# Technical Milestones for Emplacing Vitrified Waste Canisters into Horizontal Disposal Drifts in a Clay Host Formation - 10019

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## ABSTRACT

Andra carried out between 2004 and 2009 some research and development work, in order to investigate the industrial feasibility of excavating horizontal disposal boreholes in indurated clay and of safely emplacing vitrified waste canisters into them. The present document relating this activity is twofold.

The first part describes the development of two (2) full scale systems: a “Pushing Robot” and a “Push Pull Chain” which were designed for emplacing vitrified waste canisters, the basics of their functioning and the technical achievements obtained at the end of the two (2) test campaigns carried out in surface facilities. An overview of the new technical improvements contemplated is also provided.

The second part presents concisely the excavation technology used in situ (i.e. in the French Underground Laboratory at Bure) for pilot drilling various cased and uncased experimental horizontal boreholes. The case story of the preliminary excavation trials carried out in 2009 and the related technical challenges are discussed. The planning of the new test hole drilling campaigns (scheduled in 2010-2011) is also presented.

The successful completion of the Pushing Robot and Push Pull Chain test campaigns confirms the mechanical feasibility of emplacing vitrified waste canisters into horizontal disposal boreholes. The developed technologies are simple and robust. Additional simplifications and improvements are considered for the system to be operated in the future industrial repository. A new development is planned in 2010-2011.

The capacity to satisfactorily drill and case 40-80m long horizontal disposal cells in indurated clay with a minimum clearance between the borehole wall and the liner extrados is not yet fully demonstrated, but promising results pave the way for additional tests planned within the same period 2010-2011.

This technically demanding mining milestone has yet to be reached concurrently with the positive completion of the new industrial emplacement system in order to “design freeze” the global vitrified waste disposal concept.

## BACKGROUND

The background of the work carried out is embedded in Andra’s Dossier 2005 [1] which served as a reference document for the passing of the December 28$^{th}$, 2006 law now governing Andra’s activities.

### The vitrified waste and its conditioning in C type disposal packages

The vitrified waste to be emplaced is a High Level and Long Lived (HLLL) waste which contains both short-lived radionuclides, usually in large quantities (high level), and long-lived radionuclides in medium quantities. It is conditioned in “primary packages” (total volume is around 5000 m3). Each primary package of vitrified waste is placed in a watertight “over-pack” made of non-alloy steel with a thickness of

55mm. The mass of the standard disposal package thus created (also called C type disposal package) is around 2 metric tonnes.

Figure 1 shows such a C type disposal package.

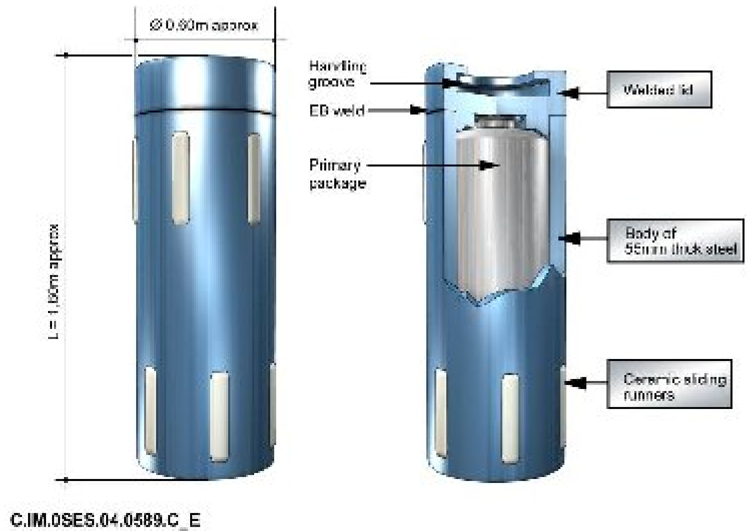


Fig. 1. C type disposal package composition concept as presented in Dossier 2005

The disposal package is equipped with 12 (six at each end) ceramic sliding runners. That feature (i) reduces the friction coefficient (hence the pushing force), when emplaced inside the steel liner of the disposal cell, and (ii) at a later stage prevents “corrosion sticking” at contact between the outer wall of the package and the inner wall of the liner, which is detrimental to a potential retrievability.

**Disposal concept design for C type packages**

The waste package disposal facilities and the transfer and emplacement processes are designed with the aim of simplifying any waste package retrieval operations which may be decided, using, if possible, similar means to the ones used for emplacement. As a result, clearances for handling purposes that must be durably maintained are provided between the package and the cell walls. An annular gap of a few centimetres (around 2.5cm at the diameter) is currently adopted. This value is compatible with the handling of the waste canisters by a pushing system (Pushing Robot or Push Pull Chain).

C type waste disposal cells are dead-end, horizontal boreholes with an excavated (drilled) diameter of approximately 0.7m. At this stage, their length has been limited to around 40m in the reference disposal concept, but it could be extended in the future to 80-100m. On closure, the cell is sealed by a swelling clay plug held mechanically by a concrete retaining plug.

The useful part of the cell consists of a permanent steel sleeve. The choice of steel is justified by its mechanical strength and the ease it offers for package handling in the cell. The sleeve is in contact with the rock. The thickness (pre-sizing is 25/35mm) of the sleeve (also called casing or lining) must guarantee the mechanical strength of the cell and support the tool thrust during excavation. A minimum annular space is required between the sleeve extrados and the borehole wall. A value of about 2cm at the radius corresponds to a conservative dimensioning and includes a margin to prevent jamming at time of excavation.

Figure 2 below shows the layout concept of such a disposal cell.

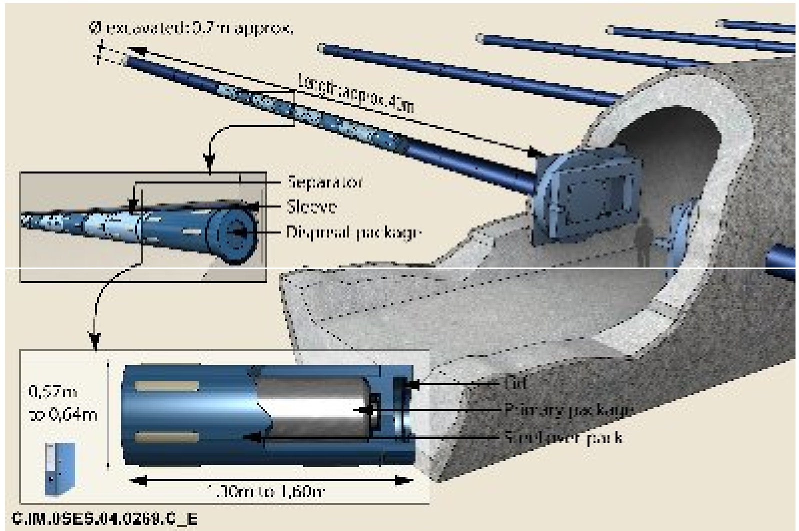


Fig. 2. Vitrified C type waste disposal cell concept as presented in Dossier 2005

**The C type package transfer from surface to the underground disposal cell mouth**

The C type package transfer process in the deep geological repository may be split into two (2) phases:

- The transfer from surface facilities to underground infrastructures (approx.550m deep). The related technical issues are not discussed in this paper.
- The emplacement per se of the waste into the disposal cells (for that second phase Andra has developed the 2 handling solutions which are presented hereafter).

The equivalent residual dose rate of disposal packages does not allow workers to handle them without radiological protection. In the repository, disposal packages are conveyed (from surface to underground) inside shielding transfer casks that are designed to limit operators' exposure below the corporate annual dose requirements prescribed by Andra (5mSv/year).

Once inside the repository underground infrastructures, the casks are conveyed to the disposal cells on a dedicated vehicle called the "Docking Shuttle". This equipment is designed to reload the cask at the crossroad to the access drift and to convey it in front of a disposal cell mouth to which it will be docked.

## THE C TYPE PACKAGE EMPLACEMENT PROCESSES

For emplacing the C type disposal packages Andra has successively developed two (2) separate systems:

- an internal device, hereafter called the "Pushing Robot" (the system is said to be "internal", because it relies on a robot that penetrates deep into the disposal cell and pushes one (1) to three (3) packages at a time up to the final location in the cell). The Pushing Robot is power-driven by a compressed air motor. Its includes two (2) pneumatic toric jacks (or packers) which are successively inflated and deflated to allow for the robot crawling inside the liner, while moving (pushing forward at time of emplacement or pulling back if retrievability is required) the disposal package. Figure 3 shows the working principle of the Pushing Robot.

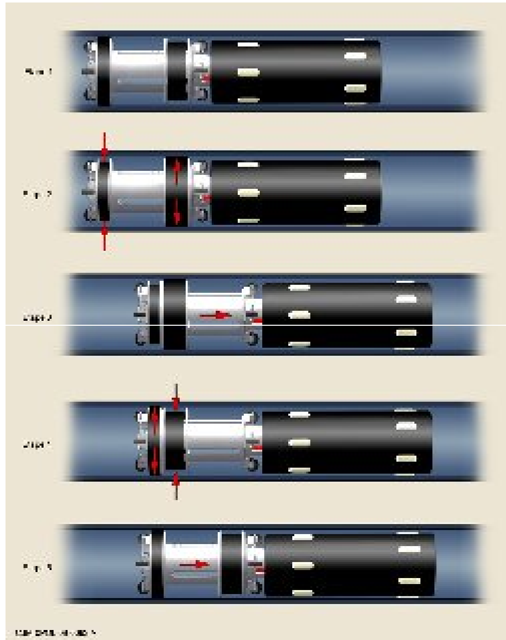

Fig. 3. Pushing Robot Working Principle

- An external device, hereafter called the “Push Pull Chain” (the system is said to be “external”, because the chain penetrates only a few decimetres into the cell head). The Push Pull Chain is electrically power driven and lodged inside a specific box mounted on top of the shielding cask. When activated, it penetrates into the cask and then pushes the disposal package (initially located inside the shielding cask) into the cell head. The package end comes at contact with that of a previously emplaced package and then the chain pushes at a time several (up to 20) packages inside the cell liner. Figure 4 shows the working principle of the Push Pull Chain.

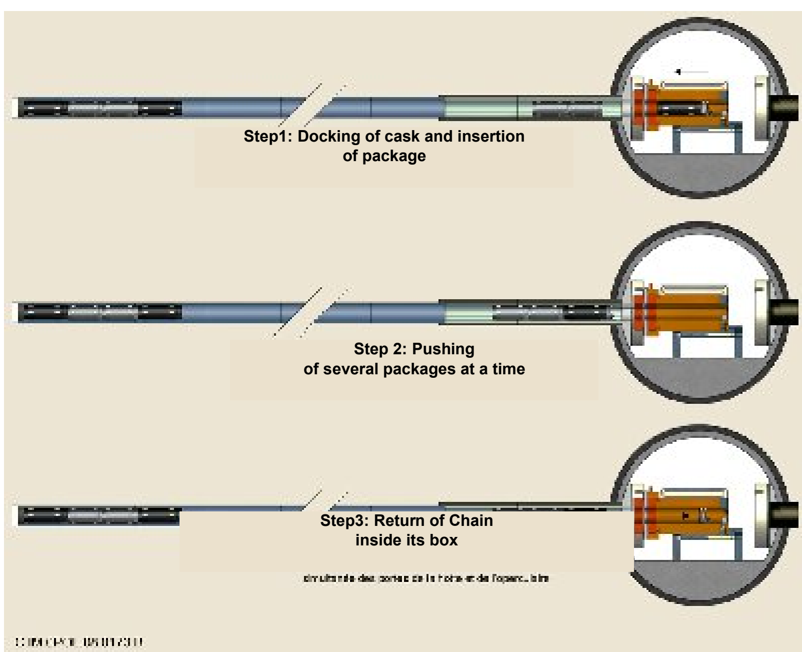


Fig. 4. Push Pull Chain Working Principle

These 2 handling systems and the related results obtained at the end of the 2 test campaigns are now discussed.

**The Pushing Robot Development**

Within the framework of the European Commission funded ESDRED Project, a research programme was launched in order to design, manufacture and test the necessary technical components for the transport and emplacement of C type packages into horizontal disposal cells excavated in indurated clay. The main objective was to check the functionality and reliability of a suitable emplacement technology. In addition, the results of the tests and investigations should provide later to the public at large valuable information on practical, down-to-earth operations likely to be encountered in the future industrial repository.

The development of this system included all the associated equipment needed to demonstrate a full emplacement sequence starting with a loaded shielding cask arriving (on the Docking Shuttle) in the access drift, followed by a docking of the cask shielding gate onto the cell mouth shielding gate and finishing with the deposition of the disposal package inside the cell lining. This development took place between mid-2004 and mid-2009.

The main development tasks were subcontracted by Andra i) to a packer manufacturer called Musthane from May 2004 to March 2006 for the Prototype phase (where the ceramic sliding runners composition and shape and the inflatable jacks design were validated), ii) to an industrial integrator called Cegelec for the full-scale design phase which lasted from July 2007 to June 2009. The full-scale design of the emplacement system comprised the following main components, which are detailed in Andra's Dossier 2005 [1].

- A simplified transport unit (Docking Shuttle) with hydraulic drive motors,
- A shielding transfer cask, providing appropriate radio-protection at all times during the transport and emplacement process,
- A docking table for connecting the transfer cask to the cell mouth, and
- A Pushing Robot to introduce the package into the disposal cell.

Figure 5 shows the arrangement of the emplacement system after docking, as it was set up, in its endurance-testing configuration. A length of 100m of liner mock-up was installed (instead of only 40m in the reference disposal cell) in order to assess the mechanical capacity of the system to work in an extended cell. A former workshop in Saint-Chamond, in the vicinity of Saint-Étienne (Loire District) was selected as a test site. The test bench components were assembled locally.

The test programme comprised performance tests and other tests to assess and to resolve operational challenges and breakdowns so that contingency plans were developed and implemented.

The development, fabrication and demonstration tests for the Pushing Robot system were successful. All the components were designed and fabricated as planned. The components were delivered to the test site between June and mid-August 2008. The test campaign followed until November 2008. The performance objectives were met with a demonstrated capacity to push up to 3 disposal packages at a time at an average travel speed (mean value over the cycle) of 1.2m/mn in a 100m long mock-up cell.

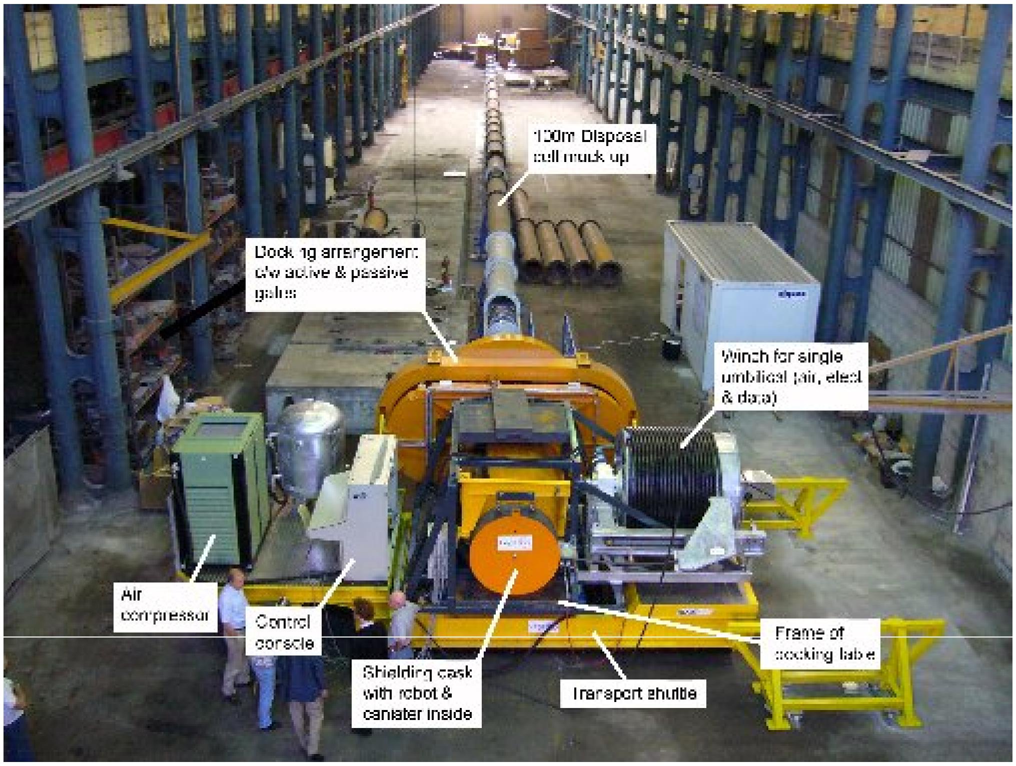


Fig. 5. General view of the Pushing Robot Demonstrator as set in Saint-Chamond

The operations were completed by an endurance-test campaign that lasted until the end of 2008. The whole system turned out to be very robust and reliable. No significant mechanical failures or design flaws were identified. Only one piece of equipment (the upper part of the electrical screw jacks used for elevating the docking table) showed abnormal wear (but no breakage occurred), when all moving pieces were dismantled for inspection and assessment of the “wear factor”.

In January 2009, Andra decided to run an additional test configuration (cf. Figure 6), in which an exaggerated theoretical shape of a TBM (tunnel boring machine used for excavating the cell) trajectory is simulated (i.e. an axis of the drilled hole, which is not straight, but curved). The results were also quite satisfactory and showed that the system strongly complied with the potential geometrical construction defect of a future disposal cell. The only observed phenomenon was an increase of the required pushing force to move the packages forward, but that increase was not detrimental to an effective and smooth emplacement process.

The emplacement system have since been moved and reinstalled in Andra’s show-room (Bure-Saudron technical centre, near the Underground Research Laboratory) where it has been operated since July 2009 for the public at large and other stakeholders.

Fig. 6. Pushing Robot Demonstrator tested with a mock-up liner in an S type configuration

**The Push Pull Chain Development**

Within the frame of the preparation of its Dossier 2009 (including additional studies on the main safety options of a repository), Andra decided to develop an alternate emplacement system. The rationale was to reduce the overall dimensions and weight of the loaded shielding cask coming with its emplacement system incorporated. Such a reduction in weight and mass is of significant interest since i) it minimizes the payload transferred from the surface facilities to the underground infrastructures, ii) it enables to reduce the cross section of the access drift, hence also reducing the cost and volume of excavated material at time of construction. The use of a Push Pull Chain technology was then selected as a promising substitute to the Pushing Robot.

The Design, Fabrication and Testing contract for the Push Pull Chain (a prototype phase only was developed within the time window available) was allocated by Andra to the same Industrial Integrator as the one selected for the "Pushing Robot", namely Cegelec. This work was carried out between September 2008 and December 2009.

The full-scale design of the emplacement system comprises the following main components, which are detailed in Andra's Dossier 2009:

- A shielding cask equipped with a rotating door and a sliding package-insertion and removal system (pushing chain), and
- A bearing structure on which the cask and the control board are assembled.

Before the pushing force is triggered, the chain is rolled up in a store box in order to minimise the length of the equipment located in the axis of movement of the load. The length, width, geometry and assembling mode of the chain links are adapted to the load to be transferred. A "pusher head" equipped with a grab is inserted between the chain and the disposal package ending.

Via a local control unit and a communication interface with the control room (Wi-Fi system), the package is introduced in (or retrieved from) the cell either in automatic or manual mode and driven either locally or by remote control.

In order to validate that process and verify at scale 1 the behaviour of the Pushing Chain and of disposal package mock-ups, a system prototype was fabricated between January 2009 and June 2009, and then mounted in a test site at Chassieu, near Lyon. The Push Pull Chain was dimensioned to enable the moving of up to 20 packages at a time. Trials took place from July 2009 to November 2009. This prototype is now being re-installed at Andra's Technology Centre, in Saudron, near the Bure Underground Laboratory (by the side of the Pushing Robot System) and should be on public display in spring 2010.

Figure 7 shows the Push Pull Chain at time of commissioning while Figure 8 provides an overall view of the test bench as set up at Chassieu.

Fig. 7. The Push Pull Chain (fully extended) and its box at rear

The test results turned out to be promising:

- The system is simple and rugged,
- The travel speed is in line with the requirements (up to 3m/mn),
- The capacity to push up to 20 packages was demonstrated,
- No damage to package endings was identified.

Fig. 8. View of test bench at Chassieu with Push Pull Chain at front

As an extension to the initial test programme, it was decided to test a new type of ceramics for the sliding runners: the first generation of runners, made of alumina, used initially for the Pushing Robot and the Push Pull Chain applications, was changed to the profit of zircon made runners. A significant progress was obtained, since the pushing force necessary to move the packages was divided by a factor 2.

## EXCAVATION OF C TYPE DISPOSAL CELL

The C type waste package concept cannot be validated as a whole without demonstrating the geo-technical capacity to excavate and case the disposal cell. For that purpose, Andra hired the services of a drilling company called CSM-Bessac who was contracted for excavation trials in the Bure URL underground facilities.

A specifically patented TBM (Tunnel Boring Machine) was designed, fabricated, installed in situ and put in operations. Figure 9 shows a schematic of the drilling machine with the borehole casing (which is moved forward as the rotating head progresses) and the guiding shoes, while Figure 10 shows the auger inside which is necessary for evacuating the cuttings.

The first 3 trial holes which were drilled between April and May 2009 produced some encouraging results:

- A depth of 20 m (half the reference target length) was reached and the borehole cased,
- An open hole was kept as such to monitor the differed behavior of the clay formation,
- The drilling parameters (weight on bit, rotating speed, rate of penetration) were measured and progressively improved.

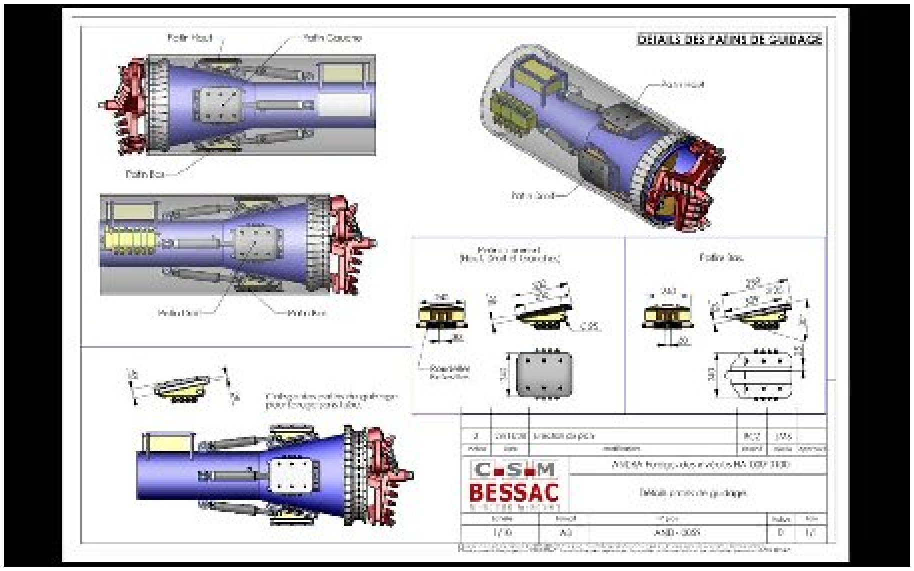


Fig. 9. Design principles of the TBM Bessac machinery (patented)

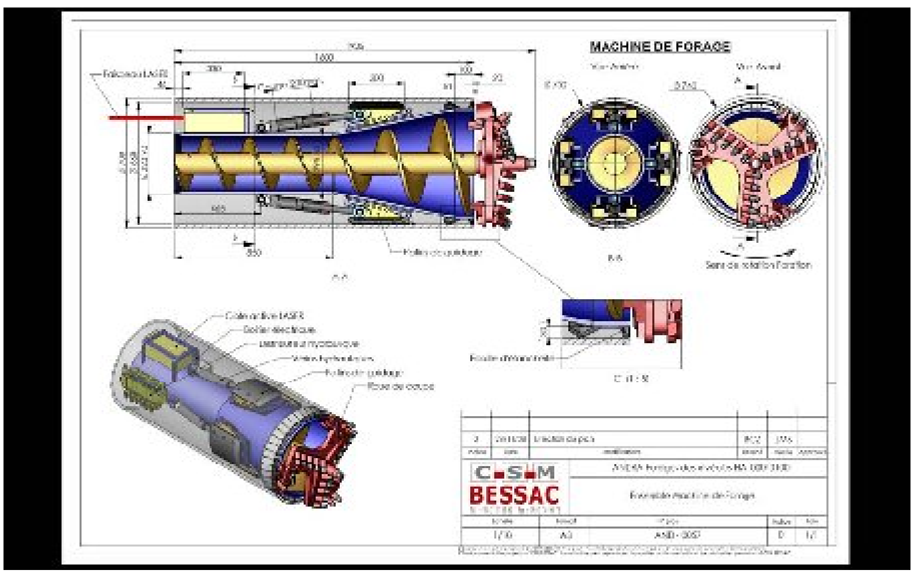


Fig. 10. Auger and evacuation details (patented)

It was however decided to postpone the remaining test campaign so as to improve the drilling system, the quality and straightness of the casing connections. It was also deemed necessary to acquire a better knowledge of the differed behaviour of the clay formation and of its interaction with the casing extrados.

Figure 11 shows the drilling machine at work in the Bure laboratory underground facilities.


Fig. 11. TBM being introduced into the cell conductor pipe

## CONCLUSION AND OUTLOOK

The successful completion of the Pushing Robot Demonstrator Test Campaign was a good and early confirmation of the mechanical capacity to safely emplace C type canisters into a horizontal disposal cell. The suitability of a ceramic material (such as alumina) for the sliding runners as well as their geometrical shape was also confirmed.

The very good performance achieved at a later stage with the Prototype Push Pull Chain emplacement system was in line with the established specifications. The use of zircon as a new friction material was also identified as an asset.

The simplification in design obtained with this alternative system paves the way for more simplifications to come in the industrial machine likely to be used in the future geological repository. Within the frame of the elaboration of the Dossier 2009 (issue now pending) a combination of the two (2) technologies is now envisaged by Andra:

- In a first phase the Push Pull Chain System, mounted on the shielding cask, would introduce (after docking to the cell mouth) the canister in the cell head first meter. The shielding cask would then be undocked and moved back (empty) to the surface facilities (for a new sequence of canister loading followed by a new transfer from surface to underground). The system envisaged is illustrated in Figure 12 (left) below. The size of the chain is dimensioned for pushing up to 3 canisters at a time only and not for 20 as implemented in the Prototype testing.
- In a second phase, the Pushing Robot system would be operated in order to emplace the disposal package deep into the cell up to its final location. In that instance, the robot is working concurrently with the shielding cask mentioned above. The system envisaged is also illustrated in Figure 12 (right) hereafter.

This new solution, which is planned to be developed and tested at full scale in 2011, is combining 3 advantages:

- An optimisation of logistics, thanks to transfer and emplacement operations run concurrently,
- A reduction of weight and dimensions of the 2 emplacement systems,

- A potentially significant economy on excavated material for the access drifts.

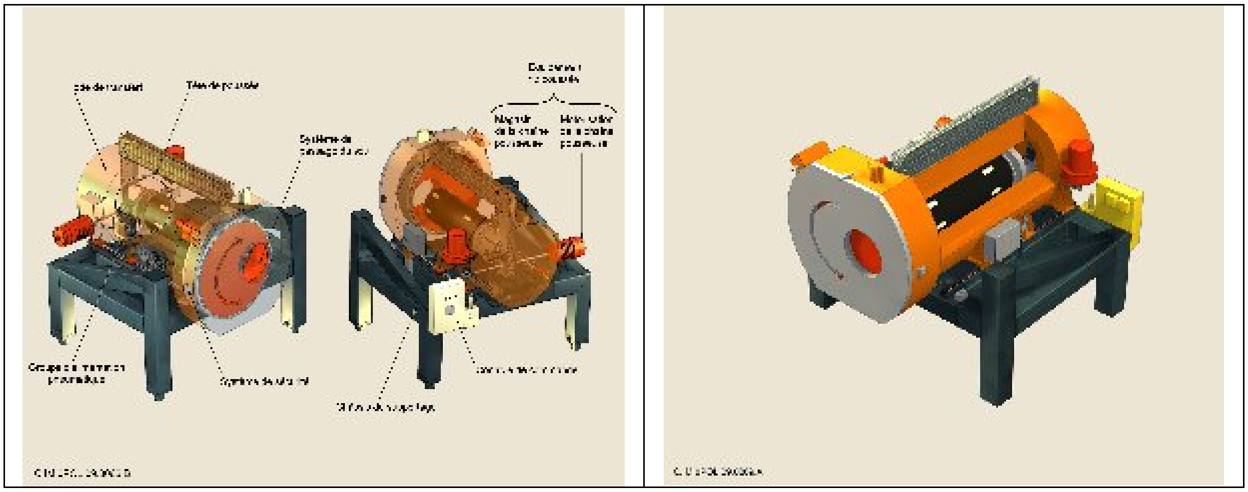

Fig. 12. Concept of the combined emplacement system - Push Pull Chain (left) and Pushing Robot (right)

The first borehole excavation results obtained with the TBM machine are promising. The modifications of the machinery and an optimization of the drilling parameters will be instrumental to demonstrate that Andra has effectively a thorough, solid and field proven disposal concept for C type waste packages. The objectives (planned end 2010-early 2011) are twofold:

- Reach (at the best possible penetrating rate) the target length of 40m, with an as straight as possible trajectory,
- Check the technology limits and in particular whether the 80-100m cell length can be achieved.

The successful completion of the newly planned excavation trials combined with a positive test campaign of the new emplacement system will be instrumental to elaborate a convincing demonstration of Andra's capacity to build and operate the future deep geological repository.

**ACKNOWLEDGMENTS**

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