Progress of the Czech Republic Deep Geological Repository Program – 16255

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ABSTRACT

The Czech Republic operates two NPPs with 6 pressurized water reactors. Czech state is fully responsible for the disposal of all radioactive waste including spent nuclear fuel and it provides the Radioactive Waste Repository Authority (SÚRAO) established in 1997. According to the RWM Policy a deep geological repository (DGR) considered to be the only feasible option for the final disposal of spent fuel. The State Policy set out important milestones for DGR development – the selection of candidate sites by 2020 and the selection of a final site by 2025. The final commissioning of a DGR is planned for 2065.

The initial stages of DGR development involved the screening of geological conditions of the whole territory. Granites would provide the most suitable rock environment for DGR siting purposes.

By the end of 2012 SÚRAO will have proposed 7 sites for the potential geological surveys and the first stage of site characterization work. Licenses for geological survey for this stage are in the force since October 2015.

Main goal of RD&D programme is to support the siting programme for the selection of the candidate sites, to adapt a DGR design on suitable sites and to support the safety case.

SÚRAO decided to enhance the extent of in-situ RD&D at a depth corresponding to that of the future DGR. In 2013 SÚRAO commenced the construction of the Bukov Underground Research Facility in the southern section of the Rožná uranium mine at a depth of 600m below the surface in crystalline rock environment.

INTRODUCTION AND BACKGROUND

At present in the Czech Republic, almost 50-60 % of electricity is currently produced at coal-fired power plants, with slightly more than 33% produced at nuclear power stations. The assumed strengthening of the role of the nuclear energy sector in the Czech Republic will naturally be reflected in the volume of radioactive waste produced, primarily spent nuclear fuel (SNF), which will eventually have to be disposed of. This change is reflected in the Updated Concept of Radioactive Waste and Spent Nuclear Fuel Management official notice of which was taken by the Government on December 15, 2014 [1] as well as in the Update of the State Energy Policy [2].

The Concept states that the nuclear power station operator should focus on the direct disposal of SNF in a DGR; however, it does not exclude the option of fuel reprocessing, particularly in view of the advanced fuel cycles of 4th generation reactors the adoption of which would reduce both the potential hazard level and volume of the waste disposed of.

Concerning the amount of SNF to be disposed of, the Updated Concept of Radioactive Waste and Spent Nuclear Fuel Management (Concept) bases estimates on data contained in the so-called Update of the Reference Design (hereinafter the Updated Reference Project) [3]. Currently it is envisaged that 4,420 tonnes of waste not acceptable in near-surface repositories and 9,910 tonnes of spent nuclear fuel from currently operational and new nuclear sources with an expected lifetime of 60 years will be disposed of in the DGR.

The Concept sets out the following milestones concerning DGR development and construction:

- 2020 selection of two potential sites
- 2025 selection of the final site
- 2050 commencement of DGR construction
- 2065 commencement of DGR operation

DESCRIPTIONS AND DISCUSSIONS

Reference Design of Deep Geological Repository

Research relating to DGR design has intensified during last decade. Work on the optimization of the first Reference Project [4] commenced almost immediately following its completion. For the purposes of optimization the DGR was divided into individual modules consisting of structures of the same or similar importance and related in terms of technological, transport or other considerations (e.g. the transport service module, the workshops and warehouses module, the SNF disposal module etc.). Moreover, a total of five variants relating to the above-ground and underground layouts of the repository complex were defined for optimization purposes, concerning which the DGR layout included in the Reference Project of 1999 formed the basic version [5]. Further variants consisted of the preparation of spent nuclear fuel (SNF) and radioactive waste (RAW) for disposal outside the deep repository complex and the consideration of the disposal of waste generated from potential SNF reprocessing. Individual modules were optimized in relation to the definition of individual variants. The assessment of individual variants took into consideration economic, safety and socio-political aspects as well as overall feasibility. The variant relating to the preparation of waste for disposal outside the repository complex was evaluated most highly primarily because of the consequent considerable reduction in the required surface area of the repository as well as favorable assessments in terms of safety and a number of socio-political aspects.

A conceptual study was prepared in 2004 which compared the various advantages and disadvantages of the horizontal and vertical disposal concepts [6]. The study also considered a potential two-level disposal variant (i.e. one level constructed below the other). The following detailed comparison of the horizontal and vertical disposal concepts [7] concluded that:

- horizontal SNF disposal is realistic and advantageous in terms of the required excavation work, i.e., the volume of excavated material is reduced;
- horizontal SNF disposal will lead to a reduction in the surface area of the SNF disposal horizon;
- the disadvantage of horizontal disposal lies in the relatively demanding nature

of waste handling associated with this concept and the underground transportation of supercontainers filled with SNF, including the final disposal of the container in the bentonite-lined nest which, clearly, will present a limiting factor should the handling technology not be fully mastered.

It was recommended that research into underground transportation and handling techniques should continue, and that verified calculations should be performed for horizontal SNF disposal configuration in terms of residual heat build-up. Calculations concerning vertical SNF disposal were performed as part of the Reference Project of 1999 [4].

Both expert estimates and data from foreign literature were employed in the compilation of the report. Based on the results of the above studies, SÚRAO subsequently commissioned a project titled “Update of the Reference Design of a Deep Geological Repository in a Hypothetical Locality”, the final report on which was completed in 2011 [3]. This reference design project was conceived as a set of partial model documentation concerning the permitting process for DGR siting. In technical terms it was designed to be a model construction project, the parameters of which corresponded to the current level of knowledge. The final site has not yet been selected, therefore a hypothetical site was chosen with properties representing the site to be selected in the future.

The design, evaluation, and selection of the optimal variants of the technical design of the DGR formed one of the first topics addressed by the reference design project. A multi-criteria evaluation was performed for individual modules considered significant in terms of the conceptual design such as the SNF and RAW disposal containers (the materials to be used and the structural design) and the layout of the repository’s above-ground and underground sections.

The base assumptions and the concept of the variant proposed in the 2011 Reference Design [3] are summarized below – see also Fig. 1:

- the design provides the potential for the simultaneous construction and operation of the repository;
- the major part of the installations and equipment which have a substantial impact on operational safety and radiation protection such as the reloading node, hot cell, and related equipment is situated in underground caverns at the 0.0 meter horizon. This design option will also result in a considerable reduction in the repository’s surface area provided that the morphology of the candidate location is suitable;
- the disposal horizon will be situated at a depth of approximately 500 meters below the surface;
- SNF packed into supercontainers will be placed in large-dimension horizontal disposal boreholes wells, while other RAW packed into concrete containers will be emplaced in high-volume horizontal chambers;
- a vertical shaft will be employed for the removal of excavated material and the transportation of personnel and materials;
- an inclined tunnel will be constructed for the transportation of waste and machinery;
- transportation in both the inclined tunnel and the disposal horizon will be rail-less.

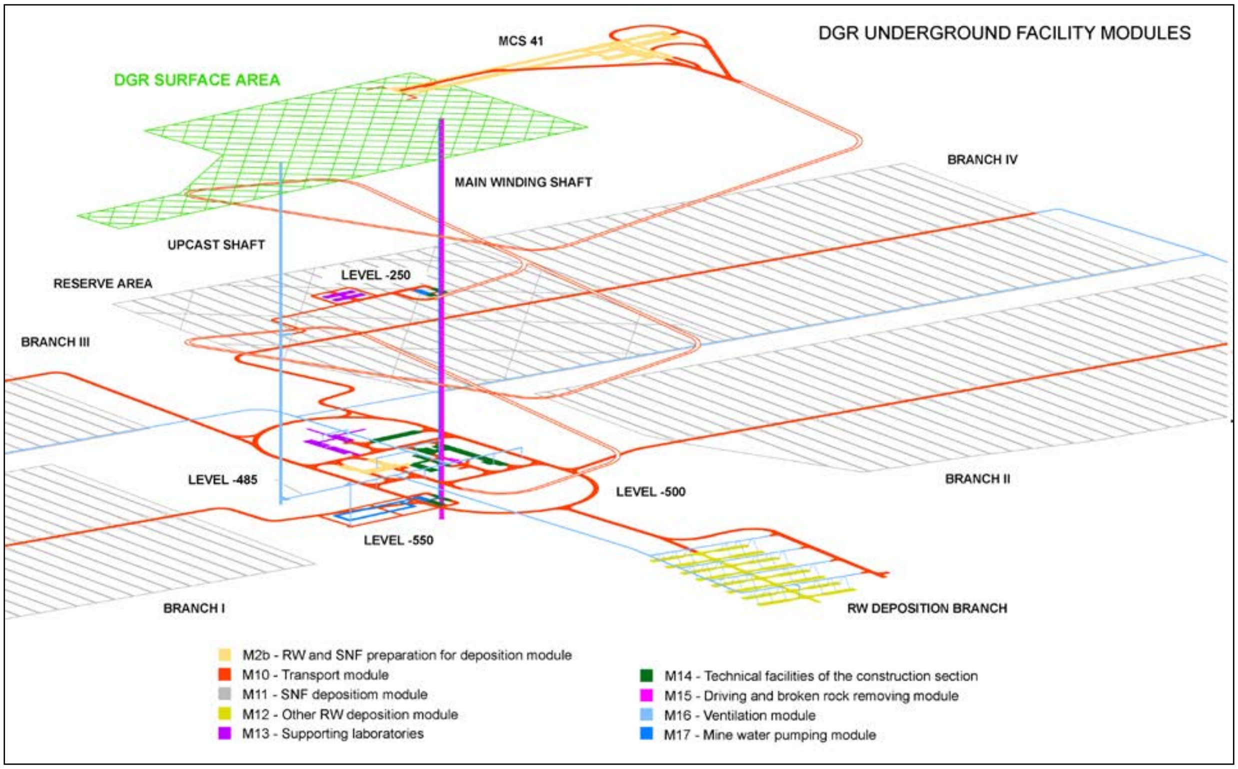


Fig. 1. 3D Layout of DGR by Reference Design 2011

Other RAW will be emplaced in a separate section at the -500 meter horizon which will have space for 2,990 concrete containers. 16 disposal chambers (15 plus one reserve), 55 meters long, 10.50 meters wide and maximum 4.80 meters high, will be excavated. Each chamber will accommodate 204 concrete containers. A further variant under consideration is that of the construction of disposal chambers for other RAW at the -250 meter horizon. This variant will be realized provided that safety analysis documentation proves the acceptability of such a solution.

Siting of Suitable Site For Deep Geological Repository

In compliance with a Government Decision of 2004 geological work at the selected candidate sites was suspended until 2009. In the following year a team of specialists led by Czech Geological Survey specialists drew up a plan of activities with concern to a hypothetical site including financial considerations and an estimate of the required time period. This document subsequently formed the basis for the planning of further work at individual candidate sites.

A pre-feasibility study was then prepared the aim of which was to prove that both the above-ground and underground sections of the deep repository could be constructed at the sites according to the design set out in the Updated Reference Project 2012; the study subsequently proved the potential for the construction of both sections of the DGR at all the candidate sites [8].

The deep repository development program further assumes that geological investigation work will commence at all six sites initially selected for site characterization [8] and at one newly-selected site. Sites 1-6 are situated in granitoid rock massifs. The newly-included Kraví hora site, located in the east of the Czech

Republic on a regional rock massif known as the Moldanubicum (Moldanubian zone) is composed of granulite, migmatized gneisses to migmatite. The site is situated near the Rožná mine, the only currently operational uranium mine in Europe, and in the immediate vicinity of the Skalka central storage facility for SNF (currently under construction).

The areas of a number of sites to be subjected to geological investigation have, for a number of reasons, been slightly modified and applications for the establishment of investigation areas have been drafted in compliance with the Geological Act. At the year 2015 SÚRAO obtained a decision from the Minister of the Environment approving investigation areas at the all seven sites. The site names and the investigation areas within the sites a and the geographical position of the sites is shown in Figure 2 which also presents a simplified geological sketch map of the Bohemian Massif, the geological unit which forms the highly predominant part of the Czech Republic and the individual zones within it.

The first investigation stage, which will involve all the sites within which an investigation area will be established in 2015, will consist of detailed remote sensing using state-of-the-art techniques, particularly the collection of new generation high-resolution radar data and detailed geological, structural and hydrogeological mapping. Rock samples will be collected during the mapping stage for use in petrographic and microstructural studies, chemical analysis, tests to determine physical and mechanical properties etc. In addition, water samples will be taken from watercourses, wells and existing deep boreholes for hydrogeological-analysis purposes.

Geophysical measurements along 200-m-distant profiles will be taken covering the whole surface areas of the candidate sites. Measurement will include the use of magnetometry surveys, geoelectric methods, resistivity measurements, VLF (very low frequency) measurements and radiometry. In addition, gravity and reflex seismic measurements will be taken to the extent necessary for the creation of 3D model of site.

Geochemical samples will be gathered along the same profiles at which geophysical measurements will be collected. Surface geochemistry techniques will be used for the identification of inhomogeneity by means of an element migration in the zone of hypergenesis model according to Burkov J. K. and Rundquist D. V [10]. The samples will be subjected to whole rock analysis in order to determine a wide range of minority (Au, Ag, As, Ba, Be, Bi, Cd, Co, Cs, Cu, Ga, Hf, Hg, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, Tl, U, V, W, Y, Zn, Zr, REE) and majority (SiO2, Al2O3, Fe2O3, CaO, MgO, Na2O, K2O, MnO, TiO2, P2O5, Cr2O3) elements including the total amount of sulfur and carbon and losses on ignition. Two methods will be used for the evaluation of the results of the chemical analysis of the samples the first of which will consist of the identification of mineralized zones, rock fractures, fault zones and mineralized objects and the second the application of the Burkov-Rundquist model of the migration of elements in endo- and hyper-genous environments.

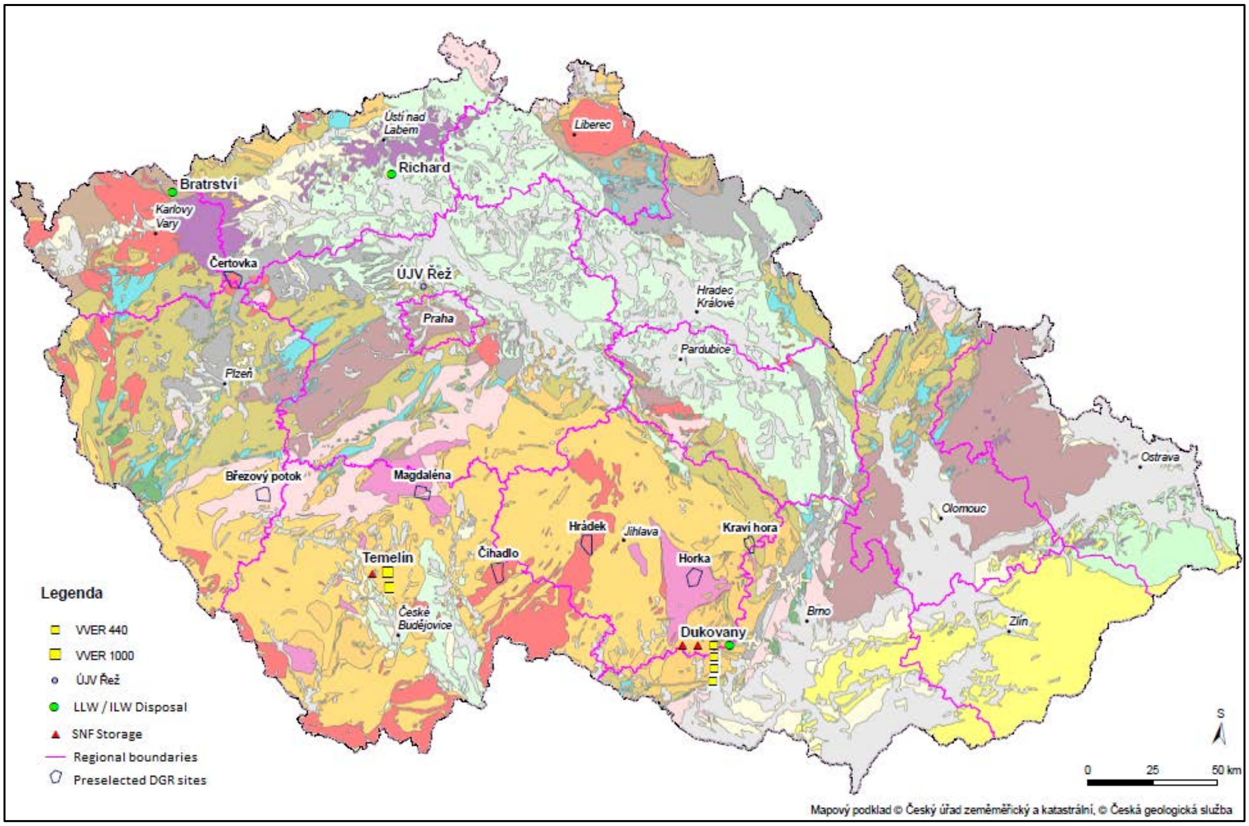
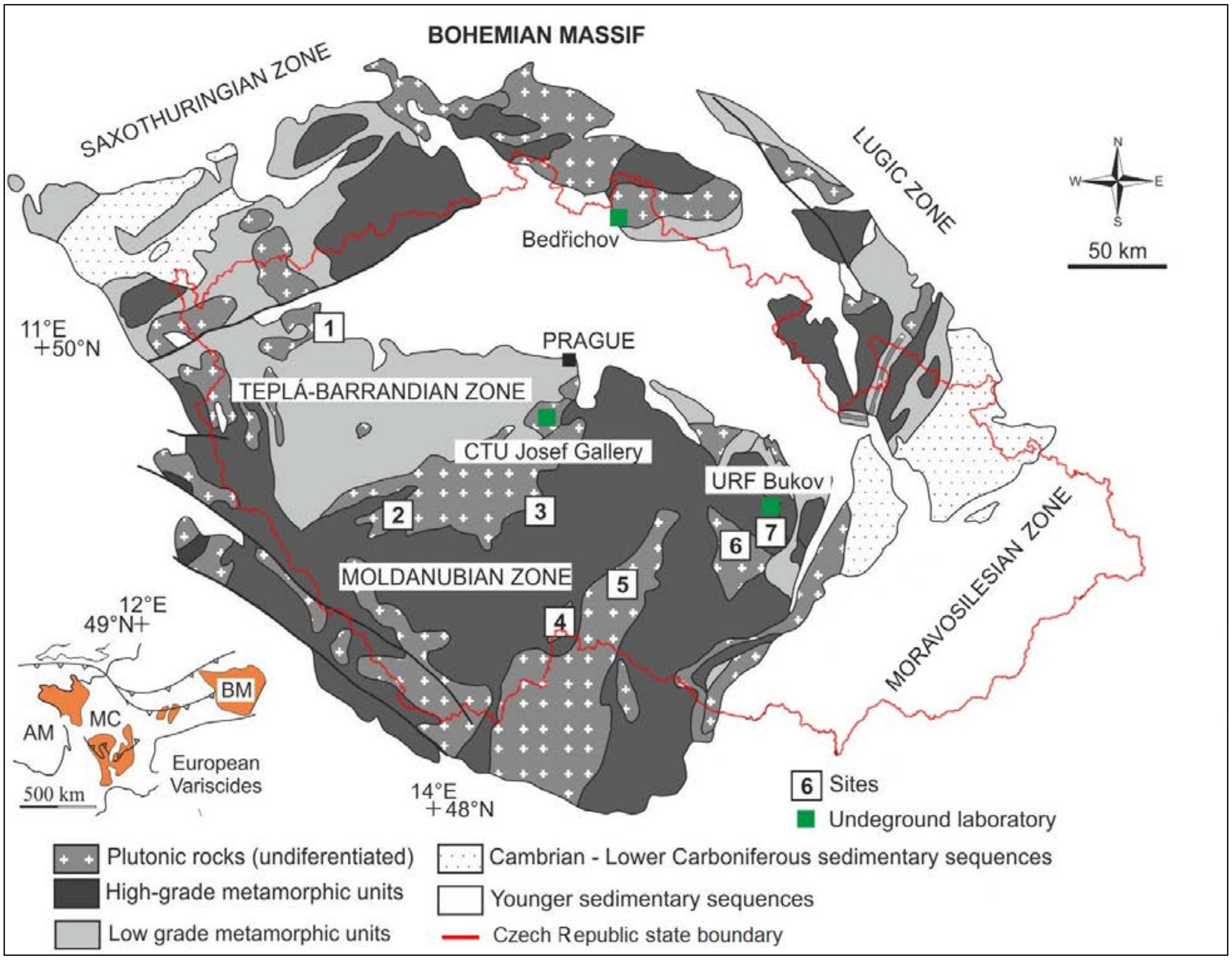


Fig. 2. Geological map of the Czech Republic and preselected DGR sites

It is expected that the results obtained, i.e. the evaluation of remote sensing, geological and structural maps, and geophysical and geochemical anomaly maps will allow the preparation of surface models of the sites and the formulation of assumptions concerning at-depth development based on which it will be possible to optimize the positioning of various types of boreholes including those to a depth of 1,000 meters. The drilling of boreholes to different depths will form the initial step in the next stage of geological investigation. It is possible that the spatial area of some of the sites investigated will subsequently be modified and, in extreme cases, certain sites will be rejected.

Underground Research Facilities

The research required for the DGR development program is currently being conducted at three underground facilities the geographical position of which is shown in Fig. 3



Name of preselected DGR sites:-(1) Certovka, (2) Brezovy potok, (3) Magdalena, (4) Cihadlo, (5) Hradek, (6) Horka, (7) Kravi hora

Fig. 3. Bohemian massif - geological position of underground research facilities supported Czech Republic DGR development programme.

Work has been underway since 2003 in the **Bedřichov Water Supply Tunnel** in northern Bohemia which was excavated in granites of the Krkonoše-Jizera Composite Massif. Interestingly, one part of the tunnel was excavated using tunnel boring machine (TBM) technology while drill and blast technology was used for the other. Following the first stage of research which focused on the compilation of geological documentation [11] the second stage focused on the area in which the excavation technology was changed. Geophysical measurements (resistivimetry and seismic) have been taken repeatedly with the aim of identifying both differences in rock deformation caused by excavation and variations in the measured values over time. In addition, temperatures at various distances from the tunnel wall have been measured and changes in temperature due to the temperature of water flowing through the tunnel monitored as were the amount and chemical composition of the groundwater which leaks into the tunnel along individual fractures, seasonal variations and dependence on climatic conditions at the surface. Movement along Sudeten trend (NW-SE) and the Krušné hory trend (NE-SW) fractures has also been monitored over the long term employing high-accuracy 3D dilatometers; movement of a few tenths of millimeters was subsequently detected [11]. All the collected data is regularly processed in the form of models. Significant attention has recently been devoted to the optimization of data collection methods as well as methods to be employed for the automated trouble-free transmission of data from the underground complex to the processing center. The data gathered has been utilized in the Czech contribution to the international DECOVALEX project. Most of the work performed in the tunnel can be characterized as generic research.

The **Josef Underground Research Center** is situated 50 km south of Prague. The original mine complex, which is made up of 7,854 meters of galleries, was excavated between 1981 and 1991 with a view to the mining of the substantial gold deposits in the area. In 2007 the Faculty of Civil Engineering of the Czech Technical University (CTU) in Prague opened an underground laboratory at the site which it named the Josef URC (Underground Research Centre). The rock environment consists of weakly metamorphosed volcanic and volcanosedimentary rock (basalts, andesites, rhyolites, tuffs and tuffites) permeated with younger intrusive rock (granite and albite granite). The main gallery with a cross-section of 9 m^2 and a length of 1,853 meters proceeds in a NNW – SSE direction; several mine workings situated between 90 and 150 meters below ground level are connected to this gallery. A number of experiments and educational programs are currently underway at the Josef URC, some of which include SÚRAO´s involvement.

The third facility consists of the **Bukov Underground Research Laboratory** (Bukov URF) the construction of which is currently nearing completion. The facility, which will play an important role in the overall DGR research and development plan, is situated within the control zone of a fully-operational uranium mine which will allow the conducting of experiments involving radionuclides, the opportunity for which is rare both in the Czech Republic and in other countries. The facility is situated in eastern Bohemia near the Kraví hora candidate site and the Rožná uranium mine (see Fig. 3). The layout of Bukov URF consists of a 70 meter-long corridor and two chambers. It is situated at a depth of 600 meters and is connected by a 320 meter-long gallery with the vertical shaft in the south part of uranium mine, out of uranium mining activities – see Fig. 4.

The rock environment is made up of gneiss and migmatite. Two horizontal boreholes, 150 meters and 100 meters long have been drilled which will allow for the characterization of the geological environment of the area surrounding the Bukov URL as well as for the testing of various geophysical methods, the conducting of hydraulic tests and general monitoring. It is planned that a further borehole will be drilled from the surface to the URL which will, among other things, provide information on the development of the geological, hydrogeological and geotechnical parameters of the rock massif with depth.

Excavation work and the compilation of detailed geological, structural and geotechnical documentation are currently nearing completion. The facility will be used principally for the in-situ long-term testing of materials to be used in the construction of waste disposal containers, the testing of new methods concerning rock environment characterization, etc.

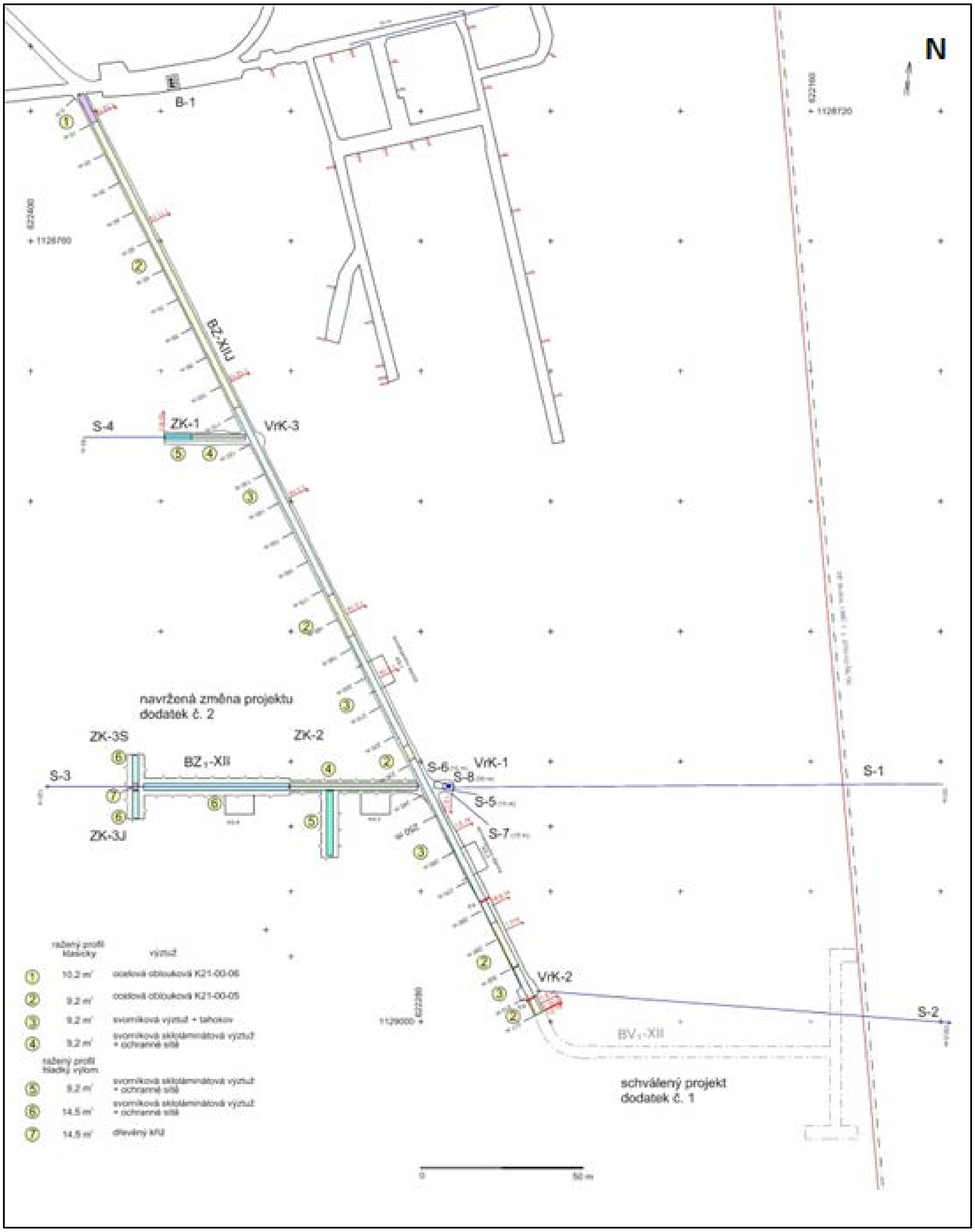


Fig. 4. Bukov URF layout

Research

Extensive research, demonstration and development activities (RD&D) involving the whole range of issues concerning DGR development have formed an integral part of the Program for the Development of the DGR in the Czech Republic from the very outset. Research activities can be divided into four stages, the first of which relates to

1994 to 1997. This stage, prior to the establishment of the Radioactive Waste Repository Authority, was characterized by a lack of relevant legislation. A number of research reports relating to individual parts of the disposal system were compiled during this period; however, the vast majority is currently considered to be of purely historical significance.

The second stage concerns the period 1998 to 2006 at the beginning after establishing of SÚRAO The research conducted during that period was of a continuous nature and included the development of the first long-term projects (e.g. the Ruprechtov natural analogue, the study of glass dyed using uranium-bearing pigments, the Mock-Up CZ project, pyrochemical fuel reprocessing, the research of temperature-impacted bentonites etc.), initial calculations of the source term and the drafting of reports concerning Czech participation in international projects which were drafted for the first time.

In 2006 SÚRAO commissioned a research project entitled “The Research of Near-Field Processes in a Deep Geological Repository for Spent Nuclear Fuel and High-level Radioactive Waste” which involved the participation of the Nuclear Research Institute Řež and three universities. The aim of the project was to identify the scientific and technical bases for the assessment of the safety functions of “the capture and minimization of the leakage” qualities of near-field processes in deep repositories for high-level radioactive waste (HLW) and spent nuclear fuel in the disposal system concept set out in the DGR reference project. One extensive research report [12] and a number of partial reports addressed practically all aspects of near-field processes and put forward recommendations for future research.

In 2007 SÚRAO commissioned a further research project entitled “Research into Processes of the Far Field Interaction of a Deep Repository for Spent Nuclear Fuel and High-level Radioactive Waste” which was conducted by the Czech Geological Survey and the Technical University in Liberec. The basic goal of the research was to define a scientific and technical framework for the evaluation of the main function of the far field in the natural barrier. The research dealt with those physical, chemical and geological processes in the geosphere which might retard the transport of radionuclides. [13].

The latest stage of RD&D activities commenced in 2015 with the approval of the “Medium-term Research and Development Plan for Deep Repository Siting in the Czech Republic for 2015-2025” [14] . This document is based on the Updated Concept of Radioactive Waste and Spent Nuclear Fuel Management, official notice of which was taken by the Government in 2014. On the basis of a detailed analysis of work conducted in the Czech Republic and other countries over the previous 20 years, RD&D targets were identified relating to the selection of two DGR candidate sites in 2020 and the selection of the final site in 2025. The identification of the RD&D to be performed during these periods is founded both on the need to characterize candidate sites to a level sufficient for the comparison of the sites in terms of feasibility, safety and repository impact on the environment and the need to prepare methodologies, tools and procedures for repository safety and feasibility assessment in such a way that the results of research activities at individual sites can be assessed. It is intended that the document will be updated on a regular basis (approximately every five years) in compliance with knowledge and experience gained through research and development work and its utilization to date in the site selection process. The opinions of all the stakeholders concerned, namely the State Office for Nuclear Safety and other state institutions – the Ministries of Industry and Trade and the Environment and the Czech Mining Authority as well as of representatives of the various communities concerned and the local public will be included in this document.

The following range of RD&D issues will be considered in the document [14]:

- requirements, suitability indicators and criteria for DGR siting;
- source term;
- geological characterization of the rock environment, its development and stability;
- RD&D required for safety assessment purposes (operational and long-term safety);
- RD&D work required for the assessment of the technical feasibility of the DGR (technical design, waste disposal containers, DGR thermal dimensioning, handling and transport, absorbing materials, sealing plugs, sealing system and underground construction work);
- research and development required for the preparation of the EIA study;
- research and development for the preparation of the monitoring program;
- research and development concerning a study of the impact of the DGR on the various social and economic aspects involved.

The document also identifies the RD&D work which should be conducted for the selection of two DGR candidate sites in 2020 and the selection of the final site in 2025. Certain activities, particularly those related to long-term safety assessment and design, can begin prior to the commencement of exploration work at the sites and, indeed, certain activities must begin prior to the commencement of exploration work in order that the results can be adequately assessed.

A number of respected Czech universities and academic institutions, namely the Czech Technical University in Prague, the Masaryk University in Brno, the Technical University in Liberec, the Institute of Geonics of the Czech Academy of Sciences , the Institute of Rock Structure and Mechanics of the Czech Academy of Sciences and other research institutions which are deeply involved in international research projects, primarily the ÚJV Řež, are currently participating in the RD&D program.

Role Of The Public in the Decision-Making Process Regarding DGR Siting

The deep repository and its siting in the Czech Republic, as in other countries, is both an important and, sometimes, controversial and sensitive issue in terms of acceptance primarily by the public concerned.

The Working Group of Dialogue on the Deep Repository (WG Dialogue), an advisory body for the Minister of Industry and Trade, was established in 2010 with the remit of improving the level of involvement of the local public in the siting process and promoting transparent dialogue between all the parties concerned with DGR development.

DGR projects for HLW and SNF disposal are of a multidisciplinary nature and have been underway in many countries worldwide for a number of decades. As far as the

Czech project is concerned, statutory representatives of the local communities of the sites concerned and non-profit organizations have made it clear that it is necessary to seek a new approach to realizing this important national project which is more in compliance with local interests and views.

The status of the WG Dialogue was upgraded at the end of 2014 and since 2015 is the regular part of the Government Council for Raw Materials and Energy Strategy, i.e. it now falls under the umbrella of the national Government. Consequently, the conclusions and recommendations of the working group can now be presented directly to the Government for discussion.

The main objective of the WG Dialogue is to improve the transparency of the DGR siting process and strengthen the role of the communities concerned, the public concerned and the micro-regions in which the candidate sites are located. The WG Dialogue is searching for a way in which to modify relevant legislation and strengthen the power of the communities concerned in the DGR siting process. The working group is currently working on preparations for the introduction of special draft legislation according to which the decision on the selection of two candidate sites and the final site in 2020 and 2025 respectively as specified in the Concept will be approved by the Government with the full consideration of the views of the communities concerned. Should the decision not contain the views of the communities concerned or should their opinions be unfavorable, it is proposed that the Government will decide only following a public hearing and subsequent discussion in the Senate and, finally, on the basis of the position taken by the Senate. It is generally considered that such a stipulation will guarantee that the voice of the communities concerned and the local public is heard and will be fully respected in the final decision. The structure of the WG Dialogue is shown on Fig. 5.

- **5** delegates of ministries and state organisations – MTI (3), MEnv. (1), SONS (1)
- 2 delegates from concerned local municipalities – in total **14**
- 1 delegate from local NGO – in total **7**
- **2** delegates from CR NGOs
- **2** delegates from both chambers of Parliament
- **1** representative from SÚRAO
- **1** lawyer - delegate nominated by municipalities
- **1** expert nominated from the Sociological Institute of the CR Academy of Sciences
- **1** scientific expert nominated by municipalities

Fig. 5. New WG for Dialogue (since 2015) as a regular part of the Government Energy and Raw Materials Strategy Committee

At present, prior to the commencement of the first stage of geological investigation work, the DGR project involves 7 sites covering a total of 40 municipalities and more than 18,000 inhabitants. The representatives of the individual sites in the Dialogue working group thus represent a relatively large group of the population with a wide range of opinions on the issues involved which provides a unique opportunity for finding a well-balanced and widely acceptable solution.

The draft legislation will not only aim to contribute to the strengthening of the role of the communities concerned and the local public in the DGR site selection process but it also suggests a more balanced method with respect to compensation both for the communities concerned and the relevant micro-regions for which future DGR construction may well provide an important economic development boost. The specific amount of compensatory contributions and support will be subjected to further discussion as will detailed stipulations in the legislation which specify the procedure concerning how individual communities will agree on their final position. In short, it is important that an acceptable approach be identified in terms of the legislative background to the DGR siting decision-making process in the Czech Republic which fully complies with the decision-making principles applied in other European countries and worldwide in this respect.

CONCLUSIONS

DGR development in the Czech Republic is governed by a relatively tight schedule – 2020 for the selection of two candidate sites and 2025 for the selection of the final site – and represents, in terms of its multidisciplinary nature and the amount of funding concerned, a unique and significant research challenge for the Czech Republic. Without the involvement and concentration of the research capacities available in the process and the support of the whole of Czech society it will simply not be possible to fulfill this task. SÚRAO and the senior state authorities involved are well aware of this fact and will make every effort to achieve the various objectives in an atmosphere of mutual cooperation.

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