UPDATE OF THE SAFETY ASSESSMENT OF THE UNDERGROUND RICHARD REPOSITORY, LITOMĚŘICE

B. Haverkamp, E. Biurrun
DBE TECHNOLOGY GmbH
Germany

M. Kučerka
Radioactive Waste Repository Authority
Czech Republic

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 project currently 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. As part of the project the previously existing repository safety assessment has been updated to quantify the effects of the changed concept in regard to the radiological consequences. The new safety assessment has not been completed yet, but preliminary results show that the new Hydraulic Cage Concept is rather insensitive to variations of assumed material properties and evolution scenarios and reduces peak annual dose rates for scenarios in connection with the direct release of mine water by about four orders of magnitude.

INTRODUCTION

The Richard Repository, situated at the outskirts of Litoměřice in the North of Czech Republic, has served as a repository for low and intermediate level institutional radioactive waste since the mid nineteen-sixties. Up to now, some 25,000 waste packages and thereby a significant activity of about 10^{15} Bq have been disposed of. Richard, originally a limestone mine excavated into a hill close to the Elbe River, was later used for military production leaving a number of well-conditioned underground cavities. The site is located at about 265 m above sea level, and has a maximum thickness of overlaying strata of about 70 m. In the past, RAWRA as operator of the 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]).

Currently DBE TECHNOLOGY in co-operation with RAWRA is carrying out a project supported by the European Commission on the elaboration of a "Solution for Closure of a Chamber in the Richard Repository". In the course of this project the safety measures foreseen in the former closure concept have been significantly enhanced and optimized. The technical implementation of the optimized concept is going to be demonstrated by the forthcoming closure of a chamber system in the Richard Repository planned to begin in 2005.

In order to quantify the radiological consequences of the changed closure concept, the 2002 SA has been adapted to acknowledge the differences in the source term resulting from the changed technical concept. Also the previously deterministic model has been exchanged by a computer model that also allows probabilistic calculations using the GoldSim computer code. The main results of these calculations demonstrating the effect of the changed closure concept are discussed in the following chapters. As a detailed description of the Richard Repository including the previous closure concept and the optimized one are given in a separate paper in this volume [2], here only the most relevant information in regard to the safety assessment calculations is briefly summarized.

Description of the Richard Repository

The Richard Repository is located in the former Richard Mine, an extensive network of tunnels and caverns. The layout of the repository is shown in Figure 1. The part of the mine workings in which the repository is located is called Richard II. Not all of Richard II is occupied by the repository. Richard II is connected to Richard I by a tunnel approximately 150 m long, and to Richard III by part of the cavern system. The repository is accessed through a horizontal tunnel with an entrance on the slopes of Bidnice Hill above Litoměřice at a height of 250 m above sea level. The distance from the entrance to the first cavern is approximately 100 m.
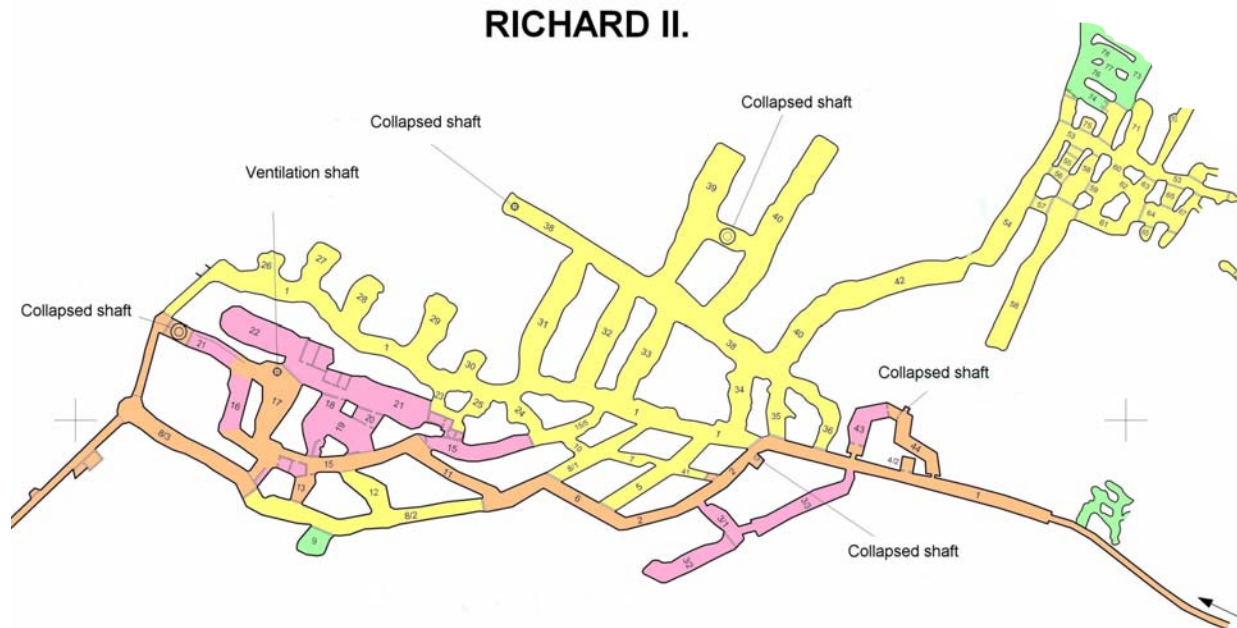
Fig. 1. Map of Richard Repository.

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. 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 bricked up once the caverns are full of waste packages.

The walls and roofs of the tunnels and caverns are supported by concrete arches and slabs, by shotcrete, by bolts into the rock, and by low concrete walls. The floor of the repository is concreted.

The repository is currently drained. The drained water is believed to come from a number of sources: groundwater infiltrating into the repository through the rock at fractures and via the shafts into the repository; from condensation in the repository; and from water entering the drainage system from outside the repository area. How much water enters the drainage system from each source is unknown.

Local Hydrogeology

Above and below the layer of limestone, in which the Richard Repository is located, there are layers of marlstone. The soil above the repository has a high content of clay. Under the marl below the repository is a thick layer of Cretaceous sandstone. The repository caverns are covered by approximately 30 to 70 m of marl, depending on their location. The thickness of the marl

below the repository is approximately 50 m and the thickness of the sandstone layer is approximately 100 m. The area contains a number of faults.

The sandstone layer is an aquifer, from which water is pumped at wells approximately 4.5 km west of Litoměřice in the bend in the River Labe (Elbe), to supply Litoměřice and the surrounding area. Two other wells situated in the town of Litoměřice extract water, but at a much lower rate than the town water supply.

The aquifer in the sandstone is fed by infiltration from above. Data provided on the location of the water table are not consistent, but the water table is some tens of meters below the repository and may be located in the marl or sandstone. The repository is therefore in partially saturated rock. Very little information is available about the rate and nature of infiltration of water in the area of the repository. The soil, marl and limestone are believed to have relatively low permeability. It is not known if water would infiltrate fairly uniformly over the area of the repository, once the repository is closed, or would flow through the repository heterogeneously, perhaps in only a few places. The shafts will be sealed before closure, but how effective the sealing will be in the long term is rather uncertain.

Previous calculations show that waters in the sandstone aquifer passing under the Richard Repository and flowing south towards the River Labe are bypassing Litoměřice. Close to the river the water is drawn west to the wells supplying Litoměřice, by the pumping from the wells and the fault pattern, the calculations suggest however that contamination from the repository would not reach the wells situated in Litoměřice (at current extraction rates).

Waste Inventory

The waste already disposed of in the repository appears mainly to be a mixture of low-level radioactive waste (LLW) and short-lived intermediate-level radioactive waste (ILW), although the wastes do contain some long-lived radionuclides. The wastes consist of solid material, low activity liquid wastes and sludges. A significant inventory of organic material may be present (including paper, cotton wool, wood, rubber, gloves, textiles, plant wastes, bedding, straw, animal excrement and animal carcasses).

Most of the disposed waste, and the waste to be sent to the facility in the future, will be sealed in steel drums. Most wastes disposed of after 1985 was packed in 200 liter drums with a concrete liner. A galvanized mild steel is used for containers. Since 1986, wastes containing significant amounts of Pu-238, Pu-239 and Am-241 have been stored separately from other wastes, in Chambers 15/1 and 15/2 and other areas. These wastes may be removed for disposal elsewhere before the Richard Repository is closed.

For the safety assessment calculations carried out as part of this study, the same best estimate for the inventory of radionuclides disposed of in the Richard Repository has been used, which was taken as basis for the 2002 SA.

Description of Former 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 and adjacent tunnels and caverns were planned to be backfilled by backfilling material with lower requirements.

Well in advance to closure of the repository the former closure concept recommended the sealing of existing shafts to the surface, which are supposed to be major contributors to the inflow of water into the existing drainage system of the mine.

2002 SAFETY ASSESSMENT OF FORMER CLOSURE CONCEPT

In the 2002 SA the repository is modeled 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 (apart from human intrusion) mainly two scenarios have been identified. For both, the Town Well Scenario and the Farm Scenario, it is assumed that the contaminated water from the mine will travel further downwards 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 for the case that mine water would be used as sole source for drinking water by an individual without any further dilution or sorption.
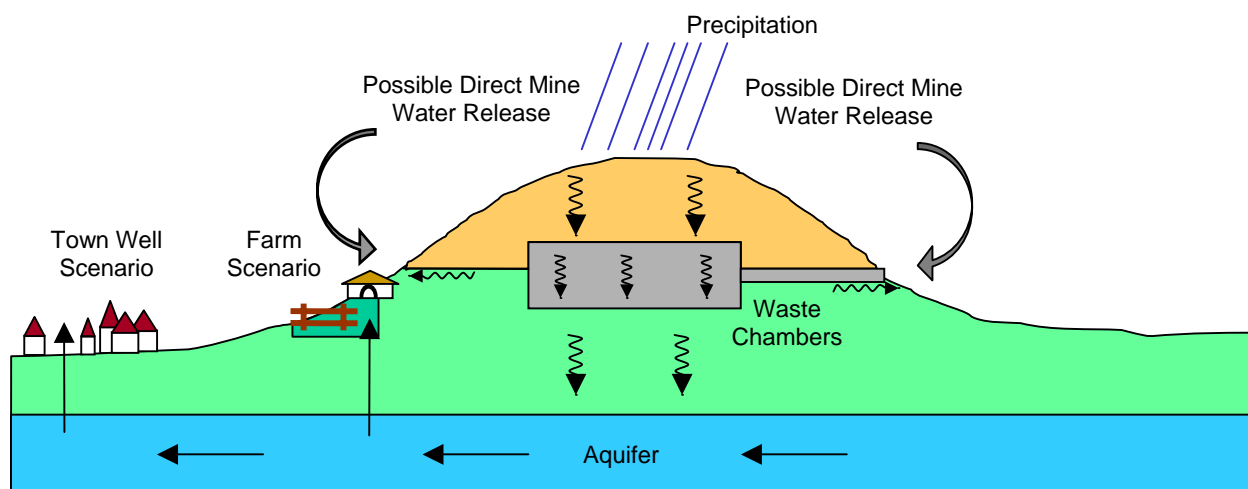

Fig. 2. Schematic view of contamination pathways for the different scenarios.

On the basis of the considered scenarios of future repository development and within the limits of the models used, the 2002 SA rendered exposure values for future generations below current regulatory limits for the Town Well and the Farm Scenario. Although the rationales of scenario selection and of some key assumptions in them lack in some aspects a clear, defensible justification, as a whole and in view of the uncertainties inherent to such work the safety assessment seems reasonable.

The Human Intrusion Scenario has not been explicitly considered here as no significant changes are to be expected from the changed closure concept.

A source of concern the direct release of contaminated mine water, which in the reference case yielded high annual dose rates well above regulatory limits. In the 2002 SA it was excluded from further consideration on the grounds that the entrance to the repository would be sealed in such a way that mine water would not be able to bypass this barrier.

When reviewing the safety assessment we considered however that regarding the direct release of mine water it has to be taken into account that:

- It is necessary to seal with high quality not only the repository entrance but also the abandoned rooms to the north of the present repository area, the connections with Richard I and Richard III, and the poorly known rooms to the north of the entrance tunnel.
- The hydraulic conductivity of the overlying and underlying marlstones is lower than the hydraulic conductivity of the limestone layer around the repository. Water inside the repository therefore will be released through this layer if no vertical fractures with high permeabilities exist in the underlying marlstone.
- There might also be preferential pathways along the limestone base or fractures inside the limestone with even higher permeabilities than the limestone itself.
- Additionally inside the underlying marlstone layer there might be preferential pathways parallel to its near horizontal bedding compared to the vertical movement through that layer.

In brief: even if necessary precautions are taken to achieve a proper long-term sealing of the access tunnels, in case of partial or total repository saturation it seems difficult to totally exclude scenarios in connection with mine water being released directly into the environment without prior dilution during transport in an aquifer.

The reference case in the 2002 SA assumes 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. This assumption 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 these scenarios.

Hydraulic Cage Closure Concept

The proposed optimization of the plan for closure of individual chambers concerns the additional installation of a "hydraulic cage" around the waste disposal chambers. The main idea of this radionuclide isolation 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 eventually present groundwater. With this, 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, would be 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.

In principle this solution is state-of-the-art to prevent groundwater from infiltrating into underground cavities, and has been considered and/or actually implemented in the proposed or in an analogous form in final repositories, e.g., in Norway (Himdalen) and Sweden (WP Cave Concept, Forsmark repository). Furthermore, the safety concept of other near-surface repositories, e.g., El Cabril in Spain, is based on similar principles.

After reviewing the different approaches followed in comparable situations and the respective technical solutions, a rather simple to apply and robust solution for the construction of a hydraulic cage as it is used in tunnel building has been developed. In principle the stacked waste is backfilled with low-permeable concrete as foreseen in the former plan for closure of individual chambers. In addition to that, this waste/concrete body is surrounded by a layer of pure concrete, which again is enclosed in a gravel layer of high hydraulic conductivity. Apart from the additional layers of pure concrete and gravel, the main steps of the former closure concept have been kept. A more detailed description of the technical implementation of this solution is given in Biurrun et al. in this volume.

Safety Advantages of the Proposed Optimization

Main effect of the hydraulic layer is the prevention of flow through the enclosed waste/concrete body by eliminating any driving forces. 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 were 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.

In the course of time e.g. carbonation might increase the diffusivity of the concrete, however, 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.

**Changes in the SA Model for the Hydraulic Cage Concept**

Prior to implementation of the proposed solution for closure of individual chambers according to the Hydraulic Cage Concept, which is planned for 2005/2006, it is essential to quantify the above-mentioned improvement concerning the radiological safety. Therefore as part of the current project an update of the 2002 SA has to be carried out taking into account the changed closure concept. Work on this update is still in progress but a model for safety performance calculations has been developed using the computer code GoldSim, which allows an assessment of the hydraulic cage system performance.

The model has been reproduced from the 2002 SA. Changes were implemented only in the source term part of the model in order to quantify the effects on the release of radionuclides caused by the different closure concepts. The absolute values of the calculated annual dose rates by this model are accordingly depending on the accuracy of the assumptions and data, on which the 2002 SA calculations were based.

Source Term Model for Hydraulic Cage Concept

As it can be supposed that a high permeability difference between the gravel layer and the waste/concrete body will persist throughout the period for safety calculations, for the Hydraulic Cage Model transport of radionuclides is restricted to diffusive fluxes.
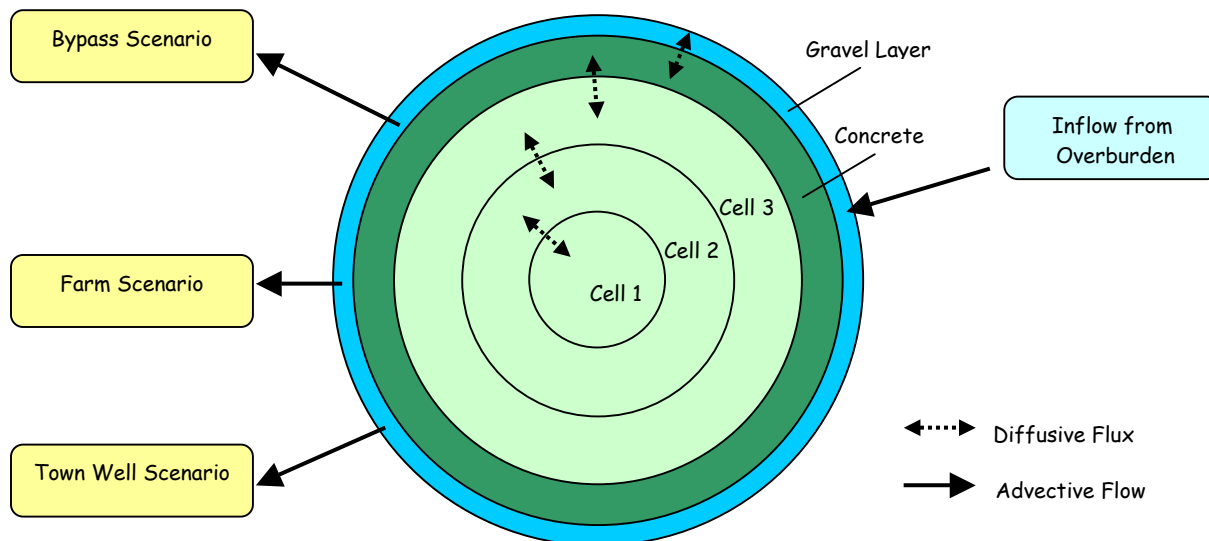
Fig. 3. Schematic model of backfilled waste chamber.

For Calculation of diffusive fluxes, the total amount of waste/concrete volume is modeled as cylindrical body separated into three segments (Figure 3). The surrounding layers of pure concrete and gravel are also modeled as cylindrical layers. The geometrical dimensions are calculated from the total amount of waste, the estimated stacking density of the drums (ca. 70%) and the mean vertical cross section of the waste chambers.

Between adjacent cells diffusive fluxes are calculated. For the results discussed below 100% saturation of the waste chambers is assumed if not stated differently.

For calculation of the diffusive fluxes initial diffusivities are assigned to the pure concrete and the waste/concrete mixture, whereas the diffusivity of the waste/concrete mixture is taken to be about 3 times higher reflecting the reduced amount of concrete within the mixture and conservatively neglecting any reducing effect of the waste.

As initial low values for diffusivity might be increased due to degradation of the concrete with time, the diffusivity values are defined as time dependent properties, which will increase towards values for pure water after a certain period. The function of increase has been chosen as an

S-shaped curve, assuming that the amount of concrete being degraded per time is slow at the beginning, increases linearly until half of the "degradation period" and decreases afterwards – again linearly – until the end of the period. Then all material has been degraded in the sense that open porosity, tortuosity, diameter of capillars etc. has been changed so far that diffusion is not hampered any more. The concrete is expected, however, to be still mechanically stable and present in the same form and volume. To take into account the less compact distribution of concrete within the waste/concrete body, the degradation period for this mixture is set to 1/3 of the period for concrete.

Comparison between Results for former Closure Concept and Hydraulic Cage

A number of calculations were carried out to verify the accuracy and purposefulness of the models by reproducing the results achieved in the SA 2002. The parameters used include whenever possible the values of the mentioned safety analysis, complemented with best estimates for missing values.
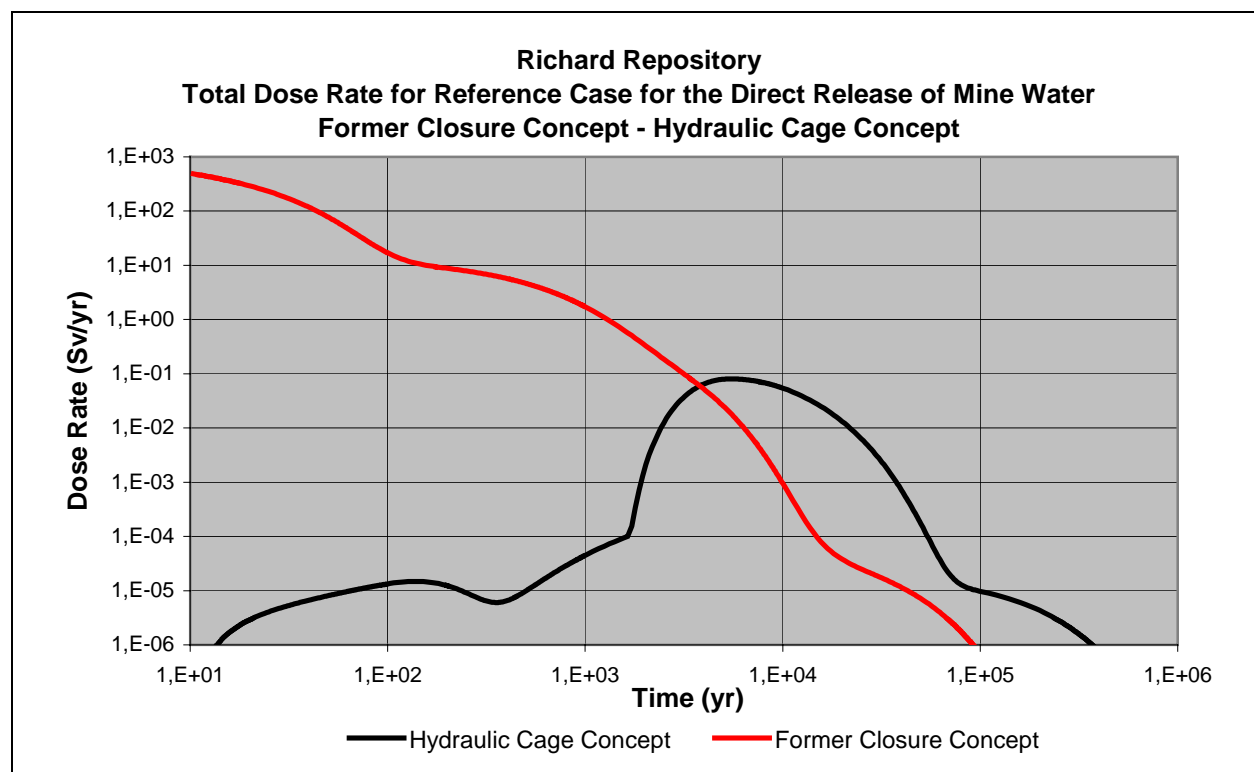

Fig. 4. Annual dose rates for the direct release of mine water (reference case), Hydraulic Cage Model and model for former closure concept.

The total annual dose rate resulting from model calculations for both source term models using the Base Case data set of the 2002 SA and assuming 100% saturation of the repository are compared in Figure 4 for the reference case in regard to direct release of mine water.

As to be expected from the principle of the hydraulic cage, radionuclide transport is effectively reduced during the first thousand years due to elimination of advective flows and low diffusivities of the concrete layer and the waste/concrete body. With progressing degradation of the waste/concrete mixture and the pure concrete, diffusivities are increasing, which leads to increasing radionuclide transport and accordingly to higher annual dose rates. For later times values for the Hydraulic Cage Model are even higher than the former closure concept model as in the latter model most of the waste has already been flushed out of the repository. The peak value of the annual dose rate is reduced by three to four orders of magnitude and appears now at about 6000 yr after closure of the repository.

Figure 5 shows that the total dose rate is composed mainly by contributions of four radionuclides, Cs-137, Am-241, Pu-239 and Np-237, out of which PU-239 is the one that is responsible for more than 90% of the peak value on its own.
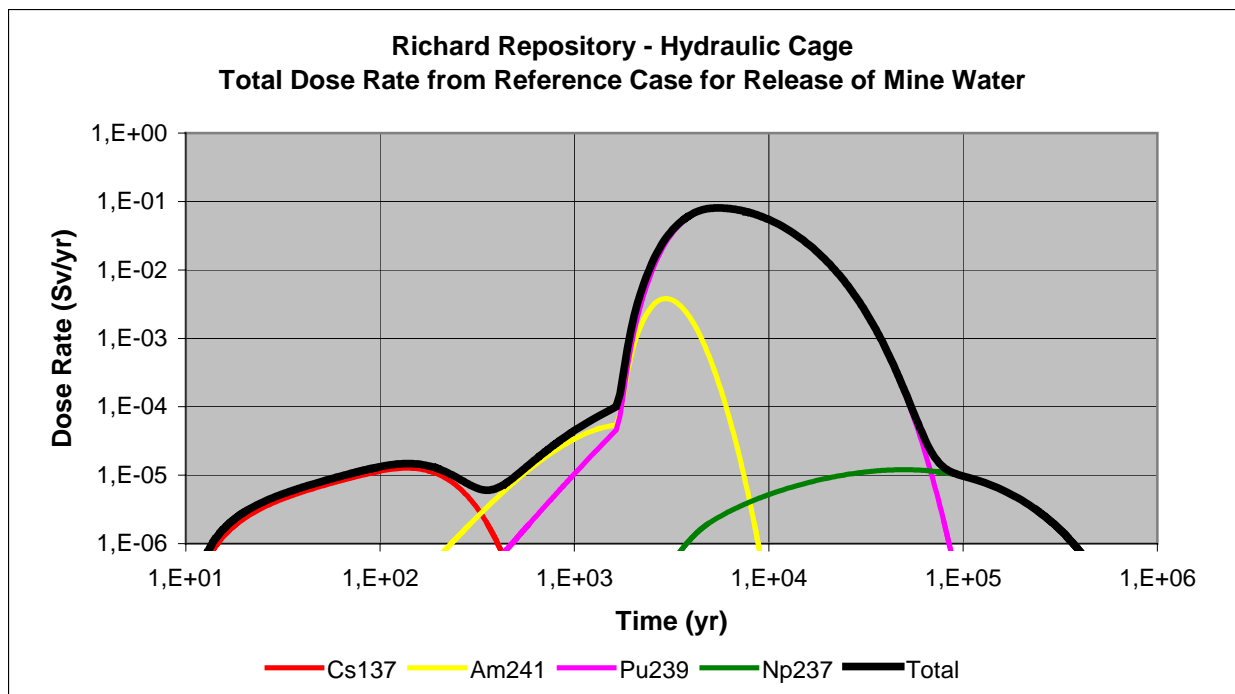
Fig. 5. Total dose rate for the Geosphere Bypass Scenario and individual dose rates for the four most important radionuclides.

Calculation of the Town Well Scenario and the Farm Scenario yielded results with peak values for the annual dose rate, which in both cases were lower by a factor of 2.5 for the Hydraulic Cage Model and shifted in time from ca. 16,000 yrs after closure to 23,000 yrs.

Sensitivity Analysis for Hydraulic Cage Source Term

Up to now calculations have been focused mainly on deterministic calculations to assess the sensitivity of the closure concept in regard to changes in the assumptions defining the performance of the repository.

The sensitivity analysis has been carried out by calculating the annual dose rate resulting from the reference case for the direct release of mine water. It has been concentrated on the effects of:

- Flow rate of water through the repository
- "Degradation period" for the concrete
- Initial diffusivity of concrete
- Mean cross section of the waste chambers
- Procedure of waste drum stacking
- Water level inside the repository

Results of the sensitivity analysis showed the robustness of the proposed concept. The most important parameter seems to be initial diffusivity of the concrete – the sensitivity analysis thus rendered important information for specifying the concrete properties to be used for backfilling. Of importance is also the degradation period for the concrete, which moves the calculated peak doses in time and the estimated flow rate. Even with rather conservative values for the concrete durability under the conditions likely to predominate in the closed site, peak doses are expected to occur not before 5,000 to 10,000 years after repository closure.

CONCLUSION

The sensitivity analysis showed that the Hydraulic Cage Concept is a fairly robust concept, which performance varies only slightly with the properties of the concrete and assumptions on degradation effects on its diffusivity. Within reasonable assumptions provided for material data and source term evolution, the Hydraulic Cage Concepts reduces the calculated dose rates for the reference case by several orders of magnitude for the first 1000 years. After a few thousand years the curves of annual dose rates calculated for the different closure concepts cross and the dose rates resulting from the Hydraulic Cage Concepts are higher than those for the former closure concept. The reason for this is the larger amount of radionuclides flushed out of the repository at earlier times in the case of the former closure concept. The time for this to happen depends more or less directly on the degradation period assumed for the concrete layer.

Although the absolute values for the calculated annual dose rate depend on the assumptions about material properties and evolution of the repository, it can be assumed that the calculated peak dose for the reference case will be reduced by about four orders of magnitude if the source term is adapted according to the Hydraulic Cage Concept. Further reduction of peak dose rates would be possible if the separately stored waste containing about 80% of total plutonium inventory were taken out of Richard for disposal, e.g., in a deep geological repository, as the peak dose is caused to more than 90% by Pu-239 (see Figure 5). Also by increasing the layer of concrete further reduction of peak annual dose rates for the bypass scenario could be reached.

REFERENCES

1. Chambers, A.V., R. Cummings and B.T. Swift: Performance of the Richard Repository, Serco Assurance, 2002.

2. Haverkamp, B., Biurrun, E. and M. Kucerka: Update of the Safety Assessment of the Underground Richard Repository, Litoměřice. WM'05 Conference, February 27 – March 3, 2005, Tucson, AZ.