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Discover bentonites, the heroes of radioactive waste repositories

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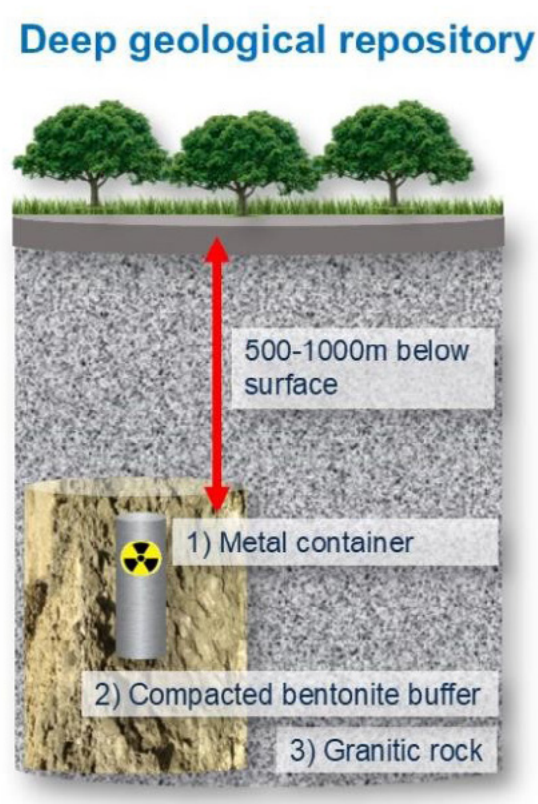
You shall not pass: explore the function of deep geological repositories and the key role of bentonite in preventing the leakage of highly radioactive waste.

The management of high-level radioactive waste (HLW) is a serious and worldwide environmental problem. There are already tons of nuclear waste that must be safely stored for at least 100 000 years for the radiotoxicity to decrease to nondangerous levels.[1] Deep geological repositories (DGRs) are the internationally accepted multibarrier storage system for isolating highly radioactive waste. Solid nuclear waste is placed in metal containers (technical barrier) that are surrounded by a sealing and backfilling buffer material (geotechnical barrier) and buried deeply (500–1000 m underground) within a stable geological formation.[2]

Bentonite is a type of clay that can be used as a geotechnical barrier due to its good mineralogical, geochemical, mechanical, and technological properties, such as high swelling capacity and good compaction properties. These fantastic characteristics are very useful for the sealing and backfilling material to maintain the integrity and stability of DGRs of nuclear waste.

The following activities are suitable for students aged 11–16. The students will learn the importance of good isolation of nuclear waste and the great properties of bentonites in the DGRs for HLW.



This diagram is simplified and not to scale.
Image courtesy of the author

Activity 1: Building a nuclear waste repository

In this activity, students build an interactive model of a deep geological repository (DGR). As previously mentioned, the DGR involves several barriers, for example: 1) a metal container, 2) compacted bentonite buffer, and 3) a granitic host rock. This activity consists of building a giant puzzle, where all the different pieces (barriers) must be positioned correctly for the safe storage of nuclear waste. The model can then be used as a basis to discuss the problem of managing radioactive waste and DGRs.

This activity can be performed in small working groups, where each group works on one step or part of the model. Preparation of the model will take around an hour.

Safety notes

Be careful when painting with the grey spray paint; if possible, do this outdoors or close to an open window.

Be extremely careful when using the box cutter (Stanley knife) to avoid cuts.

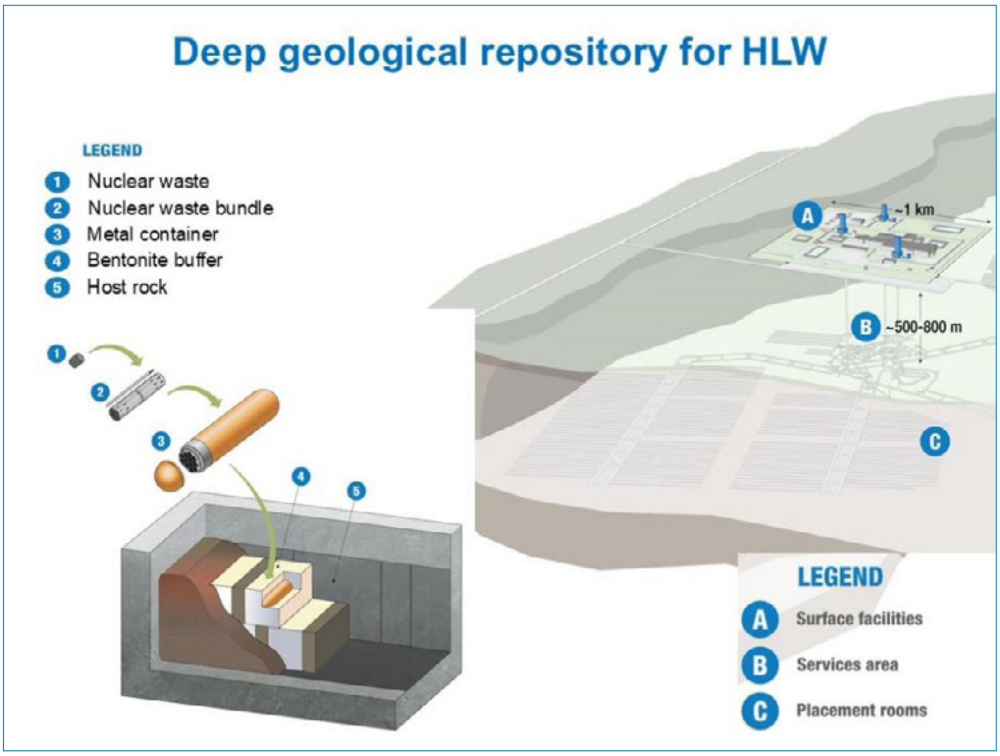
Materials

Image courtesy of the author

Materials

Per model:

- 2 cardboard toilet-paper rolls
- Yellow water-soluble paint
- 1 black marker
- 1 tubular can of potato chips (depending on the brand, approximately 23 cm in height)
- Brown water-soluble paint
- 1 orange hollow pool noodle (approx. 11 cm in diameter; approx. 23 cm high, similar to the potato chip can)
- 2 squares of foam rubber (15 cm × 15 cm × 35 cm)
- Grey spray paint
- 4–6 paintbrushes
- 1 pair of scissors
- 1 box cutter (Stanley knife)
- Radioactive waste infosheet



A diagram of a DGR designed by Canada's Nuclear Waste Management Organization (NWMO)

Image modified from CNW Group/Nuclear Waste Management Organization, used with kind permission

Procedure

1. Hand out the radioactive waste infosheet; introduce students to the problem of high-level radioactive waste (HLW) and explain that one way of safely storing it is in deep geological repositories (DGRs), where the waste is contained within various layers and then deeply buried. This nice explanation (with diagrams) of Canada's multi-barrier system can also be used.
2. Explain that the task will be to create an interactive model of a DGR.
3. To build the radioactive waste, paint the two cardboard toilet-paper rolls yellow using the paintbrushes and yellow water-soluble paint (it might be necessary to paint the rolls more than once). When the paint is dry, students can draw a radioactive symbol  with the black marker.

DGR giant puzzle

Image courtesy of the author

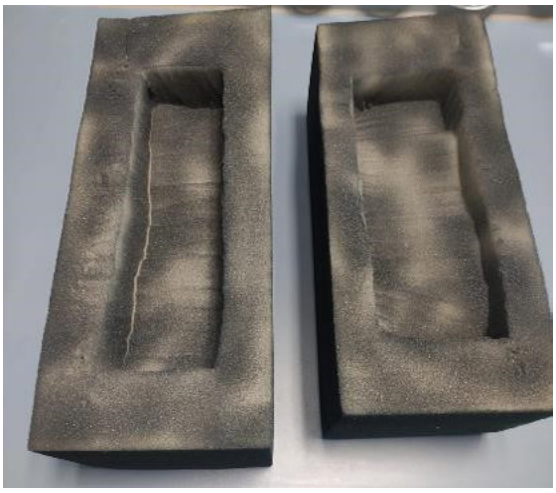
4. To build the metal container, students paint the tubular potato chip can brown using the paintbrushes and the brown water-soluble paint (it might be necessary to paint the can more than once).

Image courtesy of the author

5. To make the compacted bentonite barrier, the orange hollow pool noodle is cut into 23 cm high sections (or adapted to match the height of the tubular potato chip can). Then, it is split lengthways. This should be done with the supervision of the teacher! Note the circular holes in the side of the pool noodle in the image below are not important; this one just happened to have them.

Image courtesy of the author

6. To prepare the granitic rock barrier, a hole of approximately 6 cm wide and 24 cm high (or adapted to the size of the potato chip can surrounded by the hollow pool noodle) is made in each foam rubber square with the box cutter. Then, both foam rubber squares are painted with grey spray paint (to simulate the granite colour, although this step can be omitted if it is risky due to the lack of good ventilation).



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7. Once the components are complete, identify what the different components represent and discuss the function of each component.

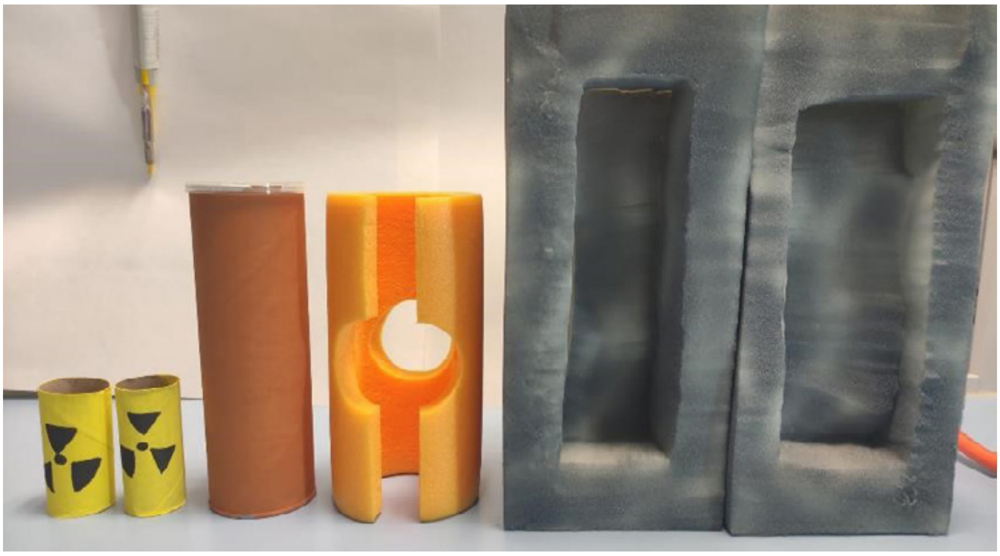
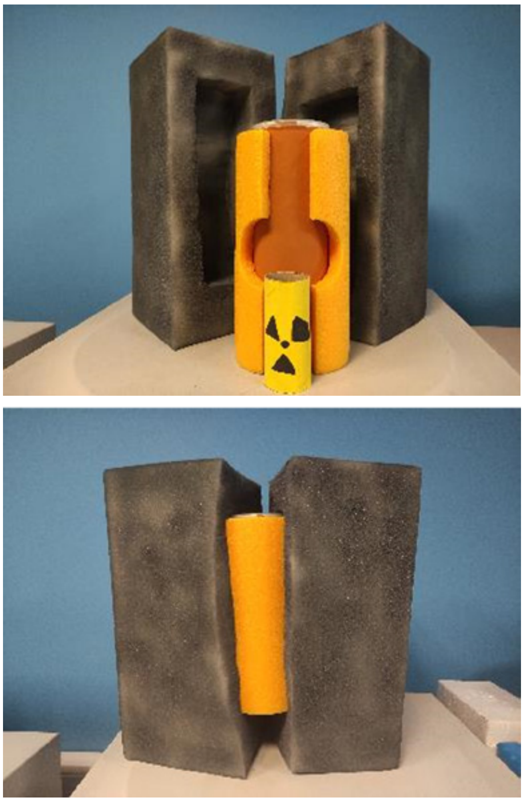


Image courtesy of the author

- What do the toilet-roll tubes represent? What dangers does the HLW pose?
- What does the potato chip can represent, and what do you think its function could be?
- What does the pool noodle represent, and what do you think its function could be?
- What does the grey foam represent, and what do you think its function could be?

8. Once the DGR is finished, students can play with the giant puzzle, describing each barrier and its material.



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9. An interesting activity is to have a race (if you build more than one DGR model). Students have to safely isolate the radioactive waste in the right order as fast as they can. To make it more challenging, the teams have to answer a question on each component correctly to obtain it.

Results/discussion

The metal canister in which the spent nuclear fuel is encapsulated is the first barrier, a technical barrier, isolating the waste.

The geotechnical barrier, often compacted bentonite, plays an important role in the safety of a DGR due to its favourable properties, such as high swelling capacity, very low permeability, good compaction properties, and good cation-adsorption capacity. Thus, bentonites will contribute to maintaining the integrity of the metal canisters, acting as a buffer against temperature and rock movements. Also, in the worst-case scenario of accidental leakage, bentonites contain, prevent, and retard the dispersion of radionuclides into the environment.[3]

The geological barrier or host rock (the natural barrier) mainly provides mechanical stability to the DGR. It must be a low-permeability rock to prevent and retard any possible leakage from the repository system.

The following questions can be used to lead further research and discussion of the activity:

- Who or what are the main producers of nuclear waste?
- Why is it important to safely dispose of HLW?

By carrying out this activity, students will learn and be aware of the importance of worldwide repository barriers by building and playing with the giant puzzle.

Activity 2: Explore bentonite's superpower in absorbing liquid waste

Compacted bentonites are used as a geotechnical barrier in nuclear waste repositories to provide good thermal, hydraulic, mechanical, and chemical isolation, to ensure the long-term stability of the DGR.

In this activity, coloured water, representing radioactive waste, is added to different bentonite types (pellet and powder) to check the great swelling capacity of bentonite and how it can block radioactive filtration to the host rock and biosphere. Depending on the bentonite compaction grade, radioactive leakage will take more or less time to go through the bentonite, thus reaching and contaminating the environment.

This activity can be performed in groups or individually. Each group/student should be assigned different water volumes. This activity takes 20–30 minutes and the final results can be checked after some hours and the next day, for better comparison.

Safety notes

When manipulating bentonite powder, do it gently because there is a respiratory risk due to the small particles.

Materials

- 1 bag of bentonite pellets (1 kg)
- 1 bottle of bentonite powder (500 g)
- 1 tablespoon (15 ml)
- Orange water-soluble paint
- 3–4 dispenser bottles (depending on the number of students)
- 1 black marker
- Plastic plates or plastic bottles/glasses (2 per group)
- Bentonite infosheet

Image courtesy of the author

Procedure

1. Hand out the bentonite infosheet and introduce bentonites and their use in DGRs.
2. Firstly, orange water-soluble paint (1/4) is mixed with water (3/4) in the dispenser bottles to prepare the liquid radioactive waste. Afterwards, students can draw a radioactive symbol on the plastic bottle with the black marker.
3. Each student/group takes two plates or bottles/glasses; to one, they add 2–3 tablespoons of bentonite powder and to the other 1–2 bentonite pellets.
4. Later, each group will pour different volumes of radioactive liquid waste onto the bentonite powder and pellets. For example, a small volume (like one tablespoon≈15 ml) to cover a small bentonite section, enough liquid volume to cover half of the bentonite powder/pellets, or enough to fully cover the bentonite powder and pellets. The bentonite will absorb the radioactive liquid by swelling. The more liquid added, the more the bentonite swells, until its maximum capacity is reached.

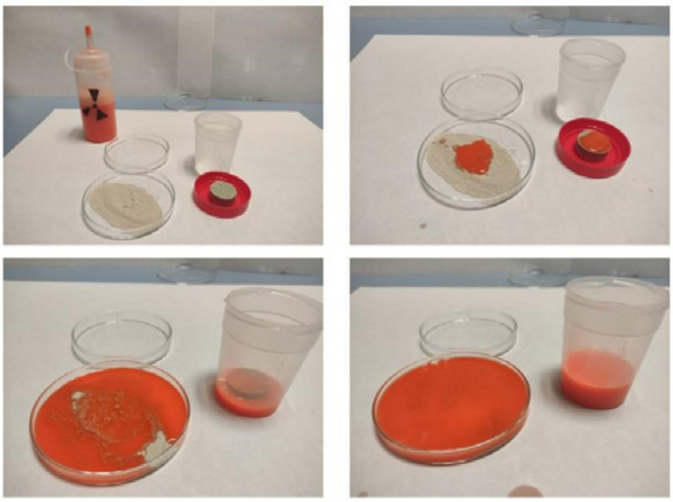

Image courtesy of the author

5. Check the bentonites after 30 minutes and the next day, to better appreciate bentonite's swelling capacity.

Results/discussion

The following questions can help to discuss the observations and understand the underlying processes:

- What do you observe when adding liquid radioactive waste to bentonite powder?
- What do you observe when adding liquid radioactive waste to bentonite pellets?
- Do you see any differences when adding more liquid volume?
- Which bentonite type absorbs more liquid? Why?
- Can you think of any other uses for bentonite based on its absorption properties? The teacher can list some examples (see the bentonite infosheet), or students can do their own research to find other applications.

When dry, the clay particles in bentonite are tightly packed together and have a small surface area exposed to the surrounding environment. However, when hydrated, water molecules are able to enter the spaces between the clay particles, causing them to expand and create a larger surface area. This expansion causes the bentonite to swell and become gel-like in consistency.

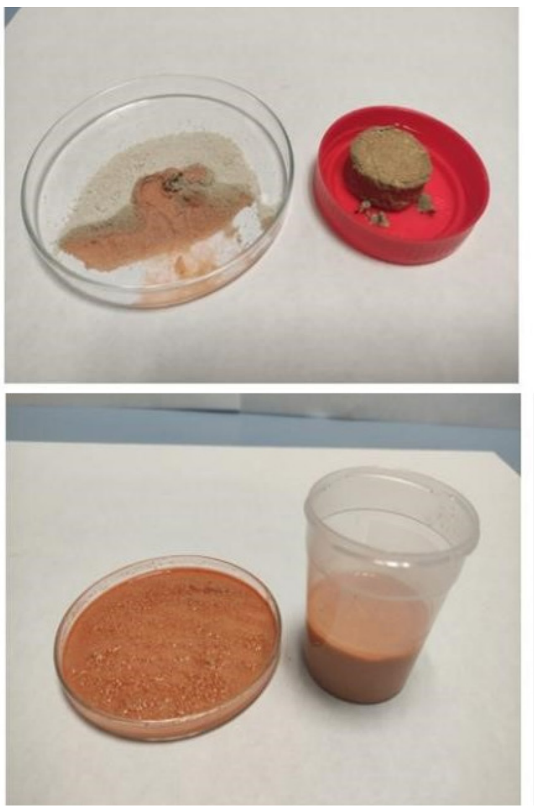

Image courtesy of the author

After 30 minutes, liquid radioactive waste will be absorbed, while bentonite powder is not visually affected. In the case of bentonite pellets, they will be partially broken down. The next day, liquid radioactive waste will be fully absorbed by bentonite, which will be swollen, and in the case of pellets, their size will be greatly increased. Bentonite pellets are compacted bentonite; therefore, they can absorb a higher water volume.

This fantastic property of bentonite prevents dispersion of the radioactive waste through the DGR if the metal container becomes corroded, allowing water to seep through, and therefore, it will protect the environment and humanity.

By performing this activity, students will easily learn about, and check for themselves, the great swelling capacity of bentonite and get a better sense of how important it is for the DGRs of nuclear waste. The properties of bentonite barriers in DGRs are still an active research topic, and as an optional extension, students can read the current research infosheet to learn about my research on microbial activity at the bentonite barrier in DGRs of nuclear waste. «

Acknowledgements

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Funded by the European Union

References

[1] Hedin A (1999) Deep repository for spent nuclear fuel. Technical report: TR-99-06. *Swedish Nuclear Fuel and Waste Management Company.*

[2] IAEA (2003) Scientific and technical basis for the geological disposal of radioactive wastes. *International Atomic Energy Agency.*

[3] Svensk Kärnbränslehantering AB (2010). Data report for the safety assessment SR-Site. Technical Report TR-10-52 SKB. *Swedish Nuclear Fuel and Waste Management Company.*

Resources

- Watch a demonstration of a Activity 1, building a DGR model.
- Watch a video explaining the DGR concept.
- Watch a video clearly explaining the problem of radioactive waste and the Swedish solution to isolate it.
- Find interesting information about the Swedish Spent Fuel Repository, which is already under construction.
- Find detailed information about the DGR multibarrier system.
- Try an educational escape game to learn about renewable energy: Cornelius S, Neuhaus A (2025) Explore energy production with the escape game 'Village of the Future'. *Science in School* **71**.
- Learn how climate change and melting sea ice can affect albedo through positive feedback: Cattadori M (2025) Albedo and ice: positive feedback in action. *Science in School* **71**.
- Use common household items like coins and paper to build a simple voltaic pile: D'Acquisto G (2025) The birth of electrochemistry: building a simple voltaic pile. *Science in School* **71**.
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- Learn how biomimicry can be an inspiring teaching tool that engages students by solving real-world problems: Dawson R (2024) Biomimicry: a nature-based approach to designing sustainable futures. *Science in School* **69**.

AUTHOR BIOGRAPHY

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