OTRERA NEW ENERGY is a spin off from CEA (Atomic Energy Commission) co-founded in 2024 by Frédéric VARAINE, Grégory CHERBUIS et Jean-Éric LUCAS and winner of the France 2030 Call for Proposals on Innovative Nuclear Reactors. OTRERA designs and develops a range of **4th generation sodium-cooled SMR** (Small and Modular) nuclear reactors.

OTRERA contribution to Committee to evaluate nuclear power option for Norway

Norway has pursued an ambitious and recognized environmental policy for many years. By rationally exploiting its natural hydropower resources for electricity production, Norway is already a virtuous state, but its growth is pushing it to implement new solutions to provide its populations and industries with abundant, carbon-free energy.

In the current international context, economic and sovereign constraints naturally apply to these new energy sources in Norway. Nuclear energy is a natural candidate to replace fossil fuels, but the risk-benefit ratio associated with this solution must be pragmatically assessed.

It is therefore vital for the Norwegian government to study the various nuclear technologies available today, without bias, in order to inform the possible options as well as the potential consequences of these choices on society.

As such, OTRERA NEW ENERGY is honoured to be able to present its vision and solution to the Committee to Evaluate Nuclear Power Options for Norway.

Issues to be addressed

From our perspective, it is necessary to implement a holistic approach to consider all aspects of the problem. Indeed, a simplistic approach that focuses on only one aspect risks promoting an attractive solution that would fail to address the fundamental issues or lead to detrimental consequences down the road.

The areas of reflection we propose are as follows:

- What are the risks to populations associated with nuclear energy?
- What is the nature of the energy produced by nuclear facilities, and how do they meet Norway's needs?
- How can nuclear energy be considered renewable and low-carbon?
- How does nuclear energy address economic and sovereign constraints?
- How do the proposed solutions meet the monitoring requirements of international agencies regarding non-proliferation?

OTRERA intends to present its understanding of these issues and how its solution addresses them.

What are the risks for populations associated with nuclear energy?

Studies conducted by the IAEA show that several causes lie at the root: organizational or human error, technical failures, inadequate design, external events, insufficient safety management, aging facilities, and maintenance issues.

In France, we are fortunate to have a highly experienced nuclear safety authority that provides high-quality oversight to ensure that the design of nuclear facilities meets the latest safety standards.

For OTRERA NEW ENERGY, mitigating accident risks is based on the following:

- A solid safety culture reflected in design choices;
- The use of proven technologies with extensive feedback;
- Complete transparency and collaboration with the French and partner country safety authorities;
- Partnerships with experienced manufacturers who share the same values;
- Close, long-term cooperation with the nuclear operator;

Because our ambition is to set a new safety standard, OTRERA proposes adding a safety barrier to its reactors. Thus, whereas current PWR, BWR, and other SMR reactors only have three barriers, we propose an additional sealed enclosure that allows us to exclude any release of gas and radioactive material in the event of an accident.

We believe this improvement is essential for SMRs intended for installation in peri-urban or industrial areas.

What is the nature of the energy produced by nuclear facilities, and how do they meet Norway's needs?

Nuclear facilities natively produce heat that can be either directly exploited or used to generate electricity. Norway already has a low dependence on fossil fuels for heating, with a significant portion of this carbon-free electricity being used to produce heat.

Optimizing the use of the energy produced helps support the country's low-carbon growth for datacenters, hydrogen production, food production, etc. From this perspective, SMRs allow for great flexibility and greater involvement of private stakeholders in the development of local energy sources.

OTRERA SMRs are optimized to produce both heat and electricity, effectively supplementing the Norwegian electricity grid. When heat consumers are close to the reactors, the cost of this heat is extremely competitive, completely carbon-free, and allows the available electricity to be allocated to other uses. OTRERA is an interesting solution to be deployed in identified areas of interest such Aure, Heim, Vardø and Halden[1].

[1] That proposal followed proposals submitted for SMR power plants in Aure and Heim municipalities, as well as Vardø municipality. Earlier this month, Halden Kjernekraft - in which Norsk Kjernekraft owns 40% - submitted a proposal for both a power plant based on multiple SMRs as well as a radioactive waste storage facility at Halden, in southeast Norway.

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The electrical power produced by the OTRERA reactors is 220 MWe, allowing for easy connection to the grid and is fully controllable. It makes it possible to effectively supplement national electricity distribution and support the local establishment of electro-intensive industries without penalizing the electricity grid.

How can nuclear energy be considered renewable and low-carbon?

Currently, nuclear energy is not considered renewable but defined as low-carbon, because the uranium used for the current generation of reactors (PWRs and BWRs) is an abundant but finite resource extracted from mines. However, OTRERA aims to recycle spent materials for its fuel, making a virtuous use of resources.

Moreover, the carbon-free aspect of nuclear energy was taken into account at the European level in 2023 in order to integrate it as a green energy into the European taxonomy and to authorize the financing of nuclear projects by the World Bank, particularly for SMR projects.

It should be noted that the OTRERA nuclear reactor uses sodium cooled fast neutron technology (SFR), known as a 4th generation, can use all stocks of depleted uranium (a by-product of enriching natural uranium with the isotope 235) and exploits nuclear fuel almost 100 times better than 3rd generation reactors. OTRERA's technology therefore significantly reduces nuclear waste, but is also compatible with France's reprocessing system, which allows for a virtuous closure of the nuclear fuel cycle.

As such, while not strictly speaking renewable, the nuclear technology of the OTRERA reactor has a minimal impact on the environment. OTRERA has been awarded the Greentech innovation label by the French Ministry of Ecological Transition.

How does nuclear energy address economic and sovereign constraints?

Economic and sovereignty constraints are fundamental when considering the long-term use of nuclear energy.

While the benefit of decarbonization is a decisive factor to consider when choosing an energy source, it cannot be achieved at any price, as this would penalize Norwegian industries and families.
Sovereignty is also a crucial factor because, as recent events have shown us, international events can have a very significant impact on the domestic and European economy when energy supplies are not sovereign.

OTRERA has integrated these economic and sovereignty factors into its design. OTRERA's technical choices are systematically challenged by a "Design to Cost" approach to guarantee its customers competitiveness with other energy production sources.

OTRERA guarantees European sovereignty over all technologies implemented in its reactors. French excellence in nuclear power, with over 65 years of operating sodium-cooled fast neutron reactors, is made available to European customers without recourse to non-European expertise.

Whether its customers are already nuclear operators or not, OTRERA offers MOX and UO_2 HALEU fuel solutions that ensure long-term supply from European suppliers.

How do the proposed solutions meet the monitoring requirements of international non-proliferation agencies?

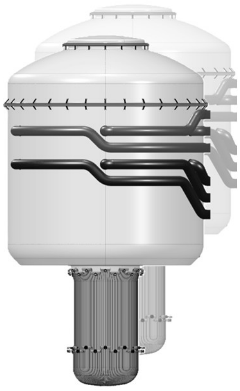
The international regulatory environment concerning nuclear non-proliferation is one of the foundations of the peaceful use of nuclear energy, and Norway is very active in implementing international verification measures.

The very design of the OTRERA reactors allows for native and cost-effective control of the radioactive inventory, as no cooling pool is required within the facility.

Indeed, the OTRERA cores incorporate sealed, gastight enclosures that ensure the radioactive inventory is maintained between two reloads every 10 years. It is even possible to lock the loading/unloading equipment so that it can only be used under international supervision.

OTRERA's clear ambition for a sustainable and competitive energy solution

At OTRERA NEW ENERGY, we are redefining nuclear power to meet decarbonization goals by 2050, the greatest challenge of our century.



We are developing a small, innovative 300 MWth (110 MWe / 180 MWth) sodium-cooled nuclear reactor that produces low-carbon electricity and heat between 100 and 180°C, to power cities and industry. The challenge for these stakeholders is to achieve Net Zero Emissions by 2050.

Our objective is to make sodium technology as competitive as possible, with a market launch in 2032, by building on the 50-year scientific and technical history of this industry of excellence.

To achieve this, we have changed the paradigm by re-examining the historical specifications for SFRs, without disrupting the technology. Drawing on our experience with sodium technology, we are proposing a simplified, modular, safe architecture in the pre-industrial phase, enabling competitive energy production and accelerated time-to-market from the first half of the 2030s.

To power the reactor, we recover plutonium and uranium from spent fuel from existing power plants, eliminating the need for uranium mining and strengthening our energy sovereignty.

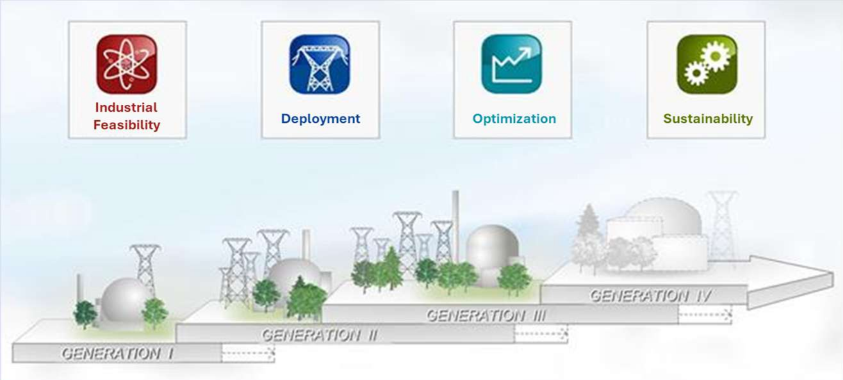
Thanks to our top-level technical team of experts and engineers, supported by highly experienced nuclear managers, we can guarantee the successful development of our reactor.

We're entering a new chapter, with a new generation of nuclear power available for the decade 2030!

Fast neutron reactors (FNR): a key technology for energy sovereignty

Generations of nuclear reactors

Each generation of reactors has its own purpose, in line with the major issues at stake at the time of their design.



[1]

The majority of reactors in operation worldwide are of generation II. In France, Generation III corresponds to the EPRs that are gradually taking over (e.g. Flamanville). Generation IV, of which OTRERA is a part, is based on “fast” neutron technology, with operating conditions that optimize the use of nuclear fuel. The four Gen IV requirements defined by the GIF are: sustainability, safety, economic competitiveness and resistance to nuclear proliferation. These reactors will be deployed alongside Gen IIIs to meet growing energy needs.

Why sodium technology?

Gen IV reactors come in a number of different types, depending on their coolant and fuel:

- *Sodium-cooled reactors (SFR)*
- *Helium-cooled high and very high temperature reactors (HTR)*
- *Gas (helium) cooled reactors (GFR)*
- *Lead or lead-bismuth cooled reactors (LFR)*
- *Molten salt reactors (MSR)*
- *Supercritical water reactors (SCWR)*

Sodium has excellent thermal conductivity at low pressure, enabling high operating temperatures (500-550°C) to be reached with passive safety. The SFR technology is the most promising of Gen IV, given the rapid time-to-market made possible by a high level of technological maturity (pre-industrial) and the accumulated experience of this field of excellence [2].

When the French FNR system was launched in the 1960s, the need for rapid plutonium production led to design choices for the core and boiler. This resulted in massive components, and consequently large building sizes and construction costs that exceeded those of today's pressurized water reactors (PWRs).

The French sodium nuclear industry has produced three prototype reactors (Rapsodie, Phénix, Superphénix) designed to prove the feasibility of industrializing sodium fast breeder reactors. In 2010, the ASTRID prototype project was launched, with an investment of nearly €750 million. The project ends in 2019, following the political decision not to build the reactor.

The shutdown of ASTRID was a turning point: ASTRID project leader Frédéric VARAINE, founding President of OTRERA, launched an extensive review of ways to improve the price competitiveness of sodium technology by rethinking the design of sodium FNR. This resulted in the OTRERA project, a reactor with an optimized core and a compact architecture, in line with today's challenges of producing energy (electricity and heat) that is carbon-free, safe and competitive.

An industrial and strategic challenge for France and Europe

The challenge of the century

Decarbonization is one of the greatest challenges of the 21st century. According to the International Energy Agency (IEA), achieving Net Zero emissions by 2050 requires a doubling of global nuclear capacity, from 415 GWe in 2022 to 916 GWe in 2050 [3]. Among the various aspects of decarbonization, heat production is a major challenge, with nearly 90% of the world's commercial heat coming from fossil fuels [4]. Heat accounts for half the world's total energy consumption and two-thirds of industrial energy demand. To address this situation, decarbonated cogeneration of electricity and heat is a viable strategy. The International Atomic Energy Agency (IAEA) points out that a nuclear reactor supplying 10 TWh of heat per year in addition to electricity production can reduce carbon emissions by up to 2 million tonnes of CO_2 per year [5].

The key to energy sovereignty

In the current geopolitical context, energy independence is a major strategic issue for Europe. The REPowerEU plan aims in particular to reduce dependence on Russian gas, oil, and coal imports. In the face of environmental and geopolitical challenges, OTRERA offers a sustainable energy solution that guarantees accessible, secure, and carbon-free energy, while promoting circular resource management.

France has developed an industrial nuclear sector that provides complete control over the entire value chain: from facility design and construction to uranium enrichment, fuel fabrication, as well as processing, recycling, and waste management. OTRERA capitalizes on this valuable industrial and technical experience and collaborates with major contractors (CEA, Orano, EDF, Framatome, etc.). OTRERA will export this knowledge in European countries where the reactors will be deployed, and establish partnerships with local industry and authorities, while promoting the sharing of their expertise.

OTRERA, a driver of industrialization

The implementation of OTRERA SMRs addresses the decarbonization challenges of industries and cities. They also serve as a lever for territorial dynamism, particularly for areas undergoing industrial reconversion or losing their attractiveness. Indeed, the availability of controllable, carbon-free, and affordable energy is an asset for maintaining and attracting economic activity over the long term.

An optimized design for OTRERA's SFR

OTRERA makes a significant value contribution to FNR through the innovation it carries out. Its major inventions are patented in line with a proactive strategy. To date, 10 patents have been filed. Some of these patents are also potentially exploitable in nuclear-related sectors such as chemistry, energy and industry.
OTRERA stands out from the competition in six key points:

Compact and economical architecture

The innovative architecture of the OTRERA reactors makes them highly compact. With a 2.5-meter-diameter vessel, compared with the 12-meter diameter of the ASTRID reactor (150 MWe version), this compactness is also reflected in the site, which has a footprint of 4 hectares. OTRERA reduces the amount of concrete required by a factor of three, drastically cutting construction costs and environmental impact. The following images show the OTRERA plant located near suburban areas:

Modular design ready for industrialization

The New Space-inspired modular design ensures short manufacturing times and low costs, while maintaining industrial scalability. OTRERA's 50 MWth primary heat exchange loops are standardized, one-time qualifiable, manufacturable and factory pre-assembled. Key components such as the vessel, control rods and heat exchange modules will be manufactured by OTRERA on a non-nuclear industrial site.

Long-lasting, high-performance core with cycle integration

OTRERA has designed a high-performance, long-cycle core that produces twice as much electricity for a given quantity of MOX (Mixed Oxide) fuel compared to classical SFR and thermal reactors. OTRERA is the only SMR able to recycle fuel material (plutonium and reprocessed uranium) from used MOX assemblies, which are currently not reprocessed and stored in pools at La Hague. This means more efficient management of nuclear materials, preservation of finite uranium resources, and a reduction in waste by a factor of two.

FNR reactors built between 1960 and 1980 (in France, Russia, Germany and the USA) made extensive use of MOX, with positive feedback. The manufacture, transport and reprocessing of this type of fuel are well known and fully managed. This makes MOX by far the most mature fuel for FNR.

OTRERA is also the only European reactor to be able to operate with two other fuel types, since MOX is expected to be available by 2040:
- Unused fuel assemblies from earlier sodium reactors, saving time and reducing costs.
- UO_2 HALEU fuel for export (plutonium-free, whose status differs from country to country). This fuel opens up new opportunities as it is a less proliferating and easy-to-use product, ideal for many countries in terms of safeguard. Moreover, it benefits from extensive industrial feedback from FNR around the world and is easy to manufacture and transport.

OTRERA's technology associated with these fuels lead to reactors that produce twice as much energy as thermal reactors such as the HTR and third generation ones, and to extended fuel cycles of up to 10 years, versus 18-24 months for current reactors. OTRERA's fuel availability and cycle advantages are contributing to accelerating the deployment of its reactors.

Accelerated deployment, First Of A Kind starting in 2032

OTRERA therefore relies on mature technology, as demonstrated by its designation as an "Industrial Reactor" in the classification issued by the French Nuclear Safety and Radiation Protection Authority (ASNR) on March 5, 2024. OTRERA is based on pre-industrial components, some prototypes of which can be seen at CEA Cadarache (electromagnetic pump, sodium/gas exchanger). The innovative design does not involve a disruptive technology, but rather overcomes the bottlenecks identified in previous sodium reactors. This guarantees fast, reliable implementation. Thanks to its high level of maturity and the French regulator ASNR's in-depth knowledge of this technology, OTRERA can directly propose an industrial reactor without the need for a demonstrator. This first reactor will provide France and Europe with a fast neutron source and will serve as a qualification tool for the key technologies of OTRERA. The reactors will be deployed in European countries, benefiting from French feedback and working with local authorities.

Enhanced safety and security

OTRERA's optimized design and operating conditions (made possible by the physical properties of sodium) guarantee maximum safety and security, as described by the French High Commissioner for Atomic Energy (HCEA) in July 2024. OTRERA features a 4th containment barrier, operates in an inert, non-pressurized atmosphere, and is located in a semi-underground building. By design, this eliminates the risk of sodium reacting with air and water. In addition, fuel handling steps are reduced as the fuel cools down in its own tank after reactor shutdown, unlike other technologies requiring an adjacent storage pool. OTRERA reactors can therefore be deployed close to suburban areas. Ad hoc regulatory studies are being carried out in cooperation with the DGEC. OTRERA is currently under review with the French regulator (ASNR), in the Preparatory Review phase.

Scalable and adaptable to high-power applications

The high modularity of OTRERA reactors enables the development of a range of reactors of different power outputs without major design modifications. OTRERA then demonstrated the feasibility of a high-power reactor concept (1000 MWe) based on the work carried out for its SMR. Thanks to this scalability, OTRERA can offer reactors tailored to different market needs, while keeping its competitive and safety advantages.

Target market and use cases

Our primary target market is Europe, where the current situation is favourable to nuclear energy. The revival of new-build programs and the call by twelve European Union member states to create the Industrial Alliance for Small Modular Reactors strengthen our position.

OTRERA's energy users include high-consumption areas, such as industry (datacenters, hydrogen and e-fuel production, Li-ion battery manufacturing, etc.), which can be grouped together in clusters, and heating networks. The objective is to supply them with electricity and heat (between 100 and 180°C, up to 500°C) at a controlled cost between 60 and 80 €/MWh (LCOE, E=Energy) to contribute to their decarbonization roadmap.

As an example, OTRERA can produce over 30,000 tonnes per year of low-carbon hydrogen by high-temperature electrolysis (HTSE/SOEC). The use of heat to vaporize the water reduces the electricity required for electrolysis and improves overall efficiency. The OTRERA reactor can also power a 200 MWe hyperscale datacenter, a type of datacenter that is responding to the exploding demand for cloud services, particularly for AI. As they are now compelled to valorize their waste heat at around 40°C, coupling with OTRERA heat enables them to reach a more suitable temperature for the market, i.e. around 120°C (for instance for district heating).

The market's main need, particularly for industrial companies, is to hedge against variations in the price of decarbonized energy (electricity and heat), using medium/long-term contracts such as PPA or futures. Moreover, the ability to supply energy to industrial companies with electro-intensive production could be included in the price of futures contracts. This is why particular attention is being paid to the LCOE, the size of the reactor, its maintenance cycles and the predictability of construction and on-site installation programs for these technologies.

OTRERA would be delighted to engage with Norwegian stakeholders to explore the potential for coupling its advanced reactor technology with local industrial and energy needs. Please contact us at contact@otrera.fr for more information.

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