Opalinus Clay Project

Demonstration of feasibility of disposal
("Entsorgungsnachweis")
for spent fuel, vitrified high-level waste and
long-lived intermediate-level waste

Summary Overview

nagra

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With the submission of the reports on the engineering project [NTB 02-02], the synthesis of geological investigations [NTB 02-03] and the safety assessment [NTB 02-05] for a deep geological repository in Opalinus Clay, Nagra – the National Cooperative for the Disposal of Radioactive Waste – has fulfilled a requirement specified by the Federal Council in its decision on Project Gewähr 1985, namely that research on disposal of spent fuel (SF), vitrified high-level waste (HLW) and long-lived intermediate-level waste (ILW) be extended to cover sedimentary formations. The Opalinus Clay Project represents the final step in the demonstration of feasibility of disposal, or "Entsorgungsnachweis". The Project is intended to provide input to the deliberations of the Swiss Federal Council on future strategy to be followed in connection with the management and disposal of SF/HLW/ILW.

This document provides an overview of the content and conclusions of the Opalinus Clay Project and clarifies its position in the ongoing waste management programme in Switzerland.

1 Position of the Opalinus Clay Project in the Swiss nuclear waste management programme

1.1 Introduction

Radioactive wastes, arising from the use of nuclear energy for electricity production and from applications in the fields of medicine, industry and research, have to be disposed of permanently and safely. This is required both by law and by the precept that our society should act in a responsible manner with respect to mankind and the environment.

In Switzerland, the producers of radioactive waste are responsible for its management; these are principally the operators of the nuclear power plants, but also the Federal Government, which is responsible for waste from medicine, industry and research (MIR waste). The waste producers adhere to this principle and approach their task seriously and with care. Their aim is to achieve, within the existing legal framework, the timely implementation of the necessary waste management facilities, for example the centralised interim storage facility (ZWILAG) of the nuclear power plants and the Federal Government's interim storage facility (BZL). Nagra (the National Cooperative for the Disposal of Radioactive Waste) was set up by the waste producers in 1972 to carry out the research and development work leading to disposal of radioactive waste. Nagra has since evolved into an internationally recognised competence centre in the field of nuclear waste management; on behalf of the waste producers, it prepares the materials used by the federal authorities as a basis for their decisions.

The tasks associated with waste management can be seen from two viewpoints. Taking the *aspect of time*, a distinction can be drawn between:

- Ongoing safe handling and interim storage of waste until such time as final disposal facilities are available. This includes waste characterisation, inventory development and conditioning of waste into a stable form suitable for later disposal.
- Preparing for and planning the final disposal facilities required on the longer term (deep geological repositories), as a basis for their later realisation. This includes defining waste management and disposal concepts and the selection of potentially suitable sites for disposal facilities (site selection).
- Implementing the final disposal facilities (construction, operation and closure of deep geological repositories).

In terms of the *radiotoxicity of the waste*, a distinction is drawn today between:

- Management of low- and intermediate-level waste (L/ILW) and
- Management of spent fuel, high-level waste and long-lived intermediate-level waste (SF/HLW/ILW).

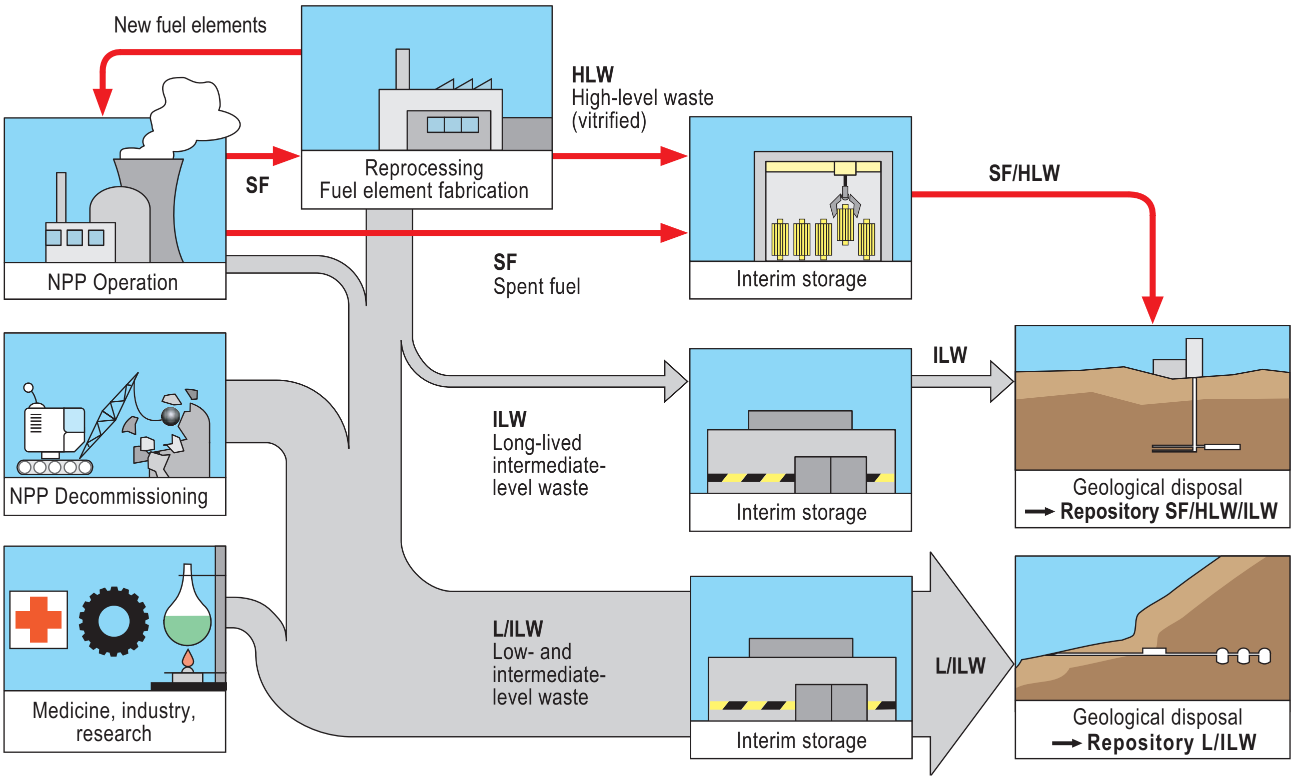


Figure 1 The Swiss nuclear waste management concept. The thickness of the arrows symbolises the relative volumes of the different waste streams. For low- and intermediate-level waste, a deep repository with horizontal access is shown, as was foreseen for the Wellenberg site. The review of the L/ILW management concept, initiated following the abandonment of the Wellenberg site, could lead to a different solution for L/ILW, but this has no impact on the findings of the Opalinus Clay Project regarding the safety and feasibility of deep geological disposal of spent fuel, vitrified high-level waste and long-lived intermediate-level waste.

1.2 Status of work on waste management, outlook

The current status of the programme can be summarised as follows:

- For storage of waste prior to final disposal, storage facilities exist at the various individual nuclear power plants, as well as at two centralised facilities: ZWILAG for all categories of waste and the facility of the Federal Government (BZL) for waste from medicine, industry and research. Waste conditioning plants also exist. The capacity of ZWILAG and the storage facilities at the nuclear power plants is sufficient to cover waste arising during the envisaged operating lifetimes of the existing power plants.
- With a view to final disposal of L/ILW, the Wellenberg site was selected, investigated and, finally, judged as probably being suitable by independent experts and the safety authorities of the Federal Government. The siting community gave the project its approval in 1994 but, based on the result of a cantonal referendum, progress had been blocked since 1995. Following modification of the disposal concept, an application was made for a concession for an exploratory drift to allow the suitability of the site to be investigated further. The concession was granted by the Government of Canton Nidwalden on 25th September 2001, but was refused by the people in a cantonal referendum on 22nd September 2002. A site that appeared to be technically suitable thus had to be abandoned for political reasons.
- With the Opalinus Clay Project, a demonstration of the feasibility of final disposal of SF/HLW/ILW in Switzerland has been submitted to the federal authorities for their review. The Project will also provide input to the deliberations of the Swiss Federal Council on the future strategy for the management of these waste categories. Nagra is proposing to the authorities that future investigations relating to deep geological disposal of SF/HLW/ILW in Switzerland should focus on the Opalinus Clay and on the potential siting area in the Zürcher Weinland. This proposal is based, on the one hand, on the systematic selection procedure conducted on the basis of safety considerations that led to identification of the Opalinus Clay and the Zürcher Weinland for the Entsorgungsnachweis; on the other hand, it is based on the results of the investigations carried out for the Entsorgungsnachweis. The selection of an actual disposal site remains the subject of a future general licence procedure, for which more extensive investigations will be necessary.

The following activities are foreseen for the coming years:

- Continuing operation and maintenance of the interim storage facilities; completion of the storage hall for low- and intermediate-level waste and start of operation of a new conditioning plant at ZWILAG.
- A review of the procedure for final disposal of L/ILW necessitated by the politically motivated negative decision on the Wellenberg site; preparing for and carrying out the associated work.
- Continuing research and preparation activities for deep geological disposal of SF/HLW/ILW in Switzerland; the option of disposal abroad (e.g. as part of a multinational project) will be followed in parallel.

Regarding the latter two points, i.e. realisation of deep geological repositories, Nagra is able to rely on the internationally recognised high level of scientific and technical know-how it has built up over the years. As part of the parliamentary deliberations on the new Nuclear Energy Law, it was required that the waste producers should present a waste management programme to the Federal Council for review and approval. To date, some of the technical components and options for such a targeted programme covering all categories of waste have already been formulated and evaluated. Following the loss of the Wellenberg site, further technical work will be necessary within the L/ILW programme. Bringing all the different components together to form a coherent and comprehensive waste management strategy will, however, be possible only after the response of the authorities to the Entsorgungsnachweis project is known and once the legal and political boundary conditions have been clarified (foreseen in the new Nuclear Energy Law). In this instance, the political powers are called upon to create a legal framework that will allow timely implementation of site-specific waste management facilities with the cooperation of the involved Cantons and local communities.

2 The components of the Entsorgungsnachweis and the motivation behind the Opalinus Clay Project

Figure 2 provides an overview of the programme for disposal of high-level waste.

The work on the Entsorgungsnachweis can be traced back to the Federal Government Ruling of 1978 on the Atomic Act. This Ruling stipulates that a project should be prepared that ensures *"the permanent, safe management and final disposal of radioactive waste arising from the power plants".* The primary aim of the Entsorgungsnachweis is to show how a geological repository for radioactive waste can be realised in such a way that is both technically feasible and meets the safety requirements prescribed by the authorities.

The direct motivation behind the Opalinus Clay Project was the requirement attached by the Federal Council to its decision of 3rd June 1988 on Nagra's Project Gewähr 1985 (cf. below) that a *demonstration of siting feasibility* should be delivered for high-level and long-lived intermediate-level waste and that studies should be extended to include *non-crystalline* (i.e. *sedimentary*) *host rocks.*

The Entsorgungsnachweis basically consists of three components (Figure 2):

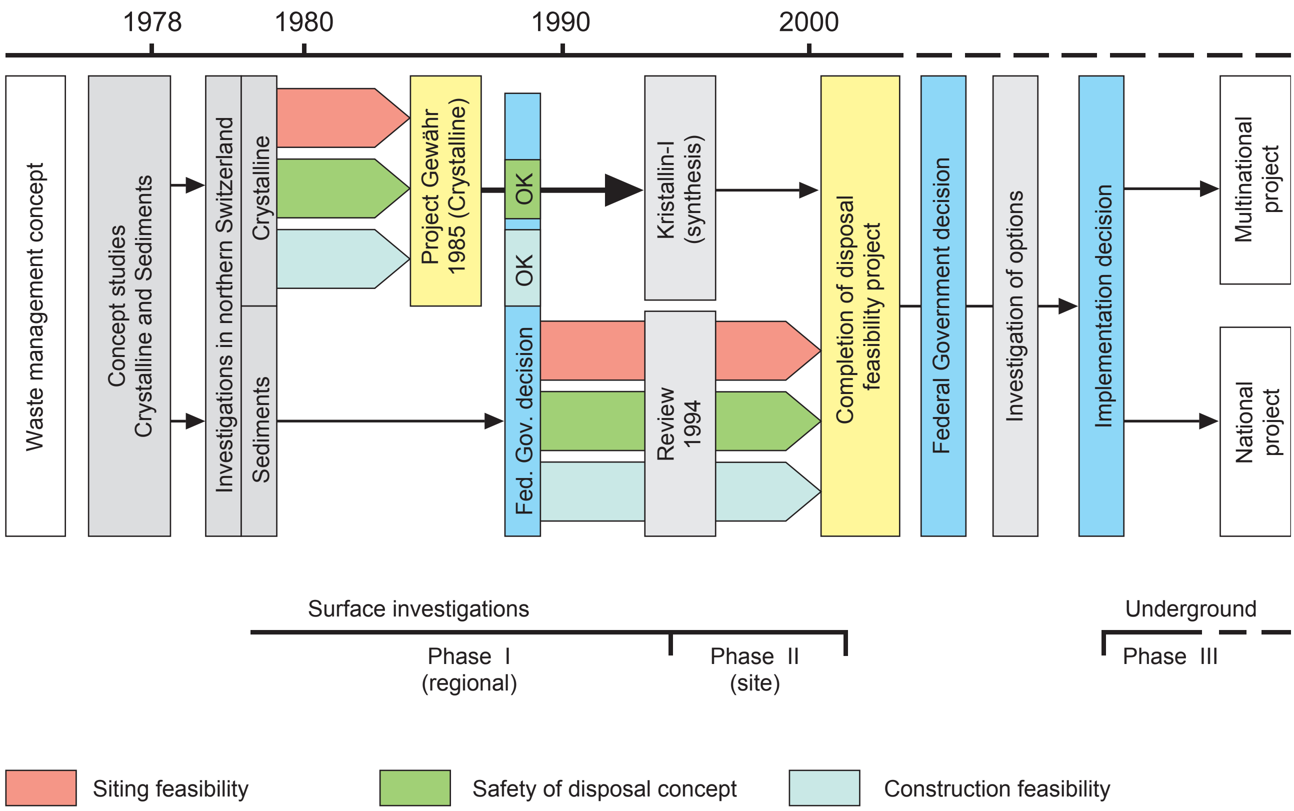


Figure 2 Key steps on the way to realising a deep geological repository for spent fuel, vitrified high-level waste and long-lived intermediate-level waste (SF/HLW/ILW). The Opalinus Clay Project documents the priority option of disposal in sedimentary formations. The option of disposal in the crystalline basement was considered in detail in Project Gewähr 1985 and in subsequent Nagra reports (e.g. NTB 93-01, 93-22). These documents are currently under review by the federal safety authorities.

- A demonstration that, in Switzerland, one or more sites exist with suitable (in terms of safety) geological and hydrogeological properties (demonstration of siting feasibility).
- A demonstration that a repository can be constructed and operated at such a site using current technology (demonstration of construction feasibility).
- A demonstration that such a repository meets the requirements specified by the authorities regarding long-term safety (demonstration of long-term safety).

Following studies on the waste management concept, civil engineering aspects and field and laboratory investigations, Nagra submitted the “assurance” project required by the 1978 Ruling – termed Project Gewähr 1985 [NGB 85-01/09] – to the Federal Government at the beginning of 1985. The project demonstrated, for all waste categories, how “permanent safe management and final disposal” can be realised in Switzerland.

The waste management concept assumes two types of repository – one for high-level and long-lived intermediate-level waste (HLW/ILW) and one for low- and intermediate-level waste (L/ILW). A model site was specified for each repository type, with representative properties as expected from the results of actual geological investigations. Based on considerations of tectonic stability and low seismic activity, Nagra’s investigations for the HLW/ILW repository focused on Northern Switzerland. Initially, the crystalline basement was in the foreground of studies, based on the wealth of international information on the rock type and the data already available for Northern Switzerland.

Drawing on the opinions and findings of the federal safety experts and the conclusions and recommendations contained in the report of the Federal Interagency Working Group on Nuclear Waste Management (AGNEB), the Federal Council delivered its decision on Project Gewähr on 3rd June 1988. The key points were:

- The demonstration of feasibility of disposal had been provided for L/ILW.
- The demonstration of long-term safety for HLW/ILW was also accepted – but not the *demonstration of siting feasibility,* i.e. the demonstration that a suitable rock body *of sufficient extent* could be found at an actual site in Switzerland.
- The demonstration of construction feasibility was accepted for all waste categories.
- The operators of the nuclear power plants were instructed to continue their work on disposal of radioactive waste and to extend their research activities in connection with HLW/ILW disposal to include sedimentary formations.

3 Selection of the Opalinus Clay host rock and the potential siting area in the Zürcher Weinland (demonstration of siting feasibility)

3.1 Systematic evaluation procedure

With the sediment programme, Nagra pursued a systematic, broadly based, transparent evaluation procedure, with sequential narrowing-down of options leading to selection of potential sedimentary host rocks and potential siting areas. The procedure, which is documented in three interim reports, was followed with the approval of the federal safety authorities and their experts.

As a first step, and based on a wealth of existing information, Nagra published a broad review of the potential suitability of sedimentary formations occurring in Switzerland for hosting a geological repository [NTB 88-25 / NTB 88-25E]. The result was that clay-rich rock formations – namely the Opalinus Clay and the Lower Freshwater Molasse (Untere Süsswassermolasse – USM) – began to emerge as the leading options. Potential siting regions for further investigation were identified for both rock types.

This was followed by a regional investigation phase (1990 – 1993) with specific field activities, with the emphasis on obtaining further geological information to allow the selection of a first-priority sedimentary host rock option and potential siting areas to be made in a transparent and comprehensible

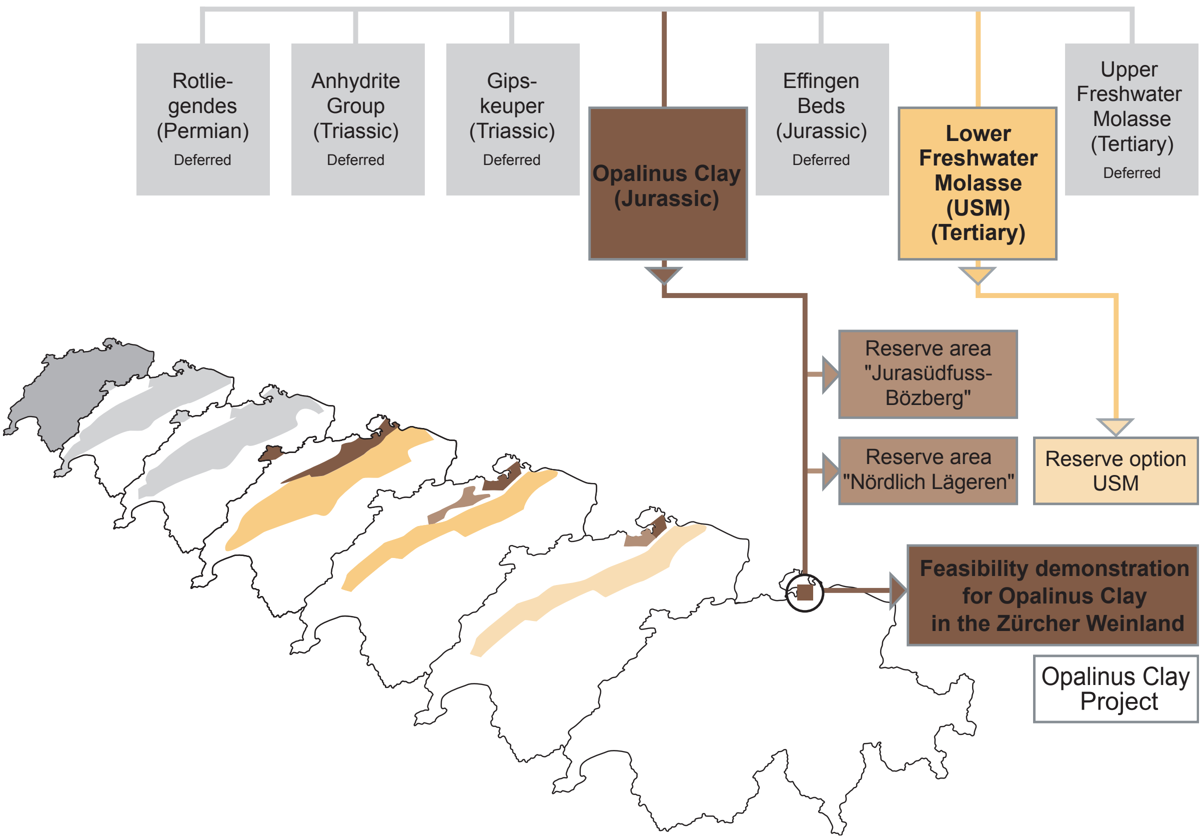


Figure 3 As part of the sediment programme, a range of host rock and siting area options were evaluated. The transparent narrowing-down procedure, which was followed closely by the authorities, finally led to selection of the Opalinus Clay in the Zürcher Weinland as a first-priority area. The procedure is documented comprehensively in several reports [NTB 88-25, 91-19 and 94-10]. The areas "Jurasüdfuss-Bözberg" and "Nördlich Lägeren" for Opalinus Clay and the Lower Freshwater Molasse area are reserve options (see also the detailed diagram in Figure 4).

manner. This also involved evaluating the results of investigations carried out by third parties, as well as published geological maps, reports and technical publications. A regional study of the USM led to this formation being classified as a reserve option with large spatial potential, but with some reservations regarding explorability.

For the Opalinus Clay option, studies led in 1994 to the identification of a first-priority area for local investigations in Canton Zürich. This selection was based on safety-related geological considerations and was approved by the regulatory authorities and their experts. The area identified corresponds more or less to the northern part of the Zürcher Weinland region [NTB 91-19, 94-10].

After 1994, the next step was a detailed characterisation of the Opalinus Clay and the Zürcher Weinland region, with the following key components:

- a 3D seismic campaign covering an area of approximately 50 km^2 [NTB 00-03]
- an exploratory borehole (Benken) [NTB 00-01]
- experiments in the Opalinus Clay as part of the international research programme in the Mont Terri Rock Laboratory (Canton Jura) and
- regionally based comparative studies of the Opalinus Clay, as well as comparisons with clay formations being investigated in other countries with a view to geological disposal.

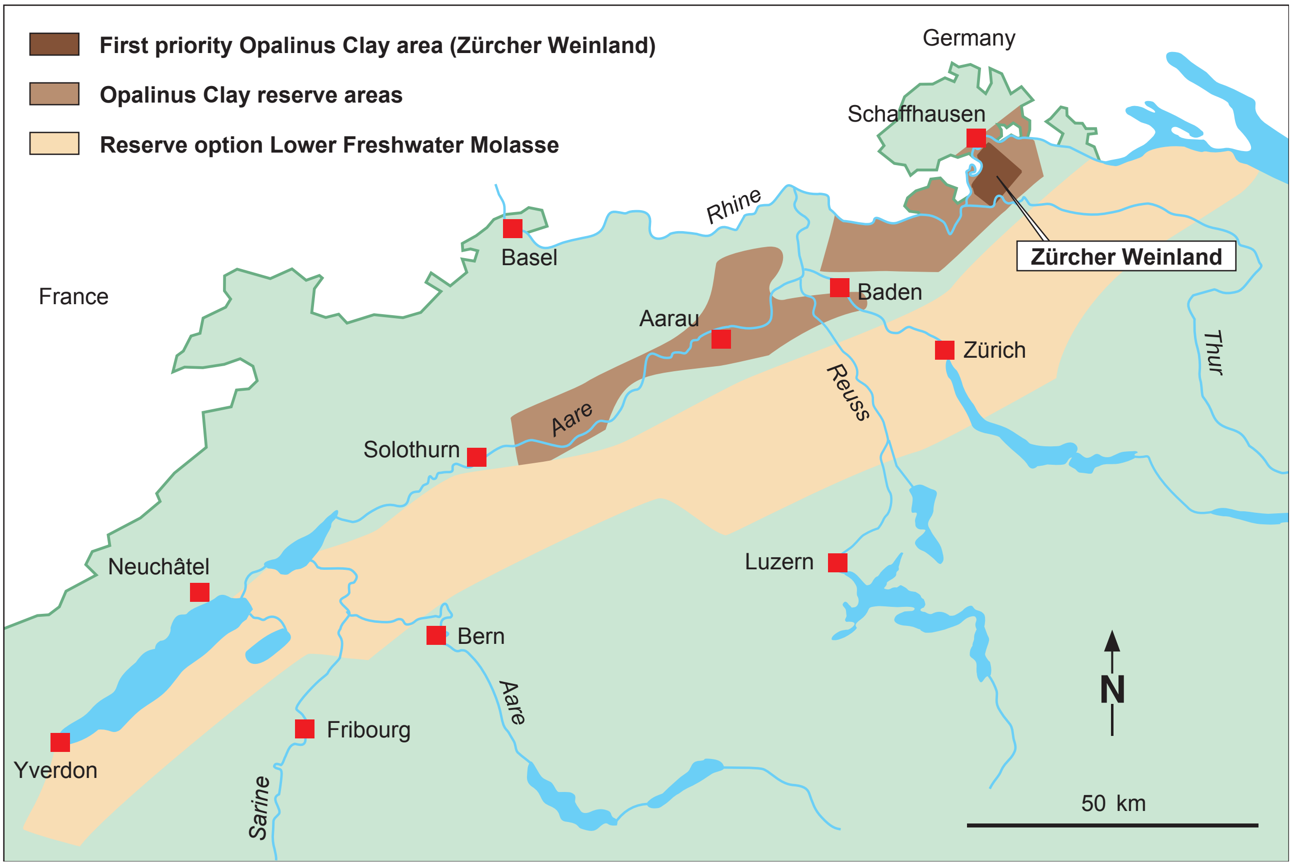


Figure 4 Map showing the sedimentary options Opalinus Clay and Lower Freshwater Molasse that reached the final round of selection. The Zürcher Weinland is the first-priority area.

3.2 Relevant properties of the Opalinus Clay in the Zürcher Weinland

The Opalinus Clay is an argillaceous sedimentary rock which takes its name from the frequent occurrence of the fossil ammonite *Leioceras opalinum* – an example of this fossil was found in the drillcore from the Benken borehole.

Figure 5 The sediment Opalinus Clay takes its name from the frequent occurrence of the fossil ammonite *Leioceras opalinum*. An example of this fossil, which is around 179 million years old, was found at a depth of 652 m in the drillcore from the Benken borehole.

In terms of lithology and mineralogy, the Opalinus Clay is a homogeneous claystone formation which was deposited uniformly over large areas of Northern Switzerland. The result of this is that parameters determined at other locations (e.g. in the Mont Terri Rock Laboratory) are transferable to the investigation area in the Zürcher Weinland. The geometric boundaries of the tectonically quiet Opalinus Clay layer in this area were determined accurately by a 3D seismic campaign. In the area investigated in the Zürcher Weinland, the rock fulfils the basic requirements for the geological environment of a deep repository:

- **Long-term geological stability:** The area is located at the outermost boundary of the region influenced by the Alps. It has a compressive stress field but, in terms of tectonics, is not significantly deformed. Seismically, it is largely inactive, with a small uplift rate of around 0.1 mm/year and a correspondingly low erosion rate. Heat flow and in situ stress are average.

- **Favourable host rock properties:** In the whole area, the Opalinus Clay occurs with sufficient thickness to host the repository and is lithologically homogeneous. It has a very low hydraulic permeability, stable geochemical conditions and rock mechanical properties that are suitable for the construction of a repository. The formations above and below the host rock are also predominantly low-permeability units and thus provide additional isolation.
- **Avoidance of and insensitivity to detrimental phenomena and perturbations:** Based on the present situation, significant alteration of favourable rock properties due to geological events (e.g. earthquakes) can be ruled out. The absence of economically viable natural resources (oil, coal, ore, geothermal) makes a conflict of use, and hence unintentional human intrusion, unlikely.
- **Explorability:** The simple topography and geological structure (homogeneity of the host rock, slight variability of facies with laterally more or less constant properties, slightly disturbed sub-horizontal bedding) ensure good explorability of the geometric conditions. It was thus possible to carry out a high-resolution 3D seismic campaign and to extrapolate the results from the Benken borehole over the entire investigation area.
- **Predictability:** The past geological evolution of the investigation area is well known. Together with the simple geological structure, this leads to a good predictability of the evolution of the host rock and the potential siting area over the time period relevant for evaluating long-term safety.
- **Flexibility:** Because of the constant thickness of the Opalinus Clay layer and its large lateral extent, there is a considerable degree of flexibility in terms of placing the facilities in the potential siting area. The slight tilt of the layer also makes it possible to select the depth of the repository.

An area of around 2 km^2 will be required for the underground repository facilities. Investigations to date indicate that, in principle, a total area of 35 km^2 is available for locating a repository (Figure 7). To provide optimum protection from long-term erosion, however, the area to the north of the Wildensbuch flexure, where the overburden is less than 600 m, is not being considered further. The remaining 22 km^2 represent an area around ten times larger than required. Within this area, 8 km^2 have been identified as the first-priority area for constructing a repository.

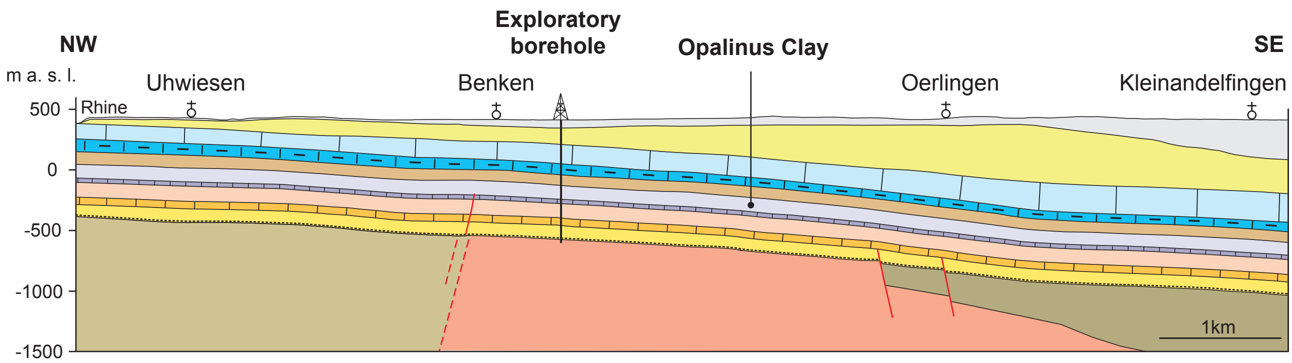
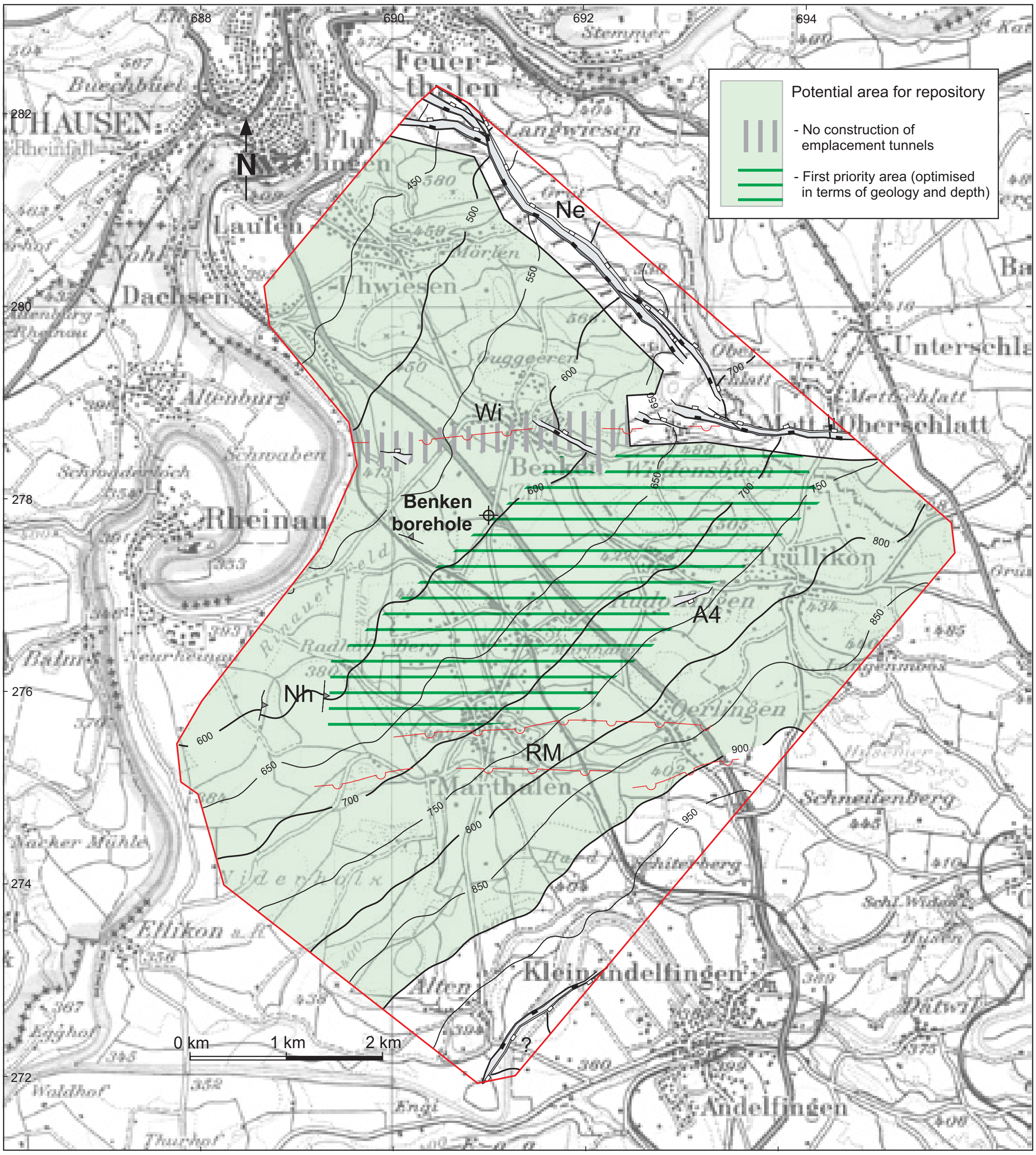


Figure 6 Geological profile through the Zürcher Weinland investigation area showing the location of the Benken borehole.



3D seismic investigation area

Isohypses of mid-level host rock
Depth in metres, relative to a reference level of 400 m a. s. l. (equidistance 50 m)

Fault Top Opalinus Clay

Fault Top Lias

Thrust

Flexure

Ne Neuhausen Fault
Wi Wildensbuch Flexure
Nh Niderholz Structure Zone
A4 Fault A4
RM Rafz – Marthalen Flexure

Figure 7 Potentially suitable area for the underground facilities of a deep repository.

4 Selected repository concept and facilities and operation of the deep repository (technical feasibility)

4.1 Selection of the repository concept

The conceptual requirements placed on a repository at the time of Project Gewähr 1985 were derived from the wording of the law ("permanent safe management and final disposal") and from the definition of these requirements in more precise and detailed terms by the federal safety authorities [HSK/KSA R-21]. The Project was based on a repository that was capable of being sealed at any time (within a few years) and would then remain passively safe on the long-term without any active human intervention.

Since then, societal demands in terms of waste management strategies have confirmed the fundamental principle of long-term safety independent of any human activity and, consequently, the concept of a geological repository. At the same time, however, it has become apparent that public feeling regarding the decision on definitive closure of a repository – which is seen by some as irreversible – is that this step should be taken only after an extended monitoring phase. Broad public discussion has taken place on this issue, leading in 1999 to the establishment of EKRA (Expert Group on

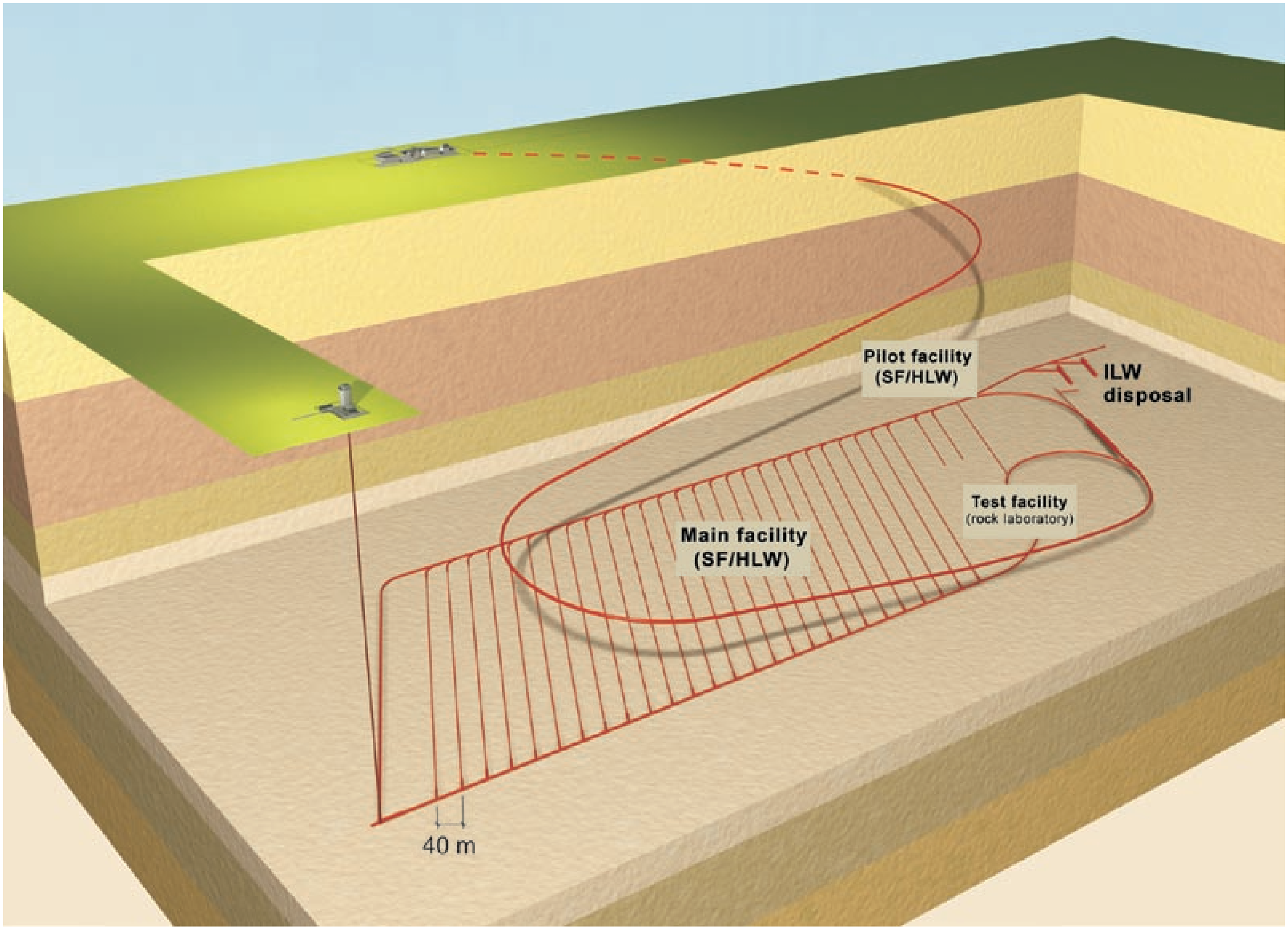


Figure 8 Schematic representation of the deep repository for spent fuel, vitrified high-level waste and long-lived intermediate-level waste in the Opalinus Clay of the Zürcher Weinland.

Disposal Concepts for Radioactive Waste) by the Department of the Environment, Transport, Energy and Communication (DETEC).

EKRA's report came to the conclusion that, given current understanding, geological disposal is the only method capable of fulfilling requirements relating to the long-term safety of man and the environment [EKRA 2000]. In order to take into account the societal requirement for a cautious approach with respect to decisions that might be difficult to reverse, the EKRA experts formulated a proposal for the layout of a geological repository which allows stepwise progress from a monitored facility to a closed repository, with the option of continuing certain monitoring activities even after (partial) closure. The concept is termed "monitored long-term geological disposal".

The concept of a stepwise procedure leading to closure of a repository was also incorporated into the draft of the new Nuclear Energy Law [Kernenergiegesetz KEG 2001]. The Law talks of a deep geological storage facility which is closed after an extended monitoring phase and thus becomes a final repository. Although parliamentary debate had not been concluded at the time of conducting the Opalinus Clay Project, it should be noted that the content of the Nuclear Energy Law in terms of the geological disposal concept was undisputed by both chambers of Parliament.

Nagra's long-term strategy, with the emphasis on long-term safety, agrees well with the concept of monitored long-term geological disposal.

The Opalinus Clay Project also includes the key features of EKRA's concept of monitored long-term geological disposal (test, pilot and main facilities) and the corresponding provisions of the new Nuclear Energy Law. Priority is thus given to long-term geological safety and a stepwise procedure leading to repository closure.

4.2 Wastes to be emplaced in the repository

The wastes to be emplaced in the planned repository are spent fuel and highly active radioactive waste from reprocessing. All wastes are disposed of in special canisters or containers. For the purpose of designing the facilities and the assessment of long-term safety (see chapter 5), it is assumed that waste will be produced by the existing nuclear power plants and that these will generate a total of 192 GW_ea within their lifetimes. This scenario gives the following waste volumes:

- Spent fuel (SF): 2065 repository canisters
- Vitrified high-level waste (HLW): 730 steel canisters
- Solidified long-lived intermediate-level waste (ILW): around 4360 m^3 (so-called cemented waste option)

Conservatively, and to cover all eventualities, an extreme variant is also considered which corresponds to an energy production of 300 GW_ea.

4.3 Facilities and operation (technical feasibility, construction feasibility)

The demonstration of construction feasibility for the underground facilities of a deep geological repository for SF/HLW/ILW in Opalinus Clay has been evaluated in the facilities project. This project is based on measured rock mechanical parameters and provides an overview of operational procedures and an evaluation of operational safety, as well as specific input for the demonstration of long-term safety.

The project comprised the following steps:

- Drawing up a general procedure for the handling and emplacement of radioactive waste, including construction of the engineered safety barriers and design of the facility in accordance with safety regulations.

- Basic design of transport and handling equipment and determination of space requirements for the various underground installations.
- Determination of the stresses on key tunnel cross-sections, definition of preliminary dimensions for the installations and consideration of construction procedures.
- Review of operational safety and ventilation during the operational phase.
- Studies on retrievability and closure of the facility.

The various structural elements and facility components were selected based on experience from other relevant projects and form a modular construction system termed the “Reference Project”.

The overall conclusion of the facilities project is that a deep geological repository for SF/HLW/ILW in the Opalinus Clay of the Zürcher Weinland can be designed, constructed, operated, monitored and, if necessary, closed within a few years using current technology and in accordance with legally prescribed requirements. Societal requirements in terms of monitoring and control can be fulfilled and retrievability of the waste is also possible.

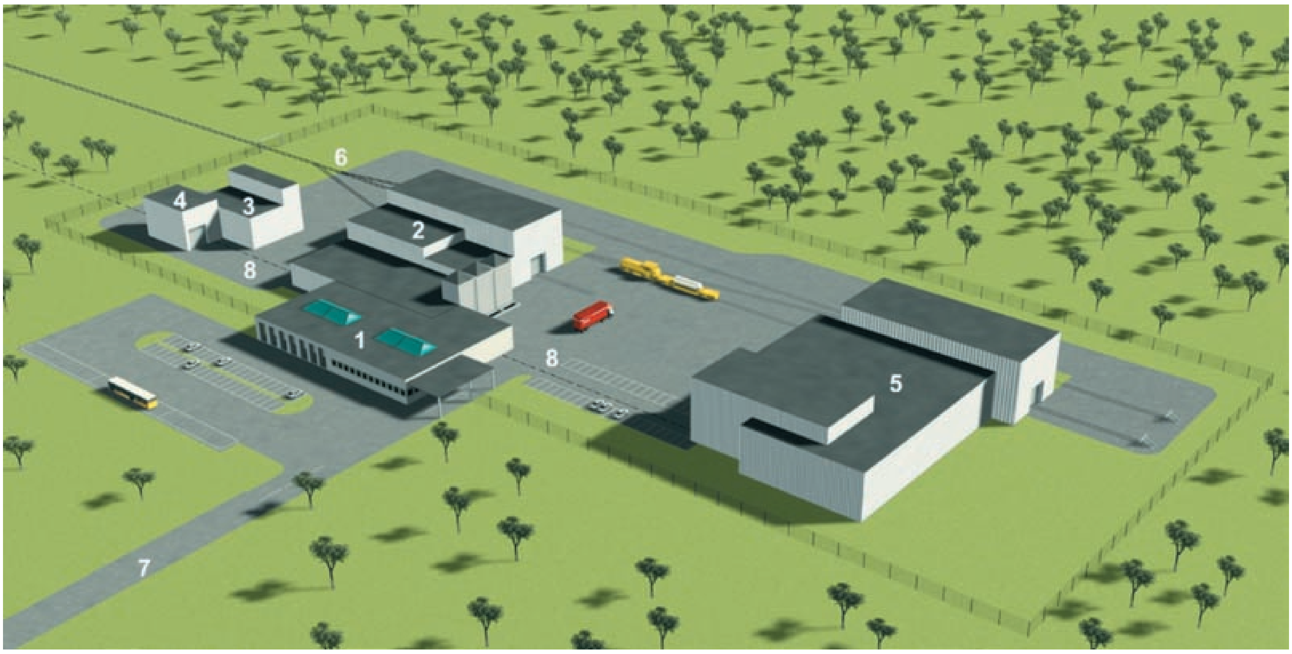


Figure 9 Schematic representation of the surface facilities in the portal zone of the repository: (1) administration, (2) operations centre, (3) ventilation, (4) equipment transition area, (5) conditioning and packaging plant for spent fuel and vitrified high-level waste, (6) rail access, (7) road access, (8) sub-surface connection between (4) and (5) to the ramp leading underground.

Figure 10 Model view of the area at the top of the shaft showing the shaft head frame with exhaust air vents (1) and auxiliary buildings (2 to 4).

5 Safety assessment (demonstration of long-term safety)

5.1 System of multiple safety barriers

The long-term safety of a geological repository in Opalinus Clay is based on a system of multiple safety barriers (Figure 11):

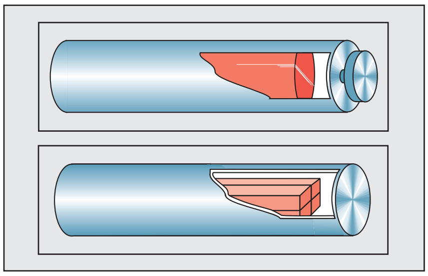
- The repository is constructed in a **stable, deep underground environment**, isolated from human activities, with minimal risk of disruptive geological events and an absence of unfavourable geological processes. There are considered to be no workable natural resources (ore, energy raw materials) or planned underground infrastructure, meaning that no unintentional human intrusion is to be expected in the future.
- The selected **host rock** – the rock in which the repository will be constructed, in this case Opalinus Clay – has an extremely low hydraulic permeability and a homogeneous pore structure, with a capacity for self-sealing of any fractures. This protects the engineered barriers and ensures that radionuclides released will be transported through the geosphere at extremely low rates.
- The **chemical conditions** in the selected host rock, which are stable on the long term, provide a series of geochemical retention mechanisms and ensure the long-term stability of the engineered safety barriers.
- The **bentonite** (a natural clay) which is used as a backfill material between the waste and the rock has similar properties to the surrounding rock and functions as **an efficient transport barrier**. It also provides a favourable chemical, thermal and mechanical environment for the waste containers.
- **Embedding the waste** in an inert matrix ensures long-term stability of the waste product.
- Encapsulating the high-level waste and spent fuel in corrosion-resistant **canisters** with high mechanical stability ensures complete containment of the waste for a long time period (at least 10,000 years), during which a large proportion of the radioactive material will decay.

5.2 Primary objective: containment of the waste at the disposal location

The system of multiple safety barriers ensures effective isolation of the waste from the human environment. A large proportion of the waste emplaced in the repository will decay during the time when the canisters are still intact and thus provide complete containment. Even after the canisters lose their integrity due to corrosion and mechanical stress, the low hydraulic permeability and the retention properties of the bentonite clay backfill and the surrounding rock ensure that the radionuclides remain **within the disposal system**, where they decay. Finally, the transport and retention mechanisms of the host rock ensure that any release of the remaining radionuclides to the surface environment by diffusion and extremely slow advection will occur at such a long time in the future and with such dilution that the radionuclide concentrations will be negligibly low.

This qualitative description was confirmed by a quantitative safety analysis carried out for a series of release scenarios. In addition to the most likely future evolution of the repository system, all deviations that can be realistically envisaged are taken into account and alternative release scenarios are evaluated. A series of “what if?” cases are also considered; these discuss phenomena that are outside the range of expected effects and processes. Such cases are selected to illustrate the functioning of the safety barriers under extreme conditions. In this way, the “robustness” of the system in the event of unexpected developments is tested.

For the purpose of evaluating safety, the federal safety authorities have specified a strict quantitative limit for maximum permissible individual dose in their R-21 Guideline [HSK/KSA R-21]. The results of the safety assessment are measured against this limit. Potential concentrations of waste nuclides in

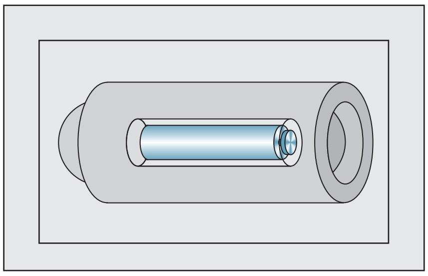


Glass matrix (in steel flask)
Confinement:
- Containment of radionuclides in glass

Attenuation of releases:
- Low corrosion rate of glass

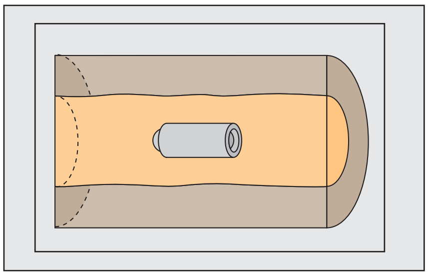
Spent fuel assemblies
Confinement:
- Containment of radionuclides in spent fuel pellets and Zircaloy cladding

Attenuation of releases:
- Low corrosion rates of spent fuel pellets and Zircaloy



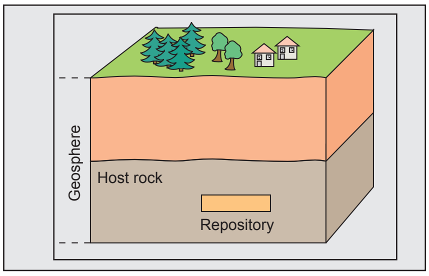
Steel canister
Confinement:
- Prevents inflow of water and release of radionuclides from waste for several thousand years

Attenuation of releases:
- Corrosion products act as reducing agent (giving low radionuclide solubilities)
- Corrosion products take up radionuclides



Bentonite backfill
Confinement:
- Long resaturation time
- Plasticity (self-sealing following physical disturbance)

Attenuation of releases:
- Low solute transport rates (diffusion)
- Retardation of radionuclide transport (sorption)
- Low radionuclide solubility in pore water



Geological barriers – Host rock
Confinement:
- Absence of water-conducting features
- Mechanical stability

Attenuation of releases:
- Low groundwater flux
- Retardation of radionuclide transport (sorption and colloid filtration)

Geological barriers – Geosphere
Confinement:
- Physical protection of the engineered barriers (e.g. from glacial erosion)

Attenuation of releases:
- Retardation of radionuclide transport (sorption)
- Dispersion

Figure 11 System of multiple safety barriers for the geological repository for spent fuel and vitrified high-level waste.

the rock are also compared with natural radioactivity levels and information on natural systems that are observed to have contained relevant radionuclides over geological timescales (so-called natural analogues) is evaluated to confirm that the assessed long-term behaviour is reasonable.

5.3 Conclusions of the Opalinus Clay Project

The studies come to the following conclusions:

- The safe disposal of spent fuel, vitrified high-level waste and long-lived intermediate-level waste is feasible in the Opalinus Clay of the Zürcher Weinland.
- Quantitative analysis shows that the area investigated in the Zürcher Weinland has properties capable of ensuring the required level of safety. Safety is assured for a wide range of scenarios that is sufficiently comprehensive to cover all realistically conceivable future evolutions of the disposal system. In all cases, the resulting radiation dose is below the limits specified by the safety authorities, in most cases by several orders of magnitude.
- The system has been shown to be robust, i.e. none of the uncertainties remaining at present in terms of system evolution would call safety into question.
- The geomechanical properties of the rock and the selected engineering project allow the repository to be constructed, operated, backfilled and closed in such a way that long-term safety is ensured.
- The information base for the selected siting region is sufficiently extensive, and the geological situation sufficiently well understood, to support the findings on safety. The geometry and structure of the host rock and the surrounding strata are well characterised through high-resolution 3D seismic measurements and investigations in the Benken borehole. The presence of a large area of undisturbed host rock could be demonstrated.
- The properties of the host rock were investigated in detail as part of the in situ experimental programme at the Mont Terri Rock Laboratory. The results agree with those from the Benken borehole.
- The future geological evolution of the siting region can be predicted fairly accurately based on the results of extensive regional geological investigations and on the fact that the general geological situation of the region is relatively simple.
- The information on the wastes and their properties is sufficient for the purpose of safety assessment, being based on more than 20 years of scientific studies in Switzerland and broad international experience. The same is true for the system of engineered barriers.

6 Conclusions and future plans

The Entsorgungsnachweis has several objectives. First among these is to investigate and demonstrate the feasibility and safety of constructing a deep geological repository for SF/HLW/ILW in Switzerland, and to provide input to deliberations by the Swiss Federal Council on the future strategy for the management of these waste categories. The Entsorgungsnachweis should also provide a basis for planning future waste management activities, including estimating costs and – not least – provide the framework for in-depth social discussion of waste management issues.

The Opalinus Clay Project meets these objectives. In particular, it shows that safe, long-term disposal of spent fuel, vitrified high-level waste and long-lived intermediate-level waste could be provided by a suitably designed deep geological repository in the Zürcher Weinland.

Based on the results of the Opalinus Clay Project and the systematically conducted selection procedure, Nagra requests the Swiss Federal Council

- to acknowledge fulfilment of the conditions attached to the findings on Project Gewähr of 3rd June 1988 and to confirm that feasibility of disposal has been demonstrated,
- to agree to focusing future investigations on the disposal of spent fuel, vitrified high-level waste and long-lived intermediate-level waste in Switzerland on the Opalinus Clay and the potential siting region in the Zürcher Weinland.

According to information from the responsible federal authorities, the detailed review of the Opalinus Clay Project documentation will take around two years, meaning that a decision by the Federal Council can be expected in 2005 or 2006.

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