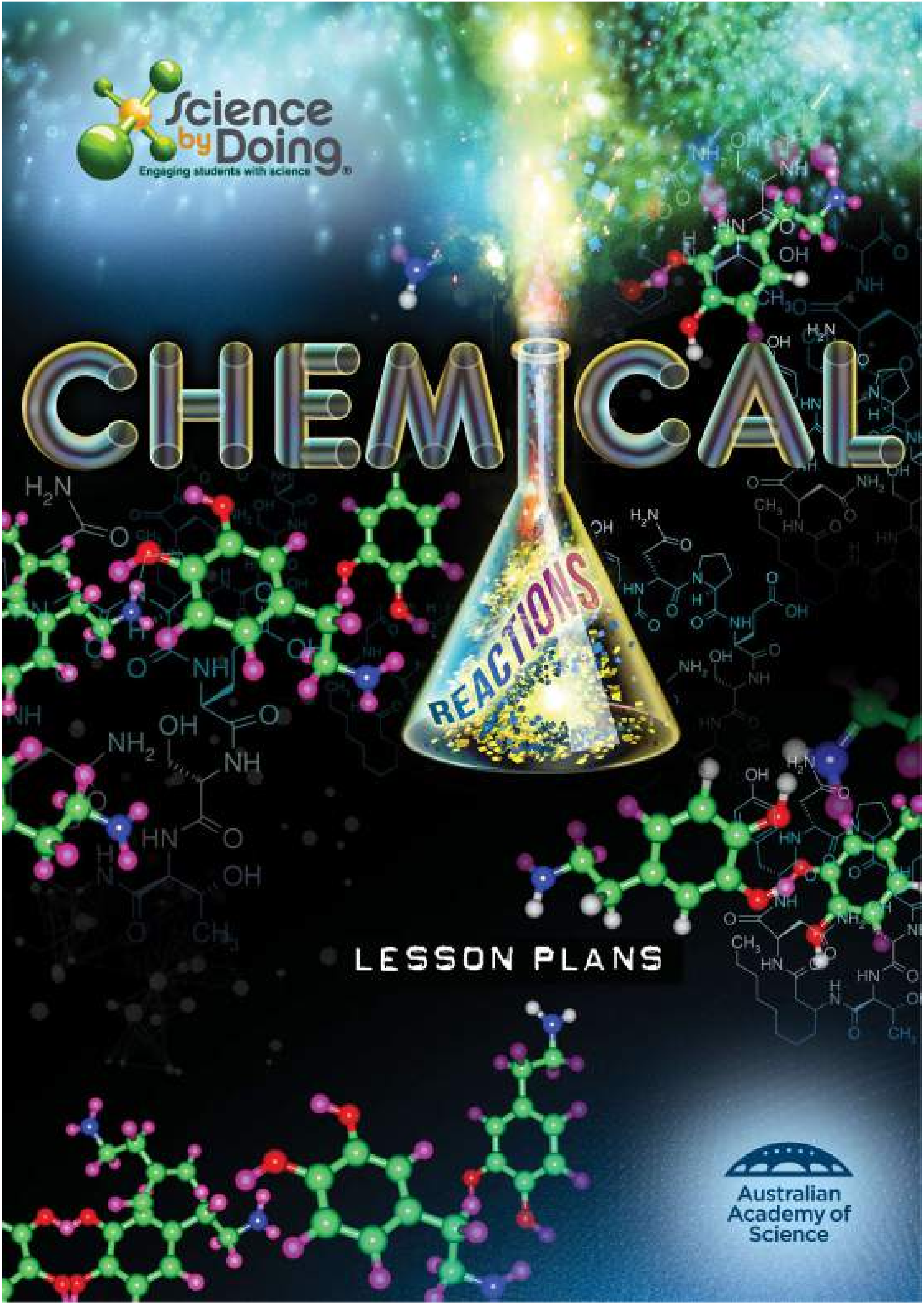
Science by Doing
Engaging students with science

CHEMICAL REACTIONS



LESSON PLANS

Australian Academy of Science

Part 5 Energy from the nucleus

Activity No	Activity Name	Lesson type	Activity Description	
5.1	What is radioactivity?	Engage, Explore & Explain Classroom& Digital Medium	Students are asked to brainstorm their current understanding of radioactivity and its effects, before using digital links to clear up misconceptions and introduce terminology. Students can complete a survey to find their annual exposure to radiation.	
5.2	Researching radioactivity	Explore & Explain Digital Medium	Students will research the history of our understanding of radiation using digital resources and also investigate the work of more recent nuclear physicists.	Optional
5.3	Detecting radioactivity	Explore, Explain & Elaborate Classroom & Digital Long	Students will learn about types of radiation and how they are detected. They carry out a simulated activity to learn about the properties of α, β and γ radiation.	
5.4	How long does it last?	Explore, Explain & Elaborate Classroom & Digital Long	Students will carry out a hands-on simulation of radioactive decay and explore applications of carbon-14 dating in a digital activity.	
5.5	Nuclear energy	Explain & Elaborate Classroom & Digital Long	Nuclear fission and fusion will be explained and compared. Students then use secondary sources to investigate the applications and problems associated with radioisotopes and present their findings to the class.	
5.6	The future	Explain, Elaborate & Evaluate Classroom & Digital Long	Students will use secondary sources to research the future of nuclear energy as an alternative source of power, compared to renewable energy sources and fossil fuels, culminating in a class debate.	

5.1 What is radioactivity?

Lesson outcomes

At the end of this activity students will be able to:

- describe radiation as energy from waves or fast moving particles
- give examples of sources of natural radiation
- distinguish between radiation and radioactive isotopes of atoms.

What ideas might your students already have?

Many students confuse radiation (particles or waves) and radioactive sources.

Key vocabulary:

Radiation, radioactive, radioisotope, unstable.

Equipment list

Each GROUP will require:

- butcher paper
- marking pen
- *Science by Doing* **Student Digital**.

Each STUDENT will require:

- ***Notebook***

Things to consider:

Asking students to brainstorm what they already know about radioactivity is a good way to start **Part 5: Energy from the nucleus**. In groups of three or four, they discuss their ideas (right or wrong). They list 'facts' on butcher paper and keep this until the end of Part 3, when they can revisit it to check if they have changed any ideas (see *Science by Doing* **Student Digital, Activity 5.1 *Notebook***).

Digital interactive resources

What is nuclear radiation? (1'): A short illustrated segment that defines the terms radiation, unstable nuclei, radioactive and radioisotope.

How damaging is radiation? (4') Corrects common misconceptions about radiation with simple facts. Introduces sources of natural radiation.

Radiation vs radioactivity (3'): Corrects misconceptions about radiation and radioactive atoms. Introduces the Geiger counter to measure radiation. Explains the ranges of alpha and beta radiation and the dangers of radioactive atoms in nuclear explosions.

Lesson plan

Step 1: Begin this segment with a brainstorm (see *Things to consider*).

Step 2: Class discussion using the stimulus material in the *Science by Doing* **Student Guide**.

Step 3: Groups use the *Science by Doing* **Student Digital** to investigate natural radiation and discuss the questions posed in the interactive. Ideas can be compared in a class discussion.

Step 4: The video resources can be viewed before students complete the ***Notebook*** questions.

Suggested questions:

1. Think of some kinds of radiation that you are exposed to every day?
2. What forms of radiation might you be exposed to occasionally?
3. Is this dangerous?
4. Do you think radiation is natural?

Follow up:

This activity sets the scene for **Part 5: Energy from the nucleus**. The ideas on butcher paper will be revisited in **Activity 5.4**.

5.2 Researching radioactivity

Lesson outcomes

At the end of this activity students will be able to:

- appreciate the contributions of named scientists in developing ideas of the nature of radioactivity
- process and analyse information from secondary sources
- present scientific ideas using appropriate language and conventions for a specific audience.

Key vocabulary:

Sievert, Becquerel, Geiger counter.

Equipment list

Each PAIR will require:

- access to *Science by Doing* Student Digital.
- ***Notebook***

Things to consider:

Discovery of radiation (9'): a good video chronology of the work of the scientists who discovered radiation – Michael Faraday, Wilhelm Rontgen, Antoine Becquerel and Marie and Pierre Curie.

Find out more

Marie Curie: Nobel Prize web site includes a biography and silent film of Marie Curie in her Paris laboratory.

The Nobel Prize in Chemistry 1911 was awarded to Marie Curie "in recognition of her services to the advancement of chemistry by the discovery of the elements radium and polonium, by the isolation of radium and the study of the nature and compounds of this remarkable element".

Sir Marcus Oliphant: two sites

Australians at work: biographical video clip of Sir Marcus Oliphant, who helped create the first atomic bomb, dropped on Hiroshima in 1945. Although it ended World War Two, he could never reconcile himself to the loss of civilian life.

RiAus website: Biography and other sources listed.

Sir Marcus Oliphant (1901-2000) was a founder of Canberra's Australian National University and a former Governor of South Australia. While at Adelaide University in 1927, he was accepted to Cambridge University, where he joined a team whose task was to split the atom. During World War Two, he developed the centimetre wave radar. After the atomic bomb was used against civilians in Hiroshima, he devoted his considerable scientific talent and energy to finding peaceful uses for atomic power.

The students should be encouraged to explore other modern day scientists using an internet search.

Teacher content information:

SI units used in measuring radiation

- **Sievert (Sv)**: used to measure the absorbed dose in biological matter, accounting for the interaction of the type of radiation and its associated linear energy transfer through specific tissues. The working SI unit is the Sievert (Sv), while the traditional unit is Rontgen equivalent man (rem). 1 rem = 0.01Sv = 10mSv

CNSC Dose Limits (non-nuclear energy worker):

Whole body = 1mSv/yr = 100 mrem/yr; skin, hands, feet = 50 mSv/yr = 5 rem/yr

- **Becquerel:** The activity of a radioactive substance is the measurement of the number of disintegrations of the atom, noted per second. The working SI unit is Becquerel (Bq), while the traditional unit is a Curie (Ci).

  1Bq = 1 disintegration per second 1 Ci = 3.7×10^{10} Bq

Lesson plan

Step 1: Introduce the historical detection of radiation by Becquerel and the Geiger counter as an instrument for measuring radiation, using the stimulus material in the *Science by Doing* **Student Guide**.

Step 2: Class watches the Discovery of radiation video and completes ***Notebook*** activities. This could be done in groups, which report their answers to the class.

Step 3: In **Find out more** students can investigate the work of scientists who have contributed to our understanding of nuclear physics.

5.3 Detecting radioactivity

Lesson outcomes

At the end of this activity students will be able to:

- explain radioactivity in terms of release of energy and particles from an unstable nucleus
- recall the difference in the nature and properties of alpha, beta and gamma radiations
- use a Geiger counter (or simulation) to investigate the properties of alpha, beta and gamma radiations.

What ideas might your students already have?

Hopefully student misconceptions have been rectified, however this is a good time to review and reinforce safety issues.

Key vocabulary:

Alpha(α) particle, beta(β) particle, gamma(γ) ray, background radiation, range, penetration.

Equipment list

Each CLASS will require:

- sources of α, β and γ radiation and stand for support
- Geiger counter and clamp/retort stand to support tube
- Lead sheets, aluminium sheets, sheets of paper and card
- metre rule.

Each PAIR will require:

- access to computer simulation of α, β and γ radiation and *Science by Doing* Student Digital.
- ***Notebook***

Things to consider:

Teacher Demonstration

Before using radioactive sources ensure you are aware of the government regulations for handling such material. Common sealed sources available for schools are cobalt-60 (gamma source), strontium-90 (beta source) and Americium-241 (alpha source). http://www.arpansa.gov.au/pubs/rps/rps18.pdf

Ensure students are a safe distance away (two metres).

Demonstrate the following:

1. **Background radiation:** set the Geiger counter to run with no radioactive sources nearby. Illustrate good scientific practice in reliability by doing three counts (one minute each) and having a student work out the average value.
2. **The effect of using a shield (penetration):** take counts as before, using the α, β and γ radiation sources, inserting in turn between the G-M tube and source paper, card, aluminium, lead (add extra pieces or thicker sheets).

Remind students that the background radiation must be subtracted each time to make a fair test.

3. **Range of radiation in air:** place the Geiger counter 10 cm from the radioactive source. Record the count for one minute, then repeat at 20 cm, 40 cm, 80 cm etc from the source. Stop when the count reaches background level. Repeat for the other sources. Alternatively, gradually move the G-M tube away from the source to illustrate decreasing counts without measuring distances. This will be less time consuming and more appropriate, particularly if the class is carrying out the simulation practical as an experimental design activity.

Investigating radioactivity simulation: students can select sources of radiation, as well as barriers (air, smoke, paper, glass, aluminium, lead) and distances at which radiation counts can be carried out. This enables experiments comparing the three types of radiation to be designed, testing ranges of penetration and effect of barriers.

Don't forget to explain that a background count in air with no radioactive source is necessary to account for natural radiation. This value should be subtracted from counts for each radioactive source. http://www.scootle.edu.au/ec/viewing/L45/index.html

Science by Doing **Student Digital Activity 5.3**: This section is important and one students will be interested in. They will watch a video and use a graph to answer ***Notebook*** questions, and complete a survey of their own exposure to radiation. You may wish to set aside a separate lesson for this, or set as homework to be discussed in a subsequent lesson.

- **Everyday exposure to radiation: Radiation 101 - Catalyst** (7'). This video covers background, natural and medical radiation. Safe levels of exposure are discussed.
- **Calculate your annual exposure to radiation**. (**Student Digital**), also reference Australian Nuclear Science and Technology Organisation (ANSTO): Ionising radiation brochure: http://www.ansto.gov.au/__data/assets/pdf_file/0017/45314/Ionising_Rad_broch_lr.pdf

Note: The estimates of exposure are based on ANSTO information. The biggest variation between people is likely to be due to medical exposures. Exposure can range from about 20μSv for a chest, arm or leg X-ray to 3000μSv for a scan of a larger area. The example value of 250μSv can be modified following discussion with students.

Teacher content information:

Extract from the Australian Government document on use of radiation in schools:

'Background radiation occurs everywhere and, in Australia, we each receive an annual whole-body dose that is typically about 2 millisievert (mSv). Medical radiation in Australia (X-rays and radioactive materials used in diagnosis), results in an average dose per person of about 1.2 mSv per year. By comparison, the dose received by the hand (not the whole body) during a standard school demonstration will be no more than 0.01 mSv (see the risk assessments in Annex 3).

Consequently, a teacher could carry out hundreds of demonstrations in a year before acquiring a dose equal to a typical background level. Doses to students observing demonstrations will be far lower.'

Sealed radioactive sources

The National Disaster Resilience Program (NDRP) provides broad guidance for sealed radioactive sources suitable for use in schools. The activities of the specified sealed sources are:

Table 3: Sealed radioactive sources for use in schools and colleges	
Radionuclide	**Max activity of sealed radioactive sources in NDRP for use in schools (kBq)**
Cobalt-60	200
Strontium-90	80
Caesium-137	200
Polonium-210	-
Radium-226	20
Americium-241	**40**

Lesson plan

Step 1: Class discussion - what makes an atom radioactive? Use the carbon isotopes in the *Science by Doing* **Student Guide** to help explain. Students write symbols for given isotopes.

Step 2: Teacher demonstration of properties of radioactive sources (optional).

Step 3: Students design and complete Investigating radioactivity simulation using links in the **Student Digital**.

Step 4: Discuss results and differences in properties observed using diagrams to illustrate. See *Science by Doing* **Student Guide** as a reference to help tabulate data.

Step 5: Students write a practical report on their experiment.

Step 6: In the digital activity, students can learn about everyday exposure to radiation. The survey of annual exposure to reactivity can be done here or as homework.

Suggested questions:

1. What is background radiation?
2. Why is it subtracted from the readings obtained using the radioactive sources?
3. Which type of radiation is least/most penetrating?
4. Which type of radiation has the smallest/largest range?
5. What material would you choose for a container used to store radioactive waste? Explain.

5.4 How long does it last?

Lesson outcomes

At the end of this activity students will be able to:

- recall what is meant by the half-life of a radioactive element and describe the pattern of decay
- explain why carbon-14 can be used to date material that was once part of a living organism
- make a presentation to demonstrate an application of carbon-14 to research.

Key vocabulary:

Half-life, radiocarbon dating.

Equipment list

Each GROUP will require:

- 100 plastic counters with a dot on one side
- bag to hold counters
- large tray.

Notebook Q5: Student needs will depend on their choice of task.

Each GROUP will require:

- cardboard for poster and drawing materials for part (a)
- access to a computer and arrangements made to show their presentation to a Year 7 class for part (b).

Things To Consider:

How does radiocarbon dating work? (2'): This video in the *Science by Doing* Digital explains the difference between C-12 and C-14, discussing the decay curve, half-life and how the ratio of C- 12:C-14 can be used to calculate the age of an object that was once part of a living thing.

This lesson would split well into two shorter lessons, the second dealing with the digital activities.

Teacher content information:

Carbon-14 dating (radiocarbon dating or simply carbon dating) is a technique that uses the decay of carbon-14 to estimate the age of organic materials, such as wood and leather, of up to about 60,000 years old. It was invented by William Libby in 1949. He was awarded the Nobel Prize in Chemistry for his work. The method has been used to date many items, including samples of the Dead Sea scrolls, Egyptian artefacts, the shroud of Turin and Otzi the ice-man. It is most frequently used to date material from archaeological sites.

The Earth's atmosphere contains several isotopes of carbon, roughly in constant proportions. These include the main stable isotope carbon-12 and an unstable isotope carbon-14. Through photosynthesis, plants absorb both forms from carbon dioxide from the air. When an organism dies, it contains the standard ratio of carbon-12 to carbon-14. The proportion of carbon-14 decreases at a known rate with time as it is not replaced after death. The half-life of carbon-14 (about 5730 years) can then be used to calculate the age of objects. Other radioisotopes can be used in a similar way to date older objects. Rubidium-87, with a half-life of 48.4 billion years, can be used to date very ancient rocks and minerals.

Lesson plan

Step 1: Begin the lesson with the group activity Radioactive decay. Students should then complete the graph and discussion questions.

Step 2: Begin a discussion of half-life by asking students to compare their graph with the graph of carbon-14 on p72 of the *Science by Doing* **Student Guide**. Use the illustrations and questions to introduce radiocarbon dating.

Step 3: Begin the digital activities by letting students browse and discuss the roll-over function to gain an understanding of how carbon-14 becomes part of all living things.

Step 4: Watch **How does radiocarbon dating work?** before answering ***Notebook*** Questions 1- 4.

Step 5: Groups should have time to choose and carry out the activity of their choice for Question 5.

Follow up:

More applications of radioisotopes, related to their half-life, will be explored in **Activity 5.5**.

5.5 Nuclear energy

Lesson outcomes

At the end of this activity students will be able to:

- distinguish between nuclear fusion and nuclear fission
- describe examples where advances in technology have significantly affected the lives of people
- evaluate the benefits and problems associated with medical and industrial uses of nuclear energy
- appreciate the importance of science in their lives and the role of scientific enquiry in increasing understanding of the world around them.

What ideas might your students already have?

Students should be reasonably well informed about radioactivity, however it is important to balance the problems associated with the use of radioisotopes with the benefits.

Key vocabulary:

Fission, fusion, dosimeter, fuel rods, control rods, coolant.

Equipment list

Each GROUP will require:

- *Science by Doing* **Student Digital**
- butcher paper for mind map

Things to Consider:

Interactive Digital Resources:

- **Nuclear power to the people:** (4'26") – an entertaining song about conservation of mass; Einstein's equation E=mc2 in connection with energy release in nuclear fusion and fission; chain reactions; power plants etc.
- **It's nuclear:** (4') This video reviews types of radiation then focuses on measuring background radiation so personnel in nuclear-powered ships and submarines remain safe. The use of dosimeters to measure workers' exposure is discussed.
- **Nuclear power plant simulation:** This simulation will help students understand how nuclear power stations function to generate electricity. It gives students control of a small power station for a fuel cycle to generate as much electricity as possible without causing a meltdown. They can manipulate the control rods and reactor temperature using coolants.

Research of applications of radioisotopes

Notebook Question 8 can be used as an individual, paired or group activity. It is also suitable as an assessment task.

In Part (a), the mind map can be done in groups or as a class activity on a whiteboard (or SMART Board), before students choose the application they will research for Part (b). Drawing lots for topics is a good way to ensure as many different areas as possible are covered.

References links in **Find out more**

- **ANSTO website:** information on all aspects of nuclear chemistry, including the OPAL Research Reactor, a video on Synchrotron, environmental protection, human health issues and waste management.
- **Radioactive metal tracers:** (3' 07") Covers the use of metal tracers e.g. technetium-99m to identify body problems.
- **Molecular nuclear medicine – making personalised treatment a reality:** (22') The use of nuclear medicine in cancer treatment. The video includes the history of radioactivity and cancer through to modern treatment techniques.
- **What is a PET scan?:** (I') Shows a positron emission tomography (PET) scan in which radioactive sugar molecules are injected to find hot spots of cancerous cells where sugar is metabolised more quickly. The fact that positrons are actually antimatter electrons shows how extraordinary some of these technologies are.
- **What is a CAT scan?:** (1'18") Shows a computerised tomography (CT) scan which produces images of thin slices of the body to look for tumours.
- **What is a bone scan?:** (1') Shows the measurement of activity and possible cancer in bones by injection of radioactive isotope to find hotspots.

Teacher content information:

A nuclear power plant is a thermal power station in which the heat source is a nuclear reactor. As is typical in all conventional thermal power stations, the heat is used to generate steam, which drives a turbine connected to a generator that produces electricity.

The core of the reactor contains fuel rods that house uranium oxide pellets. Water surrounding the fuel rods slows down neutrons so they are more likely to cause fission. Control rods can be adjusted to absorb neutrons to prevent an uncontrollable chain reaction.

Other useful links;

- **Radiotherapy:** website of the Cancer Council of Victoria, giving information on all aspects of radiotherapy as a cancer treatment.
- **Science Daily:** This website has articles on the uses of carbon-14, e.g. in dating art works and archaeology.

Lesson plan

Step 1: Begin by playing the Nuclear power to the people link. Have the class read the information on fusion and fission and discuss before they complete the tabulation activity.

Step 2: Complete digital activities on chain reactions and nuclear power plant simulation. Students complete ***Notebook*** Questions 1-7.

Step 3: Introduce the research task (Question 8 – see B) and allow students time (30 minutes) to research and prepare a report for the class.

Step 4: Presentations should be followed by a review of the positives and negatives of nuclear applications.

Suggested questions:

1. What is the basic difference between fission and fusion?
2. What are some advantages/disadvantages of using nuclear fission to produce electricity?

3. What advantage does nuclear fusion have over fission?
4. Why is nuclear fusion not used in power plants today?
5. How is the amount of electricity produced in a nuclear power plant controlled?
6. Why does Australia have a small nuclear reactor?

Follow up:

Knowledge and understanding gained in this activity will be important in **Activity 5.6**, which includes a class debate.

5.6 The future

Lesson outcomes

At the end of this activity students will be able to:

- process and evaluate information from secondary sources concerning the future of nuclear power
- use the internet to facilitate collaboration in joint projects and discussions
- present information using appropriate scientific language when discussing future energy options.

What ideas might your students already have?

Students should have some understanding of the alternative energy options from this topic and previous studies of science.

Equipment list

Each STUDENT will require:

- *Science by Doing* **Student Digital**

Things to Consider:

Hints on debate: Make sure the students have had ample opportunity to watch the resources and in their debating groups, draft a list of key points to support their debate argument. Some teacher support may be required with this stage. Go through the debate rules with the students which are listed in the *Science by Doing* **Student Guide** – especially if students are not familiar with this style of class debate. In dividing the class for the debate, give consideration to scientific and debating skills to ensure a balance between the teams. Start the debate with a confident and thoughtful student to ensure a high standard is set for both teams from the start. If the teams are not even, select a student who will be invited to speak twice for their team.

Digital Interactive resources:

- **Fukushima news report** (1’25’): report on the immediate handling of the 2011 disaster by the company. It covers contamination of ground water and seepage into the sea.
- **The future of fusion (*Catalyst*):** this program explains fusion in the context of the sun as the ultimate source of energy and compares it to coal power (carbon emissions). It looks at Joint European Torus (JET), the largest reactor built to date, and deuterium as a fuel. The conclusion is that fusion is the answer, but the question is when can it be achieved?
- **Managing nuclear waste:** ANSTO publication with facts about management and transport of nuclear waste in Australia.
- **Synroc:** an Australian invention to store nuclear waste safely in a chemically inert synthetic rock.
- **Next generation nuclear power:** Gives the negatives and positives about nuclear power. Explains safety precautions in place and discusses Generation Three Reactors as being very safe.
- **What Powers Australia** (3’17”): Interviews with people to find their views about Australian energy sources and what they think we should use in the future (solar, wind, nuclear).

Lesson plan

Step 1: Introduce students to the task by discussing the article in the *Science by Doing* **Student Guide** and using the questions to stimulate thinking about the issues. Groups should review their lists from **Activity 5.1** and discuss if and how their ideas have changed.

Step 2: Introduce the debate topic and rules. Give instructions on the planning process needed in the *Science by Doing* **Student Digital**.

Step 3: Give students' time to prepare their contributions (30 minutes).

Step 4: Class debate (see **Hints** above and instructions in the **Student Guide**).

5.7 Sample test

A sample **summative test** and **marking scheme** have been developed and are available to teachers from *Science by Doing* at sbd@science.org.au. Both are editable versions, so you can adapt them to your students' needs.

Note - *Science by Doing* provides sample assessment items and whilst every effort has been made, the security of these items cannot be guaranteed. *Science by Doing* encourages teachers to modify the items to suit individual teaching programs.

Acknowledgements

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This resource was revised in 2017 by Jef Byrne and Dr Jim Woolnough.

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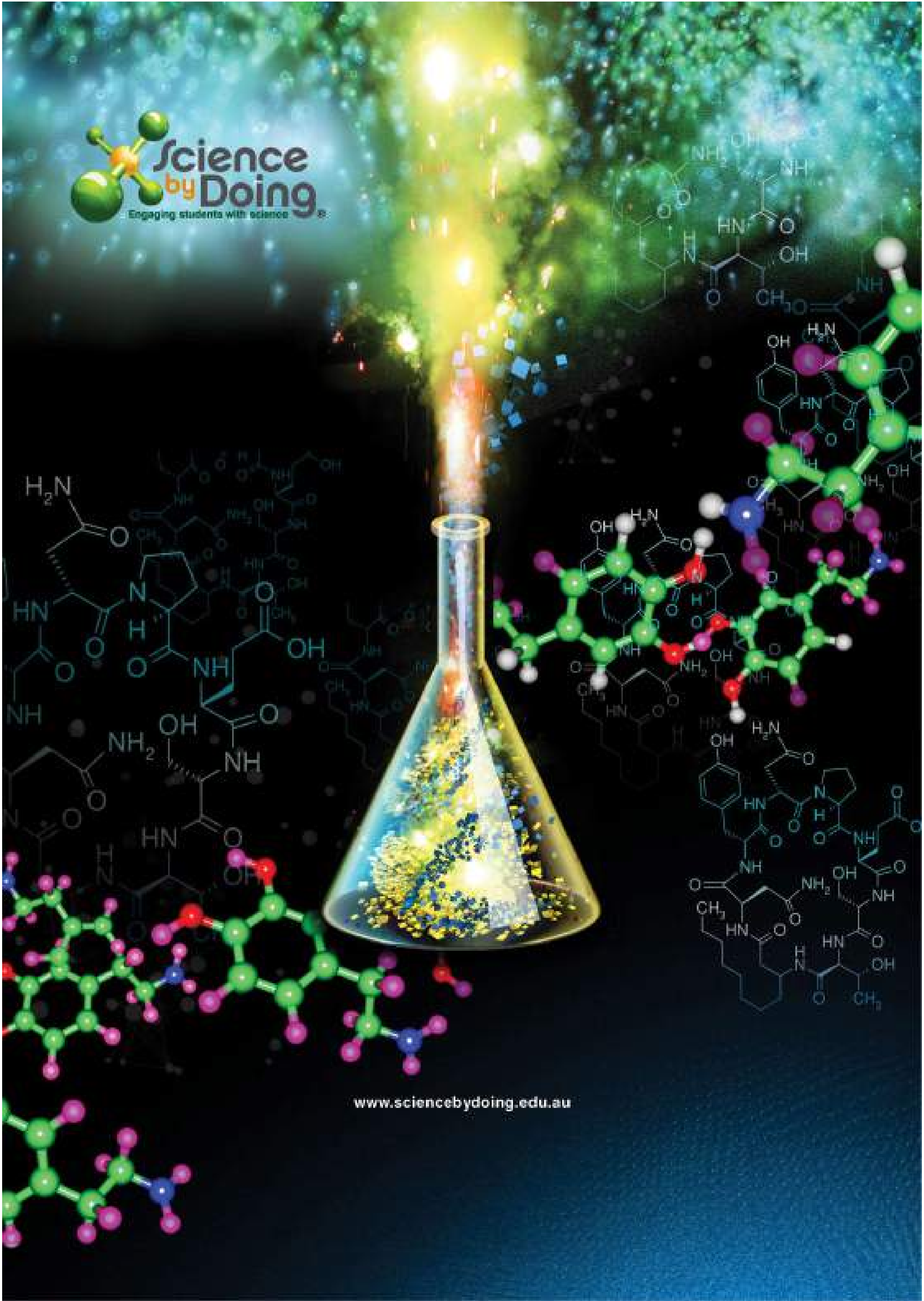
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