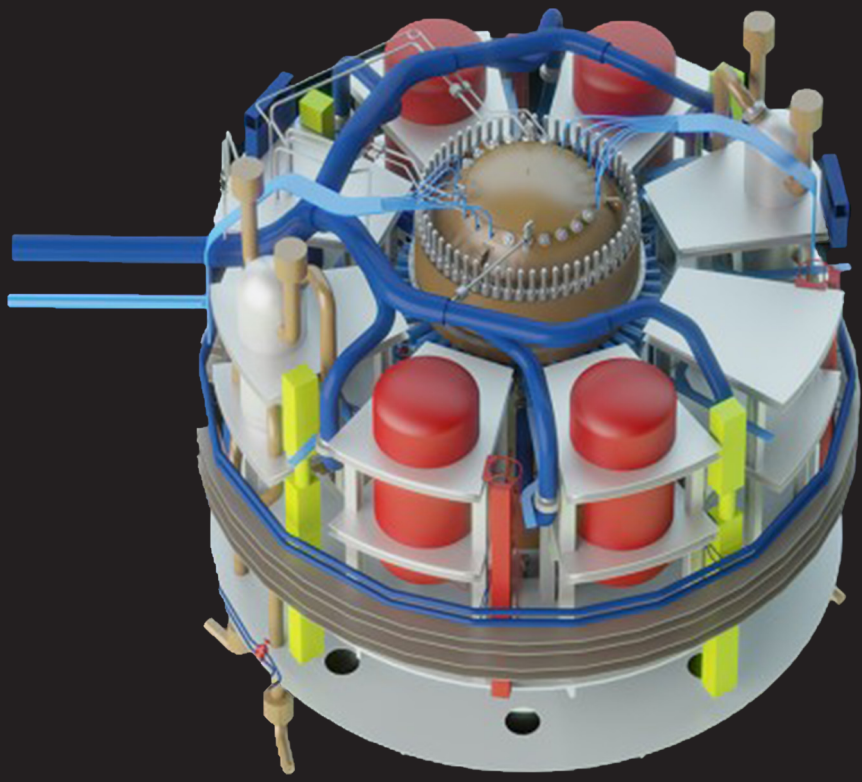
S M R

Small Modular Reactors



NUWARD SMR reactor
© EDF 2021

cea iresne

INTRODUCTION

The challenge of climate change is primarily centered around energy. In light of this, leaders across the globe are seeking to accelerate the implementation of clean energy technologies, facilitate a smooth shifts towards clean energy industries, enable inclusion and fairness, and maintain energy security.

More and more countries are making commitments to achieve net-zero emissions by 2050. « The world has a viable pathway to building a global energy sector but it is narrow and requires an unprecedented transformation of how energy is produced, transported and used globally », the International Energy Agency said in a landmark special report.

With that in mind, we do not have the flexibility to forego a low-carbon energy source. We must look for all the means in renewable energy, including nuclear energy. All the levers of decarbonisation must be deployed to achieve the objectives of carbon neutrality.

Today, unabated fossil fuels currently account for over 60% of total global electricity generation. As electricity demand increases rapidly, the main source of production needs to change, and a significant increase in the rate at which low- and zero-emission sources are deployed needs to be implemented.

Source: IEA

Checking the temperature sensors on the EVEREST loop condenser (SACO).
© A.Aubert/CEA

CONTENTS

What challenges for the French nuclear industry?

There are three major challenges for the French nuclear industry:

- Maintain: extend the life of reactors in a safe and cost-effective manner.
- Renew the nuclear fleet with new constructions.
- Innovate: new technologies (SMR, AMR), new uses, new investment models.

On 10 February 2022, the President of the French Republic announced the launch of the construction of 6 EPR2s, the first one in 2035, and the study of 8 others by 2050. The first 6 EPRs will be complemented by small modular reactors (SMRs) and «innovative» reactors producing less waste.

To support this decision, a «France 2030» investment plan has been created. The government has launched the first call for projects to develop new technologies within the nuclear energy sector. €500 million for the SMR NUWARD™ project and €500 million for innovative nuclear reactors, also known as AMRs (Advanced Modular Reactor) will be distributed.

Speech by the President of the French Republic at the United Nations General Assembly. Posted on 20 September 2022.
© France/OTAN

What is a SMR?

SMRs are nuclear reactors that are smaller in size and output compared to traditional nuclear reactors. They are designed to be more compact, portable, and flexible, which makes them ideal for use in remote areas or places with smaller electricity demand.

SMALL

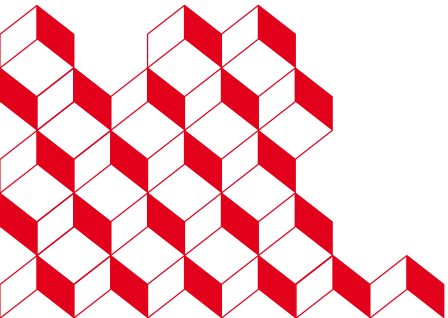
Powers below 300 MWe.

MODULAR

Modular design and construction (limited series production and site adaptations). Standardised factory production.

REACTOR

Deployment in the next decade of GEN III PWRs.



SMR vs AMR

AMRs are also low/medium power reactors but they present technological breakthroughs similar to GEN-IV (molten salts, Na, Pb, Gas). These are reactors with a slightly longer time horizon than GEN III.

The development of AMR technology (fast neutron reactor) would allow us to deploy more sustainable nuclear power. Indeed, the great advantage of fast neutron reactors lies in their ability to produce as much or more fissile material than they consume.

Fast breeder reactors can therefore, by successive recycling, use almost all the energy contained in uranium, i.e. one hundred times more than an ordinary water reactor.

Why develop SMR?

The small modular nuclear reactor project was initially intended solely to replace thermal power plants, particularly coal-fired, for export. The replacement of fossil-fired power plants is possible because of the nature of their installations and infrastructures. The power emitted by these plants is equivalent to that generated by SMRs (300 to 500 MWe).

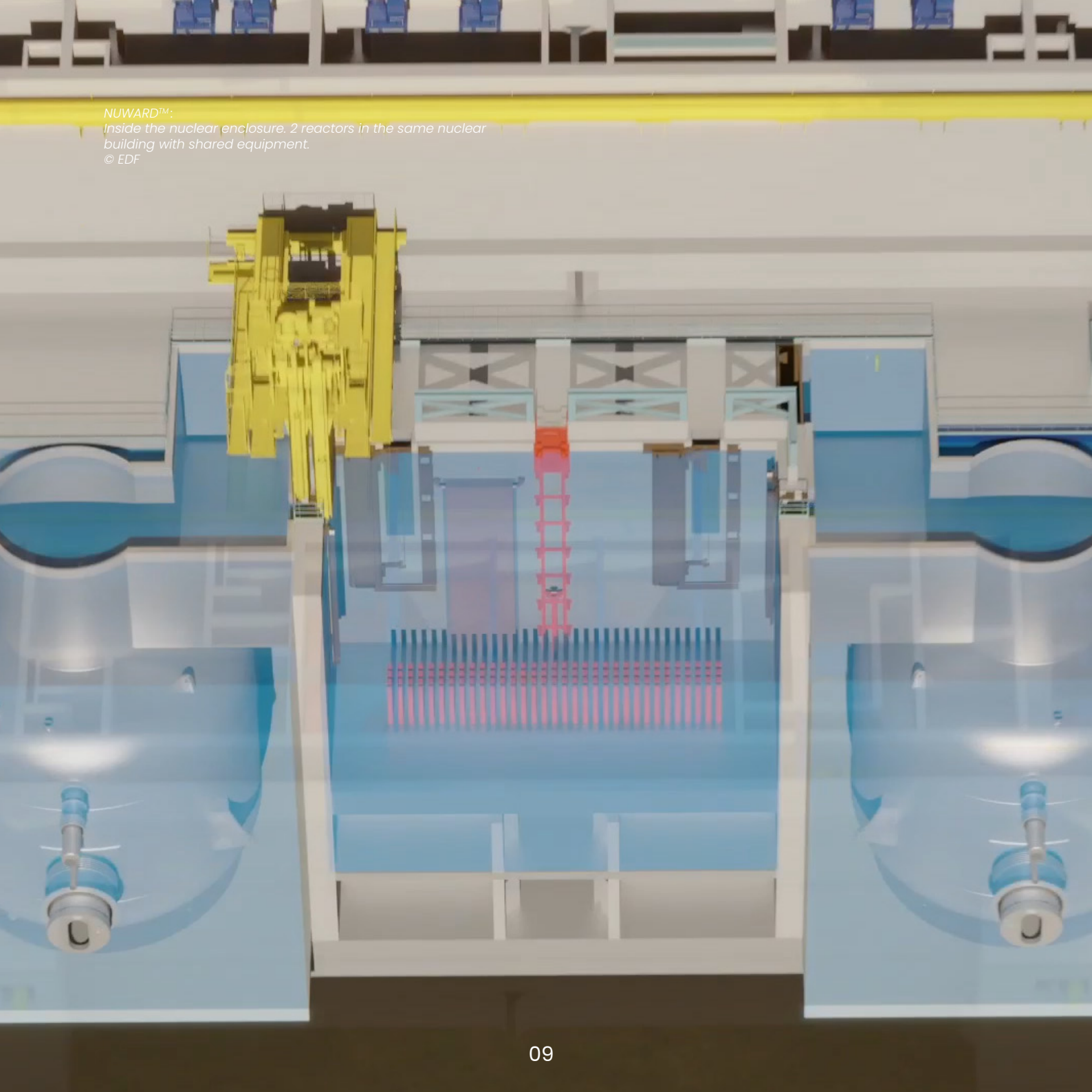
Beyond electricity, SMRs and AMRs allow an access to all energy vectors. SMRs could be used in combination with other systems to produce heat, hydrogen, e-fuels or desalinate sea water and thus decarbonise our activities (industrial etc). They can be deployed at the same time on the same reactor. These multi-purpose SMRs are hybrid nuclear systems beyond power generation.

SMR designs seek the advantages of a smaller reactor size, compensating for the loss of economies of scale.

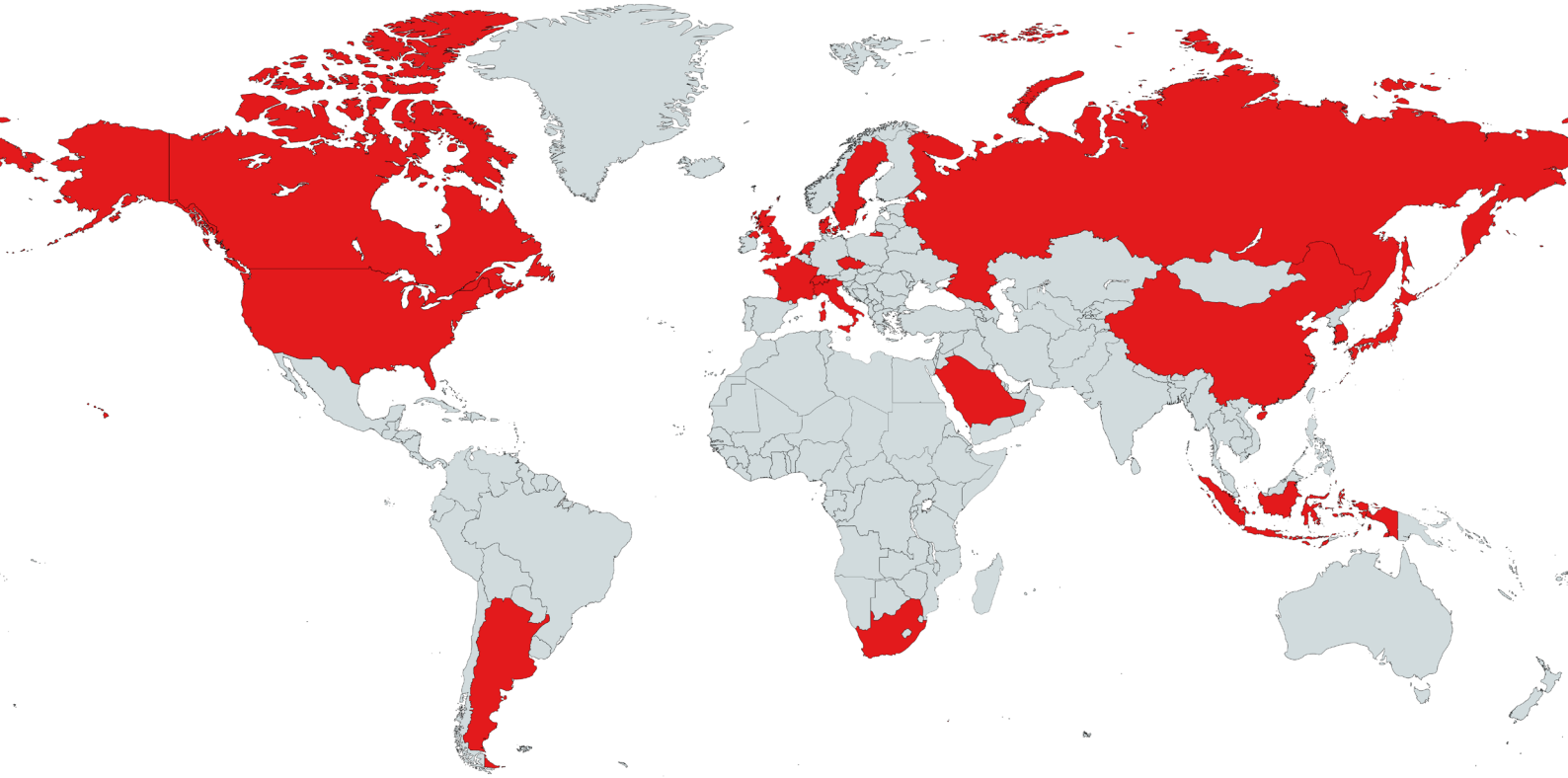
How to compensate for the loss of economies of scale to be competitive?

- The series effect: Smaller reactors but more numerous on the territory. ⟶ Large standardised production of components to obtain an economy of scale.
- Simplified design: A simplified architecture, materials, civil engineering structure as well as a fast and easy construction allow significant budgetary savings. In addition, as the reactor core is 10 times smaller than a current EPR, the large amount of water available allows for passive cooling of the reactor. This implies a simplified design and thus possible savings.
- Modular design and manufacture: cheaper factory manufacture than on-site, faster construction.
- Mutualisation of site commonalities, and proximity of easements/infrastructure.
- Reduced risk and financial costs (shorter construction time).

However, for this to work, the projects must be the same in all countries. Therefore, there is a need to harmonise the certification processes of regulatory requirements in order to benefit from a full serial effect.



NUWARD™:
Inside the nuclear enclosure. 2 reactors in the same nuclear building with shared equipment.
© EDF



Summary of global SMR technology development and deployment in 2022.
© International Atomic Energy Agency (IAEA)

SMRs: a worldwild choice

SMR projects are multiplying in :

- Europe (Denmark, Netherland, Czech Republic, Sweden, Italy, Switzerland and France),
- the United Kingdom,
- Canada,
- the USA,
- Argentina,
- Japan,
- South Korea,
- Indonesia
- Russia,
- China
- South Africa
- Saoudi Arabia

There are currently :

SMR

25 water cooled small modular reactors (land based).

8 water cooled small modular reactors (marine based)

AMR

17 high temperature gas cooled SMR

8 liquid metal cooled fast neutron spectrum SMR

13 molten salt SMR

MMR

(Micro Modular Reactor)

12 microreactors

Source: The Advanced Reactor Information System (ARIS): Advances in Small Modular Reactor Technology Developments (2022).

CEA and SMRs

The CEA has launched various R&D programmes in SMR and AMR technologies based on its different technological bricks: electrogenic and calogenic.

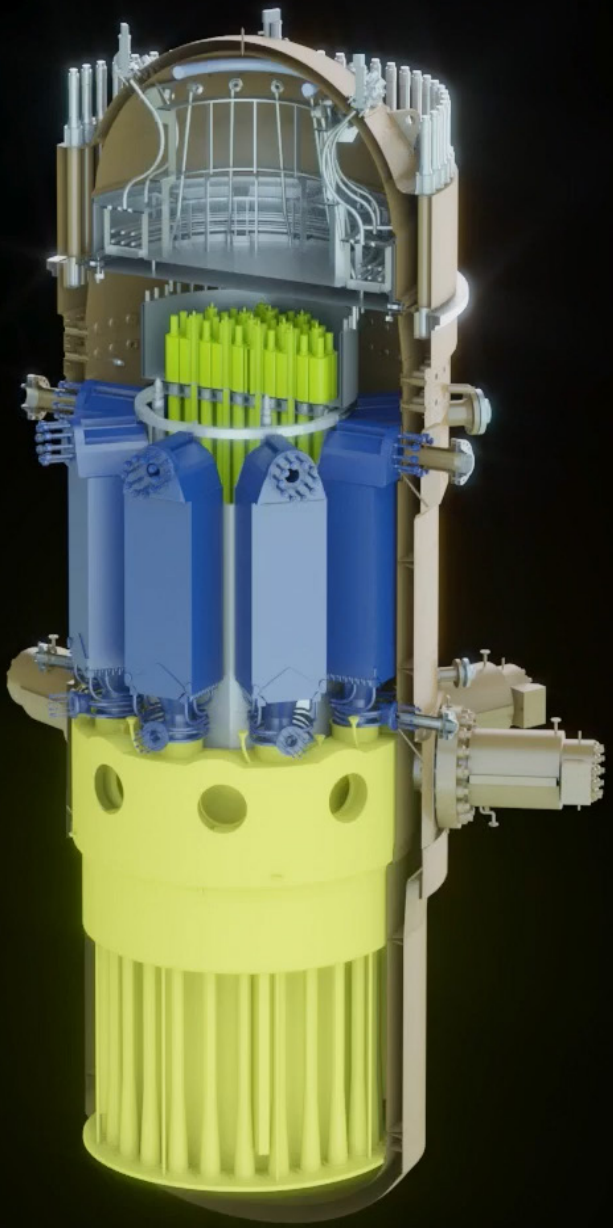
In the SMR sector, the CEA is participating in the development of NUWARD™ , which will be used mainly to produce electricity. The CEA is also studing a concept named Archeos; a 20 MWth heat-generating unit for use by local authorities and industry.
Another 500 MWth SMR draft in co-generation is being studied in order to use the heat and power capacities to produce hydrogen by high temperature electrolysis, or even, in a more distant vision, to produce e-molecules from these new reactor models.

Studies of AMR reactor designs are also being carried out at the CEA. They concern either sodium-cooled fast neutron reactors (AMR-Na), which would allow more nuclear waste to be burnt, or molten salt reactors (MSR), which are more technologically advanced.

The development of molten salt reactors has led to the creation of the start-up projet STELLARIA and the sodium-cooled reactors technologies has led to the creation of three start-ups projets : HEXANA, OTRERA & Blue Capsule.

POSEIDON platform at CEA IRESNE: COLENTEC loop for studies of steam generator clogging
© A.Aubert /CEA

NUWARD PWR.
© EDF



The French SMR: NUWARD™

Under the management of EDF, TechnicAtome, Naval Group, Tractebel-Engie and the CEA are working on the development of a French technology called NUWARD™ (« nuclear forward »). The project is an integrated PWR design to generate 340 MWe from two independent reactor units of 170MWe each housed in a single nuclear building allowing the use of shared equipment. The SMR is being developed to replace fossil-fired power plants in the 300-400 MWe, supply power to remote municipalities and energy-intensive industrial sites; and to power grids with limited capacity.

NUWARD™ will complete a rich and diversified reactor portfolio by combining proven technologies and innovation to gain in constructability, operational competitiveness and environmental performance:

- An advanced Generation III+ pressurized water reactor that has been fully integrated and meets the highest safety standards.
- The design prioritizes standardization, modular construction, and simplicity to enable efficient mass production in a factory. It offers flexibility during both the construction and operation phases, while adhering to the highest safety standards.
- A design developed to encourage load following and tailored to non-electricity generating uses.

So far CEA has contributed to NUWARD™ by :

- Contributing to the design of innovative components for Nuward (Steam Generators).
- Neutronics Studies for the core design.
- Providing expertise on the Thermal-hydraulics system code.
- Thermal-hydraulics transient studies and Validation roadmap for innovative systems.
- Experimental loops to support component performance and code validation.

2030 is the target for the first concrete.

The Archeos project

The Archeos project is a heat-generating reactor concept developed by the CEA, aimed at meeting the challenge of carbon neutrality by 2050 by producing heat; the biggest consumer of primary energy.

Archeos is a nuclear thermal generator, running on light water, providing 20 to 50 MW of heat up to 150°C. The solution is based on 4 major design axes derived from market needs:
- Strong intrinsic safety to convince local politicians.
- Simplicity of design to facilitate the safety process and lower costs,
- Ease of implementation and financing.
- Rapid deployment by reusing proven technological building blocks.

To meet France's energy needs, Archeos stands out for its imminent availability (within 10 years), its lack of need for a cold source, a footprint limited to 1 hectare (100m x 100m is sufficient) and intrinsic safety (no core meltdown scenario).

On the decarbonation market, Archeos is positioned against gas and identifies four competing players (biomass, geothermal, heat pumps and future nuclear). The market analysis also identifies a potential of 100 sites in France, with target ecosystems including agrifood, industry and local authorities.

Archeos aims to meet the essential needs of the French people (drinking, heating, eating), with the ambition of operating a fleet of 10 reactors in France by 2040.

To achieve this, in 2024 Archeos will move from an R&D project to an industrial project by bringing together new partners to develop the solution.

3D printing of a small modular 3rd-generation heat-generating reactor - Archeos project.
© A.Aubert /CEA

The emergence of start-ups

As a heavy, highly sensitive, highly skilled and ultra-regulated industry, nuclear power seemed to be reserved for governments and large companies in the sector. However, climate change has led to a renewed interest in climate tech among investors. The characteristics of SMRs have made nuclear projetcs accessible to start-ups. There are now a growing number of start-ups around the world working to generate safe, clean, and sustainable nuclear energy by developing Generation IV reactors.

The industry is shifting its focus from relying solely on research and government funding to adopting an entrepreneurial mindset and displaying heightened dynamism, which is attracting substantial private investment. However, startup are still relying on strong scientific based and expertise knowledge and know-how from highly qualified engineers and researchers. Operating in the nuclear industry poses a significant challenge for start-ups, despite the potential they hold. The sector places utmost importance on safety and security, making it highly regulated. Additionally, the international regulatory requirements further contribute to the intricate nature of this field. In the coming years, the nuclear start-up ecosystem is poised for further development. We can expect the emergence of fresh start-ups in both the fusion and fission sectors, accompanied by substantial investments from private and public sources.

In 2023, the CEA introduced to the public 4 new start-ups dedicated to SMRs and AMRs. Those start-ups are developing small innovative nuclear reactors dedicated to the decarbonisation of electro-intensive industries. With over 50 years of experience in fostering business creation, the CEA has established a dedicated acceleration program to provide support to these ventures.

Blue Capsule

- BLUE CAPSULE is designing a high temperature SMR realistic of the supply chain technology providing process heat at 700°C using the ambient air as a chilled source.
- The key components have already been used in reactor environment.

HEXANA

- HEXANA is developing a modular, factory-buildable sodium-cooled fast neutron nuclear reactor with a power of 150 MWe or 400 MWth.
- The association of the reactor with a thermal storage unit allows for a decoupling of the thermal power from the power delivered to users.

OTRERA

- OTRERA is designing an AMR-type reactor with a capacity of 110MWe and offering 105 MW of heat that can be used in cogeneration.
- The AMR is based on the 4th generation most mature Sodium Fast Reactor technologies, while integrating its own technological advances developed within the ASTRID programme.

STELLARIA

- STELLARIA designs molten salt fast reactors with a power target of 250 MWth and a capacity of up to 120 MWe of electricity.
- The capsule tank is designed to be multi-fuel and to be able to regenerate up to 100% of its fuel.

Contact

iresne@cea.fr

04 42 25 20 71

fr.linkedin.com/company/cea-iresne

IRESNE - building 707

Cadarache CEA Centre

13115 Saint-Paul-lez-Durance

cea iresne