HYDROGEOLOGICAL PARAMETERS CONCERNING LILW REPOSITORY SITE SELECTION IN SLOVENIA

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ABSTRACT

The natural characteristics of the site play an important role in the concept of radioactive waste disposal. Hydrogeological parameters are one of the most important factors affecting the ***low*** and ***intermediate level*** radioactive ***waste*** (**LILW**) repository site selection. The flow of groundwater is recognized as the dominant mechanism for transport of radionuclides from a repository to the environment.

First, some worldwide experiences of LILW repository locations in different hydrogeological conditions are briefly introduced. In order to contribute to the overall safety of repository system where the natural (geological) and engineered barriers have to be considered as whole the importance of engineered barriers from the point of the hydrogeological aspects is also mentioned.

In the case of Slovenia, a set of the six most probable combinations of *geological environment / type of disposal facility* (near surface and/or underground) including (hydro)geological and rough technological conditions was defined. Also a description is given of three important hydrogeological parameters (hydrogeological properties of rocks, hydrogeological structure and hydrodynamic conditions) considering surface and/or underground repository site selection.

Finally, the basis of the investigations used worldwide to establish the hydrogeological conditions is presented. A selection is also given of those investigations which are sufficiently reliable for establishing the hydrogeological conditions on the potential site in Slovenia.

INTRODUCTION

The natural characteristics of the site play an important role in the concept of radioactive waste disposal. Hydrogeological parameters are one of the most important factors affecting the low and intermediate level radioactive waste (LILW) repository site selection. Moreover, the flow of groundwater is recognized as the dominant mechanism for transport of radionuclides from a repository to the environment.
In new guidelines for site selection of LILW repository in Slovenia[1,2], in the frame of hydrogeological conditions, three important hydrogeological parameters are considered: hydrogeological properties of rocks, hydrogeological regime of the geological structure, and hydrodynamic conditions.

Since there is a growing need for final disposal of LILW, within the next five years some ten suitable areas for location of near surface or underground repository in Slovenia should be found. Among all other criteria, hydrogeological conditions will be considered, in the first rough stage according to desk study data and in later stages with additional site investigations.

GEOLOGICAL ENVIRONMENTS

The geological environment is represented by the host rock in which the repository is built and the geological media of the surrounding region. This rock provides protection with respect to the radioactive waste. It protects the biosphere by protecting the engineered barriers from human intrusions and the effects of weather, by providing a physical and chemical environment for the engineered barriers, and by retarding and restricting radionuclide transport to the biosphere.

From the hydrogeological point of view the main task of the geological environment is to provide a stable setting in which groundwater is predictable, and to ensure a long pathway and travel time for transport of radionuclides to the biosphere (environment). Furthermore, a suitably chosen geological environment can severely limit the extent of radionuclide migration due to dissolution and transport in groundwater.

International experience

Different types of geological environments have been investigated regarding their suitability for a radioactive waste repository, including crystalline or hard rocks (granite, basalt), argillaceous rocks (clay, shale, marl), basement under thick sedimentary rocks, evaporites (such as salt domes, or in a bedded form) and unsaturated deposits.[6,7,8] According to the geological conditions in Slovenia, only crystalline and argillaceous rocks are the matter of this paper. Some international experiences of siting of radioactive waste repositories in these rocks are presented on next pages.

First, some values of the hydraulic properties of the rocks mentioned above are presented in Tables 1 and 2.

Table 1: Typical ranges of hydraulic conductivity (k), porosity and hydraulic gradient appropriate to each rock type [7]

Rock type	k [m / s]	Porosity	Gradient	Flux [l / y . m²]	Velocity [m / y]
Plastic clay *					
Above 100 m (max)	$1,0.10^{-7}$	0,5	0,2	640	1,3
(min)	$1,0.10^{-10}$	0,3	0,02	1,6	0,0005
Below 100 m (max)	$1,0.10^{-8}$	0,5	0,2	64	0,13
(min)	$1,0.10^{-12}$	0,3	0,05	0,0016	$5,0.10^{-6}$
Shale / mudstone *					
Above 100 m (max)	$1,0.10^{-6}$	0,3	0,2	6400	21
(min)	$1,0.10^{-9}$	0,2	0,05	1,6	0,008
Below 100 m (max)	$1,0.10^{-7}$	0,25	0,2	640	2,6
(min)	$1,0.10^{-10}$	0,05	0,05	0,16	0,003
Crystallines					
Above 100 m (max)	$1,0.10^{-7}$	0,05	0,1	320	6,4
(min)	$1,0.10^{-9}$	0,01	0,001	0,032	0,0032
Below 100 m (max)	$1,0.10^{-8}$	0,01	0,1	32	3,2
(min)	$1,0.10^{-11}$	0,001	0,001	$3,0.10^{-4}$	$3,0.10^{-5}$

These average values do not include the potentially faster pathways formed by fracture zone, etc.

In Table 2 the maximum and minimum values of groundwater travel times for the same rocks and environments are illustrated.

Table 2: Approximate maximum and minimum values of groundwater travel times for the same rocks and environments as presented in Table 1.[7]

Rock type	Velocity [m/y]	Path lenght [m]	Travel time approx. [y]
Plastic clay *			
Above 100 m (max)	1,3	50	40
(min)	0,0005	100	$2,0.10^{5}$
Below 100 m (max)	0,13	50	390
(min)	$5,0.10^{-6}$	100	$2,0.10^{7}$
Shale / mudstone *			
Above 100 m (max)	21	50	2
(min)	0,008	200	$2,0.10^{4}$
Below 100 m (max)	2,6	50	20
(min)	0,003	200	$6,0.10^{4}$
Crystallines			
Above 100 m (max)	6,4	500	80
(min)	0,0032	2000	$6,0.10^{5}$
Below 100 m (max)	3,2	500	160
(min)	$3,0.10^{-4}$	2000	$6,0.10^{6}$

* In formations considered for the disposal of radioactive waste hydraulic conductivities towards the lower value are most appropriate. In such circumstances fluxes may also be so low that diffusion is the dominant transport process in some argillaceous rocks, especially in depth. In general, for $k<10^{-10}$ m/s diffusional transport is likely to be dominant.

Crystalline rocks

Crystalline rocks usually have very low porosities, they are generally fractured and often described as having dual porosities. Although the contribution of the fractures to the porosity of these rocks is minimal, the water flow (secondary permeability) is dominant, and radionuclide travel paths are likely to be considerably shorter.
These rocks are currently being considered for waste disposal by Sweden (underground LILW repository Forsmark in granites), Finland (underground LILW repositories Loviisa and Olkiluoto in granites) and Spain (near surface repository El Cabril in gneisses and mica schists). In such rocks, in areas of low relief, there is little driving potential for groundwater movement and the scale of groundwater flow system is small compared with that of argillaceous rocks. The various types of conductive zones that can exist is provided by the site characterisation work that has been carried out by SKB (Swedish Nuclear Fuel and Waste Management Co) over the past 15 years. Hierarchy of such zones is presented in Table 5.3.

Table 3: Hierarchy of discontinuities within the Swedish basement rocks used by SKB in their modelling activities.[7]

Type of zone	**Spacing** [m]	**Mean k** [m/s]
Regional fracture zone	$3{,}2 - 6{,}9.10^3$	$1{,}0.10^{-7}$
Local fracture zones	400-800	$1{,}0.10^{-8}$
Minor fracture zones	50-100	$1{,}0.10^{-9}$
Fractures *	0,4-0,8	$1{,}0.10^{-11}$
Subhorizontal fracture zones	700	$1{,}0.10^{-7}$

* The spacing between fractures lies within this range, but hydraulic measurements indicate that the ratio between the conductive and the total number of fractures is approximatelly 1:10, giving a distance between conductive fractures of the order of 4-8 m.

The situation is different in granitic rocks in the Swiss Alps which host the Grimsel Test Site (i.e. underground research laboratory for investigating the suitability of granitic rocks for radioactive waste disposal). This area, selected for experiments, is fairly fractured and has a relatively significant water flow.

Argillaceous rocks

Argillaceous rocks have many interesting properties for the isolation of radioactive waste. The potential advantages include their low permeability, their potential geological predictability and high sorption capacity for radionuclides.
These rocks are being considered by Belgium, where in the underground research laboratory at Mol investigations are ongoing for the suitability of clay rocks for HLW disposal. In the underground research laboratory of Mont Terri in northern Switzerland the suitability of clay rocks for HLW disposal is also being investigated, while in the low permeability marl host rock in Central Switzerland the location Wellenberg is planned for a shortlived LILW repository.

Use of engineered barriers

It is generally recognised that the suitability of a site does not depend on geological characteristics alone, and that engineered barriers also contribute to overall safety. In order to keep potential releases within acceptable limits, the disposal system should be developed so that the design and engineering of the repository are compatible with the characteristics of the site and the surrounding geological media. The safety of disposal is guaranteed via a system of multiple safety barriers.

A number of different relationships between the repository disposal units and groundwater can occur and effectively relate to the location of repository and its design, to the geological environment, and to the water table:

- Disposal units above the original ground surface. In such circumstances there would not normally be any contact between the waste and groundwater.
- Disposal in fairly permeable geological media, remaining above the water table. Where disposal is below the ground but above the water table the main concern will be water infiltration from above or from the sides. Water ingress is usually minimised by way of an impermeable cap, cut-off walls and by man-made drainage or pumping.
- Disposal units in low permeability geological media, entirely or partially below the water table. In this case there is always the potential for water inflow, especially over a period of time.
- Disposal in rock caverns below the water table. Groundwater will probably enter the disposal site.
- Disposal in rock caverns above the water table. There exists the potential for meteoric infiltration.

Normally, with additional geotechnic safety measures especially in less favourable geological conditions it is possible to assure the integrity of waste packages in repository. Waterflow through the repository could be reduced using different types of engineered barriers. Drainages, buffer materials, etc. are used worldwide.

SITUATION IN SLOVENIA

Geological conditions

In Slovenia, only crystalline (igneous and metamorphic) and argillaceous rocks are considered for disposal of LILW [1].

On the basis of the geological experience from other countries, and according to our own specific conditions, a set of the six most probable combinations of *geological environment / type of disposal facility* (near surface and/or undreground) [3] was defined for Slovenia, including (hydro)geological and rough technological conditions:

- Surface type of a LLW and ILW disposal site over an open aquifer
- Surface type of a LLW and ILW disposal on rock with low permeability
- Underground type of LLW and ILW disposal site in plastic rock with low permeability
- Underground type of disposal site for LLW and ILW with α-emitters in plastic rocks with low permeability

- Underground type of disposal site for LLW and ILW in hard rock
- Underground type of disposal site for LLW and ILW with α-emitters in hard rock

These form the basis for new considerations and estimations of further field investigation campaigns.

Hydrogeological parameters concerning LILW repository site selection

In 1994, the Agency for Radwaste Management started preparing basic guidelines for site selection of an underground LILW repository in Slovenia. The guidelines consist of general criteria and *geological criteria*[1,2]. The recommendations of the International Agency for Atomic Energy (IAEA) were adopted [11,12,13,14]. Among of the hydrogeological conditions, three important hydrogeological parameters (hydrogeological properties of rocks, hydrogeological regime of the geological structure, and hydrodynamic conditions) are considered.

The main characteristics hydrogeological property of the host rock is its ***permeability***. In the siting process, we are looking for a rock/geological barrier which would have the lowest possible permeability and therefore provide a long pathway and travel time for transport of radionuclides to the biosphere (environment).

The second important factor is the ***hydrogeological regime of the geological structure***. The relationships between rocks (as an overall geological system) should enable the isolation of the repository from the environment.

The ***hydrodynamic conditions*** influence the time in which contaminated water could reach the biosphere. It is important that groundwaters should have the greatest possible retarding times: these mainly depend on the hydrogeological properties of the host rocks and the hydrogeological regimes of the geological structure. It is expected that for rocks with low permeability and lower hydraulic gradients the retarding times will be greater.

MEASUREMENTS OF HYDROGEOLOGICAL PARAMETERS

In general, investigative techniques to be used for measuring hydrogeological parameters will depend on the stage of the investigations. Initially, relatively large areas will be considered, from which favourable locations may be selected for more detailed study. Hydrogeological testing techniques are used in boreholes, drilled into the potential host formation and/or into suroundings. The movement through a rock is mainly governed by hydraulic conductivity, hydraulic gradient and specific storage. In crystalline rocks the fracture system flow test has generally the following main objectives:

- providing more information on the transport of dissolved materials in the fracture system,
- developing a technique for investigating the fracture system,
- developing and refining test equipment,
- integrating the methods developed during the test with a view to preparing a comprehensive strategy for site assessment.

The investigations in such rocks are concentrated on the geometries and transmissivities of the major fracture zones, and on the relationships between these zones and the smaller fracture zones and single fractures through which the radionuclides will migrate.

The main problem with clays is that it is very difficult to make measurements in-situ without substantially affecting their properties; e.g. the direction of groundwater movement through the clay is normally subvertical, and it is not possible to measure the vertical component of hydraulic conductivity in a vertical borehole.

In Slovenia, according to the set of the six most probable combinations of *geological environment / type of disposal facility* for each of three hydrogeological parameters (hydrogeological properties of rocks, hydrogeological structure and hydrodynamic conditions) a recommendation was made for the selection of reliable investigations, by which the respective parameter could be adequately defined. The recommended hydrogeological measurements are[3]:

- hydrogeological mapping,
- measurements of piezometric levels in boreholes,
- pumping and slug tests,
- laboratory measurements on borehole cores,
- tracer tests,
- isotopic analysis of water, and
- surface water investigations (precipitation, stream discharge, evapotranspiration).

INSTEAD OF A CONCLUSION

In the surface repository site selection process in Slovenia[10], where the hydrogeological parameter *water* was considered according to four criteria (*lithology*, *drinking water resources-aquifers*, *groundwater-presence* and *surface waters-destructiveness*), the objective was to find a location with geological properties where engineered barriers need not necessarily be used to achieve the safety standards. Even geologists considered impervious rocks as the only suitable ones for the disposing site, regardless of the possibility of using engineered barriers. This was certainly the most economic way for repository construction, but on the other hand the site selection was exceptionally difficult. For consideration, the hydrogeological parameters (criteria) data of basic official geological maps were used. Hydrogeological map, still in working stage, was considered as well.

Geological host rock is only one of a number of factors which will help to maintain the integrity of the repository. Because the **overall system** constituting the ***geology***, ***hydrogeology*** and ***engineered barriers***, in the repository siting process, it is not necessarily to find a "best" specific host rock.

Given the geological environment disposal facilities, ***the focus of concentration should be on geological and hydrogeological regimes rather than on individual geological rock types***. It is also well-known that for a period of 300 years (which is considered as the time necessary for lowering down the excessive radioactivity to the normal level) ***it is possible to construct effective engineered barriers***. Considering both together, i.e. in the case of suitable geological and hydrogeological structure/regime and of use the appropriate engineered barriers, the location of the repository could be set in relatively permeable rocks (e.g. the near surface repository Centre de l'Aube in France in sandstones above clay).

But, wherever the repository is to be sited, the hydrogeological environment should be studied and understood in detail, in order to permit prediction of the potential pathways of migration of radionuclides and their interaction with the groundwater and rock. Hydrogeological conditions due to groundwater flow should be specified in detail for further works, e.g. performance assessment studies.

Since the LILW repository site selection is an interdisciplinary process, and is also greatly dependent on public opinion, the RAO Agency was able to use only official data for further site selection activities. For these reasons, it is essential to produce an official hydrogeological map as soon as possible.

DESCRIPTION OF SOME USED TERMS

Radioactive waste - For legal and regulatory purposes, radioactive waste may be defined as material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance level as established by the regulatory body, and for which no use is foreseen.
Near-surface disposal - Disposal of waste, with or without engineered barriers, on or below the ground surface where the final protective cover is a few metres thick, or in caverns several tens of metres below the surface. Typically, shortlived, low and intermediate level wastes (LILW) are disposed of in this manner.
Geological (underground) disposal - Isolation of waste, using a system of engineered and natural barriers at depths up to several hundred metres in a geologically stable formation. Typical plans call for disposal of long lived and high level wastes.
Barrier - A physical obstruction that prevents the movement of radionuclides or other material between components in a system, e.g. a waste repository. In general, a barrier can be an engineered barrier which is constructed, or a natural barrier which is inherent to the environment of the repository (i.e. geological media).
Multiple barriers - two or more barriers used to prevent radionuclide migration from and isolate waste in a disposal system.
Crystalline rocks - rocks consisting of minerals in an crystalline state, e.g. granites.
Argillaceous rocks - rocks composed of clay or having a notable proportion of clay in their composition e.g. marls, schists,...
Dual porosity - porosity in crystalline rocks is made up of three components. Two of them are important (1. The porosity of that component of the fracture network along which groundwater flow takes place and which is important in the groundwater flow, and 2. The porosity of the pores that are connected to the flowing fractures and which is important in the transport of solutes). The third component (3. The porosity that is made up of closed pores within the rock) is unlikely to play any significant part in solute transport.

REFERENCES

1. Geological Survey Ljubljana, Institute of Geology, Geotechnics and Geophysics, Geological Guidelines for Site Selection of an Underground Disposal of LILW, Ljubljana, 1995,

2. Institute for Mining, Geotechnology and Environment, Ljubljana, Geological Guidelines for Site Selection of LILW Disposal, Ljubljana, 1995,
3. Geological Survey Ljubljana, Institute of Geology, Geotechnics and Geophysics, Low and Intermediate Level Radwaste Repository Site Selection - The programme of field investigations, Ljubljana, 1995,
4. Geological Survey Ljubljana, Institute of Geology, Geotechnics and Geophysics, Hydrogeological identification of suitable geological structures for low and intermediate level radioactive waste repository site selection process in Slovenia, Ljubljana, 1997,
5. Petkovšek, B. (National Civil Engineering Institute), Urbanc, J. (Institute for Geology, Geotechnics and Geophysics); Geological parameters conditioning the choice of some types of underground repository of low and medium level radioactive waste disposal; *3rd International Symposium on Tunnel Construction and Underground Structures*, Ljubljana, 26.-28. September 1996,
6. Petkovšek, B., Marc, D., Osojnik, I., Geological Aspects of Site Selection for Low and Intermediate Level Radwaste Repository in Slovenia; Geological Problems in Radioactive Waste Isolation, Second Worldwide Review, University of California, September 1996,
7. Intera Information Technologies Ltd., The Scientific and Regulatory Basis for the Geological Disposal of Radioactive Waste, Leicestershire, United Kingdom, 1995
8. Chapman, N.A., McKinley, I.G., Hill, M.D., The Geological Disposal of Nuclear Waste, 1987,
9. Hodgkinson, D.P., McEwen, T.J., The Role of Hidrogeology in the Geological Disposal of Radioactive Waste - An Overview, *Memoires of the 22nd Congress of IAH*, Vol. XXII, Lausanne, 1990
10. IBE Low and Intermediate Level Radwaste Repository Site Selection in the Republic of Slovenia, Steps 1, 2, 3, Ljubljana, 1990,1992,1993
11. IAEA, *Safety Series No. 60*, Criteria for Underground Disposal of Solid Radioactive Wastes, Vienna, 1983
12. IAEA, *Safety Series No. 111-G-4.1*, Siting of Geological Facilities, A Safety Guide, Vienna, 1994
13. IAEA, *TRS No. 216*, Site Investigations for Repositories for Solid Radioactive Wastes in Shallow Ground, 1982
14. IAEA, *TRS No. 256*, Techniques for Site Investigations for Underground Disposal of Radioactive Wastes, 1985
15. IAEA, Radioactive Waste Management Glossary, Vienna, 1993