nagra. we care

annual report 2018

A short overview of Nagra

Nagra is Switzerland's national technical competence centre in the field of deep geological disposal of radioactive waste. It was founded in 1972. The waste producers are responsible for the disposal of the waste and finance Nagra's work. The members of the Nagra Cooperative are the operators of the nuclear power plants, the interim storage facility Zwilag and the Swiss Federal Government. Out of a strong sense of responsibility for the long-term protection of man and the environment, around 120 employees are involved daily in performing this important work.

Our mandate

Nagra is responsible for planning, constructing and operating deep geological repositories in Switzerland. It conducts a comprehensive research programme in two Swiss rock laboratories and maintains an intensive collaboration with other waste management organisations and research facilities in Switzerland and abroad. The Waste Management Programme and the Research, Development and Demonstration (RD&D) Plan form the basis for planning Nagra's work. In the context of the Federal Government's site selection process, Nagra develops the technical-scientific basis for the Federal Council's decision-makings.

Foreword

Corina Eichenberger, President of the Board of Directors

In 2018, the Federal Council concluded Stage 2 of the Sectoral Plan process and signalled the beginning of the final stage. Stage 2 was characterised by constructive collaboration between the authorities, siting regions and siting Cantons. Transparent information and ongoing dialogue are central to finding answers to our questions. I am pleased to report that trust in the Sectoral Plan process has continued to increase as evidenced by its broad acceptance in the official consultation procedures.

Last year, Nagra also had to address an unpleasant issue in connection with its information trips. After an anonymous complaint was filed in the summer, Nagra temporarily suspended these trips. As expected, the Office of the Attorney General determined after preliminary clarifications that there were "clearly no grounds" for the criminal charges of granting and accepting an advantage. The trips are disclosed in the Waste Management Programme, which is approved by the Federal Council. One purpose is to provide members of the regional conferences and politicians with the opportunity to gain in-depth information, with participants forming their own impressions of disposal facilities abroad. The information tours will be continued in 2019.

The collaboration between all involved parties will intensify in Stage 3. After in-depth geological investigations in the siting regions, we will be occupied with the upcoming discussion on the layout of the surface infrastructure. At the end of Stage 3, the fundamental political decision on the disposal sites in Switzerland will be made. The signs are auspicious. In Stage 2, we created an excellent starting position with three promising siting regions. We are curious to find out which ones come out on top.

At this point, I would like to thank everyone involved in the successful outcome of Stage 2 after seven work-intensive years: first and foremost, the Nagra staff, the Executive Board and the Board of Directors.

Corina Eichenberger

Thomas Ernst, Chief Executive Officer

The site selection process is entering the decisive phase: With its decision of 21st November 2018, the Federal Council concluded Stage 2 of the Sectoral Plan for Deep Geological Repositories and initiated the third and final stage. Nagra is responsible for investigating the siting regions Jura Ost, Nördlich Lägern and Zürich Nordost in depth. In addition, the Federal Council issued various requirements for protecting the siting regions, placing the surface infrastructure and continuing regional participation, thus forming a solid basis for developing the main components of the general licence procedure.

Nagra moved the investigations in the three siting regions ahead intensively, especially the preliminary work for the complex deep borehole campaign that began in March 2019. By the end of 2018, the Department for the Environment, Transport, Energy and Communications (DETEC) had granted three permits for deep boreholes; no objections were lodged against these and they are thus legally valid. Work on the deep boreholes in Bülach and Trüllikon began in 2019, and they are expected to fundamentally expand the geological database over the next years. With this additional knowledge, Nagra is expected to make an informed decision by 2022 regarding the selection of the sites for which it will prepare general licence applications.

The progress made in the Sectoral Plan process is very encouraging. Stage 3 will be very challenging for all involved parties and will determine the course of the final site selection for a deep geological repository in Switzerland.

I am grateful to all the participants from the Federal Government, the Cantons, the communities and the regions for their constructive cooperation. My special thanks go to all of Nagra's employees who devote themselves on a daily basis to this unique cross-generational task that is in the interest of all of Switzerland.

Dr. Thomas Ernst

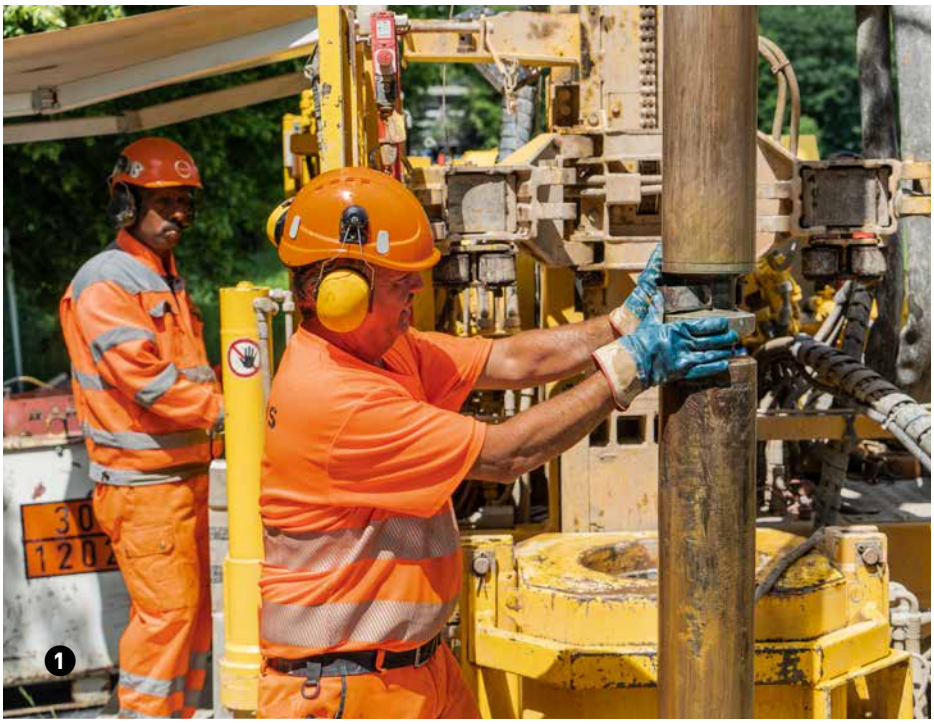
2018 in images

1 PREDICTING THE FUTURE BASED ON PAST EVENTS
To understand erosion processes occurring at the surface, Nagra conducts Quaternary borehole investigations in near-surface deposits of unconsolidated rock.

2 EXPLORING UPLIFT
In the spring, precision height measurements are conducted in the Bözberg area to verify whether the height profile has changed over time.

3 BIDDING FAREWELL TO AN ESTEEMED EXPERT
In June, the impressive career of Piet Zuidema, a long-serving member of Nagra's management team, is honoured with a farewell seminar in Zürich.

4 UNDERGROUND IMAGING
Beginning in the autumn of 2018, Nagra constructs drill sites for deep boreholes in Bülach and Trüllikon to complete the overall geological picture; drilling will start in 2019.



5 GO-AHEAD FOR STAGE 3
On 21st November, the Federal Council initiates Stage 3 of the site selection process for deep geological repositories; this is announced by the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Nuclear Safety Inspectorate (ENSI) at a media conference. Nagra will now drill deep boreholes for further in-depth investigation of the siting regions Jura Ost, Nördlich Lägern and Zürich Nordost. In addition, the Federal Council approves Nagra's Waste Management Programme subject to conditions.

6 NEW NAGRA EXHIBIT
With the help of iPads and so-called augmented reality technology, it is possible to explore a drill site and a deep borehole.

7 START OF A NEW EXPERIMENT
At the Grimsel Test Site, a long-term experiment begins in December that will provide important data on the behaviour of bentonite material under realistic conditions.

Guiding principles for waste

How is waste management legally regulated, and what do the waste management and financing concepts look like? Answers to these questions are provided in this section.

Legal framework
The waste producers must ensure that radioactive materials are handled in such a way as to minimise waste production and that the resulting waste is safely disposed of. The legal provisions applying to this are contained in the Nuclear Energy Act and the Nuclear Energy Ordinance. The overarching principle is the long-term protection of humans and the environment. All radioactive waste must be disposed of in deep geological repositories in Switzerland.

"The overarching principle applying to the disposal of radioactive waste is the long-term protection of humans and the environment."

In line with the polluter pays principle, the duty of disposal lies with the waste producers. They are responsible for covering current costs as well as financing the decommissioning of the nuclear installations and waste disposal.

The procedures for general, construction and operating licences for a repository are focused at the federal level. The general licence for a nuclear installation is subject to a parliamentary decision and an optional national referendum. Participation of the siting Cantons, neighbouring Cantons and neighbouring countries in the process is required by law.

In accordance with the revised Energy Act that came into force on 1st January 2018, new nuclear power plants may no longer be constructed, but existing ones can continue to operate as long as they are safe. The reprocessing of spent fuel assemblies continues to be prohibited, and the moratorium has been extended until June 2020.

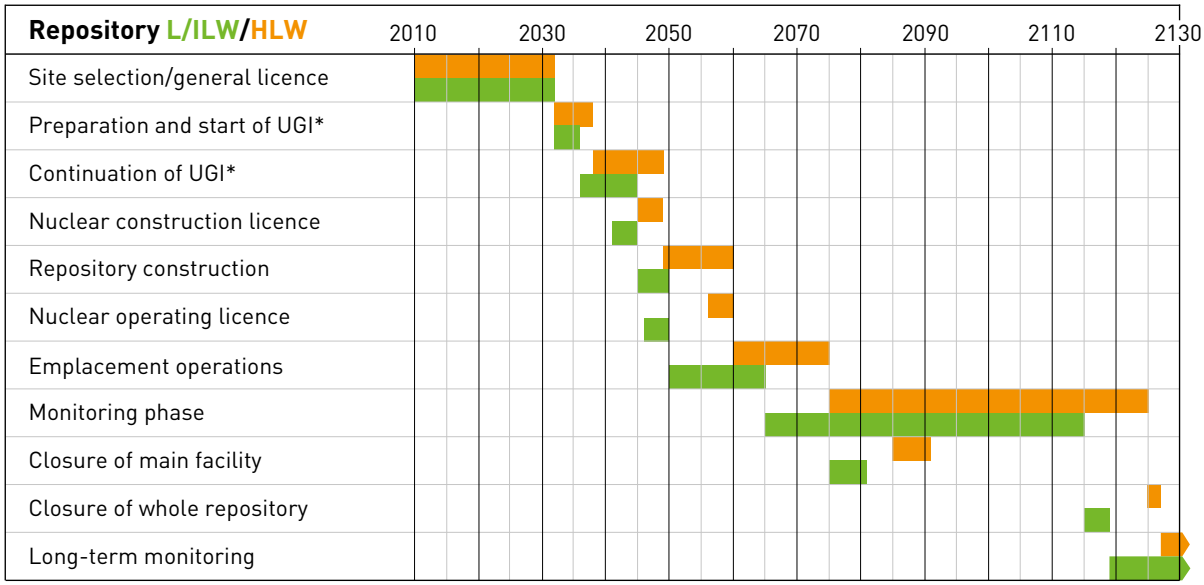
Approach to waste management
Nagra's two feasibility demonstrations for low- and intermediate-level waste (L/ILW) and high-level waste (HLW) were approved by the Federal Council and show that safe deep geological repositories can be constructed in Switzerland. The Waste Management Programme describes the procedures for the planning, construction, operation and closure of a deep geological repository, and also includes information on origin, types and volumes of radioactive waste, its allocation to the repositories and the repository conceptual design. In addition, it contains a realisation plan for the construction of the deep geological repositories, a financing plan and information on the duration and capacity of interim storage. It also describes Nagra's information concept.

Nagra has to update the Waste Management Programme every five years and submit it to the federal authorities. In 2016, Nagra submitted the updated Waste Management Programme 2016 as well as the Research, Development and Demonstration Plan 2016 along with swissnuclear's Cost Study. Following the review of the Programme by the Swiss Federal Office of Energy (SFOE), the Swiss Federal Nuclear Safety Inspectorate (ENSI) and the Federal Nuclear Safety Commission (NSC), it was approved by the Federal Council in December 2018 subject to conditions.

In Switzerland, radioactive waste and materials arise from the production of nuclear energy in the nuclear power plants and from applications in medicine, industry and research. The waste is continually prepared for interim storage or deep geological disposal and is characterised and inventoried. As L/ILW and HLW have different properties, they have to be disposed of in separate emplacement rooms: in a repository for L/ILW and in one for HLW. These can be realised at two different sites or as a combined repository at the same site.

Nagra has prepared realisation plans for the L/ILW and HLW repositories (see Figure). These describe the basic sequence of activities and outline the work that has to be done up to the closure of the repositories.

management



*UGI = underground geological Investigations

Realisation plan for the L/ILW and HLW repositories based on current planning.

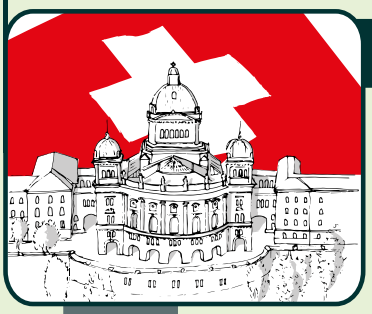
Securing the funding

The Waste Disposal Fund secures the costs of disposal and reprocessing of radioactive waste from the nuclear power plants. The Decommissioning Fund covers the costs of decommissioning and dismantling of the nuclear facilities as well as the disposal of the resulting waste. The operators of the nuclear power plants contribute to both Funds, which are under federal supervision. For electricity generated with nuclear power, the consumer pays around 1 Rappen (= cent) per kilowatt hour to fund decommissioning and waste disposal. At the end of 2018, the accumulated capital in the Waste Disposal Fund amounted to around CHF 5.1 billion and in the Decommissioning Fund to around CHF 2.4 billion. For more detailed information, please visit www.stenfo.ch (Documentation › Search › Topic Financial results). A new feature of the Cost Study 2016 submitted by swissnuclear is the consideration of cost surcharges for risks and inaccuracies in predictions. The cost estimate forms the basis for determining the contributions to be paid by the operators of the power plants into the Decommissioning and the Waste Disposal Funds.

In Switzerland, the search for repository sites is regulat

Many participants are involved in this process. Their tasks are clearly separated.

Federal Council
Parliament
DETEC



Nuclear Waste Management Advisory Board
This board advises the Federal Department of the Environment, Transport, Energy and Communications (DETEC) on the implementation of the site selection process.

AGNEB
The Swiss Federal Workgroup for Nuclear Waste Disposal (AGNEB) drafts position statements for the attention of the Federal Council and addresses questions on waste disposal.

Consultation

SFOE
The Swiss Federal Office of Energy leads the Sectoral Plan process.

Cantons
The affected Cantons are involved in the search for sites.

AdK
The "Cantonal Commission" ensures cooperation between government representatives of the siting Cantons and the affected neighbouring Cantons and countries.

AG SiKa
The Cantonal Working Group on Safety plans and coordinates the safety-based evaluations by the siting Cantons.

FKS
The "Technical Coordination Group of Siting Cantons" plans the operational activities of the siting Cantons relating to safety, spatial planning, communication and regional participation.

KES
The Cantonal Expert Group on Safety supports and advises the Cantons with the assessment of safety-related documents.

ed in the Sectoral Plan for Deep Geological Repositories.

Sectoral Plan for Deep Geological Repositories

The Sectoral Plan process includes three stages. Numerous bodies participate in the process, which is under the lead of the SFOE. Cantons and communities are involved, as are neighbouring countries, interested organisations, associations, political parties and the public. Nagra develops the technical and scientific foundation, proposes siting regions and sites and will submit the general licence applications for the repositories in Stage 3. The Swiss Federal Nuclear Safety Inspectorate (ENSI) reviews Nagra's proposals from the perspectives of safety and engineering feasibility. For this, it consults external experts. Following the consultation and participatory processes, the responsible authorities and the Federal Council make an overall assessment at the end of each stage.

ENSI

The Swiss Federal Nuclear Safety Inspectorate is the regulatory authority and monitors the site investigations.

Nagra

The National Cooperative for the Disposal of Radioactive Waste has the task of planning and realising safe waste disposal in deep geological repositories.

Main actors

TFS

The Technical Forum on Safety discusses and answers technical and scientific questions raised by interested parties and the public.

Regional conferences

The regional conferences form the core of regional participation, giving communities, organised interest groups and the public a platform where they can raise their concerns.

Neighbouring countries

The affected neighbouring countries are represented in different bodies.

Further participants

- Communities
- Political parties
- Interest groups
- Associations
- Public

Maurus Alig has been Coordinator Major Project Sectoral Plan Stage 3 / General Licences at Nagra since July 2016. He studied geosciences at the University of Bern.
Patrick Senn has been Division Head Planning & Construction of Deep Geological Repositories since October 2016. He completed an engineering degree at the Ecole Polytechnique Fédérale in Lausanne.

Current status of work

Two members of Nagra's Executive Board, Maurus Alig and Patrick Senn, provide answers to questions on the conclusion of Stage 2 and the tasks awaiting Nagra in the final stage.

What does the decision of the Federal Council on Stage 2 mean for Nagra?
Maurus Alig: To form the basis for a decision on narrowing down the siting regions in Stage 2, many employees put in a huge amount of work together with Piet Zuidema. I was not part of the team at that time, but I am sure that, for everyone involved, the decision of the Federal Council means far more than just the start to Stage 3. It is also an acknowledgement from the highest authorities of the work performed to date. As Project Coordinator for Stage 3, I benefit from all of the work conducted previously, thanks to which we are entering the home stretch of the site selection process. However, we started working on Stage 3 well before this. For example, we have already carried out 3D seismic surveys in all the remaining siting regions.

What preparations were made for the deep boreholes?
Patrick Senn: First, we defined the goals of the deep borehole campaign. Then, we selected suitable drill sites from which to explore the siting regions. These drill sites are located around the siting regions. To generate relevant information for Stage 3, the drill sites must, on the one hand, be located close enough to where disposal areas can be placed. On the other hand, we do not want to cause any damage to the containment zones where we can emplace the waste – those are our prime sites. We had to develop work programmes describing the drilling concept and the investigations in the boreholes and on the drill cores. Our newly established team could then call for public tenders and award contracts to many companies, including drilling companies, engineering consultants, security companies and so on. Due to the tight schedule, the preparation work was partly conducted in tandem and before DETEC had granted the first deep borehole permits. In late 2018 and early 2019, we then constructed the drill sites at Bülach and Trüllikon 1 and have now started drilling.

How would you assess the progress of the work?
Patrick Senn: In general, the work is well under way. We were able to carry out all the procurements, and there were no objections to awarding the contracts. We accomplished everything that could be done before beginning the drilling work. My team faced many challenges over a year and a half. After this intensive period, we are very pleased that the drilling phase has started out well and that we are receiving the first data and drill cores. It is particularly gratifying to see how the ideas, plans and descriptions we put on paper are now being realised in the field. Of course, there are always some surprises during the drilling process; this is simply unavoidable.

> "After this intensive period, we are very pleased that the drilling phase has started out well and that we are receiving the first data and drill cores."
>
> *Patrick Senn*

What insights do deep boreholes provide?
Patrick Senn: With the deep boreholes, we will complete the overall geological picture of the underground in the three siting regions to allow a conclusive comparison. One purpose of the deep boreholes is the depth calibration of the 3D seismic measurements, which provide images of the underground geometry and depict the boundaries of the rock layers. The 3D model in this case is based on the measured travel time of seismic waves. Deep boreholes allow us to convert time into metres of depth. We thus obtain a geological model of the underground with all the rock formations at the correct depth. At the same time, we also want to learn more about the properties of the individual rock types. For this purpose, we extract rock samples from drill cores for laboratory investigations and conduct measurements directly in the borehole. For example, we are interested in the exact composition, hydraulic conductivity and mechanical properties of the rock formations. Most of all, we are interested in the Opalinus Clay and the confining geological units lying directly above and below it.

How important are the deep boreholes for the general licence applications?
Maurus Alig: The deep boreholes are mainly needed for comparing the three siting regions and selecting the best one. Naturally, we will also obtain a lot of information for the general licence application (cf. text-box). The demonstration of disposal feasibility approved by the Federal Council and recognised internationally as being exemplary confirms the realisation of fundamentally safe deep geological disposal in Switzerland. We are confident that the safety case – which is required for the general licence application – can confirm once more, based on more robust data, that the protective objectives can be met and that long-term safety is assured.

"Based on present-day knowledge, we have three excellent regions from which we have to choose the safest one."

Maurus Alig

What challenges lie ahead in Stage 3?
Maurus Alig: One challenge is to specify the auxiliary access facilities and thus the entire surface infrastructure in cooperation with the siting regions and Cantons. However, the real challenge in Stage 3 is to select the safest site for each repository type. Based on present-day knowledge, we have three excellent regions from which we have to choose the safest one. The evaluation of the siting regions is done using 13 safety-based criteria listed in the Sectoral Plan and in accordance with ENSI's specifications. The comparison will show the individual strengths and weaknesses of the siting regions in terms of these criteria. These differences must then be weighed in the decision-making process within the framework of a balancing of interests. Figuratively speaking, we have three five-star hotels and must select the best one.

Patrick Senn: Of course, it would be a lot easier for us if we had only one five-star hotel alongside two three-star hotels. However, the present-day situation in this narrowing-down process is that we have three excellent siting regions. One of the reasons we enjoy our work so much is that it presents us with great challenges to be overcome.

Maurus Alig: We have to select the most suitable siting region and balance interests in a transparent and comprehensible way. This applies to both the responsible authorities and the public in the siting regions. During Stage 3, the regions will once again invest a lot of time and effort in cooperating with us to determine the location of the surface infrastructure. For them, the challenge lies in constructive collaboration in a project that they do not even want to be a part of. It is thus very important to provide information as soon as possible, to reach out to the public in the regions, to listen to them and to answer their questions in an understandable way. The region with the safest site for a deep geological repository will assume responsibility on behalf of all of Switzerland, and we must acknowledge and appreciate this. If we continue to work together constructively, we will all benefit.

The Federal Council has approved the Waste Management Programme 2016. What does this mean?
Maurus Alig: The regular reporting in the form of the Waste Management Programme helps to keep an eye on the long-term perspective up to the time when the repositories have been closed. This allows the next step to be better organised. The process stipulates a staged approach. In Stage 3, the "only" goal is to select the site, and we will define the main features of the facility along with the sites for the surface infrastructure. The decision of the Federal Council on the Waste Management Programme gives us security and confirms that we are making the right plans on a long-term basis. However, we are often asked questions where a sensible reply can only be given at a later point. To use another comparison: Before the New Railway Link through the Alps (NRLA) was constructed, the question voters were faced with was whether they wanted a NRLA at all. They did not debate what trains would pass through the tunnels and even less what kind of seats the trains would have and whether they would provide internet access. In the same way, we will answer detailed questions later on.

Patrick Senn: At the moment, the political decision to be made is where to construct the deep geological repository. Only after the general licence has been granted by the Federal Council will we plan in detail how to construct the drifts in the Opalinus Clay. After a further permit has been granted, we will construct an access structure at the determined site to deepen our knowledge with underground geological investigations. It is our task to show that our assumptions are accurate.

WHAT IS A GENERAL LICENCE APPLICATION?

Deep geological repositories require a general licence from the Federal Council. The general licence applications, submitted by Nagra, include a description of the main features of the facilities in the proposed siting regions. The general licence specifies the location and the approximate size and layout of the most important components. More detailed descriptions of the installations, procedures and technologies will be required later for the construction licence and operating licence applications.

In brief

Site selection for deep geological repositories: Where are we today?
On 21st November 2018, and in accordance with the recommendations of ENSI and the NSC for Stage 2, the Federal Council decided on the further in-depth investigation of the three siting regions Jura Ost, Nördlich Lägern and Zürich Nordost in Stage 3. Jura-Südfuss, Südranden and Wellenberg remain as reserve options. This decision was preceded by an open consultation phase involving the participation of the Federal Government, Cantons, cities, local communities, organisations, planning associations, political parties and individuals, as well as German states, districts and communities. The 1566 responses received (Switzerland: 438, Germany: 1126, Austria: 2) show that the principle "Safety has the highest priority" is recognised. The Sectoral Plan is considered to be a suitable instrument for site selection and is supported by the majority. The further investigation of the three regions is largely undisputed. Germany is asking to be more involved in Stage 3 and criticises the proximity of the surface facilities to the national border.

"By 2022, Nagra expects to be able to announce which sites it considers best suited for constructing the deep geological repositories."

What will happen in Stage 3?
Nagra is investigating the remaining siting regions and comparing them with one another from a safety-based perspective. ENSI clarified the specifications for this process and published these in November. They concern the site selection process and also the order in which Nagra must identify the sites for the L/ILW and HLW repositories. First, Nagra must create the basis for evaluating each siting region by developing a site-specific repository project considering the geology, conducting safety analyses and evaluating the geology based on the 13 safety-based criteria stipulated in the Sectoral Plan. Based on this, Nagra compares the siting regions in an overall evaluation and proposes the site for the HLW repository followed by the site for the L/ILW repository. In addition, it will investigate whether the two repositories will be joined into a combined repository or whether they will be constructed in separate siting regions.

By 2022, Nagra expects to be able to announce which sites it considers best suited for constructing deep geological repositories and will then submit a corresponding general licence application around 2024. After the responsible federal authorities have reviewed the application and a consultation process has been held, the decision on granting the general licence is first passed to the Federal Council and then to the Federal Assembly. A decision is expected around the year 2030 and is subject to an optional national referendum. The L/ILW repository should be operational by 2050 and the HLW repository by 2060.

Concretising the surface infrastructure
With its decision on Stage 2, the Federal Council approved the siting areas selected by Nagra for surface facilities as an interim result. In Stage 3, Nagra will further specify the surface infrastructure in the siting regions remaining in the process. This involves optimising the layout of the surface infrastructure, designating areas for auxiliary access facilities, identifying potential sites for construction installations and discussing site access and development.

In the second quarter of 2019, Nagra will communicate site-specific proposals for the surface infrastructure. These will then be discussed in collaboration with the siting regions and Cantons to ensure that the needs of the regions are considered to the greatest extent possible. Together with the regional conferences, Nagra will also investigate variants of the surface facilities without an encapsulation plant, which means constructing the encapsulation plant outside the siting region in question. The regional conferences will then draft position statements on the concretisation of the surface infrastructure. Nagra will consider these when specifying the different elements of the surface infrastructure for the general licence application.

"I ENJOY COMBINING TECHNICAL ASPECTS WITH COMMUNICATION NEEDS."
Philipp Senn, Programme Coordinator

"My main duties include the coordination of processes between Nagra and other stakeholders in the context of the Sectoral Plan", says the geologist Philipp Senn with a smile. "Or, to put it simply: on Nagra's behalf, I make sure that the participants – internal and external – are working side-by-side on current topics". Involving so many actors is both rewarding and challenging, adds Senn. For the current projects, Nagra still has quite a lot to prepare internally before it can involve external parties. At present, Philipp Senn coordinates the Nagra-internal information on projects relating to deep borehole investigations or Nagra's proposals for the surface infrastructure.

The upcoming concretisation of the surface infrastructure has kept Philipp Senn very busy over the last months. Together with other Nagra project managers, and in consultation with the SFOE, he has been preparing the way for the regional collaboration. "This work, along with the many discussions related to it, was very important from my point of view", he adds. It will form a sound basis for the discussion of the proposals on the placement of the surface infrastructure in the regions and clarify Nagra's contribution in the run-up to these discussions. "This is an intensive period", he emphasises. "But I am confident that these preliminary clarifications help everyone involved and will lead to a constructive dialogue with the regions".

Philipp Senn likes to link the threads in conversations thematically: "I particularly enjoy combining technical aspects with communication needs". Occasionally, these discussions take some time, but ultimately the aim is to listen to the concerns of the dialogue partners, thus contributing to the creation of an atmosphere that is conducive to constructive discussions. "My impression is that the discussions are conducted more objectively than before", he emphasises. Radioactive waste disposal has become an ongoing issue for some, "But I can detect the willingness to work together in a constructive manner", Philipp Senn concludes.

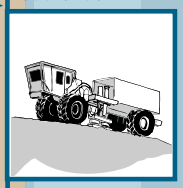
WHAT DOES THE SURFACE INFRASTRUCTURE CONSIST OF?

The surface infrastructure comprises all facilities located at or close to the surface that are required for realising and operating a deep geological repository. The surface infrastructure can include site development infrastructure, a surface facility, auxiliary access facilities, construction site equipment and interim depots. The waste is delivered to the surface facility and prepared for emplacement. Aside from the main access for the transport of the waste from the earth's surface to its underground emplacement location, auxiliary access facilities are also needed. These supply the underground part of the repository with water, electricity and fresh air and allow the transport of building materials and people.

With the three-stage Sectoral Plan to deep geologi

Nagra: Starting from a blank map of Switzerland in Stage 1, six geological siting regions were identified as suitable for a repository from a safety perspective.

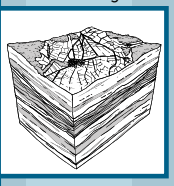
Nagra: 2D seismics in Jura Ost, Jura-Südfuss, Nördlich Lägern and Südranden



Collaboration with the regions: Siting areas identified for the surface facilities

Federal authorities and other stakeholders: Evaluation, public consultation and preparation for the **Federal Council decision** on Stage 2

Nagra: 3D seismics in Jura Ost, Nördlich Lägern and Zürich Nordost



Nagra: Submission of applications for deep boreholes; permitting procedure

Nagra: Deep borehole investigations in the remaining siting regions

Collaboration with the regions: Concretising and specifying the surface infrastructure

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021

The Federal Council approves the conceptual part of the Sectoral Plan for Deep Geological Repositories

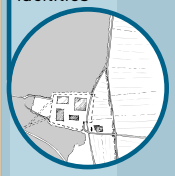
Nagra submits the first Waste Management Programme 2008

The SFOE announces the siting proposals of Nagra
L/ILW repository: Jura Ost, Jura-Südfuss, Nördlich Lägern, Südranden, Wellenberg and Zürich Nordost
HLW repository: Jura Ost, Nördlich Lägern and Zürich Nordost

Nagra publishes its RD&D (Research, Development and Demonstration) Programme

Federal Council approves the results of Stage 1

Nagra announces potential siting areas for the surface facilities



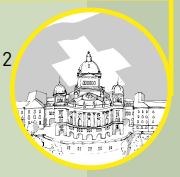
Federal Council approves Nagra's 2008 Waste Management Programme

Nagra submits siting proposals for Stage 2 to the SFOE: The regions Jura Ost and Zürich Nordost should undergo further investigation in Stage 3

ENSI publishes its safety-based review of Nagra's siting proposals and recommends that Nördlich Lägern should also be carried forward to Stage 3

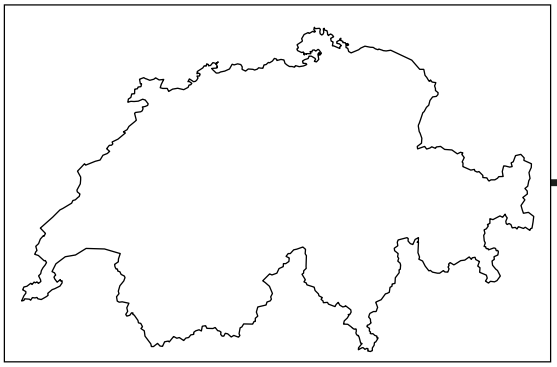
Nagra submits the Waste Management Programme 2016 along with the updated Research, Development and Demonstration (RD&D) Programme

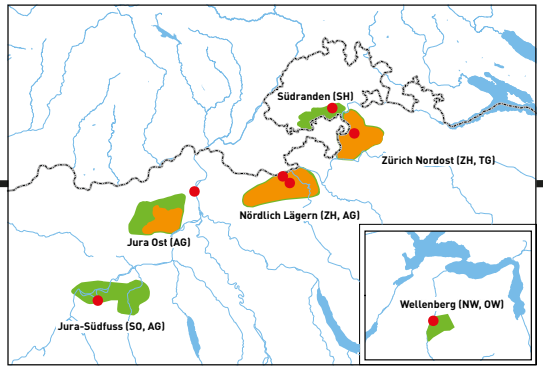
Federal Council decision on Stage 2 and on the Waste Management Programme 2016



Starting-point: Blank map of Switzerland / selection criteria: safety and engineering

Federal Council decision on Stage 1





cal repositories: retrospective and outlook

Federal authorities and other stakeholders: Evaluation, public consultation and preparation for the **Federal Council decision** on Stage 3 / general licence

Nagra: Preparing and submitting the general licence applications

2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

Nagra announces the sites for which it will submit general licence applications and defines the siting areas for the surface infrastructure

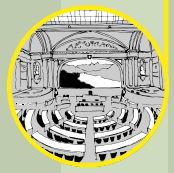
Nagra submits general licence applications for a L/ILW and HLW repository or a combined repository

?

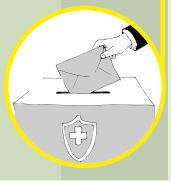
Nagra submits an application for underground geological investigations

Federal Council decision on Stage 3 / general licence

Approval by Swiss Parliament

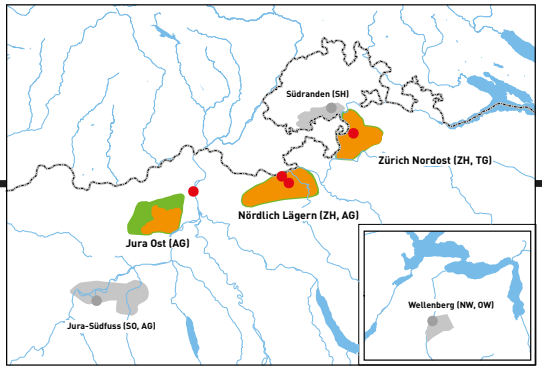


Optional national referendum



feasibility

Federal Council decision on Stage 2



General licence applications for a L/ILW and HLW repository or a combined repository

?

(as of March 2019)

Gaudenz Deplazes has been working for Nagra since 2012. The Project Manager Geology investigates the properties and deposition conditions of sedimentary rocks based on outcrop, drilling and seismic data. He also investigates the long-term evolution of the landscape and is responsible for the sedimentological analysis of the drill cores collected from the Quaternary and deep boreholes.
Herfried Madritsch is Senior Project Manager Geosciences and has been working for Nagra since 2009. He works on the interpretation of the 3D seismic measurement data and was involved with identifying the drill sites. He is also responsible for the overall coordination of the Quaternary boreholes.

Geosciences & field investigations

Investigations on long-term evolution
Nagra is using layers of unconsolidated rock to investigate the evolution of the terrain surface during the Quaternary period. The Quaternary began around two million years ago and continues into the present, making it the most recent geological period. The goal of the investigations is to derive scenarios of future long-term evolution – particularly with regard to terrain erosion over the course of several hundreds of thousands of years. These findings help Nagra to make more reliable statements about the long-term safety of a deep geological repository.

Overview of the investigation methods
Unconsolidated rock was deposited during the Quaternary when global ice ages and glacial advances from the Alps occurred repeatedly. The glaciers dug channels (valleys) into the solid rock. With 2D seismics, Nagra can locate the deepest point in a profile section in the area of such valleys. At these locations, Quaternary borehole investigations can be carried out at a depth between ten and a few hundred metres to characterise the unconsolidated rock filling the valleys.

2D seismics for Quaternary investigations
Within the framework of the Quaternary investigations, Nagra already conducted 2D seismic measurements in Northern Switzerland in the winter of 2016/2017. In 2018, the measured data were further processed and analysed. It was thus possible to successfully depict the depth and form of the glacial channels that are filled with unconsolidated rock today. Nagra used this information to search for suitable drill sites and submitted corresponding permit applications to the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

First Quaternary investigations successfully completed
Shortly before the turn of the year 2017/18, Nagra received DETEC's first permit for the Quaternary borehole in Riniken. Further DETEC permits followed in 2018 – all with conditions attached but without objections. The first Quaternary borehole investigation started in Riniken in March 2018 and was completed in April. After this, borehole investigations were successfully conducted in Untersiggenthal, Gebenstorf-Brüel, Gebenstorf-Vogelsang and Marthalen-Oobist. The Quaternary borehole begun in Neuhausen in November 2018 was completed at the beginning of 2019. Five additional Quaternary boreholes will follow.

With the Quaternary borehole investigations, it is possible to verify the seismic images of the underground. In addition, Nagra was able to collect numerous rock samples, so-called drill cores, from the valley sediments. The drill cores were delivered to the University of Bern where they are photographed and investigated in detail using different methods. It is thus possible to analyse the chronological sequence of the channel formation and infilling as well as the relevant evolutionary processes.

Reconstructing the history of rivers
To reconstruct the past evolution of the landscape, Nagra collected samples in 2018 not only from boreholes but also from natural rock faces, former quarries and gravel pits. The investigations focused on the so-called "Deckenschotter" (cover gravels), which are old river sediments deposited on hills that document where rivers once flowed. By dating them, it is possible to reconstruct how large rivers cut into the landscape in the past. Dating samples that are between several hundreds of thousands of years and up to around two million years old is very complex, which is why several methods were used in parallel in cooperation with different universities.

In 2018, Nagra also started a comprehensive project on climate evolution together with two research institutes. With the help of climate models, it is possible to investigate what conditions in the past facilitated rapid erosion processes by glaciers and at what point in the future similar conditions can be expected. The findings will also be included in future erosion scenarios.

3D seismics provide an image of the underground
In the winters of 2015/16 and 2016/17, a comprehensive 3D seismic survey was carried out in the

siting regions Jura Ost, Nördlich Lägern and Zürich Nordost. The time-consuming processing and analysis of the 3D seismic data progressed according to schedule. In 2018, Nagra informed the regulatory authorities about the results at several meetings. It is already evident that the quality of the data is very good and that the information required for delimiting and investigating the containment-providing rock zone is highly conclusive.
The density of information could be significantly increased compared to 2D seismics, and Nagra now has a continuous, high-resolution three-dimensional image of the underground.

"The results from the measurements were important for determining the future approach in the deep borehole investigation campaign."

The initial evaluation of the 3D seismic measurement data focused on mapping the boundaries and fault zones of the rock layers. The results from the measurements were important for determining the future approach in the deep borehole investigation campaign. Nagra was able to use the data to verify the locations of the drill sites determined based on the 2D seismic data. Nagra also collected important information for the evaluation of the geological properties and the available space in the siting regions. The 3D seismic investigations have confirmed Nagra's previous assumptions:

- There is sufficient available space in all the siting regions to plan the repository projects.
- In the northern part of the Nördlich Lägern siting region, the presence of a wide tectonically overprinted zone was confirmed, which is not suitable for hosting a repository. Based on current knowledge, there is sufficient available space for a safe disposal project to the south of this zone.
- To be able to sufficiently characterise the geological properties of this area with deep boreholes if needed, Nagra prepared an application for an exploration permit to drill an additional borehole in the Nördlich Lägern siting region. It was submitted to the Swiss Federal Office of Energy in December 2018.

Deep boreholes provide an insight

Beginning in 2019, Nagra will conduct a series of deep borehole investigations in the three potential siting regions Jura Ost, Nördlich Lägern and Zürich Nordost (cf. interview on page 10 ff.). Their purpose is to complete the overall geological picture of the siting regions. Which deep boreholes will be drilled and how many will be needed will depend on initial results, but it is unlikely that all the boreholes will be needed. With the additional insight gained from the investigations, Nagra expects to announce by 2022 for which sites it will prepare and submit a general licence application.

The deep borehole investigations will focus on the thickness, permeability and mechanical properties of the host rock Opalinus Clay in which the deep geological repository will eventually be constructed. The low-permeability confining geological units located directly above and below the Opalinus Clay are also of interest.

Preparing for the deep boreholes

By early 2018, Nagra had submitted 22 applications for deep boreholes to DETEC and addressed objections and responses that arose during the public inspection periods. The additional drill site in the Nördlich Lägern siting region is situated within the community of Stadel. In early 2019, the corresponding exploration permit was opened for public inspection at the local community office. In August 2018, DETEC granted the first three deep borehole permits for Bülach, Trüllikon 1 and Marthalen, and construction of the drill sites in Bülach and Trüllikon 1 began in October 2018.

To be ready to begin drilling, complex preparation work and planning continued in 2018. In this context, numerous procurements and contract agreements were made with companies involved in the implementation process. Along with affected landowners and communities, the public were informed in detail about the planned deep borehole campaign.

Deep borehole investigation programme
Beginning in 2019, extensive laboratory investigations will be conducted on drill cores recovered from deep boreholes. For example, deformation experiments will be carried out to analyse the behaviour of the Opalinus Clay with a view to planning the construction of the underground installations (see page 26). To obtain conclusive results despite the high volume of samples, Nagra conducted test measurements with sample material obtained from the Mont Terri Rock Laboratory in 2018. As a result, the test procedure could be improved and Nagra demonstrated that measurement data from different laboratories are comparable as long as the same procedures are applied. Finally, detailed instructions were drafted for the sample collection and preparation as well as for the measurement procedures.

The samples must be carefully recovered from the boreholes and hermetically sealed directly at the drill site. This is particularly crucial for the chemical investigations of the porewaters in the Opalinus Clay. Conclusions can thus be drawn on the transport processes of water and dissolved substances in the Opalinus Clay over long time periods.

Borehole measurements
Investigations are not only conducted in the laboratory but also directly in the borehole. One method is so-called "packer testing" which is used to determine the hydraulic conductivity of rocks. Packers allow selected sections inside the borehole to be isolated. The pressure is then increased in the test interval. If the hydraulic conductivity of the rock is low, the pressure in the test interval remains constant or decreases only slowly. By contrast, the pressure drops rapidly if the hydraulic conductivity of the rock is high.

To determine the interfaces between the different rock types, the gamma radiation is measured in the borehole: Every rock contains natural radioactive isotopes that emit gamma radiation when they decay. If the rock type changes, e.g. from a calcareous rock to an argillaceous one, the natural radioactivity also changes. The measurement allows conclusions to be drawn regarding the clay content of the rocks because clay minerals contain potassium which has a high content of radioactive isotopes. The clay content determines how impermeable a rock is.

BUILDING BRIDGES – GIVING NAGRA A HUMAN FACE
Lukas Oesch, Project Manager Regional Participation

The geologist Lukas Oesch is one of three project managers who look after the concerns raised in the siting regions for deep geological repositories. In Nördlich Lägern, he is in touch with local authorities, cantonal administrations, members of the regional conference and private individuals such as landowners on whose property the drill sites will be constructed. "My presence gives Nagra a human face, and at the same time I build bridges", he says. And he emphasises: "An important part of my job is to get the outside view and listen to any questions, and to bring all of this back to Nagra". Being in touch with the property owners is both challenging and rewarding, Oesch adds. For the Quaternary investigations, for example, one issue was deciding together with the farmers on when to proceed so that the cultivation of their fields would be impacted as little as possible. "When talking to the affected parties, it is often possible to find a compromise that works for both sides", he says.

Lukas Oesch also conducts guided tours of the rock laboratories and, at trade exhibitions, he can be found at Nagra's stand. "I pay close attention to speaking comprehensibly and avoiding technical jargon", he explains. "In a rock laboratory, people often experience an "a-ha" moment and see that we conduct serious research and will not simply bury the radioactive waste in a hole out in a field somewhere." During discussions with visitors, he has noticed that most people support safe radioactive waste disposal in Switzerland and see the need for deep geological repositories. "The very best science and the very best borehole are of no use to us if people do not have confidence in us", Oesch states. In his opinion, the key to trust is honest and transparent communication. "Seen this way, talking about our results is just as important as producing them", he concludes.

Free borehole information hotline in Switzerland
Lukas Oesch and his colleagues also provide support for the free hotline (phone 0800 437 333) that Nagra has set up for the public for questions regarding deep boreholes.

Safety analyses

Demonstrating long-term safety
For the general licence application, Nagra has to prepare an overall assessment of the long-term safety of a deep geological repository - a so-called "Safety Case". In the reports submitted in support of the general licence application, Nagra brings together all the arguments and analyses that describe, quantify and demonstrate the safety of the repository. Aside from the quantitative safety analyses, this demonstration also includes supplementary qualitative safety assessments and provides information on the reliability of the statements made. The focus in 2018 lay on compiling the argumentation and documentation structure, which also involved preparing a handbook on managing uncertainties.

"For the demonstration of long-term safety that Nagra has to provide for the general licence application, consistent arguments are imperative. This requires comprehensive coordination with other sections of the company and results in a very exciting collaboration."

Thomas Kämpfer
Section Head, Safety Analyses

"In my opinion, contributing to the intergenerational project on deep geological disposal is a very valuable task. We are concerned with the safety of the repository for the next million years and, for this time period, we model the transport through the argillaceous rock into the biosphere."

Priska Hunkeler
Project Manager, Safety Analyses

Modelling radionuclide migration
The focus of the safety analyses lay on revising the calculation models for the migration of volatile radionuclides, which are mainly transported in the gaseous phase. These volatile substances include simple organic compounds containing carbon-14 (C-14). In 2018, Nagra developed a model that now simultaneously considers the transport of radionuclides in both the liquid and gaseous phases. This model includes the latest findings from the now concluded EU research project "CAST" (CArbon Source Term).

Analysing and optimising operational safety
The focus of the operational safety analysis was on a systematic incident analysis based on current installation and operating concepts. The analysis of potential incident sequences such as fire was conducted for both the L/ILW repository and the HLW repository. The goal of these analyses in the current early project phase of the facility development is to continually optimise the safety of the facilities. For the radiological incident analysis, dose calculations were carried out for all L/ILW waste package types under normal operating conditions as well as for relevant bounding incidents. In addition, the dose was calculated for the operating personnel and for the population living in the vicinity of the repository. With these analyses, Nagra could demonstrate, in compliance with legal and regulatory requirements, that the complete spectrum of incidents can be reliably controlled through the implementation of appropriate measures and safety systems.

Materials performance

Alternative protection from corrosion
Spent fuel assemblies and high-level waste are repackaged from transport and storage casks into disposal canisters before emplacement in a repository. These contain the waste for at least 10 000 years. Once the canisters have corroded, further safety barriers become effective and retain the radioactive waste in the repository.

For spent fuel assemblies and high-level waste, Nagra plans to use disposal canisters made of carbon steel as the reference material and copper-coated steel canisters as an alternative. In 2018, Nagra looked at what other coating materials would also be suitable and investigated nickel and titanium alloys as well as ceramics. Assessment criteria included production technology, the mechanical integrity of the canisters, the resistance of the coating to environmental impacts and behaviour with regard to microbially induced corrosion.

Assessment of different alloys
Some alloys are highly corrosion-resistant and have been proposed abroad as a material for disposal canisters. Nickel alloys are widely used in industry, and the coating technology is advanced. However, they would be affected by microbially induced corrosion, which results in large uncertainties regarding mechanisms and rates of corrosion reactions. By contrast, titanium alloys are resistant to several types of corrosion. Weaknesses in titanium alloys regarding creep and embrittlement can be dealt with using special production technology so that the lifetime of the disposal canisters can be reliably predicted.

Ceramic materials are also resistant to microbially induced corrosion, but their coating technology is less advanced. Compared to metal coatings, they have several disadvantages that are not easily overcome, such as high brittleness or a thermal expansion different from that of the base material. In addition, ceramic coatings must be much thicker than those made of metal, and they are generally too porous to satisfy requirements. Some ceramic materials do have potential but further developments are necessary before feasibility can be fully assessed.

Evaluating cement-based backfill
In its disposal concept for high-level waste, Nagra plans to use bentonite as a reference material for backfilling the emplacement drifts. In 2018, Nagra also assessed a cement-based backfill with regard to its advantages and disadvantages for long-term safety. The requirements on the backfill served as the basis for the assessment and resulted in a provisional selection of cement and concrete recipes as well as production and backfilling strategies. Based on the selected concept, assessment aspects included repository-induced effects (thermal, chemical, mechanical and hydraulic) as well as radionuclide release and transport.

“In its disposal concept for high-level waste, Nagra plans to use bentonite as a reference material for backfilling the emplacement drifts.”

The overall result was that high canister temperatures damage the concrete and increase its porosity, leading to a decrease in compressive strength. Due to overburden pressure, cracks form in the cement, negatively impacting canister lifetime. A first evaluation of the repository-induced effects in a cement-backfilled high-level waste repository has shown that using a cement-based backfill may be technically feasible and present limited long-term risks, but that considerable efforts are needed to develop and demonstrate a robust disposal concept that would ensure compliance with all safety-relevant requirements such as canister lifetime and the buffer function of the backfill.

The geographer and spatial planner Livia Schälli has been looking at the aspects of environmental law and spatial planning concerning the surface infrastructure since April 2018. She is also involved in a comparative life-cycle assessment of the different repository types and sites.

Martin Stiefel has been Section Head Facilities and Operation for a year. The mechanical engineer is responsible for designing and planning the facilities of deep geological repositories. This includes electromechanical and operational questions for both the underground and surface infrastructure.

Facilities & operation

Deciding on the main features of the facilities
In Stage 3, the operating concepts and facility systems will be further developed and specified. The goal is to describe the main features of all the facilities of the deep geological repository by the time the general licence application is submitted, which is in line with basic engineering planning.

To prepare for the further concretisation and improvement of the facility concepts, the radiation protection concepts were reviewed and further developed in 2018 for all three potential repository types (separate repositories for L/ILW and SF/HLW as well as a combined repository). Based on this, it was possible to derive the requirements to be met by the facilities and systems. The radiation protection concepts ensure the protection of humans and the environment from any radiation impact during the routine operation of the facilities. By contrast, incident analyses (cf. incident analysis, page 22) investigate what can go wrong when handling radioactivity and how suitable measures can prevent such an incident.

Considering an external location for the encapsulation plant
Before emplacement underground, the fuel assemblies and high-level waste (SF/HLW) are transferred from transport and storage casks to disposal canisters in an encapsulation plant. When planning the location of the surface facilities in Stage 2, the question arose whether the encapsulation plant had to be integrated into the surface facility of the repository, or whether it could be located externally. In its results report on Stage 2, the Federal Council stated that, in Stage 3, Nagra could consider placing the encapsulation plants outside the siting region. This would be done in collaboration with the regional conferences and the corresponding siting Canton.

Processes in a future SF/HLW encapsulation plant can be compared to those at the interim storage facility (Zwilag). In 2018, Nagra therefore began to investigate what synergies could be used if one option were to construct an encapsulation plant at the Zwilag site. Several solutions were outlined for embedding such a plant into the existing Zwilag infrastructure. The Zwilag site is located in close proximity to the potential surface facility site JO-3+ on the opposite side of the Aare river. Examining transport options also included locations for a river crossing between the two areas, taking into account spatial and environmental planning requirements.

“The Federal Council stated that, in Stage 3, Nagra could consider placing these encapsulation plants outside the siting region.”

Closure, sealing and waste retrieval investigated
In 2018, a newly formed interdisciplinary project team worked on the closure and sealing of a deep geological repository. Research was conducted on what information is already available, what legal provisions exist and how Nagra's partner organisations address these issues. The current factual situation regarding the retrieval of radioactive waste from a deep geological repository was also clarified.

Construction & environment

Planning the underground infrastructure
A deep geological repository is constructed beneath the earth's surface and consists of underground structures such as tunnels, drifts and caverns. This underground infrastructure includes access structures leading from the surface to the underground disposal level. In 2018, Nagra continued planning these installations and took into account feedback from expert reports on Stage 2 and the requirements that would be imposed by a disposal level located at greater depth. Specifically, the profiles of tunnels, drifts and caverns were updated and supplemented along with the corresponding concepts for excavating and securing them.

In 2018, Nagra used these studies as the basis for determining the procedure for constructing the underground facilities. The current disposal concept plans to place the high-level waste in emplacement drifts and low- and intermediate-level waste in emplacement caverns. The underground facilities can be excavated by blasting or using roadheaders or tunnel boring machines. Due to the small diameter of the emplacement drifts in the Opalinus Clay, they will probably be constructed with tunnel boring machines for reasons of construction logistics. The tunnels will be reinforced with a supporting concrete liner, which ensures structural safety as well as work safety by preventing the weathering and detachment of the Opalinus Clay. When excavating with a tunnel boring machine, the tunnel is either secured with shotcrete or with prefabricated elements made of reinforced concrete.

At the same time, the constitutive rock mechanical model for Opalinus Clay was further developed. It describes the behaviour of the rock under mechanical stress – such as during tunnel construction – and is one of the models for the structural analyses required for designing the underground facilities. For the further development of the model, rock mechanical laboratory experiments were conducted on Opalinus Clay drill cores and the results were input into the constitutive model. Drill cores recovered at various depths from the deep boreholes in Stage 3 will provide further data.

PLANNING THE DEEP GEOLOGICAL REPOSITORY: FROM CONCEPT TO DETAIL
Peter Grünberg, Project Manager Nuclear Facilities

Peter Grünberg already had dealings with Swiss waste disposal before he joined Nagra: "We recycled americium-241, which can be found, for example, in Swiss smoke detectors", he explains. The 38-year-old studied waste management and clean-up of contaminated sites as well as radiation physics in Dresden, Germany. As project engineer, he was also involved in compiling the operating manual for the planned German disposal site at the Konrad mine (Schacht Konrad).

Since 2013, Peter Grünberg has been Nagra's Project Manager for Nuclear Facilities. "I manage the design of those parts of the facility where radioactive waste will be handled, and plan appropriate radiation protection measures", he says. He enjoys working with external partners. "You keep getting different perspectives on the questions, and this helps Nagra to ensure that the latest developments in science and technology are implemented", adds Grünberg.

Internal cooperation is also important to him: "To be able to assign clear tasks to our external contractors, we must clarify internally what requirements a part of the facility must fulfil". Currently, Nagra is developing a Requirements and Configuration Management system in line with the increasing complexity of the planning. "For every element of a deep geological repository, precise requirements are defined and we also note where these come from, for example whether they are legal requirements or based on research findings", explains Grünberg. Particularly in a project extending over several decades, this helps to ensure that nothing is forgotten and that decisions remain transparent. "Such data management is also valuable for the verification steps in the licensing procedure", he states. "This allows us to show that a particular part of the installation does indeed meet the requirements imposed on it".

Peter Grünberg is also involved intensively in working on the cost studies for deep geological disposal that Nagra compiles every five years on behalf of swissnuclear. The very time-consuming and complex work for the 2021 Cost Study already started in mid-2018.

"I like how multi-faceted and varied my job is and that society also benefits from my work", he emphasises. He does not mind if the realisation of the deep geological repositories takes time because safety has the highest priority. In conclusion, he adds with a smile: "If I'm lucky, I might still be around when the deep geological repository starts operating. But it might have to be accessible with a Zimmer-frame."

Nagra's proposals for the location of the surface infrastructure
In Stage 3, Nagra will concretise the surface infrastructure of the repository in collaboration with the siting regions.

The surface infrastructure includes:
- A surface facility where the radioactive waste delivered for emplacement is encapsulated and brought underground via the main access,
- Separate auxiliary access facilities that provide the underground section of the repository with water, electricity and fresh air and also serve as transport facilities for staff and construction materials,
- Further areas for construction installations and for connecting the facilities to an existing transport network.

With the decision of the Federal Council on Stage 2, the approximate location of the surface facility was determined as an interim result in the Sectoral Plan process. Based on the results of the 3D seismic investigations, Nagra identified an area in each of the remaining siting regions for the location of the main underground connection area (HEB). The HEB is a planning perimeter for the future so-called central area of the deep geological repository. This is where the accesses from the earth's surface converge and where the logistics for the construction and operation of the deep geological repository as well as the facilities for fresh air distribution are arranged. The other underground structures of the repository will also be accessed from the central area, in particular the disposal zones. The main access can consist of either shafts or tunnels. The auxiliary accesses are generally designed as shafts that are linked to the HEB. As opposed to the siting areas for surface facilities, there is correspondingly less flexibility in designing the layout of the auxiliary access facilities.

Concretising the installations of the surface infrastructure has the following goals: The site for the surface facility is optimised, and variants with or without the encapsulation plants are investigated. The different functions such as ventilation, construction and operation accesses will be specified, depending on the different realisation phases. The surface areas required for the auxiliary access facilities must be arranged within a certain perimeter above the HEB.

In 2018 and early 2019, Nagra developed proposals for different configurations of the surface infrastructure for each siting region. External experts were involved in this process, and the responsible cantonal departments were consulted. In optimising the sites for the surface facility and the search for suitable areas for the auxiliary access facilities, Nagra also had to consider different construction-, operation- and safety-related factors, mas well as environmental and spatial-planning aspects, along with guidelines from the Federal Office for Spatial Development (FOSD).

Nagra will submit its proposals in the second quarter of 2019. Within the framework of the Sectoral Plan process under the lead of the SFOE, these will then be further developed in collaboration with the regional conferences and siting Cantons. Based on the responses and feedback, Nagra will specify the location and function of the elements of the surface infrastructure for every site that has been selected for the preparation of a general licence application.

During his studies to become a nuclear engineer, Valentyn Bykov completed several internships as well as his masters and doctoral theses with Nagra. He now works on decommissioning waste from nuclear power plants. To characterise this waste, he carries out numerous calculations and modelling studies. The nuclear engineer Stefano Caruso has been working for Nagra since 2011. As the Main Project Manager Inventories & Logistics, he is responsible for the characterisation and inventorying of Switzerland's high-level waste and spent fuel assemblies. He is also an advisor to international working groups of the OECD/NEA, IAEA and EURATOM.

Inventories & logistics

Optimisation of disposal containers

Nagra is refining its disposal concept, which also involves optimising the disposal containers for low- and intermediate-level waste. The concept has to consider the current state of the art in science and technology and outline optimisations and improvements. For the easier handling of the concrete containers during emplacement in a deep geological repository, Nagra has replaced the previously envisaged containers with smaller and lighter types (LC-84 and LC-86). In 2018, the development work on these containers was continued under Nagra's lead. One of the results was a weight decrease achieved by reducing the proportion of steel in the reinforcement of the containers. After the construction plans had been revised, Nagra issued a tender for a pilot series and collected and evaluated the offers. The first three containers of each type will be available for testing in mid-2019. In 2018, progress was also made in the conditioning of decommissioning waste. Conditioning includes all the work necessary to prepare the waste for interim storage or disposal in a deep geological repository: mechanical reduction, decontamination, compaction, incineration, embedding in a waste matrix and packaging. In addition, a suitable mortar type was identified for the backfill. Cement mortar is used to backfill remaining cavities inside the concrete disposal container with the decommissioning waste.

Cooperation in decommissioning planning

For the upcoming decommissioning of the Mühleberg nuclear power plant from the end of 2019, Nagra provided support in characterising and inventorying the expected decommissioning waste. The radiological characterisation of the reactor pressure vessel, internals and concrete structures was completed. The results are available by component and in high resolution. This significantly optimises cost estimates and strategies for dismantling and packaging needed for planning the decommissioning. In early 2018, Switzerland adopted the lower international waste exemption limits (cf. text-box). As a result, larger volumes of low-level radioactive decommissioning waste will arise. This must be held in decay storage or, if it meets certain conditions and has the approval of the licensing authorities, it can be recycled. To cope with these volumes, Nagra compared alternatives to existing concepts for the management of decommissioning waste. Nagra also carried out similar work for the Beznau nuclear power plant.

In addition, Nagra supported all the nuclear power plant operators and the Paul Scherrer Institute with the legally required disposability certification, which evaluates whether new waste packages and conditioning procedures meet the requirements for a future deep geological repository. The Model Inventory of Radioactive Materials (MIRAM) was updated and refined with the new knowledge gained from the decommissioning planning.

RADIOLOGICAL PROTECTION ORDINANCE AND EXEMPTION LIMITS

The revised Radiological Protection Ordinance (RPO) dated 26th April 2017 came into effect on 1st January 2018. The latest recommendations of the International Commission on Radiological Protection (ICRP 103) and the International Atomic Energy Agency have thus been implemented into national law. A further goal of the revision is improved harmonisation with European legislation.

The exemption limits have been lowered. The resulting increase in the waste volume can be partly compensated with a 30-year decay storage period meaning that, after 30 years, there still remains 15% more waste than there would have been before the introduction of the new limits. The radioactive waste destined for decay storage due to the modified exemption limits is very low-level radioactive waste that was previously considered inactive (based on the exemption limits valid until the end of 2017).

Grimsel Test Site

Number of research partners: **20**

Creating the framework for additional experiments

In the 35th year since research projects began at the Grimsel Test Site, Nagra and its international partners agreed on the programme and strategy for the next GTS project phase VI, which will last from 2019 to 2023. As a result, Nagra was able to extend its partner agreements and, based on these, also began extending the specific experiment agreements. The agreement with the Oberhasli hydropower plant (KWO) was also modified and implemented correspondingly. This ensures the necessary planning security beyond the next project phase, which is particularly important for the new long-term experiments.

The Federal Office of Public Health (FOPH) was informed about the extension of GTS phase VI and the new radionuclide experiments during the annual inspection. The FOPH is the supervisory authority for the rock laboratory for projects involving radioactive tracers.

Experiments under realistic conditions

The CFM and LTD projects include experiments with radionuclides conducted directly in the rock (for the names and acronyms of the experiments, cf. page 32 f.). The focus of the LTD project is on the diffusion of radionuclides in undisturbed rock. The CFM project investigates the influence of colloids – microparticles of organic or inorganic origin – on the transport of radionuclides in the vicinity of fractures and shear zones. Both projects have reached important milestones.

In late 2018, the CFM long-term experiment with radionuclides (CFM-LIT) in the radiation-controlled zone was overcored to a depth of approximately six metres. Overcoring the main part of the experiment with the radioactive bentonite source is planned for early 2019. In the new experiment "In-situ Bentonite Erosion Test" (CFM i-BET), the erosion behaviour of bentonite material will be investigated under realistic conditions. The installation was completed in December 2018. A set of different sensors will now record the changes in the bentonite over the next two to three years. Several instrumented observation boreholes in the near-field will be used to collect sample material. This will provide important information on the erosion behaviour of bentonite – for example, by the formation of colloids. Colloids can form at the interface between bentonite and granite.

In the LTD project, the in-situ experiment "Monopole 2" was concluded. Three boreholes were used to extract sample material from the area where radionuclides were circulated in the granite. This material was sent to Finnish, Czech and Japanese project partners for analyses to determine the distribution of the radionuclides H-3 (tritium in the form of HTO) and Cl-36.

In preparation for the extended project phase, the search for, and characterisation of, a suitable site for the planned follow-up experiments of the LTD project began in 2018. In these experiments, the diffusion of radionuclides will be investigated in the vicinity of a water-conducting fracture or a shear zone. The previous experiments were conducted in intact granite.

New experiments on cement and bentonite barriers

The CIM project includes long-term circulation experiments in which the migration behaviour of C-14 and I-129 through cement barriers will be studied under realistic conditions in terms of scale, water chemistry and mineralogy. These radionuclides play an important role in dose calculations for safety analyses. The plan is to circulate a tracer cocktail with C-14 and I-129 in a borehole backfilled with mortar that has been in contact with granite and groundwater for twelve years. As part of implementing the experiments (design study, characterisation and selection of the experiment location), the first field and laboratory investigations were begun in 2018. Sample material was sent to the CRIEPI and Mitsubishi Materials laboratories in Japan for analysis.

Experiment agreements were signed with the CIM project partners for the first project phase that will last for five years. In November, a partner meeting also took place in Tokyo.

Investigating the influence of high temperatures

Spent fuel assemblies will continue to emit heat even after their emplacement in a deep geological repository. This must be taken into consideration when optimising the spatial extent of a repository so that the safety-related requirements on the bentonite barriers can be met.

The goal of the HotBENT project is to investigate the effect of temperatures above 150 degrees Celsius on the early evolution and saturation of the engineered bentonite barrier. Elevated temperatures in a bentonite barrier can lead to the restructuring of minerals and precipitations, which can influence the swelling properties of such a backfill. These phenomena are known from laboratory experiments but have not yet been investigated under realistic repository conditions. The HotBENT experiment offers such conditions with natural saturation and the impact of overburden pressure.

Decades-long full-scale test

In 2018, Nagra and its international HotBENT project partners worked on a detailed experiment design and on preparing the construction of this large-scale experiment designed to last two to three decades. The elevated temperatures will be produced with modules that consist of a heater enclosed in bentonite. The experiments will be conducted with different types of bentonite and under varying boundary conditions, such as additional water intake or cement lining of the tunnel walls. The current models will define the final design, the monitoring programme and the duration of the experiment. The implementation of the experiment is planned for 2019.

"I ENJOY EXCHANGING INFORMATION WITH OTHER RESEARCHERS."

Andrew Martin, Project Manager Geosciences

"The rocky coastline of southern Wales inspired my passion for geology at a young age", says Andrew Martin who is from Wales. "So, I decided to study geology at Cambridge and I then obtained my doctorate in Japan". He has a strong bond with Japan: "While working for the Japanese Atomic Energy Agency, I was involved in the site selection process for a deep geological repository and coordinated the translation into English of Japanese texts on the programme for long-lived intermediate-level waste". He then joined a consulting firm and managed projects for the Japanese nuclear waste management organisation, NUMO. "I wanted to experience other programmes, too, so in 2006 I joined Nagra", Martin explains.

At the Grimsel Test Site, he manages experiments that are carried out directly in the rock. "I mainly examine the migration of radionuclides through fractured granite or through cement barriers in a radiation controlled zone", Martin states. Since traces of radioactive substances are used, he is responsible for complying with the Swiss Radiological Protection Ordinance. "We also examine the corrosion of metals for disposal containers in an oxygen-free environment and under realistic conditions", he continues and adds that partner organisations are involved in every research project. "We offer our partners ideal research conditions", he says, and notes that not all countries can afford their own underground laboratory.

"I enjoy exchanging information with other researchers, particularly with those from Japan", Andrew Martin emphasises. He is pleased to make a contribution to the safe disposal of radioactive waste. "Implementing a waste management solution is not just challenging from a political and societal point of view, but also from an engineering and economic perspective", Martin says. "This makes it even more important that my generation follows through with this."

MAJOR EXPERIMENTS AT THE GRIMSEL TEST SITE

CFM Formation and migration of colloids and their influence on the mobility of radionuclides

CIM Testing the migration properties of C-14 and I-129 through cement barriers

EBS Lab Experiments with components of engineered barriers as well as parameter determination

GAST Gas seal test: gas-permeable tunnel seals for a L/ILW repository under realistic conditions and on a realistic scale

HotBENT Investigation of the safety function of bentonite barriers exposed to elevated temperatures

ISC Controlled hydraulic stimulation of existing fault zones; experiment run by the Swiss Competence Center for Energy Research – Supply of Electricity

LASMO Monitoring and characterisation of the geosphere

LTD Long-term diffusion of radionuclides

MaCoTe Corrosion experiments with components of the engineered barriers

Plug experiment Engineering studies and demonstration experiments on repository design

KEY EXPERIMENTS IN THE MONT TERRI ROCK LABORATORY

CI Mineralogical interaction between claystone and cement

CI-D Diffusion across the concrete/claystone interface

DB Cored borehole through the Opalinus Clay

DF Drilling fluids for Opalinus Clay

DR-A Diffusion and retention of radionuclides

DR-B Long-term diffusion experiment

FE-M 1:1 emplacement experiment for investigating the near-tunnel environment (FE) with sub-projects on gas evolution (FE-G) and monitoring

FS-A Laboratory investigations of hydromechanical properties of tectonically reactivated Opalinus Clay

FS-C Imaging the long-term integrity loss of disturbed host rock zones

GC Investigation and conceptualisation of tectonic fracture patterns

GD Analyses of geochemical data

HA-A Variability of the hydraulic and geophysical properties of the Opalinus Clay

HE-E Behaviour of the engineered barriers under the influence of heat

IC-A Corrosion behaviour of various types of metal in bentonite

MA Investigation of microbial reactions

MA-A Microbial processes in the bentonite barrier

PE Characterisation of the sandy facies pre-excavation

SO-C Facies analysis of the upper Opalinus Clay and the transition to the Passwang Formation

SW-A Preparation of a large-scale sealing experiment

TS Testing possibilities for tunnel support in sandy facies

WS-I Understanding the self-sealing of excavation damaged zones and tectonic faults

Mont Terri Rock Laboratory

At the Mont Terri Rock Laboratory in Canton Jura, the Swiss Federal Office of Topography (swisstopo) leads an international research project on the hydrogeological, geochemical and geotechnical characterisation of the Opalinus Clay formation. Nagra participates in numerous experiments that contribute to evaluating the safety and engineering feasibility of a deep geological repository in Opalinus Clay.

Test tunnel extensions

The extension of the Mont Terri Rock Laboratory creates space needed for new experiments. Extension work started in March 2018 and will continue until late 2019, but the first experiments are already being conducted, such as Nagra's TS experiment (cf. page 32 for test acronyms). This experiment involves testing different support systems for tunnels in the sandy facies of the Opalinus Clay. The experiment will provide insight into the rock and system behaviour between the liner and the rock during the excavation process in the Opalinus Clay. There are three types (facies) of Opalinus Clay in the rock laboratory that contain different proportions of clay minerals, quartz and calcite. The sandy facies contains more quartz and calcite than the shaly facies.

"The extension of the Mont Terri Rock Laboratory creates the space needed for new experiments."

Monitoring mechanical stress

The TS experiment extends over three consecutive 15-metre-long tunnel sections that have been secured with shotcrete, steel arches and, once again, shotcrete. The distinction between the two shotcrete sections lies in the time of ring closure, i.e. when concrete was introduced into the tunnel invert. Creating such a ring results in a stiffer lining and prevents further rock deformations. The rock and system behaviour is captured by a dense grid of optical deformation measurements and three tunnel cross-sections equipped with fibre-optic cables. The fibre-optic cables in and around the lining measure the expansion and compression of the lining and allow conclusions to be drawn on the mechanical stress.

The resulting knowledge is used to verify the predicted rock and system behaviour during excavation of the repository structures. An additional goal is to demonstrate the feasibility of linear support of the rock using steel arches.

The steel arch support is a special structural feature in argillaceous rocks. Its use in the sealing sections of a deep geological repository would ensure direct contact between the rock and the granular bentonite material, thus preventing potential release pathways for radionuclides in the concrete lining. Cracks resulting from the degradation of concrete represent potential release pathways for radionuclides. Such cracks can occur with the ageing of concrete, for example as a result of corrosion through chemical interaction with groundwaters containing sulphur. Mechanical overloading can also result in cracking.

Alternative to steel arches

Alternative concepts for the sealing segment envisage supporting the entire rock surface with shotcrete during construction and emplacement. Slots are cut into the shotcrete just before the tunnel is backfilled with granular bentonite, so that the backfill is again in direct contact with the rock.

New insights into gas generation

With the "Full-Scale Emplacement" (FE) experiment conducted at the Mont Terri Rock Laboratory, Nagra is accumulating practical experience for the future emplacement of high-level waste. The experiment started in 2015 and its main goal is to demonstrate the impact of heat generated by the radioactive waste in a deep geological repository. For this purpose, three heaters were installed in a test tunnel in the Opalinus Clay to simulate the heat production of spent fuel assemblies. The tunnel was then entirely backfilled with granulated bentonite mixture and sealed with a five-metre-thick concrete plug. The behaviour of the Opalinus Clay and the bentonite under the impact of heat will now be observed over a ten-year period. The gradual partial saturation of bentonite with pore-

water must also be taken into consideration. The test tunnel was also equipped to allow investigation of gases with sensors or extracted samples (FE-G experiment), leading to new insights that are explained below.

During the construction of the FE tunnel, ambient air entered the tunnel due to ventilation. After the tunnel was backfilled, the ambient air was still present in the interstices in the granulated bentonite. Scientists are interested in the behaviour of this residual air when porewater from the Opalinus Clay slowly infiltrates into the bentonite in the tunnel over the next decades. Based on previously available models, scientists expected the oxygen contained in the tunnel's residual air to disappear over decades or even longer. It is known that oxygen is consumed, for example, through reactions with the iron sulphide pyrite contained in bentonite and Opalinus Clay or through bacterial activity. However, the measurement sequences conducted at the rock laboratory delivered an unexpected result: After just a few months, the test tunnel was largely oxygen-free. The exact process must be studied in depth. With regard to the safety of a deep geological repository, rapid oxygen depletion is good news because, without oxygen, the disposal canisters containing the spent fuel assemblies will corrode at an even slower rate.

Gases in porewater also investigated

Researchers were also interested in the porewater still contained in the pores of the Opalinus Clay. It contains several gases, for example, light hydrocarbons such as methane. The investigations confirmed what previously conducted experiments had already shown: Gases contained in the porewater interact with the tunnel atmosphere before the water even penetrates into the near-field. The near-field consists of the inside of the tunnel and a zone a few dozen centimetres thick in the Opalinus Clay of the tunnel wall.

"JUGGLING THE DIFFERENT ASPECTS OF MY JOB IS EXCITING AND FUN."

Irina Gaus, Head of Research & Development

Irina Gaus has been working for Nagra since late 2007. She has a doctorate in hydrogeology.

Irina, what does being the Head of Research and Development involve?

As head of research and development projects for Nagra, I set priorities and make sure that important issues are sufficiently covered. We work on many scientific topics at the same time and require different approaches to solving these. Juggling these different aspects of my job is an exciting challenge.

What are Nagra's research priorities?

In the safety case for the general licence applications, we must demonstrate the long-term safety and feasibility of deep geological disposal. Everything that goes into this documentation must be sufficiently substantiated. It is very important to us that our arguments are solid. We set our priorities in areas where we must reduce uncertainties or gain deeper knowledge of processes. One example is erosion, where we carry out research using glaciation models or Quaternary boreholes. At the moment, our projects on the safety barriers of a deep geological repository also include the optimisation of disposal containers or the handling of gas. Later on, we will have to carry out underground geological investigations at the selected repository site for the construction licence application. For an operating licence, we must then conduct demonstration experiments to show that emplacement and retrievability are feasible.

How do you cooperate with external partners?

Nagra has experts on every topic. They consult with each other within Nagra and coordinate and monitor external cooperation with scientifically independent competence centres such as universities or research institutes that perform the work here in Switzerland and abroad. The results are then integrated into the safety case and are also included in the higher-level reporting for the general licence application. We attach great importance to having our research findings evaluated by external experts who are at the top of their specialist fields.

International Services and Projects (ISP)

Nagra employs many experienced scientists and can also reach out to a competent external pool of experts. Nagra is thus able to effectively support its partners and other organisations from around the world with their projects.

In 2018, Nagra further expanded the collaboration with its partners. The workshops and training courses conducted by the ISP Division were a particular highlight. Participants were able to gain considerable knowledge and had the opportunity to exchange experience.

Successful practical courses

In February 2018, a practice-oriented workshop was conducted with the Japanese waste management organisation NUMO, focusing on seismic exploration and the interpretation of seismic measurement data. Aside from basic theoretical knowledge, the participants received real data from Nagra's most recent geophysical measurement campaigns, providing them with a first impression of how to interpret data. In addition, geological structures and formations were explained and visualised. The workshop allowed participants to better assess the challenges associated with planning and carrying out sophisticated measuring campaigns.

In June 2018, a one-week seminar was conducted within the framework of the Grimsel Training Centre on the topic "Bentonite properties and applications". Eight experts addressed various aspects of bentonite, which is a key component of the multi-barrier system of a deep geological repository. Participants learned more about the properties of bentonite, how they are analysed in laboratories and how important bentonite is for the long-term safety of a repository. In addition, they received information on the large-scale experiments conducted in the rock laboratories and on how bentonite is treated in the latest numerical models. The programme also included practical laboratory experiments with bentonite.

In October 2018, a workshop was conducted together with RWM, Nagra's sister organisation in the UK. The workshop focused on the planning and implementation of field investigations for the characterisation of the underground. The UK will have to conduct investigations similar to Nagra's and, for this reason, RWM is interested in Nagra's experience and in the staff members who are actively involved in preparing for and implementing such investigations. Aside from the technical aspects and the resulting knowledge, the workshop also helped to develop a better understanding of the management, staffing and organisation needed for successful exploration campaigns.

INTERNATIONAL SERVICES AND PROJECTS (ISP)

Nagra's ISP Division is responsible for projects with funding sources outside the Swiss national programme, as well as for the Grimsel Test Site. The activities cover a wide spectrum of projects in the radioactive waste management field – strategic programme planning, specification of waste inventories, site selection, characterisation and evaluation, repository design, safety case development, safety analyses, public communication, focused training and know-how build-up, as well as projects in other scientific and technical fields such as geothermal exploration.

Above: Participants attending the Grimsel Training Centre course on "Bentonite properties and applications" enjoyed perfect conditions - including the weather.
Below: At present, around twenty partner organisations from different countries participate in the experiments conducted at the Grimsel Test Site. Representatives of the partner organisations gather at the annual meeting of the "International Steering Committee" (ISCO). In 2018, the focus of the exchange was on the extension of the GTS Project Phase VI.

International collaboration

EDRAM: High-level exchange of expertise
Between June 2016 and June 2018, Thomas Ernst presided over the EDRAM Association (International Association for Environmentally Safe Disposal of Radioactive Materials) of the leading waste management organisations worldwide. EDRAM promotes the exchange of expertise, experience and knowledge between these organisations at management level. At the annual meetings, participants present the latest developments in their programmes and discuss strategic questions. In 2018, a meeting was held with high-ranking representatives of the International Atomic Energy Agency with the purpose of promoting mutual understanding and collaboration.

Knowledge transfer over generations
In 2018, the expert group "Preservation of Records, Knowledge and Memory across Generations" (RK&M) concluded its work on topics related to the cross-generational transfer of knowledge and information on deep geological repositories. The OECD/NEA founded the expert group in 2011, and Nagra (cf. text-box) and the SFOE were also involved. Deep geological repositories are designed to ensure long-term safety without the need for human intervention. Safeguarding knowledge and information on the repositories can also contribute to preventing inadvertent intrusion by humans and to allowing future generations to make well-informed decisions regarding the repositories.

"Deep geological repositories are designed to ensure long-term safety without the need for human intervention."

Developing a new strategy
In the past, considerations of how to pass on knowledge and information to the next generations concentrated on marking the disposal site and archiving all relevant information. Between 2011 and 2018, the expert group built up a profound understanding of the topic and developed a new approach. In its final report, the group emphasised that there is no single medium that can ensure the transfer of knowledge and information over long periods of time. Instead, a strategy should be developed in which the different components mutually supplement and strengthen each other and ensure redundancy by using several transmission methods. The development of such a strategy should involve a wide spectrum of participants – waste management organisations, safety authorities, national and local authorities, communities and society in general – to maximise the chances of transmitting a message comprehensibly. The final report contains a "tool box" for the development of a global strategy for preserving and transmitting information that includes a selection of 35 different methods along with guidelines for combining and implementing them.

International exchange on long-term safety
The symposium of the Nuclear Energy Agency's "Integration Group for the Safety Case" (IGSC) took place in autumn 2018. Nagra presented the latest developments in the Swiss site selection process, with particular emphasis on the role of safety. Topics included the recently concluded extensive probabilistic sensitivity analyses on the release of radionuclides for the L/ILW and HLW repository (cf. Nagra's annual report 2017). The purpose of the symposium was an exchange with experts from national waste management programmes worldwide. Such events focusing on the long-term safety of deep geological repositories contribute to the use of synergies in this key field of expertise and to conducting work based on the current state of science and technology.

New European programme EURAD
For decades, the European Atomic Energy Community (EURATOM) has been working together on handling and managing radioactive waste. Waste management organisations such as Nagra, technical support organisations and research bodies from 23 countries will now deepen their collaboration with EURAD, the new European Joint Programme on Radioactive Waste Management. This will support member states and complement their national programmes that have advanced to varying degrees. A joint research, development and demonstration (RD&D) programme was developed and submitted to the EU Commission in Septem-

ber 2018. Assuming the support of the proposal by the Commission, the EURAD activities are scheduled to begin in June 2019.

Nagra is fully engaged

Nagra is participating in the EURAD programme in three work packages, as well as in a knowledge exchange network. The work package "GAS" aims to increase the understanding of how gas is transported through clay materials and should demonstrate how gas generation in a repository can be handled safely. Aside from international organisations, other Swiss partners are involved, such as the technical university in Lausanne (EPFL), the university of applied sciences in Zürich (ZHAW) and the Paul Scherrer Institute (PSI). The work package "HITEC" focuses on the impact of thermal loading from high-level waste on the performance of the engineered and geological barriers of a deep geological repository. The third work package deals with the characterisation of spent fuel assemblies and the impact of extended dry storage on their integrity. Nagra's research partner PSI is involved with the more fundamentally oriented work packages on the migration of radionuclides, the application of numerical models and near-field interactions. Co-funding is planned in areas where Nagra also sets priorities.

"FROM MY POINT OF VIEW, IT WOULD BE A HUGE MISTAKE TO THROW OUT ALL THE PAPER."

Anne Claudel, Section Head Information Management and Deputy Division Head Finance, Controlling & Human Resources

"In a nutshell, it is my job to make sure that the Nagra staff can access all the information they need to perform their work", says Anne Claudel. She also makes sure that the information is stored and remains available for later. The French native studied information and communication sciences as well as art history and archaeology. Accumulating and archiving information is one of her daily tasks. "In the case of the deep geological repository project, we are talking about 100 to 150 years", she emphasises. Here too, she has to ensure that all the information on the project is available for this entire time period and beyond.

But not just this: Anne Claudel is also active in the area of information management. "In a technical-scientific and dynamic work environment, it is very important that people exchange know-how and pass on their knowledge, for example when long-term staff members and experts retire or resign", she explains. For this purpose, she has developed guidelines that transform knowledge back into information. According to Claudel, who can look back on 20 years of experience working for Nagra, digitalisation has facilitated and accelerated the transfer of information, yet she points out: "The electronic medium might not be ideal over the long term." Future requirements could be vastly different. Nagra has around 40,000 documents stored in an electronic document management system, but the important documents are also archived in paper form. "We have not yet found a better medium. From my point of view, it would be a huge mistake to throw out all the paper", she adds.

But Anne Claudel's tasks far exceed the above. She also monitors the decisions made by the national and cantonal parliaments on deep geological disposal as well as those made abroad. She stays on top of all developments and can provide information at any point in time. She also belongs to an international expert group of the NEA, the OECD's Nuclear Energy Agency. Twelve countries, including Sweden, Finland and the USA, have worked on a strategy in recent years for storing knowledge on deep geological repositories over many generations. "On the one hand, I perform my work thinking of immediate data storage and short- and medium-term information and knowledge management, but I also look ahead to the next 50,000 years", Anne Claudel emphasises. "This captivates me time and again."

Renate Spitznagel has been working for Nagra since 1995. Among other responsibilities, she organises tours for visitor groups to the Grimsel Test Site and the Mont Terri Rock Laboratory. She is the point of contact for external visitors and the staff members guiding the tours.
Beat Stefani has worked for Nagra for 27 years. He is responsible for assembling and dismantling Nagra's exhibition stands. His duties also include storing and maintaining the material in the Nagra depot in Mellingen.

Public outreach

Still a major attraction

The "Journey through time to a deep geological repository" remained one of the main attractions at regional trade fairs in 2018. By means of virtual-reality glasses, visitors to the exhibition can experience the construction and operation of a deep geological repository in a 3D film. The "Journey through time" was present at 19 trade exhibitions, markets and other events. It was also used at a cantonal school and a symposium for geologists. In the autumn, the exhibition was expanded to include an exhibit on deep boreholes. With the help of iPads and augmented reality technology, it is possible to explore a drill site and see what experiments are conducted in a borehole and how drill cores are recovered. In addition, visitors can learn more about rock formations, especially about the Opalinus Clay, which is being more closely investigated during the deep borehole campaign.

In 2019, re-created animations will further modernise the "Journey through time". The so-called motion-capture process and improved rendering techniques combined with glasses with a higher definition make the experience more realistic and intensive for visitors.

Off to the tunnels: Visiting the rock laboratories

The two rock laboratories – Grimsel (Canton Bern) and Mont Terri (Canton Jura) – are international research platforms and a central component of Nagra's public relations activities. The guided tours to the rock laboratories are very popular. During 2018, 1355 people visited the Grimsel Test Site and 4047 people toured the Mont Terri Rock Laboratory. Due to ongoing expansion work at the Mont Terri Rock Laboratory, organising and coordinating the tours was more challenging. During the tour, visitors can experience the research work being conducted by Nagra and its partners up-close, and being surrounded by rock gives them a sense of the long geological time dimensions. For visitors from the siting regions Jura Ost, Nördlich Lägern and Zürich Nordost, including those who had won a tour by participating in Nagra's competition held at exhibitions, the Mont Terri Rock Laboratory held four open-days, and the Grimsel Test Site opened its doors for a further four days.

For film enthusiasts

In 2018, Nagra produced five films which it published on its YouTube channel. Two explanatory films provide answers to questions often asked at exhibitions: "What is radioactivity?" provides information on the different radiation types and shows how to effectively protect against radioactivity. The film "Radioactive waste disposal in a deep geological repository" explains why such repositories are the safest solution for radioactive waste disposal and the only one to be accepted by scientists worldwide. The film also explains why radioactive waste should not be stored at the earth's surface for thousands of years.

Trade fairs and exhibitions	**19**
Users visiting nagra.ch	**59 922**
School projects	**24**

Three new short films also explain what Nagra is working on. For the video "Tours of Nagra's Grimsel Test Site", adolescents were accompanied on their visit to the rock laboratory and asked about their impressions. The two-part short film "Nagra's Quaternary boreholes" shows what a drill site looks like and why Nagra conducts Quaternary borehole investigations, but it also provides information on why Nagra is investigating past erosion processes and how it can use the resulting knowledge to better predict the future evolution of the landscape. At the end of the year, a new explanatory film on deep boreholes was added. Nagra also published a special brochure on this subject, providing a good overview of the purpose and the sequence of investigations in the boreholes. The brochure can be ordered or downloaded under www.nagra.ch > publications.

You can find Nagra's latest films on its YouTube channel:

Earth sciences blog has moved
The blog on earth sciences (www.erdwissen.ch) was started in 2011 and enjoys a steadily growing fan community. It was operated by Nagra as an independent channel. The blog is not compatible with use on mobile devices, which is why it was integrated into Nagra's blog (www.nagra-blog.ch) in September. Interested individuals can read popular contributions from the world of geology under the heading "Earth sciences". The associated Facebook page delivers daily popularscience contributions.

Increased number of visitors at www.nagra.ch
The Nagra website reached more people in 2018 than in the year before: On average, there were 228 sessions per day, and the number of users rose by 19 per cent. Aside from Nagra's landing page www.nagra.ch, the sites with the most visitors were "What is radioactivity" and "Geology of Switzerland". According to statistics, "disposal how" is more frequently visited than "disposal where".

Nagra's information trips temporarily suspended
Nagra informs the wider public about topics relating to radioactive waste disposal. Its information concept is presented in the Waste Management Programme that was approved by the Federal Council. The Programme refers to information trips that have been conducted to waste management facilities abroad since the 1980s. All members of the Swiss Parliament are invited, as well as members of the regional conferences from the potential siting regions, members of the cantonal parliaments and community authorities from the potential siting regions, associations and other interested individuals. Participants from the entire political spectrum are given the opportunity to inform themselves on site about the disposal concepts in other countries and to exchange their experiences. Due to the packed programme, participants have no free time at their disposal. Nagra bears the costs of the two- to three-day trips, which are also accompanied by representatives of the federal authorities (SFOE, ENSI) who provide information and expertise.

Following an anonymous complaint, the Office of the Attorney General carried out preliminary investigations in the summer of 2018, whereupon Nagra suspended the two fact-finding missions planned for 2018. In late 2018, the Office of the Attorney General reached the conclusion that Nagra's fact-finding missions are legal. According to the decision of the Office, the offences of granting and accepting advantages are "clearly not fulfilled". Therefore, no proceedings will be instigated and Nagra will resume these tours in 2019.

In touch with the media
In 2018, the media office was also intensively involved with the conclusion of Stage 2, the start of Stage 3 and the deep borehole investigations. The highlight was the annual media conference in Bülach at the end of September, where Nagra provided information on the deep borehole campaign. Following this, the deep boreholes were picked up in a Swiss television news programme, all major print media and several radio programmes. Almost 90 articles were published as a result of the media conference. The media conference at which Nagra released the news that the Office of the Attorney General was carrying out preliminary investigations into Nagra's fact-finding tours also received attention. Less was reported on the following media conference stating that the Office of the Attorney General had come to the conclusion that the trips were legal.

Attractive information packages for schools and young people

The exchange of information with the young generation is and will remain an important concern of Nagra. In 2018, Nagra staff visited around 30 school classes. A favourite exercise was a simulated podium discussion where students were asked to argue for or against a deep geological repository in their hometown. In addition, numerous school classes visited the Mont Terri Rock Laboratory or the Grimsel Test Site where they could gain an insight into research on the disposal of radioactive waste. The requests for school materials remained constant; the diverse range of experiment sets allowing students to conduct their own experiments on radioactivity is particularly popular. A pleasing development in the autumn of 2018 was that around two dozen students took up Nagra's offer to support them with their school-leaving or final apprenticeship exams. This involved interviewing Nagra staff or visiting a rock laboratory.

In July, Nagra accompanied students from the Interlaken and Gstaad secondary schools on a tour through the Grimsel Test Site with a camera.

Voices from the siting regions

Andrea Weber is a member of the management body of the regional conference for Nördlich Lägern and co-leader of the expert group on safety. She studied German and classics and is community president of Niederweningen.

How do you perceive the collaboration with Nagra?
As very pleasant. The staff are highly competent, solution-oriented and communicative. The first Nagra presentations at the regional conferences were full of technical jargon, and the slides were hugely overladen, but Nagra adapted quickly and now faces us as an educated and motivated lay audience. I appreciate that Nagra always takes the time to answer our questions. When the expert group on safety needs a speaker, Nagra representatives always have time for us.

The two information trips I have been on with Nagra were a highlight for me. They were very informative and neutral, and I was able to establish contacts with the Swiss Federal Office of Energy and with members of other regional conferences. I also learned a lot about nuclear waste disposal in Sweden. Visiting the Asse mine in Germany was particularly impressive.

What are the main challenges in searching for a disposal site?
As soon as a disposal site has been announced, it is imperative that the public be informed more comprehensively. Nagra must start thinking about construction traffic at an early stage because it will present a noticeable burden.

In general, the public is not very interested in waste disposal, so everyone involved must become more active. The regional conferences could publish more information through community newspapers. I use our community assemblies to provide information, and the public appreciates this. Nagra is well on track with information events such as tours of the drill sites or the rock laboratories. Another important approach is to involve critics from Switzerland, but the German side should also be taken seriously. However, ultimately, this is a Swiss concern.

The German scholar and musicologist Martin Steinebrunner heads the German coordination office for deep geological repositories in Switzerland, which organises the involvement of the German side in the Sectoral Plan process.

How do you perceive the collaboration with Nagra?
My collaboration experience with Nagra is positive. Nagra is a competent dialogue partner and always lends an ear to questions and discussions.

I was involved in Nagra's workshop for developing a code of conduct and, in my opinion, Nagra clearly adheres to it. What I found difficult were the scope and reader guidance for Nagra's dossiers on Stage 2. This could be improved and, in my opinion, has made it difficult to review the documents.

What are the main challenges in searching for a disposal site?
Personally, I felt that the process for identifying the sites for the surface facilities in Stage 2 was not transparent enough: In the regional conferences, alternatives were discarded too early and too easily. I fear that the evaluation process for a separate location for an encapsulation plant will be more about creating acceptance than about carefully balancing the pros and cons. When this impression arises and takes root – that decisions are political rather than factual – the consequences can be toxic for a procedure that relies on trust and must cultivate acceptance. It is crucial to avoid giving the impression that the process lacks transparency. Decisions must be based on fact.

Occasionally, the "Germans" are portrayed as fundamental opponents and naysayers. This is a distorted image. We support Switzerland's efforts to realise the safest possible deep geological repository, but we need to raise our concerns. The sites are often located only a few hundred metres away from German soil. This proximity means that all of us are equally affected. I am convinced that whoever becomes involved in a critical and constructive manner can get to the bottom of the matter and raise his or her own questions, which will contribute to the success of this Herculean task. Such impulses are needed to optimise safety.

Gerry Thönen works in regional management and is in charge of the head office of the Jura Ost regional conference. He has a degree in sociology, political philosophy and German.

How do you perceive the collaboration with Nagra?
The collaboration with Nagra works very well and constructively, also extending beyond the "compulsory component". We receive useful answers to our questions and concerns.

Most specialists have learned to convey their knowledge to non-specialists in a comprehensible manner without descending into the trivial realm and can adapt to their dialogue partners. I appreciate people who, in the course of a discussion, can admit, "I don't know" or "We don't know that yet".

What are the main challenges in searching for a disposal site?
It is important to pay attention not just to the technical aspects of the process but also to the societal ones. Geology and construction technology play a central role but, ultimately, society will decide on the construction of a deep geological repository.

The societal study has revealed a polarisation between opponents of a deep geological repository and people who contribute to the process in a constructive manner. This polarisation could increase in the future by the "import" of yet more opponents, and the situation could become more militant. At the cantonal level, the siting discussion has a strong political element. The leaders of the siting process and politicians must insist on compliance with the rules of play and be ready to intervene and defuse situations should the need arise.

The Sectoral Plan process is a very costly procedure, but in my opinion every attempt to shorten it would result in expensive and time-consuming extra loops. We expect the Canton to take the concerns of our region into account to the greatest degree possible. Ideally, region and Canton should act together towards a common goal.

A member of the Liberal Democratic Party, Beatrice Salce is community president of Benken and a master painter. She heads the expert group on surface infrastructure of the Zürich Nordost regional conference.

How do you perceive the collaboration with Nagra?
The collaboration is good. Nagra always lends an ear to my concerns. The community of Benken has been in contact with Nagra since a deep borehole was drilled there in 1998. There are critical voices, too, but proponents and opponents of a deep geological repository can now conduct more constructive dialogues than before.

Should the safest site for a deep geological repository happen to be located in our region, it is very important to collaborate with Nagra and find the best solution possible.

What are the main challenges in searching for a disposal site?
The Swiss Federal Office of Energy (SFOE) must involve and inform the population more – including the younger generation. Acceptance can only be achieved when the conditions are right. For this reason, the surface infrastructure of a repository would have to be embedded into our wine region as optimally as possible and its visibility kept to a minimum.

The site selection process has been going on for years, and we "Benkemers" are somewhat tired of it. To address this concern, we have formed a "disposal commission" to inform our population in a familiar environment. We expect the SFOE and Nagra to keep the population informed promptly and conclusively about the site selection process.

All the involved parties must take care not to confuse the public or to lose its trust. Opinions still differ on the decision on the siting area for a surface facility. I hope that the Canton, more specifically the cantonal government council, will provide us with more attention and support. The communities affected by the infrastructure facilities carry the burden and must work together. The radius of those affected must not expand any further. In the expert groups, we are looking for an efficient approach to finding solutions; we are not trying to draw attention to ourselves or to gain financial advantages.

Board of Directors

Corina Eichenberger
President of the Board of Directors

Dr. Willibald Kohlpaintner
Vice President
Axpo Power AG

Dr. Philipp Hänggi
BKW Energie AG

Dr. Thomas Kohler
Alpiq AG

Dr. Stephan W. Döhler
Kernkraftwerk Leibstadt AG

Dr. Michaël Plaschy
Kernkraftwerk Gösgen-Däniken AG

Ronald Rieck
Zwilag Zwischenlager Würenlingen AG

Dr. Thierry Strässle
Swiss Confederation

Peter Zbinden
Erlenbach (ZH)
former Chief Executive Officer of AlpTransit Gotthard AG

Board of Directors and annual general meeting
The Board of Directors held four meetings and a closed meeting to handle ongoing business. At all the meetings, the main focus was on supporting the Sectoral Plan process. The Board of Directors also took note of the planned research and development projects for 2019 and approved a corresponding framework credit. The Technical Committee met four times, and the Commission for Communication and Information held two meetings. The Finance Commission also met twice to consider the closing of the annual accounts for 2017, the budget for 2019 and the accumulated accounts.

The annual general meeting of the members of the Nagra Cooperative was held in Bern on 26th June 2018. The members approved the annual report and accounts for 2017. New elections were due as the three-year term of office had expired. Andreas Pfeiffer from NPP Leibstadt submitted his resignation, and Willibald Kohlpaintner from Axpo Power AG was newly elected onto the Board of Directors. All other previous members of the Board were re-elected; Corina Eichenberger remains President.

Members of the Cooperative
Swiss Confederation
Bern

Alpiq AG
Olten

Axpo Power AG
Baden

BKW Energie AG
Bern

Kernkraftwerk
Gösgen-Däniken AG
Däniken

Kernkraftwerk Leibstadt AG
Leibstadt

Zwilag Zwischenlager
Würenlingen AG

Technical Committee
Dr. Thomas Kohler
Chairman
Alpiq AG

Finance Commission
Urs Helfer
Chairman
Axpo Power AG

Commission for Communication and Information
Dr. Philipp Hänggi
Chairman
BKW Energie AG

Commission for Legal Affairs
Hansueli Sallenbach
Chairman
Axpo Holding AG

Statutory Auditor
PricewaterhouseCoopers AG
Zürich

Organisational structure

Executive Board of Nagra

Dr. Thomas Ernst
Chief Executive Officer

Dr. Markus Fritschi
Deputy CEO / Division Head Collaboration Sectoral Plan & Public Outreach

Maurus Alig
Coordinator Major Project Sectoral Plan Stage 3 / General Licences

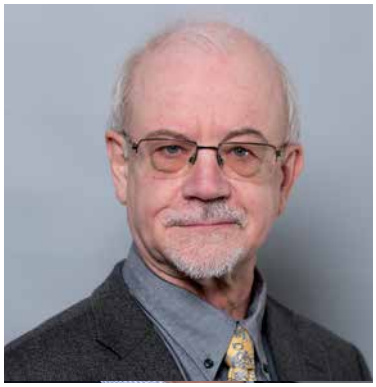
Reto Beutler
Division Head Finance, Controlling & Human Resources

Patrick Senn
Division Head Planning & Construction of Deep Geological Repositories

Dr. Tim Vietor
Division Head Safety, Geology & Radioactive Materials

Further members of the Nagra management team

Dr. Irina Gaus
Head of Research & Development



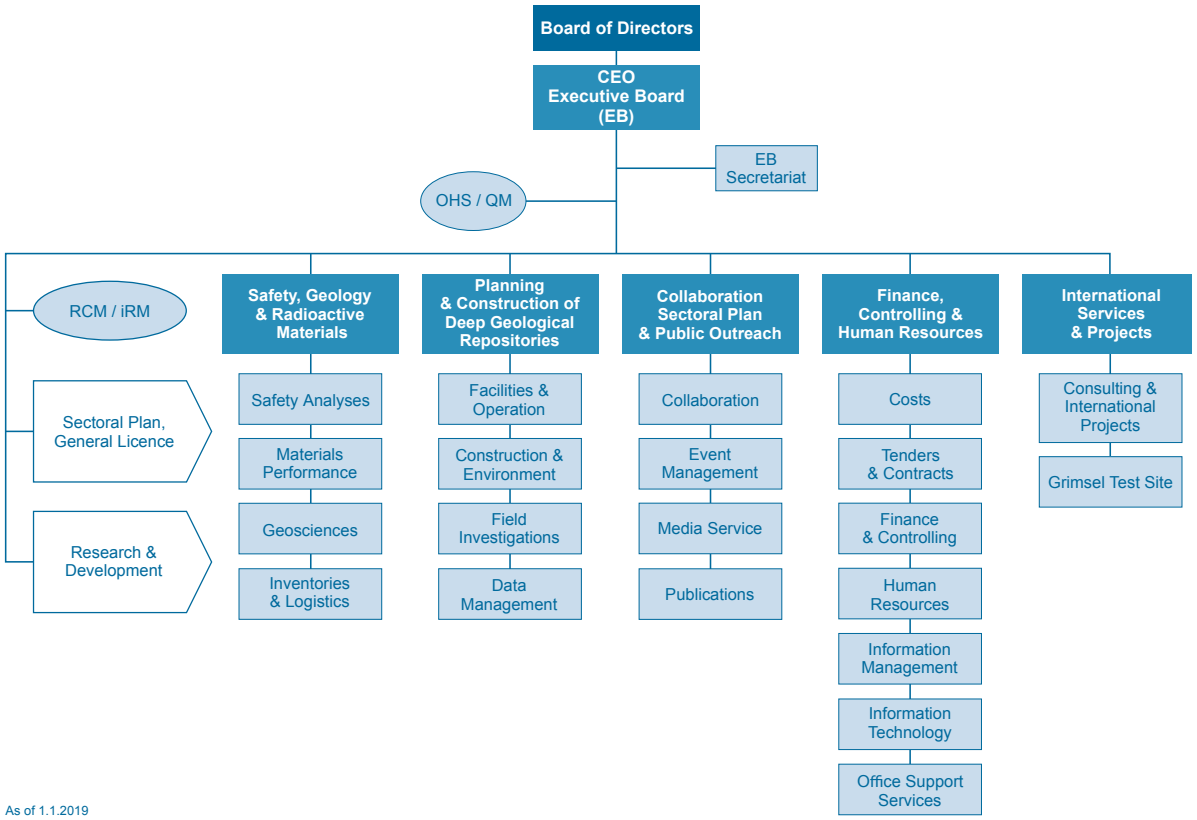
Dr. Harald Maxeiner
Deputy Division Head Safety, Geology & Radioactive Materials

Armin Murer
Deputy Division Head Collaboration Sectoral Plan & Public Outreach

Dr. André M. Scheidegger
Deputy Coordinator Major Project Sectoral Plan Stage 3

Dr. Stratis Vomvoris
Division Head International Services and Projects

Organigram of the head office



As of 1.1.2019

RCM: Requirements and Configuration Management
iRM: integrated Risk Management
OHS: Occupational Health and Safety
QM: Quality Management

Head office

At the end of 2018, Nagra had 123 employees excluding apprentices (113 permanent employees and ten temporary employees). Together, they fill 101.9 full-time positions (apprentices excluded).

Domenico Mignone has been working for Nagra as Section Head Costs since 2016. After studying electrical engineering, he completed a Master of Business Administration degree. Cost planning keeps him busy on a daily basis: from Nagra's budget to the Cost Study 2021.
Nadin Stenz has been Nagra's Head of Human Resources since 2008 and coordinates all personnel matters. After completing a commercial apprenticeship with a vocational diploma, she continued her training as a personnel and management specialist.

Annual financial statements 2018

Comments on the annual financial statements 2018

The current financial statements for 2018 were prepared in line with the provisions of the relevant Swiss legislation, in particular the articles on commercial accounting and financial reporting of the Code of Obligations for individual financial statements (Art. 957 to 962).

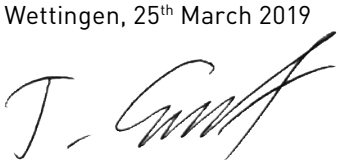
Total expenditure minus proceeds from sales of goods and services and other income is borne by the members of the Cooperative, which results in a balanced year-end result.

Total income increased by CHF 9.5 million compared to the previous year, mainly as a result of higher project and staff expenditure (CHF 4.0 million), as well as extraordinary buy-in costs for the pension fund due to the change from a defined benefit plan to a defined contribution plan (CHF 5.7 million). Net income from sales of goods and services remained stable.

Other operational expenditure, depreciation and the financial result decreased by CHF 0.2 million.

Further information can be found in the notes to the annual financial statements.

Wettingen, 25th March 2019



Dr. Thomas Ernst, Chief Executive Officer

Balance sheet

Note	Assets	31.12.2018 CHF	31.12.2017 CHF
	Current assets		
	Cash and cash equivalents	18 028 645	17 168 125
C1	Trade receivables	446 932	323 533
	Due from third parties	446 932	323 533
C2	Other current receivables	172 340	162 647
	Due from third parties	172 340	162 647
C3	Non-invoiced services	2 004 605	1 755 988
C4	Accrued income and prepaid expenses	379 957	558 593
	Total current assets	**21 032 478**	**19 968 886**
	Capital assets		
C5	Tangible fixed assets	1 530 341	1 729 962
	Total capital assets	**1 530 341**	**1 729 962**
	Total assets	**22 562 819**	**21 698 848**
	Equity and liabilities		
	Current borrowed capital		
C6	Trade payables	6 927 677	5 466 273
	Due to third parties	6 921 285	5 438 809
	Due to members of the Cooperative	6 392	27 464
	Other current liabilities	1 770 044	1 021 432
	Due to third parties	1 765 704	1 017 837
	Due to members of the Cooperative	4 340	3 595
C7	Advance payments received	1 766 458	1 631 483
C8	Deferred income and accrued expenses	11 958 640	13 439 660
	Total current borrowed capital	**22 422 819**	**21 558 848**
	Total liabilities	**22 422 819**	**21 558 848**
C9	**Equity**		
	Cooperative capital	140 000	140 000
	Annual profit (annual loss)	–	–
	Total equity	**140 000**	**140 000**
	Total equity and liabilities	**22 562 819**	**21 698 848**

Explanations page 60 ff.

Profit and loss account

Note		1.1. – 31.12.2018 CHF	1.1. – 31.12.2017 CHF
C10	**Net proceeds from sales of goods and services**		
	Net proceeds from services for third parties	2 336 907	2 547 296
	Research contributions from third parties	562 861	23 668
	Net proceeds from services for Cooperative members	540 520	785 148
	Total net proceeds from sales of goods and services	**3 440 288**	**3 356 112**
C11	**Contributions of members of the Cooperative**		
	Contributions to administration costs	700 000	700 000
	Contributions to project expenditure	61 064 102	51 602 784
	Total contributions of members of the Cooperative	**61 764 102**	**52 302 784**
	Other operating income	**88 771**	**139 272**
	Operating income (total output)	**65 293 161**	**55 798 168**
C12	Cost of materials (project expenditure)	37 249 014	34 602 520
C13	Staff costs	19 326 831	17 956 652
C14	Other operational costs	2 783 333	2 819 854
C5	Depreciation and value adjustments on fixed assets	205 314	221 855
	Operating result	**5 728 669**	**197 287**
	Financial income	–123 414	–59 878
	Financial costs	87 977	148 173
	Ordinary result	**5 764 106**	**108 992**
C15	Extraordinary, non-recurring or prior-period expenditure	5 650 393	–
	Annual profit before taxes	**113 713**	**108 992**
	Direct taxes	113 713	108 992
	Annual profit (annual loss)	**–**	**–**

Explanations page 60 ff.

Cash flow statement

Note		1.1. – 31.12.2018 CHF	1.1. – 31.12.2017 CHF
	Annual profit [+] / annual loss [-]	–	–
C5	Depreciation and value adjustments on fixed asset items	205 314	221 855
	Change in net current assets		
C1	Decrease [+] / increase [-] trade receivables	–123 399	–54 960
C2	Decrease [+] / increase [-] other current receivables	–9 693	–59 669
C3	Decrease [+] / increase [-] non-invoiced services	–248 617	–84 723
C4	Decrease [+] / increase [-] prepaid expenses	178 636	580 329
C6	Decrease [-] / increase [+] trade payables	1 461 404	–7 310 675
	Decrease [-] / increase [+] other current liabilities	748 612	–553 578
C7	Decrease [-] / increase [+] advance payments received	134 975	109 797
C8	Decrease [-] / increase [+] deferred income and accrued expenses	–1 481 020	9 021 588
	Cash flow from operating activities	**866 212**	**1 869 964**
C5	Investments in fixed assets	–5 692	–341 556
	Cash flow from investment activities	**–5 692**	**–341 556**
	Cash flow from financing activities	**–**	**–**
	Change in cash and cash equivalents	**860 520**	**1 528 408**

Change in cash and cash equivalents	**2018**	**2017**
Cash and cash equivalents as at 1st January	17 168 125	15 639 717
Cash and cash equivalents as at 31st December	18 028 645	17 168 125
Net increase/decrease in cash and cash equivalents	**860 520**	**1 528 408**

Explanations page 60 ff.

Notes to the annual financial statements

A) General information

Accounting legislation
The current financial statements were prepared in line with the provisions of Swiss law, in particular the articles on commercial accounting and financial reporting of the Code of Obligations for individual financial statements (Art. 957 to 962).

Company, name, legal form and registered office
Nagra, National Cooperative for the Disposal of Radioactive Waste,
Hardstrasse 73, Postfach 280, 5430 Wettingen

Type of audit
According to legal requirements (Art. 727 par. 2 of the Code of Obligations), the annual financial statements of Nagra are subject to an ordinary audit.

Currency used for the accounting
The accounting is in the national currency (Swiss Francs; CHF).

Cash flow statement
The cash and cash equivalents form the basis for the presentation of the cash flow statement. Cash flow from operating activities is calculated using the indirect method.

Approval of the annual financial statements
The Board of Directors approved the annual financial statements on 25th March 2019 on behalf of the annual general meeting.

B) Information on the principles applied in the annual financial statements

The main positions in the annual financial statements are assessed as follows:

Cash and cash equivalents
Cash and cash equivalents comprise petty cash and credit balances on bank accounts. They are carried at nominal value. Foreign currency positions are carried at the exchange rate on the reporting date.

Trade receivables
Trade receivables are reported at the invoiced amount minus the allowances made for the bad debts provision. The allowance is formed based on the maturity structure and recognisable credit risks.

Receivables and payables towards involved parties
These positions are exclusively receivables and payables towards involved parties (i.e. the members of the Cooperative).

Non-invoiced services
The capitalised work in progress and the advance payments received result exclusively from contracts for third parties. For the ongoing projects, all expenditure is capitalised in work in progress, and all advance payments received are booked as a liability.

Fixed assets
Fixed assets are reported at acquisition cost minus the accumulated depreciation over the estimated useful lifetime of each asset category. Investments in hardware below CHF 20k (one-off) and software below CHF 100k (one-off) are debited directly to the income statement.

The lifetimes for depreciation fall within the following bandwidths for the individual categories that are relevant for Nagra:

Land	Depreciation only in the case of value impairment
Buildings	20 to 50 years
Operating and business equipment	5 to 10 years
IT hard- and software	2 to 3 years

Tenant fixtures are written off over the duration of the tenancy or, if shorter, over the useful lifetime of the asset, or are debited directly to the income statement.

Expenditure on repairs and maintenance that does not add value is debited directly to the income statement. Renewals that change the useful lifetime of assets are capitalised.

Assets removed from operation or sold are written off on the assets account at their acquisition values and the accumulated depreciation. The resulting profits or losses are entered in the income statement.

Payables
All payables are carried at nominal value. Services received and incurred liabilities are deferred according to the period.

Provisions
Provisions are formed when, based on events that have occurred in the past, the company has a legal or factual obligation, the extent and due date of which are unknown but can be estimated.

C) Information, breakdowns and explanations on the annual financial statements

C1) Trade receivables
The increase compared to the previous year (CHF 123k) is due exclusively to new international projects. As there were no identifiable credit risks as per the end of 2018, no value adjustment was made.

C2) Other current receivables
Other current receivables include cash contributions for securing the centralised billing procedure of the Swiss Federal Customs Administration (CHF 50k) and for securing the fulfilment of a customer contract (EUR 20k). Domestic and foreign VAT credit balances amount to CHF 79k.

C3) Non-invoiced services
Non-invoiced services consist of accrued internal services and third-party services for various projects. Project-specific verification is available.

C4) Accrued income and prepaid expenses

Accrued income and prepaid expenses comprise the open reimbursement of PSI (CHF 198k), the prepayments for Suva 2019 (CHF 123k), as well as credits received (CHF 59k).

C5) Tangible fixed assets

	Land and buildings	Office and workshop	Vehicles	Total
	CHFk	CHFk	CHFk	CHFk
Acquisition value per 01.01.2017	**1 825**	**772**	**646**	**3 243**
Additions		183	159	342
Disposals			–113	–113
Reclassifications				0
Acquisition value per 31.12.2017	**1 825**	**955**	**692**	**3 472**
Additions		6		6
Disposals				0
Reclassifications [1]			–23	–23
Acquisition value per 31.12.2018	**1 825**	**961**	**669**	**3 455**
Accumulated depreciations per 01.01.2017	**435**	**651**	**547**	**1 633**
Additions	30	126	66	222
Disposals			–113	–113
Reclassifications				0
Accumulated depreciations per 31.12.2017	**465**	**777**	**500**	**1 742**
Additions	30	111	65	206
Disposals				0
Reclassifications [1]			–23	–23
Accumulated depreciations per 31.12.2018	**495**	**888**	**542**	**1 925**
Carrying value per 01.01.2017	**1 390**	**121**	**99**	**1 610**
Carrying value per 31.12.2017	**1 360**	**178**	**192**	**1 730**
Carrying value per 31.12.2018	**1 330**	**73**	**127**	**1 530**

(1) Correction for 2015

C6) Trade payables

Compared to the previous year, trade payables increased by CHF 1 462k to CHF 6 928k. This is due mainly to initial expenditure for the newly launched deep borehole campaign.

C7) Advance payments received

Advance payments received are for accrued internal services and third-party services for various projects. Project-specific verification is available. Because of the slightly higher volume of third-party contracts, the advance payments received per 31.12.2018 (CHF 1 766k) are slightly higher than in the previous year (CHF 1 631k).

C8) Deferred income and accrued expenses

Deferred income consists mainly of outstanding amounts for services in the amount of CHF 5 419k that are due mainly to outstanding settlements and are largely based on services already rendered at the beginning of the deep borehole campaign. The deferred income also consists of the balancing of the annual financial statements that will be reimbursed to the members of the Cooperative (CHF 4 698k). The deferral for outstanding vacation time and overtime amounts to CHF 1 842k.

C9) Equity
The Cooperative capital is unchanged with CHF 140k and is divided into 140 share certificates of CHF 1000 each, with 7 certificates of 20 shares each being distributed.

C10) Net proceeds from sales of goods and services
Net proceeds showed slight decreases in both the proceeds from third parties and from the NPP operators. The proceeds from research projects increased again.

C11) Contributions of the members of the Cooperative
The contributions of the members of the Cooperative are invoiced on a quarterly basis according to the budget approved by the Board of Directors. A deviation from the budget leads to an additional charge or a credit that is booked in the year of accounting as prepaid expenses or deferred income. This results in an annual result of CHF 0.

According to the decision of the ordinary general meeting held on 26th June 2018, the implementation of the special agreement on Nagra's financing results in compensation payments to the NPP operators of CHF 1.2 million (assets and liabilities in the same amount) for the year 2018. For Nagra, the balance is zero. Nagra will arrange settlement in 2019, which is why the individual positions are not included in the balance sheet for 2018.

C12) Cost of materials (project expenditure)
The project expenditure is made up as follows:

External services for:	**2018**	**2017**
	CHFk	CHFk
Projects	25 683	22 593
Communication	1 904	1 776
Fees (ENSI, SFOE)	9 097	9 558
Travel expenses	565	676
Total	**37 249**	**34 603**

C13) Staff costs
Staff costs, including social contributions, increased compared to the previous year by 7.6% to CHF 19 327k as part of the resource planning approved by the Board of Directors. The higher expenditure is due mainly to an increase in the staffing level and higher recruitment costs. The average staffing level in 2018 was 100.6 full-time positions, 5.2 temporary positions and 1.4 internships (2017: 100.1 full-time positions, 1.0 temporary position, 1.6 internships).

C14) Other operational costs
Other operational costs include rents and expenditure on property of CHF 1 134k, expenditure on informatics of CHF 490k and further operational costs of CHF 1 159k.

C15) Extraordinary, non-recurring or prior-period income
The change from defined benefits to defined contributions for the PKE pension scheme was implemented on 1st April 2018. The Board of Directors had approved this change. This involves a buy-in to the higher coverage rate of the defined contributions scheme in the amount of CHF 5.7 million, which was booked as extraordinary expenditure.

D) Further information

Liabilities towards pension schemes

As of 31.12., there were the following liabilities towards pension schemes:	**31.12.2018**	**31.12.2017**
	CHF	CHF
Contribution statement December	226 494	196 093
Final account from buy-in to the contributions scheme	391 946	–

Contingent liabilities
Nagra is not involved in any legal actions, legal disputes, regulatory or tax investigations, inquiries or other legal procedures that could have financial consequences for the annual financial statements for 2018.

As of 31st December 2018, there were no guarantee obligations.

Risk assessment
On 26th June 2018, the Board of Directors approved Nagra's risk report for 2018.

Research and development activities
The ongoing experiments in both rock laboratories (partly with international participation) will be continued and supplemented as needed. Bundling the R&D activities into the overall research and development project within the framework of the organisational development of Stage 3 of the Sectoral Plan has proven to be effective.

Accumulated accounts including adjustments

Note	Total income	Increase 2017 CHF	Adjustment payments 2017 CHF	Status 31.12.2017 CHF	Increase 2018 CHF	Adjustment payments 2018 CHF	Status 31.12.2018 CHF
	Swiss Confederation	1 490 443	–	40 534 551	1 763 714	–	42 298 265
	Axpo Power AG	11 640 327	–3 948 715	302 909 742	13 775 318	–310 626	316 374 434
	BKW Energie AG	6 194 474	–866 917	143 065 581	7 282 544	–595 641	149 752 484
	Kernkraftwerk Gösgen-Däniken AG	13 738 077	–5 887 013	392 381 622	16 318 503	1 252 198	409 952 323
	Kernkraftwerk Leibstadt AG	18 539 463	10 702 645	465 089 997	21 924 023	–345 931	486 668 089
	Contributions to project expenditure	**51 602 784**	**–**	**1 343 981 493**	**61 064 102**	**–**	**1 405 045 595**
	Contributions to administration costs	700 000	–	90 270 000	700 000	–	90 970 000
	Contributions of Cooperative members to Nagra	**52 302 784**	**–**	**1 434 251 493**	**61 764 102**	**–**	**1 496 015 595**
	Contributions GNW	**–**	**–**	**65 265 331**	**–**	**–**	**65 265 331**
E1	**Total contributions**	**52 302 784**	**–**	**1 499 516 824**	**61 764 102**	**–**	**1 561 280 926**

Explanations page 67 ff.

Note	Total expenditure	Increase 2017 CHF	Status 31.12.2017 CHF	Increase 2018 CHF	Status 31.12.2018 CHF
	Geoscientific studies	6 562 700	210 697 436	6 679 268	217 376 704
	Nuclear technology and safety	1 600 747	52 835 737	1 587 273	54 423 010
	Radioactive materials	1 468 066	47 065 684	1 565 677	48 631 361
	Facility planning	1 003 932	32 948 737	1 687 138	34 635 875
	Generic (non-site-specific) work	3 535 448	112 506 471	3 865 065	116 371 536
	General programme costs	4 205 100	98 333 519	6 675 835	105 009 354
	Fees and compensation	4 810 303	70 011 202	4 548 514	74 559 716
	L/ILW programme	**23 186 296**	**624 398 786**	**26 608 770**	**651 007 556**
	Geoscientific studies	10 702 930	366 019 480	13 065 527	379 085 007
	Nuclear technology and safety	2 390 299	76 746 284	2 354 940	79 101 224
	Radioactive materials	944 846	28 100 003	939 449	29 039 452
	Facility planning	1 005 201	27 769 771	1 840 428	29 610 199
	Generic (non-site-specific) work	4 792 179	131 393 890	4 530 974	135 924 864
	General programme costs	3 820 282	83 086 585	7 175 519	90 262 104
	Fees and compensation	4 760 751	71 732 025	4 548 495	76 280 520
	HLW programme	**28 416 488**	**784 848 038**	**34 455 332**	**819 303 370**
E2	**Project expenditure for repository programmes**	**51 602 784**	**1 409 246 824**	**61 064 102**	**1 470 310 926**
	Administration and general project expenditure	**700 000**	**90 270 000**	**700 000**	**90 970 000**
	Total expenditure for L/ILW and HLW programmes, administration and general project expenditure	**52 302 784**	**1 499 516 824**	**61 764 102**	**1 561 280 926**

Explanations page 67 ff.

Notes to the accumulated accounts

The accumulated treatment of the contributions of the members of the Cooperative and the application of these contributions forms the basis, at the time of waste disposal, for any adjustments of payments among the members. It also indicates which work has resulted in project-related expenditure.

The structure of the total income is oriented primarily to the operating accounts.

E1) Contributions of the members of the Cooperative

The contributions of the members of the Cooperative towards covering project costs are calculated based on the thermal output, the service lifetime-weighted output and the expected waste volumes of the individual nuclear power plants of the members.

The contributions of the members in the total amount of CHF 61.8 million (CHF 52.3 million in the previous year) correspond to those in the income statement. A contribution of CHF 0.7 million to administration costs is included.

The implementation of the special agreement on the financing of Nagra in accordance with the decision of the extraordinary general meeting held on 18th September 2017 and the ordinary general meeting held on 26th June 2018 results in compensation payments among the NPP operators. These compensation payments are now shown based on the project costs (without interest), which led to a restatement of the individual contributions of the operators in 2017. The compensation payments for 2018 will be arranged by Nagra in 2019.

The GNW contributions include payments by GNW for contract work on the Wellenberg project. This project is terminated.

E2) Project-specific expenditure for the repository programmes

The two repository programmes (L/ILW and HLW) basically have the same structure in the presentation of the accumulated accounts and are oriented towards the most important technical tasks to be performed up to the completion of waste disposal activities. If there is no explicit reference to a specific programme, the following explanations of the individual positions apply to both projects.

a) Geoscientific investigations
Geological investigations for identifying potential siting regions comprise geological studies in the investigation area of Northern Switzerland for the deep geological disposal of high-level waste, as well as the processing of geological information for the low- and intermediate-level waste repository.

b) Nuclear technology and safety
The work comprises the safety-based evaluation of potential siting regions, laboratory studies on the near-field and on the different backfill materials.

c) Radioactive materials
This includes expenditure on assessing the disposability of waste packages and on ongoing documentation and inventorying of radioactive waste.

d) Facility planning
This position includes expenditure on developing the concepts for the surface and underground facilities for the repositories for HLW and L/ILW.

e) Generic (site-independent) investigations
This includes work on developing methodologies, modelling and validation of the models used in safety analyses, laboratory studies, participation in the work in the rock laboratories (Grimsel and Mont Terri) and the research programmes of the EU.

f) General programme costs
This expenditure results from programme management, expenditure on cost studies and public relations activities.

g) Fees and compensation
This includes the fees passed on to Nagra from the regulatory and safety authorities.

Report of the Statutory Auditor

Report of the Statutory Auditor on the financial statements
As statutory auditor, we have audited the accompanying financial statements of Nagra, National Cooperative for the Disposal of Radioactive Waste, which comprise the balance sheet, income statement, cash flow statement and notes, for the year ended December 31, 2018.

Management's responsibility
Management is responsible for the preparation of the financial statements in accordance with the requirements of Swiss law and the Cooperative's articles of incorporation. This responsibility includes designing, implementing and maintaining an internal control system relevant to the preparation of financial statements that are free from material misstatement, whether due to fraud or error.

Management is further responsible for selecting and applying appropriate accounting policies and making accounting estimates that are reasonable in the circumstances.

Auditor's responsibility
Our responsibility is to express an opinion on these financial statements based on our audit. We conducted our audit in accordance with Swiss law and Swiss Auditing Standards. Those standards require that we plan and perform the audit to obtain reasonable assurance whether the financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the financial statements. The procedures selected depend on the auditor's judgement, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or to error. In making those risk assessments, the auditor considers the internal control system relevant to the entity's preparation of the financial statements in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the entity's internal control system. An audit also includes evaluating the appropriateness of the accounting policies used and the reasonableness of accounting estimates made, as well as evaluating the overall presentation of the financial statements. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

Opinion
In our opinion, the financial statements for the year ended December 31, 2018 comply with Swiss law and the Cooperative's articles of incorporation.

Report on other legal requirements
We confirm that we meet the legal requirements on licensing according to the Auditor Oversight Act (AOA) and independence (article 906 CO in connection with article 728 CO and article 11 AOA) and that there are no circumstances incompatible with our independence.

In accordance with article 906 CO in connection with article 728a paragraph 1 item 3 CO and Swiss Auditing Standard 890, we confirm that an internal control system exists which has been designed for the preparation of financial statements according to the instructions of Management.

We recommend that the financial statements submitted to you be approved.

PricewaterhouseCoopers AG

Thomas Wallmer
Audit expert
Auditor in charge

Jonas Schwegler
Audit expert

Zürich, 25th March 2019

Appendices

Waste inventories and volumes

Radioactive waste arises mainly from electricity production in the five Swiss nuclear power plants. It is also produced from the use of radioactive materials in the areas of medicine, industry and research (MIR waste).

Waste volumes at the end of 2018
Nagra maintains a centralised database of all waste packages as a service to the waste producers. The following table shows the volumes and activities of waste prepared for geological disposal as of the end of 2018. The table does not contain pre-conditioned raw wastes and waste packages prepared for processing in the Zwilag plasma furnace, for example.

Conditioned waste (31st December 2018, figures rounded)	**Volume (m^3)**	**Activity (Bq)**
Nuclear power plants	3 532	$2.5 \cdot 10^{15}$
Zwilag	2 366	$7.5 \cdot 10^{18}$
Federal Government's interim storage facility (MIR) (waste from medicine, industry and research)	1 578	$1.2 \cdot 10^{16}$

The Zwilag waste consists of waste packages delivered to the interim storage facility from the power plants, waste packages from the plasma furnace and steel flasks with vitrified high-level waste from reprocessing.

Predicted waste volumes and inventories for deep geological disposal

Planning the geological repositories requires input in the form of information on expected waste volumes. The total volume of waste for disposal will be around 92,000 cubic metres packaged in disposal containers (see table for details). The volume of waste from the NPPs and Zwilag results from the given operating lifetimes; the volume of waste from medicine, industry and research is based on the end of operation of the L/ILW repository.

Predicted waste volumes (47-/60-year NPP operation)[1]	**L/ILW (m³)**		**ATW (m³)[2]**		**HLW/SF (m³)**	
	conditioned	packaged	conditioned	packaged	conditioned	packaged
BA-KKW Operational waste from the NPPs (from cleaning systems and mixed waste), incl. post-operational phase	8 320	31 249				
RA-KKW NPP reactor waste (activated components)	478	1 811				
SA-KKW NPP decommissioning waste	18 378	26 803				
WA-KKW NPP reprocessing waste			99	414	114	398
BA-ZWI Zwilag operational waste	6	22				
SA-ZWI Zwilag decommissioning waste	461	563	24	24		
BA-MIF MIR waste collected from the FOPH and operational waste from PSI	3 645	8 432	168	634		
SA-MIF Decommissioning waste from PSI and CERN	10 578	10 578				
BEVA/OFA Waste from the future encapsulation/surface facilities for the L/ILW & HLW repositories	651	2 302				
SF Spent fuel assemblies					1 365	9 004
Total volumes	**42 517**	**81 760**	**291**	**1 072**	**1 479**	**9 402**
Percentage (rounded)	96.0 %	88.6 %	0.7 %	1.2 %	3.3 %	10.2 %
Activity [Bq][3]	$7.9 \cdot 10^{16}$ Bq		$2.2 \cdot 10^{16}$ Bq		$1.9 \cdot 10^{19}$ Bq	
Percentage	0.4 %		0.1 %		99.5 %	

[1] Basis: Waste Management Programme and Cost Study 2016
Operating lifetime: NPP Mühleberg 47 years (till 2019), other NPPs 60 years
Takes into account the planned revision of the Radiological Protection Ordinance and decay storage of radioactive materials for a maximum of 30 years with subsequent conventional disposal
For explanations on the current waste volumes compared to previous modelling assumptions (MIRAM), see Nagra NTB 16-01

[2] ATW = Alpha-toxic waste

[3] Activity inventory for reference year 2075

Elsbeth Melion manages the reception and maintains the mailing list for publications. She also organises the annual company outing for the entire staff. Elsbeth started working for Nagra in 1982.
Rocco Cipriano has been working for Nagra since 2008. He is responsible for the smooth operation of the offices in Wettingen. In addition, Rocco is Deputy Safety Officer.

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