ANSWERS TO PROBLEMS

Chapter 1

3. 146.
4. A = 32, N = 78, Z = 52.
5. (a) 16, 55, 82; (b) 54.
8. (a) 10, 8; (b) 10, 10.
9. 0.72% x 19 kg = 0.14 kg
10. 50 L x 1.1 kg/L + 1 kg = 56 kg. No.
11. 2.3E14 tonnes/mm^3.

Chapter 2

6. 25 keV. Increase.
11. (a) 2.9 m; (b) 5.9 mm.
12. (a) 11.8 mm; (b) because they lose so much less energy per unit distance travelled.
13. Beta particles have a range of energies from 0 to E_{max}: the betas with very low energy will have less range than alphas.
14. 0.039 – 0.085 mm for 4.5 to 8 MeV α.
15. 6.5 m by calculation, or use Fig. 2.14.
18. Increased bremsstrahlung was produced in the glass walls of the beaker when the water evaporated.
19. 2^{19} = 5.2E5.
22. 230, 90.
23. 230, 90.
26. K-41.
27. β^+.
30. Th-231, Pa-231, Ac-227, Th-227, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Po-211, Pb-207.
32. 1/8.
33. (a) 1; (b) 3.3; (c) 6.6.
34. 7 dps, 8E6 dps, 9E12 dps.
35. (a) 30 y; (b) 0.175 mg; (c) 0.0625 mg
36. (d) became Ba-137 (see Table 1.1, use Fig. 2.24).
37. Yes, the missing Co-60 became Ni-60.
38. 750 Bq, 250 Bq, 0 Bq.
39. 16 d; I-135 has decayed completely in a few days, Cs-137 remains unchanged.
40. Assume weight = 70 kg = 0.245 kg K = 2.87E-5 kg K-40 = 4.3E20 atoms of K-40. Activity = nλ = 7300 Bq.
41. 4.4E9 y.
51. Elastic scatter with D atoms in heavy water.
52. He-4 = 42, C-12 = 115, U-238 = 2172. Helium is a gas: the low density means that the reactors would be gigantic.
54. Yes, by neutron activation.
56. (a) no, because there are no neutrons. (b) no.
57. Yes.
62. The short-lived fission products have decayed, so the Sr-90 represents a greater fraction of the remaining activity.
64. D_2O loss is 12.2 TBq = 24.4 kg or 22.1 L (D_2O is 10% denser than H_2O.)

Chapter 3

5. 1 mSv (gamma only).
6. 3 + 0.6 x 5 + 1 = 7 mSv. This is the dose to skin., the whole-body dose will be 6 mSv.
7. Yes (dose = energy/mass).
9. (c) 10 μSv x 2^{20}.
10. (c) 10 J ÷ 100 kg = 0.1 Gy.

Chapter 4

3. 33 mSv x 4%/1000 mSv = 0.13%.
4. 4% and 0% (10 mSv of gamma will kill him in a couple of weeks.

Chapter 5

4. SDSD, SDDS, DDSS, DSSS.
5. 5 mSv; yes; 4 mSv (see p. 117).
7. (a) 290 μSv; (b) 690 μSv.
8. (a) Dec 21 (assuming no days off), (b) Dec 31 (merry Christmas).
9. 7.4 mSv

10. 12.5 mSv
11. (a) H_{WB} = 10.4 mSv, H_S = 60.4 mSv.
    (b) H_{WB} = 3.6 mSv, H_S = 430.6 mSv.
12. 5.2 mSv. Yes, a total dose of 3.7 mSv once saves 5.2 mSv every year.

Chapter 6

1. (d)
2. (d)
3. Well?
4. 250 μGy/h, 35 mGy/h;
   25 μGy/h, 4 mGy/h.
5. (a) Hand & Shoe Monitor (Fig. 6.8), β,γ.
   (b) Full Body Monitors (Fig. 6.9), β, γ.
   (c) Cont. Mon. (Fig. 6.10), α, β, γ.
   (d) Neutron Meter (Fig. 6.11), neutrons.
6. (a) Port. Cont. Meter. (Fig. 6.13), β, γ.
   (b) Low Range Gamma Survey Meter, 5016 Type, (Fig. 6.14), γ.
   (c) Low Range Gamma Survey Meter, FAG Type, (Fig. 6.21), γ.
7. (a) Emerg. Gamma Meter (Fig. 6.5), γ.
   (b) Tritium Ion Chamber (Fig. 6.6), H^3.
   (c) Low Range Beta Survey Meter (Fig. 6.17), β.
8. (a) Alpha Cont. Meter (Fig. 6.33), α.
   (b) Wide Range Gamma Survey Meter, see Fig. 6.34), γ.
   (c) Vehicle Monitor (Fig. 6.35), γ.
   (d) Self-Serve Thyroid Monitor (Fig. 6.38), γ.
8. (e) Whole-Body Counter (Fig. 6.39), γ.
   (f) Liquid Scint. Counter (Fig. 6.41), β.
   (g) Portal Monitor (Fig. 6.42), γ.
9. PAD (TLD also).
10. (a) 7a, (b) 6b, 6c, (c) 7c,
    (d) 8a, (e) 6a, (f) PAD, TLD,
    (g) TLD, (h) 5d, (i) 5d.
11. (b) High background of 8 - 9 cps, or contamination on the detector, or meter selected to “battery-check”.
12. (a) H_S = 64 mSv, H_D = 4 mSv,
    (b) 4 mSv, (c) no change.
13. (a) α = 7 cps, β = 10 cps.
    (b) α = 47 Bq, β = 50 Bq.
15. About 30 s.
17. Initial net count = 250 – 150 = 100 cpm,
    Final net count = 175 – 125 = 50. $T_{1/2}$ = 7 d.
18. Go to Security.
19. See pages 164 – 165.
21. 10 μSv/s = 36 mSv/h.
22. See page 170.
23. a = F, b = T, c = T, d = T, e = T, f = T, g =T, h = F, i = T unless PAD read over 0.05 mSv, j = T, k = T, l = T, m = F.

Chapter 7

3. 1.2 mSv. 37 min.
12. At least 20 h, more if the apparent half-life increases as the short-lived activity decays. 1/3 mSv/h.
13. (a) yes; (b) beta radiation from the piece of fuel; (c) pretty good, the mean dose is about half; (d) see chapter 4.
7. LD_{50} ≈ 4 Sv (p. 97) = 12 min at 20 Sv/h.
8. (a).
9. (b).
10. all are True.
11. a = 2, b = 1, c = 3, d = 4, e = 4, f = 5, for (g) take the portable AGM (Fig. 7.15).
12. (a)
13. a,e,d.
14. As you approach the source, the beta dose rate should increase faster than given by the inverse square law, so the answer is too low.
15. (a) N-16, O-19; (b) 4 mSv/h.
16. (a) Noble gases; (b) 4 mGy/h;
    (c) 0.9 mSv;
    (d) H_D = 0.9 mSv, H_S = 2.9 mSv:
    (e) short-lived particulates.
19. N, C, D, C, C, D.
20. (c).

Chapter 8

5. 10 d.
6. 120 d.
7. b.
9. a = T, b = T, c = T, d = T, e = F.
10. c, e.
11. d.
12. a = Y, b = X, c = X, d = X, e = Y.
13. e.
14. a.
15. 20 mSv.
16. H_D = 1.2 mSv, H_S = 1.6 mSv.
17. 1600 GBq/kg = 1760 GBq/L
= 88 GBq/50 mL = 88 ALI = 1.8 Sv.
18. With a wetted surface of 1500 cm^2
= 0.15 m^2 = 0.15 g intake = 0.24 GBq
= 0.24 ALI = 4.8 mSv.
19. Chris = 15 μSv, Dan = 25 μSv.
20. See page 242.
21. 80 μSv. Yes, we won't get any more samples, so H_∞ is our best estimate. (Tritium concentrations below 1E4 Bq/L are ignored.)
22. The main reason is that the moderator water spends a much greater fraction of its time in the core than PHT water does. The PHT system is hot and pressurised, therefore more likely to leak and cause airborne tritium hazards, so it should not be allowed to mix with the highly tritiated moderator water.
23. See Figs. 8.2 and 8.3.
24. About 8 d.
25. 0.95 MBq/L.
26. Less (actually 0.59 MBq/L), because some tritium is eliminated during the intake.
27. Defective fuel with PHT leak.
28. They are all equal.
29. They are the same; we are comparing weighted dose.
30. Yes.
31. c.
32. b.
33. See page 250.
34. 25 μSv/h; Chemistry Lab analysis of sample.
36. b.
37. 2 h (PAD reads gamma only).
40. It makes it simple to take a shower before you get counted – this will reduce the chances of detecting surface rather than internal contamination.
41. Iodine may no longer be detectable in urine, but it may still be present in the thyroid.
42. c.

Chapter 9

2. All zero.
3. a = 1, b = 5, c = 1, d = 0, e = 1, f == 0.
4. d.
5. 510 cps.
6. They can't.
9. Portable Contamination Meter.
10. No; no loose allowed.
11. Well?
16. 80 μSv/h.
17. 1 μSv/h if you believe that the difference in the two counts is significant (it isn't).
18. a, e, f.
19. (a) bubbler;
(b) gamma background was too high;
(c) use the grab sample method (p. 286).
20. a = 10 μSv/h; b = 40 μSv/h; c = 10 μSv/h; d = 40 μSv/h; e = connect two bubblers in series and check for tritium in the second.

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21. f.
24. a = U; b = N; c = U; d = C; e = N; f = N.
27. He took his respirator off to talk to his co-workers while in the boiler.
34. (a) 159; (b) 100; (c) Phil could have been wetted with D_2O, or he could have taken longer to undress himself (he would be exposed to tritium while getting out of plastics).
35. (a) 3 mSv gamma + 0.05 mSv tritium.
(b) See page 307.
36. (a) 6.0 mSv, (b) 5.2 mSv
(c) Yes, it is ALARA. But you will need Shift Supervisor approval, because you intend to depart from the standard radiation protection procedures. This is done with a Safety Work Plan discussed in Chapter 12.
42. (a) yes; (b) no; (c) Shift Supervisor;
(d) Health Physicist.

43. So that a burst hose or leaking fitting will not result in excessive air consumption. This is very important in areas that are not accessible at power. Large air leakage into such areas can cause ventilation imbalance, spread of airborne contamination and loss of recoverable heavy water vapour.

Chapter 10

1. Int = d + c = 0.70
   Ext = b + c = 2.40
   Shallow = a + b +c = 4.80.
2. Int = 0.26 + 0.70 = 0.96
   Ext = 1.46 + 2.40 = 3.86
   Total = 3.86 + 0.96 = 4.92
   Shallow = 1.72 + 4.80 = 6.52
3. 6.52 + 12 (LH) = 18.52
4. We were shut down all of March.
5. Any part of the extremity dose that is seen by the torso TLD will be counted twice in extremity dose, because dose records adds shallow dose to measured extremity dose.
6. Although you might think it doesn't, the high element-4 reading on your TLD will alert us to expect a DIF from you. Get ready for some grief when it doesn't come.
7. We use the PAD gamma results for both.
8. For better dose control.
9. Because the predicted committed dose may be wrong, e.g., more exposure to come, or other than 10 d half-life.
10. If you terminate your employment at PLGS.
11. 20 – (10 + 0.4 + 0.3 + 0.5 + 0.2) = 8.6 mSv.
12. 0.
13. The dose limit is actually 100 mSv in five years with not more than 50 mSv in any one year (page 117). If the person is really needed and well short of 100 mSv in five years, HP may approve.
14. (a) 1.00 mSv, (b) 1.45 mSv.
15. See Table 10.1.
16. Al = 7 d, Marylin = 7 d, Mickey = 28 d, Mike = 28 d.
17. (a) He must have had committed tritium dose greater than 0.01 mSv. (b) April 16.
18. (c).
19. 11 mSv.

Chapter 11

1. Quadricells have thicker shielding walls.
2. If we accidentally drop the waste and spill the contents, rain run-off would spread contamination all over the place.
4. See third paragraph on page 377.
5. Yes
7. Not for airborne, but a big decrease in liquid DELs at Gentilly, because of the drinking-water pathway via the St. Lawrence river.
8. 0.11% + 0.00058% + 0.0061% = 0.117%. Tritium increase indicates PHT or moderator leak. Presence of I-131 means PHT leak. It also shows that there were more fission products from defective fuel than we normally have, otherwise the relative increases for I-131 and tritium would have been the same.
9. The public DACs are based on the dose limit of 1 mSv/y rather than 20 mSv/y. The public breathes the air for 8760h/y, not 2000h/y. When you consider the food pathway, the public DACs will be further reduced (remember, our procedures eliminate this pathway at work).
10. Any ideas?
11. Belts & braces.
12. The LEM detects gamma only. The LEM sample is analysed in the HP Lab.
13. We don't expect radioiodine to be released from anywhere other then the Spent Fuel Bays.
14. Filter efficiency is about 99.97%, so 0.03%.
15. We increased our sampling frequencies to those of the operational program. First criticality was July 25, 1982.
16. We didn't need to buy the sites, nor supply electricity and fencing; the residents tell us of any equipment failures; and it good P.R. because we send them the results in layman's language.
17. See last paragraph of page 374.
18. Keep all doors shut, so that the ventilation system can run as intended.