Marks 6

- In March 2011 after a tsunami flooded the Fukushima Daiichi nuclear power plant, three of the six reactors went into meltdown, and by 31 March had released large quantities of the nuclides detailed in the table below.

Radioisotope	Initial activity of quantity released (10^{15} Bq)	Half-life
^{131}I	511	8.02 days
^{137}Cs	13.6	30.17 years

Given that the only stable nuclide of iodine is ^{127}I, would you expect the primary decay mechanism for ^{131}I to be α, β^-, or β^+ decay? Briefly explain your reasoning.

Calculate the decay constant for ^{131}I.

Answer:

Calculate the initial mass of ^{131}I released.

Answer:

THIS QUESTION CONTINUES ON THE NEXT PAGE.

	Marks
One method of determining whether further radionuclide leaks are occurring is to monitor the relative activities of the different nuclides as a function of time. Calculate the expected activity due to each of these nuclides exactly 3 years after the release. Assume no more has subsequently escaped from the reactors.	6

Activities	^{131}I:	^{137}Cs:

Caesium has no biological role in the human body, and is usually only present in trace amounts. On ingestion, even non-radioactive Cs isotopes are considered toxic as they are capable of partially substituting for chemically similar elements. Name a chemically similar element. State one chemically-significant difference between ions of this element and Cs^+ ions.

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

- Calculate the activity (in Bq) of a 1.00 g sample of $^{137}Cs^{131}I$, if the half lives of the caesium and iodine are 30.17 years and 8.02 days respectively.

Marks 8

Answer:

Both nuclides in $^{137}Cs^{131}I$ are beta emitters, and the daughter nuclides are stable. Describe the sample after it has been melted and allowed to resolidify after (a) 3 months and (b) 300 years.

Marks 8

- The generation of energy in a nuclear reactor is largely based on the fission of either ^{235}U or ^{239}Pu. The fission products include every element from zinc through to the *f*-block. Explain why most of the radioactive fission products are β-emitters.

Much of the fission yield is concentrated in two peaks, one in the second transition row and the other later in the periodic table. Identify the missing "sister" products of the following daughter nuclides of ^{235}U by writing balanced nuclear equations. The fission reactions are triggered by the absorption of one neutron, and release three neutrons upon disintegration of the short-lived ^{236}U nucleus.

^{141}Ba	
^{95}Sr	

Many of the fission products are short lived, and spent fuel rods are eventually contaminated by longer-lived species. The radioactivity of spent fuel can be modelled simply by the exponential decay of the ^{137}Cs and ^{90}Sr. The % yields and half lives of these nuclides are given in the table.

nuclide	%Yield *per fission event*	Half-life (years)
^{90}Sr	4.505	28.9
^{137}Cs	6.337	30.23

After use, nuclear fuel rods are stored in ponds of cooling water, awaiting safe disposal. If 3 % of the mass of used fuel rods consists of fission products of ^{235}U and ^{239}Pu, what percentage of the mass is made up by each of these nuclides?

^{90}Sr:	^{137}Cs:

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What are the specific activities of ^{90}Sr and ^{137}Cs in Bq g^{-1}?

Marks 8

^{90}Sr:	^{137}Cs:

Assuming the majority of the activity of a spent fuel rod to be due to these nuclides, what will be the activity of a 1 tonne fuel rod 100 years after placing it in the pond?

	Answer:

How long does it take 1.0 g of ^{231}Th to decay to the same activity as 1.0 g of ^{232}Th?

Marks 3

Answer:

- The isotope ^{37}Ar has a half-life of 35 days. If each decay event releases an energy of 1.0 MeV, calculate how many days it would take for a 0.10 g sample of ^{37}Ar to release 22.57×10^3 kJ (enough energy to boil 10.0 L of water)?

Marks 3

Answer:

- The isotope ^{222}Rn decays to ^{214}Bi in three steps. Identify all possible decay paths for this process, including all the intermediate isotopes along each path and the identity of the decay process involved in each individual step.

3

• In the spaces provided, explain the meaning of the following term. You may use an example, equation or diagram where appropriate.	**Marks**
half-life	**1**

- Explain why a sustained fission chain reaction can only occur when a critical mass is prepared.

Marks 2

- The half life of ^{3}H is 12 years. Calculate how long it takes (rounded to the nearest year) for the activity of a sample of tritium to have dropped to 0.1% of its original value.

2

Answer:

- Consider the following list of unstable isotopes and their decay mechanisms.

3

$^{33}_{17}Cl \rightarrow {}^{0}_{+1}e + {}^{33}_{16}S$ half-life = 2.5 s

$^{32}_{15}P \rightarrow {}^{0}_{-1}e + {}^{32}_{16}S$ half-life = 14.3 days

$^{199}_{82}Pb \rightarrow {}^{0}_{+1}e + {}^{199}_{81}Tl$ half-life = 90 minutes

$^{13}_{7}N \rightarrow {}^{0}_{+1}e + {}^{13}_{6}C$ half-life = 10 minutes

From this list, select the isotope that best satisfies the following requirements. Provide a reason for your choice in each case.

Requirement	Isotope	Reason for choice
Isotope used in medical imaging		
Decay represents the transformation of a neutron into a proton		
The isotope with the highest molar activity		

• In the spaces provided, explain the meaning of the following term. You may use an example, equation or diagram where appropriate.	**Marks**
nucleogenesis	**1**

Marks

- Balance the following nuclear reactions by identifying the missing nuclide. **3**

$$^{36}_{17}\mathrm{Cl} + {}^{0}_{-1}\mathrm{e} \rightarrow \boxed{}$$

$$^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\alpha + \boxed{}$$

$$^{238}_{92}\mathrm{U} + {}^{12}_{6}\mathrm{C} \rightarrow 4\,{}^{1}_{0}\mathrm{n} + \boxed{}$$

- The half life of ^{90}Sr is 29 years. Calculate the remaining activity (in Bq) of a sample containing ^{90}Sr after 100 years given that the initial activity was 1000 Bq. **2**

Answer:

- The three unstable isotopes $^{33}_{17}\mathrm{Cl}$, $^{77}_{36}\mathrm{Kr}$ and $^{27}_{12}\mathrm{Mg}$ are unsuitable for use in medical imaging. For each isotope, provide a reason why it is unsuitable. The following data may be of use: **3**

$^{33}_{17}\mathrm{Cl} \rightarrow {}^{0}_{+1}\mathrm{e} + {}^{33}_{16}\mathrm{S}$ half-life = 2.5 s

$^{77}_{36}\mathrm{Kr} \rightarrow {}^{0}_{+1}\mathrm{e} + {}^{77}_{35}\mathrm{Br}$ half-life = 75 minutes

$^{27}_{12}\mathrm{Mg} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{27}_{13}\mathrm{Al}$ half-life = 9.5 minutes

Marks

- Balance the following nuclear reactions by identifying the missing nuclide. **3**

$$^{55}_{26}\text{Fe} + {}^{0}_{-1}\text{e} \rightarrow \boxed{}$$

$$^{63}_{28}\text{Ni} \rightarrow {}^{63}_{29}\text{Cu} + \boxed{}$$

$$^{28}_{14}\text{Si} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{0}\text{n} + \boxed{}$$

- Identify the decay mechanism for the following three unstable nuclides given that the only stable isotopes of Pr and Eu are $^{141}_{59}\text{Pr}$, $^{151}_{63}\text{Eu}$ and $^{153}_{63}\text{Eu}$. There are no stable isotopes of Rn. **3**

Isotope	Nuclear Decay Mechanism
$^{142}_{59}\text{Pr}$	
$^{150}_{63}\text{Eu}$	
$^{222}_{86}\text{Rn}$	

Marks

- Balance the following nuclear reactions by identifying the missing nuclide. **3**

$$^{55}_{26}\text{Fe} + {}^{0}_{-1}\text{e} \rightarrow \boxed{}$$

$$^{232}_{90}\text{Th} \rightarrow {}^{4}_{2}\alpha + \boxed{}$$

$$^{218}_{84}\text{Po} \rightarrow {}^{0}_{-1}\text{e} + \boxed{}$$

- Over 50 years, the activity of a sample of strontium-90 decreases from 1000 Bq to 303 Bq. Calculate the half-life of strontium-90 (in years) to the nearest year. **2**

Answer:

- Identify three desirable properties of an unstable isotope to be used in medical imaging. **3**

Marks

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide. **3**

$$^{36}_{17}\mathrm{Cl} + {}^{0}_{-1}\mathrm{e} \rightarrow \boxed{}$$

$$^{236}_{92}\mathrm{U} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\,\boxed{}$$

$$^{99}_{42}\mathrm{Mo} \rightarrow {}^{0}_{-1}\mathrm{e} + \boxed{}$$

- The half-life of plutonium-239 is 24110 years. How many years (to the nearest year) must pass after $^{239}_{94}\mathrm{Pu}$ is produced for the number of $^{239}_{94}\mathrm{Pu}$ atoms to decay to 0.01000 of the original number? **3**

Answer:

- Provide a brief explanation of the process by which nuclear radiation causes biological damage. **2**

- Tritium, ${}^{3}_{1}H$, in nuclear warheads decays with a half life of 12.26 years and must be replaced. What fraction of the tritium is lost in 5.0 years?

2

ANSWER: