UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 2003/2004

September – Oktober 2003

ZCT 533/4 - Dosimetri dan Perlindungan Sinaran

Masa : 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi **EMPAT BELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.

Jawab kesemua LIMA soalan. Pelajar dibenarkan menjawab semua soalan dalam Bahasa Inggeris ATAU Bahasa Malaysia ATAU kombinasi kedua-duanya.

1. (a) Perihalkan kuantiti-kuantiti yang digunakan untuk mencirikan suatu medan sinaran.

(20 markah)

(b) Suatu alur sinar γ melalui sekeping plumbum berketebalan 2 cm. Alur tuju itu mengandungi 30% foton 0.4 MeV dan 70% foton 1.5 MeV. Ketumpatan plumbum ialah 11.3 g cm^{-3}.

(i) Hitung purata $\left(\overline{\mu/\rho}\right)_{\Phi}$ yang akan dicerap oleh suatu pembilang foton.

(ii) Hitung purata $\left(\overline{\mu/\rho}\right)_{\Psi}$ yang akan direkodkan oleh suatu meter fluens tenaga.

(iii) Tentukan nisbah fluens foton tembus terhadap fluens tuju.

(30 markah)

(c) Udara kering berisipadu 1 cm^3 pada STP menerima foton dengan fluens 10^5 foton m^{-2}. Tenaga foton ialah 0.662 MeV.

(i) Hitung bilangan pasangan ion yang dihasilkan.
(ii) Tentukan dedahan dan dos terserap dalam isipadu udara tersebut.

(50 markah)

2. (a) Jelaskan makna kerma dan dedahan. Terbitkan suatu perhubungan antara dedahan dan kerma pelanggaran.

(40 markah)

(b) Pertimbangkan suatu foton bertenaga 0.662 MeV memasuki suatu isipadu sensitif *V*. Suatu interaksi Compton tunggal berlaku dalam *V* dan suatu foton terserak 0.2 MeV dan juga suatu foton bremsstrahlung 0.1 MeV meninggalkan *V*. Elektron yang terhasil dalam *V* menggunakan setengah tenaga kinetiknya sebelum terlepas dari *V*.

(i) Lakarkan suatu gambarajah untuk menunjukkan tindakbalas-tindakbalas yang berlaku dalam *V*.

(ii) Tentukan kerma dan dos terserap dalam *V*, anggap $V = 10^{-5}$ m^3 dan ketumpatannya 1 kg m^{-3}.

(60 markah)

3. (a) Jelaskan teorem Fano.

(20 markah)

(b) Jika bahantara dinding *w* suatu dosimeter tidak serasi dengan bahantara rongga *g*, yang manakah di antara dua bahantara tersebut yang harus diserasikan dengan bahantara *x* yang di dalamnya pengukuran dos akan dilakukan. Jelaskan.

(40 markah)

(c) Bincangkan sebab-sebab utama penerbitan semula perhubungan rongga Bragg-Gray oleh Spencer. Spencer kemudiannya telah mengutarakan teori rongganya sendiri. Nyatakan perbezaan-perbezaan utama antara kedua-dua teori tersebut.

(40 markah)

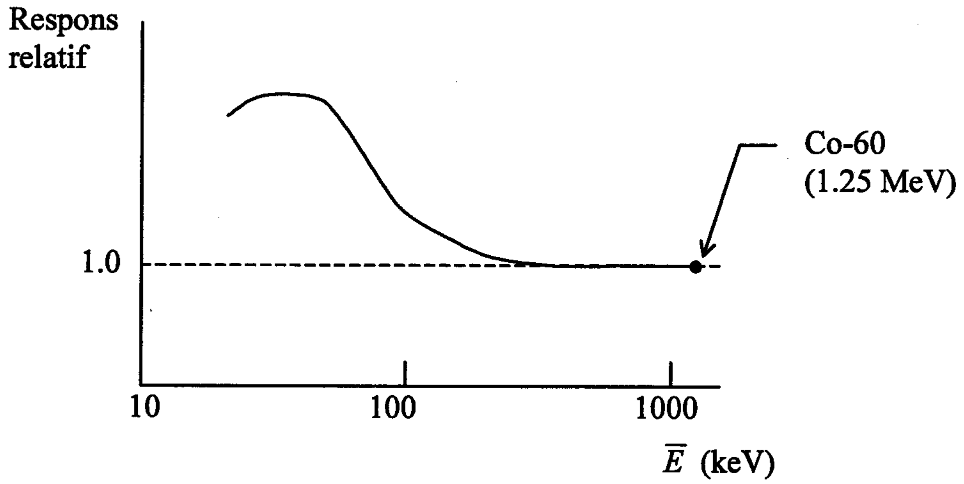
4. (a) Bincangkan sebarang <u>empat</u> ciri umum suatu dosimeter yang mesti dipertimbangkan sebelum menggunakannya untuk pengukuran dos.

(40 markah)

(b) Bincangkan mekanisme asas pendarkilau haba yang berlaku dalam suatu dosimeter pendarkilau haba, sertakan rajah-rajah jika perlu.

(30 markah)

(c) Bacaan relatif dosimeter per unit dedahan tipikal bagi suatu dosimeter pendarkilau haba LiF terhadap tenaga foton purata $\overline{E}$ ditunjukkan dalam Rajah 1 di bawah.



Rajah 1

Dengan menggunakan jadual yang disertakan, bincangkan bagaimana respons relatif dosimeter dari 20 keV hingga 1000 keV dianggarkan.

(30 markah)

5. (a) Perihalkan radiolisis air apabila suatu alur sinaran berinteraksi dengan bahan biologi.

(30 markah)

(b) Perihalkan tindakan langsung dan tindakan tak langsung sinaran dalam bahan biologi.

(30 markah)

(c) Berikan sebab-sebab mengapa suatu sawar perlindungan perlu diletakkan di antara pesakit dan juruadiograf ketika mengambil radiograf atau memberikan radioterapi. Nyatakan tiga jenis bahan yang lazim digunakan sebagai sawar dan jelaskan sifat-sifat setiap bahan tesebut yang menjadikannya sesuai.

(40 markah)

APPENDIX A.2. Conversion Factors

$$1\ \text{kg} = 5.6095 \times 10^{29}\ \text{MeV}$$
$$1\ \text{amu} = 931.50\ \text{MeV}$$
$$\text{Electron rest mass} = 0.51100\ \text{MeV}$$
$$\text{Proton rest mass} = 938.26\ \text{MeV}$$
$$\text{Neutron rest mass} = 939.55\ \text{MeV}$$
$$1\ \text{electron volt (eV)} = 1.6022 \times 10^{-19}\ \text{J} = 1.6022 \times 10^{-12}\ \text{erg}$$
$$1\ \text{joule (J)} = 10^{7}\ \text{erg}$$
$$1\ \text{coulomb (C)} = 2.9979 \times 10^{9}\ \text{esu}$$
$$1\ \text{gray (Gy)} = 1\ \text{J/kg} = 10^{2}\ \text{rad} = 10^{4}\ \text{erg/g}$$
$$1\ \text{sievert (Sv)} = 1\ \text{J/kg}$$

Energy-wavelength conversion:

$$1.23985 \times 10^{-6}\ \text{eV m}$$
$$12.3985\ \text{keV Å}$$

Exposure conversion:

$$1\ \text{roentgen (R)} = 2.58 \times 10^{-4}\ \text{C/kg}$$
$$1\ \text{C/kg} = 3876\ \text{R}$$

TABLE A-3b - WATER	$\bar{Z} = 7.51$
$\rho = 1000\ \text{kg/m}^3$	
3.343×10^{26} elect./kg	

TABLE A-3a - AIR	$\bar{Z} = 7.78$
$\rho = 1.205\ \text{kg/m}^3$ (at NTP)	
3.006×10^{26} elect./kg	

TABLE A-3d - BONE	$\bar{Z} = 12.31$
$\rho = 1650\ \text{kg/m}^3$	
3.192×10^{26} elect./kg	

TABLE A-3c - MUSCLE	$\bar{Z} = 7.64$
$\rho = 1040\ \text{kg/m}^3$	
3.312×10^{26} elect./kg	

...5/-

Appendix B.2. Data Table for Compounds and Mixtures[a]

Material	Density (g/cm^3)[c]	Electron density (10^{23} e/g)	I (eV)[d]
A-150 plastic[b]	1.127	3.306	65.1
Adipose tissue (Fat, ICRP)[b]	0.92	3.363	63.2
Air[b]	1.205×10^{-3}	3.006	85.7
Bone, cortical (ICRP)[b]	1.85	3.139	106.4
Calcium fluoride, CaF_2	3.18	2.931	166
Carbon dioxide, CO_2	1.842×10^{-3}	3.010	85.0
Cesium iodide, CsI	4.51	2.503	553
Lithium fluoride, LiF	2.64	2.786	94.0
Lucite, $(C_5H_8O_2)_n$	1.19	3.248	74.0
Muscle, skeletal (ICRP)[b]	1.04	3.308	75.3
Mylar, $(C_{10}H_8O_4)_n$	1.40	3.134	78.7
Nylon, type 6 $(C_6H_{11}NO)_n$	1.14	3.299	63.9
Polycarbonate $(C_{16}H_{14}O_3)_n$	1.20	3.173	73.1
Polyethylene $(C_2H_4)_n$	0.94	3.435	57.4
Polyimide $(C_{22}H_{10}N_2O_5)$	1.42	3.087	79.6
Polypropylene $(C_3H_5)_n$	0.90	3.372	59.2
Polystyrene $(C_8H_8)_n$	1.06	3.238	68.7
Polyvinyl Chloride $(C_2H_3Cl)_n$	1.30	3.083	108.2
Pyrex (borosilicate glass)[b]	2.23	2.993	134
Silicon dioxide, SiO_2	2.32	3.007	139.2
Silver bromide, AgBr	6.47	2.629	487
Sodium iodide, NaI	3.67	2.571	452
Teflon, $(C_2F_4)_n$	2.20	2.890	99.1
TE gas (methane-based)[b]	1.064×10^{-3}	3.312	61.2
TE gas (propane-based)[b]	1.826×10^{-3}	3.314	59.5
TE liquid (no sucrose)[b]	1.070	3.313	74.2
Water, H_2O	0.9982	3.343	75.0

[a] Data from Berger and Seltzer (1983)
[b] See compositions in Appendix B.3
[c] Assuming T = 20°C., P = 1 atm., and Charles' Law for gases applies.
[d] I is the mean excitation potential for stopping power, see Chapter 8.

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Photon Energy (MeV)	Air			Water			ICRU Compact Bone			ICRU Striated Muscle		
	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ
0.01	5.04	4.61	4.61	5.21	4.79	4.79	20.3	19.2	19.2	5.30	4.87	4.87
0.015	1.56	1.27	1.27	1.60	1.28	1.28	6.32	5.84	5.84	1.64	1.32	1.32
0.02	0.758	0.511	0.511	0.778	0.512	0.512	2.79	2.46	2.46	0.796	0.533	0.533
0.03	0.350	0.148	0.148	0.371	0.149	0.149	0.962	0.720	0.720	0.375	0.154	0.154
0.04	0.248	0.0668	0.0668	0.267	0.0677	0.0677	0.511	0.304	0.304	0.267	0.0701	0.0701
0.05	0.206	0.0406	0.0406	0.225	0.0418	0.0418	0.346	0.161	0.161	0.224	0.0431	0.0431
0.06	0.187	0.0305	0.0305	0.205	0.0320	0.0320	0.273	0.0998	0.0998	0.204	0.0328	0.0328
0.08	0.167	0.0243	0.0243	0.185	0.0262	0.0262	0.209	0.0537	0.0537	0.183	0.0264	0.0264
0.10	0.155	0.0234	0.0234	0.171	0.0256	0.0256	0.181	0.0387	0.0387	0.170	0.0256	0.0256
0.15	0.136	0.0250	0.0250	0.151	0.0277	0.0277	0.150	0.0305	0.0305	0.150	0.0275	0.0275
0.2	0.124	0.0268	0.0268	0.137	0.0297	0.0297	0.133	0.0301	0.0301	0.136	0.0294	0.0294
0.3	0.107	0.0287	0.0287	0.119	0.0319	0.0319	0.114	0.0310	0.0310	0.118	0.0317	0.0317
0.4	0.0954	0.0295	0.0295	0.106	0.0328	0.0328	0.102	0.0315	0.0315	0.105	0.0325	0.0325
0.5	0.0868	0.0297	0.0296	0.0966	0.0330	0.0330	0.0926	0.0317	0.0317	0.0958	0.0328	0.0328
0.6	0.0804	0.0296	0.0295	0.0894	0.0329	0.0329	0.0856	0.0315	0.0314	0.0886	0.0326	0.0325
0.8	0.0706	0.0289	0.0289	0.0785	0.0321	0.0321	0.0751	0.0307	0.0306	0.0778	0.0318	0.0318
1.0	0.0635	0.0280	0.0278	0.0706	0.0311	0.0309	0.0675	0.0297	0.0295	0.0699	0.0308	0.0306
1.5	0.0517	0.0256	0.0254	0.0575	0.0284	0.0282	0.0549	0.0272	0.0270	0.0570	0.0282	0.0280
2	0.0444	0.0236	0.0234	0.0493	0.0262	0.0260	0.0472	0.0251	0.0249	0.0489	0.0259	0.0257
3	0.0358	0.0207	0.0205	0.0396	0.0229	0.0227	0.0382	0.0221	0.0219	0.0392	0.0227	0.0225
4	0.0308	0.0189	0.0186	0.0340	0.0209	0.0206	0.0331	0.0204	0.0200	0.0337	0.0207	0.0204
5	0.0276	0.0178	0.0174	0.0303	0.0195	0.0191	0.0297	0.0192	0.0187	0.0300	0.0193	0.0189
6	0.0252	0.0168	0.0164	0.0277	0.0185	0.0180	0.0274	0.0184	0.0178	0.0274	0.0183	0.0178
8	0.0223	0.0157	0.0152	0.0243	0.0170	0.0166	0.0244	0.0173	0.0167	0.0240	0.0169	0.0164
10	0.0205	0.0151	0.0145	0.0222	0.0162	0.0157	0.0226	0.0168	0.0159	0.0219	0.0160	0.0155

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APPENDIX D.3. (*Continued*)

Photon Energy (MeV)	Tin			Photon Energy (MeV)	Lead		
	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ		μ/ρ	μ_{tr}/ρ	μ_{en}/ρ
0.0010	11130	11110	11110	M_1 edge	—		
0.0015	3960	3950	3950	0.003854	1493	1454	1453
0.0020	1963	1954	1954				
0.0030	713	705	705	0.004	1333	1298	1297
				0.005	767	747	747
0.0039288	367	360	360	0.006	493	479	479
L_3 edge				0.008	238	230	230
0.0039288	1118	1067	1067				
				0.010	136.6	131.0	130.7
0.0040	1067	1019	1019				
				0.0130406	70.1	66.2	66.0
0.0041573	973	930	930	L_3 edge			
L_2 edge				0.0130406	165.7	128.8	128.8
0.0041573	1244	1187	1187				
				0.015	114.7	91.7	91.7
0.0044648	1016	971	971				
L_1 edge				0.0152053	112.0	89.6	89.6
0.0044648	1264	1207	1207	L_2 edge			
				0.0152053	145.4	113.0	113.0
0.005	919	880	880				
0.006	561	540	539	0.015855	129.3	101.7	101.6
0.008	259	250	249	L_1 edge			
				0.015855	159.2	123.0	123.0
0.010	141.6	136.5	136.4				
0.015	45.8	43.7	43.6	0.02	85.5	69.2	69.1
0.020	21.2	19.83	19.81	0.03	29.1	24.6	24.6
0.0291947	7.61	6.83	6.82	0.04	13.80	11.83	11.78
K edge				0.05	7.71	6.57	6.54
0.0291947	45.4	16.70	16.69	0.06	4.87	4.11	4.08
				0.08	2.37	1.924	1.908
0.030	42.1	16.18	16.17	0.088005	1.865	1.494	1.481
0.04	18.77	9.97	9.96	K edge			
0.05	10.20	6.25	6.24	0.088005	7.30	2.47	2.47
0.06	6.34	4.20	4.19				
0.08	3.07	2.19	2.18	0.10	5.78	2.28	2.28
0.10	1.720	1.257	1.250	0.15	2.07	1.164	1.154
0.15	0.634	0.446	0.442	0.2	1.014	0.637	0.629
0.20	0.333	0.211	0.209	0.3	0.406	0.265	0.259
0.30	0.1649	0.0853	0.0843	0.4	0.233	0.1474	0.1432
0.4	0.1163	0.0536	0.0530	0.5	0.1614	0.0984	0.0951
0.5	0.0948	0.0423	0.0416	0.6	0.1249	0.0737	0.0710
0.6	0.0811	0.0358	0.0353	0.8	0.0886	0.0503	0.0481
0.8	0.0667	0.0301	0.0294	1.0	0.0708	0.0396	0.0377
1.0	0.0578	0.0270	0.0264	1.5	0.0518	0.0288	0.0271
1.5	0.0462	0.0233	0.0226	2	0.0455	0.0259	0.0240
2.0	0.0410	0.0220	0.0210	3	0.0417	0.0260	0.0234
3.0	0.0366	0.0219	0.0205	4	0.0415	0.0281	0.0245
4	0.0355	0.0232	0.0212	5	0.0424	0.0306	0.0259
5	0.0353	0.0247	0.0221	6	0.0436	0.0331	0.0272
6	0.0357	0.0262	0.0230	8	0.0467	0.0378	0.0294
8	0.0370	0.0292	0.0245	10	0.0496	0.0419	0.0310
10	0.0387	0.0319	0.0258				

UNIVERSITI SAINS MALAYSIA

First Semester Examination
2003/2004 Academic Session

September - October 2003

ZCT 533/4 - Dosimetry and Radiation Protection

Time : 3 hours

Please check that the examination paper consists of **FOURTEEN** printed pages before you commence this examination.

Answer all FIVE questions. Students are allowed to answer all questions in English OR Bahasa Malaysia OR combinations of both.

1. (a) Describe the quantities used to characterise a radiation field.

(20 marks)

(b) A narrow γ-ray beam passes through a 2 cm thick lead. The incident beam consists of 30% 0.4 MeV photons and 70% 1.5 MeV photons. The density of lead is 11.3 g cm^{-3}.

(i) Calculate the average $(\overline{\mu/\rho})_{\Phi}$ which will be observed by a photon counter.

(ii) Calculate the average $(\overline{\mu/\rho})_{\Psi}$ which will be recorded by an energy fluence meter.

(iii) Determine the ratio of the transmitted photon fluence to that of the incident fluence.

(30 marks)

(c) A volume of dry air 1 cm^3 at STP received a fluence of photons 10^5 photons m^{-2}. The photon energy is 0.662 MeV.

(i) Calculate the number of ion pairs produced.
(ii) Determine the exposure and the absorbed dose in the air volume.

(50 marks)

2. (a) Explain the meaning of kerma and exposure. Derive a relationship between exposure and collision kerma.

(40 marks)

(b) Consider a photon of 0.662 MeV entering a sensitive volume V. A single Compton interaction occurs in V and a 0.2 MeV scattered photon as well as a 0.1 MeV bremsstrahlung photon leaves V. The electron generated in V spends half of its kinetic energy before escaping from V.

(i) Sketch a diagram to show the reactions taking place in V.

(ii) Determine the kerma and the absorbed dose in V, assuming that $V = 10^{-5}$ m^3 and its density is 1 kg m^{-3}.

(60 marks)

3. (a) Explain the Fano theorem.

(20 marks)

(b) If the medium of the wall w of a dosimeter does not match the medium of the cavity g, which of the two medium should be matched to the medium x in which the dose measurement is to be carried out. Explain.

(40 marks)

(c) Discuss the main reasons for the rederivation of Bragg-Gray cavity relation by Spencer. Spencer went on to promote his own Spencer cavity theory. State the main differences between the two theories.

(40 marks)

4. (a) Describe any <u>four</u> general characteristics of a dosimeter which must be considered before using it in any dose measurement.

(40 marks)

(b) Discuss the basic mechanisms of thermoluminescence occuring in a thermoluminescent dosimeter, provide diagrams where necessary.

(30 marks)

(c) The typical relative dosimeter reading per unit exposure for a LiF thermoluminescent dosimeter with respect to the mean photon energy $\overline{E}$ is shown in Figure 1 below.

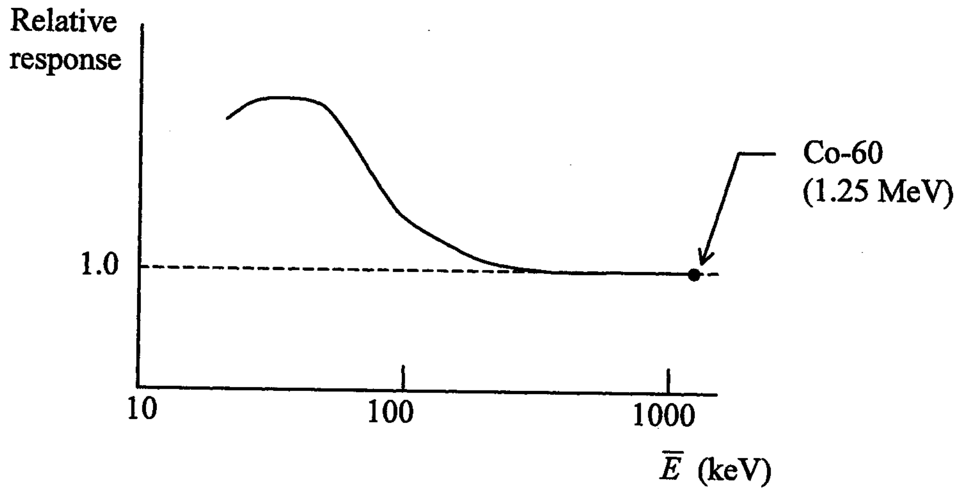

Figure 1

Using the appropriate table enclosed, discuss how the relative response of the dosimeter from 20 keV up to 1000 keV was estimated .

(30 marks)

5. (a) Describe the radiolysis of water when a radiation beam interacts with a biological material.

(30 marks)

(b) Describe the direct action and the indirect action of radiation in a biological material.

(30 marks)

(c) Give reasons why it is desirable to have a protective barrier between the patient and the radiographer when taking radiographs or giving radiotherapy. State three materials commonly used for such a barrier and explain the properties of each material which make them suitable.

APPENDIX A.2. Conversion Factors

$1\ kg = 5.6095 \times 10^{29}\ MeV$
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Nylon, type 6 $(C_6H_{11}NO)_n$	1.14	3.299	63.9
Polycarbonate $(C_{16}H_{14}O_3)_n$	1.20	3.173	73.1
Polyethylene $(C_2H_4)_n$	0.94	3.435	57.4
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Silver bromide, AgBr	6.47	2.629	487
Sodium iodide, NaI	3.67	2.571	452
Teflon, $(C_2F_4)_n$	2.20	2.890	99.1
TE gas (methane-based)[b]	1.064×10^{-3}	3.312	61.2
TE gas (propane-based)[b]	1.826×10^{-3}	3.314	59.5
TE liquid (no sucrose)[b]	1.070	3.313	74.2
Water, H_2O	0.9982	3.343	75.0

[a] Data from Berger and Seltzer (1983)
[b] See compositions in Appendix B.3
[c] Assuming $T = 20°C.$, $P = 1$ atm., and Charles' Law for gases applies.
[d] I is the mean excitation potential for stopping power, see Chapter 8.

Photon Energy (MeV)	Air			Water			ICRU Compact Bone			ICRU Striated Muscle		
	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	μ/ρ	μ_{tr}/ρ	μ_{en}/ρ
0.01	5.04	4.61	4.61	5.21	4.79	4.79	20.3	19.2	19.2	5.30	4.87	4.87
0.015	1.56	1.27	1.27	1.60	1.28	1.28	6.32	5.84	5.84	1.64	1.32	1.32
0.02	0.758	0.511	0.511	0.778	0.512	0.512	2.79	2.46	2.46	0.796	0.533	0.533
0.03	0.350	0.148	0.148	0.371	0.149	0.149	0.962	0.720	0.720	0.375	0.154	0.154
0.04	0.248	0.0668	0.0668	0.267	0.0677	0.0677	0.511	0.304	0.304	0.267	0.0701	0.0701
0.05	0.206	0.0406	0.0406	0.225	0.0418	0.0418	0.346	0.161	0.161	0.224	0.0431	0.0431
0.06	0.187	0.0305	0.0305	0.205	0.0320	0.0320	0.273	0.0998	0.0998	0.204	0.0328	0.0328
0.08	0.167	0.0243	0.0243	0.185	0.0262	0.0262	0.209	0.0537	0.0537	0.183	0.0264	0.0264
0.10	0.155	0.0234	0.0234	0.171	0.0256	0.0256	0.181	0.0387	0.0387	0.170	0.0256	0.0256
0.15	0.136	0.0250	0.0250	0.151	0.0277	0.0277	0.150	0.0305	0.0305	0.150	0.0275	0.0275
0.2	0.124	0.0268	0.0268	0.137	0.0297	0.0297	0.133	0.0301	0.0301	0.136	0.0294	0.0294
0.3	0.107	0.0287	0.0287	0.119	0.0319	0.0319	0.114	0.0310	0.0310	0.118	0.0317	0.0317
0.4	0.0954	0.0295	0.0295	0.106	0.0328	0.0328	0.102	0.0315	0.0315	0.105	0.0325	0.0325
0.5	0.0868	0.0297	0.0296	0.0966	0.0330	0.0330	0.0926	0.0317	0.0317	0.0958	0.0328	0.0328
0.6	0.0804	0.0296	0.0295	0.0894	0.0329	0.0329	0.0856	0.0315	0.0314	0.0886	0.0326	0.0325
0.8	0.0706	0.0289	0.0289	0.0785	0.0321	0.0321	0.0751	0.0307	0.0306	0.0778	0.0318	0.0318
1.0	0.0635	0.0280	0.0278	0.0706	0.0311	0.0309	0.0675	0.0297	0.0295	0.0699	0.0308	0.0306
1.5	0.0517	0.0256	0.0254	0.0575	0.0284	0.0282	0.0549	0.0272	0.0270	0.0570	0.0282	0.0280
2	0.0444	0.0236	0.0234	0.0493	0.0262	0.0260	0.0472	0.0251	0.0249	0.0489	0.0259	0.0257
3	0.0358	0.0207	0.0205	0.0396	0.0229	0.0227	0.0382	0.0221	0.0219	0.0392	0.0227	0.0225
4	0.0308	0.0189	0.0186	0.0340	0.0209	0.0206	0.0331	0.0204	0.0200	0.0337	0.0207	0.0204
5	0.0276	0.0178	0.0174	0.0303	0.0195	0.0191	0.0297	0.0192	0.0187	0.0300	0.0193	0.0189
6	0.0252	0.0168	0.0164	0.0277	0.0185	0.0180	0.0274	0.0184	0.0178	0.0274	0.0183	0.0178
8	0.0223	0.0157	0.0152	0.0243	0.0170	0.0166	0.0244	0.0173	0.0167	0.0240	0.0169	0.0164
10	0.0205	0.0151	0.0145	0.0222	0.0162	0.0157	0.0226	0.0168	0.0159	0.0219	0.0160	0.0155

APPENDIX D.3. *(Continued)*

Photon Energy (MeV)	Tin μ/ρ	Tin μ_{tr}/ρ	Tin μ_{en}/ρ	Photon Energy (MeV)	Lead μ/ρ	Lead μ_{tr}/ρ	Lead μ_{en}/ρ
0.0010	11130	11110	11110	M_1 edge	—		
0.0015	3960	3950	3950	0.003854	1493	1454	1453
0.0020	1963	1954	1954				
0.0030	713	705	705	0.004	1333	1298	1297
				0.005	767	747	747
0.0039288	367	360	360	0.006	493	479	479
L_3 edge				0.008	238	230	230
0.0039288	1118	1067	1067				
				0.010	136.6	131.0	130.7
0.0040	1067	1019	1019				
				0.0130406	70.1	66.2	66.0
0.0041573	973	930	930	L_3 edge			
L_2 edge				0.0130406	165.7	128.8	128.8
0.0041573	1244	1187	1187				
				0.015	114.7	91.7	91.7
0.0044648	1016	971	971				
L_1 edge				0.0152053	112.0	89.6	89.6
0.0044648	1264	1207	1207	L_2 edge			
				0.0152053	145.4	113.0	113.0
0.005	919	880	880				
0.006	561	540	539	0.015855	129.3	101.7	101.6
0.008	259	250	249	L_1 edge			
				0.015855	159.2	123.0	123.0
0.010	141.6	136.5	136.4				
0.015	45.8	43.7	43.6	0.02	85.5	69.2	69.1
0.020	21.2	19.83	19.81	0.03	29.1	24.6	24.6
0.0291947	7.61	6.83	6.82	0.04	13.80	11.83	11.78
K edge				0.05	7.71	6.57	6.54
0.0291947	45.4	16.70	16.69	0.06	4.87	4.11	4.08
				0.08	2.37	1.924	1.908
0.030	42.1	16.18	16.17	0.088005	1.865	1.494	1.481
0.04	18.77	9.97	9.96	K edge			
0.05	10.20	6.25	6.24	0.088005	7.30	2.47	2.47
0.06	6.34	4.20	4.19				
0.08	3.07	2.19	2.18	0.10	5.78	2.28	2.28
				0.15	2.07	1.164	1.154
0.10	1.720	1.257	1.250	0.2	1.014	0.637	0.629
0.15	0.634	0.446	0.442	0.3	0.406	0.265	0.259
0.20	0.333	0.211	0.209				
0.30	0.1649	0.0853	0.0843	0.4	0.233	0.1474	0.1432
				0.5	0.1614	0.0984	0.0951
0.4	0.1163	0.0536	0.0530	0.6	0.1249	0.0737	0.0710
0.5	0.0948	0.0423	0.0416	0.8	0.0886	0.0503	0.0481
0.6	0.0811	0.0358	0.0353				
0.8	0.0667	0.0301	0.0294	1.0	0.0708	0.0396	0.0377
				1.5	0.0518	0.0288	0.0271
1.0	0.0578	0.0270	0.0264	2	0.0455	0.0259	0.0240
1.5	0.0462	0.0233	0.0226	3	0.0417	0.0260	0.0234
2.0	0.0410	0.0220	0.0210				
3.0	0.0366	0.0219	0.0205	4	0.0415	0.0281	0.0245
				5	0.0424	0.0306	0.0259
4	0.0355	0.0232	0.0212	6	0.0436	0.0331	0.0272
5	0.0353	0.0247	0.0221	8	0.0467	0.0378	0.0294
6	0.0357	0.0262	0.0230				
8	0.0370	0.0292	0.0245	10	0.0496	0.0419	0.0310
10	0.0387	0.0319	0.0258				