UNIVERSITI SAINS MALAYSIA

Peperiksaan Kursus Semasa Cuti Panjang
Sidang Akademik 1994/95

Jun 1995

ZCT 533/4 - Dosimetri dan Perlindungan Sinaran

Masa : [3 jam]

Sila pastikan bahawa kertas peperiksaan ini mengandungi TIGA muka surat yang bercetak sebelum anda memulakan peperiksaan ini. Tujuh mukasurat sifar juga diberikan bersama.
Jawab KESEMUA EMPAT soalan.
Kesemuanya wajib dijawab dalam Bahasa Malaysia.

1. (a) Terangkan maksud seimbangan zarah bercas dalam kes tiada pengecilan berlaku pada sinaran foton.

(20 markah)

(b) Suatu dosimeter pengionan yang berdinding nipis didedah pada 100 R sinar ^{60}Co. Tetapi bacaan dalam dosimeter hanya memberi 80 R. Jelaskan. Nyatakan langkah-langkah yang anda perlu lakukan untuk mendapat bacaan yang benar.

(25 markah)

(c) Nyatakan teorem kaviti Bragg-Gray merujuk pada medan sinaran foton dan neutron.

(20 markah)

(d) Isipadu 0.3 cm^3 kaviti udara mengandungi 2.5 x 10^{10} pasangan ion yang dihasilkan oleh sinar γ ^{137}Cs. Katakan suatu blok graphite diletak pada kedudukan kaviti itu. Hitungkan dos serapan dalam blok graphite.

(35 markah)

2. (a) Terangkan kuantiti-kuantiti yang digunakan untuk menghuraikan medan sinaran.

(15 markah)

(b) Terangkan maksud dos serapan dan dedahan. Bilakah kuantiti dedahan digunakan?

(15 markah)

...2/-

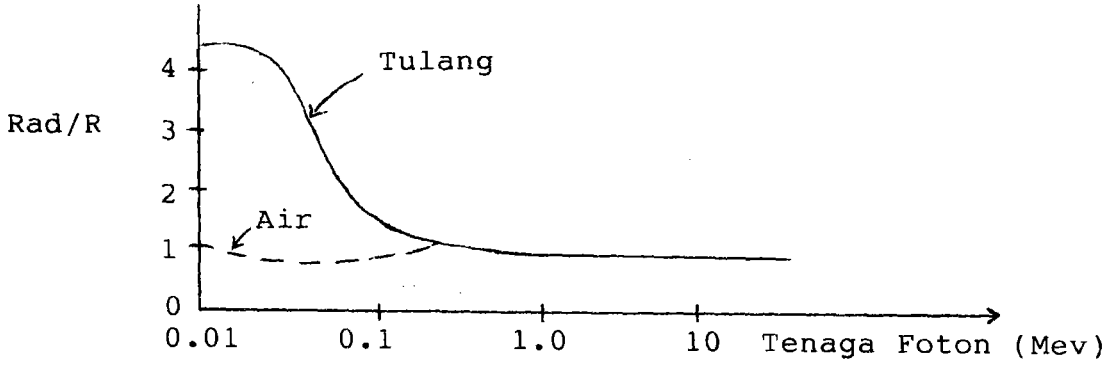
(c) Isipadu udara 1 cm^3 pada STP menerima fluens 10^{15} foton m^{-2}. Tenaga fotonnya ialah 0.1 Mev.

(i) Hitungkan bilangan pasang ion yang dihasilkan.

(ii) Tentukan dedahan dan dos serapan dalam isipadu udara itu.

(40 markah)

(d)



Bincangkan sebab-sebab rad/R bagi tulang berbeza dari rad/R bagi air pada tenaga yang rendah tetapi lebih kurang sama pada tenaga yang tinggi.
Mengapa rad/R ~ 1 bagi air tetapi rad/R ~ 5 bagi tulang pada tenaga rendah?

(30 markah)

3. (a) Berikan takrifan bagi dosimeter. Bincangkan fungsi-fungsi bagi dinding dosimeter.

(20 markah)

(b) Jika bahantara dinding tidak bersesuaian dengan bahantara isipadu gas, manakah bahantara yang perlu bersesuaian dengan bahantara x di mana pengukuran dos dilakukan. Jelaskan jawapan anda.

(20 markah)

...3/-

(c) Terbitkan perhubungan antara dedahan X dengan dos serapan D pada suatu titik P dalam suatu bahan. Dedahan X dibacakan di dalam ruang bebas dengan suatu dosimeter udara.

(30 markah)

(d) Bagi suatu bim ^{60}Co, dosimeter pengionan memberi bacaan 43 R pada suhu 25°C dan tekanan 740 mm Hg. Bacaan telah dibetulkan bagi faktor kalibrasi. Bagi dedahan ini, hitungkan dos serapan pada tisu (jisimnya kecil) yang diletakkan pada kedudukan dosimeter itu. (Anggapan tisunya setara dengan air)

(30 markah)

4. (a) Berikan maksud bagi kuantiti stokastik dan kuantiti bukan stokastik. Berikan contoh bagi setiap kuantiti.

(20 markah)

(b) Dalam kawasan dos rendah, beberapa model digunakan untuk mendapatkan anggaran risiko bagi kanser. Bincangkan model-model itu dan kelemahan dalam model-model itu.

(30 markah)

(c) Di dalam dosimetri foton, air dianggapkan setara dengan tisu tetapi bagi dosimetri neutron air tidak boleh dianggap setara dengan tisu. Mengapa?

(20 markah)

(d) Suatu ion chamber A-150 setara dengan tisu mempunyai ketebalan dinding 0.52 g cm^{-2} dan $N_x A_{ion}$ 4.60×10^9 R/C bagi sinar γ ^{60}Co. Hitungkan nilai A (respons per unit dos serapan dalam tisu bagi sinar γ). Juga hitungkan B/A bagi chamber ini yang mengandungi gas TE dan disinari dengan 4.2 Mev neutron.

B = respons per unit dos serapan dalam tisu bagi neutron.

Anggapkan $(W_n/e)_g/(W_\gamma/e)_g = 1.062$

(30 markah)

- oooOooo -

APPENDIX A.2. Conversion Factors

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

Energy–wavelength conversion:

1.23985×10^{-6} eV m
12.3985 keV Å

Exposure conversion:

1 roentgen (R) = 2.58×10^{-4} C/kg
1 C/kg = 3876 R

TABLE A-3b · WATER $\bar{Z} = 7.51$

$\rho = 1000$ kg/m^3

3.343×10^{26} elect./kg

TABLE A-3a - AIR $\bar{Z} = 7.78$

$\rho = 1.205$ kg/m^3 (at NTP)

3.006×10^{26} elect./kg

TABLE A-3d - BONE $\bar{Z} = 12.31$

$\rho = 1650$ kg/m^3

3.192×10^{26} elect./kg

TABLE A-3c - MUSCLE $\bar{Z} = 7.64$

$\rho = 1040$ kg/m^3

3.312×10^{26} elect./kg

526

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.

APPENDIX D.3. *(Continued)*

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 E. *(Continued)*

Carbon (Graphite)

ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	STOPPING POWER TOTAL	CSDA RANGE	RADIATION YIELD	DENS.EFF. CORR. (DELTA)
MeV	MeV cm²/g	MeV cm²/g	MeV cm²/g	g/cm²		
0.0100	2.014E+01	3.150E-03	2.014E+01	2.820E-04	8.665E-05	1.920E-03
0.0125	1.694E+01	3.161E-03	1.695E+01	4.179E-04	1.036E-04	2.481E-03
0.0150	1.471E+01	3.168E-03	1.471E+01	5.767E-04	1.199E-04	3.073E-03
0.0175	1.305E+01	3.172E-03	1.305E+01	7.575E-04	1.355E-04	3.695E-03
0.0200	1.177E+01	3.176E-03	1.177E+01	9.595E-04	1.506E-04	4.347E-03
0.0250	9.913E+00	3.184E-03	9.916E+00	1.424E-03	1.796E-04	5.736E-03
0.0300	8.626E+00	3.194E-03	8.629E+00	1.966E-03	2.073E-04	7.236E-03
0.0350	7.679E+00	3.204E-03	7.682E+00	2.582E-03	2.340E-04	8.843E-03
0.0400	6.950E+00	3.215E-03	6.953E+00	3.267E-03	2.597E-04	1.055E-02
0.0450	6.372E+00	3.228E-03	6.375E+00	4.019E-03	2.847E-04	1.236E-02
0.0500	5.901E+00	3.241E-03	5.904E+00	4.835E-03	3.090E-04	1.425E-02
0.0550	5.510E+00	3.255E-03	5.513E+00	5.712E-03	3.327E-04	1.624E-02
0.0600	5.179E+00	3.270E-03	5.183E+00	6.648E-03	3.558E-04	1.832E-02
0.0700	4.652E+00	3.303E-03	4.655E+00	8.688E-03	4.008E-04	2.271E-02
0.0800	4.249E+00	3.337E-03	4.253E+00	1.094E-02	4.441E-04	2.740E-02
0.0900	3.931E+00	3.375E-03	3.935E+00	1.339E-02	4.860E-04	3.237E-02
0.1000	3.674E+00	3.414E-03	3.677E+00	1.602E-02	5.268E-04	3.760E-02
0.1250	3.204E+00	3.523E-03	3.207E+00	2.353E-02	6.243E-04	5.166E-02
0.1500	2.886E+00	3.640E-03	2.890E+00	3.156E-02	7.168E-04	6.694E-02
0.1750	2.657E+00	3.764E-03	2.661E+00	4.059E-02	8.059E-04	8.320E-02
0.2000	2.485E+00	3.896E-03	2.489E+00	5.032E-02	8.911E-04	1.003E-01
0.2500	2.245E+00	4.179E-03	2.249E+00	7.152E-02	1.055E-03	1.363E-01
0.3000	2.087E+00	4.489E-03	2.092E+00	9.462E-02	1.213E-03	1.760E-01
0.3500	1.977E+00	4.820E-03	1.981E+00	1.192E-01	1.367E-03	2.129E-01
0.4000	1.896E+00	5.173E-03	1.901E+00	1.450E-01	1.518E-03	2.524E-01
0.4500	1.835E+00	5.545E-03	1.841E+00	1.718E-01	1.668E-03	2.922E-01
0.5000	1.788E+00	5.935E-03	1.794E+00	1.993E-01	1.817E-03	3.321E-01
0.5500	1.752E+00	6.340E-03	1.758E+00	2.274E-01	1.966E-03	3.719E-01
0.6000	1.722E+00	6.759E-03	1.729E+00	2.561E-01	2.115E-03	4.114E-01
0.7000	1.679E+00	7.637E-03	1.687E+00	3.147E-01	2.416E-03	4.891E-01
0.8000	1.650E+00	8.559E-03	1.659E+00	3.745E-01	2.719E-03	5.648E-01
0.9000	1.631E+00	9.523E-03	1.640E+00	4.352E-01	3.026E-03	6.382E-01
1.0000	1.617E+00	1.053E-02	1.627E+00	4.964E-01	3.337E-03	7.091E-01
1.2500	1.599E+00	1.318E-02	1.612E+00	6.509E-01	4.133E-03	8.756E-01
1.5000	1.593E+00	1.602E-02	1.609E+00	8.062E-01	4.954E-03	1.028E+00
1.7500	1.594E+00	1.901E-02	1.613E+00	9.614E-01	5.799E-03	1.167E+00
2.0000	1.597E+00	2.213E-02	1.619E+00	1.116E+00	6.665E-03	1.295E+00
2.5000	1.608E+00	2.870E-02	1.637E+00	1.423E+00	8.450E-03	1.522E+00
3.0000	1.621E+00	3.561E-02	1.657E+00	1.727E+00	1.029E-02	1.720E+00
3.5000	1.634E+00	4.281E-02	1.677E+00	2.027E+00	1.218E-02	1.894E+00
4.0000	1.647E+00	5.026E-02	1.697E+00	2.323E+00	1.410E-02	2.051E+00
4.5000	1.658E+00	5.792E-02	1.716E+00	2.616E+00	1.606E-02	2.193E+00
5.0000	1.669E+00	6.576E-02	1.735E+00	2.906E+00	1.803E-02	2.323E+00
5.5000	1.679E+00	7.378E-02	1.753E+00	3.193E+00	2.003E-02	2.443E+00
6.0000	1.689E+00	8.193E-02	1.771E+00	3.476E+00	2.204E-02	2.555E+00
7.0000	1.706E+00	9.865E-02	1.804E+00	4.036E+00	2.610E-02	2.758E+00
8.0000	1.720E+00	1.158E-01	1.836E+00	4.585E+00	3.020E-02	2.939E+00
9.0000	1.733E+00	1.334E-01	1.867E+00	5.125E+00	3.432E-02	3.104E+00
10.0000	1.745E+00	1.513E-01	1.896E+00	5.657E+00	3.845E-02	3.256E+00
12.5000	1.769E+00	1.971E-01	1.966E+00	6.952E+00	4.877E-02	3.591E+00
15.0000	1.787E+00	2.444E-01	2.032E+00	8.202E+00	5.903E-02	3.879E+00
17.5000	1.803E+00	2.927E-01	2.095E+00	9.414E+00	6.918E-02	4.133E+00
20.0000	1.816E+00	3.417E-01	2.157E+00	1.059E+01	7.917E-02	4.361E+00
25.0000	1.836E+00	4.417E-01	2.278E+00	1.284E+01	9.861E-02	4.755E+00
30.0000	1.852E+00	5.435E-01	2.396E+00	1.498E+01	1.173E-01	5.088E+00
35.0000	1.865E+00	6.466E-01	2.512E+00	1.702E+01	1.351E-01	5.376E+00
40.0000	1.877E+00	7.508E-01	2.627E+00	1.897E+01	1.522E-01	5.628E+00
45.0000	1.886E+00	8.559E-01	2.742E+00	2.083E+01	1.685E-01	5.854E+00
50.0000	1.895E+00	9.617E-01	2.857E+00	2.262E+01	1.841E-01	6.057E+00
55.0000	1.903E+00	1.068E+00	2.971E+00	2.433E+01	1.991E-01	6.241E+00
60.0000	1.910E+00	1.175E+00	3.085E+00	2.598E+01	2.133E-01	6.411E+00
70.0000	1.922E+00	1.391E+00	3.313E+00	2.911E+01	2.401E-01	6.712E+00
80.0000	1.932E+00	1.608E+00	3.541E+00	3.203E+01	2.648E-01	6.974E+00
90.0000	1.942E+00	1.826E+00	3.768E+00	3.477E+01	2.875E-01	7.206E+00

APPENDIX E. *(Continued)*

Air (Dry)

ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	STOPPING POWER TOTAL	CSDA RANGE	RADIATION YIELD	DENS.EFF. CORR. (DELTA)
MeV	MeV cm²/g	MeV cm²/g	MeV cm²/g	g/cm²		
0.0100	1.975E+01	3.897E-03	1.976E+01	2.883E-04	1.082E-04	0.0
0.0125	1.663E+01	3.921E-03	1.663E+01	4.269E-04	1.299E-04	0.0
0.0150	1.445E+01	3.937E-03	1.445E+01	5.886E-04	1.506E-04	0.0
0.0175	1.283E+01	3.946E-03	1.283E+01	7.726E-04	1.706E-04	0.0
0.0200	1.157E+01	3.954E-03	1.158E+01	9.781E-04	1.898E-04	0.0
0.0250	9.753E+00	3.966E-03	9.757E+00	1.451E-03	2.267E-04	0.0
0.0300	8.492E+00	3.976E-03	8.496E+00	2.001E-03	2.618E-04	0.0
0.0350	7.563E+00	3.986E-03	7.567E+00	2.626E-03	2.955E-04	0.0
0.0400	6.848E+00	3.998E-03	6.852E+00	3.322E-03	3.280E-04	0.0
0.0450	6.281E+00	4.011E-03	6.285E+00	4.085E-03	3.594E-04	0.0
0.0500	5.819E+00	4.025E-03	5.823E+00	4.912E-03	3.900E-04	0.0
0.0550	5.435E+00	4.040E-03	5.439E+00	5.801E-03	4.197E-04	0.0
0.0600	5.111E+00	4.057E-03	5.115E+00	6.750E-03	4.488E-04	0.0
0.0700	4.593E+00	4.093E-03	4.597E+00	8.817E-03	5.049E-04	0.0
0.0800	4.198E+00	4.133E-03	4.202E+00	1.110E-02	5.590E-04	0.0
0.0900	3.886E+00	4.175E-03	3.890E+00	1.357E-02	6.112E-04	0.0
0.1000	3.633E+00	4.222E-03	3.637E+00	1.623E-02	6.618E-04	0.0
0.1250	3.172E+00	4.348E-03	3.177E+00	2.362E-02	7.826E-04	0.0
0.1500	2.861E+00	4.485E-03	2.865E+00	3.193E-02	8.968E-04	0.0
0.1750	2.637E+00	4.633E-03	2.642E+00	4.103E-02	1.006E-03	0.0
0.2000	2.470E+00	4.789E-03	2.474E+00	5.082E-02	1.111E-03	0.0
0.2500	2.236E+00	5.126E-03	2.242E+00	7.212E-02	1.311E-03	0.0
0.3000	2.084E+00	5.495E-03	2.089E+00	9.527E-02	1.502E-03	0.0
0.3500	1.978E+00	5.890E-03	1.984E+00	1.199E-01	1.688E-03	0.0
0.4000	1.902E+00	6.311E-03	1.908E+00	1.456E-01	1.869E-03	0.0
0.4500	1.845E+00	6.757E-03	1.852E+00	1.722E-01	2.048E-03	0.0
0.5000	1.802E+00	7.223E-03	1.809E+00	1.995E-01	2.225E-03	0.0
0.5500	1.769E+00	7.708E-03	1.776E+00	2.274E-01	2.401E-03	0.0
0.6000	1.743E+00	8.210E-03	1.751E+00	2.558E-01	2.577E-03	0.0
0.7000	1.706E+00	9.258E-03	1.715E+00	3.135E-01	2.929E-03	0.0
0.8000	1.683E+00	1.036E-02	1.694E+00	3.722E-01	3.283E-03	0.0
0.9000	1.669E+00	1.151E-02	1.681E+00	4.315E-01	3.638E-03	0.0
1.0000	1.661E+00	1.271E-02	1.674E+00	4.912E-01	3.997E-03	0.0
1.2500	1.655E+00	1.588E-02	1.671E+00	6.408E-01	4.906E-03	0.0
1.5000	1.661E+00	1.927E-02	1.680E+00	7.900E-01	5.836E-03	0.0
1.7500	1.672E+00	2.284E-02	1.694E+00	9.382E-01	6.784E-03	0.0
2.0000	1.684E+00	2.656E-02	1.711E+00	1.085E+00	7.748E-03	0.0
2.5000	1.712E+00	3.437E-02	1.747E+00	1.374E+00	9.716E-03	0.0
3.0000	1.740E+00	4.260E-02	1.783E+00	1.658E+00	1.173E-02	0.0
3.5000	1.766E+00	5.115E-02	1.817E+00	1.935E+00	1.377E-02	0.0
4.0000	1.790E+00	5.999E-02	1.850E+00	2.208E+00	1.583E-02	0.0
4.5000	1.812E+00	6.908E-02	1.882E+00	2.476E+00	1.792E-02	0.0
5.0000	1.833E+00	7.838E-02	1.911E+00	2.740E+00	2.001E-02	0.0
5.5000	1.852E+00	8.787E-02	1.940E+00	2.999E+00	2.211E-02	0.0
6.0000	1.870E+00	9.754E-02	1.968E+00	3.255E+00	2.422E-02	0.0
7.0000	1.902E+00	1.173E-01	2.020E+00	3.757E+00	2.845E-02	0.0
8.0000	1.931E+00	1.376E-01	2.068E+00	4.246E+00	3.269E-02	0.0
9.0000	1.956E+00	1.584E-01	2.115E+00	4.724E+00	3.692E-02	0.0
10.0000	1.979E+00	1.795E-01	2.159E+00	5.192E+00	4.113E-02	0.0
12.5000	2.029E+00	2.337E-01	2.262E+00	6.323E+00	5.156E-02	0.0
15.0000	2.069E+00	2.895E-01	2.359E+00	7.405E+00	6.181E-02	0.0
17.5000	2.104E+00	3.464E-01	2.451E+00	8.444E+00	7.185E-02	0.0
20.0000	2.136E+00	4.042E-01	2.539E+00	9.446E+00	8.167E-02	0.0
25.0000	2.185E+00	5.219E-01	2.707E+00	1.135E+01	1.006E-01	0.0
30.0000	2.226E+00	6.417E-01	2.868E+00	1.315E+01	1.186E-01	7.636E-03
35.0000	2.257E+00	7.630E-01	3.020E+00	1.485E+01	1.357E-01	5.984E-02
40.0000	2.282E+00	8.855E-01	3.167E+00	1.646E+01	1.520E-01	1.378E-01
45.0000	2.302E+00	1.009E+00	3.311E+00	1.801E+01	1.676E-01	2.266E-01
50.0000	2.319E+00	1.133E+00	3.452E+00	1.948E+01	1.825E-01	3.192E-01
55.0000	2.334E+00	1.258E+00	3.592E+00	2.090E+01	1.968E-01	4.120E-01
60.0000	2.347E+00	1.384E+00	3.731E+00	2.227E+01	2.104E-01	5.029E-01
70.0000	2.369E+00	1.637E+00	4.006E+00	2.486E+01	2.361E-01	6.762E-01
80.0000	2.387E+00	1.892E+00	4.279E+00	2.727E+01	2.598E-01	8.365E-01
90.0000	2.403E+00	2.148E+00	4.551E+00	2.954E+01	2.818E-01	9.842E-01

APPENDIX E. *(Continued)*

Water (Liquid)

ENERGY	STOPPING POWER COLLISION	STOPPING POWER RADIATIVE	STOPPING POWER TOTAL	CSDA RANGE	RADIATION YIELD	DENS.EFF. CORR. (DELTA)
MeV	MeV cm²/g	MeV cm²/g	MeV cm²/g	g/cm²		
0.0100	2.256E+01	3.898E-03	2.257E+01	2.515E-04	9.408E-05	0.0
0.0125	1.897E+01	3.927E-03	1.898E+01	3.728E-04	1.133E-04	0.0
0.0150	1.647E+01	3.944E-03	1.647E+01	5.147E-04	1.316E-04	0.0
0.0175	1.461E+01	3.955E-03	1.461E+01	6.761E-04	1.492E-04	0.0
0.0200	1.317E+01	3.963E-03	1.318E+01	8.566E-04	1.663E-04	0.0
0.0250	1.109E+01	3.974E-03	1.110E+01	1.272E-03	1.990E-04	0.0
0.0300	9.653E+00	3.984E-03	9.657E+00	1.756E-03	2.301E-04	0.0
0.0350	8.592E+00	3.994E-03	8.596E+00	2.306E-03	2.599E-04	0.0
0.0400	7.777E+00	4.005E-03	7.781E+00	2.919E-03	2.886E-04	0.0
0.0450	7.130E+00	4.018E-03	7.134E+00	3.591E-03	3.165E-04	0.0
0.0500	6.603E+00	4.031E-03	6.607E+00	4.320E-03	3.435E-04	0.0
0.0550	6.166E+00	4.046E-03	6.170E+00	5.103E-03	3.698E-04	0.0
0.0600	5.797E+00	4.062E-03	5.801E+00	5.940E-03	3.955E-04	0.0
0.0700	5.207E+00	4.098E-03	5.211E+00	7.762E-03	4.452E-04	0.0
0.0800	4.757E+00	4.138E-03	4.762E+00	9.773E-03	4.931E-04	0.0
0.0900	4.402E+00	4.181E-03	4.407E+00	1.196E-02	5.393E-04	0.0
0.1000	4.115E+00	4.228E-03	4.120E+00	1.431E-02	5.841E-04	0.0
0.1250	3.591E+00	4.355E-03	3.596E+00	2.083E-02	6.912E-04	0.0
0.1500	3.238E+00	4.494E-03	3.242E+00	2.817E-02	7.926E-04	0.0
0.1750	2.984E+00	4.643E-03	2.988E+00	3.622E-02	8.894E-04	0.0
0.2000	2.793E+00	4.801E-03	2.798E+00	4.487E-02	9.826E-04	0.0
0.2500	2.528E+00	5.141E-03	2.533E+00	6.372E-02	1.161E-03	0.0
0.3000	2.355E+00	5.514E-03	2.360E+00	8.421E-02	1.331E-03	0.0
0.3500	2.235E+00	5.913E-03	2.241E+00	1.060E-01	1.496E-03	0.0
0.4000	2.148E+00	6.339E-03	2.154E+00	1.288E-01	1.658E-03	0.0
0.4500	2.083E+00	6.787E-03	2.090E+00	1.523E-01	1.818E-03	0.0
0.5000	2.034E+00	7.257E-03	2.041E+00	1.766E-01	1.976E-03	0.0
0.5500	1.995E+00	7.747E-03	2.003E+00	2.013E-01	2.134E-03	1.103E-02
0.6000	1.963E+00	8.254E-03	1.972E+00	2.265E-01	2.292E-03	2.938E-02
0.7000	1.917E+00	9.312E-03	1.926E+00	2.778E-01	2.608E-03	7.435E-02
0.8000	1.886E+00	1.043E-02	1.896E+00	3.302E-01	2.928E-03	1.267E-01
0.9000	1.864E+00	1.159E-02	1.876E+00	3.832E-01	3.251E-03	1.835E-01
1.0000	1.849E+00	1.280E-02	1.862E+00	4.367E-01	3.579E-03	2.428E-01
1.2500	1.829E+00	1.600E-02	1.845E+00	5.717E-01	4.416E-03	3.944E-01
1.5000	1.822E+00	1.942E-02	1.841E+00	7.075E-01	5.281E-03	5.437E-01
1.7500	1.821E+00	2.303E-02	1.844E+00	8.432E-01	6.171E-03	6.866E-01
2.0000	1.824E+00	2.678E-02	1.850E+00	9.785E-01	7.085E-03	8.218E-01
2.5000	1.834E+00	3.468E-02	1.868E+00	1.247E+00	8.969E-03	1.069E+00
3.0000	1.844E+00	4.299E-02	1.889E+00	1.514E+00	1.092E-02	1.288E+00
3.5000	1.858E+00	5.164E-02	1.910E+00	1.777E+00	1.291E-02	1.484E+00
4.0000	1.870E+00	6.058E-02	1.931E+00	2.037E+00	1.495E-02	1.660E+00
4.5000	1.882E+00	6.976E-02	1.951E+00	2.295E+00	1.702E-02	1.821E+00
5.0000	1.892E+00	7.917E-02	1.971E+00	2.550E+00	1.911E-02	1.967E+00
5.5000	1.902E+00	8.876E-02	1.991E+00	2.802E+00	2.123E-02	2.102E+00
6.0000	1.911E+00	9.854E-02	2.010E+00	3.052E+00	2.336E-02	2.227E+00
7.0000	1.928E+00	1.185E-01	2.047E+00	3.545E+00	2.766E-02	2.453E+00
8.0000	1.943E+00	1.391E-01	2.082E+00	4.030E+00	3.200E-02	2.652E+00
9.0000	1.956E+00	1.601E-01	2.116E+00	4.506E+00	3.636E-02	2.831E+00
10.0000	1.968E+00	1.814E-01	2.149E+00	4.975E+00	4.072E-02	2.992E+00
12.5000	1.993E+00	2.362E-01	2.230E+00	6.117E+00	5.163E-02	3.341E+00
15.0000	2.014E+00	2.926E-01	2.306E+00	7.219E+00	6.243E-02	3.633E+00
17.5000	2.031E+00	3.501E-01	2.381E+00	8.286E+00	7.309E-02	3.885E+00
20.0000	2.046E+00	4.086E-01	2.454E+00	9.320E+00	8.355E-02	4.107E+00
25.0000	2.070E+00	5.277E-01	2.598E+00	1.130E+01	1.039E-01	4.487E+00
30.0000	2.089E+00	6.489E-01	2.738E+00	1.317E+01	1.233E-01	4.806E+00
35.0000	2.105E+00	7.716E-01	2.876E+00	1.496E+01	1.418E-01	5.082E+00
40.0000	2.118E+00	8.955E-01	3.013E+00	1.665E+01	1.594E-01	5.326E+00
45.0000	2.129E+00	1.021E+00	3.150E+00	1.828E+01	1.762E-01	5.544E+00
50.0000	2.139E+00	1.146E+00	3.286E+00	1.983E+01	1.923E-01	5.741E+00
55.0000	2.148E+00	1.273E+00	3.421E+00	2.132E+01	2.076E-01	5.921E+00
60.0000	2.156E+00	1.400E+00	3.556E+00	2.276E+01	2.222E-01	6.087E+00
70.0000	2.170E+00	1.656E+00	3.827E+00	2.547E+01	2.496E-01	6.383E+00
80.0000	2.182E+00	1.914E+00	4.096E+00	2.799E+01	2.747E-01	6.641E+00
90.0000	2.193E+00	2.173E+00	4.366E+00	3.035E+01	2.978E-01	6.871E+00

APPENDIX F. *(Continued)*

En/MeV	ΔEn/MeV	Tissue Appx	Bone (Femur)	Muscle ICRU	Std Man	A-150 Plast
.820+00	.400-01	.202-08	.133-08	.204-08	.201-08	.210-08
.860+00	.400-01	.207-08	.137-08	.210-08	.206-08	.215-08
.900+00	.400-01	.214-08	.141-08	.217-08	.213-08	.219-08
.940+00	.400-01	.224-08	.147-08	.227-08	.222-08	.224-08
.980+00	.400-01	.241-08	.158-08	.245-08	.239-08	.230-08
.105+01	.100+00	.245-08	.160-08	.248-08	.242-08	.237-08
.115+01	.100+00	.242-08	.160-08	.246-08	.241-08	.247-08
.125+01	.100+00	.252-08	.166-08	.256-08	.251-08	.256-08
.135+01	.100+00	.261-08	.172-08	.265-08	.260-08	.266-08
.145+01	.100+00	.265-08	.175-08	.269-08	.264-08	.275-08
.155+01	.100+00	.273-08	.180-08	.277-08	.272-08	.283-08
.165+01	.100+00	.283-08	.187-08	.287-08	.282-08	.291-08
.175+01	.100+00	.287-08	.190-08	.291-08	.286-08	.259-08
.185+01	.100+00	.298-08	.197-08	.303-08	.297-08	.306-08
.195+01	.100+00	.300-08	.199-08	.304-08	.299-08	.313-08
.210+01	.200+00	.309-08	.207-08	.313-08	.309-08	.328-08
.230+01	.200+00	.314-08	.210-08	.318-08	.314-08	.337-08
.250+01	.200+00	.326-08	.220-08	.331-08	.327-08	.352-08
.270+01	.200+00	.341-08	.232-08	.346-08	.341-08	.370-08
.290+01	.200+00	.355-08	.246-08	.360-08	.356-08	.398-08
.310+01	.200+00	.368-08	.251-08	.373-08	.367-08	.391-08
.330+01	.200+00	.401-08	.278-08	.406-08	.400-08	.426-08
.350+01	.200+00	.410-08	.287-08	.415-08	.409-08	.446-08
.370+01	.200+00	.420-08	.294-08	.425-08	.419-08	.450-08
.390+01	.200+00	.413-08	.290-08	.418-08	.413-08	.449-08
.420+01	.400+00	.425-08	.296-08	.431-08	.424-08	.447-08
.460+01	.400+00	.425-08	.293-08	.431-08	.424-08	.442-08
.500+01	.400+00	.448-08	.307-08	.455-08	.446-08	.446-08
.540+01	.400+00	.437-08	.303-08	.444-08	.437-08	.458-08
.580+01	.400+00	.457-08	.316-08	.464-08	.456-08	.468-08
.620+01	.400+00	.469-08	.328-08	.475-08	.469-08	.493-08
.660+01	.400+00	.481-08	.330-08	.489-08	.479-08	.475-08
.700+01	.400+00	.501-08	.342-08	.510-08	.498-08	.481-08
.740+01	.400+00	.525-08	.367-08	.537-08	.526-08	.515-08
.780+01	.400+00	.522-08	.374-08	.529-08	.522-08	.559-08
.820+01	.400+00	.517-08	.364-08	.525-08	.516-08	.531-08
.860+01	.400+00	.534-08	.371-08	.542-08	.531-08	.523-08
.900+01	.400+00	.544-08	.387-08	.551-08	.542-08	.561-08
.940+01	.400+00	.548-08	.397-08	.555-08	.548-08	.589-08
.980+01	.400+00	.561-08	.400-08	.566-08	.559-08	.573-08
.105+02	.100+01	.574-08	.408-08	.582-08	.571-08	.577-08
.115+02	.100+01	.616-08	.439-08	.624-08	.611-08	.602-08
.125+02	.100+01	.614-08	.448-08	.621-08	.612-08	.636-08
.135+02	.100+01	.638-08	.467-08	.645-08	.635-08	.656-08
.145+02	.100+01	.663-08	.489-08	.670-08	.659-08	.695-08
.155+02	.100+01	.682-08	.511-08	.687-08	.679-08	.734-08
.165+02	.100+01	.691-08	.521-08	.695-08	.688-08	.761-08
.175+02	.100+01	.701-08	.528-08	.705-08	.698-08	.769-08
.185+02	.100+01	.711-08	.537-08	.715-08	.708-08	.784-08
.195+02	.100+01	.724-08	.547-08	.727-08	.720-08	.793-08
.210+02	.200+01	.739-08	.565-08	.742-08	.735-08	.820-08
.230+02	.200+01	.737-08	.574-08	.739-08	.735-08	.836-08
.250+02	.200+01	.733-08	.581-08	.734-08	.732-08	.851-08
.270+02	.200+01	.735-08	.591-08	.736-08	.736-08	.858-08
.290+02	.200+01	.723-08	.595-08	.724-08	.726-08	.871-08