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MAIN IMAGE: **The 100-tonne Magne truck is the world's first vehicle for final disposal of nuclear waste. The radioactive material is encased in a copper canister placed inside a shielded tube at the rear of the vehicle**

No man's land

VENTURING WHERE ANGELS FEAR TO TREAD, THE MAGNE FULLY AUTONOMOUS WASTE DISPOSAL TRUCK HAS BEEN DESIGNED TO CARRY SPENT NUCLEAR FUEL CANISTERS DOWN TO THEIR FINAL RESTING PLACE 450M UNDERGROUND

Tunnels 450m below ground will be the future workplace for what is probably the world's largest fully automatic robot. At a trial site near the Oskarshamn nuclear facility in Sweden, the 100-tonne Magne autonomous truck has been designed to handle spent nuclear fuel at a planned deep geological repository.

In March 2011, the company that manages Sweden's nuclear waste, SKB (Svensk Kärnbränslehantering, or Swedish Nuclear Fuel and Waste Management Company), filed an application with the country's government for permission to build the world's first final repository for spent nuclear fuel.

All over the world, spent fuel is currently held in intermediate storage above ground, awaiting final disposal. Sweden and Finland are the only countries to have made firm proposals for final repository, with the Forsmark facility in Sweden scheduled to be the first to open, in 2025.

CASE STUDY

The wheels enable accurate positioning of the vehicle above the deposition hole before a hoist at the back of the vehicle lowers the canister into its designated place. The legs secure the position of the vehicle during the depositing process. The cylindrical radiation shield is manoeuvred using hydraulic cylinders capable of moving 50 tonnes

The fully autonomous Magne is an instrumental part of the disposal process at the Swedish final repository. The vehicle is currently being developed at a trial site near the Oskarshamn nuclear facility, some 500km from its future workplace. The version currently undergoing tests is a prototype for the trucks that will eventually handle the copper canisters with spent nuclear fuel in the final repository. The objective is to show that the 27-tonne canisters can be safely handled, placed in their designated spaces and, if necessary, retrieved.

"We will make a thousand operations during this year and next year – deposition and retrieval – to ensure that the process works as we want it to," says Per Ernfors, team leader for the project.

Magne is a fully automatic and driverless vehicle. While the current prototype does have a driver's cab, this is only for testing purposes and is unlikely to feature on the final vehicle. The driverless machine will instead be controlled by WiFi from a control centre. The load is held in a cylindrical tube, which also acts as a radiation shield, at the rear.

The current prototype may or may not be used in active service, depending on the modifications that turn out to be necessary. Only one or two such vehicles are likely to ever be produced.

Strong vehicle

Meaning 'the strong one' and weighing in at an impressive 100 tonnes when fully loaded, Magne takes its name from the son of Thor, the god of thunder in ancient Nordic mythology. The vehicle is designed by SKB and built by Germany-based Herbst, a specialist manufacturer of mining and tunnelling vehicles. However, being much larger and more robust – 14.1m long, 3m wide and 4.2m high – Magne has very little in common with the vehicles it normally manufactures.

Magne has been developed in parallel with the final repository at Forsmark. It became clear early on that a vehicle would be required for moving the canisters into their final storage places. The technology was developed during the 1990s and the first prototype saw the light of day in 1999. This was a vehicle running on a railway track and much larger than the current prototype.

Although many of the systems now used on Magne are derived from this earlier prototype, the vehicle itself turned out to be too large to make the concept viable. Tests convinced the design team that it would be preferable to have a smaller vehicle running on wheels.

"With each tunnel 300m long and with room for 40 canisters, filling one tunnel will take three months before operations move on to the next tunnel. This would have meant the railway track had to be re-laid every three months. With a smaller vehicle, we can also use smaller tunnels, which means less rock needs to be removed and less material is needed to fill the tunnel afterwards," explains Ernfors.

Rubber wheels also enable better positioning over the deposition hole. To avoid deflation, the tyres are filled with polyurethane foam.

Another reason for the redesign was that the original prototype had a radiation shield which could be separated. Even during short periods of time, this could have potentially exposed workers to radiation, so it was modified for the second iteration.

ABOVE CENTRE: **Rear navigation scanner along with the deposition hole scanner, which measures the position of the deposition hole in relation to the machine**

ABOVE LEFT: **Forward navigation scanner**

ABOVE RIGHT: **As the vehicle positions itself above a deposition hole, a reflector at the centre of the cover is detected by a Sick position finder that signals to the control system to stop the machine when the reflector is exactly beneath the sensor. When the cover is opened, a Sick distance sensor measures the depth of the deposition hole to calculate how far the canister needs to be lowered. The top of the image also shows a laser pointer and a camera that facilitate positioning above the hole during manual operation**

Self-guided study

Magne is programmed to find its own way, without a driver, through the tunnel system, position itself above the correct deposition hole and then lower its stabiliser legs to ensure it remains in a fixed position. The 5m copper canister is lowered with millimetre-precision into the bentonite-clad deposition holes. "We only have 10mm of free movement within the deposition hole. The canister has to be positioned exactly, so that it does not damage the bentonite cladding," explains Ernfors.

To find its way without the railway track, the vehicle has been equipped with a Navitec laser navigation system of a type used in mining vehicles. When arriving in a new area, the area is first scanned while driving through to produce a map for navigation, using the rough surfaces of the tunnel walls as reference points. With this data, the vehicle can drive autonomously to the designated deposition hole with very high accuracy, as the system navigates to within 27mm of the designated route. The vehicle has a turning circle of just 8m, enabling it to negotiate tight spaces.

"It is a modified system of the type used on Sandvik mining vehicles, but with one significant difference," says systems engineer Heikki Laitinen, responsible for the onboard systems. "Mining vehicles use articulated steering while Magne uses all-wheel steering to maximise manoeuvrability. This means the wheels have to follow a different route compared to a vehicle with articulated steering,"

The engine is a 320hp Deutz V6 which drives a hydraulic pump and four hydraulic motors from Bosch-Rexroth, with Kessler planetary gears, one on each wheel. All-wheel drive and steering eliminates the need for gearboxes and many other transmission components. Top speed is 5km/h (3mph) and despite its weight, the vehicle is able to stop in 1m. The brakes use wet discs from Kessler, cooled by hydraulic fluid.

> **"THE SYSTEM NAVIGATES TO WITHIN 27MM OF THE DESIGNATED ROUTE"**

The onboard control system operates with a Sauer-Danfoss CANbus system from, of a type normally used in forestry machinery. "The many onboard systems require a system that enables high data flow," explains Laitinen.

A positioning system from Sick, also using laser technology, enables fine-tuning of Magne's position over the deposition hole. Final positioning is controlled by two industrial cameras from Omron, offset by 90° from each other, and fitted inside the shielded tube holding the load.

Using standard components

The use of standard components has kept design costs down, although the mix of vehicle automation and industrial automation systems means interfaces are required. The laser system runs on Ethernet, the machinery systems on CANbus and the industrial camera on Ethernet and serial communications. The required interfaces have been developed in-house at SKB.

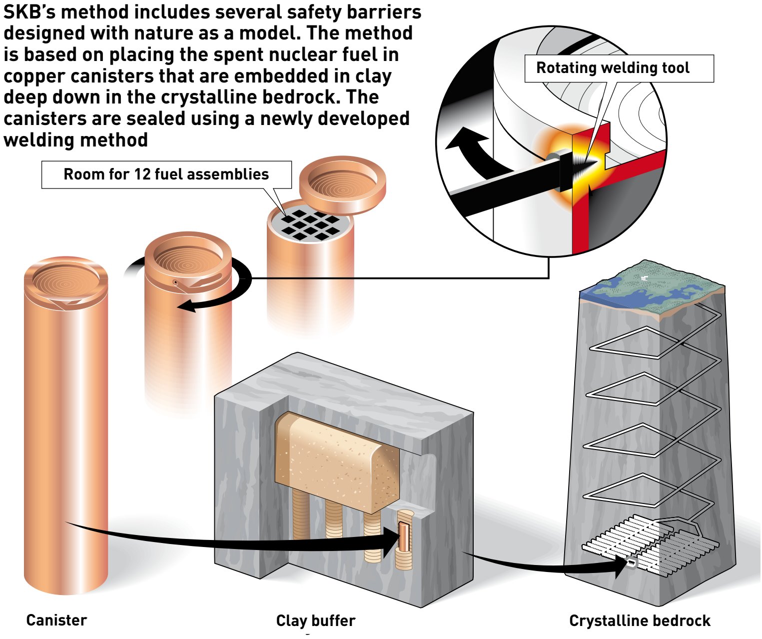
Bosch supporting legs are used for levelling, with hydraulics from Sauer. Fully automatic, their levelling is accurate to within ±1°, while delivering feedback data of the length of extension while an inclinometer senses position, communicating via CANbus.

With the load ready for deposition, the vehicle sends a request to the control centre to open the hole cover, using an electric motor with variable speed control. Because the canister is radioactive, Magne is equipped with a radiation shield made from 140mm steel and 140mm ethylene plastic to protect against gamma radiation. The cylindrical tube with radiation shield is manoeuvred using Bosch hydraulic cylinders capable of handling 50 tonnes, taking into account the weight of the cylinder itself, as well as its 27-tonne load. A hoist with two hydraulic motors, supervised by a Sauer control system, lowers the load into the deposition hole.

No personnel will be required underground during the operation. The autonomous navigation offers high levels of safety as well as higher precision and more predictable performance than manual operation.

"During testing, depositing a canister took four and a half hours with an operator. With Magne, only 30 minutes is required," Laitinen says. "Many processes at the plant are time-critical, but with such predictable performance, we'll avoid delays that could otherwise have severe knock-on effects, safely and efficiently." **iVT**

SKB's method includes several safety barriers designed with nature as a model. The method is based on placing the spent nuclear fuel in copper canisters that are embedded in clay deep down in the crystalline bedrock. The canisters are sealed using a newly developed welding method



Source: SKB

Designed for the world's only final nuclear grave

Magne is designed to deposit spent nuclear fuel at the world's only final repository, in Forsmark, Sweden. At the moment, the spent fuel is in intermediate storage at the Oskarshamn facility to cool down and reduce radiation over a period of 40 years. The application to build the final repository sets out how the material will be kept safe in the underground facility for the next 100,000 years, using barriers that have been proved to protect against radiation over long periods of time in the natural environment.

Before transfer to the final repository, the fuel is encapsulated. The spent fuel rods are surrounded by ductile iron which is covered by a 50mm layer of copper. The copper canister is 5m long, 1m in diameter and weighs 25-27 tonnes.

The canister is deposited in a circular deposition hole, 8m deep and with a diameter of 1.85m, drilled in a tunnel 450m below the surface, into the rock. After the operation, the drill hole is sealed and the site marked. The deposition hole is lined with bentonite clay, which gives added protection and prevents against ingress of ground water. When the storage facility is full, the whole tunnel will be filled with bentonite clay.

The canister is designed to withstand forces of up to 1*g* in each direction. If it should be subjected to undue forces, for instance because of an accident during the depositing process, it will be retrieved and returned to the processing plant, where it can remade to avoid compromising the integrity of the barrier.