TOPIC 19: IONISING RADIATIONS

This *Topic* (dated February 2019) is an updated version of *Topic 19*, which appeared in the 3rd edition of *Topics in Safety* (ASE, 2001). It has been extensively re-written and is mainly concerned with the justification for practical work and dispelling the many misconceptions that surround radioactivity.

19.1 Introduction

Since the 2001 version was written, both SSERC (for schools in Scotland) and CLEAPSS (for schools in the other parts of the UK, and Crown Dependencies) have issued excellent, detailed guidance on managing ionising radiations in school science, and there is no point in replicating it here. The CLEAPSS guide L93 is not a restricted document and it is available to non-members because the DfE part-funded a previous edition. The guidance from SSERC is broadly the same as that from CLEAPSS, but there are some differences to note. In Scotland, there is a requirement for schools to obtain approval from the Scottish devolved government education department. This is done through SSERC. In England, Wales and NI, there is no such requirement. There is an anomaly with English sixth-form and FE colleges - a remnant of legislation that wasn't repealed - which means that they need to obtain government department approval. However, the Department for Education has written to CLEAPSS to say approval can be assumed if the sixth form or FE college uses only those sources in the CLEAPSS Standard School Holding (see L93).

Radioactivity can be an emotive issue. There is likely to be a range of audiences for whom this Topic will be relevant. This includes those working in all types of schools and colleges, education authority staff (e.g. science or health and safety advisers), those involved in the nuclear industry, and members of the public (e.g. on school governing bodies or school boards). Consequently, there is more in this Topic than science teachers will need for their daily lesson planning on radioactivity.

19.2 Acquiring and managing sources

There are several things you need to put into place before acquiring and using radioactive sources. These are detailed in SSERC and CLEAPSS guidance, but here is an overview.

- Only obtain sources that are recommended by SSERC or CLEAPSS. If not, you could end up with a hefty disposal charge, or have to pay environment regulator permit charges.
- Appoint a teacher responsible for overseeing the safe use and storage of the sources. This person is usually referred to as the Radiation Protection Supervisor (Schools).
- Install a suitable and secure storage cabinet.
- Make sure you have suitable monitoring equipment.
- Your employer must consult and if necessary appoint a suitable Radiation Protection Adviser (RPA). A teacher is highly unlikely to hold the required qualification to be an RPA.
- Your employer must obtain a registration from the HSE (or HSENI in NI).

19.3 Practical work with ionising radiations

19.3.1 Why carry out practical work with radioactive materials?

There are many persuasive reasons, but there are two that need illuminating in particular. First, if practical work on radioactivity is done entirely through simulation, it gives the unintended message that low-level radioactivity is too dangerous to be done at your school. (That said, with social media, pupils may quickly pick up that many schools do have radioactive sources in practical work and come to the conclusion that your school department is too frightened, or impoverished, to do the practical work.)

Secondly, ionising radiations are studied in schools because it was the investigation of their properties that led to the enormous improvement in understanding of atoms in the 20th century. A student at a grammar school in 1900 could well have used a chemistry textbook which included the warning: '*The student should not be led into the error of thinking that atoms are real: they are merely a convenient construct for understanding the way in which the elements combine in particular proportions'.* The study of this subject is therefore of vital importance to the structure of science as a whole.

By undertaking practical work, pupils can appreciate:

- the supreme patience and determination of the early researchers who had to work with insensitive apparatus;
- the excitement of detecting something so incredibly small as the behaviour of an individual atom;
- the evidence for the different types of ionising radiation and the tracks of ion pairs left by the passage of the radiation;
- the randomness in a physical situation (since this is almost the only place in school physics where anything is less than completely predictable);
- how hazardous substances and agents can be handled safely with appropriate control measures and so develop public understanding of hazard, risk and risk assessment;
- why many members of the public have developed disproportionate fear towards this subject as a result of exaggeration in the media; and
- the importance of a balanced understanding of radioactivity, so that members of a democratic society are better able to make informed judgements and decisions.

19.3.2 Detecting radioactive emissions

Radioactive emissions cannot be detected directly by any of the human senses. Carrying out practical work shows the importance of instrumentation and of regular checking of instrumentation to make sure it is working.

19.3.3 Detecting individual atoms

A spark counter can be used to demonstrate, as separate sparks, the individual alpha particles from a source of low activity. Each alpha particle comes from the decay of one atom. Ionisation cans connected to an electrometer show the relative ionising effects of alpha and beta particles. Less direct evidence could be obtained using a GM tube and scaler. Every other experiment in school science requires millions of atoms to be involved if any effect is to be observed.

19.3.4 Properties of different radiations

Simple demonstrations with sources of the common types of ionising radiation allow them to be distinguished by their differing abilities to penetrate matter. This is more convincing when the detectors used are specific to the types of radiation.

Alpha radiation	spark counter, solid-state detector, ionisation can, thin end-window GM tube, cloud chamber
Beta radiation	end-window GM tube, ionisation can, possibly diffusion cloud chamber
Positron (beta+) radiation	end-window GM tube, also the gamma photons from positron-electron annihilation.
Gamma radiation, x-rays	Metal-wall GM tube (although lower-energy photons are also detected by ionisation of the GM fill gas), scintillation detector and photomultiplier.

It is difficult to demonstrate the differences in the cloud chamber tracks due to α, β and γ radiation but after the class has seen the α tracks they could be shown pictures of the other two.

19.3.5 Understanding randomness

There is no way of predicting exactly when a particular atom with an unstable nucleus will decay. But when there are many atoms, you can predict with good accuracy what percentage of them will decay in a particular time. Demonstrations with weak sources show the randomness of the decay but, in order to gain a feel for it, it is helpful to use analogues as well. Many schools use dice. However, there are other analogues which have been used to great effect, such as that devised by Professor Lowarch which used phosphor-bronze balls rolling down an inclined surface with holes in it. This is one aspect where the additional use of computer simulations is justified. However, it can be difficult for learners to realise the strange behaviour of unstable nuclei that can remain in an unstable state for very long periods before ejecting radiation.

19.4 Hazards and risks from ionising radiations

19.4.1 Hazards

The understanding of the underlying biology that causes ionising radiation ill-health has moved on since the 2001 version of this Topic. There is now good evidence that carcinogenesis is caused by clustered double-strand breaks in DNA in such a way that the normal cell death or repair pathways are disrupted. (ICRP2007[1]). There remains no agreement on any safe threshold of exposure, so the precautionary *linear no threshold* model is used: any exposure carries a risk.

There are two useful categories of hazard: external exposure and internal exposure. The first comes from irradiation from a source, the second from contamination entering the body.

19.4.2 Minimising the risks

The risks are very low in using standard school sources. To obtain a significant exposure you would have to do something very foolish. To place it in perspective, you would receive a much greater radiation dose from cosmic radiation flying to Spain for your holiday than the dose from correctly carrying out a demonstration practical with a small school-science teaching source.

The three principles of minimising risk from external radiation are time, distance and shielding.

- Do not handle the sources for longer than is necessary. Mostly, the sources only need to be handled for a few minutes while the demonstration is being set up.
- Keep a sensible distance from the sources, at least 300 mm from your trunk, when handling the sources. Use forceps to manipulate the cup sources.
- Use shielding. This is not commonly appropriate for school sources because the sources are relatively low activity, but the plated brass holders for beta sources give some degree of useful shielding.

For unsealed sources, such as handling uranyl nitrate solutions, wear disposable gloves and ensure good hygiene to minimise the chance of contamination entering your body.

19.4.3 The regulations regulating the risks

The acquisition, storage, use and ultimately disposal of radioactive sources are closely regulated. The two principal pieces of legislation are the *Ionising Radiations Regulations* 2017, and the *Environmental Permitting Regulations* 2016 (and equivalent legislation from the devolved national governments). There are conditional exemptions that schools should make full use of. It is important to stress that these exemptions are conditional and if schools fail to adhere to the conditions, they

[1] *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103.

will be breaching the law. The SERCC and CLEAPSS guidance explains the conditions for the exemptions.

19.5 Misconceptions from teaching

At KS4 (and equivalent levels), radioactivity is generally simplified as the instability of nuclei and the consequent spontaneous nuclear emissions. Three types of emission are commonly studied: alpha, beta and gamma. Students pick up the false idea that each radionuclide emits either alpha radiation, beta radiation or gamma radiation, and that there is no other type of radioactive emission. This is reinforced by schools holding radioactive sources labelled as an alpha source (e.g. americium-241), a beta source (e.g. strontium-90) and a gamma source (e.g. cobalt-60 and caesium-137).

Unstable nuclei undergo an initial nuclear transition by one or more decay modes to move towards stability. The predominant initial decay modes are alpha emission, beta emission, positron (or beta+) emission and electron capture, all of which change the number of protons and neutrons in the nucleus. (There are other but less common initial decay modes.) The changed nucleus is commonly called the daughter nucleus. Consequently, after the initial nuclear transition, the atom becomes a different element. Although there are four predominant initial decay modes, positron emission and electron capture are often omitted by GCSE syllabuses; this makes learning about medical physics somewhat tricky because positron emission tomography is used in diagnostic imaging. With beta emissions, electron antineutrinos are also emitted, and with electron capture and positron emissions, electron neutrinos are also emitted, but in simplified teaching models, neutrinos and antineutrinos go unmentioned, possibly because they are very difficult to detect and certainly not with school-science equipment.

Following the initial transition by alpha emission, beta emission, positron emission or electron capture, the daughter nucleus is often left in an excited state and within a very short time (with a few exceptions) it decays to a lower energy state by emission of gamma radiation. The excited nucleus can also decay to a lower energy state by transferring energy directly to an inner orbital electron; this electron, called a conversion electron, is emitted from the atom, and x-rays are subsequently emitted when a higher energy orbital electron fills the vacancy left by the emitted conversion electron. x-rays are also emitted after electron capture, again as a higher energy orbital electron fills the vacancy left by the captured electron. Gamma emission, conversion electron emission and x-ray emission do not change the nucleon number.

As an example of simplification to be wary of, the americium-241 school source is commonly labelled an alpha radiation source and used to demonstrate the characteristics of alpha radiation. However, it also emits gamma radiation, conversion electrons and x-ray radiation. This explains some of the anomalous behaviour when demonstrating this ‘alpha’ source using a thin-window Geiger-Muller detector. In the same vein, cobalt-60 and caesium-137 are beta emitters; the gamma radiation is emitted by the excited daughter nuclei. In school cobalt-60 and caesium-137 sealed sources, the beta radiation is usually partially blocked by an integral aluminium filter.

The decay schemes of radionuclides are rarely as simple as described in school textbooks. Some radionuclides have more than one initial decay mode. Potassium-40 is mainly a beta emitter, but a small percentage, ~ 0.001%, decays by positron emission. Bismuth-212 is another example, 36% of the initial decay is by alpha radiation, the other 64% by beta. For more information, the National Nuclear Data Center at Brookhaven National Laboratory is an excellent reference: http://www.nndc.bnl.gov/nudat2/.