UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Tambahan
Sidang Akademik 2000/200 1

April/Mei 200 1

ZCT 533/4 - Dosimetri dan Perlindungan Sinaran

Masa : 3 jam

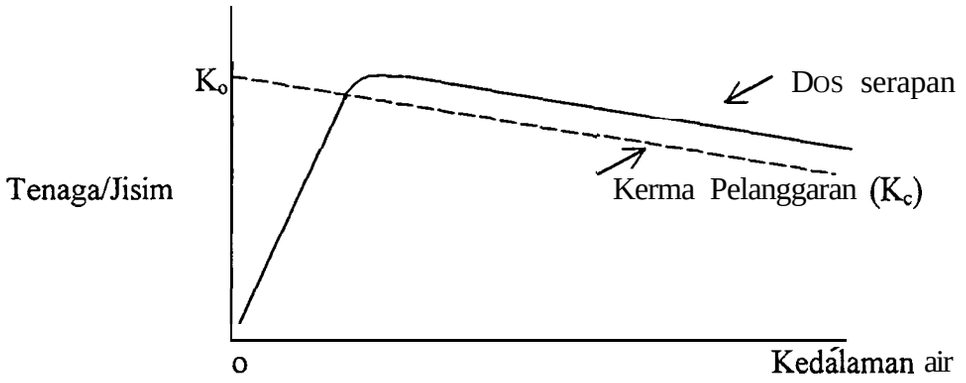
Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEBELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.

Jawab kesemua EMPAT soalan. Kesemuanya wajib dijawab dalam Bahasa Malaysia.

1. (a) Jelaskan perbezaan antara kerma dan dos serapan. Tentukan perhubungan antara dos serapan dan dedahan.

(20/1 00)

(b) Terangkan maksud seimbangan zarah bercas (CPE).



Graf di atas menunjukkan kerma dan dos serapan yang didapati apabila fantom air disinari dengan sinar foton selari yang bertenaga tinggi yang datangnya dari udara. Terangkan data yang diperhatikan di dalam graf

(35/100)

.. 2/-

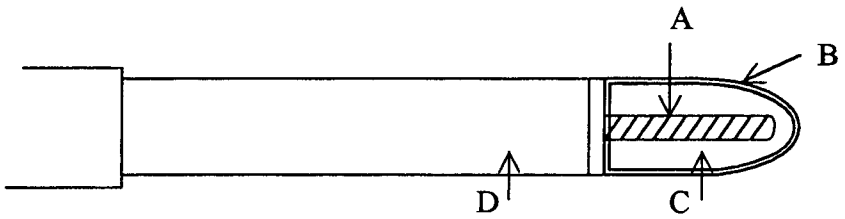
(c) Suatu alur foton mempunyai spektrum tenaga dari 0 MeV ke 6 MeV dan taburan fluensnya diberi oleh $\phi(E) = E^2 - 2E$ foton/m^2 MeV.

Hitungkan

(i) jumlah fluens
(ii) fluens tenaga purata
(iii) kerma purata apabila foton bertindak dengan air
(iv) dos serapan purata. Nyatakan sebarang anggapan yang digunakan.

(45/100)

2. (a)



Rajah menunjukkan suatu kebuk ion 'thimble'.

(i) Namakan setiap bahagian yang dilabelkan A, B, C, D.

(ii) Nyatakan bahan yang digunakan untuk membina setiap bahagian dan terangkan sebab jenis bahan itu digunakan. Juga terangkan fungsinya.

(20/100)

(b) Biasanya N_{gas} bagi suatu kebuk ion dihitungkan. Mengapa? Terangkan bagaimana N_{gas} dihitungkan. Tunjukkan langkah-langkah perhitungan dengan jelas.

(30/100)

(c) Suatu kalibrasi bagi dos serapan perlu dilakukan untuk bim foton 10 MV dari suatu linear accelerator. Huraikan dengan teliti semua langkah dan persamaan yang perlu dilakukan kalau protokol AAPM digunakan.

(50/100)

3. (a) Nyatakan teorem kaviti Bragg-Gray (B-G). Terangkan had kegunaannya merujuk kepada sinaran foton dan neutron.

(20/100)

... 3/-

(b) Pertimbangkan dua kebuk pengionan kaviti udara yang sama tetapi dindingnya berbeza. Satu kebuk mempunyai dinding aluminium sementara yang satu lagi mempunyai dinding graphite. Anggapkan tiada pengecilan berlaku pada foton yang bertenaga 1 MeV apabila melalui dinding dan kebuk ion bertindak seperti kaviti B-G.

(i) Ketebalan dinding perlu melebihi julat elektron sekunder dari foton 1 MeV. Mengapa?

(ii) Hitungkan nisbah cas yang dihasilkan dalam kedua-dua kebuk ion.

(iii) Jelaskan perbezaan dalam nilai cas yang terhasil.

(iv) Kebuk ion manakah yang lebih sesuai untuk mengukur dos dalam tisu? Jelaskan.

(40/100)

(c) Suatu kebuk ion yang berdinding nipis didedahkan kepada 100R sinar ^{60}Co. Tetapi bacaan dalam dosimeter hanya memberi 80R. Jelaskan.

Faktor kalibrasi bagi kebuk ion adalah jitu.

(20/100)

(d) Jelaskan maksud dan kepentingan tenaga spesifik z dan dos serapan D.

(20/100)

4. (a) Huraikan bagaimana proses termoluminesens (TL) berlaku. Kemudian terbitkan dos serapan dalam dosimeter TL jika dedahan X (Ckg^{-1}) dari sumber ^{60}Co diketahui dalam ruang bebas.

(30/100)

(b) Jelaskan bagimana bacaan relatif per unit dedahan bersandar kepada tenaga daripada 20 keV ke 1 MeV bagi TLD LiF dan CaF_2. Berikan sebab-sebabnya.

(30/100)

(c) Suatu bim Co-60 dikalibrasikan dalam udara. Bacaan berikut didapati:

Dedahan bagi satu minit	: 52R
Empat dedahan yang pendek dan dedahan setara dalam satu minit	: 50R
Tekanan	: 750 mmHg
Suhu	: 25°C

... 4/-

Kebuk ion udara mempunyai faktor kalibrasi C = 0.984

$$\left[C = \frac{\text{Bacaan dari dosimeter piawai}}{\text{Bacaan dari dosimeter biasa}} \right]$$

$\beta = 1.004$

(i) Hitungkan ralat bagi timer.
(ii) Hitungkan dos-serapannya dalam air.

(40/100)

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

Photon Energy (MeV)	Aluminum			Silicon			Calcium			Copper		
	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	26.2	25.5	25.5	34.1	33.3	33.3	96.5	91.6	91.6	224.2	160.	160.
0.015	7.90	7.47	7.47	10.2	9.75	9.75	30.1	28.6	28.6	74.1	59.4	59.4
0.02	3.39	3.06	3.06	4.36	4.01	4.01	12.9	12.2	12.2	33.7	28.2	28.2
0.03	1.12	0.868	0.868	1.41	1.14	1.14	3.98	3.60	3.60	10.9	9.50	9.50
0.04	0.565	0.357	0.357	0.693	0.472	0.472	1.78	1.50	1.50	4.88	4.24	4.24
0.05	0.367	0.184	0.184	0.435	0.241	0.241	0.994	0.764	0.764	2.61	2.22	2.22
0.06	0.277	0.111	0.111	0.319	0.144	0.144	0.646	0.444	0.444	1.60	1.32	1.32
0.08	0.201	0.0562	0.0562	0.223	0.0700	0.0700	0.363	0.196	0.196	0.768	0.573	0.573
0.10	0.170	0.0386	0.0386	0.184	0.0459	0.0459	0.255	0.109	0.109	0.462	0.302	0.302
0.15	0.138	0.0285	0.0285	0.145	0.0312	0.0312	0.168	0.0497	0.0497	0.223	0.106	0.106
0.2	0.122	0.0276	0.0276	0.128	0.0292	0.0292	0.138	0.0371	0.0371	0.157	0.0597	0.0597
0.3	0.104	0.0282	0.0282	0.108	0.0294	0.0294	0.112	0.0318	0.0318	0.112	0.0370	0.0370
0.4	0.0926	0.0287	0.0287	0.0961	0.0298	0.0298	0.0980	0.0309	0.0309	0.0942	0.0318	0.0318
0.5	0.0844	0.0287	0.0286	0.0875	0.0298	0.0298	0.0886	0.0304	0.0304	0.0835	0.0298	0.0298
0.6	0.0779	0.0286	0.0286	0.0806	0.0296	0.0295	0.0813	0.0300	0.0299	0.0762	0.0287	0.0286
0.8	0.0682	0.0279	0.0277	0.0708	0.0289	0.0288	0.0712	0.0291	0.0289	0.0659	0.0272	0.0271
1.0	0.0613	0.0270	0.0269	0.0634	0.0279	0.0277	0.0639	0.0280	0.0278	0.0590	0.0261	0.0258
1.5	0.0500	0.0247	0.0245	0.0517	0.0255	0.0253	0.0519	0.0257	0.0254	0.0479	0.0237	0.0233
2	0.0431	0.0229	0.0226	0.0447	0.0237	0.0234	0.0452	0.0240	0.0236	0.0419	0.0222	0.0217
3	0.0353	0.0206	0.0202	0.0367	0.0214	0.0210	0.0377	0.0220	0.0214	0.0359	0.0211	0.0202
4	0.0311	0.0193	0.0188	0.0324	0.0202	0.0196	0.0340	0.0213	0.0205	0.0332	0.0211	0.0200
5	0.0284	0.0185	0.0179	0.0297	0.0194	0.0187	0.0317	0.0211	0.0200	0.0318	0.0214	0.0200
6	0.0266	0.0181	0.0172	0.0279	0.0191	0.0182	0.0304	0.0211	0.0198	0.0310	0.0220	0.0202
8	0.0244	0.0177	0.0168	0.0257	0.0187	0.0177	0.0289	0.0215	0.0198	0.0307	0.0234	0.0209
10	0.0232	0.0176	0.0165	0.0246	0.0188	0.0175	0.0284	0.0222	0.0201	0.0310	0.0248	0.0215

Photon Energy (MeV)	Hydrogen			Carbon			Nitrogen			Oxygen		
	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	0.385	0.00986	0.00986	2.32	1.97	1.97	3.77	3.38	3.38	5.82	5.39	5.39
0.015	0.376	0.0110	0.0110	0.797	0.536	0.536	1.19	0.908	0.908	1.75	1.44	1.44
0.02	0.369	0.0135	0.0135	0.434	0.208	0.208	0.602	0.362	0.362	0.830	0.575	0.575
0.03	0.357	0.0185	0.0185	0.253	0.0594	0.0594	0.304	0.105	0.105	0.373	0.165	0.165
0.04	0.346	0.0231	0.0231	0.205	0.0306	0.0306	0.229	0.0493	0.0493	0.257	0.0733	0.0733
0.05	0.335	0.0271	0.0271	0.185	0.0233	0.0233	0.196	0.0319	0.0319	0.211	0.0437	0.0437
0.06	0.326	0.0306	0.0306	0.174	0.0211	0.0211	0.181	0.0256	0.0256	0.190	0.0322	0.0322
0.08	0.309	0.0362	0.0362	0.162	0.0205	0.0205	0.164	0.0223	0.0223	0.168	0.0249	0.0249
0.10	0.294	0.0406	0.0406	0.152	0.0215	0.0215	0.154	0.0224	0.0224	0.156	0.0237	0.0237
0.15	0.265	0.0481	0.0481	0.135	0.0245	0.0245	0.136	0.0247	0.0247	0.137	0.0251	0.0251
0.2	0.243	0.0525	0.0525	0.123	0.0265	0.0265	0.124	0.0267	0.0267	0.124	0.0268	0.0268
0.3	0.211	0.0569	0.0569	0.107	0.0287	0.0287	0.107	0.0287	0.0287	0.107	0.0288	0.0288
0.4	0.189	0.0586	0.0586	0.0953	0.0295	0.0295	0.0953	0.0295	0.0295	0.0957	0.0295	0.0295
0.5	0.173	0.0593	0.0593	0.0870	0.0297	0.0297	0.0870	0.0297	0.0296	0.0871	0.0297	0.0297
0.6	0.160	0.0587	0.0587	0.0805	0.0296	0.0295	0.0805	0.0296	0.0295	0.0805	0.0296	0.0296
0.8	0.140	0.0574	0.0574	0.0707	0.0289	0.0288	0.0707	0.0289	0.0289	0.0707	0.0289	0.0289
1.0	0.126	0.0555	0.0555	0.0637	0.0279	0.0279	0.0636	0.0280	0.0279	0.0637	0.0280	0.0278
1.5	0.103	0.0507	0.0507	0.0519	0.0256	0.0255	0.0518	0.0256	0.0255	0.0518	0.0256	0.0254
2	0.0875	0.0465	0.0464	0.0443	0.0235	0.0234	0.0444	0.0236	0.0234	0.0445	0.0236	0.0234
3	0.0691	0.0399	0.0398	0.0356	0.0206	0.0204	0.0357	0.0207	0.0205	0.0359	0.0208	0.0206
4	0.0581	0.0353	0.0352	0.0305	0.0187	0.0185	0.0308	0.0189	0.0186	0.0310	0.0191	0.0188
5	0.0505	0.0319	0.0317	0.0271	0.0174	0.0171	0.0274	0.0177	0.0173	0.0278	0.0179	0.0175
6	0.0450	0.0292	0.0290	0.0247	0.0164	0.0161	0.0251	0.0167	0.0163	0.0255	0.0171	0.0166
8	0.0375	0.0253	0.0252	0.0216	0.0151	0.0147	0.0221	0.0156	0.0151	0.0226	0.0160	0.0155
10	0.0325	0.0227	0.0225	0.0196	0.0143	0.0138	0.0203	0.0149	0.0143	0.0209	0.0154	0.0148

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	2.333E-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	8.055E-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	1.740E-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

Aluminum

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	1.649E+01	6.559E-03	1.650E+01	3.539E-04	2.132E-04	3.534E-04
0.0125	1.398E+01	6.700E-03	1.398E+01	5.192E-04	2.583E-04	4.937E-04
0.0150	1.220E+01	6.798E-03	1.221E+01	7.111E-04	3.016E-04	6.538E-04
0.0175	1.088E+01	6.871E-03	1.088E+01	9.284E-04	3.435E-04	8.332E-04
0.0200	9.844E+00	6.926E-03	9.851E+00	1.170E-03	3.840E-04	1.031E-03
0.0250	8.338E+00	7.004E-03	8.345E+00	1.724E-03	4.616E-04	1.483E-03
0.0300	7.287E+00	7.059E-03	7.294E+00	2.367E-03	5.353E-04	2.005E-03
0.0350	6.509E+00	7.100E-03	6.516E+00	3.093E-03	6.058E-04	2.593E-03
0.0400	5.909E+00	7.133E-03	5.916E+00	3.900E-03	6.736E-04	3.246E-03
0.0450	5.430E+00	7.162E-03	5.437E+00	4.783E-03	7.390E-04	3.960E-03
0.0500	5.039E+00	7.191E-03	5.046E+00	5.738E-03	8.022E-04	4.732E-03
0.0550	4.714E+00	7.217E-03	4.721E+00	6.763E-03	8.636E-04	5.560E-03
0.0600	4.439E+00	7.243E-03	4.446E+00	7.855E-03	9.232E-04	6.440E-03
0.0700	3.998E+00	7.295E-03	4.005E+00	1.023E-02	1.038E-03	8.351E-03
0.0800	3.661E+00	7.350E-03	3.668E+00	1.284E-02	1.147E-03	1.045E-02
0.0900	3.394E+00	7.411E-03	3.401E+00	1.568E-02	1.252E-03	1.271E-02
0.1000	3.177E+00	7.476E-03	3.185E+00	1.872E-02	1.353E-03	1.513E-02
0.1250	2.781E+00	7.659E-03	2.789E+00	2.714E-02	1.593E-03	2.175E-02
0.1500	2.513E+00	7.865E-03	2.521E+00	3.659E-02	1.816E-03	2.907E-02
0.1750	2.320E+00	8.096E-03	2.328E+00	4.693E-02	2.028E-03	3.694E-02
0.2000	2.174E+00	8.344E-03	2.183E+00	5.804E-02	2.231E-03	4.525E-02
0.2500	1.972E+00	8.888E-03	1.981E+00	8.217E-02	2.616E-03	6.280E-02
0.3000	1.839E+00	9.487E-03	1.849E+00	1.083E-01	2.982E-03	8.116E-02
0.3500	1.747E+00	1.013E-02	1.757E+00	1.361E-01	3.335E-03	9.997E-02
0.4000	1.680E+00	1.082E-02	1.691E+00	1.652E-01	3.678E-03	1.190E-01
0.4500	1.630E+00	1.154E-02	1.642E+00	1.952E-01	4.016E-03	1.380E-01
0.5000	1.592E+00	1.230E-02	1.604E+00	2.260E-01	4.349E-03	1.569E-01
0.5500	1.563E+00	1.309E-02	1.576E+00	2.575E-01	4.680E-03	1.757E-01
0.6000	1.540E+00	1.390E-02	1.554E+00	2.894E-01	5.009E-03	1.943E-01
0.7000	1.507E+00	1.560E-02	1.522E+00	3.545E-01	5.664E-03	2.307E-01
0.8000	1.486E+00	1.739E-02	1.503E+00	4.206E-01	6.319E-03	2.661E-01
0.9000	1.473E+00	1.925E-02	1.492E+00	4.874E-01	6.976E-03	3.005E-01
1.0000	1.465E+00	2.119E-02	1.486E+00	5.546E-01	7.636E-03	3.339E-01
1.2500	1.457E+00	2.630E-02	1.484E+00	7.231E-01	9.306E-03	4.138E-01
1.5000	1.460E+00	3.177E-02	1.491E+00	8.912E-01	1.101E-02	4.898E-01
1.7500	1.466E+00	3.752E-02	1.504E+00	1.058E+00	1.274E-02	5.632E-01
2.0000	1.475E+00	4.350E-02	1.518E+00	1.224E+00	1.449E-02	6.349E-01
2.5000	1.493E+00	5.605E-02	1.549E+00	1.550E+00	1.808E-02	7.757E-01
3.0000	1.510E+00	6.924E-02	1.580E+00	1.869E+00	2.173E-02	9.145E-01
3.5000	1.526E+00	8.292E-02	1.609E+00	2.183E+00	2.544E-02	1.051E+00
4.0000	1.540E+00	9.702E-02	1.637E+00	2.491E+00	2.918E-02	1.183E+00
4.5000	1.552E+00	1.115E-01	1.664E+00	2.794E+00	3.296E-02	1.311E+00
5.0000	1.564E+00	1.263E-01	1.690E+00	3.092E+00	3.675E-02	1.433E+00
5.5000	1.574E+00	1.413E-01	1.715E+00	3.386E+00	4.055E-02	1.550E+00
6.0000	1.583E+00	1.567E-01	1.739E+00	3.675E+00	4.436E-02	1.661E+00
7.0000	1.599E+00	1.879E-01	1.787E+00	4.242E+00	5.197E-02	1.868E+00
8.0000	1.613E+00	2.200E-01	1.833E+00	4.795E+00	5.955E-02	2.055E+00
9.0000	1.625E+00	2.526E-01	1.877E+00	5.334E+00	6.708E-02	2.226E+00
10.0000	1.636E+00	2.858E-01	1.921E+00	5.861E+00	7.454E-02	2.384E+00
12.5000	1.658E+00	3.706E-01	2.029E+00	7.127E+00	9.281E-02	2.727E+00
15.0000	1.676E+00	4.574E-01	2.134E+00	8.328E+00	1.105E-01	3.016E+00
17.5000	1.691E+00	5.459E-01	2.237E+00	9.472E+00	1.275E-01	3.265E+00
20.0000	1.704E+00	6.357E-01	2.340E+00	1.056E+01	1.438E-01	3.484E+00
25.0000	1.726E+00	8.180E-01	2.544E+00	1.261E+01	1.745E-01	3.857E+00
30.0000	1.743E+00	1.003E+00	2.746E+00	1.450E+01	2.027E-01	4.168E+00
35.0000	1.757E+00	1.190E+00	2.947E+00	1.626E+01	2.287E-01	4.435E+00
40.0000	1.769E+00	1.379E+00	3.148E+00	1.790E+01	2.528E-01	4.669E+00
45.0000	1.780E+00	1.569E+00	3.349E+00	1.944E+01	2.751E-01	4.878E+00
50.0000	1.789E+00	1.761E+00	3.550E+00	2.089E+01	2.959E-01	5.068E+00
55.0000	1.797E+00	1.953E+00	3.751E+00	2.226E+01	3.152E-01	5.241E+00
60.0000	1.805E+00	2.147E+00	3.951E+00	2.356E+01	3.333E-01	5.401E+00
70.0000	1.818E+00	2.535E+00	4.353E+00	2.597E+01	3.662E-01	5.687E+00
80.0000	1.829E+00	2.927E+00	4.755E+00	2.817E+01	3.953E-01	5.938E+00
90.0000	1.838E+00	3.320E+00	5.158E+00	3.019E+01	4.214E-01	6.161E+00

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	1.846E+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

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.