Role of Proper Closure for the Bátaapáti Radioactive Waste Repository

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Abstract: Proper final closure of a radioactive waste repository ensures that the evolution of the disposal system will take place as predicted and as evaluated by the post-closure safety assessment. It is of prominant significance to achieve this in cases where the overall performance of the system depends highly on only a few engineered barrier elements. This is the case for the Bátaapáti radioactive waste repository currently under construction in southern Hungary. Due to the special hydraulic compartmentalization of the site, unique engineering solutions must be designed and applied during the final closure of the repository. It is proved that the bulkheads constructed in the access tunnels where they had penetrated the major sealing zones play the most significant role in ensuring that the requirements regarding safety will be met. In this article the hydraulic compartmentalization of the site is discussed from the perspective of what influence it has on long-term safety and the possible engineered barrier system components are analysed based on their roles in achieving the desired post-closure conditions.

Keywords: radioactive waste; safety assessment; hydraulic compartmentalization; engineered barrier system; hydrogeological modelling; system analysis

1   Introduction

One of the major issues regarding nuclear energy is waste management. In recent years national programs have been in progress worldwide for the final disposal of radioactive wastes. Most of the programs—mainly the ones dealing with high level and/or long-lived wastes and especially spent fuels—use the geological disposal concept [1] to provide adequate safety for humans, for the biosphere, and for the whole environment. Geological disposal utilizes the defence in depth concept in which several, natural and engineered, barriers provide multiple layers of safety to achieve a robust disposal system within which single component defects have only a limited imact on the performance of the whole system.

For the low and intermediate level radioactive waste repository currently under construction at Bátaapáti in southern Hungary the geological disposal concept was adopted to meet national safety criteria. The repository is located at a granitic site some 250 m below surface. It will accept solid and solidified radioactive wastes originating from the Paks Nuclear Power Plant [2]. Due to the relative long half-lifes of some of the wastes in the inventory 200 000 years must be considered during the post-closure safety assessment [3]. For such a long timeframe it is inevitable that both the natural (geological) and engineered barriers must contribute to the containment, retardation and isolation of radionuclides from the biosphere.

In this article, first the genaral geological conditions of the site are introduced. Then a discussion is provided on what influence those conditions have on the predicted post-closure evolution of the disposal system. Based on these, we are going to analyse what roles certain engineered barrier system elements may play, and finally we will draw some conclusions regarding the requirements defined for these components.

2   Geological Conditions

In this section the geological conditions of the site are presented. The emphasis is on the unique hydrogeological characteristics of the site as radionuclide transport will take place in the groundwater system. Understanding how the flow system had worked before the exploration and construction activities started can lead us to predict how it will evolve after the repository will be closed and how certain closure components may influance that.

2.1   General Geology

The Bátaapáti site has a relatively simple geology with Carboniferrous granitic rocks — monzogranite, monzonite, diorite — underlying a (generally about 50 m thick) Pleistocene loess cover [4]. The uppermost part of the granite is weathered and has different characteristics compared to the fresh rocks. Some alkalic basalt dykes are found to penetrate both the fresh and the weathered granitic rocks. Since the site lies only a few kilometers away from the Submecsek Zone (a major strike-slip horizontal fault line) its fracture system is well developed and shows evident signs of being under the influence of this major tectonic line. The properties of the fracture system of a granitic site are very important for the assessment of long-term safety as radionuclide transport will take place almost exclusively in the open fractures.

2.2 Hydraulic Compartmentalization

The most unique feature of the site is its hydraulic compartmentalization [5]. Hydraulic compartmentalization means that the site is divided into separate blocks among which there is very limited hydraulic communication and connection. In case of the Bátaapáti site this division is caused by fault seal zones striking in an E—W and in a N—S direction (Figure 1). Since these fault zones represent the highest elements in fracture hierarchy [6] they break the connections among fractures on different sides of these zones. The fault seal zones themselves have a well developed inner structure with a highly altered core zone in the middle followed by highly fractured zone on one or both sides [7]. The core of the zone is made up of fragments originating from the neighbouring granitic rocks, it has a considerable amount of swelling clay mineral content in it which results in it being almost impermeable.
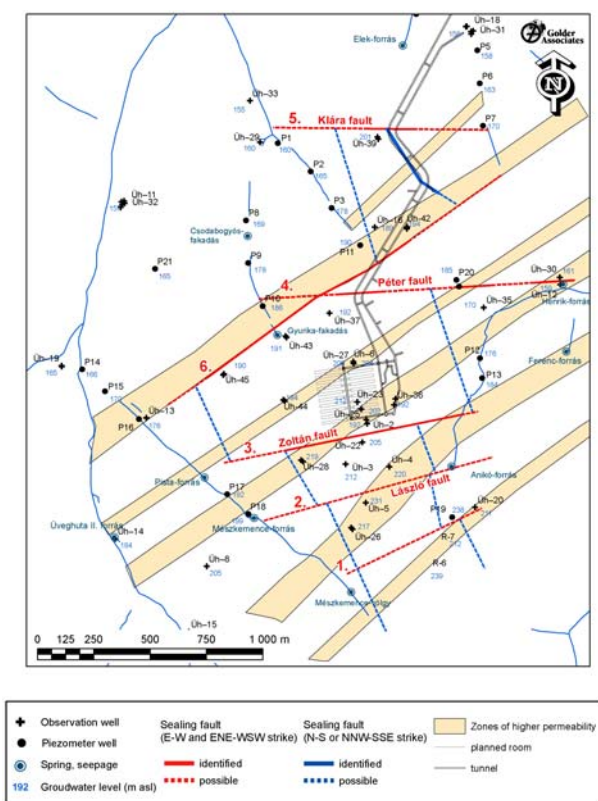

Figure 1
The hydraulic compartmentalization of the site after [8]

This hydraulic compertmantilzation has numerous adventageous characteristics in regard with radioactive waste disposal [6]. Since the hydraulic blocks have very limited connections with each other, any hydraulic process occuring in a block will have limited influence on what happens in the other blocks. This system — together with the highly transmissive fracture zones extending to hundreds of meters and creating good spatial connectivity within blocks — generates extremely low spatial variability in hydraulic potentials and therefore also in hydraulic gradients within blocks, whereas the different blocks can be identified most accurately by their different hydraulic potentials. The very characteristic sudden changes in hydraulic potentials (called head jumps) identify the locations of the fault seal zones [5].

The sealing properties of the fault seal zones limit the infiltration which can reach the fresh granitic rocks and with it the velocity of groundwater flow. On the other hand, the weathered granite layer on the top will have a much higher infiltration and — since the deep groundwater and the waters flowing within the weathered part are mixed before discharge — it ensures considerable amount of dilution to occur before the potentially contaminated groundwater reaches the biosphere.

3   Possible Post-Closure System Evolution Scenarios

The long-term safety assessment deals with the post-closure evolution of the disposal system and evaluates its impact on the biosphere. Since the assessment has to be carried out over a timeframe of hundreds of thousands of years it is almost impossible to predict with confidence what will occur. It is therefore necessary to develop possible scenarios — alternative evolutions of the disposal system — and assess each and every one to make sure that there doesn't exist a scenario in which the safety criteria are not met. In case such a possible evolution is identified it is of utmost importance to investigate what causes it to fail the standards and accordingly change the necessary components in the disposal system to avoid this malfunctioning.

3.1   Determining Factors of Scenarios

The development of possible scenarios for the Bátaapáti site was carried out based on the methodology of identifying scenario generating FEPs [9]. (FEP is the acronym for Features, Events and Processes that must be considered during the safety assessment.) In recent analyses it was determined [6, 10] that failing to construct a proper bulkhead in the access tunnels where they had penetrated the E—W striking major fault seal zones causes the greatest deviation from the normal scenario. In the following paragraphs the results of some detailed modelling tasks evaluating this scenario are presented and analysed.

3.2   Comparison of Scenarios from the Perspective of Long-Term Safety

The first evidence that improper closure of the repository may lead to increased levels of radiation in the biosphere came from the hydrogeological model investigating how different designs of the access tunnels affect the flow-field [11]. It was demonstarted that the only way to regenerate the hydraulic compartmentalization of the groundwater flow system after final closure of the repository was to emplace bulkheads with low hydraulic conductivities in the access tunnels right where they had penetrated the fault seal zones (Figure 2a). In all the other cases, regardless of the properties of the bulkheads or the backfill materials used in the access tunnels, the flow rate alongside the access tunnels increased considerably and even the bulkheads had only local influence on the flow-field (Figure 2b). It was concluded that the increased flow-rates would lead to shorter travel times and to higher fluxes for radionuclides.
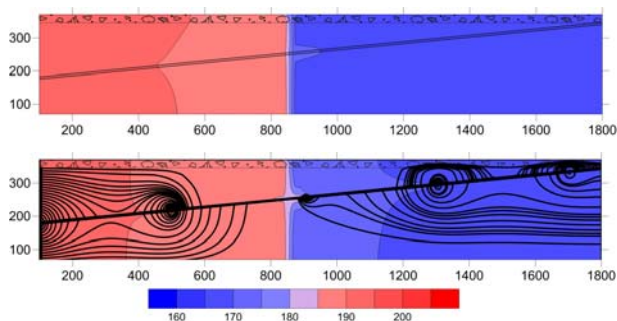

Figure 2

Comparison of hydraulic potential distribution and flow rate alongside the access tunnels as a function of the location of bulkheads. In Figure 2a (upper) the single bulkhead is located at the fault seal zone penetration, whereas in Figure 2b (lower) several bulkheads are constructed but none at penetration after [11]

A more site-specific, detailed, site-scale hydrogeological model [12] is the basis of the current safety assessment [13]. It includes all the currently known and assumed hydrogeological features like the fault seal zones and the high transmissivity fracture zones, and it differentiates between zones in which the transmissivity distribution is shifted towards the relatively low and towards the relatively high values (shown as shaded zones in Figure 1). It also includes the whole repository system with all the tunnels and chambers.

This model was used to investigate how the groundwater system will behave as a function of different engineering solutions applied for the final closure of the repository. The preliminary results of the model [12] indicate that the characteristics of the flow-field will depend mainly on how low permeability can

be achieved at the bulkheads in the access tunnels. In case the ekvivalent hydraulic conductivity of the bulkheads is lower than or at least comparable to the ekvivalent hydraulic conductivity of the fresh granite (Figure 3b) then the hydraulic compartmentalization of the groundwater system will be regenerated after closure regardless of what solutions are applied to the other components of the engineered barrier system. If this cannot be achieved then the general flow-field at the site will change so much from what has been observed during the exploration of the site and construction of the repository that the utilization of available information will be extremely difficult and will include a very high degree of uncertainty. This case will also result in the transport of contaminants occuring alongside the access tunnels (Figure 3a).
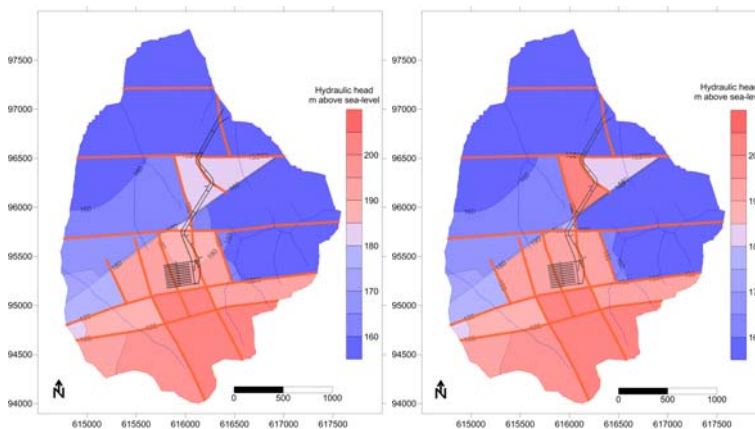

Figure 3

Calculated hydraulic potential distribution as a function of performance of closure measures. Figure 3a (left) represents the case when the hydraulic conductivity of the bulkhead is high, whereas Figure 3b (right) shows the case for proper sealing after [12]

The best scenario is if the bulkheads, constructed at both places where the access tunnels had penetrated major E—W striking fault seal zones (Péter- and Klára fault on Figure 1), have a hydraulic conductivity lower than 1×10^{-10} m/s. In this case the original hydraulic compartmentalization will be regenerated in such a way that a hydraulic block will exist alongside the tunnels between these fault zones with higher hydraulic potential than the block in which the repository is located (Figure 3b). Consequently, no advective flux will be possible alongside the access tunnels towards the biosphere and all the contaminants released from the repository will have to be transported through the geosphere. It has been proven that transport through the geosphere — especially if low hydraulic gradients are observed — can be characterized to have extremely good retardation capabilities even for generally not-retarding radionuclides like ^{3}H, ^{36}Cl and ^{129}I [14].

4   Role of Engineered Barrier System Elements

Results of the site-scale hydrogeological model were used in a preliminary safety assessment [10] to identify the most important engineered barrier system elements connected to the final closure of the repository. The flow rates through the disposal chambers and alongside the tunnels calculated for different cases by the hydrogeological model were coupled with contaminant flux release for a single chamber originating from a detailed safety model.

A sensitivity analysis was carried out by using the Monte Carlo method with 100 realizations for all three waste types. The results (Figure 4) show that the calculated effective dose in the biosphere is best correlated with the ekvivalent hydraulic conductivity of the bulkheads (and their close environment) constructed at the fault seal zone penetrations [10]. It was also concluded that the ekvivalent conductivity of this zone is more sensitive on the properties (hydraulic conductivity and geometry) of the excavation damaged zone (EDZ) around the tunnel and on how good sealing can be achieved between the bulkhead and the neighbouring elements than on the actual hydraulic conductivity of the bulkhead itself. All the other barrier elements have minimal direct impact on the calculated doses. It can be concluded from these results that the other closure elements have only a secondary function of limiting the effect of adverse processes that may degrade the bulkhead.
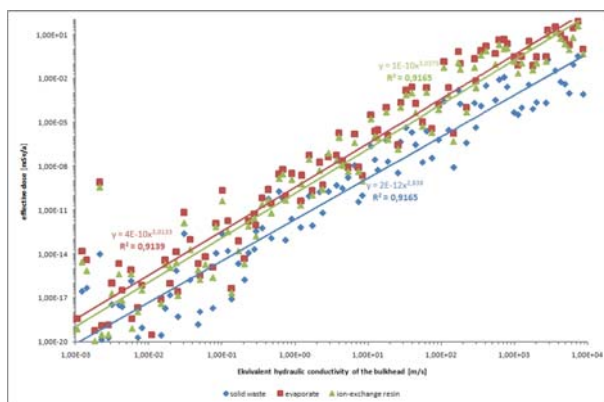

Figure 4

The correlation between ekvivalent hydraulic conductivity and effective dose for different waste types after [10]

5   Requirements Defined for Proper Closure

As described in the previous section, the ekvivalent hydraulic conductivity of the bulkheads emplaced at the fault seal zone penetrations is the only element showing strong correlation with the final result of effective dose in the biosphere and therefore requirement could only be determined for this single parameter. Previous modelling results suggested [15] that it must be in about 3×10^{-8} m/s — which equals the ekvivalent hydraulic conductivity of the host rock — to provide the necessary retardation capabilities. Based on the results (Figure 5) from the coupled modelling activities described earlier this value could be increased to 2×10^{-7} m/s [10]. Deterministic results achieved by using the same model show that even this value can be deemed a bit conservative. By using deterministic models it was proven that by using 5×10^{-7} m/s for the ekvivalent hydraulic conductivity of the bulkheads and changing the parameter values for the other elements within ranges of feasability, there was not a single result which exceeded the dose constraint of 1×10^{-4} Sv/yr.
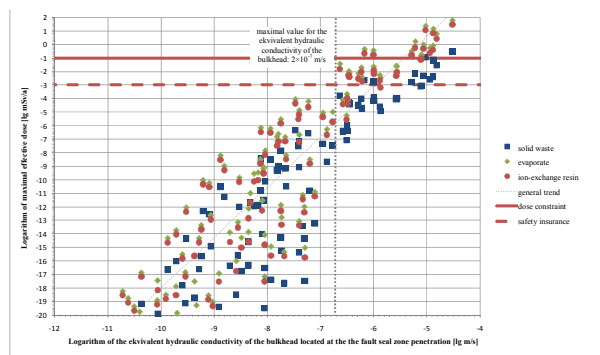

Figure 5

The requirement for the ekvivalent hydraulic conductivity of the bulkhead at the penetrated fault seal zone based on the Monte Carlo simulation for all three waste types after [10]

Conclusions

The hydraulic compartmentalization of the Bátaapáti site provides beneficial conditions for radioactive waste disposal but it also requires unique engineering solutions to be applied. The long-term evolution of the system is highly dependent on the performance of a single engineered barrier component, the low-permeable bulkheads constructed in the access tunnels where they had penetrated the E—W striking major fault seal zones. Using sensitivity analysis and by calculating correlations between closure elements and effective doses, a safety function criterion of $<2\times10^{-7}$ m/s ekvivalent hydraulic conductivity could be determined for the bulkheads.

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