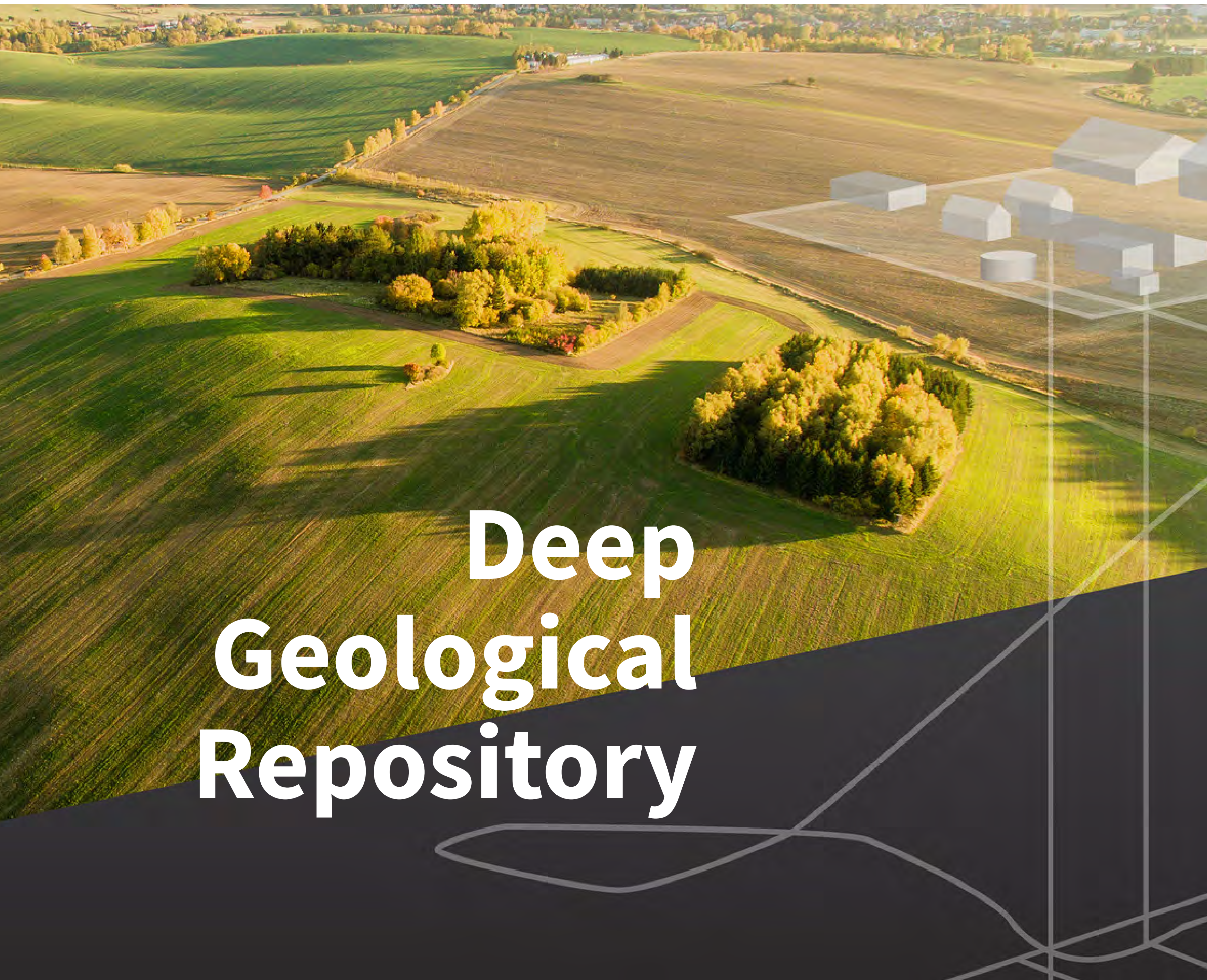
SÚRAO | RADIOACTIVE WASTE REPOSITORY AUTHORITY



Deep Geological Repository

Deep geological repository for radioactive waste and spent nuclear fuel

Czech Radioactive Waste Repository Authority (SÚRAO)

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Contents

4 — Basic information

6 — What is a deep geological repository?

8 — What will the deep geological repository look like?

10 — Deep geological repository safety

12 — Comparison with the natural world

14 — Benefits of the deep geological repository for the region

15 — Approaches worldwide to deep geological disposal

17 — Development of a deep geological repository in the Czech Republic

18 — Operational repositories

19 — Social Responsibility

Basic information

What is SURAO?

SURAO is a government technical organisation that is responsible for finding safe solutions to radioactive waste disposal issues for current and future generations.

What is SURAO's mission?

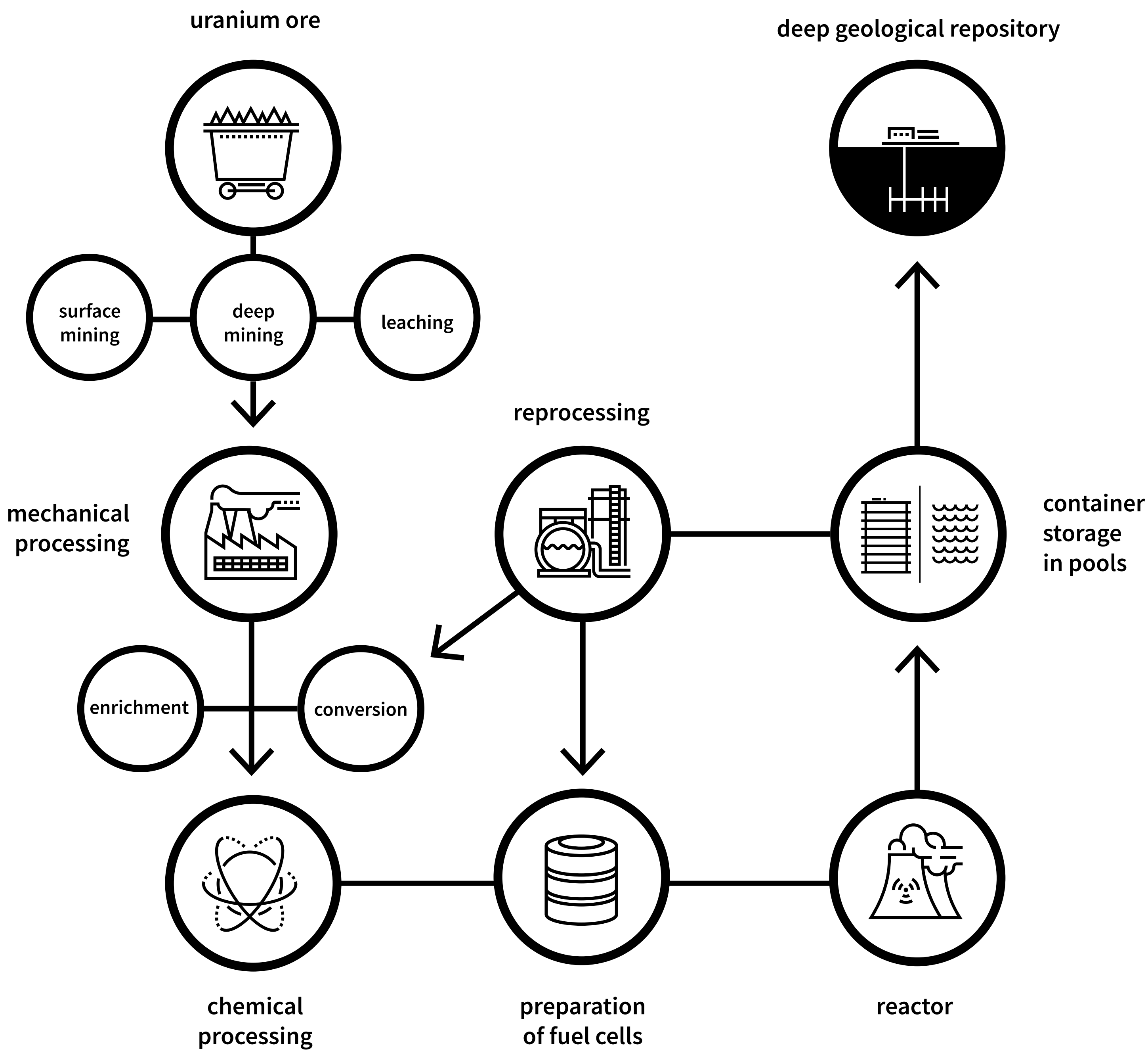
SURAO's mission is to ensure the safe disposal of current and future radioactive waste in accordance with nuclear safety and human and environmental protection requirements.

Who is responsible for disposal?

The state guarantees the disposal of radioactive waste. In accordance with the Atomic Act, SURAO, as a state organisational unit, fulfils a number of functions related to the safe management of all types of radioactive waste and research and development activities in the field of radioactive waste management, including the development of the future Czech deep geological repository project.

Financing from the nuclear account

The financing of the management of radioactive waste is based on the "producer pays" principle. The total cost of the development of the future deep geological repository, including its construction, operation and eventual closure, is currently estimated at approximately CZK 130 billion. Part of the costs relate to the search for suitable sites and the detailed characterisation of the rock environment at the selected site. The funding for the construction of the deep geological repository is being accumulated in a special account at the Czech National Bank which is administered by the Ministry of Finance. Every year more than one billion crowns is deposited in the "nuclear account" by the operator of the Czech Republic's two nuclear power plants, CEZ, a.s., and other radioactive waste producers. In addition to the construction of the deep geological repository, funding from the account is used for the operation, reconstruction and closure of currently operational repositories. At the end of 2018, the nuclear account held approximately CZK 28.4 billion.

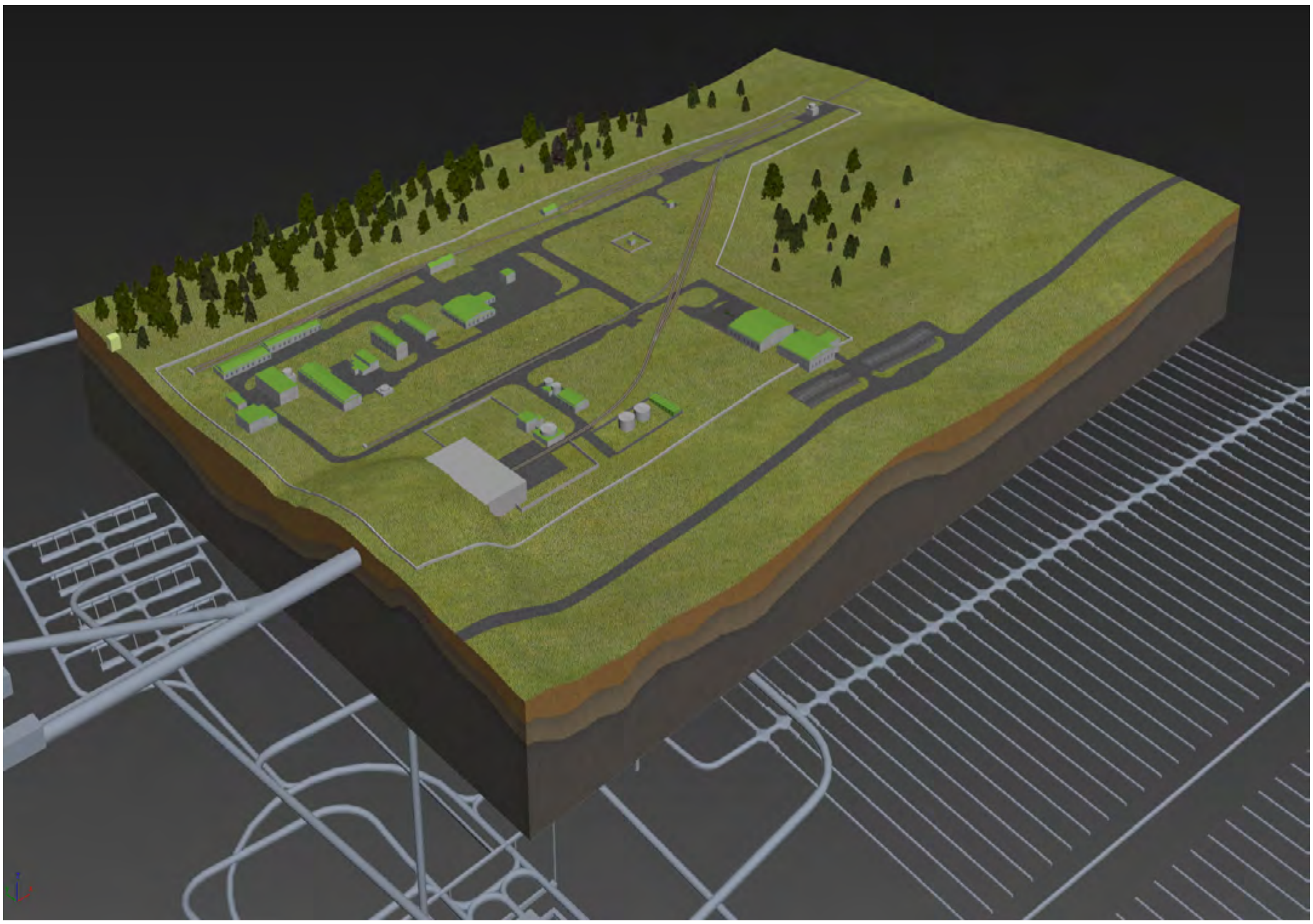


scheme of the nuclear fuel process

What is a deep geological repository?

Deep geological repositories for radioactive waste are sophisticated technological facilities where spent fuel from nuclear reactors and, to a lesser extent, high-level waste generated in the nuclear energy industry, research and healthcare sectors is permanently disposed of. It is expected that the Czech repository will be located in a suitable crystalline rock massif around 500 metres below the earth's surface. According to the Nuclear Waste Management Concept, the construction phase will commence in 2050, with the start of operation in 2065. In the meantime, research, exploration and design work will continue as will dialogue with the public related to the siting and development of the repository. However, it must not be assumed that this is a simple matter. Spent nuclear fuel and high-level radioactive waste must be safely isolated from the environment for hundreds of thousands of years. It is, therefore, no surprise that detailed discussions are underway on this issue at national and global levels and important questions must be answered. This publication, therefore, aims to clarify some of the most important issues involved.

After considering all the options available, the Czech Republic and the vast majority of other countries that operate nuclear power plants worldwide, consider the construction of a deep geological repository to be the only realistic, responsible and technically and economically feasible solution.



visualisation of the potential layout of the deep geological repository

Spent nuclear fuel treatment options

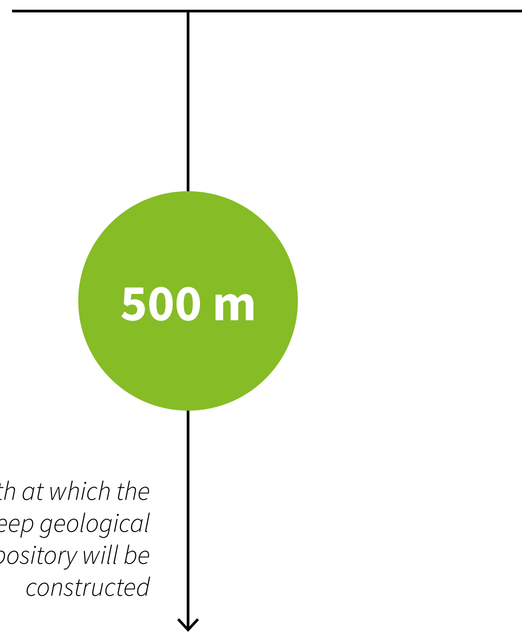
Spent nuclear fuel and high-level waste already exist in the Czech Republic. Around 100 tonnes of such materials is produced each year, most of which consists of spent nuclear fuel from nuclear power plants. The State Energy Concept considers electricity produced from nuclear sources to be one of the nation's energy production pillars now and into the future. The deep geological repository is, therefore, being designed for the disposal of spent fuel from the operation of existing nuclear power plants and other planned nuclear sources, the combination of which forms the basis for the technical design and calculations of the capacity of the future repository (currently estimated at around 10,000 tonnes of spent fuel).

Experience over the past thirty years clearly indicates that spent nuclear fuel and high-level waste can be stored safely, for example in special metal or concrete waste disposal packages (containers), the walls of which are thick enough to provide a shield against radioactive radiation and to isolate the material, thus providing for the protection of humans and the environment. A further option involves the reprocessing of spent nuclear fuel. However, even following reprocessing, a certain amount of high-level waste remains which has to be disposed of in deep geological repositories. Hence, countries that reprocess spent fuel (such as France) are also planning the construction of deep geological disposal facilities.

Meanwhile, spent nuclear fuel is stored at the respective nuclear power plant

Six nuclear reactors are currently in operation in the Czech Republic - four at the Dukovany NPP and two at the Temelín NPP - which produce more than 30% of the country's electricity requirements. While spent nuclear fuel cells at first glance appear to be the same as fresh fuel cells, they differ from fresh fuel, which is not radioactive, in terms of the high radioactivity of a number of elements formed during the fission reaction. Spent nuclear fuel is transferred from the nuclear reactor to nearby cooling pools where it is stored for several years. The fuel is subsequently transferred from the pools to so-called CASTOR containers which are then emplaced in dry storage facilities within the respective nuclear power plant complex. After 50 to 60 years of storage, the activity of the spent nuclear fuel in the containers decreases by approximately 200 times. The CASTOR containers take the form of cast iron cylindrical vessels, the 37 cm-thick walls of which prevent the escape of radiation from the spent nuclear fuel so that staff are able to work close to the containers if required. The capacity of one container is around 10 tonnes of spent nuclear fuel.

Dukovany NPP storage area



depth at which the deep geological repository will be constructed

What will the deep geological repository look like?

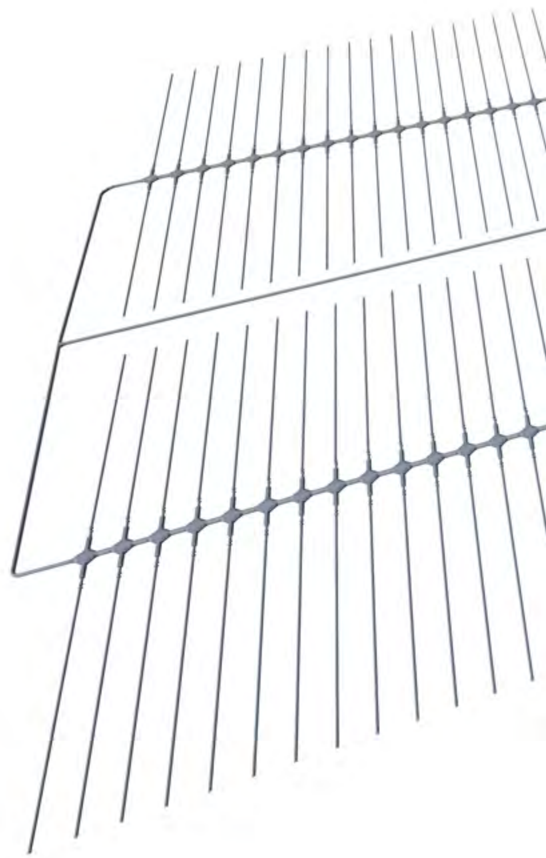
The conceptual design of the Czech Republic's deep geological repository is similar to that of such projects in other countries. The final design of the repository, e.g. the location of the various buildings, the extent of the surface area required, etc., will depend largely on the conditions at the finally chosen site. SURAO will make every effort to take into account the requirements and suggestions of the affected municipalities and citizens and blend the surface buildings as carefully as possible into the surrounding environment so as not to disturb the local landscape and natural habitats. The major part of the facility will be located underground and the surface complex will be constructed employing a minimalistic approach.

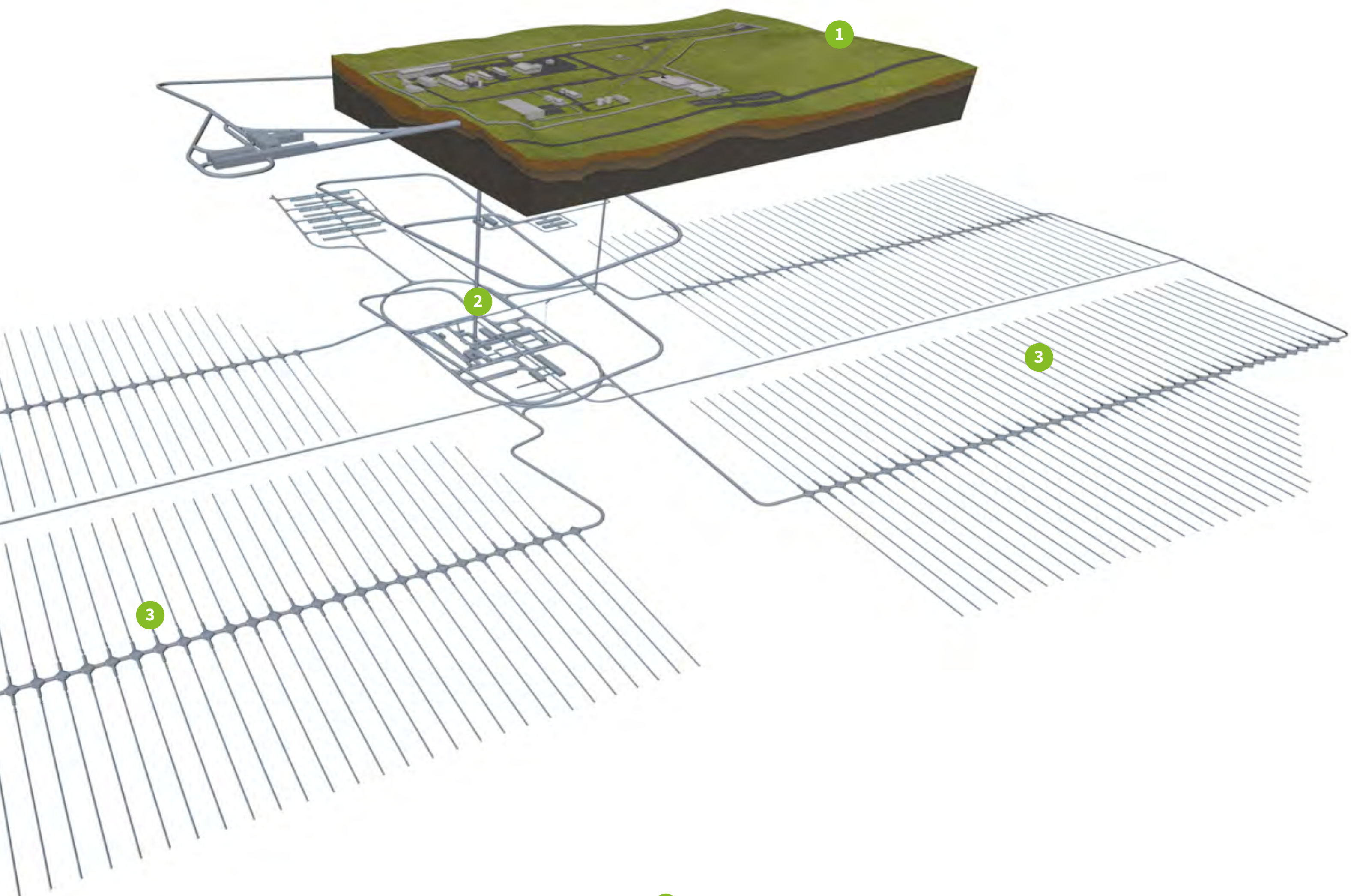
Surface area

The size of the surface complex will depend both on the final design and the conditions prevailing at the chosen site. The most recent version of the project from 2018 assumes an area of 10-15 hectares, with the so-called active zone, in which the CASTOR containers will be handled, expected to take up just 2.1 hectares. The remainder will consist of areas for the handling of excavated rock, administrative buildings, power supply equipment, mining facilities, ventilation equipment, mining services workshops and railway sidings. If the excavated rock is handled outside the immediate complex, it will reduce the required area by half or even more. It is expected that upon arrival at the repository, the spent nuclear fuel and other radioactive materials will be transferred to special repository disposal packages, transported underground and finally disposed of. The disposal areas will be excavated gradually in accordance with disposal requirements, i.e. the underground section of the repository will not be built in one single phase. It is assumed that the repository will be in operation for approximately 100 years.

Underground complex

The underground disposal complex will be connected to the surface area by two inclined access tunnels and, possibly, a ventilation shaft so as to allow for the separation of the routes used for the transport of the waste disposal packages from that used for the excavation of disposal areas, the access of workers to the underground complex, ventilation and escape routes as required by safety regulations. The disposal corridors (boreholes) will be excavated at a depth of approximately 500 metres (depending on the geological conditions at the selected site) in a stable geological formation. One of the options considered for the disposal of spent nuclear fuel containers is shown in the figure below. The final choice of the appropriate disposal method will be made according to the most appropriate technology available at the time of the final decision on construction (around 2050).





1 **surface area**

2 **access shafts and tunnels**

3 **disposal areas**

Deep geological repository safety

No deep geological repository can be constructed and operated without a credible demonstration of its safety. Safety analysis studies conducted employing mathematical models will be refined on a regular basis with the help of newly-acquired knowledge and data obtained from in-situ research. The multiple-barrier systems used in the deep geological repository will ensure that radioactivity remains effectively isolated from the environment. The barriers will consist of a natural geological element (the rock massif) and man-made so-called engineered barriers that will support each other in such a way as to ensure the safety of the repository for a sufficiently long period of time.

The natural and engineered barrier safety system

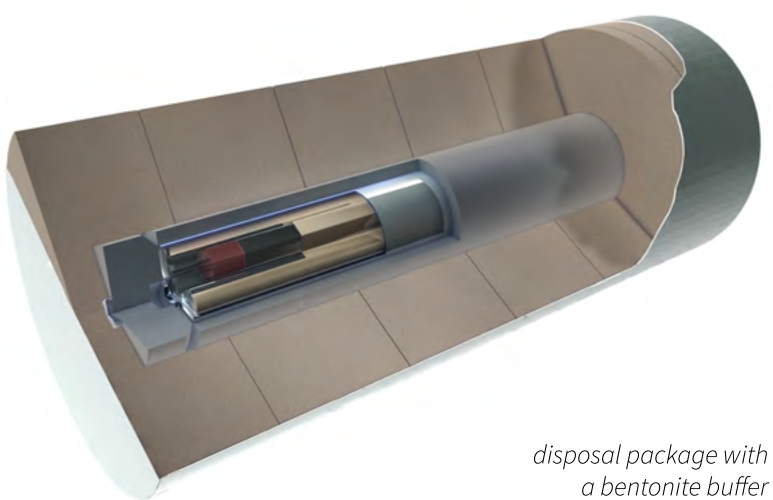
Fuel Cells: They are designed to withstand extreme conditions in the reactor. The uranium dioxide fuel pellets are secured in rods made of a durable zirconium alloy.

Metal waste disposal package: This special long-term waste disposal package will play an important role in ensuring the long-term safety of the deep geological repository in terms of ensuring nuclear safety and radiation protection. The package is required to fulfil a number of strict requirements, including long-term sealing ability and resistance to the chemical environment of the repository and ambient pressure. Therefore, the material from which the storage container will be made must be mechanically resistant and resistant to all types of corrosion and retain its properties even after prolonged exposure to radioactivity. Spent nuclear fuel cells and other high-level waste will be enclosed within such waste packages.

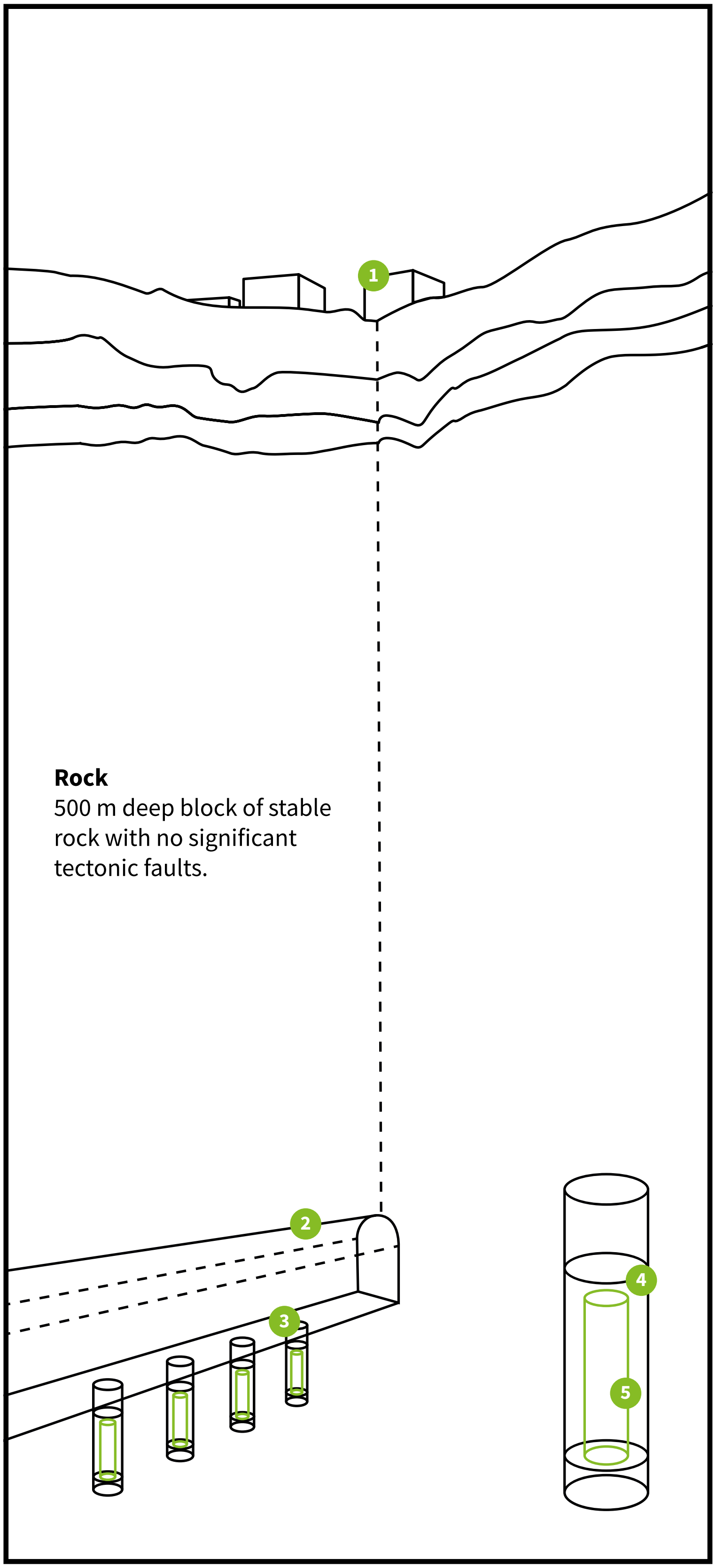
The basic design variant envisages that the waste package (container) will have two layers, i.e. the inner stainless steel container and an outer casing of carbon steel. The outer casing will have a thickness that will be determined by the requirement that even after being subjected to corrosion over tens of thousands of years, its mechanical stability will be maintained. In the same way, the thickness of the inner casing will be such that it provides for mechanical stability after the outer shell corrodes, i.e. it provides an additional safety feature. The fuel cells will be emplaced using a specially-designed installation container. The disposal containers will then be surrounded by a clay material (bentonite) which will protect them from contact with water and mechanical damage. Bentonite also has excellent sorption properties that will provide a further safety feature within the overall disposal system.

fuel cells

waste disposal package



disposal package with a bentonite buffer



1 **Surface area**

Total area	9–14 ha
Normal operation	in 90% of the area
Handling of radioactive waste	in 10% of the area

Employment positions

During the construction period	140–200
During operation	250–300

Secondary employment positions
(related services e.g. catering, accommodation, leisure activities, etc.) 60–80

2 **Disposal corridor**

3 **Disposal borehole**
The waste disposal package is emplaced in the borehole and sealed with a bentonite filling.

4 **Filling material (bentonite buffer)**
Bentonite is a clay material that is formed by the weathering of volcanic rocks. Its various properties include very low permeability (in case of saturation), swelling ability, plasticity, thermal conductivity and rheological stability (that ensure the extremely long-term stability of the behaviour of the bentonite barrier).

5 **Waste disposal package**
Fuel cells are emplaced in waste disposal packages that are subsequently emplaced in disposal boreholes.

Underground area
Disposal and handling of spent nuclear fuel and high-level waste packages.

Underground area (depends on the excavation and container disposal methods finally selected) 2–3 km^2

Predicted number of waste disposal packages:

Existing sources:	4,900
New nuclear sources:	2,700
Construction:	2050–2064

Comparison with the natural world

The natural world provides us with proof of the effectiveness of safety barriers. The processes that might occur within the repository can be investigated not only via computer models and laboratory research; indeed, evidence that the disposal system will meet the strict conditions imposed to ensure long-term safety is also available from the study of natural phenomena known as analogues, some of which have been under development for millions of years. These natural phenomena are employed by scientists to verify and further refine mathematical models of the disposal system.

1. Oklo natural reactor in Africa
One of the world's best known analogues consists of a natural nuclear reactor located in a uranium deposit at Oklo in Gabon, Africa. Two billion years ago, a spontaneous chain reaction occurred at the site similar to that we see in today's nuclear reactors. The radioactive elements produced by the reaction have been proved to move extremely slowly within the surrounding rock, i.e. at a rate of approximately just 10 metres per 1 million years.

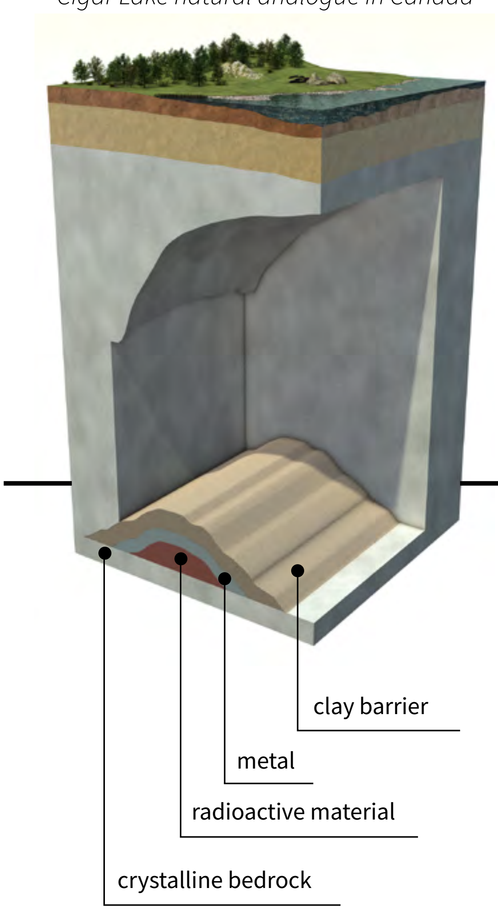
2. Uranium deposit at Ruprechtov in the Czech Republic
A similar but smaller natural analogue is being subjected to research in the Czech Republic, which is known for its abundance of uranium ore. The investigation of the movement of uranium in clays in the vicinity of a uranium ore deposit at Ruprechtov in West Bohemia has proved that, here too, the uranium penetrates into the surroundings extremely slowly and cannot be detected at the surface.

3. Cigar Lake radioactive material deposit, Canada
1.3 billion years ago a uranium ore deposit with a uranium concentration of 60% was created at a depth of 430 metres below the Cigar Lake in Canada. More than a million cubic metres of this rich uranium ore lies over a granite massif and is covered with a roughly 30-metre layer of clay. Measurements have repeatedly shown that no uranium has yet penetrated the surface.

4. Metal objects recovered from the sea
Nature also provides scientists with the opportunity to verify the durability of metal materials from which containers for deep geological disposal can be produced. For example, copper objects taken from Greek and Egyptian ships that have been lying on the seabed for more than two and a half thousand years have proven to be virtually undamaged by corrosion.

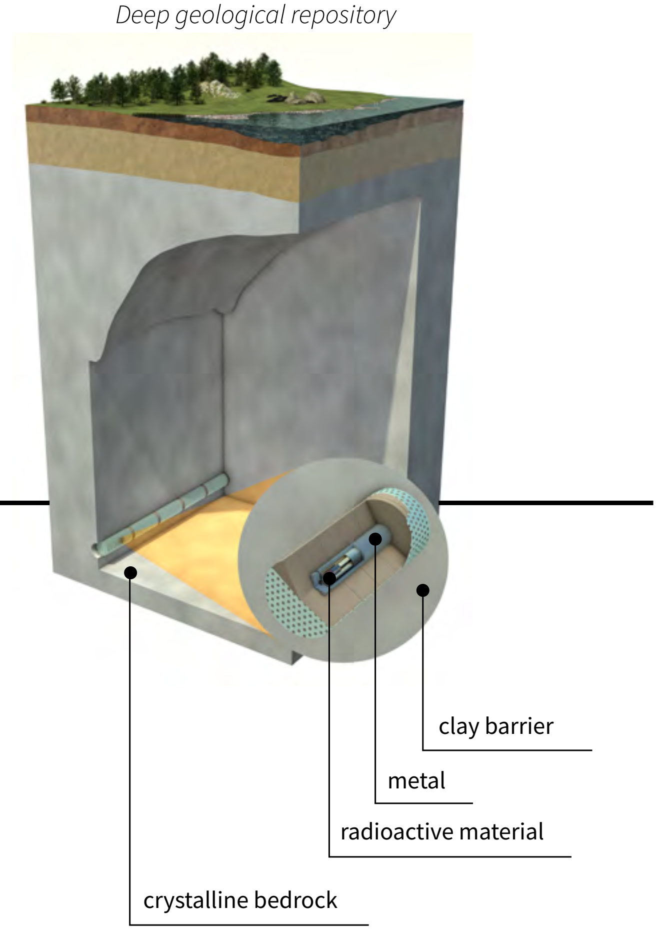
Through the study of such materials, scientists are able to verify calculations on the rate of corrosion of metals that will be deposited deep underground in the absence of free oxygen. Thus, it can be assumed that disposal containers made of durable materials will remain intact for tens of thousands to hundreds of thousands of years in the deep geological repository environment.

Cigar Lake natural analogue in Canada



-500 m

Deep geological repository



Benefits of the deep geological repository for the region

Employment **Infrastructure** **Improvement in services**

SURAO is well aware of the importance of providing municipalities and their citizens not only with sufficient information but also with sufficient powers and guarantees throughout the deep geological repository development process. SURAO makes every effort to achieve cooperation and agreement on a partnership basis both on the process itself and the final solution.

The construction of the deep geological repository is not only a technically fascinating and complex project, but also an important project in terms of investment which will provide a range of economic benefits.
Analysis performed to date suggests that the project will:

- provide employment in the region,
- improve transport infrastructure and serviceability,
- improve local services,
- supplement municipal budgets.

The finally selected site will receive direct investment via SURAO over the long term thus ensuring the benefits of investment for future generations.

Employment
The initial phases of the project will provide significant employment opportunities for the whole of the region. While the number of people who will be involved in the construction stage will vary over time, it is anticipated that at least 200 new employment positions will be created for local inhabitants, rising to 300 people during the operational phase. Moreover, further indirect employment and business opportunities will be created via the operation of the repository, e.g. through restaurants and catering, accommodation and other services and technical tourism.

Infrastructure
The construction of the deep geological repository will also lead to the rebuilding of existing, and the construction of new, access infrastructure, particularly the modernisation of transport routes.

Improvement in services
The construction and operation of the deep geological repository will require the creation of new, and the expansion and improvement of existing, services for repository personnel and their families.

Financial contributions to municipal budgets

According to legislation, defined financial contributions must be provided during the deep geological repository site selection process to municipalities in whose cadastral areas so-called investigation and/or protected areas are established. Those municipalities in which investigation work is conducted are entitled to contributions that are determined according to the extent of the area subjected to study and which may amount to several million crowns per year. In addition, each municipality in which protected areas are defined will be entitled to claim a lump sum contribution from the nuclear account of CZK 50 million in addition to the annual statutory contribution.

Approaches worldwide to deep geological disposal

Geological surveys and other preparations for the construction of deep geological repositories are underway in most countries that produce energy from nuclear sources. While a number of countries have already decided on the appropriate site for, and the method of construction of, their deep geological repositories, others are still conducting the research required to make such a decision.

Research of suitable rock environments for repository siting
Several types of rock have been investigated worldwide as potentially suitable environments for the construction of deep geological repositories: crystalline (mainly granite or gneiss) and sedimentary rocks (clays, tuffs and salt deposits). The construction and safe operation of such repositories has already been demonstrated for all these rock types. Finland and Sweden have opted for crystalline rock environments, while solid claystone rock massifs have been chosen in France and Switzerland. It is expected that the Czech deep geological repository will be constructed in crystalline rocks, i.e. granite or gneiss.

The selection of a site is a long-term process involving the participation of the public
The selection of the site for repository construction is a long-term process that involves the public and experts from a variety of disciplines such as geophysicists, geochemists, engineering geologists, hydrogeologists, project designers and economists, environmental experts, sociologists etc. In all the countries concerned, one of the most important aspects of the site selection process concerns discussions with the public, in particular the inhabitants and representatives of the sites considered for the construction of the deep geological repository, the opinions of whom make up a crucial consideration in terms of the final decision. It is essential that they have trust in the safety of the repository and accept the facility as part of the future development of the municipality and the wider region.

Sweden
Ten nuclear reactors account for 40% of Sweden's electricity generation. Spent nuclear fuel is currently stored at the CLAB central storage facility located near the Oskarshamn nuclear power plant. As early as in 2009 the final site for the construction of a deep geological repository was selected in a granite massif at the Osthammar site near the Forsmark nuclear power plant. Double-walled containers (steel, copper) will be used for disposal purposes. It is planned that operation will commence in 2020-2030. Research into the development of the deep geological repository lasted several decades and included the construction of the Äspö underground research laboratory in a granite rock environment 450 metres below the earth's surface. In recent years, extensive efforts have been made to demonstrate the construction and operation of the deep geological repository under real conditions, including

Onkalo

the drilling of boreholes, the conducting of disposal stability studies, the dummy disposal of 30-tonne disposal containers using a prototype disposal machine, etc. The underground laboratory attracts thousands of visitors every year.

Finland
Four nuclear reactors produce 30% of the country's total electricity generation and a further reactor is currently under construction. Spent nuclear fuel is stored in wet interim storage facilities (pools) at the respective nuclear power plant complex. It is planned that the Finnish deep geological repository will be put into operation in 2020 at the Olkiluoto site near the town of Rauma. The construction of an underground research laboratory commenced in 2004 as the first step towards the construction of the future deep geological repository. The compilation of the final safety studies and the application process for building permits began in 2014 and in autumn 2015 the Finnish government granted Posiva a licence to construct the deep geological repository. Finland thus became the first country in the world to grant a licence for the construction of a spent nuclear fuel disposal facility.

France
The 58 nuclear reactors that are currently in operation produce 75% of the country's electricity requirements. Spent nuclear fuel is stored at intermediate storage facilities and roughly three-quarters is reprocessed, which results in the production of high-level waste which is "vitrified", i.e. incorporated into a glass matrix, and stored in special containers pending its final disposal. It is expected that the construction of the French deep geological repository will commence sometime in the next decade. An underground research laboratory is in operation at the Bure site, the purpose of which is the investigation and demonstration of the properties of the rock environment at the site finally selected for deep geological repository construction.

Switzerland
Five nuclear reactors provide around 40% of the country's electricity requirements. Up to 2005, spent nuclear was reprocessed abroad; however, in 2006 this practice was suspended for a period of ten years. Spent fuel and the high-level waste returned to Switzerland following reprocessing is stored at the Zwilag processing and storage facility. The deep geological repository development programme assumes the siting of the repository at a suitable location in claystone rocks. At present, 3 sites (Nördlich Lägern, Jura Ost and Zürich Nordost) are under consideration and it is expected that the most suitable sites will be decided in 2020. The final confirmation of the sites via referenda (as is usual in Switzerland) is expected in 2029. The date of the commencement of the operation of the repository is planned for 2060.

Onkalo

Development of a deep geological repository in the Czech Republic

The development of deep geological repositories is a long-term and extremely complex process involving a variety of research and project disciplines. Whichever country is involved, it takes several decades to decide on the final site and design variant.

Between 1989 and 2002, the selection of sites for the construction of the Czech deep geological repository was based primarily on the assessment of the geological characteristics of potential areas including the distance of the sites from potentially seismically-active faults, the descriptiveness of the sites as expressed by the occurrence of extraneous bodies of rock, veined rocks, mineral deposits and structures that exhibited geodynamic activity, and criteria related to the Nature Protection Act. Based on these criteria, in 2002 SURAO selected 6 sites, all in granite rock environments: Čertovka (Lubenec, Blatno - Ústí nad Labem region), Březový potok (Pačejov, Chanovice - Plzeň region), Magdaléna (Jistebnice, Vlksice - South Bohemia region), Čihadlo (Pluhův Žďár, Lodhéřov - South Bohemia region), Hrádek (Nový Rychnov, Rohozná – Vysočina region) and Horka (Budišov, Oslavička – Vysočina region). Following a review of archival geological information, the Kraví hora site in the Žďár area was added to the list of candidate sites and, in 2016, geological and technical research studies were commissioned by SURAO aimed at determining other potential sites in the vicinity of the Dukovany and Temelín nuclear power plants.

In 2014 and 2015 two comprehensive projects were launched aimed at providing research support for SURAO with regard to the assessment of repository safety and feasibility including the evaluation of the environmental impact of repository construction at the various sites. At the same time, a number of other studies were commissioned for the assessment of the acceptability of the siting of the deep geological repository by the affected municipalities. More than 400 experts from more than 30 research organisations participated in these projects that resulted in the compilation of more than 150 background reports that summarised the geological, hydrogeological and geochemical conditions prevailing at the sites. Based on the information obtained, preliminary safety analyses were prepared employing mathematical and computer models, which provided predictions of the ability of the sites to isolate radioactive waste from the environment over the required period of time. The projects also included the specification of general indicators set out in SURAO documentation. As with all the other countries that are involved in the development of deep geological repositories, the site assessment background reports were based on a thorough analysis of archive data on the sites, foreign expertise and the results of surface research.

Technical reports are available for download at www.surao.cz.

The selection of the final site for deep geological repository construction will be preceded by extensive research and the collection of data that will provide a detailed description of local conditions. In recent years, SURAO has conducted a range of research and monitoring projects including field reconnaissance, sampling and monitoring, the monitoring of dust and the occurrence of radon, seismic measurements and remote sensing using both satellites and aircraft. The geological, hydrogeological and related research allowed for the compilation of 3D geoscientific models of the rock subsoil, based on which it was possible to further assess the sites. SURAO is currently working on research that will assist in the decision-making process concerning the reduction of the number of sites. In addition to the collection of geological data, research has also been conducted aimed at the assessment of the socio-economic situation of the regions involved. The research addressed how construction would affect employment, businesses, infrastructure and other relevant factors, including the attitudes of local inhabitants to potential investment in their areas.

Operational repositories

Richard repository

The Richard subsurface repository is located near the town of Litoměřice in part of the Richard II former limestone mine and has served for the disposal of so-called institutional waste, i.e. waste generated in the healthcare industry and research sectors, since 1964.

Bratrství repository

The Bratrství subsurface repository is located in part of a former uranium mine of the same name near the town of Jáchymov. The repository, which has been in operation since 1974, is intended for waste originating from the healthcare industry and research sectors that contains exclusively naturally-occurring radionuclides.

Dukovany repository

The Dukovany repository occupies an area of 1.3 hectares and consists of a system of reinforced concrete chambers built on the surface. It is intended exclusively for the disposal of low-level waste generated via the operation of the Czech Republic's two nuclear power plants. It is not used for the storage or disposal of spent nuclear fuel, nor will it be in the future. The repository was put into operation in 1995, making it the country's most recently constructed repository.

Social Responsibility

The storage and disposal of radioactive waste has been underway in the Czech Republic for more than 60 years. While spent nuclear fuel can be stored for many decades or can be reprocessed and partially reused, resulting in the production of high-level waste, the fact remains that such waste must eventually be isolated from the environment for a sufficiently long period of time. Of a number of options for the isolation of high-level radioactive waste considered worldwide, the safest and most technologically and economically feasible involves its disposal in stable rock massifs where it is possible to preserve the integrity of the disposal containers over the long term and thus prevent the escape of radionuclides. Reliable technologies are already available for the safe interim storage of radioactive materials and the construction of deep geological repositories. Most advanced countries that generate electricity from nuclear sources, including the Czech Republic, collect and deposit funds for the construction of such facilities in so-called nuclear accounts. In several countries (for example Sweden and Finland) suitable sites have already been found for the construction of deep geological repositories. Moreover, the safety of these facilities has been demonstrated and agreement has been reached with the local municipalities concerned. For other countries, including the Czech Republic, this will present a challenge for many years to come. The foundation of the successful conclusion of deep geological repository projects is fully respecting the principles of safety, health and environmental protection and developing partnerships with the affected municipalities that include guarantees of their full participation in the decision-making process and provide benefits in terms of their future development.

SURAO aims to ensure that comprehensive information on radioactive waste management is readily available to all interested parties, particularly in those regions in which operational repositories are located and in areas that have been identified for the potential construction of the Czech deep geological repository. Those interested in learning more about radioactive waste disposal facilities and the technology used in the handling of nuclear waste are welcome to visit SURAO’s information centres and points located around the country. Further information can be found at www.surao.cz and via SURAO on Facebook.

Information centres and points:
SÚRAO, Prague
Richard repository, Litoměřice
Bratrství repository, Jáchymov
Dukovany repository, Rouchovany
Bystřice nad Pernštejnem

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