WHITEPAPER

ADAPTING TO THE NEW NUCLEAR LANDSCAPE:

ROLE OF FLOW CONTROL IN DELIVERING SUSTAINABLE ENERGY SECURITY

ABOUT CELEROS FLOW TECHNOLOGY

Celeros Flow Technology (Celeros FT) represents a major force in flow control technology. Combining exceptional engineering expertise with trusted brands, we have supported our customers to improve efficiency and reduce emissions since our inception in 2020. Celeros FT brands include ClydeUnion Pumps, Copes-Vulcan, M&J Valve, GD Engineering, Plenty, and S&N Pumps. Each is a recognized and respected leader in its chosen field.

Our involvement in the nuclear power market began with the first-ever industrial-scale nuclear power plant and continues with nuclear class 1, 2, and 3 pump and valve installations in more than 65% of operational nuclear power plants worldwide.

In addition to our involvement in the commercial nuclear power market, we continue to provide flow control solutions to the world's naval nuclear fleets, research reactors, and other nuclear facilities. We have four nuclear-accredited facilities in the US and Europe. Our market-focused research and development programs ensure that our solutions match the demanding requirements of current and future technologies, such as generation IV, fusion, and small modular reactors.

1.0 INTRODUCTION

Nuclear energy is undergoing a renaissance after decades in the wilderness. This, in turn, has raised some serious challenges for the supply chain.

The skills and equipment required to maintain older nuclear plants or extend their operational life are in short supply. New plant designs, aiming to lower construction costs and improve efficiency, are not yet standardized, making governments and some supply chain partners reluctant to commit significant investment to developing the equipment that may be required.

This whitepaper provides an overview of the current challenges facing the nuclear sector. Using flow control solutions as an example, it examines how historical events have affected the nuclear supply chain and what implications this has for supporting the existing nuclear fleet into the 21st century. It also considers the technologies and skills necessary to deliver new nuclear solutions to address the twin challenges facing the world today: energy security and climate change.

2.0 NUCLEAR ENERGY – LESSONS FROM HISTORY

American novelist Pearl S. Buck famously said, "If you want to understand today, you have to search yesterday." History is certainly important in understanding the current state of the global nuclear industry — for example, why it is grappling with the challenges of an aging fleet on the one hand and an urgent need to develop new, more flexible solutions on the other.

The first nuclear reactor to produce electricity came online in 1951. Based in Idaho, USA, the Experimental Breeder Reactor (EBR-1) was cooled using liquid metal. Three years later, Russia completed its first grid-connected nuclear power plant at Obninsk. The first nuclear-powered submarine, the USS Nautilus, was launched in 1955, and the world's first, full-scale, atomic electric power plant was commissioned in 1957. The 60 MWe Shipping port demonstration pressurised water reactor (PWR) reactor in Pennsylvania operated until 1982.[1]

The 1960s and 70s were a boom time for the development and construction of commercial nuclear reactors. Promoted as a cheap and perpetual source of electricity, nuclear energy was seen as the power source of the future. France was a leading exponent and at one time generated up to 75% of its power through nuclear reactors.[3] The US also developed a large fleet of nuclear plants, which has accounted for around 20% of the country's energy generation since 1990.[4]

However, the accident at Three Mile Island in 1979, followed by Chernobyl in 1986, saw global investment and support for nuclear power decline. Subsequently, the nuclear power industry entered a period of stagnation. Many reactor orders were canceled and the few that came online during the mid-80s were little more than matched retirements.[5]

The late 1990s and 2000s were marked by a higher degree of safety in plant operations, which began to win back public opinion: but the Fukushima Daiichi accident in 2011 was another reputational blow. Many countries initiated comprehensive safety reviews, while others canceled their nuclear development programs altogether. Fukushima Daiichi also demonstrated that extreme weather conditions caused by climate change were a new and substantial threat to safety, resulting in major improvements to the way nuclear energy plants are regulated and designed today.[6]

10%

The proportion of US electricity generated from disassembled Russian nuclear warheads until 2013.[2]

48 GWe

Nuclear capacity lost globally between 2011 and 2020 as 65 reactors were either shut down or mothballed following the Fukushima Daiichi accident.[7]

3.0 DRIVERS FOR CHANGE

During the early 21st century, three key imperatives have prompted a reassessment of nuclear power as part of the global energy mix: dwindling fossil fuel resources, the need to reduce environmental impacts, and growing concerns around energy security.

3.1 Fossil Fuel Depletion

Fossil fuels — such as coal, oil, and natural gas — have been the backbone of global energy production for decades. In 2023, global oil production reached a record level of just over 96 million barrels per day.[8] As reserves dwindle, the cost of extraction increases. This causes fossil fuels to become more expensive and less economically viable. Nuclear energy, on the other hand, relies on uranium: far more abundant and can be extracted at a relatively stable cost. By investing in nuclear energy, countries can reduce their reliance on depleting fossil fuel reserves and mitigate the economic impacts of rising extraction costs.[9]

3.2 Climate Change

Climate change is a second imperative for reducing and ultimately replacing fossil fuels. Fossil fuels are by far the largest contributor to global climate change, accounting for over 75% of global greenhouse gas emissions and nearly 90% of all carbon dioxide emissions[10]. The Paris Agreement, adopted in 2015, aims to limit global warming to well below 2°C above pre-industrial levels, with efforts to limit the increase to 1.5°C.[11] At COP28, more than 120 governments signed the Declaration acknowledging the growing health impacts of climate change on communities and countries, including health implications due to air pollution.[12] Achieving these targets requires a substantial reduction in greenhouse gas emissions. Nuclear energy offers a reliable and low-carbon alternative to fossil fuels and can make a significant contribution to emission reduction targets, contributing to global efforts to combat climate change.

3.3 Energy security

Energy security is an increasing concern for many nations, particularly those heavily dependent on fossil fuel imports. Recent events, including COVID-19 and the Russian invasion of Ukraine, have highlighted the diversification of energy sources as essential to the reduction of vulnerability to supply disruptions and price volatility. By incorporating nuclear energy into their energy mix, countries can enhance their energy security and reduce their dependence on imported fossil fuels. This not only helps to mitigate the economic risks associated with fluctuating fossil fuel prices but also reduces the geopolitical risks linked to fossil fuel supply chains. With a low carbon footprint, nuclear energy also offers a stable, reliable source of power that can complement other renewable energy sources, such as wind and solar. Plants built today will operate for 60 or more years. As the electricity from nuclear plants is reliable, nuclear can directly displace fossil fuels from a country's electricity mix, reducing a country's import dependency and diversifying its energy mix.[13]

It will require the continued safe operation of existing nuclear power plants, plus the evolution of new nuclear capacity, to deliver the necessary capacity to decarbonize the global energy supply and provide a safe, secure means of sustainable power generation.

36.8 Billion Tonnes

Of CO2 released into the atmosphere in 2022 from energy-related activities.[14]

4.0 MAINTAINING THE EXISTING NUCLEAR FLEET

There are over 415 operational nuclear reactors in the world today.[15] The majority are at least 30 years old, but the five oldest – including two in the US and one in Switzerland – have each been operating for more than 55 years.[16] There are also around 160 nuclear-powered submarines and aircraft carriers operating in our oceans.[17] Until they can be replaced, these civilian, research, and military nuclear reactors require regular assessment and / or lifecycle extension programs to maintain operational safety and regulatory compliance. Operators in the US, for example, are now looking to achieve a lifecycle of 60–80 years for their existing nuclear power plants.[18]

Lifecycle extension is a complex process and involves multiple factors, including continued regulatory compliance, equipment obsolescence, skills retention, and supply chain resilience.

4.1 Continued Compliance

Periodic safety reviews (PSR) can be undertaken to obtain an overview of nuclear power plant safety, justify operation beyond the original design life, and to determine reasonable and practicable modifications to maintain a high level of safety during continued operation. The International Atomic Energy Agency (IAEA) has also developed a series of safety standards that define the requirements and pre-conditions of the regulatory body for Long Term Operation (LTO), including the authorization processes applied to LTO, and the regulatory practices and documentation to prepare for and implement LTO.[19]

Documentation is key to compliance: validation of materials, processes, and consumables requires a recorded history to ensure integrity. The original equipment specification needs to be immaculate, with any changes logged so that it is possible to re-engineer components over time. This includes ensuring continuity of supply for the materials from which the components are made, be it steel for housings or rubber composites for seals.

Documentation also plays a key role in the ongoing safety and reliability of critical equipment. The retention of documents and records over the lifetime of a nuclear site therefore requires a collaborative effort between equipment suppliers, the operator, and the maintenance team.

4.2 Managing Obsolescence

The lifetime of a nuclear plant and the lifetime of the components and equipment on which it relies can be quite different, so obsolescence is a key consideration for LTO. Where original parts are no longer available, replacements must be proven to perform the same task and to the same standards as the original certified product. This is a considerable undertaking for the operator and their supply chain.

Most nuclear operators have their own boards of obsolescence, which require full details of any components that are likely to go out of production during the reactor's lifetime, so that shortfalls and lack of availability can be predicted as far as possible. The ability of a lifecycle partner to work with them and provide transparency in this regard is crucial.

Celeros FT has an advantage here: we combine OEM with aftermarket services, so we can make a commitment that critical equipment — such as pumps and valves, plus their constituent components — will not become obsolete, and that parts availability is guaranteed for the lifetime of the correct maintenance is undertaken throughout the project's lifecycle.

4.3 Retaining skills

Given a life extension period of up to 80 years, it is very unlikely that the engineer who installed the equipment originally will be on hand throughout to maintain it — they certainly wouldn't be available when the power station is due for decommissioning! So, the ability to capture knowledge and ensure continuity of expertise is essential for a successful LTO. With this in mind, it's crucial to put training and other processes in place throughout the nuclear supply chain to capture knowledge and ensure correct maintenance is undertaken throughout the project's lifecycle.

Upskilling the supply chain also helps to reverse the effects of the pause in new-build nuclear projects that occurred in the US and Western European countries in the 1990s. Many companies either significantly reduced their investment in the nuclear sector or walked away altogether. Consequently, the nuclear supply chain is much leaner now and will need to be reinstated to meet renewed demand.

USD 2 Billion

Estimated cost of shutdowns and outages in South Korea's nuclear fleet due to parts supplied with fraudulent certifications.[20]

CASE STUDY

IMPROVING PWR PERFORMANCE

CLYDEUNION PUMPS RECIPROCATING PUMP

Prior to 1990, many PWR nuclear power plants in the USA experienced premature failure of their reciprocating coolant charging pumps. Typical symptoms included excessive packing leaks, valve cracking and failure, and gas entrainment. The centrifugal pump alternative was expensive and involved major plant design changes.

ClydeUnion Pumps (a Celeros FT brand) collaborated with several nuclear plant operators to investigate the root cause of the reciprocating pump failures and develop a cost-effective, long-term solution that increased mean time between failures and eliminated costly pump changeouts — this lowered the cost of operation and improved efficiency.

5.0 DELIVERING NEW NUCLEAR CAPACITY

Nuclear reactors are complex and costly projects to deliver. There are wide variations in reactor design and regulatory requirements from country to country, causing difficulties in managing risk, and a limited industry base for accessing the materials and skills. Delivering new nuclear capacity is going to require considerable political commitment and significant investment to achieve — backed by a knowledgeable and secure supply chain.

According to McKinsey, the world requires an additional 400-800 GW of nuclear capacity to decarbonize the energy supply and achieve net zero by 2050.[21] This is a daunting task, considering the industry at its peak has grown at a maximum of approximately 30 GW per year globally (a rate achieved in the 1980s but not since). Even if new nuclear reactors begin to come online by 2030 and reach scale by 2035, achieving the necessary increase requires approximately 50 GW per year of new nuclear capacity.

Due to regulatory and cost complexities, this new capacity is unlikely to be achievable using large-scale nuclear power plants alone, so new technological solutions will be required. This is prompting the development of smaller reactor designs, such as small modular reactors (SMRs).

5.1 Small Modular Reactors

SMRs represent a significant advancement in nuclear technology, offering a more flexible, cost-efficient, and potentially safer alternative to traditional large nuclear reactors. SMRs are designed to be smaller in size, typically producing up to 300 megawatts of electricity — roughly one-third of the output of conventional nuclear power reactors

Their smaller size allows for modular construction, where components can be factory-built and then transported to the site for assembly. It is anticipated that this will reduce capital costs and construction times, ultimately making nuclear energy more affordable. It also presents new applications, because SMRs can be deployed in remote areas or on smaller grids that are not suitable for large reactors. There is even the potential for SMRS to be applied in non-electric applications, such as district heating and desalination. SMR design also incorporates advanced safety features, including passive safety systems that do not require human intervention or external power supplies to operate effectively.

The defense sector has successfully deployed smaller modular reactors (typically between 50 MW and 200 MW) to power nuclear submarines and other naval vessels for more than 60 years, which proves that compactness and modularity of design is possible. However, developing the technology for civil nuclear power generation is still a work in progress.

Even the preferred technology is yet to be determined: some SMR designs are being developed based on tried and tested PWR technology, while others are electing to use techniques such as molten salt or liquid metal.[23] Whatever reactor type is involved, SMRs are likely to require specifically designed and engineered flow control systems that can cope with different operating parameters, such as higher temperatures or pressures and different corrosive substances.

USD 500 Billion

Estimated annual capital costs for a rapid scale-up of nuclear capacity.[22]

Up to 800 GW

New nuclear capacity required to meet global net-zero targets.[24]

6.0 ROLE OF FLOW CONTROL IN DELIVERING NUCLEAR CAPACITY

Whether the nuclear power plant is old or new, large or small, flow control systems are critical in ensuring its safe, efficient, and reliable operation. Comprising specially designed valves and pumps, plus associated control equipment, flow control systems manage the flow of coolant, steam, and other fluids within the plant, directly impacting the reactor's performance and safety.

For example, flow control systems play a critical role in temperature regulation to ensure that the reactor operates within safe limits. Pressure relief valves and other control mechanisms prevent overpressure conditions that could lead to equipment failure or accidents. Flow control systems also manage the injection of chemicals needed to maintain water chemistry within safe parameters. This prevents corrosion and buildup of harmful substances, protecting the integrity of the reactor and associated systems.

By optimizing fluid control, efficient pumps and valves minimize energy consumption and contribute to overall equipment efficiency (OEE). Effective flow control also reduces mechanical stress on components, extending their operational life and reducing the frequency of maintenance, which reduces downtime and extends system longevity. Ensuring that all processes operate within safe parameters, flow control systems help nuclear plants comply with stringent safety regulations. This includes maintaining detailed records for regulatory inspections and audits. In the event of an emergency, isolation valves can quickly shut off affected sections, preventing the spread of leaks and minimizing the risk of contamination.

6.1 Supply Chain Requirements

Flow control systems are central to the success of extending the lifecycle of existing nuclear reactors and developing more agile and cost-effective new nuclear capacity. However, the fluctuating political and financial fortunes of the nuclear sector have seriously depleted the supply chain. Because the sector is so safety-driven and highly regulated, it requires several key attributes from supply chain partners tasked with the supply and maintenance of critical equipment and components.
These include:

- **Long-term commitment**, with a business model that supports the longevity of service required for nuclear applications.
- **Knowledge of the regulatory framework** and how to operate within it, including documentary procedures.
- **Expertise at technical and industry levels** that is constantly kept up to date and shared with the client.
- **Fully accredited facilities and personnel** to undertake maintenance and servicing work that cannot be performed on-site.

Unlike many who reduced investment or withdrew from the nuclear sector, Celeros FT has maintained its investment in R&D and in new facilities, as well as continuing to refine and develop its flow control portfolio for nuclear applications. Global support for maintenance and life extension, as well as the development of equipment for new nuclear applications, is undertaken at four strategically located facilities in the US, Canada, France, and UK, all of which hold nuclear accreditation to ASME "N Stamp" and / or RCC-M.

CASE STUDY

SIZEWELL C

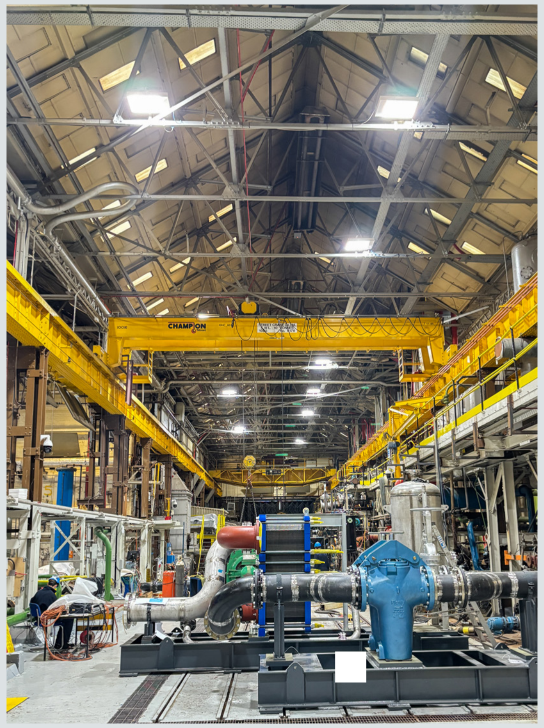
Sizewell C, the UK's newest nuclear power station, will rely on nuclear pump packages designed and manufactured at Celeros FT's nuclear-accredited facility in Annecy, France. The pumps will control the emergency feedwater system (ASG), component cooling water system (RRI), safety injection system (LHSI and MHSI), nuclear island vent / drain system (RPE), and the safety chilled water system (DEL).

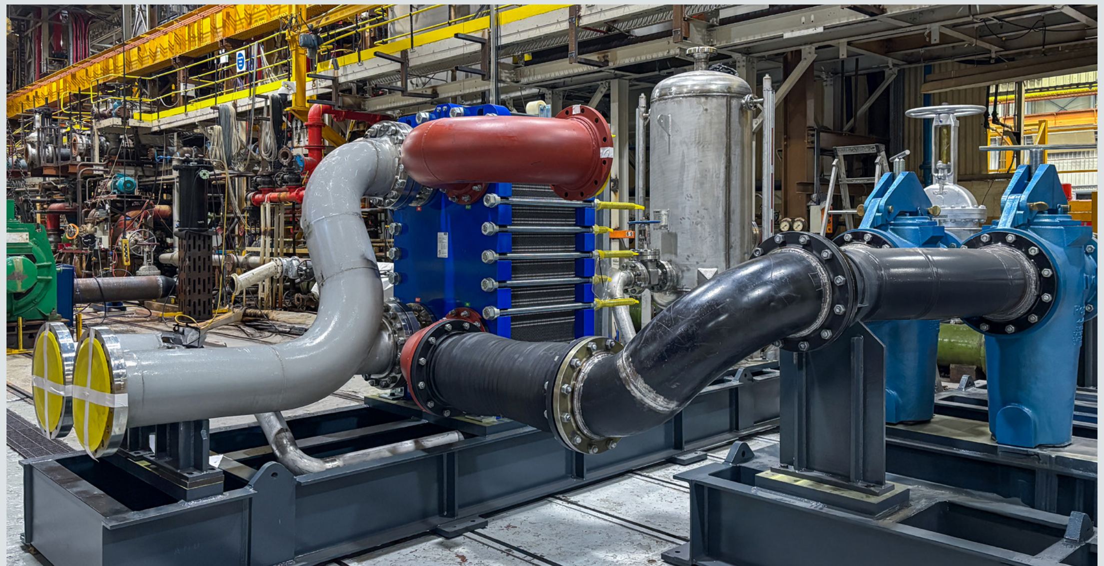
Once complete, Sizewell C will be capable of generating 3.2 gigawatts of power, sufficient to supply six million homes with low-carbon electricity for at least 60 years, and will avoid nine million tonnes of CO_2 for every year of operation.

FROM LEFT TO RIGHT: SEBASTIEN BACHERE (SIZEWELL C), BERTRAND MICHOUD (SIZEWELL C), JOSE LARIOS (CELEROS FLOW TECHNOLOGY) & JEZ EADES (SIZEWELL C)

INVESTING IN NUCLEAR

Celeros FT has invested in a modern high-temperature test loop to support its nuclear pump development programme. The test platform has the capacity to qualify and develop pumps under extreme conditions, including temperatures in excess of 200°C, very high pressures, and debris in the pumped liquid. This investment enables the company to master the entire pump development chain and is likely to be a great asset to the nuclear industry.





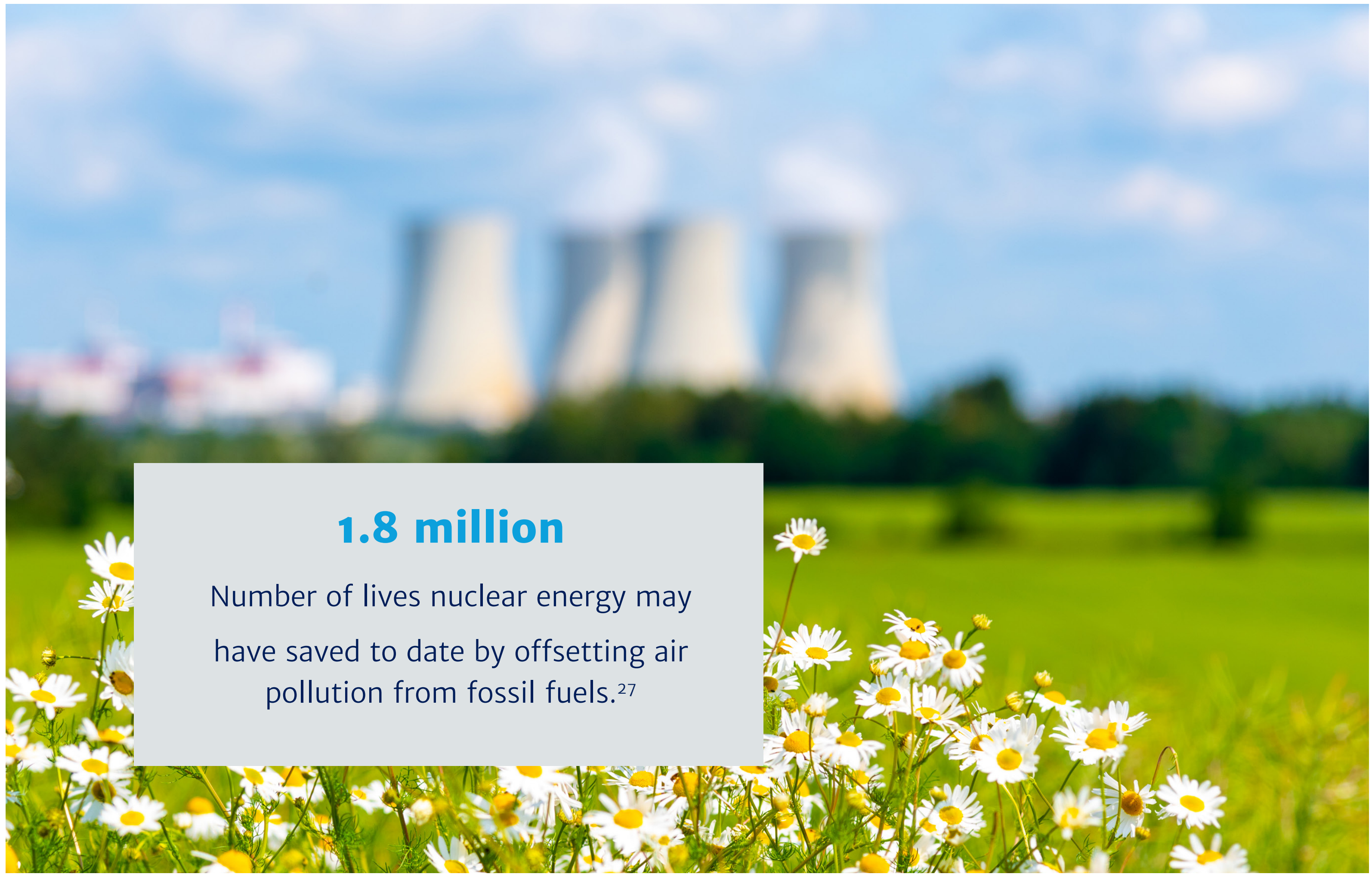
CELEROS FT TEST FACILITY

07. LOOKING AHEAD

Nuclear power has a great deal to contribute as part of a clean, resilient, and safe energy supply. At COP28, many countries and companies pledged to triple nuclear capacity to combat climate change and energy security.[25] Although many believed this was an empty pledge, statistics from the World Nuclear Association indicate that the nuclear renaissance is underway, with 154 nuclear plants currently planned or in construction, and a further 344 being proposed.[26]

The challenge ahead is to build a safe bridge between aging reactors and the deployment of new nuclear technologies. Existing reactors must maintain safety and reliability while staying economically competitive. Advanced reactors under development must be backed up by a proof of concept to successfully clear regulatory hurdles. This will require close international cooperation across the entire nuclear supply chain.

SMR technology holds great promise for the future of nuclear energy, offering a safer, more flexible, and economically viable alternative to traditional reactors. The roadmap to their implementation involves a coordinated effort across R&D, regulatory approval, demonstration projects, commercial deployment, public engagement, and international collaboration. However, it is likely that SMRs will play a significant role in meeting global energy needs while reducing greenhouse gas emissions and enhancing energy security.



1.8 million

Number of lives nuclear energy may have saved to date by offsetting air pollution from fossil fuels.[27]

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CELEROS FLOW TECHNOLOGY

SPEED
EXCELLENCE
PARTNERSHIP

WHITE PAPER

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