HYDRAULIC CAGE CONCEPT FOR WASTE CHAMBERS AND ITS TECHNICAL IMPLEMENTATION FOR THE UNDERGROUND RICHARD REPOSITORY, LITOMĚŘICE, CZECH REPUBLIC

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ABSTRACT

Richard Repository is a near surface underground repository for low and intermediate level radioactive waste of institutional origin. In the course of a joint Phare Project carried out together with the repository operator, the Czech Radioactive Waste Repository Authority (RAWRA), DBE TECHNOLOGY developed a new concept for the closure of individual waste chambers. Main technological element of this concept is the installation of a hydraulic cage around the waste chambers by attaching a gravel layer to all sides of the chamber. This hydraulic cage will prevent the development of advective flow through the waste/concrete body within the backfilled chambers by eliminating the pressure gradient as driving force for such a flow. Thus the transport of radionuclides will be restricted to diffusive fluxes, which results in a considerable decrease of potential radiological impact. In the course of the project the closure of a certain chamber system within the mine was planned up to a grade of detail, which allowed its direct realization as a pilot closure study, which started in the beginning of 2006.

1 Introduction

In the past, RAWRA as operator of the Richard Repository prepared a preliminary plan for closure of the facility including a safety assessment demonstrating the long-term safety of the disposal system (2002 SA, /1/), which is part of the repository license documentation.

In 2003 RAWRA launched an international call for tenders for the review and further development of the repository closure concept and for the detailed design of the closure of a chamber in the Richard Repository, which was awarded to DBE TECHNOLOGY GmbH. General objective of this project named "Solution for Closure of a Chamber in the Richard Repository" was to demonstrate the feasibility of safe closure of one or more disposal chambers and to improve the safety of the low-level waste packages disposed of in the Richard Repository. This Phare Project, which ended in the second half of 2005, was largely financed by the EC and co-financed by the Czech Ministry of Finance.

2 The Richard Repository

The Richard repository for radioactive waste from institutional waste producers is located in the outskirts of Litoměřice, on the shores of the river Labe, in Northern Bohemia, some 100 km Northeast of Prague. Richard is a former limestone mine, in which during WW2 an underground facility for military production was installed. To this aim a series of caverns were excavated, which at later times remained unused. The layer of limestone containing the tunnels and caverns is horizontal and approximately 4 m thick and the heights of the tunnels and caverns are up to this height. The site is located at about 265 m above sea level, and has a maximum thickness of overlaying strata of about 70 m.

With the start of nuclear research and isotopes use in medicine and industry in Czechoslovakia in the nineteen fifties the need for a facility to dispose of resulting waste arose, eventually leading in the middle of sixties to the installation of a repository in the central part of the former Richard mine (ca. 200 x 400 m). A tunnel through the repository allows access to the caverns. Packages of waste are stacked in the caverns on their sides and the entrances to the caverns were bricked up once the caverns were full of waste packages. The waste is mostly packed in standard 200-liter drums, which comply with radiation protection criteria for contact-handled waste. Up to now, some 25,000 waste packages and thereby a significant activity of about 10^{15} Bq have been disposed of with a significant proportion of long-lived radionuclides, mainly ^{241}Am, ^{239}Pu, and ^{238}Pu.

3 Reasons for the Development of a New Closure Concept

The former closure concept building the basis for the 2002 SA foresaw that the waste chambers containing stacks of waste drums would be backfilled with concrete. For this purpose the filled waste chamber would have been sealed by concrete walls, through which concrete would have been pumped into the chambers with the objective to backfill the chamber to 100%. The concrete for backfilling was supposed to have low hydraulic conductivity, below 10^{-10} m s^{-1}, and low shrinkage. The rest of the repository (main drift, entrance etc.) would have been sealed by concrete plugs while adjacent tunnels and caverns were planned to be backfilled by material with lower requirements.

In the 2002 SA the repository is modelled as a homogenous mixture of waste and concrete. A certain percentage of the precipitation infiltrates the marlstone in the overburden, percolates downwards and through the repository advectively transporting radionuclides out of the former mine. As release scenarios mainly two scenarios are identified. For both, the Town Well Scenario and the Farm Scenario, it is assumed that contaminated water from the mine will travel further downwards through the lower marlstone layer into the aquifer, from which at a certain horizontal distance contaminated water will be pumped up again to serve as drinking water in the first scenario and water supply for the operation of a small farm in the second scenario. As a third potential way of radionuclide release the direct release of contaminated mine water into the biosphere was considered. This possibility was excluded on the basis that high performance sealing of the access tunnels would prevent this to happen. Still as a reference case the annual dose rate was calculated assuming that mine water would be used as sole source for drinking water by an individual without any prior dilution (see Figure 1).

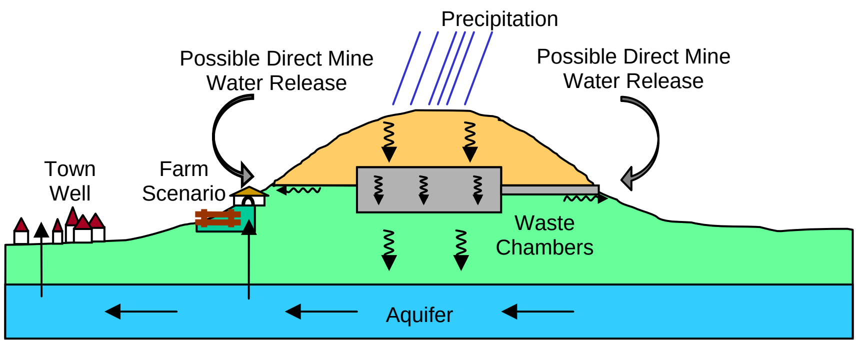

Figure 1: Schematic view of contamination pathways for the different scenarios.

While within the limits of the model used, the 2002 SA rendered exposure values for future generations below current regulatory limits for the Town Well and the Farm Scenario, the reference case yielded high annual dose rates well above regulatory limits. A comprehensive compilation of the closure concept and the site documentation including the results of the 2002 SA can be found in the Safety Report 2003 /2/.

When reviewing the safety assessment, we considered that the direct release of contaminated mine water could not be excluded just by sealing the entrance tunnel in such a way that mine water would not be able to bypass this barrier. Instead, we judged that for several reasons it would be very difficult to totally prevent direct release and even more difficult to prove that such release would be prevented in the long term. The main reason for this evaluation is that even if total long-term sealing of all access tunnels to the Richard Repository could be achieved, which would be difficult to prove, this would still not prevent the possible direct release of mine water because the hydraulic conductivity of the overlying and underlying marlstones is lower than the hydraulic conductivity of the 3-4 m thick limestone layer around the repository. Water inside the repository, therefore, will be released preferably through the limestone than through the underlying marlstone provided no vertical fractures with high permeabilities exist in that marlstone layer, which can easily be reached from all areas of the mine. Also the probability that preferential pathways might exist along the limestone base or fractures inside the limestone with even higher permeabilities than the limestone itself is considered rather high.

The assumption made for the reference case in the 2002 SA that contaminated water from the mine is released without any dilution into the biosphere and is used there by an individual as sole source for drinking water certainly is very unlikely. However, the possibility that mine water is not flowing into the aquifer but is released without much dilution at the slope of the hill into the biosphere does not seem to be very improbable. It was considered necessary, therefore, to develop a changed closure concept, which would prevent the radiological consequences from possible scenarios associated with the direct release of mine water. These considerations lead to the development of a closure concept involving the installation of a hydraulic cage around the waste chambers.

4 Hydraulic Cage Concept

The main idea of Hydraulic Cage Concept is to exclude the build-up of a pressure gradient across the disposal chamber by implementing a high permeable layer around the chamber as preferential pathway for possible groundwater inflow. Thus, the former radionuclide isolation system of the repository, which was based only on the principle of radionuclide containment by enclosing the waste with low-permeability barriers, is complemented by a redundant barrier based on an alternative, totally different working principle: avoiding water flow through the waste by eliminating the flow driving force.

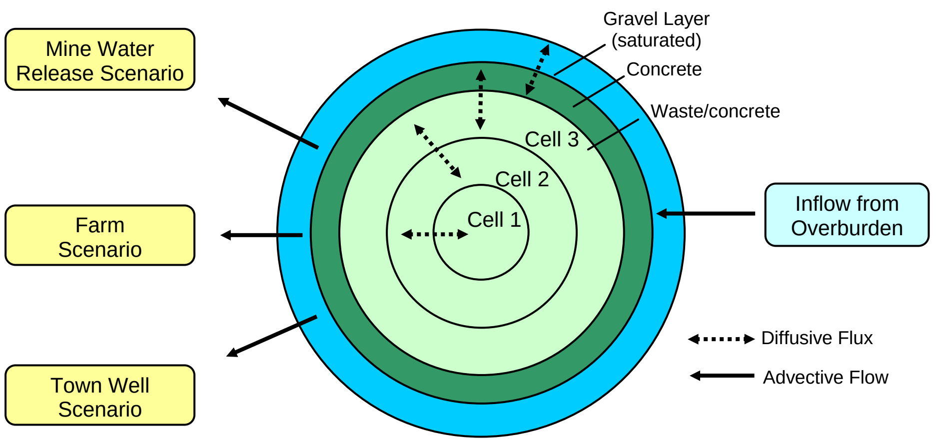

Figure 2: Source term model used for the safety assessment for the Hydraulic Cage Concept.

Due to capillary forces the concrete body might soak up water, but even if the concrete were 100% saturated, without the driving force of a pressure gradient no groundwater flux through the concrete body would result and accordingly no advective transport of radionuclides would take place. This would also be the case if the repository system as a whole was 100% saturated. The normal evolution scenario thus will be changed in such a way that no release of radionuclides will occur apart from diffusive fluxes between the waste/concrete body and the gravel layer (see Figure 2). Although, in the course of time e.g. carbonation might increase the initial diffusivity of the concrete, the difference in permeability between the low permeability zone of the gravel layer and the concrete is expected to remain at several orders of magnitude.

Flux through the concrete body can only occur if continuous fractures throughout the whole body exist. Such fractures might develop as the result of seismic incidents or other accident scenarios. Even in that case, groundwater possibly infiltrating from above in the vicinity of such a fracture will have a low tendency to pass through it, given the negligible hydraulic resistance of the hydraulic cage.

As demonstrated by the updated safety assessment taking into account the changed source term /3/, potential hazards for members of the critical group arising from the direct release of mine water are significantly reduced. For the first 2000 yrs after closure annual dose rates are reduced by more than 4 orders of magnitude. But also for the normal evolution scenarios the changed concept leads to significant improvements in regard to possible radiation exposure. For both scenarios - considered as representative for normal evolution - the peak annual dose rates derived from safety calculations were reduced by a factor 4 and the respective peak time was shifted several thousand years into the future.
In addition to reducing the potential hazards related to the different scenarios, the implementation of the Hydraulic Cage Concept also drastically reduces the probability that either of these scenarios will ever occur at all. Taking into account that, with the Hydraulic Cage System implemented, radionuclide release out of the waste/concrete body will take place only via diffusive transport, there will be hardly any release at all as long as no permanent flooding of the mine results from that water inflow. A rather likely situation, which for the former closure concept would still lead to the release of radionuclides.

5 Technical Implementation for individual Chambers

After reviewing the different technical implementation alternatives, a rather simple to apply and robust solution for the construction of the hydraulic cage, analogous to techniques used in tunnel building, was developed. In principle the stacked waste is backfilled with low-permeable concrete as foreseen in the preliminary closure plan. In addition, a layer of pure concrete, which again is enclosed in a gravel layer with high hydraulic conductivity, surrounds the waste/concrete body. A drainage and monitoring system allows monitoring the performance of the hydraulic cage before repository closure, thus allowing verifying the proper functioning for a period of up to several decades.

As the chamber-system selected for the pilot closure project was part of the non-operated area of Richard II, as first steps, the planning foresees clearance of the chambers from debris and loose rocks and securing roofs and walls with rock bolts. Subsequently the floor and the cage for the surrounding gravel layer are being prepared to reach the situation illustrated in Figure 3. As to be seen from this figure the floor consists of three layers. The underlying concrete layer together with the small concrete side walls will isolate the drainage layer in the floor from the surrounding rocks. This will allow infiltrating mine water to be conducted to the entrance of the mine for monitoring purposes. Another reason for shielding the lower marlstone, exposed at the bottom of the chamber and at the lower part of the walls, from the potentially saturated gravel layer is the fact that this marlstone has a certain swelling potential, which might have a negative influence on the permeability of the gravel layer. The gravel layer, at the chamber floor represents the lower part of the hydraulically conducting layer surrounding the waste chamber. During operational times, water entering this layer will be drained through normal water pipes leading to the tunnel entrance. Gravel filled gaps between the concrete roadway and the small concrete side walls provide the connection between the bottom gravel layer and the gravel layers to be installed at the walls. According to sensitivity analyses the thickness of the surrounding layer of pure concrete, of which the concrete roadway on top of the gravel layer represents the lower part, was set to 40 cm.

The highly permeable layer at the walls and the ceiling will be realized by attaching a steel mesh (10 cm x 10 cm x 6.3 mm) to the extruding rock bolts (about 1 rock bolt per m²). The steel mesh is to be properly fixed to the rock bolt extensions using appropriate extensions. At the wall side of the steel mesh, a geotextile mat (alternatively steel gauze could be used) has to be attached to keep the gravel inside the interstice between steel mesh and wall or roof. To complete the highly permeable layer, drainage material will be blown into the interstice between the chamber contours and the layer of steel mesh and geotextile. To prevent fresh concrete or cementitious suspension from flowing into the gravel layer during later backfilling of the chamber a watertight layer has to be attached to the steel mesh from inside the chamber. This function will be fulfilled by of a shotcrete layer of 5-10 cm thickness, which also will increase the working safety.

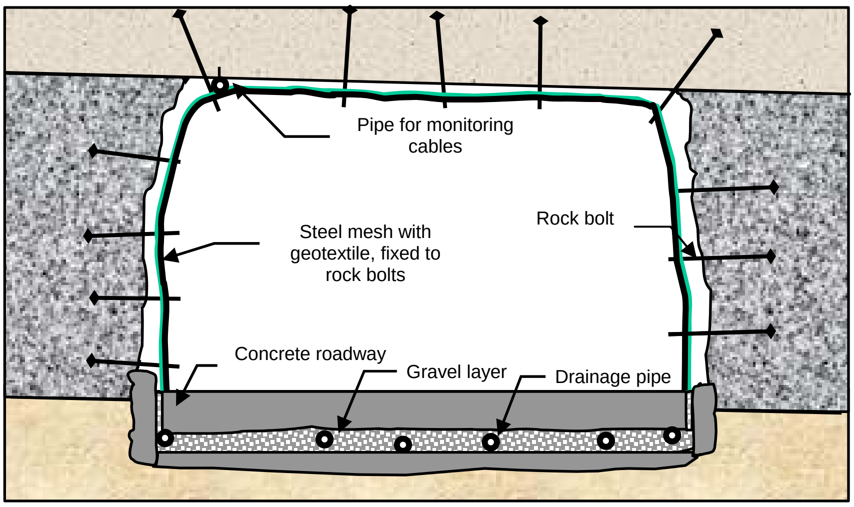

Figure 3: Cross section of disposal chamber after installation of cage for gravel layer. The different colours of the surrounding rock layers refer to: Upper Marlstone (top), Limestone (middle) and Lower Marlstone (bottom).

The construction of a 40 cm layer of pure concrete at the walls and the ceiling of the chamber can be carried out automatically during the later backfilling of the chamber if care is being taken during waste disposal that waste packages are kept in a respective distance to the walls. This requires, however, the stabilization of waste packages to prevent them from rolling or shifting towards the walls. Depending on the form and weight of the waste packages this might not be trivial. It was therefore planned to construct the 40 cm side walls prior to waste disposal, which allows an unproblematic stacking of drums or other waste packages. After this construction step the chamber is prepared for waste disposal. Completion of the enclosing layer of pure concrete around the waste/concrete body will be achieved by filling the top most part of the chamber during the later backfilling process

For the sake of simplification, in the description above the fact has been ignored that in order to comply with certain quality requirements the chamber system has to be subdivided into several segments with maximum lengths of about 20 m, which will be backfilled individually. The detail planning therefore foresees the construction of partition walls, which not only serve as separating walls for the backfilling process but also as supporting structure for the chamber-system prior to its backfilling.

Meanwhile the realization of preparation, waste disposal, and subsequent backfilling of the chamber-system has been started in the course of a further Phare Project as a pilot study for the feasibility of the technical implementation. There is a second paper to be presented at this conference, describing the experiences from the construction work and showing examples of the “real world” version of the hydraulic cage /4/.

6 References

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