# HENRY ROYCE

## NUCLEAR RADIATION DAMAGE

#### OVERVIEW

DURATION: 10 minutes TARGET AUDIENCE: Age 11+

Current nuclear energy production centres around the idea of nuclear fission, where heavy atoms are split through neutron bombardment to produce energy. These high energy neutrons will permeate the entire reactor core and can interact with other materials inside the reactor. These interactions can lead to adverse structural effects which need to be minimised in order to prevent damage to the reactor. This activity aims to demonstrate the structural damage to the crystal lattice of materials that can occur inside a nuclear reactor. This will showcase the importance of material sciences in nuclear energy production, and

the reasons why researchers try to develop and test new materials to overcome this problem.

### METHODOLOGY

1. Begin the activity by ensuring the student understands what an atom is.

2. Explain that here we are demonstrating what happens to atoms during a nuclear reaction. The white ball represents a neutron and the red balls represent atoms arranged in a crystal lattice.

3. Allow student to pull the firing mechanism back a certain distance and fire the cue ball into the ordered balls.

4. The collision between the white cue ball and the red snooker balls represents how the atoms in the crystal lattice are dispersed in a nuclear reactor.

5. At this point ask the student to point out any differences in the layout of the lattice before and after the nuclear reaction has taken place.

6. Although this is happening at a very small scale, it will affect how the materials behave at a larger scale. Use the laminated images to show how a steel rod that has been irradiated is longer than one that has not. This is known as irradiation swelling.

7. Highlight that if materials are swelling at a large scale this will damage the nuclear reactor as the swelling will lead to a pressure being exerted throughout the material, which may

#### EQUIPMENT

- Tabletop board
- Red snooker balls x24
- White cue ball
- Images showing nuclear radiation damage in various metals

lead to failure of the material. Therefore, you want to prioritise materials that will swell less.

8. Using the Transmission Electron Microscope (TEM) images you can discuss the effects of radiation damage on a much smaller scale. The darker blobs on the graph shows vacancies which are areas where there are no atoms. These are holes in the crystalline structure that have been made by the nuclear collisions. This is how we know the atomic structure of a materials is being disrupted.

9. Finally, you can also mention that in a nuclear reactor the metals will get more brittle as they get irradiated and become harder. This is a negative structural effect that can cause the materials to crack and fail unexpectedly.

To access a full equipment kit for the 'Nuclear Radiation Damage' activity contact **info@royce.ac.uk** 

This activity was developed by Paul Barron (PhD Student | FusionCDT).

#### **BACKGROUND SCIENCE**

Inside nuclear reactors, energy is produced by bombarding a heavy atom with neutrons, causing it to split into smaller atoms and release energy in a process known as nuclear fission. As the heavier atom splits, it will release a further two or three neutrons which can cause more fissions that will then release even more neutrons, leading to a cascading effect. This is known as a chain reaction.

As a result of this chain reaction, trillions of neutrons will be moving at high speeds inside a conventional reactor. The aim of any nuclear reactor is to redirect these neutrons so they can collide with atoms, therefore maintaining a constant production of energy. This energy can then be used to heat up water into steam, which can finally be used to drive a turbine to generate electricity.

However, some neutrons may instead collide with the walls of the reactor, which can cause disorder in the atomic structure and lead to adverse structural effects. This occurs as a result of knocking atoms out of their lattice sites as the neutrons collide with the walls at high speeds, leading to the creation of dislocations within the lattice of the material. The site the atom previously occupied is now empty; this is called a void. As more neutron collisions occur, this dislocation damage that occurs as a result of displaced atoms will move throughout the lattice, creating additional displaced atoms. This process is known as displacement cascade or displacement spike. This will happen continuously inside a reactor, leading to a large amount of disorder in the crystal lattice.

A major concern of this process is an increase in volume and decrease in density as a result of neutron damage, known as neutron-induced/ irradiation swelling. This is caused by the formation of vacancies and voids within the crystal lattice. As the number of vacancies increases, the same number of atoms will be forced to occupy a larger volume of space.

The displacement cascade will lead to the formation of dislocations within the crystal lattice. Before the neutron damage, the lattice of the material will exhibit a regular, nearly defect-free pattern. As the material undergoes damage inside a reactor, the lattice becomes increasingly saturated with vacancies and dislocations. This increase in defects will act as pinning points (i.e. obstacles) that significantly impede the motion of further dislocations. The material will exhibit an increase in the yield strength and a subsequent reduction in ductility. This will make the material harder and more brittle, in a process known as neutron/radiation embrittlement. Brittle materials are harder than their ductile counterparts, but they will exhibit rapid, catastrophic failure under stresses above their maximum stress (i.e. yield stress). For comparison, ductile materials will elongate and crack when subjected to high stresses, giving operators ample time to detect failure before it occurs.

#### FOLLOW UP QUESTIONS

1. Do you think the impact force of the neutron will have any effect on the damage caused to the lattice?

2. If an increase in hardness can lead to catastrophic brittle failure, should nuclear reactors use ductile materials instead to prevent this mode of failure? What could be a disadvantage of using ductile materials?

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