Department of Radiation Oncology

University of Maryland School of Medicine

Annual Physics and Radiobiology Review Course

DOSE RATIOS AND ACCELERATOR MONITOR-UNIT CALCULATIONS

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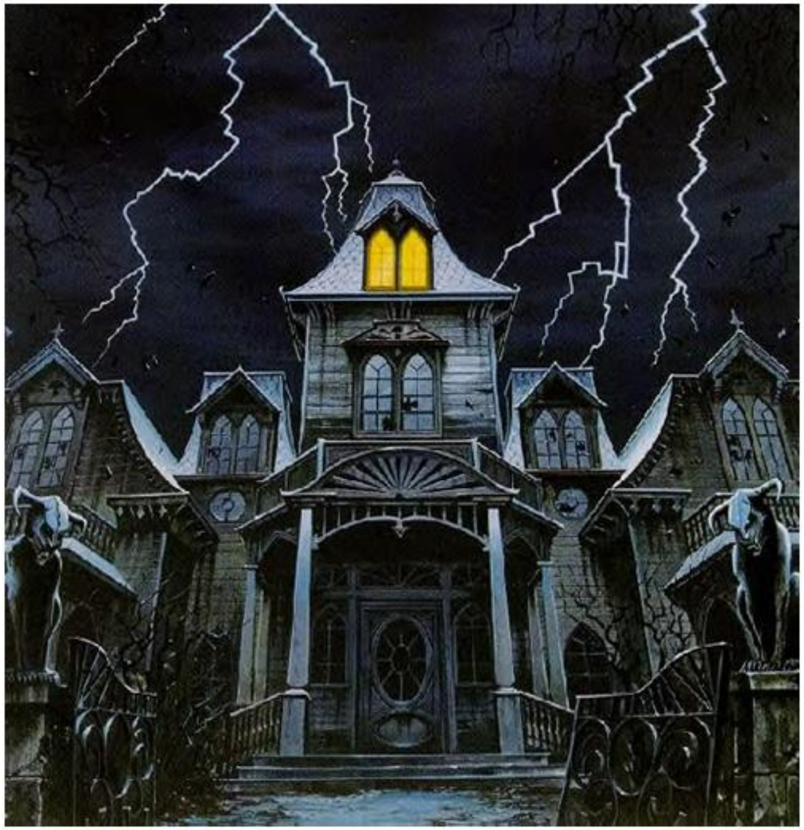
Dose Ratios and MU Calculations



Not as *scary* as you think!

- Our Goals:
  A. Actually understand things like PDDs, Inverse Square, TMRs, Scatter Factors, and other such physics terms …
  B. And then be able to use them in calculations of accelerator monitor-units

Objectives

- Understand the basic concepts underlying radiation dosimetry
- Recognize the fundamental quantities that are used to describe these basic radiation dosimetry concepts
- Apply radiation dosimetry concepts and quantities in calculations of dose in clinical radiation-oncology practice situations

Dose Ratios and MU Calculations

- Dose Ratios
  - Think measurements made in a water phantom
  - Define quantities: the ratio of doses at two points: one point different than the other because of distance, depth, and conditions of scatter (e.g. PDD)
- MU Calculations
  - Apply measured data to clinical dose calculations
  - Specifically – calculate the monitor-unit setting on the treatment unit that will deliver an intended dose

The next couple of hours

- First talk about how we characterize dose deposition in a medium … "dosimetry" (dose ratios)
- Then talk about dose-calculation methods …
  - Perform an accelerator monitor-unit (MU) calculation

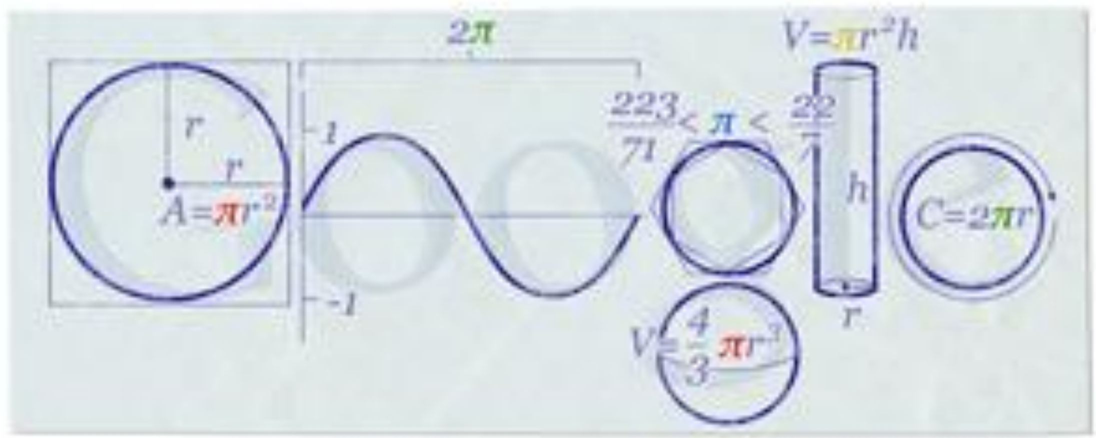
Sample Dose Calculation Problem

- A patient's whole brain is to be treated.
  - The prescribed dose is **300 cGy per fraction,** (10 fractions, 30 Gy total dose).
  - Radiation and technique are **6 MV x rays**, parallel-opposed **right and left lateral fields**
  - Prescribed dose is **to isocenter.**
  - Fields are **20x18**, **mlc**-shaped
  - The patient set up for **isocentric** treatment at mid-brain, lateral **separation 16 cm**

A word about the dose prescription

- Clearly define the dose prescription:
  - Treatment site (e.g. R Lung and mediastinum, L Breast)
  - Total dose to the site (including all boost fields)
  - Dose per fraction
  - Number of fractions
  - Fractions per day (and per week)
  - Type and energy of radiation (e.g. 6 MV x rays)
  - Technique and number of fields (e.g. 9-field IMRT)
  - Prescription point, surface, or volume
  - Special instructions (e.g. daily kV, bolus)

Who else thinks this is a pretty cool Google Logo?



Beam Data (Measured Dose Ratios)

- Quantitative description of the dose characteristics of the therapy beams
  - All units
  - All energies
- Each machine and energy has its corresponding set of beam data
  - Machine Data Book
- "Golden Data Set"

Varian 2100 6MV Scatter Factors S_c, S_p

Field Size	S_c	S_p
4	0.951	0.979
5	0.962	0.983
6	0.975	0.986
8	0.989	0.993
10	1.000	1.000
12	1.008	1.006
15	1.021	1.013
20	1.030	1.023
25	1.038	1.031
30	1.049	1.035
40	1.061	1.040

Percent Depth Dose

Varian 2100C

6MV PDD **Open Unwedged Field**

field size (cm)	4.0	5.0	6.0	8.0	10.0	12.0	15.0	18.0	20.0	22.0				
d-max (cm)	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3				
depth (cm)														
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.7				
2.0	98.7	98.8	98.9	98.8	98.9	98.7	98.7	98.6	98.4	98.4				
3.0	94.2	94.4	94.5	94.6	94.8	94.8	94.8	95.0	94.9	94.7				
4.0	89.1	89.8	90.0	90.2	90.7	90.6	90.9	91.1	91.1	91.1				
5.0	84.2	84.7	85.4	85.8	86.4	86.6	87.0	87.3	87.3	87.4				
6.0	79.3	80.1	81.0	81.5	82.1	82.7	83.2	83.6	83.6	83.8				
7.0	74.7	75.7	76.7	77.1	78.1	78.6	79.3	79.9	79.9	80.2				
8.0	70.5	71.5	72.6	73.2	74.2	74.9	75.6	76.2	76.4	76.7				
9.0	66.5	67.5	68.6	69.3	70.4	71.1	72.1	72.8	73.1	73.4	73.7	74.3	74.7	75.0
10.0	62.6	63.6	64.6	65.6	66.8	67.5	68.6	69.4	69.8	70.0	70.4	71.0	71.5	71.8
11.0	59.0	60.0	61.0	61.										
12.0	55.5	56.4	57.5	58.										
13.0	52.1	53.1	54.2	55.										
14.0	49.1	50.1	51.1	52.										
15.0	46.2	47.1	48.1	49.										
16.0	43.4	44.4	45.4	46.										
17.0	40.9	41.8	42.9	43.										
18.0	38.5	39.4	40.5	41.										
19.0	36.3	37.2	38.2	39.										
20.0	34.2	35.1	35.9	37.										
21.0	32.2	33.1	33.9	35.										
22.0	30.3	31.2	31.9	33.										
23.0	28.7	29.4	30.1	31.										
24.0	27.1	27.8	28.5	29.										
25.0	25.5	26.2	26.9	27.										
26.0	24.1	24.7	25.4	26.										

Tissue Maximum Ratio

Varian 2100's

6MV TMR **Open Unwedged Field** **100cm SAD**

field size (cm)	4.0	5.0	6.0	8.0	10.0	12.0	15.0	18.0	20.0	22.0	25.0	30.0	35.0	40.0
d-max (cm)	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2
depth (cm)														
1.5	1.000	1.000	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
2.0	0.996	0.998	0.999	0.999	0.999	0.999	0.998	0.998	0.997	0.997	0.997	0.997	0.997	0.997
3.0	0.968	0.971	0.972	0.974	0.976	0.977	0.978	0.979	0.979	0.979	0.980	0.981	0.982	0.983
4.0	0.934	0.939	0.943	0.948	0.951	0.953	0.955	0.957	0.958	0.959	0.960	0.963	0.965	0.967
5.0	0.897	0.905	0.910	0.918	0.923	0.926	0.930	0.933	0.935	0.937	0.939	0.942	0.946	0.948
6.0	0.860	0.870	0.878	0.888	0.895	0.900	0.906	0.910	0.912	0.914	0.917	0.921	0.924	0.928
7.0	0.825	0.836	0.844	0.857	0.865	0.872	0.879	0.885	0.888	0.891	0.894	0.899	0.903	0.906
8.0	0.791	0.804	0.813	0.827	0.837	0.844	0.853	0.859	0.863	0.866	0.871	0.877	0.882	0.886
9.0	0.759	0.772	0.781	0.796	0.808	0.816	0.827	0.835	0.839	0.843	0.849	0.856	0.862	0.867

Beam Data: Beam Characteristics

- <u>Measured</u> data:
  - Statement of calibration
    - How is machine calibrated?
  - Percent Depth Dose (PDDs)
    - TMRs are then calculated from PDDs
  - Profiles
    - Off-Axis Ratios
  - Output Factors
  - Transmission Factors
    - Wedges and other attenuators

Beam Data

- What's in the machine data books?

Percent Depth Dose

Varian 2100C

6MV PDD **Open Unwedged Field** **100cm SSD**

35.0	40.0
1.2	1.2
99.6	99.6
98.2	98.1
94.9	95.0
91.5	91.6
88.0	88.2
84.4	84.7
81.0	81.3
77.7	78.2
74.7	75.0
71.5	71.8
68.4	68.8
65.4	65.8
62.6	63.0
59.9	60.3
57.2	57.7
54.6	55.1
52.1	52.6
49.8	50.3
47.5	48.0
45.3	45.8
43.2	43.8
41.3	41.8
39.4	39.9
37.5	38.1
35.7	36.3
34.1	34.6
30.9	31.4
28.1	28.6
25.5	26.1
22.1	22.5
19.1	19.6

Tissue Maximum Ratio

Varian 2100's

6MV TMR **Open Unwedged Field** **100cm SAD**

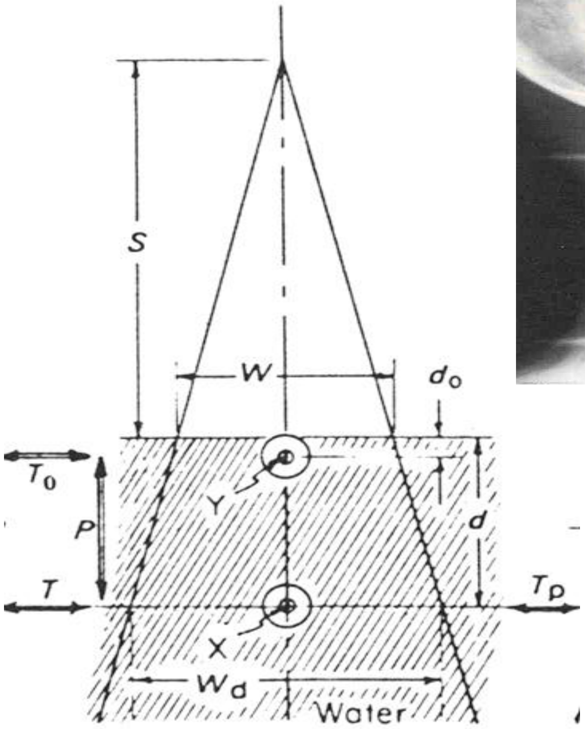
field size (cm)	4.0	5.0	6.0	8.0	10.0	12.0	15.0	18.0	20.0	22.0	25.0	30.0	35.0	40.0
d-max (cm)	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2
depth (cm)														
1.5	1.000	1.000	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
2.0	0.996	0.998	0.999	0.999	0.999	0.999	0.998	0.998	0.997	0.997	0.997	0.997	0.997	0.997
3.0	0.968	0.971	0.972	0.974	0.976	0.977	0.978	0.979	0.979	0.979	0.980	0.981	0.982	0.983
4.0	0.934	0.939	0.943	0.948	0.951	0.953	0.955	0.957	0.958	0.959	0.960	0.963	0.965	0.967
5.0	0.897	0.905	0.910	0.918	0.923	0.926	0.930	0.933	0.935	0.937	0.939	0.942	0.946	0.948
6.0	0.860	0.870	0.878	0.888	0.895	0.900	0.906	0.910	0.912	0.914	0.917	0.921	0.924	0.928
7.0	0.825	0.836	0.844	0.857	0.865	0.872	0.879	0.885	0.888	0.891	0.894	0.899	0.903	0.906
8.0	0.791	0.804	0.813	0.827	0.837	0.844	0.853	0.859	0.863	0.866	0.871	0.877	0.882	0.886
9.0	0.759	0.772	0.781	0.796	0.808	0.816	0.827	0.835	0.839	0.843	0.849	0.856	0.862	0.867
10.0	0.727	0.739	0.750	0.766	0.778	0.788	0.800	0.809	0.814	0.819	0.825	0.833	0.839	0.845
11.0	0.696	0.709	0.719	0.736	0.750	0.760	0.774	0.784	0.790	0.795	0.802	0.811	0.818	0.824
12.0	0.665	0.678	0.689	0.707	0.721	0.732	0.746	0.758	0.764	0.770	0.777	0.787	0.795	0.801
13.0	0.636	0.649	0.660	0.679	0.694	0.706	0.721	0.733	0.740	0.746	0.754	0.764	0.773	0.780
14.0	0.609	0.621	0.632	0.651	0.666	0.679	0.695	0.708	0.716	0.722	0.731	0.742	0.751	0.759
15.0	0.583	0.594	0.605	0.624	0.640	0.653	0.670	0.684	0.691	0.698	0.707	0.719	0.729	0.737
16.0	0.556	0.568	0.579	0.598	0.614	0.628	0.645	0.659	0.667	0.674	0.684	0.697	0.707	0.715
17.0	0.532	0.544	0.555	0.574	0.590	0.604	0.621	0.636	0.644	0.651	0.661	0.674	0.685	0.694
18.0	0.510	0.521	0.531	0.551	0.567	0.581	0.598	0.613	0.621	0.629	0.639	0.653	0.664	0.674
19.0	0.489	0.499	0.509	0.528	0.544	0.558	0.576	0.591	0.600	0.607	0.618	0.632	0.644	0.653
20.0	0.467	0.477	0.487	0.505	0.522	0.536	0.554	0.569	0.578	0.586	0.597	0.611	0.623	0.633
21.0	0.447	0.456	0.466	0.484	0.500	0.515	0.533	0.548	0.557	0.565	0.576	0.591	0.603	0.613
22.0	0.429	0.437	0.446	0.464	0.480	0.494	0.512	0.528	0.537	0.545	0.556	0.571	0.584	0.594
23.0	0.412	0.419	0.427	0.444	0.460	0.474	0.492	0.508	0.517	0.525	0.536	0.552	0.565	0.575
24.0	0.394	0.401	0.409	0.426	0.441	0.455	0.473	0.489	0.498	0.506	0.517	0.533	0.545	0.556
25.0	0.379	0.385	0.392	0.408	0.423	0.437	0.455	0.471	0.480	0.488	0.499	0.515	0.527	0.538
26.0	0.362	0.368	0.375	0.390	0.405	0.419	0.437	0.452	0.461	0.470	0.481	0.496	0.509	0.520
28.0	0.332	0.337	0.344	0.359	0.373	0.386	0.403	0.418	0.427	0.435	0.446	0.462	0.475	0.486
30.0	0.306	0.310	0.316	0.330	0.343	0.356	0.372	0.387	0.395	0.403	0.414	0.430	0.443	0.454
32.0	0.280	0.284	0.290	0.303	0.316	0.328	0.344	0.358	0.366	0.374	0.384	0.399	0.412	0.423
35.0	0.250	0.253	0.257	0.268	0.280	0.290	0.305	0.319	0.326	0.334	0.344	0.358	0.370	0.381

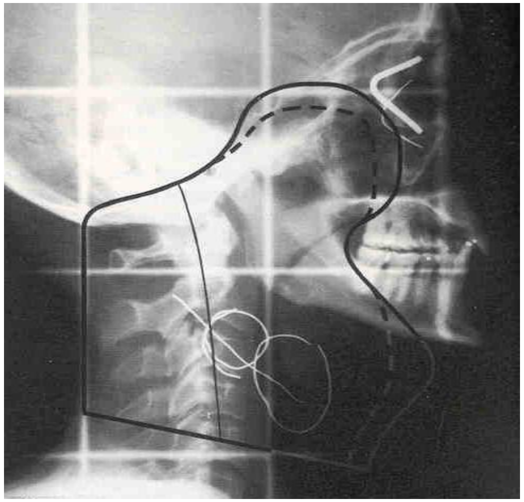
Varian 2100 6MV Scatter Factors S_c, S

Field Size	S_c	S_p
4	0.951	0.979
5	0.962	0.983
6	0.975	0.986
8	0.989	0.993
10	1.000	1.000
12	1.008	1.006
15	1.021	1.013
20	1.030	1.023
25	1.038	1.031
30	1.049	1.035
40	1.061	1.040

The Definitions of Field Size

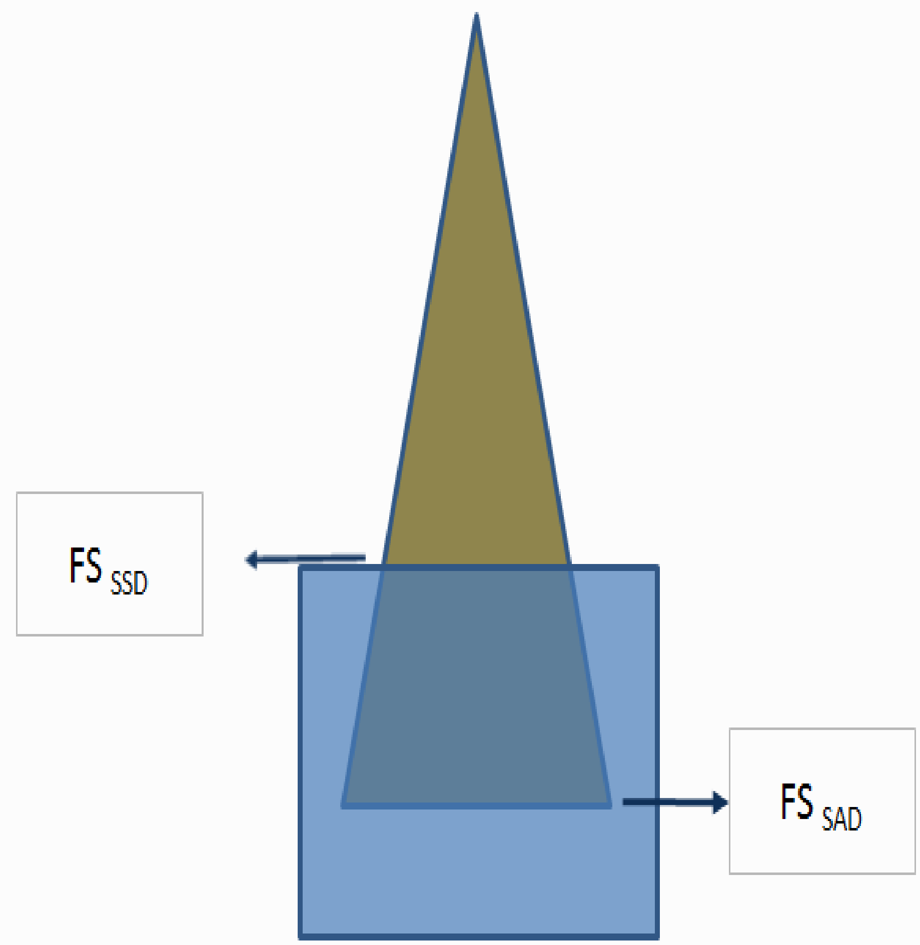
- Many details
  - How defined? … SSD, SAD
    - Field size at what distance? … beam divergence
  - How produced? … collimator jaws, multi-leaf collimator





The Definitions of Field Size

- Where defined?
  - Think … at what **<u>distance</u>** is field size defined?
  - For S**<u>S</u>**D geometries
    - Field size defined at <u>surface</u> (e.g. PDD)
  - For S**<u>A</u>**D geometries
    - Field size defined at <u>axis</u> (at depth, e.g. TMR)



Field Size: Equivalent Square

- Data are measured for square fields
- For rectangular or other fields, use …
- The "equivalent square"
  - Is the size of the square field that produces the <u>same amount of attenuation and scatter</u> (same PDD and OF) as the given field
  - Normally represented by the "<u>side</u>" of the equivalent square

Table 9.2.
Equivalent Squares of Rectangular Fields

Long Axis (cm)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
	2.0														
	2.7	4.0													
	3.1	4.8	6.0												
	3.4	5.4	6.9	8.0											
	3.6	5.8	7.5	8.9	10.0										
	3.7	6.1	8.0	9.6	10.9	12.0									
	3.8	6.3	8.4	10.1	11.6	12.9	14.0								
	3.9	6.5	8.6	10.5	12.2	13.7	14.9	16.0							
	4.0	6.6	8.9	10.8	12.7	14.3	15.7	16.9	18.0						
	4.0	6.7	9.0	11.1	13.0	14.7	16.3	17.7	18.9	20.0					
	4.0	6.8	9.1	11.3	13.3	15.1	16.8	18.3	19.7	20.9	22.0				
	4.1	6.8	9.2	11.5	13.5	15.4	17.2	18.8	20.3	21.7	22.9	24.0			
	4.1	6.9	9.3	11.6	13.7	15.7	17.5	19.2	20.9	22.4	23.7	24.9	26.0		
	4.1	6.9	9.4	11.7	13.8	15.9	17.8	19.6	21.3	22.9	24.4	25.7	27.0	28.0	
	4.1	6.9	9.4	11.7	13.9	16.0	18.0	19.9	21.7	23.3	24.9	26.4	27.7	29.0	30.

From Hospital Physicists' Association. Central axis depth dose data for use in radiotherap
Br J Radiol 1978;(suppl 11).

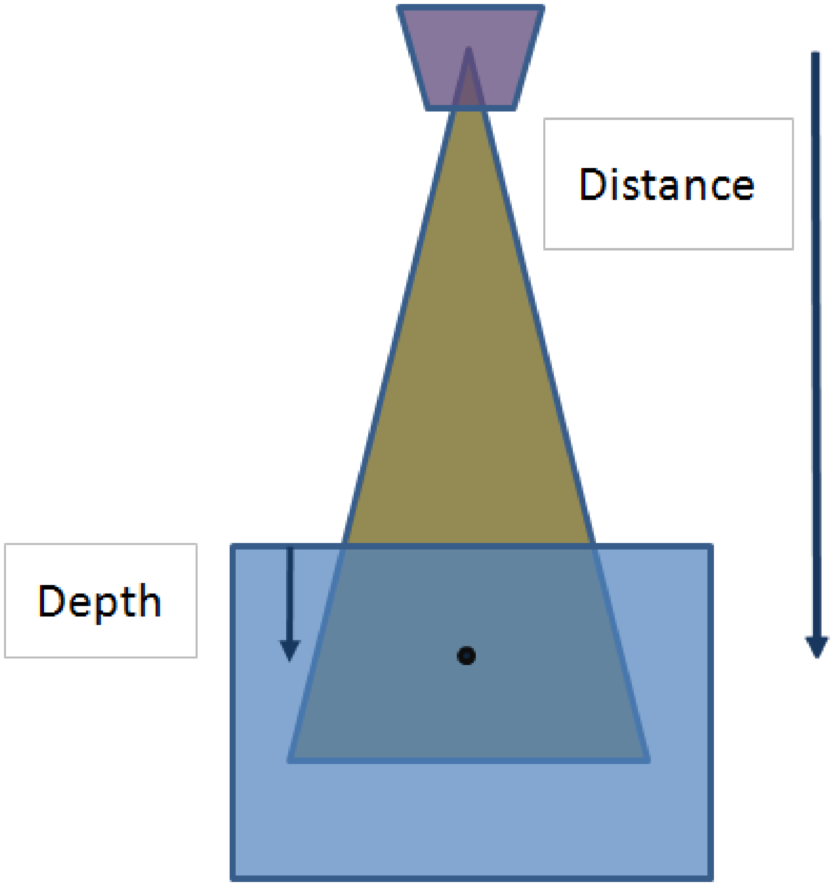
KHAN TABLE 9.2

Rectangular fields are often approximated by square fields having equivalent attenuation and scattering characteristics – the "Equivalent Square". The side, *a*, of the equivalent square of a rectangular field of length *L* and width *W* can be approximated by:

$$a = \left(\frac{2 \times L \times W}{L + W}\right)$$

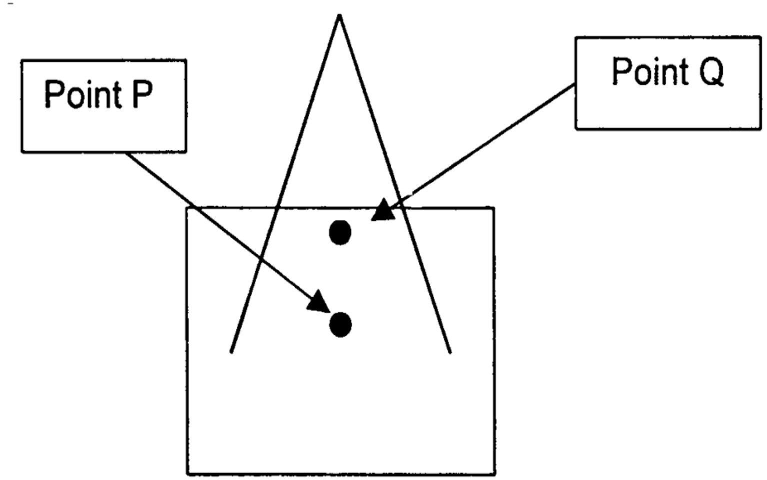
Dose Ratios Concepts: Distance and Depth

- <u>Distance</u>
  - How **far away** from the source
  - Inverse Square
- <u>Depth</u>
  - How **deep** in absorber (water, patient)
  - Attenuation
- Note **Difference** !!
  - Commonly confused



Distance, Depth, and Scatter

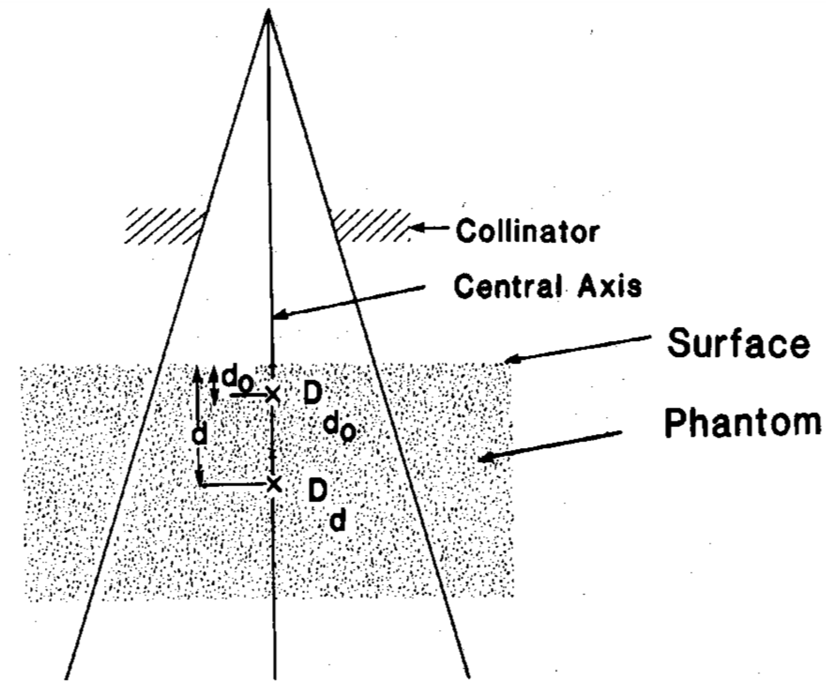
- How does the dose at point P differ from that at point Q?
  - Point P farther away
    - Inverse square
  - Point P deeper
    - Attenuation
  - Field size at Point P larger
    - More scatter



$$\left(\frac{D_P}{D_Q}\right) = \underbrace{\left(\frac{Ks(r_P)}{Ks(r_Q)}\right)}_{\text{Scatter}} \underbrace{\left(\frac{f+d_Q}{f+d_P}\right)^2}_{\text{Distance}} \times \underbrace{\left(e^{-\mu(d_P-d_Q)}\right)}_{\text{Attenuation}}$$

Percent Depth Dose (PDD)

- PDD **Notes**
  - The <u>differences in dose</u> at the two depths, d_0 and d, are due to:
    - Differences in **<u>depth</u>**
    - Differences in **<u>distance</u>**
    - Differences in **<u>field size</u>** at each depth (**scatter**)
  - **<u>Field size is defined at the surface</u>** of the phantom or patient



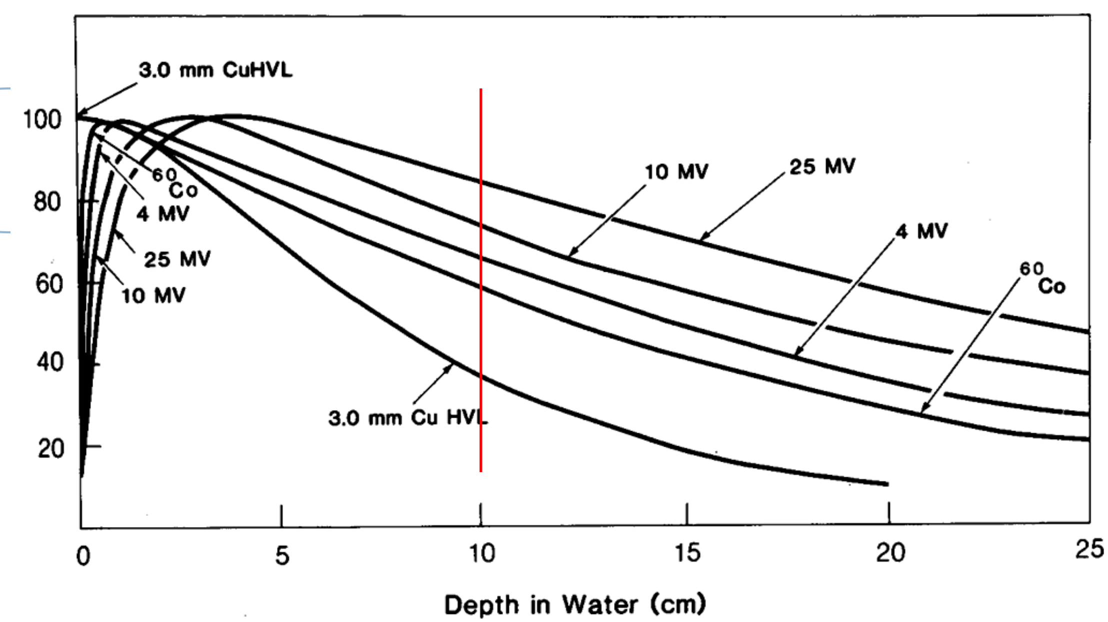
$$PDD = D_d / D_{d0}$$

PDD: Depth and Energy Dependence

- PDD Curves
  - Note change in depth of d_{max}
  - Can characterize beam quality (energy) using PDD at 10-cm depth

Build-up Region

What leads to Build-up Effect?



PDD Build-up Region

- Kerma to dose relationship
  - Kerma and dose represent two different quantities
    - Kerma is energy released
    - Dose is energy absorbed
  - Build-up region produced by forward-scattered electrons that stop at deeper depths
  - Areas under both curves are equal

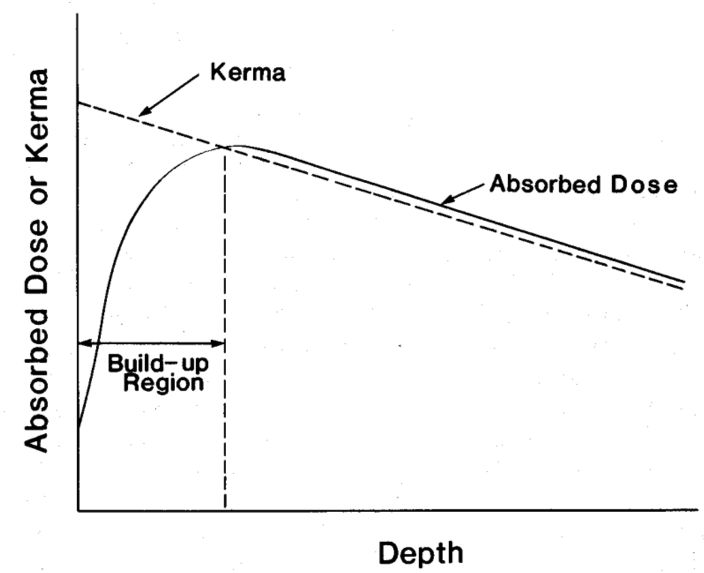


Figure 9.4. Schematic plot of absorbed dose and kerma as functions of depth.

PDD: Distance, Depth, Scatter

- Note that in mathematical description of PDD:
  - Inverse-square (distance) factor
    - Dependence on SSD
  - Attenuation (depth) factor
  - Scatter (field-size) factor

$$P(d,r,f) = 100 \times \left(\frac{f+d_m}{f+d}\right)^2 \times e^{-\mu(d-d_m)} \times K_s$$

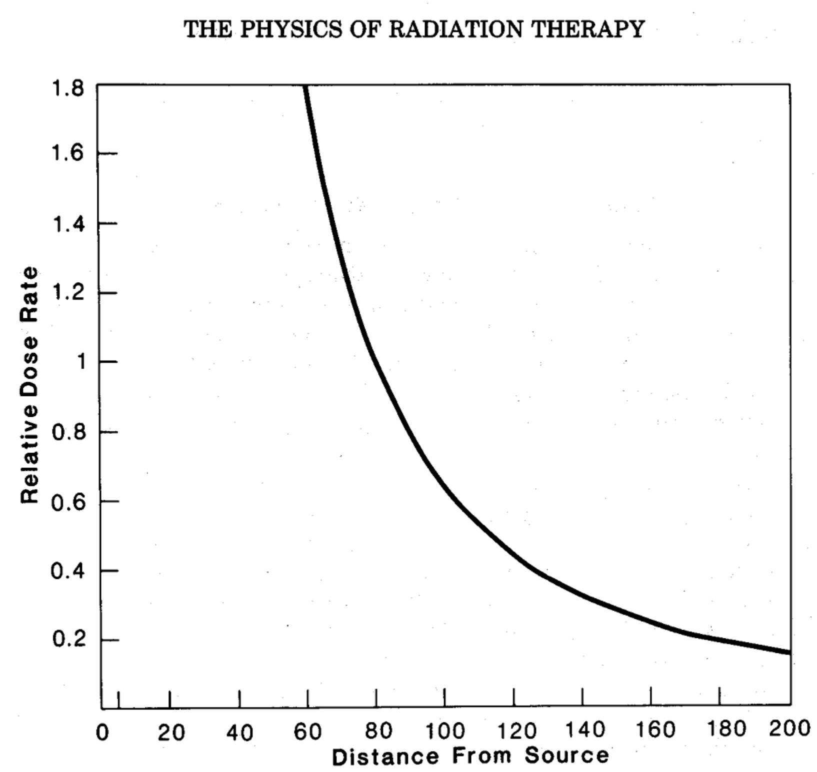
Inverse-Square (Distance) Factor

Exponential Attenuation (Depth) Factor

Scatter Build-up Factor

PDD: Effect of Distance

- Effect of inverse-square term on PDD
  - As distance increases, relative change in dose rate decreases (less steep slope)
    - Less Inverse-Square effect
    - This results in an increase in PDD (since there is less of a dose decrease due to distance), although the actual dose rate decreases



PDD Example

- If the dose in a 10x10 cm^2 field at the depth of d_{max} in water 100 cm SDD is 200 cGy, what is the dose at a depth of 10 cm?

$$PDD = D_d / D_{d0}$$

$$D_d = D_{d0} \times PDD$$

$$D_d = 200 \times 0.668 = 133.6$$

Percent Depth Dose

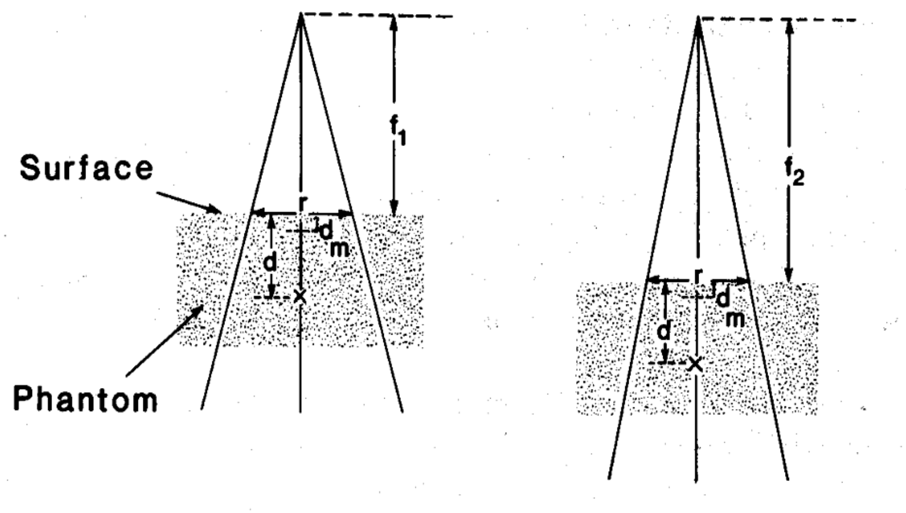
Varian 2100C

6MV PDD **Open Unwedged Field** **100cm SSD**

field size (cm)	4.0	5.0	6.0	8.0	10.0	12.0	15.0	18.0	20.0	22.0	25.0	30.0	35.0	40.0
d-max (cm)	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2
depth (cm)														
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.7	99.7	99.5	99.6	99.6
2.0	98.7	98.8	98.9	98.8	98.9	98.7	98.7	98.6	98.4	98.4	98.3	98.3	98.2	98.1
3.0	94.2	94.4	94.5	94.6	94.8	94.8	94.8	95.0	94.9	94.7	94.8	94.9	94.9	95.0
4.0	89.1	89.8	90.0	90.2	90.7	90.6	90.9	91.1	91.1	91.1	91.2	91.4	91.5	91.6
5.0	84.2	84.7	85.4	85.8	86.4	86.6	87.0	87.3	87.3	87.4	87.6	87.8	88.0	88.2
6.0	79.3	80.1	81.0	81.5	82.1	82.7	83.2	83.6	83.6	83.8	84.0	84.3	84.4	84.7
7.0	74.7	75.7	76.7	77.1	78.1	78.6	79.3	79.9	79.9	80.2	80.5	80.7	81.0	81.3
8.0	70.5	71.5	72.6	73.2	74.2	74.9	75.6	76.2	76.4	76.7	77.1	77.5	77.7	78.2
9.0	66.5	67.5	68.6	69.3	70.4	71.1	72.1	72.8	73.1	73.4	73.7	74.3	74.7	75.0
10.0	62.6	63.6	64.6	65.6	66.8	67.5	68.6	69.4	69.8	70.0	70.4	71.0	71.5	71.8
11.0	59.0	60.0	61.0	61.9	63.2	64.2	65.3	66.2	66.5	66.9	67.3	68.0	68.4	68.8
12.0	55.5	56.4	57.5	58.5	59.9	60.8	62.1	62.9	63.4	63.8	64.3	64.9	65.4	65.8
13.0	52.1	53.1	54.2	55.3	56.6	57.8	59.0	59.9	60.4	60.9	61.3	62.0	62.6	63.0
14.0	49.1	50.1	51.1	52.2	53.6	54.8	56.1	57.0	57.5	58.0	58.5	59.2	59.9	60.3
15.0	46.2	47.1	48.1	49.3	50.7	51.9	53.2	54.2	54.7	55.3	55.8	56.5	57.2	57.7
16.0	43.4	44.4	45.4	46.5	48.0	49.1	50.5	51.5	52.0	52.6	53.2	53.9	54.6	55.1
17.0	40.9	41.8	42.9	43.9	45.4	46.5	48.0	48.9	49.4	50.0	50.7	51.5	52.1	52.6
18.0	38.5	39.4	40.5	41.5	42.9	44.1	45.5	46.5	47.0	47.6	48.3	49.1	49.8	50.3
19.0	36.3	37.2	38.2	39.2	40.6	41.8	43.2	44.2	44.7	45.3	46.0	46.8	47.5	48.0
20.0	34.2	35.1	35.9	37.0	38.4	39.5	41.0	42.0	42.6	43.1	43.8	44.6	45.3	45.8
21.0	32.2	33.1	33.9	35.0	36.3	37.5	38.8	39.9	40.4	41.0	41.7	42.5	43.2	43.8
22.0	30.3	31.2	31.9	33.0	34.4	35.5	36.8	37.9	38.4	39.0	39.7	40.5	41.3	41.8
23.0	28.7	29.4	30.1	31.2	32.5	33.6	34.9	36.0	36.5	37.1	37.8	38.6	39.4	39.9
24.0	27.1	27.8	28.5	29.5	30.8	31.9	33.1	34.2	34.8	35.3	36.0	36.8	37.5	38.1
25.0	25.5	26.2	26.9	27.9	29.1	30.1	31.4	32.5	33.1	33.6	34.2	35.1	35.7	36.3
26.0	24.1	24.7	25.4	26.4	27.5	28.5	29.8	30.8	31.4	32.0	32.5	33.4	34.1	34.6
28.0	21.4	22.1	22.7	23.6	24.7	25.6	26.8	27.8	28.3	28.9	29.5	30.3	30.9	31.4
30.0	19.1	19.7	20.3	21.1	22.1	23.0	24.1	25.1	25.6	26.1	26.7	27.5	28.1	28.6
32.0	17.0	17.6	18.1	18.9	19.9	20.7	21.7	22.6	23.2	23.6	24.2	24.9	25.5	26.1
35.0	14.4	14.9	15.3	16.1	16.9	17.7	18.6	19.5	19.9	20.3	20.9	21.6	22.1	22.5
38.0	12.2	12.6	13.0	13.6	14.4	15.1	15.9	16.7	17.1	17.5	18.0	18.6	19.1	19.6

The Mayneord F Factor (no longer a mystery)

- The inverse-square term within the PDD
  - PDD is a function of distance (<u>SSD</u> + depth)
  - PDDs at given depths and distances (SSD) can be corrected to produce approximate PDDs at the same depth but at other distances by applying the Mayneord F factor
    - "Divide out" the previous inverse-square term (for SSD_1), "multiply in" the new inverse-square term (for SSD_2)



I have a patient set up at 120 cm SSD, but I only have 100 cm SSD PDD tables …

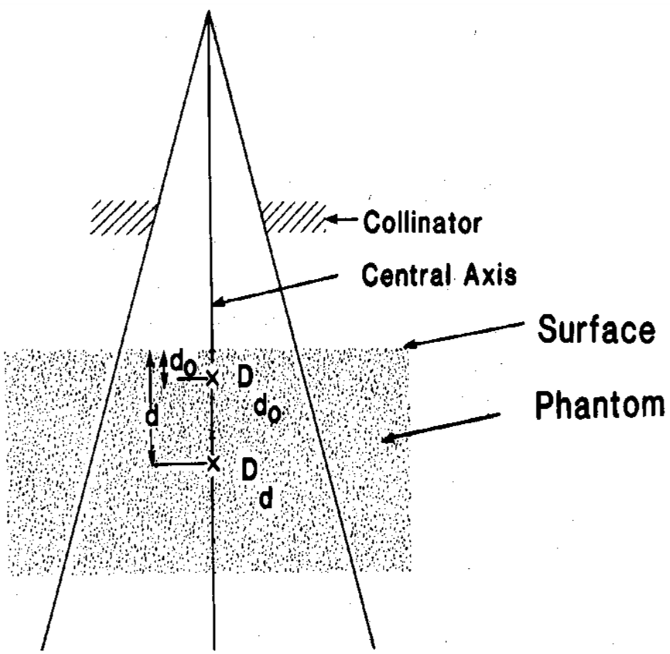
$$F = \left\{ \frac{SSD_2 + d_{\max} / SSD_2 + d}{SSD_1 + d_{\max} / SSD_1 + d} \right\}^2$$

The Mayneord F Factor

- Mayneord F – Example
- Previous Problem
  - 100 SSD, 10x10, depth 10
  - PDD was 0.668
- Now assume 120 SSD …
- Divide out 100 SSD, d_{10} inverse square, and multiply back in 120 SSD, d_{10} inverse square:

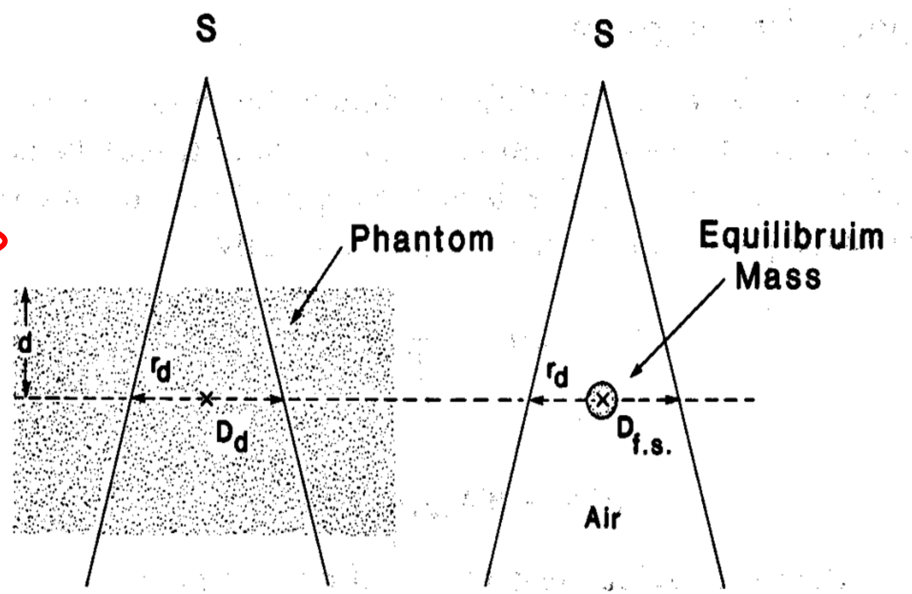
$$\left[\left(121.5 / 130\right)^2 \Big/ \left(101.5 / 110\right)^2 \right] \times 0.668 = 0.685$$

$$F = \left\{ \frac{SSD_2 + d_{max} / SSD_2 + d}{SSD_1 + d_{max} / SSD_1 + d} \right\}^2$$



TAR: A traditional yet useful quantity

- The TAR …
  - Developed for isocentric treatments
  - The ratio of doses at two points:
    - **<u>Equidistant from the source</u>**
    - That have <u>equal field sizes</u> at the points of calculation
    - **<u>Field size is defined at point of calculation</u>**
  - Relates dose at depth to dose "in air" (free space)
    - Concept of "equilibrium mass"
      - Need for electronic equilibrium – constant Kerma-to-dose relationship



$$TAR = D_d / D_{fs}$$

PSF (BSF): An extension of the TAR

- The PSF (or BSF) is a special case of the TAR when dose in air is compared to dose at the depth (d_{max}) of maximum dose
  - At this point the dose is maximum (peak) since the contribution of scatter is not offset by attenuation
- The term BSF applies strictly to situations where the depth of d_{max} occurs at the surface of the phantom or patient (i.e. kV x rays)

BACKSCATTER FACTOR (BSF)

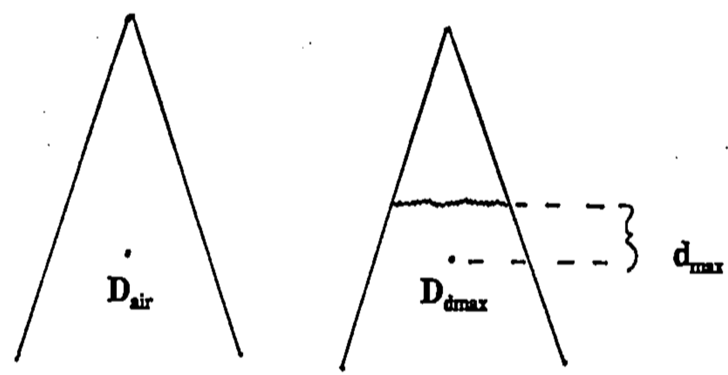
same as

$$\boxed{\textbf{PEAKSCATTER FACTOR (PSF)}}$$

$$TAR_d = D_d/D_{air}$$

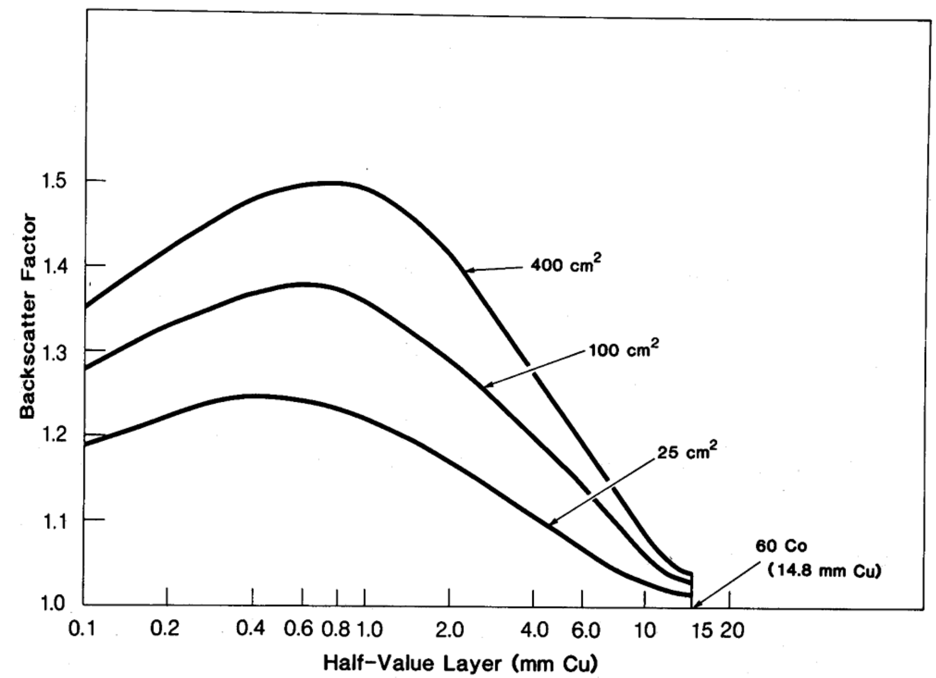
Special case:

$$\boxed{TAR_{dmax} = D_{dmax}/D_{air} = PSF}$$



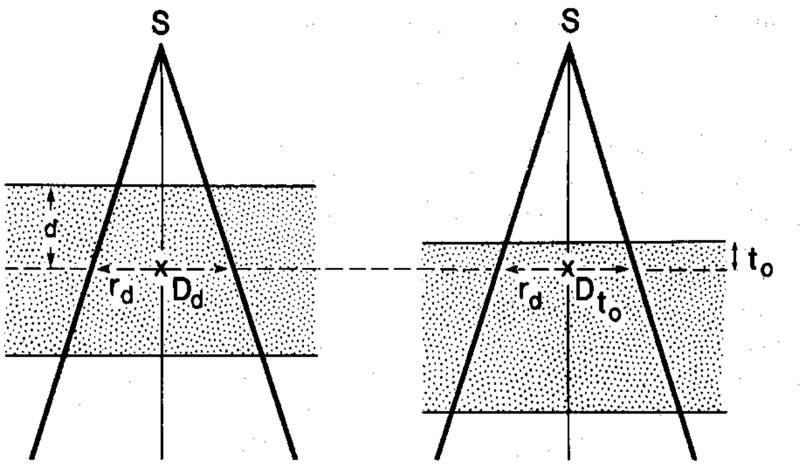
PSF Details: Energy and Field Size

- In general, scatter contribution decreases as energy increases
- Note:
  - Scatter can contribute as much as 50% to the dose a d_{max} in kV beams
  - The effect at ^{60}Co is of the order of a few percent (PSF ^{60}Co 10x10 = 1.035
  - Increase in dose is greatest in smaller fields (note 5x5, 10x10, and 20x20)



TPR and TMR: More current quantities

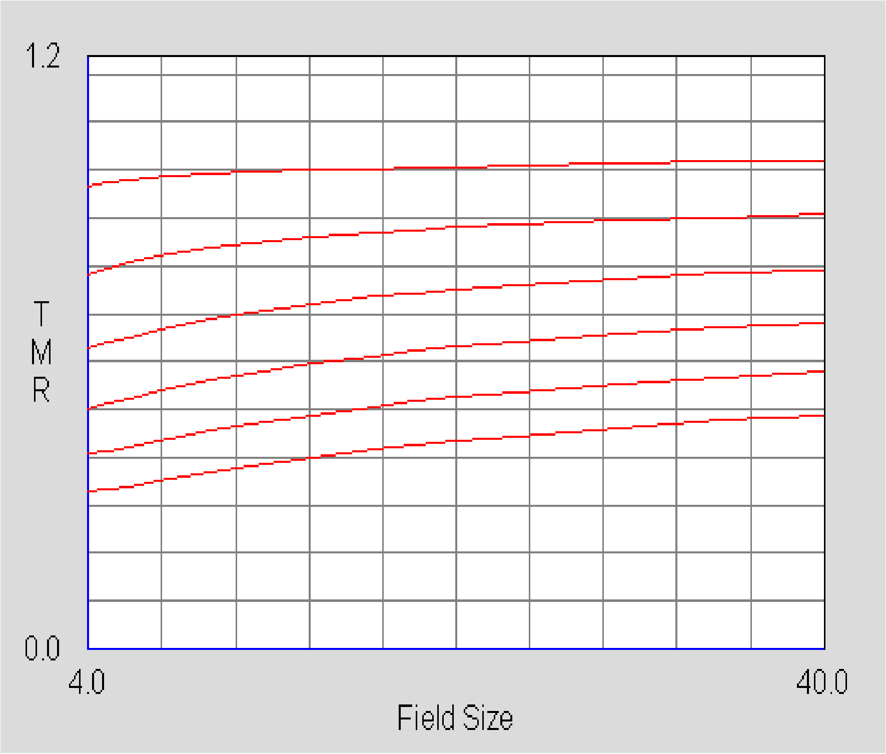
- Similar to the TAR, the TPR is the ratio of doses (D_d and D_{t0}) at two points <u>equidistant from the source</u>
  - Field sizes are equal
  - Again field size is defined at depth of calculation
  - Only attenuation by depth differs
- The TMR is a special case of the TPR when t_0 equals the depth of d_{max}



$$TPR = D_d / D_{t0}$$

TMR (and PDD) vs. Field Size: Scatter contribution vs. field size

- The TMR (or TAR or PDD) for a given depth can be plotted as a function of field size
  - Shown here are TMRs at 1.5, 5.0, 10.0, 15.0, 20.0, 25.0, and 30.0 cm depths as a function of field size
- Note the lesser increase in TMR as a function of field size
  - This implies that differences in scatter are of greater significance in smaller fields than larger fields,



TMR / PDD / TAR Relationships

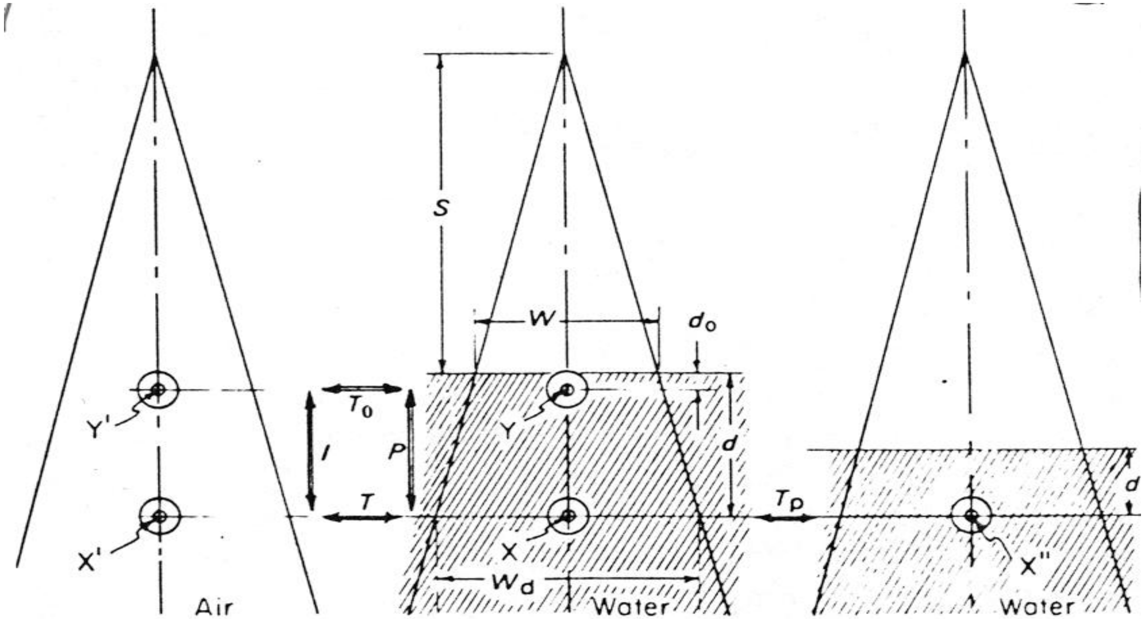
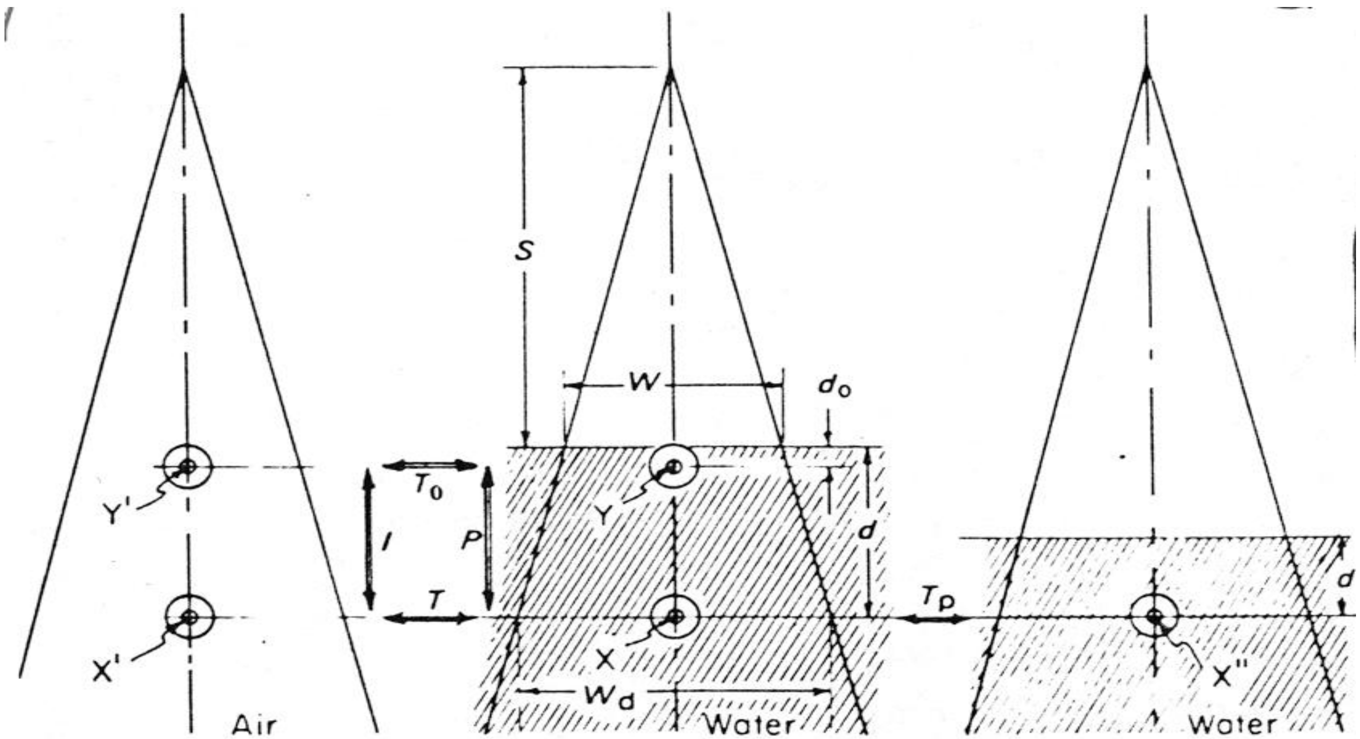


Fig. 2.1 Diagram illustrating relationships between absorbed doses used in forming percentage depth dose, tissue-air ratio and tissue-phantom ratio. All three radiation beams are identical except that the one on the left irradiates air only while the other two irradiate a water phantom. Tissue-air ratio, T, is the absorbed dose at a point such as X divided by that at X′. Percentage depth dose, P, is the absorbed dose at X divided by that at Y, expressed as a percentage. Tissue-phantom ratio, T_P, is the absorbed dose at X divided by that at X″. T_0 is the tissue-air ratio at the depth of the peak absorbed dose and I is the inverse square relationship.

From: ICRU 14

TMR / PDD Relationship

$$PDD = TMR \cdot \left(\frac{SSD + d_{max}}{SSD + d} \right)^2$$



Scatter Factors

- Characterize scatter
- Scatter factors describe field-size dependence of dose at a point
  - Often wise to separate sources of scatter
    - Scatter from the head of the treatment unit
    - Scatter from the phantom or patient
  - Measurements complicated by need for electronic equilibrium

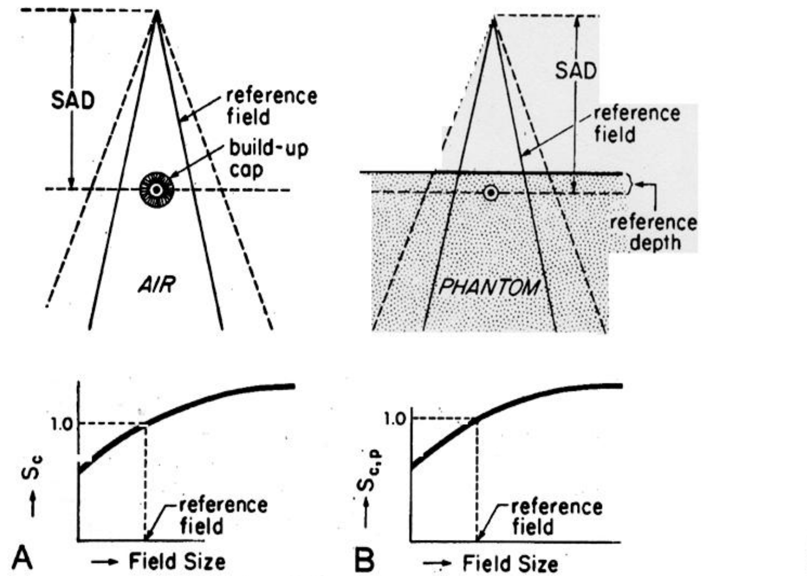


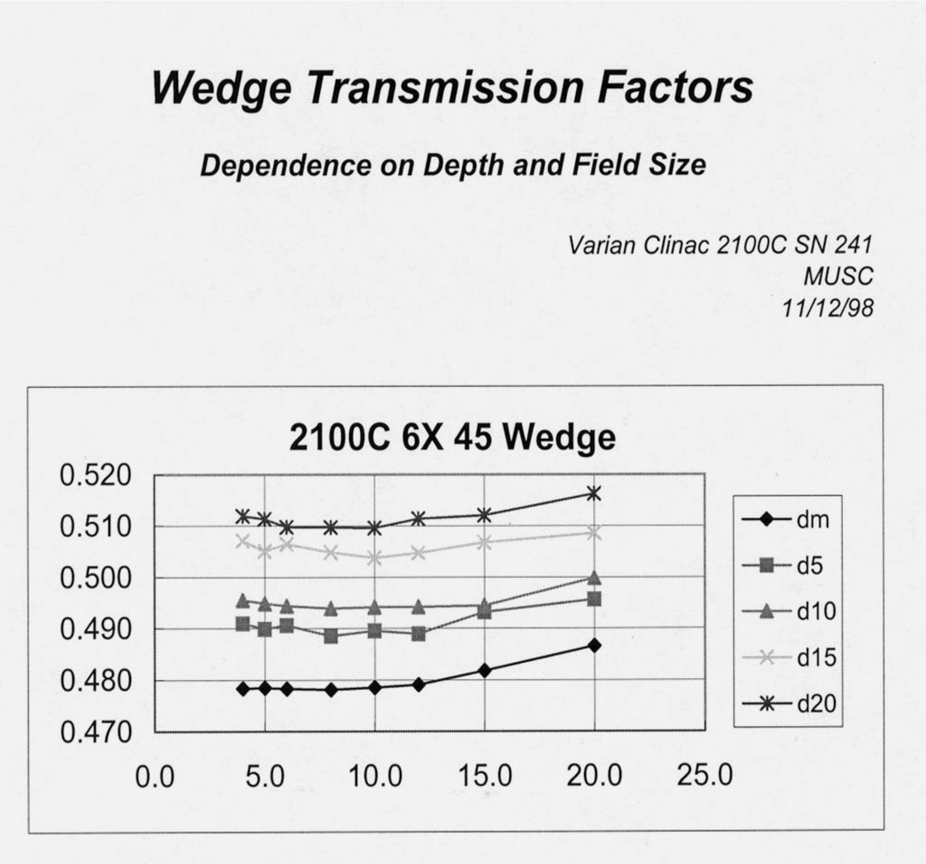
Figure 10.1. Arrangement for measuring S_c and $S_{c,p}$. **A,** Chamber with build-up cap in air to measure output relative to a reference field, for determining S_c versus field size. **B,** Measurements in a phantom at a fixed depth for determining $S_{c,p}$ versus field size. Reprinted with permission from Khan FM, Sewchand W, Lee J, Williamson JF. Revision of tissue-maximum ratio and scatter-maximum ratio concepts for cobalt 60 and higher energy x-ray beams. Med Phys 1980;7:230.

S_c = collimator scatter factor
S_p = phantom scatter factor

Khan

Transmission Factors: Wedges

- Beam intensity is also affected by the introduction of beam attenuators that may be used modify the beam's shape or intensity
  - Such attenuators may be plastic trays used to support field-shaping blocks, or physical wedges used to modify the beam's intensity
- The transmission of radiation through attenuators is often field-size and <u>depth dependent</u>
  - Wedged field PDDs



The Dynamic Wedge

- Wedged dose distributions can be produced without physical attenuators
  - With "dynamic wedges", a wedged dose distribution is produced by sweeping a collimator jaw across the field duration irradiation
  - The position of the jaw as a function of beam irradiation (monitor-unit setting) is given the wedge's "**segmented treatment table** (**STT**)
    - The STT relates jaw position to fraction of total monitor-unit setting

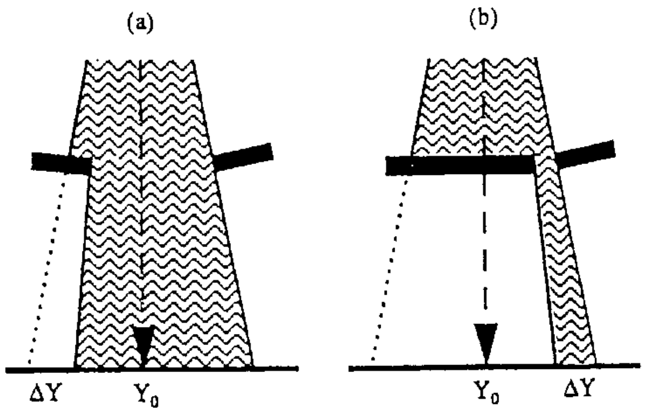
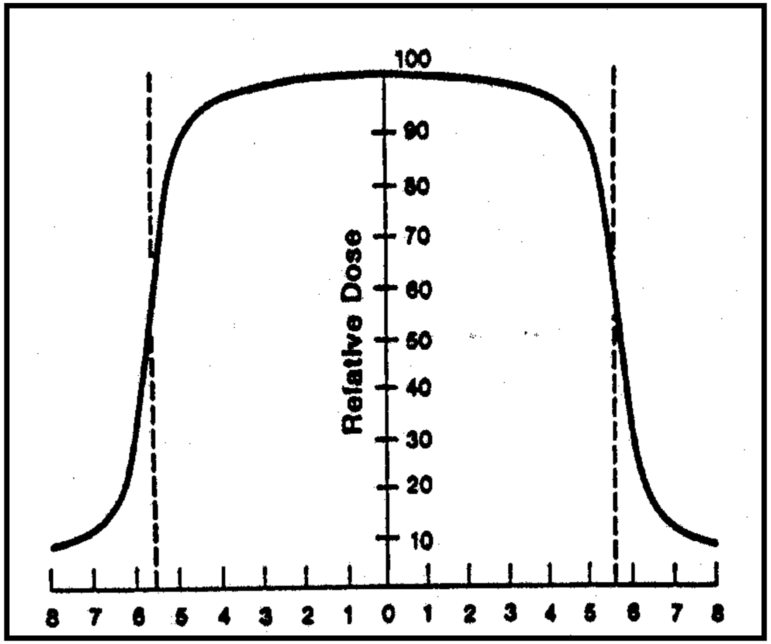


FIG. 2. An illustration of symmetry in a dynamic wedge treatment. Shown are jaw positions for two configurations during the sweep phase corresponding to a displacement of ΔY from the open field positions of (a) the moving jaw and (b) the fixed jaw.

Gibbons

Off-Axis Quantities

- To a large degree, quantities and concepts discussed up to this point have addressed dose along the "central axis" of the beam
- It is necessary to characterize beam intensity "off-axis"
  - Two equivalent quantities are used
    - Off-Axis Factors (OAF)
    - Off-Center Ratios (OCR)
  - These two quantities are equivalent

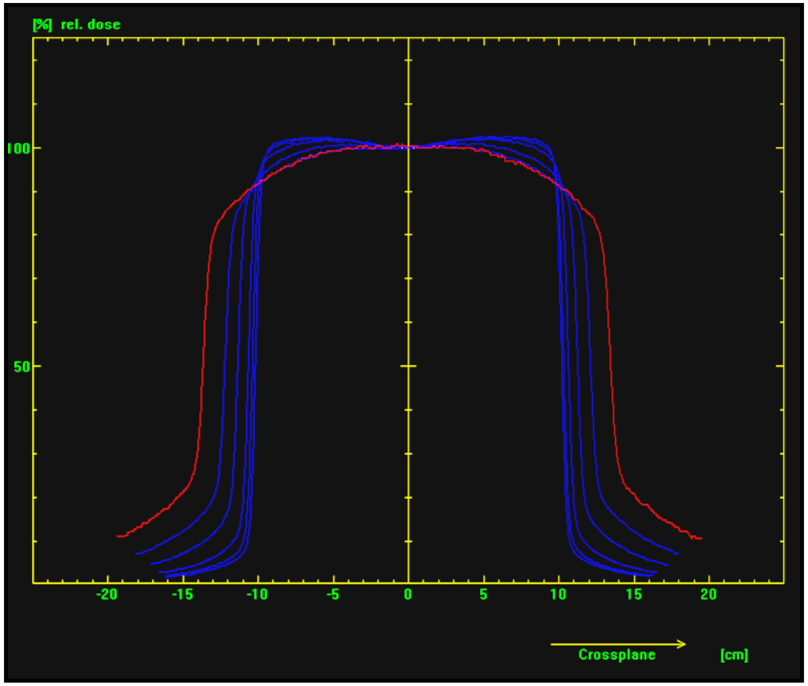


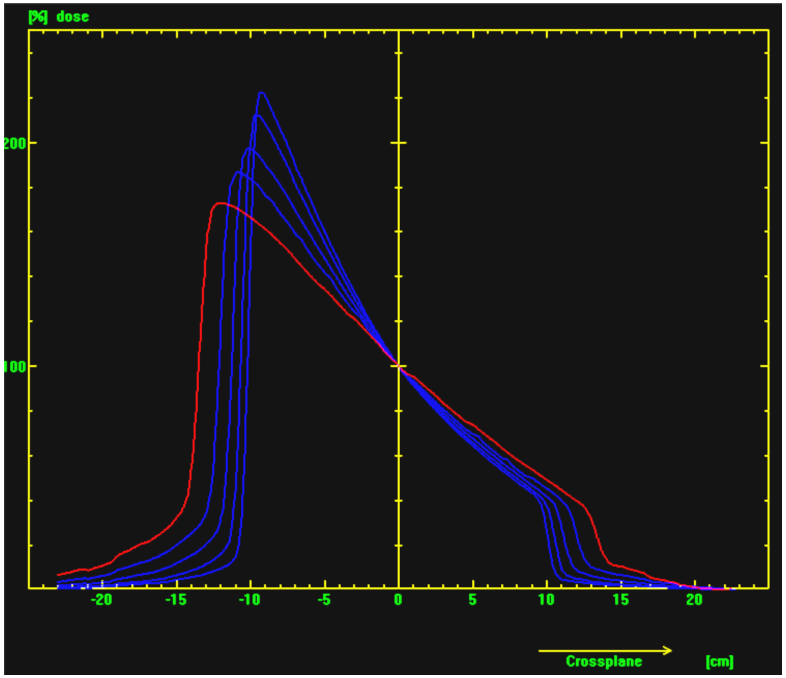
$$OAF(x,d) = D_{d,x} / D_{d,0}$$

where x = distance off-axis

Off-Axis Factors: Measured Profiles

- Off-axis factors are extracted from measured profiles
  - Profiles are smoothed, may be “symmetrized”, and are normalized to the central axis intensity

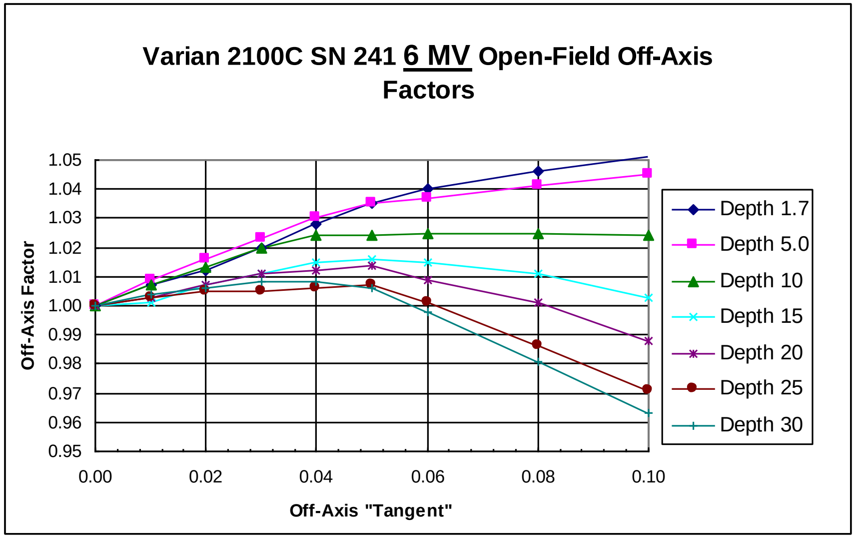




Off-Axis Factors: Typical Representations

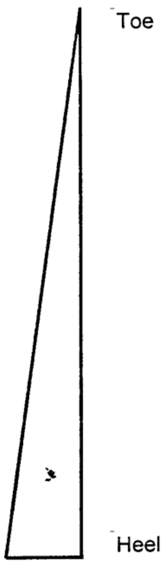
- OAFs (OCRs) are often tabulated and plotted versus depth as a function of distance off axis
  - Where "distance off axis" means radial distance away from the central axis
  - Note that, due to beam divergence, this distance varies with the distance from the source

Depth	Off-Axis "Tangent"								
	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10
	Off Axis Distance (at 100 cm field-size definition distance)								
0	0	1	2	3	4	5	6	8	10
1.7	1.000	1.007	1.012	1.020	1.028	1.035	1.040	1.046	1.051
5	1.000	1.009	1.016	1.023	1.030	1.035	1.037	1.041	1.045
10	1.000	1.007	1.013	1.020	1.024	1.024	1.025	1.025	1.024
15	1.000	1.001	1.007	1.011	1.015	1.016	1.015	1.011	1.003
20	1.000	1.003	1.007	1.011	1.012	1.014	1.009	1.001	0.988
25	1.000	1.003	1.005	1.005	1.006	1.007	1.001	0.986	0.971
30	1.000	1.004	1.006	1.008	1.008	1.006	0.998	0.981	0.963



Off-Axis Wedge Corrections

- Descriptions vary of off-axis intensity in wedged fields
  - Measured profiles contain both open-field off-axis intensity as well as differential wedge transmission
  - We have defined off-axis wedge corrections as corrections to the central axis wedge factor
    - Open-field off-axis intensity is divided out of the profile
    - The corrected profile is normalized to the central axis value



Distance Off-Axis	15 Wedge OAWC	30 Wedge OAWC	45 Wedge OAWC	60 Wedge OAWC
-6.000	1.066	1.200	1.343	1.597
-5.000	1.048	1.159	1.275	1.485
-4.000	1.036	1.124	1.212	1.379
-3.500	1.030	1.108	1.181	1.323
-3.000	1.025	1.092	1.155	1.273
-2.500	1.024	1.076	1.127	1.220
-2.000	1.013	1.059	1.104	1.171
-1.500	1.015	1.042	1.074	1.125
-1.000	1.010	1.027	1.051	1.075
-0.500	1.008	1.018	1.032	1.047
0.000	1.000	1.000	1.000	1.000
0.500	0.997	0.988	0.980	0.958
1.000	0.980	0.976	0.953	0.922
1.500	0.971	0.957	0.924	0.881
2.000	0.960	0.938	0.903	0.847
2.500	0.949	0.924	0.891	0.814
3.000	0.942	0.904	0.875	0.779
3.500	0.935	0.899	0.843	0.750
4.000	0.929	0.884	0.823	0.716
5.000	0.923	0.855	0.785	0.664
6.000	0.906	0.837	0.744	0.607

Off-Axis Distance defined at the isocenter

Dose Ratios: What have we learned

- PDDs and TMRs
  - One has inverse square and the other does not
- Field Size
  - At what distance
  - Equivalent square
- Scatter Factors
  - From accelerator head
  - From phantom (patient)

- Almost halfway there …

What have we learned?

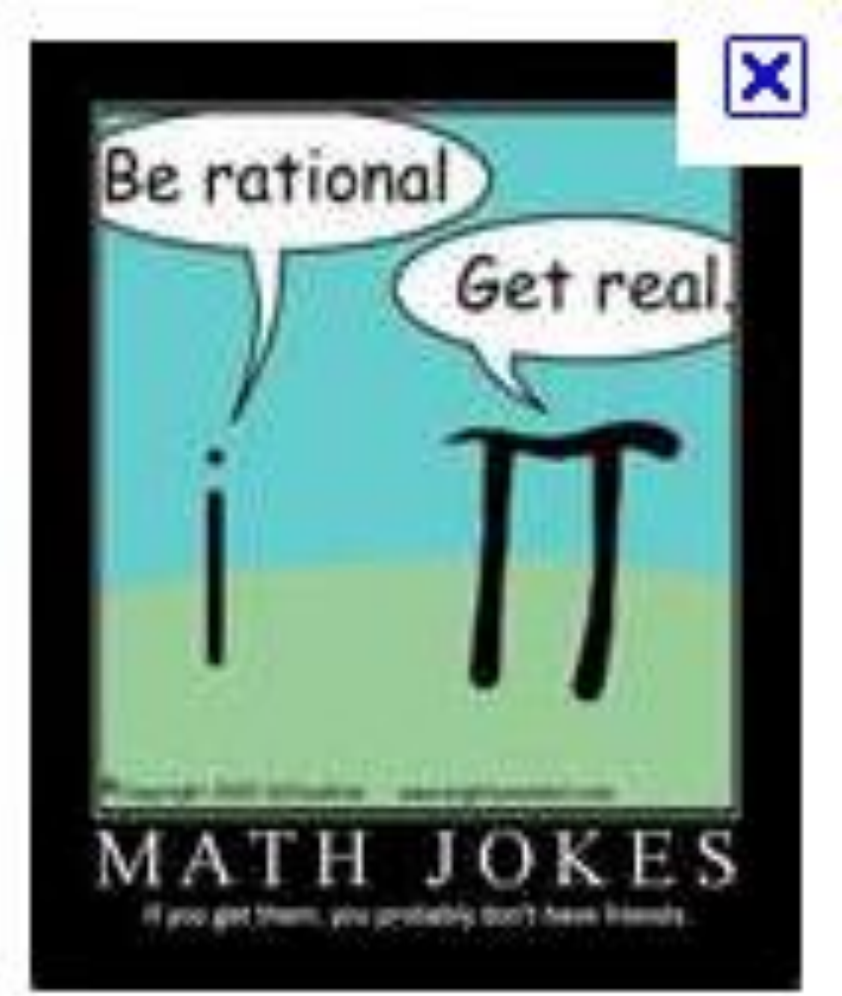
- If my field size is 10x10 at 100 cm, what is it at 120 cm?
  - 12x12

$$FS_{120} = FS_{100} \times \left({}^{120}\!/_{100} \right)$$

- If my dose in air is 100 cGy at a distance of 100 cm, what is the dose at 120 cm?
  - 69.4 cGy

$$D_{120} = D_{100} \times \left({}^{100}\!/_{120} \right)^2$$

Too “Big Bang Theory”?

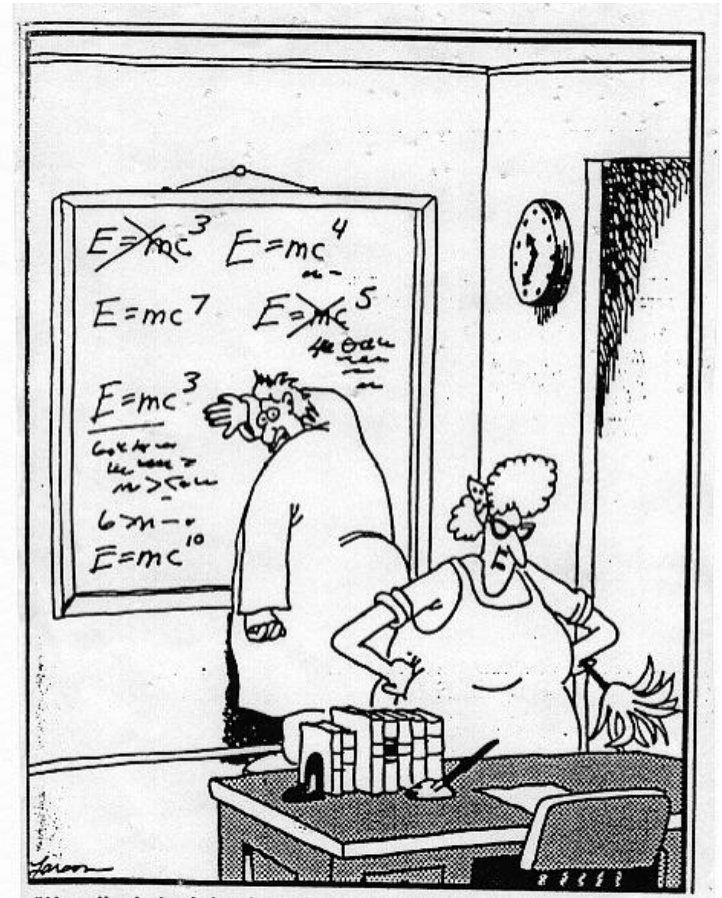


Intermission

- Take a brief break
  - Don't go anywhere!
  - 60 seconds !!
    - Stand up
    - Stretch
    - Maybe talk about PDDs, TMRs and Inverse Square …
- "Dose Calculations" is next

Now MU Calculations

- Using concepts previously discussed, calculate the monitor-unit setting of the accelerator that will deliver the required radiation dose

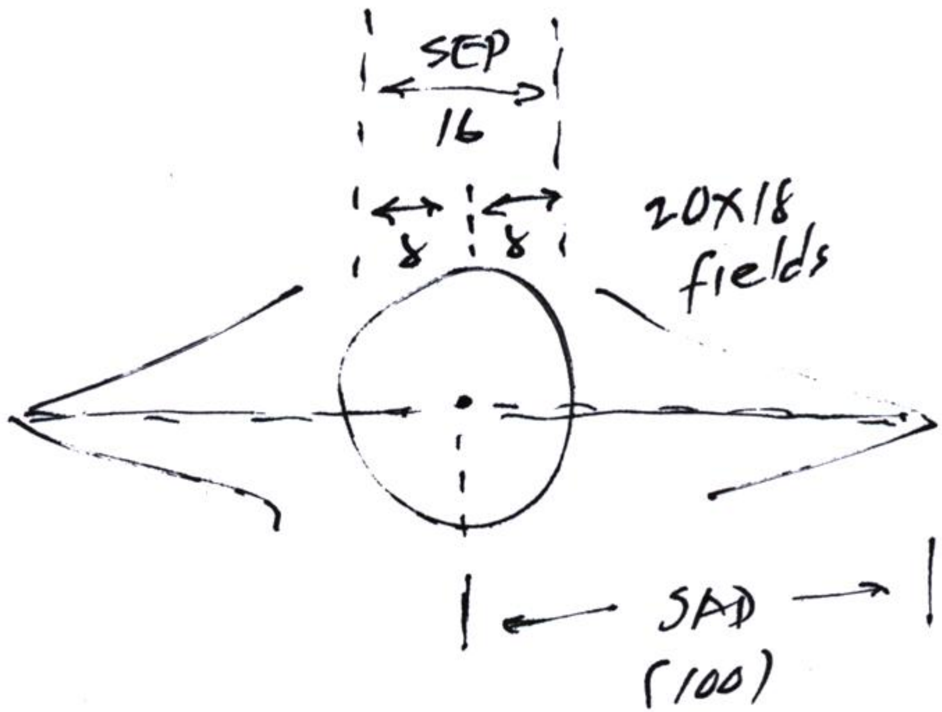


"Now that desk looks better. Everything's squared away, yessir, squaaaaaared away."

Our Sample Problem

- A patient's whole brain is to be treated.
  - The prescribed dose is 30 Gy total dose, **300 cGy per fraction**, 10 fractions, 5 fractions per week. Radiation and technique are **6 MV x rays**, parallel-opposed **right and left lateral fields**; prescribed dose is **to isocenter.**
  - Fields are **20x18**, **mlc**-shaped
  - The patient set up for **isocentric** treatment at mid-brain, lateral **separation 16 cm**

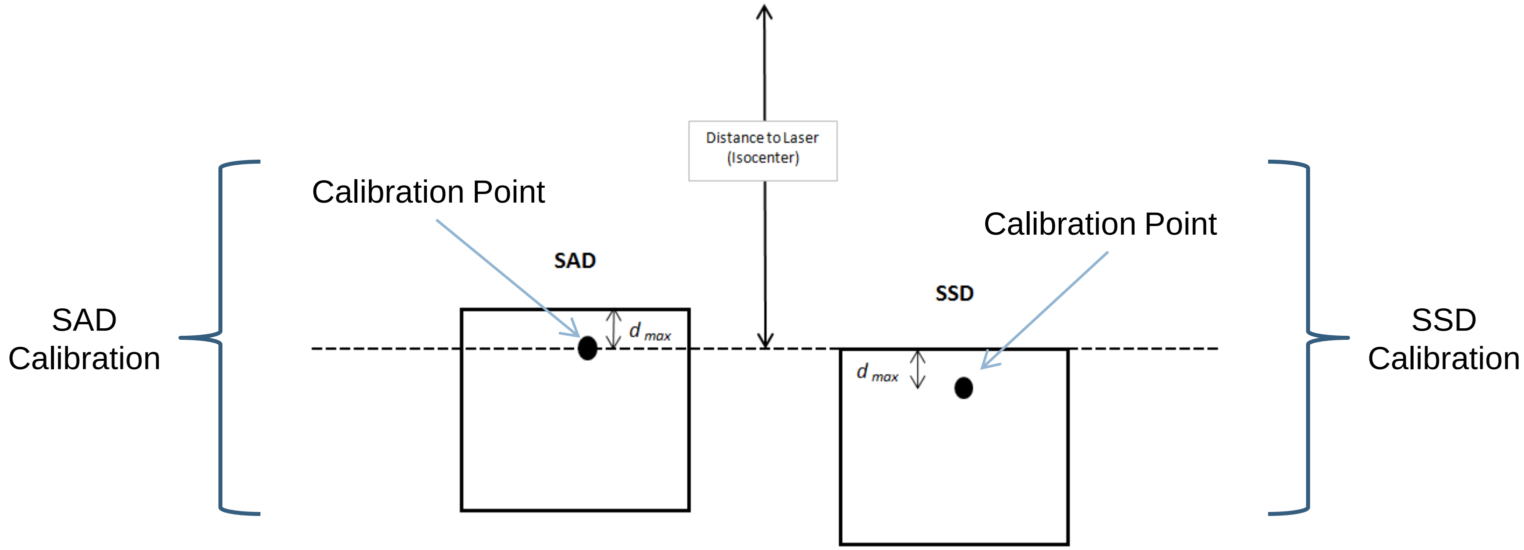
First rule of dose calcs …



make a picture

Output: From Relative Dose Ratios to Absolute Dose

- Standard calibration geometry
  - The geometry used to determine the dose output of the treatment unit
    - Treatment units are calibrated such that their **absolute dose is known at a single point (the calibration point) in a** predetermined **(standard) geometry**
    - Calibration geometries are **SAD Calibration** and **SSD Calibration**



Introduction

- **Standard calibration point and geometry (<u>SAD</u>)**
  - For linear accelerators in the Department of Radiation Oncology, **University of Maryland** School of Medicine, and commonly elsewhere, this point is located at $\boldsymbol{d_{max}}$ in a water phantom, **100 cm SAD**, along the **central axis** of an **open 10x10** field.
  - The unit is calibrated such that **<u>a dose equal to 1.0 cGy</u>** is delivered to this point **<u>per 1 Monitor Unit (MU)</u>** setting

Introduction

- Standard calibration geometry (SSD)
  - Other radiation oncology centers, UT M.D. Anderson Cancer Center for example, use an SSD calibration geometry
  - At these centers, this point is located at d_{max} in a water phantom, 100 cm SSD, along the central axis of an open standard field, most commonly the 10x10 field.
  - At this point (note – farther from the source), the unit is calibrated such that 1 monitor unit (MU) is equal to 1.0 cGy

Introduction

- Corrections to standard geometry
  - At **depths** other than d_{max}, **distances** other than the standard SAD or SSD, and for **field sizes** other 10x10, and points off of the **central axis**, corrections become necessary
    - Depth corrections are **PPDs or TMRs**,
    - Distance corrections are **Inverse-Square corrections**, and
    - Field-size corrections are **Scatter Factors.**
    - Corrections for points away from the central axis of the beam are **Off-Axis Factors**
    - Corrections are also necessary to account for transmission through beam attenuators such as wedges
    - These corrections are given in tabulated beam data where relationships to the standard geometry have been established

Corrections to standard geometry: Summary

- **Depth** corrections
- **Field-size** corrections
- **Distance** corrections
- **Off-axis** corrections
- **Attenuation** corrections

- PDD, TAR, TMR
- Output (scatter factors)
  - S_T S_P S_C
- Inv. Sq.
  - "SAD" or "SSD" Factors
- OAFs
- WFs, TFs, etc.

Formalism

- In general, the dose (*D*) at any point in a water phantom can be calculated using the following formalism:

$$D = MU \times O \times OF \times ISq \times DDF \times OAF \times TF$$

- where:
  - *MU* = monitor-unit setting
  - O = calibrated output (cGy/MU)
  - *OF* = output (scatter) factor(s): S_C, and S_P, or S_T
  - *ISq* = inverse-square correction of output (as needed)
  - *DDF* = depth-dose factors (PDD, TMR, or TAR)
  - *OAF* = off-axis factors
  - *TF* = transmission factors

SAD Beams / SAD Calibration

- When the treatment unit is calibrated in a "SAD" geometry, then for "SAD" (isocentric) beams, the formalism becomes:

$$D = MU \times S_C \times S_P \times TMR \times OAF \times TF$$

- where it is assumed that **output (scatter) factors are given by S_C and S_P,** and where it is also assumed that the **calibrated output = *1.0 cGy/MU* at the SAD.**
- Note that no inverse-square term is needed since the distance to the point of <u>dose normalization</u> is equal to the distance to the point of <u>dose calibration</u> (i.e. **both the point of dose normalization and the point at which output is defined are the same**).

SSD Beams / SAD Calibration

- When the treatment unit is calibrated in a "SAD" geometry, then for "SSD" beam calculations, the formalism becomes:

$$D = MU \times S_C \times S_P \times PDD \times ISq \times OAF \times TF$$

  - where **the inverse-square factor accounts for the change in output produced by the differences in the distances between the <u>s</u>ource and the point of <u>c</u>alibration (*SCD*) and between the <u>s</u>ource and the <u>p</u>oint of normalization (*SPD*)**

$$ISq = \left({SCD}/{SPD} \right)^2$$

Formalism Notes: Inverse Square

- The **inverse-square term** of the **SSD Beams / SAD Calibration** equation accounts for the decreased output that exists at the increased SSD + d_{max} distance relative to the output that exists at isocenter (where the machine output is *1 cGy/MU*).
  - Since the point of dose normalization (SSD + d_{max}) is further away from the source than is the point of dose definition (isocenter), the inverse square term is a factor < 1.0
  - For SAD = 100 cm treatment units, and 6 MV x rays, this inverse-square term is:

$$ISq = F_{SAD \rightarrow SSD} = \left(SCD \big/ SPD \right)^2 = \left(100 \big/ 100 + 1.5 \right)^2 = 0.971$$

  - Note **<u>that this inverse square term corrects the treatment-unit's dose output</u>**

SSD Beams / SSD Calibration

- When the treatment unit is calibrated in a "SSD" geometry, then for "SSD" beams, the formalism becomes:

$$D = MU \times S_C \times S_P \times PDD \times OAF \times TF$$

  - Again, note that no inverse-square term is needed since the distance to the point of <u>dose normalization</u> ($SSD + d_{max}$) is equal to the distance to the point of <u>dose calibration.</u>

SAD Beams / SSD Calibration

- When the treatment unit is calibrated in a "SSD" geometry, then for "SAD" (isocentric) beams, the formalism becomes:

$$D = MU \times S_C \times S_P \times ISq \times TMR \times OAF \times TF$$

  - where again the inverse-square factor accounts for the change in output produced by the differences in the distances between the **s**ource and the point of **c**alibration (*SCD*) and between the **s**ource and the **p**oint of normalization (*SPD*):

$$ISq = \left({}^{SCD}\!/_{SPD} \right)^2$$

  - The inverse-square correction in this case is a factor > 1.0, since isocenter is closer to the source than is 100 SSD + dmax.

Formalism Notes: Field Sizes

- Field sizes, unless otherwise stated, represent collimator settings
  - For most accelerators, field sizes are defined at 100 cm (the distance from the source to isocenter)
    - For **SSD beams, field sizes are defined at the surface** (normally 100 cm SSD)
    - For **SAD beams, field sizes are defined at** the **depth** of dose calculation (normally 100 cm SAD)
  - For field sizes at distances other than 100 cm, field sizes must be computed using triangulation:

$$FS_{SSD,\,d} = FS_{100} \times \left({SSD + d}\big/{100} \right)$$

Formalism Notes: Field Size Details

- Scatter Factors, PDDs, TMRs
  - S_C is a function of the collimator setting
  - S_P is a function of the size of the field:
    - at the phantom surface for SSD beams
    - at the depth of calculation for SAD beams
  - PDDs are a function of:
    - field size at the phantom surface (SSD beams}
  - TMRs are a function of:
    - field size at depth (SAD beams)

Formalism Notes: Prescribed Dose

- In general, one wishes to compute the MU setting necessary to deliver a certain dose to a defined point.
  - This dose is "**prescribed**", and
  - Its value must be known **at the point** of calculation.
- When fields are combined to produce a prescribed dose at a point, the doses from each field are computed from the relative weights of each field.
  - Thus, if a dose D_{Rx} is prescribed through multiple fields *i* each having a relative weight wt_i, then the dose D_i from each field is:

$$D_i = D_{Rx} \times \left(wt_i \Big/ \sum_i wt \right)$$

Formalism: Summary

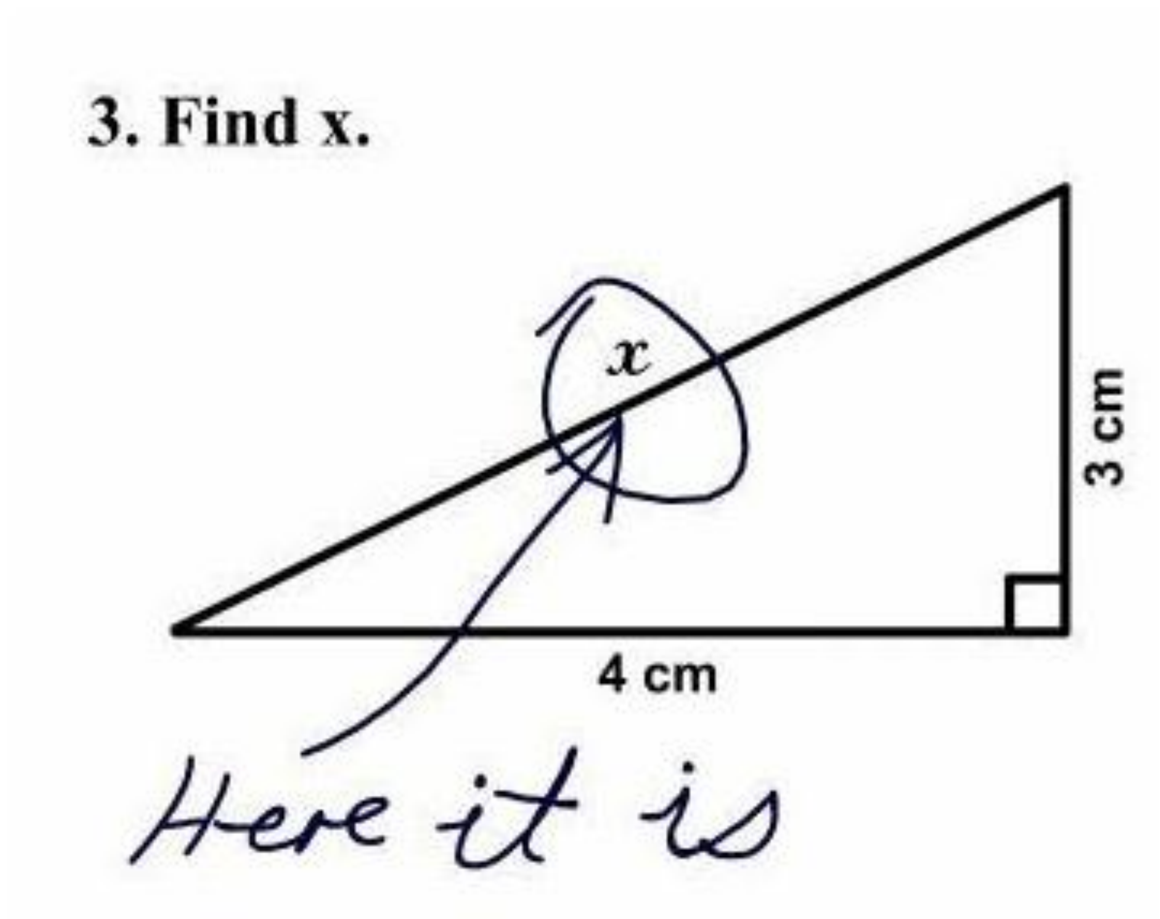
- For **SAD beams and SAD calibration:**

$$MU_i = \frac{D_i}{S_C \times S_P \times TMR \times OAF \times TF}$$

- For **SSD beams and SAD calibration:**

$$MU_i = \frac{D_i}{S_C \times S_P \times ISq \times PDD \times OAF \times TF}$$

Problems



Back to our Sample Problem …

- A patient's whole brain is to be treated.
  - The prescribed dose is 30 Gy total dose, **300 cGy per fraction**, 10 fractions, 5 fractions per week. Radiation and technique are **6 MV x rays**, parallel-opposed **right and left lateral fields**; prescribed dose is **to isocenter.**
  - Fields are **20x18**, **mlc**-shaped
  - The patient set up for **isocentric** treatment at mid-brain, lateral **separation 16 cm**

Sample Problem

- First compute equivalent squares of the fields:

$$EqSq = \left(\frac{2LW}{L+W}\right) = \left(\frac{2\times 20\times 18}{20+18}\right) = 19.0$$

- Then look up Output Factors and TMRs
  - FS = 19 cm^2 Depth = 8 cm
- Substitute in:

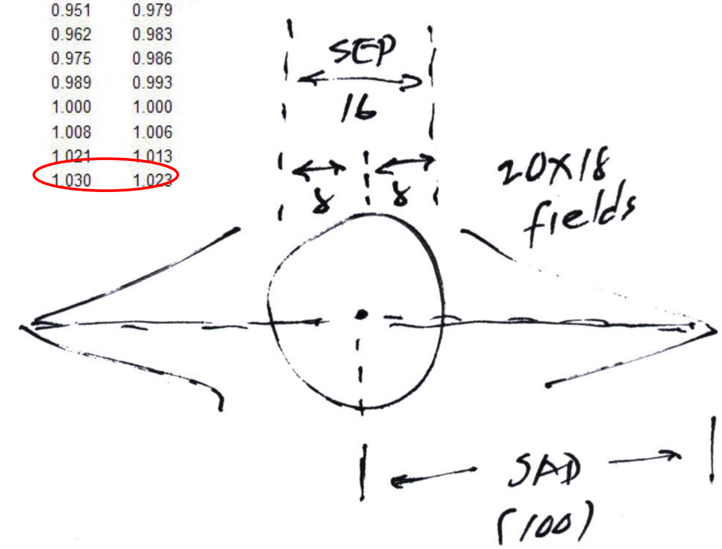
$$MU = \underbrace{\frac{Dose}{S_C \times S_P \times TMR \times OAF \times TF}}_{\text{Assumes SAD Calibration}}$$

- And you're done!

6MV TMR **Open Unwedged Field**

field size (cm)	4.0	5.0	6.0	8.0	10.0	12.0	15.0	18.0	20.0
d-max (cm)	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3
depth (cm)									
1.5	1.000	1.000	1.000	1.000	1.000	1.001	1.001	1.001	1.001
2.0	0.996	0.998	0.999	0.999	0.999	0.999	0.998	0.998	0.997
3.0	0.968	0.971	0.972	0.974	0.976	0.977	0.978	0.979	0.979
4.0	0.934	0.939	0.943	0.948	0.951	0.953	0.955	0.957	0.958
5.0	0.897	0.905	0.910	0.918	0.923	0.926	0.930	0.933	0.935
6.0	0.860	0.870	0.878	0.888	0.895	0.900	0.906	0.910	0.912
7.0	0.825	0.836	0.844	0.857	0.865	0.872	0.879	0.885	0.888
8.0	0.791	0.804	0.813	0.827	0.837	0.844	0.853	0.859	0.863

Field Size	S_c	S_p
4	0.951	0.979
5	0.962	0.983
6	0.975	0.986
8	0.989	0.993
10	1.000	1.000
12	1.008	1.006
15	1.021	1.013
20	1.030	1.023



Dose Ratios and MU Calculations

Thank You!