Assessment of the climate changes evolution for the long-term safety of the radioactive waste repository in the Czech Republic

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Abstract. Nuclear energy accounts for a significant part of the total energy production in the Czech Republic, which is currently facing a problem dealing with the high-level radioactive waste (HLW) and the spent nuclear fuel (SNF). Deep repository is the safest option for storage of HLW. Rock environment of the area must guarantee the stability of the deep geological repository for at least 100,000 years. The aim of the research is a long-term evaluation of the climatic changes of the hypothetical area of interest, which corresponds to the candidate sites for deep geological repository in the Czech Republic. The occurrences of endogenous and exogenous phenomena, which could affect site stability, were evaluated. Concerning exogenous processes, research focuses mainly on the assessment of climatic effects. The climate scenarios for the Central Europe were examined – global climate change, glaciation, and the depth of permafrost as well as CO_2 increase.

Keywords: climatic stability, radioactive waste, deep repository, glaciation, exogenous processes

1 Introduction

Many developed and developing countries all over the world including the Czech Republic produce an important portion of energy in nuclear power plants. There are two nuclear power plants in the Czech Republic – Dukovany and Temelín. Those countries have recently faced a problem of dealing with the high level radioactive waste (HLW) and the spent nuclear fuel (SNF) disposal. In the Czech Republic spent nuclear fuel and high level radioactive waste are now stored in interim storage facilities, which are situated near the nuclear power plants. Time of waste isolation in these storage facilities is expected to be 300 – 500 years [1]. In the Figure 1 there is shown the interior of the interim storage facility near the Dukovany power plant.

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Fig.1. Interim storage facility near the Dukovany power plant [2].

The deep repository is the safest option for HLW and SNF disposal. It should be located in depth of 300 to 500 m below the surface. Long-term safety is ensured by the so-called multibarrier system of the disposal, where engineering and natural barriers are used. The engineering barrier is consisted of a double-shell canister with the bentonite clay and a natural (geological) barrier is consisted of rock mass (Fig. 2). Time of the isolation of radioactive waste in deep geological repositories is tens of thousands of years [3]. Safety analyses are done for a period of 100,000 years.

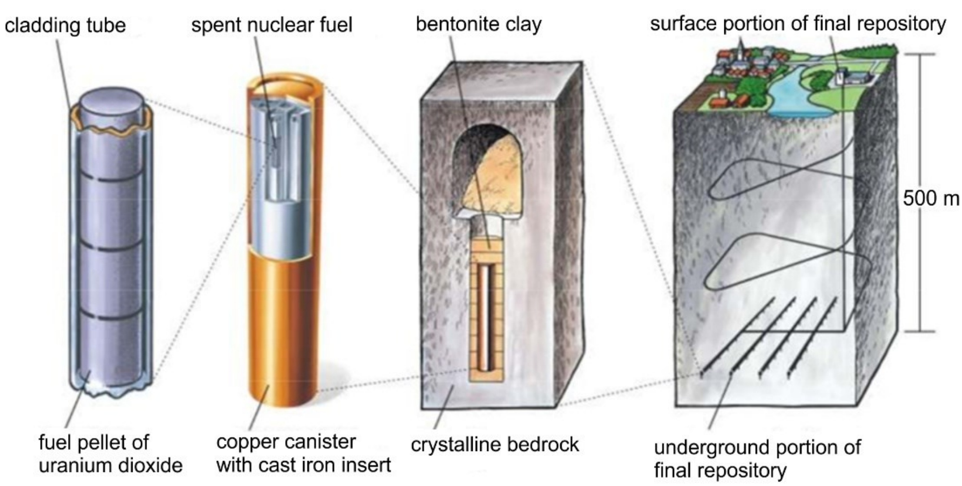

Fig.2. Multibarrier system of disposal – engineering and natural barriers (modified from [3]).

In the Czech Republic 9 candidate sites are selected. The candidate sites must comply safety criteria described the Methodological Instruction 22: Requirements, suitability indicators and site selection criteria for location of the deep geological repository [4], which is published by SUJB (State Office of Nuclear Safety). In the Czech Republic, an ambitious plan was adopted to select two potential candidate sites for deep radioactive waste repositories (1 primary and 1 backup) by 2025. Two new sites, which are located near the Dukovany and Temelín nuclear power plants, were added to the seven original sites – Kraví hora, Horka, Hrádek, Čihadlo, Magdaléna, Březový potok, Čertovka. In Fig. 1 location of the candidate sites on the geological map of the Czech Republic is represented. All candidate sites are in the crystalline rocks (plutonic magmatic rocks, metamorphic rocks), most of them in granitoid massifs with very low permeability [5].

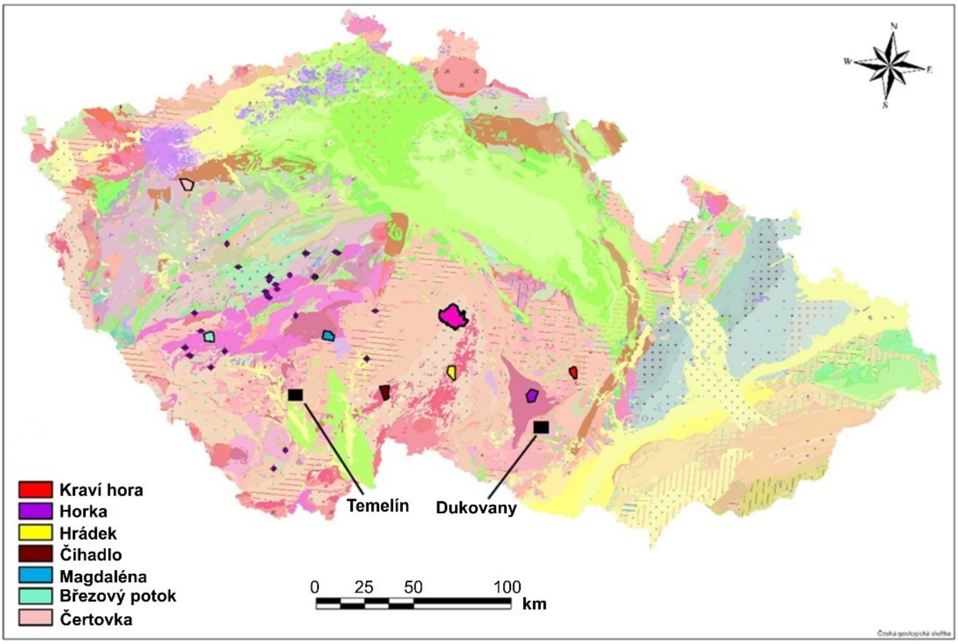

Fig.3. Candidate sites for the deep repository in the Czech Republic.

According to the Methodological Instruction 22 [4], rock environment of the area must guarantee the stability of the deep geological repository for at least 100,000 years. Thus, the occurrence of endogenous and exogenous phenomena that could affect the stability of the candidate sites is evaluated. These are the expected climate changes and their impact on the rock environment – global climate change, glaciation and increase of CO_2 during the climate warming. In addition, the influence of the geodynamic phenomena is considered, vertical movements of the Earth's crust can lead to changes in the river network and morphological gradient of the site. The influence of erosion and slope deformations is also important for the evaluation. The effects of post-volcanic phenomena are evaluated - sites with increased heat flow, occurrence of mineral and thermal waters and gas bursts. The seismic stability of the area must also be ensured [4].

Concerning exogenous processes, research focuses mainly on the assessment of climatic effects. The climate scenarios for the Central Europe will be examined, especially the influence of the ice age with the related glaciation and interglacial period and the possible depth of permafrost. The aim of further research will be the evaluation of the geological environment evolution in term of endogenous and exogenous phenomena that affect the stability of the site.

2 Numerical modelling

The most probably way of spreading the radionuclides into the environment is in the groundwater. That is why numerical models of groundwater flow and radionuclides transport are being created. The models predict behavior of the groundwater in the future resulted from the impact of groundwater quantity and quality state due to construction of disposal waste repository on the natural groundwater regime. The initial step of the numerical modelling is the construction of a conceptual model, which describes the processes governing the groundwater flow and accumulation of groundwater in the hydrogeological system. Assessment of rock massif properties and defining boundary conditions is of key importance in the conceptual model [6].

Boundary conditions are mathematical formulations specifying dependent variable – groundwater head h [m] or derived dependent variable – specific flux q [$m^3/s/m^2$] at the boundaries of the modeled area. Physical (natural) boundaries of the geohydrodynamic system is created for example by the impermeable boundaries or water recipients. Another type of the boundary conditions are so-called hydraulic conditions. This type of boundary conditions is for example the hydrogeological divides or the hydrological basins [6].

Lateral and basal boundary conditions are easier to specify. Surface boundary conditions are subject to higher uncertainty. Lateral boundary condition depends on the climate development and affects results of the simulation. Groundwater infiltration is changing, thus the supply of surface water to the deeper circulation system. Therefore, it is important to assess climate evolution for the time of safety of the deep geological repository. Hydrogeological conditions are influenced by possible glaciation of the site by the Scandinavian continental or the mountain glaciers of the Alpine type, the average air temperatures, the average rainfall and the possible occurrence of the permafrost.

3 Climatic stability

Various climate scenarios of the possible climate evolution in the Europe especially the Cenral Europe were studied [7], [8], [9], [10]. One potential climate evolution scenario for the period of 100 thousand years was compiled. Predicted climate behavior in the future should be inspired by the geological past. At the present we are living in the geological era Quaternary, which began 1.65 million years ago. Quaternary is characterized by the changing glacials (ice ages) with a duration of about 100 thousand years and interglacials (interglacial ages), which take about 20 to 50 thousand years (see Tab. 1). The last glacial (weichsel) ended 10,000 years ago. Currently interglacial called the Holocene is underway [11].

Table 1. Partition of the Quaternary with changing glacials and interglacials, (modified from [11]).

Years BP	Quaternary		Alpine glaciation		Scandinavian glaciation	
	Series	Epoch	glacial	interglacial	glacial	interglacial
10 300	Holocene					
130 000	Pleistocene	Upper	würm	riss/würm	weichsel	eem
788 000		Middle	riss mindel	mindel/riss günz/mindel	saal elster cromer	holstein
1 650 000		Lower	günz donau	donau/günz	bavel menap eburon	waal

In the past, during the peak glacials, the Czech Republic was glaciated by a Scandinavian continental glacier only in the region of the part of the Czech Republic namely Jeseníky Mountains, surrounding of city Ostrava, Frýdlant and Šluknov promotory (Fig. 4). The mountain glacier of the Alpine type affected only the part of the Šumava Mountains Krkonoše Mountains and Jeseníky Mountains [12]. The continental and mountain glaciations have never occurred in the candidate sites, so these sites are not expected to be glaciated in the future [7].

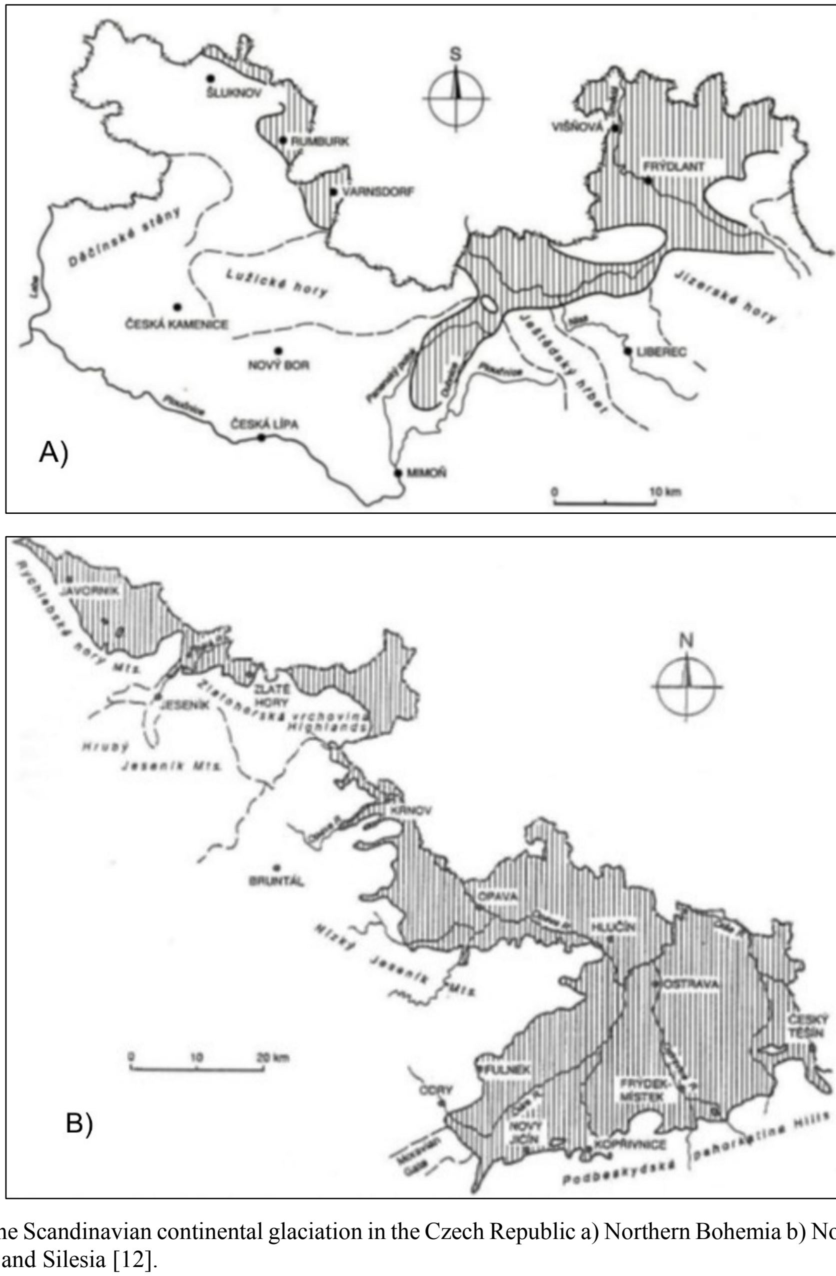

Fig. 4. The Scandinavian continental glaciation in the Czech Republic a) Northern Bohemia b) Northern Moravia and Silesia [12].

Climate depends on the climatic factors; climatic factors are Earth's orbital parameters (Milanković cycles) and the associated amount of the insolation and the greenhouse gas concentration in the atmosphere. The variability of orbital parameters will be low over the next 100 thousand years; therefore, the climate will be affected mainly by greenhouse gases, mainly CO_2 concentrations. Climate evolution can be divided into several time periods, namely the period of 300 years, 50 thousand years and 100 thousand years. The first period of time (300 years) was chosen because of the expected highest anthropogenic influence on the climate, the next time period 50 thousands years was chosen because of expected ending of interglacial and the time of 100 thousand years is the end of the guarantee the stability of the deep geological repository.

Within 300 years, the climate should be affected by the anthropogenic warming caused by CO_2 concentration. At present, CO_2 concentrations are about 400 ppmv. The pre-industrial level of CO_2 concentrations was 280 ppmv. In the Pleistocene period the concentrations were at most 300 ppmv [13]. In the future CO_2 is expected to increase up to 500 ppmv (Fig. 5), with the associated increase in average air temperature, climate humidification and rainfall. The average air temperature will range from 8 °C to 11 °C and the average rainfall will be 800 to 900 mm/year (Tab. 2).

It is expected lower precipitation in the summer and higher in the winter. Warming is likely to continue for another 50,000 years, after which time CO_2 concentrations will stabilize and slowly start to decrease.

Table 2. Average temperatures and precipitation in the limit scenarios compared to the present [7].

	recent	**maximal warming**	**maximal cooling**
average temperature	6 °C to 9 °C	8 °C to 11 °C	-7 °C to -2 °C
average rainfall	550 – 700 mm/year	800 – 900 mm/year	250 – 350 mm/year

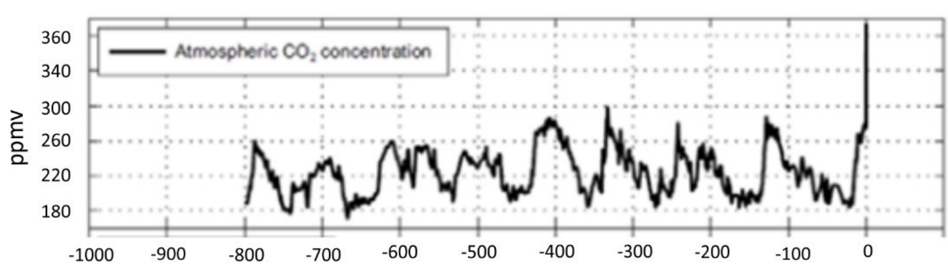

Fig. 5. The CO_2 concentrations in time (years in Ma) (modified from [13]).

There are the limit scenarios for maximum warming and humidification in the interglacial. The continuing interglacial is likely to be very long. The expected length of the interglacial is more than 50 thousand years (probably 60 to 70 thousand years). The last interglacial MIS5 (eem) lasted 55,000 years. The current interglacial is compared to the interglacial MIS11 (holstein), which lasted 25 to 30 thousand years. This interglacial was one of the warmest and the most humid interglacial in the Quaternary period. During the continuing interglacial, part of the glaciers may melt, and the level of the world ocean may rise over 4 to 6 m, in extreme conditions up to 12 m [14]. The average air temperature and the average rainfall will increase, and the climate will get wetter. There will be no permafrost and the higher surface water infiltration into the deeper groundwater collectors will occur.

After 50 thousand years the gradual cooling of the climate and the beginning of the glacial conditions are expected. The limiting scenario of the maximum cooling and drying of the climate corresponds to pleniglacial conditions. The average air temperature and the average rainfall will decrease. Maximum cooling and drying of the climate will occur. The average air temperature will range from - 7 °C to -2 °C and the average rainfall will be 250 – 350 mm/year (Tab. 2).

The permafrost will be formed to a depth of ca. 150 m below the surface. The permafrost depth is estimated by the average permafrost depth in the past glacials. In the Blahutovice-1 borehole near the town of Hranice na Moravě was measured the maximum thickness of permafrost in the Czech Republic. The thickness of the permafrost in a complex of sedimentary rocks was objectively proved to be 220 m [15]. Permafrost separates surface water circulation with the deep groundwater circulation. For the deep geological repository conditions, permafrost formation would be advantageous as it would represent a barrier to possible surface radionuclides contamination. The beginning of the glacial depends on the concentrations of CO_2 and the other greenhouse gases in the atmosphere. The beginning of glacial in 50,000 years would be possible if CO_2 concentrations will reach 280 ppmv and lower. At the higher concentrations the interglacial will be longer and the beginning of the glacial would be delayed. Over the next 100,000 peak glacial conditions are not expected. The conditions of the peak glacial should occur at the earliest up to 110 thousand years

Glaciation in the candidate sites is not expected in the next 100 thousand years. The next glacial is likely to be weaker than the previous glacials in the Quaternary period.

4 Conclusions

In this article, climatic stability and climate evolution in the Central Europe were evaluated with respect to candidate sites for the construction of a deep radioactive waste repository. The climate evolution as evaluated for the period of long-term safety of the deep geological repository, i.e. 100 thousand years. Climate evaluation will be used to create numerical model of the groundwater flow and the radionuclide transport in defining boundary conditions of the conceptual model.

In the first 50,000 years, climate warming and humidification are expected to be anthropogenically affected by CO_2 concentrations, the most the first 300 years will be affected. The climate will get wetter and air temperature and the average rainfall will increase. During the interglacial, the glaciers may melt, and the level of the world ocean may rise over 4 to 6 m. Then after the end of interglacial, the expected length is more than 50 000 thousand years (probably 60 to 70 thousand years), the climate will gradually cool and dry, and glacial conditions will begin. The conditions of the peak glacial should occur at the earliest up to 110 thousand years, i.e. after the end of the long-term safety of the deep geological repository. In glacial conditions, glaciation of candidate sites is not expected to be Scandinavian continental or mountain glacier of the Alpine type. Under these conditions, permafrost could be formed with a maximum depth of up to 150 m, permafrost will separate the surface water circulation with the deep groundwater circulation.

For ensuring the long-term safety of the deep repository the occurrences of all endogenous and exogenous phenomena, which could affect site stability, must be evaluated. Concerning exogenous processes, research focused mainly on the assessment of climatic effects. Furthermore, the influence of others endogenous and exogenous phenomena will be considered in the subsequent research of the rock environment.

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