

# gas

production, consumption  
and transport in deep  
geological repositories

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## Gases are produced in a deep geological repository after closure

### Considering gas in the safety demonstration

ENSI requires Nagra to demonstrate the long-term safety of a deep geological repository for radioactive waste and to show that the applicable safety criterion has been met: the release of radionuclides from a repository may not lead to an individual dose exceeding 0.1 millisieverts per year, which is around one-fiftieth of the average annual radiation exposure for a person living in Switzerland. The potential impacts of gas on the safety barriers of a repository have to be studied and measures for reducing gas production and its negative effects have to be evaluated.

Gases are produced by chemical processes occurring in a sealed repository for radioactive waste. Besides carbon dioxide and methane from the degradation of organic waste, the main gas produced is hydrogen from the corrosion of metals under anoxic conditions. The gas can migrate along the backfilled caverns and tunnels at the disposal level and also moves into the surrounding Opalinus Clay (see glossary). Chemical and microbial processes that consume gas prevent accumulation and hence a build-up of gas pressure (see explanation on page 6). The movement of the water present in the pores of the Opalinus Clay is closely linked with the movement of gas and gas can displace this porewater. The production, consumption and transport of gas occur very slowly.

### Ensuring that the safety barriers remain intact

The ability of a deep geological repository to retain radionuclides depends on the safety barriers remaining intact (see glossary). The formation and accumulation of gas could have an impact on one of the barriers. The Opalinus Clay host rock forms the

natural safety barrier and is particularly important for ensuring the long-term safety of the repository. The clay contains numerous small fluid-filled pores and material transport through the rock occurs very slowly by diffusion between the pores (see image on page 3). An intact pore system contributes to the long-term containment of radionuclides. Fissures in the Opalinus Clay are self-sealing due to the swelling of the clay.

### In-depth investigation of the effects of gas

Nagra has been looking intensively at the effects of gas on the long-term safety of a repository since 1997. The processes potentially involved in the production, consumption and transport of gas are being investigated in a series of experiments, for example at the Mont Terri Rock Laboratory (see image below).

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The corrosion of metals is being investigated under realistic conditions at the Mont Terri Rock Laboratory. The metals being examined are copper and carbon steel.

## Different processes lead to gas formation in a repository

### Corrosion of metals

Deep geological repositories contain metals in the radioactive waste itself, in support structures such as rock bolts and steel arches and as a material for the disposal containers. The largest component of the gas is produced by the corrosion of metals. Steel is the most common and corrodes very slowly under repository conditions to form hydrogen gas. This chemical reaction occurs under anoxic conditions and requires water, which is present in the repository as porewater. The corrosion of aluminium and zinc or nickel metal alloys also requires water and produces hydrogen gas.

### Porewater in the Opalinus Clay

Water in rocks such as Opalinus Clay is present in the form of porewater rather than as flowing water. Following the closure of a repository, the porewater moves from the surrounding Opalinus Clay host rock and into the emplacement rooms containing the waste. The water causes corrosion of metals and degradation of organic waste. This produces gases and pres-

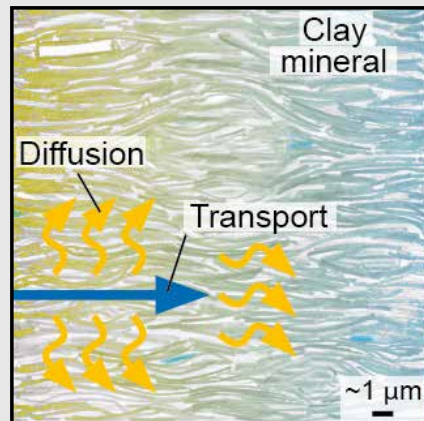
sure builds up, which partly displaces the water from the repository (see image below) back into the host rock or into the access structures. Once all the metal components have corroded and all the organic substances have degraded, the gas pressure drops and again more water enters the repository. The rate at which the porewater and any radionuclides dissolved in it migrate from the repository is so slow that the safety criterion specified by ENSI (see box on page 2) can be met at all times.

### Degradation of organic waste

L/ILW repositories in particular contain organic as well as metallic waste. These wastes mainly consist of various plastics and ion-exchange resins (see glossary). The degradation of the organic waste produces gases such as carbon dioxide and methane, but these make up less than one-tenth of the total gas volume in the repository. Degradation under anoxic conditions occurs slowly and requires both bacteria and water. Bacteria are active only when pores are sufficiently large and water and nutrients are present.

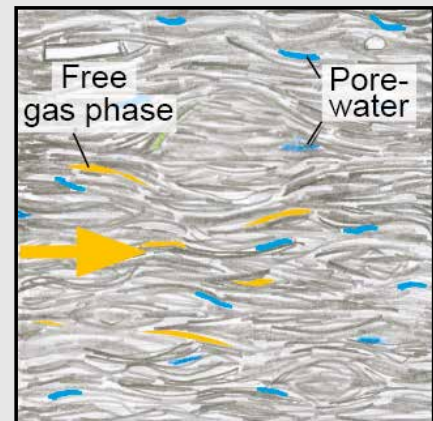
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### Description of gas transport in claystones



Transport & diffusion of dissolved gas in the fluid phase

«single phase»

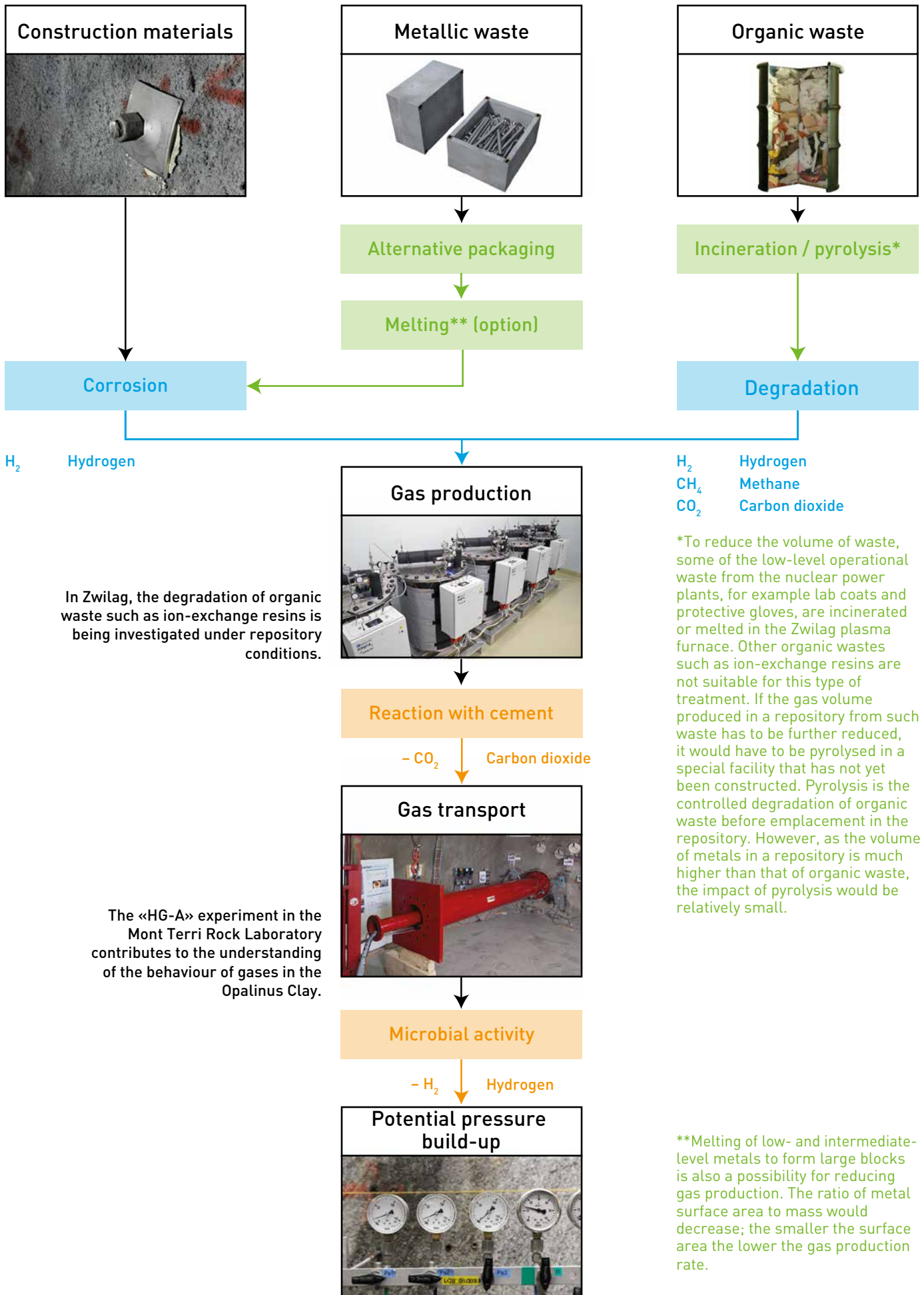


Flow of immiscible substances in a porous medium

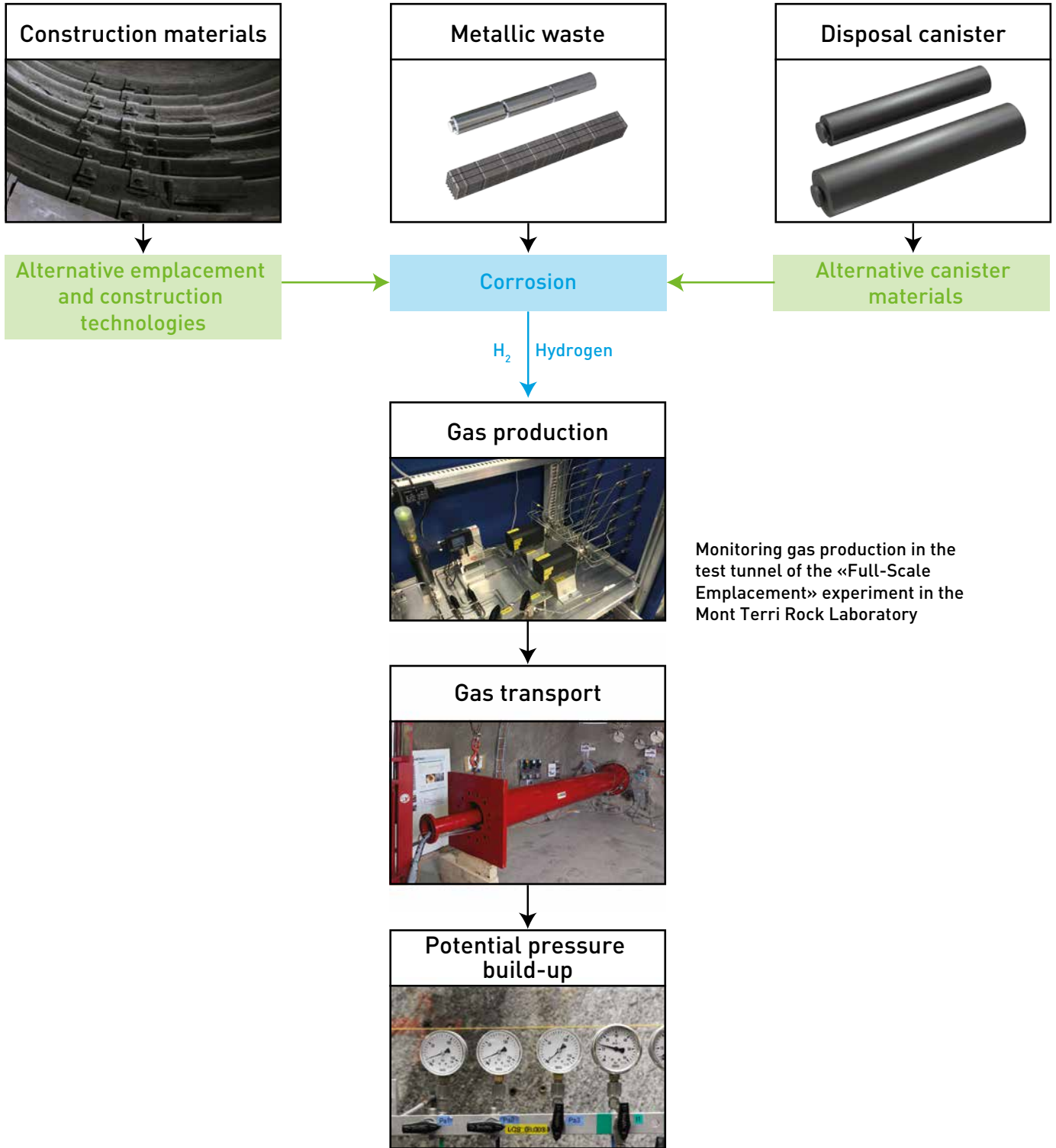
«two-phase flow»

Gas is dissolved in the porewater and migrates from pore to pore through the rock. An increase in pressure in the gas phase can result in displacement of porewater.

# Deep geological repository for low- and intermediate-level waste



# Deep geological repository for high-level waste



- Blue:** Processes leading to gas production
- Orange:** Processes that consume gas
- Green:** Processes and measures that reduce gas volumes



## Different measures can be taken to further mitigate the consequences of gas production in a repository

In both repository types, gas production is dominated by hydrogen, mainly from the corrosion of carbon steel. Various measures and processes could reduce this gas production.

### Alternative emplacement and construction technologies

As an example, calculations have been carried out to estimate the influence on gas production of the steel rails of the transport system for waste emplacement in a HLW repository or steel arches used for tunnel support. If necessary, further development and engineering studies could be carried out on replacing these installations.

### Alternative canister materials

At present, Nagra is planning to use gas-tight welded cylinders made of carbon steel with a wall thickness of 14 centimetres in the HLW repository; 80 percent of the gas comes from the corrosion of these canisters. In the relevant time period for consideration (see box on page 7), a large proportion of this could be reduced by using alternative canister materials. Nagra is therefore testing canisters made of carbon steel with a copper coating,

which is more resistant to corrosion (see image below). Coatings consisting of nickel or titanium are also being evaluated. For L/ILW waste, it is also being considered whether the metal waste containers could be replaced by other containers before emplacement. Smaller amounts of corroding metals lead to lower gas production.

### Gas-consuming microbes

Sulphate-reducing bacteria were found in the Opalinus Clay at the Mont Terri Rock Laboratory. Under anoxic conditions, these bacteria use hydrogen and the nutrient sulphate for their energy metabolism. There are also bacteria that use methane gas. How these two types of bacteria can contribute to reducing gas pressure is currently being investigated.

### Reaction with cement

The caverns in a L/ILW repository are backfilled with cement mortar. Cement chemically fixes  $\text{CO}_2$ , which reduces the gas pressure.

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Prototype of a steel canister with a copper coating

## Gases can be controlled even under unfavourable conditions and present no problem for safety

The relevant **time period for consideration** according to ENSI's requirements is the time span assumed in the models for the safety analysis calculations for a repository. The period is 1 Million years for the HLW repository and 100 000 years for the L/ILW repository.

Nagra is carrying out experiments to investigate how the Opalinus Clay and the bentonite tunnel backfill react under different gas pressures. Experiments and model calculations can also be used to estimate the expected gas volumes and gas pressures during the relevant time period (see box left).

### Compliance with safety criteria

Analyses and calculations show that, even under pessimistic assumptions, gas production will not compromise the safety functions of the host rock and the engineered barriers (see glossary) in the L/ILW and HLW repositories. There is a sufficient safety margin in all the cases that have been investigated.

### Removing gas

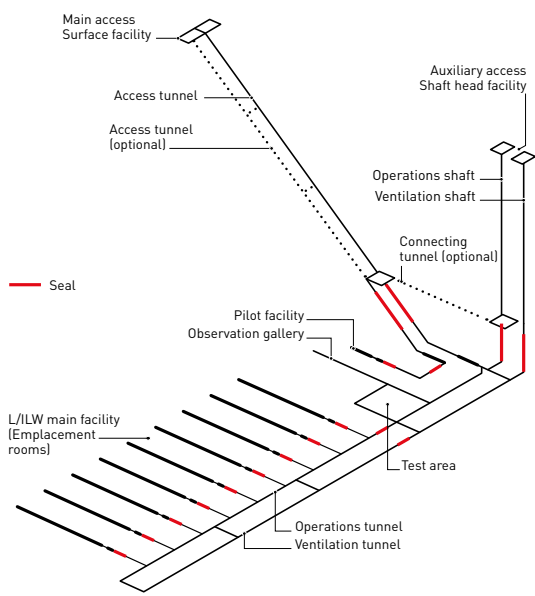
Gas moves along the tunnel walls through the excavation damaged zone (see glossary) and into the Opalinus Clay. Under the expected pressures, the gas will dissolve in the porewater of the clay and diffuse away through the pores. If more gas is produced, this can no longer dissolve completely in the porewater and gas will then accumulate and form a gas phase

which can displace the porewater. The accumulated gas will also be removed with time. To ensure that the pressures in the tunnels do not build up excessively, the gas can be removed through the tunnels and into the access structures using additional engineered measures such as gas-permeable seals (see image below). These seals retain radionuclides. Intensive international research effort is being invested in the optimisation of such seals and a 1:1 scale test is currently ongoing at the Grimsel Test Site.

### Optimisation of models

The facts summarised in this brochure are explained in detail in a report produced by Nagra in 2016 (NTB 16-03). In the coming years, the remaining uncertainties will be reduced through targeted research activities. The models of the different processes are already realistic but will be further refined through experiments.

**Simplified sketch (example) of a deep geological repository for low- and intermediate-level waste**



Claudio Köppel; Nagra

In a deep geological repository, several sealing structures are used to close the tunnels and caverns containing the radioactive waste and the access structures (e.g. operations shaft, access tunnel). These gas-permeable seals function as a barrier to water and thus retain dissolved radioactive substances. Gas can escape directly from the waste emplacement rooms and into the surrounding rock, but can also be led under controlled conditions to the access structures and from there into the rock. On their long migration through the Opalinus Clay, the dissolved radioactive substances are also retained and decay further. The maximum radiation dose at the earth's surface is thus well below the legally prescribed limit (see box on page 2).

## Glossary – explanations

In Switzerland, a deep geological repository will be constructed in the low-permeability host rock Opalinus Clay. High-level waste will be emplaced in tunnels and low- and intermediate-level waste in caverns. The tunnels and caverns are also referred to as disposal rooms.

### Safety barriers of a deep geological repository

The engineered and geological safety barriers ensure the safe containment of the radioactive waste in the repository. The engineered barriers include the waste matrix (e.g. cement or glass), the disposal containers and the backfilling of the disposal tunnels with bentonite (HLW) or the disposal caverns with cement mortar (L/ILW). Together with the surrounding rock layers (confining units), the Opalinus Clay acts as the geological barrier providing long-term stability and makes a significant contribution to the retention of radionuclides.

### Excavation damaged zone

The construction of tunnels and caverns in the Opalinus Clay causes a slight decompaction of the rock around the excavations. This so-called excavation damaged zone has a locally enhanced permeability to water and gas. However, it heals itself after a few years.

### Ion-exchange resins

These are used in the nuclear power plants to clean water circulation systems. Once the resins are spent, they are treated as radioactive waste for conditioning. The resins are pre-treated at the power plants to convert them into a form suitable for interim storage and final disposal. As much water as possible is removed by draining or drying the resins and they are then solidified with polystyrene, cement or bitumen.

**HLW:** High-level waste from the nuclear power plants, for example spent fuel assemblies

**L/ILW:** Low- and intermediate-level waste, for example operational waste from the power plants

**ENSI:** Swiss Federal Nuclear Safety Inspectorate



WWW

### Further reading

- «Production, consumption and transport of gases in deep geological repositories according to the Swiss disposal concept». NTB 16-03, December 2016
- «The Nagra Research, Development and Demonstration (RD&D) Plan for the Disposal of Radioactive Waste in Switzerland». NTB 16-02, December 2016
- Entsorgungsprogramm 2016 der Entsorgungspflichtigen NTB 16-01, December 2016 (in German with an extended English summary)
- Themenheft «Entsorgungsprogramm – daran arbeiten wir», December 2016

The documents can be found under [www.nagra.ch](http://www.nagra.ch) → Publications/Downloads.

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