$$238$ $\bf Q1.A \ rod \ made \ from \ uranium-238 (<math display="inline">92 U)$ is placed in the core of a nuclear reactor where it absorbs free neutrons.$

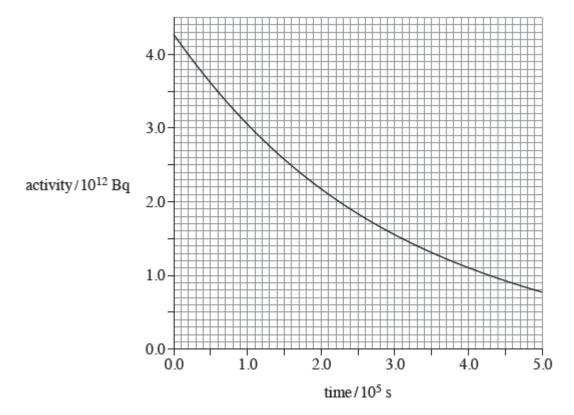
When a nucleus of uranium-238 absorbs a neutron it becomes unstable and decays to 239

neptunium–239 ($\underline{^{93}Np}$), which in turn decays to plutonium–239 ($\underline{^{94}Pu}$).

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

(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 $3.4 \times 10^{-6} \text{ s}^{-1}$.

(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.

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

(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 βparticles and gamma rays. One freshly prepared source has an activity of 3.0 × 10⁷ Bq.
 - (a) To determine the dose received by a scientist working with the source the number of gamma ray photons incident on each cm² 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 cm² 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 cm² of the scientist's body.

(3)

(2)

- (ii) At what distance from the source could the scientist now work and receive the original dose of 21 photons per second per cm².
- (c) Explain why it is not necessary to consider the beta particle emission when determining the dose of radiation the scientist receives.

(Total 9 marks)