UK Atomic Energy Authority

Radiation

Teachers' Pack

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ENGLAND SEPARATE AND COMBINED GCSE CURRICULUM LINKS

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A simple model of the atom, relative atomic mass, electronic charge and isotopes

- describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with most of the mass in the nucleus
- recall the typical size (order of magnitude) of atoms and small molecules
- describe how and why the atomic model has changed over time
- recall relative charges and approximate relative masses of protons, neutrons and electrons
- calculate numbers of protons, neutrons and electrons in atoms and ions, given atomic number and mass number of isotopes

LIGHT AND ELECTROMAGNETIC WAVES

Frequency range of the spectrum

- recall that light is an electromagnetic wave
- recall that electromagnetic waves are transverse, are transmitted through space where all have the same velocity, and explain, with examples, that they transfer energy from source to absorber
- describe the main groupings of the spectrum – radio, microwave, infra-red, visible (red to violet), ultra-violet, X-rays and gamma-rays, that these range from long to short wavelengths and from low to high frequencies, and that our eyes can only detect a limited range

Interactions of electromagnetic radiation with matter and their applications

- recall that different substances may absorb, transmit, refract, or reflect these waves in ways that vary with wavelength; explain how some effects are related to differences in the velocity of the waves in different substances
- recall that radio waves can be produced by or can themselves induce oscillations in electrical circuits
- recall that changes in atoms and nuclei can also generate and absorb radiations over a wide frequency range
- give examples of some practical uses of electromagnetic waves in the radio, micro-wave, infra-red, visible, ultra-violet, X-ray and gamma-ray regions and describe how ultra-violet waves, X-rays and gamma-rays can have hazardous effects, notably on human bodily tissues

Uses of mathematics

- apply the relationships between frequency and wavelength across the electromagnetic spectrum

ATOMIC STRUCTURE

Nuclear atom and isotopes

- describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with almost all of the mass in the nucleus
- recall the typical size (order of magnitude) of atoms and small molecules
- describe how and why the atomic model has changed over time
- recall that atomic nuclei are composed of both protons and neutrons, that the nucleus of each element has a characteristic positive charge, but that atoms of the same elements can differ in nuclear mass by having different numbers of neutrons
- relate differences between isotopes to differences in conventional representations of their identities, charges and masses

Absorption and emission of ionizing radiations and of electrons and nuclear particles

- recall that in each atom its electrons are arranged at different distances from the nucleus, that such arrangements may change with absorption or emission of electromagnetic radiation and that atoms can become ions by loss of outer electrons
- recall that some nuclei are unstable and may emit alpha particles, beta particles, or neutrons, and electromagnetic radiation as gamma rays; relate these emissions to possible changes in the mass or the charge of the nucleus, or both
- use names and symbols of common nuclei and particles to write balanced equations that represent radioactive decay
- explain the concept of half-life and how this is related to the random nature of radioactive decay
- recall the differences in the penetration properties of alpha-particles, beta-particles and gamma-rays
- recall the differences between contamination and irradiation effects and compare the hazards associated with these two.

Hazards and uses of radioactive emissions and of background radiation

- explain why the hazards associated with radioactive material differ according to the half-life involved
- describe the different uses of nuclear radiations for exploration of internal organs, and for control or destruction of unwanted tissue.

Nuclear fission and fusion

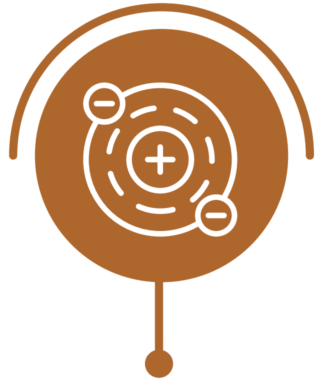
- recall that some nuclei are unstable and may split, and relate such effects to radiation which might emerge, to transfer of energy to other particles and to the possibility of chain reactions
- describe the process of nuclear fusion and recall that in this process some of the mass may be converted into the energy of radiation.

Uses of mathematics

- balance equations representing alpha-, beta- or gamma-radiations in terms of the masses, and charges of the atoms involved
- calculate the net decline, expressed as a ratio, in a radioactive emission after a given number of half-lives

Learning Objectives

Understand the relationship between ionising and electromagnetic radiation.



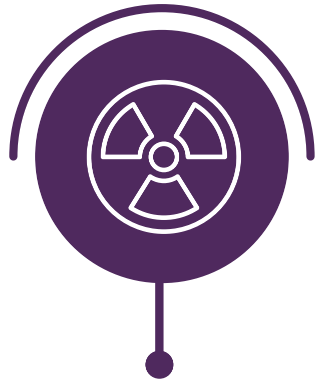
Alpha, beta, gamma and neutron radiation are different and behave differently.

Radioactive decay is a random process that can be averaged out to show an exponential decay curve.

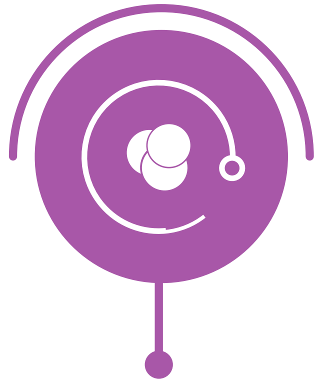
What half-lives are and how to do calculations with them.

What shielding is and how it can be used.

How to protect from radiation – time, distance and shielding.



Being irradiated is being exposed to radiation, being contaminated means having radioactive material on or in you.



Some methods of fusion use tritium fuel – a radioactive isotope of hydrogen.

Kit List

ACTIVITY 1 – RADIATION – ELECTROMAGNETIC AND IONISING

- School-appropriate radiation sources
- Extra long tongs
- Geiger counter (Geiger muller tube)
- Aluminium absorbers
- Lead absorbers
- Clamp stands as necessary
- Additional safety gear as appropriate
- Small pipe cleaner
- Medium sized pompom
- Four juggling balls or beanbags taped together

ACTIVITY 2 – CONTAMINATION, RADIATION AND SHIELDING

- Two similar torches
- Two similar boxes that can each hold a torch
- A contaminant

See Appendix A for more information.

ACTIVITY 3 – LEAD BEANBAGS

Required:

- Beanbags
- Beans – or other small items such as handful of erasers

Recommended:

- Long handled broom and dust pan
- Or regular broom and dust pan with long handles attached
- Goggles
- Labcoats
- Timers

ACTIVITY 4 – RADIOACTIVE DECAY

- Trays
- Many dice – 40 or more per group
- Optional: dice with different numbers of sides, again 40 or more per group

ACTIVITY 5 – CLOUD CHAMBERS

- Cloud chamber
- Isopropyl alcohol
- Source - likely a thoriated tungsten welding rod
- Tongs for handling the source
- Dry ice, if required for your cloud chamber
- Dry ice related safety gear such as safety goggles, suitable gauntlets

See Appendix B for more information.

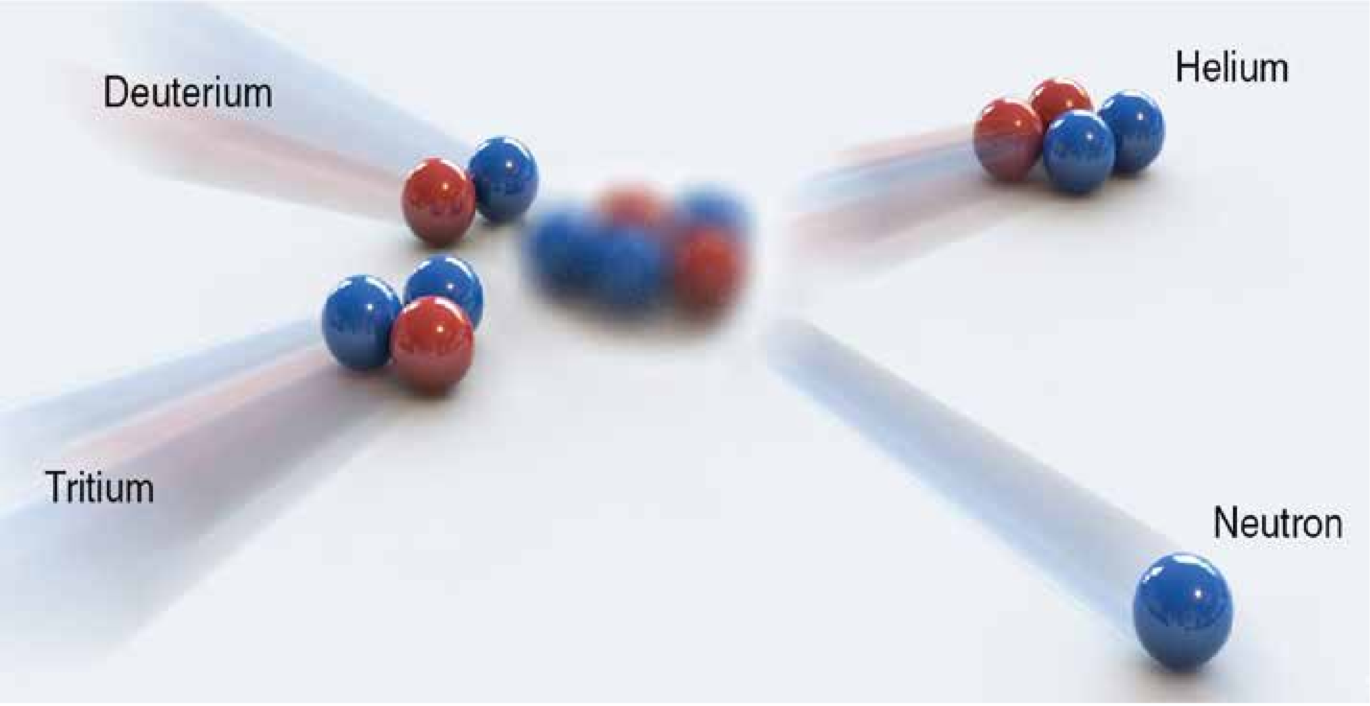
Introduction

The Sun emits light and heat. These are released as fusion reactions take place in the Sun, with hydrogen nuclei sticking together to release energy. The UKAEA and many other organisations are trying to make fusion reactions happen in machines and labs so that we can use the power source of the Sun here on Earth. Using these fusion reactions, we hope to one day turn the energy released into electricity. That electricity will have been created without consuming fossil fuels, without producing CO2 or NOx gases, and will help support growing energy demands of the future in a sustainable way.

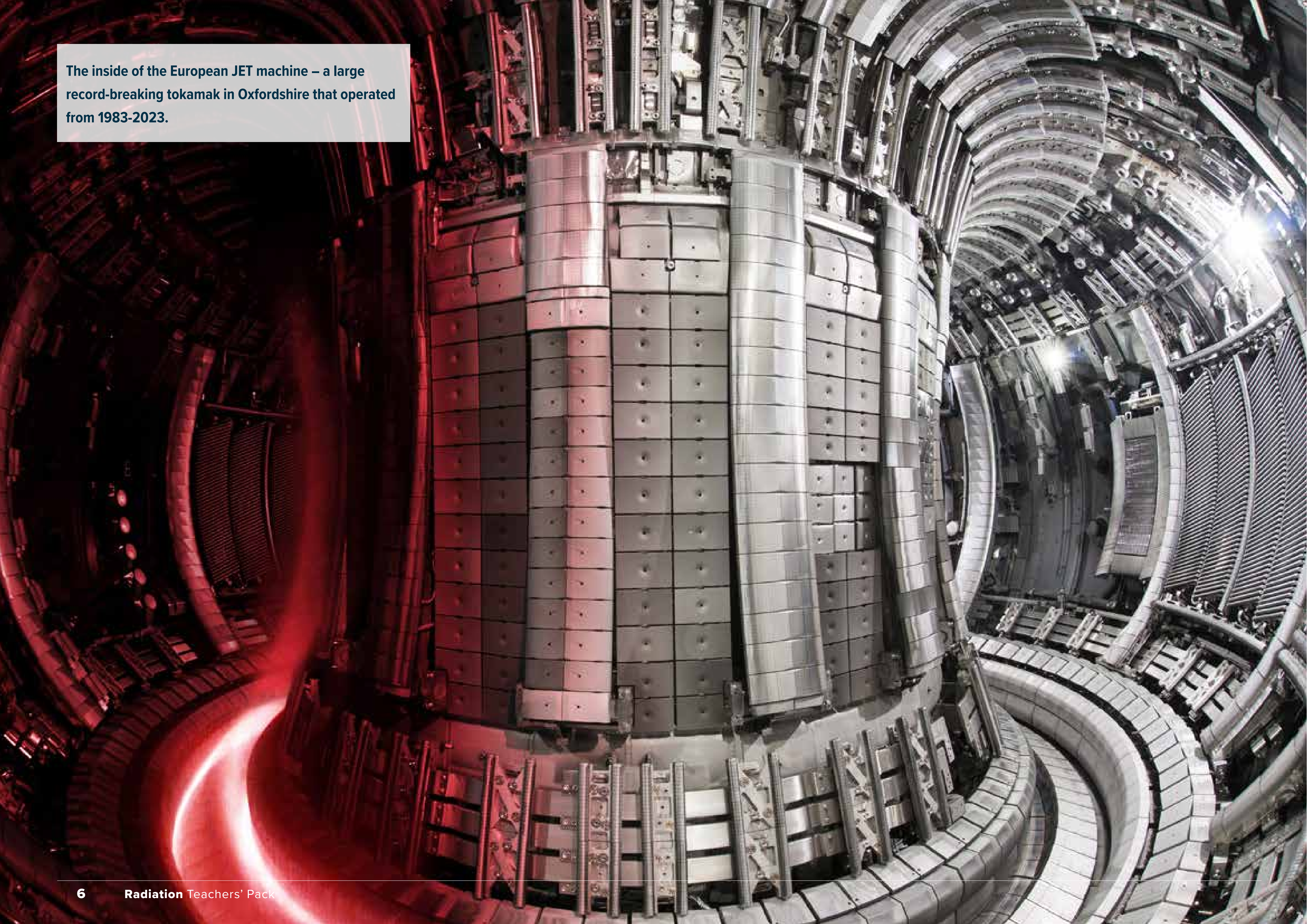
There are many different approaches to fusion. At the UKAEA, we favour tokamaks. This is a method where hydrogen gas is heated to 150 million degrees, at which point the particles crash into each with sufficient force to fuse. At this point, a helium nucleus and a neutron are formed and lots of energy is released.

Diagram of reaction

At these ridiculously high temperatures, the hydrogen gas becomes a plasma – the fourth state of matter – in which the particles are charged. As they are charged, it is possible to interact with them using magnets and electricity. We use electromagnets to confine, heat and manipulate the plasma as it spins round inside the doughnut-shaped machine.



The nuclei of two isotopes of hydrogen – deuterium and tritium – undergo fusion to create a helium nucleus and a high energy neutron. This high energy neutron is moving very fast. In the future, we hope to capture the energy from this reaction to generate clean energy in fusion power plants.



The inside of the European JET machine – a large record-breaking tokamak in Oxfordshire that operated from 1983-2023.

Radioactivity in fusion with tokamaks

The reaction inside a tokamak uses two types of hydrogen: the isotopes deuterium ^2H and tritium ^3H. Fusing deuterium and tritium is a more efficient reaction than hydrogen fusion in the Sun. Tritium is a radioactive isotope, which means that particular hydrogen atoms that have the configuration ^3H will sometimes break apart. We call this radioactive decay. When this happens, an electron is released and the ^3H becomes a ^3He atom.

Tritium has a half-life of 12.33 years. That means that if you have a large number of ^3H atoms and you were to plot the radioactivity levels of the whole amount of ^3H, then it undergoes exponential decay which you can plot with activity levels halving every 12.33 years. For any one particular ^3H atom, however, the time when it decays cannot be predicted. It could be much sooner or much later than 12.33 years. See Activity 4 for more on half-lives.

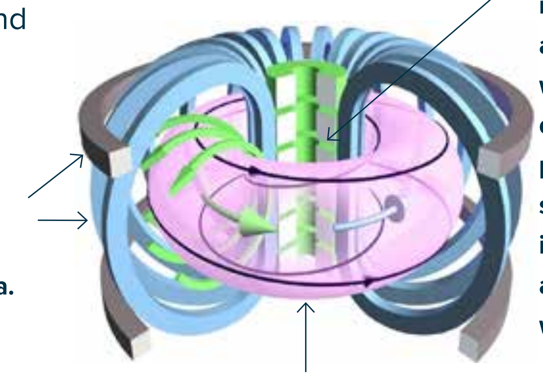
Inside a tokamak machine that is able to use ^3H fuel – JET being a hugely notable example, with many world records – only a miniscule quantity of ^3H is actually used at any time, JET only ever used 0.01g of fuel at any time; future powerplants will only use a few grams. Over time, especially in a power station setting where the machine would be running almost constantly, this will have effects. Some tritium will become embedded in the materials inside the machine – especially the wall tiles. This does mean that the inside of the machine is somewhat radioactive, but by choosing the right materials, we can minimise activation.

Another way that fusion can make the inside of the machine radioactive is through neutrons. During the fusion reaction shown above, a neutron is released. This neutron has a lot of energy and is travelling very fast. It will smash into the structural materials of the machine and can become embedded in the nucleus of the atom that it strikes.

The atom that absorbs the neutron will now have an additional neutron, which will affect its stability, and could cause it to become an unstable isotope e.g. cobalt 59 gains a neutron and become radioactive cobalt 60.. That unstable isotope will eventually emit radiation, which could affect other atoms nearby, or travel into the chamber, or even out through the machine into the torus hall, where it will be stopped by the thick concrete shield wall.

For context, apart from a few months during tritium experiments and a month or two afterwards, JET's torus hall had sufficiently low radiation levels that it is safe enough for humans to visit and take a stroll around this incredible fusion machine without any safety equipment or significant concern.

MODEL OF A TOKAMAK



The green rings in the centre are a transformer coil which induces current in the plasma, as well as shaping, confining it and holding it away from the walls.

The blue and silver rings are electromagnets which heat, shape and confine the plasma.

The hydrogen nuclei form a pink plasma or hot gas which is held away from the machine by the electromagnets.

Radiation for research

Given the low quantities of tritium used, and the neutrons which complicate matters, but also at sufficiently low levels that it's safe for a human to be a couple of metres away from the machine... why is radiation so important at the UKAEA?

We are of course very interested in safety and we are aware of possible situations that may arise due to the tritium and neutrons that we have on site. We do, however, have other more radioactive items than JET.

These radioactive sources are for research, used in "diagnostics" – machines that gather information about what's going on inside the tokamak, like measuring temperature, speed and cameras. We also have a Materials Research Facility, MRF, that analyses samples to examine their structure and characterise various properties, all at microscopic scale or smaller. Some of the samples they study are really rather radioactive! That's why their research is done inside shielded steel and concrete boxes with thick walls and for this reason they use "mechanical arms" that copy their movements inside the box rather than just gloves. These arms are mechanically coupled local-remote manipulators which use metal tendons, like bicycle brakes or tendons in your own arm, and not motors or electronics as radiation is not good for electronics.

A pair of mechanically coupled remote manipulators is shown to the right of the operator as he stands in front of the shield wall of a Hot Cell in the MRF. The yellow shape is a pane of glass with lead for additional shielding. This wall and window are very thick.

In the MRF they can analyse the structure of a material in its normal unirradiated form as well as irradiated and radioactive samples. Irradiation can cause damage to a material and affect its properties and performance. This testing can be combined with environmental control such as high or low temperatures and high magnetic fields. By studying these samples, they can learn the effects of different types of damage and go on to understand the implications of using certain materials in certain conditions.

This research can help inform engineering designs and keep people safe – not just from radiation or in fusion, but across many situations, like helping prevent bridge failures, knowing when to replace tired machinery before an incident occurs, and making things longer-lasting.

The MRF technicians are extremely skilled at doing fine work on tiny samples using manipulators such as those pictured. They train for months to perfect their skills and are to be respected. Using these manipulators is not easy.

Activity 1:
Radiation – electromagnetic and ionising

Begin with discussion on radiation, asking the group to offer words that come to mind. Ideas, types of radiation. Collect these on a whiteboard and prompt for others. This can be a good opportunity to recap different types of electromagnetic radiation, their uses and interesting snippets.

Once you have collected all the forms of radiation listed in the diagram below, show or recreate this diagram with the class. Explain that some types of electromagnetic radiation are also ionising but many are not and why neutrons are placed as they are. This diagram provides context for the relationship between ionising and electromagnetic radiation which can be useful to avoid confusion or misconceptions.

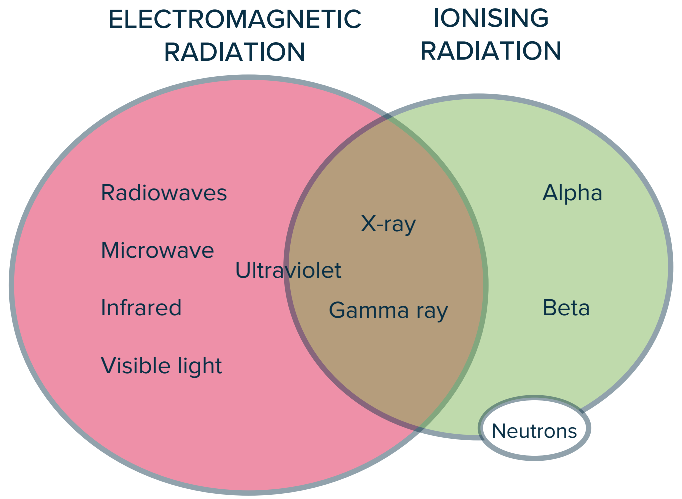
FACT BOX

Neutrons are a subatomic particle. They sit in the nucleus of the atom with the protons. In addition to alpha, beta and gamma radiation, sometimes a neutron can become dislodged and travel at speed.

Neutrons don't exactly fit with ionising radiation or electromagnetic radiation. They are indirectly ionising so can cause otherwise stable materials to become radioactive.

Next, an individual appropriately trained in handling radioactive samples, and following appropriate safety protocols, removes a source from a shielding container using tongs and uses a Geiger counter, preferably with sound to allow the class to "hear" how radioactive the sample is. A sheet of paper can be placed between the sample and the Geiger counter, then a piece of aluminium and then lead. This exercise can be repeated with a different type of source if possible and the effects of different materials in blocking radiation can be observed, with different types of radiation being affected differently by the different materials.

The source can also be moved closer to and away from the Geiger counter, to show the difference in counts received from different distances. The relationship between distance and radiation dose is not linear, although this is not especially clear from this experiment.



Alpha, beta and gamma are commonly thought of as the three forms of ionising radiation. Additionally, x-rays and some wavelengths of ultraviolet are also ionising. Neutrons have been placed with but not inside the ionising radiation set as they are not directly ionising but do cause indirect ionisations.

Explanation – what is radiation?

Radiation happens when the nucleus of an atom is unstable.

The nucleus of an atom contains protons and neutrons which are stuck together in a lump. Protons are positively charged and therefore don't really want to be close together. There are little forces which hold the protons and neutrons (called nucleons) together – you can imagine the surfaces are sticky like tape.

When you have an unstable ratio or non-optimal number of protons and neutrons in your nucleus, the forces aren't in balance and the sticky surfaces can't hold the ball together. Either a part breaks off or energy is released. When the nucleus emits radiation, the atom you started with can become a different element.

If the nucleus releases a chunk containing two protons and two neutrons, that's an alpha particle. If the nucleus releases an electron, that's a beta particle. If the nucleus emits energy, that's gamma radiation. Each of these types of radiation has energy and can damage the material that absorbs them – although they each behave differently.

Pass round the props of a small pipe cleaner in a wave shape to represent gamma radiation, a medium sized pompom for beta radiation and for an alpha particle, four beanbags (two of each of two colours) sewn or taped together.

Discussion – everyday radiation

These forms of ionising radiation don't only exist in apocalypse scenarios and superhero films – they are a lot more common than you might expect. That doesn't mean we should be scared of normal low level background radiation, but it is interesting to know that it's all around us all the time and we aren't aware of it. There are low levels of radiation in soil, in rocks such as granite, and small amounts of radioactive potassium in our bodies and food we eat. Here we use the sun as an example because light is something we can perceive.

Question for students: what forms of radiation does the sun emit?

Answer: forms including visible light, which allows us to see and allows plants to photosynthesise; infra-red, which makes us feel lovely and warm in the sun and affects temperatures around the world; and ultraviolet (UV).

Elaborate: we cannot perceive UV light in that we cannot see or feel it (or hear it…) however it does affect us and is one example of radiation we encounter on a daily basis.

Question for students: How do we protect our bodies from the sun?

Answer: wear sun cream, hats, clothing and spend time in the shade.

Elaborate: These are forms of shielding! X-ray technicians wear lead clothing and hide behind a wall to prevent unnecessary exposure. Avoiding sun burns, excess X-ray exposure and protecting yourself from radioactive sources like the ones your teacher might use to demonstrate with or those found in a nuclear (fission) power station all use the same principles.

TIME, DISTANCE AND SHIELDING

We should not be scared of going outside. Although we can be burned by the sun, most people living in the UK need more vitamin D, which we mainly create when there is sunlight on our skin. Wearing sun cream is important, but going outside is too. Similarly, we should not be afraid of the small amounts of radiation we encounter in our everyday lives.

Activity 2: Contamination, radiation and shielding

The concept of contamination with radioactive material can be confusing and difficult to successfully relate to the dose received from a radioactive source. Radiation being invisible does not make this easier. In this activity, make the “radiation” and “contamination” visible.

The “radioactive sources” (the two torches) – are each in a box “with shielding” (most of the light from the torch cannot escape). The torches are switched on, so we can visualise the “radiation” they are emitting. Firstly, open the box and pick up the torch. Shine the torch on the desk, around the room, on your arm and hand. You could put it down on the desk. The desk, the room, your arm and hand are being irradiated. They are receiving a dose of radiation. We can see where the radiation is going as the torch will light it up. Return the torch to the box.

With the torch in the box, you are now shielded from the source – you can move your hands, arms, self all around the box and will receive no dose (or only a small one, depending on how opaque your box is). You can shine the torch on your arm and hold various materials between the torch and your arm to show the shielding effects of different materials. For example, tissue paper will stop less light than thick card, aluminium foil, or a whole desk.

Take the second torch out. This torch is “contaminated”. See the kit list for suggested contaminants.

As before, shine the torch on various surfaces, not being overly carefully so that the contamination transfers to your hands, desk or other areas. You may put it down or “accidentally” drop it onto the desk. Return the torch to the box.

If using a (strongly recommended) glow in the dark contaminant, alter the lighting so it shows up. If using a different contaminant, highlight it in a relevant manner, such a use a tissue to show where water has been transferred to.

The first source, without contamination, has been returned to the box. Once the box is closed, the box’s shielding prevents any further radiation from being emitted into the room. Your body will receive no further radiation.

In contrast, the second source will continue to give radiation doses even after the torch has been returned to the box. **The contamination continues to give out radiation and the contamination is not contained inside the box.**

Explain that any contamination on your gloves, hands or desk will continue to spread as you go about your day and can be transferred to food you drink or get into your body when you rub your eyes or apply lip balm, for example. You can even demonstrate washing your contaminated hands poorly (with or without gloves) to show that sloppy handwashing will not necessarily remove all of a contaminant, even though you are likely to behave afterwards as if your hands are clean. Once your hands have been washed, it feels acceptable to for example, hold and eat a sandwich – even though you can clearly see (most likely) your hands are still rather contaminated.

With sources of similar radioactivity, it is much worse to be contaminated than briefly irradiated. With contamination, you continue to receive a dose and accumulate radiation damage, and run the additional risk of ingesting contaminated material, which will do further damage.

Activity 3: Lead beanbags

Sometimes our radioactive source might break or crumble. This can lead to dust or "crumbs" of radioactive material. How radioactive the source is will affect how easy it is to clean up. If it is a minimally active source, it may only require use of tongs and gloves. For very active sources, this could cause the person to receive too high a dose, and therefore a better solution must be found.

This better solution is to use beanbags!

Not normal beanbags, but beanbags filled with lead pellets. Lead is an excellent material for shielding radiation. Once the broken source is covered up with lead-filled beanbags, the radiation is at least mostly contained. This allows a person to approach to clean up the radioactive material together with the lead beanbags, while massively reducing the dose of radiation they receive in the process.

For the activity, place 5-10 dried beans on the floor or a desk, mostly together. Get the students to throw beanbags, aiming to cover the beans and not further scatter them.

EXTEND THE ACTIVITY

Provide a long-handled dustpan and broom (or attaching long handles to normal dustpan and broom) and get the students to work together to collect and deposit all the "radioactive" beans into a container, then seal it. They must keep themselves as far away from the source as possible to reduce their dose.

Split the students into two or more groups and get them to race each other. You can give points per beanbag required and combine it with the time taken to find a winning group (fewer beanbags and shorter times is better), or just run the dustpan and broom section as a race.

In reality, cleaning up a scenario like this would also involve a lot of work to remove contamination from the area – soaking up, washing out and containing it.

Activity 4: Radioactive decay

Let's have a look at radioactive decay and half-lives. The half-life of a radioactive material is the length of time it takes for the radioactivity to reduce by half – for the number of decays per second to reduce by half.

Roll many dice on a tray to contain them. Have the group remove all the dice that roll a one and put them into a pile. Roll the remaining dice on the tray again. Remove all the ones and place them in a separate pile. Continue to roll the remaining dice and remove all the ones into a new pile.

Have the groups plot on graphs the number of dice in each pile. For example, the first pile may contain 16 dice, which represents 16 radioactive decays happening in time period one. The second pile could have six dice – there are six decays during time period two.

VARIATIONS

Give different groups dice with different numbers of faces. This alters the probability of a decay happening in any given time period, which will change the half-life. This different half-life will correspond to a different radioactive isotope.

If you discard the dice that land on one each time, dice with fewer sides represent more radioactive isotopes with shorter half-lives. Larger numbers of sides represent isotopes that are less radioactive and have longer half-lives.

Another variation is to again use regular six-sided dice, but to change which rolls count as decays. Instead of discarding the ones, you can have different groups discard any dice that roll ones or twos, discard anything except a six. Alternatively, you can have the groups each repeat the exercise with different discard numbers.

Again, discarding only the rolls of one is the lowest probability of decay (1 in 6) and therefore represents a long half-life and a less radioactive isotope. Discarding more rolls (e.g. 1s, 2s, 3s and 4s) has a higher probability of decaying, which represents a shorter half-life and a more radioactive isotope.

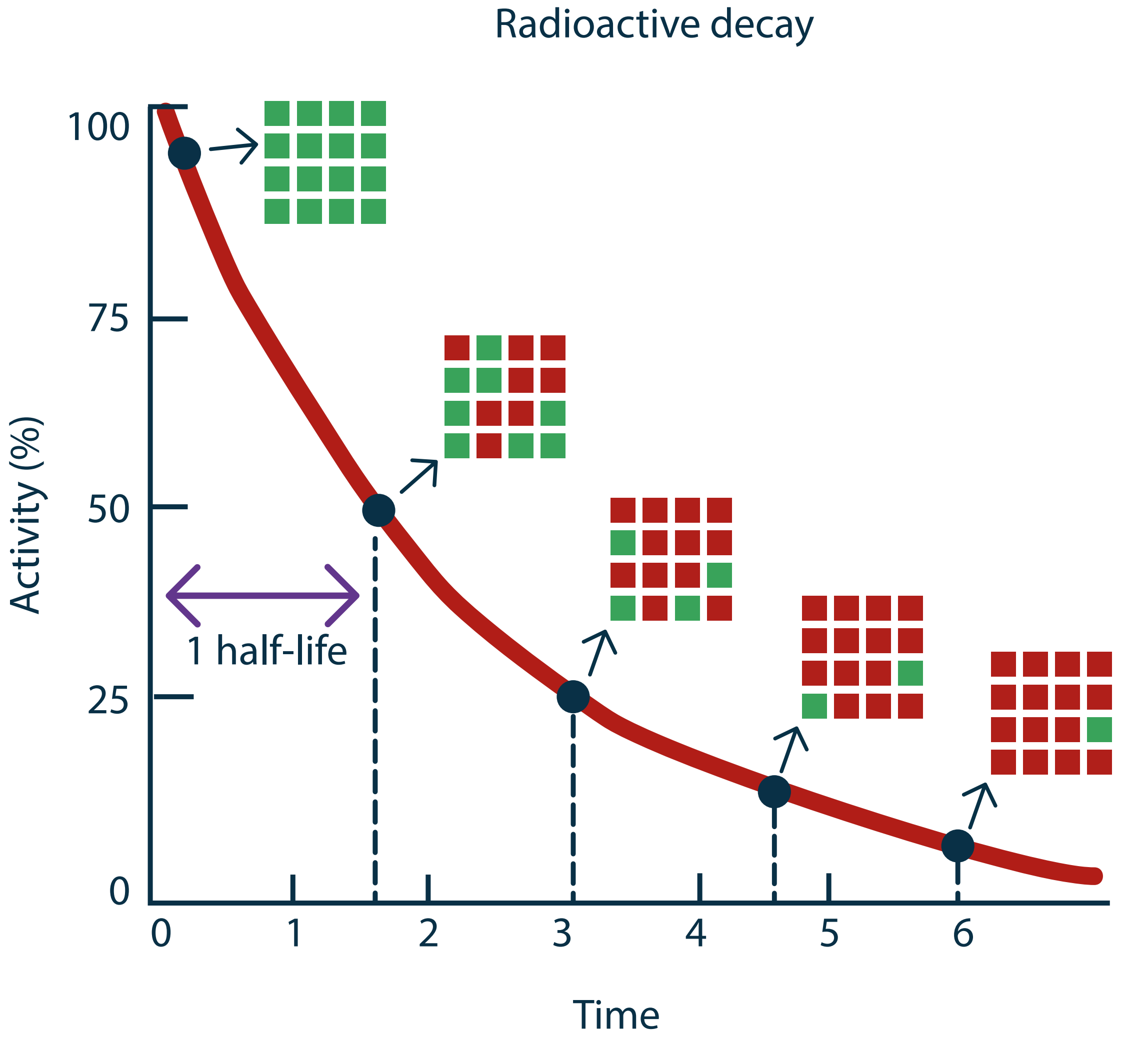
Compare the graphs. Have the groups calculate the half-lives for each graph. Note that "time period" is not defined in this exercise, so it could be a millisecond, a thousand years, 37 seconds, or any other period of time. You can assign the duration of a time period for practice doing half-life calculations.

When looking at the graphs of decays per time period, you should be able to see that the decay curve does not exactly fit every time point. This is because radioactive decay is a random process. Sometimes more atoms will decay than expected in any given time period, sometimes fewer.

This dice activity is a good way to see that any given die (atom) has a 1 in 6 chance (depending on the die) of decaying during each and any given time period, but that when you have many radioactive atoms, the pattern of exponential decay will emerge.

Repeating this exercise with a small number of dice and a large number of dice will show that using larger numbers gives smoother curves on the graph. Since a radioactive sample has a very large number of radioactive nuclei, half-lives are meaningful, relevant and accurate.

If you can get your Design & Technology department on board, you might even be able to get the students or staff to make regular 6-sized or other kinds of dice. You do not necessarily need numbers to be indented for this activity – you can paint one side a different colour, for example.



Activity 5: Cloud chambers

Radiation is invisible, silent and usually not something we can perceive, which can make it tricky to conceptualise. However, using a cloud chamber, we can indirectly see the different types of ionising radiation.

Set up the cloud chamber. Either there will need to be dry ice placed under a metal plate or the machine plugged in, and the chamber must have some alcohol added. Follow the instructions for your type of cloud chamber and bear in mind they can take 10 minutes or more to form a cloud and be ready.

A cloud chamber works by filling with alcohol "fog". This cloud is ready to turn into "rain" with any disturbance.

When ionising radiation hits the alcohol vapour, the vapour bumps into surrounding vapour and forms a clump. This leaves a little trail of cloud following the route that the radiation took. Different types of radiation make different shaped trails, which allows us to identify the type of particles in our cloud.

Refer back to the pipecleaner, pompom and beanbags. Alpha particles are big, slow, heavy and awkward. They leave short thick straight trails in the cloud. Beta radiation makes much finer trails that are often longer and may be dotted or dashed rather than continuous.

Summary

We have learned the relationship between ionising and electromagnetic radiation and neutrons. Alpha, beta and gamma radiation behave differently. We are exposed to small amounts of radiation in our environment every day.

The three aspects of reducing your exposure to radiation are time, distance and shielding. Shielding can block radiation and can be used to keep people safe. Contamination is so dangerous because you continue to receive radiation, likely resulting in a higher exposure.

Radioactive decay is random but using large numbers, we can get exponential decay graphs. This understanding of half-lives can be used to perform calculations on how radioactive something will be after a certain time.

Appendices

Appendix A

SET UP FOR ACTIVITY 2 – CONTAMINATION, RADIATION AND SHIELDING

Depending on your contaminant, it may be a good idea to put your torches into plastic bags.

Put your torches (while on) into their boxes (shielding container). The more light the box blocks the better for the demonstration as we want to have as much "shielding" as possible.

If you only have clear transparent boxes, cut some paper to line it with to help the torch light shine through less.

If your box has good "shielding", no light will come out once the box is closed.

For best effect, the contaminant will be glow in the dark. In this activity, the torches emit light and so does a glow in the dark contaminant, so it keeps the radiation substitute consistent.

Depending on what you have access to, the contaminant can be glitter, paint, chalk dust, or even water with or without colouring. Something which will transfer to other surfaces in a way that can be shown. A glow in the dark contaminant is strongly recommended if at all possible.

Ideal set up has two small fluffy torch keychains. A torch wrapped in some cotton wool will do nicely. One of them will have glow in the dark pigment on it which will sprinkle onto the desk, your hands etc as it is moved.

Failing this, put both torches inside clear plastic bags and put chalk dust on one of the bags, or paint or even water. The torch, bag and contaminant combined are your source.

When you show the contamination and where it has transferred to, this will depend on what contaminant you have used. For glow in the dark, change the lighting, for water, lay a paper towel on the surface then lift it to show where the water was. Paint will likely need no adjustment.

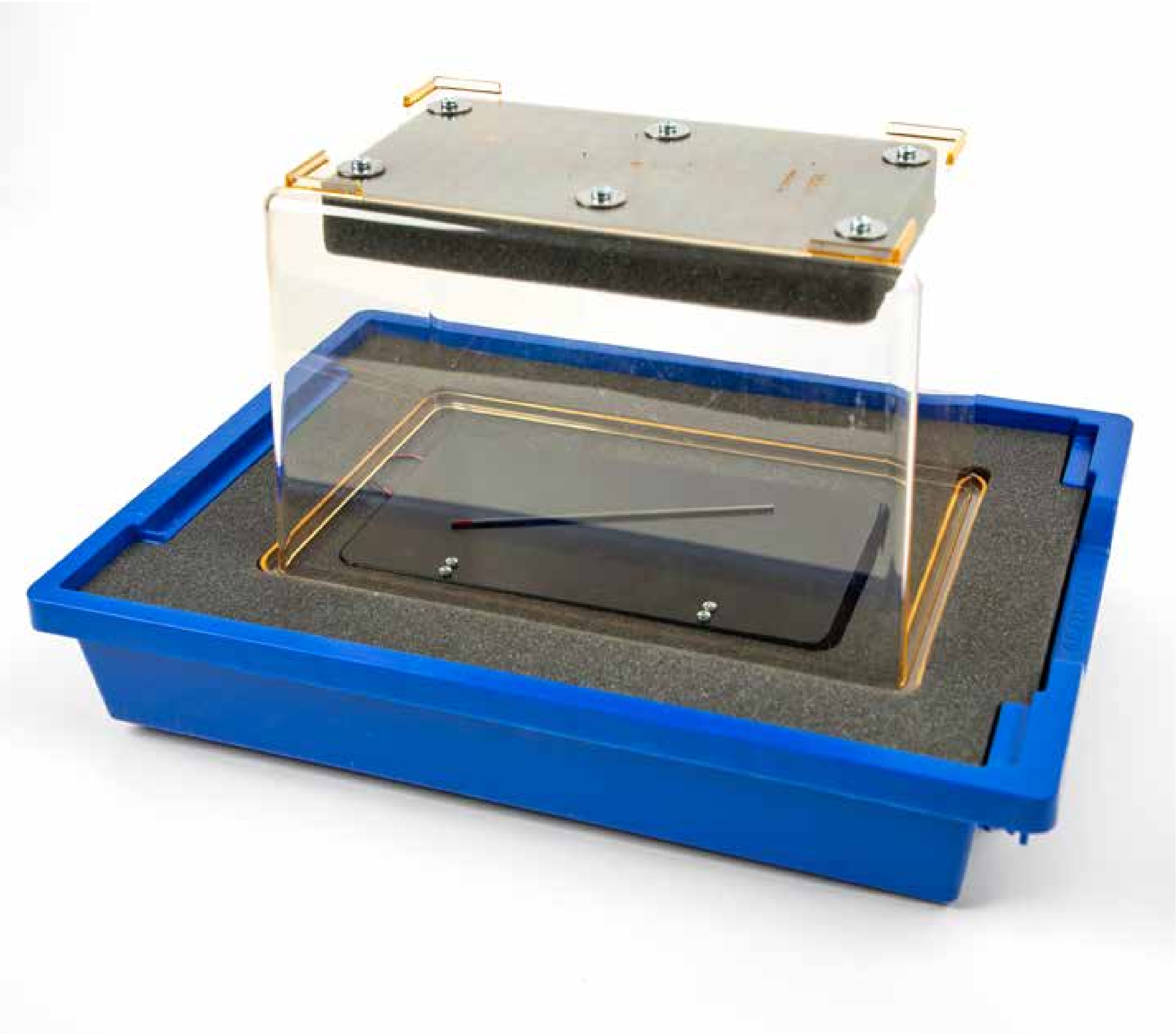
If you prefer, you can wear gloves, labcoat, goggles for this activity and even use tongs. This will likely facilitate it to be messier while still allowing relatively easy clean up. Plus it adds to the authenticity of it being a radiation activity!

Appendix B

FURTHER INFORMATION FOR ACTIVITY 5 – CLOUD CHAMBERS

Depending on the type of cloud chamber you have, you may need dry ice or to chill part of the cloud chamber in a freezer for hours beforehand. Check in advance. Dry ice can often be delivered within a couple of days. Plan your delivery date carefully. Pellets are likely a good form for a cloud chamber. Check the quantity carefully – 10kg is more than enough for a whole day of cloud chamber and costs around £60. You do not want to accidentally order 10x that.

If using dry ice, ensure an appropriate storage area is available beforehand and ensure ventilation, appropriate safety gauntlets, and other safe handling measures are used throughout, including disposal of excess. Consult your technician or cryo-trained colleague where possible.



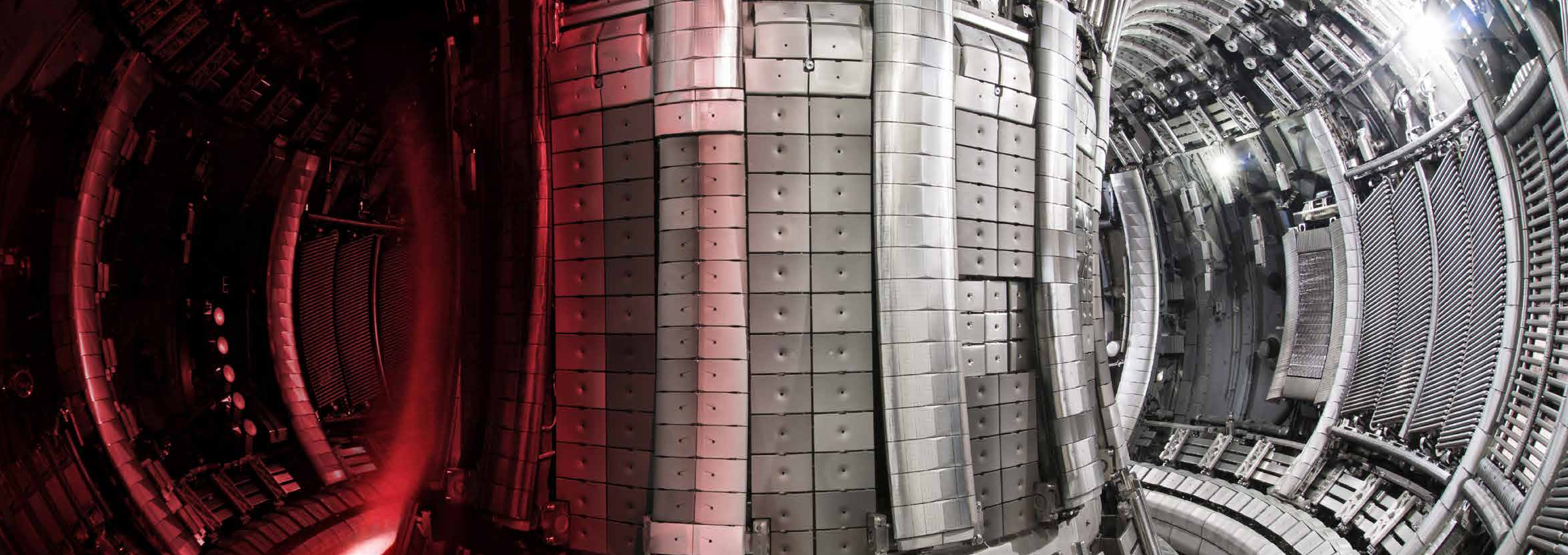
Risk assessment

DESCRIPTION OF TASK	POTENTIAL HAZARDS	WHAT COULD GO WRONG	WHAT WILL BE DONE TO CONTROL THESE RISKS?
ACTIVITY 1 **RADIATION DEMONSTRATION WITH RADIOACTIVE SOURCES**	Radioactive sources	Students could be exposed to radiation.	Demonstrator has been appropriately trained on how to handle sources properly. Room has been appropriately set up so that students are a safe distance from the sources. Additional support has been sought and provided as appropriate.
		Source could be dropped and break, contaminating the class.	Demonstrator is aware of appropriate clean up procedures, how to manage their class and how to get help from colleagues as necessary.
ACTIVITY 2 **TORCHES IN BOXES AND A CONTAMINANT**	Torch	Torch could be shone in someone's eyes.	Don't use an excessively powerful torch.
	Contaminant	Students could try to eat the contaminant.	Activity is recommended for GCSE level students. Appropriate supervision should be provided.
ACTIVITY 3 **BEANBAG TOSS AND LONG-HANDLED BROOMS**	Moving around, long handled brooms	Slips, trips and falls could occur.	Sufficiently sensible behaviour should be maintained.
ACTIVITY 4 **DICE ROLLING**	Dice	Small pieces are a choking hazard.	Activity is recommended for GCSE level students. Appropriate supervision should be provided.
ACTIVITY 5 **CLOUD CHAMBERS**	Dry ice	CO_2 could displace the air.	Dry ice must be stored and used in an area with adequate ventilation. Any excess must also be disposed of safely.
		Contact burns could occur.	Dry ice should be handled carefully with cryo gauntlets or otherwise appropriately. Students should not handle dry ice. If possible, do the dry ice set up before students arrive.
	Thoriated tungsten welding rods or other sources	Students could be exposed to radiation.	Thoriated tungsten rods are quite safe sources and should be suitable for this activity. Students should not touch the sources. Adults should model good practice when handling unsafe materials such as sources.

Please note that classroom related risks, pupil related risks and others are not included on this risk assessment.

Read and follow the guidance with your radiation source and kit. This teachers' pack cannot provide comprehensive safety information for your particular classroom setup, sources and safety equipment. Please do your due diligence and seek advice from an informed colleague or technician as appropriate. Do not handle radioactive sources or dry ice unless you feel confident in your ability to do so while maintaining the safety of yourself and everyone in your class.

Use of radioactive sources should be subject to your own internal risk assessments taking advice from sources such as CLEAPPS. A copy of the CLEAPPS risk assessment is attached as part of this pack and we would advise that you review it to ensure that it is suitable and sufficient for your needs and sources.



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Fusion is based on the same processes that powers the stars. In the face of a changing climate and dwindling fossil fuel reserves, fusion offers the potential for a safe, abundant, low carbon, reliable baseload energy supply.

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United Kingdom Atomic Energy Authority
Culham Campus
Abingdon
Oxfordshire
OX14 3DB

t: +44 (0)1235 820220
e: education@ukaea.uk

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