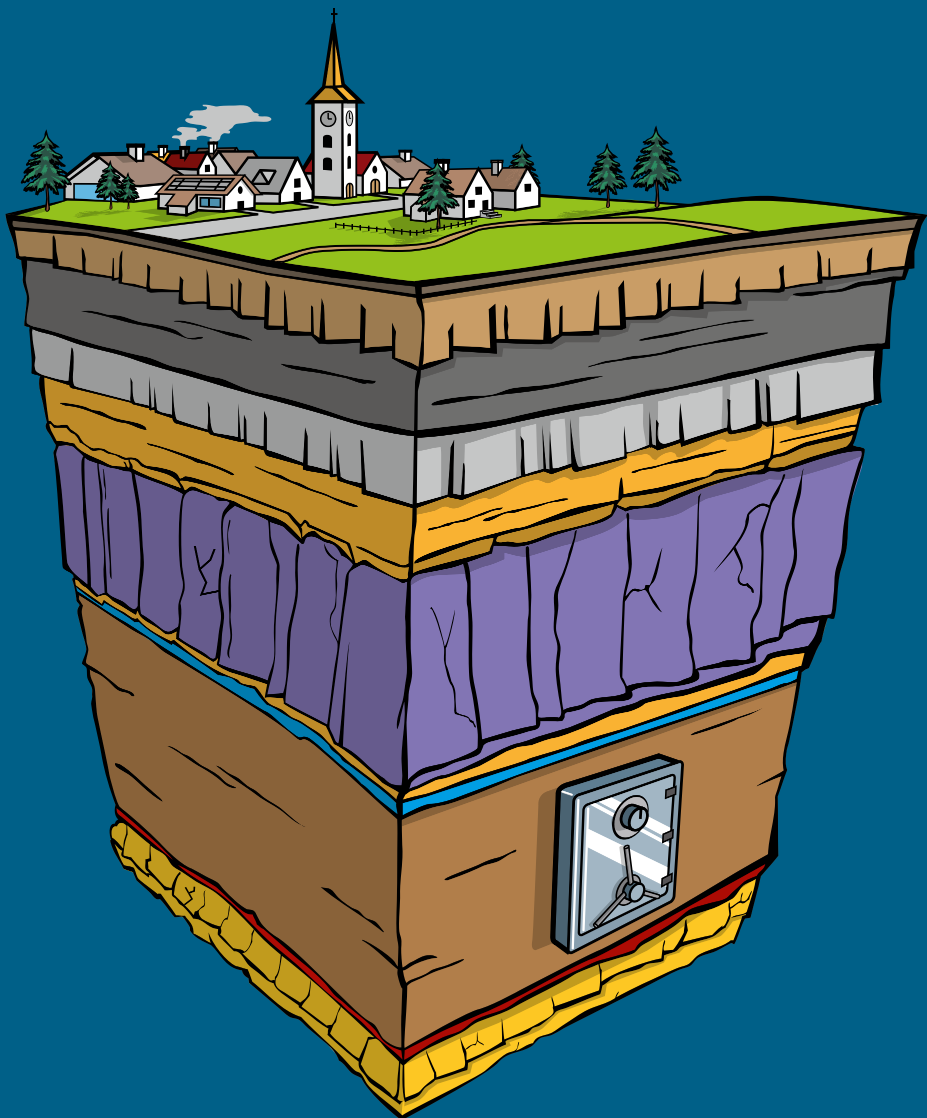
radioactive waste

where from, how much, where to?



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Imprint

This brochure explains how and where radioactive waste is produced, where it is held in interim storage and how it can be disposed of safely in deep geological repositories.

A selection of further brochures published by Nagra (in German):
Waste management programme – an insight into our work
(special issue no. 9, June 2017)

Langzeitsicherheit – Die Hauptaufgabe der Tiefenlagerung radioaktiver Abfälle
(special issue no. 8, October 2015)

Siting regions for deep geological repositories – Nagra's proposals for Stage 3
(leaflet, January 2015)

Wussten Sie, ... – Erstaunliches zu Radioaktivität und Entsorgung
(special issue no. 6, May 2013)

Erdbeben – Eine Gefahr für Tiefenlager?
(special issue no. 4, March 2010 / March 2014)

Spuren der Zukunft – Lernen von der Natur für die Tiefenlagerung von radioaktiven Abfällen
(special issue no. 1, April 2007)

Erosion – Long-term geological evolution and deep geological repositories
(special issue no. 10, October 2018)

WWW

Further reading

Reference will be made in this brochure to other Nagra publications on particular topics. These can be downloaded or ordered at **www.nagra.ch.**

Radioactive waste
Where from, how much, where to?
November 2018

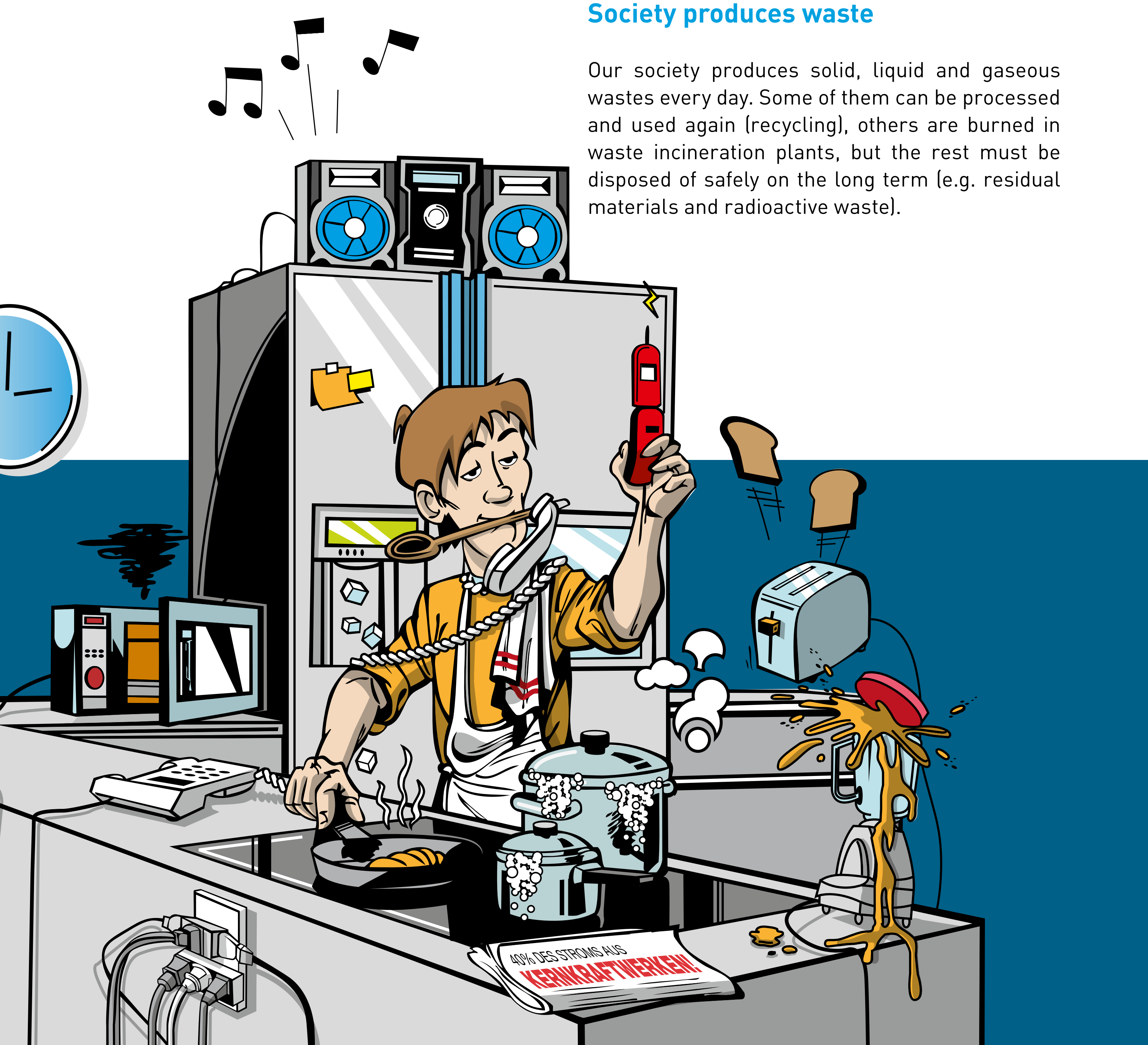
Illustrations: Cover photo, pages 4, 8, 12 and 14
W4, Wettingen

Switzerland has radioac

Radioactive waste is produced in different places. Most of it comes from the five Swiss nuclear power plants Mühleberg, Beznau I and II, Gösgen-Däniken and Leibstadt. Without proper handling, the waste is dangerous, but the associated hazard decreases continuously due to radioactive decay.

Society produces waste

Our society produces solid, liquid and gaseous wastes every day. Some of them can be processed and used again (recycling), others are burned in waste incineration plants, but the rest must be disposed of safely on the long term (e.g. residual materials and radioactive waste).



tive waste

Radioactive waste is produced in nuclear power plants

Nuclear power plants are the main producers of radioactive waste (Figure 1). Inside a nuclear reactor, the fission of atomic nuclei releases heat. This turns water into steam which drives a turbine along with the generator that produces electricity. Spent fuel is highly radioactive. Other radioactive wastes arise from the daily operation of the plants and their later dismantling and decommissioning.

... but also in medicine, industry and research

A wide range of applications in the areas of medicine, industry and research also produce radioactive waste (see Figure 2 for sources of radiation from medicine and industry, and waste from research facilities, etc.).

Figure 1
Gösgen-Däniken nuclear power plant, one of five operating in Switzerland.

© Comet Photoshopping, Dieter Enz

Paul Scherrer Institute

Nagra

Suva

Paul Scherrer Institute

Figure 2
Radioactive waste is also produced in the fields of medicine, industry and research. Examples from top to bottom:
Medical cyclotron at the Paul Scherrer Institute (PSI), old radioactive smoke detector, welding seam inspection using a radiation source, old research reactor at PSI.

Categories of radioactive waste in Switzerland

Radioactive waste is categorised as follows based on its physical properties, (Nuclear Energy Ordinance Art. 51):

1) **High-level waste** includes spent fuel assemblies that will not be used again, as well as vitrified fission product solutions from the reprocessing of spent fuel.
2) **Alpha-toxic waste is** waste with a content of alpha emitters exceeding 20 000 Becquerels per gram of conditioned waste.
3) **Low- and intermediate-level waste** includes all other radioactive waste.

WWW

Further reading
Special issue "Langzeitsicherheit – Die Hauptaufgabe der Tiefenlagerung radioaktiver Abfälle" (available in English in 2019)
www.nagra.ch

What is radioactivity anyway?

Unstable atomic nuclei that transform spontaneously are termed radioactive. There are two types of nuclear transformation, namely alpha and beta decay, which emit alpha, beta and gamma radiation. After transformation, the nucleus is stable (no longer radioactive), or it decays in further steps until it reaches a stable form.

Radioactivity is everywhere

Natural radiation has always existed. Some of it comes from the soil and rock (terrestrial radiation), and some from outer space (cosmic radiation). The natural radiation level is higher in the mountains than at lower altitudes and higher in granitic rocks than in rocks such as limestones (Figure 3). Our food and the air we breathe also contain small amounts of radioactive substances that are partly absorbed by the body.

Figure 1
Radiation is present everywhere. Natural radiation is higher in the mountains than at lower altitudes.

Aura

How long must radioactive waste be confined?

Radioactive waste contains a mix of different radioactive atoms. Its toxicity decreases as a result of radioactive decay and, after a certain amount of time, the waste reaches an activity level equivalent to that of naturally occurring substances. Generally speaking, after approximately 30 000 years, low- and intermediate-level waste reaches the radiotoxicity of granitic rock. After approximately 200 000 years, the radioactivity of spent uranium fuel will decay to the level of the uranium used to produce the fuel when it was originally mined (Figure 2). Most high-level waste emits high amounts of radiation over a limited time period, while the proportion of long-lived radioactive substances emits less radiation over a long period of time (see Figure 2).

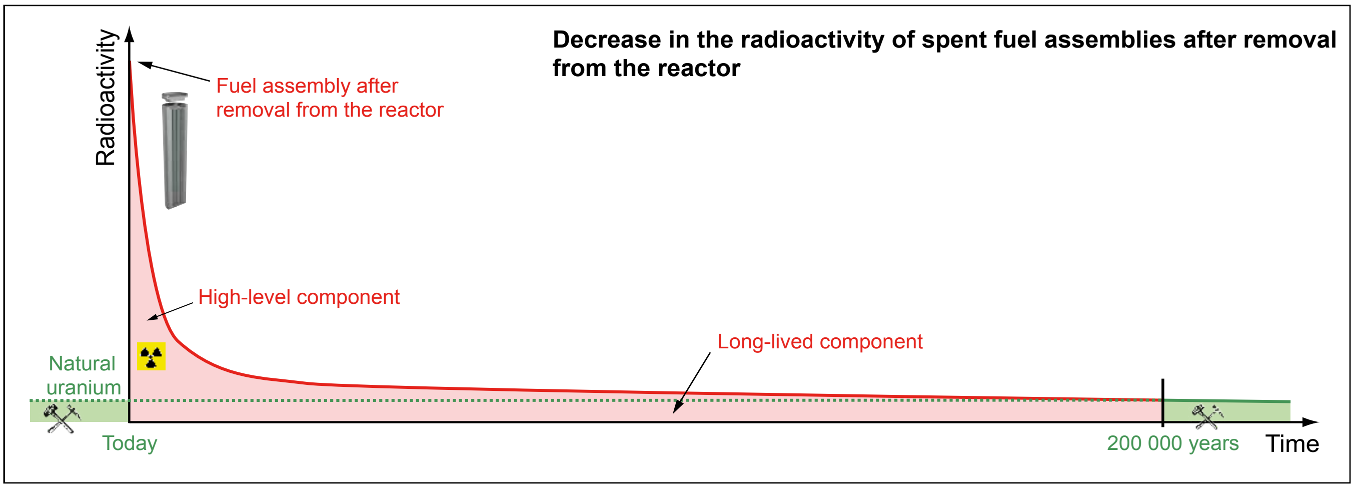
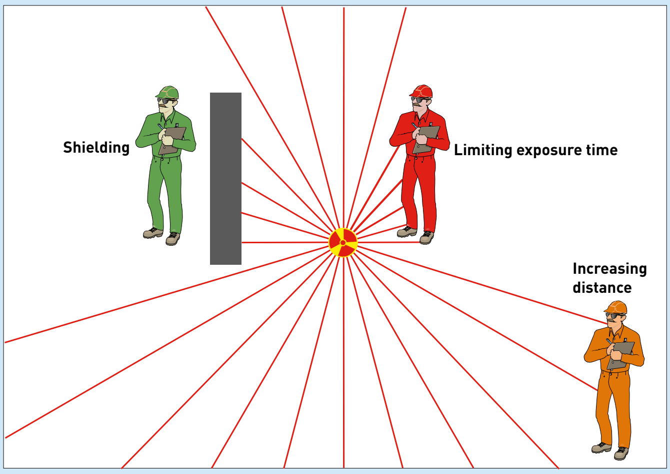


Figure 2

Using radioactive substances – protection against radiation is possible



Radioactive substances (radiation sources) are used in multiple ways. It is necessary, and also possible, to protect against radiation: by limiting the amount of exposure time, by increasing the distance to the radiation source and by using suitable shielding or confining the radioactive substances.
It is particularly important to avoid inhaling or ingesting radioactive substances as far as possible because the dose effect inside the body is much higher than it is externally.

Where and how much?

Radioactive waste is currently held in interim storage facilities. It is secure, under control, and waste handling and processing are routine operations. The volumes, composition and storage locations are precisely known.

Who is responsible for the waste?

As specified in the Nuclear Energy Act, the waste producers – under the supervision of the Federal Government – are responsible for the permanent, safe disposal of radioactive waste. The operators of the nuclear power plants and the Swiss Federal Government, which is responsible for the waste arising from medicine, industry and research, founded Nagra in 1972 with the aim of performing this important task.

Safe interim storage facilities

At present, radioactive waste is held in interim storage facilities. The nuclear power plants and the centralised interim storage facility operated by Zwilag AG in Würenlingen have sufficient capacity for all the waste arising from the operation and decommissioning of Switzerland's five nuclear power plants until such time as the deep geological repositories have been constructed (Figures 1 to 3). The waste from medicine, industry and research is stored in the Federal Government's interim storage facility, also located in Würenlingen.

Decades of experience with safe handling of high-level waste

After four to five years in the reactor, the fuel assemblies must be replaced because the content of fissile uranium has been depleted and too many fission products have accumulated. After removal from the reactor, the spent fuel assemblies are kept in storage pools (cooling ponds) for five to ten years. They are then packaged into transport and storage casks and transferred to an interim storage facility. They will be kept there until they can be transported to a deep geological repository.

Spent fuel assemblies must be disposed of as high-level waste. However, there is also a way to recycle them: In a reprocessing plant, the fissile material still contained in the fuel assemblies can be separated from the fission products and used to manufacture new fuel assemblies. The fission products represent high-level waste. Approximately 1140 tonnes, or almost thirty percent of the total amount of spent fuel expected from Switzerland's five currently operating nuclear power

Zwilag

Figure 1
All types of radioactive waste and spent fuel assemblies can be stored in the halls of the centralised interim storage facility of Zwilag AG in Würenlingen.

Zwilag

Figure 2
Hall for storing high-level waste and spent fuel assemblies at the interim storage facility in Würenlingen. By the end of 2016, 34 spent fuel assembly casks and 23 casks containing high-level waste had been deposited there.

Figure 3
Federal Government interim storage facility for radioactive waste from medicine, industry and research.

plants, were transported abroad for reprocessing up to 2006. All of the resulting waste has been taken back by Switzerland; the last return shipment was made in 2016. The moratorium in the Nuclear Energy Act prohibiting the export of spent fuel assemblies for the purpose of reprocessing is valid until 2020.

Routine handling and treatment of low- and intermediate-level waste

Low- and intermediate-level waste from nuclear power plants is processed for final disposal (e.g. by solidification or by incinerating or melting it to decrease its volume) directly at the power plants or in the Zwilag interim storage facility in Würenlingen. It is then packaged in suitable containers and stored in the interim storage facilities of the nuclear power plants or Zwilag (Figures 1 and 2). Raw wastes from medicine, industry and research are processed into a form suitable for final disposal at the Paul Scherrer Institute or at the interim storage facility and then stored in the Federal Government's facility in Würenlingen.

Small waste volumes

For a 60-year operating period (47 years for the Mühleberg NPP), the operators of the Swiss nuclear power plants expect approximately 4070 tonnes of spent fuel. When packaged in disposal canisters, and considering partial reprocessing, this waste would require around 9400 cubic metres of space. This is equivalent to the volume of eight single-family homes.

For a 60-year NPP operating period (47 years for Mühleberg), Nagra expects a total of approximately 63 000 cubic metres of low- and intermediate-level waste (including the disposal containers). Approximately half the volume consists of waste from the dismantling of the nuclear power plants. The areas of medicine, industry and research will produce approximately 20 000 cubic metres of low- and intermediate-level waste.

In total, the volume of radioactive waste to be disposed of amounts to approximately 92 000 cubic metres (including the disposal canisters, Figure 3).

Figure 1 Nagra

Drum holding solidified radioactive ion-exchange resin from a nuclear power plant.

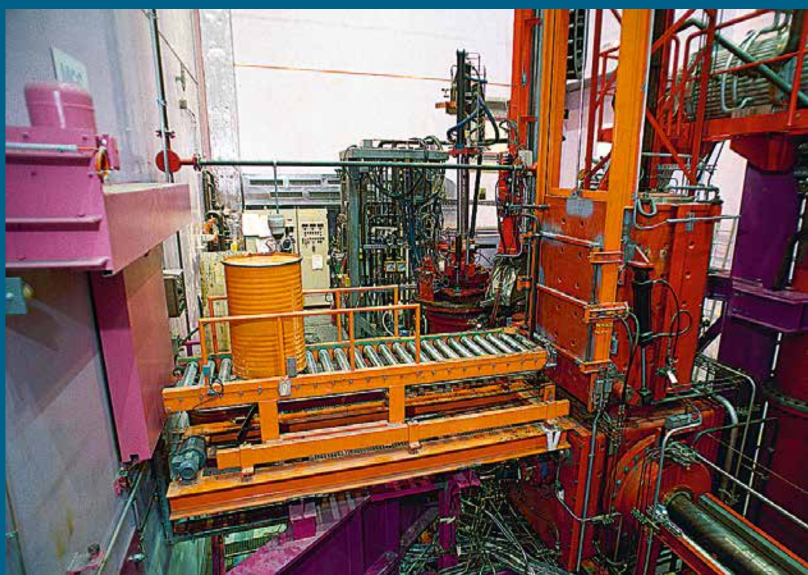


Figure 2 © Comet Photoshopping, Dieter Enz

In the plasma furnace at the Zwilag interim storage facility in Würenlingen, various types of low-level raw wastes are incinerated and melted and the glass matrix is solidified to form a slag-type mass.

Waste inventory known exactly

Nagra is responsible for maintaining a centralised inventory of all types of radioactive waste. Each waste package is entered into a database in which the precise content (i.e. embedding material, origin and composition of the waste) and the location of the packages are documented. All data can be retrieved at any time.

Routine packaging and interim storage

The raw wastes are first processed into a form that is chemically and physically stable over a long period of time and are then enclosed in suitable containers (conditioning). Spent fuel assemblies are placed directly in safety containers and held in interim storage facilities until the deep geological repositories are ready. Interim storage facilities are constructed to comply with all regulatory conditions relating to safety. Conditioning and interim storage are under the strict supervision of the safety authorities.

Waste volumes today (as of end 2016)

(conditioned waste)

At the nuclear power plants	3 620 m^3
In the Zwilag interim storage facility	2 074 m^3
In the Federal Government interim storage facility (waste from medicine, industry and research)	1 578 m^3

Additional information can be found in the Nagra leaflet "Mengen und Herkunft radioaktiver Abfälle für die geologische Tiefenlagerung" (German only).

Prognosis

(packaged, operation of the nuclear power plants for 60 years; 47 years for Mühleberg)

SF and vitrified HLW	approx. 9 400 m^3
L/ILW and ATW from the 5 NPPs	approx. 63 000 m^3
L/ILW and ATW from medicine, industry and research	approx. 20 000 m^3
Total volume	approx. 92 000 m^3

SF = spent fuel assemblies
HLW = high-level waste
L/ILW = low- and intermediate-level waste
ATW = alpha-toxic waste

Figure 3 © Comet Photoshopping, Dieter Enz

The waste volume of approximately 92 000 cubic metres is roughly equivalent to the Zürich train station terminal shown here.

Transmutation

Transmutation is repeatedly discussed as a means of transforming long-lived radionuclides into shorter-lived ones. Research into these processes is ongoing, for example at the Paul Scherrer Institute in Würenlingen. The goal is to be able to transform the long-lived components of high-level waste into shorter-lived ones in the future. Even if transmutation were to become feasible on an industrial scale, a deep geological repository would still be needed for the shorter-lived radioactive substances being produced from the process and for the remaining radioactive substances that cannot be transmuted.

The goal is deep geologi

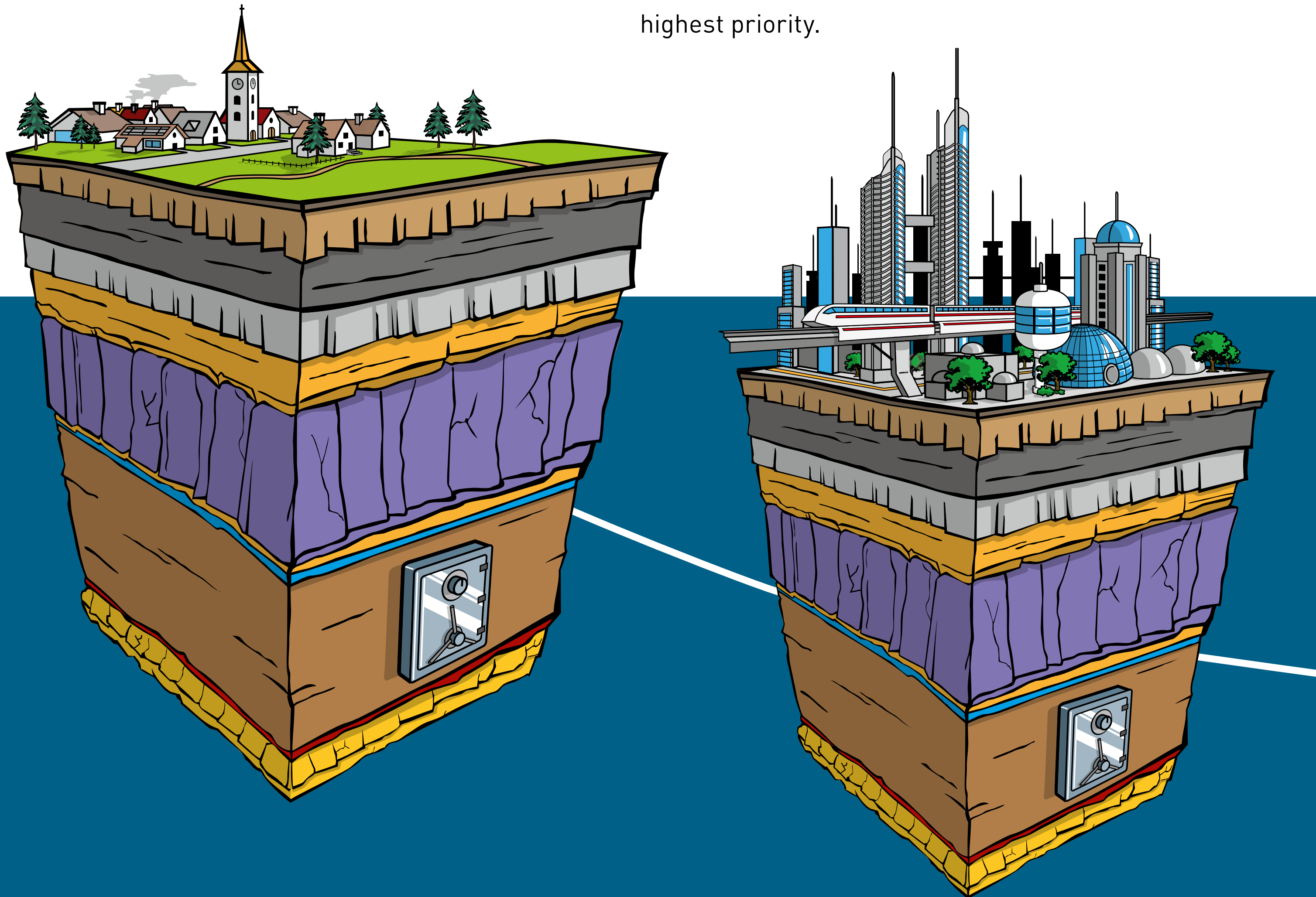
A deep geological repository is a facility located at a depth of several hundred metres waste type, it consists of emplacement drifts or caverns, a pilot repository for moni-

Why deep geological disposal

History shows that society does not remain stable over longer time periods. The past century illustrates this clearly (Figure 1). Unlike society, rock layers can be stable and maintain their properties for many millions of years. Deep underground and unaffected by events at the earth's surface, time essentially comes to a standstill (see illustrations below). If the rock layers are impermeable, they can confine substances for the necessary amount of time (Figure 2).

Internationally recognised concept

It is recognised worldwide that disposal in geologically stable rock formations can ensure safe containment of high-level and alpha-toxic waste for a sufficiently long time period. This principle is anchored in Switzerland's Nuclear Energy Act and also applies to low- and intermediate-level waste. Sweden and Finland, for example, are already operating geological repositories for the latter waste type. With its demonstrations of disposal feasibility recognised by the Federal Council in 1988 and 2006, Nagra was able to show that deep geological disposal of all types of radioactive waste is also possible in Switzerland. The long-term protection of humans and the environment has the highest priority.



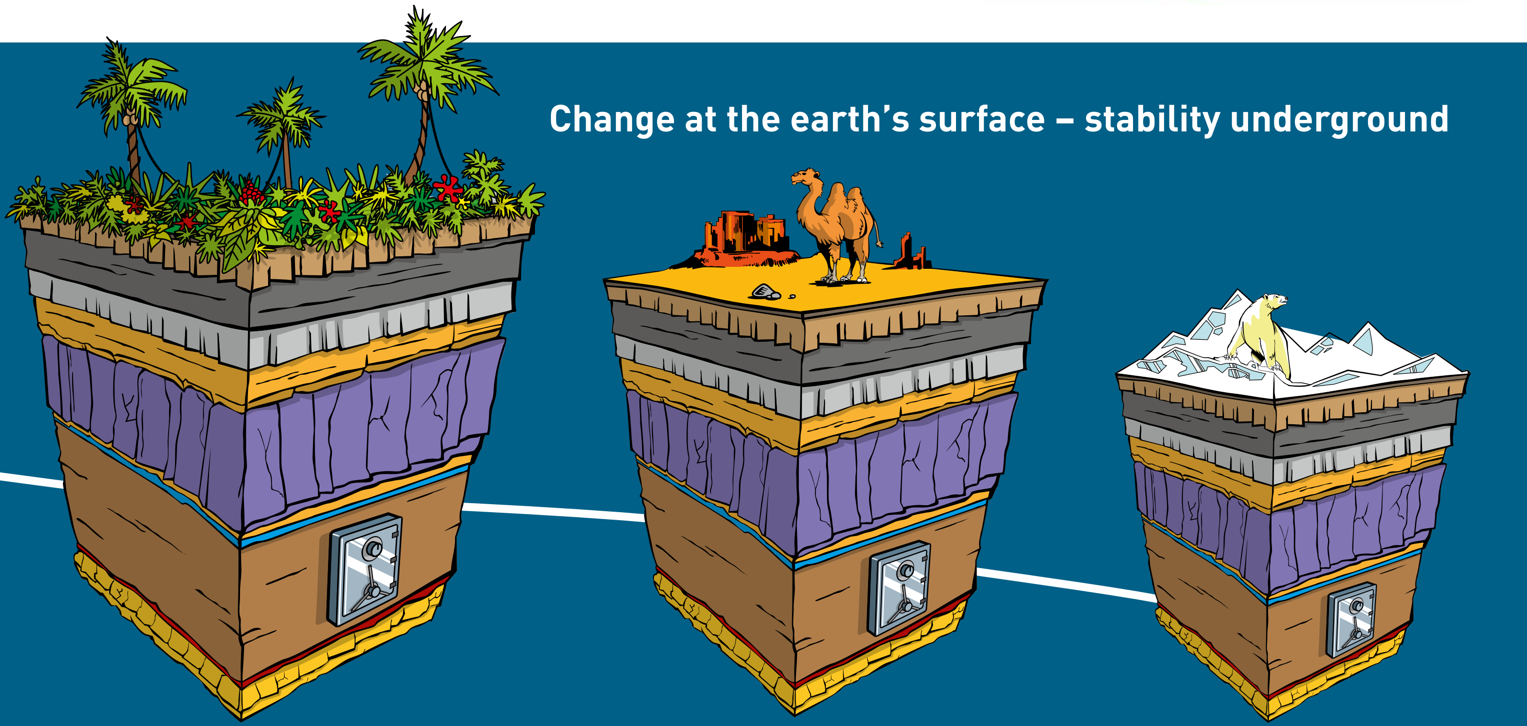
cal disposal

below the earth's surface and constructed in a suitable host rock. Depending on the toring a representative part of the waste and test areas.

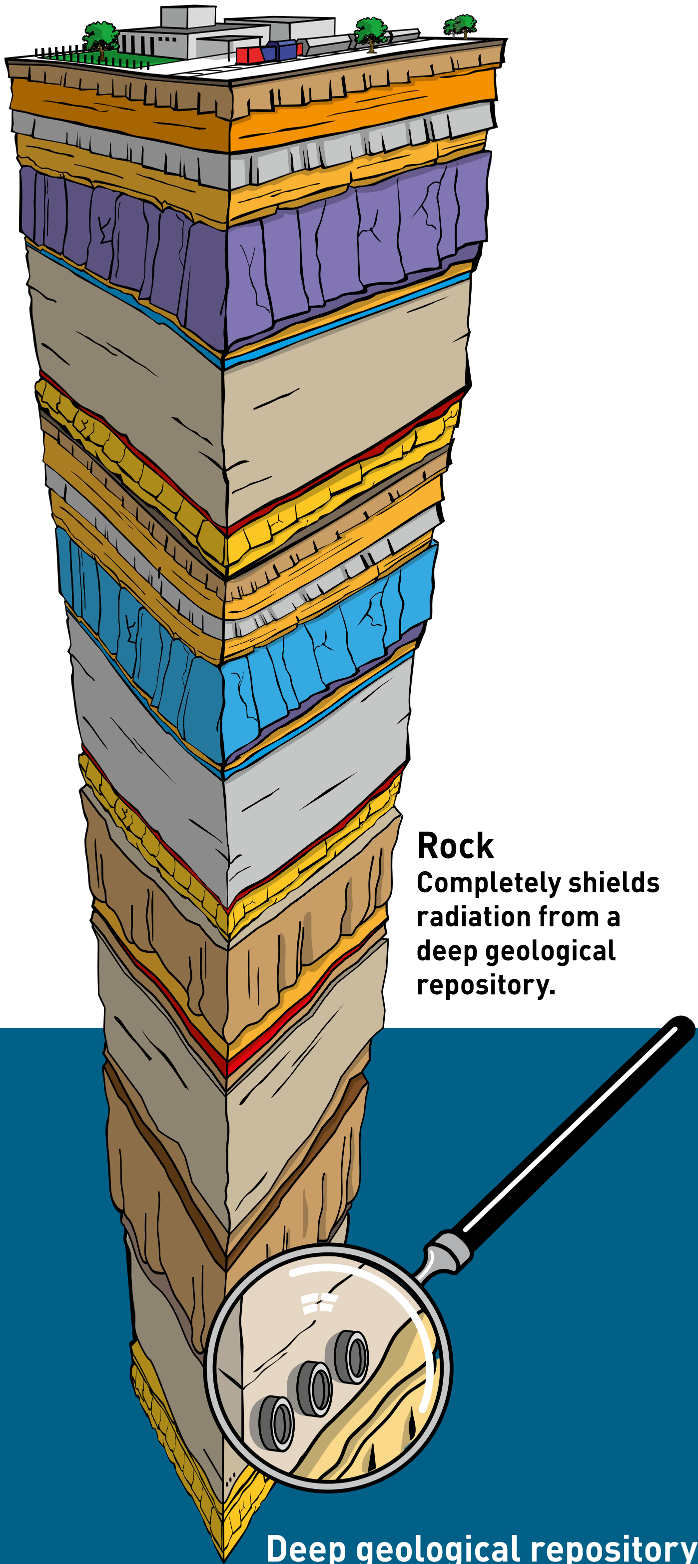
Figure 1
Over the past 100 years, Europe has witnessed two world wars and numerous social upheavals. The image is of the city of Dresden (Germany) which was destroyed in February 1945.
AP Images

Figure 2
Underground there is peace and quiet. Enclosed in amber embedded in a layer of clay and sand, the delicate parts of this insect's body have been preserved for approximately 40 million years.
University of Bonn, Germany

Change at the earth's surface – stability underground



Surface facility



Rock
Completely shields radiation from a deep geological repository.

Deep geological repository

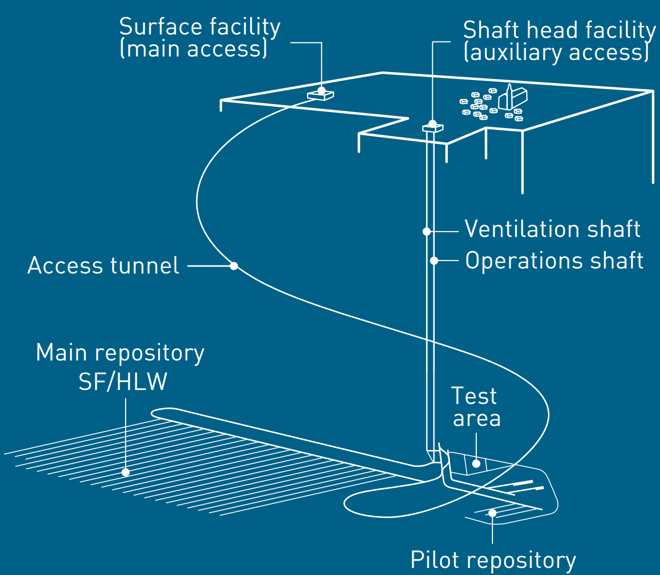
The packaged waste is emplaced in drifts or caverns. These will be backfilled and tightly sealed.

Facilities and operation of a repository

Various operational buildings will be constructed at the earth's surface; these will require an area of up to 200 by 400 metres and will resemble an industrial or commercial facility and can be adapted to the surrounding landscape. Below ground, a deep geological repository consists of emplacement drifts or caverns for the different waste types, a pilot repository and test areas (Figure 1).

The radioactive waste is transported to the underground emplacement rooms through the access tunnel. A quality assurance system ensures that only authorised waste is disposed of. After an initial monitoring phase, the main repository will be sealed, and monitoring of the pilot repository containing a representative component of the waste will continue. When the authorities decide to seal the entire facility, the installations will be dismantled and all accesses will be backfilled. The waste can still be retrieved even then.

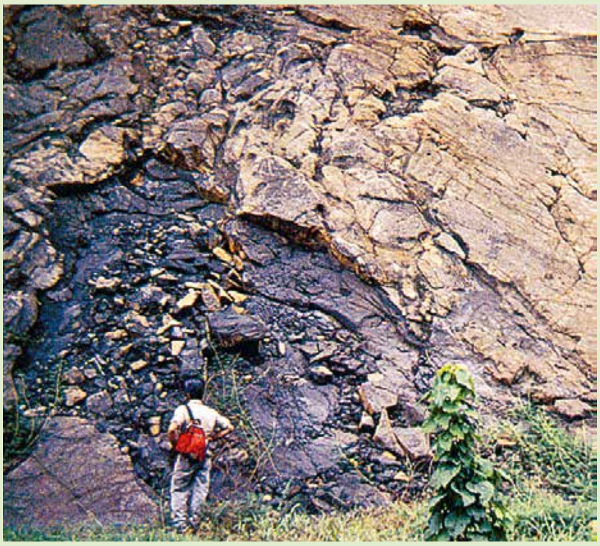
Figure 1
Deep geological repository for high-level waste



Radiation is shielded and the waste is safely contained on the long term

The radiation emitted by the waste is shielded by canisters, tunnel backfill, repository installations and the surrounding rock. At a depth of just one to two metres inside the rock, the radiation level from high-level waste is lower than the natural radiation emitted by the rock itself due mainly to the radioactive decay of naturally occurring uranium and thorium (Figure 2).

The waste must be safely contained until the radioactivity has decreased sufficiently. A system of multiple engineered safety barriers is used to isolate the waste effectively (inter alia, metal canisters and tunnel backfill consisting of granular bentonite material, Figure 2). A host rock that remains stable over a long period of time provides an additional geological barrier. It also protects the engineered barriers from environmental impacts (e.g. erosion) and water influx. This prevents water from causing radioactive substances to be dissolved from a deep geological repository and then transported to the earth's surface where they could enter the foodchain. A repository must therefore ideally be constructed in low-permeability rock. Nature demonstrates how effective such containment can be (see textbox).



Nagra

Tested by nature

In a uranium ore deposit in Oklo (Gabon, Africa), the high concentration of uranium-235 led to spontaneous nuclear reactions (nuclear fission) 1.8 billion years ago. During this process, the radionuclides (high-level waste) were contained for a long period of time in rock with no engineered safety barriers. Nature has thus already created a "nuclear reactor" and a functioning "deep geological repository for high-level waste".

Shielding radiation in a deep geological repository for high-level waste

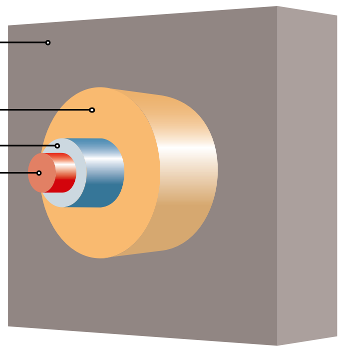


Figure 2

Further reading

On site selection: Leaflet "Siting regions for deep geological repositories – Nagra's proposals for stage 3"
On the waste management concept: Special issue "Waste management programme – an insight into our work"

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