Fall 2021 Medical Physics Qualifying Exam
for Advancement to Candidacy
Part 1
September 1, 2021
9:00-11:15 PDT

If you are in the PhD in astronomy or PhD in physics programs, stop! This is the Medical Physics version of the exam. Please download the version appropriate for your program instead.

Do not write your name on your exam papers. Instead, write your student number on each page. This will allow us to grade the exams anonymously. We'll match your name with your student number after we finish grading.

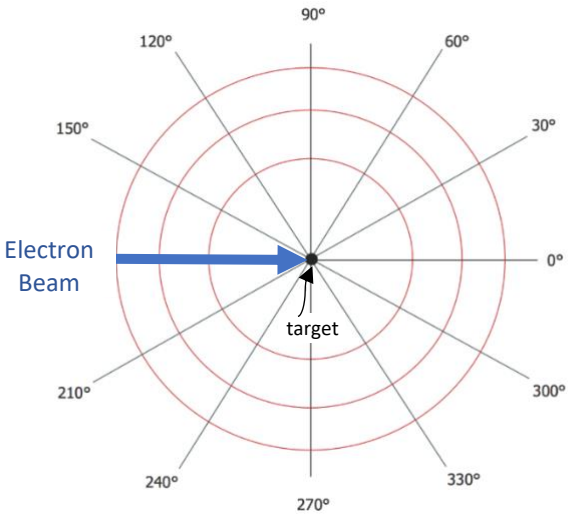
This portion of the exam has 4 questions. Answer any three of the four. Do not submit answers to more than 3 questions—if you do, only the first 3 of the questions you attempt will be graded. If you attempt a question and then decide you don't want to it count, clearly cross it out and write "don't grade".

You have 2.25 hours to complete 3 questions.
You are allowed to use one $8.5'' \times 11''$ formula sheet (both sides), and a handheld, non-graphing calculator.

Question 1

(40 marks) Newer medical linear accelerators are now offering a "flattening filter free" (FFF) mode

a. Using this blank polar graph, draw the fluence profile of the bremsstrahlung photons emitted from a tungsten target after being struck by both a 100 keV and a 10 MeV electron pencil beam (4 marks).



b. Explain the purpose of a "flattening filter" (FF) and describe its construction (composition, shape, location in linac) (3 marks).

c. Why were flattening filters traditionally important for radiotherapy planning? (3 marks)

d. In the new era of intensity modulated radiation therapy (IMRT), discuss why flattened beams might be less relevant. (4 marks)

e. In addition to modifying the beam profile describe two other ways the presence of the flattening filter affects beam properties. (6 marks)

f. Draw a standard "flattening filter" absorbed dose profile for a 10MV beam, 20 x 20cm^2 field at dmax. Normalize the graph to 1.0 at central axis. Now remove the flattening filter and draw the resulting dose profile relative to the flattened beam. (6 marks)

g. Based on your drawings in (f) would you expect the planning monitor units to go up or down for FFF beams for a large (20 x 20cm^2) lung IMRT treatment? Why? (4 marks)

h. Draw a graph approximating the central axis energy spectra for a 10 MV FF and 10 MV FFF beam. (6 marks)

i. How would the different energy spectra affect the measured percentage depth dose curve in water? Use a diagram. (4 marks)

Question 2

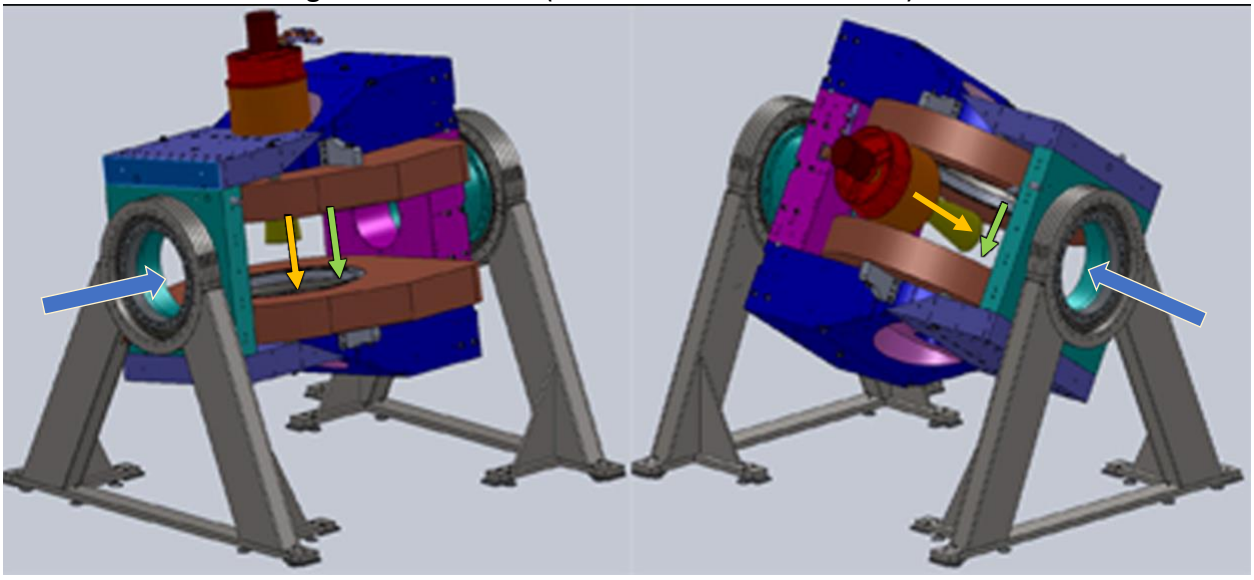
(40 marks) You are hired by a Magnetic Resonance Linear Accelerator (MR Linac) start-up company to help with the design. For this company the initial designs are shown in the figure below. Your first task is to determine if either of these designs is advantageous in terms of minimizing skin dose from electron contamination due to electrons originating in the head of the linear accelerator. In MR Linac configuration 1.) the B_o magnetic field direction is parallel to the velocity direction of the contaminant electrons. In MR Linac configuration 2.) the B_o magnetic field is perpendicular to the velocity of the contaminant electrons.

Data required for the question

Contaminant electron initial velocity direction	→
B_o Field Direction	→
Patient head/foot direction	→
Bo Field Strength	0.5 T
~Kinetic energy of contaminant electron	1.2 MeV
Rest mass energy of electron	0.511 MeV
C	3×10^8 m/s
Charge of an electron	1.602×10^{-19} C
Mass of electron	9.11×10^{-31} Kg

Assumptions for the questions below

- The magnetic field is contained between the two magnets
- Between the two magnets is a vacuum (no electron air interactions)



1.) 2.)

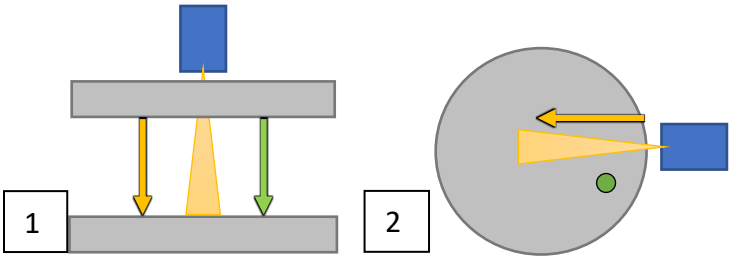
Question 2

a) Name 2 advantages & 2 disadvantages of an MR linear accelerator (linac) vs a traditional linac cone beam CT combination (8 Marks)

b) Knowing the energy of the contaminant electron, what is its velocity? (8 Marks)

c) Give an expression that describes the force of interaction of an electron with the magnetic field and give the radius of contaminant electrons. (8 Marks)

d) Two configurations for the direction of electron beam with respect to the field direction are given. In configuration 1, the beam is predominantly parallel to the field; in configuration 2, the beam is at a right angle to the magnetic field (which is drawn as coming out of the page). The magnetic field has no fringe field and is solely contained between the magnets (shown in grey). Sketch the path of contaminant electrons for each scenario. (8 Marks)



e) Assuming you are only concerned with the reduction of skin dose from contaminant electrons, decide whether one of the two configurations under part d) is favoured. State additional (geometric) restrictions to realize advantages from one of the two scenarios. (i.e how far should the patient be from the exit window of the linac head.) (8 Marks)

Question 3

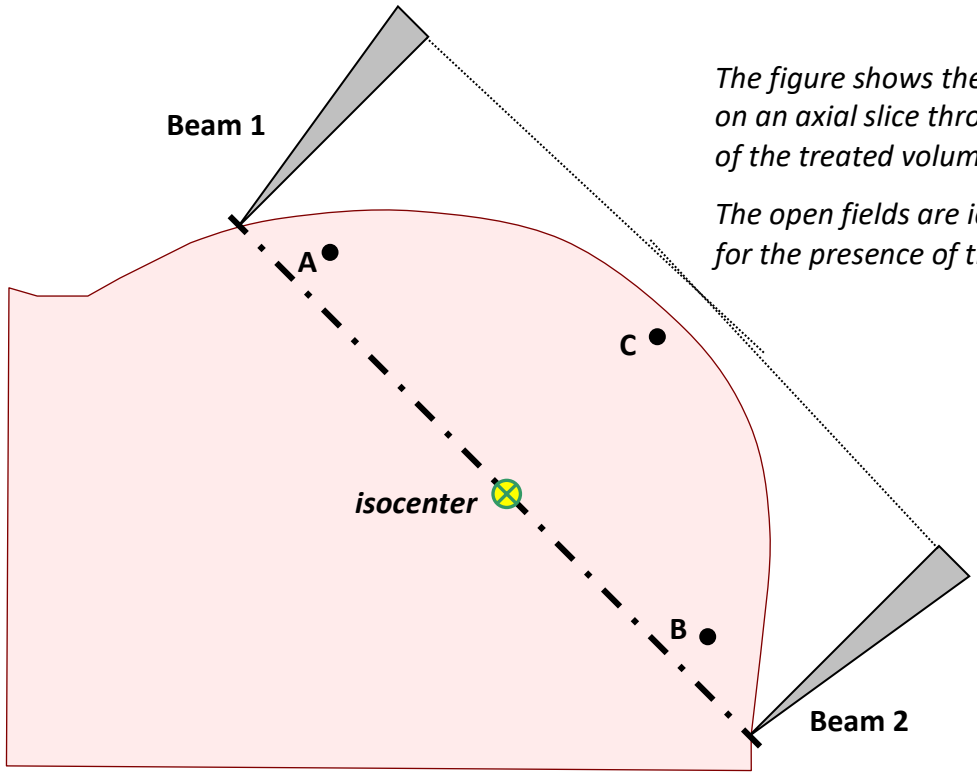
(40 marks)

a) (12 marks) The left breast of a cancer patient is treated with half-beam blocked tangential fields from a linac equipped with a motorized, "universal" 60° wedge. A partial wedging technique is used - i.e. each of Beams 1 and 2 has both open field Monitor Units (MU) and wedged field MU. Given the information in the table below, calculate the open and wedged MU for each beam if:

- dose to point A = dose to point B = dose to point C = 210 cGy

- the dimensions of both beams are the same and the beams are equally weighted, such that the open field MU are the same for Beams 1 and 2, and the wedged field MU are the same for Beams 1 and 2.

Dose per MU delivered by each beam to the points of interest:				
Point	**Beam 1**		**Beam 2**	
	open	**wedged**	**open**	**wedged**
A	1.194 cGy/MU	0.279 cGy/MU	0.481 cGy/MU	0.113 cGy/MU
B	0.481 cGy/MU	0.113 cGy/MU	1.194 cGy/MU	0.279 cGy/MU
C	0.983 cGy/MU	0.172 cGy/MU	0.983 cGy/MU	0.172 cGy/MU



The figure shows the wedged fields on an axial slice through the center of the treated volume.

The open fields are identical except for the presence of the wedge.

b) (8 marks)

(i) For the treatment of part (a), the entire irradiated volume of the breast constitutes the PTV. Indicate on the diagram approximately where the ICRU reference point for this treatment would be.

(ii) What is the purpose of the ICRU reference point, and why is it a meaningful parameter for dose reporting in 3D conformal radiation therapy?

(iii) Would you expect the dose at the ICRU point to be:

☐ greater than ☐ less than or ☐ the same as

the dose to points A,B, and C? Give an explanation for your answer.

(iv) Name two normal organs of concern that might receive significant radiation dose from the treatment described in part (a).

c) (18 marks) The internal mammary lymph node chain (*IMC*) of this breast cancer patient is to be treated with a combination of 6 MV x-rays and 12 MeV electrons, to a total dose of 200 cGy/fraction at Point **Q** in the figure below.

The **electron field** delivers 70% of the dose to point **Q**, and enters at an oblique angle in order to achieve a geometric match with the posterior border of the adjacent breast tangent fields, as shown in the figure below. The set-up SSD is 110 cm at the central beam axis.

The **x-ray field** delivers 30% of the dose to point **Q** at a gantry angle of 0° (i.e. it is not matched to the posterior border of the breast tangent fields). It is asymmetrically collimated, as shown in the figure. The set-up SSD is 100 cm at the central beam axis.

The 15 cm field dimension is perpendicular to the plane of the figure for both fields.

Neither field has customized field shaping.

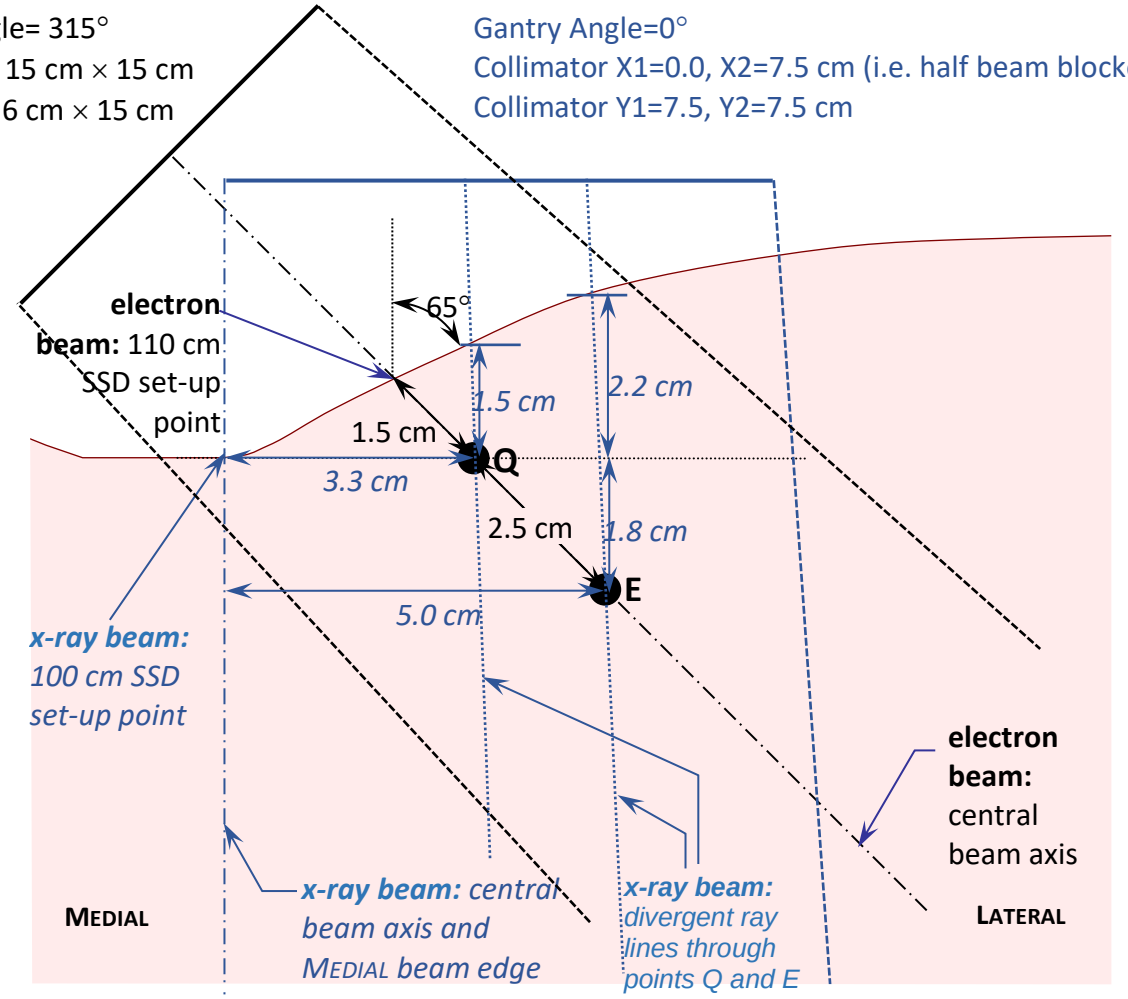
The effective source distance for the electron beam is 92 cm.

Given these conditions, use the beam data provided to determine the dose to point **E**.

Question 3

12 MeV electron beam
110 cm SSD
Gantry Angle= 315°
Applicator: 15 cm × 15 cm
Insert size: 6 cm × 15 cm

6 MV x-ray beam
100 cm SSD
Gantry Angle=0°
Collimator X1=0.0, X2=7.5 cm (i.e. half beam blocked)
Collimator Y1=7.5, Y2=7.5 cm



d) (2 marks) Provide an explanation for why the electron beam is treated at an extended SSD (110 cm), while the x-ray beam is treated at a standard SSD of 100 cm.

Question 3

Beam Data

All distances are measured in cm.

6 MV x-rays

6 MV x-ray data are normalized at d_m = 1.5 cm in phantom

Phantom Scatter Factor, S_p (r_d) (r_d = side of equivalent square field at depth d_m)

r_d	4	6	8	10	15	20	25	30	35	40
S_p	0.979	0.987	0.994	1.000	1.013	1.023	1.029	1.033	1.037	1.040

Percent Depth Dose, PDD(*d*, *r*, SSD) at SSD = 100 cm *(r = side of equivalent square field at surface)*

r	4	6	8	10	15	20	25	30	35	40
d										
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	98.5	98.7	98.8	98.8	98.7	98.6	98.6	98.7	98.7	98.7
3	94.3	94.7	95.0	95.1	95.2	95.3	95.3	95.4	95.4	95.5
4	89.6	90.2	90.7	91.0	91.4	91.5	91.7	91.9	92.0	92.1
5	84.6	85.7	86.4	86.9	87.5	87.9	88.2	88.5	88.7	88.8
6	79.9	81.2	82.1	82.8	83.7	84.2	84.6	85.0	85.3	85.5
7	75.4	76.8	78.0	78.8	79.9	80.7	81.2	81.6	81.9	82.2
8	71.0	72.7	74.0	74.9	76.3	77.1	77.7	78.2	78.6	78.9
9	66.9	68.7	70.1	71.1	72.7	73.7	74.4	75.0	75.4	75.7
10	63.0	64.9	66.4	67.5	69.3	70.4	71.1	71.7	72.2	72.5

Tissue Maximum Ratio, TMR(*d*, r_d) *(r_d = side of equivalent square field at depth, d)*

r_d	4	6	8	10	15	20	25	30	35	40
d										
1.5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.995	0.997	0.997	0.998	0.997	0.996	0.996	0.997	0.997	0.997
3	0.971	0.974	0.978	0.979	0.980	0.981	0.981	0.982	0.982	0.983
4	0.940	0.946	0.951	0.954	0.958	0.960	0.962	0.964	0.965	0.966
5	0.904	0.915	0.922	0.928	0.935	0.939	0.942	0.945	0.948	0.949

6	0.869	0.882	0.892	0.900	0.910	0.916	0.920	0.925	0.928	0.931
7	0.835	0.850	0.863	0.871	0.884	0.893	0.899	0.904	0.907	0.911
8	0.800	0.818	0.832	0.843	0.860	0.869	0.876	0.882	0.886	0.890
9	0.767	0.786	0.801	0.814	0.833	0.844	0.853	0.860	0.865	0.870
10	0.735	0.755	0.772	0.786	0.808	0.820	0.830	0.837	0.843	0.848

Machine Output

$D'(d=1.5, r_d=10, r_c=10\times10, \text{SSD}=98.5)$ = **1.000 cGy/MU**

r_c = collimator setting, X×Y

r_d = side of equivalent square field at depth, d

In-Air Output Ratio, $S_c(r_c)$

	Y	6	8	10	15	20
X	6	0.97	0.98	0.98	0.99	1.001
	8	0.97	0.98	0.99	1.00	1.010
	1	0.98	0.99	1.00	1.01	1.014
	1	0.98	0.99	1.00	1.01	1.024
	2	0.98	0.99	1.00	1.02	1.028

Open Field Off-Axis Ratio, OAR(d, x)

x = off-axis distance in plane of isocenter

d = depth

x	d			
	1.5	**2**	**4**	**6**
0	1.000	1.000	1.000	1.000
1	1.004	1.004	1.003	1.003
2	1.011	1.011	1.010	1.009
3	1.017	1.017	1.016	1.014
4	1.024	1.024	1.023	1.021
5	1.031	1.030	1.028	1.026
6	1.035	1.034	1.031	1.028

12 MeV electrons (R_p = 6.0 cm, d_m = 3.0 cm)

Percent Depth Dose

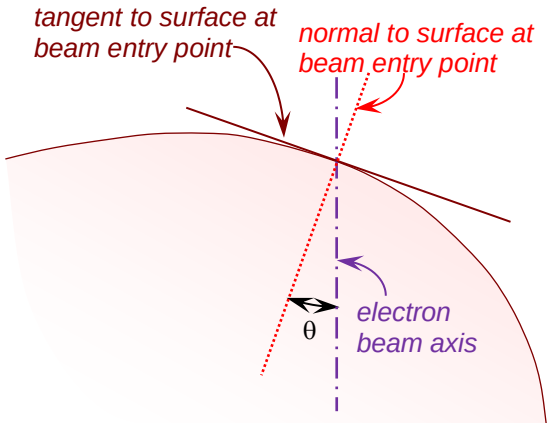
SSD=100 cm, field size ≥ 6 cm × 6 cm

d	PDD
0.00	84.0
0.20	87.4
0.40	90.3
0.60	91.7
0.80	93.0
1.00	94.3
1.20	95.3
1.40	96.0
1.60	96.7
1.80	97.3
2.00	98.0
2.20	98.4
2.40	98.8

d	PDD
2.60	99.2
2.80	99.6
3.00	100.0
3.20	99.3
3.40	98.7
3.60	98.0
3.80	94.8
4.00	91.6
4.20	86.7
4.40	80.0
4.60	71.1
4.80	62.2
5.00	53.3

Obliquity factors $CF_{obl}(\theta, d)$

	Angle of Obliquity, θ (deg)			
d/R_p	**0**	**20**	**40**	**60**
0.0	1.000	1.000	1.033	1.140
0.1	1.000	1.000	1.040	1.200
0.2	1.000	1.013	1.080	1.160
0.3	1.000	1.020	1.070	1.020
0.4	1.000	1.000	1.007	0.860
0.5	1.000	0.973	0.933	0.740
0.6	1.000	0.933	0.847	0.630
0.7	1.000	0.907	0.800	0.620
0.8	1.000	0.933	0.873	0.740
0.9	1.000	1.073	1.170	1.140
1.0	1.000	1.333	2.167	3.000



Question 3

Machine Output

$D'(d=3.0, r_a=10, r=10\times10, \text{SSD}=100)$ = **1.000 cGy/MU**

r_a = (nominal) side of square electron applicator
r = insert size (X×Y, projected to isocenter)

Electron Output Factors, $S_e(r_a, r)$, for r_a = 15

	Y	4	6	8	10	12	15
X	4	0.950	0.970	0.975	0.975	0.975	0.970
	6	0.970	0.990	0.995	0.995	0.995	0.990
	8	0.975	0.995	1.000	1.000	1.000	0.995
	10	0.975	0.995	1.000	1.000	1.000	0.995
	12	0.975	0.995	1.000	1.000	1.000	0.995
	15	0.970	0.990	0.995	0.995	0.995	0.990

Question 4

(40 marks)

a) State the advantages of Monte Carlo simulations when comparing to model-based dose calculation algorithms, and list two sources of uncertainties in dosimetric calculations with Monte Carlo. (6 marks)

A 4 MeV photon enters a graphite medium (carbon) of infinite thickness.

b) Perform Monte Carlo simulation to determine:
   (i) The interaction length of the photon, i.e., the distance the photon travels before an interaction takes place. (10 marks)
   (ii) The type of interaction (10 marks)

   Use the following pseudo-random number sequence for your simulation:

   0.314, 0.556, 0.864, 0.102, 0.081, ….

c) Explain the steps for determining the kinematic parameters (direction, energy and momentum) of each particle resulting from the above interaction. Where applicable, write down the equations that allow you to calculate these parameters. (8 marks)

d) Briefly explain the procedure for transporting the particles that resulted from the above interaction. (6 marks)

Question 4

TABLE A-4b RADIOLOGICAL PROPERTIES OF CARBON

Z=6 ρ = 2250 kg/m^3 3.008 x 10^{26} elect./kg 5.014 x 10^{25} atom/kg A=12.011

Photon energy $h\nu$	Basic Coefficients in $\left(10^{-24}\ \frac{cm^2}{atom}\right)$ or $\left(10^{-28}\ \frac{m^2}{atom}\right)$ σ_{coh} coh.	σ_{inc} incoh.	τ photo	κ pair	Interaction coef. in [cm^2/g] (To get [m^2/kg] divide by 10) $\left(\frac{\mu}{\rho}\right)$	$\left(\frac{\mu_{tr}}{\rho}\right)$	$\left(\frac{\mu_{ab}}{\rho}\right)$	Av. energy transferred or absorbed $\bar{E}_{tr}$	$\bar{E}_{ab}$	Stopping power $\bar{S}$ in $\frac{MeV\ cm^2}{g}$ $\bar{S}$*
[keV]								[keV]		
1	21.57	.2525	43820.		2198.		2197.	1.00		
1.5	19.21	.5016	14130.		709.4		708.5	1.50		93.4
2	16.69	.7730	6107.		307.1		306.2	1.99		82.6
3	12.30	1.283	1793.		90.58		89.89	2.98		68.2
4	9.243	1.690	731.7		37.23		36.68	3.94		58.3
5	7.218	1.990	360.3		18.53		18.07	4.88		51.1
6	5.857	2.208	200.4		10.45		10.05	5.77		45.7
8	4.204	2.503	78.54		4.274		3.940	7.38		37.9
10	3.247	2.704	37.66		2.187		1.891	8.65		32.6
15	1.958	3.023	9.770		.7396		.4945	10.0		24.8
20	1.294	3.192	3.725		.4117		.1930	9.38		20.2
30	.6719	3.307	.9539		.2473		.0570	6.91		16.1
40	.4082	3.300	.3634		.2041		.0297	5.83		16.0
50	.2735	3.252	.1725		.1854		.0222	5.99		17.9
60	.1957	3.188	.0941		.1744		.0200	6.89		20.2
80	.1139	3.054	.0365		.1607		.0200	9.98		21.1
100	.0742	2.924	.0176		.1512		.0213	14.1		18.5
150	.0336	2.647	.0048		.1346		.0245	27.3		12.4
200	.0190	2.431	.0020		.1229		.0266	43.2		8.95
300	.0085	2.117	.0006		.1066		.0287	80.8		5.86
400	.0048	1.899	.0002		.0954		.0295	124.		4.53
500	.0031	1.734	.0001		.0871		.0297	171.		3.78
550	.0025	1.665	.0001		.0836		.0297	195.		3.53
662	.0018	1.535	.0001		.0771		.0294	253.		3.11
800	.0012	1.410			.0708		.0289	327.		2.78
[MeV]								[MeV]		
1	.0008	1.268			.0636		.0280	.440		2.49
1.25	.0005	1.134		.0001	.0569		.0268	.588		2.27
1.5	.0003	1.031		.0016	.0518		.0256	.742	.739	2.13
2	.0002	.8795		.0064	.0444		.0236	1.06	1.06	1.97
3	.0001	.6919		.0186	.0356		.0206	1.74	1.73	1.84
4		.5772		.0308	.0305	.0187	.0185	2.46	2.43	1.78
5		.4984		.0419	.0271	.0174	.0171	3.21	3.16	1.75
6		.4405		.0502	.0246	.0163	.0160	3.98	3.91	1.74
8		.3604		.0670	.0214	.0150	.0146	5.60	5.45	1.72
10		.3069		.0840	.0196	.0143	.0138	7.30	7.06	1.72
15		.2272		.1094	.0169	.0132	.0125	11.7	11.1	1.72
20		.1823		.1321	.0158	.0129	.0121	16.4	15.3	1.73
30		.1327		.1609	.0147	.0128	.0115	26.0	23.5	1.74
40		.1055		.1798	.0143	.0128	.0112	35.8	31.3	1.76
50		.0880		.1962	.0143	.0130	.0111	45.7	38.8	1.77
60		.0759		.2069	.0142	.0132	.0109	55.7	46.0	1.78
80		.0598		.2251	.0143	.0135	.0106	75.6	59.4	1.79
100		.0497		.2404	.0145	.0139	.0104	95.6	71.7	1.81

*Av. Stopping Power in [MeV cm^2 g^{-1}] for the spectrum of electrons produced in the medium by photons of energy $h\nu$

Fall 2021 Medical Physics Qualifying Exam
for Advancement to Candidacy
Part 2
September 1, 2021
12:30-14:45 PDT

If you are in the PhD in astronomy or PhD in physics programs, stop! This is the Medical Physics version of the exam. Please download the version appropriate for your program instead.

Do not write your name on your exam papers. Instead, write your student number on each page. This will allow us to grade the exams anonymously. We'll match your name with your student number after we finish grading.

This portion of the exam has 5 questions. Answer both the first and second question as well as any of the three last 'elective' questions. Do not submit answers to more than 3 questions—if you do, only the first 3 of the questions you attempt will be graded. If you attempt a question and then decide you don't want to it count, clearly cross it out and write "don't grade".

You have 2.25 hours to complete 3 questions.

You are allowed to use one $8.5'' \times 11''$ formula sheet (both sides), and a handheld, non-graphing calculator.

Question 1 – **you must answer this question**

A regular lung cancer treatment schedule prescribes a total dose of 66 Gy in 30 fractions. The oncologist wants to reduce the number of delivered fractions to 11 (hypofractionation).

a) What dose should be used for each of the 11 fractions so that similar tumour control is achieved? Assume $\alpha/\beta = 9$ Gy for the tumour and ignore repopulation. (10 marks)

b) How does the new schedule affect the consequences for delivering dose to normal tissue (planning target volume overlap)? Assume $\alpha/\beta = 3$ Gy for normal tissue. (10 marks)

Lung-cancer patients treated (in 3-5 fractions) with stereotactic body radiotherapy (SBRT) were shown to exhibit relatively high incidence of chest wall pain and rib fractures. In SBRT, large doses per fraction, 12-20 Gy, are used and total prescription dose can be as high as 60 Gy. Follow-up studies showed that the risk of chest wall pain and rib fractures increases if the chest wall volume receiving >30Gy (V30) exceeds 30 cm^3.

c) Show graphically how V30 will be obtained from the cumulative dose-volume histogram (DVH). (10 marks)

d) Draw two examples of DVHs, one compliant with and another violating the V30 < 30 cm^3 guideline. (10 marks)

Question 2 – **you must answer this question**

Diagnostic Radiology

Imaging modalities exploit different contrast mechanism.

a) Describe the underlying mechanism of imaging contrast for each of the following four modalities: X-ray imaging, ultrasound Imaging, MRI, and PET imaging

b) Provide one clear advantage and one shortcoming of each of these four modalities

c) Describe 2 different patient-related artifacts that occur in of these four modalities and explain why they occur. How could each of these artifacts be mitigated?

d) X-rays are known to induced cancers and other negative effects in exposed populations. How can the occupational risk of exposure to radiation be reduced for staff working in a diagnostic radiology department?

An initial activity A of [177Lu]Lu-PSMA617 is injected to a patient. A fraction (η) of the radiopharmaceutical binds irreversibly to the center of a prostate cancer tumor inside soft tissue. Assume that the radiopharmaceutical localizes inside the tumor in a point (i.e., point source).

a) What is the initial dose rate from the beta particles of Lu-177 to this tumor as a function of the radius? **(10 marks)**

b) What is the absorbed dose to the tumor? **(10 marks)**

Clearly state any assumptions made to answer both parts (a) and (b).

Some relevant information about Lu-177 is provided in the table and the figure below.

Table: Decay information for Lu-177

Parent Nucleus	Parent E(level)	Parent Jπ	Parent $T_{1/2}$	Decay Mode	GS-GS Q-value (keV)	Daughter Nucleus	Decay Scheme	ENSDF file
$^{177}_{71}Lu$	0.0	7/2+	6.6443 d *9*	β^-: 100 %	496.8 *8*	$^{177}_{72}Hf$		

Beta-:

Energy (keV)	End-point energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
47.23 *23*	175.5 *8*	11.66 % *11*	0.00551 *6*
78.12 *27*	247.1 *8*	0.016 % *13*	1.2E-5 *10*
111.20 *26*	383.9 *8*	8.89 % *24*	0.0099 *3*
148.84 *28*	496.8 *8*	79.44 % *23*	0.1182 *4*

Mean beta- energy: 133.6 keV *7*, total beta- intensity: 100.0 % *4*, mean beta- dose: 0.1336 MeV/Bq-s *8*

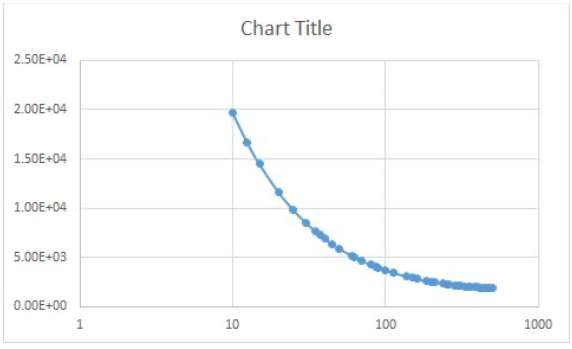


Figure: Stopping power for beta particles in water; x-axis: keV; y-axis (-dE/dx): keV/cm

We would like to reconstruct images of this patient. Consider the model *p=Ax+n*, where *p* is the measured data, *A* is the system matrix, *x* is the object (that we wish to reconstruct), and *n* is the noise.

c) Assuming a Gaussian model of noise, prove that the maximum likelihood solution is: **(5 marks)**

$$\hat{x} = (A^T A)^{-1} A^T p$$

d) If Gaussian noise variance is not equal in different detectors (e.g. count rate dependent), does the above equation hold? Provide reasoning. **(2 marks)**

e) Provide 1 reason why the equation above (part c) is not used in nuclear medicine practice. **(2 marks)**

f) In numerical analysis, fixed-point iteration is a method of iteratively solving for the fixed point of a function f(x); i.e. x^* is a fixed point of f if $f(x^*) = x^*$. If *f(x)* is continuous, one can prove that the iteration:

$$\hat{x}^{(n+1)} = f(\hat{x}^{(n)}); \text{ n=0,1,2,...}$$

converges to the fixed point.

Let us use this to derive an iterative solution to our model *p=Ax+n*, assuming a Gaussian least squares framework. Consider a function g(x) whose derivate we wish to set to zero: g'(x)=0 Then defining h(x)=x+g'(x), phrase above problem as a fixed point iteration problem, and derive an iterative solution. **(6 marks)**

g) What is the most appropriate detection noise model in nuclear medicine? What statistical iterative algorithm does one arrive at if solving the problem for that noise model? **(3 marks)**

h) What are 3 advantages of statistical reconstruction methods over analytic reconstruction methods? **(2 marks)**

Question 4 -- MRI Elective

(40 marks)

Part 1

To detect a tumour in the brain, two scans are used:
(A) contrast enhanced T1-weighted gradient echo pulse sequence
(B) T2-weighted spin echo pulse sequence.

a) What echo time, TE, and repetition time, TR, should be used in each sequence to maximize contrast between the tumour and normal brain tissue?

b) What is the total acquisition time for sequence A and B?

c) What will be the signal-to-noise ratio (SNR), for the tumour and the normal tissue in each image?

Assume the following: T1 = 1 s for the normal brain tissue, T1 = 20ms in the tumor tissue, after the contrast injection; ignore the T2* effect in the gradient echo sequence; T2 = 100 ms for the normal brain tissue and T2 = 50 ms for the tumour tissue; the image matrix size is 256x256 for both pulse sequences, and 20 slices are required to cover the relevant part of the brain; SNR for the fully recovered magnetization is 100 in both normal and tumour tissue (i.e. M_0 is the same in both). The maximum number of slices acquired in one TR is limited to TR/50 ms. (15 marks)

Part 2

Two more scans are used:
(C) contrast enhanced T1-weighted gradient echo pulse sequence with lower dose of the contrast agent than in part (1) above
(D) T2-weighted fast spin-echo sequence (FSE) with 4 k-space lines acquired in one repetition, TR.

d) Calculate TE and TR values for these two new sequences that maximize the contrast between the tumour and the normal tissue, and the total acquisition time and SNR using the assumptions above, except, T1 of the tumour is now 40 ms; the time required to collect signal for each k-space line for the FSE sequence is TE + 10 ms. (10 marks)

e) Provide a pulse sequence diagram for sequence D indicating timing parameters TR and TE as well as approximate gradient and RF timings. (10 marks)

f) Compare scans A, B, C and D by taking into consideration image quality (e.g. SNR), and patient comfort (e.g. total acquisition time, invasiveness). Which scan in your opinion would be preferable? (5 marks)

Diagnosis:

The μ_a, μ_s, and *g* values of a special type of biological tissue in the "diagnostic window" (600 – 1200 nm) are 0.0015 cm^{-1}, 0.9 cm^{-1}, and 0.88 respectively.

a) Calculate the mean-free path (mfp) between absorption events, the mfp between scattering events, and the mean scattering angle. (10 marks)

b) How many scattering events will it take for photon walking to become completely randomized in this tissue? (10 marks)

c) Assuming one intends to perform time-resolved imaging of this tissue type using ballistic photons, estimate the pulse width of the pulsed laser which should be used. The tissue has a refractive index of 1.4 and the speed of light in vacuum is $3x10^{10}$cm/s. (10 marks)

Therapy:

d) What are the three essential components for photodynamic therapy (PDT) to function properly? (6 marks)

e) Why is it possible to achieve better selectivity for tumor eradication (tumor killed while normal tissue well preserved) by using PDT as compared to other treatment modalities such as conventional cytotoxic chemotherapy? (4 marks)