SMR Development in Europe: Spotlight on the French AMR Developers

Thiphaine Medard and Mathieu Aufauvre†
OAKRIDGE SAS, 8 Rue Croix de Malte, 45000 Orleans, France
†Corresponding author: m.aufauvre@oakridge.fr

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1. Introduction

The current context in Europe and France is fostering the development of new SMR projects. As a result, European nuclear companies have been highly active in recent years, developing numerous new SMR designs. This presentation focuses on four French SMR projects.

2. The European and French Contexts for SMR

2.1. The European Context

The European Industrial Alliance on *Small* Modular Reactors was established in February 2024 [1], to accelerate SMR projects in Europe by the early 2030s. Its objectives are to:

- Facilitate and accelerate SMR projects in Europe by early 2030,
- Offer customized support to projects under the alliance,
- Enable conditions for deployment, operation and maintenance of SMR.

SMRs and AMRs (Advanced Modular Reactors) are considered essential for the energy transition and industrial decarbonization in Europe. They also play a key role in strengthening industrial competitiveness and innovation.

An initial cohort of 277 members joined the Alliance, representing five different technologies (LWR-SMRs and AMRs) and 24 designs. To qualify for support from the Alliance, projects must comply with 13 criteria, primarily focused on providing added value to the European economy and achieving net-zero objectives. Compliance with these criteria must be maintained throughout the entire duration of the Alliance's support. A total of 22 applications were received for SMR projects, of which the following 9 were selected:

- EU-SMR-LFR project (Ansaldo Nucleare, SCK-CEN, ENEA, RATEN),
- European LFR AS project (Newcleo),
- CityHeat project (Calogena, Steady Energy),
- Project Quantum (Last Energy),
- Nuward (EDF),
- European BWRX-300 SMR (OSGE),
- Rolls-Royce SMR (Rolls-Royce SMR Ltd),
- NuScale VOYGR™ SMR (RoPower Nuclear SA),
- Thorizon One project (Thorizon).

2.2. The French Context

The '*France 2030*' investment plan [2], launched in October 2021, aims to address major contemporary challenges, focusing on green transition and technological advancements. The portion of the plan dedicated to the nuclear sector supports the development of innovative reactors while ensuring improved management of radioactive substances. A budget of € 1 billion was allocated to the nuclear industry, including € 500 million to support the development of innovative projects.

The innovation continuum is composed of three phases:

Phase 1: Initial maturation phase (2 years)

Projects receive support from the CEA (French atomic energy commission) and scientific and technical assistance to reach preliminary conceptual design and assess short- and medium-term industrial prospects.

Phase 2: Proof-of-Concept phase (3 years)

The CEA provides reinforced expertise to the projects, aiming to develop a conceptual design with a system-oriented approach for informed decision-making. This phase also addresses technical, economic, commercial, societal, and environmental challenges.

Phase 3: Prototyping phase (5 years)

Projects continue to receive expert support and benefit from the CEA's experimental platforms and simulation means. The objective is to develop a demonstration prototype in a representative environment and produce at least a basic design.

The first call for proposals opened on March 2nd, 2022, and closed on June 28th, 2023. A total of 15 applications were received, of which 11 were awarded, amounting to € 130 million in subsidies.

3. Description of 4 SMR Technologies

Oakridge SAS is involved in designing and developing four SMR projects as a partner in a consortium (e.g., Thorizon) or as a technical support provider. This section will focus on these four projects, which have been recognized under the '*France 2030*' initiative and have received financial support from the French government.

3.1. Thorizon One Reactor by Thorizon

Thorizon, a spin-off from the Dutch nuclear institute NRG Energy, is a French-Dutch company with the ambition of developing a modular molten salt fast neutron reactor as a step towards closing the fuel cycle [3].

Molten salt reactor technology consists of a dissolved fuel in a liquid salt mixture at a high temperature and low pressure. The mixture is directly heated by the energy released from the fission reaction. The concept developed by the French-Dutch company, Thorizon One, is a molten salt reactor powered by an innovative system of modular cartridges (lifespan of 5 to 10 years), as shown in Fig. 1. The cartridge concept was patented by Thorizon in 2020.

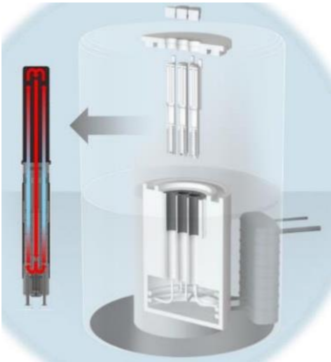

Fig. 1. Thorizon reactor illustration.

The reactor core consists of several cartridges, each equipped with its own molten salt inventory, pump (to circulate coolant), and heat exchanger (See Fig. 2). This solution addresses the issue of high-temperature corrosion in a salt environment by allowing the timely replacement of the cartridges. Reactor safety is ensured with the "walk-away safe" design. The criticality of the fission chain reaction occurs only when the pump is operational and the salt circulates through the cartridge length. Additionally, the negative temperature reactivity coefficient ensures that the reactor is self-regulating, hence enhancing safety [4].

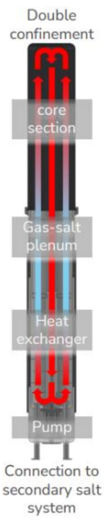

Fig. 2. Description of the patented cartridge system.

Thorizon's reactor project aims to produce either 100 MW of electricity or 250 MW of thermal power by using long-lived radioactive waste streams as fuel together with Thorium. In addition, the Thorizon One can turn 100 MW of electricity into 50-300 MW of flexible capacity, storing energy when demand is low and releasing it during peak hours. The company aims to start building its first Thorizon One reactor in 2030. To achieve this objective, the company has joined forces with Orano and Oakridge, as well as the University of Lille and Centrale Lille [5].

As part of its consortium with Thorizon, Oakridge is currently developing the reactor core design. Oakridge oversees the core design and core optimization to burn minor actinides, implying neutronics calculations. In addition, Oakridge provides the project with its French pressure vessel regulations (ESP/ESPN) expertise by transposing to molten salt reactors requirements applied to PWR.

3.2. LFR Project by Newcleo

Newcleo is a European Startup launched in September 2021, headquartered in Paris, France. The startup is committed to lead-cooled fast reactor technology and is developing a reactor prototype of 30 MWe.

Lead fast reactor systems operate with fast neutrons at atmospheric pressure and high temperature thanks to the high boiling point of liquid lead (1,749 °C). The design of the Newcleo's reactor integrates the primary pumps within the steam generators (see Fig. 3), with a coolant inlet temperature of 420 °C and an outlet temperature of 530 °C [6]. The design also incorporates two vessels. The primary vessel (i.e., reactor vessel) is a cylindrical shell with a tori-spherical head, designed to contain the primary coolant and cover gas. The safety vessel, which encloses the reactor vessel, serves as a secondary containment system capable of containing the primary coolant in the event of a reactor vessel leakage. Additionally, liquid lead enables the passive shutdown of the reactor. Newcleo's reactor has a temperature margin of several hundred degrees Celsius between the operating temperature and the safety limit. This allows thermal expansion to open the core and shut down the reactor in case of logic or operator intervention failure.

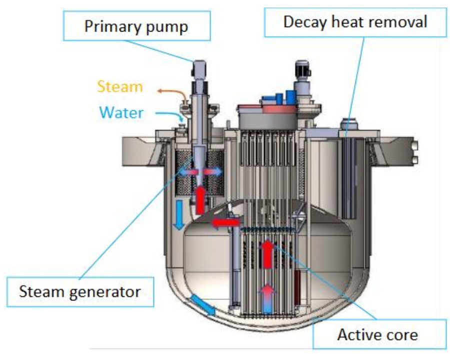

Fig. 3. Newcleo's reactor vessel, cross-section.

Fig. 1. Newcleo's reactor vessel, cross-section.

The LFR-AS-30 reactor is slated to be operational by 2031 and will be used to validate new components and solutions for future commercial reactors. By 2033, Newcleo plans to construct its First-Of-A-Kind (FOAK) commercial reactor, a 200 MWe reactor named LFR-AS-200. Concurrently, the developer is directly invested in a mixed uranium/plutonium oxide (MOX) plant to supply its future reactors. Newcleo is currently working on the Basic Design of the LFR-AS-30 reactor and its MOX production facility. The company is in the pre-licensing phase and is engaged in discussions with French nuclear regulatory bodies for both projects. The company recently announced a land acquisition in France to construct its reactor prototype [7].

Oakridge is currently involved in developing both LFR-AS-30 and the MOX production facility. Among its achievements, Oakridge carried out criticality calculations using the Monte-Carlo N-Particle Transport code to store fresh and spent fuel assemblies.

3.3. HTGR Reactor Project by Jimmy Energy

Founded in 2020, Jimmy Energy is a French startup developing a thermal generator based on high-temperature gas-cooled (HTGR) micro-reactor technology. With a thermal power of 20 MW, Jimmy aims to supply heat to the industrial market [8] by installing its reactor close to its client's industrial site.

The HTR reactor operates with two independent loops. The primary circuit extracts the heat from the core at a temperature below 500 °C using pressurized helium (1.5 MPa). The secondary loop transports the heat from the primary exchanger to the secondary exchanger using pressurized carbon dioxide (see Fig. 4). The secondary heat exchanger is designed to meet each customer's need by supplying heat in any type of coolant.

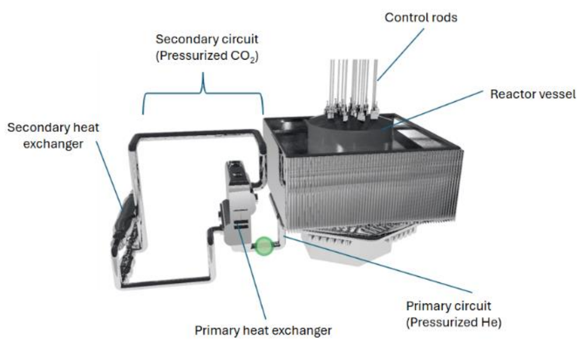

Fig. 4. Simplified schematic of Jimmy's HTGR reactor.

Jimmy's main particularity lies in the geometry of its fuel, which consists of enriched uranium "Triso" particles. This specific fuel geometry was chosen for safety reasons, as Triso particles are considered the safest fuel in the world. These particles, measuring 1 mm in diameter, are coated with three layers around the uranium core: a porous carbon buffer, a high-density carbon layer, and a silicon carbide layer, as shown in Fig. 5. The particles are then incorporated into a graphite matrix to form cylinders measuring 2.5 cm in height and 1 cm in diameter. For a generator that would last twenty years, a single fuel reloading will be scheduled after 10 years.

Fig. 5. Triso particle representation

The Jimmy HTR project is the most supported initiative under '*France 2030*', with an allocation of €32 million. On May 3, 2024, Jimmy Energy submitted a license application for the construction of its reactor to the Nuclear Safety and Radiation Protection Authority (ASNR), a service of the minister responsible for nuclear safety. On February 13, 2025, the ASNR sent Jimmy Energy a request to update its application file following an initial analysis [9]. Jimmy plans to operate its first industrial demonstrator in 2026.

As part of developing this technical solution, Oakridge supported the calculations of HVAC systems.

3.4. XAMR Reactor by NAAREA

Founded in 2020, NAAREA (i.e., Nuclear Abundant Affordable Resourceful Energy for All) is a French startup that aims to build an eXtrasmall Advanced Modular Reactor (XAMR).

NAAREA's microreactor consists of a molten salt reactor operating at close to atmospheric pressure and salt cooled. The fission reactor occurs at around 700 °C and is auto-regulated. The reactor aims to deliver an 80 MW thermal or 40 MW electrical output power. The following table (Table I) summarizes the main characteristics of this reactor.

Table I: XAMR reactor properties

Reactor type	Fast neutron reactor
Primary coolant	Molten salt mixed with radioactive waste
Coolant pressure	Close to atmospheric pressure
Coolant temperature	≈ 700 °C
Output power	40 MWe Or 80 MWth

In February 2025, NAAREA announced the commissioning of its industrial test facility and laboratory, the I-lab. This test facility is designed to conduct non-nuclear tests and experiments. The company plans to establish its first production facility by 2027, to increase reactor production over the following five years [10].

Oakridge provided technical support for the Equipment & Systems Design during the conceptual design phase of the XAMR reactor. The company contributed its expertise in nuclear safety in the conception of the fuel-draining system. In addition, support was provided for the conception of the reactor heat tracing system.

4. Conclusion

Following the launch of '*France 2030*' and President Macron's speech in Belfort in 2022, a significant financial support of €500 million, divided into three phases, has been allocated to SMR startups in France. Four of the 11 projects selected in the first phase of France 2030 were presented in this document, covering various technologies: Lead-cooled Fast Reactor, Molten Salt Reactor, and High-Temperature Gas cooled Nuclear Reactor. The selected companies are currently submitting their pre-conceptual designs in an effort to advance to the second phase of *'France 2030'* and secure additional funding of up to €80 million.

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