EXPERIMENTAL INFRASTRUCTURE IN SUPPORT OF R&D AND LICENSING PROCESS FOR LEAD FAST REACTOR TECHNOLOGY

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INTRODUCTION: The development of Lead-cooled Fast Reactors (LFRs) depends on robust experimental infrastructure to validate designs, support licensing, and build public and regulatory trust. Due to LFRs' unique operating conditions, specialized facilities are critical for addressing material and safety challenges. Furthermore, hands-on training environments are critical for cultivating the next generation of nuclear engineers, operators, and safety personnel, enabling them to develop the skills required to safely manage and innovate within these complex systems.

The LEADER project delivered the conceptual design for the European Lead Fast Reactor, a 600 MWe nuclear plant, as well as a scaled-down (125 MWe) demonstrator known as ALFRED (Advanced Lead Fast Reactor European Demonstrator) [1]. The initiative brought together 17 partners from industry, research institutions, and universities, and resulted in the detailed conceptual design of the ALFRED demonstrator. Romania has played a pivotal role in advancing the ALFRED project. In 2011, the Romanian government expressed the availability to host ALFRED demonstrator on Mioveni nuclear platform, near Pitești. This decision was consolidated in 2013 with the formation of the FALCON international consortium to coordinate the project's implementation.

To support the development of LFR technology, Romania initiated the PRO ALFRED project in 2019 [2]. This initiative aimed support the development of the experimental licensing infrastructure. The ALFRED project is expected to have a significant impact on local economy and energy sector. It is projected to create approximately 2,000 jobs in related industries and attract over 300 specialists to the ICN [3].

THE EXPERIMENTAL INFRASTRUCTURE

A comprehensive and strategically structured experimental program is being planned to support the licensing process of the ALFRED project. This effort will encompass a wide range of activities, including rigorous testing of materials, components, and equipment, as well as the demonstration of complete control over key physical and operational phenomena. In addition, the program will carry out qualification procedures and extensive validation and verification of computational models and simulation tools used in the reactor's design and safety assessment.

Beyond the licensing scope, the infrastructure associated with ALFRED will also serve as a foundation for robust research and development (R&D) initiatives, targeting the resolution of critical outstanding challenges in LFR technology. These R&D efforts will focus on several key areas, such as the behavior and long-term performance of structural materials under reactor conditions, including studies on corrosion, erosion, and material degradation. Further investigations will address thermal-hydraulic behavior within both the large reactor pool and the coolant forced flow inside the fuel assemblies, under normal operating scenarios as well as under postulated accident conditions. The chemistry of the lead coolant and the associated cover gas will also be closely examined, including the filtration technique, given their crucial role in ensuring safe and reliable reactor operation.

A particularly pressing concern is the limited understanding of irradiated structural materials in fast spectrum at large fluences. Addressing this challenge will be a core element of the ALFRED initiative. The decision to site ALFRED at the Mioveni nuclear platform is a strategic one, as it enables the efficient utilization of existing national infrastructure, including operational research reactors, post-irradiation examination laboratories, and specialized LFR experimental facilities. This co-location will facilitate seamless integration of experimental data, accelerated R&D progress, and optimized support for the demonstrator reactor itself. In Table 1 the set of large experimental infrastructures dedicated to LFR R&D and ALFRED licensing is shortly presented.

TABLE 1. LARGE LFR EXPERIMENTAL INFRASTRUCTURES IN CONSTRUCTION AT MIOVENI, ROMANIA

	Facility name	**Type and purpose**
1	ATHENA	large pool to test the main components in different thermal hydraulics regimes
2	ChemLab	Chemistry lab coupled with ATHENA, for lead and cover gas chemistry
3	ELF	large scale pool-type facility, to test the endurance and reliability under both forced circulation and natural circulation regimes
4	HELENA2	loop type facility to test components and equipment in relevant thermal-hydraulic conditions, in particular, the ALFRED hottest fuel assembly
5	HandsOn	pool type experimental facility, to demonstrate the fuel handling of fuel assemblies
6	Meltin'Pot	a set of facilities to investigate the severe accident associated phenomena

Given the strategic importance of experimental data, robust information management systems are essential to ensure its accessibility, integrity, and long-term usability. To achieve this, a dedicated coordination center—the Hub—will oversee the scientific management of the LFR experimental infrastructure. The Hub will centralize services for data collection, validation, storage, dissemination, and logistics management. Operating under an open-access model, it will welcome international researchers and projects selected through a structured application process based on merit and relevance.

The selection of the site for the experimental facilities was guided by a set of practical and strategic criteria aimed at maximizing efficiency, synergy, and sustainability. These criteria [4] included: (1) proximity to existing utility and communication networks, ensuring streamlined integration and reduced development costs, (2) clustering of experimental installations, to promote resource sharing and operational efficiency through the use of common services and infrastructure, (3) utilization of existing buildings and available space within the Mioveni nuclear platform, optimizing investment and minimizing environmental impact.

CURRENT STATUS OF PROJECT 1 (ATHENA AND CHEMLAB)

ATHENA is a large molten lead pool facility (approx. 80 m^3), designed to support R&D for LFR. It enables testing of thermal-hydraulic behavior in large lead volumes, including forced and natural circulation, and supports investigations into safety-relevant phenomena such as lead stratification, oxygen control, corrosion, and erosion. The main vessel simulates ALFRED's Reactor Vessel and allows testing of real-scale components. The system is equipped with a Fuel Pin Simulator (FPS) to replicate reactor core conditions, and a full instrumentation setup for precise experimental control. A chemical system manages oxygen levels and purifies the lead, while the secondary system operates with pressurized demineralized water using a bayonet-type heat exchanger and includes all necessary support systems (pressurizer, heaters, coolers, etc.).

ChemLab is directly connected to the ATHENA facility to enable advanced investigations of lead pool and cover-gas chemistry. Its primary goals are: (1) to develop and support chemical monitoring/control systems for long-term lead-cooled reactor operation, (2) to study interactions between liquid lead and structural materials. The facility is divided into two main components: (1) Experimental Laboratory - focuses on oxygen control, chemical solubility, and corrosion studies, (2) Structural Analysis Laboratory - provides material characterization and quantifies metal release from lead-material interactions.

In 2019, a comprehensive funding application was prepared and submitted under the framework of the Competitiveness Operational Programme (POC), a key European structural funding instrument designed to bolster research and innovation capacities across member states. The project, titled “ALFRED Phase 1 – ATHENA and ChemLab”, competed in the Large Research Infrastructures section, which is dedicated to the development of cutting-edge scientific installations with national and European relevance.

The project was funded with €20 million from the European Structural and Investment Funds (ESIF), and complemented by RATEN with €2 million from its own resources. Project was officially launched in June 2020, several months after the initial timeline envisioned by the proposal. By early 2025, the experimental infrastructure was fully installed, and all supporting equipment required for ChemLab had been procured. The next steps include the initial filling of the system with lead, involving its melting and transfer into the main vessel. This operation will be followed by a series of pre-operational tests to verify system integrity and performance under controlled conditions.

CURRENT STATUS OF PROJECT 2 (4ALFRED)

The second project, entitled 4AFLRED, is devoted to the design, construction, and operational tests for ELF, HELENA2, HandsOn, and Meltin’Pot, covering also some experimental activities in the first year after the operational tests of these experimental facilities.

ELF (Electrical Long-running Facility) is a large-scale pool-type pure lead facility, designed to test the endurance and reliability under both forced circulation and natural circulation regimes. Its dimensions and the high power installed (10 MW) allow the investigation in relevant scale of the main thermal-hydraulic phenomena, reproducing as much as possible the primary system conditions of ALFRED.

HELENA-2 is a loop-type facility, operating under both forced and natural circulation conditions. It is designed to test components and equipment from a thermal-hydraulic perspective under conditions relevant to ALFRED—particularly focusing on the hottest fuel assembly. The facility also includes plans for experimental validation of flow-induced vibrations on the ALFRED fuel assembly. Additionally, it supports testing and reliability qualification of absorber devices, such as control rods.

Hands-ON is a pool-type experimental facility to host full-scale mock-up sub-assemblies—representing fuel assemblies, absorber assemblies, or dummy assemblies—based on those used in ALFRED. The facility aims to simulate fuel handling operations for these components, offering valuable feedback on the proposed strategies and providing operational guidance.

Meltin’Pot is a research platform to investigate fuel-coolant interactions, fuel dispersion, and relocation within the coolant under severe accident conditions. The platform also focuses on studying the retention of fission products in lead and their potential migration into the cover gas, the behavior and retention of polonium isotopes in lead, and the effects of gas or steam trapping on their migration.

The project was received funding in 2024 from PoCIDIF Program (Intelligent Growth, Digitization and Financial Instruments Program 2021–2027, a co-financed program by the European Regional Development Fund (ERDF), dedicated to supporting the implementation of the national strategy and regional smart specialization strategies. The 4ALFRED project, valued at over 112 million euros, is implemented by RATEN, involving five private companies with the aim to integrate local industry in the innovative technological development. The contract started at the end of February 2025 and the operational phase for the 4 facilities is planned for the end of 2027.

EXPERIMENTAL PROGRAMME

An experimental programme was defined for ATHENA and ChemLab facilities. It supports both the licensing process for ALFRED demonstrator and the R&D activity to develop valuable solutions to the open issues of LFR technology, especially for oxygen control in large volumes, materials behaviour in corrosion and erosion conditions, chemistry of lead and cover gas.

Some activities of the experimental programme will be supported by collaborative European projects. In 2024 a first project that includes activities in ATHENA and ChemLab has received funding from HORIZON-EURATOM-2023-NRT-01 call. The project [9] is called LESTO (LEad fast reactor Safety design and TOols) and includes the following activities: (1) steady-state experimental and numerical analysis of the ATHENA facility (in forced flow and natural convection), (2) experimental investigation of PLOFA (Protected Loss of Flow Accident) in the ATHENA facility, (3) validation of the numerical approaches for simulating transients in the ATHENA pool; post-test analysis of the ATHENA transients.

For the other four facilities the experimental programme is in the conceptual phase. It will be detailed in accordance with the activities agreed with the partners form FALCON consortium.

ACKNOWLEDGEMENTS

The project “ALFRED Etapa 1, ATHENA and ChemLab (ALFRED – ETAPA 1 infrastructură de cercetare suport: ATHENA (instalaţie de tip piscină pentru experimente şi teste termohidraulice), ChemLab (laborator pentru chimia plumbului))” has received funds (co-financed) from the European Re-gional Development Fund through the Competitive Operational Program.

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