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METHODOLOGY FOR SELECTING THE FINAL AND BACKUP SITES FOR THE CZECH DEEP GEOLOGICAL REPOSITORY

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SÚRAO

REPORT NAME: Methodology for selecting the final and backup sites for the Czech deep geological repository

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Abbreviations

ČR	Czech Republic
DFN	Discrete Fracture Network
EDU	Dukovany nuclear power plant
ETE	Temelín nuclear power plant
EU	European Union
EURATOM	European Atomic Energy Community
GWTF	Ground Water Flow
DGR	Deep geological repository
IAEA	International Atomic Energy Agency
NPP	Nuclear power plant
LTD	Long term diffusion
MP	Methodological guide (SÚRAO)
MIT	Ministry of Industry and Trade
WP	Waste package
RAW	Radioactive waste
RN	Radionuclide
ILW	Intermediate-level waste

SC1	Safety Case 1 = proof of the long-term safety of the Czech disposal policy for spent nuclear fuel at the Reference Site
SDM	Site descriptive mode
SKB	Swedish radioactive waste management organisation (Svensk Kärnbränslehantering AB)
SÚJB	State Office for Nuclear Safety
SÚRAO	Czech Radioactive Waste Repository Authority
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WDP	Waste disposal package
HLW	High-level waste
SNF	Spent nuclear fuel

Explanation of terms

Safety function

The safety function refers to the functions of systems, structures, components or other parts of a nuclear facility that are significant in terms of ensuring the nuclear safety of the facility. Concerning the deep geological repository, the fulfilment of the safety function is defined by the following requirements:

- to ensure subcriticality; already included in the project,
- to ensure the use of facilities/equipment that limits the radiation exposure of workers and residents,
- to ensure the removal of residual heat,
- to prevent the leakage of radioactive substances and
- to ensure the safe handling of radioactive waste (in the surface part of the DGR).

Dose optimisation limit

The effective dose, which according to the principle of the optimisation of radiation protection (section 82 of Act No. 263/2016 Coll.), must not be exceeded. In the case of the deep geological repository, this dose is set at 0.25 mSv per year for a representative person.

Effective dose

The effective dose is the sum of the products of tissue weighting factors and the equivalent dose in irradiated tissues or organs; the tissue weighting factor is determined in Appendix 2 of decree No. 422/2016 Coll., on radiation protection and the security of radionuclide sources.

Physical protection

Physical protection is a system of technical and organisational measures that prevent the occurrence of unauthorised activities concerning nuclear facilities or nuclear materials.

Deep geological repository (DGR)

A deep geological repository is a nuclear facility that is used for the permanent disposal of radioactive waste at a depth of at least 300 m below the earth's surface so that its location fulfils nuclear safety conditions for the disposal of high-level waste.

Homogeneous block

A 50 m thick rock block bounded by regionally significant faults at a level of 500 m below the local drainage base.

Characteristics of an area that rule out the siting of a nuclear facility

The characteristics of an area that rule out the siting of a deep geological repository according to section 18 of Decree No. 378/2016 Coll. are as follows:

a) a rock environment that enables the migration of radioactive, chemical and toxic substances that could be released from disposed of radioactive waste so that, during the expected development of the deep geological repository, a representative person will be exposed to more radiation than is set by the dose optimisation limit (0.25 mSv per calendar year - section 82, Act No. 263/2016 Coll., the Atomic Act),

b) the impossibility of creating:

1) a comprehensive spatial model of the geological structure due to the complexity of the geological structure and tectonic conditions,
2) a hydrogeological model due to the difficulty of describing and predicting the hydrogeological conditions of the area for the siting of the nuclear facility, or
3) geomechanical and geochemical models of the area for the siting of the nuclear facility, or

c) the presence of geothermal energy sources.

Section 18 of Decree No. 378/2016 Coll. provides a list of the characteristics of the area that need to be evaluated, but does not provide values according to which it would be possible to compare potential areas for the siting of a deep geological repository.

The characteristic of the traversing of an area for the siting of a nuclear device by a fault, upon reaching which the siting of a nuclear facility is prohibited

The characteristics of the traversing of an area for the siting of a deep geological repository by a fault, upon reaching which the siting of a deep geological repository is prohibited according to section 6 of Decree No. 378/2016 Coll. are:

a) the occurrence of a zone of movement or seismically active fault or other movement of the earth's crust, which could lead to the deformation of a nuclear facility thus reducing nuclear safety, within a distance of 5 km,
b) the occurrence of an accompanying fault at the nuclear facility site.

Protected area

A protected area is an area in which category II nuclear materials located.

Institutional control

Institutional inspection is a set of activities that ensure the maintenance and monitoring of radioactive waste repositories and the surrounding area following closure for a period specified in the respective documentation.

Engineered barrier

A man-made barrier that prevents the transport of radionuclides through, or the loss of the safety functions of, the disposal barriers, for example waste disposal packages and sealing materials

Isolation part of the repository

A rock environment with disposed of radioactive waste without the presence of faults of regional or local significance or other structural elements that could threaten the long-term safety of the deep geological repository.

Nuclear safety

Nuclear safety is the state and ability of a nuclear facility and the persons that operate the nuclear facility to prevent the uncontrolled development of a fission chain reaction or the leakage of radioactive substances or ionising radiation into the environment, and to limit the consequences of accidents.

Nuclear facility

1) a building or operational unit, which includes a nuclear reactor that uses a fission chain reaction or other nuclear chain reaction,
2) spent nuclear fuel storage facility,
3) fresh nuclear fuel storage facility, if it is not part of another nuclear facility,
4) enrichment plant, nuclear fuel production plant or spent nuclear fuel reprocessing plant,
5) radioactive waste storage facility, with the exception of radioactive waste storage facilities that are part of another nuclear facility or other workplace where radiation activities are carried out,
6) radioactive waste repository, with the exception of repositories for waste containing exclusively naturally occurring radionuclides.

Conservative approach

A method for assessing the influence of uncertainties concerning knowledge, input data, and applied methods and models via the expert estimation or statistical evaluation of the results that includes the least favourable plausible variants.

Local drainage base

The local drainage base represents the lowest point within a considered area to which water drains from the surroundings. It is determined by local conditions, including the levels of rivers, lakes, wetlands and other natural or artificial low-lying areas. This point influences the direction and the rate of drainage of the respective area and plays a key role in terms of the assessment of the hydrological and hydrogeological regime.

Waste package

A waste package is a set of structural components that serve to completely enclose radioactive materials.

In-depth protection

In-depth protection is a protection method based on several independent levels that prevent the possibility of the exposure of workers and the population, the spread of ionising radiation and the leakage of radioactive substances into the environment.

Promising area for project research

A promising area for project research comprises the area projection of a homogeneous rock block at its base – 500 m below the local drainage base.

Site descriptive model

The visual-mathematical descriptive characterisation of a site and its regional layout, including all the relevant components of the geosphere and the surface ecosystem.

Assessment of an area for the siting of a nuclear facility

According to Decree No. 378/2016 Coll. the results of the assessment of an area for the siting of a nuclear facility must be compared with the characteristics of the site, the negative results of which prohibit the siting of a nuclear facility. The assessment must include the evaluation of:

a) the simultaneous action and mutual influence of the properties, their intensity and duration,
b) the future development of the characteristics of the area.

Nuclear facility land

The area for the siting of a nuclear facility that will be affected by the various phases of the life cycle of the facility.

Category IV workplace

A category IV workplace is, in accordance with Act No. 263/2016 Coll. and its implementing decrees, a workplace with nuclear equipment.

Project

The word project has two meanings:

1) a time-limited and comprehensive set of activities and processes, the aim of which is to introduce, create or change something specific, for example the deep geological repository project, or

2) the design of the deep geological repository.

Instead of project, the term programme is also used in the first sense of the word, for example, the deep geological repository development programme.

Radiation accident

A radiation accident is a radiation extraordinary event that cannot be handled by the forces and means of the operators or shift personnel of the person whose activities caused the radiation extraordinary event or an event that results from the discovery, misuse or loss of a radionuclide source which does not require urgent action to protect the general public

Radiation extraordinary event

A radiation emergency is an event that leads or may lead to the exceeding of radiation limits and which requires measures to prevent the exceeding of which or the worsening of the situation from the point of view of ensuring radiation protection.

Radiation protection

Radiation protection is a system of technical and organisational measures aimed at limiting the exposure of persons to and protecting the environment from the effects of ionising radiation.

Radioactive waste

Radioactive substances or items that contain or are contaminated with radioactive substances for which no further use is expected, and which do not meet the conditions for the release of radioactive substances from the workplace, as set out in Act No. 263/2016 Coll.

Reference site

Reference site – a hypothetical site located in a suitable crystalline rock block in the Czech Republic and used for the assessment of the Czech disposal policy. It is assumed that the parameters of the Reference site are average for the Bohemian Massif. For models that are tied to site-specific data, for example the terrain topology (e.g. geological, hydrogeological, etc. descriptive models), data from the site where the highest (and therefore least favourable) water flow rate is calculated is considered in the disposal layer of the model.

Representative person

An individual from the population that represents a modelled group of persons who will be most exposed to irradiation from a given source and via a given pathway.

DGR reference project (design, components, materials)

The DGR reference project (solution, components, materials) comprises the technical design of the DGR considered at a given time to be the most suitable design from the safety policy point of view. The design may change depending on the specific characteristics of the sites and the acquisition of new knowledge.

Risk

The occurrence of a phenomenon or condition that has the potential to cause damage to, or compromise the safety of, a deep geological repository. If this risk is unacceptable and no feasible technical remediation measures are available, the risk is considered to be an exclusion criterion.

Scenario

A sequence of events including, in particular, the random occurrence of an initiating event, the response of individual systems, structures and components that ensure safety and the transition of a nuclear facility to a safe or other state.

Storage of RAW/SNF

The storage of RAW/SNF is time-limited placement of radioactive waste or spent nuclear fuel in a space, object or facility with the intention of its reuse.

HLW storage facility

The HLW storage facility is intended for the storage of SNF and solid RAW produced by ÚJV Řež, a.s. and Research Centre Řež. The construction of the storage facility took place in the period 1981–1988. Trial operation began in 1995, and the storage facility has been in permanent operation since 1997.

Secured area

A secured area is an area in which category III nuclear material is located, or is a protected area.

Technical safety

Technical safety is the state of the permanent compliance of selected equipment with the respective technical requirements in which there is no threat to human health, the environment or property.

Radioactive waste repository

A space, object or facility in which radioactive waste is disposed of.

Spent nuclear fuel

Irradiated nuclear fuel that has been permanently removed from the core of a nuclear reactor and that has been designated as waste by the producer. The term spent nuclear fuel is used prior to its declaration as waste.

Decommissioning

Decommissioning is a set of administrative and technical activities aimed at the complete decommissioning of nuclear facilities and category III and IV workplaces with restrictions on their use for other activities related to the use of nuclear energy or activities that include exposure situations.

Abstrakt

Tento dokument popisuje metodiku hodnocení vybraných lokalit za účelem výběru finální a záložní lokality pro umístění hlubinného úložiště radioaktivních odpadů v České republice. Metodika hodnocení lokalit je klíčovým dokumentem procesu přípravy hlubinného úložiště. Tato metodika se zaměřuje na systematické zhodnocení čtyř vybraných lokalit, které prošly předchozími etapami hodnocení a fází zúžení počtu lokalit z 9 na 4. Metodika reflektuje požadavky výběru lokality na vyloučení potenciálních rizik na základě platné legislativy i požadavky dotčených dozorových orgánů.

Jejím cílem je komplexně zhodnotit klíčové faktory ovlivňující budoucí proveditelnost a bezpečnost hlubinného úložiště a v neposlední řadě identifikovat případné nevýhody spojené s jednotlivými lokalitami. Základním principem předkládané metodiky je strukturovaný přístup k analýze různých aspektů lokalit, s důrazem na efektivní identifikaci a prioritizaci možných rizik na základě získaných dat z dlouhodobého výzkumu vybraných lokalit i geologicko-průzkumných prací do hloubky budoucího úložiště.

Klíčová slova

Hlubinné úložiště, finální a záložní lokalita, kritérium, úložiště radioaktivního odpadu, hodnocení.

Abstract

This document describes the methodology for the evaluation of four candidate sites for the purpose of selecting the final site and a backup site for the location of the Czech deep geological repository. The site evaluation methodology comprises a key document in the process of the development of the deep geological repository. The methodology focuses on the systematic evaluation of four selected sites that were subjected to the site selection process in the DGR development stage of the reduction of the number of sites from 9 to 4. The methodology reflects the requirement of the site selection procedure to eliminate any potential risks based on legislation, as well as the requirements of the relevant regulatory authorities.

This document aims to comprehensively assess the key factors that will affect the future feasibility and safety of the Czech deep geological repository and to identify any potential disadvantages associated with the four sites. The basic principle of the presented methodology comprises a structured approach to the analysis of the various aspects of the sites focusing particularly on the effective identification and prioritisation of potential risks based on data obtained from the long-term research of the selected sites and planned geological investigation/exploration research to the depth horizon of the future repository.

Keywords

Deep geological repository, final site and backup site, criterion, radioactive waste repository, evaluation.

1 Introduction

1.1 Initial situation

Radioactive waste is generated in the Czech Republic as a result of the peaceful use of nuclear energy and ionising radiation in the industrial, healthcare and research sectors. Spent nuclear fuel (hereinafter referred to as SNF) and high-level waste from its potential reprocessing, as well as waste from the operation and decommissioning of nuclear facilities (hereinafter referred to as RAW) are considered to be risk-related radioactive waste categories. Their source comprises primarily the operation of nuclear reactors. According to Directive EU2011/70/EURATOM, Article 23, it is currently generally accepted at the technical level that the safest and most sustainable alternative in the final phase of the management of high-level waste and spent nuclear fuel consists of its deep geological disposal.

In accordance with Section 113, paragraph 1, sentence 1 of Act No. 263/2016 Coll., the Atomic Act, SÚRAO is an organisational unit of the state established by the Ministry of Industry and Trade (hereinafter also referred to as the "MIT") for the provision of activities related to the disposal of radioactive waste.

In accordance with Section 113 (5) of the Act, SÚRAO conducts its activities on the basis of a statute approved by the government and SÚRAO's annual, three-year and long-term activity plans.

According to the Statute, as approved via Government Resolution No. 212 of 22 March 2017, SÚRAO's mission is to "*ensure the safe management of radioactive waste produced to date and in the future in accordance with the government-approved Radioactive waste and spent nuclear fuel management policy for the Czech Republic and with set requirements for nuclear safety and the protection of people and the environment against the adverse effects of disposed of waste."*

The main tasks faced by SÚRAO result from the provisions of section 113 paragraph 4) a of the Atomic Act, i.e. the *"preparation, construction, commissioning, operation and closure of radioactive waste repositories."*

In accordance with section 108, paragraph 1) a of the Atomic Act, the MIT is responsible for the management of radioactive waste, including radioactive waste that results from radiation accidents and spent nuclear fuel, as well as for adherence to the Radioactive waste and spent nuclear fuel management policy (hereinafter referred to as the "**Policy**"), which it assesses on a regular basis (at least once every 10 years), and updates to the Policy if deemed necessary.

Section 108, paragraph 2) of the Atomic Act stipulates that radioactive waste and spent nuclear fuel must be managed in such a way that current and future generations are not subjected to an unreasonable technical, economic and social burden.

In accordance with section 108, paragraph 1) of the Atomic Act, the updated Policy was approved via Government Resolution No. 597/2019 dated 26 August 2019. The impulse for this update of the Policy concerned the requirements arising from Council Directive 2011/70/Euratom of 19 July 2011, which established a Community framework for the responsible and safe management of spent nuclear fuel and radioactive waste.

In accordance with Article 2 of the Policy, the following main principles must be applied when managing radioactive waste and spent nuclear fuel:

- The basic SNF disposal strategy of the Czech Republic comprises its direct disposal in a deep geological repository.
- Until the time at which the deep geological repository is put into operation, SNF and RAW that is unacceptable for disposal in near-surface repositories must be safely stored by the generator or in SÚRAO-managed facilities.
- The management of RAW and SNF and the preparation of the deep geological repository must follow legislative requirements and international recommendations, and must take into account the current level of knowledge worldwide.

In accordance with the Atomic Act and the Policy, SÚRAO is responsible for the preparation and construction of a deep geological repository for radioactive waste ("**DGR**").

In accordance with the Policy, the selection of the site for the DGR is proceeding via several stages aimed at gradually reducing the number of candidate sites and their surface areas.

In line with the Policy, the site selection stage in the period 2014-2020 included the revision of the available data and the conducting of surface geological survey research at the candidate sites without using invasive techniques. The result of this stage comprised the reduction of the number of potentially suitable sites from 9 to 4, at which detailed geophysical, geochemical and hydrogeological research, including the taking of geotechnical measurements in deep boreholes, will be conducted in the subsequent stage. Furthermore, in accordance with the Policy, the suitability of the selected sites will have to be proven via the compilation of initial safety reports that will serve to confirm the operational and long-term safety of the DGR via the compilation of feasibility studies that will evaluate both the suitability of the DGR technical design solution and the costs of its construction at each of the sites, and via studies on the impacts of the siting of the repository on the environment and the socio-economic impacts on the affected local municipalities and microregions.

The Policy sets out a preliminary schedule (not yet updated so as to take into account the conditions set out in the European Commission Regulation known as the EU Taxonomy - see below), according to which the selection of two candidate sites based on the preliminary characterisation of the sites, accompanied by the opinions of the affected municipalities, was to be completed in 2022, the final site was to be selected, again with the opinions of the affected municipalities, and an application submitted for the territorial protection of the selected site in 2025, and the operation of the DGR was to commence in 2065.

Via Resolution No. 1350 of 21 December 2020 on SÚRAO's plan of activities for 2021, the three-year and the long-term plans and the preparation of the Czech DGR project, the government approved (in statement I./2), following the completion of the multi-criteria evaluation of the then nine potential sites for the DGR, a proposal to reduce the number of sites to four for subsequent investigation research (Březový potok, Horka, Hrádek and Janoch, see Fig. 1) and the provision of information on the further research required to select two candidate sites (part IV/1528/20). Furthermore, the government resolution (statement IV/1) imposed a duty on the deputy prime minister, the minister of industry and trade and the minister of transport to submit to the government by 31 December 2030 a proposal for the siting of a final and a backup site for the future DGR.

Resolution of the Government No. 7/2023 of 11 January 2023 approved the SÚRAO plan of activities for 2023, the three-year plan and the long-term plan.

In accordance with the plan of activities, the follow-up research stage is being prepared for the four candidate sites that will allow for the obtaining of geological and other data from the expected depth of the DGR. The acquisition of this data is conditional on both the technical complexity and the approval of survey areas for special intervention into the earth's crust at the candidate sites.

Fig. 1 Map showing the 4 candidate sites for the selection of the final and backup sites

The approved plan of activities further stipulates that SÚRAO will submit applications for the determination of exploration areas at all four potential sites for the DGR in the first half of 2023 with the requirement that the permits remain valid until at least 2032. Exploration areas were determined at all 4 sites in October 2024. During the proceedings for the determination of the exploration areas, the Ministry of the Environment issued a decision in October 2024 (hereinafter referred to as the "exploration areas decision") via which, based on the application submitted by the applicant (Czech Republic – SÚRAO), the Ministry decided, in accordance with Section 4a(2) in conjunction with Section 22a(1) of the Geological Works Act, in favour of the applicant on the determination of the Březový potok, Horka, Hrádek and Janoch exploration areas for special intervention into the earth's crust for the confirmation of suitable geological, structural, hydrogeological, geomechanical and geochemical conditions for the potential construction of a deep geological repository for spent nuclear fuel and other radioactive waste.

The exploration areas decision is not yet final since proceedings are ongoing regarding appeals against the decision filed by the affected municipalities. It is necessary to wait for the final decision on the determination of exploration areas before exploration work can begin.

The exploration work in the designated exploration areas will aim to define the rock block(s) for the potential siting of the deep geological repository and the determination of its properties. The geological research will provide the data required for the detailed description of the four candidate sites and, subsequently, the selection of the final and backup sites for the construction of the deep geological repository.

A further strategic document that addresses the issue of the search for the site of the future DGR and which sets out the obligations of both the MIT and SÚRAO comprises the national territorial development policy, which serves to determine, *inter alia*, the principal territorial development priorities - see Section 31 et seq. of Act No. 283/2021 Coll. (the Building Act) Update No. 4 of the Territorial Development Policy (TDP) of the Czech Republic as adopted by Resolution No. 618 of 12 July 2021. Article 169 of the TDP imposes an obligation on the MIT, in cooperation with SÚRAO, to "select the final and backup sites for the DGR taking into account the legitimate interests of the municipalities and regions concerned and with their participation" no later than 2030.

Via Resolution No. 9/2023 dated 11 January 2023, the government approved the "Evaluation of the impacts of the EU Commission Regulation on the Taxonomy in the field of nuclear energy on the radioactive waste management system in the Czech Republic" study (**the "Taxonomy Evaluation"**). This government-approved study included the optimisation of the DGR preparation schedule, taking into account the fulfilment of the conditions set out in Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022, which amended Delegated Regulation (EU) 2021/2139 with respect to economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 concerning the specific disclosure of information in relation to these economic activities (**"EC Regulation on the EU Taxonomy"**), specifically with regard to Annex No. 1, points 4.26 to 4.28, which set out the conditions for financing nuclear energy as a transitional source to a low-carbon economy. One of the conditions of the EC Regulation on the EU Taxonomy concerns the commissioning of the DGR in 2050. This date can be achieved by optimising the schedule for the preparation of the DGR, a factor that is included in the government-approved Taxonomy Evaluation - see Appendix No. 2 to this study: "Detailed schedule of the technical and licensing stages". The optimised schedule assumed the following according to the Taxonomy Evaluation:

- Submission of applications for the designation of exploration areas in 2023,
- Designation of exploration areas in 2024, and
- Evaluation and selection of the final and backup sites in 2028.

In accordance with the schedule, SÚRAO submitted applications for the designation of exploration areas in February 2023; however, at the time of the compilation of this report (March 2025), none of the exploration areas have been legally approved, which exerts an impact on the research plan. The Taxonomy Evaluation has not yet (at the time of the finalisation of this report) been reflected in the update of the Policy or in other strategic documentation, including SÚRAO's activity plans; however, since the document has been approved via a government resolution, the government, as the highest level executive authority, confirmed the urgency of optimising the schedule for the selection of the final and backup DGR sites. One of the conditions for adhering to the optimised schedule comprises compliance with the deadlines set for the completion of the respective administrative processes, including the submission of applications for the designation of exploration areas for special intervention into the earth’s crust and the required discussion thereof while fully respecting the deadlines set out in Act No. 500/2004 Coll., the Code of Administrative Procedure.

The methodology presented herein for the selection of the final and backup sites for the construction of the DGR refers to the approach to the selection of the final and backup sites based on the exclusion of the risks identified for the respective sites, the safety assessment of the Czech DGR disposal policy, the assessment of the functioning of the barriers under the conditions prevailing at the 4 candidate sites and the comparison of the key criteria based on determining the parameters of the rock environments of the 4 sites.

This methodology will be applied during the phase of the selection of the DGR final and backup sites, concerning which one of the basic inputs will comprise the geological data obtained from the surveys for special intervention into the earth’s crust from the research stages as set out in section 3, paragraph 2 of Decree No. 369/ 2004 Coll. and other background studies as required by the Policy.

The methodology will be applied to the 4 sites that were selected in 2020 in the previous phase of the reduction of the number of sites from 9 to 4 (Vondrovic et al. 2020). The 4 sites are: Březový potok (Pilsen region, Klatovy district), Horka (Vysočina region, Třebíč and Žďár nad Sázavou districts), Hrádek (Vysočina region, Jihlava and Pelhřimov districts) and Janoch (ETE-south, South Bohemia region, Týn nad Vltavou and České Budějovice districts). These sites were selected via a multiple-stage process by a specially-appointed group of experts according to overall safety, technical feasibility and environmental impacts in accordance with the Policy, which states that “The systematic assessment of all the potential sites for the construction of the DGR shall be conducted in all the stages according to defined safety, project design, environmental and socio-economic criteria”.

The methodology for the assessment of the 4 candidate sites is based on a three-stage assessment process via which the identified risks will first be eliminated for the sites based on currently valid legislation and SÚRAO document MP.22 (Vokál et al. 2017), followed by the preliminary assessment of the long-term safety of the sites based on the evaluation of the proposed Czech SNF disposal policy and the evaluation of the functionality of the barriers under the conditions of the Reference site and, subsequently, the comparison of the sites based on defined key criteria. The key criteria serve for the description of the sites in terms of long-term safety based on their geological structure and long-term development – the level of description of the four sites is comparable. The detailed definition of the key criteria, including the methods applied to fulfil the criteria and the assessment and evaluation of the data, will be set out in a separate document. The data will be obtained from the conducting of the geological surveys for special intervention into the earth's crust, which will be performed at the sites in 2024-2028. Following a detailed assessment that takes into account the opinions of the Expert Advisory Panel II on the submitted assessment, SÚRAO will submit a proposal for the selection of the main and backup sites for the DGR to the MIT, together with a decision on the determination of exploration areas for special intervention into the earth’s crust for the purposes of the potential construction of the DGR. Based on the process referred to in section 4 of Act No. 53/2024, the ministry will subsequently continue the process in accordance with the above-mentioned legislation up to the time at which the government of the Czech Republic approves the decision on the main and backup sites for the DGR via the respective government resolution.

1.2 Related documents

The methodology is based on the requirements of currently valid Czech legislation and Policy-related documentation, in particular:

- Act No. 263/2016 Coll., the Atomic Act, as amended;
- Act No. 100/2001 Coll., on the assessment of environmental impacts and on the amendment of certain related legislation, as amended;
- Decree No. 378/2016 Coll., on the siting of nuclear facilities;
- Update of the RAW and SNF management policy in the Czech Republic, approved via a Czech government resolution of 26 August 2019;
- SÚRAO methodical instruction MP.22 (Vokál et al. 2017 - hereinafter referred to as MP.22) Requirements, suitability indicators and site selection criteria for the siting of the DGR, third edition, 27 November 2017.
- Assessment of the suitability of sites for the construction of the DGR for SNF and RAW in terms of long-term safety (Havlová et al. 2018);
- Assessment of potential DGR sites according to key environmental criteria (Krajíček et al. 2020);
- Hierarchy of criteria and indicators of the suitability of sites and the methodology for the assessment thereof (Havlová et al. 2018);
- Assessment of potential sites for the DGR in terms of key technical feasibility criteria (Butovič et al. 2020);
- Selection of potential sites for the DGR in the Czech Republic for the subsequent research stage post-2020 (Vondrovic et al. 2020);
- Assessment of the impact of the Commission Regulation on the EU Taxonomy in the field of nuclear energy on the radioactive waste management system in the Czech Republic in relation to SÚRAO's activities (Vondrovic et al. 2022);
- Technical design solution of the DGR 2023 (Hausmannová et al. 2023);
- Modelling strategy for the development of the DGR (Mikláš et al. 2023);
- Strategy for the creation of descriptive models of potential sites for the construction of the DGR in the Czech Republic (Valter et al. 2023);
- SÚRAO research and development plan 2024-2028 (Hausmannová et al. 2024).

1.3 Extent of validity

The validity of this document is limited to the selection and approval of the final and backup sites for the construction of the Czech DGR. This regulation is valid for employees of SÚRAO and other experts in the supply chain who participate in the process of the selection of the final and backup sites for the construction of the DGR. The document will be updated on a continuous basis according to new findings.

1.4 Changes to the document

This document is intended to present the methodological basis for the assessment and comparison of sites that have been deemed suitable for the construction of the Czech DGR. The document will be updated and/or refined during the subsequent stages of the preparation and evaluation of the DGR project, based in particular on the following inputs:

- **Development of detailed methodologies for the defined criteria**
  The next stage will include the detailed specification of the selection criteria and indicators in cooperation with expert working groups, which will focus on the creation of methods for the evaluation of the individual parameters and their impact on the site selection process.
- **New knowledge from the geological research of the sites**
  New knowledge obtained during the characterisation of the rock environment may influence the refinement of the input data and parameters used for the individual criteria, or even lead to the requirement for the redefinition thereof.
- **Creation and evaluation of descriptive models of the sites**
  The evaluation of descriptive models of the four sites will provide comprehensive and interrelated information that will serve to refine the overall assessment.
- **Identification of interdependencies between the characteristics considered in the various criteria**
  If significant interdependencies are identified between the various characteristics or indicators, it will be necessary to respond via the adjustment of the assessment methodology.

Any changes or updates to this document will be **discussed in advance by the Expert Advisory Panel II** aimed at ensuring the transparency of the selection process and allowing for the submission of comments from both experts and the public.

2 Approach to the selection of the final and backup sites

The selection of the final and backup sites for the DGR must be conducted in accordance with the respective legislation of the Czech Republic and reflect the requirements of the various supervisory authorities, i.e. the State Office for Nuclear Safety, the Ministry of the Environment and the Ministry of Industry and Trade. The selection process must also respect the Radioactive Waste Management Policy and correspond to international practice and experience related to the selection of sites in other countries and fully taking into account IAEA requirements and procedures.

The selection process must be clear and transparent and be logically linked to the previous stages of the DGR development project, including the reduction of the number of potential sites from 9 to 4. One of the key aspects concerns building upon the knowledge and data obtained on the sites in previous stages of the process, in which the 4 currently selected sites were subjected to multi-criteria assessments that covered safety, technical feasibility and potential impacts on the environment. The main priority in the final stage of the DGR siting process is to demonstrate the long-term safety of the host environment in combination with the engineered barriers that will be required to ensure safety throughout the life cycle of the DGR. The geological environment provides a natural, passive barrier (NEA 2008) that is of fundamental importance in terms of ensuring the long-term safety and isolation of the radioactive waste. While most of the technical challenges can be overcome, the natural properties of the geological environment, which cannot be influenced, will be crucial in terms of proving the safety of the DGR. It is, therefore, important to focus primarily on the thorough analysis of the geological conditions (SKB 2015).

The presented methodology for the selection of the final and backup sites for the DGR focuses primarily on the assessment of the geological environment, which will play the primary role with respect to ensuring the long-term isolation of the radioactive waste over a period of up to 1 000 000 years. Suitable geological properties such as the stability of the rock mass, the hydrogeological conditions and the isolation ability of the rock are essential in terms of the overall safety of the repository

In contrast, the surface part of the repository, which includes the buildings and equipment necessary for the acceptance, transfer and reloading of SNF and other RAW, can be optimised applying engineering and project design approaches. From the point of view of the operation of the surface area, the requirements concerning its lifespan refer primarily to the period of operation of the DGR, i.e. approximately 120 years. This fundamental difference in terms of the character of, and requirements for, the two parts of the repository means that different methodologies must be employed for their assessment.

One of the priority tasks for SÚRAO is, according to the updated RAW and SNF Management Policy approved via Resolution of the Government of the Czech Republic No. 597/2019, to select a suitable site for the disposal of SNF and RAW that cannot be accepted for disposal in near-surface repositories. The DGR comprises a specific type of nuclear facility in that it consists of two operational sections with differing functions in terms of the handling of radioactive substances and differing requirements concerning the lifespan of structural components and equipment. The first operational section comprises the surface area, which will house the buildings, equipment and technological infrastructure required for the operation of the DGR. The second underground operational part will host the disposal areas that will ensure the long-term isolation of the waste, i.e. for up to one million years.

Requirements for the siting of the underground complex:

The requirements for the underground part of the DGR, the disposal areas, concern primarily the properties of the rock environment, which must ensure the necessary isolation of SNF and other RAW from the environment, as well as the long-term lifespan of the engineered barriers and the retention of radioactive substances following their eventual release from the waste disposal packages (WDP). The isolation of the waste must be ensured for hundreds of thousands to millions of years, which places extraordinary demands on the stability and properties of the surrounding rock environment.

The selection of a site for the DGR is, therefore, primarily determined by the properties of the rock environment, which must be able to ensure the retardation of the flow of radionuclides. The properties of the rock environment at the candidate sites will, therefore, be investigated in detail in the coming years employing a range of geological and technical methods so that, based on a detailed interpretation of their results, a site will be selected that best meets the requirements for the necessary isolation of SNF and other RAW.

Requirements for the siting of the surface complex:

The requirements for the siting of the DGR surface area derive primarily from the requirements set out for nuclear facilities located on the surface; the duration of the construction and operation of the repository is not expected to exceed 120 years. The land on which the surface area is located does not represent a basic safety barrier as in the case of the underground complex; this area will serve primarily to ensure operational nuclear safety, radiation protection, technical safety, the monitoring of the radiation situation, the management of radiation emergencies, and the security of nuclear materials, technological infrastructures and equipment located within the surface area. The nuclear facility located within the surface area of the DGR will pose a significantly lower risk than nuclear power plants, since the potential for the release of radionuclides from the surface facility into the environment, even under emergency conditions, will be extremely low. The aim of the methodology for the siting of the surface area of the DGR (Fiedler F., Vozár M. et al. 2024) is, therefore, to prepare the siting project according to clearly defined rules while maintaining all the required functions of the DGR and taking into account the requirements of all the stakeholders concerned.

In contrast to the underground area of the DGR, the locations and distribution of the surface area structures, its spatial extent and its integration into the landscape can be influenced via the technical design of the project. It is, therefore, possible to prepare a surface area project according to the defined methodology that broadly takes into account the requirements and concerns of all the concerned parties.

The methodology will serve not only for the selection of the land area for the location of the surface area at the candidate sites, but also as a tool for communication with the relevant authorities and municipalities with concern to the selection of the land for the siting of the surface area and the preparation of the surface area construction project. The proposed methodology is, thus, primarily a tool for subsequent work at the sites in terms of the location of the surface area and the distribution of the various inherent structures. The preparation of the project will focus on the limitations set out in legislation and the technical and safety aspects, and also take into account requirements that are important from the point of view of the local communities.

The methodology for the location of the surface area will comprise a separate document to that for the underground complex, and will summarise all the requirements concerning its location; the document will be divided into two basic groups of criteria: standard and specific criteria. The standard criteria will include the consideration of the characteristics of the area in terms of Czech legislation and foreign expert recommendations, while the specific criteria will cover the requirements and opinions of all the stakeholders concerned. This methodology will not be used in the selection of the final and backup sites, rather for the location and layout of the surface areas at these sites. This approach is based both on the above-mentioned requirement to ensure the safety of the underground complex of the DGR and on the results of the previous research stage that took into account the requirements for the feasibility of the locating of the surface areas at the candidate sites. The process of the reduction of the number of sites from 9 to 4 fully considered the feasibility of the construction of the surface areas at the 4 selected sites in accordance with the legislative requirements pertaining to the surface area.

Summary:

The proposed procedure fully reflects the requirements of legislation and the supervisory authorities for the siting of the DGR primarily with respect to the assessment of the geological environment, which cannot be influenced by humans, and which will play the key role in ensuring the long-term isolation of the RAW. The methodology provides a detailed guide for evaluating the candidate sites based on a comprehensive set of criteria, which includes the geological and engineered aspects that will be critical to ensuring the long-term safety and stability of the Czech DGR.

The methodology is designed to provide objective and scientifically based information for the decision-making process. This approach will ensure that the selection of the final and backup sites is based on the best available data and analysis, thereby minimising risks and maximising the future long-term safety of the DGR.

Each of the selected sites will be subjected to detailed investigation research, which will include extensive field research and surveys, laboratory analysis and modelling that will provide the comprehensive and reliable information necessary for the final decision on the siting of the DGR.

The process is fully transparent. All the stages will be fully documented and progress on the project will be communicated to the public in order to allow for the active involvement of all the stakeholders.

If necessary, the methodology will be regularly updated on the basis of the latest scientific knowledge and international experience, thus ensuring its relevance and effectiveness throughout the process of the selection and evaluation of the candidate DGR sites.

2.1 Follow-up on previous research

Based on the data available at the time, the multi-criteria assessment conducted in 2019-2020 (Vondrovic et al. 2020) distinguished four relatively favourable sites for the construction of the DGR.

The assessment process for the reduction of the number of sites prioritised safety criteria (operational and long-term), technical feasibility and impacts on the environment. The assessment was performed via the application of two basic assessment steps:

1. assessment step I – exclusion of risks (assessment of exclusion criteria for all the sites according to the exclusion criteria listed in MP.22, as based on legislation);
2. assessment step II – assignment of priorities (comparison of the sites).

With concern to the research conducted in the previous stage (the near-surface characteristics of the nine candidate sites) and the nature of the information available, not all the defined exclusion and comparison criteria and indicators set out in document MP.22 could be evaluated (Vokál et. al. 2017). The principle of the previous assessment and comparison process primarily comprised the application of the criteria and indicators (i.e. key criteria) that provided for the sufficient differentiation of the sites as available at the time of the site assessments, i.e. 2019-2020.

The selection of the final and backup sites will take into account the existing datasets and the results of future planned research, as described in the SÚRAO Research and Development Plan 2024-2028 (Hausmannová et al. 2024). The main factor in this respect will concern the availability of data from the depth of the planned DGR disposal horizon, which will help to refine the existing knowledge and allow for the improved characterisation of the sites.

The sites were assessed in the previous stage of the process in terms of the locations of both the surface and underground structures so as to ensure a comprehensive overview of their overall suitability. Those sites that were in conflict with the so-called exclusion criteria for the siting of the DGR were excluded during the process. The process thus demonstrated the feasibility of the construction of the repository in terms of the exclusion requirements set out in legislation for all 4 subsequently selected sites. The next, more advanced, selection stage will focus exclusively on the underground characteristics of the sites. This approach is technically justified by the fact that the long-term safety of the DGR will depend primarily on the stability and isolation properties of the geological environment. Geological properties such as the depth range of the suitable rock mass, its petrographic and mineralogical composition, the hydrogeological and hydrochemical conditions and geomechanical properties are of prime importance in terms of ensuring that the disposed of radioactive waste will not pose a risk to the environment and the health of the population for up to one million years. Unlike the surface complex, which can be designed and optimised via engineering methods, the properties of the rock environment cannot be influenced or altered and, thus, must be thoroughly investigated and assessed. Therefore, it is now necessary to focus on the detailed analysis and evaluation of the geological conditions at the candidate sites in order to select the site that best fulfils the strict requirements for the long-term safety and isolation of the disposed of radioactive waste. In order to take into account the requirements regarding the surface area, which forms an integral part of the deep geological repository project, but whose service life requirements are not comparable to the underground complex, the selection process will include so-called exit studies, which will serve to assess the technical feasibility of the surface project and the safety of the site; they will also include environmental and socio-economic assessments.

2.2 Assumptions

The assessment methodology is based on the following assumptions:

- The assessment of the 4 sites will be performed in 2028-2030 aimed at selecting the final and backup sites based on data obtained from geological survey work to the depth of the future disposal horizon and the preliminary assessment of long-term safety based on the evaluation of the functionality of the SNF technical approach. The selection of the site will proceed in the form of a continuous stage-by-stage assessment based on the available data, and the data obtained from the geological research and other survey work will be used to update the site selection process. The assessment will carefully consider the reliability of the input data and calculations, and comparability between the sites will be prioritised even in the case of differences in terms of the extent and/or depth of detail of the available data.

Justification: This assumption is based on the requirements set out in the Policy and the milestones set via a Resolution of the Government of the Czech Republic dated 21 December 2020 on the plan of activities of the Czech Radioactive Waste Repository Authority (SÚRAO) for 2021, the three-year plan and the long-term plan and on the development of a DGR for radioactive waste and spent nuclear fuel in the Czech Republic. This approach will allow for the objective and fair assessment of all the sites applying a common methodological framework.

- The assessment will be performed based on international experience (SKB 2011) and recommendations concerning the selection procedure for the siting of DGRs and recommendations provided by the Site Selection Criteria working group established by the IAEA.

Justification: The applied methodology is based on the experience of other developed countries with DGR preparation programmes, and international recommendations (see e.g. SKB R-11-07).

- The assessment performed for the purpose of selecting the final and backup sites reflects the requirements set out in the Atomic Act No. 236/2016 Coll. and its implementing regulation, i.e. Decree No. 378/2016 Coll. on the siting of nuclear facilities in given stages of the decision-making process and the knowledge obtained on the sites.

Justification: Due to the schedule stated in the Policy 2019 and in the Taxonomy Evaluation document (Vondrovic et al., 2022) and the current stage of research on the development of the DGR, it is not possible that the description of the sites will correspond to the level required for the submission of the detailed documentation for the issuing of a permit from the State Office for Nuclear Safety for the construction of a nuclear facility; indeed, this is not legally required at this stage. The assessment will be based on the level of knowledge acquired in this stage of the research, primarily on data obtained from the depth of the DGR disposal horizon. However, the collection of data for the future preparation of documentation for securing a permit for the siting of a nuclear facility in accordance with the Atomic Act No. 263/2016 Coll. and Decree No. 378/2016 will proceed during this stage.

- The assessment must also be based on the requirements arising from Decree No. 378/2016 Coll. on the siting of nuclear facilities, and consider a) the depth range and dimensions of the rock mass for the siting of the underground complex of the deep geological repository and the distances from geological interfaces and tectonic faults, b) the structural-geological properties of the rock environment, including brittle and ductile tectonics, c) the origin and expected development of the rock environment, d) the suitability of the mechanical properties of the rocks in terms of ensuring the long-term stability of the natural barrier (the rock), e) the petrographic and mineralogical composition of the rock environment, f) the occurrence of heterogeneous rock environments with hydrothermal and other secondary transformations, g) the occurrence of endogenous and exogenous phenomena such as tectonic processes, seismic activity, volcanism etc. h) the groundwater circulation in terms of potential transport times, retardation, solubility and changes in the concentration of radioactive substances, i) paleo-hydrogeological processes and the climatic history, j) the vulnerability of the rock environment and the groundwater circulation in terms of long-term climatic changes, k) the physical-chemical, geochemical and microbiological properties of the geological environment, l) geomechanical properties such as the strength and deformation properties of the rocks, m) the gas permeability of the rocks, n) the thermal properties of the rock environment, o) the occurrence of human activity that could negatively influence the isolation properties of the disposal system, p) changes in the host and surrounding geological environment caused by drilling and mining activities and q) the describability and predictability of the geological structure, groundwater circulation and the physical, mechanical and geochemical properties of the rock environment.
  The assessment of the properties of the sites according to these criteria must also take into account the depth below the earth's surface at which the underground disposal areas of the DGR will be excavated. This methodical approach will ensure that the candidate sites meet all the necessary conditions for the safe and long-term disposal of radioactive waste.

  Justification: This approach fully reflects the requirements of Decree No. 378/2016 Coll. Section 18, which sets out specific requirements for the extent of, and the method for, assessing areas for the siting of the DGR. In accordance with these requirements, the assessment must take into account the isolation and containment properties of the rock environment in combination with the man-made barriers in terms of ensuring that the disposed of radioactive waste does not, during the expected development of the DGR, lead to the exposure of a representative person to higher doses of radiation than established by the dose optimisation limit. This assessment will be based on the results of the evaluation of the functionality and behaviour of the engineered barriers designed for the Czech disposal policy and the verification of their compatibility with the natural conditions pertaining at the sites. When obtaining information on the candidate sites, the original properties of the geological environment must be preserved to the greatest possible extent.

  - The assessment fully reflects the requirements of the Radioactive Waste Management Policy, which emphasises the need for the performance of a thorough and comprehensive assessment of all aspects related to safety, technical feasibility, impacts on the environment and socio-economic impacts. The Policy further sets out the requirement to ensure that the selected sites meet strict safety standards and provide long-term protection against the release of radioactive substances. The Policy also emphasises the transparency of the process and the involvement of all the relevant stakeholders, including local communities and the general public. The assessment therefore not only ensures that the technical and geological aspects are carefully investigated, but also that the views and concerns of the residents of the affected areas are taken into account. This approach guarantees that the selection of the final and backup sites will be conducted applying a maximum level of responsibility and will prioritise long-term safety and sustainability.

Justification: This assumption is based on the requirements of the Policy and the milestones set out in a Resolution of the Government of the Czech Republic dated 21 December 2020 on the plan of activities of the Czech Radioactive Waste Repository Authority (SÚRAO) for 2021, the three-year plan and the long-term plan and on the development of a DGR for radioactive waste and spent nuclear fuel in the Czech Republic. The suitability of the candidate sites will be proven via the compilation of initial safety reports, the first of which will comprise a siting study that will provide a description of both the suitability of the technical design of the deep geological repository and the costs of its construction at a given location. Studies will also be compiled that assess the safety of the sites in terms of the provisions of Section 18 of Decree No. 378/2016 Coll., studies on the impact of the siting of the repository on the environment and studies on the socio-economic impacts on municipalities and the wider microregions.

- The assessment will be performed by SÚRAO and its suppliers with the participation of the Expert Advisory Panel II. The decision on the final and backup sites will then be submitted to the Ministry of Industry and Trade as required by Act No. 53/2024 Coll.

Justification: SÚRAO has the responsibility and competences to perform its own technical assessment based on the technical criteria set out in the Policy. Supervision will be ensured by SÚRAO's partners in the final and backup site selection process via the Expert Advisory Panel II. The assessments of the sites will be based on expert assessments and evaluations based on the defined methodology.

2.3 Spatial extent of the sites

The assessment of the potential DGR sites will be conducted based on the results of the data-based and background studies. The following zones (polygons) were defined for data collection and processing purposes (see Fig. 2):

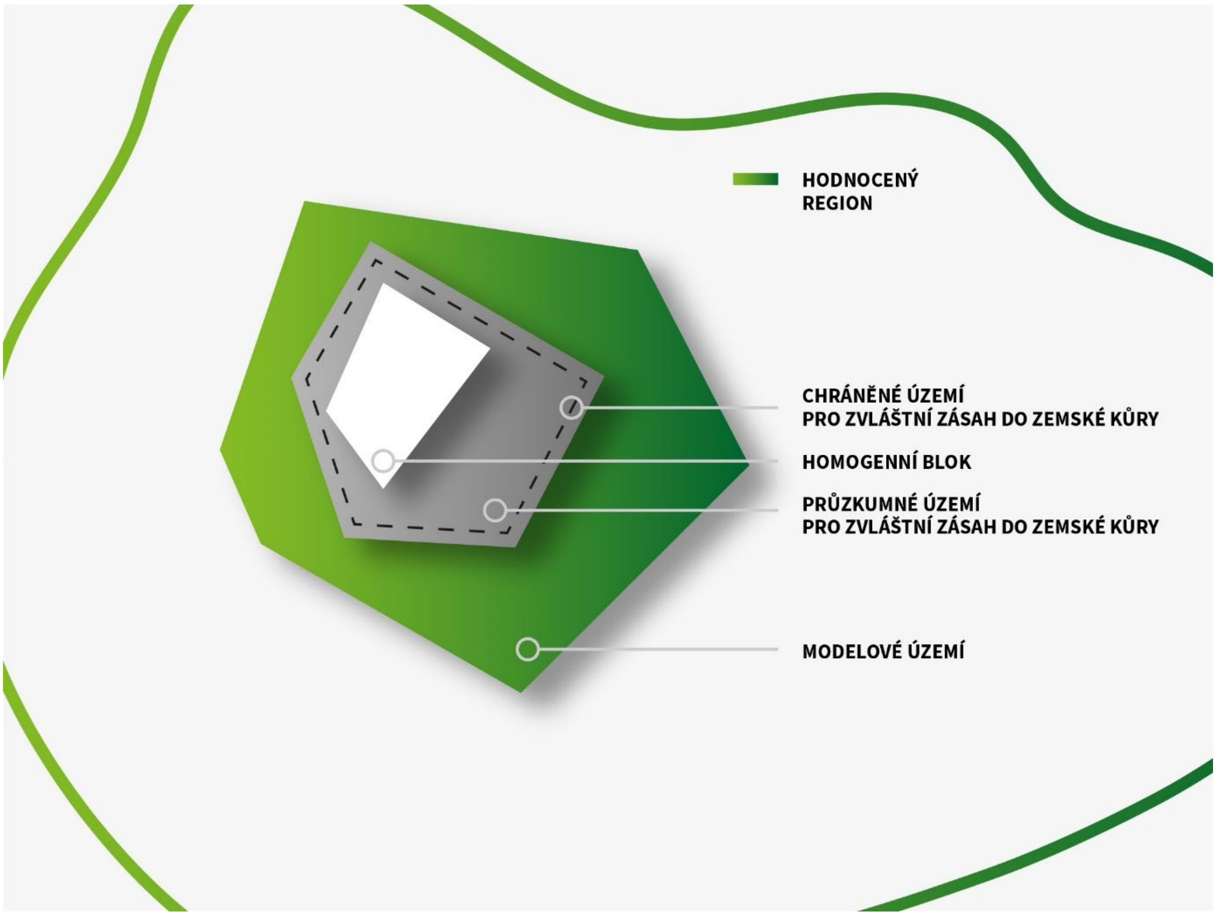

Fig. 2 Spatial extent of the description of the sites

Homogeneous block: a 50 m-thick rock block suitable for the construction of the deep geological repository located at a level of 500 m below the local drainage base and bounded by regionally significant faults including their protection zones. The homogeneity of the block reflects its suitability in terms of its long-term stability and the comparably predictable siting of the repository within it.

Research area for special intervention into the earth's crust: the area in which geological research is permitted aimed at defining the required homogeneous blocks. This is the area that (following the conducting of geological survey work), with a high degree of probability, will feature the rock environment that meets the requirements for the isolation part of the DGR.

Modelled area: the area that must be characterised in order to create site descriptive models and to form an understanding of the wider context (for various model simulations – geological, hydrogeological, transport models; the dimensions of the assessed model polygons may differ from each other). This concerns the area in the wider vicinity of the promising area for project design research, which must be subjected to the site assessment process. In particular, model simulations intended for the quantification and description of the hydrogeological conditions at the sites must be created with the application of regionally-based boundary conditions.

Assessed region: a large-scale area that must be described in order to meet the requirements of Decree No. 378/2016 Coll. (e.g. with concern to seismicity).

Protected area for special intervention into the earth's crust: an area suitable for the construction of the DGR with the delineation of the surface and underground complexes and with the assurance of the required rock cover (safety factor).

2.4 Time schedule

The time schedule for the selection of the final and backup sites is based on the SÚRAO Research and Development Plan (Hausmannová et al., 2024). The plan works with a schedule that was based on the assumption that the 4 exploration areas would be legally designated at the beginning of 2024. At the time of the writing of this report (March 2025), the 4 exploration areas have still not been officially approved, hence the need to update the time schedule. The update is based on the following assumptions:

- the quality of the outputs must be maintained,
- the optimal development of the research as supported by on-time preparation work and
- the approved designation of exploration areas by the end of Q2/2025.

The updated time schedule based on the above-mentioned assumptions is presented in Tab. 1. The schedule implies that all the data required for site assessment purposes will be available in 2028; the site assessment process itself will proceed in a continuous manner; however, the greatest intensity of the work is expected in 2029. The completion of the process of the selection of the final and backup sites is planned for 2030.

*Tab. 1 - Time schedule of the activities that will lead to the selection of the final and backup DGR sites, * denotes that the date has been changed compared to that provided in the R&D Plan (Hausmannová et al., 2024)*

no.	Activities for the selection of the final and backup sites	from	to
1	Study of the economic and socio-demographic benefits and risks of the siting of the DGR (prior to the siting of the surface area)	2022	2025
2	Final decisions on the siting of the surface areas at the 4 sites	2023	2025
3	Assessment of the functionality and reliability of the designed DGR barriers (Performance Assessment)	2021	2026
4	Verification and validation of the mathematical and computational models employed for the safety analysis of the repository	2021	2026
5	Assessment of the long-term safety of the Czech disposal policy for SNF at the Reference site	2023	2026
6	Geological research at the sites (hydromonitoring, geophysics and borehole drilling research)	2024	2028*
7	Update of the technical design solution of the buffer, backfill and filling of the ILW disposal chambers	2026	2026
8	Update of the DGR technical design solution	2024	2028*
9	Descriptive models of the selected sites	2026*	2028*
10	Studies on the economic and socio-demographic benefits (following the siting of the surface area) *	2027*	2029*
11	Assessment of the impact of the DGR on the environment and the human population ("EIA Study" DGR) - background studies on the selected sites	2027*	2029

12	Studies on the feasibility of siting at the selected sites	2027*	2029*
13	Preliminary assessment of the long-term safety of the selected sites	2026*	2029*
14	Selection of the final and backup sites		2030

2.5 Data

The assessment and comparison of the sites will be conducted based on data obtained by SÚRAO over the period 2000-2028, with particular reference to the data obtained via the geological survey work at the candidate sites. The SÚRAO Research and Development Plan 2024-2028 (Hausmannová et al., 2024) provides a summary of all the respective information to date, as well as a plan of activities aimed at obtaining the necessary data for the selection of the final and backup sites.

The following research activities will be conducted at the sites to obtain the required data

Geological research:

- Geological mapping 1:25,000 and 1:10,000
- Hydrogeological mapping 1:25,000 and 1:10,000
- Structural-geological survey
- Geomorphological and morpho-structural survey
- Remote sensing survey
- Hydrological and hydrogeological monitoring
- Geophysical research
- Drilling work and measurements in boreholes
- Borehole monitoring
- Seismological monitoring
- Engineering-geological survey
- Assessment of the physical, mechanical and transport properties of the rocks

Monitoring of the environment:

- Biological screening
- Noise study
- Dispersion study
- Detailed biological survey
- Dendrological survey
- Pedological survey

The applied assessment methodology is based on the assumption that all the important rock interfaces (higher-order faults, the interfaces of lithological units, etc.) can be identified thanks to the application of thorough geological research approaches and the data provided in previous SÚRAO projects (summaries are provided in Franěk et al. 2018, Mixa et al. 2019).

This data will be verified based on the results of the geological-exploratory research to a depth corresponding to below that of the future DGR disposal horizon (especially the borehole drilling and geophysical research).

A further assessment prerequisite concerns the potential for the creation of site descriptive models (which are made up of various sub-models, e.g. geological, hydrogeological, geomechanical models, etc.) based on the drilling of boreholes to below the depth of the future DGR. Geophysical measurements and the long-term monitoring of the sites will provide for the determination of the quantitative characteristics of the sites that will allow for their comparison.

The updated DGR project design solution, which will be determined on the basis of the DGR technical design solution (Hausmannová et al., 2023), will be used for assessment purposes. Data from the updates of the siting of the surface areas of the DGR and the DGR siting studies will be employed for the purposes of the assessment of the sites with concern to impacts on the environment, whereas the socio-economic studies will be based primarily on data provided by the Czech Statistical Office.

2.6 Descriptive models of the selected sites

In order to assess the characteristics of areas for the siting of the DGR nuclear facility and to demonstrate the describability and predictability of the sites, according to section 18 of Decree 378/2016 Coll., descriptive models of the sites will be created as part of the first stage. The results of the descriptive models will subsequently be used for the preliminary assessment of long-term safety (stage two). The third stage will involve the use of descriptive models to evaluate the selected sites based on comparative criteria. In accordance with Decree No. 378/2016 Coll., the descriptive models will consider the interpretation of both the static site parameters of the sites (e.g. the extent and structural-geological properties of the rock mass and the petrographic composition of the rock environment) and those parameters that are linked to dynamic, time-varying natural processes (e.g. the occurrence of endogenous and exogenous processes, the groundwater circulation, the physical-chemical, geochemical and microbiological properties of the geological environment and the geomechanical properties of the rock mass).

Descriptive models are generally considered to provide for the visual-mathematical descriptive characterisation of given sites and their regional configuration, including all the relevant components of the geosphere and the surface ecosystem. The main aim of descriptive models is to visualise, synthesise and interpret the local natural system based on data obtained from terrain research. Thus, they will serve to interpret the current state of the selected sites and the natural processes that occur at the sites, taking into account the regional geological past.

The descriptive models of the selected sites will be made up of several interconnected sub-models. Based on reports by Mikláš et al. (2023) and Walter et al. (2023), the following models will be created:

<u>Structural-geological descriptive model</u>

The basic objective of the creation of the structural-geological models is to determine the geometric parameters of the rock mass so as to obtain data for use in the subsequent models, including the models of the physical and chemical processes. The main purpose of this model will be to interpret the depth range and dimensions of the rock mass intended for the construction of the deep geological repository and to assess the distances from the rock block of the geological interfaces, fractures and fracture zones and tectonic faults that could provide pathways for the transport of radioactive substances. The model will also be used to interpret the structural-geological properties, origin, expected development and petrographic heterogeneity of the rock mass. The structural-geological descriptive model will, therefore, serve to interpret the lithological distribution and structural elements present in the geological makeup of the sites. It will include discrete fracture network (DFN) models that will subsequently be used for the hydrogeological, transport and geomechanical simulations. The main stochastic (statistically derived) parameters considered in DFN models, such as the connectivity or the frequency of the occurrence of hydraulically conductive fractures in the rock mass, are usually regarded as particularly important characteristics of the hydraulic properties of the rock mass. Faults and fractures also represent potential pathways for the transport of released radionuclides, as well as compounds that could adversely impact the stability of the engineered barriers. The structural-geological model will, therefore, serve for the interpretation of the existence of all the above-mentioned properties of the geological structures of the sites.

The description of the distribution of the lithological units and structural elements will influence several of the other models. The distribution of most of the material parameters of the other descriptive models, as well as some of the barrier functionality models, will be based on the lithological and structural distribution. Therefore, one of the main outputs of the structural-geological models will comprise the spatial distribution of the lithological units and structural elements such as ductile and brittle deformation zones.

Hydrogeological model

The aim of hydrogeological modelling is to provide a detailed description of the rock mass at the sites with regard to the spatial arrangement, extent, properties and hydraulic conductivity of the main fracture zones and smaller fractures. These parameters are directly related to the determination of the rate and variability of the permeability of the rock at the level of the planned repository. A further aim of the creation of these descriptive models is to provide a description of the hydrogeological properties of the rock mass near the surface in relation to the descriptive models of the surface ecosystem. Moreover, the inter-connection of the hydrogeological model with the model of the climate and geodynamic processes will play a key role in taking into account the impact of the weather and climate change on the local hydrogeological conditions.

The hydrogeological model will comprise an important tool for the assessment of both the safety of the sites and their suitability for the construction of the deep geological repository. The main purpose of the hydrogeological model is to interpret the hydrogeological conditions of the rock mass so as to allow for the assessment of their influence on the stability of the engineered barriers, concerning which the models calculate the probabilities of the distribution of flows through a randomly selected disposal well. The determination of the above flows requires the creation of reliable models of water flows in a fractured environment. The development of hydrogeological models is currently based primarily on the DFN (discrete fracture network) method, which describes water flows directly within a discrete network of fractures.

The creation of the hydrogeological model will include the construction of a precipitation-runoff model based on balance equations and the use of climate and hydrological data. Given the direct interaction between the precipitation-runoff and hydrogeological models, both models will be created within one work package. The connection of the hydrogeological models to the descriptive models of climate and geodynamic processes will play a key role in the consideration of the impacts of the weather and climatic changes on the hydrogeological conditions at the sites.

The main purpose of the hydrogeological models will be to provide for the interpretation of the advective-transport parameters of the sites. These parameters can then be used directly for the assessment of the key, comparative hydrogeological and transport criteria of the sites, or can be used as input data for the full transport models for safety analysis purposes.

Transport model

Descriptive transport models of the sites will be created aimed at determining the retardation parameters (retardation, distribution and diffusion coefficients, porosity, geometric factor) at the sites and their spatial interpretation, which will be based on a combination of archive information, the laboratory analysis of drill cores, knowledge of the spatial distribution of the geological structures and the geochemical parameters. The descriptive transport model will, in combination with the hydrogeological model, provide the input data for the modelling of the migration of radionuclides for the assessment of the long-term safety of the deep geological repository.

Hydrogeochemical model

The aim of the hydrogeochemical modelling is to characterise the hydrogeochemical conditions at the sites and to obtain site-specific data on the parameters that are important in terms of the assessment of the safety and design of the repository, e.g. the chemical composition of the groundwater, the reduction conditions, the oxygen content and the retention properties of the rock environment that are entered into the transport model.

When assessing the technical feasibility and long-term safety of the future Czech deep geological repository, it is essential to obtain data on the values of the concentrations of certain elements and substances in the groundwater. The purpose of hydrogeochemical models is, therefore, to provide a description of the processes that formed the chemical composition in connection with flow through the rock mass in both the vertical and horizontal directions. The creation of the hydrogeochemical models will serve to provide an understanding of the processes that led to the current geochemical conditions at the sites, and which have their origin in the geological past.

The models will be based on the results of the analysis of groundwater samples extracted during the drilling exploration research at the four selected sites. Given that the geochemical and hydrogeological conditions at the sites form one system, the chemical composition of the water model will serve to verify the consistency of the hydrogeochemical model with the hydrogeological and transport models.

Geothermal model

The temperature of the rock mass and its distribution are of fundamental importance in the technical design of deep geological repositories. The temperature affects the mechanical stability of the rock, the groundwater flow and the chemical-biological balance in the rock environment. The thermal properties of the rock and the temperature conditions in the rock mass will exert direct impacts on the spatial organisation and, therefore, the construction of the deep geological repository. The objective of the geothermal model will be to characterise the current temperature field and provide a description of the spatial distribution of the thermal properties within the rock mass.

The geothermal model will allow for the evaluation of the thermal processes in the rock mass based on the measurements taken of the thermal properties of the rock and will enable both the determination of the spatial distribution of heat following the disposal of SNF and the evaluation of the ability of the rock environment at the site to dissipate heat. The simulation of heat dissipation in the rock mass is important in terms of the spatial dimensioning of the DGR. The creation of the geothermal model will require the determination and justification of the method employed to describe the spatial distribution of the thermal properties of the rock (including the thermal conductivity and thermal capacity) environment in which the DGR is constructed. The model will be based (at least concerning the initial calculations) on the dependence of the thermal properties on the lithological distribution. Thus, it will be closely linked to the structural-geological model. Since the thermal properties under real conditions will not necessarily depend only on the lithological distribution and may vary, for example, depending on the structural conditions, the saturation of the rock mass, local inhomogeneities, etc., it will also be necessary to quantitatively evaluate these factors.

Geomechanical model

The geomechanical model will serve for the interpretation of the mechanical behaviour of the rock environments at the four sites, taking into account the spatial distribution of the geomechanical properties of the rock. The geomechanical model will comprise one of the models for the subsequent evaluation of the rock environment at various loading levels aimed at ensuring the stability of the natural barrier of the DGR during all the phases of its construction. The model will, thus, serve to interpret the quality of the rocks from the viewpoint of the construction and mining activities. The modelling of the mechanical properties of the rock mass, the reaction of the rock to stress from various directions and its deformation will be based on direct and indirect (core analysis) borehole research approaches. The geomechanical model will be closely linked to the structural-geological model, especially with regard to the presence of fracture systems. Whereas the structural-geological model mainly considers the geometric description of fracture systems, the geomechanical model is concerned with the origin of fracture systems, their development over the geological past and the interaction between fracture systems and the mechanical properties of less disturbed parts of the rock mass. The geomechanical model will, thus, be closely linked to both the structural-geological model and the geodynamic processes model. The geomechanical model will also serve to enhance the accuracy of the geological and hydrogeological DFN models and to estimate the development of the hydraulic conductivity with depth in the context of the descriptive hydrogeological model.

Descriptive model of climate and geodynamic processes

The aim of this model will be to obtain information on the development of climate and geodynamic processes over the geological past of the four sites that led to the current state at the sites. The main purpose of the model will be to interpret the influence of these two interrelated natural phenomena on the geological and geomorphological development of the local relief and the near-surface layer of the lithosphere. The interaction and mutual conditionality of these phenomena will be prioritised, as will their interconnection with the development of the earth's crust and the surface waters and groundwater, including their chemical composition and spatial distribution. The model will include information on the occurrence of endogenous and exogenous processes, for example, indications of tectonic movements and seismic activity in the form of deformations of the surface of the area. The model will serve for the interpretation of the rate of ongoing erosion, weathering and sedimentation, and their interconnection with vertical tectonic movements. Equally importantly, the model will take into account the main components of the atmosphere and the controlling parameters that currently influence the climate at the sites in conjunction with the geological history. The model will build upon the structural-geological and hydrogeological models, closely linked to the precipitation-runoff and biosphere models.

Descriptive model of the surface ecosystem

The aim of the ecosystem model will be to identify, describe and quantify all the relevant components of the surface ecosystems of the selected potential sites. The inputs for the descriptive model will include the results of currently performed measurement campaigns and monitoring, as well as information obtained from historical records. The main purpose of the model will be to form an understanding of the interrelationships between the biotic and abiotic components of the local ecosystems and to provide input data for the safety assessment, which will include the evaluation of the impact of the hypothetical existence of the DGR on the ecosystems of the four potential sites. A further aim of the model will be to provide the data required for the design of a programme for the monitoring of the impact of the construction of the DGR on the local ecosystem once the final site has been determined. In addition, the model will serve as a platform for the safety assessment of the final site following the closure of the DGR (the safety case).

The descriptive models of the four potential sites will be based on the information and data obtained from the geological exploration research of the surface and the underground areas via deep boreholes, the taking of geophysical measurements and the comprehensive monitoring of the sites, and will take into account the results of the data provided in previously conducted projects. The models will serve for the interpretation of the geological structure and natural relationships both within the rock mass and on the surface. They will further consider ongoing natural processes that influenced the formation of the current structures of the geosphere and relationships with the surface ecosystems. The creation of the descriptive models of the sites will require the multidisciplinary interpretation of the information obtained from the geological, structural geological, rock mechanical, rock thermomechanical, hydrogeological, hydrogeochemical, geotechnical, geodynamic, climate and surface ecosystem research.

The descriptive models of the sites will subsequently provide the input data for the preliminary assessment of the sites with regard to their long-term safety from the time of the disposal of radioactive waste in the repository up to one million years in the future. The creation of such geological descriptive models will serve, *inter alia*, to demonstrate compliance with the requirements set out in paragraph 4) of Section 18 of Decree 378/2016 Coll. which defines the conditions that preclude the creation of a comprehensive spatial model of the geological structure due to the complex nature of the geological structure and tectonic conditions at a site, or the creation of hydrogeological, geomechanical or geochemical models due to difficulties in terms of the description and predictability of the hydrogeological, geomechanical or geochemical conditions. The inability to create these models precludes the siting of the deep geological repository.

2.7 Output studies

The output studies will be compiled via the synthesis of all the information obtained on the sites. Such studies are often referred to as background studies since they serve as the basis for the selection of the final and backup DGR sites. Moreover, such studies provide evidence that the respective sites satisfy all the legislative requirements in terms of safety (i.e. they fulfil the requirements of the first and second assessment stages, see chapter 3). In addition, these studies will serve as the basis for the preparation of the application documentation for the siting of a nuclear facility at the final and backup sites (Policy 2019).

Sitability study

The sitability study will serve to verify the siting of the underground and surface areas of the DGR for the disposal of SNF and radioactive waste that cannot be accepted for disposal at existing near-surface repositories at the given site. The verification of the siting of the underground complex includes the assessment of the extent of the potentially usable rock block(s) in accordance with the expected SNF and RAW inventories and the determination of the expected volume of excavated material for the given technical design solution. The study will suggest the optimal location of the surface area at the site, including its connection to the local infrastructure and the method that will be applied for the installation of the hot cell. The study will also include an evaluation of potential conflicts of interest and identify and assess the inherent uncertainties.

Site safety assessment study (in connection with Section 18 of Decree No. 378/2016 Coll.)

This study concerns the preliminary assessment of the safety of the site in terms of Section 18 of Decree No. 378/2016 Coll. The study serves for the evaluation of all the knowledge available on the properties of the assessed site, e.g. the properties of the rock mass up to the depth at which the DGR is expected to be located. Furthermore, the study assesses the radiation exposure of a representative person during the expected development of the DGR, the inability to create descriptive models and the presence of geothermal energy sources.

Assessment of the impact of the DGR on the environment

The objective of this study is to evaluate the impact of the siting of the DGR at a given site on the various components of the environment (soil, water, air, landscape character, fauna, flora, ecosystems), public health, natural resources, cultural monuments and property. The study will be structured according to appendix 4 of Act No. 100/2001 Coll. (parts: B, C, D, E). The assessment will concern primarily the surface area or parts thereof and their connection to the existing transport infrastructure.

Socioeconomic study of the impact of the DGR at the sites

The aim of these studies is to assess the economic and socio-demographic benefits and risks of the construction of the deep geological repository at the sites. Previous stages of the siting research considered the development of the wider regions of each of the four sites (Perlín R., et al. 2024). In terms of the site assessment process, these reports will be updated once the precise locations of the surface areas at the sites have been determined, including their connection to the local transport infrastructure. These studies will then be submitted to the Ministry of Industry and Trade together with the proposal for the selection of the final and backup sites for the deep geological repository.

Supplementary studies

The assessment of the 4 candidate sites for the selection of the final and backup sites will be a long-term process, during which it can be assumed that it will be necessary to prepare supplementary studies so as to ensure the completeness of the information. For example, it is expected that studies will be compiled on issues that do not directly involve proving the long-term safety of the DGR, but will provide additional information on the sites. The outputs of these studies will form part of the process for the selection of the final and backup sites but without exerting direct impacts on the key assessment criteria

3 Site assessment process for the selection of the final and backup sites

The site assessment process for the selection of the final and backup sites is based on the multi-disciplinary processing of the relevant data and background studies according to the requirements set out in the Policy, which emphasises the need for the thorough and comprehensive assessment of all aspects related to safety, technical feasibility, environmental impacts and socio-economic impacts. The Policy states that it is essential to ensure that the selected sites meet strict safety standards and provide for long-term protection against the potential release of radioactive substances. The assessment process thus includes not only data on the geological environment and the technical feasibility of the construction of the DGR at the given site, as well as data on the evaluation of the impacts of DGR construction on the environment, but also socio-economic data. However, the primary objective of the assessment at this stage, i.e. the selection of the final and backup sites for the construction of the DGR, concerns primarily the preliminary demonstration of the long-term safety of the DGR at the selected sites, the rock environments of which must guarantee suitable and stable conditions for the functioning of the engineered barriers.

3.1 Assessment procedure

The assessment procedure is primarily based on international methodologies set out in IAEA SSG-35 and the requirements of legislation and Decree No. 378/2016 Coll., which, in section 18, sets out special requirements concerning the scope and method of the assessment areas considered for the construction of the DGR. The current assessment process will involve the detailed evaluation of the four defined potential sites. The sites will either progress to the subsequent assessment stages or could be excluded from further assessment based on the various factors considered. The conclusion of the assessment process will comprise the recommendation of a final (main) site for the construction of the deep geological repository and a backup site, both of which will fulfil all the necessary requirements. Decree No. 378/2016 Coll. states that the assessment must consider the isolation and containment properties of the rock environment in combination with the man-made barriers that will ensure that the disposed of radioactive waste does not lead to exposure for a representative person in excess of the set dose optimisation limit. The assessment must also consider the depth range and dimensions of the suitable rock mass, the structural geological properties, the mechanical properties of the rocks and their petrographic and mineralogical composition, the circulation of the groundwater and its chemical composition, the thermal properties of the rock environment and other key factors. The acquisition of information must be conducted in such a way that the original properties of the geological environment are preserved to the greatest possible extent. This approach will ensure that the selection of the final and backup sites will be based on the thorough and comprehensive assessment of all the relevant geological and environmental aspects, thereby guaranteeing the long-term safety of the DGR. The assessment must further be based on the provisions of the SÚRAO MP.22 document, which provides a summary of the requirements, indicators and criteria that are relevant in terms of the assessment of the suitability of the sites for the construction of the DGR. The assessment of the sites in the current stage will be conducted on the basis of the elimination of risks, the ability to demonstrate the functionality of the proposed SNF disposal policy at the sites and the degree of describability and predictability of the sites, which will be followed by the comparison of the sites based on the application of the key comparison criteria. The assessment will proceed via the following three basic assessment stages (see Fig. 3):

1. **Assessment stage 1** – the assessment in the initial phase will be based on the application of screening exclusion criteria as recommended by the IAEA SSG-35 methodology. The exclusion of risks will follow on from the evaluation of the results of the individual assessments of the sites with concern to the legislative requirements that govern the suitability of sites considered for the construction of the DGR according to Decree No. 378/2016 Coll., and the site descriptions, including the creation of the descriptive models of the sites;
2. **Assessment stage 2** – the demonstration of the potential long-term safety of the sites during which an assessment will be conducted of the long-term safety of the SNF technical approach at the Reference site that corresponds to a nuclear facility and the safety requirements thereof (IAEA 2015); moreover, the output transport parameters (transport times, concentrations, ...) of the Reference site will be compared with the transport parameters of the sites as determined by the descriptive models.
3. **Assessment stage 3** – the assignment of priorities (the comparison of the sites) based on the determination of the key comparative criteria and their relative advantages and disadvantages.

With respect to the scope of the work to be performed in the current stage (the characterisation of the rock mass at the depth of the DGR disposal horizon, the evaluation of the long-term safety of the SNF technical design approach at the Reference site) and the nature of the information available, selected criteria as set out in the MP.22 document that fully reflect the requirements of legislation will be applied in the current stage of the assessment of the siting of the DGR, as well as those key criteria that take into account the selection of the final and backup sites, i.e. those that refer primarily to the preliminary demonstration of long-term safety in relation to the DGR underground complex and the rock mass in which it will be located, concerning which it will be of key importance to guarantee long-term safety for up to 1 million years (Vrba et al. 2023). The principle of the assessment itself and the subsequent comparison of the sites concerns the application of such criteria (i.e. key criteria) that sufficiently define the sites in relation to proving the long-term safety of, and the technical potential to construct, the DGR at the given site.

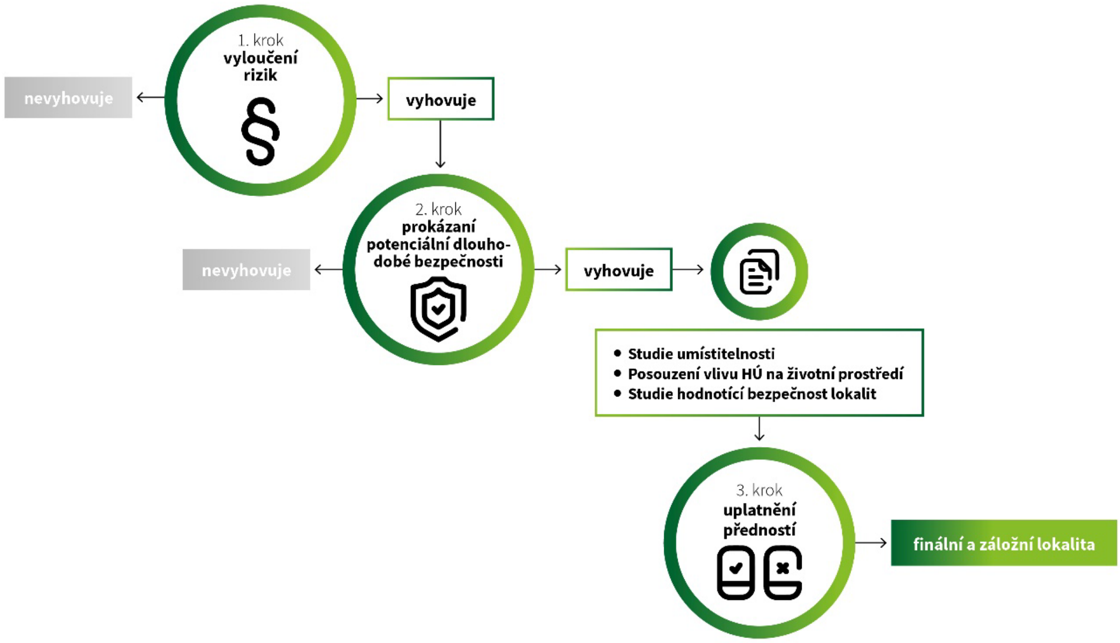

Fig. 3 Site assessment procedure

3.2 First assessment stage – exclusion of risks

When considering the construction of a DGR, it is essential to ensure that the candidate sites meet the set strict safety standards. In accordance with Czech legislation, specifically Decree No. 378/2016 Coll., and IAEA SSG-35 international recommendations, so-called screening exclusion criteria have been defined that exclude the siting of a DGR in cases where it is not possible to eliminate the adverse impacts of a given phenomenon or reduce the impacts to an acceptable level via technical means.

When assessing the potential sites, it is crucial to assess whether the identified site characteristics meet the stated requirements. If one or more of the exclusion criteria are found to apply to a given site and no effective measures are available to remedy the deficiencies, the site will no longer be considered for the construction of the DGR. However, if obstacles are detected that can be remedied either technically or administratively, the related costs will be compared with the overall costs of the construction of the repository.

Each site will be assessed on the basis of two key factors as defined by Decree No. 378/2016 Coll. Firstly, whether the information on the characteristics of the site indicates that the requirements will be fulfilled, i.e. the opportunity outweighs the risk, and secondly, whether the information indicates the occurrence of obstacles or problem issues that may render it impossible to meet the requirements, i.e. the risk outweighs the opportunity.

When identifying and assessing potential obstacles, it is necessary to employ the data that is available on the geological structure, hydrogeological conditions and properties of the rock mass at the depth of the planned repository. Decree No. 378/2016 Coll. sets out specific requirements that must be fulfilled in terms both of the site itself and the safety documentation of the DGR nuclear facility.

This section provides a detailed description of the exclusion criteria and their application to the underground complex of the repository. The assessments will be conducted by specialists in specially created working teams who will focus on the defined exploration areas for special intervention into the earth’s crust and the evaluated region. The summary of the exclusion criteria and the evaluation thereof provided below provides a clear framework for the decision-making process regarding the siting of the DGR in terms of the exclusion of risk factors.

3.2.1 Screening exclusion criteria

The output of the first stage of the assessment process will comprise a table of exclusion criteria and the evaluation thereof for each site, accompanied by a statement as to whether the site complies, and can thus proceed to stage 2 of the assessment, or should be excluded from further assessment.

The characteristics of a site that exclude the construction of a nuclear facility according to Decree No. 378/2016 Coll. are as follows:

1) Occurrence of seismically active fault zones or other movements of the earth’s crust, which could threaten the integrity of a nuclear facility and negatively impact the nuclear safety thereof, up to a distance of 5 km (section 6, paragraph 2a)
2) Occurrence of an accompanying fault at the site of a nuclear facility (section 6, paragraph 2b)
3) Regular flooding of the land of a nuclear facility as a result of extreme meteorological situations with a probability of occurrence of once per 100 years or more (section 7, paragraph 2)
4) Existence of significant bodies of groundwater that could be permanently contaminated by radioactive substances (section 8, paragraph 2)
5) Occurrence of volcanic rocks of Pliocene to Holocene age or manifestations of post-volcanic activity, especially the eruption of gases or mineral water associated with past volcanic activity, up to a distance of 5 km (section 9, paragraph 3a)
6) Occurrence of caverns and karst formations, deep mines, underground gas reservoirs and other structures located in underground spaces and the remains of previous mining activities (section 9, paragraph 3b)
7) Occurrence of pumping boreholes and dissolution technologies for the extraction of mineral resources and groundwater, including subsidence and/or deformation of the surface (section 9, paragraph 3c)
8) Occurrence of slope movements that reduce the level of nuclear safety, or the persistent unsuitable properties of the foundation soils (section 9, paragraph 3c)
9) Occurrence of the persistent unsuitable properties of the foundation soils (section 9, paragraph 3d)
10) Distance from facilities at which an explosion or fire may occur, thus rendering it impossible to implement measures to prevent threats to nuclear safety, radiation protection, the management of radiation emergencies and security (section 14, paragraph 2)

11) Encroachment of the facility into a protected zone as defined in section 15, paragraph 1a and b

Paragraph 4, section 18 of Decree 378/2016 Coll. defines the characteristics of an area that rule out the siting of a deep geological repository:

a) a rock environment that allows for the migration of radioactive, chemical and toxic substances that could be released from the disposed of radioactive waste so that during the expected development of the deep geological repository a representative person will be exposed to more radiation than that set by the dose optimisation limit,

b) the impossibility of creating sufficiently reliable[1]
   1) complex spatial models of the geological structure due to the complex geological structure and tectonic conditions,
   2) hydrogeological models due to difficulties concerning the description and predictability of the hydrogeological conditions of the area for the siting of a nuclear facility, or
   3) geomechanical and geochemical models of the area for the siting of a nuclear facility, or

c) the presence of geothermal energy sources.

A summary of the criteria is provided in Tab. 2, which also indicates the extent of the area for which the criterion will be assessed for each criterion.

[1] This SÚJB condition is interpreted as the impossibility of creating reliable models due to uncertainties resulting from the complex conditions at the site or the impossibility of obtaining sufficient information.

Tab. 2 Summary of the exclusion criteria according to Decree No. 378/2013 Coll.

ID	Definition/fulfilment	Reference	Evaluated area*1/justification	Basis/data
1	Occurrence of seismically active fault zones or other movements of the earth's crust, which could threaten the integrity of a nuclear facility and negatively impact the nuclear safety thereof, up to a distance of 5 km	section 6 para. 2a	Region Section 5a Decree No. 378/2016 coll. (up to a distance of 300 km)	Geological research, descriptive models
2	Occurrence of an accompanying fault at the site of a nuclear facility*2	section 6 para. 2b	Homogeneous block A homogeneous block of rock is a geological environment suitable for the siting of the underground part of the DGR	Geological research, descriptive models
3	Regular flooding of the land of a nuclear facility as a result of extreme meteorological situations with a probability of occurrence of once per 100 years or more	section 7 para. 2	Criterion is not relevant to the underground complex	Geological research, descriptive models
4	Existence of significant bodies of groundwater that could be permanently contaminated by radioactive substances	section 8 para. 2	Modelled area Hydrogeological model	Geological research
5	Occurrence of volcanic rocks of Pliocene to Holocene age or manifestations of post-volcanic activity, especially the eruption of gases or mineral water associated with past volcanic activity, up to a distance of 5 km	section 9 para. 3a	Homogeneous block A homogeneous block of rock is a geological environment suitable for the siting of the underground part of the DGR	Geological research

ID	Definition/fulfilment	Reference	Evaluated area*1/justification	Basis/data
6	Occurrence of caverns and karst formations at the site of the nuclear facility*2	section 9 para. 3b	Homogeneous block A homogeneous block of rock is a geological environment suitable for the siting of the underground part of the DGR	Geological research
7	Occurrence of caverns and karst formations outside the site of the nuclear facility, if there is the risk of the subsidence or deformation of the surface of the area in which the nuclear facility will be sited; with an impact on nuclear safety	section 9 para. 3b	Criterion is not relevant to the underground complex	Geological research
8	Occurrence of deep mines, underground gas reservoirs and other structures in underground spaces and the remains of historical mining activities at the site of the nuclear facility*2	section 9 para 3b	Homogeneous block A homogeneous block of rock is a geological environment suitable for the siting of the underground part of the DGR	Geological research
9	Occurrence of deep mines, underground gas reservoirs and other structures in underground spaces and the remains of historical mining activities outside the area of the nuclear facility if there is the risk of the subsidence or deformation of the surface of the area in which the nuclear facility will be sited; with an impact on nuclear safety	section 9 para 3b	Criterion is not relevant to the underground complex	Geological research

ID	Definition/fulfilment	Reference	Evaluated area*[1]/justification	Basis/data
10	Occurrence of pumping boreholes and dissolution technologies for the extraction of mineral resources and groundwater, including subsidence and/or deformation of the surface*[2]	section 9 para 3b	Homogeneous block A homogeneous block of rock is a geological environment suitable for the siting of the underground part of the DGR	Geological research
11	Occurrence of pumping boreholes and dissolution technologies for the extraction of mineral resources and groundwater, including subsidence and/or deformation of the surface if there is the risk of the subsidence or deformation of the surface of the area in which the nuclear facility will be sited; with an impact on nuclear safety	section 9 para 3b	Criterion is not relevant to the underground complex	Geological research
12	Occurrence of slope movements that reduce the level of nuclear safety	section 9 para 3c	Criterion is not relevant to the underground complex	Geological research
13	Occurrence of the persistent unsuitable properties of the foundation soils for the construction of structures important from the point of view of nuclear safety if the average speed of transverse waves in the foundation soil is lower than 360 m/s	section 9 para 3d	Criterion is not relevant to the underground complex	Geological research
14	Occurrence of foundation soil with a load capacity of lower than 0.2 MPa	section 9 para 3d	Criterion is not relevant to the underground complex	Geological research

ID	Definition/fulfilment	Reference	Evaluated area*[1]/justification	Basis/data
15	Occurrence of settling or strongly swelling foundation soils	section 9 para 3d	Criterion is not relevant to the underground complex	Geological research
16	Occurrence of foundation soil classified as medium or highly organic	section 9 para 3d	Criterion is not relevant to the underground complex	Geological research
17	Occurrence of liquefied soils	section 9 para 3d	Criterion is not relevant to the underground complex	Geological research
18	Distance from facilities at which an explosion or fire may occur originating from human activity and their by-products from the nuclear facility, thus rendering it impossible to implement measures to prevent threats to nuclear safety, radiation protection, the management of radiation emergencies and/or security	section 14 para. 2	Criterion is not relevant to the underground complex	Sitability study
19	encroachment of the land of the nuclear facility into a road protection zone	section 15 para. 2	Criterion is not relevant to the underground complex	Sitability study
20	encroachment of the land of the nuclear facility into a railway protection zone	section 15 para. 2	Criterion is not relevant to the underground complex	Sitability study
21	A rock environment that allows for the migration of radioactive, chemical and toxic substances that could be released from the disposed of radioactive waste so that during the expected development of the deep geological repository, a representative person will be	section 18 para. 4a	Modelled area	Geological research, descriptive models

ID	Definition/fulfilment	Reference	Evaluated area*1/justification	Basis/data
	exposed to more radiation than that set by the dose optimisation limit			
22	Impossibility of creating a complex spatial model of the geological structure due to the complex geological structure and tectonic conditions,	section 18 para. 4b	Modelled area Geological model	Geological research, descriptive models
23	Impossibility of creating a hydrogeological model due to difficulties concerning the description and predictability of the hydrogeological conditions of the area for the siting of the nuclear facility	section 18 para. 4b	Modelled area Hydrogeological model	Geological research, descriptive models
24	Impossibility of creating geomechanical and geochemical models of the area for the siting of a nuclear facility	section 18 para. 4b	Modelled area Geomechanical (engineering-geological) and geochemical? model	Geological research, descriptive models
25	Presence of geothermal energy sources.	section 18 para. 4b	Homogeneous block	Geological research

*1 – according to Fig. 2 Spatial extent of the description of the sites (for the purposes of their assessment)

*2 – defined in section 2c of Decree No. 378/2016 Coll., as applied to the underground complex of the DGR

The exclusion criteria resulting from the update of the Policy in relation to the environment relate only to the surface complex of the DGR and are, therefore, considered in the methodology for the siting of the surface area (Pospíšková et al. 2024).

3.3 Second assessment stage – preliminary assessment of the long-term safety of the selected sites

The preliminary assessment of the long-term safety of the DGR under the conditions of the candidate sites comprises an important step forward in terms of ensuring the suitability and stability of the rock environment for the proposed engineered barriers. The aim of stage two is to preliminarily confirm that the disposed of radioactive waste enclosed within the proposed barrier system will not pose a risk to the environment and human health over hundreds of thousands of years. The conducting of the preliminary assessment respects the requirement set out in section 18 paragraph 4a of Decree No. 378/2016 Coll.

This stage will consider only those sites that meet the requirements set out in the first stage, i.e. the sites for which no exclusion risks have been identified.

The preliminary safety assessment works with two main sources of input information. The first comprises the outputs provided by the descriptive models of the candidate sites, which provide a comprehensive source of information on the sites (geological, hydrogeological, etc.). The second source consists of the results of the generic assessment of the long-term safety of the Czech SNF disposal Policy in the context of the Reference site (hereinafter referred to SC1 - Safety Case 1), the completion of which is planned by the end of 2026.

Following this approach, as illustrated in Fig. 4, and described in more detail in chapter 3.3.2, it is possible to transfer the confidence in long-term safety from SC1 (the Reference site) to the candidate sites. The assessment results in the definition of three statements that serve to reflect the degree of transferability.

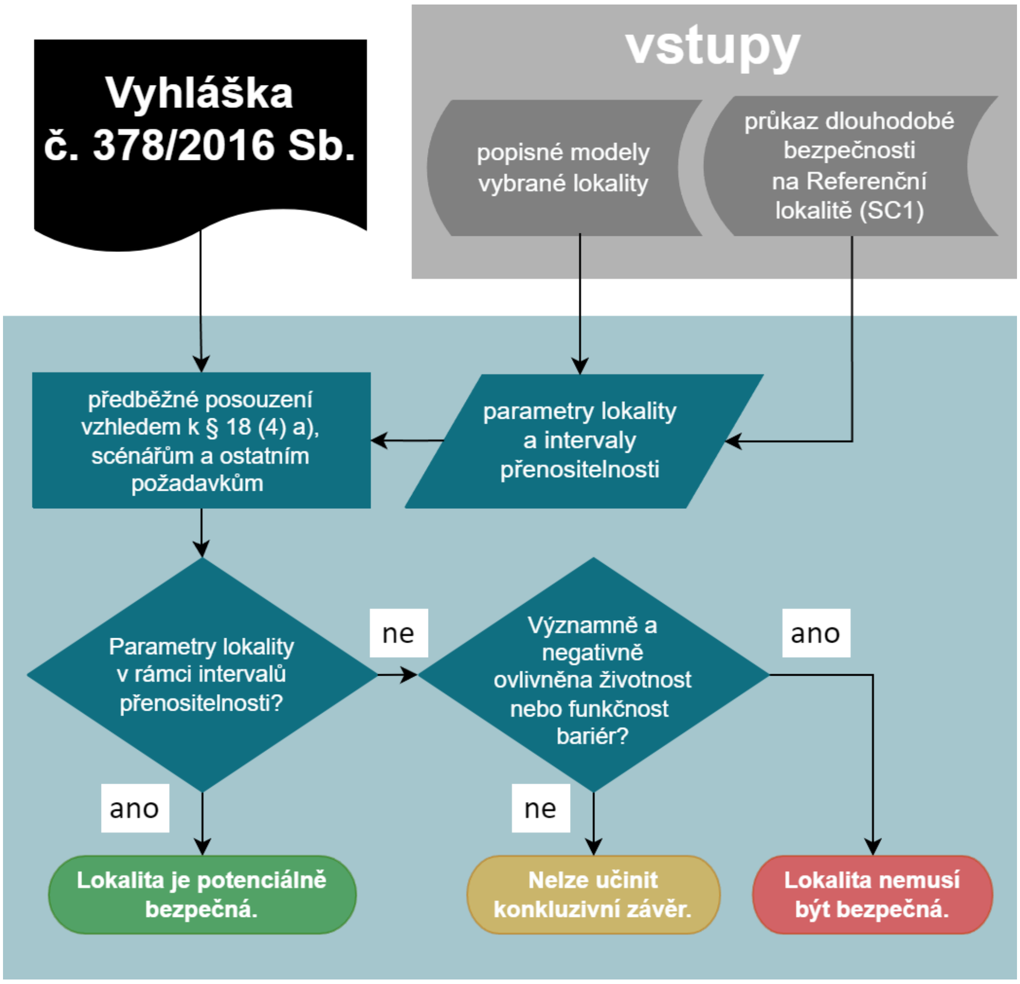

Fig. 4 Second assessment stage – preliminary assessment of the long-term safety of the selected sites

3.3.1 Proof of the long-term safety of the Czech SNF disposal policy at the Reference site

The proof of the long-term safety of the Czech SNF disposal policy with concern to the Reference site (SC1) will work with the following assumptions:

Description of the Czech disposal policy

The Czech disposal policy considered in SC1 is based on the technical design solution described in TZ 711/2023 (Hausmannová et al. 2023), which is based on the requirements of the RAW and SNF Management Policy (2019), the basic assumptions of which are:

- the disposal of non-processed spent nuclear fuel,
- the disposal of SNF in waste disposal packages (WDP),
- the WDP will consist of an outer casing of carbon steel and an inner casing of stainless steel,
- the WDP will be surrounded by a Ca/Mg bentonite buffer,
- the host environment will comprise crystalline rocks,
- the disposal horizon will be approximately 500 metres below the earth's surface,
- the disposal wells will be oriented vertically and

- the DGR will be constructed using the conventional excavation method.

The inventory is based on the Policy, while the basic input is taken from technical report TZ 694/2023 (Fejt et al. 2023).

Reference site

The Reference site consists of a hypothetical site located in a suitable block of crystalline rock in the Czech Republic. It is assumed that the parameters of the Reference site are average for the Bohemian Massif. Concerning models that are tied to site-specific data, for example the terrain topology (mainly descriptive models, e.g. geological, hydrogeological, etc.), the least favourable data from the site (i.e. the highest flow of groundwater) on which the model was based (as part of the Safety I project, 2014 2020) is applied for the groundwater flow rate at the depth of the SNF disposal horizon.

Project design solution for the underground part of the DGR

A further input to SC1 concerns the project design solution of the underground part of the DGR for the disposal of SNF at the Reference site. The project design solution for the underground part of the DGR is based on the optimisation of the sitability study (see report TZ 513/2020), which works with the inventory as reported in the Policy.

Proof of long-term safety

The objective of the assessment will consist of the proof of long-term safety (SC1), which will confirm whether the proposed Czech SNF disposal policy (Hausmannová et al., 2023) is feasible and functional under Czech crystalline rock conditions. It will also be required to demonstrate the applicability of the considered methodology for the assessment of the long-term safety of the DGR.

3.3.2 Preliminary assessment of the long-term safety of the Czech disposal policy at the candidate sites

As part of SC1, calculations will be made of the total exposure of a representative person for the considered scenarios. The input for the derivation of the transferability intervals comprises the ranges of the values of the Reference site parameters, which were considered with respect to the models used in SC1. The transferability interval is thus the range of the values of the significant parameters for which the following applies:

1) the fulfilment of the requirements for the performance characteristics of the engineered barriers

2) the calculation of the total exposure of a representative person in the context of the normal development scenario (SC1), which will not exceed the dose optimisation limit value.

It is assumed that the significant parameters will be identified via the sensitivity analysis.

Assuming that the parameters of the site fall within the transferability intervals, it can be expected that the development of the engineered barrier system will be similar to that considered in SC1 and that the total exposure of a representative person will not exceed the values set in SC1 (i.e. less than the dose optimisation limit under the normal development scenario). If any of the site parameters fall outside the transferability intervals, it is not possible to transfer confidence in the long-term safety of the DGR to the assessed site (in accordance with SC1). In such a situation, it is not possible to make a categorical conclusion on the potential unsafe nature of the site, with the exception that one of the parameters will act to significantly reduce the efficiency or service life of the engineered barrier system.

Conclusions drawn from the preliminary assessment of the long-term safety of the sites based on the results of SC1:

- **the site is potentially safe from the point of view of long-term safety** – if the parameter values obtained from the selected site are within the transferability intervals, the site proceeds to the third assessment stage.
- **no categorical conclusion can be drawn** – if the parameter values obtained from the selected site are outside the transferability intervals, the site proceeds to the third assessment stage. If, in stage 3, the site is found to be comparable or better than the other sites, it will be necessary to calculate the values assessed in SC1 (primarily the dose optimisation limit and the performance characteristics of the engineered barriers) with the parameters of the given site.
- **the site is not necessarily safe from the point of view of long-term safety** – if any of the parameters indicate a reduction in the efficiency or service life of the engineered barrier system, the site does not proceed to the third assessment stage.

This approach does not completely fulfil the requirement set out in Decree No. 378/2016 Coll., section 18 (4a), nor does it comprise a formal comprehensive preliminary safety assessment in the sense of an independent safety case for the given sites. The procedure described above is, however, in accordance with the general approach to the preliminary assessment of long-term safety for site selection purposes, which is accepted in SSG-23, para. 4.16 (IAEA 2012). At this stage, it is acceptable to work with assumptions or incomplete information on the site characteristics and the repository design solution since the main objective is to (preliminarily) assess whether the site is potentially suitable. The transfer of confidence from SC1 to the candidate sites via transferability intervals provides a valuable contribution to the selection of the final and backup sites for the construction of the DGR. A more complex calculation of the total exposure of a representative person for all radioactive waste types will subsequently be included in the process of the preparation of documentation for the siting of the DGR nuclear facility, according to Act No. 263/2016 Coll., Annex No. 1, 1a), concerning which a complete safety analysis must be conducted under the conditions of each of the sites.

Tab. 3 illustrates the scope of the long-term safety assessment for the selection of the final and backup sites and for the documentation for the siting of a nuclear facility according to Act No. 263/2016 Coll., Annex No. 1.

Tab. 3 Scope of the preliminary long-term safety assessment

Assessment area	**Preliminary long-term safety assessment for site selection purposes**	**Evaluation for the siting of a nuclear facility**
Geothermal	Analysis of the thermal properties of the rock environment of the site based on descriptive models and comparison with transferability intervals	Models of heat dissipation at the site after the closure of the DGR

Assessment area	**Preliminary long-term safety assessment for site selection purposes**	**Evaluation for the siting of a nuclear facility**
Hydrogeology	Analysis of the hydrogeological parameters of the site based on descriptive models and comparison with transferability intervals	Models of water flow at the site after the closure of the DGR and flows at the location of the disposal wells Flow models incorporating potential climate changes
Geochemistry	Analysis of the geochemical parameters of the site based on descriptive models and comparison with transferability intervals	Geochemical model after the closure of the DGR, including an analysis of the mutual influence of the SNF and ILW sections Analysis of the influence of potential climate changes.
Transport of RN in the near field of interactions	N/A	RN transport models for various scenarios
Transport of RN in the geosphere	Analysis of the transport processes of the site based on descriptive models and comparison with transferability intervals	RN transport models for various scenarios
Transport of RN in the biosphere	Analysis of the surface ecosystem of the site from the site descriptive models with the reference biosphere parameters and comparison with transferability intervals	Models of RN dissipation through the biosphere for various scenarios

3.4 Third assessment stage – assignment of priorities (comparison of the sites) based on the defined key comparison criteria

The third stage will involve the comparison of those sites that passed the assessment of the exclusion criteria in the first stage and for which it was possible to sufficiently describe the sites and to prove the functionality and compatibility of the proposed approach with the rock environment in the second stage via the assessment of the key criteria. The key criteria comprise those characteristics of the sites according to which they can be compared for the given stage of the development of the DGR (Vondrovic et al. 2020) and via which any disadvantages that a given site may exhibit in terms of the key criteria can be identified. The characteristics of the sites will be determined from current knowledge, and the identification of the characteristics of the sites that differ will be based on the assessment of the available information, primarily on data obtained from the depth of the future disposal horizon.

The main objective when selecting the final and backup sites is to ensure that the isolation and containment properties of the rock environment at the two sites, in conjunction with the engineered barriers, will effectively prevent the release of radioactive substances. Moreover, the assessment aims primarily to ensure that during the expected development of the DGR, a representative person will not be exposed to in excess of the dose optimisation limit. A further important aspect concerns the preservation of the original features of the geological environment to the maximum extent possible when obtaining information on the geological environment.

The assessment of the sites for the construction of the DGR includes a wide range of areas that are key to determining their suitability, primarily:

Geological and structural properties: Analysis of the depth range and dimensions of the suitable rock mass and the structural geological properties, including the local tectonics, and the origin and predicted evolution of the rock environment.

Mechanical and physical properties of the rock: Assessment of the mechanical properties for the long-term stability of the natural barrier (the rock), the petrographic and mineralogical composition and the occurrence of hydrothermal and other secondary transformations.

Stability of the site: Consideration of endogenous and exogenous phenomena, including tectonic processes, seismic activity, volcanism and climatic changes.

Hydrogeological and transport properties: Study of the groundwater circulation, the transport time and the retention properties of the rock.

Physical-chemical and geochemical properties of the groundwater: Evaluation of the physical-chemical and geochemical properties of the geological environment, especially the chemical composition of the groundwater.

Geomechanical and thermal properties: Investigation of the strength and deformation properties of the rock, the stress state of the rock environment and the thermal properties, including the thermal gradient.

All the above factors will be analysed based on the establishment of key comparison criteria for the given study area aimed at selecting the most suitable site for the DGR. This approach will ensure both long-term safety and the protection of the environment, thus meeting the legal requirements set out in Decree No. 378/2016 Coll., as well as ethical obligations with respect to the current and future generations.

3.4.1 Justification of the selection of the key comparative criteria for the selection of the final and backup sites for the Czech deep geological repository

The selection of the final and backup sites for the Czech deep geological repository is a process that requires the careful evaluation of a number of factors aimed at ensuring the long-term safety of the facility and minimising the risks to the environment and public health. The key comparison criteria applied to compare the sites were selected based on their suitability in terms of identifying and quantifying the parameters that are crucial for the long-term safety and operational reliability of the repository.

1. Ensuring long-term safety

The main objective of the site selection process is to ensure that the isolation and containment properties of the rock environment, in combination with the engineered barriers, effectively prevent the release of radioactive substances. The key comparison criteria were selected so as to reflect the factors that impact the transport of radionuclides and the stability of the geological environment throughout the life cycle of the deep geological repository and especially during the period following its closure up to 1 million years.

2. Regulatory requirements

The selection of the key comparison criteria was based on legislative requirements, in particular Decree No. 378/2016 Coll., on the Siting of Nuclear Facilities, which defines specific conditions for the siting of deep geological repositories and assessment requirements:

- Geological conditions (Section 6, Section 18, Paragraph 2 a, b, q) - including the composition of the rocks, their mechanical properties and the presence of fault structures.
- Hydrogeological characteristics (Section 18, Paragraph 2, h, i, k) – including the groundwater flow, retardation properties of the rocks and their sorption capacity.
- Geomechanical and physical-chemical parameters (Section 18, Paragraph 2 d, f, l, n) - which affect the stability of the underground workings and the safety functions of the engineered barriers.
- Seismic hazards and the stability of the area (Section 18, Paragraph 2 g, i, j) – concerning the probability of the occurrence of geodynamic phenomena.

The inclusion of legislative requirements when considering the key comparative criteria ensures that the evaluation of the sites complies with high-level expert requirements and international standards, as well as domestic legal regulations.

Linking of the safety indicators to the requirements of the Czech regulatory authority

When selecting the indicators to be applied in the evaluation of the individual criteria, it was deemed essential that they correspond to the safety requirements of the deep geological repository. The indicators were defined according to their suitability in terms of objectively quantifying the key properties of the rock environment and were selected in accordance with the conditions set out in the State Office for Nuclear Safety (SÚJB) BN-OD-1.2 safety manual (SÚJB, 2024). The interconnections between the various indicators and the requirements of Decree No. 378/2016 Coll. and with the recommended safety indicators are listed below:

Geological conditions (Section 6, Section 18, Paragraph 2, a, b, q)

- **Degree of brittle failure of the rock mass**: Section 18, Paragraph 2, a, b - corresponds to the **Geometry of fractures, structural character of the rock mass** safety indicator
- **Intensity of the brittle failure of the rock mass**: Section 18, Paragraph 2, a - corresponds to the **Density of the fracture network** safety indicator
- **Variability of the geological properties**: Section 18, Paragraph 2, b - corresponds to the **Mineralogy of the matrix, variability of rock bodies** safety indicator

Mechanical and physical properties of the rocks (Section 18, Paragraph, 2, d, f, l)

- **Rock strength under simple compression**: Section 18, Paragraph 2, d) - corresponds to the **Characteristics of the rock material** safety indicator

- **Modulus of elasticity and modulus of deformation**: Section 18, Paragraph 2, f - corresponds to the **Deformation properties of the rocks** safety indicator
- **Poisson ratio**: Section 18, Paragraph 2, f) - corresponds to the **Stress state in the vicinity of underground workings** safety indicator
- **Stress state**: Section 18, Paragraph 2, l) - corresponds to the **Primary stress in the rock mass** safety indicator

Stability of the site (Section 18, Paragraph 2, g, i, j)

- **Probabilistic seismic hazard assessment**: Section 18, Paragraph 2 g, i - corresponds to the **Probabilistic seismic hazard assessment** safety indicator
- **Influence of the elevation gradient and permafrost**: Section 18, Paragraph 2 j - corresponds to the **Quantification of denudation and geomorphological stability** safety indicator

Hydrogeological and transport properties (Section 18, Paragraph 2, h, i, k)

- **Flow at the location of the disposal wells**: Section 18, Paragraph 2 h - corresponds to the **Groundwater flow, transport times** safety indicator
- **Transport resistance**: Section 18, Paragraph 2 h - corresponds to the **Transport resistance in the rock environment** safety indicator
- **Distribution of contamination into the drainage areas**: Section 18, Paragraph 2 k - corresponds to the **Shannon entropy (distribution of contamination)** safety indicator
- **Retardation parameters of the rock environment**: Section 18, paragraph 2 k - corresponds to the **Sorption coefficients and retardation factors** safety indicator

Physical-chemical and geochemical properties of the groundwater (Section 18, Paragraph 2, k)

- **Chemical composition and properties of the groundwater**: Section 18, Paragraph 2 k) - corresponds to the **pH, Eh, mineralisation** safety indicator

Dimensions of the underground part of the repository (Geomechanical and thermal properties) (Section 18, Paragraph 2, l, n)

- **Dimensions of the DGR at the disposal horizon**: Section 18, Paragraph 2 n - corresponds to the **Geometry of the DGR, temperature gradient** safety indicator
- **Dimensions of the rock block reserve**: Section 18, Paragraph 2 l - corresponds to the **Rock block reserve capacity** safety indicator

3. Possibility of the objective comparison of the sites

Key comparison criteria were established so as to enable comparisons of the sites based on measurable and quantifiable indicators. Each of the criteria includes sub-indicators that reflect the specific characteristics of the sites that are important in terms of ensuring the long-term safety of the facility. This approach allows for the identification of the strengths and weaknesses of the four sites, thereby facilitating the decision-making process.

4. Consideration of data obtained from the depth of the disposal horizon

The criteria were selected with regard to the availability of data and the potential for the validation of the data based on the geological exploration research. Preference is assigned to those characteristics at the depth of the disposal horizon that can be measured or determined both from current knowledge and, in particular, from the data obtained from the geological exploration research.

5. Multidisciplinary approach

The selected key comparison criteria cover a wide range of areas from the geological and hydrogeological properties to the mechanical, physical-chemical and geochemical parameters. The multidisciplinary approach thus ensures the comprehensive assessment of each of the sites in terms of the long-term safety of the site, taking into account the critical parameters of the rock environment, thus minimising the risks associated with the application of a branch-specific assessment approach.

6. International comparability

The criteria applied correspond to those considered in the methodologies applied in other countries with more advanced deep disposal programmes (e.g. Switzerland, Sweden and Finland).

7. Ethical and inter-generational aspects

The selection of the criteria further takes into account ethical obligations with respect to future generations, the emphasis being on following the precautionary principle. The evaluation of the criteria is aimed at minimising potential risks, especially over the long term, a factor that is essential with concern to ensuring the long-term safety of the deep geological repository.

Conclusion

The specified key comparative criteria for the evaluation of the 4 potential sites for the deep geological repository in the Czech Republic reflect the adoption of a comprehensive approach to ensuring the long-term safety and technical feasibility of the facility and the protection of the environment. This methodological framework contributes to the selection of the most suitable sites in terms of meeting the strict requirements set concerning long-term safety and resilience to external and internal risk factors in accordance with the requirements of Decree No. 378/2016 Coll. and the requirements set for the safety indicators established by the Czech regulatory authority.

3.5 Specification of the key comparative criteria

The site assessment methodology based on key criteria will ensure a systematic approach to identifying the disadvantages and risks associated with the siting of the DGR. Each of the criteria is important in terms of ensuring the safety and functioning of the facility. The following descriptions of the various criteria and their scientific assessment will allow for the objective comparison of the candidate sites.

The key comparison criteria have, where appropriate, been broken down into indicators with concern to the characteristics of the sites; thus, the indicators describe defined partial characteristics of the sites that, together, will be used for the assessment of the respective key comparison criterion. The comparison of the sites at this stage will, therefore, be performed on the basis of the criteria that have the greatest informational relevance for the assessment from the point of view of long-term safety, as supported by the maximum amount of data available at the time. An overview of the key comparison criteria, including the rationale for their selection for this stage of the process, is provided below.

The criteria will be described in more detail in a follow-up study entitled “Detailed description of the comparative criteria and indicators”. Expert groups, which will be created specifically for each of the criteria so as to fully cover the necessary areas of expertise, will participate in the preparation of this document. The expert groups will be composed of both SÚRAO staff and external experts, as well as members of the Expert Advisory Panel II in the role of independent observers. The conclusions of the expert groups may impact the wording of this document, in which case it will be updated accordingly.

3.5.1 Key criterion K1: Geological and structural properties

The study of the geological and structural properties comprises one of the key criteria in the site selection process since these properties determine the long-term stability and future long-term safety of the DGR. According to section 6 and section 18, para. 2, a, b and q) of Decree No. 378/2016 Coll. geological conditions such as the composition of the rock, the mechanical properties of the rock and the presence of fault systems must be assessed; these characteristics play a fundamental role in terms of the resistance of the rock mass to seismic activity and groundwater migration. The ability to create a reliable complex spatial model of the geological structure that takes into account both the geological structure itself and the tectonic conditions, is of particular importance. The depth range of the rock mass must be sufficient to allow for the construction of the underground complex of the DGR at a depth of at least 500 metres. Unacceptable levels of uncertainty in terms of the identification and description of the regional and local fault zones may preclude the siting of the repository.

Indicator: Extent of fault structures in the rock blocks

The degree of brittle failure of the rock mass reflects the number and extent of the fault structures indicated up to the time of the selection of the sites (brittle structures along which significant movements of the rock blocks have occurred), as well as the age of the movements along these faults, if known. Faults are graded according to the SKB classification system (Andersson et al. 2000). From the point of view of the suitability of the sites, the degree of brittle failure should be as low as possible since fault structures represent the significant mechanical weakening of the rock mass, and provide potential preferential groundwater pathways, especially in crystalline rock environments. Their distribution and character will exert a significant impact on the assessment of the suitability of the sites.

Quantification: Number of fault structures.

Assessment area: Homogeneous block

Indicator: Intensity of the brittle failure of the rock mass via fractures

This indicator reflects the number of detected fracture systems and the density of the fracture networks. Fracture systems often form a dense network of usually interconnected small discontinuities in the rock mass, some of which are hydraulically conductive and, thus, may serve as potential pathways for the transport of water and the gases present in the water or, in the case of the DGR, the potential leakage of radionuclides. From the point of view of the siting of the DGR, the most suitable environment is that which features the lowest possible number of fracture systems and a low fracture density. The DFN models will be used for the comparison of the sites with concern to this indicator.

Quantification: Area of hydraulically active fractures in a unit volume of rock.

Assessment area: Homogeneous block

Indicator: Spatial variability of the geological properties

The spatial variability indicates the amount, spatial distribution and character of the rock bodies, whereas the petrological variability indicates the differing mineralogical and geochemical properties present in the various types of rock. The spatial variability describes both the horizontal and vertical distribution, i.e. the character and frequency of the alternation of individual rock bodies, at the potential DGR sites. This indicator also includes an assessment of the nature of the interfaces of the various rock bodies (e.g. flat, uneven, lobulated, tectonic, petrographic transition etc.).

Quantification: The complex spatial variability of the rock environment, with the alternation of various lithologies and complicated interfaces.

Assessment area: Homogeneous block

3.5.2 Key criterion K2: Mechanical and physical properties of the rock

The mechanical and physical properties of the rock criteria serve to define the suitability of a given host rock environment in terms of the mechanical properties. These site characteristics must be assessed according to section 18, para. 2, d, f and l) of Decree No. 378/2016 Coll. The basic characteristic concerns the average strength of the rock under simple compression determined according to the respective rock mass classifications and tests employing a uniaxial loading system. Rocks with a strength of between 100-250 MPa are considered very strong rock and correspond to the strength values of deep granitoids such as those found at the DGR sites in Finland (Olkiluoto) and in Sweden (Forsmark).

The mineralogical composition, size of the mineral grains, porosity and other structural-textural properties of the rock affect its strength and other mechanical properties. Parameters such as the modulus of elasticity, modulus of deformability and Poisson ratio are key to the creation of the geomechanical models of the sites.

The stress-deformation state of the rock mass is also important in terms of the qualitative assessment of the rock mass and the planning of the project design work. When excavating underground workings, it is crucial that the stress state is kept under control so that the stress induced around the excavation by the weight of the rock mass and other influences (e.g. the excavation method, etc.) impacts the potential deformation of the tunnel walls and the stress acting behind the walls to the minimum extent.

Indicator: Rock strength under simple compression

The rock strength under simple compression is the highest load attainable related to the unit of the original cross-section of a test specimen; it comprises the ratio of the highest load attained to the initial cross-section of the specimen as measured in the plane perpendicular to the direction of the applied force. Thus, it is the strength that the rock exhibits under uniaxial and compressive loading.

Quantification: The disadvantage concerns the testing of rocks with lower compressive strengths and extremely high rock strength values, which may exert an impact with concern to high abrasiveness values and the type of rock failure (brittle failure).

Assessment area: Modelled area

Indicator: Modulus of elasticity and modulus of deformability

The relationship between the stress and the deformation of the rock environment is described via 2 moduli. Depending on the type of deformation, which is determined for the relevant stress value, the modulus of elasticity E (from the relative elastic deformation) and the modulus of deformation Edef (from the total relative deformation) are distinguished. The higher the value of these moduli, the lower the deformability of the rock.

Quantification: The disadvantage concerns those parameter values that are not in accordance with the quantification performed for the strength of the intact rock under simple compression and do not correspond to the deformation parameters of the common crystalline rocks of the Bohemian Massif.

Assessment area: Modelled area

Indicator: Poisson ration

The Poisson ratio indicates the ratio of the axial (in the direction of the applied stress) and the transverse strain, i.e. it represents the absolute value of the proportion of relative deformations. Concerning isotropic materials, this is independent of the direction of loading, whereas for anisotropic materials, it is dependent on the direction of loading relative to the structure. Higher Poisson ratios indicate that the rock expands more in the transverse direction during compression.

Quantification: The disadvantage concerns those parameter values that are not in accordance with the quantification performed for the strength of the intact rock under simple compression and do not correspond to the deformation parameters of the common crystalline rocks of the Bohemian Massif.

Assessment area: Modelled area

Indicator: Stress state of the rock mass

The stress state of the rock mass defines the distribution of internal stresses in the rock due to loading, e.g. the geostatic stress, hydrostatic pressure or residual stress due to the historical development of the rock environment. The stress state can be a crucial factor in terms of the stability of the rock mass during the excavation of underground mine workings or the construction of deep geological repositories. It can be influenced by various factors, including the geological structure, tectonics and the hydraulic conditions within the rock mass.

Quantification: The disadvantage concerns extreme stress state values within the rock mass with high anisotropy values. Concerning the DGR disposal spaces, the stress must not reach values that could cause the deformation of the walls (e.g. spalling) of the excavated tunnels or boreholes.

Assessment area: Modelled area

3.5.3 Key criterion K3: Stability of the site

The geological structure of the area designated for the construction of the DGR must guarantee the stability of the repository for a period of at least several hundreds of thousands of years. According to section 18, para. 2 g, i and j) of Decree No. 378/2016 Coll. the occurrence of endogenous and exogenous phenomena must be assessed (g), as must the expected development of the climate (i) and the vulnerability of the rock environment in terms of long-term climatic changes (j). According to the IAEA, the host environment (2011b, I.25) of deep geological repositories must not be susceptible to the influence of future geodynamic processes and the related phenomena or other unfavourable factors (e.g. climatic changes, neotectonic movements, high seismicity) to the extent that the impacts could unacceptably threaten the safety function of the disposal system.

Indicator: Probabilistic seismic hazard assessment

The probabilistic seismic hazard assessment expresses the probability that a defined level of seismic vibration, e.g. the peak ground acceleration (PGA), will be exceeded in a given region over a certain period of time. This assessment provides a comprehensive picture of the degree of seismic risk and includes uncertainties associated with the location, the earthquake mechanism and the environmental properties.

Quantification: The probability of exceeding the PGA (g) value over a period of time, expressed as a percentage (%).

Probability levels: low risk: probability of exceeding the PGA value = 0.1g < 10%. Medium risk: probability of exceeding the PGA value = 0.1g of between 10–30%. High risk: probability of exceeding the PGA value = 0.1g > 30%.

Assessed area: Exploration area for special intervention into the earth’s crust up to a distance of 5 km, including active faults and potential sources of seismic activity.

Regional and local seismic sources (historical and current earthquake and fault data) will be taken into account.

Note: This indicator is currently included in the Methodology and will be further reviewed as part of the preparation of the specification of the detailed criteria. Its inclusion in the comparative indicators is not considered to be definitive at this stage; this will depend on further expert assessment recommendations.

Impact of the elevation gradient and permafrost on the dynamics of the relief and future geomorphological processes

The elevation gradient between the levelled surface of the area and the level of the respective local erosion base is directly proportional to the dynamics of the relief and determines the potential for the deepening of the drainage system in the future and the associated occurrence of exodynamic phenomena, including long-term changes in the relief. In addition, the influence of permafrost on changes in the hydrogeological regime must be considered.

Quantification: The maximum elevation distance (m).

Assessment area: Region

3.5.4 Key criterion K4: Hydrogeological and transport properties

The hydrogeological and transport properties criterion is of key importance in terms of assessing the suitability of the candidate DGR sites since it concerns the assessment of groundwater flow mechanisms that could significantly affect the stability of the engineered barrier system, the release of radionuclides and their subsequent transport. These properties must be assessed according to section 18, para. 2 h, i and k) of Decree No. 378/2016 Coll. The advective transport of radionuclides via flowing water is affected by a number of processes such as precipitation, dissolution, diffusion, sorption and dilution due to mixing with uncontaminated water. These processes can act to either retard or accelerate the migration of radionuclides into the surrounding environment and could exert a major impact on the long-term safety of the repository. Obtaining a thorough understanding of the hydrogeological conditions allows for the prediction of the behaviour of radionuclides in the underground environment and the design of an effective engineered barrier system that minimises the risk of the leakage of contaminants into the biosphere.

Flow in the vicinity of the DGR

It is important to assess groundwater flow mechanisms, i.e. the flow rates and directions since they affect the functionality and stability of the engineered barriers due to both the flow of water itself and the rate of the release and transport of radionuclides from the DGR complex. The assessed indicator addresses flow in the DGR area taking into account both the pressure gradient and the permeability of the rock mass. The required parameters will be obtained from the hydrogeological models, and it is assumed that they will be evaluated as probability flow rate distributions at the location of the disposal wells.

Quantification: Flow rates at the location of the disposal wells.

Assessment area: Homogeneous rock block

Indicator: Transport resistance

The transport resistance parameter serves for the characterisation of the retention of substances in a transport medium and depends on the transmissivity of the fractures and the hydraulic gradient; thus, it will be derived from the hydrogeological model. The exact definition of the parameter depends on the specific retention model employed. The indicator includes the consideration of the advective component of transport, as well as the properties of the fractures (it may also include the properties and parameters of the rock environment, depending on the retention model) through which the substance migrates.

Quantification: The indicator will be quantified by the average value of the transport resistance along transport pathways.

Assessment area: Modelled area

Indicator: Dispersion of contamination to the drainage areas

This parameter indicates the number of separate drainage areas in the wider area into which the groundwater from the DGR flows, together with the percentage shares of the DGR area that relate to the individual drainage areas. The dispersion of contamination into several drainage bases reduces the risk of the build-up of high concentrations of radionuclides in specific areas. The hydrogeological models will allow for the identification of the drainage bases and the percentages.

Quantification: The indicator concerns the assessment of the distribution of contamination into the drainage areas (taking into account the number of drainage areas and percentage distribution) and can be quantified using the formula for the calculation of the Shannon entropy:

$$I = -\sum_{i}^{N} P_i \log_2 P_i$$

Where *I* is the value of the quantified indicator and P_i is the percentage of the area of the DGR as determined using the probability of the flow of contamination to specific drainage bases mathematical model. The higher the resulting *I* value, the more favourable the situation.

Assessment area: Modelled area

Indicator: Retardation parameters of the rock environment

The time of the transport of radionuclides, in addition to advection via groundwater, also depends on the potential for the retardation of the transport of radionuclides due to migration into the rock matrix and sorption on the surfaces of fractures and their fillings, as well as the composition of the groundwater and the reaction kinetics in the groundwater. Due to the significant uncertainties associated with the transfer of rock diffusion parameter values obtained from laboratory experiments to in-situ conditions (LTD, GWTF projects), the comparison of the sites based on the potential for radionuclide diffusion into the rock matrix is not currently being considered. If the results of the sorption analysis (sorption isotherms, solubility of radionuclides) of samples from boreholes are found to be of a sufficiently representative quality for the upscaling of the sorption parameters to their spatial distribution at the site scale, the sites will be compared on the basis of the retardation potential (for example, sites with structures filled with minerals with higher sorption potential will be considered more suitable, especially in areas with expected higher concentrations).

Quantification: Sorption coefficients for representative radionuclides and their predicted concentrations.

Assessment area: Modelled area

3.5.5 Key criterion K5: Physical-chemical and geochemical properties of the groundwater

The assessment of the physical-chemical and geochemical properties of the rock mass, especially with regard to the retention properties of the rock environment, chemical composition of the groundwater, reducing conditions and oxygen content is, according to section 18, para. 2 k) of Decree No. 378/2016 Coll., key to the evaluation of the degradation processes of the engineered barriers, which are closely linked, particularly, to the chemical processes that occur when the engineered barriers and the groundwater come into contact. The basic safety requirement for the Czech DGR safety policy concerns primarily the rapid attainment of a reducing environment in the repository following closure.

Indicator: Chemical composition and properties of the groundwater

One of the favourable characteristics of groundwater in general concerns the low presence of substances that could adversely affect the rate of degradation of the waste disposal packages, the rate of the dissolution of the waste forms or the rate of the transformation of the bentonite. The pH value is also important, i.e. it should correspond to the normal values of the groundwater in crystalline environments.

Quantification: The indicator will assess the amount of dissolved substances and the pH and Eh values in the groundwater. The data will be obtained from borehole drilling research. Specific limit values are currently being defined for the Czech policy.

Assessment area: Geological characterisation research

3.5.6 Key criterion K6: Dimensions of the underground part of the repository

The geomechanical and thermal properties of the rock mass comprise essential parameters in terms of defining the geometry and dimensions of the underground part of the DGR, particularly the SNF disposal section. These properties must be assessed according to section 18, para. 2 l and n) of Decree No. 378/2016 Coll. The geomechanical parameters of the rock mass will determine the mechanical stability conditions of the underground disposal spaces. The thermal parameters of the rock mass will be decisive from the point of view of the safe dissipation of the heat that will be generated by the disposed of SNF.

The dissipation of heat will depend on the thermal parameters of the rock mass, i.e. primarily thermal conductivity, the initial temperature in the disposal horizon and the spatial variability. These parameters will determine the extent of the underground part of the DGR and, thus, influence the required dimensions of the rock mass. These requirements are reflected in the two indicators that were selected as key in terms of the assessment of the criterion.

Indicator: Dimensions of the disposal horizon of the DGR

Based on the updated DGR technical design solution, the construction of the DGR will be considered in rock masses at each of the sites; the rock masses will be documented in the respective sitability studies. The dimensions of the underground part of the DGR will vary from site to site according to the thermal properties of the rock mass. In simple terms, the smaller the DGR underground part, the more advantageous it will be in terms of its impact on the rock mass, the amount of excavated material produced, and the amounts of the materials needed to fill the disposal spaces. Moreover, the smaller the DGR, the lower the investment and operating costs.

Quantification: the dimensions of the underground part of the DGR - disposal horizon

Assessment area: DGR technical project design

Indicator: Extent of the rock block reserve

Each site has a defined area that has been identified as containing a suitable rock mass. Based on the technical design solution (feasibility study), part of the defined rock mass will be used for the construction of the underground part of the DGR. The underground structures will be subject to uncertainty in terms of unexpected local variations in the rock environment. Although some of these uncertainties have been compensated for in the technical design solution, which takes into account the 20% risk of the occurrence of unsuitable areas for the emplacement of the WDPs, from the point of view of the conservative approach to the siting of the DGR, the facility should be constructed in a rock block, the size of which provides a reserve that will allow for the reduction of space-related uncertainties.

Quantification: the ratio of the dimensions of the unused part of the rock mass to the dimensions of the underground part of the DGR

Assessment area: Homogeneous rock block

Tab. 4 provides an overview of the indicators defined for the above criteria with a description of the trend or dispersion of the determined values in terms of favourability for the siting of the DGR.

Tab. 4 Overview of the indicators employed

ID	Criterion	Indicator	Ref. to Decree 378/2016 coll.	Ref. to BN-OD-1.2	Trend
K1	**Geological and structural properties**	Extent of fault structures in the rock mass (number)	S. 18 para. 2 a), b)	corresponds to Geometry of fractures, structural character of the mass	the lower the better
		Intensity of the brittle failure of the rock mass (m^{-1})	S. 18 para. 2 a), b)	corresponds to Density of fracture network	the lower the better
		Variability of the geological properties	S. 18 para. 2 q)	corresponds to Mineralogy of the matrix, variability of rock bodies	the lower the better
K2	**Mechanical and physical properties of the rock**	Rock strength under simple compression (MPa)	S. 18 para. 2 d), l)	corresponds to Characteristics of the rock material	class R1-R2*
		Modulus of elasticity and modulus of deformability (GPa)	S. 18 para. 2 f), l)	corresponds to Deformation properties of the rocks	class R1-R2*
		Poisson ratio	S. 18 para. 2 f), l)	corresponds to Stress state in the vicinity of underground workings	the lower the better
		Stress state	S. 18 para. 2 l)	corresponds to Primary stress in the rock mass	the lower the better
K3	**Stability of the site**	Probabilistic seismic hazard assessment	S. 18 para. 2 g)	corresponds to Probabilistic seismic hazard assessment	the lower the better
		Impact of the elevation gradient and permafrost on the dynamics of the relief and future geomorphological processes (m)	S. 18 para. 2 j)	corresponds to Quantification of denudation and geomorphological stability	the lower the better
K4	**Hydrogeological and transport properties**	Flow in the vicinity of the DGR ($l.min^{-1}$)	S. 18 para. 2 h)	corresponds to Groundwater flow, transport times	the lower the better
		Transport resistance (m/year)	S. 18 para. 2 h)	corresponds to Transport resistance in the rock environment	the higher the better

ID	Criterion	Indicator	Ref. to Decree 378/2016 coll.	Ref. to BN-OD-1.2	Trend
		Dispersion of contamination to the drainage areas	S. 18 para. 2 k)	corresponds to the Shannon entropy (distribution of contamination)	the higher the better
		Retardation parameters of the rock environment ($kg_v.m_h^3$)	S. 18 para. 2 k)	corresponds to Sorption coefficients and retardation factors	the higher the better
K5	**Physical-chemical and geochemical properties of the groundwater**	Chemical composition and properties of the groundwater in the disposal horizon (unit according to the parameter)	S. 18 para. 2 k)	corresponds to pH, Eh, mineralisation	dependence on the parameter
K6	**Dimensions of the underground part of the repository**	Dimensions of the disposal horizon of the DGR (m^2)	S. 18 para. 2 n)	corresponds to Geometry of the repository, temperature gradient	the lower the better
		Extent of the rock block reserve (%)	S 18 para. 2 l)	corresponds to Reserve capacity of the rock block	the higher the better

* rock class according to the ČSN P 73 1005 standard, Engineering geological survey

The key comparison criteria evaluation process will include expert assessments that will identify the advantages and disadvantages of the candidate sites based on the information available at the time.

3.6 Uncertainties of the assessment

When selecting a site for the DGR, it is necessary, as with other decision-making processes, to consider both the data and the models that support the decision-making process and the uncertainties inherent in the data and models. Uncertainties may be of a natural character as given by the inherent randomness of natural phenomena (aleatory uncertainties), which can be quantified via the repeated taking of measurements in the form of a probability distribution and subsequently considered, for example, in stochastic calculations; however, such uncertainties cannot be eliminated. Concerning geological data, uncertainties are related to the natural spatial heterogeneity of the data. Such uncertainties are independent of epistemic uncertainties regarding the raw data, in contrast to models for which the uncertainties are defined parametrically and, thus, depend on epistemic uncertainties (the degree of knowledge).

The second type of uncertainty arises due to having insufficient knowledge or a lack of information on the system under study (epistemic uncertainties). Such uncertainties can be reduced by adding the missing data; nevertheless, compared to the previously mentioned types of uncertainty, they are difficult to quantify. In the case of models, this category further includes uncertainties caused by the conversion of a physical system into computational algorithms, or uncertainties caused by simplification (see 3.6.2). It is assumed that the geological research will serve to significantly reduce such uncertainties. The third, often underestimated type of uncertainty, which usually arises during the processing and interpretation of geological data, comprises ontological uncertainties, which are induced via the unintended use of the inappropriate methodology or the application of subjective assumptions during the processing and interpretation of the data. Such uncertainties are inherently unquantifiable; however, they can be minimised via the precise documentation of the data and the maximisation of transparency in terms of the acquisition and processing of the data, as well as the precise documentation of the models and codes employed.

3.6.1 Input data

The parameters of the rock environment will be determined based on the data available. The key data on the DGR disposal horizon level will be provided by deep borehole exploration research, i.e. data from drill cores and measurements taken in the boreholes themselves.

Such data is burdened to a certain degree with aleatory uncertainties as given by the nature of the laboratory and/or in-situ measurement approach. They comprise measurement uncertainties due to the non-precise determination of the measurement data or sampling uncertainties, which may arise when the selection of samples for analysis includes an element of randomness, which renders the samples insufficiently representative in terms of describing the system as a whole and its extrapolation over long distances. Such uncertainties can be partially quantified via taking a sufficient number of samples so as to ensure a representative description of the system; however, due to practical and financial reasons, the full quantification of such uncertainties is impossible. Nevertheless, such uncertainties will be reduced due to the relatively simple geological structures of the four sites.

The main focus of the exploration work, in terms of addressing uncertainties, will concern the reduction of epistemic uncertainties, i.e. filling the gaps in the knowledge of the parameters of the rock mass, where, in the first phase of the exploration research, it will be necessary to interpret the indirect measurements obtained of the rock mass based on the data set itself, knowledge of the site and the context of the methods applied. Subsequently, the outputs will be assessed and compared with the new sets of data obtained in the subsequent geological exploration phase. For example, the density, length and depth ranges of the geophysical measurements taken in the second phase of the detailed characterisation of the sites, as well as the refinement of the detailed surface-based research, will allow for the gradual reduction of the related uncertainties.

3.6.2 Mathematical models

Integral issues concerning the creation of models include the quantification of the uncertainties surrounding the input parameters, the analysis of the conceptual uncertainties of the models and the calculation of the propagation of these uncertainties. The creation of mathematical models and the conversion of natural processes into mathematical relationships necessarily involves the simplification or distortion of the real rock system whether due to insufficient knowledge of the modelled system (due, for example, to a lack of data), the non-deterministic nature of the input parameters, or the conscious simplification of the representativeness of the rock system for computational or other technical reasons. The analysis of the conceptual uncertainties of the various models will allow for the evaluation of the extent of the influence of simplification on the results of the models.

In addition to conceptual uncertainties, the propagation of the input parameter uncertainties will be analysed. Uncertainties concerning the input parameters are due to 1) an incomplete knowledge of the system and the input parameters and/or measurement errors (so-called observation noise), 2) the statistical nature of the natural phenomena, which can only be expressed applying a probability distribution approach. The uncertainties of the input parameters and relationships will be quantified applying the dispersion of the values, which, based on the knowledge of the uncertainties and their characteristics, can be expressed via the probability distribution or interval (uniform distribution). The propagation of uncertainties is assessed as the response of the quantities of interest of the model to the parameters of the model in the range of their uncertainties - incorporated into the model as the sampled probability distribution thereof. In the case of the application of probabilistic models, these uncertainties will be sampled over their entire range. In the case of conservative models, the value estimated to be the least favourable for the studied property of the system (for example the site) will be selected. The uncertainties of the models will be reduced via the acquisition and incorporation of new data, especially concerning the parameters that are relevant in terms of their influence on the results of the models.

The impact of the uncertainties on the results of the models will be evaluated based on the sensitivity analysis of the input parameters. If the parameters of the models are not linearly independent, the sensitivity analysis must take into account the mutual interactions between the parameters. Knowledge of the response of the models to the input data will allow research to be oriented towards obtaining parameters that contribute to reducing the uncertainties of the models.

3.7 Systematic assessment of the sites based on the defined methodology

The systematic assessment of the four selected sites based on the above-described three-stage procedure employs and combines internationally recognised methodologies and national legislative requirements so as to create a comprehensive individualised approach for the evaluation and comparison of the various options.

The application of an individualised approach to the site assessment process is essential in terms of ensuring the effective selection of the final and backup deep geological repository sites. This approach emphasises the identification of the advantages of each of the four sites that contribute to their safety, long-term stability and overall suitability, and also identifies the potential disadvantages of the sites.

The site assessment process is based on a consistent and systematic approach that combines fulfilling the minimum requirements in stages 1 and 2 and the detailed analysis of the key comparative criteria regarding the rock environments of the sites in stage 3. The main objectives are to identify the site that provides the best conditions for the location of the isolation part of the repository and to ensure the long-term safety of the disposed of waste.

The individualised site assessment process based on the defined criteria (Stage 3) involves subjecting each site to a detailed assessment of their advantages and potential disadvantages following the completion of the previous stages. This stage involves the application of assessment criteria and indicators that allow for the comparison of the sites based on their characteristics. All the criteria will be professionally assessed for each site based on the quantitative and qualitative values of the relevant indicators and other available data. Reference levels or intervals will be set for each indicator to allow for the assessment of whether the given result represents a **favourable, unfavourable or neutral state** in terms of each of the assessed criteria. These assessment levels will be defined in a report entitled the Detailed Description of the Comparison Criteria and Indicators, which will be compiled in the form of a follow-up document to this Methodology report.

For example, a site will be considered **favourable** for a given criterion provided that its characteristics exceed a defined level of favourability with concern to the safety or feasibility of the repository. It will be considered **unfavourable** if it evinces parameters that are relatively less favourable or riskier from the safety perspective. **Neutral** will indicate that the result is within an acceptable range. The detailed methodology employed in the decision-making process when comparing the sites will be described in a separate document.

This approach allows for the scientifically justified and clear comparison of the sites without using a weighting system. It is assumed that all the criteria will be assigned the same weighting. If the situation arises in which all the sites are evaluated equally for all the criteria (for example, as neutral), the decisive selection factor will comprise the extent of the rock block reserve, which is a key spatial prerequisite in terms of the construction of the repository.

The proposed assessment process will be supported by the consideration of the following standards and recommendations:

1. IAEA SSG-35: Provides the framework for the assessment of sites intended for nuclear facilities, including deep geological repositories, with the emphasis on the safety and technical aspects.
2. Decree No. 378/2016 Coll., Section 18: Requirements for the location of the deep geological repository in the Czech Republic.
3. International ISO 9001 and ISO 14001 standards: Supporting a systematic and transparent approach to the assessment process and its environmental impacts.
4. SÚRAO MP.22 methodology: Sets out the indicators and criteria for the assessment of sites in the Czech national context.

4 Conclusion

The considered methodology comprises the multi-stage assessment of the DGR candidate sites based on the requirements for the assessment of sites set out in Decree No. 378/2016 Coll. The approach allows for the thorough and comprehensive assessment of all the geological and safety aspects that must be considered with regard to the selection of the sites with respect to the long-term safety of the DGR. The methodology includes a detailed assessment of the isolation and retention properties of the rock environment, the structural geological characteristics, the mechanical and thermal properties of the rocks, the circulation and chemical composition of the groundwater and other key factors that are essential in terms of ensure the long-term safety of the repository.

The assessment procedure comprises three basic stages:

The exclusion of risks: This stage involves the assessment of the candidate sites in relation to legislative requirements for their suitability for the siting of the DGR. It also includes the detailed description of the sites and the creation of site descriptive models.

The demonstration of long-term safety: This stage involves the assessment of the long-term safety of the technical design approach with respect to SNF at the Reference site followed by the comparison of the transport parameters obtained from the site descriptive models of the individual sites with those of the Reference site.

The assignment of priorities: The final comparison of the sites based on the defined key comparative criteria so as to determine their relative advantages and disadvantages.

The application of this methodology will allow for the effective comparison of the candidate sites based on a systematic approach and the selection of the most suitable site for the construction of the deep geological repository in terms of ensuring and demonstrating the long-term safety of disposed of SNF and RAW for up to 1 million years. This methodology provides the basis for the decision-making process concerning the selection of the final and backup sites and allows for the determination of the safest and most sustainable solution for the disposal of radioactive waste.

5 References

ANDERSSON, J., STRÖM, A., SVEMAR, C., ALMÉN, K.-E., ERICSSON, L. E. (2000): What requirements does the KBS-3 repository make on the host rock? Geoscientific suitability indicators and criteria for siting and site evaluation. SKB TR-00-12, Swedish Nuclear Fuel and Waste Management Company, Stockholm, Sweden, 148 pp.

BLAHETA R., BYCZANSKI P., MALÍK J., KOHUT R., KOLCUN A., STARÝ J., HOKR M., KRÁLOVCOVÁ J., FRYDRYCH D. (2012): Tepelná analýza referenčního návrhu úložiště vyhořelého jaderného paliva. Závěrečná zpráva řešení projektu. ÚSTAV GEONIKY AV ČR, V. V. I., 39 STR.

BUTOVIČ A., ZAHRADNÍK O., GRÜNWALD L., BUREŠ P., ŠPINKA O., MARTINČÍK J., KOBYLKA D. (2020): Hodnocení potenciálních lokalit HÚ z hlediska klíčových kritérií technické proveditelnosti. – MS SÚRAO, TZ 457/2020, Praha

DOHNÁLKOVÁ M., VONDROVIC L., HAUSMANNOVÁ L., (2022): Technické řešení hlubinného úložiště 2022. - MS SÚRAO, TZ 580/2022_rev0.1, Praha

FEJT F., SUK P., FRÝBORT J., RATAJ J., (2024): Aktualizace databáze vyhořelého jaderného paliva – MS SÚRAO TZ 694/2023, Praha

FIEDLER F., MINÁRIKOVÁ V., ZAHRADNÍK O., VOZÁR M., VOKÁL A., POSPÍŠKOVÁ I., KRAJŇÁK M., LEŠKO M., BUTOVIČ A., ŠPINKA O., BUREŠ P., MLÁDEK P., VEVERKA A., HUMMELOVÁ E., BREJCHA A., HUPTYCH F., KRIVDA M., PLESKOTOVÁ M., PRÍBOJOVÁ M., ŠŤÁSTKA J. (2024): Metodika umístění povrchového areálu HÚ - MS SÚRAO TZ 767/2024, PRAHA

HAUSMANNOVÁ L, DOHNÁLKOVÁ M., MATUŠKOVÁ E., LAHODOVÁ Z., A AUGUSTA J. (2023): Technické řešení hlubinného úložiště 2023, MS SÚRAO TZ 711/2023, PRAHA

HAUSMANNOVÁ L., DOHNÁLKOVÁ M., MATULOVÁ M., ŠEDIVÝ T., VENCL M., POPELOVÁ E., AUGUSTA J., SMUTEK J., TOUŠ M., GOLUBKO A., LAHODOVÁ Z., KONOPÁČOVÁ K., LUKIN D., MATUŠKOVÁ E., MECOVÁ M., MIKLÁŠ O., POSPÍŠIL M., ŠTEFANOVÁ E A VRBA T. (2024): Plán výzkumu a vývoje SÚRAO 2024-2028, MS SÚRAO TZ 746/2024, PRAHA

HAVLOVÁ V., ČERVINKA R., PERTOLDOVÁ J., BUKOVSKÁ Z., MIXA P., HROCH T., ŠTĚDRÁ V., MILICKÝ M., ŘÍHA J. (2018): Hierarchie kritérií či indikátorů vhodnosti lokalit a způsob hodnocení lokalit, MS SÚRAO TZ285/2018, Praha

HAVLOVÁ V., PERTOLDOVÁ J., MIXA P., HROCH T., ŠTĚDRÁ V., BAIER J., MILICKÝ M., BUKOVSKÁ Z., ČERNÝ M., DUDÍKOVÁ B., DUŠEK K., FRANĚK J., GVOŽDÍK L., HOLEČEK J., JANKOVEC J., JELÍNEK J., KACHLÍKOVÁ R., KUČERA R., KUNCEOVÁ E., PETYNIAK O., POLLÁK M., RAPPRICH V., RUKAVIČKOVÁ L., ŠVAGERA O., UHLÍK J., VOJTĚCHOVÁ H., ŽÁČKOVÁ E. (2020): Hodnocení potenciálních lokalit HÚ z hlediska klíčových kritérií dlouhodobé bezpečnosti. Lokalita Hrádek. – MS SÚRAO, TZ 453/2020, Praha

KALÁB Z., ŠÍLENÝ J., LEDNICKÁ M., JECHUMTÁLOVÁ Z. (2015): Seismická stabilita území. - MS SÚRAO, TZ 26/2015, Praha

KRAJÍČEK L., SKOŘEPA Z., HUBÁČEK O., MAREK P. (2020): Hodnocení potenciálních lokalit HÚ dle klíčových environmentálních kritérií. – MS SÚRAO, TZ 456/2020, Praha

MIKLÁŠ, O., VRBA, T., LUKIN, D., LAHODOVÁ, Z., POPELOVÁ, E. (2023): Modelovací strategie pro vývoj hlubinného úložiště. MS SÚRAO TZ 698/2023, PRAHA.

MIXA P., FRANĚK J., RUKAVIČKOVÁ L., MILICKÝ M., SKÁCELOVÁ Z., HROCH T., TENENKO V., ŠPAČEK P., NOVOTNÝ J., BUKOVSKÁ Z., ČERNÍK M., DOBEŠ P., DONÁT A., HANÁK J., HANŽL P., HAVLOVÁ V., PRCHAL K., HRDLIČKOVÁ K., JELÉNEK J., JELÍNEK J., KONÍČEK P., KYCL P., LEXA O., PECINA V., PERTOLDOVÁ J., SEDLÁČEK J., SOUČEK K., STEINOVÁ J., SVOBODA J., ŠTRUPL V., ŠVAGERA O., VAVRO M., WACLAWIK P. (2019): Aktualizace a konkretizace projektu geologických prací na hypotetické lokalitě – MS SÚRAO, TZ 390/2019, Praha

Nuclear Energy Agency (NEA). 2008. "Moving Forward with Geological Disposal of Radioactive Waste: A Collective Statement by the NEA Radioactive Waste Management Committee (RW MC)." NEA No. 6433. OECD, Paris.

PERLÍN, R., KOMÁREK, M. (2024): Studie ekonomických a sociodemografických přínosů a rizik HÚ ve vybraných lokalitách pro rozvoj dotčených regionů – etapa 3 A: Identifikace a vyhodnocení možných přínosů a rizik pro dotčené regiony vyplývajících z aktuálního technického řešení HÚ (včetně umístění PA) ve vybraných lokalitách. - MS SÚRAO, TZ 775/2024

POSIVA (2013): Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto – Performance Assessment 2012. – POSIVA Report 2012-04, POSIVA Oy, Olkiluoto, Finland.

POSPÍŠKOVÁ I., A KOL. (2024): Metodika umístění povrchového areálu hlubinného úložiště. MS SÚRAO TZ 767/2024, PRAHA, dokument v přípravě

SKB (2015): TR-11-01 Long-term safetyfor the final repository for spent nuclear fuel at Forsmark. Svensk Kärnbränslehantering AB.

SKB (2011): R-11-07 Site selection – Siting of the final repository for spent nuclear fuel. Svensk Kärnbränslehantering AB.

VALTER M., MACÁKOVÁ A., MAREDA L., ŠTOR T., VENCL M. (2023): Strategie vytváření popisných modelů potenciálních lokalit pro umístění hlubinného úložiště v ČR. MS SÚRAO TZ 705/2023, PRAHA.

VOKÁL A., POSPÍŠKOVÁ I., VONDROVIC L., STEINEROVÁ L., KOVÁČIK M. A ČECH P (2017): Metodický pokyn SÚRAO MP.22, Požadavky, indikátory vhodnosti a kritéria výběru lokalit pro umístění hlubinného úložiště, vydání 03, 2017

VONDROVIC L., AUGUSTA J., VOKÁL A., HAVLOVÁ V., KONOPÁČOVÁ K., LAHODOVÁ Z., POPELOVÁ E., URÍK J., BAIER J., BUKOVSKÁ Z., BUREŠ P., BURIÁNEK D., BUTOVIČ A., [4]ČERNÝ M., DUŠEK K., FRANĚK J., GRÜNWALD L., GVOŽDÍK L., HANŽL P., HOLEČEK J., HRDLIČKOVÁ K., HROCH T., HUBÁČEK O., JELÉNEK J., JELÍNEK J., KACHLÍKOVÁ R., KOBYLKA D., KRYŠTOFOVÁ E., KUČERA R., KUNCEOVÁ E., JANKOVEC J., KRAJÍČEK L., MAREK P., MARTINČÍK J., MILICKÝ M., MIXA P., NAHODILOVÁ R., PERTOLDOVÁ J., PETYNIAK O., POLÁK M., RUKAVIČKOVÁ L., SEDLÁČKOVÁ I., SKOŘEPA Z., SOEJONO I., ŠÍR P., ŠPINKA O., ŠTĚDRÁ V., ŠVAGERA O., UHLÍK J., VERNER K., VOJTĚCHOVÁ H., ZAHRADNÍK O., ŽÁČEK V., ŽÁČKOVÁ E. (2020): Výběr potenciálních lokalit hlubinného úložiště v ČR pro navazující etapu prací po roce 2020. – MS SÚRAO, TZ465/2020, Praha.

VONDROVIC L., AUGUSTA J., BÍLÁ M., DOHNÁLKOVÁ M., DUDA V., EHLER T., GORČICA L., HAUSMANNOVÁ L., LAHODOVÁ Z., MÁČELOVÁ M., POPELOVÁ E., ROSENDORF T., URÍK J., VOKÁL A. (2022): Vyhodnocení vlivu Nařízení Komise o Taxonomii EU pro oblast jaderné energetiky do systému nakládání s radioaktivním odpadem v ČR ve vztahu k činnostem SÚRAO. – MS SÚRAO TZ 601/2022, Praha.

Legislation and regulations/decrees

Policy 2019: The Management of Radioactive Waste and Spent Nuclear Fuel in the Czech Republic Policy approved on 26 August 2019 via Resolution of the Government of the Czech Republic No. 597/2019

SÚJB Decree No. 378/2016 Coll., on the siting of nuclear facilities, CR, 2016

Decree No. 369/2004 Coll., on the design, implementation and assessment of geological work, notification of the risk geofactors and the procedure for calculating reserves of valuable deposits, CR, 2004

Act No. 100/2001 Coll., on environmental impact assessment and the amendment of certain related acts, as amended

Act No. 62/1988 Coll., Act of the Czech National Council on geological works and on the Czech Geological Office, CR, 1988

Act No. 114/1992 Coll., on nature and landscape protection, as amended

Act No. 263/2016 Coll., the Atomic Act, CR, 2016

Act No. No. 53/2024 Coll., on procedures related to the deep disposal of radioactive waste

Act No. 283/2021 Coll., the Building Act, CR, 2021

Update No. 4 of the Territorial Development Policy of the Czech Republic, 2021

Government Resolution No. 9/2023

Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 regarding economic activities in selected energy sectors and Delegated Regulation (EU) 2021/2178 regarding the specific disclosure of information in relation to these economic activities

IAEA (2011a): Disposal of Radioactive Waste, Specific Safety Requirements, No. SSR-5, Pub. 1449, – International Atomic Energy Agency, Vienna.

IAEA (2011b): Geological disposal facilities, Specific Safety Guide, SSG-14, Pub. 1483, Appendix I ”Siting of geological disposal facilities”. – International Atomic Energy Agency, Vienna.

IAEA (2015): Site Survey and Site Selection for Nuclear Installations, Specific Safety Guide, No. SSG-35, Vienna, 2015

IAEA (2016): Site Evaluation for Nuclear Installations, Safety Requirements No. NS-R-3 (Rev. 1), IAEA Safety Standards. – International Atomic Energy Agency, Vienna.

SÚJB (2024): METHODOLOGY FOR ASSESSING THE SAFETY OF THE DEEP REPOSITORY USING SAFETY INDICATORS Safety manual, BN-OD-1.2 (REV. 0.0), Prague, 2024.

Other

Agreement on cooperation between the State Office for Nuclear Safety and SÚRAO in the field of the development of the deep geological repository in the Czech Republic, Prague 2024

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