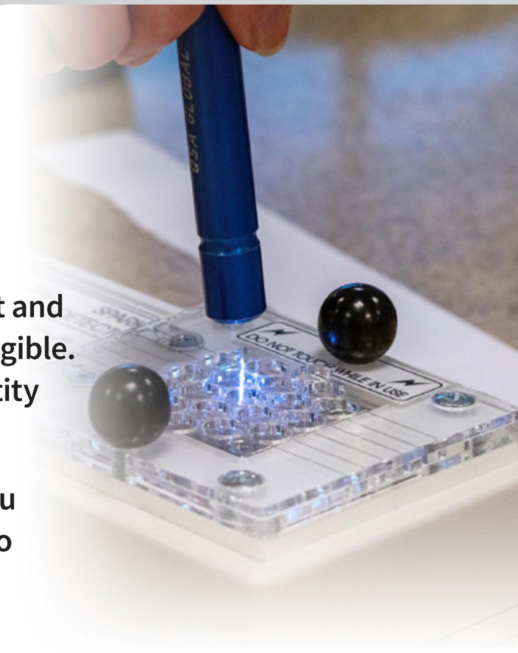
Radiation dose



This article is about the dose of ionising radiation you would receive demonstrating or observing a school science experiment involving radioactive sources. We will discuss what dose is, how we calculate it and why, if you follow SSERC guidance, any dose you receive will be negligible. Before we go on to look at dose, we first need to know about a quantity called *activity*.

If you are familiar with the terms Activity and Dose, for example if you have been teaching radioactivity to N5 and Higher, you might want to skip straight to the section entitled *Calculating dose*.

Activity

The activity (A) of a radioactive source is a property of the source itself. It is a measure of how many nuclear decays take place every second. Each decay results in the emission of radiation. If you had two caesium sources and one was more active than the other, the more active one would be emitting more radiation per second.
Activity is measured in Becquerels (Bq). One Becquerel equals one decay per second. Normally, for school sources, we'll be dealing with kilobecquerels (kBq).
The old unit of activity was the Curie (Ci). Many older sources will have their original activity stamped on them in microcuries (µCi).

1 µCi = 37 kBq

The activity of a radioactive source decreases with age. For common school sources, the following happens:
- **Americium** – no observable decrease with age
- **Caesium** – activity halves every 30 years
- **Cobalt** – activity halves every 5 years (some older cobalt sources are barely radioactive)
- **Strontium** – activity halves every 29 years

The time taken for the activity to halve is called the half-life. The half-life of americium is 433 years, which is why you will not observe a significant decrease in activity with time.

Dose

There are formal definitions of dose but for our purposes, we will think of it as a measure related to the risk of harm from exposure to ionising radiation. At this point, it must be stressed that the risk of harm from working with the materials you are allowed to handle in schools is negligible if you follow our advice. SSERC guidance is geared to making the dose as low as possible whilst still being able to carry out practical work effectively.

Dose is not the same as activity, although activity is one of the factors used in calculating dose. You could receive a very small dose from a source with a high activity if, for example, you were far from the source or had some shielding material between it and you. None of the sources that you're permitted to work with in school are considered to be high activity.

Dose depends on:
- The radiation energy absorbed by your body – we'll look at how we can keep this low.
- The type of radiation.
- The type of tissue absorbing the radiation.

Dose is measured in sieverts (Sv). 1 sievert is a large and potentially harmful dose of radiation. We will be dealing with doses of microsieverts (µSv) and nanosieverts (nSv). When carrying out certain calculations, we may have to use femtosieverts (fSv).

1 µSv = 1 millionth of a sievert (10^{-6} Sv)
1 nSv = 1 billionth of a sievert (10^{-9} Sv)
1 fSv = 10^{-15} Sv or 10^{-6} nSv

We may also use millisieverts (mSv), but usually only if we are talking about annual doses. A millisievert is one thousandth of a sievert.

Dose rate is a helpful concept. It is the dose acquired in a specified time. Here, microsieverts per hour (µSvh^{-1}) can be a useful unit. For instance, a dose rate of 2 µSvh^{-1} means a dose of 2 µSv in one hour, 4 µSv in 2 hours etc. Indoors in Scotland you can expect a dose rate of about 270 nSvh^{-1}. This is due to background radiation – the environmental radiation that we cannot avoid. Most of this comes from natural materials – rocks, building materials and the radioactive gas radon. Some comes from man-made sources – nuclear waste, nuclear accidents and the fallout from nuclear weapons. >>

If you are going to work with a radioactive source, you can reduce the dose you will receive in three ways:
- Shield yourself from the radiation
- Increase your distance from the source
- Decrease the time you spend working with the source.

Shielding
Shielding involves putting something between you and the source to absorb radiation.

An americium source emits alpha radiation and weak gamma radiation. The alpha radiation will be absorbed by a few cm of air.

A strontium source emits beta radiation. This can travel through a few metres of air before being completely absorbed. However, the metal parts that make up the source itself will shield you from beta radiation. The only radiation that is not absorbed emerges from the 'window' at the front of the source in a roughly 30 degree cone. This means that if you are behind the front of the source, you will not receive a dose of beta radiation. If it is not possible to have everyone behind the front of the source, 12 mm of Perspex can be used as a shield.

A tiny number of Scottish schools have a protactinium generator half-life source. This is non-metallic, so beta radiation emerges in all directions. A Perspex shield must be placed between the source and all onlookers. Caesium, cobalt and americium sources all emit gamma radiation. There is no effective shield that would still allow learners to observe an experiment. In the case of americium, the gamma radiation is low energy. As a consequence, the dose rate is much smaller than for caesium or cobalt.

Distance
Gamma radiation follows what is known as an *inverse square law*. Imagine the radiation spreading out in a sphere like light from a bulb. Just as the further from a bulb you are, the dimmer the light seems, the further you are from a radioactive source, the smaller the dose you receive in a given time. Because it's an inverse square law, the dose rate at 2 metres is one quarter of what it would be at 1 metre ($1 \div 2^2$). Similarly, at 3 metres it is only one ninth of what it would be at 1 metre.

Time
Inevitably, when setting up experiments, a teacher or technician may have to work only a few cm from an unshielded source. Handling tools can increase distance and dose can be kept very low by limiting the time spent manipulating radioactive materials.

Calculating dose
This example shows how we would calculate the dose rate at a particular distance from a 370 kBq caesium-137 source. Caesium-137 emits both beta and gamma radiation but the source is constructed in such a way that beta radiation is absorbed.

Dose rate (fSv h^{-1}) = dose rate constant x A/r^2

In the above calculation,
- A is the activity, in Becquerels, of the source
- r is the distance from the source
- *Dose rate constant* (strictly speaking, 'dose equivalent rate constant') is a conversion factor that depends on the radioactive substance – whether it is caesium, radium, cobalt etc. These can be found online.

Suppose a teacher is standing 1 metre from a 370 kBq Cs-137 source set up for an inverse square law experiment.

Taking the dose rate constant for caesium-137 to be 90 fSv m^2 Bq^{-1} h^{-1},

For a 370 kBq Cs source,
dose rate at 1 metre = $370 \times 10^3 \times 90/1^2$

= 33×10^6 fSv h^{-1}

= 33 nSv h^{-1}

For a demonstration lasting 30 minutes, i.e. 0.5 hours, the total dose will be 33 x 0.5 = 17 nSv

SSERC has examples of more detailed calculations. This calculation does not include any dose due to carrying the source, being close enough to manipulate equipment and so forth. These actions would result in additional doses to the body and hands. Even taking these into account, the total dose will only be of the order of 100 nSv.

Barring accidents or misuse, this scenario, or the comparable alternative involving a 185 kBq cobalt-60 source, is likely to represent one of the highest doses received when demonstrating an experiment. A school employee is likely to do no more than six demonstrations with this level of dose per year. Provided proper working procedures are followed, the chances of an employee or a learner receiving a dose above any legal limit are negligible.

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Limits

Teachers and technicians who work with radioactive materials in schools do not need to wear radiation monitors and dose records do not need to be kept. This is because no employee in a school could be designated as a “classified person”. This is a term used by the Health and Safety Executive for someone who is likely to receive a dose of 6 mSv in a year. We calculated that no employee in a school could receive such a dose by considering:

- The dose from setting up and carrying out routine practicals following SSERC guidance (see above).
- The dose from working close to a school radioactive sources storage cabinet.
- The dose from a “worst case scenario” accident (taken to be the rupture of a protactinium generator).

These dose calculations are available on request. When carrying out the calculations, we found that it would require a gross disregard for SSERC advice for an employee or learner to receive an annual dose of 1 mSv. 1 mSv is the HSE dose limit from work activities for a member of the public.

The International Commission for Radiological Protection considers any dose of less than 10 microsieverts to be negligible. We base a lot of our advice around this figure. For example, guidance on how far a storage cabinet should be located from a workstation.

Note that if you followed SSERC guidance, you would have to do 100 experiments of the sort described in the calculation to receive a dose of 10 microsieverts.

Maybe you are thinking, “OK, but isn’t no extra dose of radiation better than any extra dose of radiation, however small?” Using figures from the UK Health Security Agency’s “Ionising Radiation and You” webpage [1], we find the following, see Table 1.

Image: Cedric Fauntleroy / Pexels.com

As you can see, all of these activities give you a significantly greater dose of radiation than demonstrating a school experiment. Obviously, the purpose of the table is not to put you off eating brazil nuts, getting a dental X-ray or flying to America. It’s to highlight that there are many situations where the benefits, such as keeping your teeth in good condition, outweigh the risks of a small dose of radiation. At SSERC, we are firm believers in the educational value of working with radioactive sources in schools. Given that it is easy to keep doses to levels where the risk of harm is significantly below the threshold of what is considered to be ‘negligible’, we are convinced that the benefits greatly outweigh these risks.

Reference

[1] https://www.ukhsa-protectionservices.org.uk/radiationandyou/

Scenario	Typical dose (µSv)	Number of 100 nSv experiments you’d need to do to get a similar dose
Receiving dental X-ray	5	50
Eating 100 g of brazil nuts	10	100
Taking a return transatlantic flight	80	800

Table 1

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