

Concepts of Repository and the Functions of Bentonite in Repository Environments: A State – of – the – art review

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In an effort to secure the comfort of all aspect of life and security through electricity production, research, nuclear weapons production and medical uses, radioactive waste is being generated throughout the world as a result. Without pro – active management and protection, the hazardous nature of radioactive materials can pose serious threats to human health and the environment. A waste containment or disposal facility is required to isolate the waste from man and the biosphere to avoid any undue radiation exposure. Deep geological repository or disposal facility is considered as an effective way to isolate high level radioactive waste, HLW from the human environment, for which a multi – barrier system plays a very significant role. In this paper, literature collection was carried out, aimed to overview the present knowledge about the concepts of repository for HLW and to identify technologies that are currently available in the nuclear industry worldwide and the current state of barrier technologies for hazardous waste sites.

Key words: repository, bentonite, radioactive waste, swelling, buffer and backfill materials

1 INTRODUCTION

The purpose of this paper is to overview comprehensively the present knowledge about the concepts of deep geological repository for high level radioactive waste disposal, HLW and the role that bentonite plays in the design and construction of such facilities. It is aimed at identifying various concepts in different geological environments and how they are related, and hence might provide useful information for further research.

As defined in NUMO (2002), a repository concept for HLW includes surface and underground facilities, and engineered barrier system that are laid out in a stable in-situ rock. The surface facilities make room for the provision of infrastructure for the construction, operation and final closure of the repository. The layout can be such that there is flexibility in modification depending on the features available on the site, especially, in some situations where most of the building can be underground. Underground facilities and the engineered barriers are located several hundreds meters below the ground in a stable rock formations. Underground facilities involve the construction of shafts, disposal and access tunnels. The waste is emplaced in the disposal tunnel which is protected by engineered and natural barriers. The design of the layout of the underground facilities can also be flexible to take account of the features of the geological

The contamination of land and water by radioactive materials or waste has caused many serious environmental problems, such as nuclear emissions. Environmental radioactivity has therefore been an important area of research throughout the world since the 20th century. A report from the IAEA (2005), shows that the Russian Federation intends to double its nuclear generating capacity by 2020; China plans nearly a six-fold expansion in capacity by the same date; and India anticipates a ten-fold increase by 2022. Nguyen T. (1994), stated that, about 30 countries in the world now rely on nuclear power to produce a substantial part of their electricity need. The nuclear generating capacity of Organization for Economic Cooperation and Development (OECD) member countries represents about 80 percent of the overall world capacity. A further significant increase of installed capacity is expected over the next decade. With this increasing utilization of nuclear energy will nevertheless increase the generation of radioactive waste. This has been a source of worry by many, and the society at large continues to ask questions as to whether radioactive waste can be managed and disposed safely. With advances in technologies, the answer is yes provided all the safety requirements are met.

2 INTERNATIONAL CONCERNS

A great concern in the nuclear industry worldwide is a solution to the long-term management of spent nuclear fuel (SNF) and high level radioactive waste (HLW). Many proposals have come up from members countries about the disposal of nuclear wastes. Generally, the international consensus has been that, a permanent geologi-

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cal repository (disposal facility) for HLW is the best way to protect the public health and safety; and to protect and restore the environment (U.S. Department of energy, 2006). On this note, many of the world's nuclear nations have decided upon deep geological repositories as the long-term solution for disposal of SNF and HLW. Countries that have major nuclear power industries are in different stages of development of their radioactive waste management programs. The disposal of these wastes in deep geologic repositories means isolating radioactive waste from man and the biosphere for a period of time such that any possible subsequent release of radionuclides from the waste repository will not result in undue radiation exposure.

3 DESIGN FACTORS/ GENERAL DESIGNS

Brief overviews of different designs of waste disposal facility have been discussed by Won et al, (2007). The type of facility ultimately selected and designed, depends on the characteristics of the waste itself, as well as the site and on national strategies, social and economic factors. The type selected also depends on each country's geological conditions (granite, salt and clay environments are considered to be suitable), specific disposal requirements and regulatory approaches. The ultimate aim of the design of a geological disposal facility is to limit the release of contaminants or radionuclide to the biosphere and minimize maintenance during the post-closure phase. Generally, more reliance is being placed on multi engineered barrier systems to contain the waste. Such a system includes concrete vaults, backfilling materials, chemical barriers, stabilization of natural barriers and buffer zones.

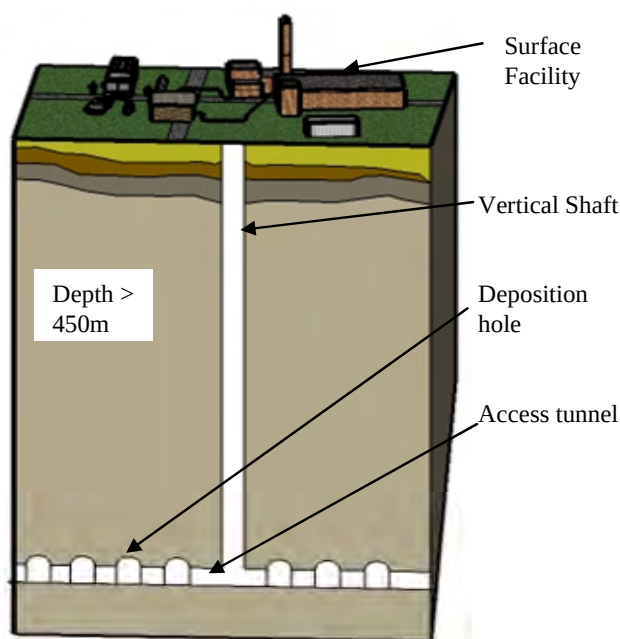


Fig.1 Profile of a deep repository

Geological repositories are generally designed to be located at depths of several hundreds meters below the ground surface through a vertical or inclined shaft de-

pending on design factors (**Fig.1**). Emplacement rooms or tunnels are then drilled from the shaft to house the waste containers (mostly copper or steel metal). In the repository, the metal containers or canisters containing the waste will be deposited in an array of large diameter boreholes drilled on the floors of the tunnel and lined with buffer material (Cho et al, 2002). The buffer is one of the major components of engineered barriers in the repository and is required to inhibit the release of radionuclide from the waste to the surrounding rock in the event of canister failure.

After the sealing of the canister in the deposition holes, the shafts and tunnels are expected to be backfilled by combining grouting and other technologies for sealing the whole system with materials having hydraulic conductivity as low as or lower than that of the host rock. This is to prevent the tunnels from becoming preferential flow paths to groundwater.

4 THE ROLE OF BENTONITE IN CONCEPTUAL DESIGNS

In many countries as stated by Cho et al, (2002), the conceptual design for an underground repository in granite formation includes the use of compacted bentonite as a buffer material. The buffer zone is one of the engineered barriers designed for the containment of radioactive materials over a long time period. It is expected to perform the following functions:

1. Protect the canister against minor rock displacement.
2. Act as an impermeable barrier to the mass transport by ground water.
3. Protect geochemical buffering and retardation capacity.
4. Conduct heat from canister to surrounding rock.

Bentonite with other mixing materials has also been proposed in the design for backfilling. The main purposes of backfilling include:

1. Low permeability for ground water.
2. Keep the canister and the buffer in place.
3. Help keep the tunnel mechanically stable.

Bentonite plays a significant role as an engineered barrier. Its roles in conceptual design programs of geological repositories by some countries in granite and sedimentary geological environments are discussed. The concepts in crystalline rock are as follows:

5 THE SWEDISH CONCEPT

For the Swedish waste disposal program, a pure, highly compacted (Volclay Mx-80) bentonite, mined in Wyoming and South Dakota areas in USA is considered as buffer material. Mx-80 is a sodium bentonite consisting of about 90% montmorillonite with silicon and aluminum as the main chemical constituents. Buffering involves lining the deposition holes with highly compacted bentonite cut into blocks to fit the hole (**Fig.2**). The space between the buffer and the host rock then filled with bentonite powder. All fractures or fissures in the excavation disturbed zones, EDZ surrounding the depositions will be grouted with bentonite to seal of the fractures or stabilize the disturbed zones resulting from the drilling of the

holes. Here, the buffer in the repository is expected to play the following roles:

1. Present a mechanical and chemical protection around the canister.
2. Limit the inward transport of corrosive substances from the groundwater to the canister surface.
3. Retard the outward travel of radionuclide from the canister to the surrounding host environment in the event of canister failure.

Deposition tunnels, shafts, boreholes and fracture zones encountered, will be backfilled and sealed using bentonite-based materials. The backfill will be a mixture of bentonite powder about 10-20% and sand of suitable grade. This is expected to provide a durable support to the rock and to restore the hydraulic conditions in the area to as near the original condition as possible. Therefore, the backfill needs to have as low hydraulic conductivity as the rock.

Backfilling is expected to start after the emplacement holes have been filled with canisters and sealed with the buffer materials. The backfilling process involves two methods: compaction of the lower part of the tunnels and spraying the upper and the roof parts of tunnels with backfilling materials. High compaction of the mixture is conducted to ensure that the right density is achieved. For example, tests at Stripa have shown that, with the compaction method, a backfill density in the range of $1.8 - 2.2 \text{ t/m}^3$ at a water content of 8 – 13% can be achieved. With the spraying method, densities in the range of $1.2 - 1.8 \text{ t/m}^3$ at a water content of 11 – 22% can be attained. The hydraulic conductivity of the backfilling material amounted to 10^{-9} m/s (10^{-7} cm/s).

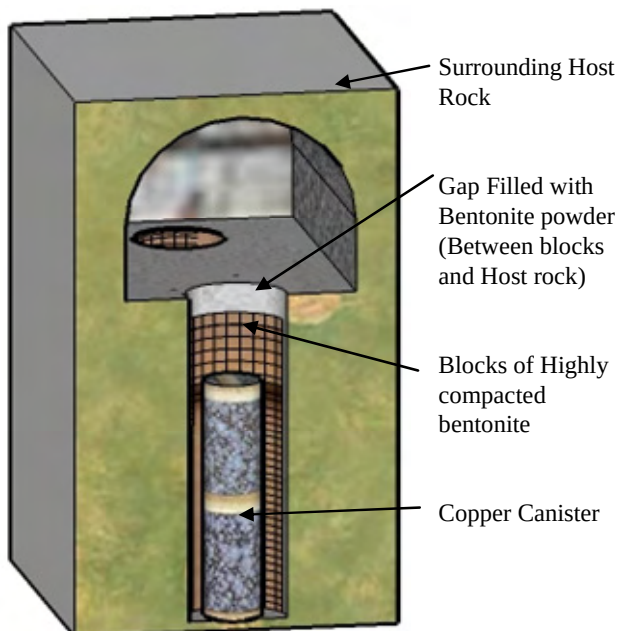


Fig.2 Section of Emplacement tunnel with deposition holes

5.1 ADVANTAGES /PROBLEMS

The desirable properties of bentonite make it useful as an engineered barrier component in a repository. It has the following advantages:

1. The bentonite buffer material provides the primary radionuclide containment in addition to the host rock and canister. This is of particular advantage since homogeneity of the properties of the rock mass can never be guaranteed.
2. The highly compacted and saturated bentonite will protect the canister against corrosive substances and also retards the migration of radionuclide in the event of canister failure.
3. Bentonite is chemically stable.

One major problem is that, knowledge about the long – term properties of some of the components of a repository such as the engineered barriers and geothermal characteristics of the environment is limited.

6 THE SWISS CONCEPT

In the Swiss geological repository concept, bentonite has been considered as a buffer material. In the deposition hole, the canister will be surrounded by highly compressed bentonite cut into blocks to fit the deposition hole. High density bentonite as stated by Hanke P.M., (1987) has been considered as a buffering material for the following reasons:

1. Low hydraulic conductivity of the compressed material inhibits groundwater inflow and retards radionuclide transport from the canister.
2. Bentonite swells when in contacts with water, thereby self- healing cavities in the bentonite as well as penetrating fine fissures in the surrounding rock.
3. The plastic properties of bentonite compensate for rock movement and prevent formation of fissures in the backfill mass.
4. It has good retardation characteristics.
5. Good thermal conductivity ensures that the heat generated by the waste is conducted away and thus avoid excessive heat built-up.

The canister will be surrounded by highly compressed blocks of bentonite. The space between the buffer and the rock will also be filled with bentonite powder for the reasons described above. Backfilling and sealing of the remaining tunnel and shaft after the operation of the repository will be carried out using a mixture of bentonite and sand. This involves two methods: compaction of the floors or lower parts of the tunnels with the backfilling materials and the top/roof by spraying.

6.1 ADVANTAGES /PROBLEMS

Apart from the natural barriers (surrounding host rock), the waste will also be enclosed by other engineered barriers which will add to the overall effectiveness of the isolation system. The good thermal conductivity of bentonite helps prevent excessive built up of heat thereby enhancing the actual disposal operation and long-term safety aspect.

However, a major drawback of the deep geological repository is the limited knowledge about the long – term

behavior and the impact of heat on the properties of the engineered barriers.

7 THE CANADIAN CONCEPT

In the Canadian concept of geological repository, the proposed material for the buffer zone as an engineered barrier is the use of bentonite. Deposition holes will first be drilled on the floors of the emplacement tunnels. These holes will be filled with bentonite and compacted into layers to give a near homogenous mass. The buffer mass in the boreholes will then be centrally augered to specific depths and diameters that can accept each canister.

Once all the deposition holes in the emplacement rooms have been filled with the canister containing the waste, the remaining access tunnels and shaft will be backfilled. A mixture of bentonite, 75% wt. and crushed granite 25%wt. has been proposed as the backfilling material. This material will be compacted in layers to achieve the specified density with a hydraulic conductivity of 10^{-10} m/s. Zones of fracturing or excavation disturbed zones will be grouted to seal off fractures or fissures in the rock.

7.1 ADVANTAGES/PROBLEMS

1. The canisters are encased in engineered barriers in addition to the natural barrier which increases the overall effectiveness of the isolation system.
2. The self – healing and swelling properties exhibited by bentonite makes it advantageous as a buffer material.
3. The thermal conductivity of bentonite gives it an added advantage as a buffer material.

The uncertainty about the long – term behavior of the natural and engineered barriers, and the impact of heat and radioactivity on the performance of the barriers are major drawbacks.

8 THE JAPANESE CONCEPT

Japan has great plans in its nuclear waste disposal programs. Vigorous researches are in progress to solve many problems in this area. Its waste isolation system is based on multiple barrier system and investigations are being conducted into backfilling and sealing materials. Grouting technology is being developed to repair and reinforce disturbed zones or fractures in the repository host rock. This is to prevent groundwater seepage and stabilize the excavations. Also, experiments are being conducted in granite to test the effects of injecting super-fine cements. Bentonite based mixtures are being researched as buffer material around the canister. Technology for backfilling is also being researched. There have been proposals on the use of bentonite as engineered barrier material.

9 CONCEPTS IN SEDIMENTARY FORMATIONS

Apart from crystalline rocks, salt and clay are the next most common rock types being considered as potential high-level repository host rocks. This is because; these are the most common rock types in most countries. Examples of countries that consider sedimentary formations

in their geological concepts include Belgium, Italy, Germany, USA and Holland. These countries include bentonite as buffer and sealing materials. The Belgian Concept is described below which is almost the same for the other countries.

9.1 THE BELGIAN CONCEPT (CLAY)

In this concept, clay is the host rock, and because of the plastic behavior of clay material, special techniques and materials are required. For example, freezing technique will be employed in the construction of the shaft. The suggested materials for buffering and sealing being considered are mainly bentonite and other clay materials. These will be used in the deposition holes to retard radionuclide migration. The bentonite will swell and ensure complete sealing of the clay surrounding the canister. Bentonite will also be used for backfilling of the tunnels. However, for the sealing of shaft, sand/gravel materials are being considered as sealing materials. Much grouting will be carried out for the stabilization of the weak zones.

9.2 ADVANTAGES/PROBLEMS

- 1 The chemical properties of the clay make it a suitable medium for the containment of radioactive waste
- 2 Self- healing of bentonite is an advantage for the effective sealing of fissures

10 CONCLUSIONS

Deep geological disposal is internationally accepted as an effective way to isolate HLW from the human environment using current technologies and without requiring any long – term active control system.

Effective functioning of geological repository is highly dependent on multi – barrier concepts consisting of the natural barrier (stable geological environment) and engineered barriers. The multi – barrier systems form a backbone in the design and construction of such a facility and should therefore be very effective.

In this study, it has been observed that, the use of highly compacted bentonite as a buffer material is being considered by most countries in their conceptual designs for underground waste disposal facility. The desirable properties of bentonite make it suitable as one of the major materials in the multi – barrier system. However, the uncertainty associated with the long – term behavior of the engineered barriers and the impact of heat and radioactivity on the performance of the barriers was observed as a major drawback. More investigations are therefore required in this area.

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