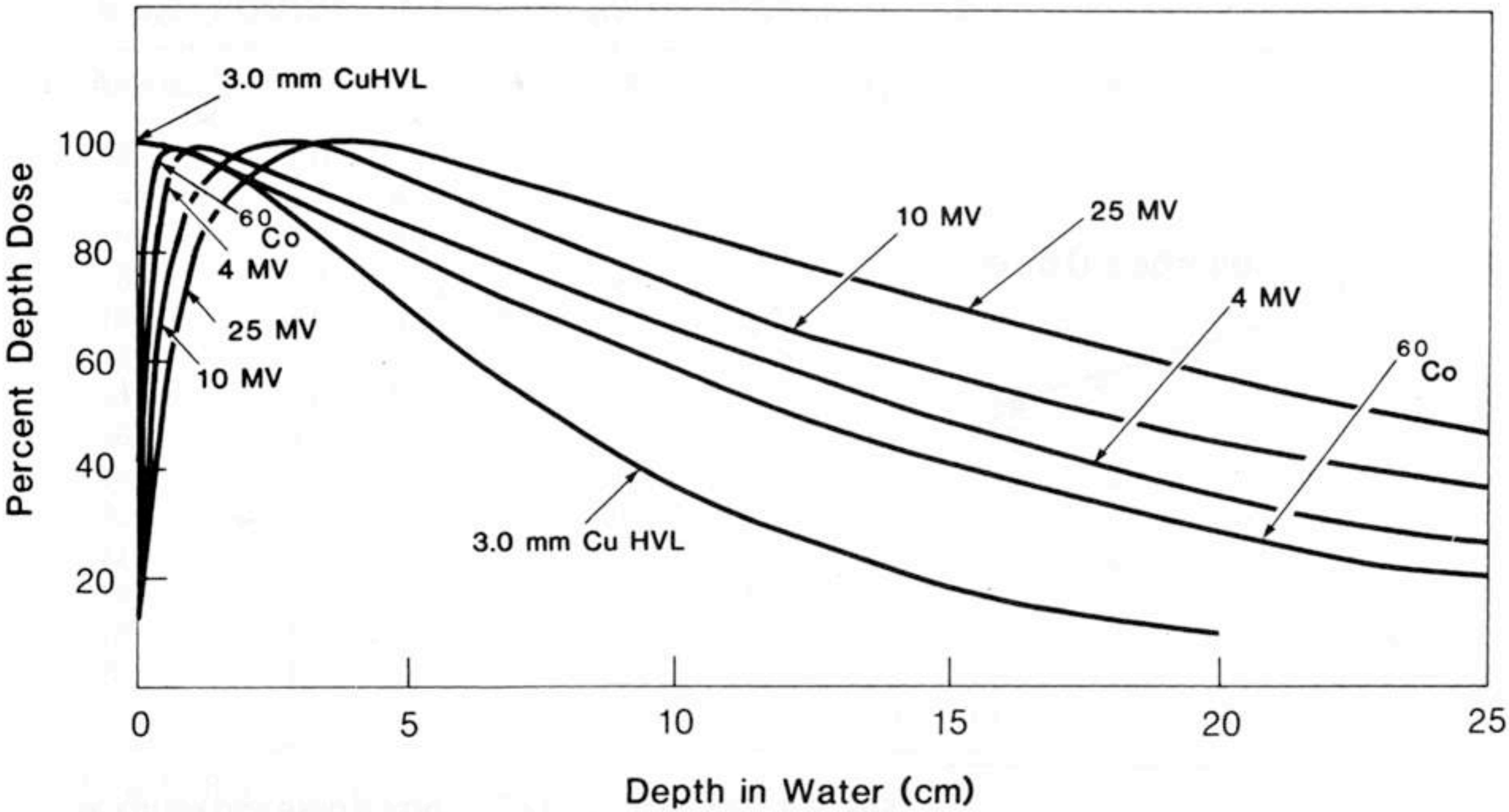


Percentage Depth Dose

- $\%D_n = D_n / D_0 \times 100\%$
- Varies w/Depth
  - Beam Energy
  - Depth
  - Field Size
  - Source Distance
  - Collimation
- 10x10, dMax



%DD vs. Photon Beam Energy



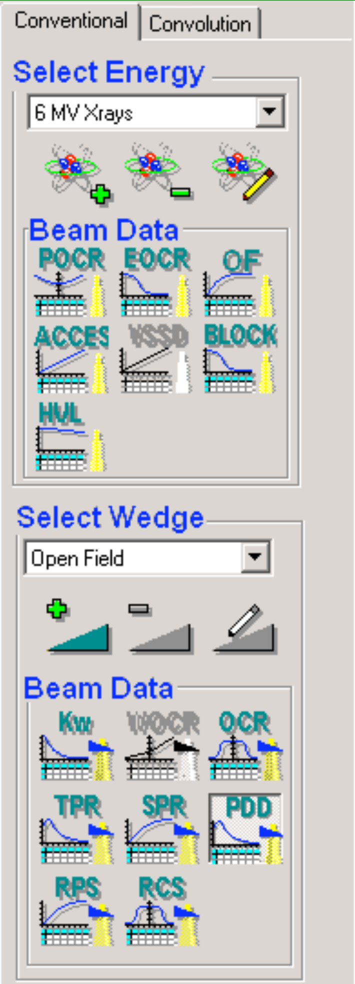
%DD Tables

TABLE 7-3 **Central Axis Percent Depth Dose for a 6-MV X-Ray Beam**

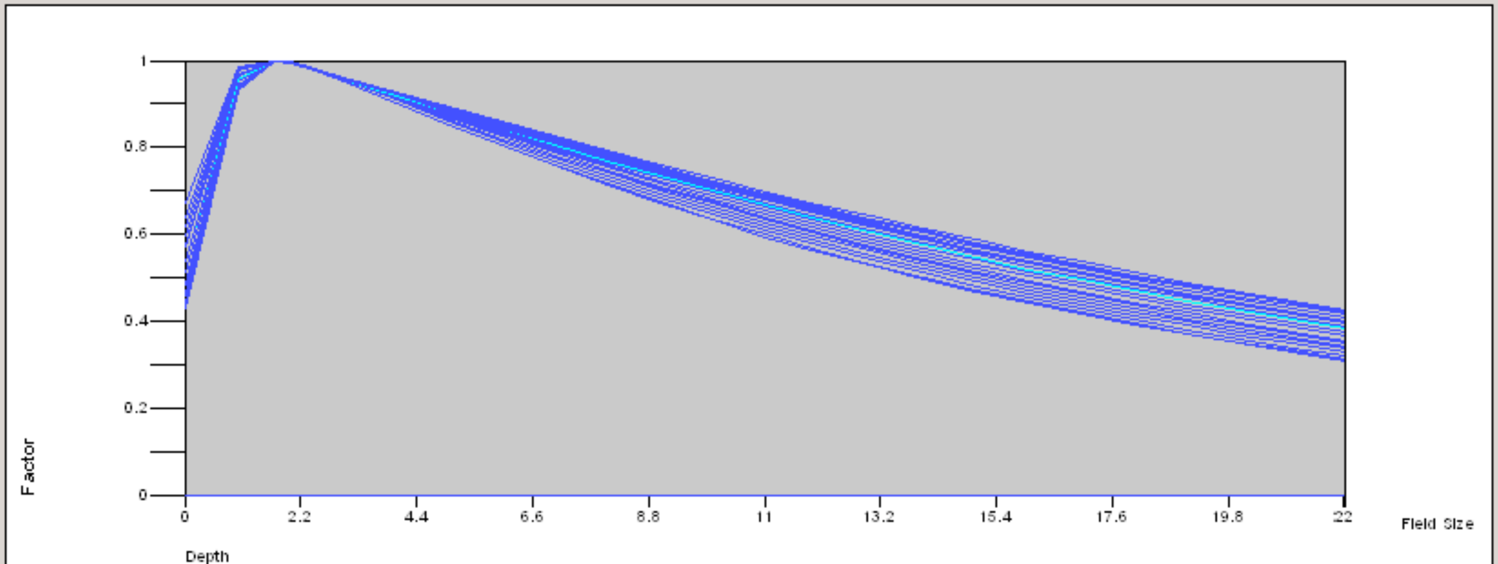
	Field Size (cm^2)											
	4 × 4	*5 × 5*	*6 × 6*	*7 × 7*	*8 × 8*	*10 × 10*	*12 × 12*	*15 × 15*	*20 × 20*	*25 × 25*	*30× 30*	*40 × 40*
NPSF	*0.981*	*0.984*	*0.988*	*0.991*	*0.994*	*1.000*	*1.005*	*1.013*	*1.023*	*1.030*	*1.035*	*1.037*
Depth												
1.5	100	100	100	100	100	100	100	100	100	100	100	100
2.0	97.8	97.8	97.9	97.9	97.9	98.0	98.1	98.1	98.2	98.2	98.2	98.3
3.0	93.6	93.7	93.7	93.8	93.9	94.1	94.3	94.4	94.6	94.7	94.8	95.0
4.0	89.5	89.6	89.8	89.9	90.1	90.4	90.6	90.9	91.1	91.3	91.5	91.9
5.0	85.5	85.7	85.9	86.1	86.3	86.8	87.1	87.4	87.8	88.1	88.3	88.8
6.0	80.8	81.1	81.4	81.6	81.9	82.5	83.0	83.5	84.0	84.4	84.7	85.3
7.0	76.2	76.6	77.0	77.3	77.7	78.4	79.0	79.6	80.4	80.8	81.2	81.8
8.0	71.8	72.2	72.7	73.2	73.6	74.5	75.2	75.9	76.8	77.3	77.0	78.5
9.0	67.5	68.1	68.6	69.2	69.7	70.7	71.5	72.4	73.4	74.0	74.5	75.3
10.0	63.4	64.1	64.7	65.3	65.9	67.0	67.9	68.9	70.1	78.8	71.3	72.2
11.0	59.9	60.6	61.3	62.8	62.6	63.7	64.6	65.7	66.9	67.6	68.2	69.2
12.0	56.5	57.3	58.0	58.7	59.3	60.5	61.4	62.5	63.8	64.5	65.2	66.2
13.0	53.3	54.0	54.8	55.5	56.2	57.4	58.4	59.4	60.7	61.6	62.3	63.4
14.0	50.1	50.9	51.7	52.5	53.2	54.4	55.4	56.4	57.8	58.7	59.5	60.6
15.0	47.1	47.9	48.7	49.5	50.3	51.6	52.5	53.6	55.0	56.0	56.7	58.0
16.0	44.6	45.3	46.1	46.9	47.6	48.8	49.8	50.9	52.4	53.4	54.2	55.5
17.0	42.2	42.9	43.6	44.3	45.0	46.2	47.2	48.4	49.8	50.9	51.7	53.1
18.0	39.8	40.5	41.1	41.8	42.4	43.6	44.7	45.9	47.4	48.5	49.3	50.7
19.0	37.5	38.1	38.7	39.3	40.0	41.2	42.2	43.5	45.0	46.1	47.0	40.4
20.0	35.3	35.9	36.4	37.0	37.6	38.0	39.8	41.2	42.7	43.9	44.0	46.2
21.0	33.4	34.0	34.5	35.1	35.6	36.8	37.9	39.2	40.7	41.8	42.7	44.2
22.0	31.7	32.2	32.7	33.2	33.8	34.9	35.9	37.2	38.7	39.8	40.7	42.2
23.0	29.9	30.4	30.9	31.4	31.9	33.2	34.1	35.3	36.8	37.9	38.7	40.2
24.0	28.2	28.7	29.2	29.7	30.2	31.3	32.3	33.5	34.9	36.0	36.8	38.3
25.0	26.6	27.1	27.5	28.0	29.5	29.5	30.5	31.7	33.1	34.2	35.0	36.5

Source: Barnes, W. H., Hammond, D. B., Janik, G. G. Beam characteristics of the Clinac 2500. Presented at Varian Users Group Meeting (1983).

MDE – Conventional PDD Tables



Percentage Depth Dose



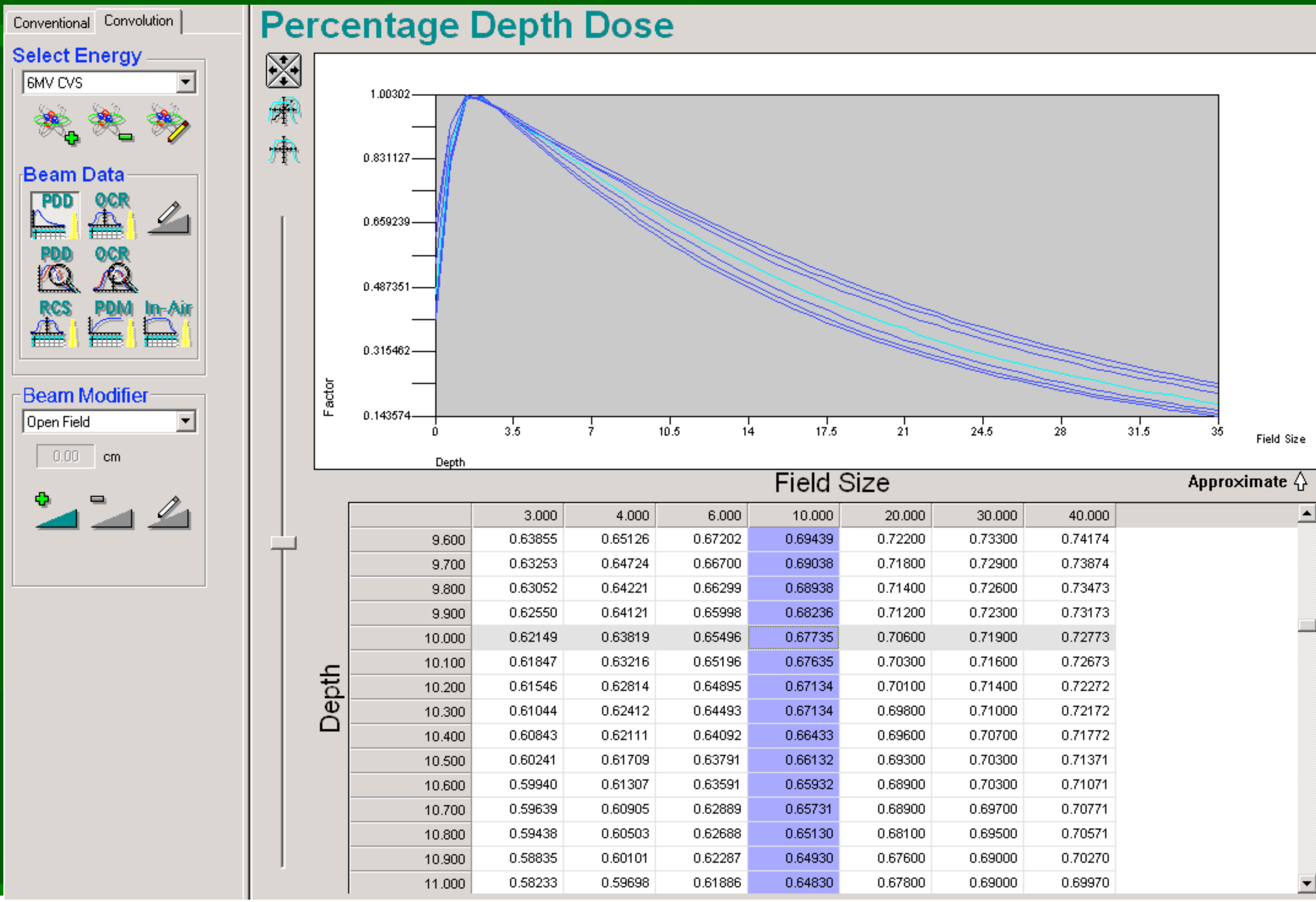
Field Size

Exact

Depth

	0.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
5.000	0.00000	0.85234	0.85307	0.86060	0.86473	0.86902	0.87117	0.87247	0.87491
6.000	0.00000	0.80472	0.80606	0.81410	0.81851	0.82530	0.82877	0.83027	0.83481
7.000	0.00000	0.75840	0.75975	0.76890	0.77479	0.78217	0.78716	0.78886	0.79331
8.000	0.00000	0.71419	0.71664	0.72590	0.73257	0.74144	0.74675	0.74875	0.75444
9.000	0.00000	0.67177	0.67403	0.68460	0.69245	0.70182	0.70694	0.71064	0.71653
10.000	0.00000	0.63275	0.63593	0.64660	0.65353	0.66410	0.67033	0.67433	0.68050
11.000	0.00000	0.59324	0.59902	0.60930	0.61751	0.62698	0.63393	0.63933	0.64571
12.000	0.00000	0.55912	0.56331	0.57450	0.58339	0.59266	0.59982	0.60572	0.61214
13.000	0.00000	0.52791	0.53071	0.54220	0.55038	0.56084	0.56781	0.57281	0.57980
14.000	0.00000	0.49700	0.50020	0.51100	0.51946	0.52972	0.53711	0.54251	0.54955
15.000	0.00000	0.46689	0.47089	0.48080	0.49045	0.50030	0.50730	0.51400	0.52071
16.000	0.00000	0.43963	0.44449	0.45355	0.46188	0.47153	0.47950	0.48605	0.49277
17.000	0.00000	0.41593	0.41925	0.42870	0.43669	0.44647	0.45419	0.46059	0.46691
18.000	0.00000	0.39166	0.39455	0.40370	0.41287	0.42219	0.42952	0.43539	0.44251
19.000	0.00000	0.36828	0.37224	0.38067	0.38963	0.39844	0.40568	0.41192	0.41878
20.000	0.00000	0.34807	0.35110	0.35980	0.36818	0.37653	0.38404	0.39038	0.39678

MDE – Convolution PDD Tables

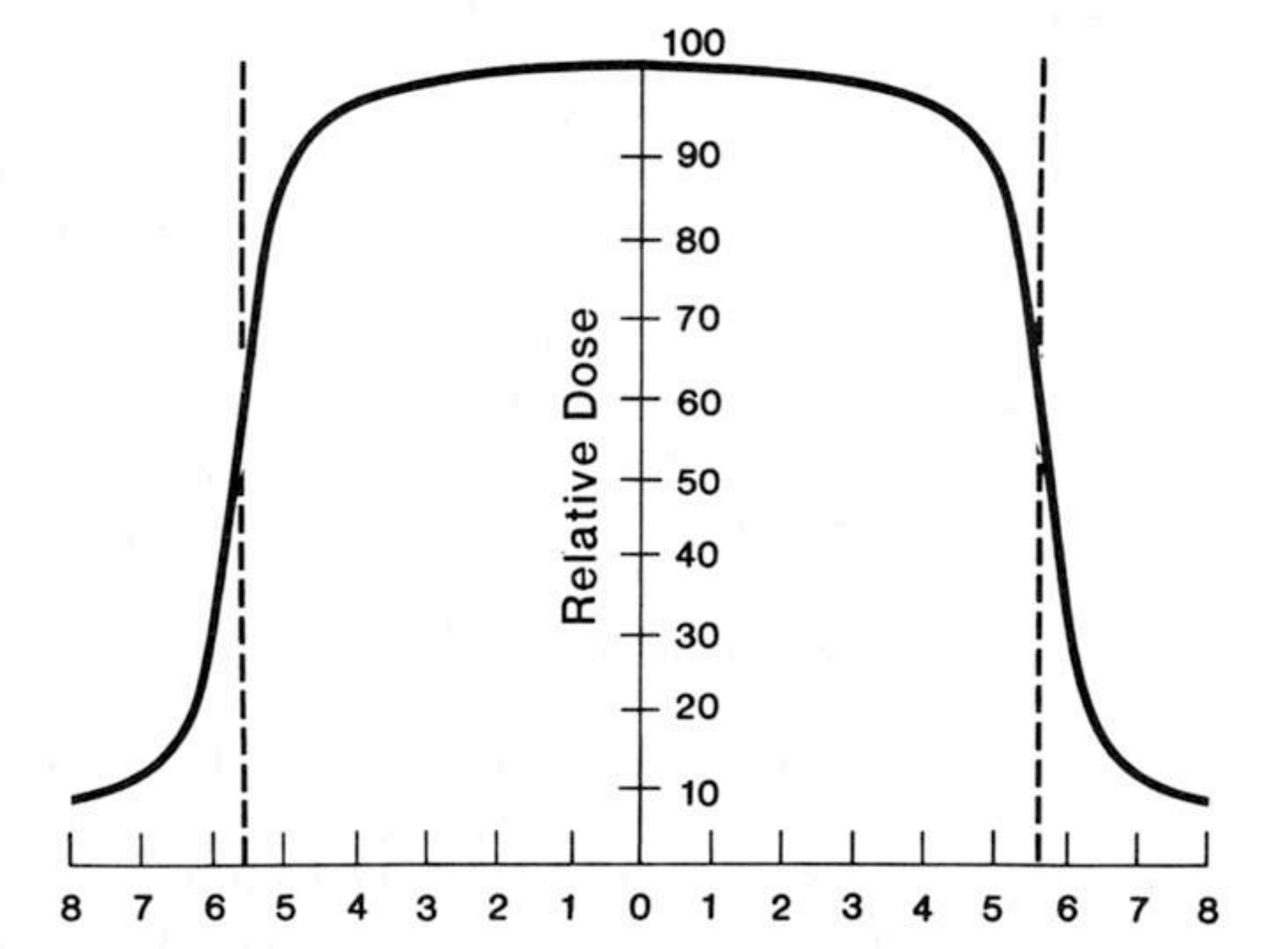


	3.000	4.000	6.000	10.000	20.000	30.000	40.000
9.600	0.63855	0.65126	0.67202	0.69439	0.72200	0.73300	0.74174
9.700	0.63253	0.64724	0.66700	0.69038	0.71800	0.72900	0.73874
9.800	0.63052	0.64221	0.66299	0.68938	0.71400	0.72600	0.73473
9.900	0.62550	0.64121	0.65998	0.68236	0.71200	0.72300	0.73173
10.000	0.62149	0.63819	0.65496	0.67735	0.70600	0.71900	0.72773
10.100	0.61847	0.63216	0.65196	0.67635	0.70300	0.71600	0.72673
10.200	0.61546	0.62814	0.64895	0.67134	0.70100	0.71400	0.72272
10.300	0.61044	0.62412	0.64493	0.67134	0.69800	0.71000	0.72172
10.400	0.60843	0.62111	0.64092	0.66433	0.69600	0.70700	0.71772
10.500	0.60241	0.61709	0.63791	0.66132	0.69300	0.70300	0.71371
10.600	0.59940	0.61307	0.63591	0.65932	0.68900	0.70300	0.71071
10.700	0.59639	0.60905	0.62889	0.65731	0.68900	0.69700	0.70771
10.800	0.59438	0.60503	0.62688	0.65130	0.68100	0.69500	0.70571
10.900	0.58835	0.60101	0.62287	0.64930	0.67600	0.69000	0.70270
11.000	0.58233	0.59698	0.61886	0.64830	0.67800	0.69000	0.69970

Sterling's Rule

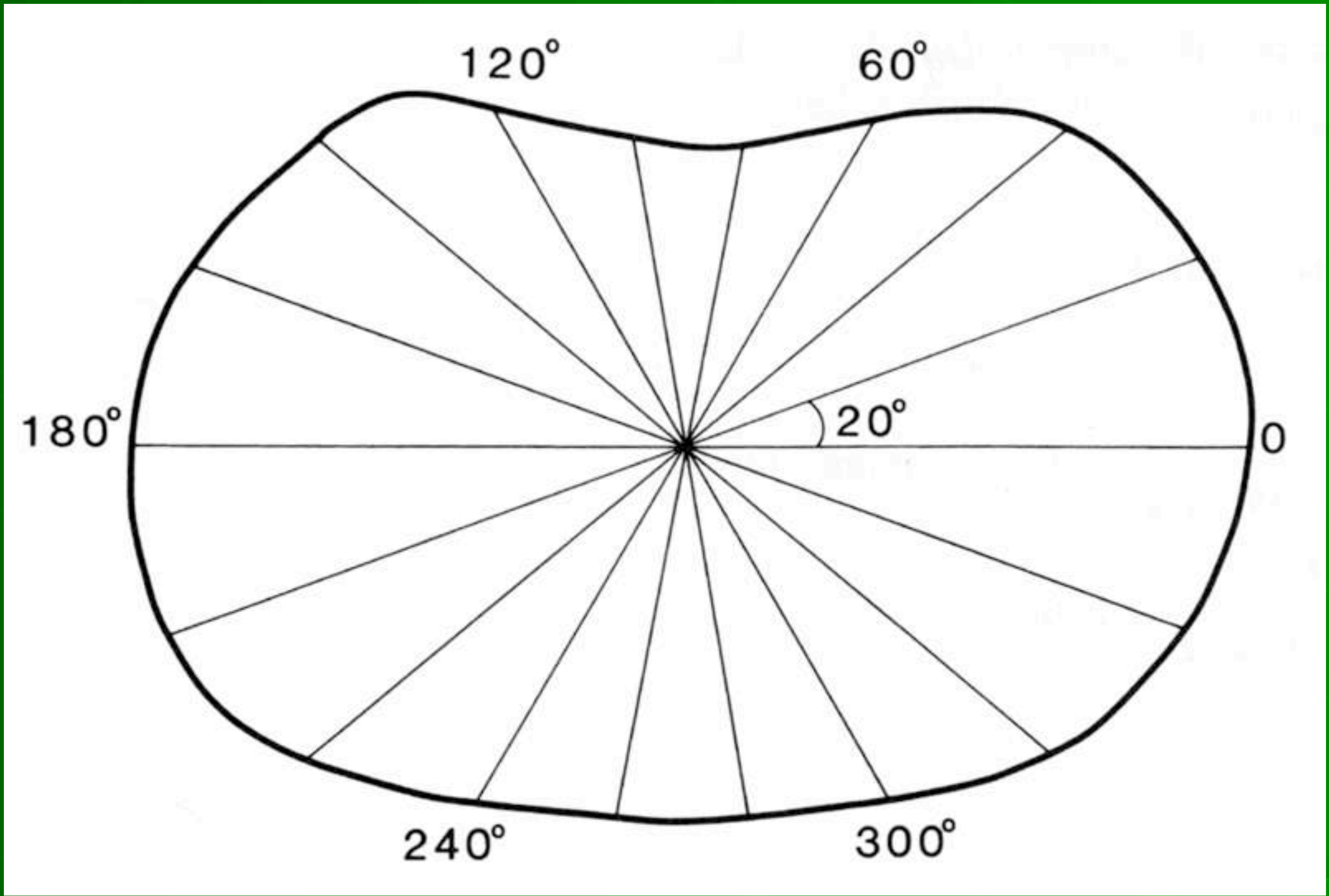
- Effective Field Size
  - This rule states that a rectangular field is equivalent to a square field if bot
h
 have the same ratio of area/perimeter (A/P)
- Example
  - 15x8 has an A/P of 2.61
  - 10.3x10.3 has an A/P of ~2.61 (2.58)
  - 4 A/P = 10.4

Transverse Profile

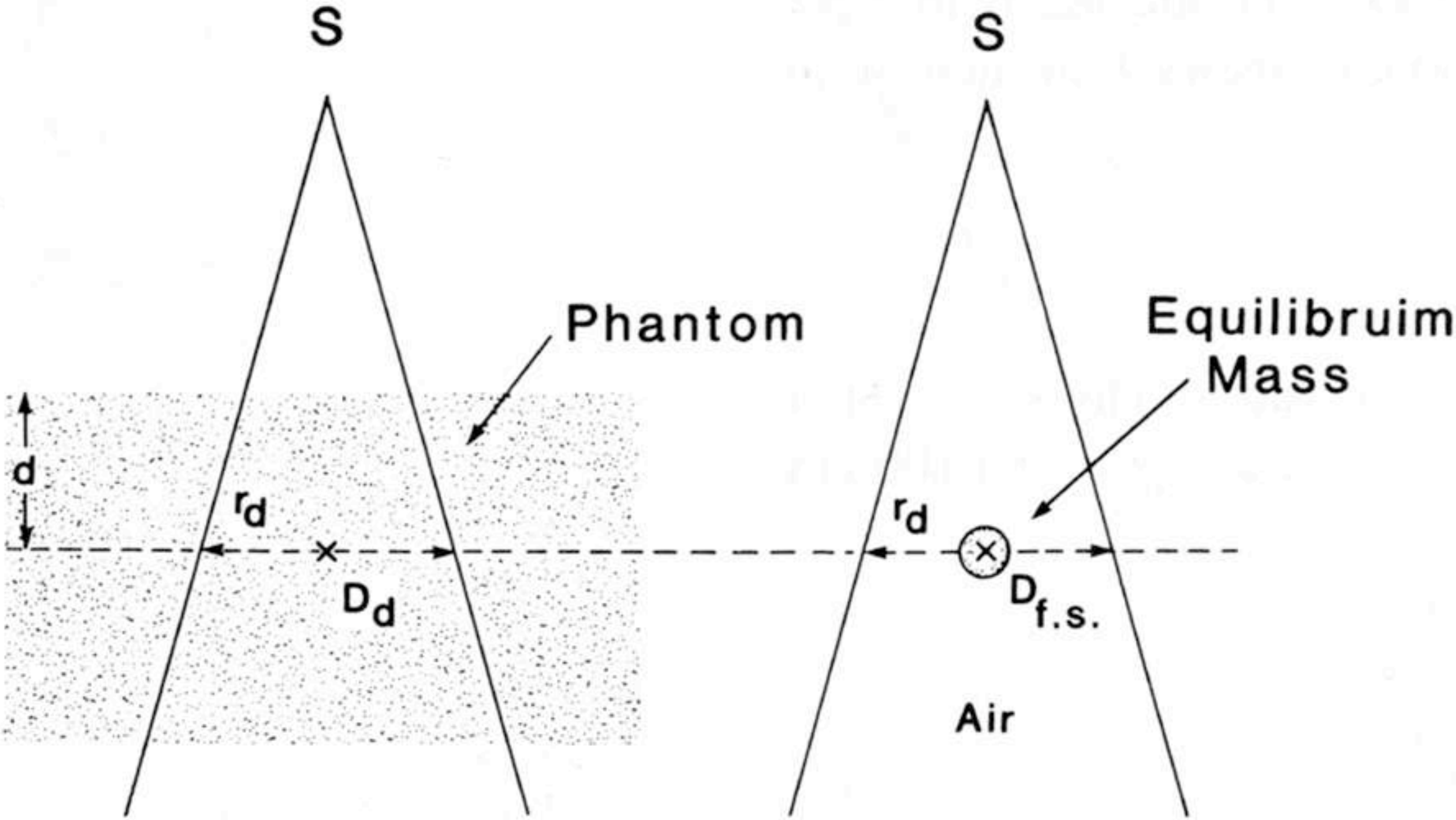


TAR Used in Calculating Arc Rotations

- Use average TAR, not average depth



TAR Measurement



Tissue Air Ratio (TAR)

- $TAR = D_d / D_{air}$
- Where:
  - D_d: dose to a small volume of tissue in a medium
  - D_{air}: dose to a small volume of tissue in air
- Depends on:
  - Energy, Depth, Field Size
- Accounts for tissue attenuation
- Used for isocenter treatments and rotational treatments

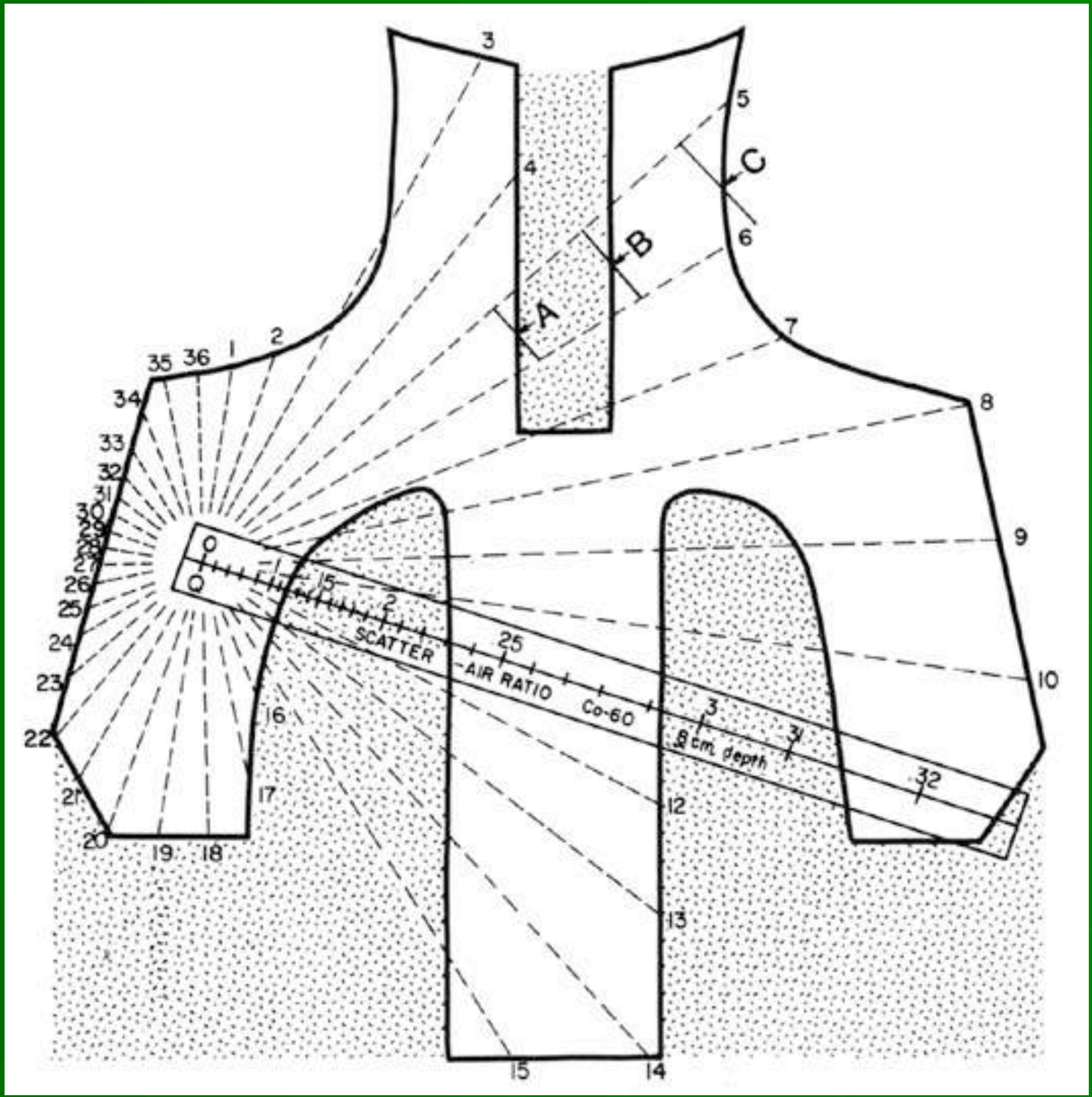
Scatter-Air Ratio (SAR)

- SAR = TAR(finite fs) – TAR(zero fs)
- Depends on:
  - Energy, Depth, Field Size
- Useful in
  do
  s
  e computation of irregularly shaped fields
- 0x0 fs:
  - hypothetical field
    rep
    r

Irregularly Shaped Fields

- Clarkson's integration
- Separates primary and secondary
- Primary contribution
  - Zero area TAR
- Secondary contribution
  - Sum of irregularly shaped scatter contribution

Clarkson's Irregular Field Calculation

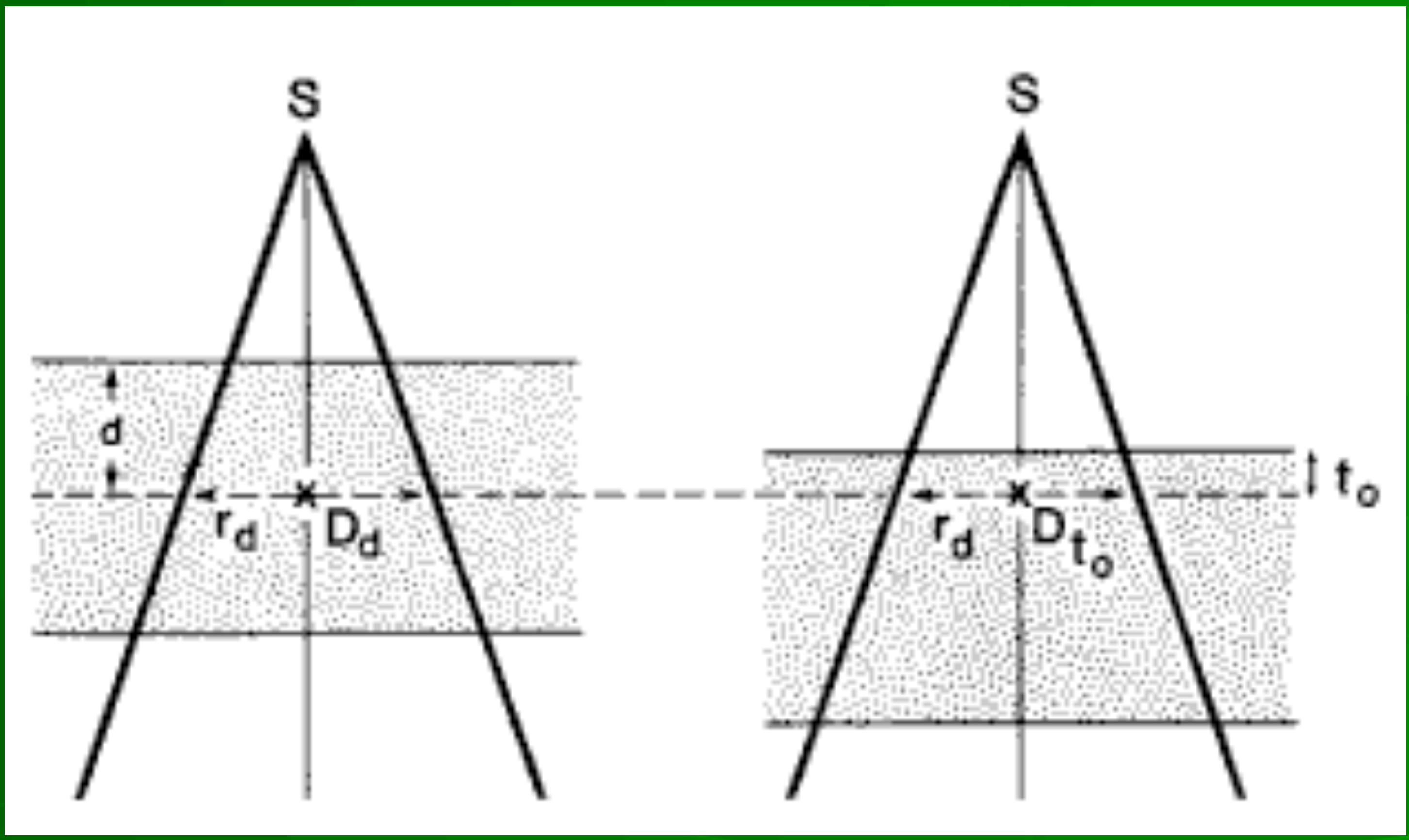


Tissue/Phantom Ratio (TPR)

- TPR = D_d / D_{ref}
- Where:
  - D_d: dose to a point in phantom
  - D_{ref}: dose at the same point at a fixed ref depth
- Depends on:
  - Energy, Depth, Field Size

TPR Measurement

- If t_0 is the ref depth of max dose, then:
  - $TMR(d, r_d) = TPR(d, r_d)$



Tissue Maximum Ratio (TMR)

- $TMR = D_d / D_{refMax}$
- Where:
  - D_d: dose to a point in phantom
  - D_{refMax}: dose at the same point at maxRef depth
- Depends on:
  - Energy, Depth, Field Size

Scatter/Phantom Ratio (SPR)

- Ratio of the dose contribution solely by scattered radiation at a given point divided by the reference dose at a selected depth in the phantom

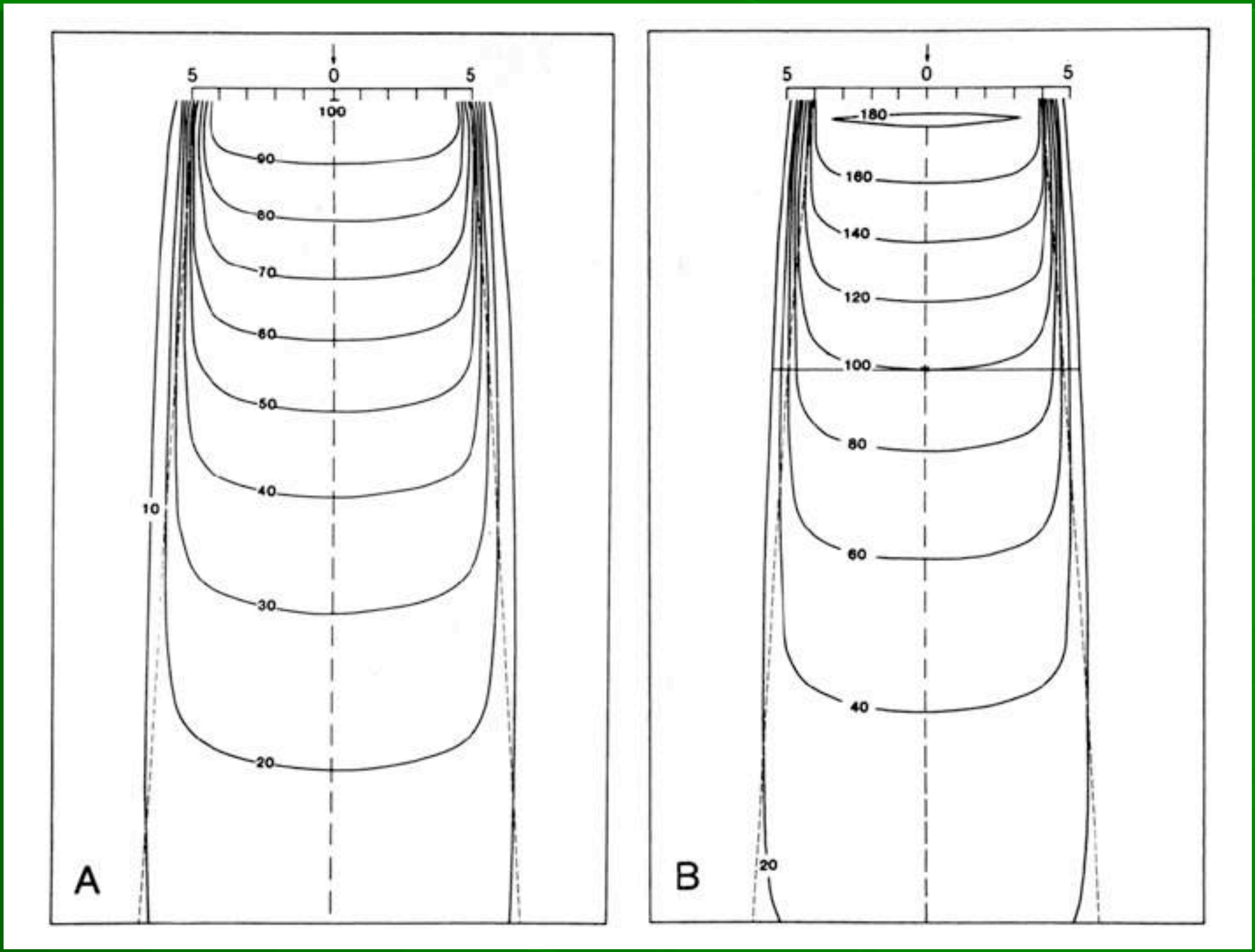
Scatter-Maximum Ratio (SMR)

- Ratio of the dose caused solely by scattered radiation at a given point divided by the maximum dose measured at the same distance from the radiation source

Isodose Curves

- Lines passing thru points of equal dose
  - Percentage of the dose at a reference point
- Dose distribution off axis
  - CAX depth dose distribution is not sufficient to characterize a radiation beam that produces a dose distribution in a three-dimensional volume.

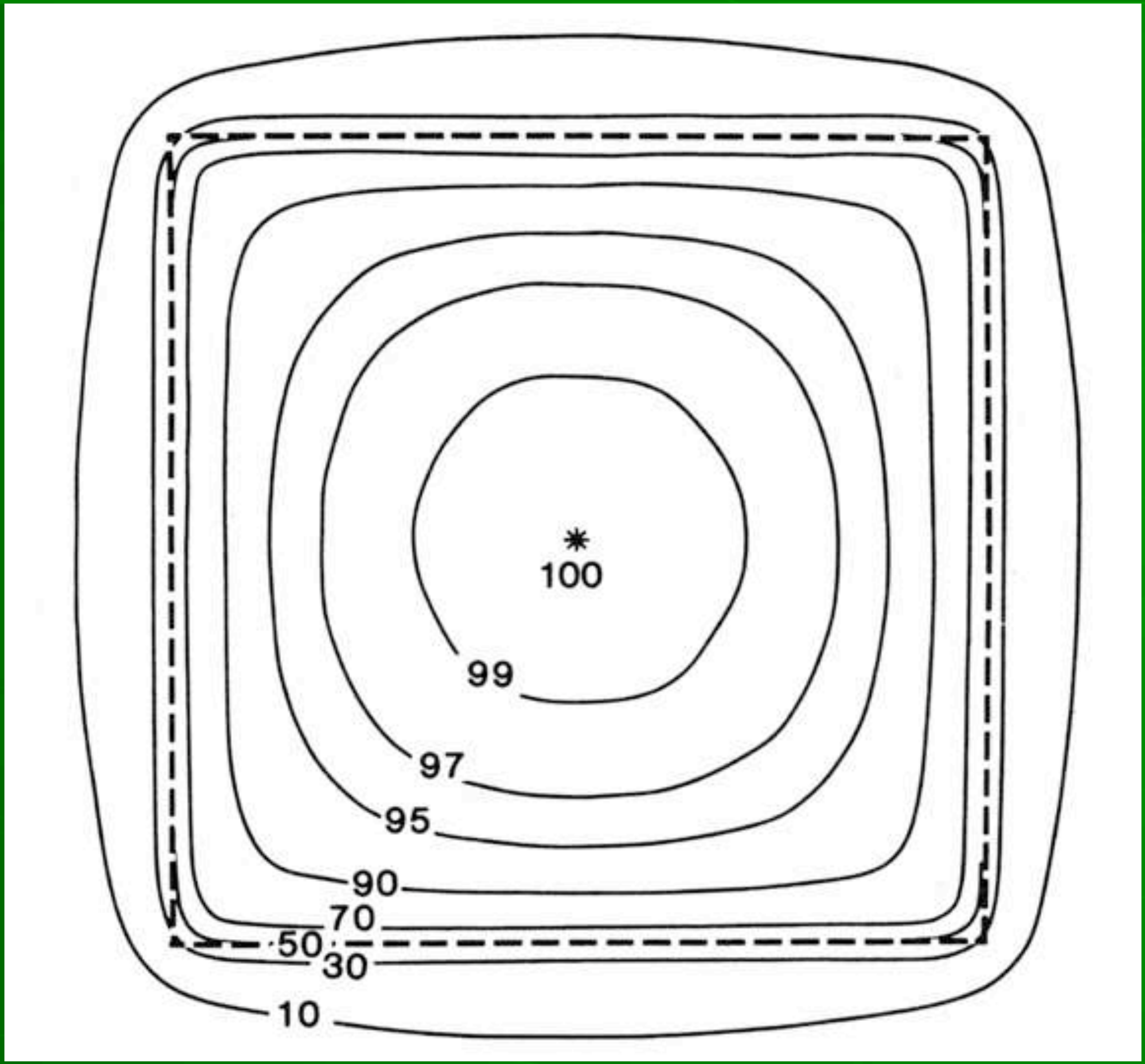
Isodose Curves



SSD normalized at dMax

SSD normalized at depth (isocenter)

Isodose Curves Perpendicular to CAX



Point Dose Calculations

- Treatment unit calibration
  - Calibrated at defined SSD (100 cm)
    - dMax, 5, 10 cm deep
  - Calibrated at isocenter
    - dMax, 5, 10 cm deep
- MU calculation depends upon calibration
- Meter Setting (MU) =

$$\frac{\text{Prescribed dose related to calibration conditions}}{\text{Calibration dose rate}}$$

Treatment at Standard SSD

- MU = Given Dose / Dose Rate at dMax
  - Given dose:
    (Rx'd dose @ depth)*100 / (%Dn) = Dose at dMax
  - Dose rate at dMax: Dm = Dc Sc Sp F
  - Dc: calibrated dose
    rat
    e
     at dm for 10x10 cm field size, or (1 cGy/MU)
  - Sc: collimator
    s
    c
    atter factor normalized to 10x10 cm field size

Treatment at Isocenter

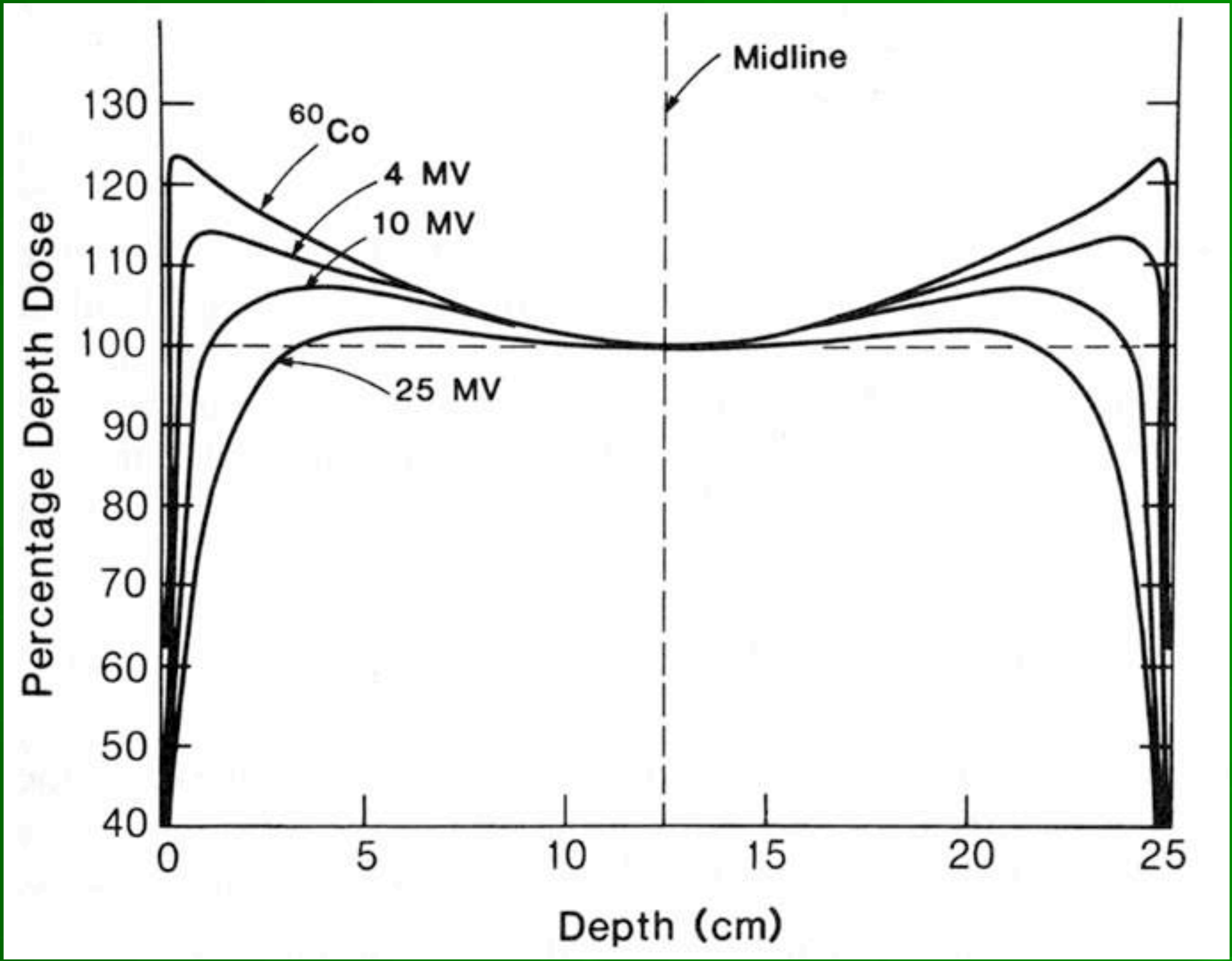
- Meter setting (MU) =
$$\frac{\text{Prescribed dose at isocenter}}{\text{Dose rate at isocenter}}$$

- Meter setting (MU) =
$$\frac{\text{Prescribed dose at isocenter}}{Dc\ [(SSD+dMax)/SAD]^2\ TMR\ Sc\ Sp\ F}$$

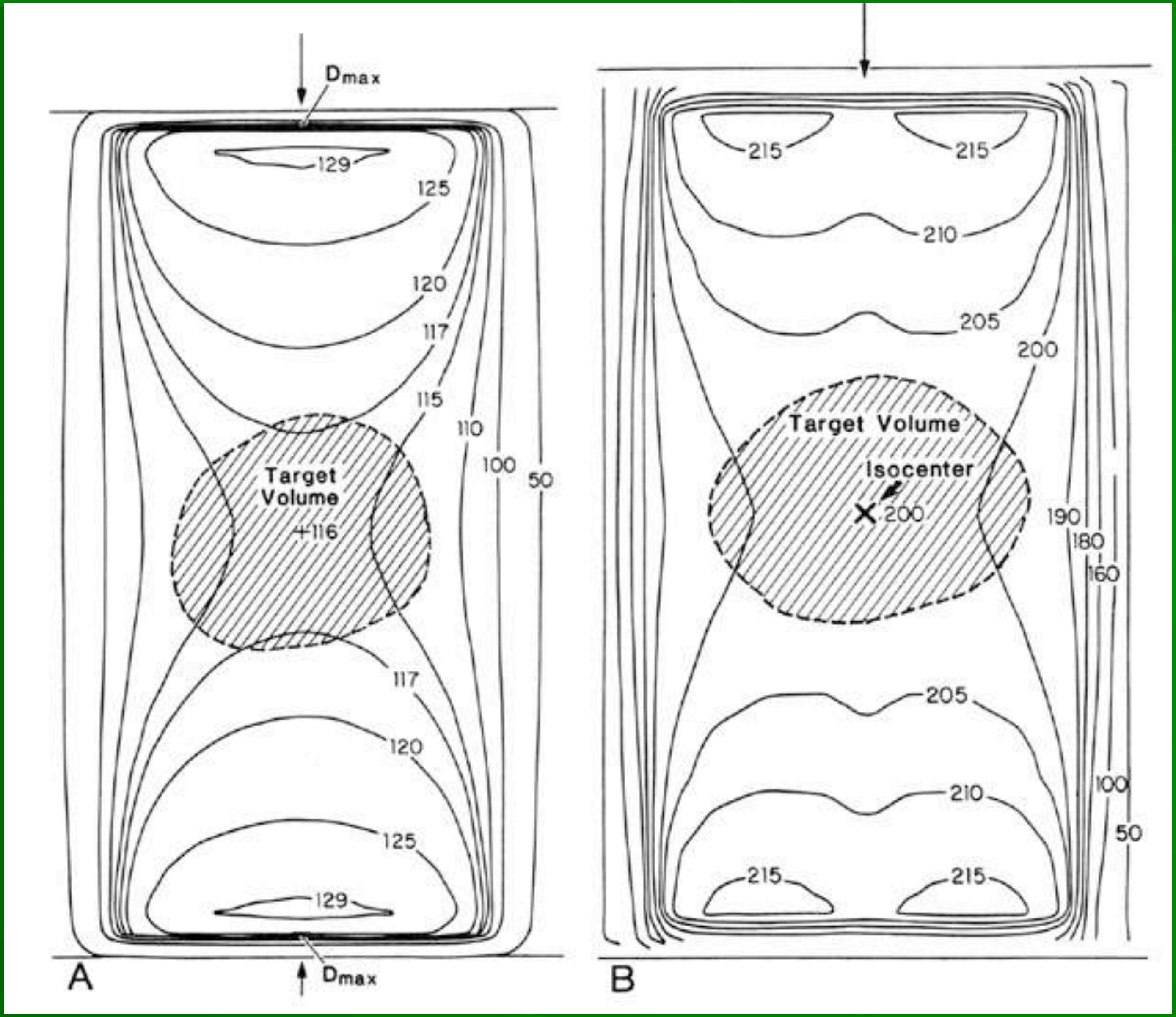
Distribution of Multiple Fields

- Parallel opposed fields – CAX
  - CAX depth dose opposed fields vs. energy
  - Equal weighted or unequal weighted beams
  - Minimum dose in mid-plane
  - Build up at entrance of both fields
  - Often normalized to 100% or dose to a point (tumor) in the patient

CAX Depth Dose vs. Energy



Parallel Opposed Beams



Example Problem

- A patient is to be treated using a AP/PA pair of fields and a SSD technique. The patient is 22 cm thick. The field size is 10x15 cm with minimal blocking, however a block tray is used. The physician prescribes 61.2 Gy at 1.8 Gy/ treatment to the 90% isodose line. The fields are equally weighted at dMax from each field. How many MU's are needed/ day for each field?

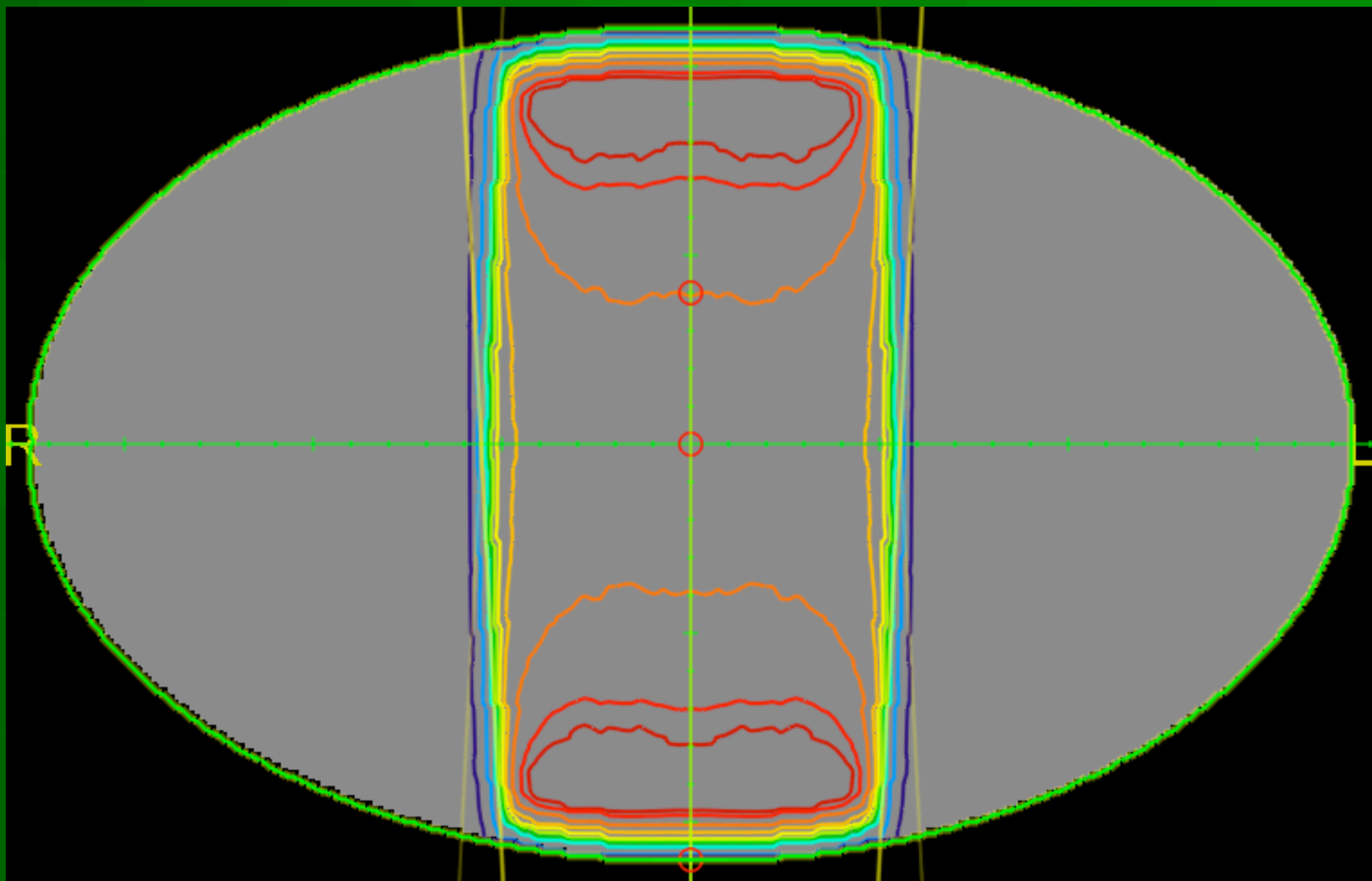
Example Problem

- A patient is to be treated using a AP/PA pair of fields and a SSD technique. The patient is 22 cm thick. The field size is 10x15 cm with minimal blocking, however a block tray is used. The physician prescribes 61.2 Gy at 1.8 Gy/ treatment to the 90% isodose line. The fields are equally weighted at dMax from each field. How many MU's are needed/ day for each field?

Answer

- MU = $\dfrac{\text{Prescribed Dose / Field / Day}}{\%DD*100*TF*ROF}$
- MU = $\dfrac{\text{180 cGy / 2 / 0.9}}{\%DD(12x12 @ d11)*TF*ROF(12)}$
- MU = $\dfrac{100}{0.6475 * 0.97 * 1.016}$
- MU = 157 MU

External Beam Plan

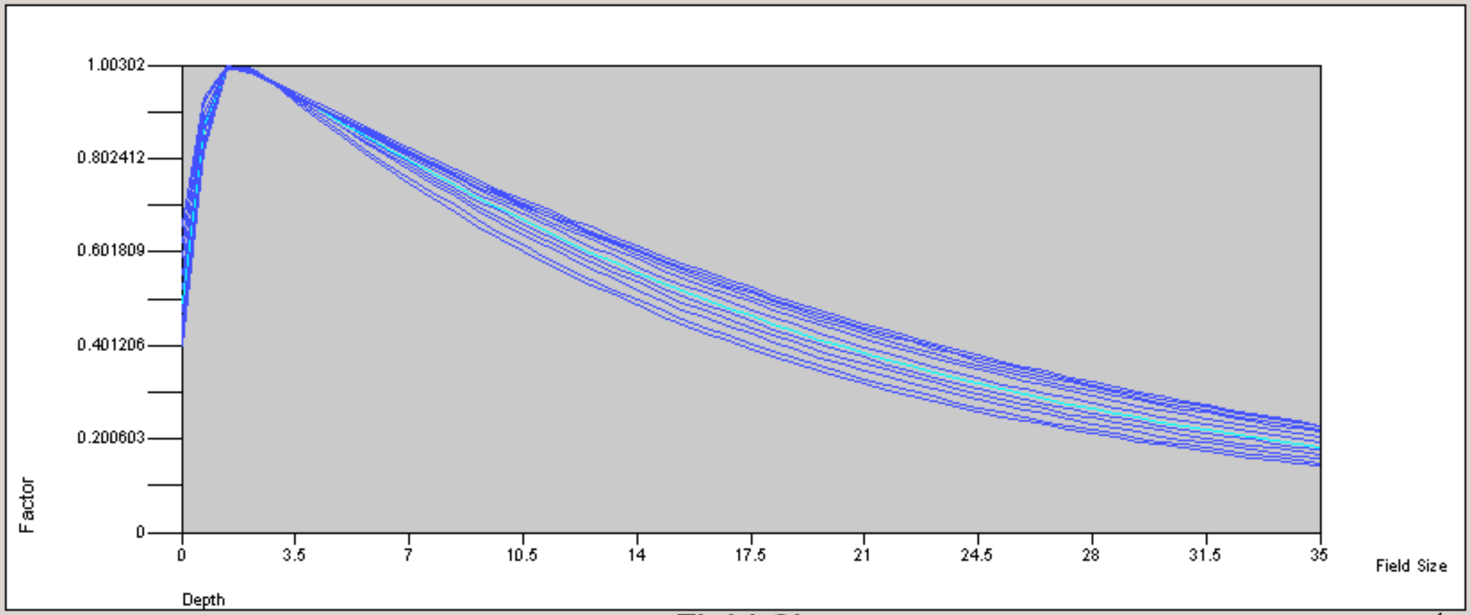


Answer

- MU = $\dfrac{\text{Prescribed Dose / Field / Day}}{\%DD*100*TF*ROF}$
- MU = $\dfrac{\text{180 cGy / 0.9 / 2 / 1}}{\%DD(12x12 @ d11)*TF*ROF(12)}$
- MU = $\dfrac{100}{0.65296 * 0.966 * 1.016}$
- MU = 156 MU

MDE – PDD 0.65296

Percentage Depth Dose



Field Size

Approximate

Depth

	3.000	4.000	6.000	8.000	10.000	12.000	15.000	20.000	25.000
10.900	0.58835	0.60101	0.62287	0.63828	0.64930	0.65697	0.66700	0.67600	0.68800
11.000	0.58233	0.59698	0.61886	0.63226	0.64830	0.65296	0.66200	0.67800	0.68500
11.100	0.58133	0.59196	0.61585	0.63126	0.64128	0.64895	0.66100	0.67300	0.68100
11.200	0.57731	0.58894	0.61284	0.62625	0.63727	0.64493	0.65900	0.66900	0.67800
11.300	0.57430	0.58492	0.61083	0.62124	0.63427	0.64193	0.65600	0.66800	0.67600
11.400	0.56928	0.58492	0.60682	0.61824	0.63226	0.63992	0.65300	0.66600	0.67200
11.500	0.56526	0.57889	0.60281	0.61623	0.62826	0.63691	0.64900	0.66100	0.66900
11.600	0.56426	0.57688	0.59980	0.61222	0.62425	0.63290	0.64400	0.66000	0.66700
11.700	0.56024	0.57286	0.59779	0.60922	0.62224	0.62989	0.64100	0.65400	0.66300
11.800	0.55622	0.56884	0.59178	0.60621	0.61924	0.62688	0.63900	0.65200	0.65900
11.900	0.55321	0.56583	0.58977	0.60120	0.61323	0.62387	0.63600	0.65000	0.65700
12.000	0.54920	0.56181	0.58576	0.59920	0.61323	0.62187	0.63200	0.64800	0.65500
12.100	0.54518	0.55879	0.58175	0.59519	0.60922	0.61685	0.62800	0.64200	0.65000
12.200	0.54217	0.55477	0.57773	0.59218	0.60521	0.61585	0.62700	0.63900	0.64800

MDE – Tray Factor 0.966

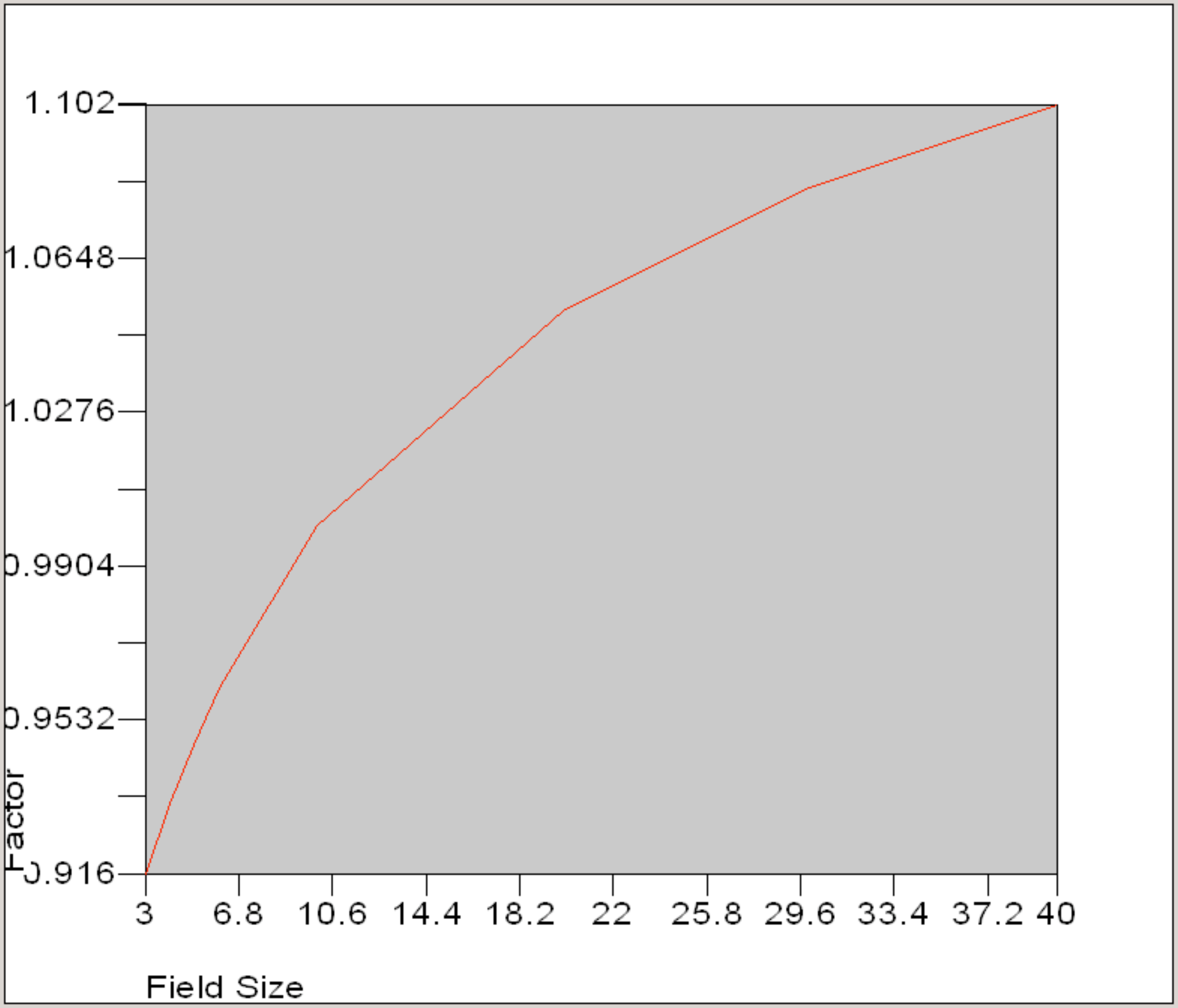
Accessories

	Name	Factor
	Block Tray	0.966

MDE – Output Factor 1.016

Output Factor

Field Size	Factor
3.000	0.91600
4.000	0.93300
5.000	0.94700
6.000	0.96100
10.000	1.00000
20.000	1.05200
30.000	1.08200
40.000	1.10200



Plan Summary

- 142 vs 156
  - Rx
  - Isodose
  - dMax
  - Field Size
  - Effective Square
  - “Fast Photon”
- 143 vs 156
  - “Scatter”

Photon Plan Summary

Prescription: 180.0 cGy to the 90.0 isodose line.
Normalization: Calc Pt #1

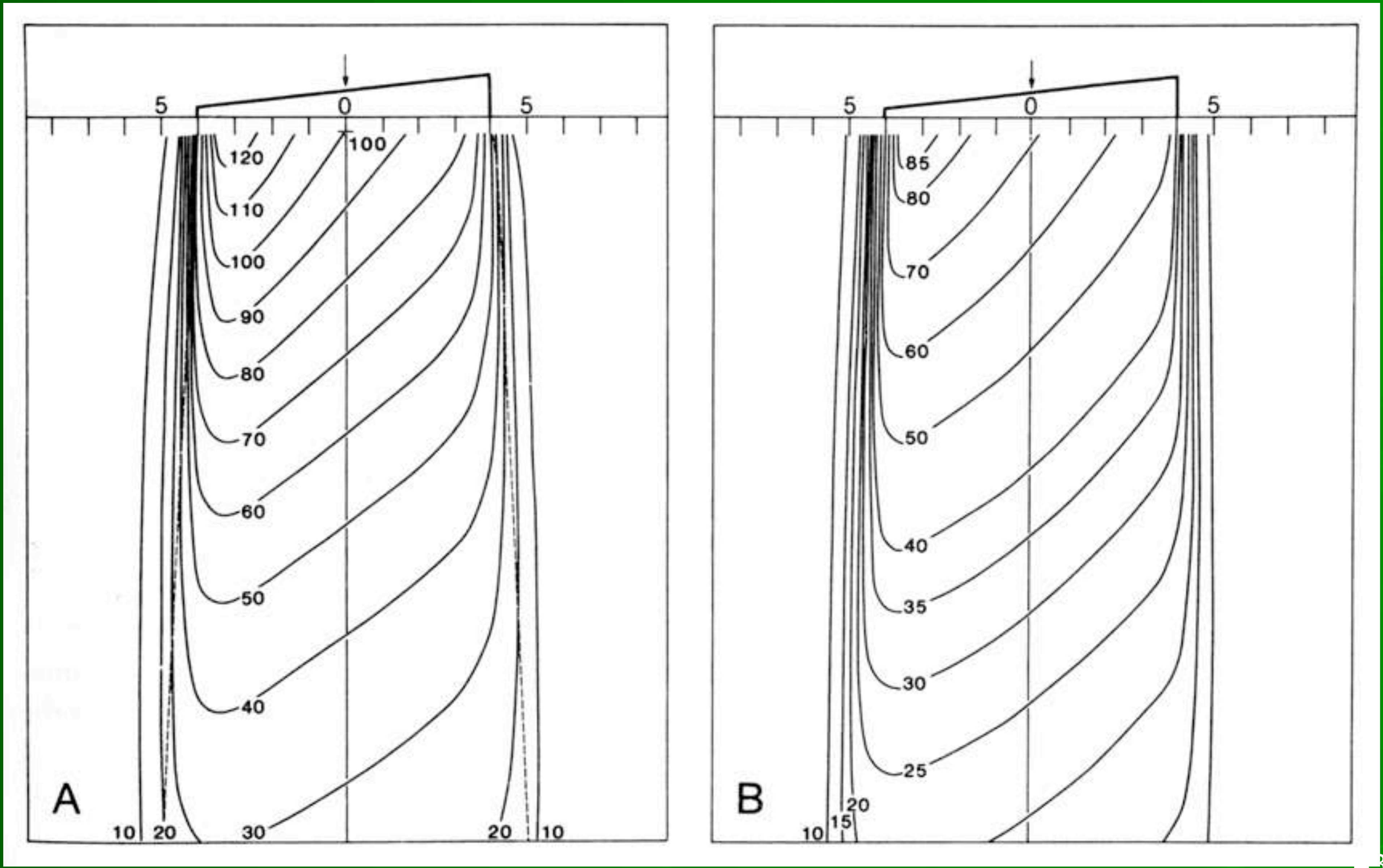
OK

	Beam #1	Beam #2
Name	Beam #1	Beam #2
Machine	Clinac 2100 (Sample Machin	Clinac 2100 (Sample Machin
Energy	6MV	6MV
Block	Yes	Yes
Wedge Name	Open Field	Open Field
Wedge Orientation	--	--
Gantry (Start°,Stop°)	0.0	180.0
Couch (°)	0.0	0.0
Couch (Lat,Vert,Long)	0.00, -22.00, 25.00	-0.00, 0.00, 25.00
Isocenter (X,Y,Z) (cm)	0.00, 0.00, 11.00	0.00, 0.00, -11.00
Fit (Volume,Margin)	none	none
SSD (cm)	100.0	100.0
Coll Angle (°)	180.0	180.0
Field Size (cm)	10.0 x 15.0	10.0 x 15.0
Coll Size (cm)	X1:5.0 X2:5.0	X1:5.0 X2:5.0
	Y1:7.5 Y2:7.5	Y1:7.5 Y2:7.5
Depth (cm)	1.50	1.50
Effective Square (cm)	12.04	11.94
TPR	1.000	1.000
RCS	1.005	1.005
RPS	1.005	1.005
Wedge Factor	1.000	1.000
Inverse Square	1.000	1.000
Bolus Thickness (cm)	--	--
Bolus Density	--	--
Accessory Trans. Factor	1.000	1.000
Total OCR	1.000	1.000
Primary OCR	1.000	1.000
Block Edge OCR	1.000	1.000
Coll Edge OCR	1.000	1.000
Wedge OCR	1.000	1.000
Weight Point	dMax	dMax
Total Weight	50.0	50.0
Dose to Weight Point (cGy)	143.2	143.2
Dose at Dmax (cGy)	143.2	143.2
Number Fractions	1	1
Machine Setting	141.9 MU	141.9 MU

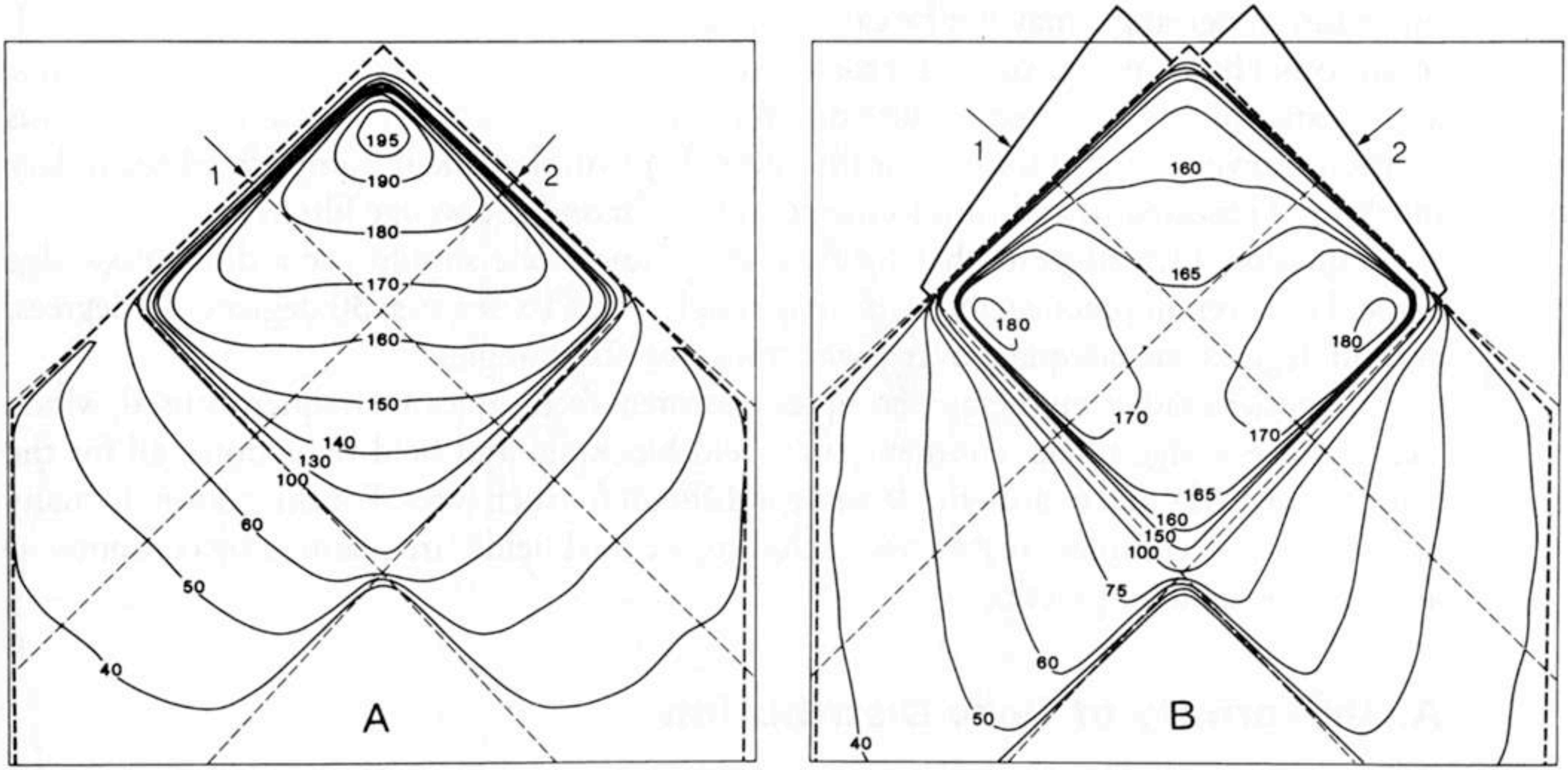
The Wedged Beam

- Metal wedge shaped filter is put in beam to tilt isodose curve
  - Angle usually defined at d10, or 50% isodose
- Types of wedge filters
  - Solid metal
  - Universal
  - Dynamic wedge
- Isodose curves change with field size
- Flatness changes with depth

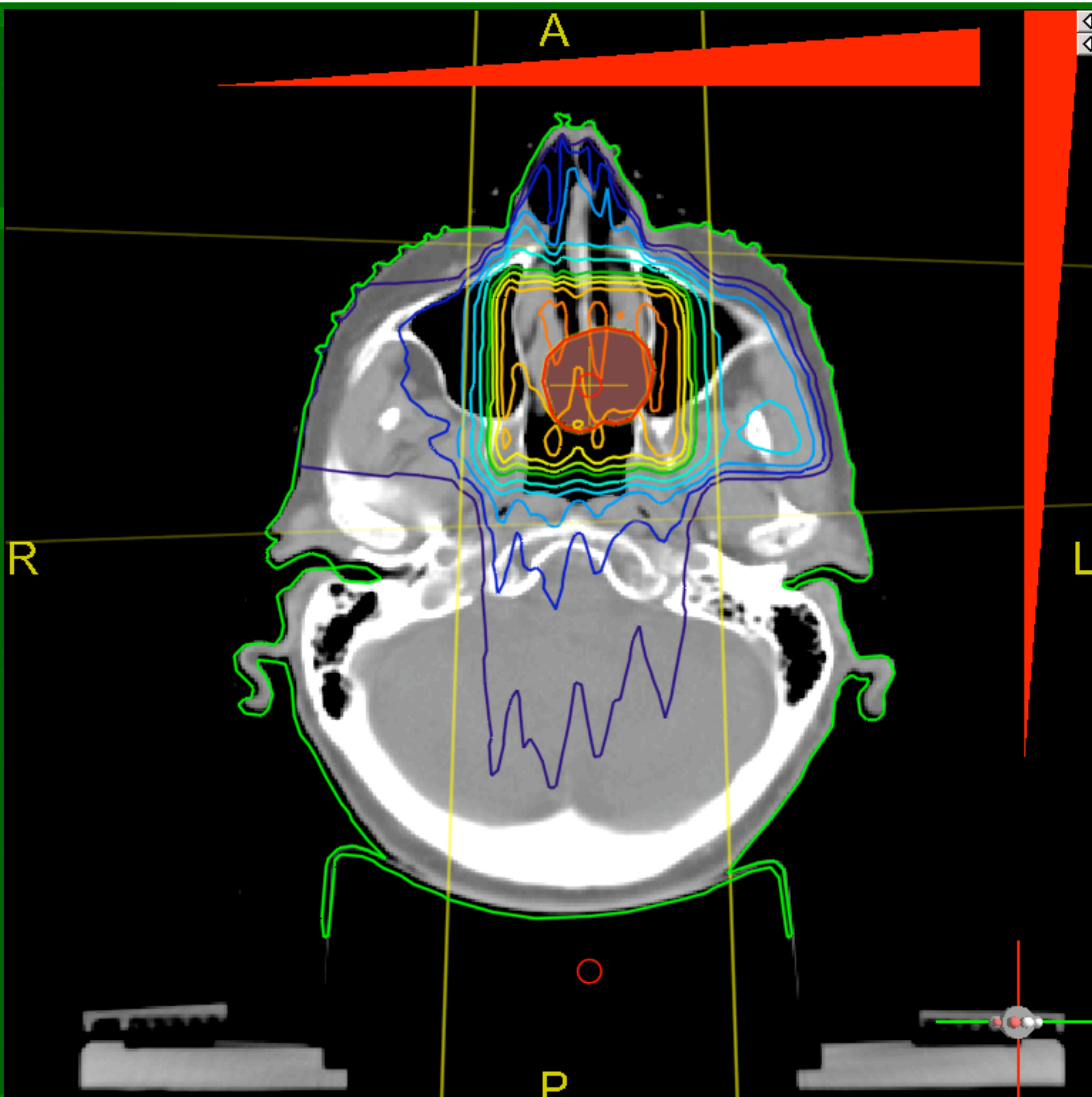
Isodose Curve of Wedged Beam



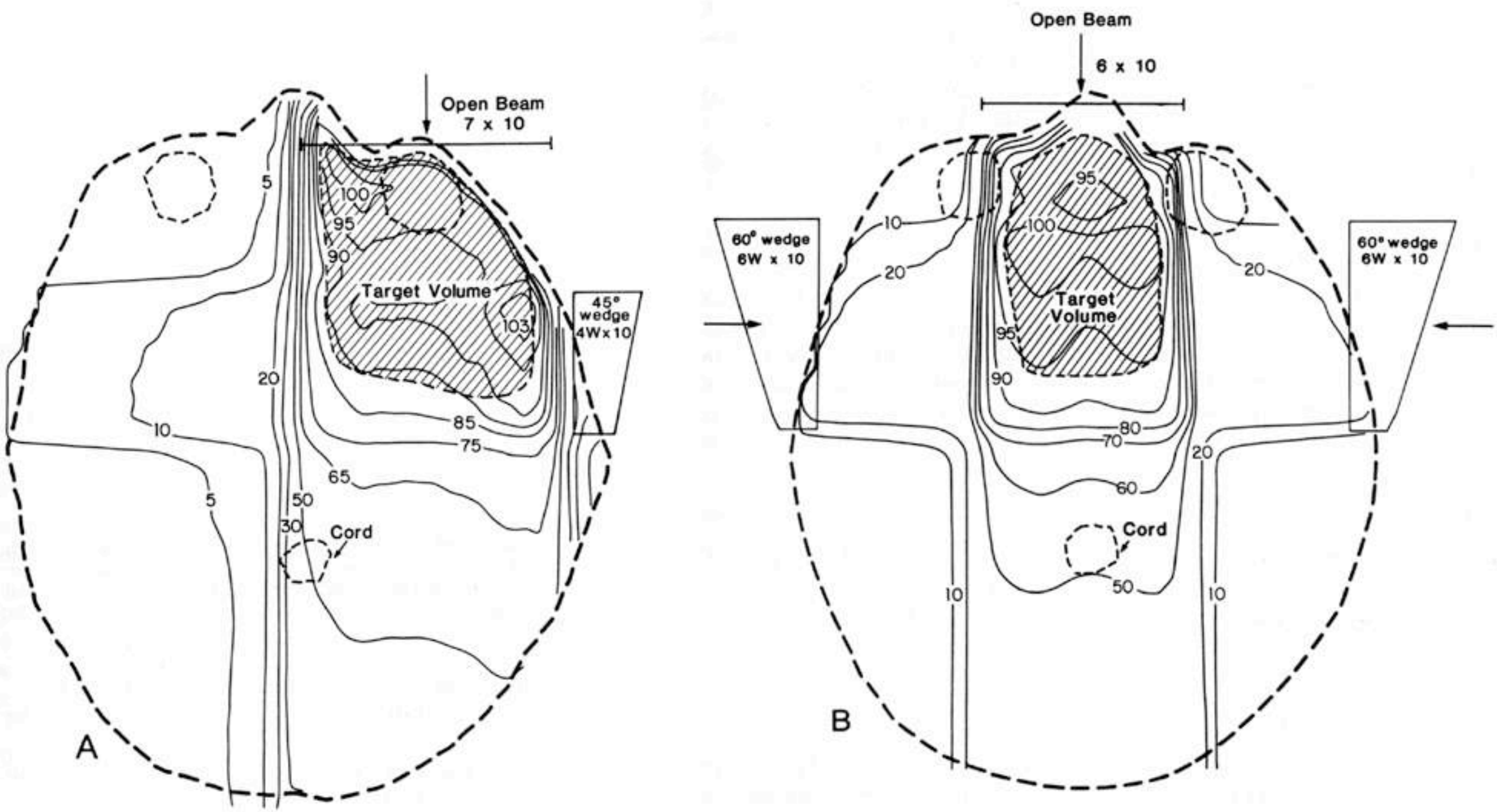
Wedged vs. Unwedged Fields




A
R
L
P


A
R
L
P

Typical Head & Neck Plan



Photon Inhomogeneity Correction

- Density affects attenuation of x-rays
- Lung with a density of 0.25-0.30 attenuates much less than normal tissue
- Bone with a higher density and atomic number attenuations x-rays more
- Inhomogeneities also affect scatter
- Lung corrections 10-15% for 5-8 cm lung tissue

Photon Beam Models

- Analytical method: %DD x OAR
- Matrix Technique: Fan lines and %DD
- Semi-Empirical Methods
  - Clarkson Integration
  - Differential Scatter – Air Ratio
  - Heterogeneity Corrections
- Co
n
v
olution Superposition Algorithm (Kernels)