LARGE SCALE TEST OF THE LONG TERM ENGINEERED CAP AT EL CABRIL LLW DISPOSAL FACILITY IN SPAIN

M. Navarro*, P. Zuloaga*, M. Ordoñez*,

Empresa Nacional de Residuos Radiactivos, S.A (ENRESA)

Emilio Vargas, 7

28043 Madrid- Spain

ABSTRACT

El Cabril disposal facility was commissioned in 1992 and has 28 concrete vaults for LLW disposal, with an internal volume of 100.000 m^3 . It also has a VLLW disposal facility, commissioned in 2008, with capacity for 130,000 m^3 in four disposal cells of whom only the first cell has been built.

One important component of the disposal system is the earthen cap providing long-term protection of the concrete vaults. The design of the cap is based on clay materials and two different designs have been considered.

A large scale experimental device has been built with a threefold objective: validating the two basic designs, verifying the thermo-hydraulic model of the system performance and supporting the enhancement of the safety assessment of the facility.

The test device includes two test areas, one for each variant, with longitudinal full size cross-sections. A complete set of temperature, humidity, capillary pressure, and heat flow sensors has been installed in different zones of each layer of the cap disposal. The sensor types were selected as a function of the anticipated humidity or capillary pressure: The cables layout allows their disposition through a single layer to a central concrete gallery containing the data collection system, thus preventing the formation of preferential infiltration pathways. The test bed is complete with segregated water collection and volume measurement at each area and layer. Beneath the cap there is a concrete structure simulating a disposal vault, where temperature, humidity and electro-chemical sensors have bee embedded with the intention of improving the thermo-hydraulic model of the disposal system behavior.

This paper describes the test bed, the first data reported and their relationship to the modeling effort made in co-ordination with the experimental work.

INTRODUCTION

With a view to defining and designing the definitive covering layer to be implemented on the Disposal Platforms at El Cabril, the decision was taken to carry out a preliminary test plan, consisting of the construction of two reduced scale covering layers to check whether the theoretical solutions proposed are in keeping with the characteristics required.

In doing this, we have enjoyed the collaboration of Spanish specialist companies and institutions such as the Polytechnic University of Barcelona, the Eduardo Torroja Sciences of Construction Institute and the research institute CIEMAT.

In addition, consideration was given to previous experiences at other similar European installations. This led to a basic design for both test covering layers.

CRITERIA AND DESIGN BASIS

The basic principles to be fulfilled by the covering layer to be implemented on the Disposal Platforms have been obtained from the experiences and references referred to in the corresponding sections, these being summarised by way of the following criteria:

- Durability of the foreseen operational period of the covering layer should be 300 years (reference 1).
- Type of covering: the multiple covering layer solution will be adopted, satisfying at least the following requirements (reference 2).
- Reduction of erosion due to the action of the wind or water runoff to entrainment limits of less than 0.5 kg/m^2 per year.
- Elimination of surface waters, channelling them and providing an adequate slope for speedy evacuation (reference 5).
- Protection against bio-intrusion, installing barriers aimed at preventing the action of small animals and the deep rooting of plant species.
- Minimisation of permeability by means of a layer of clay measuring no less than 0.60 metres in thickness, with a coefficient K (minimum) = 10 E-9 m/s.
- Limitation of water seepage through the covering layer to 1.5 l/m^2 per year (reference 6).
- Drainage of seepage in the first layers of the covering by means of a granular bed measuring at least 0.30 m in thickness and with a permeability of no less than 10 E-4 m/s.
- Placing of a PEAD membrane measuring at least 2 mm in thickness and of the protecting geo-fabrics required for the correct operation of the overall assembly.

PROPOSED TEST

Following analysis of the criteria set out above and of the data obtained from previous experiences, the performance of the following test is proposed:

Test description

The test consists of constructing two adjacent multiple layer coverings, each measuring approximately 10 x 12 m, at the upper part or summit and 12 m in length down the slope, separated by a concrete gallery from which access may be gained to the instrumentation of the different layers. The base of the slope will end in a containment wall facilitating the removal of water from certain of the layers.

As may be appreciated in figure 1, each covering is divided into four areas or zones, numbered from I-1 to I-4 in the case of covering I and from II-1 to II-4 in the case of covering II.

A group of sensors will be installed in each of these zones to measure the evolution of the temperature, water content, flows, etc. throughout the covering layer.

This division into zones and monitoring arrangement is considered to be the most adequate since in each zone the flow conditions will be those of the zone itself plus those of the previous such areas.

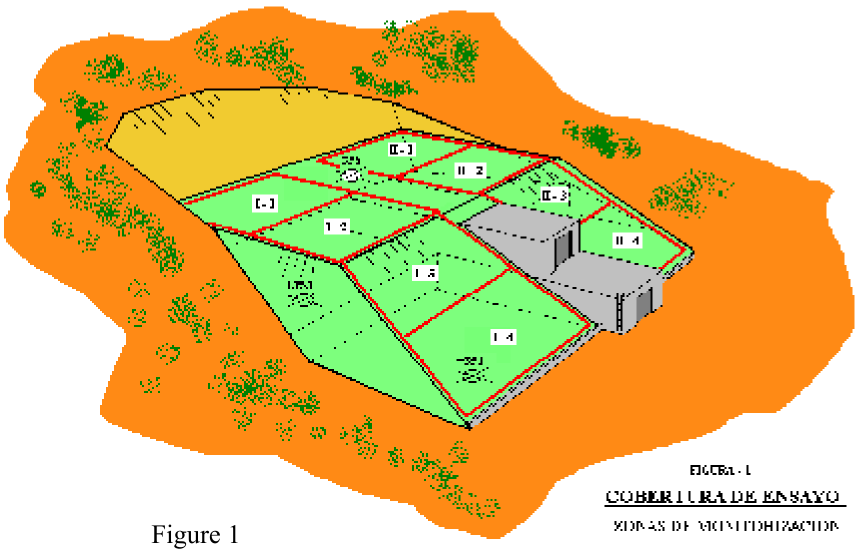

Figure 1

The layers proposed for each of the test coverings cap, known as TEST-I and TEST-II, are shown in figures 2 and 3.

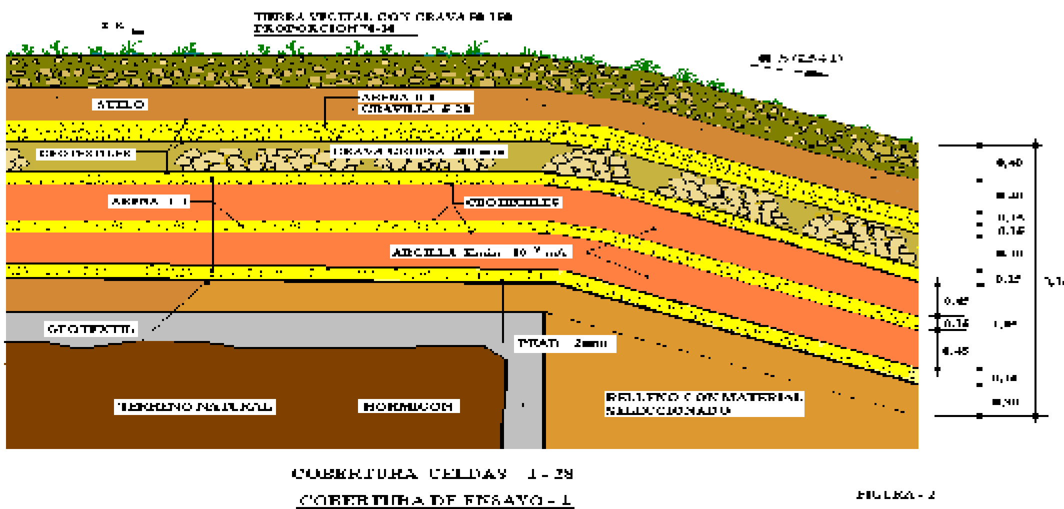

Figure 2

Figures 4 and 5 show longitudinal and transversal cross-sections of the covering test.

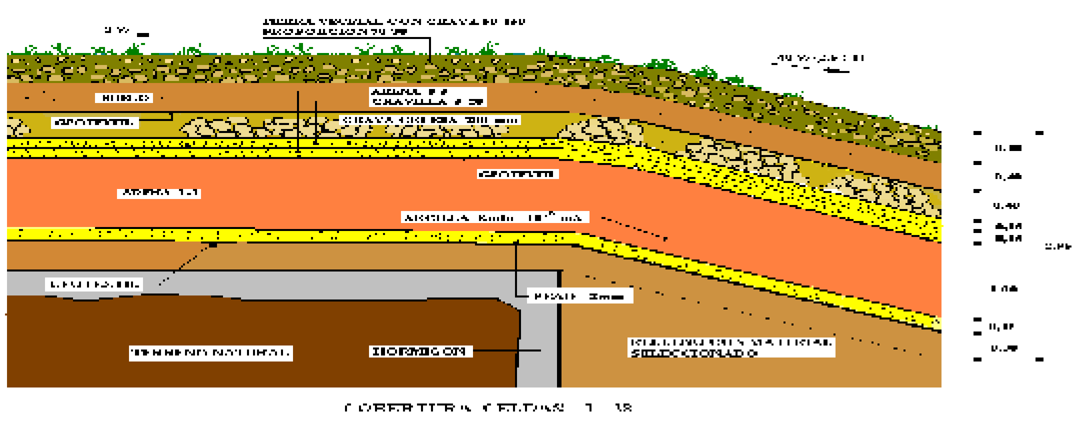

Figure 3

LONGITUDINAL CROSS-SECTION

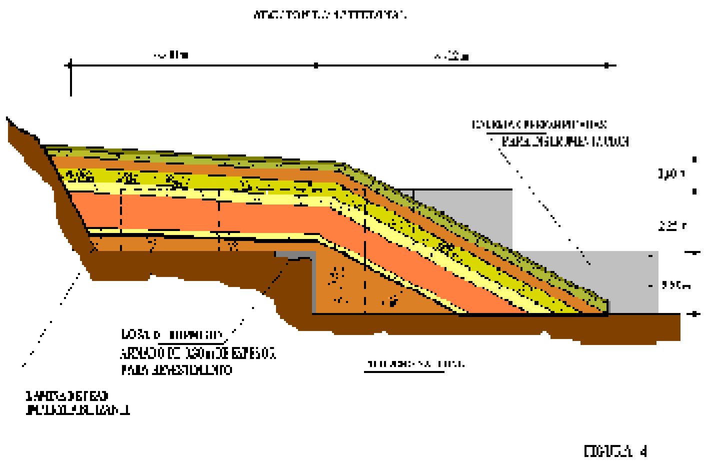

Figure 4

TRANSVERSAL CROSS-SECTION

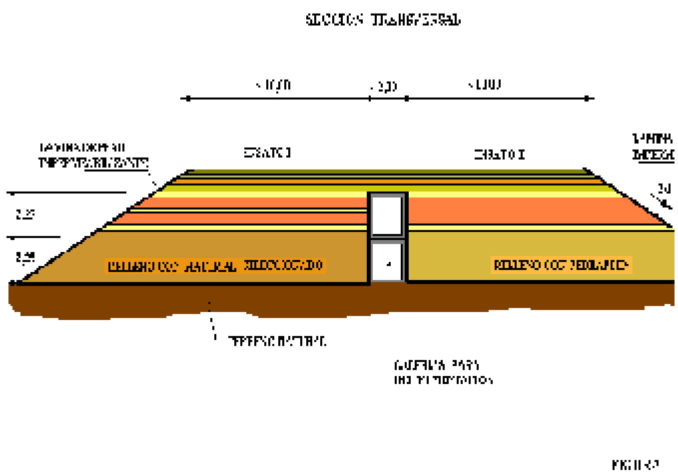

Figure 5

Instrumentation description

Sensors embedded in the covering layers

Figures 6 and 7 indicate the instrumentation selected for zones 1, 2 and 3 in each test. The zones numbered 4 (figures 8 and 9) include fewer instruments, because those areas will most probably be altered due to those areas are being used by the extraction of water device from the different layers (reference 8).

As regards the distribution of the sensors, a distinction is made between three groups: those corresponding to the acquisition of the water balance (blue in colour), those measuring capillary pressure (green in colour) and those for the heat balance (in red).

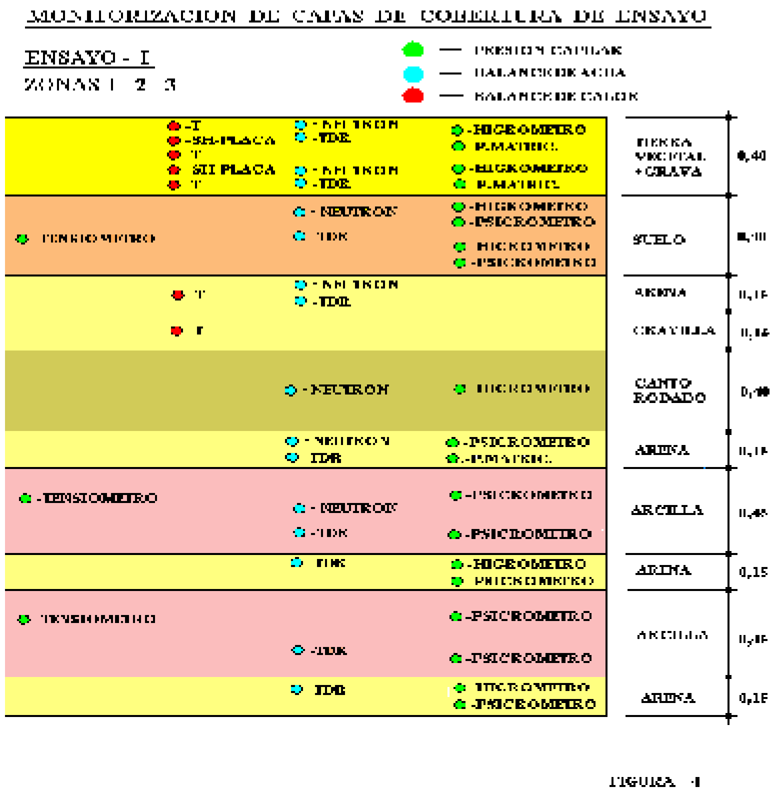

Figure 6

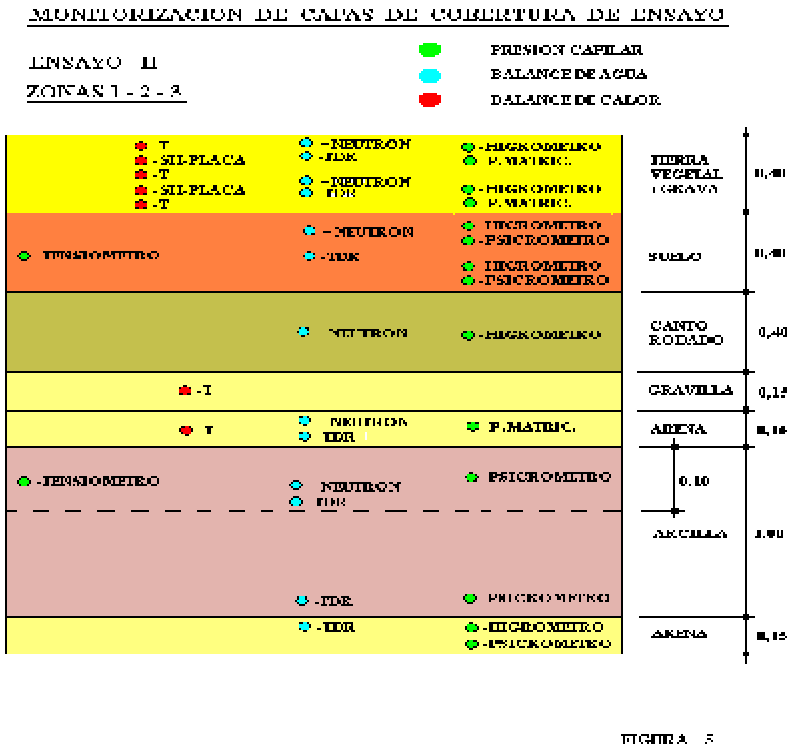

Figure 7

Fixed TDR probes are placed in each of the layers indicated. Temperature measurements are taken throughout the entire profile of the covering layer, the intensity of such measurements being higher in the upper layers, which have a more pronounced gradient.

Bearing in mind the low degree of vertical separation of the instrumentation, this may be distributed horizontally in order to facilitate positioning, as long as the horizontal distances around the theoretical positioning axis do not exceed 50 cm.

The groups of sensors corresponding to zones 1 and 2 in each test should be placed closer to the ends of the summit than to the centre, in order to measure a greater contrast of properties. The sensors in zone 3 are positioned close to the beginning of the slope.

For measurement of the deformations of the terrain and possible differential settling, 8 geo-referenced surface markers will be included, along with inclinometers buried horizontally in two rows of 6 units each, in the zone corresponding to the edge of the step in the natural terrain, which is where the greatest differential settling may be expected.

Likewise, in order to check the effect of the deformations in the PEAD sheet, three groups of three extensometers are placed on it in each of the tests, these being uniformly distributed along the upper edge of the slope.

Measurement of the erosion will be accomplished by way of two sediment traps located at the foot of the covering layer slopes, one being used in each test.

Sensors embedded in the concrete wall.

Three groups of sensors embedded in the concrete will be placed on the concrete slab simulating the cells in test II, at a distance of 1 m from the data acquisition gallery. The first group will be placed in the horizontal area at a distance of 1 m from the edge of the slope, the second in the vertical area at a distance of 1 m from the upper edge and the third below the second and separated from it by 1 m. Each such group contains the following sensors:

- 1 hygrometer
- 1 psychrometer
- 1 vibrating cord extensometer
- 1 thermocouple for the detection of temperature variations
- 1 pair of electrodes connected to the slab reinforcement

Auxiliary activities

In addition to the instrumentation indicated, various protective and preparatory tasks should be carried out to facilitate the acquisition of reliable measurements and data, these including the following:

- Construction of perimeter drains preventing external water make-up to the covering.
- Protect of excavation slope with PEAD sheeting in order to prevent water make-up to the covering layers.
- Protection of the lateral slopes of both test coverings with PEAD sheeting.
- System for the collection of water at the outlet from the different layers indicated in the two tests and of covering surface water runoff, including the installation of flow meters and sampling for measurement and characterisation.
- The following tracers were used in the different layers:
- In the topsoil layer, LiBr, Eosine-B and B
- In the soil layer, Co-EDTA and NaF
- In the upper clay later, Gd-EDTA and CaSO4
- In the lower clay later, Ili, Mo-EDTA, NaCl and B
- In the single clay layer (test II), Ili, Mo-EDTA, NaCl and B

Measurement plan

The measuring frequency will be of two types, the stored data being collected once a month.

Continuous measurements, with 1 register per hour for TDR, suction, humidity, temperature, heat flux, output flows and meteorological data and 1 register daily on soil deformations.

Periodic measurements, with monthly frequency for TDR in the neutron probe tube, chemical analysis of the outlet water and topographic markers.

Calculations

In addition to the structural calculations of the walls and instrumentation galleries, as part of the project have been developed the following calculations.

- Soil loss study

This study describes the most habitually used soil loss quantification methods, the aim being to develop an optimum solution for application in the pilot test, especially in the areas with the highest erosion rates, which will be those of the slope.

The method chosen is the sediment traps system due to its providing the most information and not being destructive, this making it compatible with the rest of the experiments.

In general, the sediment traps are positioned at the base of the embankments where the runoff drains discharge, collecting the sediments after heavy rainfall or storms.

According to the data for El Cabril, December is the month in which the highest rainfall figures are registered and in which the most intense storms and rains occur; consequently, a statistical analysis of the annual erosion rate that would occur in the area of the slope will be carried out, as complementary information to the meteorological data.

For calculation of the annual rate of soil loss the Universal Soil Loss Equation (USLE) is used, due to its being the most widely accepted equation. The Universal Soil Loss Equation may be defined as an empirical parametric model capable of assessing the rate of erosion of uniform geographical spaces through quantification of the most relevant factors.

The equation is defined by means of the following variables:

Formula 1

A = R x K x LS x C x P

Where:

A = loss of soil per unit of surface (ton/ha)

R = rain factor or rainfall erosion index (cloudburst erodability)

(J x cm/ m2 x h)

K = Soil erodability index (t x m2 x h/ha J cm)

LS = topographical factor, where L = longitudinal factor of the slope (m) and S = slope (%)

C = crop and land use factor or plant coverage factor (non-dimensional)

P = soil conservation practices factor

- Seepage and drainage capacity in the covering layers

In this study the rainfall data for El Cabril are used to estimate runoff on the basis of the slopes and nature of the surface material and flows seeping through the different covering layers in each of the tests.

The calculations performed give a theoretical annual seepage rate, which does not exceed the limit of 1 dl/m2/year in either of the tests.

- Study of dimensions and instrumentation to be installed in the test coverage

One of the main item to be held in the project is to dimension the covering layers test in order to define the degree of extrapolation between the data to be obtained from the test and those expected from the disposal cells of the Disposal platforms of El Cabril.

The assessment of test performance has been simulated by means of a finite elements stress-deformation model developed within the PLAXIS V 8.1 programme.

From the results obtained it may be deduced that both the stresses and the settling are maximum in the transition zone between the terrain and the concrete of the cells, and that the stresses in the PEAD sheet are concentrated in this area, with stresses close to plasticisation values occurring at certain points, as a result of which constructional measures should be taken to even out the stresses and prevent this threshold from being reached.

TYPE OF INSTRUMENTATION

Types of sensors selected on the basis of the measuring parameter as showed in table 1.

Table 1

Parameter	Sensor	Model	Manufacturer
Heat flux	Type T thermocouple	B50TX-CLASS 1	TC Instrumentación y Medida
	Heat flux plate	HFP01SC	Hukseflux
	Thermal properties sensor	TP01	Hukseflux
Capillary pressure	Hygrometer	HMT333	VAISALA
	Digital hygrometer	SHT75	Sensirion
	Psychrometer	PST-55-150-SF	Wescor, Inc.
	Matrix humidity probe	Campbell 229-15	Campbell Scientific
	Stress meter	STCP-850	SDEC
Water balance	TDR type probe	Campbell CS 610	Campbell Scientific
Inclination	Buried clinometer	AG 906 biaxial	Applied Geomechanics
Displacement	Vibrating cord extensometer	ST-1	Soil Instruments
		ST-4	Soil Instruments

For heat flux:

- 30 temperature probes: 6 per type of coverage in sections 1 to 3.
- 12 heat flux plates, 2 per type of coverage in sections 1 to 3.

- 10 TP01 thermal properties sensors: 2 per type of coverage in sections 1 and 2, plus 1 in section 3.

For water balance:

- 48 passive TDR type probes for fixed attachment: 9 for covering layer I in sections 1 to 3 and 7 for covering layer II in these same sections.
- 18 stress meters: 3 for covering layer I in sections 1 to 3 and 2 for covering layer II in these same sections, plus 2 in section 4 of covering layer I and 1 in section 4 of covering layer II (plus one spare).

For capillary pressure:

- 39 hygrometers: 7 for covering layer I and 6 for covering layer II in sections 1 to 3.
- 42 psychrometers: 9 for covering layer I in sections 1 to 3 and 5 for covering layer II in these same sections (plus two spares).
- 20 matrix humidity probes: 3 for covering layers I and II in sections 1 to 3 plus 1 in section 4 of covering layers I and II (plus one spare).

Geomechanical parameters:

- 2 clinometer tubes for displacement measurement buried horizontally in the zone corresponding to the edge of the step in the natural terrain (6 points each): one for each covering layer.
- 4 TDR cables 2 for displacement measurement buried horizontally in the zone corresponding to the edge of the step in the natural terrain: two for each covering layer.
- 8 topographic levelling markers: 4 for each covering layer.
- 18 extensometers for the PEAD sheet (type ST1): 9 for each covering layer.

The following shall be additional for the measurement of different parameters in the concrete simulating the cells:

<u>In fresh concrete (covering layer I)</u>:

- 3 hygrometers
- 3 thermocouples
- 3 digital hygrometers (Sensirion)
- 3 psychrometers
- 3 extensometers (type ST4)

<u>In dry concrete (covering layer II)</u>:

- 3 hygrometers
- 3 thermocouples
- 3 digital hygrometers (Sensirion)

The following data recording equipment has also been acquired:

- Recording and reading equipment for TDR
- Recording and reading equipment for CR7 psychrometers

EXECUTION OF TEST COVERING LAYER

Work began on the test covering layer in late May 2007, with excavations in an area located close to an industrial zone of El Cabril and finished in November 2008.

Following the emptying and excavation works corresponding to the drains and removal piping, the slope foot wall and cell wall simulation slabs were prepared and concreted.

The instrumentation corresponding to the concrete walls was installed during this process.

This was followed by preparation of the seating for the prefabricated parts forming the instrumentation gallery and by the positioning of these parts and linking of their joints.

The drainage troughs for the extractions from the different layers were then undertaken, along with the lower backfill of the layers in both tests.

The backfill having been completed and compacted and the suitability of the slopes having been checked, the geo-fabric and PEAD sheets were installed, these serving to isolate the covering from groundwaters or lateral seepage, which might alter the measurements obtained by the instruments.

The PEAD sheet was extended such that it covered the entire test surface (including the galleries) and was reinforced with a geo-mesh. During this phase the instrumentation corresponding to the PEAD sheet was installed, and currently the first layer of sand is being put in place. After that the clay and soil layers are placed with its imbibed sensor inside.

CONCLUSION

As an important component of the Low and Intermediate Level Waste Disposal System, the Final Cap have to provided long-term protection of the concrete vaults (300 years). For that reason a large scale test should be built to get enough data to validated the thermo-hydraulic and structural design and permit develop the license project. The design of the final cap is based on clay and polyethylene materials.

This large scale test will be under operation during five years to collect data for the project .

REFERENCES

The following documents have been taken as a reference in drawing up this report:

1. Directive 96/29 EURATOM Radiological protection for workers and public members against risk of ionization radiation.

2. IAEA/SS63 Design, construction, operation, shutdown and surveillance of repositories for solid radioactive waste in shallow ground.

3. IAEA/SSS-WS-R-1 Near surface disposal of radioactive waste.

4. ICRP/81 Radiation protection recommendations as applied to the disposal of the long-lived radioactive waste.

5. Regulatory Guide 1.60 Design response spectra for seismic design of nuclear power plants.

6. El Cabril Disposal Facility Safety Study

7. Principles and Practice of Waste Encapsulation, by Jack A. Caldwell and Charles C. Reith.

8. Testing project for the covering layer for low and intermediate level waste disposal at the El Cabril facility.