國 立 清 華 大 學 命 題 紙

八十七學年度 工科 系（所） ______ 組碩士班研究生入學考試

科目 核工原理 科號 4002 共 6 頁第 1 頁 *請在試卷【答案卷】內作答

---- Principles of Nuclear Engineering -----

Graduate School Entrance Examination

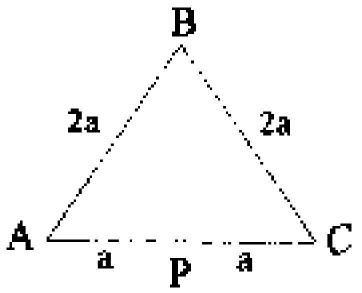
April 18, 1998

Part I

1. Briefly explain or describe the following terminology: (12%)
   a) specific burnup,
   b) burnable poison,
   c) control rod methods used in commercial BWR and PWR,
   d) neutron age,
   e) delayed critical.

2. Draw the following plots: (8%)
   a) the fission cross sections of U-238 as a function of neutron energy,
   b) the attenuation coefficients (also showing each of the three interaction processes) of lead as a function of γ-ray energy.

3. As shown, three isotropic point neutron sources, each emitting S_0 neutrons/sec, are located at the three corners of an equilateral triangle of side 2a. (8%)
   a) Find the neutron flux at the point A if the medium is a purely absorbing medium.
   b) Find the neutron current at the point P if the medium is a diffusing medium.



4. A bare, finite, multiplying, cylindrical, fast reactor, constructed of pure $_{94}Pu^{239}$ with radius R = 7 cm and height H = 13 cm, is operating at a power of 10 MW. The associated nuclear data for $_{94}Pu^{239}$ are given as follows. $\nu = 2.98$, $\sigma_\gamma = 0.26$ b, $\sigma_f = 1.85$ b, $\sigma_s = 6.82$ b, and $\rho = 19.74$ g/cm^3. Assume one-group theory and isotropic scattering, and neglect the extrapolated distance d. Determine the material buckling of the reactor. (6%)

5. The rods of a TRIGA reactor contain a zirconium hydride. The molecular formula of zirconium hydride is $ZrH_{1.7}$ and the mass density is 4.6 g/cm^3. The average scattering cross sections of $_1H^1$ and $_{40}Zr^{91.22}$ equal to 18 and 6.2 barns, respectively. Determine the average number of scatterings

that a fast (1.98 MeV) neutron in the reactor is needed before reaching the thermal-neutron energy. (6%)

6 Derive an expression for the neutron flux distribution in the radial direction about a line, isotropic, and mono-energetic neutron source emitting S_0 neutrons/cm-sec in a diffusing medium. (10%).

7. As shown in the attached Figure 1, heat transfer at solid/liquid interface with phase change can be divided into four regions. Explain the heat transfer phenomena involved in each region (4%). Usually, LWR is operated in region 2 in which the heat transfer is very effective. However, the boiling transition (point C on the curve) is a very important limiting condition of operation. Please explain the physical phenomena occurred at the boiling transition in a pressurized water reactor and in a boiling water reactor (4%). Describe the method used in LWR design to assure that this limit is not violated during normal operation (2%).

8. Loss of Coolant Accident (LOCA) is one of the Design Basis Accidents of Light Water Reactors. Emergency Core Cooling System (ECCS) was designed to mitigate LOCA. Please describe ECCS of Boiling Water Reactor and Pressurized Water React (6%). The design of ECCS has to satisfy the acceptance criteria. Please list these criteria and give the reason of inclusion these criteria (4%)

9. It is well known that the Chernobyl was caused by the positive coolant void reactivity coefficient of RBMK reactor (use graphite as moderator, boiling water as coolant). Please describe the physical meaning of the void coefficient and the mechanism of its impact on the stability of nuclear power reactor. In a boiling water reactor, the void reactivity coefficient is negative. Both of BWR and RBMK are thermal reactor and they both use boiling water as coolant. Please use the four factor formula to explain the drastic difference in their void reactivity coefficient (10%).

Hint: Four factors formula:

$$k_\infty = \eta_T \, p f \varepsilon$$

k_∞: infinity multiplication factor;

η_T: fission factor.

p: resonance escape probability;

f: thermal utilization,

ε: fast fission factor

10. The attached Figure 2 displayed the results of the thermal analysis of the hottest channel of a BWR. In the figure, T_b is the coolant temperature and T_s is the cladding surface temperature. Please explain why the coolant temperature levels off beyond point A (2%) and why the cladding surface temperature levels off beyond point B (3%)

11. 假設附圖三所示為某石化工業區一天 24 小時的溫度分佈，而石化工廠為 24 小時運轉，故不斷的自 50 公尺高之煙囪排放廢氣。如果離此石化工業區一段距離外，有一海灘。請用污染物質在大氣擴散的相關理論，說明"早安晨跑"或"人約黃昏後"較有益健康（5%）。

12. A x-ray machine technician observed the process outside the room through a window. The window is made of SiO_2 with density of 2.21 g/cm^3. The X-ray machine is about 3m from the window which is about 1.6 m above the ground. the thickness of the window is 0.5 cm. For each X-ray picture taken, the machine generated 10^9 X-rays with 0.1 MeV. Please evaluate the exposure (in terms of Roentgen) at the window outer surface (5%) and the dose equivalent of the technician for each x-ray picture (5%). (use th uncollide fluence to estimate the exposure and dose equivalent)

the molecular weight of Si is 28.09
the molecular weight of O is 16
the density of Si is 2.33 g/cm^3
the density of O2 is 0.0014 g/cm^3
the density of air is 0.00129 g/cm^3
the linear attenuation coefficient of Si for 0.1 MeV gamma is 0.4008 cm^{-1}
the linear attenuation coefficient of O for 0.1 MeV gamma is 0.2.114x10^{-4} cm^{-1}
the mass attenuation coefficient of air for 0.1 MeV gamma is 0.151 cm^2/g
one Roentgen is equivalent to the energy required to produce 1 esu charge per cm^3 of dry airat 1 atm pressure and 20 C (density is 0.001293 g/cm^3).
1 esu = 3.22 x10^{-10} coul, 1 ion = 1.602x10^{-19} coul
the energy required to create 1 ion pair is 34 eV
1 MeV = 1.602x10^{-6} erg
the quality factor of 0.1 MeV gamma is 1

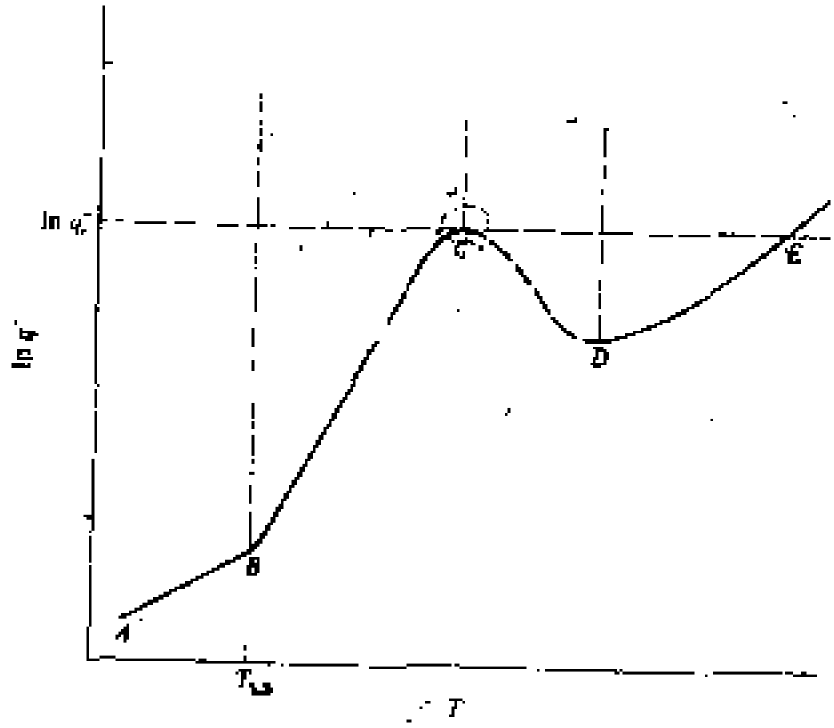


Figure 1

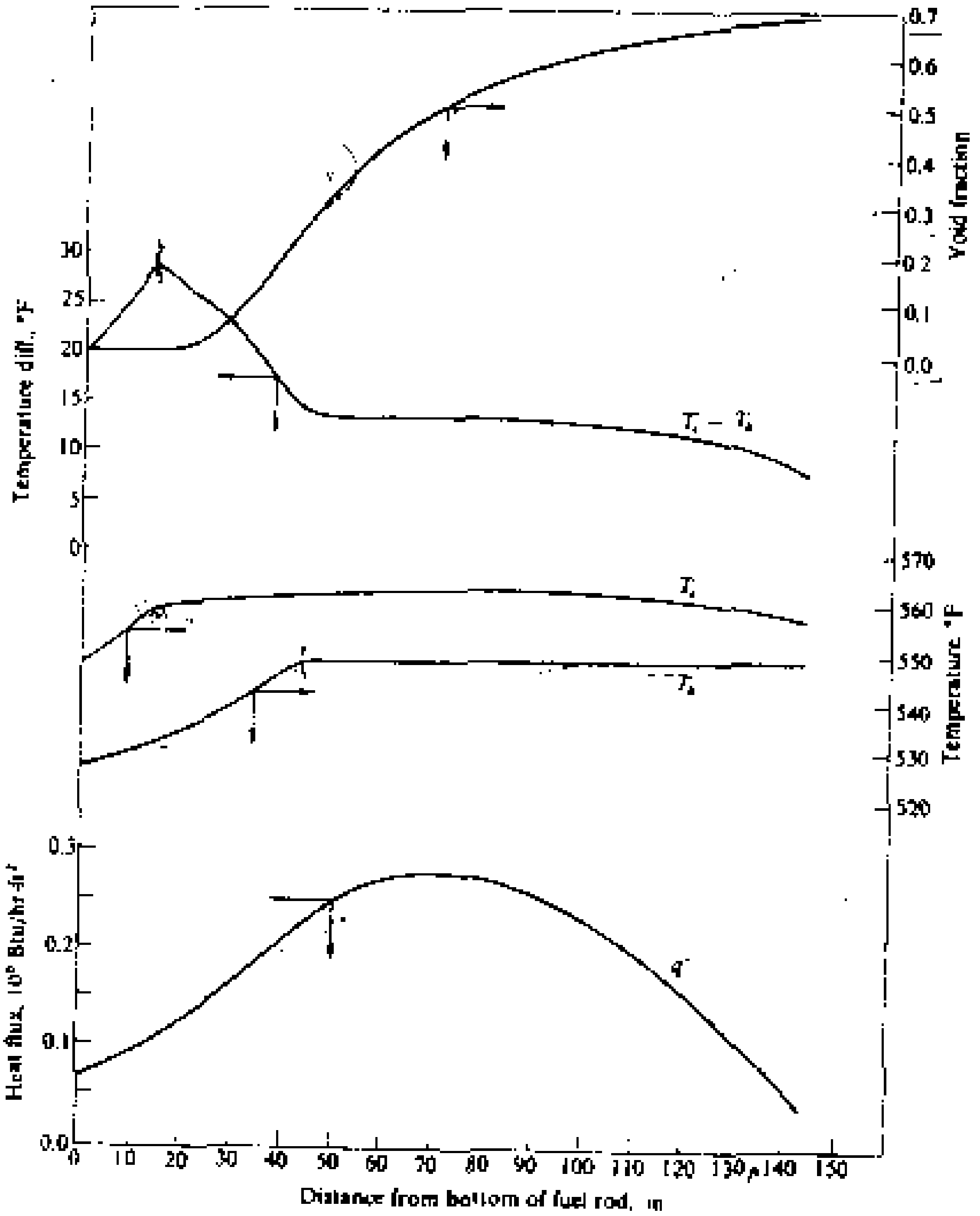
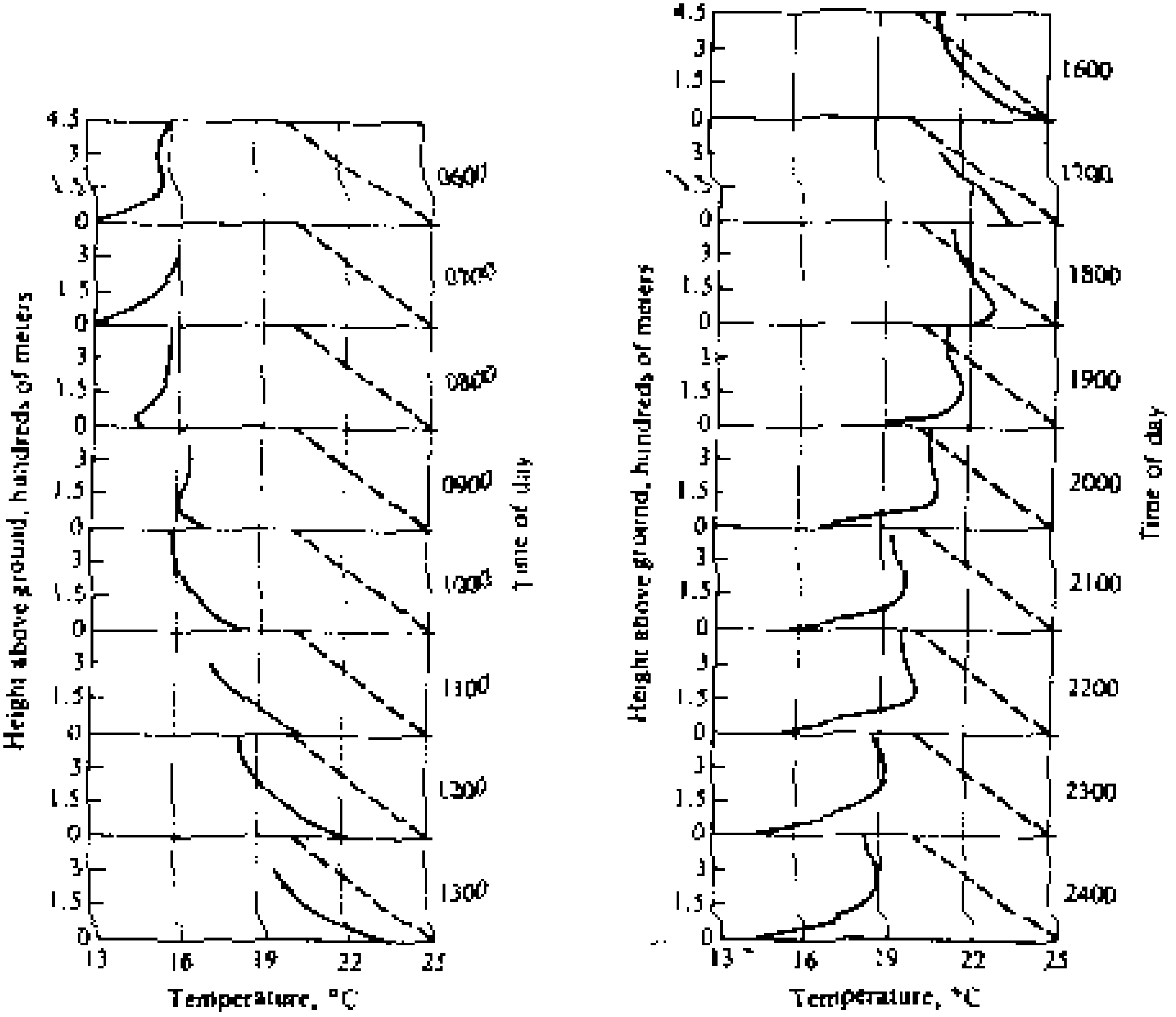


Figure 2


Height above ground, hundreds of meters
4.5
3
1.5
0
0600
0700
0800
0900
1000
1100
1200
1300
Time of day
13
16
19
22
25
Temperature, °C
1600
1700
1800
1900
2000
2100
2200
2300
2400

附圖三

[illegible]

TABLE II.5

The mass absorption coefficient for several materials, in cm²/g*

	Gamma-ray energy, MeV																	
Material	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.25	1.50	2	3	4	5	6	8	10
H	.0411	.0487	.0531	.0575	.0589	.0591	.0590	.0575	.0557	.0533	.0509	.0467	.0401	.0354	.0318	.0291	.0252	.0225
Be	.0183	.0217	.0237	.0256	.0263	.0264	.0263	.0256	.0248	.0237	.0227	.0210	.0183	.0164	.0151	.0141	.0127	.0118
C	.0215	.0246	.0267	.0288	.0296	.0297	.0296	.0289	.0280	.0268	.0254	.0237	.0209	.0190	.0177	.0165	.0153	.0145
N	.0224	.0249	.0267	.0288	.0296	.0297	.0296	.0289	.0280	.0268	.0256	.0236	.0211	.0193	.0180	.0171	.0158	.0151
O	.0233	.0252	.0271	.0289	.0296	.0297	.0296	.0289	.0280	.0268	.0257	.0238	.0212	.0195	.0183	.0176	.0163	.0157
Na	.0289	.0258	.0266	.0279	.0283	.0284	.0284	.0276	.0268	.0257	.0246	.0229	.0207	.0194	.0185	.0179	.0171	.0168
Mg	.0335	.0276	.0278	.0288	.0292	.0293	.0292	.0285	.0276	.0265	.0254	.0237	.0215	.0203	.0194	.0188	.0182	.0180
Al	.0373	.0283	.0275	.0283	.0287	.0286	.0286	.0278	.0270	.0259	.0248	.0232	.0212	.0200	.0192	.0188	.0183	.0182
Si	.0435	.0300	.0286	.0291	.0293	.0290	.0290	.0282	.0274	.0263	.0252	.0236	.0217	.0206	.0198	.0194	.0190	.0189
P	.0501	.0315	.0292	.0289	.0290	.0290	.0287	.0280	.0271	.0260	.0250	.0234	.0216	.0206	.0200	.0197	.0194	.0195
S	.0601	.0351	.0310	.0301	.0301	.0300	.0298	.0288	.0279	.0268	.0258	.0242	.0224	.0215	.0209	.0206	.0206	.0206
A	.0729	.0368	.0302	.0278	.0274	.0272	.0270	.0260	.0252	.0242	.0233	.0220	.0206	.0199	.0195	.0195	.0194	.0197
K	.0909	.0433	.0340	.0304	.0299	.0295	.0291	.0282	.0272	.0261	.0251	.0237	.0222	.0217	.0214	.0212	.0215	.0219
Ca	.111	.0489	.0367	.0318	.0309	.0304	.0300	.0290	.0279	.0268	.0258	.0244	.0230	.0225	.0222	.0223	.0225	.0231
Fe	.225	.0810	.0489	.0340	.0307	.0294	.0287	.0274	.0261	.0250	.0242	.0231	.0224	.0224	.0227	.0231	.0239	.0250
Cu	.310	.107	.0594	.0368	.0316	.0296	.0286	.0271	.0260	.0247	.0237	.0229	.0223	.0227	.0231	.0237	.0248	.0261
Mo	.922	.294	.141	.0617	.0422	.0348	.0315	.0281	.0263	.0244	.0236	.0233	.0227	.0250	.0262	.0274	.0296	.0316
Sn	1.400	.471	.222	.0873	.0554	.0403	.0346	.0294	.0268	.0248	.0239	.0233	.0243	.0259	.0278	.0291	.0316	.0339
I	1.726	.657	.300	.106	.0648	.0456	.0365	.0303	.0274	.0251	.0241	.0238	.0247	.0266	.0283	.0298	.0327	.0353
W	4.111	1.356	.531	.230	.121	.0786	.0569	.0426	.0353	.0302	.0281	.0271	.0287	.0311	.0335	.0356	.0390	.0428
Pt	4.645	1.558	.719	.262	.139	[illegible]	.0666	.0459	.0375	.0315	.0293	.0280	.0296	.0320	.0343	.0365	.0400	.0438
Tl	6.057	1.717	.791	.286	.152	.0872	.0718	.0491	.0393	.0326	.0301	.0288	.0304	.0326	.0349	.0364	.0408	.0446
Pb	6.190	1.751	.831	.294	.166	.0994	.0738	.0506	.0402	.0332	.0306	.0293	.0305	.0330	.0352	.0373	.0412	.0456
U	9.53	2.537	1.096	[illegible]	.204	.132	.0968	.0586	.0482	.0364	.0346	.0324	.0332	.0362	.0374	.0394	.0443	.0474
Air	.0233	.0251	.0268	.0288	.0296	.0297	.0296	.0289	.0280	.0268	.0256	.0238	.0211	.0194	.0181	.0172	.0160	.0153
NaI	1.466	.478	.224	.0889	.0542	.0410	.0354	.0299	.0273	.0253	.0242	.0235	.0241	.0254	.0268	.0281	.0303	.0325
H_2O	.0253	.0278	.0300	.0321	.0328	.0330	.0329	.0321	.0311	.0298	.0285	.0264	.0233	.0213	.0196	.0186	.0173	.0165
Concrete	.0416	.0300	.0289	.0294	.0297	.0296	.0295	.0287	.0278	.0272	.0256	.0239	.0216	.0203	.0194	.0188	.0180	.0177
Tissue	.0271	.0282	.0293	.0312	.0317	.0320	.0319	.0311	.0300	.0288	.0276	.0256	.0230	.0206	.0192	.0182	.0168	.0160

---

*From L. T. Templin, editor, *Reactor Physics Constants*, ANL-5800, 2nd ed., 1963; based on G. W. Grodstein, National Bureau of Standards circular 583, 1957.

TABLE II.4

The mass attenuation coefficient for several materials, in cm²/g*†

	Gamma-ray energy, MeV																	
Material	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.25	1.5	2	3	4	5	6	8	10
H	.295	.265	.243	.212	.189	.173	.160	.140	.126	.113	.103	.0876	.0691	.0579	.0502	.0445	.0371	.0321
Be	.132	.119	.109	.0945	.0847	.0773	.0715	.0628	.0565	.0504	.0459	.0394	.0313	[illegible]	.0234	.0211	.0180	.0161
C	.149	.134	.122	.106	.0953	.0870	.0805	.0707	.0636	.0568	.0518	.0444	.0356	.0304	.0270	.0245	.0213	.0194
N	.150	.134	.123	.106	.0955	.0869	.0805	.0707	.0636	.0568	.0517	.0445	.0357	.0306	.0273	.0249	.0218	.0200
O	.151	.134	.123	.107	.0953	.0870	.0806	.0708	.0636	.0568	.0518	.0445	.0359	.0309	.0276	.0254	.0224	.0206
Na	.151	.130	.118	.102	.0912	.0833	.0770	.0676	.0608	.0546	.0496	.0427	.0348	.0303	.0274	.0254	.0229	.0215
Mg	.160	.135	.122	.106	.0944	.0860	.0795	.0699	.0627	.0560	.0512	.0442	.0360	.0316	.0286	.0266	.0242	.0228
Al	.161	.134	.120	.103	.0922	.0840	.0777	.0683	.0614	.0548	.0500	.0432	.0353	.0310	.0282	.0264	.0241	.0229
Si	.172	.139	.125	.107	.0954	.0869	.0802	.0706	.0635	.0567	.0517	.0447	.0367	.0323	.0296	.0277	.0254	.0243
P	.174	.137	.122	.104	.0928	.0846	.0780	.0685	.0617	.0551	.0502	.0436	.0358	.0316	.0290	.0273	.0252	.0242
S	.188	.144	.127	.108	.0958	.0874	.0806	.0707	.0635	.0568	.0519	.0448	.0371	.0328	.0302	.0284	.0266	.0256
A	.188	.135	.117	.0977	.0867	.0790	.0730	.0638	.0573	.0512	.0468	.0407	.0338	.0301	.0279	.0266	.0248	.0241
K	.215	.149	.127	.106	.0938	.0852	.0786	.0689	.0618	.0552	.0505	.0438	.0365	.0327	.0305	.0289	.0274	.0267
Ca	.238	.158	.132	.109	.0965	.0876	.0809	.0708	.0634	.0566	.0518	.0451	.0376	.0338	.0316	.0302	.0285	.0280
Fe	.344	.183	.138	.106	.0919	.0828	.0762	.0664	.0595	.0531	.0485	.0424	.0361	.0330	.0313	.0304	.0295	.0294
Cu	.427	.206	.147	.108	.0916	.0820	.0751	.0654	.0585	.0521	.0476	.0418	.0357	.0330	.0316	.0309	.0303	.0306
Mo	1.03	.389	.225	.130	.0998	.0851	.0761	.0648	.0575	.0510	.0467	.0414	.0365	.0349	.0344	.0344	.0349	.0358
Sn	1.58	.563	.303	.153	.109	.0886	.0776	.0647	.0568	.0501	.0459	.0408	.0367	.0355	.0355	.0358	.0368	.0383
I	1.83	.648	.339	.165	.114	.0913	.0792	.0653	.0571	.0502	.0460	.0409	.0370	.0360	.0361	.0365	.0377	.0394
W	4.21	1.44	.708	.293	.174	.125	.101	.0763	.0640	.0544	.0492	.0437	.0405	.0402	.0409	.0418	.0435	.0465
Pt	4.75	1.64	.795	.324	.191	.135	.107	.0800	.0659	.0554	.0501	.0445	.0414	.0411	.0418	.0427	.0448	.0477
Tl	5.16	1.80	.866	.346	.204	.143	.112	.0824	.0675	.0563	.0508	.0452	.0420	.0416	.0423	.0433	.0454	.0484
Pb	5.29	1.84	.896	.356	.208	.145	.114	.0836	.0684	.0569	.0512	.0457	.0431	.0430	.0434	.0436	.0459	.0489
U	10.60	2.42	1.17	.452	.259	.176	.136	.0952	.0757	.0615	.0548	.0484	.0445	.0440	.0446	.0455	.0479	.0511
Air	.151	.134	.123	.106	.0953	.0868	.0804	.0706	.0636	.0567	.0517	.0445	.0357	.0307	.0274	.0250	.0220	.0202
NaI	1.57	.568	.305	.155	.111	.0901	.0789	.0657	.0577	.0508	.0465	.0412	.0367	.0351	.0347	.0347	.0354	.0366
H_2O	.167	.149	.136	.118	.106	.0966	.0896	.0786	.0706	.0630	.0575	.0493	.0396	.0339	.0301	.0275	.0240	.0219
Concrete	.169	.139	.124	.107	.0954	.0870	.0804	.0706	.0635	.0567	.0517	.0445	.0363	.0317	.0287	.0268	.0243	.0229
Tissue	.163	.144	.132	.115	.100	.0936	.0867	.0761	.0683	.0600	.0556	.0478	.0384	.0329	.0292	.0267	.0233	.0212

---

*From L. T. Templin, editor, *Reactor Physics Constants*, ANL-5800, 2nd ed., 1963; based on G. W. Grodstein, National Bureau of Standards circular 583, 1957.

†Mass densities of the elements are given in Table II.3. For air at 1 atm and 20°C, $\rho = 1.293 \times 10^{-3}$ g/cm³; ρ(NaI) = 3.67 g/cm³; ρ(tissue) ≈ $\rho(H_2O)$ = 1 g/cm³; ρ(concrete) = 1.95–2.40 g/cm³.