A Cable Car Transfer System for the Cigéo Access Ramps – An Original Approach - 17035

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ABSTRACT

Andra is currently implementing the detailed engineering phase of the step-wise design of Cigéo (the French HLW and IL-LLW Deep Geological Repository). Various technical issues are at stake, including the definition and development of a key component: a funicular ("cable-car") system dedicated to the transfer (down the access ramp and leading to the underground infrastructures) of the shielding casks housing the waste disposal containers (packages).

The present paper starts with a brief description of the Cigéo architecture (i.e. the surface utilities, the service and nuclear ramps, the various shafts and finally the underground facilities). A focus is then made on the "nuclear ramp" dedicated to the transfer of the waste containers lodged inside the casks (those latter weighing some 100 to 130 metric tons each) and its main geometrical characteristics (slope, length, diameter, structure).

Then a discussion follows to detail the rationale having led to the choice of a somehow "sophisticated" funicular transfer system, at the expense of what could be called "more conventional" and more straightforward transport solutions (like a transfer system by trucks or by rack and pinion trains). A systematic comparison is finally made between the various solutions, explaining and rating the pros and cons of each concept, via a multi-criteria analysis. This technical choice (and the related justification approach) was submitted to an Experts review at the end of the Preliminary Design phase of Cigéo and comforted by their strong support before the design freeze of this solution was integrated in Cigéo.

The following part of the paper is then focused on a description of the main technical components and the mechanical performance of the cable-car system, its current state of design and the set of qualification tests (of key safety components) to be implemented before its effective construction.

This article concludes with a timeline of the qualification tests and developments to come. The positive outcomes of this future technical test campaign will also pave the way for the future instruction of the Cigéo licensing file, scheduled as of mid-2018.

BACKGROUND

Andra's DGR (aka Cigéo) is composed of three main areas: two surface facilities (respectively dedicated to primary waste receiving/conditioning and to civil engineering/mining support activities) and one underground facility where the IL-

LLW and HLW packages will be disposed of in dedicated vaults or micro-tunnels. The two surface facilities are distant from each other by a few kilometers. This somehow strange (for a new observer) “split” layout is linked to historical reasons (siting policy with two “departments” at stake) was (in a paradoxical way) perceived as an advantage for the technical solution described in the present paper (Figure 1 shows the 3D Cigéo layout as represented at the end of the basic engineering studies).

Andra considers the connection between the surface facilities and the underground repository to be a strategic and key component of the Cigéo project, and more particularly for the safety of the operations associated with the transfer of waste packages from surface to underground (the mass transported down the ramp, including the shielding cask, is some 100 to 130 metric tonnes).

Since 2007, Andra has structured its approach to the study and search for transfer solutions according to a number of technical guidelines. It also benefited from collaboration with other European nuclear regulatory agencies in considering the various systems adopted by them and their associated development methodologies.

The rationale was to compare existing and innovative solutions for the transport of heavy loads, down relatively steep inclines, and adapt a transfer system best suited to the primary functions required to operate a radioactive-waste repository buried some 500 m underground according to the functional analysis and operational safety constraints specified for Cigéo.

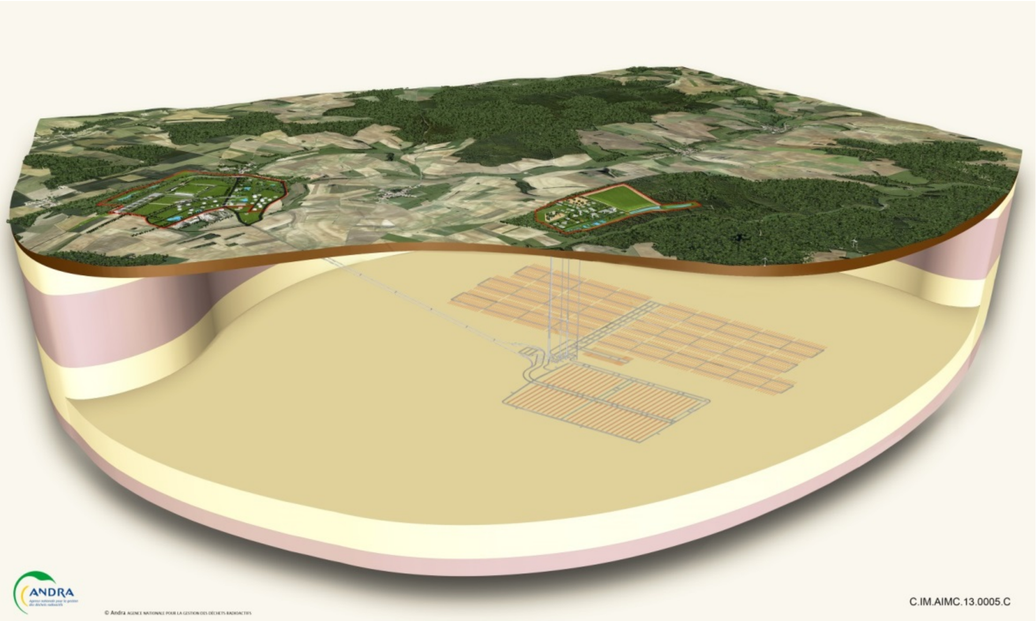

Figure 1: 3D view of Cigéo facilities (Andra, 2015)

The methodology implemented by Andra follows the development timeline here below:

- Search for solutions, preliminary dimensioning, and multi-criteria analysis (2007/2008),
- Selection of the two most appropriate solutions (2009),
- Development of studies for these 2 best solutions at the same level of technical justification (2010),
- Filing of patents related to each of the selected solutions (2011-2012),
- Analysis and selection of one solution for Cigéo (2013),
- Selection of a "turnkey contractor" and development of engineering studies for this solution (2014),
- Qualification testing of "components important for safety" for the selected solution (2017/2018),
- Qualification dossier submitted to the regulatory authorities (ASN) (2018/2020),
- Building and commissioning of the transfer system (2025),
- Assistance in operating and maintaining the system provided by the turnkey contractor for a five-year period (2025-2030).

SELECTION OF TRANSFER SOLUTIONS

The functional analysis defined six life-cycle situations related to the systems (solutions) under study:

1. Surface transhipment,
2. Transfer,
3. Underground transhipment,
4. Reversibility (retrievability),
5. Maintenance and revamping/retrofitting,
6. Blockage of the ramp transmission system.

Their associated main functions were as follows:

i) FP1: transport an IL-LLW or HLW cask from the surface to underground and vice versa,

ii) FP2: transport an IL-LLW cask from the transfer system to the underground (drift) transfer carts,

iii) FP3: transport an HLW cask from the transfer system to the underground (drift) transfer carts.

As shown in Figure 2, three main categories of technical solutions, suitable for fulfilling the desired functions according to several ramp percent inclines, were possible:

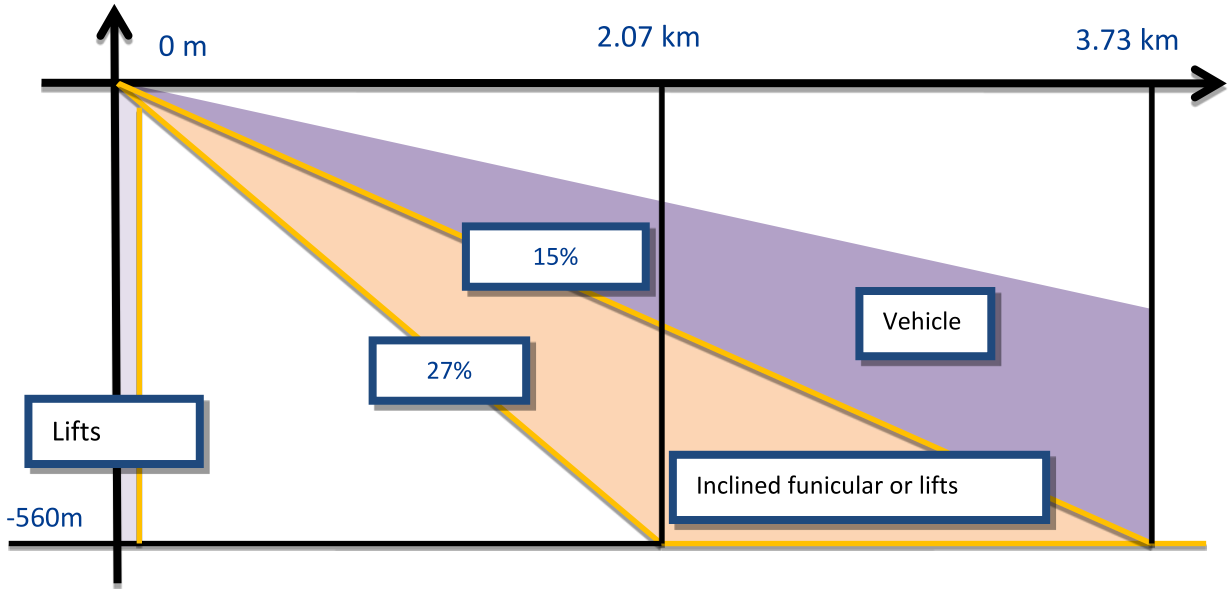

Figure 2: Transport solutions according to depth, dip and distance

1. In mining, the incline of the ramps is generally between 3 and 15%. Driving force may be achieved using tyres fitted on vehicles developed from existing technologies or vehicles via rack-and-pinion systems for inclines of up to around 25%.
   The length of the runway (around 5 km) and the reduced travel speed (5-10 km/h) in Cigéo lead to significant cycle times. In the event of a fire, the vehicle thermal load poses a major risk for both the transfer cask and the surrounding infrastructure. This thermal load is mainly related to the tyres and the drive power on board this type of solution.

2. Ramps with inclines between 10° and 45°, for which inclined funicular/lift solutions are possible references related to this type of transfer, exist for heavy loads. The drives are generally offset on the surface to facilitate maintenance and reduce the on-board thermal load.

3. The vertical shafts, with two balanced rotating pulleys fully suspended on the head cables. The risks of free fall during cask emplacement in the shaft cage or during transfer must be considered for both of the solutions. As with the funiculars, these systems present a very low fire risk. It should also be noted that the weight of the heaviest casks (130 tonnes) exceeds the maximum weights usually

transferred in shafts. In addition, access to the machinery and the shaft-blockage scenarios remain a challenge.

The search for possible technical solutions based on the first main function (FP1: transport an ILW-LL or HLW cask from the surface to underground and vice versa) led to the selection and evaluation of the following transfer systems:

- Trailer with tractor unit mounted on a rack railway,
- Rubber-tyred trailer and tractor unit,
- Rail-mounted trailer with rubber-tyred tractor unit,
- Rubber-tyred trailer and tracked tractor unit,
- Self-propelled vehicle mounted on a railway,
- Self-propelled vehicle mounted on a rack railway,
- Self-propelled rubber-tyred vehicle ,
- Self-propelled tracked vehicle,
- Cable-driven conveyor,
- Stationary conveyor,
- Vertical lifts.

The multi-criteria analysis was carried out in four steps:

1. Definition of the categories/criteria and their weightings,
2. Scoring of the solutions to be compared,
3. Calculation of the comparison,
4. Analysis of the results.

The approach primarily focused on internal and/or external studies conducted to identify solutions, followed by analyses that included multiple criteria such as safety, simplicity, robustness, gauge size, design feasibility, technological limitations, and obsolescence rates. This structured multi-criteria analysis, which was extensively shared with experts outside the Cigeo project, prompted Andra in 2009 to select the following two solutions for further (basic) engineering study in the year 2010:

- The self-propelled vehicle,
- The funicular system.

SUMMARY OF BASIC ENGINEERING STUDIES CARRIED OUT

The input data considered for the studies were:

- the incline is in the shape of a straight line with a 15% dip,

- the distances travelled by the vehicle during the transfer operations in the ramps are 5 km upward and 5 km downward, between 4 and 8 km in the horizontal drifts,
- the ramp and horizontal drifts have an effective diameter of 7 metres, drift turns have a minimum radius of 250m,
- operating temperature is between +10°C and +30°C,
- vehicle is operated 225 working days a year,
- transfer of packages to repository zones is carried out in 3 six-hour shifts (the remaining six-hour shift is reserved for maintenance).

The self-propelled vehicle

The vehicle architecture consists of three articulated modules, the central one transporting the shielding cask, as illustrated in Figure 3. It is equipped with Michelin X-TERMINAL T tyres (Size 310/80 R22.5).

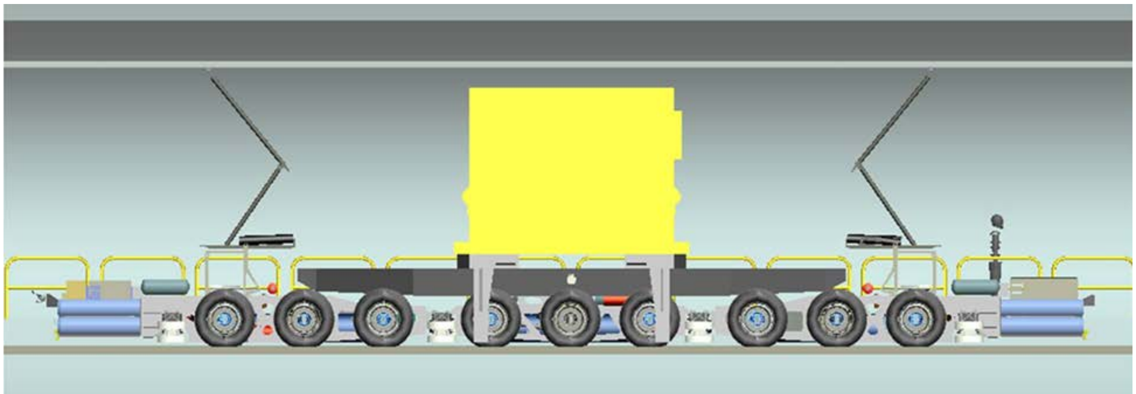

Figure 3: Transport solutions according to depth, dip and distance

The "Top-Ground" electric drive solution is selected to make it possible to do without attached articulated systems. The width of the contact strips accommodates sideways movements and tilting of the vehicle. Current is returned by a third rail and the vehicle is fitted with two collector shoes as shown in Figure 4

The brake system includes a nominal brake and an emergency/parking brake. The vehicle is fitted with four steering axles, two per end module, while four rows of rollers are mounted to protect the transfer shielding cask if the vehicle goes off course.

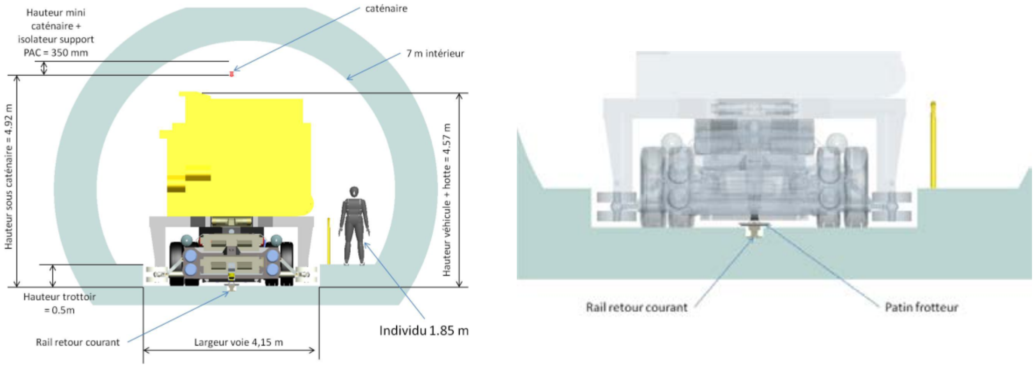

Figure 4: Current is returned on ground mounted rail

The funicular system

The funicular general layout (Laurent et al, 2014 (1)) is shown in Figure 5; while Figure 6 provides a focus on the ground level loading station (the underground level unloading station layout is similar).

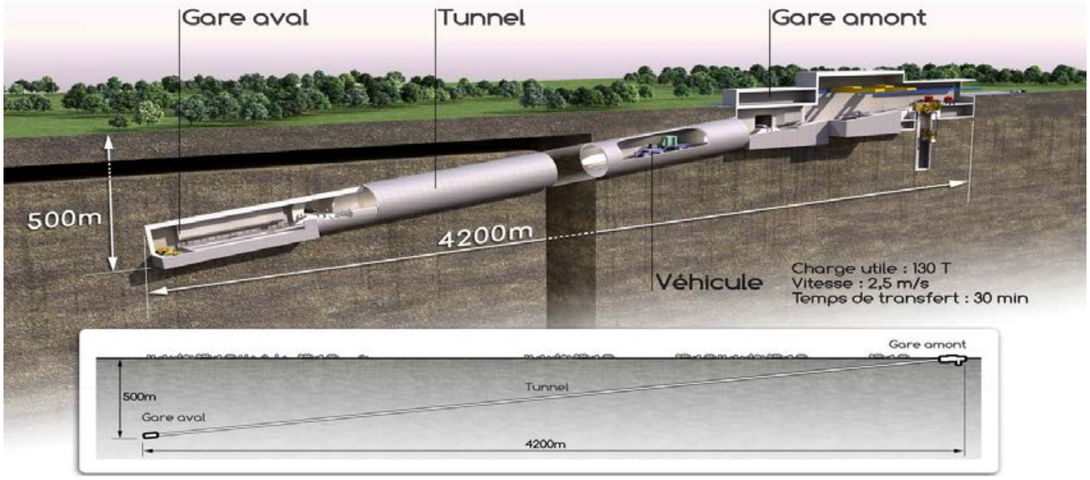

Figure 5: Funicular general layout

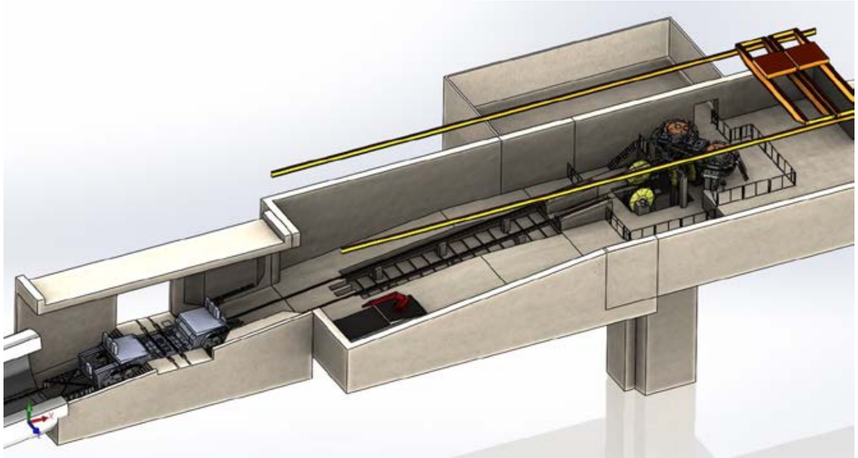

Figure 6: Funicular ground level loading station layout

The funicular functioning principle is based on a sheaving system, as shown in Figure 7.

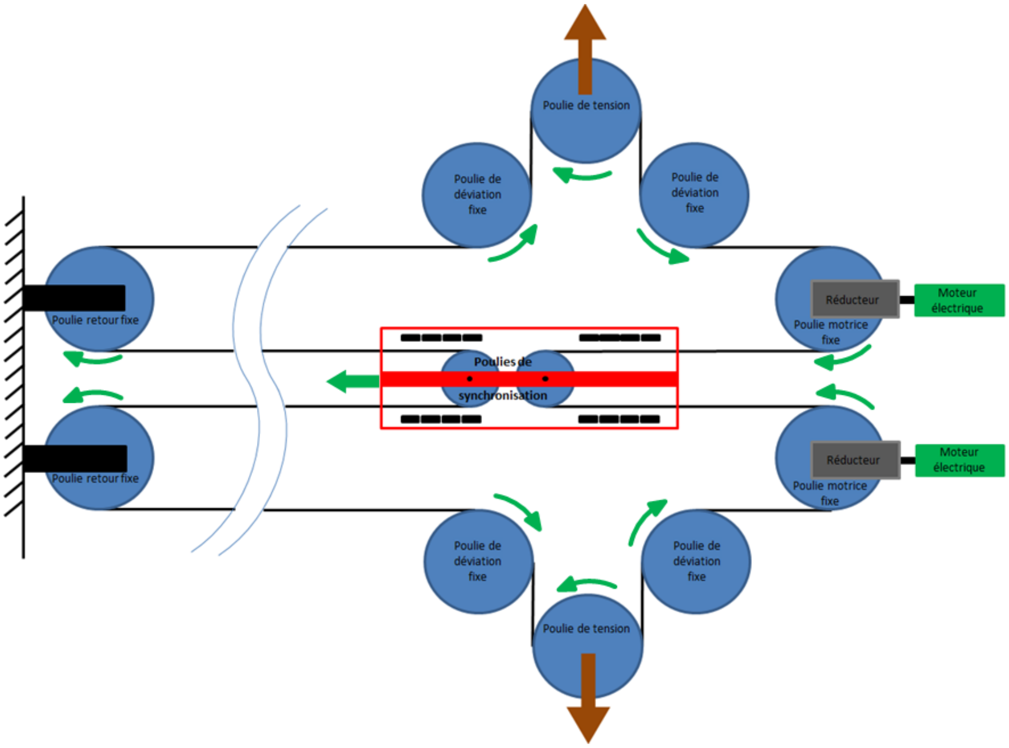

Figure 7: Funicular sheaving system with electric drive on right (surface)

The vehicle travels on 16 track mounted wheels, each of which is fitted at each corner on two-step rocker arms. This solution ensures that the contact between each wheel and the track is continuous and that loads are equally distributed. In addition, it distributes the loads more evenly when the brakes are applied. The rocker arms are fitted on suspension actuators. The wheels have a diameter of nearly 900 mm.

The vehicle's brakes must automatically be applied in the event of excess speed, slack in the cable, or back driving is detected. The vehicle is fitted with emergency stop brakes and backup emergency brakes (as shown in Figure 8).

i) Emergency brakes may be applied in the following cases:

- The automatic control system detects a system malfunction,
- Leaks occur in the hydraulic circuits of the emergency brakes,
- Slack in the cable.

“Jaw-type” brakes are used on the emergency brake system.

ii) Backup emergency brake

The backup emergency brake is automatically engaged when all attempts to stop the vehicle have failed or when excess speed of 20% is detected. As with the emergency brakes, the backup emergency brake is engaged automatically.

The backup emergency brake system consists of track friction brakes. These brakes, arranged above the tracks, are rigidly connected directly to the vehicle chassis. They come into contact with the heads of the rails and a friction resistance resultant opposite the movement of the vehicle occurs. As a result, the braking force is directly proportional to the weight of the vehicle.

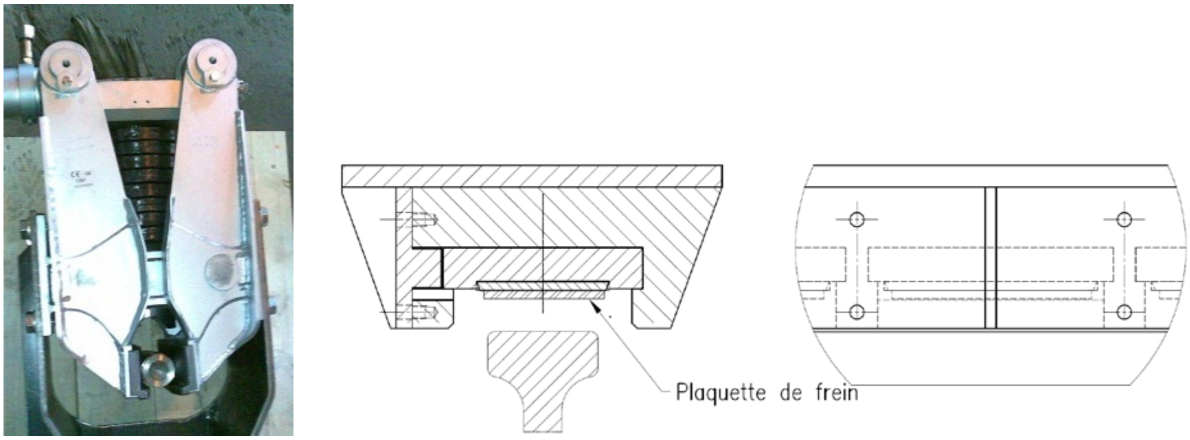

Figure 8: Jaw-type brake (left) and track friction brake (right)

The electrical drive is a direct drive. This means that considerably fewer parts need to be monitored and less maintenance is required. It also means that the drive output is greater, and its noise and volume are lower. The funicular has redundant two drive pulleys. In the event one of the systems fails (i.e. one of the drive pulleys jams) the other pulley allows the vehicle to be brought back or operated at half speed. The drive pulleys are decelerated by the electric drive during normal deceleration of the vehicle upon its arrival at a station or if a non-critical fault occurs. The service brakes are applied when the vehicle is stopped at the upstream and downstream stations. The drive emergency brakes are similar to the service brakes.

Since the risk of the cable slipping off its pulley cannot be dismissed, devices for recapturing the cable and automatically shutting down the vehicle are provided in the sensitive areas. To prevent this risk, anti-slip devices are installed along the entire path, particularly at the inlet and outlet of the rocker arms and pulleys.

These systems serve as the safeties for the entire machinery, which is fitted with the following:

- Set of coders: they send the cable speed and the position and direction of travel of the vehicle to the PLC.
- Anti-slip devices: they mechanically prevent the cable from slipping out of the pulleys.
- Monitoring of the seats of the pulleys.

EXPERT REVIEW

A systematic qualitative comparison of the 2 solutions (see below) was submitted for review by a group of independent experts, in 2013. The review outcomes are summarized in the table below. The comparison took also into account the self-propelling vehicle considered by SKB for its own DGR. The comparison outcomes are not detrimental of SKB’s legitimate choices, but reflect the “key drivers” of Andra’s choices: rate of operability, position and quantity of thermal load, maintenance throughout life cycle, flux.

Susceptibility of the connection designs to the discriminating subjects

SUBJECT		SELF-PROP. VEHCL		FUNICULAR		Comments
Reliability		Highly complex on-board automatic systems.	🔴	Available as standard on existing equipment.	🟢	Confirmed by manufacturer OEF on MAFFI and SKB and by the OEF of funicular and cable-driven transfer systems.
OEF on equivalent systems		SKB OEF on existing repository rather negative (tyre slippage and premature wear).	🔴	Existing equipment with equivalent characteristics at AXPO in Switzerland (200 t on a 24% incline for 3800-m track).	🟢	OEF clearly shows that the technological limits have been reached for self-propelled vehicles weighing more than 100 tonnes and used on inclines of 12-15%.
System under development or being operated by the other European agencies		Only SKB is studying the implementation of a self-propelled vehicle for transferring transport casks.	🔴	All the agencies use cable or rack railways for transfers.	🟢	Note that the SKB vehicle trip rate is 150 transfers a year, i.e. 1 per day max. vs the rate at Cigeo: 12 daily trips, i.e. 1800 per year. On this basis, an initial estimation gives a vehicle-travel distance of 40,000 km per year.
Heat load		Heat load located beneath the transfer cask	🔴	Moved to the surface to facilitate access by the fire brigade to extinguish fires.	🟢	Challenge of the transfer cask withstanding extreme temperatures if the self-propelled vehicle DCC is 100,000 MJ. (Temp. > 1000°C in the drifts: "furnace effect")
Ease of automation		Difficult to implement. Only driver control currently available (SKB OEF).	🔴	Easy and already available. Good automation OEF.	🟢	SKB OEF shows the difficulty in automating self-propelled vehicles in the underground structures.
Size of the circulation structures		The tyred vehicles have longer and wider gauges than those of the track-guided carts.	🔴	The size of the steel rollers makes it possible to reduce the gauge and length of the vehicle	🟢	For example, the vehicle has a length of 18 m vs 6 m for the cart mounted on the tracks. The gauge criterion is considered to be significant on account of its impact on the diameter of the ramp and drift structures (hence a higher investment cost with the self-propelled vehicle).
Transshipments		E.g. 2 transshipments for one ILW-LL trip	🟢	4 transshipments for one ILW-LL trip	🟡	2 transshipments with the self-propelled vehicle vs 4 with the funicular. The transshipments are identical in both cases (height of 150 mm). However, the positioning time is greater with the self-propelled vehicle than with the track-guided systems. If the cart is placed aboard the funicular, the number of transshipments is equivalent (RCF conclusion).
Intersection management		Underground intersection management for changes in direction is very tricky in the underground infrastructure.	🔴	Change of direction on the 7 turntables at Cigeo. Reliability and robustness for a very footprint.	🟢	Y-shaped intersections compatible with the circulation of a self-propelled vehicle are considered to be deal breakers for the underground infrastructure.
Docking accuracy		Direct docking with the self-propelled vehicles is impossible given the required accuracies and the sideways direction of cask transport.	🔴	The mechanical guidance of the track-mounted carts allows repetitive, high-precision accuracies.	🟢	Manufacturer OEF from the Hague about difficulties in docking the MAFFI includes various collisions between the vehicles and the platform.
Preventive maintenance		Surface maintenance (specialised workshop) for the self-propelled vehicles and in the ramps for the electric power supplies and substations.	🟢	Essentially surface maintenance in the machinery building and on the track (rails)	🟢	Maintenance of the components supplying electric power to the self-propelled vehicle in the drifts and the runway remains significant compared to the low maintenance required for funicular tracks. Also, maintenance of the containment doors to be fitted at 400-m intervals evens out the maintenance criterion between the two solutions.
Curative maintenance		Curative maintenance of a broken-down vehicle in the ramp remains a challenge given the weight of the vehicle and the cramped conditions.	🟡	Curative maintenance is essentially carried out in the machinery building on the surface. Load lowering is planned for the remainder of the facility.	🟢	Given the amount of cable-driven equipment used around the world and the design standards imposed by the RM5 guide and inspected by STRMTG, situations involving downtime of these systems are under better control.
Regeneration		The complexity of the on-board computer systems and the management of invisible guidance require regular regeneration in the event of rapid obsolescence of the on-board components.	🔴	The system's simplicity makes it, apart from automated control systems, well-resistant to obsolescence.	🟢	The more the system is simple (i.e. by making use of basic, proven technologies), the more robust it is in terms of regeneration, hence a lower cost of ownership and good robustness for century-long service life.
Susceptibility to change		The technological limitations do not make it possible to attempt to increase the weight beyond 130 t.	🔴	The design of a cable-driven system (such as a funicular) make it possible to increase the capacity provided significant adjustments are made.	🟡	The funicular poses no real technological limitations for a change, even significant, in weight. AXPO, the Swiss electricity supplier, uses a 200-t funicular along a 24% incline.
Cost		The investment cost during the T1 phase and the operating costs are higher than those for the funicular.	🟡	The investment cost during the T1 phase and the operating costs are lower than those for the vehicle.	🟢	
Fire compartmentalisation		Placing containment sectors every 400 m with normally-open doors is expensive and requires maintenance in the ramps for the 9 sections.	🔴	No containment doors, which helps to reduce this cost, enhance the reliability of the transfer function, and reduce ramp maintenance.	🟢	It should be noted that if power is supplied by an overhead line (as recommended by several manufacturers of self-propelled vehicle), it will be difficult to place containment doors every 400 m and the passage of the overhead line may make containment impossible. The scenario of a vehicle fire against the door would extend the containment sector to 800 m.

CONCLUSIONS AND PERSPECTIVES

Discussions with our European counterparts were conducted in parallel to these studies to evaluate the various designs considered for the surface-to-underground connections, assess the reasons for their respective choices, and benefit from operating experience feedback obtained from underground repositories currently in operation.

Andra’s evaluators and the French waste generators provided us with their own critical analyses on the matter and, where appropriate, with their own transfer solutions during working groups or alternative studies to the Cigéo projects.

Lastly, Andra’s system engineering contractor reviewed all the possible solutions within this outline and, based on its own multi-criteria analysis, came to a decision that matched that of Andra's. Thus Andra's knowledge database was used for this purpose by the system engineering contractor and integrated in the detailed engineering now ongoing.

These studies and discussions brought to light two main categories of solution that differ primarily in terms of the driving force (drive) position:

- Either attached to the top or bottom of the ramp (lift, funicular, winch, etc.).
- Or placed on the load-bearing vehicle (self-propelled vehicle, rack-and-pinion train, etc.).

At this stage of the project, Andra's final choice is for a cable-driven funicular system belonging to the first category of solutions, complete with machinery installed in the surface facilities (Reboul et al, 2014 (2)).

The work ahead is scheduled as follows:

- Designing, manufacturing, testing and qualifying the emergency brakes (back up emergency brakes) systems embarked on the funicular cart: 2017-2018,
- Detailed engineering of the funicular system components: 2017-2018,
- According to Cigéo general reference operating schedule: workshop drawings, manufacturing, delivery to site, integration and assembly inside the ramp, finally site testing and site commissioning must be compatible with the following milestone: “funicular operational” by 2025.

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