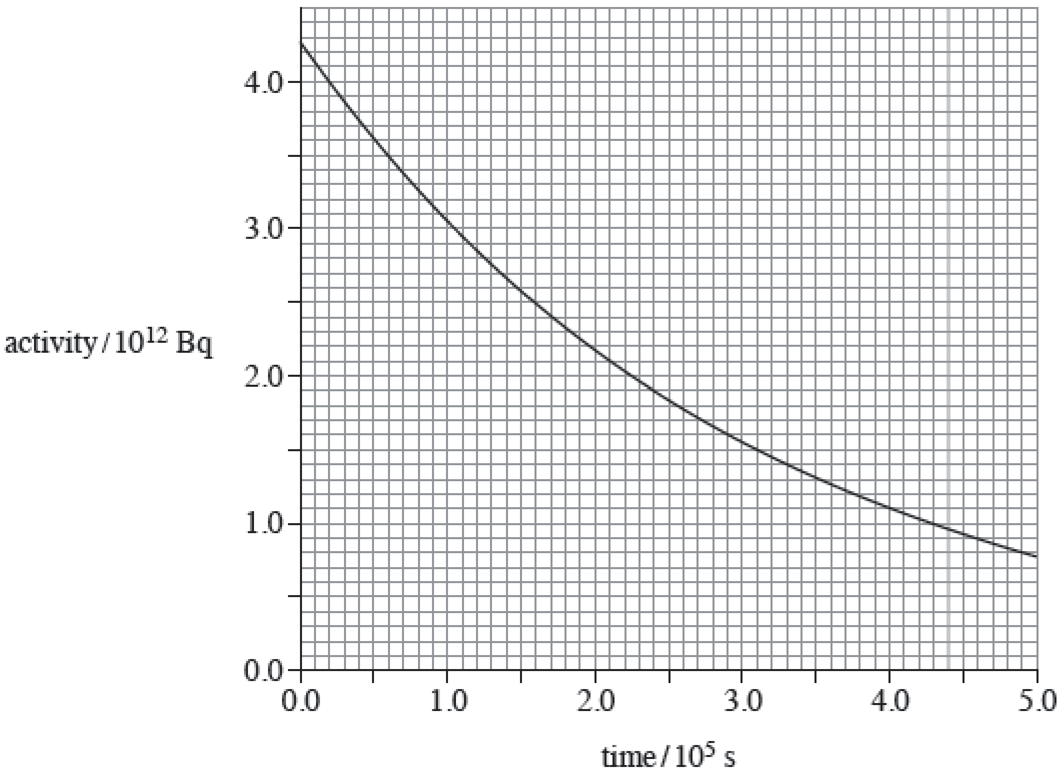
Q1. A rod made from uranium−238 ($^{238}_{92}\mathrm{U}$) is placed in the core of a nuclear reactor where it absorbs free neutrons.
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}\mathrm{Np}$), which in turn decays to plutonium−239 ($^{293}_{94}\mathrm{Pu}$).

(a) Write down the nuclear equation that represents the decay of neptunium−239 into plutonium−239.

(2)

(b) A sample of the rod is removed from the core and its radiation is monitored from time t = 0 s.
The variation of the activity with time is shown in the graph.



(i) Show that the decay constant of the sample is about $3.4 \times 10^{-6}\ s^{-1}$.

(2)

(ii) Assume that the activity shown in the graph comes only from the decay of neptunium.

Estimate the number of neptunium nuclei present in the sample at time $t = 5.0 \times 10^5$ s.

number of nuclei ....

(1)

(c) (i) A chain reaction is maintained in the core of a thermal nuclear reactor that is operating normally.

Explain what is meant by a chain reaction, naming the materials and particles involved.

....

....

....

....

(2)

(ii) Explain the purpose of a moderator in a thermal nuclear reactor.

....

....

....

....

....

....

(2)

(iii) Substantial shielding around the core protects nearby workers from the most hazardous radiations. Radiation from the core includes α and β particles, γ rays, X−rays, neutrons and neutrinos.

Explain why the shielding becomes radioactive.

....

....

....

....

(2)
(Total 11 marks)

Q2. A thermal nuclear reactor is shut down by inserting the control rods fully into the core. Which line, **A** to **D**, shows correctly the effect of this action on the fission neutrons in the reactor?

	number of fission neutrons	average kinetic energy of fission neutrons
A	reduced	reduced
B	reduced	unchanged
C	unchanged	reduced
D	unchanged	unchanged

(Total 1 mark)

Q3. Potassium-42 decays with a half-life of 12 hours. When potassium-42 decays it emits β^- particles and gamma rays. One freshly prepared source has an activity of 3.0×10^7 Bq.

(a) To determine the dose received by a scientist working with the source the number of gamma ray photons incident on each cm^2 of the body has to be known.

One in every five of the decaying nuclei produces a gamma ray photon. A scientist is initially working 1.50 m from the fresh source with no shielding. Show that at this time approximately 21 gamma ray photons per second are incident on each cm^2 of the scientist's body.

(2)

(b) The scientist returns 6 hours later and works at the same distance from the source.

(i) Calculate the new number of gamma ray photons incident per second on each cm^2 of the scientist's body.

(3)

(ii) At what distance from the source could the scientist now work and receive the original dose of 21 photons per second per cm^2 .

(2)

(c) Explain why it is not necessary to consider the beta particle emission when determining the dose of radiation the scientist receives.

....

....

....

(2)
(Total 9 marks)