1. (a) (i) proton number 82 and nucleon number 214 **(1)**

(ii) Pb **(1)** 2

(b) (i) kinetic energy [or <u>electrostatic</u> potential energy] **(1)**

(ii) $\Delta m = \frac{E}{c^2}$ **(1)**

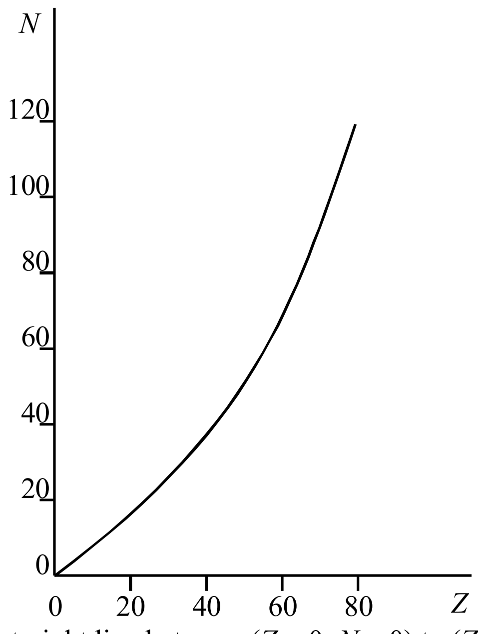
$= \frac{8.6 \times 10^{-13}}{(3 \times 10^8)^2} = 9.6 \times 10^{-30}$ kg **(1)** 3

[5]

2. 100y = $100 \times 365 \times 24 \times 3600$ (= 3.15×10^9 s) **(1)**
energy needed = $3.15 \times 10^9 \times 300$ **(1)** $\times 10$ **(1)** (= 9.46×10^{12} J)
number of disintegrations = $\frac{9.46 \times 10^{12}}{3.2 \times 10^{-11}}$ (= 2.96×10^{23}) **(1)**
number of moles needed = $\frac{2.96 \times 10^{23}}{6.02 \times 10^{23}}$ (= 0.49) **(1)**
molar mass = 0.239kg **(1)**
mass needed = $0.49 \times 0.239 = 0.117$ kg **(1)**

[7]

3. (a)



straight line between ($Z = 0$, $N = 0$) to ($Z = 20$, $N = 20$) **(1)**
curving upwards to $Z = 80$; $N = 110 – 130$ **(1)** 2

(b) (i) A = any region below the line of stability
but $N > 80$and $Z > 60$

(ii) B = any region above and close to the line of stability **(1)**

(iii) C = any region below and close to the line of stability **(1)** 3

(c)

mode of decay	change in proton number, Z	change in neutron number, N
α emission	–2	–2
β^- emission	+1	–1
β^+ emission	–1	+1
e capture	–1	+1
p emission	–1	0
n emission	0	–1

(1)(1) (1) – lose one mark for each row in error 3

[8]

4. (a) energy needed to separate **(1)**
nucleus into constituent nucleons **(1)** 2

(b) (i) mass defect = 26 × 1.00728 + 30 × 1.00867 **(1)**
+ 26 × 0.00055 **(1)** – 55.93493 = 0.529(u) **(1)**
binding energy = 0.529 × 931 = 492 (MeV) **(1)**
binding energy per nucleon $\frac{492}{56}$ = 8.8 (MeV) **(1)**

(ii) mass defect = $0.529 \times 1.66 \times 10^{-27} = 8.8 \times 10^{-28}$ (kg) **(1)** 6

[8]

5. (a) (i) $\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3420 \times 365 \times 24 \times 3600}$ **(1)**
$= 6.43 \times 10^{-12}$ (s^{-1}) **(1)**

(ii) $N = \frac{1}{\lambda}\frac{dN}{dt} = \frac{450 \times 10^3}{6.43 \times 10^{-12}}$ **(1)**
$= 7.0 \times 10^{16}$ **(1)** 4

(b) (i) pass through with no [or very small] deflection **(1)**

(ii) volume of nucleus << volume of atom (*)
[or nucleus small and atom mostly empty space] (*)
most of mass in nucleus (*)
nucleus has positive charge (*)
size of nucleus << separation (*)
(*) any two **(1)** **(1)** 3

[7]

6. (a) (i) which atom decays **(1)**
at what time is chance **(1)**

(ii) isotopes are (different forms) of same element **(1)**
same proton number, Z, different nucleon number, A
[or with same number of protons but different number of neutrons] **(1)**

half-life is time for number of nuclei to halve
[or to halve activity] **(1)**
for a particular isotope **(1)**

$\frac{dN}{dt} = -\lambda N$ **(1)**

λ is constant of proportionality [or probability of decay] **(1)**
[or λ is probability of decay **(1)** in unit time **(1)**] max 6

(b) (i) $\lambda = \frac{\ln 2}{8.04 \times 24 \times 3600}$ **(1)** $= 1.0 \times 10^{-6}\ s^{-1}$ **(1)**

(ii) $N = \frac{5.0 \times 10^4}{1.0 \times 10^{-6}}$ **(1)** $= 5.0 \times 10^{10}$

(iii) $\ln\left(\frac{N_0}{N}\right) = \lambda t$ **(1)**

$t = \frac{\ln\left(\frac{5.4 \times 10^{10}}{5.0 \times 10^{10}}\right)}{1.0 \times 10^{-6}}$ **(1)** $= 7.7 \times 10^4$ s **(1)**

$= \frac{7.7 \times 10^4}{3600}$ = 21(.4) (hour) **(1)** max 6

[12]

7. (a) (i) (inner) orbiting electron [or electron surrounding the nucleus] **(1)**
captured by a <u>proton</u> (in the nucleus) **(1)**
converted into a neutron **(1)** QWC

(ii) daughter nuclide/nucleus/atom might be excited and energy given up as electromagnetic radiation
[or orbiting electrons drop down to fill space
(left by captured electron)] **(1)** QWC

(iii) $^{203}_{83}\text{Bi} \rightarrow {}^{203}_{82}\text{Pb} + {}_{1}\beta^{+}$ **(1)** + $\nu_{(e)}$ **(1)** (+Q) [allow ${}^{0}_{1}e^{+}$ for ${}_{1}\beta^{+}$] max 5

(b) (i) (use of $N = N_0 e^{-\lambda t}$ and $N \propto$ activity gives)
$290 = 1200 \exp(-\lambda \times 24 \times 60 \times 60)$ **(1)**
$\lambda = \dfrac{\ln(1200/290)}{24 \times 60 \times 60}$ **(1)** (= 1.64×10^{-5} s^{-1})

(ii) (use of $T_{½} = \ln 2/\lambda$ gives) $T_{½} = \dfrac{\ln 2}{1.64 \times 10^{-5}}$ **(1)**
$= 4.2(3) \times 10^4$ s **(1)** (= 11.(7) hr)
(use of $\lambda = 1.6 \times 10^{-5}$ s^{-1} gives $T_{½} = 4.3 \times 10^4$ s or 12 hr)

(iii) (use of $\dfrac{\Delta N}{\Delta t} = \lambda N$ gives) $(-)1200 = (-)1.64 \times 10^{-5}\, N$ **(1)**
$N = 7.3(2) \times 10^7$ (nuclei) **(1)**
(use of $\lambda = 1.6 \times 10^{-5}$ s^{-1} gives $N = 7.5 \times 10^7$ (nuclei)) max 5

[10]

8. (a) (i) alpha **(1)**

(ii) two different track lengths **(1)**
short range particles have lower energy than long range particles **(1)**
particles in each range have same energy **(1)** 4

(b) (i) ${}^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + \alpha$ **(1)** (+Q)

(ii) ${}^{235}_{92}\text{U} \rightarrow {}^{231}_{90}\text{Th} + \alpha$ **(1)** *(+Q)*

(iii) U–235 **(1)**

because of the <u>inverse</u> relationship

between half–life and alpha particle energy **(1)**

(iv) because the Th–90 nucleus is neutron–rich <u>compared</u>

with U–235 [or Pu–239] **(1)** 5

[9]

9. (a) ($R^3 = R_0^3 A$)

plot R^3 against A with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$R^3/10^{-45}$ m^3
carbon	2.66	12	18.8
silicon	3.43	28	40.4
iron	4.35	56	82.3
tin	5.49	120	165.5
lead	6.66	208	295

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient

e.g. gradient = $\dfrac{300 \times 10^{-45}}{213}$ **(1)** (= 1.41×10^{-45} m^3)

r_0 (= gradient)$^{1/3}$ **(1)**

= $(1.41 \times 10^{-45})^{1/3}$ = $1.1(2) \times 10^{-15}$ m **(1)** *alternative:*

plot R against $A^{1/3}$ with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$A^{1/3}$
carbon	2.66	12	2.29
silicon	3.43	28	3.04
iron	4.35	56	3.83
tin	5.49	120	4.93
lead	6.66	208	5.93

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient
e.g. gradient = $\dfrac{6.72\times10^{-15}}{6.0}$ **(1)** = (1.1(2) × 10^{-45} m^3)
r_0 = gradient **(1)**
= 1.1(2) × 10^{-15} m **(1)**
[or plot lnR against lnA...] max 8

(b) assuming the nucleus is spherical
ignoring the gaps between nucleons
assuming all nuclei have same density
assuming total mass is equal to mass of constituent nucleus
any one assumption **(1)**

M = $\dfrac{4}{3}\pi R^3\rho$ **(1)**

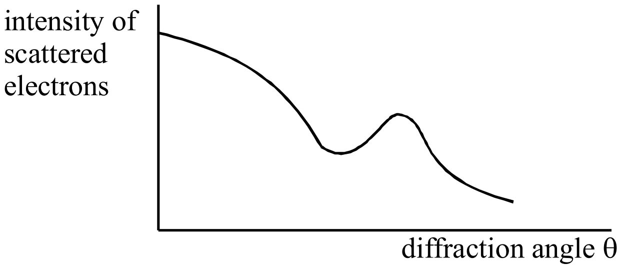
$\left(\therefore M = \dfrac{4}{3}\pi R_0^3\, a\rho\right)$

$\left(\therefore \rho = \dfrac{3m}{4\pi R_0^3}\right) = \dfrac{3\times1.67\times10^{-27}}{4\pi\times(1.12\times10^{-15})^3}$ **(1)**

= 2.8 × 10^{17} kgm^{-3} **(1)** 4

[12]

10. (a)

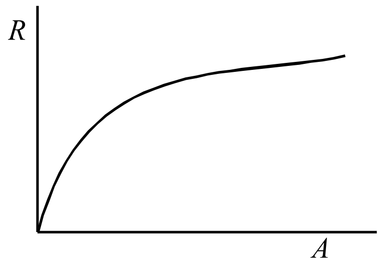


graph shows a minimum **(1)**
which does not touch the axis **(1)** 2

(b) the (de Broglie) wavelength of high energy electrons is comparable to nuclear radii [or not subject to the strong nuclear force] **(1)** 1

(c) nuclear density is constant **(1)**
separation of neighbouring nucleons is constant
[or nucleons are close-packed] **(1)** 2

(d)



correct curve **(1)** 1

(e) $R = r_0 A^{\frac{1}{3}}$ **(1)**

$R_0 \left(= R_c \left(\frac{A_0}{A_c} \right)^{\frac{1}{3}} \right) = 3.04 \times 10^{-15} \times \left(\frac{16}{12} \right)^{\frac{1}{3}}$ **(1)**

$R_0 = 3.35 \times 10^{-15}$ m **(1)** 3

[9]

11. (a) (i) ${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} > {}^{236}_{92}\text{U}$

(ii) ${}^{236}_{92}\text{U} \rightarrow {}^{145}_{56}\text{Ba} + {}^{87}_{36}\text{Kr} + 4\,{}^{1}_{0}\text{n}$ **(1)** 2

(b) ($\Delta m = m_u - m\text{Ba} - m\text{Kr} - 4m_n$, electron masses balance)
$\Delta m = 236.04573 - 144.92694 - 86.91340 - 4 \times 1.00867$ **(1)**
$= 0.17071\text{u}$ **(1)**
$Q(= 0.17071 \times 931.3\text{MeV}) = 159(\text{MeV})$ **(1)** 3

[5]

12. (a) (i) $T_{1/2} = 50$ s **(1)** (from graph)

(ii) $\lambda = \dfrac{\ln 2}{50}$ **(1)** $= 0.014\text{s}^{-1}$ **(1)**

(iii) $N = \dfrac{A_0}{\lambda}$ **(1)** $= \dfrac{2.4 \times 10^5}{0.014} = 1.7(1) \times 10^7$ **(1)** 5

(b) (i) elapsed time = 50s = 1 half-life **(1)**
$N_{30} = N_0 e^{-30\lambda}$ **(1)** $= 1.71 \times 10^7\ e^{-30 \times 0.014} = 1.12 \times 10^7$ **(1)**
$\therefore$ no. decayed from $t = 30$s to $t = 80$s is $\dfrac{1.12 \times 10^7}{2} = 0{\cdot}56 \times 10^7$ **(1)**

[*alternative (b)(i)*
$N_{30} = N_0 e^{-30\lambda}$ and $N_{80} = N_0 e^{-80\lambda}$ **(1)**
give 1.12×10^7 **(1)** and 0.56×10^7 **(1)**
number decayed $(= 1.12 \times 10^7 - 0.56 \times 10^7) = 0.56 \times 10^7$ **(1)**]

(ii) energy released $= 0.56 \times 10^7 \times 1.0 \times 10^{-12} = 5.6 \times 10^{-6}$ J **(1)** max 4

[9]

13. (a) (i) a neutron strikes the <u>nucleus</u> **(1)**
nucleus splits into <u>two</u> fragments **(1)**

(ii) some electrostatic Ep converted to E_k of fragments **(1)**
some electrostatic Ep used to overcome strong interaction **(1)**
some electrostatic Ep used to increase surface energy **(1)**

(iii) fission fragments repel and collide with other atoms in fuel rod **(1)**
high energy fission neutrons enter moderator
[or collide with moderator atoms] **(1)**
atoms gain Ek due to collisions (and vibrate more) **(1)**
temperature depends on the average E_k of (vibrating) atoms **(1)**
a chain reaction occurs **(1)** max 8

(b) energy from fuel per year at 100% efficiency

$= 1600(\text{MW}) \times 3.2 \times 10^7$ s $\approx 5.0 \times 10^{16}$ (J) **(1)**

energy supplied from fuel per year at 25% efficiency

$\approx 4 \times 5.0 \times 10^{16} \approx 2.0 \times 10^{17}$(J) **(1)**

energy released per kilogram of fuel

$= 200 \times 1.6 \times 10^{-13} \times 6.0 \times 10^{23} \times \dfrac{1}{0.238}$ **(1)** $\times 0.03 \approx 2.4 \times 10^{12}$ (J) **(1)**

mass of fuel needed per year = $\dfrac{2.0 \times 10^{17}}{2.4 \times 10^{12}} \approx 8 \times 10^4$ kg **(1)** 5

[13]

14. (a) (i) ${}^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\alpha$ **(1)** + ${}^{234}_{90}\text{Th}$ **(1)**

(ii) $\Delta m = 238.05076 - 4.00260 - 234.04357 = 0.00459$(u) **(1)**
$Q = 931 \times 0.00459$ (MeV) **(1)**
= 4.3MeV **(1)** 5

(b) (i) overall change in proton number (= 92 – 82) = 10
change in proton number due to α particles (= 8 × 2) = 16 **(1)**
therefore $\Delta Z = -6$ for the β^- particles corresponding to the
six β^- particles **(1)**

(ii) proton changes to a neutron plus a positron
[or p $\rightarrow n + \beta^+ (+ \nu_e + Q)$] **(1)**
Pb-206 has a lower neutron to proton ratio than U-238 **(1)**
α alpha emission raises the neutron to proton ratio slightly **(1)**
β^- emission lowers the ratio (more) **(1)**
β^+ emission increases neutron to proton ratio **(1)**
positron emission competes with α emission but is
energetically less favourable **(1)** max 6

[11]

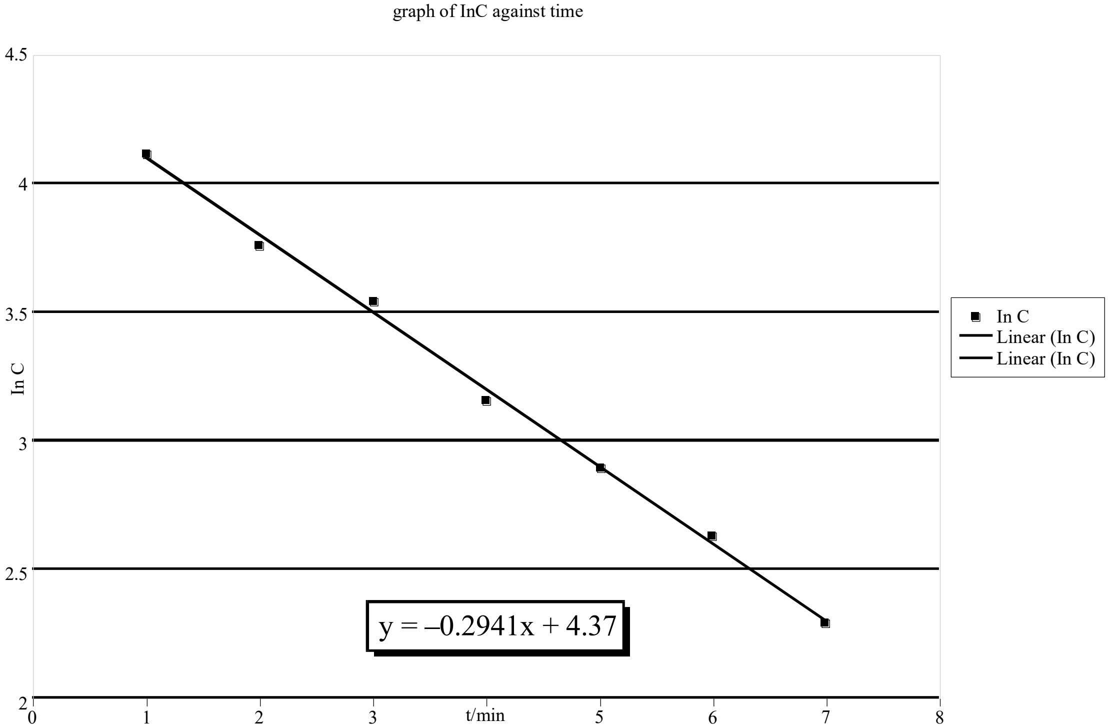
15. (a) time for half of (active) nuclei (of radioactive substance) to decay **(1)** 1

(b)

t/minute	0	10	20	30	40	50	60
number of counts in 30s, *C*	60	42	35	23	18	14	10
ln *C*	4.094	3.738	3.555	3.135	2.890	2.639	2.303

Correct values of ln *C* above **(1)** 1

(c) (i) seven points correctly plotted **(1)** **(1)** [six points correct **(1)**]



(ii) best straight line through points **(1)**

sensible scale **(1)**

(iii) from sensible triangle on graph **(1)**

gradient **=–** **(1)** 0.030 [0.294] **(1)** (min $^{-1}$) (min $^{-1}$) max 5

(d) (i) $C = C_0 e^{-\lambda t}$, ln C – ln $C_0 = -\lambda t$

hence using $y = mx + c$, λ = (–)gradient **(1)**

(ii) half–life = $\dfrac{\ln 2}{\lambda} = \dfrac{0.693}{0.03}$ **(1)** = 23 min **(1)** 3

(e) count over longer period than half minute [or repeat experiment] **(1)**

use stronger source **(1)**

use background count correctly**(1)** max 2

(f) for ^{14}C, $\lambda = \dfrac{0.693}{T_{1/2}}$ $= 1.21 \times 10^{4}$ (year) **(1)**

$-\lambda t \left(= \ln \dfrac{R}{R_0} \right) = \ln \left(\dfrac{5.2}{6.5} \right)$ **(1) =** -0.223 **(1)**

$t = \dfrac{0.223}{1.21 \times 10^{-4}}$ = 1840(year) **(1)** 4

[16]

16. (a) (i) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{98}_{38}Sr + ^{135}_{54}Xe + 3\,^{1}_{0}n(+Q)$ **(1)**

(ii) three correct positions to within ±2 on x-axis **(1) (1)**
(one mark if two correct)

(iii) *estimate of energy released*:
binding energy of U-235 nucleus = (235 × 7.5)
= 1763(±15)(MeV) **(1)**
binding energy of Sr-98 = (98 × 8.6)
= 843(± 15)(MeV) **(1)**
binding energy of Xe-135 = (135 × 8.4)
= 1134(± 15)(MeV) **(1)**
binding energy released = 1134 + 843 – 1763
= 214MeV **(1)**
(±40MeV) max 6

(b) (i) 235g of U-235 releases $6 \times 10^{23} \times 214 \times 1.6 \times 10^{-13}$J
$= 2.1 \times 10^{13}$(J) **(1)**
1.0 kg of uranium containing 3% U-235 contains
30g of U-235 **(1)**
energy from 1.0kg of uranium = $\dfrac{2.1 \times 10^{13} \times 30}{235}$
$= 2.6 \times 10^{12}$J [[1.6×10^{25} MeV]] **(1)**

(ii) *advantage*:
less mass of fuel used **(1)** because more energy per kilogram **(1)**
[alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
or any statement **(1)** argued **(1)**]
disadvantage:
hazardous waste **(1)** because fission products are radioactive **(1)**
[alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
or any statement **(1)** argued **(1)**] max 6

[12]

17. (a) $m = 4.0026 \times 1.66 \times 10^{-27}$ (kg) **(1)**
(= 6.6×10^{-27} kg – electron masses are not significant)
kinetic energy $(= \frac{1}{2} m\upsilon^2) = 0.5 \times 6.65 \times 10^{-27} \times (2.00 \times 10^7)^2$ **(1)**
(= 1.33×10^{-12} J) 2

(b) loss in k.e. = gain in p.e. **(1)**
loss of ke. [or 1.33×10^{-12}] $= \dfrac{Qq}{4\pi\varepsilon_0 R}$ **(1)** $\left(= \dfrac{2Ze^2}{4\pi\varepsilon_0 R} \right)$

$R = \dfrac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 1.33 \times 10^{-12}}$ **(1)**
$= 2.73 \times 10^{-14}$ m **(1)** 4

(c) *any valid point including*:
strong force complicates the process (*)
scattering caused by distribution of protons not whole nucleon distribution (*)
α particles are massive causing recoil of nucleus which complicates results (*)
(*) any **one (1)** 1

[7]

18. (a) (i) proportion of U-235 is greater than in natural uranium **(1)**

(ii) induced fission more probable with U-235 than with U-238 **(1)** 2

(b) (i) for steady rate of fission, one neutron per fission required to go on to produce further fission **(1)**
each fission produces two or three neutrons on average **(1)**
some neutrons escape [or some absorbed by U-238 without fission] **(1)**
control rods absorb sufficient neutrons (to maintain steady rate of fission) **(1)**

(ii) neutrons need to pass through a moderator **(1)**
to slow them (in order to cause further fissions or prevent U-238 absorbing them) **(1)**
neutrons that leave the fuel rod (and pass through the moderator) are unlikely to re-enter the same fuel rod **(1)**
makes it easier to replace the fuel in stages **(1)** max 5

[7]

19. (a) (i) most alpha particles undeflected **(1)**
some through small angles **(1)**
(very) small (but significant) number deflected through > 90° **(1)** max 2

(b) atom mostly empty space **(1)**
positive charge concentrated **(1)**
in a volume much less than total volume [or radius] **(1)** max 2

[4]

20. (a) (i) proton number = 36 **(1)**
neutron number = 56 **(1)**

(ii) krypton **(1)** 3

(b) one-fifth efficiency so total output $\left(= 10 \times \frac{100}{20}\right.$ = 50(MW) **(1)**
energy in one day = $50\times 10^6 \times 24 \times 3600$(J) **(1)** ($4.32 \times 10^{12}$ J)
fission atoms per day = $\frac{4.32\times10^{12}}{3.2\times10^{-11}}$ $=1.35 \times10^{23}$ **(1)** 3

[6]