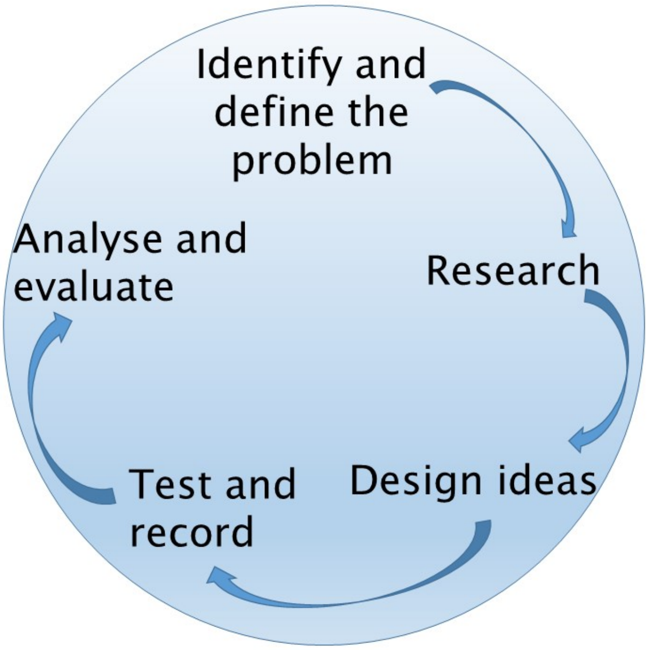
Burying Nuclear Waste – Student Booklet

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.

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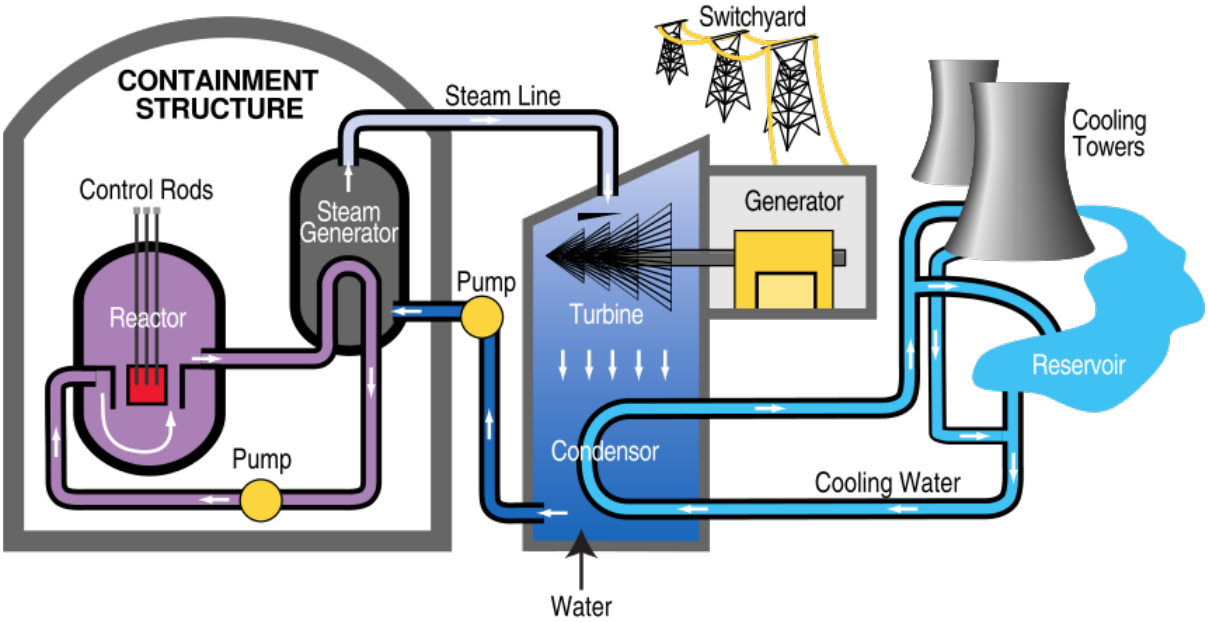


Figure 1. Image showing the key parts of a nuclear reactor and how it generates electricity. (Tennesee Valley Authority, 2018)

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. How does a nuclear reactor create electrical energy? Name the types of reaction and energy transfers that occur at each stop, using a labelled diagram.
2. What type of radiation is produced at a nuclear reactor?
3. What are the units of measurement for nuclear radiation?
4. What are the potential hazards to human health of nuclear waste? Outline the amount of damage expected from a range of exposure doses.
5. Are all living things negatively impacted by radiation?
6. Can it impact your health to eat plants or animals which contain high levels of radiation (for example, plants grown near the Chernobyl site)?
7. What does half-life mean (in terms of radioactive materials)?
8. What are the different levels of nuclear waste, and how are they treated?
9. How is nuclear waste monitored, once disposed of?
10. What other activities produce nuclear waste (other than power generation)?
11. Which countries currently use nuclear power (list at least 10)?
12. What tectonic setting does Australia have? Add a labelled diagram to your answer.
13. Is Australia considered geologically stable or very active? Use your knowledge of tectonic processes to aide your explanation.
14. Have there been any proposed burial sites for nuclear waste in Australia in the past? If so, where?
15. What are some of the key features an ideal nuclear burial site would have?

Science
Technology
Engineering and
Mathematics

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).
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.
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.

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 each type of radation?
3. Which type of radiation was easiest to block (blocked by the most materials)?
4. Were all materials the same thickness?
5. Could this difference in thickness of materials have impacted your results?
6. What type of casing would you recommend for disposal of nuclear waste? Explain your answer.
7. Some granites can be quite radioactive, such as the bedrock in Aberdeen, Scotland. Does this knowledge change your answer to question 6? If so, why?

Evaluation

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

Decay Rate Modelling

Objective

To model radioactive decay of elements, using popcorn.

Equipment

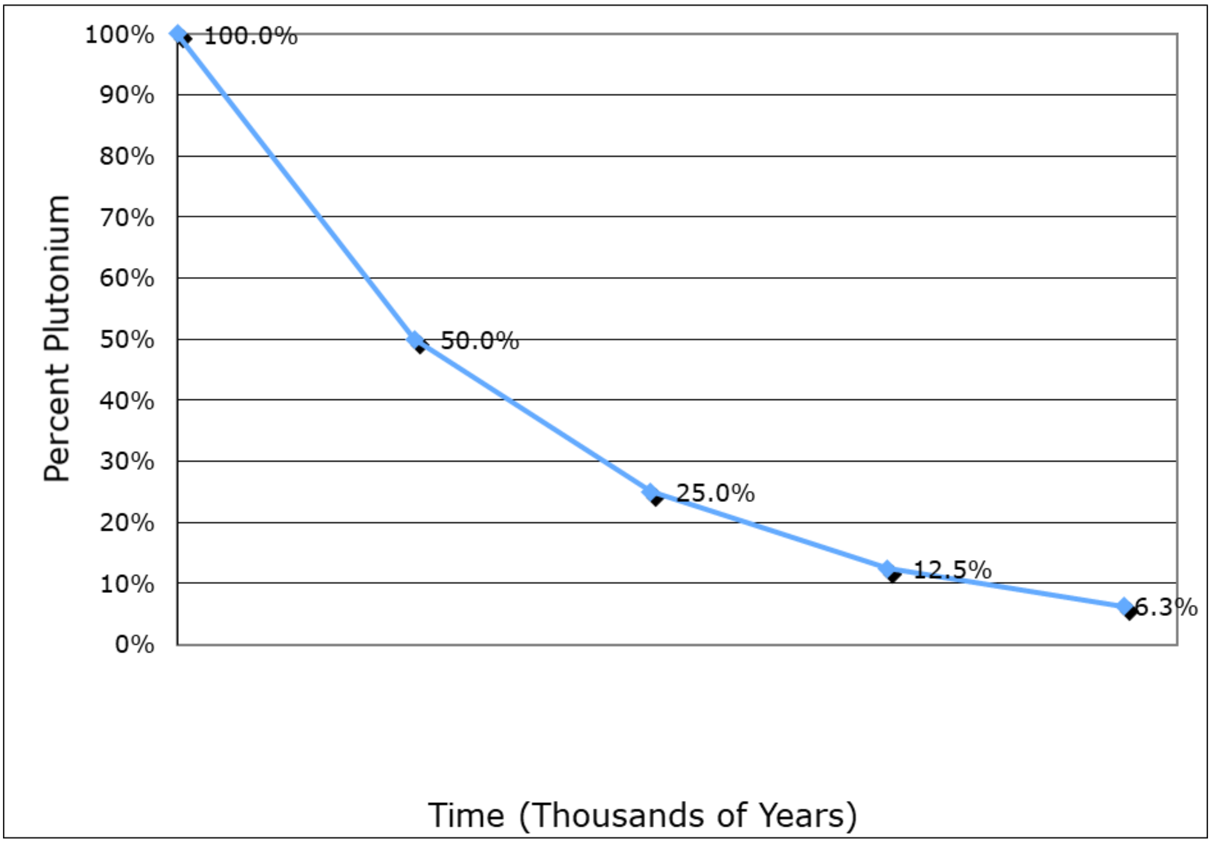
- Bag of popcorn (with allocated time written on it)
- Microwave
- Newspaper
- Stopwatch (or phone timer)

Method

1. Research radioactive decay and half-life (if you haven't already).
2. Create a method for your investigation – using popcorn to model the radioactive decay of the element 'Kernalite (Ke)' to 'Popcornium (Pc)'. Hint: In most microwaves popcorn takes two minutes to start popping. We recommend timing from then on.
3. Work with other teams to collect results for radioative decay over time intervals (we recommend 10 seconds).
4. Create a table to record your data.
5. Show your method and data collection table to your teacher before carrying out the investigation.

Results and Analysis

1. Record your data, and that of your classmates into a table. Don't forget to work out the percentage of parent (Ke) and daughter (Pc).
2. Plot a graph of % Ke versus time (s).
3. Use this graph to calculate the popping time of the 'unknown' sample the teacher will give you.
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.



6. 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?
4. What could have caused experimental error?
5. What are the strengths and weaknesses of using popcorn as a model for radioactive decay?
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?

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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.

Method

1. Research the following terms relating to the properties of rocks – crystalline, porous, permeable, cemented, consolidated and chemical reactivity.
2. Design a series of experiments by which you can test rock samples provided to you by your teacher for each of these properties.
3. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Analysis

1. Which rock type(s) are most suitable for burying nuclear waste in? Use your research to justify your answer.
2. Highlight areas on a geological map of Australia where there are large (10 km^2 +) areas of suitable rock types.
3. 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.

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.
2. Go to the USGS Earthquakes Earthquake database to search for historical earthquakes above your threshold in Australia (we recommend searching across the last 50 years): https://earthquake.usgs.gov/earthquakes/search/
3. 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?
2. What was the largest magnitude earthquake in the past 50 years for each?
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.
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:

Evaluation

1. Overall, how geologically stable is Australia compared to your other chosen country?
2. What are the strengths of your investigation into the probability of an earthquake above your threshold occurring in Australia on any given day?
3. What are the weaknesses of your investigation into the probability of an earthquake above your threshold occurring in Australia on any given day?
4. Is there other information that should be considered as part of this investigation?
5. Would you use this information as part of your report on the suitability of burying nuclear waste, if not – why not?

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 at least four different nuclear waste disposal sites across the world to complete a short report or case study table.
   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 your reference your information and consider the source – will it have a particular bias?

Evaluation

1. Have there been any reports of loss of life, including local flora and fauna, following an accident at a nuclear waste storage location?
2. From this research, are there any particular geological formation types that you would recommend/not recommend in your report?
3. Evaluate to what extent you believe each source to be biased.

Designing a Solution

Objective

To design and test a model burial site for radioactive waste and evaluate the effectiveness of your design.

Method

1. Brainstorm which material(s) you think will be best to bury your nuclear waste in so that it doesn't leak.
2. Come up with a plan to model the burial of nuclear waste, and a test that would simulate the piercing of the casing the waste is contained in during an earthquake. Draw a labelled diagram to show your set up, with an equipment list.
3. Show this to your teacher before conducting the investigation.

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.