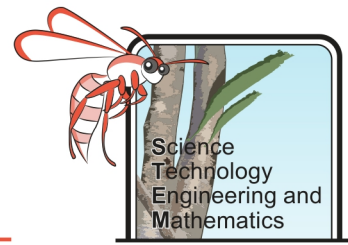


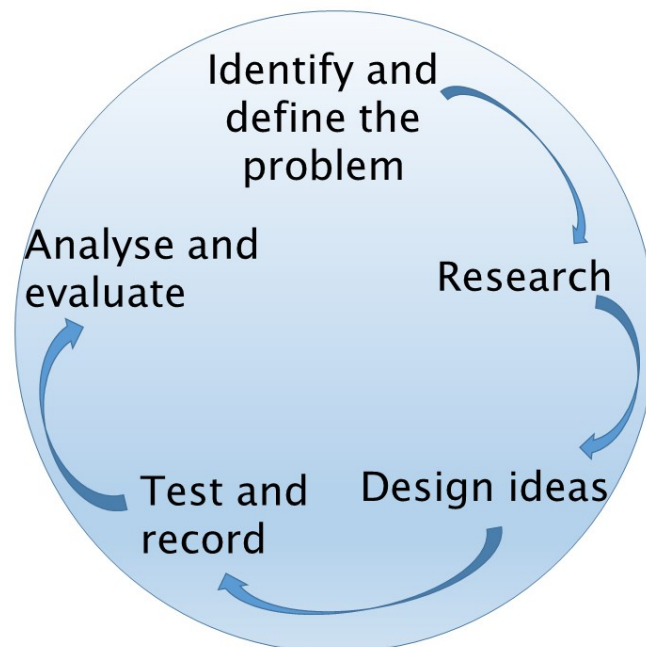
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The Challenge

With populations increasing at an exponential rate and the volume of electronic devices being used in everyday lives escalating, not to mention the increased use of transport, it is vital that Australia can provide a future energy mix that supports modern lifestyles. Nuclear power is undoubtedly a means of producing vast amounts of energy with relatively low emissions and without reliance on the weather, however, one of the main issues with nuclear power is what to do with the waste.

Your challenge is to investigate the issues with nuclear waste and to produce a report, which could be provided to government, outlining if and where nuclear waste could be safely buried.



Background Information

Nuclear power plants mainly use enriched uranium as their source of fuel. In a nuclear power plant the fuel is compacted into fuel rods, which are surrounded by a fluid in the reactor. The fuel undergoes a controlled chain reaction which gives off heat, thus heating the surrounding fluid. The hot fluid then heats water, creating steam which turns turbines, to generate electricity.

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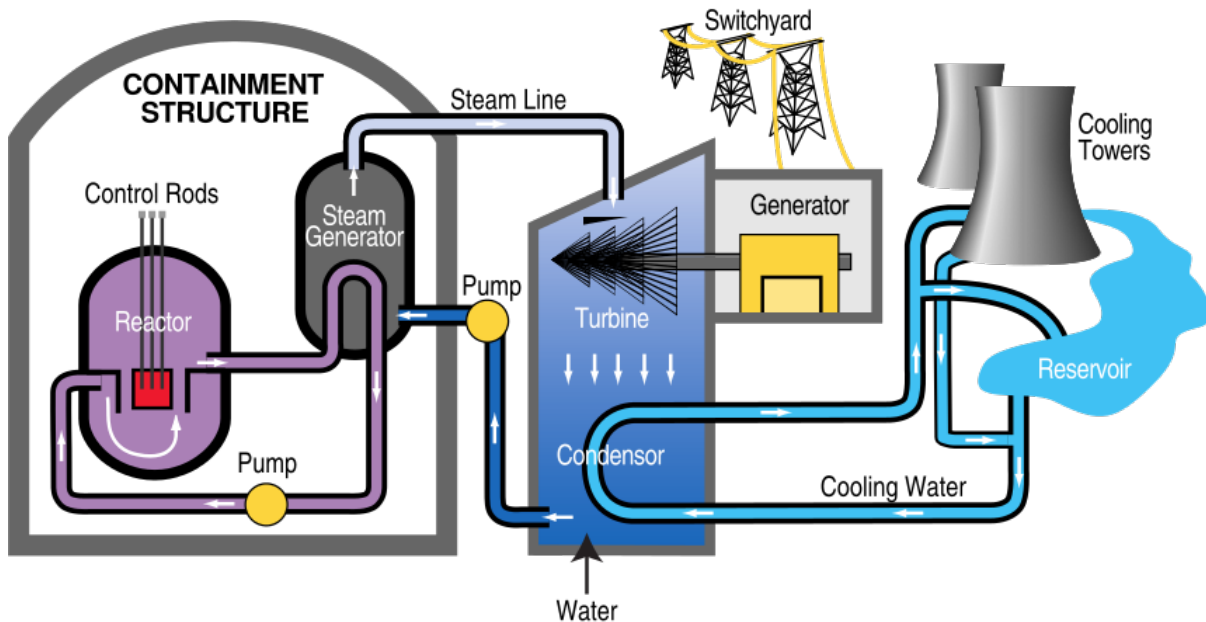
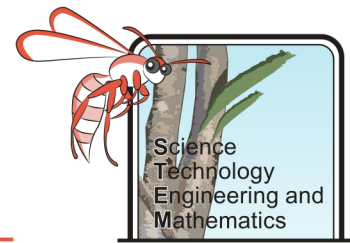


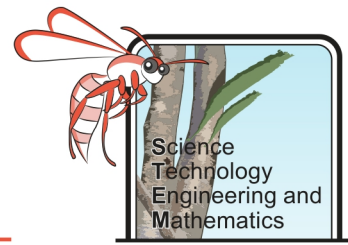
Figure 1. Image showing the key parts of a nuclear reactor and how it generates electricity. (Tennessee Valley Authority, 2018)

Nuclear waste is radioactive, and therefore it is very important that it is disposed of safely. At present the most common method of nuclear waste disposal is to bury it in a geologically stable area (far from any faults or volcanic areas). The waste is buried around 500 – 1,000 m below the surface, with the aim to permanently isolate it from the human environment.

Some issues with burying the waste can be that the material that it is stored in starts to crack, allowing water in which can become contaminated. Some radioactive isotopes also can remain radioactive for very long periods of time (several hundreds of thousands of years), which makes it very hard to monitor and to be confident that there will be no geological changes affecting it over this time period.

A suitable solution to deal with nuclear waste is one of the most important factors in making decisions around nuclear power generation in Australia.

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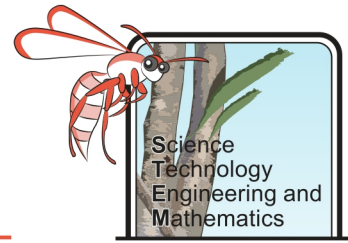
Background Research

1. What type of radiation is produced by a nuclear reactor?

2. How does a nuclear reactor create electrical energy? Explain the process using a labelled diagram.

3. What are the potential hazards to human health of nuclear waste?

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4. What does half-life mean (in terms of radioactive materials)?

5. What are the different levels of nuclear waste, and how are they treated?

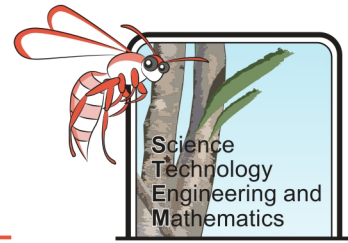
6. How is nuclear waste monitored, once disposed of?

7. What other activities produce nuclear waste (other than power generation)?

8. Which countries currently use nuclear power (list at least 10)?

9. How old are the oldest rocks in Australia?

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10. What tectonic setting does Australia have? (Hint: look at a map of tectonic plates of the world). Add a labelled diagram.

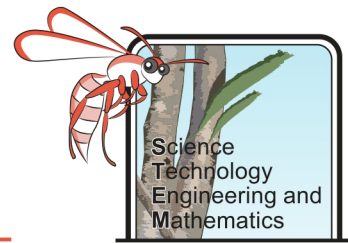
11. Is Australia considered geologically stable or very active? Use your knowledge of tectonic processes to aid your explanation.

12. Have there been any proposed burial sites for nuclear waste in Australia in the past?

Location	Reference

13. What are some of the key features an ideal nuclear burial site would have?

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Blocking Radiation

Objective

To determine how to block different types of radiation (alpha, beta and gamma).

Method

Note: Due to the type of materials that are being used this investigation is by teacher demonstration. Please listen and observe carefully (especially to safety instructions).

1. Your teacher will be demonstrating how materials block three types of radiation (alpha, beta and gamma). This will be done using a Geiger counter, a piece of equipment that detects radiation. Your teacher will set the Geiger counter onto the desk and ask you to measure the counts (noises from the counter) over a one minute period. This is the background radiation in the room (the level of normal radiation, don't worry everywhere has a background radiation level).

Background radiation in our classroom = _____ counts/minute

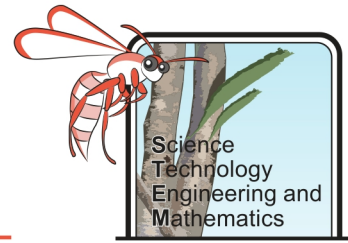
2. Your teacher will take out different sources of radioactive material to demonstrate different effects. What happens when the source is moved away from the Geiger counter?

3. Your teacher will now bring out a source of alpha radiation, observe what happens when the Geiger counter is moved closer and then further away.

Observation: _____

4. Now they will place a range of objects between the source of alpha radiation and the Geiger counter. Measure how many counts per minute the Geiger counter reads and place this in your table (which you need to create, see below).
5. Repeat this process for the sources of beta and gamma radiation too.
6. Complete table two – to remove the background radiation reading from each of your results (counts per minute – background radiation in counts per minute) to get true readings for each material.

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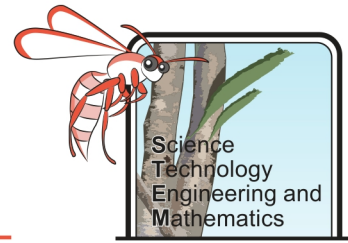
Results and Analysis

1. Create a table to show the number of counts per minute detected when each material blocked (wholly or partially) each of the radiation sources. Record your findings into this table. Hint: don't forget to adjust for background radiation.

2. Which materials were able to block alpha radiation?

3. Which materials were able to block beta radiation?

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4. Which materials were able to block gamma radiation?

5. Which type of radiation was easiest to block (blocked by the most materials)?

6. Were all materials the same thickness?

7. Could this difference in thickness of materials have impacted your results?

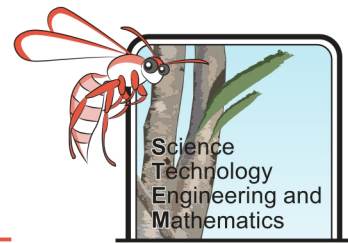
8. What type of casing would you recommend for disposal of nuclear waste?
Explain your answer.

9. Some granites can be quite radioactive, such as the bedrock in Aberdeen, Scotland. Does this knowledge change your answer to question 8? If so, why?

Evaluation

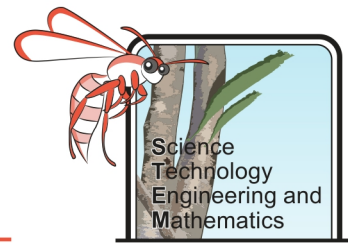
1. Was your experiment a fair test? If not, why not?

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2. What improvements could you make the experiment to make your results more reliable?

3. What future experiments could you do to improve your recommendations/conclusions?



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Decay Rate Modelling

Objective

To model radioactive decay of elements, using popcorn.

Equipment

- Bag of popcorn (with allocated time written on it)
- Microwave
- Newspaper
- Stopwatch (or phone timer)

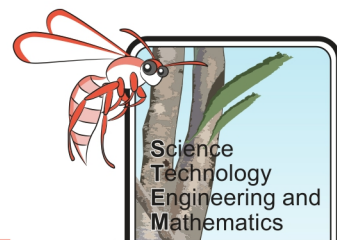
Method

1. When it is your turn, put your bag of popcorn in the microwave with the time set to 2 minutes.
2. As soon as you hear the first pop start timing using the stopwatch, and stop the microwave once you have reached your allocated time (written on your bag).
3. Count and record the number of kernels (Kernalite) and popped corn (Popcornium) in the class results table.
4. Open the pre-cooked bag of popcorn your teacher has given you (unknown cooking time).
5. Count the number of kernels (Kernalite) and popped corn (Popcornium) and record this in the second table

Results and Analysis

Bag Number	Popping time (seconds)	Number of Kernalite Ke (parent)	Number of Popcornium Pc (daughter)	Total Ke + Pc	% Ke (parent) /Total *100	% Pc (daughter) /Total *100
1	10					
2	20					
3	30					
4	40					
5	50					
6	60					

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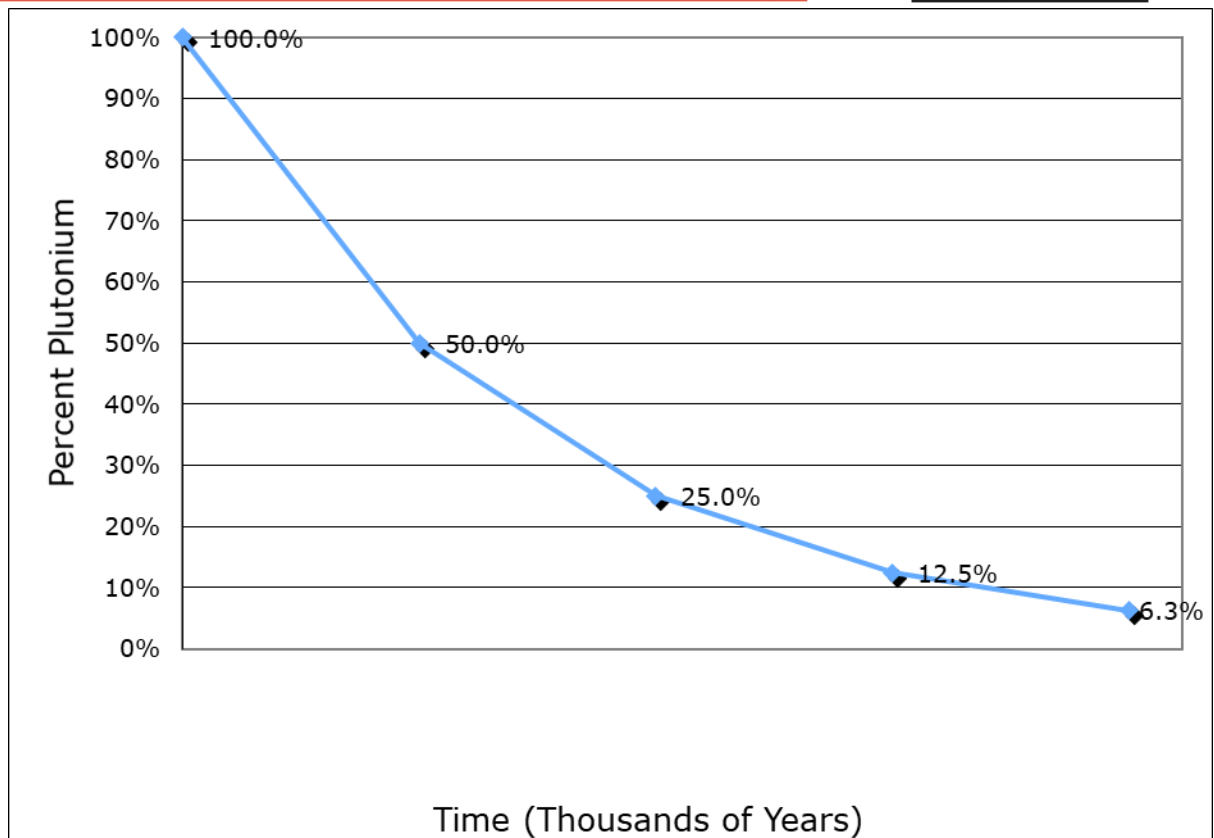
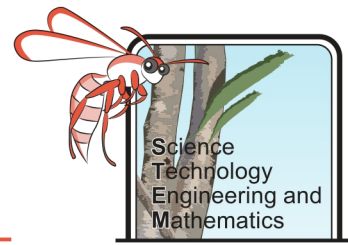
1. Record data from the whole class into the table above.
2. Work out the percentage of parent (Ke) and daughter (Pc) for each bag.
3. Using the data in the table plot a graph of % Ke versus time (s) ensuring you add a line/curve of best fit.
4. Record the data for your sample of unknown cooking time in the table below. Use your graph (question 3) to work out the popping time for this bag and for those from the rest of your class.

Bag Letter	Number of Kernalite Ke (parent)	Number of Popcornium Pc (daughter)	Total Ke + Pc	% Ke (parent) /Total *100	% Pc (daughter) /Total *100	Popping Time
A						
B						
C						
D						
E						
F						

5. What is the half- life of the popcorn? (How long does it take for the number of Ke (kernalite/kernels) to reach 50%?)

-
6. The radioactive waste from spent fuel rods consist primarily of cesium-137 and strontium-90, but it may also include plutonium. The half-lives of these radioactive elements can differ quite extremely. Plutonium has a half-life that can stretch to as long as 24,000 years. (Wikipedia, 2018) Add numbers to the horizontal axis on the graph to show this.

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7. After 10,000 years roughly what percentage of the parent (plutonium) will be left?

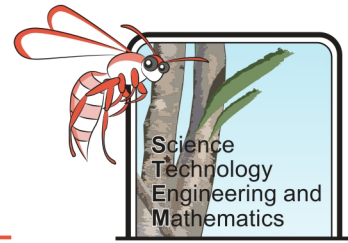
Evaluation

1. How similar was your popcorn decay curve to a radioactive decay curve?

2. What did the kernels popping represent in the model?

3. Were there any outliers in your experiment? How do you know?

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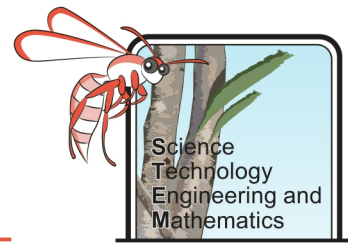
4. What could have caused experimental error?

5. What are the strengths and weaknesses of using popcorn as a model for radioactive decay?

Strengths	Weaknesses

6. As nuclear waste has such a long half-life, what are some key considerations that would need to be made before disposing of it?

Burying Nuclear Waste – Student Booklet



Investigating Rocks

Objective

To investigate the properties of different rock types and evaluate their strengths and weakness in relation to storing nuclear waste.

Background Information

Most nuclear waste is buried underground at a depth of 500 – 1,000 m below the surface. This is a long way to dig through very hard rock, and can be challenging. The surrounding bedrock is very important to ensure the safety of the waste, or more importantly the safety of living things near where the waste is buried. If ground water can reach and pass through where the waste is stored it can carry some nuclear isotopes with it. If the surrounding rocks are weak or crumbly they can collapse and this can mean the burial chamber is not stable – again this can lead to water leaching in. As nuclear waste can be reactive for thousands of years it is vital that it will be secure for the whole of this time.

Equipment

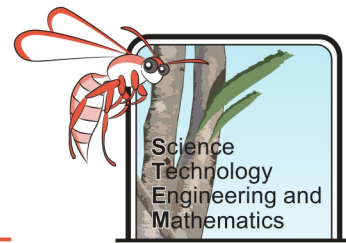
- Device with internet connection
- Hand lens
- Safety glasses
- Rock samples
- Pipette
- Beaker of water
- Dilute acid (in a stopper bottle)
- Paper towel

Research

Research the definitions for the following terms for properties of rocks.

Property	Definition
Crystalline	
Porous	
Permeable	
Cemented	
Consolidated	

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Property	Definition
Chemical reactivity	

Preparation

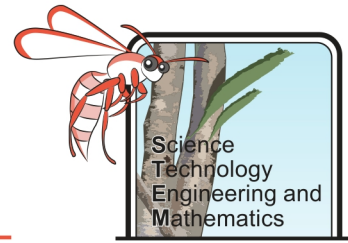
1. Create a method for testing each of the rock properties listed above.
2. Make a results/observations table.
3. Show your method and table to your teacher before you conduct your investigation.

Method

Results

As you conduct the tests above for each of your rock samples complete the following table.

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Analysis

1. Which of the rock types were permeable?

2. Which rock type(s) are most suitable for burying nuclear waste in? Use your research to justify your answer.

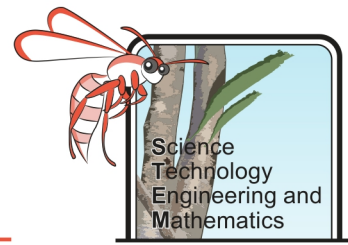
3. Highlight areas on a geological map of Australia where there are large (10 km² +) areas of suitable rock types.

4. Use the Geoscience Australia earthquake hazard map:
<http://www.ga.gov.au/interactive-maps/#/theme/hazards/map/earthquakehazards>
to exclude any areas which are unsuitable.

Evaluation

1. Were there any properties that you were unable to test? If so, suggest how you could test these.

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Probability of Earthquakes

Objective

To determine the probability of an earthquake occurring which may disturb buried nuclear waste causing leakage.

Background Information

Earthquakes are generally reported by their magnitude, or more correctly – Moment Magnitude. This is a modified version of the Richter scale which was devised in the 1930s by Charles Richter.

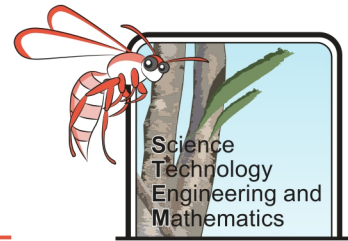
You will have heard the magnitude of earthquakes being reported on the news, and probably have a good understanding that the larger the earthquake the more energy is released. However, the Moment Magnitude is not a linear scale, in fact for each unit of increase (1, 2, 3...) the earthquake will be 10 times bigger and release around 32 times more energy.

Magnitude	Earthquake Effects
< 2	Rarely felt by people and may, at most, make light fittings swing.
2 – 3	Sometimes felt, but not usually recognised by people as an earthquake – feels like a passing truck.
3 – 4	Felt by most people nearby, may cause cracks to appear in plaster.
4 – 5.5	Felt by all nearby, can cause chimneys to collapse and damage to buildings, depending on the quality of construction.
5.5 +	Buildings will be damaged, ground will be cracked and underground pipes broken.

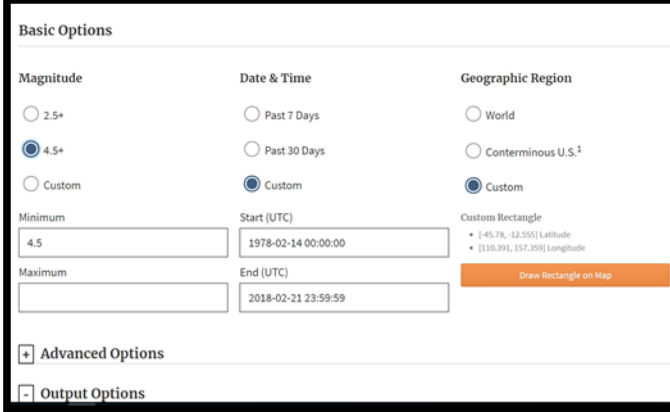
Method

1. Considering the information in the table above, which magnitude (threshold magnitude) would concern you if you lived near buried nuclear waste? Explain why.

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- Go to the USGS Earthquakes Earthquake database to search for historical earthquakes in Australia: <https://earthquake.usgs.gov/earthquakes/search/>



The screenshot shows the 'Basic Options' section of the USGS Earthquake database search interface. It is divided into three columns: Magnitude, Date & Time, and Geographic Region. Under Magnitude, the '4.5+' radio button is selected. Under Date & Time, the 'Custom' radio button is selected, with a start date of '1978-02-14 00:00:00' and an end date of '2018-02-21 23:59:59'. Under Geographic Region, the 'Custom' radio button is selected, with a 'Draw Rectangle on Map' button. There are also sections for 'Advanced Options' and 'Output Options' which are currently collapsed.

Figure 2. Screenshot of USGS Earthquake database search, showing available options to select.

- Customise your magnitude, putting the minimum as your answer to question 1. Customise your date and time, so that you can see all the earthquakes in the past 50 years. Choose your geographic region by drawing the rectangle on the map to select as much of Australia as you can, without including other countries or lots of surrounding ocean.
- In the output options select CSV – which will enable you to open the data set in an Excel spreadsheet.
- Do the same for another country, such as Finland, or France, which has numerous underground nuclear waste storage depositaries.

Results and Analysis

- How many earthquakes in the past 50 years were there above your chosen threshold in each country?

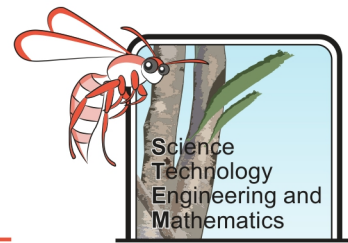
Australia:

(selected country):

- What was the largest magnitude earthquake in the past 50 years for each?

Australia:

(selected country):



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3. What is the probability of an earthquake above your chosen threshold NOT occurring on any given day in Australia (show your working)?

4. Use the multiplication rule for probabilities to determine the probability of an earthquake above your chosen threshold NOT happening for two consecutive days in a row. E.g. if the probability was 90 % then $0.9 \times 0.9 = 0.81$ – therefore the probability of an earthquake NOT happening the day after another is around 81 %

5. Continue using the multiplication rule to find out when the probability of an earthquake above your chosen threshold NOT occurring is less than 50%. An example has been done for you below:

No. of days	1	2	3	4	5	6	7
Probability of NOT occurring	0.9	0.81	0.73	0.66	0.59	0.53	0.48

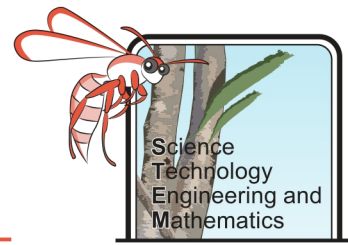
No. of days									
Probability of NOT occurring									

Evaluation

1. Overall, how geologically stable is Australia compared to your other chosen country?

2. Would you use this information as part of your report on the suitability of burying nuclear waste, if not – why not? Is there more specific information you would like to include? Is there more information you would like to find out?

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Case Studies

Objective

To use case studies to compare the strengths and weaknesses of different burial sites for nuclear waste.

Background Information

Many countries have been using nuclear power as a source of energy for decades and therefore have accumulated nuclear waste. There are many burial sites globally, some of which have been hosting waste since the 1980s. Most of the sites, fortunately, have not had any issues or reports of nuclear waste leaching into the surrounding areas, however, this has not been the situation for all.

Method

1. Research different waste disposal sites to complete the table below.

Information you should try to include:

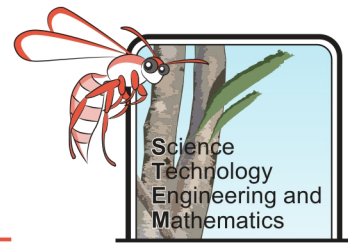
- How much waste is stored?
- How deep is the waste buried?
- What type of waste is it?
- How long has it been stored?
- How far are the sites from towns?
- Have any leakages been found?
- Have there been any accidents?

Make sure you reference your information and consider the source – will it have a particular bias?

Results and Analysis

Site	Country	Status	Geology	Has anything gone wrong, if so what and why?
Asse	Germany			
WIPP, Yucca Mountain	USA			

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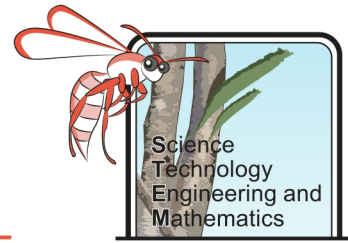
Site	Country	Status	Geology	Has anything gone wrong, if so what and why?
Hanford, Washington	USA			
Grimsel	Switzerland			

Evaluation

1. Have there been any reports of loss of life, including local flora and fauna, following an accident at a waste storage location?

2. From this research, are there any particular geological formation types that you would recommend/not recommend in your report?

Burying Nuclear Waste – Student Booklet



Designing a Solution

Objective

To design and test a model burial site for radioactive waste.

Equipment

- Balloon with food colouring in, filled to about the size of a ping pong ball
- Material to bury the balloon in - e.g. plaster of Paris, salt, clay, sand
- Transparent plastic cup
- Wooden kebab skewer

Method

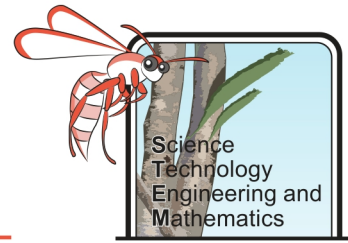
1. Brainstorm which material(s) you think will be best to bury your nuclear waste in so that it doesn't leak.

Which material have you chosen and why?

-
2. Come up with a plan using the equipment list above to model the burial of nuclear waste and to produce a leak during an earthquake. Draw a labelled diagram to show your set up.

3. Show this to your teacher before conducting the investigation.

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Results and Analysis

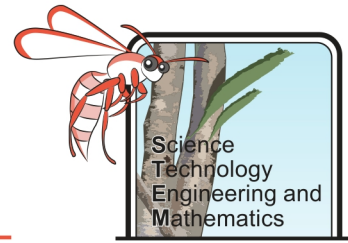
1. How effective was your model at preventing the “waste” from leaking? Explain your answer.

2. How realistic do you think the model was? Make comparisons to different rock types which could be used to bury waste in.

Evaluation

1. What improvements would you make to:
 - a) The model
 - b) The experimentto make it a more realistic test?

Burying Nuclear Waste – Student Booklet



Reporting to Government

Objective

Present the findings of your research, via a written report, presentation or video, outlining if and where nuclear waste could be safely buried in Australia.

Method

Include in your presentation:

- Why you think an area is suitable/not suitable
 - discussing the geological setting (possible earthquakes/the suitability of the rock types etc.) You should include a geological map, showing the rock types in the area, and a hazard map.
- What depth do you suggest burying the waste at, and why.
- Use supporting evidence from your investigations and case studies to explain why it would be suitable/not suitable to bury nuclear waste.

You may wish to make a model design of your intended plan, showing how you will seal and store the waste.