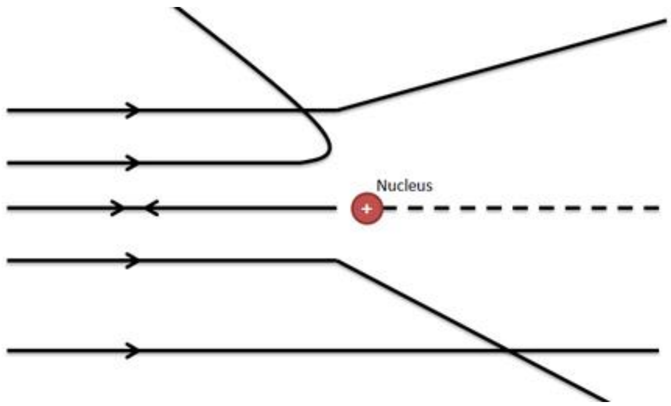
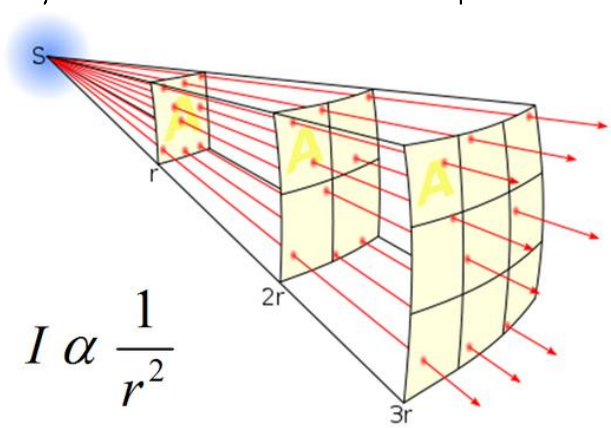
U8 - Nuclear physics

Describe the Rutherford Gold Foil experiment	Fire a stream of positively charged α particles to a thin film of gold IN an evacuated chamber. *This film is only a couple ions thick.*
What are the results of the Rutherford Gold Foil Experiment? What does these mean?	● Most α particles went **straight through** - most of atom is empty space. ● Some α particles **deflected marginally** and even fewer **bounced back** - very small dense positive charge. ○ This backscattering couldn't be explained by the plum pudding model.  *As shown, the closer the more the α gets to the nuclear, the more it's deflected. Even very fast alpha particles are deflected so it must be very dense.*
How law does γ radiation follow?	The intensity of radiation follows the inverse square law.  $I \alpha \frac{1}{r^2}$

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<td>Draw the graph showing the line of stability and explain it</td>
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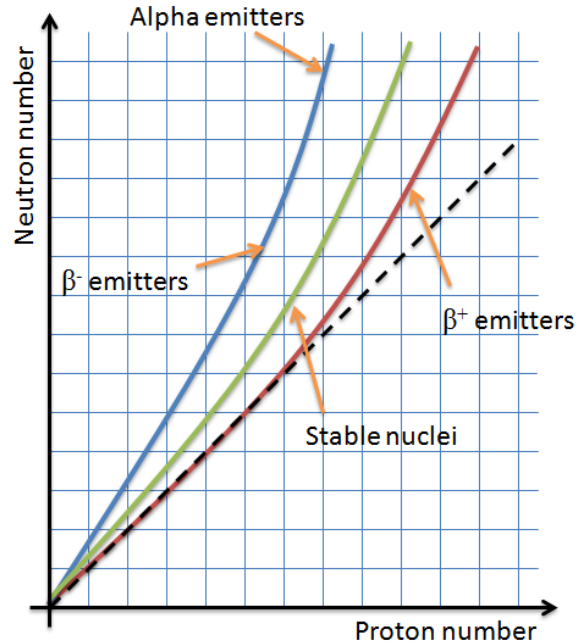

Alpha emitters are near the top at around Z = 60.

- Blue line - neutron rich so decays with a neutron turning into a proton.
- Red line - proton rich so decays with a proton turning into a neutron.
- The decay arrow acting towards the line of stability are as shown:

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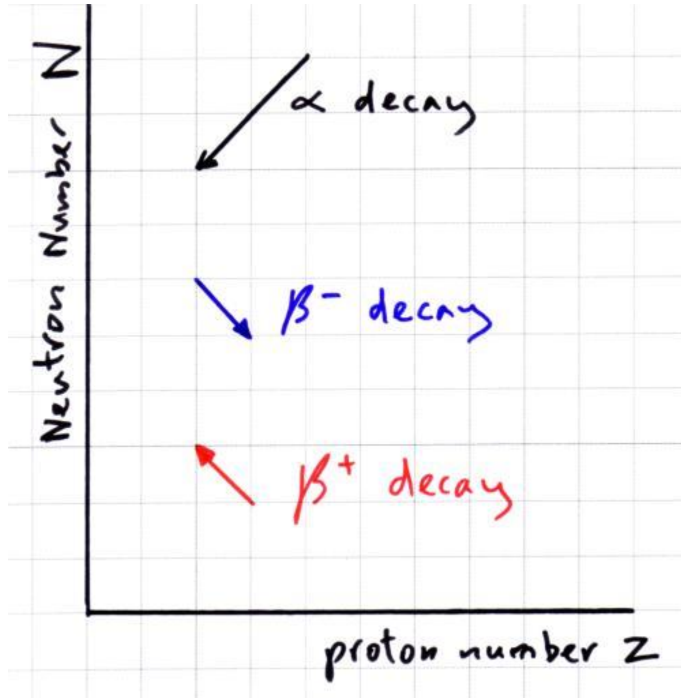
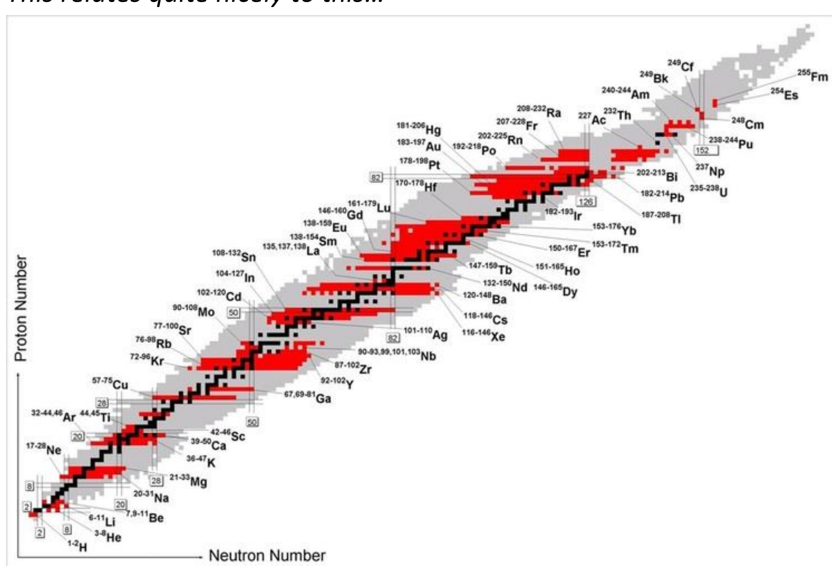
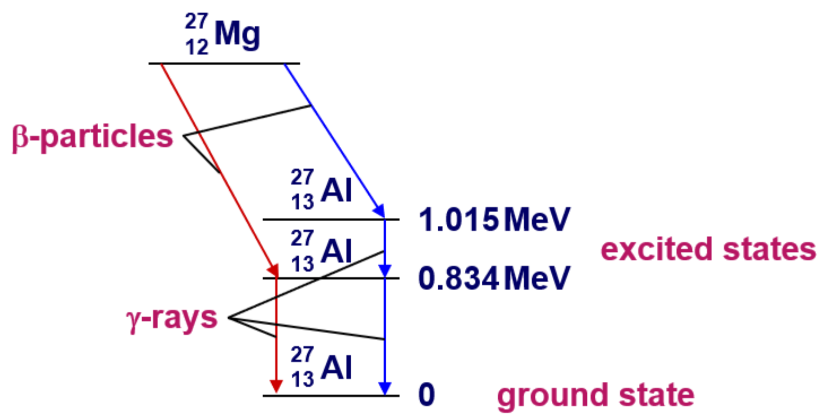
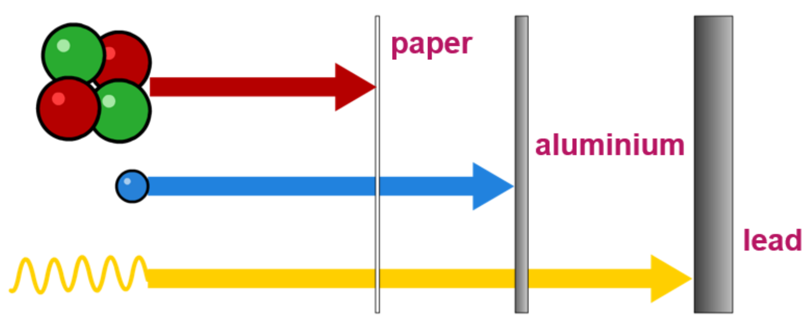
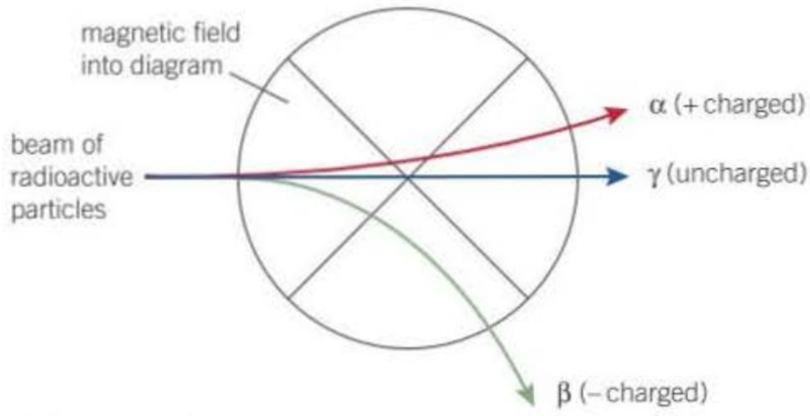


You can see that for light isotopes where z = 20, the stable nuclei have an an equal number of protons and neutrons. For heavier nuclei, they need more neutrons than protons to dilute the electrostatic repulsion between positively charged neutrons.

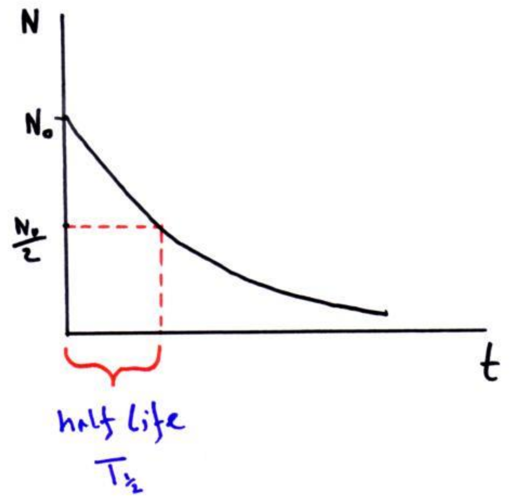
This relates quite nicely to this…

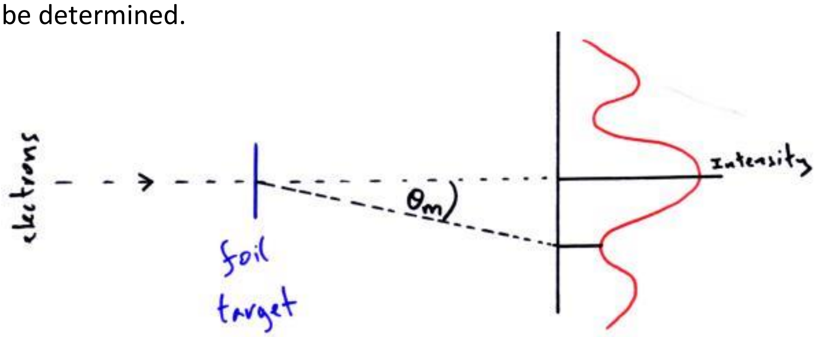


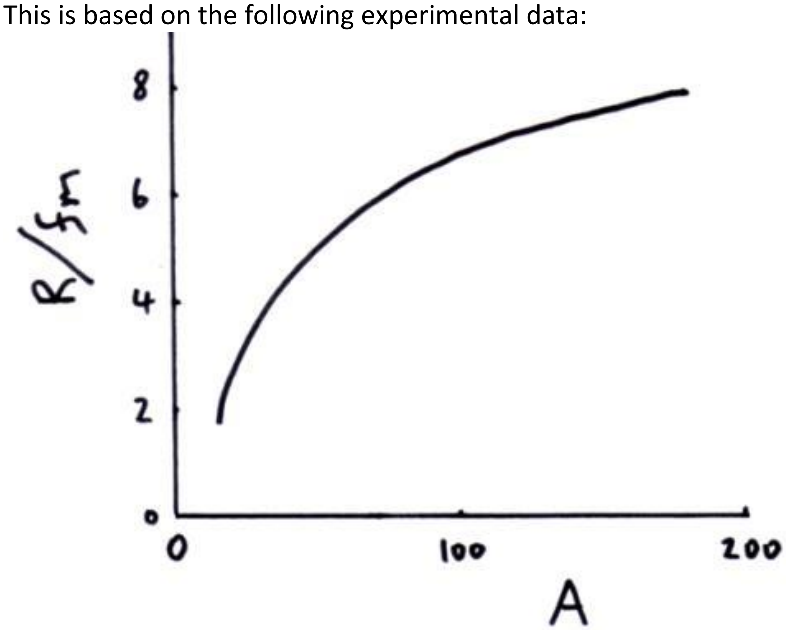
What happens during alpha decay and why?	$${}^{A}_{Z}X \longrightarrow {}^{(A-4)}_{(Z-2)}Y + {}^{4}_{2}\alpha$$ A radioactive parent nuclide decays into a lighter daughter nuclide by emitting an alpha particle as the strong nuclear force can no longer hold the nuclide together. *This is because nucleons on opposite sides of the nucleus repel each other.*
What are metastable states? How are they formed and what happens to them?	• When a nucleus decays into a daughter nucleus, it is in an **excited state**. • Upon de-exciting, it emits a photon which is a **gamma ray.** 
How does α, β and γ radiation vary in penetration?	1. Alpha particles are stopped by a few cm of air / thin sheet of paper. 2. Beta particles are stopped by a few mm of aluminium. 3. Gamma ray intensity is halved by 10cm of lead. 
How do α, β and γ radiation vary in simple electric and magnetic fields?	• α particle - deflected less than β particle and in the opposite direction if travelling at same speed. • β particle - deflected more than α particle.

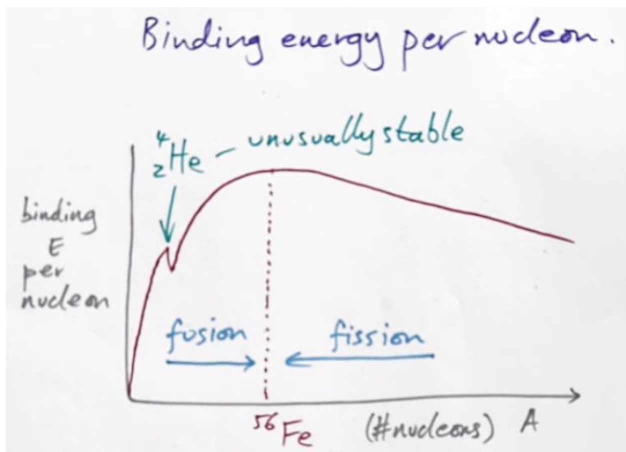
	• γ wave - no charge so unaffected.  *This is very similar for electric fields.*
Where does background radiation come from? (both natural and man-made)	• Natural: 1. Cosmic rays. 2. Natural radioactive material in rocks / soil. 3. Radon gas. • Man-made: 1. Medical sources. 2. Nuclear power stations. 3. Nuclear tests.
What uses are there of alpha particles?	Smoke detectors. *They're not used in the body because of how ionising they are. They're only dangerous if they get into your body. Gamma rays are more dangerous as they can penetrate your body.*
How should you handle radioactive sources safely?	1. Use long tweezers (around 30cm). 2. Return to container when finished to limit exposure time. 3. Point away from body holding at arms length.
What should be measured before carrying out an experiment using radioactivity?	Measure radiation count rate over a course of several minutes.
How should you deal with anomalies during a radioactivity experiment?	Don't ignore them, use them when calculating means. *Since radioactive decay is a random process., you cannot predict when an individual nucleus will decay. Yet with a large number of nuclei, you can use a statistical approach.*

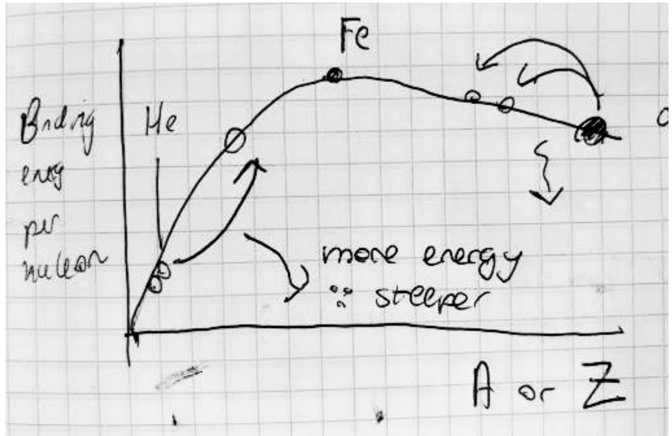
What is the activity of a sample defined as?	The average number of disintegrations per second measured in **becquerels (Bq)**. $$activity = \frac{\Delta N}{\Delta t}$$ *ΔN = change in number of undecayed nuclei* *Δt = change in time in seconds*
What is the decay constant λ defined as?	The probability that a nucleus will decay in the next second **(s^{-1})**. $$\frac{\Delta N}{\Delta t} = -\lambda N$$ So… $$A = \lambda N$$ *This makes sense if you think about it since multiplying the probability of decay per second by the number of nuclei will give you the number of decays per second.* *And using differential equations of $dN/dt = -\lambda N$, you can derive:* $$N = N_0 e^{-\lambda t}$$
What is the half-life of sample?	The half-life is the time for half the nuclei to decay.

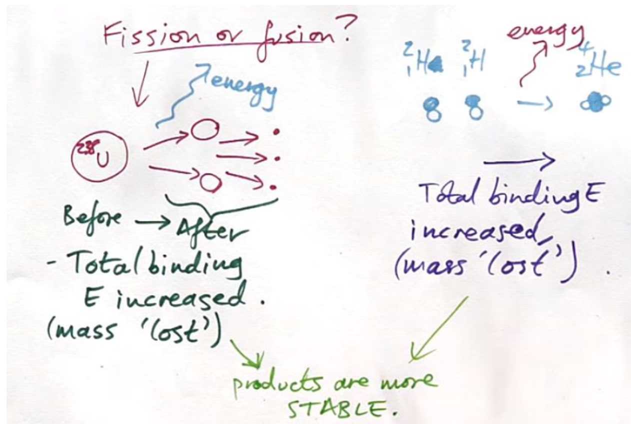
	 Which can also be given by the following equation: $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ Which can be derived from the following: $N = N_0 e^{-\lambda t}$
How does radioactive dating work?	Once a plant or animal dies, its carbon-14 content gradually decreasing and by comparing the amount found on the ancient artifact with the amount we would expect, we can date it. *We often assume the proportion of carbon-14 in the atmosphere has stayed constant which depends on whether the amount of cosmic rays penetrating the atmosphere was the same.*
How can radioactive tracers be used?	To detect for leaks in a pipe since the count-rate will increase where the leak occurs since the pipe will block both alpha and beta emissions. *Here gamma rays would not be suitable since the pipe wouldn't block this.*

How is radioactivity used in sterilization?	Gamma rays can be used to sterilize medical instruments and keep food fresh for longer.
What is radioactivity used in radiotherapy-cancer treatment?	Uses gamma sources to attack cancerous cell. *It relies on cancerous cells being affected by radiation more than others.*
How can nuclear radius be determined by closest approach?	Fire an alpha particle at the nucleus which will transfer its kinetic energy into potential energy (as 2 positive charges are approaching) as it approaches the nucleus. Loss in E_K = gain in potential energy by the field, E_P as shown: $$E_K = E_P$$ $$E_K = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q_\alpha Q_n}{r}$$ $$r = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q_\alpha Q_n}{E_K}$$ *This kinetic energy of an electron relies on $v << c$ in $E_K = \frac{1}{2} mv^2$.*
How can electron diffraction be used to determine the nuclear radius? Why is this better?	Electrons are directed at a foil target of the atom whose radius is to be determined.  *The intensity isn't 0 at the first minima because some electrons.*

	The first minimum θ_m is used in the following equation (which you don't need to know): $$r = \frac{0.61\lambda}{\sin\theta_m}$$ *Where λ is the DeBroglie wavelength of an electron. The 0.61 reflects the fact this is a 'circular aperture'.* As electrons are leptons don't experience the strong interaction (whereas alpha particles, used to determine radius by closest approach).
How is the approximate nuclear radius and nucleon number related?	$$R = r_0 A^{1/3}$$ *Where R is the nuclear radius (m), r_0 is the radius of a nucleon, approximately 1.3 fm, and A is the nucleon number.* This is based on the following experimental data: 
What is mass defect?	The difference between the mass of the separate nucleons added together and when all the nucleons are together in the nucleus.

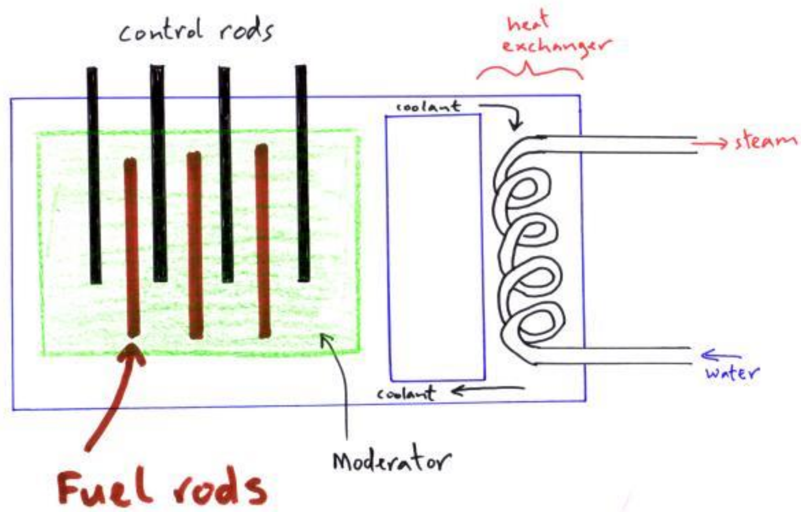
	The latter is less since it is more stable when it is together. When a nucleus is formed, this mass is released as energy.
What is binding energy?	The energy required to separate the nucleus into its individual separate nucleons This is related to mass defect by the following: $$\text{Binding Energy} = \text{Mass Defect} \cdot c^2$$ *This is equal to the lost potential energy when the nucleons came together into a nucleus.*
Draw and describe the graph for 'Binding Energy per Nucleon' v 'Nucleon Number'	 *Remember that helium is unusually stable - hence why we get alpha particles during radioactive decay.* ● The greater the binding energy the person, the more stable a nucleus is (as show iron). ● We can get energy out by 2 ways as nuclei progress closer towards iron: ○ Fusion occurs to the left of iron as lighter nuclei fuse into heavier nuclei. ○ Fission occurs to the right of iron as heavy nuclei split into lighter nuclei. *This is shown below:*





Where in both cases, energy is given out and products become more stable. It is less stable as you go further right as the strong nuclear force cannot hold all the neutrons together.

It gets more stable towards iron as a lot more energy is required to remove each nucleon from its nuclide. For this reason, its difficult to fuse heavy nuclei or fission light nuclei as more energy is required than you get out.

Draw and describe a nuclear reactor (5 parts)	 1. Fuel rods - contain the uranium used in fission. 2. Moderator - slows down fast-moving neutrons (through collisions) into slow neutrons called thermal neutrons. 3. Control rods - move in and out of the core to slow down / speed up the rate of fission. 4. Coolant - cools down the core by transferring the energy to the water in the heat exchanger. 5. Heat exchanger - water turns into steam which turns a turbine connected to a generator. *The coolant may be water, despite this, there is always water in the heat exchanger. It still runs when the reactor isn't on since nuclei as still decaying.*
What moderators are used in nuclear fission and what requirements do these moderators fulfil?	● Water or graphite. 1. Small/light nuclei. 2. Shouldn't be radioactive when bombarded with neutrons. 3. If solid (like graphite), requires high melting point. 4. Available in large amounts.
What material is used for control rods and what factors affect it?	Boron since… ● It absorbs neutrons. ● Has a high melting point.
What is used for the coolant in nuclear fission?	● Water or carbon dioxide 1. Should have a high specific heat capacity. 2. Be non-corrosive. 3. Be stable at high temperatures.

How are nuclear reactors defined to minimise risk of exposure to radiation?	1. Shielding: ■ Steel casing and several metres of concrete surround the reactor core. 2. Emergency shutdown: ■ Control rods are dropped into the reactor if the rate of fission increases.
How are different levels of radioactive waste handled?	● Low - protective clothing and obsolete equipment buried underground. ● Intermediate - parts of reactor put in steel drums and are encased in concrete for underground storage. ● High - very radioactive materials are vitrified (fused into gas blocks) and stored underground. ● All in a geologically stable site. *Glass is used as it is nonporous and doesn't decay.*
What is critical mass and supercritical mass under nuclear physics?	● Critical mass: ○ The minimum mass required for a chain reaction be self-sustaining, continuing at its own steady rate. ○ Anything less and the reaction peters out. ○ On average, one neutron from each fission will cause a further fission. ● Supercritical mass: ○ Used in nuclear reactors and atomic bombs. ○ Several new fissions follow each fission. ○ The rate is then controlled using the rods. *Note that not all neutrons will go on to cause fission, some will escape into the surroundings.*
How does a cloud chamber work?	● You have super-saturated water vapour molecules. ● When an ionising particle passes through, it triggers the formation of water droplets.
Why does the count rate for β^- decay decrease further from the source?	As different β^- decay particles start out with different amounts of kinetic energies