University of Sheffield

Materials -
a SUBJECT
that MATTERs

# Professor Russell Hand

## Glass and Nuclear Materials

# Why developing new glasses isn't a WASTE of time

## What is Materials Science and Engineering?

MSE is defined as an ‘interdisciplinary subject, bridging the physics and chemistry of matter towards engineering applications and industrial manufacturing processes.’ The programme content spans from foundations in physics and chemistry to the mechanical, electrical, magnetic, and optical properties of materials, and the design, manufacture and applications of metals, alloys, ceramics, polymers, composites, and biomaterials.

MSE continues to establish itself amongst engineering disciplines and is offered as a degree course across the UK at the Universities of Birmingham, Cambridge, Imperial College London, Leeds, Loughborough, Manchester, Oxford, Queen Mary, Sheffield and Swansea, as well as Materials Chemistry being offered at St Andrews and Glasgow.

**Key Learning outcomes**

**What is radioactive waste vitrification?**

Turning the radioactive waste into a glass!

In this case the radioactive elements from the waste become bonded into the glass at the atomic scale.

The nuclear waste being in this glass form doesn't get rid of the hazardous elements, but it prevents those elements from being released into the surrounding environment, allowing the nuclear waste to be stored and disposed of safely.

**Why are we looking at developing new glass compositions for this?**

We typically use **borosilicate glasses** (these involve two glass formers, namely silica and boron oxide). The combination of glass formers in borosilicate glasses means that a good combination of processing **temperature and chemical durability** is achieved!

Borosilicate glasses are used therefore to vitrify the radioactive waste that is **well characterised** and therefore well understood.

There is also waste on UK sites and in other parts of the world that are **legacy wastes**. These are wastes generated at the early days of the nuclear programme and are not well characterised and understood. We therefore need to develop **new glass compositions** to immobilise this legacy waste. This legacy waste may have something about it that makes it particularly difficult to incorporate into a borosilicate glass at a suitably high level and so **developing new chemistries** is necessary to accommodate the legacy wastes in a better way.

If we can only put a small amount of waste into a glass, the process becomes an inefficient one which is not ideal!

## GCSE topics this episode could be taught alongside…

**Chemistry**

- Structure and Bonding

**Physics**

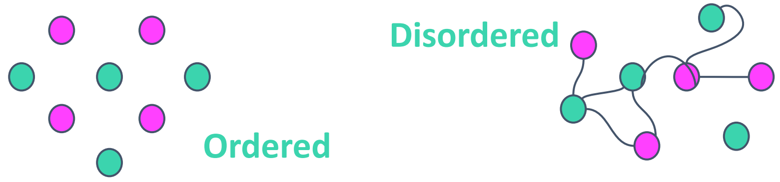
- Nuclear (radioactivity, fission and fusion)

**Physics**

- Temperature (expansion and contraction)

**How does this episode go beyond the curriculum?**

**The structure of glass…**




We are surrounded by glasses; windows are glass, we drink out of glasses, but what are they from a materials science perspective?

Glasses are classed as materials which have a **disordered, amorphous structure**. Glasses are materials which **lack long range order**. At the atomic scale this means that we preserve the structure of the liquid from which the glass was made rather than this being crystallised into a regular array.

**Crystals** have a defined **atomic order** which means that once we know the position of a few atoms we essentially know and can easily predict the position of all the atoms in the structure.

This is not the case for glass which demonstrates **no periodicity**. This lack of an ordered structure at the microscopic scale giver rise to interesting properties at the macroscopic scale. As glasses do not have planes of atoms which are able to slide past one another, the structure makes them a brittle material as stress in the structure cannot be relieved.

Students have learnt about fission, fusion and how energy is released from these processes… but **what is a closed cycle process?**

A closed cycle process is a **nuclear fuel cycle** in which the **spent fuel is reprocessed**, and partly reused. Over time fuel becomes uneconomic to use in the reactor due to the fission products that develop.

Spent fuel consists of around 96% Uranium and 1% plutonium, the rest consisting of highly radioactive waste products [1]. Current reprocessing plants separate the fuel chemically into the three components. The leftover radioactive element uranium, as well as different isotopes of plutonium in the spent fuel will be extracted for it to be reused as new fuel. Similarly, to freshly mined uranium, the recovered uranium can be re-enriched and returned to the fuel cycle. The plutonium can be mixed with uranium to create mixed oxide fuel, and this then reduces the need for enrichment and processing of depleted uranium.

If the spent fuel is not reprocessed, then the cycled is called an 'open' or 'once-through' fuel cycle instead.

*Around a third of the fuel used in nuclear reactors is reprocessed [1].*

# Key definitions

| Radioactive waste | Ceramic | Spent fuel | Radioactive isotope | Legacy Waste |
|---|---|---|---|---|
| Any waste containing radioactive isotopes that we no longer need. The radioactive elements produce higher levels of radiation than natural background radiation making the waste hazardous.<br><br>It can take many forms, from contaminated waste, such as safety gear people have worn with radioactive material on the surface to used fuel from a nuclear reactor. | The term describes a broad range of materials made by processing inorganic raw materials at high temperatures. These include enamel, concrete, cement, pottery, brick, porcelain, and chinaware.<br><br>Ceramics are wide-ranging in composition and can be crystalline or glass-like, pure, or single-phase materials and mixtures of two or more discrete substances. | Spent fuel is comprised of irradiated fuel elements, such as uranium and plutonium and has usually been extracted from reactors.<br><br>It is therefore highly radioactive and so requires remote handling and heavy shielding when dealt with. | An unstable form of a chemical element which releases radiation as it breaks down through radioactive decay to become more stable.<br><br>Unstable atoms are those containing a different number of neutrons and protons, or excess energy in their nucleus. | Legacy waste is radioactive wastes that were produced in the early days of the UK's nuclear programme.<br><br>These wastes may not be well characterised or understood due to being produced at a time when waste storage and treatment post process was not well planned. |

## Questions to think about

**Why are glasses used for this process instead of other materials like ceramics?**
There are many advantages of using glasses for vitrification.

1. **Volume reduction is one advantage**. Borosilicate glasses are known for having very low coefficients of thermal expansion, more so than any other common glass. This makes them more resistant to thermal shock and means that they expand less when heated through a given temperature rise. This is ideal in the vitrification process as it makes processing the glass cheaper and easier than other materials.
2. Glasses have a l**ack of long-range order**. A disordered structure means that they can accommodate a wide variety of chemical compositions within the glass which is important in the vitrification process to deal with a wide range of fission products and a large spectrum of elements.
3. **Ceramics are less good** for immobilising a wide range of elements due to them having a crystal structure which makes positioning of elements more restricted.
4. Glass is also **compatible with high level waste**, waste that poses the highest radiological hazard.

**Questions to think about**

**What does the future look like for safe radioactive waste disposal alongside the development of new glasses?**

## A repository

There is currently no definite plan in the UK for a repository, but one will need to be developed as the long-term solution to the storage of nuclear waste. A repository is a deep underground environment which is well isolated from the surface and so can be used to safely dispose of the nuclear waste. The period the waste needs to be stored for depends on the type of waste and its constituent radioactive isotopes. Currently waste is stored above ground but long term it is not appropriate to rely on these above ground structures.

## Second use of glasses

We could use glasses to vitrify other forms of waste- not just nuclear waste. These waste forms would not present a radiological hazard but would present a chemical hazard and so would still need to be dealt with through proper processing methods.

## Discussion Topics

### Where does nuclear waste come from?

Radioactive waste mainly comes from fuel reprocessing. In the UK this comes from our 'civilian programme' which is a closed fuel cycle. Waste can also come from making the fuel in the first place, nuclear power generation, medical isotopes, rare-earth mining, nuclear weapons processing, or any other areas where radioactive material is used, and waste is generated. For example, even our smoke alarms contain a small amount of radioactive material!

Radioactive waste can be classified as low, intermediate, and high. Low level waste is waste such as tools, rags, clothing, and equipment likely to contain short-lived radioactivity. Intermediate level contains higher amounts of radioactivity and high-level waste that poses the highest radiological hazard, requiring cooling and shielding.

## Discussion Topics

### What is the main type of hazard that arises from the waste?

As the radioactive isotopes in the waste decay, they release particles which are hazardous to lifeforms. The hazards presented may be physical, chemical, biological, or radiological.

**Radiological hazards** are the main hazard and arise from radioactive chemicals releasing harmful radiation into their surroundings. This radiation can be harmful soon after exposure but may also be dangerous for years and decades later. The radiological hazard at the very least will always be present. It will eventually decay but this happens over extremely long periods- in some cases it can take up to millions of years!

## Discussion Topics

### Why is research in this area so challenging?

Research is challenging in the nuclear industry and implementation of new processes and challenges is particularly challenging when compared with other industries due to the strict safety requirements that must be met. Dealing with radioactive waste creates a hazardous environment and so waste must be handled remotely and processes must be safe. As much research work as possible is done using inactive isotopes to limit hazard but at some point, actual radioactive materials must be used.

We are already making glasses, but new glasses created will need to be compatible with existing production technologies, or new technology that adheres to the standards will have to be developed.

## Additional Resources

**BBC teach-how is glass made?**
https://www.bbc.co.uk/teach/class-clips-video/chemistry-ks4-gcse-how-is-glass-made/zj4vrj6

**Cyberphysics Radioactivity Revision Crossword**
(Interactive computer version)
https://www.cyberphysics.co.uk/crosswords/radioactivitywithclues.htm
(Printable worksheet version)
https://www.cyberphysics.co.uk/crosswords/noninteractive/RadioactivityCrossword.pdf

**How much radioactive waste is there in the UK? Government blog**
https://nda.blog.gov.uk/how-much-radioactive-waste-is-there-in-the-uk/


**REFERENCED FACTS**
[1] https://www.iaea.org/sites/default/files/18/10/nuclearfuelcycle.pdf