UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2003/2004

Feb / Mac 2004

JNK 502/3– SISTEM PENUKARAN TENAGA

Masa : 3 jam

ARAHAN KEPADA CALON :

Sila pastikan bahawa kertas soalan ini mengandungi **SEMBILAN (9)** mukasurat dan **SEMBILAN (9)** halaman lampiran dan **LAPAN (8)** soalan yang bercetak sebelum anda memulakan peperiksaan.

Sila jawab **LIMA (5)** soalan sahaja.

Calon boleh menjawab semua soalan dalam Bahasa Malaysia. Jika calon ingin menjawab dalam Bahasa Inggeris sekurang-kurangnya **SATU (1)** soalan perlu dijawab dalam Bahasa Malaysia.

Setiap soalan mestilah dimulakan pada mukasurat yang baru.

Lampiran:

1)	Appendix 1	(1 lampiran)
2)	Saturated Water – Temperature Table	(1 lampiran)
3)	Saturated Water – Pressure Table (Concluded)	(1 lampiran)
4)	Superheated Water – (Continued)	(2 lampiran)
5)	Enthalpy of formation, Gibbs function of Formation, and Absolute Entropy	(1 lampiran)
6)	Table – Delayed – neutron parameter for the common fuel isotopes	(1 lampiran)
7)	Solar Constants [For Northern Latihudes]	(1 lampiran)
8)	Partial List of Isotopes	(1 lampiran)

Serahkan **KESELURUHAN** soalan dan jawapan kertas peperiksaan ini kepada Ketua Pengawas di akhir sidang peperiksaan. Pelajar yang gagal berbuat demikian akan diambil tindakan disiplin.

KETUA PENGAWAS : Sila pungut :

(a) **KESELURUHAN** kertas soalan ini (tanpa diceraikan mana-mana muka surat) dan mana-mana kertas soalan peperiksaan ini yang berlebihan untuk dikembalikan kepada Bahagian Peperiksaan, Jabatan Pendaftar, USM.

Peringatan :

1. Sila pastikan bahawa anda telah menulis angka giliran dengan betul.

...2/-

S1. Sebuah loji kuasa gabungan 200kw mempunyai data berikut:

A 200 kw combine power plant has the following data:

Turbin gas

Gas turbine

Nisbah tekanan:	**8:1**
pressure ratio of gas turbine:	*8:1*
Suhu masukan udara:	**30°C**
Air inlet temperature:	*30°C*
Suhu maksimum dalam gas turbin:	**1073K**
Maximum temperature in the gas turbine:	*1073K*

Penjana stim rawatan haba

Heat recovery steam generator

Pemanasan tambahan di HRSG

Supplementary heating is provided in the HRSG

Suhu masukan gas ekzos: 700°C

Exhaust gas inlet temp: 700°C

Suhu keluaran gas ekzos:100°C

Exhaust gas outlet temp: 100°C

Loji stim

Steam Plant

Keadaan stim selepas penjana: 40bar at 400°C

Steam leaving the steam generator: 40bar at 400°C

Tekanan pemeluwap: 0.05

...3/-

Condenser pressure: 0.05

Data relevan

Relevant data

c_p (Ekzoz gas)= 1.11 kJ/kgK

c_p (exhaust gas)= 1.11 kJ/kgK

Nilai kalori bahanapi= 41000kJ/kg

CV of fuel= 41000kJ/kg

c_p(udara)= 1.005kJ/kgK

c_p(air)= 1.005kJ/kgK

k = 1.4 (Air), k = 1.3 (combustion gas)

k= 1.4

Gunakan carta Mollier yang dibekal

Use Mollier chart provided

[a] **Lakarkan gambarajah skima loji.**

Sketch the schematic diagram of the plant

(20 markah)

[b] **Tentukan kecekapan terma loji.**

Determine the thermal efficiency of the plant

(80 markah)

S2. **Sebuah loji kuasa biojisim adalah dicadang. Berikut adalah data yang relevan:**

A biomass power plant is to be proposed. The following are the relevant data:

Kuasa terjana:	**12 MW**
Kos kapital:	**RM5000/kW**
Kadar faedah:	**8% per year flat rate**
Masa operasi loji:	**25 years**
Kecekapan terma loji:	**21%**

...4/-

Faktor muatan:	**0.8**
Bilangan pekerja:	**20**
Average salary:	**RM 50,000**
Gaji purata:	**RM10MJ/kg (dry)**
Kos biojisim (pengangkutan)	**RM16.00/ton**
Kos penyelenggaraan	**RM0.09/kWh**
Kandungan kelembapan	**50%**

Power generated:	*12 MW*
Capital cost:	*RM5000/kW*
Interest rate	*8% per year flat rate*
Duration of the plant:	*25 years*
Thermal efficiency of the plant:	*21%*
Capacity factor:	*0.8*
No. of employee:	*20*
Average salary:	*RM 50,000*
Heating value of biomass:	*RM10MJ/kg (dry)*
Biomass cost (transportation)	*RM16.00/ton*
Maintenance cost	*RM0.09/kWh*
Moisture content of biomass	*50%*

[a] Tentukan jumlah kos bagi penjanaan kuasa

Determine the total cost for power production.

(80 markah)

[b] Jika Lembaga Elektrik Negara membeli kuasa pada RM0.167 /kWh, adakah cadangan loji ini berekonomi

If the Electricity Generating Board buys the power at RM0.167 kwh, is the proposed plant economical.

(20 markah)

S3. [a] Terangkan dengan ringkas perbezaan diantara dandang tiub air dengan dandang tiub api dan penggunaannya.

Explain briefly the difference between water tube and fire tube boilers and their application.

(30 markah)

[b] A sebuah loji stim mempunyai data berikut bagi dandang tiub air:

Kadar alir stim:	**5000 kg/h**
Tekanan stim selepas dandang:	**60bar**

...5/-

Suhu stim	**400°C**
Suhu air suap:	**40°C**
Nilai haba bahanapi biojisim	**16MJ/kg**
Kecekapan terma dandang	**70%**

A steam power plant has the following data for the water tube boiler:

Steam flow rate:	*5000 kg/h*
Steam pressure after the boiler:	*60 bar*
Steam time	*400°C*
Feedwater temperature:	*40°C*
Biomass heating value	*16MJ/kg*
Thermal efficiency of the boiler	*70%*

Tentukan:

Determine

[i] Kadar suapan biojisim yang diperlukan.

The mass flow rate of biomass fuel required.

(50 markah)

[ii] Jika sebuah "economiser" digunakan untuk meningkatkan kecekapan dandang ke 80% dan suhu air suap dihadkan pada 100°C, apakah kadar alir jisim biojisim.

If an economiser is used to increase the efficiency of the boiler to 80% and the feedwate temp limited to 100°C, what is the new mass flow rate.

(20 markah)

S4. [a] Terangkan secara ringkas perbezaan jenis-jenis penggas.

Explain briefly the types of gasifier

(30 markah)

[b] Sebuah sistem penjanaan kuasa penggasan biojisim 50 kWe dicadangkan bagi penggunaan di kawasan pedalaman. Data berikut adalah diberikan:

A 50 kWe biomass gasification power generating system is to be proposed for rural application. The following data are available:

Nilai haba	**15MJ/kg**
Agen penggasan	**udara**
Kecekapan penggas	**70%**

...6/-

Nilai kalori gas terhasil	**4MJ/m³**
Kecekapan gen set diesel	**30%**
Penjimatan minyak diesel	**60%**

Komposisi isipadu gas terhasil:

CO	**20%**
CO_2	**20%**
H2	**15%**
N2	**45%**

Kandungan air terpeluwap 10kg/kg biojisim

Biomass heating value:	*15MJ/m³*
Gasifying agent	*Air*
Gasifier efficiency	*70%*
Calorific value of the producer gas	*4MJ/m³*
Diesel engine gen set efficiency	*30%*
Amount of diesel oil saved	*60%*

Volumetric composition of the (dry) producer gas:

CO	*20%*
CO_2	*20%*
H2	*15%*
N2	*45%*

The amount of water condensed is 10kg/kg of biomass

Tentukan :

Determine :

[i] Kadar alir gas terhasil

The flow rate of producer gas

[ii] Kadar ali udara

The flow rate of air

[iii] Kadar biojisim yang diperlukan

The rate of biomass fuel used

[iv] Kecekapan keseluruhan

Overall efficiency of the system

(70 markah)

...7/-

S5. [a] **Terangkan dengan ringkas operasi sebuah sel bahanapi.**

Briefly explain the operation of a fuel cell.

(20 markah)

[b] **Terangkan fenomena termoelektrik.**

Describe the thermoelectric phenomena.

(15 markah)

[c] **Sel bahanapi beroperasi pada 400°C. Hidrogen dibekal pada 1.5 bar dan oksigen 1.6 bar. Andaikan stim dihasilkan pada 1 bar. Tentukan voltan keluaran and kecekapan penukaran.**

A fuel cell operates at 400°C. Hydrogen is supplied at 1.5 bar and oxygen is supplied at 1.6bar. Assuming that steam is produced at 1 bar from the reaction process. Determine the output voltage and the conversion efficiency.

(65 markah)

S6. [a] **Dengan bantuan satu gambarajah, terangkan secara ringkas prinsip kerja sebuah menara sistem logi penjanaan kuasa suria-elektrik.**

With the aid of a diagram briefly describe the working principle of a solar-electricity power tower generating system.

(40 markah)

[b] **Sebuah dinding bangunan batu bata merah sebelah Barat terletak pada 35 darjah garis lintang Utara dan 114 darjah garis bujur Barat. Kirakan fluks tenaga suria gabungan antara penyerapan langsung dan resapan-berselerak pada jam 5.00 petang waktu penjimatan siang tempatan dan pada 16hb. Ogos apabila keadaan langit cerah.**

[Sila rujuk lampiran-lampiran berkaitan]

The West wall of a red-brick building is located at 35 degrees North latitude and 114 degrees West longitude. Evaluate the combined absorbed direct and diffuse-scattered solar energy flux at 5.00 p.m daylight savings time on August 16, if the sky is clear.

[Please refer to the associated appendix].

(60 markah)

S7. [a] **Senaraikan 4 jenis sistem reaktor nuclear dan terangkan satu daripadanya sebagai satu logi kuasa dengan bantuan satu gambarajah skema.**

...8/-

List 4 types of nuclear power reactor systems and describe one of them as a power plant with the aid of a schematic diagram.

(30 markah)

[b] Kira kala reaktor stabil dan kereaktifan lebihan dalam peratus dan dalam dalam-jam kereaktifan, jika 5 peratus kereaktifan dimasukkan kedalam sebuah reaktor haba genting dengan bahan api PU-239. Berapa lamakah untuk reaktor genting tersebut menjana kuasa dari 100 W ke 3800 MW setelah kereaktifan tersisip.

Find the stable reactor period and the excess reactivity, in percent and in in-hour of reactivity, if 5 percent of reactivity are inserted into a critical thermal reactor fueled with Pu-239. How long will it take the critical reactor to go from a power of 100 W to 3800 MW after the reactivity insertion?

(40 markah)

[c] Atom Uranium-235 melalui kereputan alpha (helium-4 nukleus) dengan pancaran 0.17 – mev sinar gamma. Kira tenaga kinetik nukleus dan butir alpha yang terbentuk.

Uranium–235 atoms undergo alpha (a helium – 4 nucleus) decay with the emission of a 0.17 – mev gamma ray. Find the kinetic energy of the product nucleus and the alpha particle.

(30 markah)

S8. [a] Terangkan perbezaan di antara kincir angin paksi tegak dan paksi mendatar dengan bantuan enam lakaran-lakaran rekabentuk berlainan jenis.

Describe the differences between vertical-axis and horizontal-axis windmills, with the aid of six sketches of the different types of design.

(40 markah)

[b] Angin berkelajuan 15 m/s pada 1 tekanan atmosphera piawai dan suhu 15°C. Kirakan:

A 15-m/s wind is at 1 standard atm pressure and 15°C temperature. Calculate:

(i) jumlah ketumpatan kuasa di dalam aliran angin

the total power density in the wind stream

(ii) ketumpatan kuasa boleh capai maksimum

...9/-

the maximum obtainable power density

(iii) **ketumpatan kuasa boleh capai yang sesuai kesemuanya di dalam W/m²**

a reasonably obtainable power density, all in W/m²

(iv) **jumlah kuasa (kW) dikeluarkan jika garis pusat turbin ialah 100m, dan**

the total power (in kW) produced if the turbine diameter is 100 m, and

(v) **Kilasan dan paksi tujah N jika turbin tersebut beroperasi pada 40 put/min dan kecekapan maksimum.**

The torque and axial thrust N if the turbine were operating at 40 rev/min and maximum efficiency.

(60 markah)

-oooOOOooo-

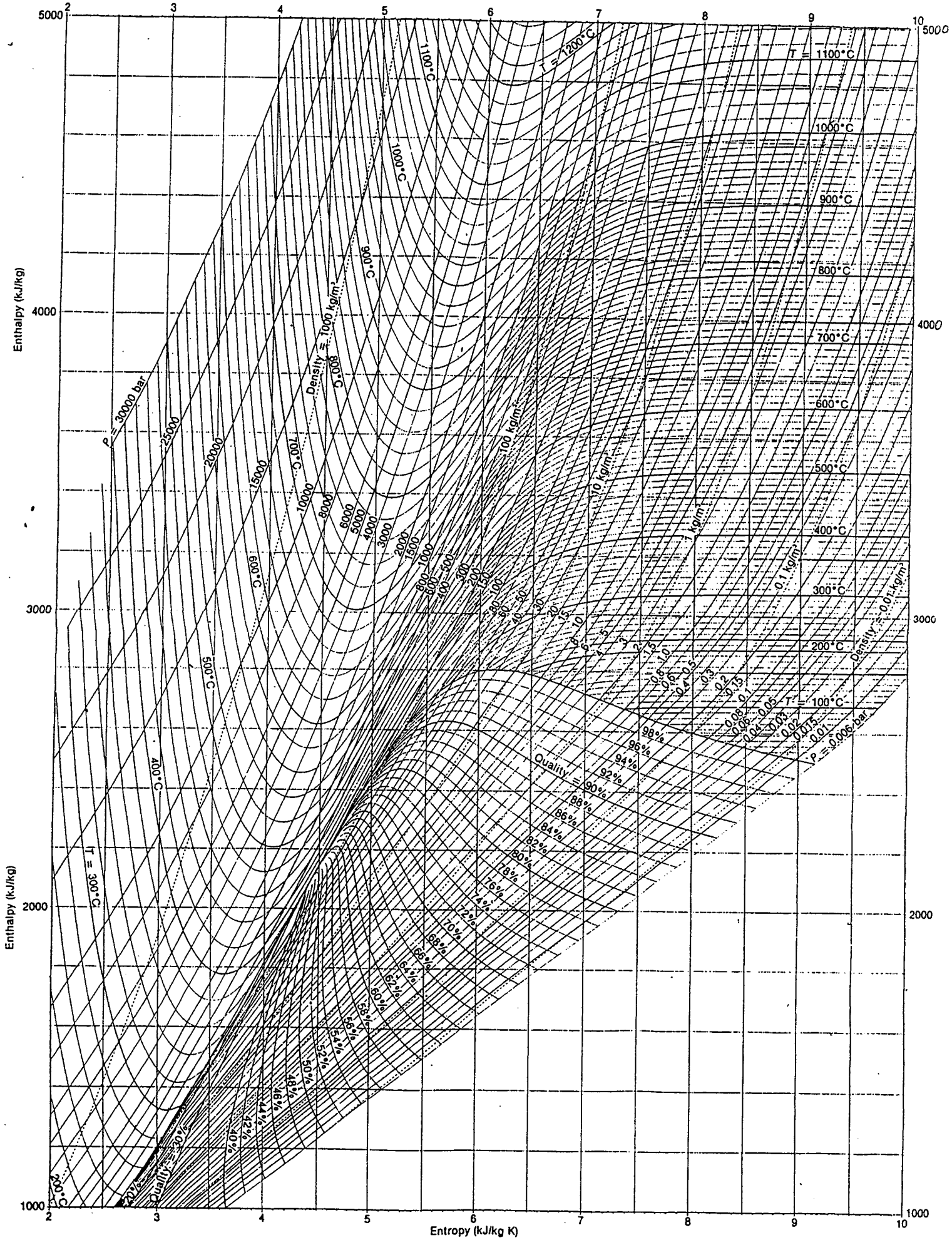

Figure 1.6 Mollier chart.

TABLE A–4

Saturated water—Temperature table

H_2O

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg: Sat. liquid, v_f	Specific volume, m³/kg: Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Internal energy, kJ/kg: Evap., u_{fg}	Internal energy, kJ/kg: Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Enthalpy, kJ/kg: Evap., h_{fg}	Enthalpy, kJ/kg: Sat. vapor, h_g	Entropy, kJ/kg · K: Sat. liquid, s_f	Entropy, kJ/kg · K: Evap., s_{fg}	Entropy, kJ/kg · K: Sat. vapor, s_g
0.01	0.6113	0.001000	206.14	0.0	2375.3	2375.3	0.01	2501.3	2501.4	0.000	9.1562	9.1562
5	0.8721	0.001000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008
15	1.7051	0.001001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	0.2245	8.5569	8.7814
20	2.339	0.001002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	0.2966	8.3706	8.6672
25	3.169	0.001003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	0.3674	8.1905	8.5580
30	4.246	0.001004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	0.4369	8.0164	8.4533
35	5.628	0.001006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	0.5053	7.8478	8.3531
40	7.384	0.001008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	0.5725	7.6845	8.2570
45	9.593	0.001010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	0.6387	7.5261	8.1648
50	12.349	0.001012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	0.7038	7.3725	8.0763
55	15.758	0.001015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	0.7679	7.2234	7.9913
60	19.940	0.001017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	0.8312	7.0784	7.9096
65	25.03	0.001020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	0.8935	6.9375	7.8310
70	31.19	0.001023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	0.9549	6.8004	7.7553
75	38.58	0.001026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001040	1.982	397.88	2102.7	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159
	Sat. press., MPa											
100	0.10135	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
105	0.12082	0.001048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8	1.3630	5.9328	7.2958
110	0.14327	0.001052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5	1.4185	5.8202	7.2387
115	0.16906	0.001056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0	1.4734	5.7100	7.1833
120	0.19853	0.001060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3	1.5276	5.6020	7.1296
125	0.2321	0.001065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
130	0.2701	0.001070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5	1.6344	5.3925	7.0269
135	0.3130	0.001075	0.5822	567.35	1977.7	2545.0	567.69	2159.6	2727.3	1.6870	5.2907	6.9777
140	0.3613	0.001080	0.5089	588.74	1961.3	2550.0	589.13	2144.7	2733.9	1.7391	5.1908	6.9299
145	0.4154	0.001085	0.4463	610.18	1944.7	2554.9	610.63	2129.6	2740.3	1.7907	5.0926	6.8833
150	0.4758	0.001091	0.3928	631.68	1927.9	2559.5	632.20	2114.3	2746.5	1.8418	4.9960	6.8379
155	0.5431	0.001096	0.3468	653.24	1910.8	2564.1	653.84	2098.6	2752.4	1.8925	4.9010	6.7935
160	0.6178	0.001102	0.3071	674.87	1893.5	2568.4	675.55	2082.6	2758.1	1.9427	4.8075	6.7502
165	0.7005	0.001108	0.2727	696.56	1876.0	2572.5	697.34	2066.2	2763.5	1.9925	4.7153	6.7078
170	0.7917	0.001114	0.2428	718.33	1858.1	2576.5	719.21	2049.5	2768.7	2.0419	4.6244	6.6663
175	0.8920	0.001121	0.2168	740.17	1840.0	2580.2	741.17	2032.4	2773.6	2.0909	4.5347	6.6256
180	1.0021	0.001127	0.19405	762.09	1821.6	2583.7	763.22	2015.0	2778.2	2.1396	4.4461	6.5857
185	1.1227	0.001134	0.17409	784.10	1802.9	2587.0	785.37	1997.1	2782.4	2.1879	4.3586	6.5465
190	1.2544	0.001141	0.15654	806.19	1783.8	2590.0	807.62	1978.8	2786.4	2.2359	4.2720	6.5079
195	1.3978	0.001149	0.14105	828.37	1764.4	2592.8	829.98	1960.0	2790.0	2.2835	4.1863	6.4698

TABLE A–5

Saturated water—Pressure table (*Concluded*)

Press., *P* MPa	Sat. temp., T_{sat} °C	*Specific volume,* m³/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg · K		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.40	195.07	0.001149	0.14084	828.70	1764.1	2592.8	830.30	1957.7	2790.0	2.2842	4.1850	6.4693
1.50	198.32	0.001154	0.13177	843.16	1751.3	2594.5	844.89	1947.3	2792.2	2.3150	4.1298	6.4448
1.75	205.76	0.001166	0.11349	876.46	1721.4	2597.8	878.50	1917.9	2796.4	2.3851	4.0044	6.3896
2.00	212.42	0.001177	0.09963	906.44	1693.8	2600.3	908.79	1890.7	2799.5	2.4474	3.8935	6.3409
2.25	218.45	0.001187	0.08875	933.83	1668.2	2602.0	936.49	1865.2	2801.7	2.5035	3.7937	6.2972
2.5	223.99	0.001197	0.07998	959.11	1644.0	2603.1	962.11	1841.0	2803.1	2.5547	3.7028	6.2575
3.0	233.90	0.001217	0.06668	1004.78	1599.3	2604.1	1008.42	1795.7	2804.2	2.6457	3.5412	6.1869
3.5	242.60	0.001235	0.05707	1045.43	1558.3	2603.7	1049.75	1753.7	2803.4	2.7253	3.4000	6.1253
4	250.40	0.001252	0.04978	1082.31	1520.0	2602.3	1087.31	1714.1	2801.4	2.7964	3.2737	6.0701
5	263.99	0.001286	0.03944	1147.81	1449.3	2597.1	1154.23	1640.1	2794.3	2.9202	3.0532	5.9734
6	275.64	0.001319	0.03244	1205.44	1384.3	2589.7	1213.35	1571.0	2784.3	3.0267	2.8625	5.8892
7	285.88	0.001351	0.02737	1257.55	1323.0	2580.5	1267.00	1505.1	2772.1	3.1211	2.6922	5.8133
8	295.06	0.001384	0.02352	1305.57	1264.2	2569.8	1316.64	1441.3	2758.0	3.2068	2.5364	5.7432
9	303.40	0.001418	0.02048	1350.51	1207.3	2557.8	1363.26	1378.9	2742.1	3.2858	2.3915	5.6722
10	311.06	0.001452	0.018026	1393.04	1151.4	2544.4	1407.56	1317.1	2724.7	3.3596	2.2544	5.6141
11	318.15	0.001489	0.015987	1433.7	1096.0	2529.8	1450.1	1255.5	2705.6	3.4295	2.1233	5.5527
12	324.75	0.001527	0.014263	1473.0	1040.7	2513.7	1491.3	1193.3	2684.9	3.4962	1.9962	5.4924
13	330.93	0.001567	0.012780	1511.1	985.0	2496.1	1531.5	1130.7	2662.2	3.5606	1.8718	5.4323
14	336.75	0.001611	0.011485	1548.6	928.2	2476.8	1571.1	1066.5	2637.6	3.6232	1.7485	5.3717
15	342.24	0.001658	0.010337	1585.6	869.8	2455.5	1610.5	1000.0	2610.5	3.6848	1.6249	5.3098
16	347.44	0.001711	0.009306	1622.7	809.0	2431.7	1650.1	930.6	2580.6	3.7461	1.4994	5.2455
17	352.37	0.001770	0.008364	1660.2	744.8	2405.0	1690.3	856.9	2547.2	3.8079	1.3698	5.1777
18	357.06	0.001840	0.007489	1698.9	675.4	2374.3	1732.0	777.1	2509.1	3.8715	1.2329	5.1044
19	361.54	0.001924	0.006657	1739.9	598.1	2338.1	1776.5	688.0	2464.5	3.9388	1.0839	5.0228
20	365.81	0.002036	0.005834	1785.6	507.5	2293.0	1826.3	583.4	2409.7	4.0139	0.9130	4.9269
21	369.89	0.002207	0.004952	1842.1	388.5	2230.6	1888.4	446.2	2334.6	4.1075	0.6938	4.8013
22	373.80	0.002742	0.003568	1961.9	125.2	2087.1	2022.2	143.4	2165.6	4.3110	0.2216	4.5327
22.09	374.14	0.003155	0.003155	2029.6	0	2029.6	2099.3	0	2099.3	4.4298	0	4.4298

TABLE A–6

Superheated water (*Continued*)

H_2O

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 4.0 MPa (250.40°C)				P = 4.5 MPa (257.49°C)				P = 5.0 MPa (263.99°C)			
Sat.	0.04978	2602.3	2801.4	6.0701	0.04406	2600.1	2798.3	6.0198	0.03944	2597.1	2794.3	5.9734
275	0.05457	2667.9	2886.2	6.2285	0.04730	2650.3	2863.2	6.1401	0.04141	2631.3	2838.3	6.0544
300	0.05884	2725.3	2960.7	6.3615	0.05135	2712.0	2943.1	6.2828	0.04532	2698.0	2924.5	6.2084
350	0.06645	2826.7	3092.5	6.5821	0.05840	2817.8	3080.6	6.5131	0.05194	2808.7	3068.4	6.4493
400	0.07341	2919.9	3213.6	6.7690	0.06475	2913.3	3204.7	6.7047	0.05781	2906.6	3195.7	6.6459
450	0.08002	3010.2	3330.3	6.9363	0.07074	3005.0	3323.3	6.8746	0.06330	2999.7	3316.2	6.8186
500	0.08643	3099.5	3445.3	7.0901	0.07651	3095.3	3439.6	7.0301	0.06857	3091.0	3433.8	6.9759
600	0.09885	3279.1	3674.4	7.3688	0.08765	3276.0	3670.5	7.3110	0.07869	3273.0	3666.5	7.2589
700	0.11095	3462.1	3905.9	7.6198	0.09847	3459.9	3903.0	7.5631	0.08849	3457.6	3900.1	7.5122
800	0.12287	3650.0	4141.5	7.8502	0.10911	3648.3	4139.3	7.7942	0.09811	3646.6	4137.1	7.7440
900	0.13469	3843.6	4382.3	8.0647	0.11965	3842.2	4380.6	8.0091	0.10762	3840.7	4378.8	7.9593
1000	0.14645	4042.9	4628.7	8.2662	0.13013	4041.6	4627.2	8.2108	0.11707	4040.4	4625.7	8.1612
1100	0.15817	4248.0	4880.6	8.4567	0.14056	4246.8	4879.3	8.4015	0.12648	4245.6	4878.0	8.3520
1200	0.16987	4458.6	5138.1	8.6376	0.15098	4457.5	5136.9	8.5825	0.13587	4456.3	5135.7	8.5331
1300	0.18156	4674.3	5400.5	8.8100	0.16139	4673.1	5399.4	8.7549	0.14526	4672.0	5398.2	8.7055
	P = 6.0 MPa (275.64°C)				P = 7.0 MPa (285.88°C)				P = 8.0 MPa (295.06°C)			
Sat.	0.03244	2589.7	2784.3	5.8892	0.02737	2580.5	2772.1	5.8133	0.02352	2569.8	2758.0	5.7432
300	0.03616	2667.2	2884.2	6.0674	0.02947	2632.2	2838.4	5.9305	0.02426	2590.9	2785.0	5.7906
350	0.04223	2789.6	3043.0	6.3335	0.03524	2769.4	3016.0	6.2283	0.02995	2747.7	2987.3	6.1301
400	0.04739	2892.9	3177.2	6.5408	0.03993	2878.6	3158.1	6.4478	0.03432	2863.8	3138.3	6.3634
450	0.05214	2988.9	3301.8	6.7193	0.04416	2978.0	3287.1	6.6327	0.03817	2966.7	3272.0	6.5551
500	0.05665	3082.2	3422.2	6.8803	0.04814	3073.4	3410.3	6.7975	0.04175	3064.3	3398.3	6.7240
550	0.06101	3174.6	3540.6	7.0288	0.05195	3167.2	3530.9	6.9486	0.04516	3159.8	3521.0	6.8778
600	0.06525	3266.9	3658.4	7.1677	0.05565	3260.7	3650.3	7.0894	0.04845	3254.4	3642.0	7.0206
700	0.07352	3453.1	3894.2	7.4234	0.06283	3448.5	3888.3	7.3476	0.05481	3443.9	3882.4	7.2812
800	0.08160	3643.1	4132.7	7.6566	0.06981	3639.5	4128.2	7.5822	0.06097	3636.0	4123.8	7.5173
900	0.08958	3837.8	4375.3	7.8727	0.07669	3835.0	4371.8	7.7991	0.06702	3832.1	4368.3	7.7351
1000	0.09749	4037.8	4622.7	8.0751	0.08350	4035.3	4619.8	8.0020	0.07301	4032.8	4616.9	7.9384
1100	0.10536	4243.3	4875.4	8.2661	0.09027	4240.9	4872.8	8.1933	0.07896	4238.6	4870.3	8.1300
1200	0.11321	4454.0	5133.3	8.4474	0.09703	4451.7	5130.9	8.3747	0.08489	4449.5	5128.5	8.3115
1300	0.12106	4669.6	5396.0	8.6199	0.10377	4667.3	5393.7	8.5475	0.09080	4665.0	5391.5	8.4842
	P = 9.0 MPa (303.40°C)				P = 10.0 MPa (318351.06°C)				P = 12.5 MPa (327.89°C)			
Sat.	0.02048	2557.8	2742.1	5.6772	0.018026	2544.4	2724.7	5.6141	0.013495	2505.1	2673.8	5.4624
325	0.02327	2646.6	2856.0	5.8712	0.019861	2610.4	2809.1	5.7568				
350	0.02580	2724.4	2956.6	6.0361	0.02242	2699.2	2923.4	5.9443	0.016126	2624.6	2826.2	5.7118
400	0.02993	2848.4	3117.8	6.2854	0.02641	2832.4	3096.5	6.2120	0.02000	2789.3	3039.3	6.0417
450	0.03350	2955.2	3256.6	6.4844	0.02975	2943.4	3240.9	6.4190	0.02299	2912.5	3199.8	6.2719
500	0.03677	3055.2	3386.1	6.6576	0.03279	3045.8	3373.7	6.5966	0.02560	3021.7	3341.8	6.4618
550	0.03987	3152.2	3511.0	6.8142	0.03564	3144.6	3500.9	6.7561	0.02801	3125.0	3475.2	6.6290
600	0.04285	3248.1	3633.7	6.9589	0.03837	3241.7	3625.3	6.9029	0.03029	3225.4	3604.0	6.7810
650	0.04574	3343.6	3755.3	7.0943	0.04101	3338.2	3748.2	7.0398	0.03248	3324.4	3730.4	6.9218
700	0.04857	3439.3	3876.5	7.2221	0.04358	3434.7	3870.5	7.1687	0.03460	3422.9	3855.3	7.0536
800	0.05409	3632.5	4119.3	7.4596	0.04859	3628.9	4114.8	7.4077	0.03869	3620.0	4103.6	7.2965
900	0.05950	3829.2	4364.8	7.6783	0.05349	3826.3	4361.2	7.6272	0.04267	3819.1	4352.5	7.5182
1000	0.06485	4030.3	4614.0	7.8821	0.05832	4027.8	4611.0	7.8315	0.04658	4021.6	4603.8	7.7237
1100	0.07016	4236.3	4867.7	8.0740	0.06312	4234.0	4865.1	8.0237	0.05045	4228.2	4858.8	7.9165
1200	0.07544	4447.2	5126.2	8.2556	0.06789	4444.9	5123.8	8.2055	0.05430	4439.3	5118.0	8.0937
1300	0.08072	4662.7	5389.2	8.4284	0.07265	4460.5	5387.0	8.3783	0.05813	4654.8	5381.4	8.2717

TABLE A–26

Enthalpy of formation, Gibbs function of formation, and absolute entropy at 25°C, 1 atm

Substance	Formula	$\bar{h}_f^\circ$ kJ/kmol	$\bar{g}_f^\circ$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol · K
Carbon	$C(s)$	0	0	5.74
Hydrogen	$H_2(g)$	0	0	130.68
Nitrogen	$N_2(g)$	0	0	191.61
Oxygen	$O_2(g)$	0	0	205.04
Carbon monoxide	$CO(g)$	−110,530	−137,150	197.65
Carbon dioxide	$CO_2(g)$	−393,520	−394,360	213.80
Water vapor	$H_2O(g)$	−241,820	−228,590	188.83
Water	$H_2O(\ell)$	−285,830	−237,180	69.92
Hydrogen peroxide	$H_2O_2(g)$	−136,310	−105,600	232.63
Ammonia	$NH_3(g)$	−46,190	−16,590	192.33
Methane	$CH_4(g)$	−74,850	−50,790	186.16
Acetylene	$C_2H_2(g)$	+226,730	+209,170	200.85
Ethylene	$C_2H_4(g)$	+52,280	+68,120	219.83
Ethane	$C_2H_6(g)$	−84,680	−32,890	229.49
Propylene	$C_3H_6(g)$	+20,410	+62,720	266.94
Propane	$C_3H_8(g)$	−103,850	−23,490	269.91
n-Butane	$C_4H_{10}(g)$	−126,150	−15,710	310.12
n-Octane	$C_8H_{18}(g)$	−208,450	+16,530	466.73
n-Octane	$C_8H_{18}(\ell)$	−249,950	+6,610	360.79
n-Dodecane	$C_{12}H_{26}(g)$	−291,010	+50,150	622.83
Benzene	$C_6H_6(g)$	+82,930	+129,660	269.20
Methyl alcohol	$CH_3OH(g)$	−200,670	−162,000	239.70
Methyl alcohol	$CH_3OH(\ell)$	−238,660	−166,360	126.80
Ethyl alcohol	$C_2H_5OH(g)$	−235,310	−168,570	282.59
Ethyl alcohol	$C_2H_5OH(\ell)$	−277,690	−174,890	160.70
Oxygen	$O(g)$	+249,190	+231,770	161.06
Hydrogen	$H(g)$	+218,000	+203,290	114.72
Nitrogen	$N(g)$	+472,650	+455,510	153.30
Hydroxyl	$OH(g)$	+39,460	+34,280	183.70

Source: From JANAF, *Thermochemical Tables* (Midland, MI: Dow Chemical Co., 1971); *Selected Values of Chemical Thermodynamic Properties,* NBS Technical Note 270-3, 1968; and *API Research Project 44* (Carnegie Press, 1953).

TABLE
Delayed-neutron parameters for the common fuel isotopes

Group, *i*	Energy for uranium-235 fission, MeV	Half-life, s	Total neutrons from fission, %		
			Uranium-235	Uranium-233	Plutonium-239
Prompt	≈2.00	<0.001	99.359	99.736	99.790
1	0.25	55.72	0.021	0.023	0.007
2	0.56	22.72	0.140	0.079	0.063
3	0.43	6.22	0.126	0.066	0.044
4	0.62	2.30	0.253	0.073	0.069
5	0.42	0.61	0.074	0.014	0.018
6		0.23	0.027	0.009	0.009
Total delayed-neutron fraction =			0.641	0.264	0.210

SOLAR CONSTANTS
[FOR NORTHERN LATITUDES]

Date	Angle of declination δ	Equation of time, min	A_S,† kW/m²‡	B_S,† am§	C_S†	Day of year
January						
1	−23.0	−3.6	1231	0.142	0.057	1
11	−21.7	−8.0	1230	0.142	0.058	11
21	−19.6	−11.4	1229	0.142	0.058	21
31	−17.3	−13.5	1224	0.142	0.058	31
February						
1	−17.0	−13.6	1223	0.143	0.059	32
11	−13.9	−14.4	1218	0.143	0.059	42
21	−10.4	−13.8	1213	0.144	0.060	52
28	−7.6	−12.6	1206	0.147	0.063	59
March						
1	−7.4	−12.5	1205	0.148	0.063	60
11	−3.5	−10.2	1195	0.152	0.067	70
21	0.0	−7.4	1185	0.156	0.071	80
31	4.3	−4.3	1169	0.164	0.079	90
April						
1	4.7	−4.0	1167	0.165	0.080	91
11	8.5	−1.1	1151	0.172	0.088	101
21	12.0	1.2	1135	0.180	0.096	111
30	14.9	2.8	1126	0.185	0.104	120
July						
1	23.1	−3.4	1086	0.206	0.135	182
11	22.1	−5.6	1085	0.206	0.135	192
21	20.6	−6.2	1084	0.207	0.136	202
31	18.1	−6.2	1091	0.205	0.132	212
August						
1	17.9	−6.2	1092	0.205	0.132	213
11	15.2	−5.1	1099	0.203	0.126	223
21	12.0	−3.1	1106	0.201	0.122	233
31	8.7	−1.5	1120	0.193	0.113	243
September						
1	8.2	0.0	1122	0.192	0.112	244
11	4.4	3.3	1136	0.185	0.097	254
21	0.0	6.8	1150	0.177	0.092	264
30	−2.9	9.9	1162	0.172	0.086	273
October						
1	−3.3	10.2	1164	0.171	0.086	274
11	−7.2	13.1	1177	0.166	0.079	284
21	−10.8	15.3	1191	0.160	0.073	294
31	−14.3	16.2	1200	0.157	0.070	304
November						
1	−14.6	16.3	1201	0.156	0.069	305
11	−17.5	15.9	1211	0.153	0.066	315
21	−20.0	15.1	1220	0.149	0.063	325
30	−21.7	11.3	1224	0.147	0.061	334
December						
1	−21.9	11.0	1224	0.147	0.061	335
11	−23.0	6.8	1228	0.144	0.059	345
21	−23.45	2.0	1232	0.142	0.057	355
31	−23.1	−3.1	1231	0.142	0.057	365

PARTIAL LIST OF ISOTOPES

Element Chemical symbol Atomic weight	Atomic number Z	Atomic mass number A	Isotopic mass, amu	Natural abundance, %	Half-life†	Type of decay†
Electron	−1	0	0.000549			
Neutron	0	1	1.008665		11.7 m	β^-
Hydrogen	1	1	1.007825	99.985		
H	1	2	2.01410	0.015		
1.00797	1	3	3.01605		12.26 y	β^-
Helium	2	3	3.01603	0.00013		
He	2	4	4.00260	99.99987		
4.0026	2	5	5.01230		2×10^{-21} s	α
	2	6	6.01888		0.8 s	β^-
	2	8	8.03750		0.122 s	β^-
Nickel	28	57	56.9394		36.1 h	K
Ni	28	58	57.9353	68.30		
58.710	28	59	58.9342		8.0×10^4 y	K
	28	60	59.9308	26.13		
	28	61	60.9310	1.09		
	28	62	61.9283	3.56		
	28	63	62.9286		100.0 y	β^-
	28	64	63.9280	0.92		
	28	65	64.9291		2.56 h	β^-
Copper	29	58	57.9456		3.30 s	β^+
Cu	29	60	59.9375		24.0 m	β^+
63.546	29	61	60.9327		3.30 h	β^+
	29	62	61.9316		9.80 m	β^+
	29	63	62.9298	69.20		
	29	64	63.9288		12.9 h	$\beta^+/K/\beta^-$
	29	65	64.9278	30.80		
	29	66	65.9288		5.10 m	β^-
	29	67	66.9278		61.0 h	β^-
Zinc	30	62	61.9339		9.30 h	β^+
Zn	30	63	62.9330		38.8 m	β^+
65.370	30	64	63.9291	48.60		
	30	65	64.9283		243.6 d	K/β^+
Thorium	90	227	227.0277		18.7 d	α
Th	90	228	228.0287		1.91 y	α
232.038	90	229	229.0316		7340 y	α
	90	230	230.0331		80,000 y	α
	90	231	231.0347		25.5 h	β^-
	90	232	232.0382	100.00	1.41×10^{10} y	α
	90	233	233.0387		22.2 m	β^-
	90	234			24.2 d	β^-
Uranium	92	227	227.0309		1.30 m	α
U	92	228	228.0313		9.30 m	α/K
238.03	92	229	229.0335		58.0 m	K/α
	92	230	230.0339		20.8 d	α
	92	231	231.0363		4.30 d	K
	92	232	232.0372		73.6 y	α
	92	233	233.0395		1.65×10^5 y	α
	92	234	234.0409	0.006	2.4×10^5 y	α
	92	235	235.0439	0.720	7.1×10^8 y	α
	92	236	236.0457		2.39×10^7 y	α
	92	237	237.0469		6.75 d	β^-
	92	238	238.0508	99.274	4.51×10^9	α
	92	239	239.0526		23.5 m	β^-
	92	240	240.0546		14.1 h	β^-

Solar emissivities

Materials	Infrared (low-temp.) radiation	Solar radiation
Building materials:		
Red brick, tile, concrete	0.85–0.95	0.65–0.77
Yellow and buff brick	0.85–0.95	0.50–0.70
Plaster	0.90–0.95	0.50–0.70
Asphalt pavement	0.90–0.95	0.82–0.88
Roofing materials:		
Asphalt	0.90–0.95	0.86–0.90
Galvanized iron, dirty	0.25–0.35	0.87–0.91
Galvanized iron, new	0.20–0.30	0.64–0.68
Roofing paper	0.85–0.95	0.85–0.90
Slate	0.90–0.98	0.85–0.95
Paints:		
Aluminum (bright), gilt	0.25–0.65	0.30–0.50
Black, flat	0.95–0.98	0.85–0.95
Dark (red, brown, green, etc.)	0.75–0.95	0.65–0.83
White, flat	0.95–0.99	0.12–0.25
Metals:		
Aluminum, nickel, chromium (polished)	0.02–0.10	0.10–0.40
Copper, brass, monel metal (polished)	0.02–0.15	0.30–0.50
Dull aluminum, brass, copper, and polished iron	0.20–0.50	0.40–0.65
Iron oxide	0.60–0.65	0.70–0.80