Technical report 423/2019

METHODOLOGY USED FOR REDUCING THE NUMBER OF SITES FOR THE DEEP GEOLOGICAL REPOSITORY IN THE CZECH REPUBLIC IN 2019-2020

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Prague, 2019

SÚRAO

TITLE OF THE REPORT: Methodology used for reducing the number of sites for the deep geological repository in the Czech Republic in 2019-2020

PROJECT NAME: Development of the Deep Geological Repository

Bibliographic record:

VONDROVIC L., AUGUSTA J., VOKÁL A., HAVLOVÁ V., KONOPÁČOVÁ K., LAHODOVÁ Z., POPELOVÁ E., URÍK J., BUKOVSKÁ Z., BUTOVIČ A., FRANĚK J., HROCH T., JELÍNEK J., KOBYLKA D., KRAJÍČEK L., MILICKÝ M., MIXA P., PERTOLDOVÁ J., SKOŘEPA Z., ŠTĚDRÁ V., ŠVAGERA J., UHLÍK J., ZAHRADNÍK O., ELIÁŠ M., PROCHÁZKOVÁ P. (2019): Methodology used for reducing the number of sites for the deep geological repository in the Czech Republic in 2019-2020 – MS SÚRAO, TZ 423/2019

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Abbreviations:

AHP	Analytical hierarchisation process
DFN	Discrete fracture network
DGR	Deep geological repository
DSS	Decision support system
EDU	Dukovany nuclear power plant
EdZ	Excavation disturbed zone
EDZ	Excavation damaged zone
EIA	Environmental impact assessment
ETE	Temelín nuclear power plant
EU	European Union
EURATOM	European Atomic Energy Community
GIS	Geographic information system
HLW	High-level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate-level waste
LANDEP	Landscape ecological planning
MDE	Multi-destination evaluation
NNS	New nuclear sources
NPP	Nuclear power plant
RAW	Radioactive waste
SNF	Spent nuclear fuel
SÚJB	State Office for Nuclear Safety
SÚRAO	Czech Radioactive Waste Repository Authority

UNESCO	United Nations Educational, Scientific and Cultural Organisation
WDP	Waste disposal package

1 Introduction

1.1 Starting point

Radioactive waste is generated in the Czech Republic via the peaceful use of nuclear energy and ionising radiation in the industry, healthcare and research sectors. Spent nuclear fuel (hereinafter referred to as SNF) and high-level waste from its reprocessing (if applied), and radioactive waste generated via the operation and decommissioning of nuclear facilities (hereinafter referred to as RAW) comprise radioactive waste risk categories. The source of such waste is primarily the operation of nuclear reactors. According to Article 23 of Directive EU2011/70/EURATOM, it is currently generally accepted at the technical level that the safest and most sustainable alternative for addressing the final stage of high-level waste and spent nuclear fuel management is the disposal of such waste in deep geological repositories. With respect to the Czech Republic, this principle is further supported in the "Concept of RAW and SNF management in the Czech Republic" state strategic document of 2002 and the update thereof of 2019 (hereinafter referred to as the Concept), which proposes the final disposal of such waste in deep geological formations.

The aforementioned Concept obliges the state to develop a deep geological repository, the commissioning of which is planned for 2065. The Czech Radioactive Waste Repository Authority (hereinafter referred to as SÚRAO) is a state technical organisation, the activities and management of which are regulated by Section 113 of Act No. 263/2016 Coll., the Atomic Act. SÚRAO's mission is to ensure the safe disposal of existing and future radioactive waste in accordance with set requirements for nuclear safety and the protection of the population and the environment, and in accordance with the currently valid Concept.

The methodology presented in this report for the reduction in the number of candidate sites for the deep geological repository involves the application of the suitability indicators and criteria described later in this report and in the SÚRAO MP.22 document (Vokál et al. 2017) that allow for the comparison of the nine currently considered candidate sites for the location of the deep geological repository for SNF and RAW (Fig. 1), and the subsequent recommendation of preferred sites to the government of the Czech Republic with a view to the next stage of work concerned with the further development of the deep geological repository. The methodology will be applied with the aim of reducing the number of candidate sites for the location of the deep geological repository as determined by the results of SÚRAO-commissioned research projects conducted in the period 2014-2019. The sites are: Březový potok (Plzeň region, Klatovy district), Čertovka (Plzeň and Ústí-nad-Labem regions, Louny and Plzeň-north districts), Čihadlo (South Bohemia region, Jindřichův Hradec district), Horka (Vysočina region, Třebíč and Žďár nad Sázavou districts), Hrádek (Vysočina region, Jihlava and Pelhřimov districts), Janoch (ETE-South, South Bohemia region, Týn nad Vltavou and České Budějovice districts), Kraví Hora (Vysočina and South Moravia regions, Žďár nad Sázavou and Brno-venkov districts), Magdaléna (South Bohemia region, Písek and Tábor districts) and Na Skalním (EDU-West, Vysočina region, Třebíč district). These sites have been subjected to multi-stage assessments by specialists in the areas of safety, technical feasibility and environmental impacts. The assessment methodology presented herein is based on the application of weighting criteria to the data obtained up to autumn 2019. The data provided for the characterisation of the sites on the basis of their near-surface geological structures; the level of the description of the sites is comparable. Following the completion of the assessment process, and in line with recommendations from the specially-established Expert Advisory Panel based on the assessment studies, a proposal concerning preferred sites for the next stage of SÚRAO-led research work will be submitted to the responsible ministry (the Ministry of Industry and Trade). Following the standard inter-ministerial comments procedure, the proposal of the preferred sites will be submitted to the Government of the Czech Republic for approval.

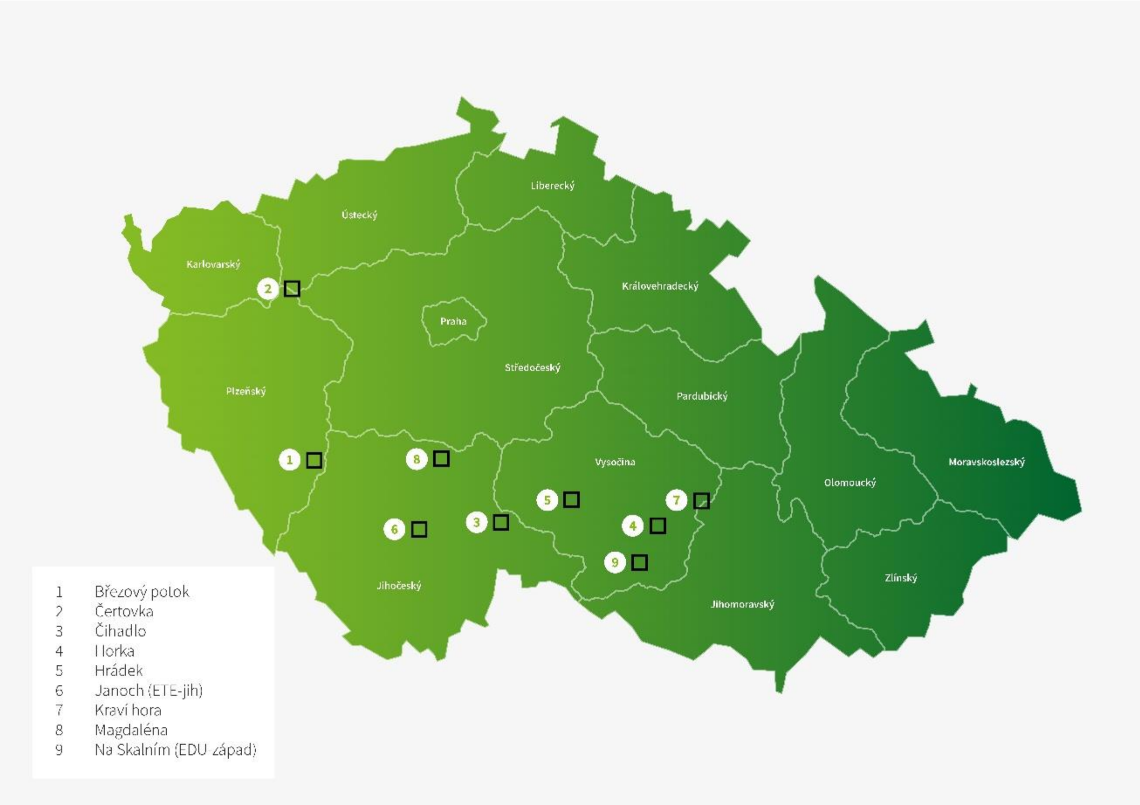

Fig. 1 Potential sites for the Czech deep geological repository in 2014-2019

1.2 Related documents

The methodology presented in this report is based on requirements set out in Czech legislation and other relevant conceptual materials, in particular the following:

- Act No. 263/2016 Coll., the Atomic Act, as amended;
- Act No. 100/2001 Coll., on Environmental Impact Assessment and on amendments to certain related Acts, as amended;
- Decree No. 378/2016 Coll., on the siting of nuclear facilities;
- Update of the Concept of RAW and SNF Management in the Czech Republic (hereinafter referred to as the Concept), approved by a Government of the Czech Republic resolution on 26 August 2019;
- SÚRAO MP.22 methodological guidelines (Vokál et al. 2017 - hereinafter referred to as MP.22), Requirements, suitability indicators and criteria for the selection of sites for the location of a deep geological repository, third edition, 27 November 2017.

1.3 Validity

The validity of this report is limited to the approval of the determined preferred sites by the Czech government in 2020. The report serves for the more detailed description of the assessment methodology determined via MP.22 criteria for the reduction in the number of sites from nine to four in 2019-2020. The criteria are valid for both SÚRAO employees and other experts in the supply chain who participate in the process surrounding the assessment and the reduction in the number of potential sites for the deep geological repository.

2 Approach to DGR site selection

The selection of a site suitable for the location of the future deep geological repository for SNF and RAW (DGR) comprises several sub-stages as determined by the Concept and the requirements of the Czech government. The sites will be assessed during each selection stage according to the criteria set out in the MP.22 management document. The criteria are based on the requirements of Czech legislation and IAEA recommendations.

The assessment methodology presented herein is based on the following assumptions:

- The assessment process and the reduction in the number of sites will be conducted in 2019-2020 based on data obtained from the surface and near-surface components of the sites with uncertainties remaining in terms of the siting of the underground and surface complexes of the nuclear facility.

  Rationale: This assumption is based on the requirements of the Concept and the milestones set out in Resolution of the Government of the Czech Republic No. 464 of 18 July 2018 and a decision of the SÚRAO (supervisory) Board - Minutes of the 5th meeting of the SÚRAO Board, Resolution 01/05, January 2019.

- The assessment will be conducted in the form of the summarisation of the following aspects: safety (long-term and operational), technical feasibility and environmental impacts.

  Rationale: The applied criteria were defined for the above-mentioned areas in the MP.22 document. The methodology described in this report, however, considers only the technical criteria, i.e. the “acceptability of the proposal by the municipalities concerned” criterion is not taken into account in the methodology and it will not be applied at the technical level for site comparison purposes. Socio-economic factors will be considered in the context of higher-level decision-making processes, but not at the technical assessment level.

- The assessment process will proceed in two stages. The first stage will comprise the testing of the various exclusion criteria as set out in MP.22 and the Atomic Act, No. 263/2016 Coll. according to the degree to which they apply; the second stage will consist of the comparison of the sites according to so-called key criteria (indicators) as defined by the methodology described in this report.

  Rationale: Due to the various uncertainties inherent in the currently available descriptions of the sites, it is not always possible to clearly determine whether a given criterion respects all the exclusionary requirements. The assessment of the exclusion criteria will, therefore, take into account the highest possible level of knowledge of the characteristics of the sites, and those criteria and indicators that best allow for the differentiation of the sites during this phase will be emphasised in the mutual comparison process.

- Those sites that are assessed as being relatively more suitable at this stage will not necessarily be confirmed as such in the next site characterisation stage; therefore, those sites that do not advance to the stage of research as decided according to the methodology considered in this report will be considered as backup sites, and SÚRAO reserves the right to return them to the assessment process.

  Rationale: Due to the current level of knowledge and the relatively high number of sites, it is not yet possible to unambiguously confirm that certain criteria, including exclusion criteria, are met or not. Should it be determined that exclusion criteria apply according to Decree No.

378/2016 Coll. at a site during the next stage of research, the site will be excluded from the characterisation process and will be replaced by one of the backup sites.

- The evaluation of the range of indicators will be based on the expert judgment of the respective specialists due to the uncertainties associated with the relatively limited amount of information available.

  Rationale: Due to the nature of the data from the sites, it will not always be possible to treat such data with a high degree of certainty with respect to some of the criteria and indicators (they will always be burdened with a certain level of uncertainty of the information available). SÚRAO will, therefore, apply an expert evaluation approach to cases where the determination of the value of a certain indicator and the determination of the weightings of the criterion indicators are based on expert estimation by the relevant expert team, and the weightings of the criteria will be set according to the multi-criteria analysis (see Chapter 5.4).

- The assessment performed aimed at reducing the number of sites does not, and indeed cannot, fully meet the requirements arising from the Atomic Act, No. 236/2016 Coll. and its implementing regulations, i.e. Decree No. 378/2016 Coll. on the siting of nuclear installations.

  Rationale: Due to the schedule set out in the Concept and the stage of development of the DGR, it is not possible that the scope of the site description process be at the level required for the detailed documentation needed for the issuance of a permit from the State Office for Nuclear Safety for the siting or construction of nuclear facilities. Therefore, it is currently not possible to fully document all the requirements imposed by legislation on the siting of a nuclear facility at all the candidate sites, especially due to the absence of data from the planned depth of the DGR. Therefore, only those criteria will be evaluated for which sufficient information that can be documented or expertly determined is available.

- The assessment process will be performed by SÚRAO and its team of suppliers; the assessment process will subsequently be confirmed by the Expert Advisory Panel.

  Rationale: SÚRAO is responsible for conducting its own technical assessment. Supervision will be provided by other experts with knowledge of the process through the Expert Advisory Panel. The assessment of the criteria and indicators for the various sites will be based on the evaluation of the technical issues involved in the process by a team of specialists who have long-term experience of the issues involved.

- The assessments conducted concerning the reduction in the number of sites will consider indicator “grading” values where available, as well as the weightings of the individual criteria and indicators.

  Rationale: The assessment process will be based on the consideration of the significance of the various criteria and indicators. The significance of the criteria and, where appropriate, the indicators included in the respective criterion, will be determined by their weightings (importance). The weightings of the criteria will be determined using the Analytical Hierarchical Process (AHP), see Saaty (1980). With regard to the stage of the DGR development process and the uncertainty of the various indicators, their weightings will be determined via expert estimates compiled by the relevant expert teams.

3 Data used and specific site description areas

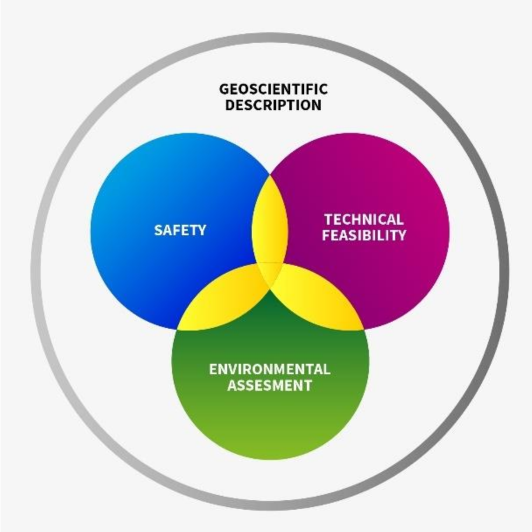

Fig. 2 Characteristics of the data used

3.1 Data used

The assessment and comparison of the sites will be performed on the basis of data obtained by SÚRAO in the period 2000-2019 with an emphasis on the synthesis of the data in the form of descriptive models of the sites created mainly in the period 2014-2018 (see the review in Havlová et al. 2018 a-i, Vokál et al. 2018 a-i, Marek et al., 2018 a-g, Krajíček et al., 2018, Bureš et al., 2018 a-d, Špinka et al., 2018 a-c, Navrátilová et al., 2018, Hanžl et al., 2018, Martinčík et al., 2018 a-i). The geological data that forms the basis of the description and subsequent evaluation of the sites (Fig. 2) was obtained based on the extensive study of the near-surface components of the sites and the detailed research of archived data that was obtained without the conducting of technical (especially drilling) work. Thus, the data is limited and burdened by a certain degree of uncertainty arising from the absence of data from the anticipated depth of the DGR. The assessment methodology is based on the assumption that all the significant rock interfaces (higher-order faults, lithological unit contacts, etc.) will be identified via the high-quality geological research results already available and the results of previously conducted SÚRAO research projects (summary in Franěk et al. 2018, Mixa et al. 2019). The final assumption concerns the application of descriptive models of the sites (e.g. geological, hydrogeological and transport models - Havlová et al. 2018 a-i, Vokál et al. 2018 a-i) and the updating thereof based on subsequent geophysical research results (Mixa et al. 2019), which can be used so as to determine the quantitative hydrogeological characteristics of the sites for the effective comparison thereof. Furthermore, the assessments will also include the consideration of the results of updated DGR design proposals (update of the results of reports by Bureš et al. 2018 a-d, Špinka et al.2018 a-c, Navrátilová et al. 2018, Hanžl et al. 2018). With respect to the consideration of environmental impacts, the assessment process will take into account data on the preliminary siting of the surface complex of the DGR and on previously conducted Environmental Impact Studies (Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Hanžl et al. 2018, Navrátilová et al. 2018, Skořepa et al., 2018 a, Marek et al., 2018 a-g, Krajíček et al., 2018, Skořepa et al., 2018 b), also taking into account the latest knowledge resulting from ongoing geophysical research activities (Mixa et al. al. 2019).

3.2 Assessment areas

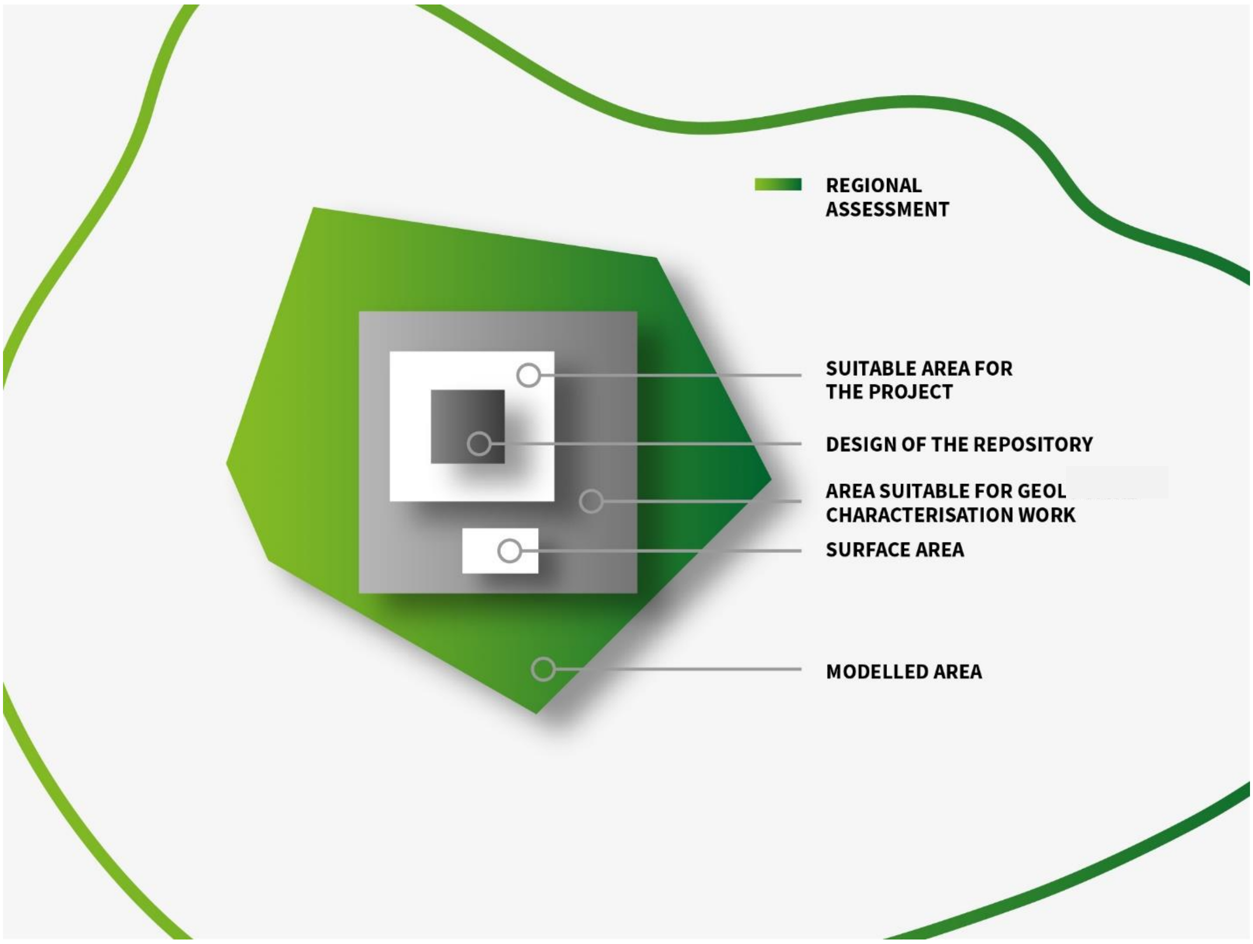

Fig. 3 Site description areas for assessment purposes - main components

The assessment of the candidate sites for the DGR will be conducted at various levels of detail. Based on the results of research conducted to date in various areas (e.g. Havlová et al. 2018 a-i, Vokál et al. 2018 a-i, Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Marek et al. 2017 a-g, Navrátilová et al. 2018, Málek et al. 2018, Zahradník et al. 2020, Butovič et al. 2020), the following aspects were defined for assessment purposes:

a) **Design of the repository:** the minimum extent of the repository at the respective site defined on the basis of a preliminary design proposal for each site taking into account the vertical disposal method and the updating thereof based on data obtained from geophysical research projects. With respect to the comparison of the sites, the vertical disposal mechanical excavation variant will be applied which, while it is the "gentlest" method with respect to the rock environment, it produces the highest volume of excavated material of the various options available. Moreover, a preliminary safety analysis has already been conducted for this variant (Trpkošová et al. 2018). The repository design (the disposal wells) covers the consideration of spatial units (polygons) already defined for the location of the DGR, as well as potentially suitable rock blocks at the sites (hereinafter referred to as homogeneous blocks). Only those polygons that define areas for SNF and RAW disposal are included in the assessment process.

b) **Surface area:** areas with minimum conflicts of interest on the surface at the various sites that are deemed preliminarily suitable for the siting of the surface complex of the DGR.
c) **Suitable area for the project:** a rock block at a depth of approx. 500 m below the surface of the terrain, without the occurrence of category I faults, that will form the isolation component of the repository (i.e. a rock block that is preliminarily suitable for the location of the disposal wells). The isolation part of the facility is defined in the polygons as an area suitable for the conducting of geological work.
d) **Homogeneous block:** a block of rock at a depth of approx. 500 m below the surface of the terrain which is suitable for the project and which features no category II faults or rock areas that cannot be used in the project (see below).
e) **Unusable rock areas** are defined as areas that are potentially suitable for disposal, but which have dimensions (especially in terms of volume) that cannot practically be used for disposal purposes.
f) **Area suitable for geological characterisation work:** an area in which geological investigation work is deemed possible in the future aimed at precisely defining the area best suited to the project, i.e. an area in which it is highly probable that geological characterisation work can conducted for the determination of the rock mass that best meets requirements concerning the isolation part of the DGR.
g) **Modelled area:** the area that needs to be characterised in order to create descriptive models of the sites that provide for a clearer understanding of the broader context (for various modelled simulations - geological, hydrogeological and transport models; the extent of the assessed modelled polygons may differ considerably). The modelled area covers the wider vicinities of areas deemed suitable for the project, and is important with respect to the assessment process in terms of obtaining selected criteria and suitability indicator values. Modelled simulations for the purpose of the quantification and description of the hydrogeological conditions of the sites must take into account regional boundary conditions. Furthermore, the modelled area is closely linked to the assessment of indicators that rely on data obtained from the wider region (e.g. the assessment of the stability of both the site itself and the local climate).
h) **Regional assessment:** the larger-scale area that must be characterised in order to meet the requirements of Decree No. 378/2016 Coll. (concerning e.g. seismicity).

4 Assessment

4.1 Assessment procedure

The SÚRAO MP.22 document provides a summary of the requirements, indicators and criteria that are relevant in terms of the assessment of the suitability of a site for the location of the DGR. The assessment of the sites in the current stage will be conducted with respect to safety (operational and long-term), technical feasibility and environmental impact criteria. The assessment will be conducted in the form of two basic assessment stages (Fig. 4):

1. First assessment stage - risk exclusion (assessment of the exclusion criteria in all areas according to the exclusion criteria set out in MP.22, Tab. 1);
2. Second assessment stage - benefits analysis (comparison of the sites).

In view of the research conducted in the current phase of development (the near-surface characterisation of the nine sites) and the limited extent of the information available, not all of the defined exclusion and comparison criteria and indicators from MP.22 can presently be applied. The principle of the assessment and comparison presented herein comprises the application of such criteria and indicators (i.e. key criteria) according to Chapter 4. which serve to sufficiently differentiate the sites and which can reasonably be applied at the time of the site assessment process.

Fig. 4 Site assessment process

4.2 First assessment stage – risk exclusion

In accordance with Czech legislation and international recommendations, the MP.22 document defines criteria that exclude the siting of the DGR in the event that no suitable technical or administrative remediation measures are available. If such measures exist, the costs of their implementation will be included in the costs of the construction of the DGR.

If the assessed site is in conflict with any of the exclusion requirements or criteria (Tab. 1) and no suitable technical or administrative remediation measures are available, the site will no longer be considered for further research (see Fig. 4) and will be included in the excluded site category.

For each of the sites, the following factors will be assessed in terms of exclusion criteria based on requirements defined in Decree No. 378/2016 Coll. (see Tab. 1 for a summary of the exclusion criteria):

1) **The information available on the assessed properties of the site leads to the conclusion that the requirement will be met (the opportunity outweighs the risk), i.e. no property has been identified at the site that leads to it being excluded in terms of the location of the repository.**
2) **The information obtained on the assessed properties indicates an obstacle or problem in terms of meeting the respective requirement, or potential problems with the demonstration thereof (the risk outweighs the opportunity).**
3) **Insufficient data is available to assess the respective criterion at any given stage of the site selection process.**

Should any obstacles be identified that may prevent the siting of the DGR at a given site, the potential for the remediation of the obstacle or problem by means of technical or administrative measures will be considered. The fact that at any given stage of the assessment process it is clear that there is a lack of information on the geological structure at the depth of the repository, the hydrogeological situation or the properties of the rocks at the depth corresponding to that of the DGR, will burden the assessment process with a degree of uncertainty. A further assessment uncertainty factor comprises the approximation of information from the surface characterisation research, which is often based on expert estimates provided by the various research teams. A number of indicators serve for the assessment of the entire wider area and not the land on which the DGR will be sited (surface and underground parts) (see Section 2 of Decree No. 378/2016 Coll.). The “land of a nuclear facility” refers to that part of the wider area determined for the siting of the DGR in which the facility will be directly located and that will be affected during its life cycle following closure. In the case of the underground complex, this comprises the rock block that forms the isolation part of the DGR at a depth of 500 m. The decree often sets out the fulfilment of certain requirements concerning siting and the documentation of safety only for the land of the DGR. Moreover, it is necessary to assess whether the presence of an obstacle is significant, insignificant or can be overcome via technical means. A summary of the exclusion criteria is provided in Tab. 1. Exclusion criteria will be assessed for the underground and surface complexes of the repository and the wider region (see Fig. 3) by specialist research teams with concern to safety (long-term and operational), technical feasibility and environmental impacts.

Tab. 1 Summary of the exclusion criteria

ID	Criterion	Criterion description/value	Source	Area of assessment
1.	**Project exclusion criteria**			
1.1	**Size of the usable rock mass**	The usable rock mass must be of such dimensions that, in compliance with technical and safety requirements, it is able to host the expected amount of waste to be disposed of with a reserve. Fulfilment: the dimensions of the rock mass will be evaluated based on the expected amount of waste to be disposed of (9500 tonnes of SNF and 4500 m^3 of HLW/ILW).	Decree No. 378/2016, Sect. 18 (2) a)	Promising area for the project construction work Rationale for the assessment area: this area represents the target lithology for disposal and, as such, is assessed in terms of a territorial reserve.
1.2	**Hydrogeological conditions**	Very unfavourable hydrogeological conditions for the siting of the DGR may lead to the exclusion of some parts of the repository area; however, as a rule, most unfavourable conditions can be remedied via technical or administrative measures. The preliminary criterion is the value of water flow into the disposal wells (0.1 l/min) and the disposal tunnels (0.25 l/min). Fulfilment: this criterion will not yet be assessed due to a lack of data from the disposal depth.	Decree No. 378/2016, Sect. 18 (4) a)	Promising area for the project construction work Rationale for the assessment area: this criterion is closely linked to the disposal area, i.e. to the conditions found following excavation.
1.3	**Ensuring stability for construction**	Occurrence of: a) volcanic rocks of the Pliocene to Holocene eras or indications of post-volcanic activity, in particular the outflow of gases or mineral waters associated with past	Decree No. 378/2016, Sect. 9 (3) a)	Surface area Rationale for the assessment area: these requirements arise mainly from Decree No. 378/2016, concerning the land of the nuclear facility (see above), in

ID	Criterion	Criterion description/value	Source	Area of assessment
		volcanic activity; to a distance of 5 km. Fulfilment: the occurrence of such rocks will be assessed based on geological data available on the sites (Franěk et al. 2018) and the relevant geophysical project (Mixa et al. 2019).		this case the surface area.
		b) phenomena according to para. 2 c) 1. caverns and karst formations, 2. deep mines, underground gas storage facilities and other facilities constructed in underground spaces, and indications of previous mining activities, 3. pumping wells and other infrastructure for the extraction of minerals and groundwater, including the subsidence or deformation of the surface, and that: 1. on the land of the nuclear facility or 2. outside the land of the nuclear facility if there is the risk of the subsidence or deformation of the surface of the area for the siting of the nuclear facility with a potential impact on nuclear safety. Fulfilment: this criterion will be assessed on the basis of the ongoing IG mapping of	Decree No. 378/2016, Sect. 9 (3) b)	

ID	Criterion	Criterion description/value	Source	Area of assessment
		the candidate sites and data obtained from the geological description of the sites (Franěk et al. 2018, Mixa et al. 2019).		
		c) slope movements that reduce nuclear safety Fulfilment: this criterion will be assessed on the basis of the ongoing IG mapping of the candidate sites (Aue et al.; Rout et al.; Pospíšil et al.; Schröfel et al., 2018).	Decree No. 378/2016, Sect. 9 (3) c)	
		d) persistently unsuitable foundation soil properties, namely 1. unsuitability of the foundation soils for the foundations of components important from the point of view of nuclear safety; in the case that the average speed of transverse waves in the foundation soil is lower than 360 m/s, 2. occurrence of foundation soil with a loading capacity of less than 0.2 MPa, 3. occurrence of sedimentary or strongly swellable foundation soils, 4. the presence of a foundation soil classified as moderately organic or highly organic, or 5. occurrence of soil liquefaction. Fulfilment: this criterion will be assessed on the basis of the ongoing IG mapping of the candidate sites (Aue	Decree No. 378/2016, Sect. 9 (3) d)	

ID	Criterion	Criterion description/value	Source	Area of assessment
		et al. 2018; Pospíšil et al. 2018; Schröfel et al., 2018)		
1.4	**Number and complexity of conflicts of interest**	Characteristics that are in conflict with a protection or safety zone shall result in the exclusion of the consideration of the construction of a nuclear facility. This constitutes the interference of the land of the nuclear facility in a protection zone pursuant to Section 15, para. 1 a) and b) of Decree No. 378/2016 Coll., i.e.: a) road protection zone, b) railway protection zone, Fulfilment: this criterion will be assessed in terms of the potential for the siting of the surface area on the basis of the assessment of conflicts of interest	Decree No. 378/2016, Sect. 15 (2)	Surface area Rationale for the assessment area: this concerns requirements set out mainly in Decree No. 378/2016 referring to the land of the nuclear facility, in this case the surface area.
2.	**Long-term safety exclusion criteria**			
2.1	**Geological characteristics**			

ID	Criterion	Criterion description/value	Source	Area of assessment
2.1.1	**Describability and predictability of the homogeneous rock blocks**	The geological conditions of the repository must allow for the creation of a credible complex, spatial geological model. The depth extent of the rock mass must be sufficient with regard to the maximum expected depth of the repository (minimum of 400 m). An unacceptable degree of uncertainty in the identification and description of regional and local fault zones and other geological structures may preclude the siting of the repository. In the first phase of surface geological research, however, this factor is not necessarily excluding and can be used to compare the sites. Fulfilment: this criterion will be assessed on the basis of 3D structural-geological models of the sites (Franěk et al. 2018)	Decree No. 378/2016, Sect. 18 (4) b)	Promising area for the project construction work Rationale for the assessment area: this area defines the design of the repository and, as such, assumes the geologically most suitable area for the location of the DGR at the site.
2.1.2	**Variability of the properties**	If the variability of the properties is such that it does not allow for the preparation of a reliable 3D geological, hydrogeological, geomechanical and geochemical model, the site shall be excluded. In the first phase of surface geological research, however, this factor is not necessarily excluding and can be used to compare the sites. Fulfilment: this criterion will be assessed on the basis of the 3D structural-geological models of the sites (Franěk et al. 2018) and data provided by the geophysical research project (Mixa et al. 2019).	Decree No. 378/2016, Sect. 18 (4) b)	Promising area for the project construction work Rationale for the assessment area: this area defines the design of the repository and, as such, assumes the geologically most suitable area for the location of the DGR at the site.

ID	Criterion	Criterion description/value	Source	Area of assessment
2.2	**Hydraulic characteristics**			
2.2.1	**Presence of aquifers in the isolation part of the repository**	The presence of aquifers (i.e. a hydraulically permeable environment with a significant water supply) in the isolation part of the repository constitutes an exclusion criterion for the siting of the repository. Fulfilment: the accumulation capacities of the rock will be assessed according to hydrogeological models of the sites and data from the HEIS VUV national water resources database.	Decree No. 378/2016, Sect. 8 (2)	Promising area for the project construction work Rationale for the assessment area: this area defines the design of the repository and, as such, assumes the most suitable area for the location of the DGR at the site. The assessment process will be based on hydraulic models of the sites and the environmental assessment.
2.2.2	**Difficulty of creating hydrogeological models and predicting the development of hydrogeological conditions at the site**	Unacceptable uncertainties due to the difficulty of determining the influence of fault zones and other structures when creating hydrogeological models of the sites. In the first phase of surface geological research, however, this factor is not necessarily excluding and can be used to compare the sites. Fulfilment: this criterion will be assessed on the basis of the hydraulic models of the sites.	Decree No. 378/2016, Sect. 18 (4) b) 2	Modelling of the area; hydraulic model of the site Rationale for the assessment area: the difficulty of creating a model for the wider area will be assessed, i.e. including the boundary condition areas.
2.3	**Site stability**			
2.3.1	**Earthquakes and the presence of potentially active faults over the next hundreds of thousands of years (seismic stability)**	The site of a nuclear installation and at a distance of up to 5 km from the border thereof, must not feature any faults potentially capable of shifting with manifestations on or near the surface. Maximum potential magnitude and soil vibration acceleration values, however, may be	Decree No. 378/2016, Sect. 6 (2) a)	Regional assessment Rationale for the assessment area: the presence of potentially active faults will be assessed according to Decree No. 378/2016 to a distance of 5 km.

ID	Criterion	Criterion description/value	Source	Area of assessment
		used for site comparison purposes. Fulfilment: this criterion will be assessed on the basis of the seismically active faults database report (Málek et al. 2018). No relevant data on the age and activity of tectonic disturbances as obtained by SÚRAO (tectonic networks, Mixa et al. 2019) is applicable to the assessment of potentially active faults at specific sites. If no movement has been demonstrated or indicated along a fault over the last 2.6 million years, it is assumed that the fault is not active and does not pose a direct risk.		
2.3.2	**Sinking or uplift of the surface of the area (vertical movements of the earth's crust)**	The siting of the repository is excluded at sites at which movements of the earth's crust are greater than 1 mm/year. Fulfilment: this criterion will be evaluated on the basis of the assessment of the vertical stability of the area according to Hroch and Pačes (2015).	Decree No. 378/2016, Sect. 18 (2) g)	Area modelling Rationale for the assessment area: due to the absence of in-situ data from the sites obtained via long-term monitoring, regional data according to Hroch and Pačes (2015) will be used.
2.3.3	**Post-volcanic phenomena**	Sites with post-volcanic phenomena (gas outflows, hot water, etc.) will be excluded. Fulfilment: this criterion will be evaluated on the basis of already-performed geological characterisation research work (Franěk et al. 2018, Mixa et al. 2019).	Decree No. 378/2016, Sect. 9 (3) a) 2.	Area modelling Rationale for the assessment area: the wider surroundings of the site will be evaluated on the basis of the requirements of Decree No. 378/2016, i.e. within a distance of 5 km.
2.4	**Characteristics that could lead to the disturbance of the repository via future human activities**			

ID	Criterion	Criterion description/value	Source	Area of assessment
2.4.1	**The presence of old mine workings**	No old mine workings must be present on the proposed site of a nuclear facility. Fulfilment: data on the presence of old mine workings will be obtained from the Geofond - CR database.	Decree No. 378/2016, Sect. 9 (3) b)	Promising area for the geological characterisation research work Rationale for the assessment area: in terms of intrusion characteristics, the highest probability of intrusion in terms of the occurrence of mineral resources concerns only the target lithology for the DGR, i.e. in the promising area for geological characterisation research work.
2.4.2	**The presence of mineral resources**	There must be no mineral resource reserves at depths greater than 100 m. Fulfilment: data on the presence of old mine workings will be obtained from the Geofond - CR database.	Decree No. 378/2016, Sect. 18 (2) o)	Promising area for the geological characterisation research work Rationale for the assessment area: in terms of intrusion characteristics, the highest probability of intrusion in terms of the occurrence of mineral resources concerns only the target lithology for the DGR, i.e. in the promising area for geological characterisation research work.

ID	Criterion	Criterion description/value	Source	Area of assessment
2.4.3	**The presence of underground water or geothermal energy sources**	The rock environment must not contain significant water sources or have the potential for the use of geothermal energy. Fulfilment: data from national databases (e.g. Heis-VÚV, eagri.cz, etc.) will be used to assess underground water reserves and, in the case of geothermal energy potential, the assessment will be conducted in relation to the assumed thermal gradient.	Decree No. 378/2016, Sect. 8 (2), Sect. 18 (4) c)	Promising area for the geological characterisation research work Rationale for the assessment area: in terms of intrusion characteristics, the highest probability of intrusion concerns the presence of underground water reserves in a promising area for the geological characterisation work.
3.	**Exclusion criteria for the siting of a nuclear installation concerning operational safety**			
3.1	**Natural phenomena**			
3.1.1	**The occurrence of faults**	a) Occurrence of a zone with a physically or seismically active fault or other movement of the earth's crust that could result in damage to the nuclear installation, thus negatively affecting nuclear safety; up to a distance of 5 km, or	Decree No. 378/2016, Sect. 6 (2) a)	Surface area Rationale for the assessment area: this concerns requirements set out in particular in Decree No. 378/2016 concerning the land of the nuclear facility, in this case the surface area.
		b) Occurrence of an accompanying fault at the site of the nuclear installation. This criterion will be combined with the criterion for assessing seismicity in terms of long-term safety Fulfilment: this issue will be evaluated together with criterion 2.3.1	Decree No. 378/2016, Sect. 6 (2) b)	Surface area Rationale for the assessment area: this concerns requirements set out in particular in Decree No. 378/2016 concerning the land of the nuclear facility, in this case the surface area.
3.1.2	**Flooding**	Regular flooding of the site of the nuclear installation due to extreme meteorological situations with a probability of occurrence of once every 100 years or higher.	Decree No. 378/2016, Sect. 7 (2)	Surface area Rationale for the assessment area: this concerns requirements set out in particular in Decree No. 378/2016 concerning the land of

ID	Criterion	Criterion description/value	Source	Area of assessment
		Fulfilment: this issue will be evaluated together with criterion 2.3.1		the nuclear facility, in this case the surface area.
3.2	**Factors influencing the management of exceptional situations**			
3.2.1	**Proximity to an international border**	Proximity to an international border or settlements that negatively influence the feasibility of the emergency plan.	Decree No. 378/2016, Sect. 17; Decree No. 378/2016, Sect. 16 b) 3.	Surface area Rationale for the assessment area: this concerns requirements set out in Decree No. 378/2016: the assessment of the area must be conducted up to a distance of 30 km.
3.2.2	**Ensuring access for rescue units**	The lack of access for fire, mining rescue and ambulance services.	Decree No. 378/2016, Sect. 17	Surface area Rationale for the assessment area: this relates to requirements set out in Decree No. 378/2016. These factors are based on the specific location of the nuclear installation.
3.2.3	**Ensuring information and evacuation**	The impossibility of communicating timely information to, and the evacuation of, the population.	Decree No. 378/2016, Sect. 17	Surface area Rationale for the assessment area: this relates to requirements set out in Decree No. 378/2016. These factors are based on the specific location of the nuclear installation.
3.2.4	**Ensuring measures against sabotage**	The inability to secure the facility against sabotage precludes the siting of the DGR.	Decree No. 378/2016, Sect. 17	Surface area Rationale for the assessment area: this relates to requirements set out in Decree No. 378/2016. These factors are based on the specific location of the nuclear installation.
4.	**Exclusion criteria in terms of environmental impacts**			
4.1	**Occurrence of specially protected natural areas**			

ID	Criterion	Criterion description/value	Source	Area of assessment
4.1.1	**Occurrence of a UNESCO biosphere reserves**	The area designated for the surface area must not feature a UNESCO biosphere reserve (Article 1 of Ministry of Foreign Affairs communication No. 159/1991, Coll. Convention Concerning the Protection of the World Cultural Heritage). Definition: World Heritage List	Communication from the Ministry of Foreign Affairs No. 159/1991	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.
4.1.2	**Occurrence of national parks**	The area intended for the surface area of the DGR must not be situated in a national park. Definition: Annexes Nos. 1 - 4 of Act No. 114/1992, Coll.	Act No. 114/1992, Coll.	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.
4.1.3	**Occurrence of a protected landscape area**	The area intended for the surface area of the DGR must not be situated in a protected landscape area. Definition: Central nature protection register.	Act No. 114/1992, Coll.	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.
4.1.4	**Occurrence of national natural monuments and national nature reservations**	The area intended for the surface area of the DGR must not be situated in areas with the occurrence of national natural monuments and national nature reservations (in all cases this refers to so-called specially protected natural area categories). Definition: Central nature protection register.	Act No. 114/1992, Coll.	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.
4.1.5	**Occurrence of a Natura 2000 site (Area of European Importance, Bird Protection Areas)**	The area intended for the surface area of the DGR must not be situated in Areas of European Importance and must not interfere with Bird Protection Areas. Definition: Area of European Importance – National register, Bird	Act No. 114/1992, Coll.	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.

ID	Criterion	Criterion description/value	Source	Area of assessment
		Protection Areas - Government regulation.		
4.1.6	**Occurrence of nature reserves and natural monuments**	The area intended for the surface area of the DGR must not be situated in nature reserves or at sites with natural monuments Definition: Central nature protection register.	Act No. 114/1992, Coll.	Surface area Rationale: this criterion is specifically linked to the surface part of the DGR.

4.3 Second assessment stage - benefits analysis

Fig. 5 Criteria applied in the second assessment stage

The second stage will comprise the comparison of the candidate sites that have not been excluded according to the exclusion criteria (Fig. 4) employing the weighted assessment of the key criteria summarised according to the areas of safety, technical feasibility and environmental impacts (Fig. 5). Key criteria comprise those site characteristics according to which the sites can be compared at the given stage of DGR development. The assumption is that they comprise both characteristics that can be determined/estimated from current knowledge and characteristics according to which the sites differ based on the evaluation of available information. A further assumption is that these characteristics do not correlate with each other (for example, they are not based on the recalculation of the same basic information).

The key criteria are further divided into indicators, which reflect the specific properties of the sites. Indicators thus comprise partial characteristics of the sites that are used for the assessment of the respective key criterion. The comparison of the sites at this stage will, therefore, be conducted on the basis of those criteria that bear the highest degree of information relevance for the assessment process, the evaluation of which, in turn, is based on the availability of a sufficient amount of data. An overview of the key criteria, including the rationale for their selection for application in this phase, is provided in Tab. 2.

Tab. 2 Overview of the MP.22 criteria and the rationale for their applicability in the site comparison process in the given selection stage (application Y - yes, the assessment will be applied in this stage for site comparison purposes; N - no, the criterion will not be applied in this stage for site comparison purposes).

Criterion designation in MP.22	Applied Y/N	Rationale
Project criteria		
Size of the usable rock mass	Y	At each stage of site selection, the site must be inspected in terms of spatial requirements for the location of the underground part of the repository (emplacement of 9500 tonnes of SNF and 4500 m^3 of RAW) and in terms of the size of the territorial reserve. For the purposes of site comparison, this is referred to as criterion C1.
Parameters concerned with the underground excavation methods and the mechanical properties of the rocks	N	This criterion is not evaluated due to the current lack of meaningful data from the anticipated depth of the repository. The orientation data obtained from surface outcrops (temperature and mechanical parameters, (Petružálek 2017; Hanák et al. 2015, 2017, 2018; Navrátilová et al. 2018) are included in the evaluation of criterion C1, specifically via thermo-technical and thermo-mechanical calculations (Kobylka 2019). Based on the mechanical parameters of the rocks, stability calculations have been performed, upon which, in addition to the thermal properties, the overall size of the repository will depend (Bureš et al. 2018 a-d, Špinka et al. 2018 a-c).
Thermal properties of the rocks	Y	The thermal properties of the rocks are included in the evaluation of criterion C1, specifically via the thermo-technical and thermo-mechanical calculations (Kobylka 2019). Based on these calculations, the spaces between the disposal wells at specific sites have been determined, a factor that is taken into account in terms of the total area of the repository, and which constitutes a parameter considered in the project design for the respective site (Bureš et al. 2018 a-d, Špinka et al.2018 a-c). A separate evaluation of the thermal properties of the rocks would mean evaluating the same site properties twice.
Hydrogeological conditions	Y	In the broader sense, the hydrogeological conditions as related to the rock environment and water management are used in the assessment of the C5, C6 and C10 criteria. In addition, as defined in MP.22, this criterion is linked to specific rock characteristics during the construction of the repository (especially high water inflows, the chemistry and aggressiveness of the water etc.). In the current stage of evaluation, however, it is not

Criterion designation in MP.22	Applied Y/N	Rationale
		possible to determine or predict the hydrogeological conditions of individual disposal wells and corridors.
Ensuring the stability of construction elements	N	This criterion is evaluated in the context of the exclusion criteria for the siting of the surface area; it will not be used for comparison purposes due to the absence of these phenomena in terms of the location of the surface area (Bureš et al. 2018 a-d; Špinka et al.2018 a-c). The siting of the DGR buildings is outside these areas; the sites are the same in terms of this criterion (Bureš et al. 2018 a-d; Špinka et al.2018 a-c; Hanžl et al. 2018; Navrátilová et al. 2018).
Infrastructure availability	Y	Infrastructure is in place at all the sites for the construction of the surface area and the underground part of the repository (Bureš et al. 2018 a-d, Špinka et al.2018 a-c Hanžl et al. 2018, Navrátilová et al. 2018). The sites can be compared according to the removal of excavated material, i.e. the elimination of a potentially significant adverse effect. This factor will make up criterion C2.
Number and complexity of conflicts of interest	N	This criterion will not be used for the comparison of the sites; it is possible at all the sites to determine the design of the surface area without the occurrence of conflicts of interest (e.g. Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Hanžl et al. 2018, Navrátilová et al. 2018). In addition, the assessment of conflicts of interest is identical to that of environmental impacts in key criteria C10 to C13.
Costs	N	At this stage, the construction costs are directly linked to the size of the repository and the amount of excavated material, which depends on the mechanical and thermal parameters that are included in the rock block size criterion. This criterion is included in the assessment of criterion C1.
Safety criteria		
Geological characteristics		
Describability and predictability of homogeneous blocks	Y	At this stage, knowledge of the geological structure comprises important input data for the assessment of the areas and the creation of descriptive models of the sites and the design projects. Moreover, a sufficient amount of representative data is currently available for the assessment of this criterion (Franěk et al. 2018, Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Hanžl et al. 2018, Navrátilová et al. 2018, Mixa et al. 2019, Havlová et al. 2018 a-i). The geological characteristics affect all aspects of the DGR (safety and feasibility) and constitute an important factor in defining the underground and above-

Criterion designation in MP.22	**Applied Y/N**	**Rationale**
		ground parts of the repository. In the site selection phase and the search for suitable rock blocks, the comparison of the sites in terms of geological criteria is essential. Therefore, these characteristics will be included for site comparison purposes as criterion C3.
Variability of properties	Y	At this stage, knowledge of the geological structure comprises important input for the evaluation of the areas and for the creation of descriptive models of the sites and the project design. At the same time, a sufficient amount of representative data is currently available for the evaluation of this criterion (Franěk et al. 2018, Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Hanžl et al. 2018, Navrátilová et al. 2018, Mixa et al. 2019, Havlová et al. 2018 a-i). The geological characteristics affect all areas of the DGR (safety and feasibility) and comprise an important factor in terms of defining the underground and above-ground parts of the repository. Thus, the comparison of the sites concerning geological criteria is essential in the site selection phase and the search for suitable rock blocks. Therefore, these characteristics will be included for site comparison purposes as criterion C4.
Availability of data	N	In the current stage, the sites enjoy the same level of geological description data (Franěk et al. 2018, Mixa et al. 2019). Thus, this criterion will not be applied for comparison purposes.
Hydraulic characteristics		
Presence of aquifers in the isolation part of the repository	N	The isolation part of the rock mass must not include an environment with a significant accumulation of underground water or an environment that is very water permeable. The presence of aquifers is assessed in the context of the exclusion criteria. Water management and the presence of water resources in the surface areas of the sites are assessed via criterion C10.
Difficulty of creating hydrogeological models and predicting the development of the hydrogeological conditions at the site	N	The difficulty of creating such models is assessed via the exclusion criteria; it will not be used for the comparison of the sites. Hydrogeological and transport models were created for each of the sites in 2019 (Baier et al. 2020 a,b, Černý et al. 2020 a,b, Jankovec et al. 2020 a,b, Uhlík et al. 2020 a,b, Polák et al. 2020). These models reflect the information obtained from the Geofyzika project (Mixa et al. 2019). The model creation methodology is described in Uhlík et al. 2018. All the data for the partial indicators of criteria C5 and C6 is derived from the information provided by these models.

Criterion designation in MP.22	Applied Y/N	Rationale
Rock permeability and water flow rate	Y	Rock permeability and the groundwater flow rate comprise important parameters that influence the transport characteristics of the sites and the results of the safety assessments (Trpkošová et al. 2018). Their assessment is conducted in the form of partial indicators of criterion C5. All the values of the indicators of criteria C5 and C6 are derived from information provided by the afore-mentioned models.
Identification of drainage bases	Y	The identification and determination of the number of drainage areas comprise important outputs from the hydraulic and transport models of the potential DGR sites. The transport characteristics of the sites are of fundamental importance for the future location of the repository (Trpkošová et al. 2018). The identification of drainage bases is considered via criterion C6 in the context of the assessment of the suitability, and the reduction in the number, of sites.
Transport characteristics		
Radionuclide transport time	N	The transport time of radionuclides is directly proportional to the groundwater flow rate (Říha et al. 2018). The transport characteristics of the sites are assessed via the partial indicators of criteria C5 and C6. The sources of information consist of the above-mentioned hydrogeological and transport models.
Solubility of radionuclides in groundwater	N	Due to the lack of knowledge of the composition of the groundwater at the depth of the repository (Červinka and Gondolli 2016) at the sites, this criterion will not be applied at this stage of the assessment process. It can only be reliably evaluated following the conducting of borehole drilling exploration research at the sites.
Dilution due to mixing with uncontaminated water	Y	Due to uncertainties (the absence of detailed data from the depth of the repository, especially concerning the nature of the fracture network), dilution characteristics are included as a partial indicator of criterion C5. The sources of information consist of the above-mentioned hydrogeological and transport models.
Stability of the site		
Earthquakes and the presence of potentially active faults for hundreds of thousands of years (seismic stability)	Y	The determination of the geodynamic characteristics and the conducting of a seismic risk assessment constitute important legislative requirements in terms of the siting of nuclear facilities (according to Decree No. 378/2016). Moreover, these factors will have to be documented and continuously assessed in the future as part of the licensing process. This criterion will be considered in terms of the comparison of the sites together with the criterion concerning the sinking or uplift of the surface of the areas via criterion C7.

Criterion designation in MP.22	Applied Y/N	Rationale
Sinking or uplift of the surface of the area (vertical movements of the earth's crust)	Y	The development of the relief and the dynamics thereof play an important role concerning the hydraulic simulations and, especially, with respect to the definition of DGR development scenarios (Havlová et al. 2018 a-i). This criterion will be considered in terms of the comparison of the sites for site assessment purposes together with the criterion concerning earthquakes and the presence of potentially active faults for a period of hundreds of thousands of years via criterion C7. These criteria were combined due to the relatively small differences between the sites in these respects (Havlová et al. 2018 a-i, Vokál et al. 2018 a-f, Kaláb et al. 2015, Nývlt and Dobrovolný 2015, Hošek et al. 2015) and in terms of their significance. At the same time, however, the stability characteristics and the dynamics of the development thereof will have a significant influence on the determination of safety assessment scenarios.
Post-volcanic phenomena	N	This criterion will be assessed in the evaluation of the exclusion criteria; it will not be applied for comparison purposes.
Climate change	N	Due to the absence of data and the minor differences between the sites, this criterion will not be applied at this stage for the comparison of the sites, Nývlt and Dobrovolný (2015). Regional data only is available, including the definition of the relevant scenarios.
Characteristics that could lead to the disturbance of the repository via future human activities		
The presence of old mine workings	Y	This criterion is assessed in the context of the exclusion criteria; it will be combined with the mineral reserves criterion in criterion C8 due to their high degree of mutual correlation.
The presence of mineral resources	Y	This criterion will be used for the comparison of sites via criterion C8 as a significant intrusion factor.
The presence of underground water or geothermal energy sources	Y	This criterion will be used for the comparison of the sites via criterion C10. The presence of geothermal energy sources is assessed as an exclusion criterion.
Factors that indicate previous human intrusion into the rock environment	N	This criterion will not be used in the comparison of the sites since it is directly related to the "presence of old mine workings and mineral resources" criterion; it is thus assessed via criterion C8.
Compatibility of the rock environment with the proposed engineered barrier system		
Thermal properties	N	This criterion is taken into account in the thermo-technical calculations (Kobylka 2019), which are included in the evaluation of criterion C1. Due to the absence of data from the depth of the repository (assessment of rock environment compatibility) and uncertainties regarding the selection of the damping and sealing materials, it will only be possible to assess this criterion after obtaining

Criterion designation in MP.22	Applied Y/N	Rationale
		data from the depth of the repository. At the same time, this criterion may be influenced by the technical design solution (composition of the container materials, damping and sealing materials).
Hydraulic properties	N	The hydraulic properties of the isolation part of the repository required for the evaluation of this criterion are not available in the current site assessment stage. These are properties that concern the immediate proximity of the disposal area (isolation part of the repository).
Mechanical properties	N	The mechanical properties of the isolation part of the repository required for the evaluation of this criterion are not available in the current site assessment stage. Currently available mechanical data (e.g. Petružálek 2017) concerns only the surface outcrops of the sites, and is evaluated via criterion C1.
Physico-chemical and geochemical properties of the groundwater	N	With respect to the evaluation of this criterion, the composition of the groundwater at the depth of the repository is not yet known. Only the composition of water from the Bukov URF (Červinka and Gondolli 2016) and the surfaces of the sites (Mixa et al. 2019, Franěk et al. 2018) is currently known.
Microbiological properties	N	With respect to the evaluation of this criterion, the composition of the groundwater and data on microbial settlements at the depth of the repository at the sites are not yet known due to the application of methods to date that describe only the near-surface structures of the sites.
Gas permeability	N	With respect to the evaluation of this criterion, the parameters of the fracture networks at the depth of the repository at the candidate sites are not yet known. Only data from surface outcrops is currently available (Kabele et al. 2018).
Natural phenomena		
Seismicity	N	This criterion is evaluated via combined criterion C7.
The occurrence of active faults	N	This criterion is included in the combined criterion C7. With respect to the evaluation of this criterion, no relevant data is yet available on the seismic activity of the fault networks at the sites, i.e. their age and relative movements (Franěk et al. 2018, Mixa et al. 2019).
Flooding	N	This criterion depends on the location of the surface areas which, in all cases, are located outside flood areas; thus, there is no difference between the sites in this respect (Bureš et al. 2018 a-d, Špinka et al. 2018 a-c, Hanžl et al. 2018, Navrátilová et al. 2018). In addition, this criterion may be influenced by the finally selected project design solution.
Groundwater circulation	N	This criterion is evaluated via criterion C5.

Criterion designation in MP.22	Applied Y/N	Rationale
Biological phenomena	N	This criterion will not be applied at this stage, although it could be influenced by the finally selected project design solution. This issue is, however, included in key criterion C11.
Natural fire events	N	This criterion will not be applied at this stage; however, it may be influenced by the finally selected project design solution.
Human-induced phenomena		
Plane crashes (and similar events)	N	This criterion will not be applied at the current stage; it may be considered in the project design solution.
Human-induced explosions and fires and the products thereof	N	This criterion will not be applied at the current stage; it may be considered in the project design solution.
Presence of other nuclear installations and other industrial or other installations	N	This criterion will not be applied at the current stage; it may be considered in the project design solution.
Spread of radioactive material		
Climatic and meteorological conditions	N	This criterion will not be applied at present due to uncertainties in terms of the siting of the surface area.
Circulation of surface and groundwater	N	This criterion is evaluated via criteria C5 and C6.
Current land use	N	This criterion is included in the evaluation of criterion C13.
Population distribution and density and its development in terms of the spread of radioactive substances	Y	This criterion will be applied for site comparison purposes as criterion C9.
Factors influencing the management of exceptional situations		
Proximity to an international border	N	This criterion will not be applied at the current stage; it may be considered in the project design solution.
Ensuring access for rescue units	N	This criterion will not be applied at the current stage; it may be considered in the project design solution. In addition, the establishment of rescue units at each of the surface areas is being considered (Bureš et al. 2018 a-d, Špinka et al.2018 a-c Hanžl et al. 2018, Navrátilová et al. 2018).
Ensuring information and evacuation	N	This criterion will not be applied at the current stage; it may be considered in the project design solution.
Ensuring measures against sabotage	N	This criterion will not be applied at the current stage; it is a technical issue that is the same for all the sites.

Criterion designation in MP.22	Applied Y/N	Rationale
Environmental criteria		
Occurrence of a UNESCO biosphere reserves	Y	This criterion is evaluated via criterion C11.
Occurrence of national parks	Y	This criterion is evaluated via criterion C11.
Occurrence of a protected landscape area	Y	This criterion is evaluated via criterion C11.
Occurrence of national natural monuments and national nature reservations	Y	This criterion is evaluated via criterion C11.
Occurrence of a Natura 2000 site (Areas of European Importance, Bird Protection Areas)	Y	This criterion is evaluated via criterion C11.
Occurrence of nature reserves and natural monuments	Y	This criterion is evaluated via criterion C11.
Occurrence of nature parks	Y	This criterion is evaluated via criterion C11.
Impact on surface and groundwater	Y	This criterion is included in the assessment process via criterion V10.
Underground spaces cannot be in hydrogeological communication with subsurface irrigation	N	This criterion is included in the assessment process via criterion C5
Impacts on the climate and the air	N	At this stage, at the current level of the project design solution (reference design), this criterion will not be applied. The impacts on the climate will be insignificant at all the sites; the emission characteristics will be similar at all the sites.
Impacts on the acoustic situation	N	At this stage, at the current level of the project design solution (reference design), this criterion will not be applied. The sources of noise will be similar at all the sites. The impacts on residential and recreational development are evaluated via criterion C13.
Impacts on the rock environment and natural resources	Y	The impacts on the rock environment are assessed in terms of the amount of excavated material and are evaluated via criterion C2. The impacts on natural resources are assessed via criterion C8.

Criterion designation in MP.22	Applied Y/N	Rationale
Impacts on public health and the environment	Y	This criterion is evaluated via criteria C12 and C13 (public health - non-radiation effects) and C10 to C12 (other components of the environment).
Impacts on geological and paleontological phenomena	Y	This criterion is evaluated via criterion C11.
Impacts on flora and fauna and ecosystems	Y	This criterion is evaluated via criterion C11.
Impacts on the soil	Y	This criterion is evaluated via criterion C12.
Impacts on the landscape	Y	This criterion is evaluated via criterion C11.
Impacts on internationally recognised habitats (e.g. wetlands, forests, arable land, etc.)	Y	This criterion is evaluated via criterion C11.
Impacts on property and cultural monuments	Y	This criterion is evaluated via criterion C13.
Impacts on transport or other infrastructure	N	This criterion depends on the routing of transport and other infrastructure; therefore, it will not be evaluated in the current stage. This criterion may be influenced by the finally selected project design solution.
Impact on the use of the affected area	Y	This criterion is evaluated via criteria C12 and C13.

4.4 Description of the key criteria at the indicator level

The key criteria, as defined in the previous chapter, were further sub-divided by the working team into so-called assessment indicators, which further expand upon and serve for the evaluation of the various criteria.

4.4.1 Criterion C1: Size of the usable rock mass

Description of the criterion: the technical design solution of the DGR must primarily respect the structural and tectonic conditions of the host rock mass in order to fully meet the various long-term safety requirements. The potentially usable rock blocks must be at such a depth and at a sufficient distance from aquifers so as to prevent human access to the waste, to ensure that the repository is not affected by surface processes and to prevent the rapid migration of radionuclides into water-bearing fault zones. A sufficient depth for the DGR for the disposal of spent nuclear fuel is considered to be several hundred metres beneath the earth's surface. One of the most important features of the rock environment concerns the density of smaller fracture zones and larger fractures that preclude the emplacement of waste disposal packages (WDP) in the rock mass. However, it is not possible to assess this property as part of the geological research of the surface, i.e. in the initial site selection phase (9 sites). From the point of view of feasibility, it should be taken into account that the disposal spaces may intersect with a number of brittle deformations (fractures and cracks), fracture zones and other lithological and structural inhomogeneities. Simple faults can be remedied during the drilling stage using grouting compounds, which must be carefully selected so that they do not adversely affect the various components of the engineered barriers. Areas that feature more serious inhomogeneities should be excluded. When determining the size of the massif, it is necessary to take into account sufficient distances from significant faults/fractures both to ensure long-term safety and the mechanical stability of the underground spaces. The Czech DGR reference concept considers engineered barriers for the disposed of spent nuclear fuel based on a “WDP-bentonite” system. The most limiting condition of the disposal system as a whole concerns the limit temperature of approximately 100°C, at which the degradation and loss of the safety functions of bentonite may occur. The residual heat output of the spent nuclear fuel and the thermal properties of the engineered barriers and the rock environment thus constitute two of the most important basic design parameters, important in terms of the assessment of the rock mass for its usability for the location of the DGR. A further important project parameter concerns the WDP disposal method. The construction of the DGR is being considered with one or two disposal horizons. Furthermore, both vertical disposal in wells drilled in disposal corridors and disposal in horizontal boreholes are currently being considered.

The following indicators have been defined for this criterion:

C1a Usability of the rock blocks

Description of the indicator: the indicator is determined as a percentage of the area required for the construction of the SNF disposal sections and RAW chambers of the total area of the potentially usable disposal area. The sizes of the disposal areas are based on a project design proposal (Zahradník et al. 2020) that takes into account distances between the WDPs determined on the basis of thermal and stability calculations (Kobylka et al. 2019), which include:

- thermal properties of the rock and an initial temperature at a depth of 500 m during disposal that do not exceed a limit temperature of 95°C throughout the lifetime of the DGR,
- mechanical and physical parameters of the rock that allow for the safe excavation of the underground spaces and minimise the occurrence of excavation damaged zones.

The area of the underground part of the DGR will be determined based on the above calculations and data from reports that evaluate the mechanical and thermal properties of representative lithologies at the various sites, Petružálek et al. (2017), and fully considering the technical requirements for the construction of the DGR (excavation technology, drainage, ventilation, etc.). For comparison purposes, a conservative option with the largest volume of excavated material (a combination of the vertical disposal method and machine excavation) was selected. The minimum axial distances between the WDPs and the various loading corridors, in combination with the technical requirements for the construction of the DGR (excavation technology, drainage, ventilation, etc.), will determine the dimensions of the underground disposal area for SNF. The chambers intended for the disposal of RAW shall be included in the total disposal area with regard to the determination of the usability of the homogeneous block only if it is not possible to locate them other than at the same level as that of the SNF disposal area (500 m beneath the earth’s surface).

Quantification: the percentage of the usable area of the rock blocks (promising area for the project construction work without any areas that are unusable with respect to safe disposal, i.e. mainly fracture structures).

Assessed area: promising area for the project construction work.

Rationale of the area of evaluation: the definition of rock blocks suitable for the design (from the project point of view) of disposal areas (homogeneous blocks) and, thus, rock blocks that are potentially usable.

C1b Fragmentation of the area

Description of the indicator: the indicator expresses the extent to which the defined suitable rock mass is fragmented, and represents the number of individual partial rock blocks in which the DGR can be effectively constructed and RAW disposed of with regard to the size and shape of the blocks. Due to the current uncertainty concerning the real geological and hydrogeological conditions, it is desirable that the potentially usable rock environment consists of as few rock blocks as possible (ideally just one completely compact block).

Quantification: the number of fragmented blocks in the area that can be used for the disposal of SNF and RAW.

Assessed area: promising area for the project construction work.

Rationale of the area of evaluation: the definition of rock blocks suitable for the design (from the project point of view) of disposal areas (homogeneous blocks) and, thus, rock blocks that are potentially usable.

C1c Fragmentation of the underground part of the DGR

Description of the indicator: the indicator takes into account the number of parts into which the disposal spaces for the SNF in the underground complex of the DGR will be divided, i.e. one compact space or several smaller, interconnected spaces. The division is related to the spatial requirements according to the final project design and the potential of the sites in terms of the expected geological and hydrogeological conditions. The division of the disposal spaces into several smaller areas raises the prospect of potential complications with drainage and ventilation, the prolongation of the transport of waste for disposal and increases in construction costs.

Quantification: the number of parts that make up the SNF disposal space, designed with regard to the density and orientation of 1st and 2nd category faults, i.e. the layout of the usable disposal spaces.

Assessed area: promising area for the project construction work.

Rationale of the area of evaluation: the definition of a specific project design solution to which the indicator relates.

4.4.2 Criterion C2: Infrastructure availability

Description of the criterion: in order to ensure the construction and operation of the DGR, with respect to the preparation of the project, requirements are set concerning accessibility for construction and connection to infrastructure systems, both transport and technical. According to studies conducted to date, connection to the necessary transport and technical infrastructure systems is possible at all the candidate sites, thus the differences between the sites can be expressed only in terms of the financial costs of connecting to the existing infrastructure. Since the primary aim of this site assessment phase is to reduce the number of sites at which a safe and environmentally-friendly DGR can be constructed, economic indicators are not yet being considered. Therefore, only the following indicator was defined for this criterion, which is currently seen as more relevant than economic considerations:

C2a Potential for the permanent disposal of excavated material in the vicinity

Description of the indicator: the indicator reflects the expected excess volume of excavated material from the construction of the underground part of the DGR after deducting the expected volume of the disposal sites for this material in the vicinity (existing quarries within a range of up to 25 km). During the construction of the DGR, a large amount of excavated material will be produced. Although it will be possible for a large part of it to be used as building materials, the demand for this material at the time of the construction of the DGR cannot be predicted in this stage of the process. Therefore, in this phase of the DGR development process, excavated material is considered to be a negative DGR construction externality, and the potential for its disposal near the site of production an advantage for the selection of the candidate site.

Quantification: the excess amount of excavated material, i.e. the volume (m^3) of generated excavated material after consideration of the volume of potential disposal sites for this material in the immediate surroundings of the candidate sites.

Assessed area: an area up to 25 km driving distance from the site of the DGR surface area.

Rationale of the area of evaluation: a distance of 25 km was set as the maximum distance with concern to the technical aspects of transporting the material (number of transports per day), etc.

4.4.3 Criterion C3: Describability and predictability of the homogeneous blocks

Description of the criterion: the geological conditions of the repository must allow for the creation of a reliable complex spatial geological model. The depth extent of the rock mass must be sufficient with regard to the maximum expected depth of the repository (minimum of 400 m). An unacceptable degree of uncertainty in terms of the identification and description of regional and local fault zones and other geological structures may preclude the siting of the repository. However, in this phase of the DGR site selection process (the reduction in the number of candidate sites from 9 to 4), involving the conducting of mostly surface geological research, this factor will not necessarily be considered to be excluding, but may be used for the comparison of the sites.

The following indicators have been defined for this criterion:

C3a Degree of the brittle failure of the massif - fault structures

Description of the indicator: the indicator reflects the number and extent of fault structures indicated to date and the age of movements along such faults, if known. Faults are classified according to the SKB classification (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 both significant mechanical weaknesses in the rock mass and preferential groundwater pathways, especially in crystalline rock environments. Their distribution and character exert a significant impact on the assessment of site suitability. The nature of faults is given by the SKB classification system compiled by Anderson et al. (2000), according to which a 1st category fault comprises the most significant structure, which could lead to the significant mechanical weakening of the rock massif. Moreover, such faults may act as preferential groundwater pathways or as barriers. Furthermore, they may be associated with extensive alterations and fracturing in the rock environment. Category 2 faults are of a lower extent than category 1 faults. The spatial distribution of faults also exerts a significant effect on the assessment of suitability. For example, it is more advantageous if the faults in a given block (polygon) are concentrated in two tectonic zones with a relatively homogeneous rock environment between them than if the faults are distributed throughout the polygon in the form of a regular dense network.

Quantification: the evaluation of the indicator for each site compared to the other sites: 1 - lowest degree of brittle failure via fault structures, i.e. the absence of first and second order structures according to the SKB classification, 5 – a high degree of brittle failure via the fault structures of several systems; the presence of a large number of fault structures of all orders according to the SKB classification.

Assessed area: the modelled area - structural diagrams of the areas via 3D structural-geological modelling (Franěk et al. 2018, Mixa et al. 2019).

Rationale of the area of evaluation: the tectonic schemes compiled (Mixa et al. 2019) represent the most comprehensive view of the tectonic structure of the sites to date and, as such, cover the sites with the consideration of a reserve.

C3b Degree of brittle failure of the massif - fracture systems

Description of the indicator: the indicator reflects the number of detected fracture systems and the density of the fracture networks. Fracture systems often form dense networks of small discontinuities in the rock mass and they are usually interconnected. Parts of such networks are hydraulically conductive and may serve as potential pathways for the migration of water and gases contained in the water or, in the case of the DGR for the potential escape of radionuclides. From the point of view of the siting of the DGR, the most suitable environment is that with the lowest possible number of fracture systems and a low fracture density. Parameter P_{21} (the total length of fracture traces per unit area) for the representative lithology (lithology in which the siting of the DGR is assumed) for the siting of the DGR at the sites will be evaluated. The parameter will be determined based on data obtained from Kabele et al. (2018). Parameter P_{21} will be applied as a result of the compilation of DFN models in the DFraM program (Kabele et al. 2018), which were created primarily for hydraulic simulation purposes. The comparison of the sites will, therefore, proceed on the basis of field structural data from the outcrops documented in detail for the creation of the DFN models. In the case of normally semi-planar outcrops, parameter P_{21} best captures the degree of rock mass failure directly from the structural data obtained. Thus, a comprehensive set of data collected by means of a uniform methodology for all the sites will be used for assessment purposes. In addition, parameter P_{30} is also mentioned in Kabele et al. (2018) and related literature. This mathematically determined parameter, which describes the number of fractures per unit volume, contains elements of the applied computational procedures (large numbers of small fractures) that do not influence its use in hydraulic simulations (which is their primary purpose), but affect the overall structural evaluation. Thus, they will not be used in the comparison of the sites.

The arithmetic mean, calculated from the P_{21} parameter values for all the outcrops documented for the representative lithology of the sites, were used for the assessment. The average was chosen since at a number of sites it was often impossible, due to the poor initial situation, to assess in detail more than a small number of outcrops. In the case of a relatively low number of input values, the use of the median is not ideal, i.e. it is more suitable for larger data sets (larger numbers of outcrops). The average suitably reflects even a small number of outcrops with a significant P_{21} parameter value, which would not be reflected in the case of the use of the median. The P_{21} parameter was evaluated for 7 sites (not for the Na Skalním (EDU-west) and Janoch (ETE-south) sites). This parameter was determined by experts as being the most representative parameter since it best reflects the detection of fractures when comparing field observations and models (it evinces the lowest statistical error than other parameters, e.g. P_{30}). With concern to the Na Skalním (EDU-west) and Janoch (ETE-south) sites, the comparison was conducted of available field measurements of fractures obtained via field-based research. The data on the Na Skalním site (EDU-west) agreed very well with that on the Horka site and, since both belong to the same lithological unit, the resulting assessment of this site was similar to that of the Horka site. In the case of the Janoch site (ETE-south) it was possible to base the assessment on lithologically similar parts of the metamorphic Moldanubian complexes found at some of the other sites or on the brittle structures found at the Kraví hora site.

Quantification: the assessment of the indicator in cases where the necessary data obtained via structural-geological characterisation research for the purposes of DFN modelling was available: 1 – the lowest total length of fracture traces per unit area (m^2) for a representative lithology; 5 – the highest total length of fracture traces per unit area (m^2) for a representative lithology. The evaluation will also take into account new findings reported in Mixa et al. (2019). For those sites for which the necessary data is not available, the assessment will be performed via a comparison based on the experience of the respective expert team.

Assessed area: areas modelled by the DFN and 3D geological models (Kabele et al. 2018, Franěk et al. 2018, Mixa et al. 2019).

Rationale of the area of evaluation: in the case of the availability of data from the DFN models, the data from those lithological components that represent the target lithology for the siting of the DGR will be considered. However, since this is of limited extent, data on fracture systems obtained via other methods from the conducting of other relevant projects (e.g. Mixa et al. 2019) will be included in the assessment process.

C3c Degree of ductile deformation

Description of the indicator: the indicator reflects the number of ductile structures and the complexity of the site environment in terms of ductile deformation events. It includes an expert estimate of the intensity of ductile deformation and the complexity of the resulting deformation structures, i.e. foliation and linearisation. In general, the more complex and intense the manifestations of ductile deformation, the more complicated the rock environment is in terms of geotechnical parameters; at the same time there is a higher probability of the occurrence of brittle structures. Of the various ductile elements, only foliation - magmatic and metamorphic – will be included in the assessment; this is the only ductile element that can be documented in sufficient quantities for the assessment of all nine sites (information on rarely observed lineations, fold and other ductile structures and ductile shear zones does not meet the condition of being available in a sufficient amount for assessment purposes).

Quantification: 1 - the lowest degree of ductile deformation; only one generation of ductile structures is determined; 5 - the highest degree of ductile deformation; incidence of a large number of loaded ductile structures with complicated mutual relations.

Assessed area: promising area for the project design work.

Rationale of the area of evaluation: ductile deformations (magmatic structures and metamorphic foliation) may affect the predictability of the properties of the rock block for the siting of the repository. Furthermore, they exert a direct influence on the material properties of the rocks (e.g. Bukovská and Verner 2018) and, thus, are directly related to the evaluation of the quality of the area of the proposed DGR.

4.4.4 C4 Variability of the geological properties

Description of the criterion: a large degree of variability of the geological properties that does not allow for the creation of reliable 3D geological, hydrogeological and geochemical models constitutes one of the exclusion criteria. However, in this phase of the DGR site selection process (the reduction in the number of candidate sites from 9 to 4), concerning which mostly only surface geological research has been conducted, this factor is not considered to be excluding and can be used for site comparison purposes.

The requirement for the assessment of the variability of the rock environment is set out in Decree No. 378/2016 Coll. Section 18, 4b. Spatial and petrological variability were chosen on the basis of the availability of detailed data from the assessed sites (Franěk et al. 2018 and Mixa et al. 2019).They are the only two independent rock environment variability parameters which, from the geological perspective, can be applied with a sufficient degree of credibility with respect to the currently available amount and quality of data from all 9 sites. The expert assessment of spatial variability enables the indication of the amount, spatial distribution and character of the rock bodies, while the petrological variability collectively indicates the various mineralogical and geochemical properties of the various rock types (e.g. the variability of the composition of varieties of granite present at the site is combined under the item “granite”). Both of these independent parameters play an important role in terms of the assessment of the geological properties and homogeneity of the rock environment.

The following indicators have been defined for this criterion:

C4a Spatial variability of the rock environment

Description of the indicator: the indicator reflects the spatial arrangement of the rock bodies, i.e. the geometric relationships between, and the shapes of, the various bodies. This factor is described in the form of a three-dimensional rock body which is made up of a single rock type (according to Mixa et al. 2019, Franěk et al. 2018) or a dominant rock type. The spatial variability captures the horizontal and vertical distribution, i.e. the nature and frequency of the alternation of the various rock bodies in the vicinity of the DGR site, usually at a scale of units of up to hundreds of metres. For example, a site at which two contrasting rock types alternate repeatedly to a relatively low extent will exhibit a low degree of petrographic variability, whereas a high degree of spatial variability may present complications in terms of the design of the DGR. This indicator also includes an assessment of the nature of the contacts between the various rock bodies (e.g. straight, uneven, lobed, tectonic or petrographic transition).

Quantification: 1 – the simple spatial variability of the rock environment in the horizontal and vertical directions with simple contacts between the rock bodies, 5 - very complex spatial variability of the rock environment with the alternation of various lithologies and with complicated contacts between the rock bodies.

Assessed area: promising area for the project design work.

Rationale of the area of evaluation: the distribution of the rock blocks is based on the requirement for the uniformity of the properties of the repository; hence, this factor is assessed in terms of a promising area for the project design work.

C4b Petrological variability of the rocks

Description of the indicator: the indicator reflects the degree of homogeneity of the rock environment in terms of the range of rock types defined for the various sites (see Mixa et al. 2019). The petrological variability reflects differences in the content of the major, minor and accessory rock-forming minerals, the grain size and textural features. These properties are based on detailed petrological descriptions at both the macroscopic and microscopic levels. The petrological variability may affect the thermal conductivity, the production of radiogenic heat and the migration of fluids.

Quantification: 1 - simple petrological variability, i.e. the contents of the main and secondary minerals, their grain size and textural features do not differ with concern to the lithology, 5 - high petrological variability, i.e. the contents of the main and secondary minerals, their grain size and textural features differ significantly with concern to the lithology.

Assessed area: promising area for the project design work.

Rationale of the area of evaluation: the distribution of the rock blocks is based on the requirement for the uniformity of the properties of the repository; hence, this factor is assessed in terms of a promising area for the project design work.

4.4.5 Criterion C5: Water flow characteristics in the vicinity of the DGR and the transport characteristics (water flow rate in the repository and the permeability of the rock mass)

Description of the criterion: the evaluation of the hydrogeological and transport characteristics of the site (such as the analysis of the direction, size, flow velocity and transport between the repository and identified drainage areas, Fig. 6) constitutes important input information for the assessment of the safety of the DGR. Radionuclides could potentially migrate from the repository only in the liquid or gaseous phases, and only if the sealing effect of the engineered barriers is disrupted. The formation of gases in the disposal area is undesirable and is prevented via the technical design of the SNF disposal system. The most important pathway for the spread of radionuclides into the surrounding environment (the biosphere) is considered to be their migration via flowing groundwater.

Crystalline host rocks, which are assumed in the Czech DGR Concept, are very impermeable (Uhlík et al. 2015), and groundwater flows at the anticipated depth of the DGR via fracture systems. The characteristics of groundwater flow in the crystalline rocks of the Bohemian Massif are described in detail in Krásný et al. (2012). Thus, the siting of the DGR must be optimised with regard to the occurrence of preferential groundwater flow pathways associated mainly with fault zones. The velocity and magnitude of groundwater flow comprise important factors that influence the potential transport of radionuclides both in the disposal area (the near-field of interactions) and in the rock mass (the remote-field of interactions). With respect to addressing the various problems associated with the siting of the DGR, the descriptive (qualitative) approach is insufficient. Groundwater flow and transport must also be quantified for the purposes of the safety assessment of the future DGR.

For the purposes of describing and quantifying the hydrogeological and transport conditions of the assessed candidate DGR sites, models of the groundwater flow and advective transport from the DGR areas were compiled for each site. The modelling work took place in three phases in cooperation with experts from PROGEO, the Technical University of Liberec, ÚJV Řež and the Czech Geological Survey. Firstly, regional models (version 1.1) were created, followed by detailed (version 1.2) and finally-updated detailed models (version 1.3). The final updating of the models reflected new data obtained from the latest structural research projects (Mixa et al. 2019). The updated siting of the DGR was also taken into account in accordance with a siting study compiled by Zahradník et al. (2019).

The research conducted via foreign modelling approaches to the siting of deep geological repositories was summarised by Uhlík et al. 2015, and a description of the methodology applied for the creation of, and overview of selected results from, regional groundwater flow models (hydrogeological models) are provided in Uhlík et al. 2016. Moreover, similar information on detailed hydrogeological models is contained in Uhlík et al. 2018, and a summary report on transport models created on the basis of detailed hydrogeological models is available in Říha et al. 2018.

The detailed hydrogeological and schematic transport models of the sites (version 1.3) are described in Baier et al. (2020 a,b) for the Hrádek and Březový potok sites, Černý et al. (2020 a,b) for the Čertovka and Magdaléna sites, Jankovec et al. (2020 a,b) for the Janoch (ETE-south) and Na Skalním (EDU-west) sites, Uhlík et al. (2018 a,b) for the Horka and Kraví hora sites and Polák et al. (2018) for the Čihadlo site. The input and output data sets provided by these models provided the basis for the assessment of the various indicators of the C5 criterion (as well as the C6 indicators described in the following chapter). The choice of indicators for criterion C5 was based on a list of the hydrogeological and transport properties of the geosphere, the consideration of which is essential in terms of the assessment of the long-term safety of the DGR (Safety Case; Turva et al. 2012).

The following indicators have been defined for criterion C5:

C5a Flow time from the DGR to the drainage area

Description of the indicator: based on the hydrogeological and transport models of the candidate DGR sites and their updating, the lower (25%) quartile of the advective progression of groundwater will be determined between the DGR area and drainage areas.

Quantification: value (in years). Longer progression times form a prerequisite for the efficient functioning of the rock environment as a natural barrier. Conversely, sites with shorter progression times (flow rates from the DGR to drainage areas) are less suitable from this point of view.

Assessed area: hydrogeological model.

C5b Flow rate at the DGR level

Description of the indicator: based on the hydrogeological models of the candidate DGR sites and their updating, the maximum velocity of groundwater flow will be determined in the rock mass in the area and at the level of the DGR.

Quantification: value of the maximum groundwater flow rate ($m.year^{-1}$). Lower velocities form a prerequisite for the efficient functioning of the rock environment as a natural barrier. Sites with more rapid flow through the DGR area are less suitable from this point of view.

Assessed area: hydrogeological model.

C5c Permeability in the DGR area

Description of the indicator: based on the hydrogeological models of the candidate DGR sites and their updating, the maximum permeability of the rock mass will be determined at the level and in the area of the planned DGR.

Quantification: the value of the maximum permeability ($m.s^{-1}$) of the rock mass without the presence of failure zones. Sites with higher rock mass permeability values are less suitable from this point of view. A lower degree of permeability forms a prerequisite for the efficient functioning of the rock environment as a natural barrier.

Assessed area: hydrogeological model.

C5d Descending vertical flow component

Description of the indicator: based on the hydrogeological models of the candidate DGR sites and their updating, the proportion of the DGR area with a descending vertical flow component will be determined.

Quantification: the percentage (of the DGR area). A larger area with a descending flow component will serve to extend the transport pathways. Therefore, sites with lower proportions of the vertical descending groundwater flow component will be deemed less favourable.

Assessed area: hydrogeological model.

C5e Maximum permeability of failure zones up to 500 m from the DGR boundary

Description of the indicator: based on the hydrogeological models of the candidate DGR sites and their updating, the maximum permeability of the rock environment will be determined related to the occurrence of failure zones at the level of the DGR up to a distance of 500 m from the boundary of the disposal areas.

Quantification: the value of the maximum hydraulic conductivity ($m.s^{-1}$). Higher failure zone permeability levels in the vicinity of the DGR will be deemed less favourable from the point of view of siting.

Assessed area: hydrogeological model.

C5f Specific flow in the DGR area

Description of the indicator: based on the hydrogeological models of the candidate DGR sites and their updating, the magnitude of groundwater flow through the DGR area as normalised by its area (specific flow) will be determined.

Quantification: the specific flow ($l.s^{-1}.km^{-2}$) of groundwater through the DGR. The amount of groundwater that flows through the DGR forms a crucial parameter for the process of the release of radionuclides into the geosphere. If a small amount of water flows through the disposal wells, only a small amount of radionuclides may be released into the geosphere and migrate further into the environment. Higher specific flow values are less suitable from this point of view.

Assessed area: hydrogeological model.

C5g Dilution ratio

Description of the indicator: based on the hydrogeological and transport models (advective transport only; without disintegration, sorption, reactions or dispersion – for a conservative tracer) of the candidate DGR sites and their updating, the proportion of the maximum modelled concentration of the modelled substance in the near-surface zone and in the DGR area will be determined.

Quantification: the percentage value. Higher values will indicate lower suitability due to the lower degree of the dilution of contamination during advective transport from the DGR. Conversely, lower values will indicate the more extensive mixing of the groundwater from the DGR area towards the drainage area.

Assessed area: hydrogeological model.

4.4.6 Criterion C6: Identification and location of drainage bases

Description of the criterion: the identification of places at which groundwater may drain from the DGR (drainage bases) is important in terms of the safety of the site. Groundwater flow constitutes an important factor that influences the mobility of radionuclides in the rock environment. The DGR should ideally be sited so that the transport pathways of radionuclides that lead to drainage bases are as long as possible and that the transport of radionuclides is as slow as possible.

One of the most unfavourable characteristics of sites for the location of the repository comprises the occurrence of just one dominant drainage base, to which radionuclides from the entire area of the repository will migrate following the end of the service life of the engineered barriers. The primary recipient of the groundwater, which will potentially be contaminated with radionuclides in the DGR area, will comprise the sediments of valley floodplains and, subsequently, the river network. The knowledge of the number of sections (and length) of the river network into which the groundwater will drain from the DGR complex provides valuable information on the degree of dispersion of potential radionuclide contamination.

In accordance with requirements set out in MP.22 for the characterisation of DGR drainage areas, four indicators were defined for this criterion that comprehensively provide for the description of the dispersion of transport routes from the DGR area to the drainage sites. Modelled calculations of the transport from the DGR complex consider the migration of a conservative tracer substance. The results obtained approximate to the transport of the most mobile radionuclides (e.g. ^{129}I, ^{36}Cl). The transport processes of other radionuclides (reacting, sorbing) will be more retarded, i.e. a more favourable rate of migration than that suggested by the modelled results.

The following indicators have been defined for this criterion:

C6a Number of drainage streams

Description of the indicator: the number of streams into which the entire disposal area of the DGR will drain.

Quantification: the number of streams into which contaminants from the DGR will drain via the flow of groundwater. Drainage via a single stream is deemed unfavourable.

Assessed area: hydrogeological model.

C6b Extent of drainage from the DGR area via a single stream

Description of the indicator: a stream via which the greater part of the DGR disposal area will drain.

Quantification: percentage. The selection of the stream with the maximum share of drainage from the DGR disposal area. A high percentage of the drainage of the DGR disposal area via a single stream is deemed unfavourable. Conversely, lower values indicate the dilution of radionuclides over a larger area of the river network.

Assessed area: hydrogeological model.

C6c Extent of drainage from the DGR area into a single river basin

Description of the indicator: the drainage basin into which the greater part of the DGR disposal area will drain.

Quantification: percentage. The selection of drainage basins with the maximum share of drainage from the DGR disposal area and outflow to areas outside the area considered by the hydrogeological models. A high percentage of the drainage of the DGR disposal area into a single river basin is deemed unfavourable. Conversely, lower values indicate the dilution of radionuclides in other drainage basins.

Assessed area: hydrogeological model.

C6d Horizontal distance of the DGR from the drainage location (m)

Description of the indicator: the horizontal distance between the boundary of the DGR disposal area and the nearest drainage area for groundwater from the DGR complex.

Quantification: distance (m). Sites at which the drainage of groundwater from the DGR will proceed directly in the overburden of the DGR (zero distance between the drainage point and the boundary of the DGR) will be deemed less suitable from this point of view.

Assessed area: hydrogeological model.

Rationale of the area of evaluation: the evaluation of the above characteristics is based on the extent of the modelled areas, which were defined with respect to set model requirements (zero flow through the model) and according to regional water courses. The extent of the described areas (up to 400 km^2) allows for the assessment of the above parameters with sufficient accuracy.

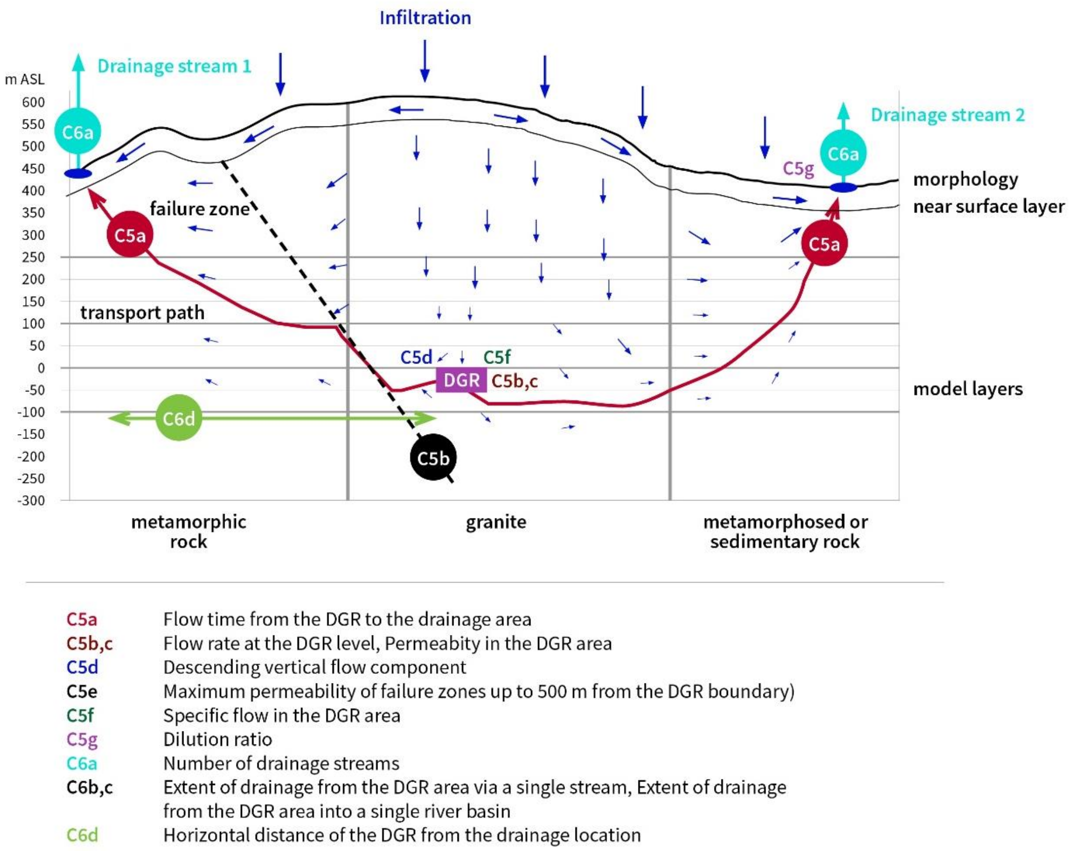

Fig. 6 Illustration of the hydrogeological indicators

4.4.7 Criterion C7: Seismic and geodynamic stability

Description of the criterion: the geological structure of the area for the siting of the DGR must guarantee the stability of the facility over at least hundreds of thousands of years. According to Section 18, paragraph 2, g), i) and j) of Decree No. 378/2016 Coll. the occurrence of endogenous and exogenous phenomena (g) expected climate development (i) and the vulnerability of the rock environment to long-term climate change (j) must be assessed. According to the IAEA, the DGR host environment (IAEA 2011 b) should not be susceptible to damage caused by future geodynamic processes and related subsequent phenomena and other factors (e.g. climate change, neo-tectonic movements, high seismicity) to the extent that such effects could lead to unacceptable damage to any of the safety features of the disposal system.

The following indicators have been defined for this criterion:

C7a Value of the maximum horizontal acceleration

Description of the indicator: the value was determined by means of the PSHA method (Málek et al. 2018) for a probability of 50% and a repetition time of 10^5 years. The lower limit of the annual frequency was considered to be 10^{-6} and seismic hazard curves were determined for the 16%, 50%, 84% and mean quantiles. The disaggregation of the seismic hazard formed part of the calculation. The seismic threat to the sites is determined in particular via the distance from the first two significant zones and the frequency of weak near earthquakes.

Quantification: the horizontal acceleration value in $m.s^2$ for a 50% probability level and a repetition time of 10^5 years is considered.

Assessed area: seismic model according to Málek et al. (2018).

Rationale of the area of evaluation: the evaluated area is based on PSHA analysis methodology applied up to a distance of 300 km from the site of a nuclear facility; assessment polygons were also defined for this factor in Málek et al. (2018).

C7b Elevation gradient

Description of the indicator: the elevation gradient between the height of the levelled surface of the area and the level of the relevant local erosion base is directly proportional to the dynamics of the relief and determines the potential for the lowering of the drainage system in the future and the associated emergence of exodynamic phenomena, including long-term changes.

Quantification: the maximum value of the elevation difference (m) is considered.

Assessed area: modelled area – Franěk et al. (2018).

Rationale of the area of evaluation: the indicator relates to the potential for the uplift of the area which will influence the pressure conditions (gradient) of flow at repository depth. Hence, the assessment includes the area covered by the regional geological models according to Franěk el al. (2018).

C7c Percentage of the relief area affected and reshaped by young cycles of reverse erosion and slope deformations

Description of the indicator: significant manifestations of reverse erosion indicate unbalanced river flow catchment conditions caused by movements of the erosion base, i.e. vertical movements of the earth's crust, and result in the lowering of the drainage system to a greater than anticipated extent. This indicator exerts an impact on the future derivation of site development scenarios.

Quantification: in percent.

Assessed area: modelled area – Franěk et al. (2018).

Rationale of the area of evaluation: the indicator relates to the potential for the erosion of the area surrounding the repository. Hence, the assessment includes the area covered by the regional geological models according to Franěk el al. (2018).

C7d Occurrence of volcanic rocks of the Paleogene to Holocene eras and acids

Description of the indicator: the presence of tertiary and quaternary volcanic rocks and related post-volcanic phenomena are associated with areas that witnessed recent geodynamic activity, including tectonic movements; this factor provides an indication of the long-term stability of the area. The presence of acids in the vicinity of the site may exert a negative effect on the engineered barriers of the repository.

Quantification: the occurrence of volcanic rocks of the Paleogene to Holocene eras and the occurrence of acids are considered in terms of the potential incidence of these phenomena. The non-occurrence of the phenomena = 1, the occurrence of the phenomena = 5.

Assessed area: the occurrence of volcanic rocks at a distance of up to 5 km from the potential DGR area and the occurrence of acids at a distance of up to 25 km from the potential DGR area.

4.4.8 Criterion C8: Characteristics that could lead to the disturbance of the DGR via future human activities

Description of the criterion: the disturbance of the repository by future human activities will, according to international recommendations (the HIDRA project, EURATOM PAMINA, etc.), most likely be due to the following reasons:

1. the disturbance of the repository in order to recover the disposed of SNF as a secondary raw material or for other purposes;
2. disruption of the repository in order to use the available resources in the area following the loss of information on the existence of the repository.

With respect to the reason mentioned in point 1), it is not possible to prevent or reduce the probability of the disturbance of the repository in the future. However, those who penetrate into the repository will know what it contains, will need these materials (for whatever purpose) and will have the necessary technical means and economic resources to so. Such events concern intentional disturbance, which is not assessed in terms of impacts on humans as recommended by the International Commission on Radiation Protection (ICRP). However, it is important to prevent the unintentional disturbance of the repository by humans following the loss of information on the existence of the repository.

The following indicator has been defined for this criterion:

C8a Raw material deposit conditions at the site (mining areas, register of protected deposit areas, prediction of the presence of minerals)

Description of the indicator: reserved raw material deposit areas, mineral reserves and the forecasts thereof comprise strategic factors in terms of the development of the country and, as such, the presence of significant mineral reserves may constitute an excluding criterion when assessing and comparing the suitability of the candidate sites.

Quantification: no/insignificant/significant/yes.

Assessed area: promising area for the geological characterisation research work.

Rationale of the area of evaluation: the presence of mineral reserves and potential intrusion into the site due to its raw materials deposit potential depends on the direct indication of the existence of such deposits. Since the repository will be located at a depth of several hundred metres below the surface in pre-determined rock blocks, the area above this level will provide a sufficient reserve for the assessment of the raw materials deposit potential of the site.

4.4.9 Criterion C9: Phenomena influenced by the spread of radioactive materials

Description of the criterion: with respect to the future DGR, this factor primarily concerns the assessment of the impact of a possible emergency situation involving the hot chamber in which the SNF will be removed from the storage and transport containers and inserted into waste disposal packages. In the event of the spread of radionuclides through the atmosphere and the interaction of negative processes such as the malfunction of the filters of the hot chamber when opening a storage/transport package with damaged fuel cells, radioactive substances may be released into the environment via the ventilation system. The spread of radioactive materials might also occur in the event of an emergency situation during the transport of the SNF from the storage facility to the DGR. Longer distances and more frequent shipments will increase the likelihood of such an emergency.

The following indicators have been defined for this criterion:

C9a The distribution and density of the population and its development in terms of the spread of radioactive material

Description of the indicator: the assessment of population density must be performed in accordance with Section 17, Decree No. 378/2016 Coll., on the siting of nuclear facilities. While this factor is not excluding, it can be used to compare the sites via the calculation of the collective dose. The collective dose, which is used to compare radionuclide releases from nuclear facilities is directly proportional to the population density around the nuclear facility; it is determined as the sum of all the effective doses of persons living in the vicinity of such a facility. The effective dose is multiplied by the number of people in given age groups (child of 3 months, 1, 5, 10, 15 years and adults) since the effect of radiation differs between age categories. Thus, the larger the population, the greater the collective dose. Moreover, the calculation of the collective effective dose requires a knowledge of the prevailing direction and strength of the wind in order to determine the direction of the potential spread of radioactive substances. Since accurate meteorological data from the sites is not available at this stage of the assessment process, data from the nearest Czech Meteorological Institute monitoring station was used to calculate the collective effective dose. Since this data may differ from real values at the sites, the calculation of the collective effective dose is subject to significant uncertainty and cannot be used for site comparison purposes. Hence, the population distribution and density indicator is used instead.

Quantification: size of the population.

Assessed area: up to 10 km from the point of discharge of air from the hot chamber (DGR surface area) into the atmosphere.

Rationale of the area of evaluation: a distance of 10 km from the hot chamber outlet was determined based on the results of the HARP program, which served for the calculation of the collective effective dose. The impact of the potential release of radionuclides on the population in conditions where the chimney of the hot chamber will have a maximum height of 15 m above the ground and the hot chamber will work with spent nuclear fuel that was removed from the reactor at least 65 years previously would be greatest in the vicinity of the outlet. At greater distances, the effective dose is orders of magnitude lower (Martinčík et al. 2018 a-i).

C9b Distance from nuclear power plants

Description of the indicator: the probability of the occurrence of an emergency event during the transport of containers with SNF is proportional to the distance of the sites from nuclear power plants with SNF storage facilities, and the frequency of the shipment of SNF. In order to calculate the total distance travelled to the site, the current distance via the railway infrastructure is multiplied by the number of trains that will be dispatched from the storage facility. One of the assumptions for the calculation is the transport of three storage/transport containers per shipment.

Quantification: number of shipments of storage/transport containers.

Assessed area: the indicator is not linked to the area but to the distance to nuclear power plants.

Rationale of the area of evaluation: the distance of the site from a nuclear power plant is determined as the distance of the surface area of the DGR from the spent nuclear fuel storage facilities of the Dukovany and Temelín nuclear power plants.

4.4.10 Criterion C10: Impact on surface waters and water resources

Description of the criterion: the assessment of the potential impact of the DGR (over the whole of its life cycle - construction, operation, closure) on surface waters and groundwater, including water sources used for the supply of the population.

The following indicators have been defined for this criterion:

C10a Impact on the runoff conditions and surface water quality in the immediate vicinity of the DGR surface area

Description of the indicator: the indicator reflects the presence of watercourses and water areas in the area affected by the construction of the surface part of the DGR (surface area, mining facilities outside the surface area, related transport infrastructure - special-purpose road connection, railway siding). The impact on the local runoff conditions may be significant especially in the case of the surface area, and depends mainly on the extent of the remediation of the local landscape (spatial extent and elevation of the natural terrain) in relation to the size of the receiving catchment area and its hydrological characteristics. The direct impact concerns only the receiving catchment area and, potentially, related tributaries (small watercourses affected by the location of the surface area of the DGR). Subsequent flows in higher-order river basins may also be indirectly affected. Any change in the runoff conditions may also exert a significant impact on the biota dependent on the pre-existing hydrological conditions, including the drying and wetting of the land. In comparison with the influence of the DGR surface area, the impacts of the construction of the transport infrastructure will be less significant due to the availability of standard technical solutions (culverts, the bridging of streams). The quality of the surface water may be affected by oil spills or the leaching of excavated earth deposits. However, standard technical and organisational measures can be adopted in order to minimise the risk.

Quantification: the impact is directly dependent on the extent of the remediation of the local landscape (spatial extent and elevation of the natural terrain) and the occurrence of watercourses and water areas in the surface area of the DGR and its immediate surroundings, and is inversely proportional to the size of the affected river basin, i.e. the relative content of water of the receiving catchment area (compared to the other sites). Grading of the impact: 1 – 5, where 1 is most favourable.

Assessed area: the surface area of the DGR and its immediate surroundings (approximately to the extent of the affected part of the receiving catchment area).

Rationale of the area of evaluation: the extent of the assessed area is derived from the expected range of the potential impacts. It is, therefore, directly dependent on the aspects mentioned above (location of the surface area within the affected river basin, landscape remediation, distance from watercourses).

C10b Impact on water sources near the DGR

Description of the indicator: the indicator reflects the presence of registered sources of drinking water and water protection zones I and II within the areas considered promising for the conducting of future geological characterisation research work, the yield or quality of which could (theoretically) be affected during the life cycle of the DGR. The subject of the evaluation process comprises water sources that supply the public water system and their significance in terms of the number of inhabitants supplied. The areas covered by the assessment comprise the number of registered water sources, their yield and the total area of water protection zones I and II in the assessed area and their spatial relationships (distance, location) to the DGR surface area, mining facilities outside the surface area and access roads. With respect to smaller settlements, the existence of domestic wells is generally assumed, regardless of the extent to which they are used.

Quantification: the distance of the water source from the DGR surface area, i.e. promising area for the project design work, the extent of the overlapping of water protection zones I and II with the surface area or the promising area for the project design work, and the number and yield of registered water resources.

Graded evaluation of the potential impact: 1 - 5.

Assessed area: promising area for the geological characterisation research work.

Rationale of the area of evaluation: impacts on water resources, i.e. their yield in the crystalline rock environments of the sites could only occur in the immediate vicinity of the DGR as a result of a change in the direction of the groundwater flow by the formation of a cone of depression or the “opening” of new drainage pathways in the rock massif (e.g. tectonic faults). As a safety reserve, promising areas for the geological characterisation research work were defined with an overlap into the wider area of interest as defined for the assessment of indicator 10c in cases where the boundaries of the promising area for the project design work and the geological characterisation research work are identical.

C10c Impact on significant water sources in the wider area

Description of the indicator: the indicator reflects the existence of significant water sources in the wider area of the DGR site. Since significant water sources are not defined in legislation, for the purposes of the site assessment process such sources are considered those that supply at least 3,000 inhabitants. This limit is derived from the provisions of Section 3 par. 1 of Act No. 128/2000 Coll., on municipalities, as amended, according to which a municipality with this (or a higher) population is considered to be a town. The significance of this impact is directly dependent on the number of inhabitants supplied from water sources as defined in this way.

The risk of such an impact concerns the existence of potential areas of groundwater drainage from the level of the disposal area of the DGR. Such areas have been determined via calculations based on the updated versions of mathematical models of groundwater flow at the sites (Havlová et al. 2020 a-i). The drainage areas of deep crystalline zones are usually bound to the drainage base of the respective area (watercourse channels) and to the intersection of such channels and significant fault zones. The final demonstration of the absence of such impacts on these sources, or the availability of measures to ensure their protection, will be addressed in the relevant safety reports according to parts a), b) and e) of point 1 of Annex 1 to the Atomic Act.

Quantification: the number of significant sources and the evaluation of potential impacts on such sources.

Graded evaluation of the potential impact: 1 - 5.

Assessed area: promising area for the project design work + 5 km reserve.

Rationale of the area of evaluation: with respect to the evaluation of potential impacts on significant water sources, safety reserve areas with radii of 5 km from the proposed DGR sites have been defined so that it is possible to include all the significant water sources that might be affected by the flow of water from the depth of the repository to the respective drainage bases according to the hydraulic models created of the sites.

4.4.11 Criterion C11: Impacts on nature and landscape protection

The criterion includes an assessment of the impact of the construction and operation of the DGR, including the related transport infrastructure, on nature and the landscape, concerning which certain restrictions (protective conditions) apply to the siting, construction and use of such a facility as defined in the Nature and Landscape Protection Act and the implementing regulations thereof.

The following indicators have been defined for this criterion:

C11a Impacts on biodiversity (flora, fauna, ecosystems, small specially protected areas, internationally protected habitats, territorial ecological stability systems, other natural habitats, significant landscape components)

Description of the indicator: the indicator reflects the occurrence of protected species of flora and fauna and their habitats, including internationally protected habitats, small specially protected areas, other naturally valuable habitats and significant landscape components and their spatial links (distance + terrain relief) in relation to the DGR surface area and the related transport infrastructure. The most significant impacts are associated with direct intervention in such protected areas via the siting of the DGR surface area, access roads and railway sidings (= construction directly in such habitats). The impacts on such characteristics and phenomena in the vicinity of construction sites (approximately up to a distance of the first hundreds of metres) are significant, especially with concern to the construction of deep geological repositories (noise disturbance, negative impacts on migrating species, the expansion of non-native species due to changes in habitat conditions, water and soil pollution via oil spills).

Quantification: the impacts will be directly proportional to the share of the area of such natural phenomena affected by the construction of the DGR surface area (or other surface buildings outside the main DGR surface area) of the total area. In the case of territorial ecological stability system bio-corridors, the impact will depend on the extent of and method used for traversing the DGR surface area and will be inversely proportional to the distance of the DGR surface area (or other surface buildings outside the main DGR surface area) from the natural phenomena, taking into account mutual spatial linkages. In addition to the distance from the DGR construction site, the extent of the impact could be reduced by the existence of spatial barriers (relief, forests). In the case of the transport infrastructure, the degree of impact depends on the length of roads/railway sidings and the extent to which they traverse such areas of important natural phenomena.

Graded evaluation: 1 – 5.

Assessed area: surface area, related transport infrastructure (access roads, railway sidings), including adjacent areas within the range of the potential occurrence of such impacts. The extent of the assessed area may be influenced by the local morphology, e.g. terrain elevations may serve as shielding barriers.

C11b Impacts on migration corridors and areas important for migration

Description of the indicator: the indicator reflects the existence of animal migration corridors and areas important for migration and their spatial links to the DGR surface area and transport infrastructure - distance, terrain relief, siting of the DGR surface area in areas important for migration, length and method of the traversing of such areas and corridors by the transport infrastructure. Migration barriers comprise transport routes (especially roads) with a high intensity of traffic that traverse migration corridors and areas important for migration. One of the indirect impacts consists of noise interference from construction work on, and the subsequent operation of, the surface area. Reducing the migratory permeability of the area (especially for large mammals) exerts an impact on animal populations that exist in confined spaces.

Quantification: the impact will be inversely proportional to the distance from the surface area to migration corridors, taking into account mutual spatial connections. In the case of areas important for migration, only the positioning of the surface complex in such areas, or the overlapping of the surface complex and such areas, are assessed. With concern to access roads, only the length and the way in which they cross migration corridors and areas important for migration are assessed.

Graded evaluation: 1 – 5.

Assessed area: the surface area, related transport infrastructure (access roads, railway sidings), including adjacent areas affected by such impacts (noise from traffic, from the construction site and from the operation of the DGR). Due to the fact that a number of other factors exert significant impacts on migration corridors and migration areas in addition to noise sources and the fact that it is not possible to define the exact area that will be affected based on the current level of knowledge, this indicator will be assessed in terms of the whole of the potential DGR sites (the area defined for geological characterisation research work).

C11c Impacts on Natura 2000 bird areas and sites of European importance

Description of the indicator: The aim of Natura 2000 protected areas is to protect rare and endangered species of birds and other animals, plants and rare natural habitats in the EU. The system defines two types of areas - bird areas and sites of European importance. The distance is assessed of the DGR surface area from such areas or the downstream distances along watercourses depending on the reason for protection. The territorial integrity of neither Natura 2000 bird areas nor sites of European importance is affected by any of the candidate DGR sites.

Quantification: the impact will be inversely proportional to the direct distance of such areas from the DGR surface area, and inversely proportional to the downstream distance (in the case of aquatic objects).

Graded evaluation: 1 – 5.

Assessed area: surface area, related transport infrastructure (access roads, railway sidings), including adjacent areas within the range of the potential occurrence of such impacts. The nature of these impacts is similar to those of indicator C11a.

C11d Impacts on the landscape

Description of the indicator: the indicator includes impacts on specific characteristics of the landscape (scale, dominant aspects, visual linkages) and related natural, cultural-historical and aesthetic factors. The scope of the DGR research field work and visual exposure compared to the current use of the landscape, the existence of natural parks and the use of designated forest areas are assessed. The potential creation of a landfill site for excavated material is not included in this evaluation indicator (it is assessed as part of indicator C2a).

Quantification: the impact will occur according to the extent, character and visual exposure of the areas affected by the siting of the DGR surface area.

Graded evaluation: 1 – 5.

Assessed area: the extent of the area impacted (especially) by the surface area is fundamentally dependent on the visual exposure of the areas in which the surface complex is located.

4.4.12 Criterion C12: Impacts on agricultural land and land intended for forestry

The assessed criterion includes estimated requirements for the use of agricultural land and land intended for forestry due to the construction of the DGR.

The following indicators have been defined for this criterion:

C12a Impact on agricultural land

Description of the indicator: the indicator expresses the extent of the use of agricultural land (especially of land included under protection classes 1 and 2) due to the construction of the DGR surface area and the related transport infrastructure.

Quantification: the impact occurs whenever permission is granted to use agricultural land for the siting of the DGR surface area or the related transport infrastructure, and will be directly proportional to the amount of agricultural land required, with respect particularly to the use of high quality agricultural land (protection classes I and II). In the case of linear transport infrastructure, the extent of the use of such land is derived from the lengths of those sections that traverse agricultural land.

Graded evaluation: 1 – 5.

Assessed area: surface area, related transport infrastructure.

C12b Impact on land intended for forestry

Description of the indicator: the indicator expresses the extent of the use of land intended for forestry and the respective protection zones (taking into account the higher importance of protected forests and special purpose forests) due to the construction of the DGR surface area and the related transport infrastructure. In the case of linear transport infrastructure, the extent of the use of such land is derived from the lengths of those sections that traverse land intended for forestry.

Quantification: the impact will be directly proportional to the extent of the use of land intended for forestry. The occurrence and extent of protected forests and special purpose forests will also be taken into account.

Graded evaluation: 1 – 5.

Assessed area: surface area, related transport infrastructure.

4.4.13 Criterion C13: Impacts on the population, property and protected monuments

Description of the criterion: the criterion includes an assessment of the disturbance of the quality of life and the recreational environment, as well as changes in the use of buildings and impacts on protected monuments.

The following indicators have been defined for this criterion:

C13a Disruption of well-being factors

Description of the indicator: the disruption of "well-being factors" will occur mainly via increases in noise and emissions in the local residential and recreational environments (not necessarily beyond the relevant public health limits). The indicator reflects the character of residential building development (continuous/individual) and recreational buildings and facilities and their distance from the surface area, and the related transport infrastructure, taking into account the existence of shielding barriers (landscape relief, forested areas).

Quantification: the impact is inversely proportional to the distance of residential buildings and recreational facilities from the surface area, and from the related transport infrastructure taking into account the existence of shielding barriers (relief, forest areas in the intermediate area).

Graded evaluation: 1 – 5.

Assessed area: surface area, related transport infrastructure (access roads, railway sidings), including intermediate areas with respect to a range of expected impacts.

C13b Impacts on residential, recreational and listed buildings

Description of the indicator: the indicator reflects the occurrence and number of residential, recreational and listed buildings in the immediate vicinity of the surface area and the related transport infrastructure, concerning which purchase or change of use cannot be ruled out due to the impossibility of ensuring the quality of the local environment or compliance with the relevant public health limits.

Quantification: the impacts will be directly proportional to the occurrence of residential, recreational and other buildings in the defined surface area and in its immediate vicinity and in the vicinity of access roads/railways.

Points evaluation: 1 – 5.

Assessed area: surface area, mining facilities outside the surface area, related transport infrastructure, including the immediate surroundings.

4.4.14 Criteria C11 - C13 – rationale for the concentration of the assessment on the surface area

In the case of criteria C10 - C13, the sources of potential impacts on the population, environmental components and cultural and historical monuments comprise, in particular, the following:

- the surface area and other components located on the earth's surface outside the surface area (ventilation shafts, landfill sites, parking areas);
- related transport and technical infrastructure (especially the connection of the surface area to the road and railway network, electricity supply);
- underground part of the DGR (mined component).

From the point of view of the overall DGR life cycle, the occurrence of the most significant impacts is expected in the DGR preparation and construction phases. From this point of view, there are no differences between the candidate sites. A summary of the occurrence of potential impacts associated with the above-mentioned DGR components is provided in the table below:

Tab. 3 Summary overview of the occurrence of potential impacts associated with the above-assessed DGR components

Component of the environment	**Surface area**	**Related transport and technical infrastructure**	**Underground part of the DGR**
Population	Yes	Yes	Partly[1)]
Climate	Yes	Yes	No
Air	Yes	Yes	No[2)]
Surface and underground water	Yes	Yes	Yes (underground water)
Biodiversity	Yes	Yes	No
Landscape	Yes	Yes	No[3), 4)]
Soil (agricultural + forestry)	Yes	Yes	No
Cultural and historical value (monuments)	Yes	Yes	No

Notes:

[1)] *Noise and vibration from mining work*

[2)] *Ventilation shafts are not considered a significant source of pollution at this level of detail.*

[3)] *The excavated material landfill site is considered to be part of the surface components.*

[4)] *The impacts of mining on the surface are considered negligible at this stage (with regard to the predominant character of the rock environment at all the candidate sites).*

It is clear from the above table that when assessing the candidate sites in terms of non-radiation impacts, the main focus of attention concerns the surface area and the related transport infrastructure. The effects of other construction components outside the surface area (ventilation shafts) are not included at this stage mainly because their location, spatial extent and method of construction (from the surface, from underground) have not yet been determined.

The construction of the technical infrastructure (e.g. water supply, waste water disposal, gas supply, etc.) are not included due to the significantly lower risk of potential impacts on the environment.

5 Site assessment process

The assessment of the sites by determining their qualitative order of suitability involves the application of a process known as “multicriteria decisional analysis”, a typical feature of which is the comparison of several factors, variants, etc. on the basis of various criteria (requirements, properties), which are represented by asymmetric quantities and the values thereof.

The method applied to compare the criteria must be objective and robust, and it must be capable of processing both qualitative and quantitative variables. Such requirements are generally met by the multicriteria decisional analysis (MCA) method, Triantaphyllou E. (2000), which addresses the evaluation of variants according to several criteria. A rating obtained based on one criterion will not necessarily match the rating obtained from another criterion. Multicriteria analysis must, therefore, be able to solve the differences between differing criteria. The aim of the MCA method is to provide for the classification and summarisation of the available information and provide the most appropriate solutions, concerning which certain requirements have been placed.

The basic aim of the analysis is to compile a suitable model, based on which it is possible to determine the final “utility value” of the various factors compared. The utility value can be expressed by means of a range of variables such as price, the quality of the brand, points values, ratio to the standard, etc. With respect to issues where it is necessary to classify the variants (in this case the candidate sites) from the most to the least suitable, the process involves arranging the variants on the basis of their mutual differences, i.e. it is necessary to differentiate the sites to the greatest possible extent.

The evaluation of the sites is based on the comparison of selection criteria, which represent the various requirements (properties) that the sites must fulfil (for more details on the description of the criteria, see Chapter 4.3). Since some of the criteria cover a broad area of requirements, most of the criteria were further broken down into so-called indicators that represent specific properties, phenomena or states. The evaluation process will be performed in the form of several mutually independent successive stages:

The determination of the values of the indicators, H_i, with respect to their physical variability, and conversion to grades, X_i (see chapter 5.2).

The determination of the significance (weighting) of the indicator within a given criterion, see Tab. 5.

Based on the definition of the indicators and criteria, and independently of the indicator values, the weightings of the criteria are determined according to the preferences of the decision-maker (expert). Only via the setting of criteria weightings can the most and least suitable sites be unambiguously determined (see Chapter 5.4).

The results of the assessment model clearly depend on the input assessment data. The data comparison method described below was derived with the aim of determining the order of the sites in terms of suitability as part of the selection process for the final site for the DGR in 2019-2020. The aim is to compare the candidate sites based on the key criteria and indicators described above in Chapter 4.

5.1 Processed data

In the case of the site evaluation process, the data comprises the values of the various indicators, which represent certain characteristics (properties, phenomena) of each site. These indicator values can be divided into three basic groups:

- qualitative – indicator values that express a property as defined by a verbal description;
- quantitative – indicator values that express a given property via a specific numerical value, a continuous numerical interval, that represents a specific physical scalar quantity or share, expressed as a percentage;
- quasi-logical – indicator values that express the non/existence of a phenomenon, or the degree of its significance.

Tab. 4 provides an overview of the values of the indicators applied in relation to the relevant criterion; each indicator is accompanied by a description of the nature of the primary value (type) via which it is expressed and an explanation of the scale of the value (trend).

Tab. 4 Types of indicator values

ID	Criterion designation	ID	Indicator designation	Primary value type	Trend
C1	**Size of the usable rock mass**	C1a	Usability of the rock blocks	number (%)	the lower the better
		C1b	Fragmentation of the area	number	the lower the better
		C1c	Fragmentation of the underground part of the DGR	number	the lower the better
C2	**Infrastructure availability**	C2a	Potential for the permanent disposal of excavated material in the vicinity	number	the lower the better
C3	**Describability and predictability of the homogeneous blocks**	C3a	Degree of the brittle failure of the massif - fault structures	grade	the lower the better
		C3b	Degree of brittle failure of the massif - fracture systems	grade	the lower the better
		C3c	Degree of ductile deformation	grade	the lower the better
C4	**Variability of the geological properties**	C4a	Spatial variability of the rock environment	grade	the lower the better
		C4b	Petrological variability of the rocks	grade	the lower the better
C5	**Water flow characteristics in the vicinity of the DGR**	C5a	Flow time from the DGR to the drainage area	number	the higher the better

ID	Criterion designation	ID	Indicator designation	Primary value type	Trend
	and the transport characteristics	C5b	Flow rate at the DGR level (m.year^{-1})	number	the lower the better
		C5c	Permeability in the DGR area (m.s^{-1})	number	the lower the better
		C5d	Descending vertical flow component (% of the DGR area)	number	the higher the better
		C5e	Maximum permeability of failure zones up to 500 m from the DGR boundary (m.s^{-1})	number	the lower the better
		C5f	Specific flow in the DGR area (l.s^{-1}.km^{-2})	number	the lower the better
		C5g	Dilution ratio (%)	number	the lower the better
C6	**Identification and location of drainage bases**	C6a	Number of drainage streams	number	the higher the better
		C6b	Extent of drainage from the DGR area via a single stream	number (%)	the lower the better
		C6c	Extent of drainage from the DGR area into a single river basin	number (%)	the lower the better
		C6d	Horizontal distance of the DGR from the drainage location (m)	number	the higher the better
C7	**Seismic and geodynamic stability**	C7a	Value of the maximum horizontal acceleration (m.s^{-2})	number	the lower the better
		C7b	Elevation gradient	number	the lower the better
		C7c	Percentage of the relief area affected and reshaped by young cycles of reverse erosion and slope deformations	number (%)	the lower the better

ID	Criterion designation	ID	Indicator designation	Primary value type	Trend
		C7d	Occurrence of volcanic rocks of the Paleogene to Holocene eras and acids	quasi-logical quantification	the lower the better
C8	**Characteristics that could lead to the disturbance of the DGR via future human activities**	C8a	Raw material deposit conditions at the site	quasi-logical quantification	the lower the better
C9	**Phenomena influenced by the spread of radioactive materials**	C9a	The distribution and density of the population and its development in terms of the spread of radioactive material	number	the lower the better
		C9b	Distance from nuclear power plants	number	the lower the better
C10	**Impact on surface waters and water resources**	C10a	Impact on the runoff conditions and surface water quality	grade	the lower the better
		C10b	Impact on water sources near the DGR	grade	the lower the better
		C10c	Impact on significant water sources in the wider area	grade	the lower the better
C11	**Impacts on nature and landscape protection**	C11a	Impacts on biodiversity	grade	the lower the better
		C11b	Impacts on migration corridors and areas important for migration	grade	the lower the better
		C11c	Impacts on Natura 2000 bird areas and sites of European importance	grade	the lower the better
		C11d	Impacts on the landscape	grade	the lower the better
C12	**Impacts on agricultural land and**	C12a	Impact on agricultural land	grade	the lower the better

ID	Criterion designation	ID	Indicator designation	Primary value type	Trend
	land intended for forestry	C12b	Impact on land intended for forestry	grade	the lower the better
C13	**Impacts on the population, property and protected monuments**	C13a	Disruption of well-being factors	grade	the lower the better
		C13b	Impacts on residential, recreational and listed buildings	grade	the lower the better

As can be seen from Tab. 4 above, the indicators are represented by differing types of values. Therefore, for the purposes of the overall assessment, it is necessary to unify them so that the subsequent calculation of the assessment is credible. Since the conversion of a qualitative description to a numerical scale is possible only via a grading or points system, the numerically expressed indicators are converted in the same way (via their conversion to grades). In order to maintain the maximum degree of objectivity of the assessment process, it was decided that the conversion of the numerical values of the indicators (where relevant) into grades would be reassessed by specialist expert teams for the given issue. This was considered the only way in which to manage the degree of uncertainty in determining the given values, since the relevant experts are well aware of the related uncertainties from the stage in which the various characteristics (indicators) were determined. The conversion to a graded scale for the quasi-logical indicators was much more decisive, i.e. the degree of the fulfilment of the given indicator was expressed in the form YES to NO. The above-mentioned expert procedure was then applied to convert the various indicator values into a uniform graded scale with a range of 1 to 5 (the higher the grade, the lower the quality) which emphasises the qualitative assessment of the various indicators for each site.

5.2 Conversion of the real values of the H_i indicators to X_i graded scales

For site assessment purposes, it was necessary to identify the various differences between the sites.

The primary values of the indicators were represented by various types of values:

- Descriptive values expressed by the expert assignment of a grade value ($\mathbf{X_i}$) for each indicator for each site.
- Quasi-logical values - YES/rather YES/rather NO/NO.
- Real values representing the scalar reflection of a physical quantity.

In order to unify the indicator values on a consistent basis, it was necessary to convert the real values ($\mathbf{H_i}$) to grade values ($\mathbf{X_i}$), but in such a way that their informative ability was maintained, especially from the point of view of the differences between the sites.

However, before making the conversion, it was necessary to determine the significant trend represented by the given indicator.

For those indicators that expressed increasing quality (acceptability) with decreasing values (the lower, the better), the conversion was performed according to the equation:

$$X_i^L = 1 + 4 \times \frac{H_i^L - H_{i,min}}{H_{i,max} - H_{i,min}} \quad (5.1)$$

where: X_i^L expresses the grade value of the i-th indicator, the j-th site

H_i^L is the real value of the i-th indicator for the j-th site according to the partial assessment

$H_{i,min}$ is the lowest real value of the i-th indicator

$H_{i,max}$ is the highest real value of the i-th indicator

$i \in \langle 1; N \rangle$ (number of indicators, according to the respective criterion)

$L \in \langle 1; 9 \rangle$ (number of sites)

For those indicators that expressed increasing quality (acceptability) with increasing values (the higher, the better), the conversion was performed according to the equation:

$$X_i^L = 1 + 4 \times \frac{H_{i,max} - H_i^L}{H_{i,max} - H_{i,min}} \quad (5.2)$$

where: X_i^L expresses the grade value of the i-th indicator, the j-th site

H_i^L is the real value of the i-th indicator for the j-th site according to the partial assessment

$H_{i,min}$ is the lowest real value of the i-th indicator

$H_{i,max}$ is the highest real value of the i-th indicator

$i \in \langle 1; N \rangle$ (number of indicators, according to the respective criterion)

$L \in \langle 1; 9 \rangle$ (number of sites)

For calculation purposes, it was necessary to set limit values, i.e. $H_{i,min}\ a\ H_{i,max}$ for each indicator. If it was not possible to determine these values objectively, then they were solved via the values $H_{i,min}\ and\ H_{i,max}$ within the collection of sites for the relevant indicator.

According to the above equations, (5.1) and (5.2), grade values were distributed within the interval $\langle 1; 5 \rangle$, where the value 1 is the most favourable (most advantageous) value of the given indicator and the value 5 is the least favourable (most disadvantageous) value of the indicator; the other values were distributed proportionally within this interval $\langle 1; 5 \rangle$.

The only partial adjustment of the calculation of the grades for criteria C5 and C6 concerned two indicators related to the permeability of the rock environment (C5c and C5e), concerning which the decimal logarithm values were entered into the equation for the calculation of the grade instead of the original indicator values. The reason comprised the elimination of the non-linear occurrence of the permeability values.

5.3 Determination of the weightings of the indicators

The indicators of the key criteria defined above, which were used to determine the overall value of each criterion, were assigned weightings by the respective expert teams. The weightings of the indicators were defined via the expertise of the relevant specialists whose task was to determine the relative values and characteristics of the indicators as they did when determining the grades of the values thereof. When determining the weightings, the teams of specialists objectively assessed the various mutual relationships from the viewpoint of specific specialised issues. The determination of the weightings of the various indicators is explained in Tab. 5.

Tab. 5 Determination of the weightings of the indicators

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
C1	**Size of the usable rock mass**	C1a	Usability of the rock blocks	74%	The size of the homogeneous blocks and the disposal spaces that are included in this indicator fundamentally affect the siting of the DGR with respect to the disposal level. The degree of utilisation of the defined suitable homogeneous blocks is thus perceived as the most important indicator with the highest weighting in terms of the comparison of the sites with respect to the C1 criterion. The weighting of the indicator was determined via the Saaty method by the CTU expert team. (Butovič et al. 2019).
		C1b	Fragmentation of the area	9%	This indicator describes the fragmentation of the respective area into several homogeneous blocks. The fragmentation of the area will only partially affect the layout of the disposal spaces (and, thus, overall feasibility) in the underground complex of the DGR. The indicator reflects cases in which the area of interest is divided into several fragments, each of which is smaller than the required disposal area. In such cases, however, since the fragmentation of the area is considered directly in the fragmentation of the underground part of the DGR indicator (C1c), it is not necessary to consider this factor in this context. Thus, the indicator provides a general idea of the overall fragmentation of the area, which will not influence the project design provided there is no increase in the requirements concerning the disposal

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
					space. Hence, the fragmentation of the area indicator is accorded the lowest weighting. The weighting of the indicator was determined via the Saaty method by the CTU expert team. (Butovič et al. 2019).
		C1c	Fragmentation of the underground part of the DGR	17%	The fragmentation of the underground part of the DGR is determined by the technological requirements for the excavation, construction and operation of the DGR and partly by the fragmentation of the area. These factors significantly reduce the efficiency of the use of the homogeneous blocks for disposal. The weighting of the indicator was determined via the Saaty method by the CTU expert team. (Butovič et al. 2019).
C2	**Infrastructure availability**	C2a	Potential for the permanent disposal of excavated material in the vicinity	100%	There is only one indicator under this criterion, therefore it will be applied in full.
C3	**Describability and predictability of the homogeneous blocks**	C3a	Degree of the brittle failure of the massif - fault structures	70%	In the crystalline environments of all 9 sites, of all the geological indicators, faults exert by far the greatest influence on the safety of the repository - especially on the hydraulic and geomechanical parameters of the rock environment. At this stage of the site evaluation process, since higher-order fault structures define the total potential rock volume for disposal planning and repository design purposes (Andersson et al. 2000), this indicator was accorded the highest weighting.
		C3b	Degree of brittle failure of the massif - fracture systems	20%	The weighting was chosen due to the level of representativeness of the evaluated data, which was based solely on the research (Kabele et al. 2018) of a limited number of surface outcrops at the sites. In addition, the hydraulic models of the sites (Uhlík et al. 2018) applied the equivalent porous media (EPM) method with deterministically determined higher-order structures.

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
		C3c	Degree of ductile deformation	10%	The internal anisotropy of the rocks as indicated by ductile deformation exerts only a small impact on the safety characteristics of the rock environment under the given conditions; moreover, no complicated ductile structures can be expected in the target lithologies for the siting of the repository (Franěk et al. 2018, Mixa et al. 2019).
C4	**Variability of the geological properties**	C4a	Spatial variability of the rock environment	75%	The indicator expresses the vertical and horizontal distribution of the properties of the rock mass, on the basis of which it is possible to consider the inhomogeneity of the rock environment in which changes in the migration of fluids may occur. Alternations and the irregular shapes of rock bodies complicate the geotechnical parameters and the calculations associated with the long-term safety of the repository and, moreover, increase the uncertainty of the 3D geological models (Franěk et al. 2018). The spatial arrangement of the rock bodies expresses the vertical and horizontal distribution of lithological boundaries, on the basis of which it is possible to consider the inhomogeneity of the rock environment and the properties thereof. Frequent alternations of the lithologies and the irregular shapes of rock bodies lower the degree of suitability for DGR siting both from the geotechnical point of view for repository construction and in terms of the calculations necessary to ensure the long-term safety of the repository. Furthermore, they increase the uncertainty of the 3D geological models and, not least, contribute to the localisation of fragile structures at the various interfaces. Inhomogeneities in the form of calcium-silicate rocks may indicate the presence of caverns in the rock massif. Since the spatial arrangement of the rock bodies exerts a significant impact on safety,

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
					a significant weighting was assigned to this indicator.
		C4b	Petrological variability of the rocks	25%	The petrological variability exerts an impact on the mechanical properties of the rocks under specific conditions (rheological, thermal conductivity and the production of radiogenic heat, fluid migration etc.); however, the impact on safety is relatively low, which was confirmed by the expert assessment. According to the hydraulic models created to date and discussions with hydrogeologists, the influence of brittle tectonics is disproportionately more significant in the rock environment from the point of view of safety than the petrological variability or, for example, ductile rock structures.
C5	**Water flow characteristics in the vicinity of the DGR and the transport characteristics**	C5a	Flow time from the DGR to the drainage area	20%	All the selected indicators for the C5 criterion are closely related to the safety of the sites. The weightings for the various indicators were set relatively evenly based on a discussion between experts in the field. The indicators characterise both the groundwater flow ratios (C5b, c, d, e, f) and the transport ratios of the sites (C5a, C5g). The indicators that characterise groundwater flow were accorded a total weighting of 60% and the transport indicators 40%. The lowest weightings (10%) were accorded to those indicators that were based “only” on an expert estimation and the accepted input assumptions of the models (C5b, C5c, C5e). The C5d and C5f indicators were assigned higher weightings (15%) since their assessment included data on the geometry of the sites (terrain height and river network distribution). Weightings of 20% each were assigned to the C5a and C5g transport indicators.
		C5b	Flow rate at the DGR level ($m.year^{-1}$)	10%	
		C5c	Permeability in the DGR area ($m.s^{-1}$)	10%	
		C5d	Descending vertical flow component (% of the DGR area)	15%	
		C5e	Maximum permeability of failure zones up to 500 m from the DGR boundary ($m.s^{-1}$)	10%	
		C5f	Specific flow in the DGR area ($l.s^{-1}.km^{-2}$)	15%	
		C5g	Dilution ratio (%)	20%	

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
C6	**Identification and location of drainage bases**	C6a	Number of drainage streams	30%	The indicators of the C6 criterion characterise the dispersion of the transport routes from the area of the DGR. The weightings were determined for the various indicators on the basis of discussions between the relevant experts. The indication of the dispersion of advective transport pathways expressed by the number of drainage flows (C6a, 30%) and the proportion of drainage from the DGR into the river network were accorded the highest weightings (total of 70%) (indicators C6b and C6c - both 20%). Due to the greater uncertainty of the calculation, the indicator of the distance of the DGR from the drainage basins, C6d, was assigned a lower weighting (30%).
		C6b	Extent of drainage from the DGR area via a single stream	20%	
		C6c	Extent of drainage from the DGR area into a single river basin	20%	
		C6d	Horizontal distance of the DGR from the drainage location (m)	30%	
C7	**Seismic and geodynamic stability**	C7a	Value of the maximum horizontal acceleration ($m.s^{-2}$)	25%	The value of the maximum horizontal acceleration for seismic phenomena is directly proportional to the manifestation of earthquakes and related accompanying phenomena, which are able, without warning and in a very short time, to significantly negatively affect the safety of the DGR. This indicator expresses the potential seismic hazard, the assessment of which is set out in Decree No. 378/2016 Coll.
		C7b	Elevation gradient	25%	The elevation gradient between the level of the surface area and that of the local erosion base is directly proportional to the dynamics of the local relief and determines the potential for the lowering of the drainage system in the future and the associated occurrence of exodynamic phenomena, including long-term changes in the relief.

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
		C7c	Percentage of the relief area affected and reshaped by young cycles of reverse erosion and slope deformations	25%	The significant manifestation of reverse erosion is associated with the unbalanced gradient conditions of river flows, which are caused by movements of the erosion base, i.e. vertical movements of the earth's crust. This results in the increased intensity of erosion processes which, over the long term, may result in significant changes to the local relief, including the lowering of the surface in the DGR overburden and changes in the hydrological and hydrogeological regime.
		C7d	Occurrence of volcanic rocks of the Paleogene to Holocene eras and acids	25%	The presence of Tertiary and Quaternary volcanic rocks and related post-volcanic phenomena are linked to areas with recent geodynamic activity, including tectonic movements, thus providing an indicator of the long-term stability of the area, especially in terms of endogenous processes. The presence of acids in the vicinity of the site may exert a negative impact on the DGR engineered barriers. The requirement for the assessment of the volcanic rocks of the Paleogene to Holocene eras and post-volcanic phenomena is set out in Decree No. 378/2016 Coll.
C8	**Characteristics that could lead to the disturbance of the DGR via future human activities**	C8a	Raw material deposit conditions at the site (mining areas, register of protected deposit areas, prediction of the presence of minerals)	100%	
C9	**Phenomena influenced by the spread of radioactive materials**	C9a	The distribution and density of the population and its development in terms of the spread of radioactive material	90%	The population density is known with a high degree of accuracy. From the point of view of certainty, this factor comprises a reliably determinable parameter; therefore, it was assigned a weighting of 90%.

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
		C9b	Distance from nuclear power plants	10%	Since the relevant data on the sites for determining the total distance of the surface area from NPP sites is not equally relevant, a weighting of just 10% was assigned to this indicator.
C10	**Impact on surface waters and water resources**	C10a	Impact on the runoff conditions and surface water quality	30%	A slight preference for indicators that consider the protection of water resources is expressed in criterion C10 (C10b and C10c) due to the direct link with potential impacts on the health of the population. The allocation of a higher weighting was limited by the fact that the potential impacts on runoff conditions and the quality of the surface water (C10a) may also affect biota and habitats whose conditions are dependent on the existing hydrological conditions of the area concerned including the drying out and wetting of the land The direct impact concerns only the catchment area of the recipient watercourse and, potentially, the tributaries thereof (small watercourses affected by the location of the surface area). Subsequently, flows in higher-order river basins may be indirectly affected.
		C10b	Impact on water sources near the DGR	35%	The potential impact on water resources comprises a crucial factor not only in terms of water as a component of the environment but, especially, concerning the supply of drinking water to the population and the elimination of potential health risks. The source of the impact will comprise exclusively local water sources, i.e. local (municipal) water mains systems and domestic wells in the surrounding settlements (in relation to both the surface area and the area deemed promising for the project design work).
		C10c	Impact on significant water sources in the wider area	35%	Significant water resources are considered to be those resources that supply 3000 or more inhabitants. The indicator concerns the potential impact on the supply of drinking water to the population.

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
C11	**Impacts on nature and landscape protection**	C11a	Impacts on biodiversity	25%	The indicators that comprise the C11 criterion reflect all the main topics and phenomena addressed by Act No. 114/1992 Coll., on nature and landscape protection. With regard to the current level of knowledge of the natural conditions of the various sites and on the basis of the precautionary principle, a conservative approach was adopted when determining the weightings of the individual indicators, with a relatively limited degree of mutual differentiation. The reason for this approach was to avoid delays with respect to certain aspects of the evaluation procedure. The phenomena observed in C11a represent the most important components with respect to the ecological stability of the affected areas.
		C11b	Impacts on migration corridors and areas important for migration	20%	Any reduction in the migratory permeability of the area (especially for large mammals) exerts a negative impact on the affected animal populations.
		C11c	Impacts on Natura 2000 bird areas and sites of European importance	30%	Natura 2000 protected areas have been established throughout the EU for the protection of rare and endangered species of birds and other animals, plants and natural habitats. In view of the provisions of the Nature and Landscape Protection Act, Natura 2000 areas enjoy an extremely high level of protection.
		C11d	Impacts on the landscape	25%	The minimisation of the impacts of the construction of the DGR (especially the surface area) on the landscape comprises fundamental aspects of both the Nature and Landscape Protection Act (Section 12) and the Building Act (Section 18, para. 5)

ID	Criterion designation	ID	Indicator designation	Weighting	Rationale
C12	**Impacts on agricultural land and land intended for forestry**	C12a	Impact on agricultural land	30%	The mutual relationship between the weightings of these two indicators is based on the general assumption of the higher ecological stability of forested areas that that of agricultural land. This assumption is not exclusive however, e.g. some permanent grasslands (extensively mown meadows) may have a high degree of ecological stability. Nevertheless, at the given scale and with regard to the level of knowledge of the assessed sites, this simplification is deemed acceptable.
		C12b	Impact on land intended for forestry	70%	
C13	**Impacts on the population, property and protected monuments**	C13a	Disruption of well-being factors	50%	The allocation of equal importance to the two indicators of criterion C13 is based on the content thereof. In the case of indicator C13a, this concerns a so-called "soft impact" (subjective), which will exert a long-term impact (at least during the construction of the DGR). The minimisation of this impact may significantly contribute to the acceptance of the DGR by the populations of the surrounding settlements.
		C13b	Impacts on residential, recreational and listed buildings	50%	This a one-off but significant impact, which may affect the property rights of the owners of the buildings and facilities affected.

For the needs of the assessment of criteria C10-C13, the following procedure was compiled to allow for the comparison of the impacts of the surface area and selected components of the underground complex:

1) the breakdown of selected MP.22 criteria into sub-criteria (indicators) according to the approach followed by the EIA process where the assessment of impacts on a given component of the environment is structured in the form of separate topics for material or legislative reasons (e.g. impacts on runoff conditions, water quality, the ecological stability system, small specially-protected areas etc.);
2) the formulation of general initial assumptions for the emergence of specific impacts;
3) the creation of a list of input information (parameters) that will allow for the determination of the probable origin of such impacts and the estimation of their significance by the respective experts;
4) the definition of the basic principles according to which the various impacts are assessed by members of the research teams concerned (comments procedure).

The C10 - C13 comparative criteria also include phenomena which, in terms of the siting of the surface area, comprise potential exclusion criteria. As part of the assessment (comparison) process, the occurrence of such phenomena is also monitored in the vicinity of the surface area, e.g. the construction of access roads. The reason comprises efforts to cover all the aspects considered by the EIA process when assessing the candidate sites, since the occurrence of potential impacts cannot be limited solely to those areas directly affected by the siting of the DGR surface complex.

5.4 Determination of the criteria weightings

Due to the relatively high number of compared criteria (more than 10), concerning which it is difficult to estimate the significance of all the criteria, the quantitative pairwise comparison (Saaty 1980) method was applied so as to objectively determine the weightings of the criteria by the various experts. According to this method, all the pairs of criteria are assessed both mutually and quantitatively according to the explanation provided in Tab. 6. If the criterion is more significant, the numerical value given in Tab. 6 is recorded in the matrix as shown in Tab. 7, whereas if the criterion is less significant, the inverse value is recorded in the matrix.

If the mutual difference is smaller than the description expressed in Tab. 6, it is also possible to apply intermediate values, i.e. 2, 4, 6 and 8.

Tab. 6 Preferences applied for the pairwise assessment of the criteria

Numerical value	Explanation
1	The criteria are equally important
3	The first criterion is slightly more important than the second
5	The first criterion is strongly more important than the second
7	The first criterion is very strongly more important than the second
9	The first criterion is absolutely more important than the second

The assessment of the values of the Saaty pairwise comparison was conducted with the participation of SÚRAO specialists and the working teams set up for the various issues considered. An overview of the members of the assessment teams is provided in a separate annex to this report. All the experts had sufficient knowledge and experience to enable them to determine the relative importance of the various criteria in relation to each other.

Tab. 7 Example of a Saaty matrix for n criteria

Criterion	C1	C2	C3	C4	C5	...	Cn
C1	1	3	2	5	6		1
C2	1/3	1	1/2	3	4		1/3
C3	1/2	2	1	4	5		1/2
C4	1/5	1/3	1/4	1	2		1/5
C5	1/6	1/4	1/5	1/2	1		1/6
...							
Cn	1	3	2	5	6		1

Following the completion of the Saaty matrix of pairwise comparisons by each of the expert teams, the matrices were checked to ensure that they met the requirements for the next stage of the assessment procedure. The checking process comprised the verification of the consistency of the matrices, which involved the verification of the fact that the expert opinions were consistent and did not result in contradictions in terms of the comparison of the various criteria. The degree of consistency was verified using the CR consistency ratio.

The consistency of the pairwise comparison matrix $S = (s_{ij})$ can be defined as follows:

Component x_i is s_{ip}-times more important than component x_p (according to the given evaluation criterion) and, further, component x_p is s_{pj}-times more important than component x_j; then component x_i is $s_{ij} = s_{ip} \times s_{pj}$- times more important than component x_j.

While concerning the comparison of qualitative criteria, the full consistency of the pairwise comparison matrix is somewhat exceptional, when comparing quantitative criteria, the pairwise comparison matrix is perfectly consistent since the weightings, the values of the quantitative criteria, are known, i.e. $v_i > 0$ and $v_j > 0$ and the following applies to the components of the pairwise comparison matrix:

$S_{ji} = v_i / v_j$. If the given relationship holds, the matrix $S = (s_{ij})$ is reciprocal and consistent.

The consistency index is, therefore, important for the success of the analytical hierarchisation process (AHP) method. It holds that the maximum eigenvalue of a square matrix (λ_{max}) of the pairwise comparison $S = (s_{ij})$ for type m x m, which is always reciprocal but does not have to be consistent, λ_{max} is greater than or equal to m. If the matrix $S = (s_{ij})$ is consistent, it always holds that $\lambda_{max} = m$. The consistency index is referred to as the CI number calculated from the equation:

$$CI = \frac{\lambda_{max} - 1}{m - 1} , \quad (5.3)$$

where λ_{max} is the eigenvalue of the matrix and m is the order of the matrix.

The CI consistency index is, therefore, equal to 1 for a consistent matrix. The inconsistency of the matrix is expressed by the extent of the deviation of the CI from the value 1 and is given by the consistency ratio (CR).

With respect to the consistency ratio calculations, Saaty derived so-called random inconsistency indices for various orders of matrices, see e.g. Saaty 2008. From the ratio of CI and RI we obtain the resulting ratio of the consistency of the pairwise evaluation matrix which, according to Saaty, should be less than 0.1, i.e. 10%. This means that the following relationship holds:

$$CR = \frac{CI}{RI} < 0{,}1 , \quad (5.4)$$

Those experts whose Saaty matrices showed inconsistencies, i.e. the consistency ratio was not less than 0.1, were asked to adjust their comparison in order to meet the consistency condition of the matrix.

Since each of the above pairwise comparison matrices $S = (s_{ij})$ (from each of the assessment experts) expressed the mutual relationship of the significance of their components (criteria), it was necessary to normalise these values in order to obtain the resulting values of the weightings w_k of the various criteria. The following equation was deemed to best describe the geometric mean of the rows of the matrix S (Crafword et al. 1985) for each k = 1, 2, ..., m.

$$w_k = \sqrt[m]{\prod_{j=1}^{m} s_{ij}}, \quad (5.5)$$

The resulting weightings of the various criteria W_k for each k = 1, 2, ..., m were determined as the arithmetic mean of the weightings of the various assessment experts, i.e.

$$W_k = \frac{1}{h}\sum_{h=1}^{h} w_k, \quad (5.6)$$

where: W_k is the resulting average weighting of the relevant criterion,

w_k is the weighting of the relevant criterion from each assessment expert,

h is the number of assessment experts.

5.5 Mathematical assessment

As mentioned in chapters 5.1 to 5.4, the following procedures were followed prior to the overall assessment:

1. for each site and each indicator, a grade X_i (the real number from the interval $\langle 1; 5 \rangle$) was determined on the basis of the value of the indicator,

2. the weightings of the significance of the v_j indicators were determined within the relevant criterion,

3. the respective experts completed the Saaty matrix of pairwise comparisons, which was followed by the calculation of the individual weighting vectors of the various criteria $W_h = (w_{hk})$ from each of the assessment experts,

4. the resulting weightings of the criteria were determined by the arithmetic mean of the weighting vectors of the individual assessment experts $W_k = (W_{kl})$.

Since the grade values of the indicators expressed the qualitative evaluation of the assessment experts, these grades had to be converted in accordance with the requirement for the differentiation of the sites over the whole of the range of $\langle 1; 5 \rangle$ - standardised so that the most advantageous were graded 1, the least advantageous graded 5 and the others linearly distributed in a defined interval. The standardisation of the grade values of the assessment experts to the specified interval range of $\langle 1; 5 \rangle$ was performed according to the formula:

$$Y_i = 1 + 4 \times \frac{X_i - X_{min}}{X_{max} - X_{min}}, \quad (5.7)$$

where:

Y_i standardised grade of the i-th indicator,

X_i grade value of the i-th indicator according to the assessment expert,

X_{min} the lowest grade value of the indicator according to the assessment expert,

X_{max} the highest grade value of the indicator according to the assessment expert,

Example:
The grade values of indicator X from the assessment expert: (1.0; 1.2; 1.2; 2.5; 2.7; 2.8; 3.0; 3.2; 3.8), where: X_{min} = 1.0; X_{max} = 3.8.

The resulting Y grades of the given indicator X according to equation 5.7 are:

(1,000; 1,286; 1,286; 3,143; 3,429; 3,571; 3,857; 4,143; 5,000)

For the overall evaluation, the multicriteria analysis model consisted of the following components:

Indicators - X_i in the range of each of the criteria, or the standardised value of the grade Y_i.

Indicator weighting - v_i that determines the significance of the relevant indicator in the given criterion.

Criteria - K_j in the total number of 13, i.e. that j = 1, 2, ..., 13.

Criterion weighting - W_j determined as the average value of the weightings of the criteria of the assessment experts according to the Saaty pairwise comparison matrix.

Grade of the site - Z_L, determined by the sum of the products of the values of the criteria and their weightings, where L = 1, 2, ..., 9.

For each site, the values of the relevant criteria were determined according to the relationship:

$$K_j^L = \sum_{i=1}^{n_j} Y_{i,j}^L \times v_{i,j} \quad (5.8)$$

where: K_j^L is the value (grade) of the *j-th* criterion of the *L-th* site (j=1, 2, ..., 13, L = 1, 2, ..., 9),

$Y_{i,j}^L$ is the standardised value (grade) of the *i-th* indicator of the *j-th* criterion of the *L-th* site (j=1, 2, ..., n_j),

$v_{i,j}$ is the weighting of the *i-th* indicator of the *j-th* criterion,

n_j is the number of indicators of the *j-th* criterion.

The resulting utility value of each site was determined according to the formula:

$$Z_L = \sum_{j=1}^{13} K_j^L \times W_j \quad (5.9)$$

where: Z_L is the final grade of the given site,

K_j^L is the value (grade) of the *j-th* criterion of the *L-th* site (j=1, 2, ..., 13, L = 1, 2, ..., 9),

W_j is the weight of the relevant *j-th* criterion.

The above calculations (5.8 and 5.9) served for the determination of the final grades for each site. The overall grades for all the sites were then classified in ascending order, thus determining the order of the sites from the most suitable to the least suitable.

5.6 Uncertainties of the assessment

The process of the assessment and comparison of the sites was burdened by a certain degree of uncertainty with respect particularly to the defined indicators. These uncertainties can be divided into three groups based on the origin of the values assigned to each indicator in terms of the type of, and approach to, the assessment thereof:

1) Expert determination of the values of the indicators

The uncertainties associated with this evaluation approach concern the variability of possible changes in the value of the relevant indicator. The prediction of the variability of the values of the indicators was based on the professional knowledge and experience of the assessment experts, thus ensuring that the uncertainties were balanced by the assessments of the relevant experts in the respective field. The evaluation of the indicators (especially those of criteria C3 and C4) was based on the agreement of several experts.

2) Modelled determination of the values of the indicators

This concerns uncertainties that arose from the modelled simulations, especially concerning criteria C5, C6 and C7. In this case, the values of the indicators were the result of the mathematical processing of models that were created for all the sites via the same approach. Since specific values were applied so as to ensure the relative comparison of the sites, it follows that the uncertainties were at the same relative level for all the sites and, therefore, did not affect their mutual comparison.

3) Parameters of the rock environment

The main uncertainty relates to the development of the properties of the rock environment with depth. In this case, the degree of uncertainty is partially eliminated by the relatively simple modelling of the sites, the uniform assessment approach and the same level of site description. The indicators of those criteria that can only be determined with a detailed knowledge of the rock conditions at repository depth (e.g. mechanical properties, compatibility with the engineered barrier system) will be assessed in detail at a later stage of the DGR development project.

4) Parameters based on the location of specific parts of the repository

The uncertainty of these parameters concerns the specific location of the surface area (criteria C1, C2, C11, C12 and C13) and the underground complex (partly criteria C5 and C6). In this case, the uncertainties are balanced by the assessment of the relevant adequate area related to the siting of the respective part of the DGR and the properties that (or have the potential to) influence the relevant indicator and, thus, the associated uncertainties (modelled area, promising area for the geological work, promising area for the project design work, surface area, etc.).

The uncertainties inherent in the assessment of the criteria as identified by the participating experts were included in the process of determining the values of the weightings of the various criteria via the Saaty method (Chapter 5.4), i.e. the relative comparison of the significance of the criteria. The uncertainties arising from the data were further considered in the relevant follow-up assessment reports.

6 Conclusion

The methodology described in this report is based on the multi-criteria analysis of the assessment of “utility properties” that serve for the comparison of the candidate sites via the allocation of grades that reflect the level of acceptability. The assessment process was based particularly on data obtained from the study of the candidate sites in the period 2014 - 2019.

The criteria that were of sufficient relevance (sufficient knowledge was available) in the current stage of the research work to enable the comparison of the sites were selected for assessment purposes from the comprehensive list of criteria set out in the MP.22 document, i.e. criteria that must be fulfilled for the siting of the DGR.

The basic procedures of the methodology described in this report will also be applied in the next site evaluation stage (for the selection of the final and backup sites). In this case, it will be necessary to update and clarify the methodology based on the assumption that more detailed data and information will be available so as to allow for the conducting of an assessment process that is based on all the criteria set out in the MP.22 document. This level of knowledge will then allow for the application of a methodology based on the weighting principle in a way that is similar to the approach used for risk assessment purposes.

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