Nuclear Science Study Guide
The ANSTO Nuclear Science Study Guide is an initiative of the Australian Nuclear Science and Technology Organisation, designed to assist high school teachers engage and involve their students.

Nuclear science is the study of the atomic world. Atoms make up everything – from our bodies and the Earth to the drugs that we take and the materials we use. Being able to see these atoms is crucial to understanding more about the world around us, as well as the structure of living organisms.

From understanding Ice Age environments to combatting disease, techniques in nuclear science are revolutionising the way scientists work. These notes will allow teachers to help their students explore the many science topics that use nuclear science techniques.

The notes offer both variety and flexibility of use for the differentiated classroom. Teachers and students can choose to use all or any of the five sections – although it is recommended to use them in sequence – and all or a few of the activities within each section.

The guide uses the ‘Five Es’ instructional model designed by Biological Sciences Curriculum Study, an educational research group in Colorado, USA. It has been found to be extremely effective in engaging students in learning science and technology. It follows a constructivist or inquiry-based approach to learning, in which students build new ideas on top of the information they have acquired through previous experience. Its components are:

Engage Students are asked to make connections between past and present learning experiences and become fully engaged in the topic to be learned.

Explore Students actively explore the concept or topic being taught. It is an informal process where the students should have fun manipulating ideas or equipment and discovering things about the topic.

Explain This is a more formal phase where the theory behind the concept is taught. Terms are defined and explanations given to models and theories.

Elaborate Students develop a deeper understanding of sections of the topic.

Evaluate Teacher and students evaluate what they have learned in each section.

WEBSITES

Australian Nuclear Science and Technology Organisation: http://www.ansto.gov.au


ANSTO Bragg Institute on nuclear science research: http://www.ansto.gov.au/research/bragg_institute


CERN: the Large Hadron Collider: http://lhc.web.cern.ch/lhc
Vanessa Peterson smashes most stereotypes about materials scientists. She’s a woman excelling in one of the most male-dominated sciences, plus she’s young – at 34, Peterson heads the Energy Project at the Australian Nuclear Science and Technology Organisation (ANSTO), a program that aims to revolutionise energy systems.

Peterson works as both a research scientist and instrument scientist, overseeing ANSTO’s multimillion-dollar neutron scattering equipment.

Neutron scattering is used to study how materials look and behave at the atomic level, and Peterson runs neutron scattering experiments for scientists from around the world at ANSTO’s Sydney facility. She’s also using these techniques for her own research, investigating energy-carrying materials.

Petroleum has been the world’s preferred energy carrier for over 100 years, but it’s a limited resource and produces climate-altering chemicals (chiefly carbon dioxide) when it releases its energy.

Lithium-ion batteries are another widely used lightweight option and are currently the preferred energy carrier for electric cars. The ultimate replacement fuel would be hydrogen. It’s exceptionally light, can be extracted from water and doesn’t produce polluting by-products, but as a gas it takes up a lot of space.

So Peterson is now investigating new materials that interact with hydrogen at the atomic level to carry it in a condensed, accessible form.

Already she has attracted international attention for her discovery of a new type of atomic interaction that enables hydrogen to be stored in a smaller space. “This work could change our approach to how we store and deliver energy entirely,” Peterson says.

Growing up in the then-undeveloped far western Sydney area of Green Valley, Peterson loved foraging for materials she’d drag home and build with. At high school she was interested in science and enjoyed the processes of exploration and discovery, but wasn’t sure it was something she could be paid to do.

She decided to study applied chemistry at the University of Technology, Sydney. She was exposed to research as a career option while on placement at an ANSTO facility as part of an undergraduate industry program. “I was then really engaged by science and haven’t looked back.”

Peterson balances her job’s intellectual grind with a highly physical response – rock climbing.

“Rock climbing … parallels the science: it’s problem-solving, it’s meditation. It forces you to focus on the task at hand.” – Karen McGhee

Did you know that because of the many applications of nuclear technology, a career in nuclear science covers a range of scientific and engineering disciplines including:

- Physics
- Chemistry
- Biology
- Environment
- Earth Sciences
- Forensic
- Archaeology
- Materials Science
- Radiochemistry
- Climate processes
- Hydrology
- Mechanical Engineering
- Electrical Engineering
- Electronic Engineering
- Drafting
- Mechatronic Engineering (robotics)

No matter where your interests lie, there is likely to be a way that nuclear technology can be applied to your industry. As a result, there are many pathways you can take to achieve a career in nuclear science – you can study engineering, life sciences or medicine and still use nuclear science in your work.
Nuclear technologies allow us to see a world that was previously invisible, and are helping scientists to find solutions to global problems such as climate change, energy shortages and health issues.

**WHAT IS NUCLEAR SCIENCE?**

Nuclear science is the study of the atomic world. Atoms make up everything – from our bodies and the Earth to the drugs that we take and the materials we use. Being able to see these atoms is crucial to understanding more about the world around us, as well as the structure of living organisms.

Atoms are constructed of three main building blocks (known as subatomic particles): protons, neutrons and electrons. Protons are positively charged, neutrons have no charge and electrons are negatively charged. The protons and neutrons are packed together in the centre of an atom to form a nucleus. They are held together by strong nuclear forces. The electrons move around the nucleus in shells with different energy states. Their negative charge keeps them separate from each other but near the nucleus, because they’re attracted to the protons. In a stable atom with a balanced charge, the number of protons is the same as the number of electrons.

**TWO ISOTOPES OF CARBON**

The number of protons determines which element on the periodic table the atom will be. For this reason, the number of protons in the nucleus is known as the atomic number. If an atom gains or loses protons, it becomes an atom of a different element.

If an atom loses or gains electrons, it can change its charge and become an ion. If an atom changes its number of neutrons it becomes an isotope of that element. There are hundreds of different isotopes – some are natural and some are artificial. A radioisotope is an isotope with an unstable nucleus because its nucleus is too big or the proportion of protons and neutrons make it difficult for the nucleus to hold together. This is called a radionucleus and it releases energy, which is emitted as radiation.

Nuclear science is also used to create many of the materials that we rely on every day – from medical radioisotopes to irradiated silicon used in industrial processes.
WHAT IS RADIATION?

Radiation is energy that travels (or radiates) out in waves or particles from its source. Everything from heat, radio waves, X-rays and microwaves is a type of radiation, and every object in the universe emits radiation.

There are two categories of radiation: ionising or non-ionising.

Non-ionising radiation includes low energy waves such as light waves or radio waves. Ionising radiation, on the other hand, changes the electron balance of a stable atom by either adding or knocking an electron out of the atom therefore changing the atom into an ion.

Three Types of Nuclear Ionising Radiation

**Alpha Radiation**
In alpha radiation (also called alpha decay), the alpha particle (α) released from the nucleus has two protons and two neutrons, so it is essentially a helium nucleus.

**Beta Radiation**
In beta radiation, or decay, a neutron is converted to a proton and an electron. The electron is emitted (β⁻).

**Gamma Radiation**
Gamma radiation is high-energy electromagnetic radiation (γ). Gamma radiation can be released by itself or along with alpha and beta radiation.

Nuclear reactors use a process known as nuclear fission, where an atom is split when it is hit by a neutron. Only certain elements will split in this way, such as Uranium-235, plutonium-239 and thorium-234. When one of these ‘fissile’ atoms is hit by a neutron, the atom splits into two smaller atoms and often, more than one free neutron, which can each knock into more fissile atoms, creating more splits and more neutrons. This 'chain reaction' needs to be controlled, but can be used to create great quantities of heat, such as in nuclear power reactors, or to create large quantities of neutrons, which can be directed into beams and used to research the nature of other materials.

Some amount of alpha, beta and gamma radiation is emitted by nuclear reactors but they are not used as a source of these particles, in fact the radioactive particles produced in reactors are absorbed by shielding such as water, lead, concrete or other materials.
There are two main types of machines that can produce the high-energy particle beams used in research: reactors and accelerators.

**Reactors**

Reactors are used to start, maintain and control the process of nuclear fission. Fission is when a neutron hits an atom, splitting it apart into smaller atoms and releasing more neutrons. If those neutrons then hit other atoms, they will also split and when this happens repeatedly this phenomenon is called a nuclear chain-reaction.

Only certain isotopes of certain elements are fissile (can be split by fission); for example, one isotope of uranium, U235, is fissile, while another isotope, U238, is not.

Nuclear fission also gives off energy, and large reactors are used in power plants to convert this energy into electricity. Smaller reactors are used by researchers to create neutron beams that can help them visualise the atomic structure of most materials. Research reactors can also make radioisotopes and irradiated materials that are used in medicine and industrial processes. In nuclear reactors, design features and control rods are used to regulate the chain reaction so it does not go too fast. Further, cooling systems are used to prevent the core of the reactor from getting too hot and melting down.

**Large Hadron Collider**

The Large Hadron Collider is a huge particle accelerator. It sits 175 m below the ground on the outskirts of Geneva in Switzerland. It accelerates beams of protons and lead ions (also known as hadrons) to extreme speeds and smashes them into one another. The goal of the collisions is to recreate the conditions that were present just after the Big Bang. By doing this, particle physicists hope to fill in some of the gaps in knowledge about what fundamental particles make up the universe and how they interact with each other. The standard model of particle physics does this to a degree. However, an essential part of this is the Higgs boson – something that may not exist. The standard model predicts its existence, but to date, no definitive physical evidence of its existence has been found.

**Accelerators**

Rather than rely on nuclear fission, accelerators rapidly speed up particles (to almost the speed of light) and direct them into defined beams using electromagnetic fields. There are different types of accelerators, including synchrotrons and cyclotrons. While synchrotrons cannot be used to create radioisotopes, cyclotrons can produce neutron-poor isotopes that are mostly used in medical diagnostics. Particle accelerators can create very high-energy X-ray, proton, photon and electron beams that can be used for research and complement much of the work that can be done with reactors.

**THE OPAL REACTOR**

OPAL, or the Open Pool Australian Lightwater reactor, is a nuclear reactor devoted to research and commercial uses, operated by at the Australian Nuclear Science and Technology Organisation (ANSTO). The 20-megawatt reactor opened in 2007 and is considered state-of-the-art technology. The reactor has several key uses, including production of radioisotopes for use in medical imaging and cancer treatment and production of neutron beams for fundamental materials research.
Australia has a synchrotron, several medical cyclotrons and a research reactor.

The Australian Synchrotron, which opened in July 2007, is located in Melbourne and provides high-energy light, from infrared to X-rays, to researchers and medical practitioners.

Australia’s only research reactor is known as the Open Pool Australian Lightwater (OPAL) reactor and is housed at the Australian Nuclear Science and Technology Organisation (ANSTO). Using the neutron beams produced by the reactor and techniques such as neutron scattering, researchers are able to investigate areas like materials engineering, life sciences, climate change and mining. OPAL also produces radioisotopes for medical and industrial applications. Although it was only opened in 2007, OPAL is already one of the world’s top five leading research reactors.

What are the Safety Risks of Nuclear Science?

Any ionising radiation can change the structure of an atom by ionising it. As our cells are made up of atoms, radiation can therefore alter our cells and lead to cancer, depending on exposure. While research reactors release radiation, it is contained and managed safely.

Many people are concerned with the risks of nuclear science (partially because of the negative associations with atomic bombs and nuclear war), but most nuclear facilities are research-focused and extremely safe. For example, the water inside the OPAL reactor is not hot enough to boil a kettle, averaging at 40°C. And all reactors are designed to shut down at any sign of tremor or failure in the system.

However, there can be risks associated when a larger amount of radiation is produced. These risks are well-managed, but when unforeseen circumstances occur there can be accidents. In March 2011, some of the nuclear reactors at the Fukushima Power Plant in Japan went into meltdown and released radiation into the atmosphere after a 9.0 magnitude earthquake and a 14.2 m tsunami. The Fukushima Daiichi nuclear power plant survived the earthquake intact and shut down automatically at the first sign of tremors, even though it was only built to survive a 7.9 magnitude earthquake and this one was 30 times more powerful. However, the 14.2 m tsunami that followed was too much for the 40-year-old plant and brought the reactor to the brink of meltdown, resulting in the release of radiation. The exact amount of radiation released and its impact is still being calculated.

In another famous incident in 1986, a nuclear power plant in Chernobyl, in the former Soviet Union, went into meltdown and released radiation into its surroundings after an accidental explosion. The initial explosion resulted in the death of 56 people, but the World Health Organisation (WHO) forecasts that the long-term number of deaths resulting from radiation exposure in the region could be as high as 4,000. As at 2005, WHO was only recognising the deaths of the 56 emergency workers.

While there have been tragedies in the nuclear industry, it’s important to remember that nuclear isn’t the only dangerous form of energy – coal-fired power plants kill nearly 24,000 people a year in the U.S. from asthma, cave-ins, and circulation and respiratory problems. Finally, the safety of nuclear reactors is continually being improved.

There are safety risks associated with radiation, but radiation is all around us constantly – it comes from the Sun and space, in the rocks and soil beneath our feet and even in certain foods. The nuclear industry is responsible for producing less than a thousandth of the radiation that we are exposed to on a daily basis.
A brief introduction to how nuclear science has developed.

1895 Wilhelm Röntgen discovers X-rays.

1898 Marie Curie discovers the radioactive elements radium and polonium.

1911 George von Hevesy conceives the idea of using radioactive tracers, which is later applied to medical diagnosis among other things. Von Hevesy won the Nobel Prize in Chemistry in 1943 as a result of his discovery.

1927 Herman Blumgart first uses radioactive tracers to diagnose heart disease.

1932 James Chadwick proves the existence of neutrons.

1938 Two German scientists, Otto Hahn and Fritz Strassman, demonstrate nuclear fission.

1939 Albert Einstein sends a letter to President Roosevelt telling him about German research that could potentially lead to a bomb. As a result, Roosevelt begins looking into a nuclear bomb for the U.S.

1942 The Manhattan Project is secretly formed to build a bomb before the Germans, and in December the first self-sustaining nuclear chain reaction is demonstrated under the squash court at the University of Chicago. Enrico Fermi supervises the design and assembly of an ‘atomic pile’ - an early nuclear reactor.

1945 The U.S. begins testing the first atomic devices and in August two bombs are dropped on Japan.

1946 Physicist Maria Goeppert Mayer develops her ‘nuclear shell model’ explanation of how neutrons and protons within atomic nuclei are structured. Her work explains why nuclei of some atoms are more stable than others, and why some elements have different atomic forms, called isotopes. She will go on to win a Nobel Prize in Physics in 1963 for her work.

1949 Radiocarbon dating (carbon-14 dating) is developed by J. R. Arnold and W. F. Libby; it becomes one of the most widely used and best-known methods of dating carbon-based material.

1951 The first usable electricity is produced from nuclear fission at the U.S. National Reactor Testing Station.

1958 Australia’s first research reactor, the High Flux Australian Reactor (or HIFAR), begins operating.

1967 The Institut Laue–Langevin in France is founded; it is still the most powerful research reactor in the world.

1979 In March, Three Mile Island Nuclear Powerplant near Harrisburg, Pennsylvania suffers a partial core meltdown. Minimal radioactive material is released.

1986 The Chernobyl Nuclear Reactor meltdown and explosion occur in the former Soviet Union in April. There is a large amount of radiation released into the atmosphere.

1990s Research reactors continue to deliver breakthroughs for scientists and in a variety of fields, and nuclear power plants continue to grow in number, particularly in France and the U.S.

2005 Nuclear power provides 6.3% of the world’s total energy.

2007 ANSTO’s OPAL reactor is opened, as well as the Australian synchrotron.

2009 As of December, the world had 436 nuclear reactors – a slight decline from 2007.

2011 A 9.0 magnitude earthquake hits Japan, followed by a tsunami that puts the Fukushima nuclear power plant into meltdown.

FAST FACTS YOU MIGHT NOT KNOW ABOUT NUCLEAR SCIENCE

- There’s more to nuclear science than power plants; nuclear technologies help scientists understand our bodies and the world around us and are used by doctors to save thousands of lives. Nuclear science is also used in archaeology, climate change research, environmental science, mining and material science.

- The nuclear industry releases less than one thousandth of the radiation we’re exposed to - most comes from natural sources.

- Many research reactors, including Australia’s OPAL reactor, produce only a small amount of contained radiation – less than enough to boil a kettle of water.

- On average, every Australian will have at least one nuclear medicine procedure in their lifetime.

- Australia does not have any nuclear power plants.
UNDERSTANDING WETLAND ECOSYSTEMS

It is often hard to work out the complex predator–prey relationships in wetlands. But scientists can use nuclear science to analyse the isotopic signature of different animals to work out what they eat and where they stand in the food web.

Every food contains naturally occurring radioisotopes and when animals eat, traces of these radioisotopes are incorporated into their tissues, leaving a signature of the food they’ve ingested.

Studying these isotopic signatures allows scientists to monitor changes in the food web under different environmental conditions, and see which parts of the ecosystem might be struggling. This can be useful in times of drought or flood, and researchers are currently using this technique on yabbies to monitor Australia’s threatened Murray–Darling basin river system.

REVEALING THE INNER YOU

Nuclear medicine scans can be used to examine our organs, tissues and bones. They can diagnose sports injuries, cancers, infections and other maladies. These scans are now so commonplace that, on average, each of us will have one during our lifetime.

One type of scan is SPECT (single-photon emission computed tomography) imaging. Patients undergoing a SPECT scan are injected with a radiopharmaceutical, a chemical that emits small amounts of gamma radiation. The drug travels through the body and is absorbed by the part of the body that needs to be examined, for example the lungs or the heart.

The patient is placed in the SPECT machine, which has a gamma camera. The camera moves slowly around the patient, detecting the gamma radiation emitted from their body. It then produces a 3-D image, which doctors can use to detect changes in the patient’s body.
**USING COSMIC RAYS AND RADIOISOTOPES TO MEASURE WHEN ICE AGES**

Glaciers are large, moving bodies of ice. When glaciers move forward, they create moraines (boulders, stones and other debris) ground up from the bedrock in which they move. This debris is deposited as moraines at the end of the glacier.

As the ice begins to retreat, the moraines are exposed to an influx of cosmogenic isotopes, which are made when cosmic rays hit gas molecules in the upper atmosphere. ANSTO scientists can study the amount of these isotopes in a natural environment to help date how old parts of the environment are, and also measure the rate of erosion.

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**THE SUN’S NATURAL ENERGY**

The Sun is a huge nuclear fusion reactor that radiates the Earth with particles and energy. Infrared radiation heats the Earth. Ultraviolet energy gives us sunburn and suntan. Too much exposure to the Sun’s radiation can cause changes in human cells, which can lead to cancer.
MAKING CHEMICAL REACTIONS MORE EFFICIENT

Neutron scattering allows scientists to see what X-rays cannot. They look at materials from the inside out, understanding their atomic structure and how materials respond to various stimuli, such as magnetic fields and extreme temperatures.

Atoms are mostly made up of empty space. When a beam of neutrons is directed at a sample object, most of the neutrons therefore pass straight through. The neutrons that hit the nucleus of atoms in the sample object are scattered, creating a diffraction pattern that can be studied. The image to the left is a single-crystal neutron diffraction pattern which is used in the development of new drugs.

UNRAVELLING FARMING AND METALLURGY IN ANCIENT CHINA

ANSTO and the Chinese Academy of Sciences have shed new light on interaction between Eastern and Western cultures, with new evidence suggesting that East-West trade began more than 2,000 years earlier than history books document. With ANSTO’s STAR accelerator, scientists used radiocarbon dating on the remains of wheat, millet and other items such as bones, and have dated human farming practices to around 4650 BC. Interestingly, it seems that bronze-working was introduced to China from the West. By analysing the radioisotopes in the bronze tools and slag, scientists estimate the oldest bronze tools in China date back at least 4000 years.
Radiation warning signs signal areas where there is a risk of unsafe levels of radiation. If a vehicle carries this sign, it means that at some stage it will be carrying radioactive substances.

Scientists from ANSTO and the CSIRO Department of Materials Science and Engineering have combined photochromic (light-sensitive) molecules, such as spiropyran, to develop a molecule that changes colour from deep purple to yellow depending on the amount of carbon dioxide in the air. This combination results in a ‘visual chemical sensor’, which can monitor air quality and carbon dioxide levels without the aid of electronic equipment. It’s a very handy tool in remote or confined places which lack the proper equipment. How might this technology be useful to help the environment?

Have a look at the photographs related to nuclear science. Discuss the following questions with other class members.

1. Describe what you see in each image.
2. How do you think each image relates to nuclear science?
3. Make a list of all the uses of nuclear science that you can think of in your daily life or the life of your family.
4. Make a list of all the ways that natural background radiation might reach you on a day-to-day basis. Where does this radiation come from?
5. What have you learnt about nuclear science that you didn’t know before reading the captions that go with the image?
6. How do you think the discovery of radiation has impacted on our society, both in the knowledge it has brought as well as the technology it has promoted the development of?
7. What kinds of qualifications do you think someone working in the field of nuclear science might need?
8. Do you think that most people are informed enough about the role of nuclear science in daily life? Where can they go to get information?
9. What kinds of things would you like to know more about in relation to radiation and nuclear science?
The aim of the Explore section is for the students to investigate some of the ideas around nuclear science and radioactivity. It is intended that the students make their own discoveries as they work around the stations in the room. The stations should take approximately 10–15 minutes each. Each station has corresponding activities in the following pages.

Some of the activities will need preparation. The table below lists the equipment and preparation required.

<table>
<thead>
<tr>
<th>Station name</th>
<th>Materials list</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSTO website</td>
<td>A computer to access: <a href="http://www.ansto.gov.au/education/nuclear_information">http://www.ansto.gov.au/education/nuclear_information</a></td>
</tr>
<tr>
<td>Model of an isotope</td>
<td>A range of recycled scrap materials</td>
</tr>
<tr>
<td></td>
<td>A computer to access: <a href="http://www.chem4kids.com/files/atom_isotopes.html">http://www.chem4kids.com/files/atom_isotopes.html</a></td>
</tr>
<tr>
<td>Background radiation</td>
<td>Geiger counter</td>
</tr>
<tr>
<td></td>
<td>Collection of rocks</td>
</tr>
<tr>
<td></td>
<td>Mobile phones</td>
</tr>
<tr>
<td></td>
<td>Microwave ovens (if possible) or any other items students may find interesting to test for background radiation</td>
</tr>
<tr>
<td>Calculate your annual background radiation dose</td>
<td>A computer to access: <a href="http://www.new.ans.org/pi/resources/dosechart/">http://www.new.ans.org/pi/resources/dosechart/</a></td>
</tr>
<tr>
<td>Electromagnetic spectrum</td>
<td></td>
</tr>
<tr>
<td>Marshmallow decay</td>
<td>Pink and white marshmallows</td>
</tr>
<tr>
<td></td>
<td>Toothpicks</td>
</tr>
<tr>
<td></td>
<td>Periodic table with atomic numbers</td>
</tr>
<tr>
<td>Diffraction patterns with light</td>
<td>Torch</td>
</tr>
<tr>
<td></td>
<td>10 cm² piece of paper with a pinhole in the middle</td>
</tr>
<tr>
<td></td>
<td>Flat white surface to project light onto</td>
</tr>
<tr>
<td>Diffraction patterns with laser</td>
<td>Laser</td>
</tr>
<tr>
<td></td>
<td>Retort stand</td>
</tr>
<tr>
<td></td>
<td>Flat white surface to project laser onto</td>
</tr>
<tr>
<td></td>
<td>Human hair or thin wire</td>
</tr>
<tr>
<td></td>
<td>A computer to view the following videos:</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.nationalstemcentre.org.uk/elibrary/resource/2015/electron-diffraction-tube">http://www.nationalstemcentre.org.uk/elibrary/resource/2015/electron-diffraction-tube</a></td>
</tr>
</tbody>
</table>
**STATION 1 ANSTO WEBSITE**

**TASK** Go to the website: http://www.ansto.gov.au/education/nuclear_information and complete the activities below.

1. Click on each of the four categories on the webpage and fill in at least three interesting things you read about within these categories.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Information I found interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>About nuclear science</td>
<td></td>
</tr>
<tr>
<td>Benefits of nuclear science</td>
<td></td>
</tr>
<tr>
<td>What ANSTO does</td>
<td></td>
</tr>
<tr>
<td>Managing radioactive waste</td>
<td></td>
</tr>
</tbody>
</table>

**STATION 2 MODEL OF AN ISOTOPE**

1. Go to the following website to learn about isotopes: http://www.chem4kids.com/files/atom_isotopes.html.

2. Use recyclable materials to make a model of an atom showing neutrons, protons and electrons.

3. Convert your model of an atom to an isotope of that atom.

4. What are the strengths of your model? What are its limitations, i.e. how is it not like a real isotope?

5. Present your model to the class explaining why it is an isotope of a particular atom.
**EXPLORE**

### STATION 3 BACKGROUND RADIATION

1. Radioactivity is all around us. A Geiger counter is used to record the amount of radioactivity that an object is emitting.

2. Use the samples provided or choose some objects around the classroom or school and record the amount of radiation the object gives off by using the Geiger counter.

3. Record your observations in the table below, or create a similar one in your exercise book.

<table>
<thead>
<tr>
<th>Object</th>
<th>Radiation counts in one minute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Which object gave off the most background radiation?

2. Did the amount of background radiation you recorded surprise you? Why or why not?

### STATION 4 CALCULATE YOUR OWN BACKGROUND RADIATION


2. Answer questions to find out your personal annual background radiation exposure.

3. Are you above or below the accepted radiation background level?

4. Now calculate the annual background level for
   
   a. A pilot who travels more than 100,000 miles per year
   
   b. A patient who has had an X-ray and a medical procedure such as a nuclear medicine scan
   
   c. Someone who lives at high altitude in a concrete house.

5. How could any of the above people change their lifestyle to reduce the amount of background radiation they were exposed to?
EXPLORE

STATION 5 DIFFERENT TYPES OF RADIATION ON THE EM RADIATION SCALE

1. Put a circle around the types of radiation you have heard about before.
2. Put a square around the types of radiation you get daily exposure to.
3. Put a triangle around the types of radiation that are harmful.
4. Put a diamond around the types of radiation you actively avoid.

STATION 6 MARSHMALLOW DECAY

1. Study the images of alpha decay and beta decay and remember that the number of protons = atomic number.

1. Using the white marshmallows as protons and the pink marshmallows as neutrons, make a ball-shaped radioactive nucleus of an oxygen-16 atom (8 protons and 8 neutrons).
2. Oxygen-16 is stable and will never decay, but we will use it in this activity to demonstrate the theory of decay. Remove an alpha particle from your marshmallow oxygen 16 atom - ie, two protons and two neutrons.
3. Use the periodic table to work out which element oxygen-16 has decayed to.
4. Now make carbon-14, an isotope of stable carbon-12, with the marshmallows. Remove a neutron and replace it with a proton and an electron that is emitted. This is beta decay and is how carbon-14 decays.
5. Use the periodic table to work out which element carbon-14 has decayed into.
STATION 7 DIFFRACTION OF LIGHT

1 One application of nuclear science is to fire subatomic particles like neutrons or electrons at structures too small to see even with powerful microscopes. The diffraction patterns of these subatomic particles help scientists identify their structure.

2 Predict what kind of light pattern you will see when you shine a torch light through the pinhole in the square of paper and draw it here.

3 Now shine the torch through the pinhole and project it onto a flat white surface. You might need to move the torch and paper back and forth to focus the light. Draw what you see.

4 Why do you think the light didn’t just shine straight through the hole and produce a single beam with the shadow of the paper around it? Why is a diffracted pattern different to a shadow pattern? What happens to the path of light during diffraction?

5 Is the projected image the same with a larger hole in the paper? Cut a larger hole in another piece of paper to find out.

STATION 8 DIFFRACTION OF LASER BEAM

1 Turn on the laser so that a spot is projected onto a flat white surface. Be careful not to look directly at the laser source.

2 Predict what you think will happen to the laser spot if you place a human hair or thin piece of wire in the beam of the laser. Draw your prediction here.

3 Secure a human hair vertically between two clamps, one above the other, on a retort stand and place it in the beam of the laser.

4 Note the pattern made by the diffraction of the laser beam and draw it here.


6 Summarise diffraction in your own words.

7 Now watch the video of the diffraction of an electron beam at http://www.nationalstemcentre.org.uk/elibrary/resource/2015/electron-diffraction-tube.

8 How did the demonstrator show that this was an electron beam and not a light beam?

SUMMARY QUESTIONS

1 Which was your favourite station and why?

2 What did you learn from this circuit of activities?

3 What would you like to learn more about in relation to nuclear science and radioactivity?
TEACHER’S INFORMATION

In this section, we explain the science of nuclear technologies by getting students to read four articles related to the science being conducted at ANSTO (Australian Nuclear Science and Technology Organisation).

Prior to reading one or all of the articles, we have included a general brainstorm about nuclear science.

Each article has its own glossary and comprehension activities.

A questioning toolkit is provided at the end of all four articles to stimulate student thinking promoting discussion around nuclear science.

ARTICLE ONE  OPAL: ANSTO’S RESEARCH REACTOR

This article provides an overall introduction to the characteristics and role of the OPAL (Open Pool Australian Lightwater) reactor located at Lucas Heights south of Sydney. The maintenance of the reactor is discussed, as well as the range of uses of the OPAL facilities in research and industry.

FAST FACTS:
• OPAL is extremely versatile and the uses of neutron science are virtually unlimited
• Around 500 scientists from Australian universities and from 28 countries use ANSTO’s Neutron Beam Facilities for research every year.
• OPAL produces medical radioisotopes to diagnose and treat heart disease and a range of cancers. One in two Australians will need the nuclear medicines produced in OPAL.
• OPAL irradiates around 10% of the world’s silicon chips which are then used in mobile phones, computers and engine controllers

ARTICLE TWO  HOW SAFE IS THE OPAL RESEARCH REACTOR?

This informative article examines the safety features of the OPAL research reactor and the ANSTO site.

FAST FACTS:
• OPAL’s output is only enough to warm the water within the reactor pool to about 40 degrees Celsius
• OPAL is able to withstand much greater earthquake loads than other industrial buildings, high-rise units and dams.
• OPAL’s reactor core is about the size of a two-drawer filing cabinet and is located in a 13-metre deep open pool filled with demineralised light water (ordinary water).
• The depth of the water above the core ensures that staff working in the area above the pool are shielded from radiation.
• Airline pilots are exposed to more radiation than nuclear workers at ANSTO.
• Australia was the first country in the world to sign the Nuclear Non-Proliferation Treaty.
• A report issued by the Nuclear Threat Initiative in January 2012 ranked Australia as the country with the best nuclear material security processes in the world.
• Scientists at ANSTO have developed forensic techniques to detect theft or trafficking of illicit nuclear material, and also methods to operate reactors on low-enriched uranium. These techniques are being shared with other countries that have a nuclear industry to improve nuclear safety.
**ARTICLE THREE  NUCLEAR TOOLS FOR CLIMATE CHANGE**

This article discusses some of the research undertaken by ANSTO that dates water samples in underground water supplies to learn more about how long it takes water to recycle. With Australia facing water access issues in the future, the more we understand the long-term changes in the water cycle, the more we will be able to optimally manage our clean water supply.

**FAST FACTS:**
- The many benefits of nuclear technology are historically misunderstood.
- At ANSTO, nuclear technology is used to address a plethora of environmental issues including climate change, water resource sustainability and air pollution.
- “We are part way through a program to generate high resolution records of rainfall variability over the last 1000 years using cave stalagmites which contain the records of past rainfall embedded in their atomic structure.”

**ARTICLE FOUR  NUCLEAR SCIENCE RESEARCH – TRACKING CANCER**

This short article looks at the latest technology in cancer treatment assisted by new nuclear science research.

**FAST FACTS:**
- Recent research at ANSTO has led to a newly discovered pharmaceutical which will help doctors more effectively pinpoint the region where a melanoma has spread.
- High-contrast imagery makes it easier for doctors to see cancerous cells among normal tissue.
- More accurate localisation of cancerous cells should lead to more effective treatment.

**INITIAL BRAINSTORM**

Before you start to read the articles on nuclear research, complete the following Y chart to open up class discussion about nuclear technology and find out what you already know.

(The Y brainstorm will take up a whole page and ask the students to explain:

- **What does it look like?** Write in here any facts you know about nuclear science or nuclear reactors and what they do.
- **What does it sound like?** Write in here some of the debates you might have heard in the media about nuclear reactors.
- **What does it feel like?** Write in here your feelings about the use of nuclear science for research into things such as: learning about the environment and helping treat patients with diseases such as cancer.)

When you have read the articles on nuclear research, you can come back to this Y-chart and add in more detail. Use a different colour for the added information.
ANSTO’S OPEN POOL Australian Lightwater (OPAL) reactor is a state-of-the-art 20-megawatt reactor that uses low enriched uranium (LEU) fuel to achieve a range of research, scientific, industrial and production goals.

Opened by Prime Minister John Howard in 2007, OPAL is one of a small number of reactors with the capacity for the commercial production of radioisotopes. This capacity, combined with the open pool design, the use of LEU fuel and the wide range of applications, places OPAL among the best research reactors in the world.

While OPAL is the centrepiece of ANSTO’s research facilities, the suite of neutron beam instruments housed next to the reactor building and operated by the Bragg Institute represent a significant addition to ANSTO’s research capabilities. Senator Chris Evans, the Minister for Tertiary Education, Skills, Science and Research, recently congratulated ANSTO’s contribution to science.

“Congratulations to the ANSTO scientists whose innovative research is already being used by industry around the world,” said Senator Evans.

OPAL is operated and maintained by the Reactor Operations group within the Nuclear Operations division.

THE ROLE OF RESEARCH REACTORS
While virtually every research reactor is unique, OPAL is one of a number of similar production facilities around the world, including the Safari-1 reactor in South Africa, the HFR reactor at Petten in the Netherlands and the NRU reactor at Chalk River in Canada. These reactors play a vital role in society by functioning as ‘neutron factories’, producing isotopes for several important purposes, including the production of radioisotopes for cancer detection and treatment, and neutron beams for fundamental materials research.

OPAL’s operation staff cooperate with their international colleagues to share information and knowledge both directly through formal collaboration agreements and via various international organisations and forums.

OPAL USER GROUPS
OPAL is used by members of the scientific, medical, environmental, industrial and security communities, as well as Australian universities.

While OPAL is extremely versatile and the uses of neutron science are virtually unlimited, OPAL’s main uses are:

- Irradiation of target materials to produce radioisotopes for medical and industrial applications
- Research in the field of materials science using neutron beams and associated instruments
- Analysis of minerals and samples using neutron activation techniques and delayed neutron activation techniques
- Irradiation of silicon ingots (termed neutron transmission doping or NTD) for use in the manufacture of electronic semiconductor devices.

OPERATION CYCLE
OPAL typically operates in cycles of 30–35 days followed by a short refuelling outage to remove two or three spent fuel elements and replace them with new fuel elements. During these types of outages, OPAL’s reactor operations team also performs preventive and corrective maintenance.

In addition, there are longer maintenance outages (extended maintenance) to enable more extensive inspections, refurbishment and maintenance. ANSTO aims to operate the reactor for 300 days each calendar year.

INSIDE OPAL
The heart of the reactor is a compact core of 16 fuel assemblies arranged in a 4 × 4 array, with five control rods controlling the reactor power and facilitating shutdown. OPAL uses LEU fuel containing just under 20% uranium-235. In terms of security
and nuclear safeguards, this is a distinct advantage over earlier research reactors, some of which required enrichment levels as high as 95% uranium-235 (weapons grade).

OPAL’s fuel assemblies (core) are cooled by demineralised light water (ordinary water) and are surrounded by a zirconium alloy ‘reflector’ vessel that contains heavy water. The reflector vessel is positioned at the bottom of a 13-metre-deep pool of light water. The open pool design makes it easy to see and manipulate items inside the reactor pool. The depth of the water ensures effective radiation shielding of staff working above the pool. The heavy water maintains the nuclear reaction in the core by ‘reflecting’ neutrons back towards the core.

**ACTIVITY 1 GLOSSARY**

Create a glossary. Use the table to define any science words that are related to this article.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Reactor</td>
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<td>OPAL</td>
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<td>ANSTO</td>
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<td>Preventative</td>
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<td>Corrective</td>
<td>maintenance</td>
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<tr>
<td>Control rod</td>
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<tr>
<td>Fuel assembly</td>
<td></td>
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<tr>
<td>Demineralised light water</td>
<td></td>
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<tr>
<td>Heavy water</td>
<td></td>
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</tbody>
</table>
**ARTICLE ONE  OPAL: ANSTO'S RESEARCH REACTOR**

**ACTIVITY 2  COMPREHENSION AND SUMMARISING**

1. When you have read the article carefully, write down as many things you learnt about the OPAL reactor that you can remember. Write each fact in a different box in the grid below. Don’t worry if you can’t fill all the squares.

2. Once you have filled as many squares as you can, walk around the room and trade your facts with other members of the class by giving them one of yours in exchange for one of theirs. Write the new fact in the boxes below until you have filled all 20 squares with information about the OPAL reactor.

3. When you have finished, have a class discussion to find out which facts were the easiest to remember and why. Which facts do you think are the most important to learn about the OPAL reactor? Which facts are the most interesting?

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**ARTICLE TWO HOW SAFE IS THE OPAL RESEARCH REACTOR?**

THE OPAL RESEARCH REACTOR'S design and integrated safety features mean it is extremely safe; a fact confirmed by independent analysis.

ANSTO operates the OPAL (the Open Pool Australian Lightwater) research reactor at Lucas Heights. OPAL is a state-of-the-art facility customised to meet Australia's long-term needs. It performs a wide range of functions, including the production of radiopharmaceuticals for nuclear medicine, and the provision of neutron beams for research.

**RESEARCH REACTOR**
OPAL is a research reactor. It generates roughly 20 megawatts of heat using around 30 kg of uranium. This is very small when compared to a typical nuclear power reactor, which may operate at a thermal output of around 3,000 megawatts to generate 1,000 megawatts of electricity and contain around 100,000 kg of uranium.

To put it another way, OPAL's output is only enough to warm the water within the reactor pool to about 40°C, as opposed to heating water hot enough to generate high-pressure steam to drive turbines.

**INDEPENDENT ANALYSIS**
Because of its size, its design and integrated safety features, OPAL is extremely safe. The safety analysis shows how the design of the OPAL reactor meets design safety requirements, and necessary licensing requirements. This safety analysis has been subject to independent review and approval by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

The reactor's security design is integrated into the overall ANSTO site system, which includes 24-hour protection by the Australian Federal Police. The security design has also been subject to independent review and approval by the relevant Commonwealth bodies. Following are some brief details on OPAL's safety features.

**DESIGN AND CONSTRUCTION**
The design and construction of OPAL ensures effective protection of reactor personnel, the general public and the environment against radiological hazards. Airline pilots are exposed to more radiation than nuclear workers at ANSTO. The reactor building is constructed out of reinforced concrete, which provides the physical boundary to contain radiation emissions that may result in the very unlikely event of release of radioactivity inside.

The reactor building also protects the reactor from external events, including aircraft collisions and earthquakes. Indeed, OPAL is able to withstand much greater earthquake loads than other industrial buildings, high-rise units and dams. Expert geologists have confirmed that the site is geologically stable.

**THE REACTOR CORE**
OPAL's reactor core is about the size of a two-drawer filing cabinet and is located in a 13 m-deep open pool filled with demineralised light water (ordinary water). The pool itself is constructed from stainless steel and is embedded in a block of high density concrete that also absorbs radiation. The depth of the water above the core ensures that staff working in the area above the pool are shielded from radiation.

The reactor core consists of 16 fuel assemblies, which contain low-enriched uranium, and five control rods made from hafnium, a material that strongly absorbs neutrons. The control rods maintain the reactor at the desired power while the reactor is operating and also act as the first shutdown system when required. The reactor core is surrounded by heavy water contained in a reflector vessel that reflects neutrons back into the core and thus, maintains the ongoing nuclear reaction.

**SHUT DOWN AND CONTAINMENT**
OPAL's automated and highly reliable safety features include two independent safety systems that are able to quickly and independently shut down the reactor core.

OPAL's first shutdown system quickly inserts (by gravity and assisted with compressed air) the five control rods into the
reactor core, absorbing neutrons in the core and thus stopping the nuclear chain reaction. The second shutdown system partially drains the reflector vessel of its heavy water, allowing more neutrons to escape the core and thus stopping the nuclear chain reaction. Both shutdown systems are fail-safe and can function independent of the availability of electrical power.

CORE COOLING
During power operation, the core is cooled by forced circulation of the pool water driven by two of the three pumps of the primary cooling system. When the reactor is shut down, residual heat from the reactor core is dissipated by pool water that circulates naturally upwards through the core.

CONTAINMENT
If necessary, the reactor building can be isolated from the external environment. The containment includes systems to trap radioactive material in high-efficiency particulate filters (these filters physically remove contaminants), as well as activated charcoal for trapping radioactive iodine. With these containment systems in place, conservative modeling demonstrates that radiation doses to members of the public would be well below acceptable limits.

AUSTRALIA’S ROLE IN REGULATING NUCLEAR SAFETY
Australia has been very proactive in regulating the safety of nuclear science, not just locally but around the world. Australia was the first country to sign the Nuclear Non-Proliferation Treaty, which aims to stop the use of nuclear weapons and promote the peaceful use of nuclear technology.

An independent report by the Nuclear Threat Initiative, released in January 2012, ranked Australia as the country with the best nuclear material security processes in the world, with a score of 100 out of 100. The Nuclear Threat Initiative rates countries based on five key factors:

- the nuclear quantities and sites including transportation and the amount of materials;
- security control measures including physical and personnel measures;
- global norms including transparency, international legal and voluntary commitments;
- domestic commitments and capacity including independent regulatory oversight, legislative protections and safeguards; and
- societal factors including political stability and corruption prevention measures.

Australia was also the first country to use low-enriched uranium in a research reactor. As such, it is impossible to produce weapons-grade material in the OPAL reactor. Scientists at ANSTO are now sharing the knowledge of how to run a reactor with low-enriched uranium with other countries that have a nuclear industry, in order to reduce proliferation risks.

ANSTO has also developed forensic techniques to detect theft or trafficking of illicit nuclear material, and are sharing them with other countries.

ACTIVITY 1 GLOSSARY
Creating a glossary. Use the table to define any science words that are related to this article.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Radiopharmaceuticals</td>
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<td>Nuclear medicine</td>
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<td>Uranium</td>
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<td>ARPANSA</td>
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<td>Reactor core</td>
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<td>Hafnium</td>
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<td>Shut down</td>
<td></td>
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<td>Containment</td>
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<tr>
<td>Nuclear chain reaction</td>
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</tbody>
</table>
ACTIVITY 2 COMPREHENSION AND SUMMARISING

1 Complete the following table to compare the amount of uranium needed to generate the necessary energy for the OPAL and a normal nuclear power reactor to function.

<table>
<thead>
<tr>
<th>Type of reactor</th>
<th>Megawatts of heat</th>
<th>Amount of uranium needed to generate this heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPAL research reactor</td>
<td></td>
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<tr>
<td>Normal nuclear power reactor</td>
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</table>

2 What is the role of the Australian Federal Police at ANSTO?

3 Why do you think the independent analysis of the safety features at ANSTO are necessary?

4 How are staff members who work at the OPAL research reactor protected from radiation?

5 How is the building that houses the OPAL reactor designed to protect it against natural disasters?

6 What is the role of the water in the pool of the reactor?

7 Outline the two shutdown systems that are activated if there is a problem with the reactor.

8 How does the process of ‘containment’ help protect the environment from radiation if there is a problem?
THE MANY BENEFITS of nuclear technology are historically misunderstood. The word ‘nuclear’ conjures up thoughts of cold war, radioactive fall-out and threats to health and peace. But our world is surrounded by radioactive materials, and measuring these with sensitive instruments reveals much about Earth’s building blocks, its biological systems and how they function. Life on this planet has existed peacefully with low-level radioactivity for nearly four billion years.

At the Australian Nuclear Science and Technology Organisation (ANSTO), nuclear technology is used to explore a plethora of environmental issues including climate change, water resource sustainability and air pollution. The sensitivity of the tools used at ANSTO provides insights into these areas, which are impossible using other techniques.

Professor John Dodson, Head of ANSTO’s Institute for Environmental Research, explained that ANSTO’s nuclear science facilities offer Australian researchers state-of-the-art technology for understanding past, present and future climates.

“Past climates leave their signatures in a variety of places including tree rings, ice cores, corals and cave stalagmites,” said Dodson. “For example, ANSTO has dated water from bores in the Great Artesian basin, showing it contains rainfall that fell over 300,000 years ago. We need to know this and the rate of artesian water replenishment if we are to make use of it as a sustainable water resource.

“In these times of water scarcity Australian cities and towns are turning more and more to groundwater as a source because surface water resources have become over-exploited,” he said.

“However, we know precious little about groundwater reserves and we need to get smart about them, along with developing sensible recycling and economical water use for long-term water security.

“With Australia occupying about 5.4 per cent of the global land mass but with only one per cent of its water, we have problems unlike other nations,” Dodson said.

ANSTO is now embarking on a project to enhance understanding of the water resources of south-western Australia, which has one of Australia’s most rapid population growth rates. Most of the surface water resources are already fully exploited and rainfall has decreased in recent decades. Perth needs to identify sound ways of ensuring water security.

Groundwater around Perth rises and falls with the winter rainfall patterns (at appropriate lag intervals). However, the rate at which this occurs, and the age of the groundwater, is only broadly known. Nuclear tools are being used to measure the age of groundwater and, with the help of Water WA, ANSTO scientists will establish the age of water in various aquifers. This will help form a basis for comparison with longer term rainfall records.

Dodson explained that the recent decline in rainfall is based on knowledge from the measured meteorological records, which are little more than 100 years old.

“We are part-way through a program to generate high resolution records of rainfall variability over the last 1000 years for the region using cave stalagmites which contain the records of past rainfall embedded in their atomic structure,” he said.

“This will provide a better basis for understanding recent rainfall changes and reveal if the rainfall in the last few decades is unusual, or if it is the norm.”

The study will also reveal the recurrent rate of long drought periods, as well as heavy rainfall decades, and tell scientists how important tropical and southerly rainfall systems are in the mix of rainfall received. These will empower decision makers to plan water use from appropriate baselines.

Atmospheric dust also has a direct impact on climate systems and human health.

“Australia is the largest source of atmospheric dust in the Southern Hemisphere and the liberation of dust into the atmosphere has impacts well beyond our shores, although much of this dust is valuable topsoil,” Dodson said.

“ANSTO has established protocols for measuring bushfire smoke, soil erosion, household fires and pollution from cars and industry. We know the season cycles in the Sydney Basin and the origins of atmospheric air masses which drive some of the change and this information helps us to assist nations overseas to assess and manage their own air pollution problems.

“Overall, the growth of nuclear science is very exciting and at ANSTO our work and the work of other groups we support, needs to be better understood by the community, especially the benefits of managing the world of today and tomorrow,” Dodson concluded.
### ACTIVITY 1 GLOSSARY

Create a glossary. Use the table to define any science words that are related to this article.

<table>
<thead>
<tr>
<th>Term</th>
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<tr>
<td>Low-level radioactivity</td>
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<td>Ground water</td>
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<td>Aquifer</td>
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<td>High-resolution records</td>
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<td>Cave stalagmites</td>
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<tr>
<td>Atomic structure</td>
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### ACTIVITY 2 COMPREHENSION AND SUMMARISING

After reading the article write down five separate pieces of information that you found interesting in the article. Now pretend this information is a response to a question and design five comprehension or summarising questions to match each of your ‘responses’. Swap your questions with someone else and have a go at responding to them.

<table>
<thead>
<tr>
<th>Interesting information from the article</th>
<th>Question written to the interesting information</th>
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A NEWLY DISCOVERED isotope will help doctors better detect the spread of melanomas. Melanomas are a type of skin cancer caused by prolonged exposure to UV rays. According to Cancer Australia they represent 9.5% of all cancer diagnoses made in Australia.

Oncologists have previously used the radioactive compound FDG (fludeoxyglucose) to locate several types of cancer, including melanoma. FDG is a glucose analogue with a high affinity for cancer cells. And because it’s a radiopharmaceutical it emits radiation, meaning that doctors can use a positron emission tomography (PET) scan to trace it and any cancer cells associated with it.

Recent research undertaken by the Australian Nuclear Science and Technology Organisation (ANSTO) and the Peter MacCallum Cancer Centre is developing a compound that can more effectively pinpoint the region where a melanoma has spread.

The compound, called 18F-MEL050 or simply MEL050, can hone in on a melanoma by searching for melanin protein inside cells and binding to it. This also allows for high-contrast imagery, making it easier for doctors to see cancerous cells among normal tissue.

“Using MEL050, we can track and localise secondary melanoma metastasis [where a melanoma has spread through the skin or lymph nodes],” explains Ivan Greguric, an ANSTO nuclear radiopharmaceutical chemist. “A lot of [cancer] treatment options, such as chemotherapy, are very expensive and ineffective,” he adds. “A more accurate localisation of cancerous cells should lead to a more effective treatment regimen.” - Oliver Chan

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**ACTIVITY 1 GLOSSARY**

Creating a glossary. Use the table to define any science words that are related to this article.

<table>
<thead>
<tr>
<th>Term</th>
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<td>Melanoma</td>
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<td>UV radiation</td>
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<td>Oncologist</td>
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<td>FDG</td>
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<td>Glucose analogue</td>
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<td>High affinity</td>
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<td>Metastasis</td>
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<td>Lymph node</td>
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</table>
**ACTIVITY 2 COMPREHENSION AND SUMMARISING**

**SUMMARISING AND INQUIRING ACTIVITY**
We have provided a series of discussion questions in the form of a questioning toolkit. Choose some or all of the questions, or ask some of your own.

Further reading on questioning toolkits:
- [http://www.fno.org/nov97/toolkit.html](http://www.fno.org/nov97/toolkit.html)

Write your ideas and opinions relating to each of the different types of questions.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Your ideas and opinions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential questions: these are the most important and central questions. They probe the deepest issues that confront us and can be difficult to answer.</td>
<td></td>
</tr>
<tr>
<td>What kind of research is carried out at ANSTO?</td>
<td></td>
</tr>
<tr>
<td>How is the OPAL reactor different to a nuclear power station?</td>
<td></td>
</tr>
<tr>
<td>Sifting and sorting questions: these questions take us to the heart of the matter, like an archaeologist digging for clues.</td>
<td></td>
</tr>
<tr>
<td>Do the benefits of having nuclear reactors outweigh the risks?</td>
<td></td>
</tr>
<tr>
<td>How do the risks of harm caused by nuclear reactor disasters compare to other disasters such as car accidents, or unavoidable medical issues caused by overeating or smoking?</td>
<td></td>
</tr>
<tr>
<td>What kind of damage can an accident at a nuclear reactor do to the people who work there and the environment?</td>
<td></td>
</tr>
<tr>
<td>How are nuclear reactors made safe?</td>
<td></td>
</tr>
<tr>
<td>Hypothetical questions: questions designed to explore the possibilities: the ‘what ifs?’ They are useful when we want to test our hunches.</td>
<td></td>
</tr>
<tr>
<td>Do you think some anti-nuclear protestors might change their mind about nuclear reactors if their lives were saved with the use of medical devices such as radioactive isotopes?</td>
<td></td>
</tr>
<tr>
<td>What if Australia had a nuclear power station, how might your life, or the life of other Australians be different?</td>
<td></td>
</tr>
<tr>
<td>If you were able to visit ANSTO at Lucas Heights in Sydney, what questions would you like to ask the experts there about nuclear research?</td>
<td></td>
</tr>
<tr>
<td>Provocative questions: questions to challenge convention.</td>
<td></td>
</tr>
<tr>
<td>Should it be the cancer patients that vote to support whether or not nuclear reactors for research and medicine should be built?</td>
<td></td>
</tr>
<tr>
<td>Is it hypocritical to be antinuclear with regards to nuclear power but pronuclear with regards to nuclear research that can help save lives?</td>
<td></td>
</tr>
<tr>
<td>Do you think people who fear nuclear reactors don’t understand anything about them?</td>
<td></td>
</tr>
</tbody>
</table>
ABOUT THE COSMOS MATRIX

WHAT IS THE COSMOS SCIENCE MATRIX?
A learning matrix such as the COSMOS Science Matrix is a flexible classroom tool designed to meet the needs of a variety of different learning styles across different levels of capabilities. Students learn in many different ways – some are suited to hands-on activities, others are strong visual learners, some enjoy intellectually challenging, independent hands-off activities, while others need more guidance. The matrix provides a smorgasbord of science learning activities from which teachers and/or students can choose.

CAN I USE THE MATRIX FOR ONE OR TWO LESSONS, OR FOR A WHOLE UNIT OF STUDY?
Either! The matrix is designed to be time flexible as well as educationally flexible. A time frame for each activity is suggested on the matrix. Choose to complete one activity, or as many as you like.

IS THERE ROOM FOR STUDENT NEGOTIATION?
Yes! Students can be given a copy of the matrix and choose their own activities, or design their own activities in consultation with their classroom teacher.

CAN I USE THE MATRIX FOR A CLASS ASSESSMENT?
Yes! You can set up a point system – perhaps one lesson equals one point. Students can be given a number of points to complete. If they choose less demanding activities, they will have to complete more of them.

WHAT DO THE ROW HEADINGS MEAN?

<table>
<thead>
<tr>
<th>ROW HEADING</th>
<th>DESCRIPTION OF ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific procedure</td>
<td>Hands-on activities that follow the scientific method. Includes experiments and surveys. Great for kinaesthetic and logical learners, as well as budding scientists.</td>
</tr>
<tr>
<td>Science philosophy</td>
<td>Thinking about science and its role in society. Includes discussion of ethical issues, debates and hypothetical situations. An important part of science in the 21st century.</td>
</tr>
<tr>
<td>Being creative with science</td>
<td>For all those imaginative students with a creative flair. Great for visual and musical learners and those who like to be innovative with the written word.</td>
</tr>
<tr>
<td>Science time travel</td>
<td>Here we consider scientific and technological development as a linear process by looking back in time or travelling creatively into the future.</td>
</tr>
<tr>
<td>‘Me’ the scientist</td>
<td>Personalising the science experience in order to engage students more deeply.</td>
</tr>
<tr>
<td>Communicating with graphics</td>
<td>Using images to communicate complex science ideas.</td>
</tr>
<tr>
<td>ICT</td>
<td>Exploring the topic using computers and the Internet.</td>
</tr>
</tbody>
</table>

WHAT DO THE COLUMN HEADINGS MEAN?

<table>
<thead>
<tr>
<th>1. READ AND REVISE</th>
<th>2. READ AND RELATE</th>
<th>3. READ AND REVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed to enhance student comprehension of information.</td>
<td>Gives the student the opportunity to apply or transfer their learning into a unique format.</td>
<td>Involves the more challenging tasks of analysing, and/or assessing information in order to create and express new ideas and opinions.</td>
</tr>
</tbody>
</table>
Conduct an experiment to learn about half-life and radioactive decay. See Activity 1.

Conduct an experiment to investigate radioactivity with a Geiger counter. See Activity 2.

Build a cloud chamber to be able to track radioactivity and then put it through a scientific test to find out more about ... such as testing to see if different types of radiation (alpha, beta or gamma) leave the same footprint. See Activity 3.

After reading the article(s), what are your thoughts on nuclear reactors for research and for generating electricity?

Find an article on research carried out at a nuclear reactor and complete Activity 4 to think about it more deeply.

Read a range of articles on the nuclear debate and choose one that is pro-nuclear and one that is anti-nuclear. Prepare a presentation that ... and any other criteria you think useful. Apply the criteria in order to assess which argument is the most convincing.

Create a scrapbook, cartoon or mural using information from the article(s) to showcase the OPAL reactor. Include information on how they work, and the benefits and drawbacks of having them in Australia.

There are many uses for radioactive isotopes. Pick one of the following radioisotopes and research its uses and then ... Carbon-14, Barium-137, Uranium-235

Or Create models of alpha, beta and gamma decay to show the difference between them. Or you could do a series of radioactivity experiments and use different types of radiation to make a hurricane glass.

Build a model nuclear research facility to help educate people about nuclear science. You might want to model a ... to identify the different parts and then write a small panel of explanatory text like the ones they have in museums.

Imagine it is 2120. All the fossil fuels in the world have been used up and humans have made the transition to a world in which energy is generated from nuclear fusion. You have decided to launch a new project to develop the energy source in which you are interested. What would it be? Where would it be located? What would it take to get it up and running? Write an essay about it, including the pros and cons.

Imagine you are a science journalist interviewing any one of the people in the articles you have read about nuclear science. Use the text in the articles as a guide to which questions to ask and how the interviewee might respond. You can act out the interview to the class.

You are a scientist who is concerned about finding fun ways for students to learn about research reactors. Design a list of ideas for activities you could do with your science class. Brainstorm with your students about possible games, such as a game about science, a game of charades, celebrity heads, who wants to be a millionaire, 50/50 or any other game that you find suitable.

You are an education scientist at ANSTO and have to present a lesson to a group of students about radioactive decay. Create an activity for your students to investigate radioactivity with a Geiger counter and devise a set of rules or mnemonics to help the students remember the difference.

These science activities are designed to help reinforce the key concepts and ideas you have learnt about nuclear science while studying this unit.

"Elaborate with Graphics (CTC)" is designed to develop the thinking and reasoning skills that are essential for science.
<table>
<thead>
<tr>
<th></th>
<th>READ AND REVISE</th>
<th>READ AND RELATE</th>
<th>READ AND REVIEW</th>
</tr>
</thead>
</table>
| **Scientific Procedure** | Yr 7 – ACSIS129, ACSIS130, ACSIS131, ACSIS133  
Yr 8 – ACACCIS144, ACSIS145, ACSIS146, ACSIS148  
Yr 9 – ACSSU177, ACSIS169, ACSIS170, ACSIS171, ACSIS174  
Yr 10 – ACSIS203, ACSIS204, ACSIS205, ACSIS208 | Yr 7 – ACSIS129, ACSIS130, ACSIS131, ACSIS133  
Yr 8 – ACACCIS144, ACSIS145, ACSIS146, ACSIS148  
Yr 9 – ACSSU177, ACSIS169, ACSIS170, ACSIS171, ACSIS174  
Yr 10 – ACSIS203, ACSIS204, ACSIS205, ACSIS208 | All ACSIS outcomes from 7 to 10.  
Yr 9 – ACSSU177 |
| **Science Philosophy** | Yr 7 – ACSHE120, ACSHE121  
Yr 8 – ACSHE135, ACSHE136  
Yr 9 – ACSSU177, ACSHE161, ACSHE228, ACSIS174  
Yr 10 – ACSHE195, ACSHE230, ACSIS208 | Yr 7 – ACSHE120, ACSHE121  
Yr 8 – ACSHE135, ACSHE136  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSHE120, ACSHE121  
Yr 8 – ACSHE135, ACSHE136  
Yr 9 – ACSSU177, ACSHE160, ACSHE228, ACSIS174  
Yr 10 – ACSHE194, ACSHE230, ACSIS208 |
| **Being Creative with Science** | Yr 7 – ACSHE120, ACSIS133  
Yr 8 – ACSHE135, ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSHE160, ACSHE228, ACSIS174  
Yr 10 – ACSIS208 |
| **Science Time Travel** | Yr 7 – ACSHE120  
Yr 8 – ACSHE135  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSHE119, ACSHE223, ACSIS133  
Yr 8 – ACSHE134, ACSHE226, ACSIS148  
Yr 9 – ACSSU177, ACSHE157, ACSHE158, ACSIS174  
Yr 10 – ACSHE191, ACSHE192, ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208, ACSIS230 |
| **‘Me’ the Scientist** | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 |
| **Communicating with Graphics** | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSSU186, ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208, ACSIS230 |
| **ICT** | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 | Yr 7 – ACSIS133  
Yr 8 – ACSIS148  
Yr 9 – ACSSU177, ACSIS174  
Yr 10 – ACSIS208 |

**THE COSMOS SCIENCE MATRIX**

**READ AND REVISE**

- Yr 7 – ACSIS129, ACSIS130, ACSIS131, ACSIS133
- Yr 8 – ACACCIS144, ACSIS145, ACSIS146, ACSIS148
- Yr 9 – ACSSU177, ACSIS169, ACSIS170, ACSIS171, ACSIS174
- Yr 10 – ACSIS203, ACSIS204, ACSIS205, ACSIS208

**READ AND RELATE**

- Yr 7 – ACSIS129, ACSIS130, ACSIS131, ACSIS133
- Yr 8 – ACACCIS144, ACSIS145, ACSIS146, ACSIS148
- Yr 9 – ACSSU177, ACSIS169, ACSIS170, ACSIS171, ACSIS174
- Yr 10 – ACSIS203, ACSIS204, ACSIS205, ACSIS208

**READ AND REVIEW**

- All ACSIS outcomes from 7 to 10.
- Yr 9 – ACSSU177

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**Scientific Procedure**

- Yr 7 – ACSIS129, ACSIS130, ACSIS131, ACSIS133
- Yr 8 – ACACCIS144, ACSIS145, ACSIS146, ACSIS148
- Yr 9 – ACSSU177, ACSIS169, ACSIS170, ACSIS171, ACSIS174
- Yr 10 – ACSIS203, ACSIS204, ACSIS205, ACSIS208

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**Science Philosophy**

- Yr 7 – ACSHE120, ACSHE121
- Yr 8 – ACSHE135, ACSHE136
- Yr 9 – ACSSU177, ACSHE161, ACSHE228, ACSIS174
- Yr 10 – ACSHE195, ACSHE230, ACSIS208

---

**Being Creative with Science**

- Yr 7 – ACSHE120, ACSIS133
- Yr 8 – ACSHE135, ACSIS148
- Yr 9 – ACSSU177, ACSIS174
- Yr 10 – ACSIS208

---

**Science Time Travel**

- Yr 7 – ACSHE120
- Yr 8 – ACSHE135
- Yr 9 – ACSSU177, ACSIS174
- Yr 10 – ACSIS208

---

**‘Me’ the Scientist**

- Yr 7 – ACSIS133
- Yr 8 – ACSIS148
- Yr 9 – ACSSU177, ACSIS174
- Yr 10 – ACSIS208

---

**Communicating with Graphics**

- Yr 7 – ACSIS133
- Yr 8 – ACSIS148
- Yr 9 – ACSSU177, ACSIS174
- Yr 10 – ACSIS208

---

**ICT**

- Yr 7 – ACSIS133
- Yr 8 – ACSIS148
- Yr 9 – ACSSU177, ACSIS174
- Yr 10 – ACSIS208
Radioactive isotopes decay over time. The time it takes for half of the nuclei in a sample of a radioisotope to decay is known as its half-life. In this experiment, you will be using counters to model the radioactive decay of a radioisotope and find its half-life.

**AIM**
To model the process of radioactive decay.

**MATERIALS**
- 100 plastic counters with a mark on one side of each – these act as radioactive nuclei
- A plastic container with a lid (takeaway containers work well)
- Graph paper

**METHOD**
1. Place the counters in the container.
2. Place the lid on the container.
3. Shake the container.
4. Shake out the counters that land with their mark facing down and place them on the paper towel. These are the nuclei that have decayed.
5. Count the number of remaining nuclei and record in the table provided in the results section.
6. Repeat steps 1 to 5 (recording the results as a different throw number) until you have no counters left.
7. Repeat the experiment twice more.
8. Draw a line graph where the Y-axis is the remaining counters (radioactive nuclei) and the X-axis is the number of tosses (half-lives).
   Plot your average results on the graph. The line graph represents the half-life of a substance.

**RESULTS**

<table>
<thead>
<tr>
<th>THROW NUMBER</th>
<th>SET 1 NUMBER OF REMAINING COUNTERS</th>
<th>SET 2 NUMBER OF REMAINING COUNTERS</th>
<th>SET 3 NUMBER OF REMAINING COUNTERS</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

**DISCUSSION**
1. What is the half-life of the radioactive counters?
2. If you started with 900 radioactive nuclei, how many would remain undecayed after three half-lives?
3. The half-life of the radioactive isotope iodine-131 is eight days.
   Calculate the amount of iodine-131 that would be left in a 100 gram sample after 8, 16, 32, and 80 days.
4. Evaluate the effectiveness of this experiment as a simulation for radioactive decay.
5. There are many uses for radioactive isotopes. Pick one of the following isotopes and research its uses.
6. Discuss some of the problems associated with using radioactive isotopes.

**CONCLUSION**
Write a concise conclusion for this experiment that relates back to the aim.
ACTIVITY 2 MEASURING RADIOACTIVITY

BACKGROUND INFORMATION:
A Geiger counter is an instrument used to measure radiation given off from objects. When alpha, beta or gamma radiation enters the Geiger counter there is a pulse of electric current produced. The pulse of the current is measured by the counter in order to represent the amount of radiation. The unit used by the Geiger counter for radioactivity is counts per second (c/s), which is the total number of α/β particles and γ-photons per second, or the becquerel (Bq), which equates to one decay per second.

PART 1 AIM – To use a Geiger counter to measure the radioactivity of a range of radioactive sources.
PART 2 AIM – To investigate what materials will stop the transmission of alpha, beta and gamma sources of radioactivity.
PART 3 AIM – Investigate the relationship between distance and intensity of a radioactive source.

MATERIALS:

<table>
<thead>
<tr>
<th>Geiger Counter</th>
<th>Other common substances that you want to test for radioactivity e.g. water, your skin, books, TV</th>
<th>Range of alpha, beta and gamma radioactive isotopes -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruler</td>
<td>10cm by 0.5mm of the following:</td>
<td>• Americium-241 – α source</td>
</tr>
<tr>
<td></td>
<td>• paper</td>
<td>• Bismuth-210 – α and β source</td>
</tr>
<tr>
<td>Retort stand</td>
<td>• wood</td>
<td>• Caesium-137 – β and γ source</td>
</tr>
<tr>
<td>Boss head</td>
<td>• glass</td>
<td>• Cobalt-60 – γ source</td>
</tr>
<tr>
<td>Clamp</td>
<td>• copper</td>
<td>• Polonium-215 – α source</td>
</tr>
<tr>
<td>Graph paper</td>
<td>• polyethylene</td>
<td>• Polonium-218 – α source</td>
</tr>
<tr>
<td></td>
<td>• lead</td>
<td>• Radium-226 – α source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strontium-90 – good β source</td>
</tr>
</tbody>
</table>

PART 1 MEASURING THE RADIOACTIVITY OF RADIOACTIVE SOURCES AND SOME COMMON HOUSEHOLD/CLASSROOM OBJECTS.

AIM
To use a Geiger counter to measure the radioactivity of a range of radioactive sources.

METHOD
1. Place the ruler on a flat surface.
2. Place the Geiger counter at the 20cm mark.
3. Turn the Geiger counter on and measure the amount of background radiation coming from the room. Record your results in the table.
4. Now take one of your radioactive sources and place it on the 0 cm mark of your ruler. Record the reading on the Geiger counter.
5. Repeat this for all your radioactive sources and any other household/classroom objects you want to test for radioactivity. Make sure you record your results in the table provided.

RADIOACTIVITY MEASUREMENTS OF A RANGE OF OBJECTS

<table>
<thead>
<tr>
<th>Source</th>
<th>Radioactivity (c/s) – reading on the Geiger counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Why do you need to measure the background radiation in the room?
2. Which objects gave off the most radioactivity?
3. What is happening to the atoms of an object when it is giving off radiation?
4. Which objects gave off the least radioactivity?
5. Why did you need to keep the objects all at 20cm from the Geiger counter?
6. Research Geiger counters. Include a diagram and explanation of how the Geiger counter works.

CONCLUSION
Write a sentence to summarise your results and respond to the aim.
ELABORATE

PART 2  WHAT TYPES OF MATERIALS WILL BLOCK RADIATION FROM ALPHA, BETA AND GAMMA SOURCES?

AIM
To investigate what materials will stop the transmission of alpha, beta and gamma sources of radioactivity.

METHOD
1. Place the ruler on a flat surface.
2. Place the Geiger counter at the 20 cm mark of the ruler.
3. Place the alpha source at the 0 cm mark.
4. Measure the radioactivity of your source.
5. Set up a retort stand with a clamp at the 10 cm mark.
6. From the clamp hang one of your targets (either paper, wood, copper, lead, polyethylene).
7. Hang the target from the clamp in front of the source at the 10 cm mark.
8. Record the radioactivity.
9. Replace the target with another type and record the radioactivity.
10. Repeat with the other target material types.
11. Repeat the whole experiment with a range of other alpha, beta and gamma sources.

AIM
Investigate the relationship between distance and intensity of a radioactive source.

RADIOACTIVE SOURCES AND TARGETS

<table>
<thead>
<tr>
<th>Source</th>
<th>Alpha, beta or gamma Emission</th>
<th>Target</th>
<th>Radioactivity with target material absent (c/s)</th>
<th>Radioactivity with target present (c/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>Paper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Copper</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Lead</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Polyethylene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>Paper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td></td>
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<td>Glass</td>
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<td>Copper</td>
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<td></td>
<td>Lead</td>
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<tr>
<td></td>
<td>Polyethylene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma</td>
<td>Paper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td></td>
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<td></td>
<td>Lead</td>
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<tr>
<td></td>
<td>Polyethylene</td>
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</tr>
</tbody>
</table>

DISCUSSION
1. What materials stopped the alpha particles from travelling?
2. What materials stopped the beta particles from travelling?
3. What materials stopped the gamma particles from travelling?
4. Which particles (alpha, beta or gamma) do you think would be the most harmful to the human body? Why?

CONCLUSION
Write a sentence that summarises the results and responds to the Aim.
**PART 3 MEASURING THE EFFECT OF DISTANCE FROM A RADIOACTIVE SOURCE.**

**AIM**
Investigate the relationship between distance and intensity of a radioactive source.

**METHOD**
1. Place the ruler on a flat surface.
2. Place the Geiger counter at the 1 cm mark.
3. Measure the background radiation in the room (no source present).
4. Place an alpha source on the 0 cm mark of the ruler.
5. Measure the radioactivity of the source with the Geiger counter at the 1 cm mark. Record your results.
6. Move the Geiger counter to the 2 cm mark. Record radioactivity.
7. Repeat with the Geiger counter at the 4 cm, 8 cm, 16 cm marks.
8. Repeat the whole experiment with other alpha, beta or gamma sources.

**RESULTS**
Background radiation reading _____________

**RADIOACTIVITY AND DISTANCE FROM THE SOURCE.**

<table>
<thead>
<tr>
<th>Source</th>
<th>Distance from source (cm)</th>
<th>Radioactivity (c/s)</th>
<th>Radioactivity minus background radiation (c/s) (fill out during the discussion section)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
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<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
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**DISCUSSION**
1. Calculate the radioactivity of each reading minus the background radiation and record in the table above.
2. Why do you need to account for the background radiation in your calculations?
3. For each source create a graph that shows the relationship between distance and radiation intensity.
4. Do all the sources show the same pattern? Explain the pattern shown by each.
5. Extrapolate your graph and predict the counts you would expect with the source at distances of 30 cm, 60 cm and 120 cm.
6. If you halve the distance to a radioactive source, by what amount does this change the intensity of the radioactivity?
7. How could this relationship be represented by an equation?
8. Use the equation you have derived to determine what the radiation reading would be for your sources at a distance of 15 cm, 50 cm and 75 cm.

**CONCLUSION**
Write a sentence to summarise results and respond to the aim.
ACTIVITY 3 BUILD A CLOUD CHAMBER TO TRACK RADIOACTIVITY

INTRODUCTION:
Radiation cannot be seen, heard, smelt, tasted or felt. But you can see the tracks it leaves in a dense gas. This activity directs you through the building of a cloud chamber that is used to be able to see the footprint of radiation.

AIM:
To identify the footprint made by radiation.

MATERIALS:
• Glass or plastic transparent jar with lid that is also transparent
• Black paint
• Blotting paper and scissors
• Ethyl alcohol
• Masking tape
• A radioactive source
• Dry ice and metal tongs for handling the dry ice
• Styrofoam
• Torch

METHOD:
1. Before you begin the experiment, paint the bottom of the transparent jar with black paint.
2. Cut the blotting paper so that it fits flush with the inside of the transparent jar just as a cardboard toilet roll fits neatly inside the middle of the toilet roll. The blotting paper should fit to the bottom and top of the inside of the jar.
3. Remove the blotting paper from inside the transparent jar and cut two rectangle windows in it as shown below.

4. Replace the blotting paper back inside the transparent jar.
5. Pour enough ethyl alcohol into the jar to cover the bottom of the jar. The alcohol will be absorbed into the blotting paper and then begin to evaporate into the middle of the container to make a dense gas.
6. Place the radioactive source into the clear container, place the lid on and then seal the lid with the masking tape.
7. Place the transparent container on the dry ice to super chill it.
8. Wait five minutes and then darken the room. Shine the torch light through the windows in the blotting paper while you look through the lid. You should see a puff and kind of swirling trails as the radioactivity condenses the gas as it moves through. If you do not see the puff and trails, cool the jar on the dry ice for longer.
9. Describe or draw what you see in the results section.

RESULTS:
Describe what you saw inside the cloud chamber.

DISCUSSION:
1. Give an example of where else you might use the evidence of the presence of something to know that it is there.
2. Watch the short YouTube video http://www.youtube.com/watch?v=NeyrHIKvpYM and compare the results of these students loud chamber to yours.
3. Watch this video of a cloud chamber designed to detect muons, which are particles similar to electrons. How is it the same as the cloud chamber you used? How is it different?

CONCLUSION:
Write a conclusion that summarises your results and responds to your aim.
ACTIVITY 4  NUCLEAR SCIENCE IN THE MEDIA

WHAT TO DO:
• Collect a nuclear science article that has been published in the mass media and that you find interesting.
• Read that article carefully so that you have a solid grasp of its contents.
• Complete the following questions in relation to your article.
• Present your article and discussion questions (from question 8) to the class.

THINGS TO THINK ABOUT:
1. What is the title of your chosen article?
2. Who wrote the article, where and on what date was it published?
3. Why did you choose this article?
4. Write a brief summary of article.
5. List the positive impacts of issues raised in this article.
6. List the negative impacts of some issues raised in this article.
7. What did you learn from this article?
8. Suggest two questions that could be raised in relation to the topic material in the article that could be used to promote discussion.
9. Identify anything new you learnt or new questions that were asked around the article after the class discussion.
10. Suggest how group discussion and asking questions can help create new knowledge or ideas.
Find the following words hidden backwards, forwards, diagonally, downwards and upwards:

ATOM
PROTON
ELECTRON
NEUTRON
PARTICLE
ACCELERATOR

REACTOR
NUCLEAR
RADIATION
ALPHA
BETA
GAMMA

CYCLOTRON
ENERGY
ISOTOPE
RADIOISOTOPE
DIFFRACTION
EM RADIATION

DECAY
HALF-LIFE
PHYSICS
SYNCHROTRON
IONISING
NUCLEAR SCIENCE CROSSWORD

ACROSS
5. Radiation that releases a particle that is a helium nucleus (two protons and two neutrons)
8. A type of ionising radiation
9. Nuclear reactors can be used to generate this
10. Large Hadron Collider (abbreviation)
12. A radioactive isotope
13. A type of non-ionising radiation (two words with space)
16. This creates and controls the chain reaction of atom-splitting that results in nuclear fission
17. Natural radiation that’s all around us
18. An isotope of an element has a different number of these
20. Australian Nuclear Science and Technology Organisation (abbreviation)

DOWN
1. Used as fuel in a reactor
2. Radiation that releases an electron
3. Radiation used to make images of our bones
4. The LHC in Geneva is undergoing experiments to help understand the first moments of this (two words with space)
6. This rapidly speeds up particles almost to the speed of light
7. This is used to detect the presence of radiation (two words with space)
11. Radioisotopes can be used to cure this disease
14. Ionising radiation can damage this molecule in the nucleus of our cells
15. The biggest nuclear reactor in the Solar System
19. Open Pool Australian Lightwater (abbreviation) reactor
EVALUATE

CREATING YOUR OWN NUCLEAR SCIENCE QUIZ

1 Ask each student to call out a word related to nuclear science. Record these on the board.

2 Each student must pick six words from the board and write a definition for each.

3 Students then pick four more words from the board and write a paragraph describing them. They should highlight their chosen words in the paragraph.

4 Students create a concept map showing all they have learnt about nuclear science using at least half the words from the board. They should show links between words and write along lines connecting words to show how the terms are related.

NUCLEAR SCIENCE INDIVIDUAL UNIT REVIEW

<table>
<thead>
<tr>
<th>PERSONAL SUMMARY</th>
<th>WHERE TO NOW?</th>
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<tr>
<td>List the five most interesting things you learnt about nuclear science when studying this unit of work.</td>
<td>Write five questions that have arisen when studying this unit of work on nuclear science.</td>
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</table>

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<th>SOMETHING ETHICAL</th>
<th>TAKING ACTION</th>
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<td>List as many ethical issues you can think of that arose during your study of nuclear science.</td>
<td>If you were a science leader in the world today and money and borders were not an obstacle, what would you see the future of nuclear science to be for research, medicine and energy?</td>
</tr>
</tbody>
</table>

TAKE AN ONLINE QUIZ

A short quiz of 12 questions with feedback given at the end of the quiz:
http://www.softschools.com/quizzes/chemistry/nuclear_chemistry/quiz745.html

This quiz has 15 multiple-choice questions and gives you feedback after each question and a running score:
http://www.sciencegeek.net/Chemistry/taters/Unit1NuclearChemistry.htm