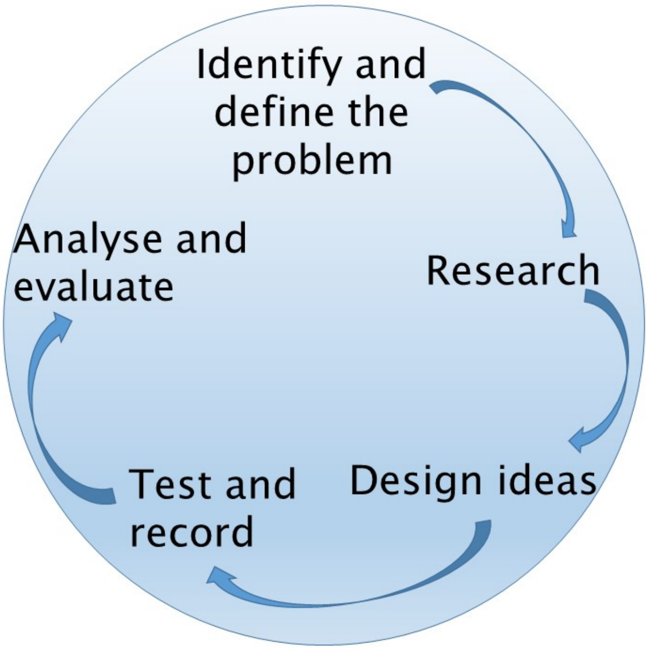
Burying Nuclear Waste – Student Booklet

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.

Burying Nuclear Waste – Student Booklet

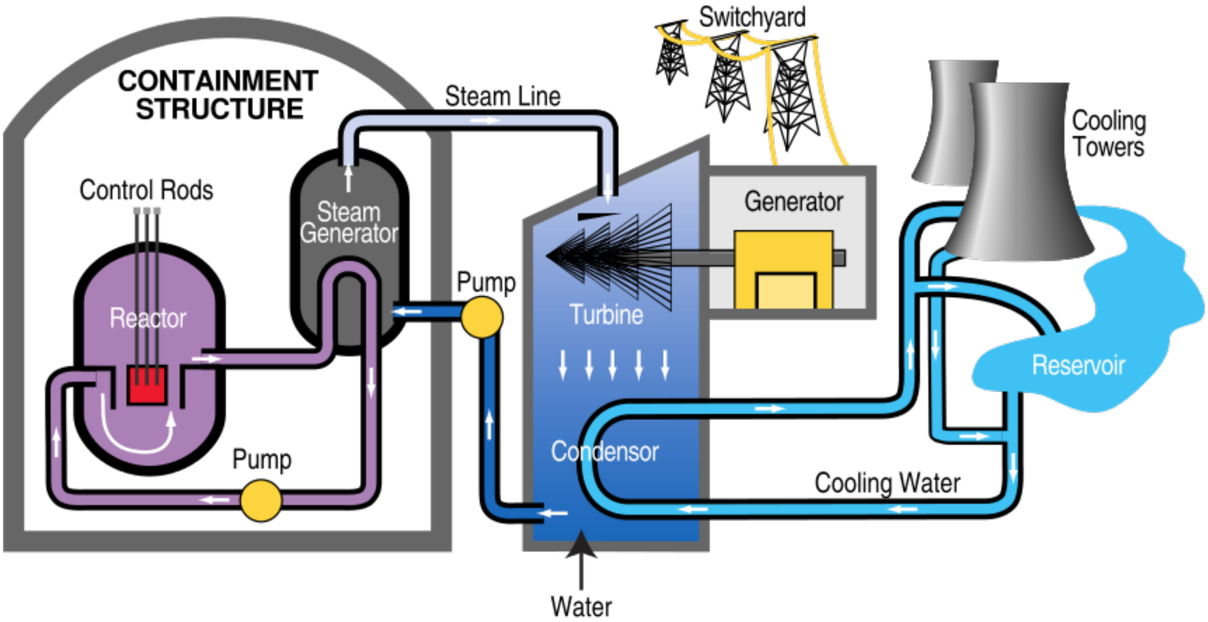


Figure 1. Image showing the key parts of a nuclear reactor and how it generates electricity. (Tennesee Valley Authority, 2018)

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.

Background Research

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

Suggested site: http://www.world-nuclear.org/information-library/safety-and-security/radiation-and-health/nuclear-radiation-and-health-effects.aspx

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

Suggested site: http://www.world-nuclear.org/nuclear-basics/how-does-a-nuclear-reactor-make-electricity.aspx

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

Suggested site: https://www.epa.gov/radiation/radiation-health-effects

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

Suggested sites: https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/radioactive-waste-safety or https://ukinventory.nda.gov.uk/about-radioactive-waste/how-do-we-manage-radioactive-waste/

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

Suggested sites: https://phys.org/news/2017-12-physicists-method-nuclear.html and https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/radioactive-waste-safety

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

Suggested site: https://en.wikipedia.org/wiki/Radioactive_waste#Medicine

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

Suggested site: https://en.wikipedia.org/wiki/Nuclear_power_by_country

8. How old are the oldest rocks in Australia?

____

Suggested site: https://australiascience.tv/oldest-rocks-in-the-pilbara-pre-date-plate-tectonics/

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

____

____

____

____

Suggested sites: https://www.worldatlas.com/articles/major-tectonic-plates-on-earth.html and http://www.ga.gov.au/scientific-topics/national-location-information/landforms/australian-landforms-and-their-history

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

Location	Reference

Suggested sites: http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/appendices/radioactive-waste-repository-store-for-australia.aspx and https://en.wikipedia.org/wiki/Nuclear_power_in_Australia

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 each of the objects listed in the results table below 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 first table.
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.

Burying Nuclear Waste – Student Booklet

Results and Analysis

1. Complete table one to give the raw readings for each material investigated.

Radiation Source	**Raw counts per minute when blocked by:**									
	Paper	**Aluminium**	**Lead**	**Concrete**	**Glass**	**Water**	**Salt**	**Sandstone**	**Granite**	**Limestone**
Alpha										
Beta										
Gamma										

2. Complete table two to give the actual readings, minus the background radiation reading measured at the start.

Radiation Source	**Adjusted counts per minute when blocked by: (raw reading – background reading)**									
	Paper	**Aluminium**	**Lead**	**Concrete**	**Glass**	**Water**	**Salt**	**Sandstone**	**Granite**	**Limestone**
Alpha										
Beta										
Gamma										

3. Which materials were able to block alpha radiation?

4. Which materials were able to block beta radiation?

5. Which materials were able to block gamma radiation?

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

____

7. Were all materials the same thickness?

____

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

____

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

____

____

____

Evaluation

1. What could you do for a future investigation to make this a fair test?

____

____

____

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.

Results and Analysis

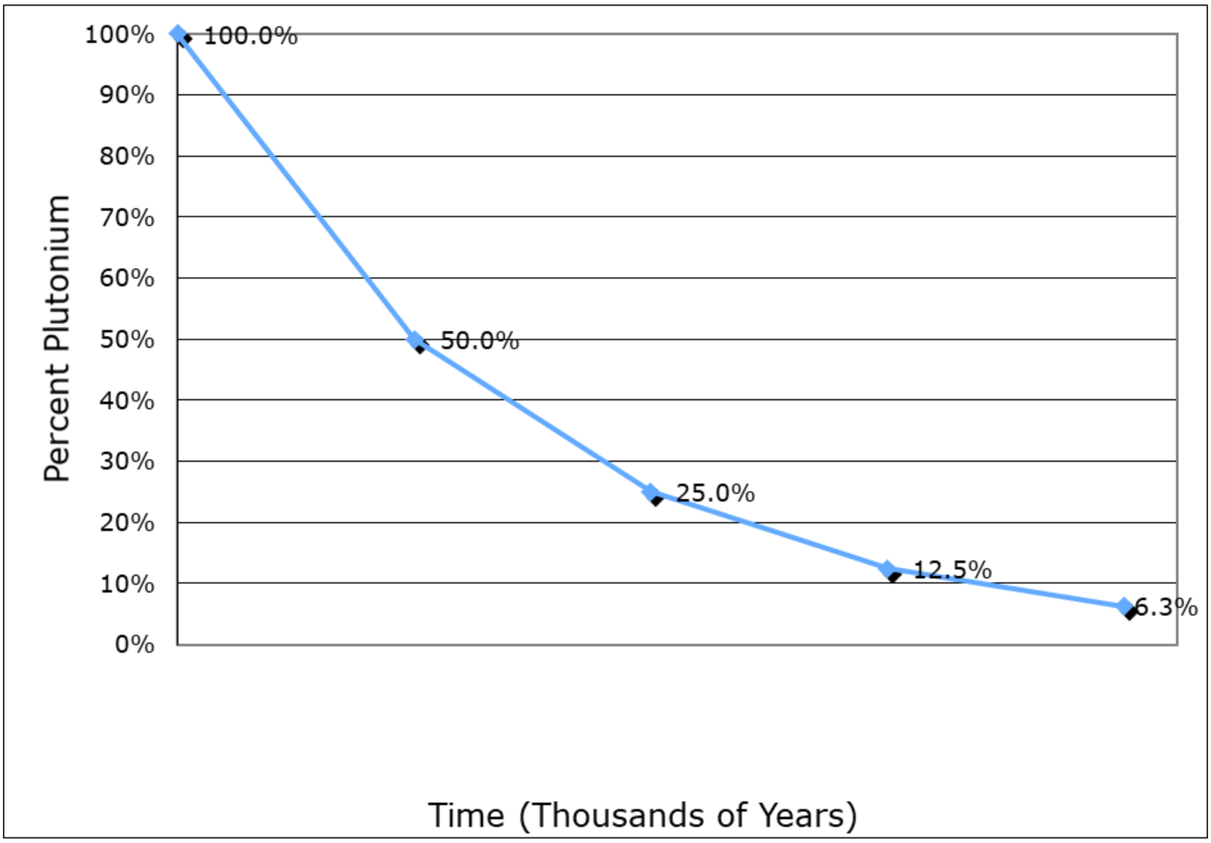
Bag Number	**Popping time (seconds)**	**Number of Kernalite Ke (parent)**	**Number of Popcornium Pc (daughter)**	**Total Ke + Pc**	**% Ke (parent) /Total *100**	**% Pc (daughter) /Total *100**
1	10					
2	20					
3	30					
4	40					
5	50					
6	60					

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

____

5. 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.



Evaluation

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

____

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

____

____

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 properties of rocks.

Property	**Definition**
Crystalline	Suggested site: https://www.britannica.com/science/crystalline-rock
Porous	Suggested site: http://www.ssc.education.ed.ac.uk/BSL/geography/porousd.html
Permeable	Suggested site: http://www.ssc.education.ed.ac.uk/BSL/geography/porousd.html
Cemented	Suggested site: https://www.britannica.com/science/cementation-sedimentary-rock
Consolidated	Suggested site: https://www.mindat.org/glossary/consolidated_sediment

Chemical reactivity	Suggested site: https://www.researchgate.net/figure/Sedimentary-rocks-arranged-according-to-their-reactivity-and-geology-A-sample_fig1_309965869

Method

1. Fill in the table below by competing the following:
    - Crystalline? – can you see clear crystals in the rock using the hands lens (these crystals (minerals) will have regular structures and often reflect light)
    - Porous? – drop water on the sample using a pipette. Is the water absorbed?
    - Permeable? – if the water (above) is absorbed it means the sample is permeable.
    - Cemented? – using the hand lens can you see grains that are stuck (cemented) together?
    - Consolidated? – rub the rock sample with your thumb – do pieces break off? If so it is not consolidated.
    - Chemically reactive – drop a small amount of dilute acid onto your rock sample does it react (look and listen for a reaction)? ***Don't forget to wear safety glasses for this test in particular.***

Results

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

Rock Name	Crystalline?	Porous?	Permeable?	Cemented?	Consolidated?	Chemically Reactive?

Analysis

1. Which of the rock types were permeable?

____

____

2. Which of the rock types were chemically reactive?

____

____

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

____

____

____

____

4. Highlight areas on a geological map of Australia where there are large (10 km^2 +) areas of suitable rock types.

5. 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 these.

____

____

____

____

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.

____

____

____

An initiative supported by Woodside and ESWA

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

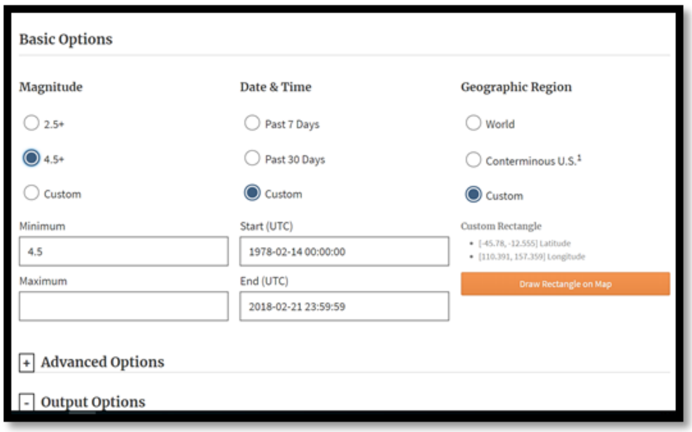


Figure 2. Screenshot of USGS Earthquake database search, showing available options to select.

3. 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.
4. In the output options select CSV – which will enable you to open the data set in an Excel spreadsheet.
5. Do the same for another country, such as Finland, or France, which has numerous underground nuclear waste storage depositaries.

Results and Analysis

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

Australia:
(selected country):

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

Australia:
(selected country):

3. Calculate the average number of days between earthquakes above your threshold occurring by dividing the number of days in 50 years by the number of earthquakes above your threshold value which happened during that time. Show your working.

Australia	Other country

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?

____

____

____

____

____

____

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.

Results and Analysis

Site	**Country**	**Status**	**Geology**	**Has anything gone wrong, if so what and why?**
Asse	Germany			
Suggested sites		*https://en.wikipedia.org/wiki/Asse_II_mine*		*https://euobserver.com/beyond-brussels/132085*
WIPP, Yucca Mountain	USA			
Suggested sites		https://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository#Geology and https://www.usatoday.com/story/news/politics/2018/06/03/yucca-mountain-congress-works-revive-dormant-nuclear-waste-dump/664153002/		
Hanford, Washington	USA			
Suggested sites		https://en.wikipedia.org/wiki/Hanford_Site		https://www.tri-cityherald.com/news/local/hanford/article214069424.html

Site	**Country**	**Status**	**Geology**	**Has anything gone wrong, if so what and why?**
Grimsel	Switzerland			
Suggested sites		*http://www.grimsel.com/*		*https://lenews.ch/2017/12/13/swiss-fact-switzerland-has-enough-nuclear-waste-to-fill-zurich-train-station/*

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

Science Technology Engineering and Mathematics

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. Bury your balloon and wooden stick in your chosen material so the stick is just touching the surface of the balloon.
3. Take a photo of your set up.
4. Leave your experiment overnight to allow the material to settle/dry
5. Take another photo of your set up.
6. Slowly push down on the wooden stick (to represent the piercing of the casing nuclear waste has been buried in) and shake the cup gently (to represent an earthquake).
7. Make and record any observations.

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 experiment
   to make it a more realistic test?

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.