M1.(a) $(3.0 \times 10^{-10}/24) \times 6.02 \times 10^{23}$ seen ✓

(7.52×10^{10})

1

(b) Decay constant = $(0.69 / 14.8\ h^{-1})$ or $1.3 \times 10^{-5}\ s^{-1}$ ✓

$A = 1.30 \times 10^{-5} \times 7.5 \times 10^{10}$ ✓

9.75×10^{5} Bq ✓

Allow 2 or 3 sf

Allow use of $A = \lambda N$ with an incorrectly calculated decay constant

3

(c) Activity 3.5 h later should be $A = 9.8 \times 10^{5}\ e^{-0.0466 \times 3.5}$ ✓

8.33×10^{5} Bq ✓

Volume of liquid = $(8.33 \times 10^{5} / 3600) \times 15 = 3470\ cm^{3}$ ✓

3

(d) Estimate gives 3700 compared with 3500 ✓

Flask has more mass than average / liquid is not water ✓

2

[9]

M2.D

[1]

M3.D

[1]

M4.(a) (i) λ (= ln 2 / $T_{1/2}$ = 0.693 / 5740) = 1.2 × 10^{-4} (yr^{-1}) ✓
(1.21 × 10^{-4} yr^{-1})

only allow 3.83 × 10^{-12} s^{-1} if the unit has been changed
working is not necessary for mark

1

(ii) (use of $N_t = N_o e^{-\lambda t}$ and activity is proportional to N
$A_t = A_o e^{-\lambda t}$)
0.375 = exp - (1.21 × 10^{-4} × t) ✓
$t = \frac{\ln\left(\frac{1}{0.375}\right)}{1.21\times10^{-4}}$ ✓
t = 8100 or 8200(yr) ✓

1st mark substitution, allow EC from (i)
2nd mark rearranging, allow EC from (i)
Allow t / $T_{1/2}$ = 2 ^{n} approach
3rd mark no EC (so it is not necessary to evaluate a CE)
so max 2 for a CE
full marks can be given for final answer alone. A minus in the final answer will lose the last mark

3

(b) (i) (it is difficult to measure accurately)
the small drop / change in activity / count-rate
the small change / drop in the ratio of C-14 to C-12 ✓

the activity would be very small / comparable to the background
or the ratio of C-14 to C-12 is too small
or there are too few C-14 atoms
or there is very little decay
or the level of C-14 (in the biosphere) is uncertain (this long ago) ✓

1st mark needs some reference to a change in count-rate or activity for the mark
be lenient in 2nd mark
in reading a script assume C-14 is the subject. Eg 'there is little activity to work with' scores mark. Also allow any reasonable suggestion. Eg carbon may have been removed by bonding to surrounding material
Don't allow, 'All the carbon has decayed'

2

[6]

M5. (a) $(^{206}_{76}\mathrm{X} \rightarrow {}^{206}_{82}Pb + \beta \times {}^{0}_{-1}\beta + \beta \times \overline{\nu_e})$

$\beta = 6$ ✓

1

(b) (i) the energy **required** to split up the nucleus ✓

into its individual neutrons and protons/nucleons ✓

(or the energy **released** to form/hold the nucleus ✓

from its individual neutrons and protons/nucleons ✓)

2

(ii) 7.88 × 206 = 1620 MeV ✓ (allow 1600-1640 MeV)

1

(c) (i) U, a graph starting at 3×10^{22} showing exponential fall passing through

0.75×10^{22} near 9×10^{9} years ✓

Pb, inverted graph of the above so that the graphs cross at 1.5×10^{22} near 4.5×10^{9} years ✓

2

(ii) (*u* represents the number of uranium atoms then)

$$\frac{u}{3 \times 10^{22} - u} = 2$$

$u = 6 \times 10^{22} - 2u$ ✓

$u = 2 \times 10^{22}$ atoms

1

(iii) (use of $N = N_o e^{-\lambda t}$)

$2 \times 10^{22} = 3 \times 10^{22} \times e^{-\lambda t}$ ✓

$t = \ln 1.5 / \lambda$

(use of $\lambda = \ln 2 / t_{1/2}$)

$\lambda = \ln 2 / 4.5 \times 10^{9} = 1.54 \times 10^{-10}$ ✓

$t = 2.6 \times 10^{9}$ years ✓ (or 2.7×10^{9} years)

3

[10]

M6. boron numbers correct: A = 11; Z = 5

B1

β^{+} correct: A = 0; Z = (+)1

B1

v_e (not anti neutrino) with numbers correct: 0,0

B1

3

[3]

M7. (a) correct numbers for beta+ (0, (+)1) and chromium (52)

B1

(electron) neutrino with correct numbers (0,0)

B1

2

(b) W^{+}/W/(intermediate vector) boson (not Z boson)

B1

1

[3]

M8. (a) plutonium is toxic/large mass of plutonium

B1

harmful if released into atmosphere/explosion occurred

B1

alphas dangerous when ingested/during launch etc

B1

max2

(b) unaffected

B1

chemical bonding involves electrons (atomic)
radioactivity is nuclear (owtte)/same number of nuclei present

B1

2

(c) (i) $T_{½} = \ln 2/\lambda$

C1

2.51×10^{-10}

A1

2

(ii) molar mass calculated (0.270 kg)

C1

use of 33 kg

C1

number of moles in sample (122.2)

C1

multiplication of value by Avogadro's number

C1

7.36×10^{25}

A1

5

(iii) (c) (i) × (c) (ii)

C1

1.83×10^{16} cao

A1

Bq

B1

3

(d) (i) uranium correct (234,92)

B1

alpha correct (4,2) – accept He or α symbol

B1

2

(ii) use of 1 g generating 500 mW

C1

16500 W total

C1

recognition that activity × energy of one alpha = power

C1

9.00×10^{-13} (J)

A1

4

[20]