THE ADAPTATION OF NATURAL (GEOLOGICAL) BARRIERS FOR RADIOACTIVE LILW NEAR SURFACE DISPOSAL IN ROMANIA

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ABSTRACT

According to the Minimum Disturbance (MD) Design philosophy (as stated by Dr. Carl-Olof Morfeldt, Mineconsult-Sweden), it is a good practice to proceed with a significant knowledge of geology in order to adapt engineering approaches to nature; in fact, this is considered to be a fundamental principle. The geological setting for a waste disposal site is the starting point for both defining current in situ conditions and predicting the future conditions. This paper describes how the Romanian radioactive waste disposal program was implemented for low and intermediate level wastes (LILW). The selection process for LILW disposal at the near surface included 37 potential sites → 3 candidates sites → 2 candidates sites → 1 preferred site – Saligny, which is near to the main waste producer, the Cernavoda Nuclear Power Plant (NPP). Geological criteria were established at the beginning of the selection process: lithological, petrographical, tectonical, seismological, hydrogeological, geotechnical, etc. To select a preferred site, the adequacy of transport facilities and public acceptance criteria were also used. Safety analyses were done to predict the future behavior of the geological barrier – a thick unsaturated zone including red clay with, mainly, a smectitic mineralogical component – with use of specific software, SUTRA, SWMS – 2D, and CHAIN – 2D.

In both of the candidate sites, Cernavoda and Saligny, the maximum extension of the contaminant H3 remains inside of the red clay barrier and well above the main aquifer of the Cernavoda area, which is hosted in Barremian limestone. Geoengineering works are planned to improve the upper soil layer (loess) properties with respect to wetting sensibility and erosion by compacting and treating with different admixtures (cement, bentonite, consolid etc.) and by locating the site in a minimum wetting compressibility area. At the same time, an additional barrier will be added to integrate the site conditions at time of construction. In addition, the determination of specific radionuclide migration parameters for actual site samples was accomplished for estimating the contamination risk values. The main objective in this flexible Romanian design was to minimize the disturbance of pristine geological settings and the need for large-scale engineering barriers as much as reasonable possible.

INTRODUCTION

The above text expresses a new way to tackle the engineering problems for each type of construction that is implementing to the environment. In other words, for the achievement of a successfully transplant, without rejection phenomena, is necessary a deep knowledge of the environment characteristics (geology, morphology, seismology, tectonic, clime, etc.), and then an adaptation of the construction characteristics to those.

From here results the MDD concept, a modern designing concept, in opposition to the arrogance of master of the overruling nature, of the middle of the century and communist atheism.

The paper describes the selection process and the characterisation of a Romanian final deposit for low and medium radioactive wastes by the concept adaptation of geological barrier. The choice and characterisation of the sites by the presence and valuation of some natural barriers (ex. red clay from the quaternary loess base in South Dobrogea) that to impede the radioactive contamination, was in the centre of attention of the geologists, seismologists, physicists, constructors and technologists team from different institutes which are involved in that process.

The engineering works are proposing the morphology conservation and the actual geological characterisation, on one hand, and the performance improvement of the geotechnical and hydrogeological parameters of the foundation field, which is composed by quaternary loess, on the other hand.

In the IAEA safety fundamental documents "the Principles of Radioactive Wastes Management – the objective of the radioactive waste management is to deal with radioactive waste in the manner that protects human health and the environment now and in the future without imposing undue burdens of future generations".

The shown analysis and modelling are taking into consideration that fundamental principle, making obvious the natural barrier performance composed by unsaturated zone which is including smectitic red clay with a thickness about 45 m.

The conservation of the actual morphology and protecting the natural humidity, by the created loess pillow both under construction and on the neighbourhood slopes, as well as of the final roof, is responding to that principle and protecting the main aquifer from which the habitants are supplying, and is impeding the decontaminated evaporation.

MULTI-BARRIER CONCEPT

The multi-barrier concept is based using both natural engineered components of the site and repository system to prevent or to delay migration of the waste's radionuclides.

The multi-barrier system is composed of three major components: *1. The waste package; 2. The engineered structures; 3. The natural (geological) environment.*

The first barrier of the waste isolation system consists of encapsulation or stabilisation matrix and waste package envelope. In practice, wastes from the solid or solidified residues (e.g. ion exchange brad resins, chemical precipitates and evaporation concentrates) or under shape of some miscellaneous materials (cloth, metals scrap, plastic, etc.) with particles of radionuclides, which are, usually, immobilised in a encapsulated or stabilised matrix (e.g. cement, resin, bitumen) inside of a steel container or concrete, forming a waste package that is ready to be disposal.

The second barrier – the engineered structures consist of man made structures between waste package and host geology. For the surface disposal, that includes the concrete vaults, the capping system (roof) and the back fill material.

The third barrier – surrounding of repository is a long term and the most important component of the multi-barrier system. That includes the host geology and ground water especially and the effect of the waste, whose properties vary in time, in a future behaviour of host geology. The geology environment acts as massive physical and chemical buffer to processes dominating in the repository.

In the case, where radionuclides are mobilised out from repository into the host geology, there are two main factors controlling the nuclide transport: path length and flow rate of the ground water, and the physical and chemical characteristics of the path route, particularly, host geology ability is to retard the movement of the radionuclides.

Uncertainties regarding the performance of each these barriers increase with time, but is very evident, after the man made structures leave lost their retarding capacity within some hundreds or thousands of years, **the natural (geological) barrier still exists**.

SITE SELECTION PROCESS FOR LILW DISPOSAL SITE FOR CERNAVODA NPP. THE INVESTIGATION PROGRAMME.

The site selection process was a staged one. Firstly, the selection of Dobrogea region was a reasoned by:

- this area includes the Cernavoda NPP;
- this area the lowest precipitation quantities in Romania.

In *area survey stage* the regional geological map and a new seismotectonical map were made.

Specific general criteria were applied in order to select or to avoid one site or other from the 37 potential selected sites mainly they are geological ones.

Some of them are shown here:

- Seismological criterion – the selection of the area with maximum seismic observed intensity no more than I = 7 (MKS). This is the South Dobrogea area;
- Tectonical criterion – the avoidance of the active faults or arias (e.g. Capidava – Ovidiu fault or North Dobrogea area);
- Natural (geological) barrier presence – clayey layers with presumed low permeability and good retention capacity. In South Dobrogea there is a quasi continuous red clay layer with smectitic main mineralogical component or a thick unsaturated layer above red clay – dry quaternary loessoid soils without significant variation of moisture content in time;
- Stratigraphical criterion – the avoidance of limestone area on the surface with carstic phenomena or includes big aquifer (e.g. the Jurassic limestone aquifer - supplier for the population which leave near Black Sea);
- Other criteria – was, also, considered in the screening stage: access road to allow the transportation, existing land resources, avoidance of the flooding, landslides and erosion areas, population distribution, historical monuments, archaeological sites, etc.

Three candidates or selected sites and a minimum investigation programme was performed: 3 drillings and 1-2 refraction seismic section for each site:

- Cernavoda and Saligny sites, located near Cernavoda NPP, having similar geological conditions which have 40-50 m thickness, dry loessoid soils and red clay in their base. Main aquifer – Barremian limestone upper limit is decreasing in depth from Saligny (80-100 m) to Cernavoda (120-140 m);
- Mireasa site, at 20 km from Cernavoda NPP, is on a old platformic greenish schist with or no loessoid layer above;

After preliminary investigation, the Mireasa site was abandoned due to impredictible water infiltration – in the drilling process, the water circuit was lost and Lugeon test identified sectors with k > 10 L on the first 60 m drilled.

The *characterisation stage* involves both the Saligny and Cernavoda sites to demonstrate their safety and the environmental requirements.

The investigation programme includes the specific tests for:

- hydrogeological tests in borehole and pits;
- static or dynamic characteristics of geological layers;
- geotechnical characteristics and engineered modification;
- radionuclides migration in host geology.

At this stage, other considerations were taken into account to establish the preferred sites:

- co-location with nuclear power plant for economic benefits;
- reducing the potential burden of public acceptance;
- minimisation of waste transport requirements.

The Saligny site, adjacent to Cernavoda NPP, was declared as the preferred site and the programme for *site confirmation* was performed in 97-98's, following few main points:

- the hydrogeological structures and characteristics of aquifer using:
  - lizimetric measurements for unsaturated zone;
  - piezometric drillings with permeability tests for Eocene and Aptian local aquifers;
  - piezometric drillings with pumping tests for main aquifers.
- the selection of maximum thickness of red clay area;
- the adapted geo-engineering works to improve the geotechnical characteristics of loessoid soils in an experimental area with 3 m loessoid backfill. The upper 0.5 m part was mixed with different admixtures in different percents of cement or bentonite. Three different tests was made to evaluate the improvement of the foundation quality - plate bearing tests, permeability tests and Pinhole tests;
- the selection of the area with minimum deformability by zoning on the base of the specific geotechnical parameters including wetting sensibility and compressibility;
- the determination of the parameters of the specific radionuclides migration (H_3, Co, Sr, Cs) on both water and soil samples;
- modelling of the contamination risk using specific software.

According to IAEA terminology, the Saligny site is a confirmed site after the preliminary safety assessment approval by Romanian regulatory body.

SALIGNY SITE CHARACTERISTICS

First step in our investigation program was to contour the extension of main geological formations in a large area included the former "Cernavodă candidat site". This was a frame to corelate the results of in situ or laboratory lists in order to obtain the horizons (geotechnical) and zones (hydrogeological) with quasihomogenious properties. These are presented in the next fig. 1, 2 and table 1, 2, 3.

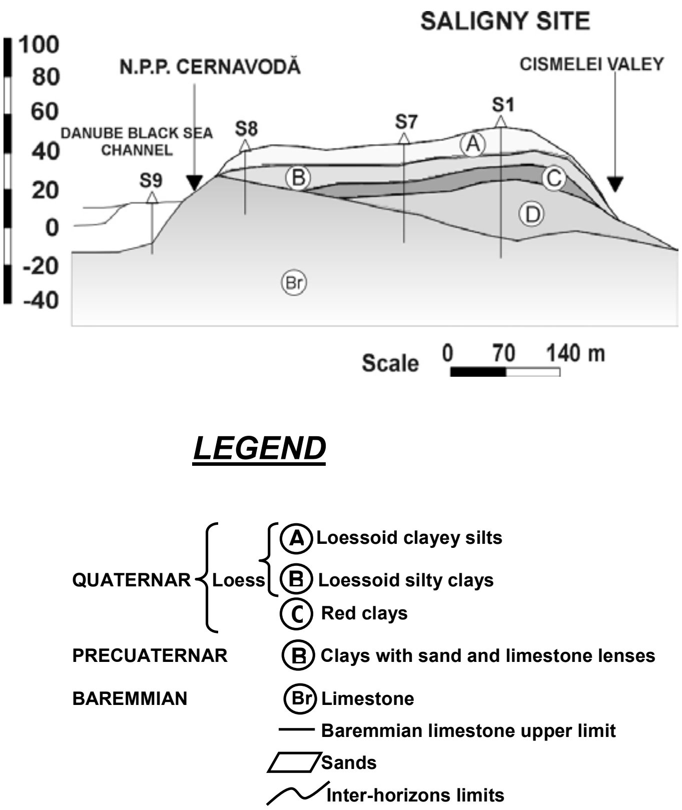

Fig. 1. Geotechnical Zoning

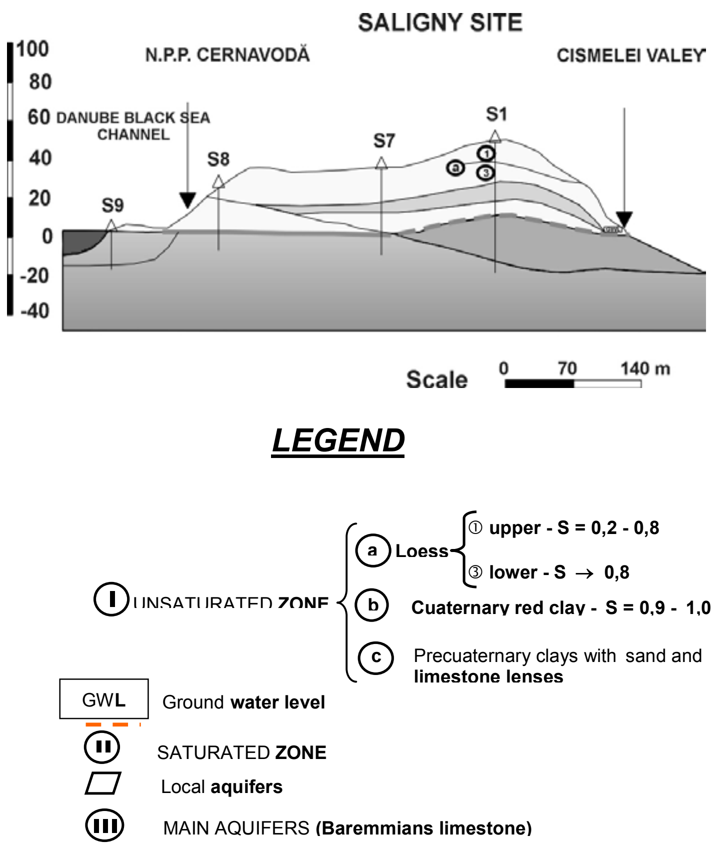

Fig. 2. Hydrogeological Zoning

Table I. Grain-size distribution. - Horiz. "A"

GEOTEC Lab STAS 1234-74		AGK Lab DIN 18123		Unified Soil classification	
ϕ [mm]	%	ϕ [mm]	%	ϕ [mm]	%
>0.25	0	>0.06	10	>0.073	10
0.25-0.05	13	0.06-0.02	40	<0.0073	90
0.05-0.005	69	0.02-0.005	30		
0.005-0.002	9	0.005-0.002	9		
<0.002	9	<0.002	11		

Table II. Main geotechnical parameters - Horiz. "A"

Porosity n	43 - 48 %
Natural volumetric weight density γ_n	15-18 kN/m^3
Natural volumetric weight density γ_d	13-15 kN/m^3
Plasticity index I_p	20 - 35
Natural water content W	5 - 15 %
Degree of saturation S_r	0.2 - 0.8
Angle of internal friction ϕ	15-20°
Cohesion c	50-70 kN/m^2
Deformation modulus M_{2-3}	10-15 MN/m^2
Velocity of the seismic longitudinal waves V_L	300-450 m/s
Apparent specific electric, resistivity ρ	120-140 Ωm

Table III. Hydrogeological and migration parameters

Hydrogeological zone	Unsaturated zone I NH				Saturated zone II
	a. Loess		***b.red clay***	c.precuaternary clay	Precuaternary clay/sat.sandy lenses
Parameters	1. dry	2.par.saturated			
Moisture content W%	4-6	6-20	***10-25***	10-25	
Saturation ratio S_r%	15-20	20-80	***80-90***	70-100	
Porosity n%	45-50	40-45	***35-38***	30-35	
Pores volume ccm/g	0.1-0.16		***0.06-0.1***	0.04-0.172	
Pores radius μm	0.6-0.72	0.02-0.7	***0.1-1***	0.08-0.3	
Clay fraction <2μm	16		***36***	2-70	
Smectit (%in clay)	50		***69.5***	54	
Smectit (% in sample)	7.5		***25.4***	14	
Permeability K cm/s	10^{-4}-10^{-5}		***10^{-6}-10^{-7}***	10^{-3}-10^{-7}	
C_s Distribution ratio K_d mg/g	15		***54***	18.8	
Retardation factor R	23		***692***	49	
Sr Kd mg/g	4		***14***	18	
R	7		***180***	116	
Co Kd mg/g	13		***69***	80	
R	20		***884***	513	
Cs137 Kd mg/g	995		***3810***	1100	
R	3820		***48769***	7071	
Co60 Kd mg/g	33		***29***	40	
R	126		***371***	257	

MAIN GEOLOGICAL BARRIER - UNSATURATED ZONE, INCLUDING THE RED CLAY - TOTAL PROTECTION OF THE MAIN AQUIFER - SAFETY ASSESSMENT FOR SALIGNY SITE.

There are too many factors controlling the nuclides transport on Saligny site where the nuclides are mobilised out of the repository into the host geology:

- the path length (45 m) and infiltration rate between repository and ground water level means the unsaturated zone – dry loessoid soils and red clay in their base having certain ability to retain the radionuclides. This is the main protector for the main aquifer hosted by the Barremian limestone.

Between unsaturated zone and aquifer – the partially saturated zone consist clayey layer with sandy or limy lentils (local aquifers) without connection between them. Only in the lower part, there are connections between these local aquifers and Barremian limestone (main aquifer):

- the path length and flow rate of the ground water if the contaminant pass trough the unsaturated zone then it could be reach the main aquifer (80 m depth).

There is a direct relationship, a reversible one, between Danube and Barremian aquifer. Only in the spring season when the Danube levels are big (12 m above Black Sea level) then, the leaked contaminant would be possible to spread around the site. Otherwise when the Danube levels are small (5 m above Black Sea level) then, the leaked contaminant would be transported and diluted by Danube waters. The maximum variation of the Barremian aquifer level is 3 m (7.5 – 10.5 m above Black Sea level).

The big channel between Danube and Black Sea is like a good governor by its constant levels – 8.5 above Black Sea level. The minimum variations are induced in the aquifer, downhill of the canal lock. The tracers' test is programmed for the next year and the modelling of the water circulation will be computed.

The loessoid backfill – a geo-engineering adapted work, which improves the wetting compressibility and the erosion resistance of the loessoid soils, is like a link between disposal construction and host geology. By its decreased permeability and increased retention capacity, it is composing itself in a new barrier where the retarding process could be longer.

To evaluate the performance of the geological barrier, the modelling of H_3 migration through the unsaturated zone was taken into account.

Two conservative conditions have been set:

- no modification in the contaminant during 300 years;
- the continuos infiltration rate is all the time, much more the real one;
- the genuine dry condition for loessoid soils would be preserved.

Both natural conditions and the effect of the backfill were simulated. Using computer codes for the tritium migration modelling, as VS2DT, SWMS-2D, CHAIN 2D, and different operators

(Bucharest University, Technical University from Bucharest and Karlsruhe University – Germany), was not observed significant differences between them.

For the preliminary safety assessment, the most important conclusion is that maximum extension of tritium migration is less than 30 m depth, remaining in the upper part of the red clay more over (50 m) main aquifer (fig.3). The extension of Co, Sr, Cs are less than 10 m in loessoid soils only.

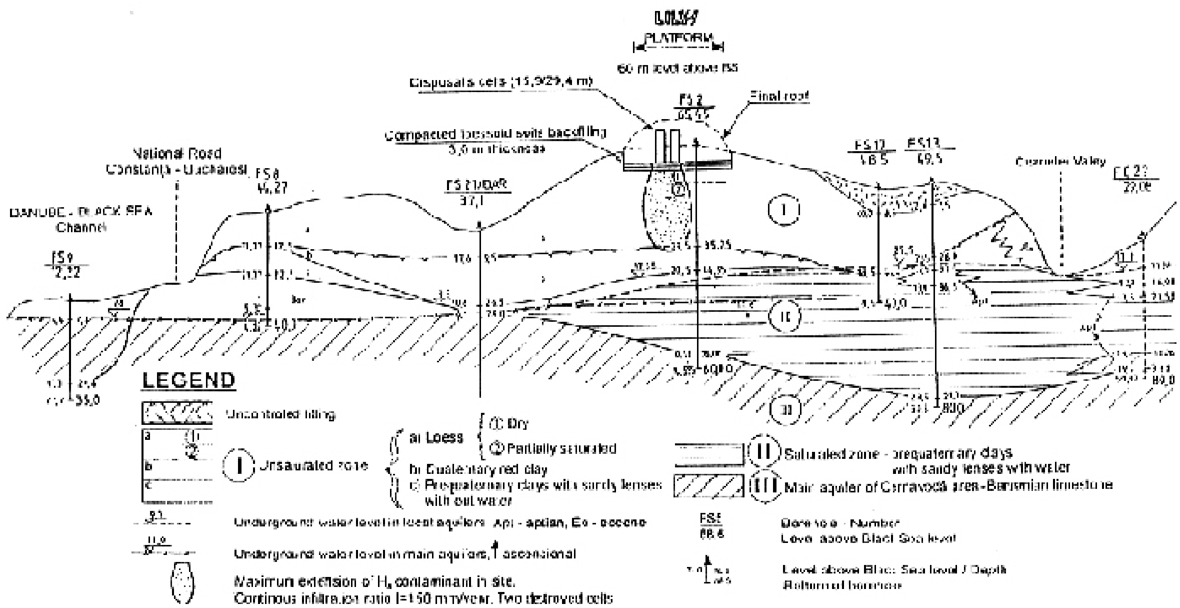

Fig.3. Maximum extentsion of H3 contaminant in saligny siteChain 2d softwareTransverse section

THE ADAPTED ENGINEERING WOKS IN LOESSOID SOILS.

Zoning of the wet compressibility conditions. Choosing the better area

The variability of three analysed parameters (porosity – n%, critical pressure – σ_{cr}, and the wetting specific settlement – I_m) was expressed as zoning maps according to Romanian standardised classification criteria and using the geostatistical method of universal kriging. The maps were realised at the proposed foundation level and on them was overlapped another map with disposal cells contour.

The obtained maps show that the most part of the foundation field is formed by soils with slow and medium wetting sensivity, excepting the small marginal areas.

Site improvement for repository facilities

The main point of our research was to test "in situ" a bearing layer of compacted loess to improve the bearing capacity of the field, to increase the erosion resistance and to delay the transport of the radionuclides.

In that end in view, an experimental area was realised (see the above chapter) to choose the improvement techniques: plate bearing, permeability, and Pinhole tests.

After the determinations of the optimum compacting wetness – $W_{opt.}$ by Proctor test and the thickness of the compacted layers, 13 layers were applied, making 16 passages of static and vibratory tamping roller for each layer. The 3.0 m embedded compacted loess was obtained. The last 2 layers of the backfill – 0.5 m thickness, was divided in four slices: slice 1 -compacted loess without admixtures; slice 2 - 8% cement + 2% bentonite; slice 3 – 7% cement + 3% bentonite and slice 4 – 5% cement + 2% bentonite. On the undisturbed and disturbed samples were made migration tests. The results are shown in the table no. 4.

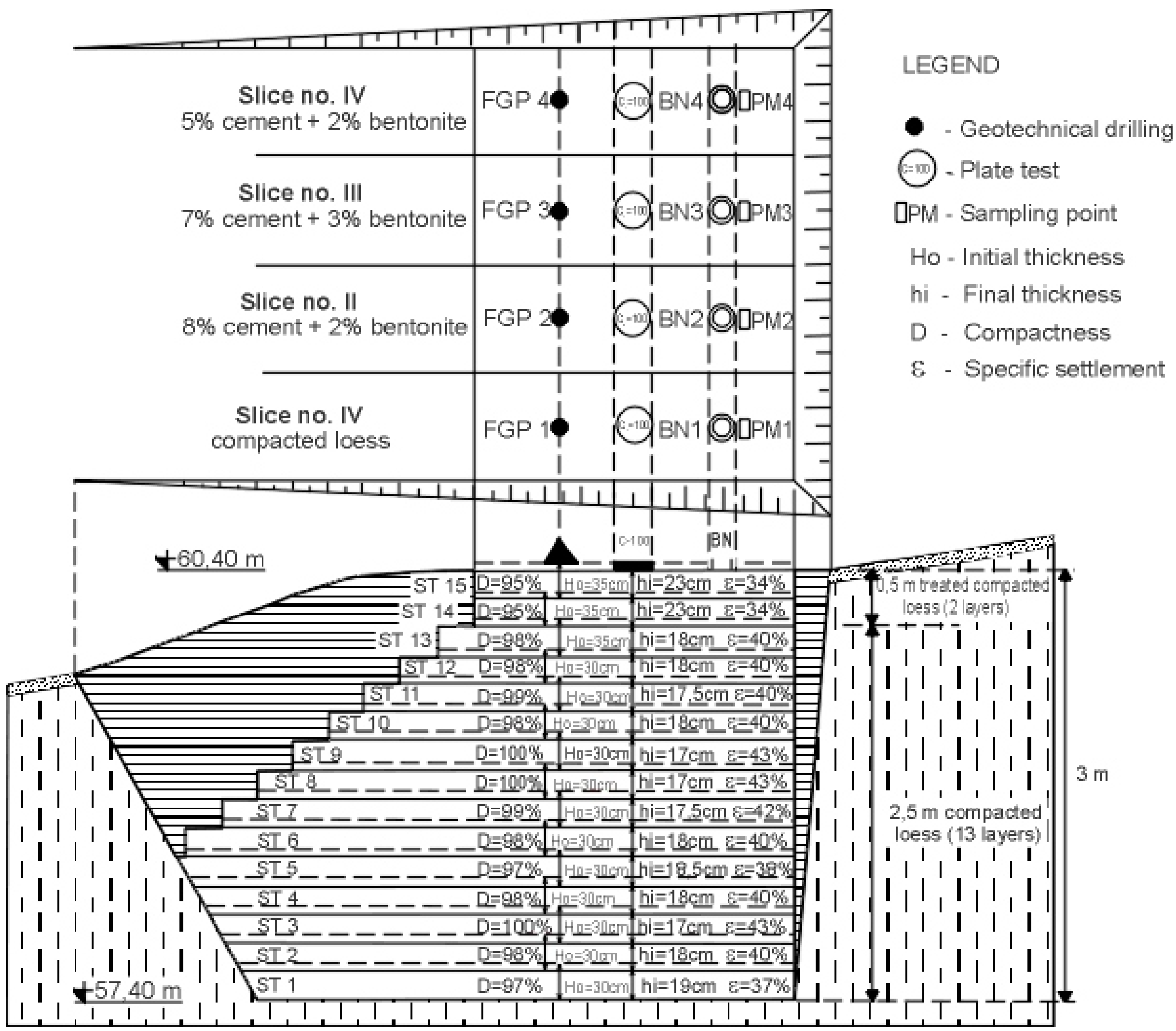

Fig. 4. Scheme of the experimental area in situ tests

Table IV. The tests results in experimental area

Material	Plate bearing Ed (KPa)	Permeability K cm/m^3	Vp m/s	Pinhole tests BS 1377/5-90	Migration tests – In batch test – Distribution coef. Kd (mg/l)			
					^{3}H	^{241}Am	^{137}Cs	^{60}Co
II	251 541	2,8 x 10^{-5}	886	-	0,3553	1013	550,80	41,80
III	123 662	2,2 x 10^{-5}	676	ND_1-ND_2	0,3236	10805	550,73	45,45
IV	129 396	-	-	ND_2-ND_3	0,4071	1887	283,16	36,57
I	36 480	7,7 x 10^{-5}	386	ND_1-ND_2	0,2088	15589	603,57	39,74

II = 8% c + 2%b; III = 7%c + 3%b; IV = 5%c + 2%b; I = untreated.
c = cement; b = bentonite;

The admixtures of 8% cement and 2% bentonite from the geotechnical point of view conferred the most important increase, but migration and Pinhole test results are no so convincing, more tests are necessary.

MONITORING OF THE DISPOSAL SITE

Hydrogeological zoning means different zones with quasi-homogenous hydrogeological conditions (see above chapter) was used as a frame for monitoring of the Saligny site.

In order to monitories the moisture contents variation, now and in the future, inside unsaturated zone was done:

- one meteolizimetric station for water infiltration rate;
- one special drilling (30 m), monthly neutronic logs for moisture content variation.

In order to monitories the water table variation and chemical characteristics in different aquifers was done:

- special equipped drillings for *local aquifers* - Eocene or Aptian, sandy or limy lentils – until 40-60 m depth;
- special equipped drillings for *main aquifer* – Barremian limestone – cased until to the upper part of this and it is equipped, inside, with perforated pipe.

MINIMUM DISTURBANCE DESIGN IN SALIGNY SITE

The implementing process of the disposal's construction (structures) in host geology of Saligny site with minimum disturbance of environment would be divided in two main parts:

- the maintenance of the actual natural conditions by:
  - minimum excavation as low as reasonable;
  - the excavated loessoid material could be used as:

    - backfill material (compacted and treated) under cells disposal;
    - filling intracells material (treated with bentonite or so);
    - final roof layers material;
    - slope material (compacted or treated).
  - minimum settlements under construction:
    - selection of the zone of minimum compressibility;
    - limited maximal load of construction = 2.5 da/cm^2.
  - minimum erosion phenomenon – all of the disposal components including visiting gallery, water pipe line and others will be inside of the compacted loessoid soils in perfect tightness conditions;
  - final roof will be designed inside of actual morphological line of the hill (more or less) with continuous slopes from the top of disposal to natural slopes.
- the sizes and performances of the another two engineered barriers (especially structures) would be in accordance with the natural barrier performance as low as reasonable possible, means more less total costs.

A team is including physicists, engineers, geologists, computing specialists and continue relationship with regulatory body, environmental institutions would be involve in that process.

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