

Prototype Pushing Robot For Emplacing Vitrified Waste Canisters Into Horizontal Disposal Drifts

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ABSTRACT

Within the French Underground Disposal concept, as described in ANDRA's (Agence National pour la Gestion des Dechets Radioactifs) Dossier 2005, the Pushing Robot is an application envisaged for the emplacement (and the potential retrieval) of "Vitrified waste packages", also called "C type packages". ANDRA has developed a Prototype Pushing Robot within the framework of the ESDRED Project (Engineering Studies and Demonstration of Repository Design) which is co-funded by the European Commission as part of the sixth Euratom Research and Training Framework Programme (FP6) on nuclear energy (2002 – 2006).

The Rationale of the Pushing Robot technology comes from various considerations, including the need for (1) a simple and robust system, capable of moving (and potentially retrieving) on up to 40 metres (m), a 2 tonne C type package (mounted on ceramic sliding runners) inside the carbon steel sleeve constituting the liner (and rock support) of a horizontal disposal cell, (2) small annular clearances between the package and the liner, (3) compactness of the device to be transferred from surface to underground, jointly with the package, inside a shielding cask, and (4) remote controlled operations for the sake of radioprotection.

The initial design, based on gripping supports, has been replaced by a "technical variant" based on inflatable toric jacks. It was then possible, using a test bench, to check that the Pushing Robot worked properly. Steps as high as 7 mm were successfully cleared by a dummy package pushed by the Prototype..

Based on the lessons learned by ANDRA's regarding the Prototype Pushing Robot, a new Scope of Work is being written for the Contract concerning an Industrial Scale Demonstrator. The Industrial Scale Demonstration should be completed by the end of the second Quarter of 2008.

INTRODUCTION AND BACKGROUND

The National Radioactive Waste Management Agency, or ANDRA (Agence Nationale pour la Gestion des Dechets Radioactifs), has developed a Prototype Pushing Robot for the emplacement and the potential retrieval of "Vitrified waste packages", also called "C type packages". This work was carried out within the framework of the ESDRED Project (Engineering Studies and Demonstration of Repository Design) which is co-funded by the European Commission as part of the sixth Euratom Research and Training Framework Programme (FP6) on nuclear energy (2002 – 2006).

The Vitrified Waste and Its Conditioning in C type Packages

The vitrified waste (conditioned as a C type package) 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 to very large quantities.

Class C waste consists of fission products and minor actinides separated out during fuel reprocessing. This waste is conditioned by incorporating it into a glass matrix. Glass has a particularly high and long-lasting confinement capacity provided the physical-chemical properties of the environment are favorable.

Conditioning waste involves (i) solidifying and immobilising waste produced in dispersible form (usually liquid) and (ii) placing the waste in a container to facilitate handling and storage at industrial facilities. This first conditioning yields “primary packages”. The total volume of “primary package” C type waste to be emplaced is 4,770 cubic metres (m³).

Primary packages must then be set into “disposal packages”. To prevent the inflow of water onto the waste during the thermal phase, each primary package of vitrified waste is placed in a watertight over-pack throughout this phase. This over-pack is made of non-alloy steel with an effective thickness of 55 millimeters (mm), dimensioned very conservatively to withstand corrosion for a thousand years. The mass of the standard disposal package is almost 2 tonnes.

Disposal Concept Design for C Type Waste

A Disposal Concept consists of disposal cells (underground caverns), excavated in the argillite formation, containing waste disposal packages.

The architecture studied contains disposal cells for various categories of waste within specific repository zones. The repository zones for Class B and C waste and, if applicable, Spent Fuel (SF) are therefore physically distinct from each other.

The waste package disposal facilities and processes are designed with the aim of simplifying any waste package retrieval operation, which may be decided by future generations. Preference is notably given to the use of similar means to the ones used for emplacement. As a result, clearances for handling purposes that can be durably maintained are provided between the packages and/or between the packages and the cell walls. These clearances are minimized, however, with a view to limiting geomechanical disturbances.

The design of Class C waste disposal cells is the result of the search for a physical and chemical environment suited to the packages, and of the thermal design associated with heat dissipation by conduction through the rock. As a result, the thermal load per unit surface area is limited not only on a repository scale but also on a cell scale.

Class C waste disposal cells are dead-end, horizontal boreholes with an excavated diameter of approximately 0.7 m. At this stage, their length has been limited to around 40 m, a length considered reasonable in view of construction and handling techniques. The boreholes have a metallic sleeve, which supports the argillites and enables package handling for their emplacement and possible future retrieval. They contain from 6 to 22 C type packages.

Packages characterized by moderate thermal power may be disposed side by side – this is the case of package type C0. For packages with higher thermal power (package types C1 to C4), a conceivable storage period prior to emplacement in the repository has been determined in order to limit thermal disturbance. The duration of this storage period is 60 to 70 years depending on the type of package. After such a storage period, the residual thermal power of the packages still requires them to be separated by spacers in a single disposal cell. Fig. 1 below shows the layout concept of such a disposal cell.

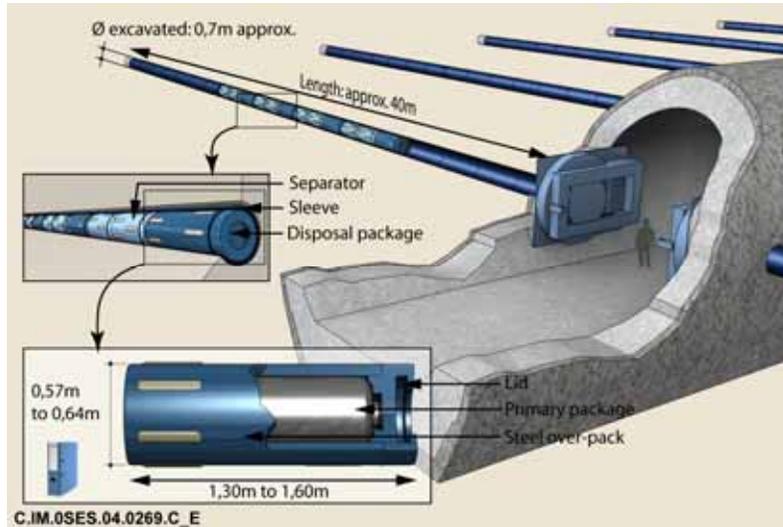


Fig. 1. Vitrified C type waste disposal cell (fully filled in) before sealing operations

At closure, the cell is sealed by a swelling clay plug held mechanically by a concrete retaining plug.

The part of the cell used for disposal is shielded by 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 of the sleeve must guarantee the mechanical strength of the disposal cell and support the tool thrust during excavation. The strength calculations led to a pre-sizing thickness of 25 mm.

A minimum annular space is required between the sleeve and the ground. The maximum value, of about one centimeter at the radius, corresponds to a conservative dimensioning and includes a margin to prevent jamming at the time of excavation and emplacement of the sleeve.

Functional clearance between package and sleeve allows waste-package handling (emplacement and retrieval) to take place. A total diameter clearance of a 3 centimeters (cm) is currently used. This value is compatible with the handling of the packages by a pushing robot.

A metal plug is intended to ensure radiological protection during disposal cell sealing operations, thereby eliminating the need to use the protection transfer cask during the installation of the swelling clay (hence possible with simple and reliable non-nuclear methods). Preliminary design calculations have been performed to limit the dose rate in the access drift to less than 3 microsieverts per hour ($\mu\text{Sv/h}$). The metal plug can consist of a steel cylinder approximately 50 cm long (two thirds devoted to biological protection and one third adapted for gripping by handling tools), possibly covered with ceramic to prevent adhesion to the sleeve (under the effect of corrosion).

The C Type Package Transfer from Surface to the Disposal Cell Mouth

The principle for transferring the disposal packages between the surface installations and the disposal cells depends mainly on radiological protection considerations. The residual rate of equivalent dose around the disposal packages makes it impossible to handle them without radiological protection for the personnel. The principle adopted therefore consists of putting the packages into a shielded so-called "radiological protection" transfer cask within the surface installations. This transfer cask is then moved to the entrance of the disposal cells where the disposal packages are extracted and then placed in their final position in the disposal cell.

The cycle of transferring the protective transfer casks containing the disposal packages from the surface installations to the disposal cells consists of the four following stages:

- Loading the transfer cask at the surface;

- Transferring the transfer cask into the shaft;
- Transferring the transfer cask through the drifts; and
- Docking the transfer cask at the head of the cell.

The transfer casks used for transferring the disposal packages are designed to only contain a single disposal package. They are dimensioned to meet the following two requirements:

- They have a radiological protection function of limiting the exposure of personnel to below the limits of the annual dose (5 milliSv/year).
- They also contribute to maintaining the confinement of the radionuclides if the transfer casks are accidentally dropped in the descent shaft.

A transfer cask consists of a handling frame with a shielded container on top. The container is equipped with a shielded door for loading and unloading the packages from the side. In the case of Class C waste, the shielded container is cylindrical and the door is a "sliding" type. In both cases, the transfer cask is fitted with an on-board mechanical unit consisting of a pushing robot, used to extract the packages and place them into the disposal cell.

The shielded container has walls made of steel/Plaster/Polyethylene with Boron addition (PPB)/steel sandwich panels. The PPB, a neutron-absorbing material, has been chosen because of the type of radiation emitted by vitrified Class C wastes and SF. The total thickness of the side walls, bottom and the door is of the order of 400 mm for the C type waste package transfer cask.

The loaded weight of the C type waste package transfer cask is about 41 tonnes.

THE C TYPE PACKAGE EMPLACEMENT CONCEPT

The disposal packages for Class C wastes weigh about 2 tonnes. Type C1 and C4 packages are about 0.60 m in diameter and about 1.60 m long. Type C0 packages are 0.65 m in diameter and about 1.30 m long. The placing of such cylindrical radioactive packages into a horizontal disposal cell of circular section requires a remote-controlled machine capable of being contained in the shielded transfer cask and of being able to transferring the packages to their final position with a functional clearance between the packages and the cell as small as possible.

The equipment studied, complying with the principle described above, consists of three parts:

- A mobile robot;
- A fixed equipment mounted on the chassis of the protective transfer cask; and
- Fixed equipment installed at the head of the disposal cell.

The robot is connected to the fixed equipment of the transfer cask by means of an umbilical cable. The fixed equipment at the head of the cell contributes with the transfer cask to the radiological protection of personnel.

The Pushing Robot

The pushing robot is an entirely hydraulic apparatus. The choice of hydraulics is mainly related to the fact that this technology allows the design of small-sized, but high-powered piece of equipment. This aspect is also very suitable for the size constraints that characterize the environment in which the waste-package handling process takes place.

This robot consists of a frame equipped with rollers and a series of hydraulic jacks. Its dimensions are about 1.30 m long and 0.55 m in diameter.

The robot fulfills two functions that are conducted one after the other: (1) pushing the package; and (2) moving the robot body. These two functions are accomplished by two main mechanisms activated by jacks:

(1) an axial pusher; and (2) four side jaws. Two side jaws serve to block the robot body and the other two block the axial pusher. The role of the longitudinal jack is to push the packages.

A gripper situated at the head of the robot allows the packages to be withdrawn.

During the pushing phase, the robot body is maintained in a fixed position by means of the side jaws being forced/locked against the steel sleeve. These jaws are unlocked between pushing phases and the robot body moved forward by retracting the longitudinal jack. The kinetics of the pusher robot is illustrated in Fig. 2.

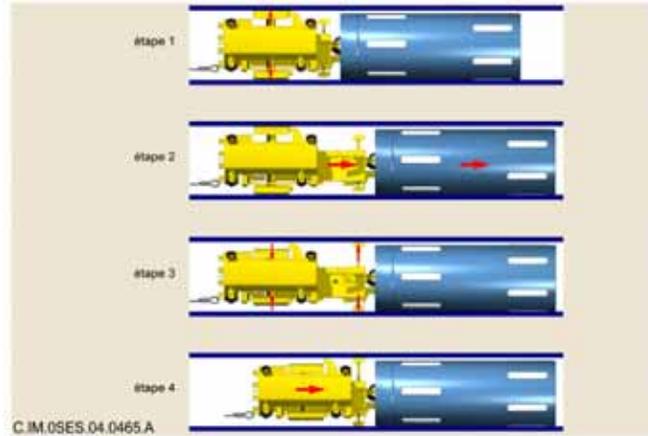


Fig. 2. Illustration of the principle of the pushing robot operation

The fixed equipment attached to the transfer cask consists of a return winch and a hydraulic unit that supply the robot with demineralized water for operating the jacks. The return winch allows the robot to be brought back in the event of a breakdown. This equipment is connected to the robot by a cable and flexible hydraulic pipes.

The shielded container is equipped with a moveable sleeve containing the packages and the pusher. This sleeve can move over about 80 cm to ensure a physical continuity with the cell sleeve, which in turn is connected to the shielded trap door installed at the head of the disposal cell.

The head of a disposal cell consists of a shielded trap door composed of a fixed part connected to the cell sleeve and a sliding door operated by the door of the transfer cask when this is docked. This shielded trap door provides the cell's radiological protection, plus supplementary protection when the transfer cask is docked. This protection, provided by a thick layer of steel/PPB composite material, is similar to that of the design of the transfer cask walls.

Description of the Process for Waste Emplacement Inside the Disposal Cell

A cycle of emplacing C type packages is divided into the following three stages:

1. The transfer cask is docked on the shielded trap door at the head of the cell. The doors of the transfer cask and shielded trap door are then mechanically coupled. The door of the transfer cask is the motor that drives that of the disposal cell.
2. The robot activates the transfer of the disposal package to its final position in the disposal cell according to a "step-by-step" advance process.
3. The robot is brought back into the transfer cask using a return winch installed on the transfer cask outside frame. The doors of the shielded trap door and the transfer cask are then shut.

The time to complete a full cycle of pushing a package in place over a distance of about 20 m is estimated to require about 2 hours.

THE PROJECT DEVELOPMENT OF THE PUSHING ROBOT CONCEPT: OBJECTIVES AND PROCUREMENT PROCESS

The use of the pushing technology as an emplacement means for the C type canisters have not been successfully tested so far (either by ANDRA or by the other national implementers). The need for a practical feasibility test was identified as a priority by ANDRA and will be implemented within the context of the ESDRED Project.

Objectives

The main objectives established within the contract for the design, manufacturing and testing of a prototype pushing robot system are listed below:

- The primary objective was to demonstrate the technical feasibility of using a “Prototype Pushing Robot” for moving C type canisters into a horizontal disposal cell steel tube (inner steel sleeve). It included designing, fabricating and testing a very basic version of an emplacement system, with a simplified shielding cask mock up and a short length (around 6 m) of inner steel sleeve, to move a simplified mock-up of the C type canister (scale 1 for the outside diameter (OD) and for the length, the actual weight and an external geometry identical to the real one).
- The second objective was to confirm the suitability of the material and shape selected for the ceramic sliding runners (a technical choice, which was also questioned by the external Experts in December 2003) and to evaluate the extent of wear potentially induced on the sliding track by the back and forth movements of the C type canister.
- The third objective was to determine the main operational characteristics of the system and to assess their extrapolation to the future full-scale industrial demonstrator.
- The fourth objective was to evaluate the performance and the various limitations of the system (vis-à-vis its environment and its failure potential) and to take them into account for the design & construction of the future full scale industrial demonstrator.
- The fifth and final objective was to identify potential improvements which would be taken into account in the future full scale industrial demonstrator.

Procurement Process

In order to perform the work programme described above, ANDRA decided to subcontract and go through a procurement Process. The activities completed included:

- Preparation of technical specifications and of tender documents (as of May 2004);
- Selection of six pre-qualified firms and submission of Tender Documents (November 2004);
- Receipt of five bids and opening of bids (January 2005);
- Bid analysis, contract negotiation and execution of Contract (awarded to MUSTHANE and their sub-contractor CREATIV ALLIANCE) on the 25th of April, 2005; and
- Kick off meeting on the 26th of April, 2005 and subsequent implementation of contract.

This competitive bid process (and analysis of the various technical offers presented) enabled ANDRA to make its final choice regarding the technical options to be considered, which comprised either the initial basis of design (as contained in the Scope of Work) or the “Technical Variants” proposed by the various bidders. It was one of the “Technical Variants”, proposed by MUSTHANE’s sub-contractor CREATIV ALLIANCE, that was finally selected as the best suited approach to address the problems discussed above. The working principle of the Technical Variant selected is illustrated in Fig. 3. The reasons for selecting such a Technical Variant are exposed below by comparison to the basis of conceptual design contained in the original Scope of Work of the Request for Proposal (RFP).

Note: In parallel to this RFP process, ANDRA successfully implemented (outside the ESDRED Project) a qualification test programme of its own related to the “ceramic sliding runners” fixed on the overpack. The ceramic material (alumina) was selected and the shape of runners was finalized within this programme. The results obtained enabled ANDRA to order the fabrication of several sets of ceramic sliding runners and ensure their subsequent delivery to MUSTHANE, who needed to insert them into the grooves (housings) located at both extremities of the C type dummy canister used for the test campaign.

Justifications of the Technical Choices Made and Design Description

A comparison is made below between the conceptual design as proposed by ANDRA in the Scope of Work and the one proposed by MUSTHANE / CREATIV ALLIANCE in their technical bid and subsequently developed in the implementation of its work.

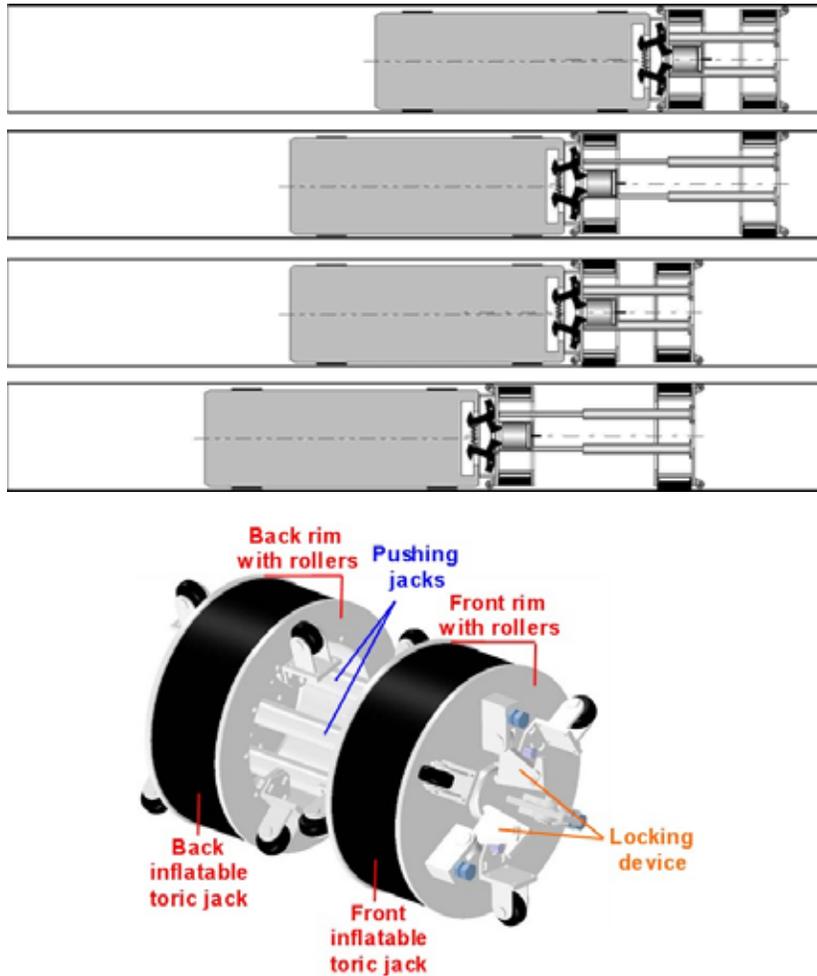


Fig. 3. Illustration of the working principle of the pushing robot (Technical Variant) (top) and schematic view of the pushing robot prototype (bottom)

Major Differences Between the Initial Concept and the “Technical Variant”

The main differences between the initial concept and the actual Prototype are as follows:

- Gripping supports (mounted on radially actuated hydraulic jacks) designed to resist the thrust on the canister are replaced by a unique “back inflatable toric jack” at the back of the robot.
- Return gripping supports (mounted on small radially actuated hydraulic jacks) are replaced by a unique “front inflatable” toric jack to the front of the robot.

- The canister retrieval system made up of three small longitudinal hydraulic jacks and a locking jack are replaced by a single central jack combined with three fingers (with return springs) actuated by an inflatable bag.

Motivations & advantages of design variations

Following are the three main reasons for the replacement of radially actuated hydraulic jacks by inflatable toric jacks:

- 1) Substituting pneumatic jacks for hydraulic oil jacks reduces the risk of potential pollution.
- 2) Thrust stresses are applied evenly on cell walls, therefore avoiding risks of out of round wear of the tube.
- 3) The mechanism is simplified, thereby making it more robust.

As for the canister retrieval system, the concept selected is also simpler and therefore more cost effective and more reliable. It is also pneumatic, therefore avoiding risks of pollution due to hydraulic oil leakage. Thus, the general principle of having an intrinsically safe (“fail safe”) system is achieved.

DESCRIPTION OF THE PROTOTYPE PUSHING ROBOT

General Description

The main components of the Pushing Robot Prototype are:

- A main inflatable toric jack at the back of the robot (comparable to a tire), mounted on a support rim fitted with trolleys used to take up pushing-pulling reactions of the canister;
- A secondary inflatable toric jack at the front of the robot, mounted on a second support rim, also fitted with wheels, designed to immobilize the robot during the return of the pushing-pulling jacks;
- A set of three hydraulic double-acting pushing jacks connecting both rims for longitudinal pushing-pulling (500 mm stroke);
- A set of three locking dogs actuated by a pneumatic locking jack to the front of the robot for canister retrieval (removal) and repositioned by a set of springs when the locking jack is at rest; and
- A set of solenoid valve block assemblies with hoses and control cables for the operation of all hydraulic and pneumatic jacks; and
- A set of digitalized sensors transmitting information.

Terminology used for the various jacks

In order to avoid confusion between the various types of jacks used in the robot, the following names are used in the rest of the report:

- For longitudinal jacks: “Hydraulic Pushing jacks” or “Pushing jacks”;
- For toric jacks: “Inflatable support jacks” or “Support jacks”; and
- For the central jack: “Pneumatic locking jack” or “Locking jack”,

Toric Jacks or Support Jacks

Both front and back toric support jacks have distinct functions. The back support toric jack is mainly used to resist the reactive forces created when the canister is moved in the cell. Incidentally, it can be used to remove an empty robot. The front support toric jack is only used for the return of the pushing jacks during their “step-by-step” movement (it is only subject to the travel force of a half robot on wheels estimated at less than 100 kilogrammes (kg)).

As the friction forces that need to be developed by these two support toric jacks are quite different, the “front” toric jack may have a smaller bearing surface. However, for the sake of cost reduction, one type only

was produced. The two toric support jacks are therefore identical in the prototype. They may be optimized in the industrial version. This type of toric jack has a number of benefits for the robot, including:

- It applies forces that are evenly spread over the full circumference of the cell inner sleeve (hence, no risk of out of round wear of the tube).
- The contact of an elastomer strip (slug) over the full circumference of the cell inner sleeve maximizes the efficiency of the jack and reduces its bearing surface. The elastomer-steel contact under air pressure provides expected friction coefficients from 0.5 to 0.7 (regular values selected by MUSTHANE for platform stands (jack-up) work in water):
- The toric structure of the support jacks is similar to the rim of a wheel with a hollow part in the middle of the rim. This room makes it possible to fit hydraulic pushing jacks in there, reducing the robot overall dimensions (length).
- The rubber toric jacks make covers (slugs) make it possible to absorb minor alignment defects, thereby simplifying the construction because the jacks can be rigidly fixed to the front and back rims.
- This type of inflatable toric jack requires practically no maintenance.

Pushing jacks

Several solutions were considered for the longitudinal pushing jacks, including:

- Pneumatic jacks were found to be very bulky due to their lower working pressure restricted to 7 to 10 bars, or exceptionally 16 bars. They may also move on in fits and starts due to the compressibility of the air during canister pushing.
- Hydraulic oil jacks were found to be the most cost effective solution compared with water jacks and the highest-performance option when the volume is the same, as they can work at high pressures (70 bars in nominal capacity, 160 bars to 250 bars in full capacity for common series and more when required for special series).
- Hydraulic water jacks were found to be more costly – they are not recommended at temperatures beyond 65 degrees centigrade (°C), which may be the case in the real future disposal cells.
- Electric jacks (off the shelf) failed to meet the push-pull requirement (too weak).

The maximum stroke for longitudinal pushing jacks is 500 mm (in compliance with specifications). In view of what was found above and of the constraints listed below:

- The central position of the canister retrieval system makes it difficult to have a single central pushing jack (unless the length of the robot is significantly extended);
- The stability of the unit (basic support on at least three points); and
- The unit pushing force capacity of off the shelf jacks (should easily exceed the thrust requirements),

The option of a unit of three parallel hydraulic oil jacks mounted at 120° was selected.

Canister Locking System (for Retrieval)

The option of three star-shaped fingers (or “dogs”) brought back in their initial position by three triangle-shaped springs was selected for safety reasons. Each dog is attached by two springs. All three dogs can therefore be brought back even in the case when one spring would break.

A pneumatic central locking jack was also selected for its “fail safe” aspect. Indeed, in case of a drop in air pressure, the piston is automatically retracted by the springs in their dog return movement. Consequently, in case of an accidental air pressure drop, the robot will be automatically disconnected from the canister and brought back with the manual winch.

The central piston is moved by the pneumatic central locking jack, which is a MUSTHANE air bag, developing a 170 kg pushing force at 7 bars. This solution is more cost effective than developing a pneumatic

joint piston. It is also more reliable and requires practically no maintenance. The piston proper is fitted with bearing balls, ensuring its travel in its sleeve under the action of the air bag or return springs.

Pneumatic and Hydraulic Piping

It was decided to control pneumatic and hydraulic distribution via solenoid valves located on the robot. The number of umbilical cables is therefore reduced to an absolute minimum; namely:

- A 12 mm OD master compressed air supply pipe (exhaust being provided via a hole directly opened in the tube forming the cell);
- A hydraulic outward pipe (13 mm inside);
- A hydraulic return pipe (13 mm inside); and
- A 12 mm diameter, 20-strand multiple-conductor electric cable for 24V power supply used to control solenoid valves and for feedback from sensors.

DESCRIPTION OF TEST BENCH AND OTHER DEMONSTRATION EQUIPMENT

The Test Bench

The test bench consisted of (see Fig. 4):

- Two 4.50-m sections of pipe, one as a mock up of the shielding cask and the other a mock up of the disposal cell inner steel sleeve;
- Two 1-m-long central observation sections (picture windows) fitted with a system for creating a step in the middle of the bench (simulating the gaps and steps likely to be encountered at the docking of the cask with the cell mouth); and
- A 2.50-m launch table to position the canister and robot on the bench.

The unit is mounted on adjustable X, Y and Z feet.

Height adjustment (Z) of mobile parts was made with a manual hydraulic jack; and setting at desired height was made via jack screws. An optical ray (laser) combined with targets at the ends of the two halves of the bench was used to adjust “defects” needed for configuration tests of cells with an imperfect geometry.

Registration of Parameters, Control system and Control Panel

A system to record the main operating settings for the robot is provided with the unit. For this purpose, all sensors and measuring equipment data are digitalized for the transfer of data to a laptop.

A symbolic representation of the robot on the screen was used to remotely monitor the various operations; and a number of time curves are directly drawn during the test (hydraulic & pneumatic pressure, calculated thrust and pulling, measured thrust, travels of the canister and robot).

Settings saved in a database were used to create (using Excel) all curves desired based on observations made during the tests, including progress curves based on thrust.

In order to be able to observe with a delay all the reactions of the robot and canister with its runners in the test bench, it was decided to record all parameters measurable at a frequency in the order of one tenth of a second. All information was recorded and displayed either on the control panel or on the monitor screen.

The control panel face displays the following three types of information (see Fig. 4):

- Actions, which can be controlled by the operator;
- Feedback from some of the sensors; and
- Status of parts of the system.



Fig. 4. General view of the test bench, also showing the Prototype Pushing Robot and the Control Panel

The Dummy Canister

As the function of the dummy canister is to perform representative tests with an object that is geometrically comparable to future real C type canisters, it was made out of cast iron due to easy manufacturing, resistance to corrosion and possible further tests. The dummy canister was fabricated from a pre-form casting that could be machined on the outside to obtain the right OD and bored on the inside to provide the required weight.

The material selected for its foundry qualities was cast iron GLJ 250 (standard EN 1561) having the following mechanical specifications:

- Density: 7.2 kg/cm³; and
- Rc: 84 kg/mm² (840 megaPascals (MPa)).

The pre-form is machined on the outside and bored on the inside to the exact diameter as calculated for achieving an objective weight of 2,041 kg +/- 1%. A screwed and glued cast iron plug closes the open end.

TEST PROGRAMME

Purposes of the Test Programme

The purposes of the test programme, in order of priority, were to:

- Verify that the overall pushing robot system ran correctly according to the specific design, which was proposed by the Subcontractor as a Technical Variant, and accepted by ANDRA;
- Confirm the suitability of the sliding runner design choice made by ANDRA (following a pre-development of this item on a separate test bench), as far as the selected ceramic material (alumina) and the defined shape were concerned;

- Assess the required pulling and pushing forces for a sound operation of the overall system (for the mock up used in the feasibility test and by extrapolation for an industrial scale demonstrator);
- Determine the required operating parameters (air pressure, hydraulic pressure, speed of translation);
- Check that the overall emplacement performance (average speed in automatic mode for a 6-m travel) was equal to or better than the specified one;
- Characterize the capability of the overall system to tolerate operational “anomalies” (e.g., air loss or hydraulic pressure drop);
- Determine the capability of the system to deal with geometric irregularities, such as bumps or steps along the waste emplacement path. A geometric default–combination test had to be conducted (and justified as being the most critical combination); and
- Provide operational parameters with a precision of $\pm 5\%$ and tolerance margins for geometry defects with a precision of $\pm 10\%$.

Main Tests Carried Out

The list of the main tests, which have been carried out, is provided below. For a given geometrical configuration of the test bench, most of the tests were run successively in manual and automatic modes, and with a hydraulic flow (from the hydraulic unit) varying between 12 litres per minute (l/min) and 36 l/min. The hydraulic pressure variation had a direct impact on the instantaneous and average traveling speed of the robot. The simulated geometrical defaults had an impact on the functioning of the system and helped the assessment of the Robot’s robustness. Following is a listing and concise description of the conducted tests:

1. Properly aligned bench:

- Manual mode test at 12 l/min flow rate;
- Automatic mode test at 12 l/min flow rate;
- Return trip test in manual mode at 36 l/min flow rate;
- Return trip test in automatic mode at 36 l/min flow rate;
- Return trip test with and without load in automatic mode at 36 l/min flow rate; and
- Manual mode test at 36 l/min flow rate (maximum speed).

2. Misaligned bench:

- Test with 2 mm step (mixed automatic one-way trip / manual return);
- Test with 7 mm step (Manual or Auto mode); and
- Test at 12 l/min flow rate with 7 mm step and relative alignment defect of 1% (manual mode).

Observations and Conclusions from the Test Campaign

The experiences and lessons learned from the test campaign are summarized below.

Successes:

- Excellent behavior of the robot per se and of the toric jacks;
- No difficulties of any type with the ceramic sliding runners as presently designed;
- Excellent passing capabilities of robot with canister above specified defects;
- Retrievability of canister with robot checked; and
- Average traveling speed in automatic mode measured on an outward trip with full hydraulic power (36 l/min flow for the hydraulic unit) = 1.1 m/min (versus the 0.5 m/min specified in the Scope of Work).

Difficulties encountered:

- Jamming occurred (on return trip of robot) when passing the polycarbonate window connection. This type of incident was due to the relative flexibility of this material versus carbon steel. Such a case should not be encountered in the real repository situation where only carbon steel material is employed. The problem was solved on the bench by adding steel flanges between the large windows.

Main achievements:

- The contract was carried out starting late April 2005 and successfully completed by mid February 2006. The selected Contractor (MUSTHANE/CREATIV ALLIANCE) was responsive and complied with the requirements (performance specifications) contained in the Scope of Work.
- The Prototype Pushing Robot system design turned out to be very rugged and efficient. The ceramic sliding runners also resisted very well to all the shocks induced by the back and forth movements of the canister (including when sliding over “steps”). No significant wear on the sliding runners could be noticed, while the alteration of the slide track was considered as normal and of little impact to an industrial application.
- Overall, the test programme ran as initially planned and the most representative tests specified in the Scope of Work were successfully implemented. The nominal case functioning parameters were determined and registered, and the tolerances and limitations of the system relative to geometrical anomalies were observed.
- The only minor operational problem met was due to the difficulty encountered for the determination of the effective pushing/pulling forces applied by the robot when moving the canister. The initial method of determination (a computation based on the longitudinal hydraulic jack pressure measurement was deemed unreliable and was replaced by a direct measurement of the pushing force value (provided via a load cell). The test campaign was completed with a 1.5 month delay.
- Some recommendations for improvements/adaptations of the system design regarding the subsequent Industrial Scale Demonstrator were proposed by the Subcontractor. These recommendations and lessons learned by ANDRA’s will be taken into account in the next development phase.
- The basic concern (as raised by the external Experts during ANDRA’s technical review in December 2003) regarding the relevancy of an emplacement solution based on a Pushing Robot Technology (and the associated use of ceramic sliding runners fitted onto the canister) was positively answered, paving the way for launching the Industrial Scale Demonstrator Phase in the year to come.
- The numerous pictures taken and the various videos made during the experiment were extensively used to support technical presentations made by ANDRA in front of the “Commission Nationale d’Evaluation” and other stakeholders. Those media materials will later be adapted for the Public at large (on the ESDRED website in particular).
- Finally, the “Pushing Robot Prototype” test campaign was also an opportunity to convene the European Commission (EC) Project Officers and the ESDRED Partner representatives at a “Test Show” in Willems (MUSTHANE premises, near Lille) on the 25th of October 2005, to demonstrate the basic functioning of the system.

Note: The test bench should is now erected and displayed in ANDRA’s show room in Limay (vicinity of Paris) for demonstration sessions to a selected audience (mainly journalists and decision makers).

OUTLOOK

Conclusion

The successful completion of the Pushing Robot Prototype Test Campaign is a good confirmation and a practical justification for the technical choices made within the framework of the French repository concept for the methodology of emplacement of a C type canister 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 performance achieved with the prototype pushing robot emplacement system is in line with the established specifications. The simplification in design obtained within the framework of the Contract looks favorable for more simplifications to come in the pending industrial-scale demonstrator.

Improvements Considered for the Industrial-Scale Demonstrator

Two categories of improvements are foreseen. The first category relates to the ones which, even without any further technical evolution of the pushing robot design per se, should be integrated into the existing system for industrial operations. The second category relates to those that offer a further simplification and an optimization of the existing design. The main points for improvements are listed below:

- All the sensors and as much as possible all the wiring / hose / cable bundles and their related connections should be integrated in a built-in way in the final construction in order to maximize the industrial finish of the equipment and improve its ruggedness (operational reliability).
- The weak elements (such as the trolley supports and the hydraulic jack fittings) should be reinforced, while the rim shoulders have to be chamfered for a smoother travel over the steps.
- The pushing robot compactness should also be improved: the preliminary prototype robot is built with two toric jacks with a similar annular contact area, while the front one could be significantly reduced, since the retaining force necessary for moving the robot alone (on its trolley) is less than 100 kg (this is not a force, this is a mass/weight). This adaptation would reduce the overall length of the robot and therefore could have a favorable impact on the overall length and weight of the future real transport shielding cask.
- The hydraulic jacks are potential sources of hazard (leakage of fluid) and their use implies the need for two hydraulic hoses and for a hydraulic unit (installed on the transport shuttle in a real underground repository). Their replacement by electrical pushing jack(s) would: i) enable a reduction in the number of umbilicals / hoses following the Robot as it pushes the canister forward inside the tube; and ii) facilitate the design and fabrication of a composite (integrated) feed line mounted on a controlled feed reel compatible with the potential extension of the disposal cell length from 40 m up to 60 m or more.

Perspectives for the Industrial Scale Demonstrator

Based on the lessons learned by ANDRA's regarding the Prototype Pushing Robot, a new Scope of Work is being written for the Contract concerning the Industrial Scale Demonstrator. The Industrial Scale Demonstration should be completed by the end of the second Quarter of 2008.

The technical programme content should include (only tentative at this stage) the following:

- The improvements mentioned above;
- The design and fabrication of the Shielding Cask with all its functionalities;

- The design and fabrication of a dynamic docking system (between cask and cell) with the corresponding Gamma gates;
- The design and fabrication (if possible) of a controlled cable reel (for a composite umbilical) compatible with a disposal cell length of approximately 100 m (by comparison with a 40-m length in the reference repository design);
- The design and fabrication of two separate recovery systems; one for the robot in the cell, and one for the canister when passing from the cask into the cell; and
- Long term tests (to assess the reliability and ruggedness of the various components over an extended period of time).