Assessing the Potentialities of Integrated Modelling during Early Phases of Siting and Design of a Geological Repository: the REGIME Exercise

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Abstract: This paper presents the safety assessment exercise "REGIME" (Repository Evaluation performed by GRS and IRSN through a Modelling Exercise) performed jointly by GRS and IRSN. The main objective of the project is to test the ability of integrated modelling to contribute to site selection and repository conception in the context of high-level radioactive waste disposal. The project is divided in two parts. Phase 1 consisted in studying different flow patterns in a given geological context. The selected hydrogeological contexts and three site locations potentially favourable for hosting a repository are described. Phase 2, under progress, aims at evaluating the role of limitation of releases played by the different components of the disposal system taking into account possible dysfunctions. The main issues to be addressed in phase 2, the modelling outline and the scenarios to be studied are presented.

1 INTRODUCTION

This paper describes a joint safety assessment exercise undertaken by the Final Disposal Department of GRS Köln and the Office for Safety Evaluation of Waste Disposal of IRSN. This exercise, called REGIME (Repository Evaluation performed by GRS and IRSN through a Modelling Exercise), continues the collaboration initiated in the frame of previous projects (European projects EVEREST and SPA).

The main objective of the project is to test the ability of integrated modelling to contribute to site selection and repository conception and to define jointly a methodology so as to test whether integrated modelling can bring useful information on these. It is a matter of developing an original use of these tools that are usually dedicated to assess the radiological impact of geological disposal of radioactive waste.

According to the country-specific situations and the current objectives and priorities of national programs, the joint work is expected to demonstrate how integrated modelling can contribute to the elaboration of a site selection methodology and to assess the performances of the various repository components for different site characteristics, mainly hydrogeological patterns, so as to highlight the merits of various design options.

In order to reach these objectives, REGIME is divided in two parts:

- Phase 1 consists in studying different flow patterns in a given geological context and in selecting particular hydrogeological contexts and site locations potentially favourable for hosting a repository that will be further studied in phase 2.

- Phase 2 aims at evaluating the role of limitation of releases played by the different components of the disposal system, accounting for various geological and hydrogeological settings as well as possible dysfunctions of the components. Geological and hydrogeological settings of interest for Phase 2 will be those selected in phase 1.

The results of phase 1 and the main issues to be addressed in phase 2 are briefly discussed hereafter.

2 GEOLOGICAL SETTING

2.1 Choice of the geological context with regard to the objectives

The choice of the geological context for the REGIME exercise was made taking into account two major aspects with regard to the objectives:

- the need to define an illustrative case within a realistic context: The objective of the project is not to work on one particular site currently under study in France or Germany, so as to avoid any possible confusion between ongoing feasibility studies of radioactive waste disposal and the present exercise. However, the wish was also to avoid pure theoretical work and thus to use data that would as far as possible be representative of field reality. The decision to work on a geological layout close to reality was accordingly taken. In order to draw conclusions that should be generic but applicable to situations of concern at present in both countries, a sedimentary site was preferably selected for the purpose of the exercise.

- the need to study a large set of hydrogeological contexts and a variety of disposal site location: Geological and hydrogeological settings, like geometry of sedimentary layers and tectonic features as well as contrasts of permeability, are expected to cover a variety of plausible disposal sites. Starting from these settings, the main objective of REGIME phase 1 is to adapt flow parameters in order to generate a set of configurations that are contrasted with regard to flow pattern, host rock thickness and depth, or distance to conductive faults. Phase 2 will consist in investigating the potential influence of repository design options for each selected configuration. This process, which may be leading to rather fictive hydrogeological patterns, is not an attempt to investigate the parameter variability caused by the actual uncertainty of existing site-specific data, but aims at defining a set of configurations of interest to proceed with the second phase of the project.

In accordance with these constrains, GRS and IRSN selected a site located in the Northern German Basin presenting the advantages to be a real geologic sedimentary clay site characterized by a variety of host rock thickness, regional faults and hydrogeological settings. This site was already studied by GRS [1,2] who compiled hydrological data.

3 Phase 1 calculations and analysis

3.1 Geological site description

The selected model area is based on a vertical 2D-cross-section (Fig 3.1). It represents a geological situation located at the southern border of the Northern German Basin near the Weser stream cut through the Weser Mountains at about 50 km west from Hannover. It stretches over a length 34.5 km from the southern slope of the Weser Mountains to the till-plains topography of the northern following flat land. The maximum elevation in the Weser Mountain ridge is about 430 m, the average surface altitude of the northern plain is about 40 m above see level.

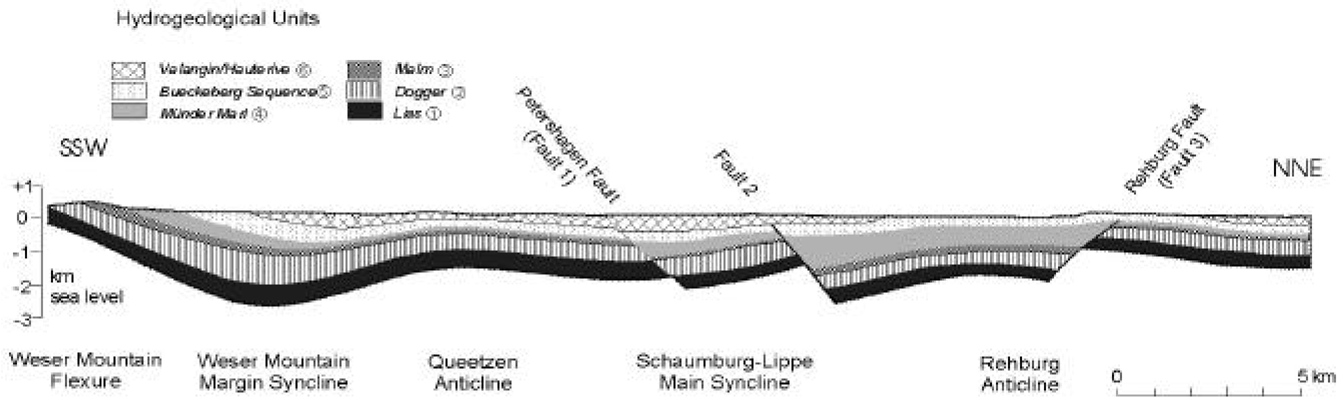

Fig. 3.1: Geological model cross-section. The Münder Marl layer is considered as the host rock.

3.2 Hydrogeological model

The bedding conditions of the Mesozoic strata series are fairly well known from deep drilling and geophysical measurements carried out for oil finding purpose in the model area. The hydraulic conductivities were estimated using sedimentological investigation results and are listed in table 3.1.

Tab. 3.1: Hydraulic conductivities of the reference case.

Hydrogeological Unit	Hydraulic conductivity K [m/s].
6 Lower cretaceous (Valangin/Hauterive)	1E-10
5 Bückeberg Sequence (Wealden)	1E-8
4 Münder Marl (Upper Tithon)	1E-10
3 Malm (Upper Jurassic)	1E-7
2 Dogger (Middle Jurassic)	1E-8
1 Lias (Lower Jurassic)	1E-10
Faults	1E-10

These data constitute "a reference case" on and against which flow calculations were performed (Fig 3.2).

In order to investigate a wide variety of the regional groundwater flow system, 11 test cases with deviating values of the hydraulic conductivity were defined (host-rock or faults more or less permeable for example). An example of different flow patterns obtained is shown in figure 3.2. Calculations performed point out a general flow pattern trend depending on model areas: the southern model part (south of fault 1) is affected by high gradients across the host-rock, the centre model part (between faults 1 and 2) is hydraulically shielded by the two faults, and the northern model part (between fault 2 and 3) is influenced by upward hydraulics gradients of which intensity depends on host-rock permeability value.

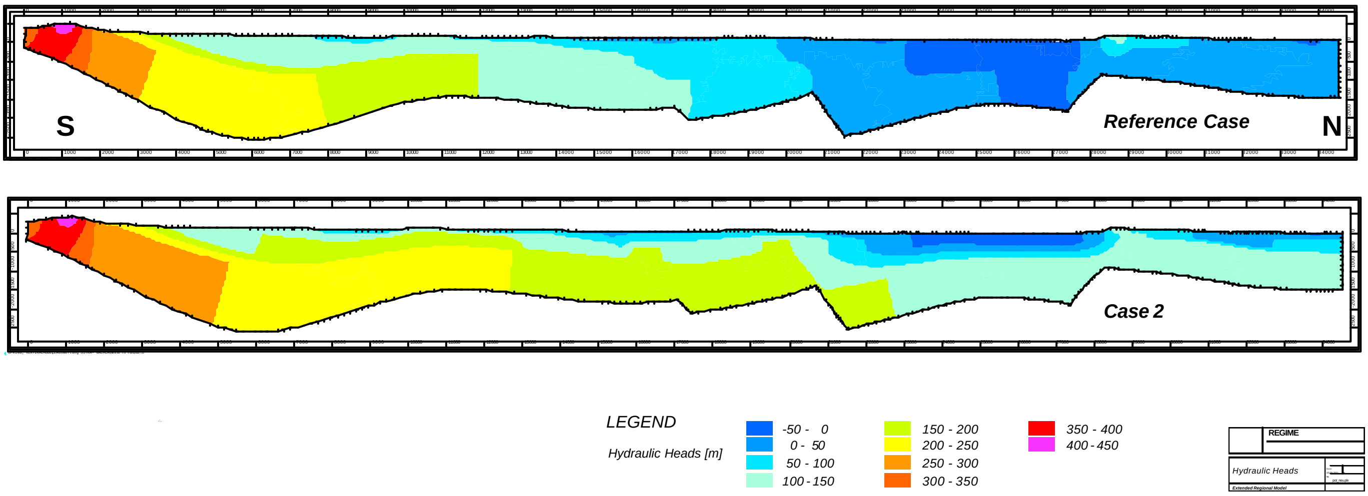

Fig 3.2: Head distribution [m]; reference case and case 2 (faults and Malm layers permeabilities increased to 1E-5 m/s)

3.3 Repository locations

In addition, five potential repository site locations were chosen (Fig 3.3) with regards to distance to faults, distance to surface (depth) and host rock thickness. All of them are fictitious and have no reference to existing mines or other subsurface facilities.

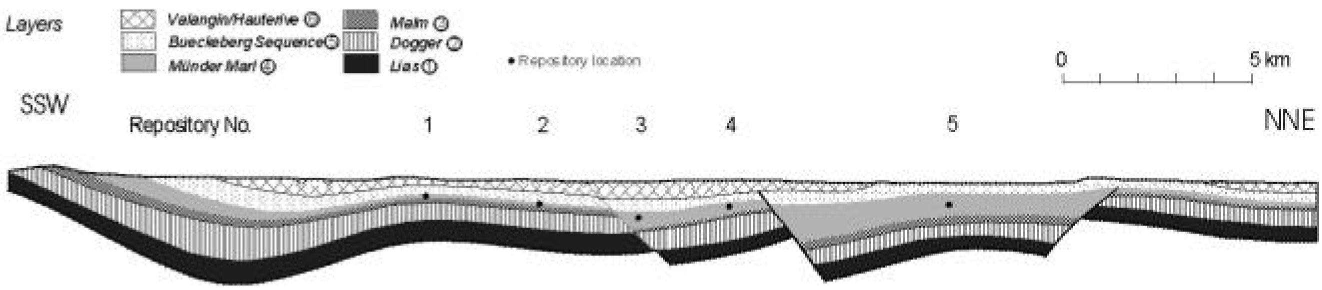

Fig.3.3: Repository locations.

The most important repository site locations and properties are listed in table 3.2. For transport calculation, each repository site is represented as a point without any spatial expansion (fixed nodes assigned with transport boundary conditions representing a radionuclide source).

Tab. 3.2: Repository locations and characteristic site properties.

No.	Location	Characteristic site properties
1	Southern model part, 4880 m south of fault 1	Relatively thin host rock thickness (100 m), comparatively low depth
2	Southern model part, 1875 m south of fault 1	Relatively thin host rock thickness (100 m), close to fault 1
3	Area between fault 1 and 2, 500 m north of fault 1	Relatively large host rock thickness (450 m), comparatively large depth, close to fault 1
4	Area between fault 1 and 2, 1015 m south of fault 2	Relatively large host rock thickness (320 m), close to fault 2
5	Area between fault 2 and 3, 3900 m south of fault 3	Maximum host rock thickness (600 m), far distance to faults

3.4 Example of calculation results

As an example of the transport calculation results, figures 3.4 and 3.5 present the concentration plumes calculated after 100.000 years for each location site in two drastically different hydrogeological contexts.

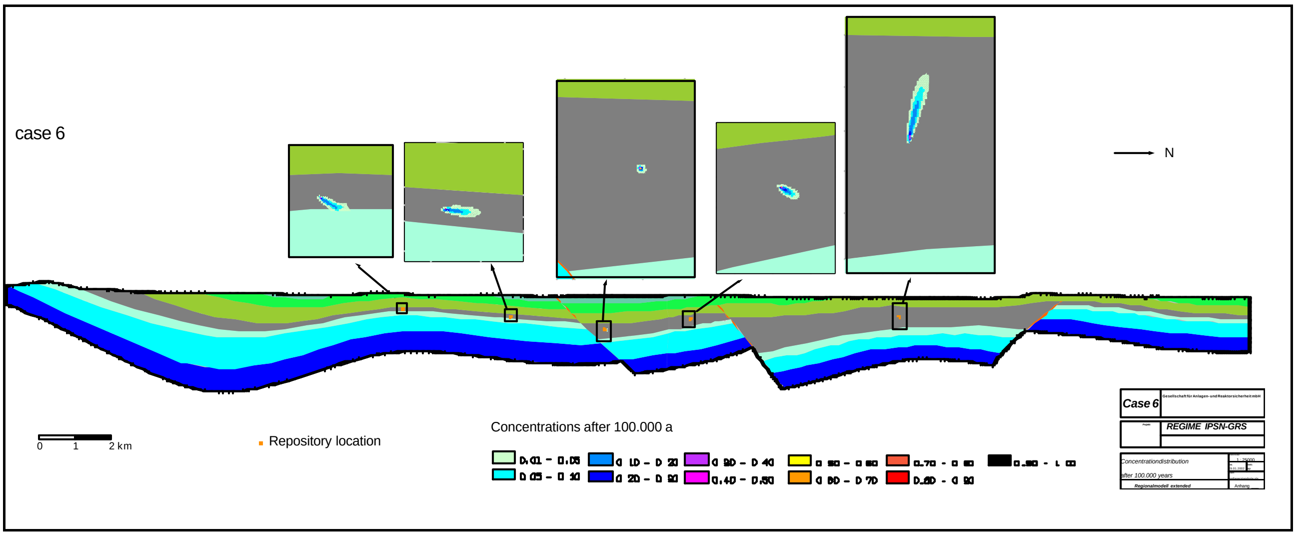

Figure 3.4: Concentration field after 100.000 years, case 6

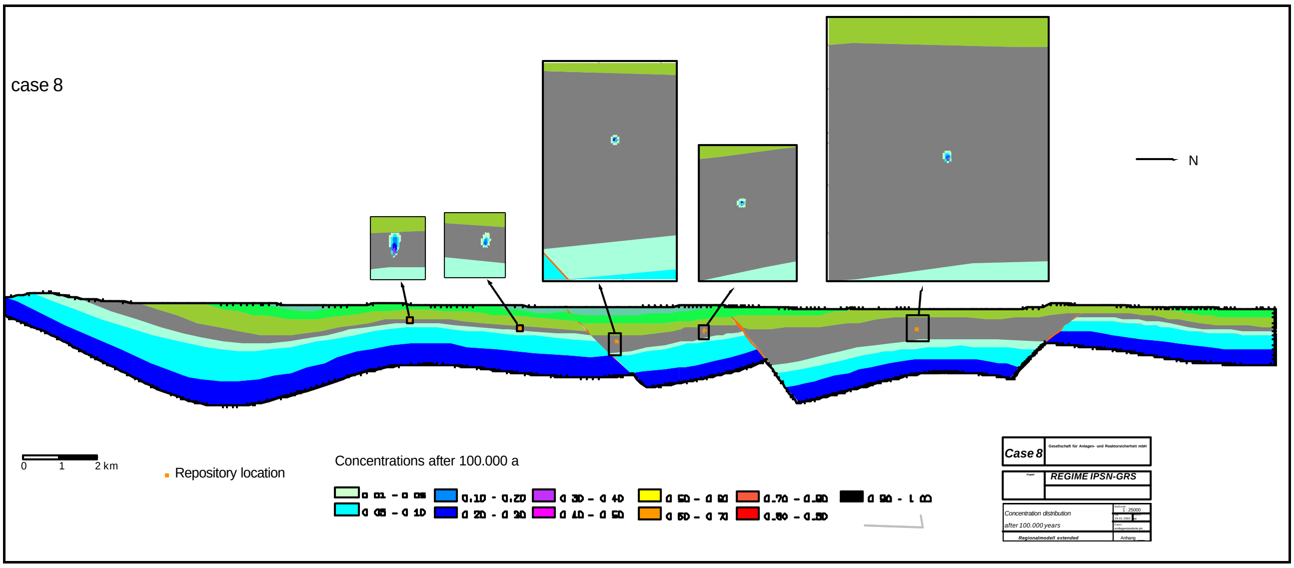

Figure 3.5: Concentration field after 100.000 years, case 8

From a general point of view (for the majority of site locations), radionuclide transport is mainly convective in case 6 but mainly diffusive in case 8.

In order to select relevant hydrogeological test cases as well as relevant repository site locations for REGIME phase 2 project, host-rock isolation performance (for each test case and each site location) was assessed in terms of the main transport mechanisms occurring. For the various flow pattern / site location that have been defined, the host-rock isolation potential is characterised by:

A: **diffusion**-dominated transport due to low groundwater velocities caused by **low head gradients**

B: **diffusion**-dominated transport despite significant hydraulic gradients but due to **low conductivities of the host-rock**.

C: **advection**-dominated transport but **sufficient thickness of the host rock**.

D: **advection**-dominated transport but **concordant flow direction** along the host-rock.

E: **advection**-dominated transport and **non-concordant/vertical flow direction** within the host-rock.

3.5 Selecting process for phase 2

The selection process for locations and hydrogeological patterns to be further investigated during phase 2 was based on two sets of criteria:

- Select configurations that would allow studying the influence of A, B and C conditions of flow on disposal safety (conditions D and E being considered as poorly compatible with conditions that would be looked for in view of hosting a repository: concordant flow (D) is indeed of poor robustness as a safety feature and condition E shows too large groundwater velocities).

- Select geological settings of interest for cases complying with A, B and C flow conditions: mainly a variety of thickness of host-rock and proximity to faults.

Finally, 3 new locations were selected, showing the characteristics resumed in table 3.3.

Tab. 3.3: Modified repository locations for project phase 2.

New N°	Location	Characteristic site properties
1	Southern model part, 1875 m south of fault 1	Relatively thin host rock thickness (100 m), close to fault 1, condition B
2	Area between fault 1 and 2. 2000 m distance to each fault	Relatively large host rock thickness (350 m), comparatively large cover, conditions A
3	Area between fault 2 and 3, 3900 m south of fault 3	Maximum host rock thickness (600 m), far distance to faults, condition C

4 Phase 2 description – future work

The objective of REGIME phase 2 consists in evaluating the role played by the different components of the disposal in the limitation of radionuclide release, by combining various geological and hydrogeological settings as well as possible components dysfunctions. The geological and hydrogeological settings of interest for phase 2 were selected among situations studied in phase 1.

Modelling will be performed at "vault scale". It means that only a small fraction of the repository is represented (typically a few disposal vaults, a drift and a shaft) but an explicit description of the various components of the system is required. Thus, the numerical model needs to treat objects of a meter scale or decametre scale (waste packages, engineered barriers, backfill, seals, Excavation Damaged Zone and shafts) together with geological and environmental settings of a kilometre scale. Once built up, such modelling allows discriminating the efficiency of each component when influenced by internal and external factors (hypothesis will be made on various source terms, performances of engineered barriers and Excavation damaged Zone, intensity and directions of hydraulic gradients, proximity of fault…). Finally, calculations should allow to quantify and assess the efficiency of the components of a repository, when considering normal and altered evolution of the repository.

The feasibility of this type of "vault" scale modelling has already been tested by IRSN. The method has proved its potential efficiency in discriminating the role of some components of the disposal (for example seals)[3]. Accordingly, a simplified repository model (shaft, main drift, disposal tunnels, EDZ) as shown on figure 4.1 will be implemented for REGIME. As REGIME phase 1 hydrogeological model mesh is two-dimensional, a reduced part of this mesh will be extended in the east-west direction by translation in order to include 3D simplified repository model mesh at a chosen repository location.

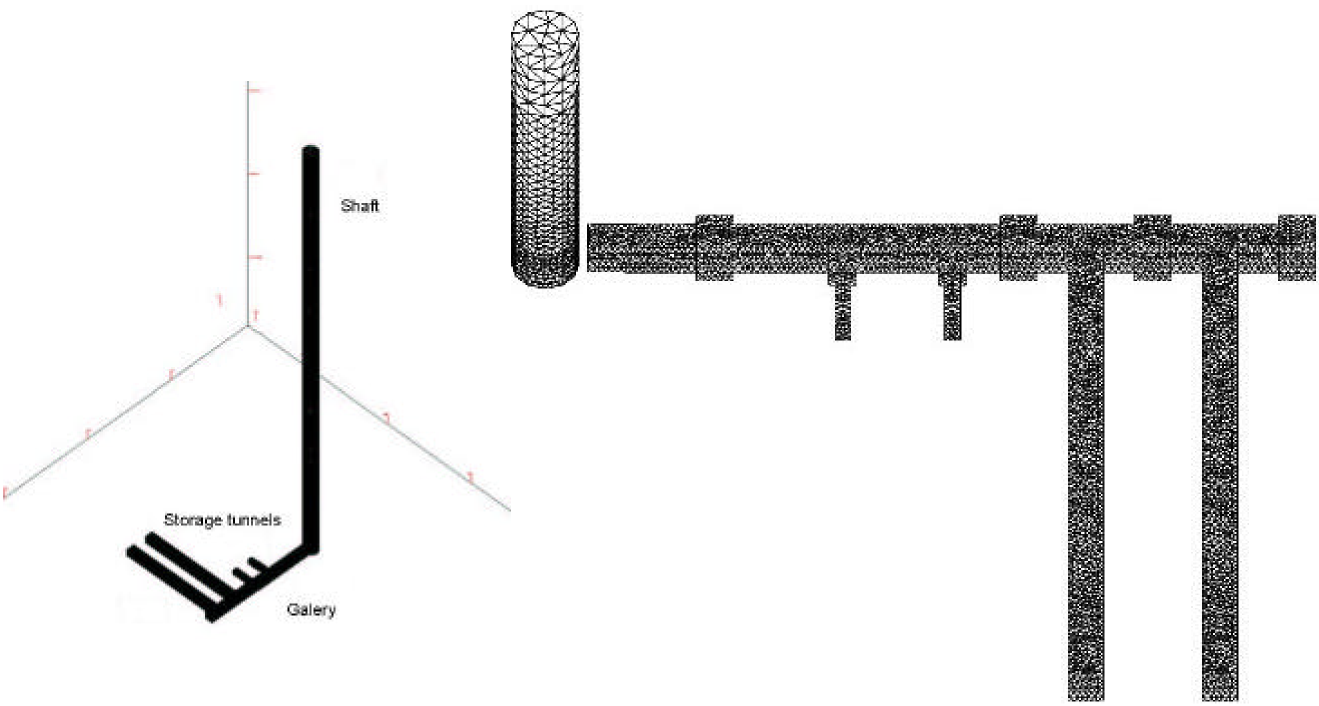

Fig 4.1: 3D views of the simplified repository mesh.

The calculations will be performed given scenarios selected from a systematic study depicting combinations of different local flow patterns, different states of efficiency of disposal components and different families of radionuclides. For the latter, the various radionuclides are sorted into categories according to their half-life, presumable solubility limits and sorption capacity. Calculations will then be limited to one representative radionuclide of each category. An example of the method is illustrated in table 4.1.

Table 4.1 Possible situations

					Assumption of local flow features		
					No bypass	Leaking shaft	Leaking shaft + fracture
Selected radionuclides for transport simulation	Long Lived	Soluble	Non sorbed	129I, 36Cl	X	X	X
			Sorbed	135Cs	X	X	X
		Non soluble	Non sorbed	107Pd?	X	X	X
			Sorbed	U, Np, Th, Tc, Zr	X	X	X
	Medium Lived	Soluble	Non sorbed	14C	X	X	X
			Sorbed	94Nb, 231Pa	X	X	X
		Non soluble	Non sorbed	79Se	X	X	X
			sorbed	239Pu, 245Cm, 246Cm, 59Ni	X	X	X
	Short Lived	Soluble	Non sorbed	3H, 90Sr	-	X	X
			Sorbed	137Cs	-	X	X
		Non soluble	Non sorbed	63Ni	-	X	X
			Sorbed	241Am, 244Cm	-	X	X
Possible states of simulated repository features							
Source Term	Nominal properties				X	-	-
	Early defect				-	-	-
	Increased release (glass - spent fuel)				-	X	X
Engineered Barrier	Nominal properties				X	-	-
	Transport properties altered				-	-	-
	Chemical properties altered				-	-	-
	All properties altered				-	X	X
Plugs	Nominal properties				X	-	-
	Transport properties altered				-	-	-
	Chemical properties altered				-	X	X
Seals	Strong hydro-chemical properties				X	-	-
	Backfill properties				-	X	X
Excavation Dammaged Zone	Geosphere properties				X	X	X
	Geosphere chemistry altered				-	-	-

Finally, results will be analysed upon multiple criteria, mainly:

- the fluxes and/or concentrations in various locations of the system (namely near field, shafts and fractures, geological barrier, aquifers and biosphere) can be used as well as radionuclide residence time,

- the quantified influence of each component on the total flux of radionuclides,

- the efficiency of each repository component with regard to each family of radionuclide and accounting for local and regional flow pattern.

5 Conclusion

A geological model that allows testing a large set of hydrogeological context and variety of disposal site locations was selected for the purpose of the REGIME project.

Analysis of transport calculations with regard to main transport mechanisms led to select three repository site locations for the follow-up of the project, featuring various appropriate flow conditions: diffusion-dominated transport due to low hydraulic head gradients or low conductivity of the host-rock or advection dominated transport in a thick host-rock.

In these a priori favourable hydrogeological contexts, integrated modelling at vault scale of a simplified repository will be implemented in order to investigate the role played by the different components of a disposal with regard to various scenarios assumptions. In particular, the purpose of phase 2 is to study in which manner the hydrogeological situation may influence, for altered evolution scenarios, the limitation of radionuclide release.

6 References

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