Preparing for the ABR Part 2 Therapy Board Exam - Handout

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Disclaimer: The following is an overview of physics constants, equations, & concepts that might be helpful in preparing for the Part 2 exam that are *not* provided by the ABR on exam day. Visit http://www.theabr.org/ic-rp-calc for the list of constants provided on exam day. The accuracy of the information in this handout is not guaranteed nor is it intended for clinical use. Use at your own risk.

1. General

1.1. Important Constants

1 amu	1.66×10^{-27} kg = 931 MeV
1 Ci	3.7×10^{-10} Bq = activity of 1g ^{226}Ra
R-to-rad *in air*	0.876 rad/R = 0.876 cGy/R

1 U (air kerma strength)	cGy-cm^2/h = μGy-m^2/h
1 R	2.58×10^{-4} C/kg
1 mg Ra eq	8.25×10^{-4} R/h

1.2. Isotopes – γ Emitters

Isotope	Γ_x (R-cm^2/mCi-h)	Avg. γ E (keV)	HVL in Pb (mm)
^{226}Ra	8.25 (R-cm^2/mg-h)	0.83 MeV	14
^{192}Ir	4.69	0.38 MeV	2.5
^{137}Cs	3.26	0.66 MeV	5.5
^{60}Co	13.07	1.25 MeV	11
^{125}I	1.46	28 keV	0.025
^{103}Pd	1.48	21 keV	0.01
^{198}Au	2.38	0.41 MeV	2.5

1.3. Isotopes – β Emitters

- ^{90}Sr (0.546 MeV, 28.8 y) → ^{90}Y (2.28 MeV, 64 hr) → ^{90}Zr
- ^{89}Sr (1.46 MeV, 50 d) → ^{89}Y
- Electron range in air: 4 m for 2 MeV

2. Radiation Protection

2.1. Dose Equivalent & Effective Dose Equivalent

$$H_E = \sum_T w_T H_T = \sum_T w_T H_T \sum_R w_R D_T$$	w_T = weighting factor for tissue, T (unitless) H_T = **dose equivalent** delivered to tissue T (Sv) w_R = relative weighting factor for radiation R (Sv/Gy) D_T = **absorbed dose** delivered to tissue T from radiation R (Gy) H_E = **effective dose equivalent** (Sv)

2.2. Permissible Doses

Exposure Limits			
Occupational	50 mSv/y	**Public**	
Lens	150 mSv/y	Frequent	1 mSv/y
Extremities	500 mSv/y	Infrequent	5 mSv/y
Cumulative	Age (y) x 10 mSv/y	Lens, other	50 mSv/y
Fetal	5 mSv *total*		
	0.5 mSv/mo		

Transporting Radioactive Isotopes			
	White I	Yellow II	Yellow III
Max surface (mrem/h)	0.5	50	200
Transport index	0	1.0	10

Cancer Induction Probability
5% per Sv (ICRP 60)

2.3. Shielding

Primary: $P = \frac{WUT}{d^2} B_p$	**Secondary**$_{\text{Scatter}}$: $P = \frac{\propto WT}{d_{sec}^2 d_{sca}^2} \frac{F}{400} B_s$	**Secondary**$_{\text{Leakage}}$: $P = \frac{0.001WT}{d_l^2} B_l$
P = permissible dose W = workload (500-1000Gy/Wk)	T = occupancy factor Work areas = 1 Corridors, Offices = ¼- ½ Waiting Rooms, Bathrooms = 1/16 – 1/8	U = use factor Floor = 1 Wall = ¼, Ceiling = ¼- ½
α = scatter-to-primary ratio off the scatterer at 1m		F = field size at scatterer

Rule of thumb: If secondary & leakage barriers differ by at least 3 HVLs, the thicker of the 2 is enough. Otherwise, add 1 HVL to the thicker of the 2.

Skyshine

Photons: $D = 0.249x10^6 \frac{B_{xs} D_{io} \Omega^{1.3}}{d_i^2 d_s^2}$	**Neutrons:** $H = 0.84x10^{-5} \frac{B_{ns} \Phi_0 \Omega}{d_i^2}$

D = dose equivalent rate at ground level (nSv/s); D_{io} = x-ray dose rate at 1m from target (cGy/s)
Ω = solid angle of radiation beam (steradians); B_{XS}=roof shielding transmission ratio
D_i = distance (m) from xray target to 2m above roof; d_s = distance (m) from iso to pt. where dose equiv rate is D
H = nSv/s due to neutrons at ground level; B_{ns}=roof shielding transmission ratio for neutrons
Φ_0 = neutron fluence rate ($cm^{-2}s^{-1}$) at 1m from the target

Typical TVLs (cm)

Energy (MV)	120kVp (CT)	6	10	15	18	20
Concrete	*6.6*	*35*	*40*	*44*	*45*	*46*
Lead	*0.09*	*5.5*	*5.6*	*5.7*	*5.7*	*5.7*

2.4. Scatter & Secondary Particles

- Max energy of 90^o Compton scattered photon = 0.511MeV
- Photoneutron production energy threshold for photons = 10MeV

2.5. Radioactive Seed Disposal

- Seeds can be discarded after 10 half-lives

3. Monitor Unit Calculations

3.1. General Equations

SAD Setup (TPR/TMR/TAR):	*SSD Setup (PDD):*
$MU = \dfrac{D}{S_c(r_c)S_p(r_d)TMR(r_d,d)OF\left(\dfrac{SAD+d_{max}}{SSD+d}\right)^2}$	$MU = \dfrac{D}{S_c(r_c)S_p(r_{d_{max}})PDD(r,d)OF\left(\dfrac{SAD+d_{max}}{SSD+d}\right)^2}$
r = field size at surface r_d = field size at calc point r_c = coll. setting at SAD d = depth of calc point d_{max} = depth of max dose OF = other factors – wedge, tray, off-axis	

3.2. PDD to TAR/TMR Equations

$TAR(r_d,d) = \dfrac{PDD(r,d)}{100}\left(\dfrac{SSD+d_{max}}{SSD+d}\right)^2 BSF(r)$	$TMR(r_d,d) = \dfrac{PDD(r,d)}{100}\left(\dfrac{SSD+d_{max}}{SSD+d}\right)^2 \dfrac{S_p(r_{d_{max}})}{S_p(r_d)}$

3.3. PDDs at SSD_1 to PDDs at SSD_2

$$PDD_{SSD_2} = PDD_{SSD_1}\left(\frac{SSD_2+d_{max}}{SSD_2+d}\right)^2\left(\frac{SSD_1+d}{SSD_1+d_{max}}\right)^2$$

3.4. SAR Equations

$SAR(d,r_d) = TAR(d,r_d) - TAR(d,0)$	SAR isolates scatter component from TAR values
$\overline{TAR} = TAR(d,0) + \overline{SAR}$	Irregular fields: $\overline{TAR}$ is obtained & used for MU calcs

3.5. Penumbra, Gap, & Collimator Rotation Equations

$P_d = \dfrac{s(SSD+d-SCD)}{SCD}$	$gap = \dfrac{d}{2}\left(\dfrac{L_1}{SSD_1}+\dfrac{L_2}{SSD_2}\right)$	$\tan\theta_{coll} = \dfrac{L/2}{SSD}$
d = prescription depth SCD = source collimator distance $L_{1,2}$ = size of field 1 or 2 s = source focal spot size (≈3mm for linac) Θ_{coll} = collimator angle for CSI field		

3.6. Beam Characteristics – Photons & Electrons

Note: approximate values for 10x10; values vary between linacs

	d_{max}	%DD (0cm)	%DD (10cm)	TPR (10cm)
6 MV	1.5	49	67	0.84
10 MV	2.8	33	74	0.88
15 MV	2.9	30	77	0.89
18 MV	3.5	17	79	1
6 MeV	1.5	72	**Electron Beam Properties:**	
9 MeV	2.3	78	d_{90} (cm) ≈ E(MeV)/4 d_{80} (cm) ≈ E/3	
12 MeV	2.9	82	range ≈ E/2	
16 MeV	3.6	89	$\bar{E}_z = \bar{E}(1-d/R_p)$ $\overline{E_0} = 2.4R_{50}$	
20 MeV	2.1	91	Pb shield thickness: 0.5mm/MeV; Cerrobend 20% thicker	

3.7. Heterogeneity Corrections

$$CF = \frac{TAR(d_1 + \rho_2 d_2 + d_3)}{TAR(d_1 + d_2 + d_3)}$$	CF corrects the dose calculation for heterogeneities. The MU will be increased by a factor of 1/CF.

3.8. Wedges

3.8.1. Hinge Angle

$$\theta_{wedge} = \varphi_{hinge}/2$$	θ_{wedge} = wedge angle φ_{hinge} = hinge angle = angle between central axes of wedge fields

3.8.2. Universal Wedge Angle

$$\tan\theta_{simulated} = B * \tan\theta_{universal}$$	B = weight of wedged field = D_{wedge}/D_{tot} D_{wedge} = dose from universal wedged field D_{tot} = total dose prescribed

3.9. Timer Error

$$M_1 = n\dot{M}(t_{short} + \Delta t) = \dot{M}(t_{tot} + n\Delta t)$$	$$M_2 = \dot{M}(t_{tot} + \Delta t)$$	$$\Delta t = \frac{t_{tot}(M_2 - M_1)}{M_1 - nM_2}$$

$\dot{M}$= charge collection rate   n = number of short measurements (≥10)

t_{short} = short measurement time Δt = timer error t_{tot} = nt_{short} = total measurement time

M_1 = total charge collected over n short measurements

M_2 = total charge collected over 1 measurement session of length t_{tot}

3.10. Patient Thickness vs. Dose Uniformity

Energy	Max:Midline Dose 30cm Thickness
^{60}Co	1.4
4MV	1.25
10MV	1.15
24MV	1.05

See Khan 3rd ed. p. 211-2

Dose ratios start at 1.0 for 10cm thickness

Dose ratios increase approximately as thickness squared

3.11. Compensators, Bolus, & Spoilers

- Compensators – account for missing tissue while maintaining buildup region
- Spoilers – increase angular spread of phase space of electrons; degrade electron beam energy
- Bolus – shift PDD buildup region toward skin surface

$$t_c = TD\frac{\tau}{\rho_c}$$	t_c = **photon** compensator thickness TD = tissue deficit (cm) τ = thickness ratio, function of distance between compensator & absorber ρ_c = density of compensator material

4. Dosimetry

4.1. TG-51

Overview: The TG-51 protocol yields absorbed dose in water in Gy at the point of measurement in absence of the ion chamber. Must be performed in a water phantom of at least 30 x 30 x 30cm.[3]		
Photon Beams: energies between ^{60}Co and 50MeV		
$D_w^Q = M k_Q N_{D,w}^{60_{Co}}$	$M = M_{raw} P_{ion} P_{pol} P_{elec} P_{TP}$	$P_{ion} = \frac{1 - V_H/V_L}{M_{raw}^H/M_{raw}^L - V_H/V_L}$
$P_{pol} = \frac{\lvert M_{raw}^- - M_{raw}^+ \rvert}{M_{raw}^{+/-}}$	$P_{TP} = \frac{273.2 + T}{273.2 + 22.0} \frac{760}{P}$	
D_w^Q = dose to water for beam of quality Q determined by %dd(10)$_x$ M_{raw}= uncorrected chamber reading k_Q = quality conversion factor Correction factors: P_{ion} = recombination P_{pol} = polarity P_{elec} =electrometer P_{TP} = temperature-pressure		
Electron Beams: energies between 4 and 50MeV		
$D_w^Q = M k_{ecal} k'_{R_{50}} P_{gr}^Q N_{D,w}^{60_{Co}}$	$d_{ref} = 0.6R_{50} - 0.1cm$	
$P_{gr}^Q = \frac{M_{raw}(d_{ref} + 0.5r_{cav})}{M_{raw}(d_{ref})}$	$R_{50} = \begin{cases} 1.029I_{50} - 0.06 & 2 \le I_{50} \le 10cm \\ 1.059I_{50} - 0.37 & I_{50} > 10cm \end{cases}$	
k_{ecal} = photon-electron quality conversion factor (chamber dependent) $k'_{R_{50}}$ = electron quality conversion factor (chamber and beam energy dependent) P_{gr}^Q = electron gradient correction factor d_{ref} = reference depth r_{cav} = cylindrical ion chamber radius R_{50} = depth of 50% dose with respect to maximum I_{50} = depth of 50% ionization with respect to maximum after upstream shift of 0.5r_{cav}		

4.2. Cross-Calibration of Parallel Plate Chamber for Electron Dosimetry

- Determine depth of d_{ref} (cm)
- Measure charge collected with cylindrical & parallel plate chambers with measurement point at d_{ref}
- Calculate $(k_{ecal} N_{D,w}^{60_{Co}}) = (M k_{ecal} k'_{R_{50}} P_{gr}^Q N_{D,w}^{60_{Co}})^{cyl} / (M k'_{R_{50}})^{pp}$

4.3. Measuring Electron PDD Curves

- Measure ionization curve
- Shift curve upstream if necessary
- Correct for inverse square
- Determine average electron energy with depth
- Scale curve by stopping power ratios at each depth

5. Radiation Biology

5.1. Biological Effective Dose

$BED = Nd\left(1 + \frac{d}{\alpha/\beta}\right)$	N = number of fractions d = dose per fraction α/β = linear quadratic factors; 3 for typical tumors, 10 for normal tissue

6. Film

6.1. Optical Density

$OD = log_{10}\left(\frac{I_0}{I}\right)$	OD = optical density I_0 = incident light intensity I = transmitted light intensity

7. Brachytherapy

7.1. TG-43 Dose Calculation Formalism

$D = S_k \wedge \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$	S_k = air-kerma strength (U) $\wedge$ = dose-rate constant at (r_0, θ_0) (cGy/U) $G(r,\theta)$ = geometry factor (-) g (r) = radial dose function (-) $F(r,\theta)$ = anisotropy function (-) r = radius from center of mass of source (cm) θ = angle between source axis & calculation point (°) r_0 = 1cm θ_0 = 90°
$G(r,\theta) = \begin{cases} 1/r^2 & \text{point source approximation} \\ \beta/Lr\sin\theta & \text{line source approximation} \end{cases}$	β = angle subtended by source (radians) L = length of source
$g(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G(r_0,\theta_0)}{G(r,\theta_0)}$	$F(r,\theta) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G(r,\theta_0)}{G(r,\theta_0)}$

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