M1.(a) $^{239}_{93}Np \rightarrow\ ^{239}_{94}Pu +\ ^{(0)}_{(-1)}\beta^- +\ ^{(0)}_{(0)}\bar{\nu}$ ✓✓

First mark for one anti-neutrino or one beta minus particle in any form e.g. e^-. If subscript and superscripts are given for these they must be correct but ignore the type of neutrino if indicated.
The second mark is for both particles and the rest of the equation.
Ignore the full sequence if it is shown but the Np to Pu must be given separately for the mark.

2

(b) (i) $T_{1/2}$ 2.0 → 2.1 × 10^5 s ✓
then substitute and calculate
$\lambda = \ln 2 / T_{1/2}$ ✓

$T_{1/2}$ may be determined from graph not starting at zero time.
Look for the correct power of 10 in the half-life – possible AE.

Or
(substitute two points from the graph into $A = A_o e^{-\lambda t}$)
e.g. $0.77 \times 10^{12} = 4.25 \times 10^{12} \exp(-\lambda \times 5 \times 10^5)$ ✓
then make λ the subject and calculate ✓
(the rearrangement looks like
$\lambda = [\ln (A_o / A)] / t$
or $\lambda = -[\ln (A / A_o)] / t$)

Allow the rare alternative of using the time constant of the decay
$A = A_o \exp(-t / t_{tc})$
from graph t_{tc} = 2.9→3.1 × 10^5 s ✓
$\lambda = 1 / t_{tc} = 3.4 \times 10^{-6}\ s^{-1}$ ✓
No CE is allowed within this question.

both alternatives give
λ = 3.3 → 3.5 × 10^{-6} s^{-1} ✓

For reference
$T_{1/2} = 2.0 \times 10^5$ s gives
$\lambda = 3.5 \times 10^{-6}\ s^{-1}$ and
$T_{1/2} = 2.1 \times 10^5$ s gives
$\lambda = 3.3 \times 10^{-6}\ s^{-1}$.

2

(ii) (using $A = N\lambda$
$N = 0.77 \times 10^{12} / 3.4 \times 10^{-6} = 2.2(6) \times 10^{17}$)

allow 2.2 → 2.4 × 10^{17} nuclei ✓

A possible route is find $N_o = A_o / \lambda$

then use $N = N_o e^{-\lambda t}$.

Condone lone answer.

1

(c) (i) uranium (– 235 captures) a neutron (and splits into 2 smaller nuclei / fission fragments) releasing more neutrons ✓

First mark for uranium + neutron gives more neutrons.

Ignore which isotope of uranium is used.

(at least one of) these neutrons go on to cause further / more splitting / fissioning (of uranium– 235) ✓

Second mark for released neutron causes more fission.
The word 'reaction□ may replace 'fission□ here provided 'fission / splitting of uranium□ is given somewhere in the answer.

2

(ii) **Escalate if clip shows critical mass in the question.**
the moderator slows down / reduces the kinetic energy of neutrons ✓
so neutrons are absorbed / react / fission (efficiently) by the uranium / fuel ✓

owtte
***Possible escalation**.*

2

(iii) neutrons are absorbed / collide with (by the nuclei in the shielding) ✓

Second mark is only given if neutrons appear somewhere in the answer.

converting the nuclei / atoms (of the shielding) into unstable isotopes (owtte)

No neutrons = no marks.

Making it neutron rich implies making them unstable.

2

[11]

M2.B

[1]

M3.(a) number of gamma ray photons per sec = $\frac{3.0 \times 10^7}{5}$ (= 6.0 × 10^6)

B1

correct use of $4\pi r^2$; substitution of data

$\frac{6.0 \times 10^6 \text{ or } 3.0 \times 10^7}{4 \times \pi \times 150^2}$ = 21.2

NB they may determine number per m^2 and divide by 10 000

B1

(b) (i) decay constant = 0.69 / 12 = 0.0575 h^{-1} or 1.6 × 10^{-5}
(or time =.5 half life)

Cl

dose = $21e^{-(6 \times 0.0575)}$

dose = 21 / 20.5

Cl

or new (gamma) activity = 6 × 10^6 $e^{-(6 \times 0.0575)}$
or new (total) activity = 3 × 10^7 $e^{-(6 \times 0.0575)}$

Cl

15 (gamma rays per cm^2 per second) Condone 14.8 – 14.9
(no up)

Al

(ii) clear attempt to apply inverse square law

Cl

1.3 (1.26) m

Al

(c) beta particles are more heavily ionising than gamma radiation
or
loses energy rapidly by ionising the air / matter

Bl

beta particle range / penetration (in air) is low
or
beta particle range
is about 30 cm
or

is less than 1.5 m
or
is much lower than gamma radiation
NB: mention of not able to penetrate skin or clothing is talk out

Bl

[9]