Appendix B

Answers to Exercises

Chapter 2 (**1**) 1.553×10^{22} atoms ^{235}U. (**2**) 0.10. (**3a**) 2111 m s^{-1}. (**3b**) 0.0462 V. (**4**) 472 V. (**5**) 11.00934 u. (**6**) 0.1293 nm. (**7**) 8.311×10^{17} molecules at average translational energy, corresponding to 2919 K. (**8**) 2.080. (**9**) 4 (3.7) stages. (**10**) 0.030 m. (**11b**) $\alpha = 1.097$. (**11c**) 22 (21.8) stages. (**12**) 5.742 kgSW.

Chapter 3 (**1**) 8.261 MeV nucleon^{-1}. (**2**) 1.58×10^{6} times. (**3**) 135 350 km. (**4**) Fusion ~7 times more. (**5**) Neutron-binding energies are 1.02, 2.76, and 1.04 MeV below average value for ^{236}U, ^{239}U, and ^{240} Pu, respectively. (**6**) 6.26, 8.37, 8.73, 7.49 MeV nucleon^{-1} for ^{10}B, ^{27}Al, ^{59}Co and ^{236}U, respectively. (**7**) $Z = 4.8$ ($^{10}_{5}$B stable), 12.6 ($^{27}_{13}$Al stable), 26.4 ($^{59}_{27}$Co stable), 91.8 ($^{239}_{92}$U unstable, $^{239}_{93}$Np unstable, $^{239}_{94}$Pu the least unstable).

Chapter 4 (**1**) 0.088 MeV, ^{235}U. (**2a**) 0.87 MeV. (**2b**) 0.46 MeV (measured 0.51 MeV). (**3**) 99 eV. (**4**) 1.26 keV. (**5**) 547 keV (measured 662 keV). (**6**) 1.28×10^{9} y. (**7**) 5.9×10^{9} y. (**8**) 1.84×10^{22} J y^{-1}. (**9a**) 16.9 GBq. (**9b**) 3.0×10^{-10} m^3. (**11a**) 1.46×10^{4} Bq. (**11b**) 8.09×10^{8} atoms. (**12**) $t_{½} = 104$ h and 99 Bq, $t_{½}$ 4.4 h and 1030 Bq, respectively. (**13**) R_0 507 cpm for $t_{½}$ 107 min. R_0 440 cpm for $t_{½}$ 24 min (cf. ^{208}At 98 min, ^{206}At 31 min half-lives). (**14**) 2.3×10^{5} y.

Chapter 5 (**1**) 0.131 Bq m^{-3}. (**2**) 9.8×10^{6} y. (**3**) ~266 Bq/kg C. (**4**) Probably true. (**5**) 1.7×10^{9} y. (**6**) 5.0×10^{8} y. (**7**) 3.7×10^{9} y. (**8**) U 0.0012, Th 0.0014, K 0.00023 W m^{-2}. (**9a**) 193 t. (**9b**) 459 000 t. (**10**) Japan 17.6 y, Argentine 52.7 y, France 211 y.

Chapter 6 (**1**) From (6.11) R 5.8 mg cm^{-2}, from Fig. 6.6 ~6 mg cm^{-2}. (**2**) E_α 2.0 MeV. (**3**) 0.71 mm. (**4**) e$^-$ 3.8 m, H$^+$ 23 cm, α 3.3 mm. (**5**) Al 0.030, Ni 0.012, Pt 0.0074 mm. (**6**) 6.54×10^{7} γ m^{-2} s^{-1}. (**7**) ^{3}H 5 µm, ^{14}C 270 µm, ^{32}P 5.3 mm, ^{90}Sr 1.1 mm. (**8**) 2.92×10^{8} m s^{-1}. (**9**) Lead $118 500, concrete $3 730. (**10**) Na_K 57.53, Na_L 58.54, I_K 25.43, I_L 53.80 keV. (**11**) 72% and 52%. (**12**) 28, 39, and 49 g cm^{-2}. (**13a**) E_{max} 0.62 MeV. (**13b**) ~0.8 MeV. (**14a**) 9.7 days. (**14b**) 19 min. (**15**) 0.54 m. (**16a**) 7.0 cm. (**16b**) 11.9. (**16c**) 2.5.

Chapter 7 (**1a**) 1.47×10^{5}. (**1b**) 2.94×10^{4}. (**1c**) 972. (**2**) ~1.2%. (**3**) 38 pGy. (**4**) 0.34%. (**5**) ~11%. (**6**) ^{90}Sr 0.10, ^{90}Y 0.068, ^{3}H 2.5 keV µm^{-1}. (**7**) 6.3 mGy/s. (**8**) 38 pF.

Chapter 8 (**1a**) 1.33 GBq. (**1b**) 2.5%. (**2a**) 25 µm. (**2b**) 1.05×10^{5} µm^{-1}. (**2c**) 4.6 nm. (**2d**) 3.8 eV atom^{-1}. (**2e**) 29 400 K. (**3**) 0.11 µM. (**4**) 0.88 Bq. (**5**) 5.8 V. (**6a**) 509 µs. (**6b**) 12.53. (**6c**) 17.84. (**7**) 3.1×10^{10} counts. (**8**) 45 ns. (**9a**) 6.6 µg cm^{-2}. (**9b**) 1.59. (**9c**) 71%. (**10a**) 9.33 ± 0.11 cps. (**10b**) ± 0.072 cps. (**11**) 0.54%.

Chapter 9 (**1**) 4.7 liter. (**2**) 24%. (**3**) 21.0%. (**4**) 1.1 mg. (**5**) 45 ppm Ga. (**6**) 20.4%. (**7**) 3.32×10^{-4} s^{-1} M^{-1}. (**8**) Calculated log(β_n) values are: 6.1, 10.6, 13.8. (**9**) $\log\beta_4 = 15 \pm 1$ and $\log K_{DC} = 0 \pm 0.3$. (**10**) 29 m^3. (**11**) −0.24 V. (**12**) optimal separation at pH ~4. (**13**) 99.9% U with 9.8% La.

Chapter 10 In general see text in chapter 10. (**1**) Isotropic flux above 1 GeV. No variation with solar activity. (**2a**) High energy particles; ~70% p, ~20% α, ~0.7% Li + Be + B ions, ~1.7% C + N + O ions, rest $Z > 10$. (**2b**) Mostly not. (**3**) 200-300 cps. (**4**) see §10.1, energy to mass conversion. (**5a**) Gravitation, the electromegnetic force, the weak and strong interaction forces. (**5b**) See e.g. Tables 10.2 and 10.3. (**6a**) See §10.5. (**6b**) See §10.5. (**7**) Radiation pressure, recoil in γ-emission, interaction with gravitation fields. (**8**) See §10.6.

Chapter 11 (**1a**) 10. (**1b**) 10. (**2a**) 2.19×10^{6} m s^{-1}. (**2b**) 0.003%; no. (**3**) 21 MHz. (**4**) 2.689x2/3. (**5**) 1i, 2g, 3d, 4s; 56 nucleons. (**6**) ~280 MeV (**7a**) 7/2, $3.81 \times (1/5)$. (**7b**) 5, $4.50 \times (2/5)$. (**7c**) 5/2. (**8a**) 0.108. (**8b**) 7/2 (also observed). (**9**) 1p1/2. (**10a**) 43.8 and 307 keV. (**10b**) 3.47 fm (8.68 fm from (3.7), meas. 5.48 fm). (**11**) 12.925 T. (**12**) 3.2×10^{9} y. (**13**) 8.86×10^{10} y, hindrance factor 1.2

Chapter 12 (**1a**) 37.3 MeV (**1b**) 1 305 m s^{-1}, 0.035 eV. (**2**) 46.4 fm. (**3a**) 32.9 b sr^{-1}. (**3b**) 0.423 m. (**4**) 0.75 MeV. (**5a**) 38.7 fm. (**5b**) 7.56 fm. (**6a**) 8.03 MeV. (**6b**) −1.64 MeV. (**7**) 3.09×10^6 m s^{-1}. (**8**) 3.57×10^{-28} kg. (**9**) 77.3 MeV. (**10**) Q (0.87 MeV) > 0, $^5_2$He thus unstable. (**11a**) −5.85 MeV. (**11b**) 6.38 MeV. (**11c**) 2.98 MeV. (**11d**) 6.38 MeV.

Chapter 13 (**1a**) 10.4 cm. (**1b**) 9.0 MeV. (**1c**) ~ ^{38}Ar. (**2**) Between 1:st and 2:nd. (**3a**) 10 kW. (**3b**) 228 m s^{-1}. (**3c**) 2 646 m s^{-1}. (**4**) 7.6×10^{11} n m^{-2} s^{-1}. (**5**) 4.11 m. (**6a**) L_2 = 1.410 cm, L_3 = 1.73 cm. (**6b**) 109.4 MHz. (**7**) H^+ 11.8 MeV, 0.80 T; D^+ 23.6 MeV, 1.598 T: He^{2+} 46.9 MeV, 1.588 T. (**8**) 1.01×10^{10} s^{-1}. (**9**) 8.53×10^3 g. (**10a**) 35. (**10b**) 78.75 MeV. (**10b**) 124.4 MeV.

Chapter 14 (**1**) 9.9×10^{-8} s^{-1}. (**2**) 6.0%. (**3a**) 3.18×10^{14}. (**3b**) 5.04×10^{-3}%. (**3c**) max 29 kW. (**4**) 36.4 m^{-1}. (**5a**) 0.52%. (**5b**) yes. (**6**) light 103.4 MeV, heavy 74.3 MeV. (**7**) 1.78 MeV. (**8**) $E_\gamma \geq 11.46$ MeV. (**9**) 1.1×10^9 K.

Chapter 15 (**1**) 28 PBq/kg Na. (**2**) 0.106. (**3**) 0.85 TBq. (**4a**) 1.56×10^7 s. (**4b**) 0.145. (**5**) 4 873 cps. (**6**) 10.5 d.

Chapter 16 (**1**) n,γ on ^{196}Hg, or n,2n on ^{198}Hg. (**2**) 79%. (**3**) ^{239}Pu from d,n in ^{238}U. (**4**) ^{248}Cm and FP; ^{253}Es and ^{249}Cm; ^{250}Cm and FP. (**5**) 2.30 n/fiss. (**6**) possibly ^{259}Sg. (**7**) Am(III) has larger ionic radius than Eu(III). (**8**) 0.085 W. (**9**) 5 f^{14} $7s^2$. (**10**) Pu(III)/Pu(IV) ~ 970 mV, Pu(IV)/Pu(V) ~ 1050 mV, Pu(V)/Pu(VI) ~ 930 mV; correct values in Fig. 22.3.

Chapter 17 (**1a**) 1.9 keV. (**1b**) ~ $2.6.8 \times 10^{-33}$. (**2**) 49 MW. (**3**) 566 liter. (**4**) 5.36×10^{11} kg s^{-1}. (**5**) 1.68%. (**6**) Water power ~ 9.8×10^7 W, fusion ~ 1.2×10^{15} W.

Chapter 18 (**1**) ^{3}H 163.5 Bq, ^{14}C 2.85 kBq, ^{40}K 4.40 kBq, Ra and daughters 0.93 Bq, sum 7.41 kBq/70 kg. (**2**) 2.92×10^{-4} g. (**3**) 1.25×10^{-3} g. (**4a**) 124 µSv y^{-1}. (**4b**) 39 µSv y^{-1}. (**5**) 10 mSv. (**6a**) 4.37 MeV. (**6b**) 698 million. (**7**) 1.14 µs.

Chapter 19 (**1**) $465 million. (**2**) 0.765 kg ^{235}U. (**3a**) 7 oil tankers (7.1). (**3b**) One train car (8.9 t). (**3c**) 4 train cars (75.4 t). (**4**) 21 collisions (20.63). (**5**) 1.896. (**6**) η = 2.022, f = 0.750, k_∞ = 1.451. (**7**) 1.257 m. (**8**) 2.131 m side. (**9a**) Λ = 0.607. (**9b**) r = 0.256 m. (**10**) 23.1%. (**11**) ~ 33 100 times. (**12**) 3.41×10^{12} atoms s^{-1}. (**13**) 9.0 h. (**14**) 3.07 kg.

Chapter 20 (**1**) ~ 34 000 kg. (**2**) 14 600 m^3. (**3a**) 0.64 s. (**3b**) 193 GJ. (**4**) ^{36}Cl, ^{37}Cl, ^{40}K, and ^{42}K. (**5a**) ^{232}Th(n,2n)^{231}Th(β^-)^{231}Pa(n,γ)^{232}Pa(β^-)^{232}U. (**5b**) Yes. (**6**) 60%. (**7a**) Rest heat cooling to the sea. (**7b**) HV-stability more important. (**8**) Recirculated back to off-gas system (multiplies decay time).

Chapter 21 (**1**) 674 and 1202 °C. (**2a**) 1.40 kg. (**2b**) Effective cross-sections (Fig. 19.5), self-screening, and capture to ^{240}Pu. (**3**) 152 d. (**4a**) 2.333 kg ^{235}U. (**4b**) 1.141 kg ^{235}U. (**5**) See Figs. 20.4, 5.1 and text in §20.3.1. (**6a**) 31.6 kg FP. (**6b**) 0.91%. (**7a**) ~ 20 PBq. (**7b**) Ce, Pr, Cs, and Rh. (**8a**) 8.7×10^5. (**8b**) 3.9×10^2. (**9**) 404 MBq ^{238}Pu, 94 MBq ^{240}Pu. (**10**) 9.04×10^{15}. (**11a**) 95 kW. (**11b**) 34 cylinders. (**11c**) 1.5 reactor years. (**12**) Ru 710 kg, 10.2 TBq kg^{-1}; Rh 153 kg, 47 TBq kg^{-1}; Pd 456 kg, 2.92 GBq kg^{-1}.

Chapter 22 (**1**) See e.g. §21.13.1 and Fig. 22.10 (**2**) All. (**3**) Np as NpO_2^+, Pu as Pu^{4+}. (**4a**) See §21.13.3. (**4b**) ASSE salt dome, WIPP bedded salt. (**5**) 9×10^{-9} M. (**6**) $10^{-18.2}$. (**7a**) E = 0.739 − 0.236 pH (V). (**7b**) Eh > −0.681 V. (**8a**) Worst case 11 MBq. (**8b**) No, time of arrival is ~ 429 y in the future.

Appendix A (**1a**) 1.5%. (**1b**) 99.9%. (**1c**)2.7×10^{-6}%. (**1d**)8×10^{-4}% .(**2**) Use smaller solution for P; $\theta_{extr} = 8.60$, $\theta_{wash} = 94.6$.