

FT BIG READ. ENERGY

As nuclear power makes a comeback, France is exploring new ways to dispose of materials that can remain radioactive for 300,000 years. But public opposition to the plans remains as fierce as ever.

By Anna Gross and Sarah White

Every morning, Benoit Gannaz places a small black device in his breast pocket to make sure his work is not killing him. Like every worker at the Chooz A nuclear power facility in northern France, he carries a detector that measures ionising radiation levels at all times.

The reactor was turned off more than three decades ago and the most hazardous materials removed soon after, but nobody here is taking any chances — least of all the project manager overseeing the challenging and lengthy process of decommissioning Chooz A. Gannaz's job is to ensure the remaining hazardous materials on site are removed and stored away safely now that the lifecycle of the reactor is at an end.

The risks are manageable though, he says. Radioactive exposure is measured in sieverts. One would make you sick, five would likely kill you. In more than 15 years in the field, Gannaz says the highest annual exposure he ever received was 0.05 mSv, or a thousandth of a sievert.

"Do you think everyone who works outside is afraid of sunburn? Not really, they wear sunscreen. Not everyone who works in nuclear is afraid of radiation," he says, standing a few steps away from a shimmering pool that holds thick wedges of highly radioactive metal. "I'm more afraid if the doctor sends me to get an X-ray I don't need — that's the equivalent of 6 months of work for me."

But the abundance of caution at Chooz A — one of six colossal nuclear reactors that are in the process of being shut down by EDF, the state-controlled utility company that owns and runs all of France's nuclear power plants — underscores the high level of sensitivity still surrounding the technology even in France, the last bastion of nuclear



The nuclear dilemma: where to put the waste

52 nuclear reactors are currently under construction in 19 countries, including in China, Russia and India



power in Europe.

The potential for catastrophic melt-downs at nuclear plants, such as the accident in Chernobyl in 1986, has led governments to move away from the technology. After the Fukushima nuclear disaster 10 years ago, Germany announced it would shut down all of its nuclear power plants by 2022 and Belgium vowed to close all of its facilities by 2025.

However, there has been a wave of renewed interest in nuclear power over the past year. The governments of France, the US, China and India have all recently come out in favour of building new nuclear plants in the years ahead, with French president Emmanuel Macron expected to outline new orders in the coming weeks.

Investments in nuclear are expected to total \$45bn in 2022 and \$46bn in 2023, up from \$44bn in 2021, according to analysis by Rystad Energy, with 52 reactors at present under construction in 19 countries worldwide.

The appeal of nuclear is the need for a reliable, carbon-free source of energy to complement clean yet inconsistent energy sources such as solar and wind power. The European Commission recently included nuclear power in its so-called "green taxonomy" of industries eligible for sustainable finance, provoking criticism from some scientists and climate change activists.

Yet as momentum grows for a new generation of nuclear power plants in Europe and elsewhere, there is little discussion of the huge costs and complexity of dismantling the plants at the end of their approximately 50-year lifespan. And nobody has yet given a satisfactory answer to the question of what to do with thousands of metric tonnes of high-level nuclear waste, some of which can remain radioactive, and thereby lethal, for up to 300,000 years.

Treating waste seriously

A quarter-million metric tonnes of spent fuel rods are believed to be spread across 14 countries worldwide, mostly collected in cooling pools at closed-down nuclear plants, as engineers and waste specialists puzzle over how to dispose of them permanently. Many believe these are sitting ducks for terrorist organisations and that they could potentially cause catastrophic spills or fires.

The cost of maintaining these sites can be extraordinary, and last for decades. Sellafield in the UK, for example, contains the largest stock of untreated nuclear waste on earth, including 140 tonnes of plutonium.

Though the plant was shut down in 2003, it remains the biggest private employer in Cumbria. More than 10,000 people continue to undertake a colossal expensive clean-up that is

Cigeo (industrial geological disposal center)

A French site for storing radioactive waste. Planned in-service date is 2035, with storage complete by 2150

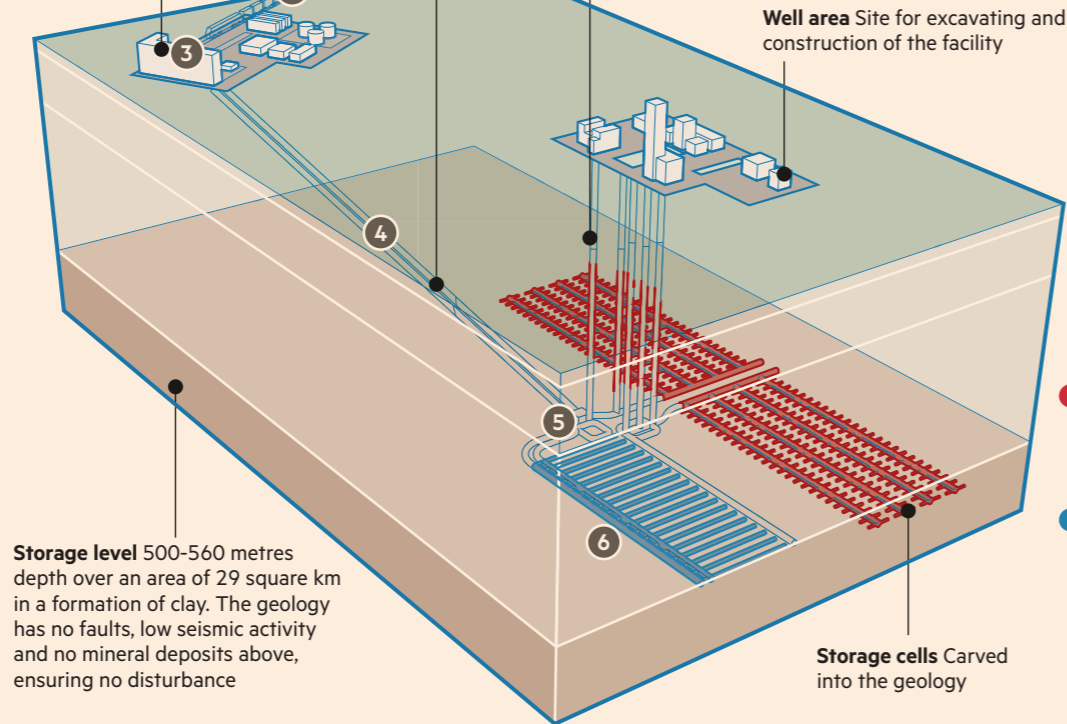
The facility

Descending area Site of maintenance buildings and equipment and rail terminal

Descent Two 10-metre wide, 4.2km long tunnels. One transfers packages to storage areas, one is for maintenance

Vertical shafts Five connect the storage area site to the well area

Well area Site for excavating and construction of the facility



Storage level 500-560 metres depth over an area of 29 square km in a formation of clay. The geology has no faults, low seismic activity and no mineral deposits above, ensuring no disturbance

Storage cells Carved into the geology

The process

- 1 Waste from plants, packaged in accident-proof containers is processed in La Hague where reusable uranium and plutonium is extracted
- 2 It is then sent to Cigeo, mainly by rail at a rate of five trains per year during the pilot phase and five per month in operation
- 3 In the descending area, it's checked and placed in storage containers
- 4 It is transferred to the storage level by a funicular at walking pace
- 5 Remotely controlled robot shuttles move packages to the cells
- 6 Even as the cells decay over thousands of years, the facility is sited so that the geology's nature will contain the radioactivity

The two most dangerous types of waste will be stored. Just 3% of France's waste but 99% of the radioactivity:

High activity waste (HA)

Mainly waste from spent fuel with a lifespan of several hundred thousand years. HA waste is mixed with molten glass and encased in stainless steel

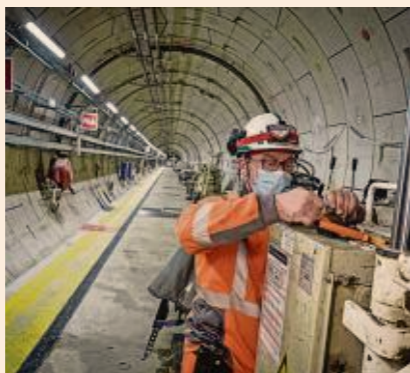
Long-lived intermediate level waste (LLMW)

Also has a lifespan of several hundred thousand years but with an average level of radioactivity 1,000 times lower than HA. Examples of this type of waste are residues from metal structures in reactors and waste from effluent. It is encased in either concrete or metal

Graphic: Ian Bott
Sources: EDF, FT research

Above and below: Construction has begun on nuclear waste storage tunnels under the ground in Bure, France, but locals like Anne-Marie and Jacques Henn, bottom, say they do not want to live near them

Magali Delporte/FT



'It is a supposedly low-carbon energy source, but you have to build the reactors. It's such a destructive solution'

expected to take more than 100 years and cost above €90bn.

"Nowhere in the world has anyone managed to create a place where we can bury extremely nasty nuclear waste forever," says Denis Florin, partner at Lavoisier Conseil, an energy-focused management consultancy in Paris. "We cannot go on using nuclear without being adult about the waste, without accepting we need to find a permanent solution."

With the Chooz A reactor, France is attempting to do just that — and in the process create a prototype for how decommissioning could be done more efficiently. If it succeeds, it could help convince environmentalists that nuclear power has a part to play in creating a greener planet. But there is still a heavy dose of popular opposition to the best option there is on the table for the waste: burying it.

The legacy of a spent reactor

The challenge with cleaning up Chooz A is not so much the site itself as the materials once contained within. The facility was shut in 1991, and within three years 99.9 per cent of the most highly radioactive materials had been evacuated to a specialist plant 620km away in La Hague, in the north-west of France.

According to French law, the most highly radioactive elements of a plant, the fuel and the rods, should be removed as quickly as possible once the plant has been shut down — in stark contrast to policy in most other parts of the world, where the most hazardous products are handled last.

Some of these products have since been recycled. In a process pioneered by France, many of the uranium, plutonium and fission chemicals have been

reprocessed into new fuel at the La Hague site, while waste chemicals that cannot be reused have been vitrified, or turned into glass, for short-term storage in shallow sites underground.

Though EDF says the 25,000 tonnes of spent fuel it has reprocessed at La Hague are enough to power France's nuclear fleet for 14 years, critics point to the fact that the fuel can only be reused once and the process itself creates yet more radioactive waste, without providing a long-term solution.

The dismantling of the rest of Chooz A began in 2007, after it received legal permission from the state, and is due to be completed by 2024, at a total cost of €500mn. But the most hazardous waste removed from the site will remain radioactive for centuries to come, and perhaps millennia.

"Only a state or a religion will live as long as the waste, and maybe not even them," says Florin.

Countries have toyed with ejecting such waste into space or burying it deep under the seabed, but these ideas were eventually deemed either impossible or too dangerous.

Only one long-term solution is broadly considered safe and feasible: deep geological repositories, where radioactive material can be stored several hundred metres below ground in formations of clay, rock salt and granite that have not moved for millions of years.

But no one has yet managed to do it. The US has come close; it pumped \$15bn into a project to bury waste beneath Yucca Mountain in Nevada, but the initiative was eventually abandoned in the face of intense and sustained public backlash. Similar opposition from local communities has dogged attempts to

find burial sites in Germany, the UK and Japan.

Some countries have earmarked provisional sites to try again. After a decades-long planning and negotiation process with a remote island community, Finland will bury its radioactive waste in copper tubes in a tomb 1,400 feet below the granite bedrock in Olkiluoto island. The burial site is expected to begin operation in 2023.

France has identified its own site, just outside Bure, 300km east of Paris, in which radioactive waste might be entombed. Consisting of a research centre sitting above a web of tunnels and vaults almost 500 metres below ground, the Cigeo project has so far cost €2.5bn and involved 25 years of research.

The French government is due to decide this year whether to declare the site officially viable as a storage option, setting in motion another sequence of construction and authorisation stages that would lead to the first toxic samples being deposited between 2035 and 2040.

The ambition is to seal all the tunnels irreversibly from 2150, with residues encased in blocks of cement or steel within the ultimate barrier — a subterranean layer of clay with the ideal properties to entrap any material that eventually seeps out. This seeping material should lose its radioactive qualities within the 100,000 years it would take them to permeate other strata.

Resistance is fissile

But Cigeo has attracted the same kind of vocal opposition found at other potential burial sites. And, as a result Bure, a village of fewer than 100 inhabitants, has become a battleground where protesters have regularly clashed with

police over the future of the site. Demonstrators have set up a "house of resistance" in Bure that has become a magnet for anti-nuclear protesters around the country. The former barn is equipped with a projection room, mattresses to welcome guests and a cosy communal kitchen.

Campaigners say the Bure site has become representative of a broader cause. "Beyond the waste, it's nuclear production above all else that worries us," says a 29-year-old jurist who gave his name as Antoine, one of a handful of campaigners manning the fort on a snowy February morning. "It's a supposedly low carbon source of energy, but you've got to build the reactors... it is such a dangerous and destructive solution."

Yet the state holds that the undeniable risks of nuclear energy are outweighed by its potential benefits as a cost-effective way of cutting CO2 emissions. According to a report last year from French grid operator RTE, France's cheapest way to reach carbon neutrality by 2050 would involve building 14 new reactors.

Under the scenarios RTE presented, if France built no new nuclear reactors and relied exclusively on expanding renewables and extending the lifespan of existing nuclear, this would cost €10bn more per year than other options including new reactors, with the cost of decommissioning factored into the final bill.

But that may not factor in the costs of convincing French citizens to host such facilities in their backyards. Bure resident Anne-Marie Henn, a retiree, says the project has forced her and her artist husband Jacques to give up on their dream of creating a painting atelier in an annex to their home. "We'd like to leave, but our house isn't worth anything any more," she says.

Ed Lyman, senior global security scientist with the Union of Concerned Scientists, who has spent decades researching nuclear power safety, says the science behind burying waste is robust, and the dangers of corrosion or leakage minimal. But there remain real risks for the public, he says, such as accidents happening when materials are transported to the site.

"There may be a price [communities] are willing to accept in order to stomach

'Nowhere in the world has anyone created a place where we can bury extremely nasty nuclear waste forever'

the waste and its risks, but we don't know what that price is yet," he adds. "If it's high enough, it will ultimately add to the cost of disposal."

Local authorities have poured millions of euros of subsidies and compensation into the area to support the project and residents. In Bure, that has translated into sizzly lampposts lining every street alongside the barns and stone houses; households have also got fibre optic internet connections and sanitation networks have been improved. "We've got to deal with this crap," Henn says. "At the very least we can benefit a bit from [subsidies]."

But the concerns of many communities go way beyond immediate dangers to more existential questions: how can we ensure that not just our children and grandchildren, but people living thousands of years in the future have the knowledge and understanding to handle toxic waste responsibly? And how can we be sure that the storage containers we have developed now will stand the test of time?

"What we'll be getting here is the really dangerous core of the waste," Henn says, adding that it was "the generations to come" that worried her.

Andra, the French state agency responsible for nuclear waste management which built the Cigeo site, is considering ways to warn future generations of what lies deep below Bure — perhaps by inscribing microscopic information on a hard disk of sapphire, designed to withstand erosion, should the site be forgotten. "Even if we lose our collective memory, the storage site will be safe," says spokesperson Audrey Guillemet.

If these kinds of innovations fail to impress French lawmakers and the site does not win approval, that leaves the government with a problem that goes far beyond the billions spent on construction.

"Some 50 per cent of the [nuclear] waste destined to come here eventually already exists," says Guillemet. Forget the next generation of power plants; the decades-old materials Gannaz and his predecessors have removed from Chooz A are a problem that needs a solution. If it is not Bure, then what is it?