UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2008/2009

November 2008

ZCE 331/4 – Radiation Biophysics
[Biofizik Sinaran]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **ELEVEN** printed pages before you begin the examination.

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

Instruction: Answer **ANY FIVE (5)** questions only. Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab **MANA-MANA LIMA (5)** soalan sahaja. Pelajar dibenarkan menjawab semua soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]*

.../2-

1. a) Explain the process of α–decay and calculate the velocity of α–particles produced in the disintegration of Ra-226 (226.0254 amu) to Rn-222 (222.0175 amu). Draw the energy spectrum diagram.
[Terangkan proses reputan-α dan hitungkan halaju zarah-α yang dihasilkan dalam penyepaian Ra-226 (226.0254 amu) kepada Rn-222 (222.0175 amu). Lakarkan gambarajah spektrum tenaga.]

(30/100)

b) In a radioactive process, Nitrogen–12 is found to be decayed to Carbon–12 with positron emission. In this process valence electron from main atom also released simultaneously. Calculate the energy released in the process and explain the important step in this decay. (Given mass of $^{12}N_7$ = 12.02278 amu, Mass of $^{12}C_6$ = 12.003803 amu).
[Dalam suatu proses radioaktif, Nitrogen–12 didapati mereput kepada Karbon–12 dengan pancaran positron. Dalam proses ini, elektron valens daripada atom utama juga dikeluarkan secara serentak. Hitungkan tenaga yang dieluarkan dalam proses tersebut dan terangkan langkah penting dalam pereputan ini. (Diberi jisim $^{12}N_7$ = 12.02278 amu, Jisim $^{12}C_6$ = 12.003803 amu)]

(20/100)

c) A 1.8 mCi source of radon ($T_{1/2}$ = 3.83 days) is permanently implanted into a patient.
[Suatu 1.8 mCi sumber radon ($T_{1/2}$ = 3.83 hari) diimplan secara kekal ke dalam seorang pasien.]

i) Find the decay constant.
[Cari pemalar reputan.]

ii) Express the half life and mean life of this source in SI unit with their definition.
[Ungkapkan setengah hayat dan min hayat sumber tersebut dalam unit SI dengan takrifannya.]

iii) What is the relation connecting half life and mean life?
[Apakah persamaan yang menghubungkan setengah hayat dan min hayat?]

...3/-

iv) Determine the radiation emitted by radon.
[Tentukan sinaran yang dikeluarkan oleh radon.]

(50/100)

2. a) Explain the basic differences between the interaction of electron with matter and interaction of photons with matter.
[Terangkan perbezaan antara interaksi elektron dengan jirim dan interaksi foton dengan jirim].

(20/100)

b) In an X-ray interaction experiment, a series of 5 absorbers of same material, each of 1cm thickness, with an absorption coefficient of 10% are used. Calculate the intensity of radiation transmitted through the absorbers using :
[Dalam eksperimen interaksi sinar-X, suatu siri 5 penyerap terdiri daripada bahan yang sama, setiap satunya ketebalan 1cm, dengan pekali penyerapan 10% digunakan. Hitungkan keamatan sinaran terpancar menerusi penyerap-penyerap menggunakan :]

i) the definition of absorption coefficient and
[takrifan pekali penyerapan dan]

ii) the exponential law of absorption process
[hukum eksponen proses penyerapan]

iii) Justify which one of these two is more correct with valid reasons.
[Justifikasikan yang mana satu daripada soalan (i) dan (ii) adalah lebih tepat. Berikan alasan-alasan yang sah]

(50/100)

c) A cobalt-60 unit gives the γ-ray photon exposure at a rate of 120 R/min at 1 meter when the source is 'on'. Protection regulations require that when the source is 'off' the radiation level at 1 meter distance be less than 2 mR/hr. If the emitted photons are of 0.6 MeV, determine the thickness of lead shielding required. (Given density of lead is 11.3 gm/cm^3)
[Suatu unit Kobalt-60 memberikan dedahan foton sinar-γ pada kadar 120 R/min pada jarak 1 meter bila sumber di 'on'. Peraturan perlindungan memerlukan bila sumber itu di 'off' aras sinaran pada jarak 1 meter menjadi kurang daripada 2 mR/hr. Jika foton terpancar adalah 0.6 MeV, tentukan ketebalan perisaian plumbum yang diperlukan. (Diberi ketumpatan plumbum = 11.3 gm/cm^3)]

(30/100)

3. a) What is photoelectric absorption? Discuss the importance of these interactions with human tissue and lead using log scale graphs. Compare these interactions and analyze the dependence of photoelectric absorption on the atomic number of the absorber.
[Apakah itu penyerapan fotoelektrik? Bincangkan kepentingan interaksi tersebut dengan tisu manusia dan plumbum dengan menggunakan graf skala log. Bandingkan interaksi tersebut dan analisakan kebergantungan penyerapan fotoelektrik ke atas nombor atom penyerap.]

(50/100)

b) What are the deciding parameters in the coulomb-force interactions? Define them and discuss the various cases arise in this type.
[Apakah parameter-parameter penentu dalam interaksi daya-coulomb? Takrifkannya dan bincangkan pelbagai kes yang timbul dalam jenis ini.]

(30/100)

c) Define the terms "Energy transfer coefficient" and "Energy absorption coefficients" in photon interaction and write the formula to calculate them.
[Takrifkan istilah "pekali perpindahan tenaga" dan "pekali penyerapan tenaga" dalam interaksi foton. Tulis formula bagi menghitungkannya.]

(20/100)

4. a) Explain the basic features of a typical TLD reader with schematic diagram.
[Terangkan ciri-ciri asas suatu pembaca TLD dengan menggunakan suatu rajah sekmatik]

(50/100)

...5/-

b) A γ-ray exposure of 5.6 C/kg is available in lithium fluoride TLD in gray scale under TCPE conditions. The TLD chip is enclosed in Teflon capsule of 2.88 mm thickness. If the exposed chip is square of 3 mm^2 dimension that weighs 5 mg, determine the average absorbed dose. Calculate the energy fluence of the stopped medium.
[Dedahan sinar-γ 5.6 C/kg terdapat dalam lithium fluoride TLD dalam skala kelabu di bawah keadaan TCPE. Cip TLD itu diletakkan dalam ruangan kapsul Teflon yang mempunyai ketebalan 2.88 mm. Jika cip itu adalah empat segi sama dengan luas permukaan 3 mm^2 dan jisimnya 5 mg, tentukan dos terserap purata. Hitungkan fluens tenaga dalam cip itu]
(50/100)

5. a) What do you meant by linear stopping power? Discuss any three factors that can influence the linear stopping power of a material.
[Apakah yang dimaksudkan dengan kuasa penghenti linear? Bincangkan mana-mana tiga faktor yang boleh mempengaruhi kuasa penghenti linear itu]
(30/100)

b) Explain the meaning of kerma and absorbed dose
[Terangkan makna kerma dan dos terserap]
(25/100)

c) State the assumptions used in Bragg-Gray theorem
[Nyatakan anggapan yang digunakan dalam teorem Bragg-Gray]
(25/100)

d) The total absorption cross section in oxygen for photon of energy 1 MeV is 1.69 units and for photons of energy 2 MeV is 1.18 units whereas for a photon of energy 3 MeV it becomes 9.56 units. Justify the reasons for this contradiction.
[Keratan rentas jumlah penyerapan dalam oksigen untuk foton dengan tenaga 1 MeV adalah 1.69 unit dan untuk foton dengan tenaga 2 MeV adalah 1.18 unit. Manakala, untuk suatu foton dengan tenaga 3 MeV ianya menjadi 9.56 unit. Berikan justifikasi mengenai pertentangan ini.]
(20/100)

...6/-

6. a) Discuss the general method of producing radionuclides.
[Bincangkan kaedah umum bagi menghasilkan radionuklid]

(20/100)

b) Referring to the radiation dose, explain in detail how the survival curve of mammalian cell could be found in the lab? Label all the important parameters in the curve and explain their meaning.
[Merujuk kepada dos sinaran, terangkan dengan terperinci lengkung servival sel mamalia boleh didapati di dalam makmal. Labelkan semua parameter penting dalam lengkung itu dan terangkan maksudnya]

(30/100)

c) Explain the differences in the mammalian cell survival curves of X-rays and α-ray. Give the reasons.
[Terangkan perbezaan antara lengkung survival sel mamalia bagi sinar-X dan sinar- α. Berikan sebab-sebabnya]

(30/100)

d) Write a short note on
[Tulis nota ringkas mengenai]

i) the common biological effects of radiation
[kesan biologi terhadap sinaran]

ii) the use of tracer techniques in radio therapy
[penggunaan teknik penyurih dalam radioterapi]

(20/100)

...7/-

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

Energy-wavelength conversion:

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

Exposure conversion:

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

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:

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

Carbon, Z = 6
Multiply data by 0.05014 to get cm^2/g
—or by 0.005014 to get m^2/kg

Photon Energy (MeV)	Compton With and Without Coherent $_e\sigma + {}_e\sigma_R$	Compton Without Coherent $_e\sigma$	Photoelectric $_e\tau$	Nuclear and Electron Pair $_e\kappa_{nuc}$	Nuclear and Electron Pair $_e\kappa_{elec}$	Total With and Without Coherent $_e\mu$	Total With and Without Coherent $_e\mu - {}_e\sigma_R$
1.00 −02	6.11 +00	3.84 +00	3.93 +01	—	—	4.54 +01	4.31 +01
1.50 −02	5.06 +00	3.77 +00	1.06 +01	—	—	1.57 +01	1.44 +01
2.00 −02	4.53 +00	3.71+ 00	4.01 +00	—	—	8.54 +00	7.72 +00
3.00 −02	4.00 +00	3.58 +00	9.99 −01	—	—	5.00 +00	4.58 +00
4.00 −02	3.73 +00	3.47 +00	3.79 −01	—	—	4.10 +00	3.85 +00
5.00 −02	3.54 +00	3.37 +00	1.93 −01	—	—	3.73 +00	3.56 +00
6.00 −02	3.39 +00	3.27 +00	1.15 −01	—	—	3.51 +00	3.39 +00
8.00 −02	3.17 +00	3.10 +00	4.50 −02	—	—	3.21 +00	3.15 +00
1.00 −01	3.00 +00	2.96 +00	2.16 −02	—	—	3.02 +00	2.98 +00
1.50 −01	2.69 +00	2.66 +00	5.75 −03	—	—	2.69 +00	2.67 +00
2.00 −01	2.45 +00	2.44 +00	2.29 −03	—	—	2.45 +00	2.44 +00
3.00 −01	2.13 +00	2.12 +00	6.46 −04	—	—	2.13 +00	2.12 +00
4.00 −01	1.90 +00	1.90 +00	2.77 −04	—	—	1.91 +00	1.90 +00
5.00 −01	1.74 +00		1.49 −04	—	—	1.74 +00	
6.00 −01	1.61 +00		9.27 −05	—	—	1.61 +00	
8.00 −01	1.41 +00		4.68 −05	—	—	1.41 +00	
1.00 +00	1.27 +00		2.89 −05	—	—	1.27 +00	
1.50 +00	1.03 +00		1.35 −05	1.60 −03	—	1.03 +00	
2.00 +00	8.79 −01		8.61 −06	6.40 −03	—	8.86 −01	
3.00 +00	6.92 −01		4.82 −06	1.84 −02	2.41 −04	7.11 −01	
4.00 +00	5.77 −01		3.29 −06	2.98 −02	9.91 −04	6.08 −01	
5.00 +00	4.98 −01		2.52 −06	4.00 −02	1.95 −03	5.40 −01	
6.00 +00	4.40 −01		2.01 −06	4.90 −02	3.00 −03	4.93 −01	
8.00 +00	3.60 −01		1.44 −06	6.42 −02	5.12 −03	4.30 −01	
1.00 +01	3.07 −01		1.12 −06	7.66 −02	7.01 −03	3.90 −01	
1.50 +01	2.27 −01		—	1.00 −01	1.09 −02	3.38 −01	
2.00 +01	1.82 −01		—	1.17 −01	1.40 −02	3.14 −01	
3.00 +01	1.33 −01		—	1.41 −01	1.87 −02	2.93 −01	
4.00 +01	1.05 −01		—	1.58 −01	2.21 −02	2.86 −01	
5.00 +01	8.80 −02		—	1.71 −01	2.48 −02	2.84 −01	
6.00 +01	7.59 −02		—	1.81 −01	2.71 −02	2.84 −01	
8.00 +01	5.98 −02		—	1.96 −01	3.06 −02	2.86 −01	
1.00 +02	4.97 −02		—	2.07 −01	3.31 −02	2.90 −01	

Photon Energy (MeV)	Lead (Plumbum) ($cm^2\ g^{-1}$) μ/ρ	μ_{tr}/ρ	μ_{en}/ρ	Air (Udara) ($cm^2\ g^{-1}$) μ/ρ	μ_{tr}/ρ	μ_{en}/ρ
0.5	0.1614	0.0984	0.0951	0.0868	0.0297	0.0296
0.6	0.1249	0.0737	0.0710	0.0804	0.0296	0.0293
0.8	0.0886	0.0503	0.0481	0.0706	0.0289	0.0289
1.0	0.0708	0.0396	0.0377	0.0635	0.0280	0.0278
1.5	0.0518	0.0288	0.0271	0.0517	0.0256	0.0254
2	0.0455	0.0259	0.0240	0.0444	0.0236	0.0234
3	0.0417	0.0260	0.0234	0.0358	0.0207	0.0205

...9/-

TABLE A-9

ABSORPTION COEFFICIENTS

σ—Compton scattering; σ_k—Compton Energy Transfer; σ_{coh}—coherent scattering; τ—photoelectric; π^n—pair production by nucleus; π^e—pair production by electrons (triplet) μ/ρ—total mass; μ'/ρ—total mass excluding coherent; μ_{en}/ρ—mass energy absorption.

	Hydrogen Z = 1 5.997×10^{23} atoms/gm 5.997×10^{23} electrons/gm						Carbon Z = 6 ρ = 2.25 gm/cm³ (graphite) 0.5016×10^{23} atoms/gm 3.010×10^{23} electrons/gm					
Photon Energy (Mev)	σ	σ_k	τ	μ'/ρ	μ/ρ	μ_{en}/ρ	σ	σ_{coh}	τ	μ'/ρ	μ/ρ	μ_{en}/ρ
	$\times 10^{-24}$ cm²/atom			cm²/gm			$\times 10^{-24}$ cm²/atom			cm²/gm		
.01	.6404	.0077	.0046	.385	.385	.00986	3.84	3.04	39.3	2.16	2.32	1.97
.015	.6289	.0138	.0011	.376	.376	.0110	3.77	1.53	10.6	.721	.797	.536
.02	.6179	.0196		.369	.369	.0135	3.71	.98	4.01	.387	.434	.208
.03	.5974	.0295		.357	.357	.0185	3.58	.46	.999	.230	.253	.0594
.04	.5786	.0380		.346	.346	.0231	3.47	.24	.379	.193	.205	.0306
.05	.5614	.0451		.335	.335	.0271	3.37	.13	.198	.179	.185	.0223
.06	.5455	.0509		.326	.326	.0306	3.27	.09	.115	.170	.174	.0211
.08	.5172	.0610		.309	.309	.0362	3.10	.08	.045	.158	.162	.0205
.10	.4927	.0685		.294	.294	.0406	2.96	.06	.022	.150	.152	.0215
.15	.4436	.0812			.265	.0481	2.66	.03	.006	.134	.135	.0245
.2	.4064	.0886			.243	.0525	2.44	.02	.002	.122	.123	.0265
.3	.3534	.0958			.211	.0569	2.12	.01	.0006	.106	.107	.0287
.4	.3166	.0982			.189	.0586	1.900		.0003		.0953	.0295
.5	.2891	.0986			.173	.0593	1.735		.0001		.0870	.0297
.6	.2675	.0984			.160	.0587	1.605				.0805	.0295
.8	.2349	.0959			.140	.0574	1.410				.0707	.0288
1.0	.2112	.0929			.126	.0555	1.267				.0635	.0279
			Triplet π^e	Pair π^n					Triplet π^e	Pair π^n		
1.5	.1716	.0849		.00004	.103	.0507	1.029			.002	.0517	.0255
2	.1468	.0777		.00018	.0875	.0464	.878			.006	.0443	.0234
3	.1151	.0664	.00004	.00051	.0691	.0398	.690		.0002	.018	.0356	.0204
4	.09596	.0582	.0002	.00083	.0581	.0352	.577		.0010	.030	.0305	.0185
5	.08285	.0519	.0003	.00111	.0505	.0317	.498		.0019	.040	.0271	.0171
6	.07322	.0471	.0005	.00137	.0450	.0290	.441		.0030	.049	.0247	.0161
8	.05988	.0399	.0008	.00179	.0375	.0252	.360		.0051	.064	.0216	.0147
10	.05098	.03487	.0012	.00213	.0325	.0225	307		.0070	.076	.0196	.0138
15	.03771	.02670	.0018	.0028	.0253		.226		.011	.099	.0169	
20	.03025	.02201	.0023	.0033	.0214		.1814		.014	.116	.0156	
30	.02199	.01643	.0031	.0040	.0174		.1319		.019	.140	.0146	
40	.01746	.01327	.0037	.0045	.0153		.1048		.022	.157	.0142	
50	.01456	.01121	.0041	.0048	.0140		.0874		.025	.170	.0142	
60	.01254	.00979	.0045	.0051	.0132		.0752		.027	.180	.0142	
80	.00988	.00776	.0051	.0056	.0123		.0593		.030	.195	.0148	
100	.00820	.00651	.0056	.0059	.0118		.0492		.033	.207	.0145	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

Jadual

Oxygen, Z = 8
Multiply by 0.03764 to get cm^2/g
or by 0.003764 to get m^2/kg

Photon Energy (MeV)	Compton With and Without Coherent $a\sigma + a\sigma_R$	Compton Without Coherent $a\sigma$	Photoelectric $\times 10^{-28} m^2/atom$ $a\tau$	Nuclear and Electron Pair $a\kappa_{nuc}$	Nuclear and Electron Pair $a\kappa_{elec}$	Total With and Without Coherent $a\mu$	Total With and Without Coherent $a\mu - a\sigma_R$
1.00 - 02	1.06 + 01	5.12 + 00	1.43 + 02	-	-	1.54 + 02	1.48 + 02
1.50 - 02	8.00 + 00	5.03 + 00	3.81 + 01	-	-	4.61 + 01	4.31 + 01
2.00 - 02	6.84 + 00	4.94 + 00	1.51 + 01	-	-	2.19 + 01	2.00 + 01
3.00 - 02	5.74 + 00	4.78 + 00	4.13 + 00	-	-	9.87 + 00	8.91 + 00
4.00 - 02	5.20 + 00	4.63 + 00	1.64 + 00	-	-	6.84 + 00	6.27 + 00
5.00 - 02	4.87 + 00	4.49 + 00	8.00 - 01	-	-	5.67 + 00	5.29 + 00
6.00 - 02	4.63 + 00	4.36 + 00	4.48 - 01	-	-	5.08 + 00	4.81 + 00
8.00 - 02	4.29 + 00	4.14 + 00	1.78 - 01	-	-	4.47 + 00	4.32 + 00
1.00 - 01	4.05 + 00	3.94 + 00	8.54 - 02	-	-	4.13 + 00	4.03 + 00
1.50 - 01	3.60 + 00	3.55 + 00	2.32 - 02	-	-	3.62 + 00	3.57 + 00
2.00 - 01	3.27 + 00	3.25 + 00	9.30 - 03	-	-	3.28 + 00	3.26 + 00
3.00 - 01	2.84 + 00	2.83 + 00	2.65 - 03	-	-	2.84 + 00	2.83 + 00
4.00 - 01	2.54 + 00	2.53 + 00	1.13 - 03	-	-	2.54 + 00	2.54 + 00
5.00 - 01	2.32 + 00	2.31 + 00	6.11 - 04	-	-	2.32 + 00	2.31 + 00
6.00 - 01	2.15 + 00	2.14 + 00	3.82 - 04	-	-	2.15 + 00	2.14 + 00
8.00 - 01	1.88 + 00		1.92 - 04	-	-	1.88 + 00	
1.00 + 00	1.69 + 00		1.19 - 04	-	-	1.69 + 00	
1.50 + 00	1.37 + 00		5.57 - 05	2.86 - 03	-	1.38 + 00	
2.00 + 00	1.17 + 00		3.54 - 05	1.14 - 02	-	1.18 + 00	
3.00 + 00	9.23 - 01		1.98 - 05	3.27 - 02	3.22 - 04	9.56 - 01	
4.00 + 00	7.69 - 01		1.35 - 05	5.30 - 02	1.32 - 03	8.24 - 01	
5.00 + 00	6.65 - 01		1.03 - 05	7.11 - 02	2.60 - 03	7.38 - 01	
6.00 + 00	5.87 - 01		8.22 - 06	8.70 - 02	3.99 - 03	6.78 - 01	
8.00 + 00	4.80 - 01		5.88 - 06	1.14 - 01	6.83 - 03	6.01 - 01	
1.00 + 01	4.09 - 01		4.61 - 06	1.36 - 01	9.34 - 03	5.54 - 01	
1.50 + 01	3.03 - 01		-	1.77 - 01	1.45 - 02	4.95 - 01	
2.00 + 01	2.43 - 01		-	2.08 - 01	1.87 - 02	4.69 - 01	
3.00 + 01	1.77 - 01		-	2.50 - 01	2.49 - 02	4.52 - 01	
4.00 + 01	1.41 - 01		-	2.79 - 01	2.95 - 02	4.49 - 01	
5.00 + 01	1.17 - 01		-	3.01 - 01	3.31 - 02	4.52 - 01	
6.00 + 01	1.01 - 01		-	3.19 - 01	3.61 - 02	4.56 - 01	
8.00 + 01	7.98 - 02		-	3.46 - 01	4.05 - 02	4.66 - 01	
1.00 + 02	6.62 - 02		-	3.65 - 01	4.39 - 02	4.75 - 01	

...11/-

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 cm^2/g	MeV cm^2/g	MeV cm^2/g	g/cm^2		
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	2.446E-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