THE DEVELOPMENT OF THE RESEARCH INFRASTRUCTURE IN SUPPORT OF ALFRED DEMONSTRATOR IMPLEMENTATION IN ROMANIA

DEZVOLTAREA INFRASTRUCTURII DE CERCETARE ÎN SPRIJINUL IMPLEMENTĂRII REACTORULUI DE DEMONSTRATIE, ALFRED, ÎN ROMÂNIA

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Abstract: *ALFRED (Advanced Lead Fast Reactor European Demonstrator) project aims to build a 125 MWe demonstrator as a crucial step towards the commercial deployment of LFR technology and for the development of the LFR-Small Modular Reactor.*

In order to support the licensing process and the research on the open issues a dedicated infrastructure was planned. It consist of six experimental facilities and a coordination Hub. The paper presents this new infrastructure, its planned operation in synergy with other international centres. The main focus is on the novelty of the concepts and their huge potential to boost the applied research in Romania.

Keywords: nuclear, generation IV, research infrastructure, open issues

Rezumat*: Proiectul ALFRED (Advanced Lead Fast Reactor European Demonstrator, Reactorul de demonstratie al tehnologiei reactorilor cu neutroni rapizi, raciti cu plumb topit, LFR) are ca scop construirea unui demonstrator avand puterea de 125 MWe ca un pas crucial către*

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implementarea comercială a tehnologiei LFR, precum și pentru dezvoltarea sistemului LFR-SMR.

In sprijinul desfasurii activitatilor de autorizare precum si al gasirii de solutii pentru aspectele deschise, o infrastructură experimentala dedicată va fi construita pe platforma nucleara de la Mioveni. Acesta infrastructura constă din șase instalații experimentale și un centru de coordonare. Lucrarea prezintă componentele acestei infrastructuri, stadiul de implementare, precum si aspectele sinergice in relatia cu alte centre internaționale. O atentie speciala este acordata explicarii noutatii conceptelor, unicitatii instalatiilor, dimensiunii adecvate pentru eliminarea efectelor de scala, precum și potențialul de stimulare a cercetarii aplicative din tara noastra.

Cuvinte cheie: energie nucleară, Generația IV, infrastructură de cercetare, aspecte deschise

1. Introduction

Lead Fast Reactor is one of Generation IV technologies recommended by GIF [1] and European Strategies (SNETP Strategic Agenda [2], In Europe three Generation IV systems are supported by the strategic documents: Sodium cooled Fast Reactors (SFR), Lead Fast Reactors (LFR), and Gas Fast Reactors (GFR).The viability of these technologies will be tested by their demonstrators: ASTRID (SFR), ALFRED (LFR), and ALLEGRO (GFR).

ALFRED was designed, at conceptual level, in the frame of FP7-LEADER project [3] based on the collaboration of 17 partners from industry, research and academia.

ALFRED is a very compact system. The configuration of the primary system is pool-type. It eliminates all problems related to out-of vessel circulation of the primary coolant. The core design has been driven by the implementation of the so called “walk away” and “adiabatic” reactor concepts [4]. The adopted core configuration of ALFRED is constituted by wrapped Hexagonal Fuel Assemblies. The fuel is MOX type with hollow pellets and a low active height in order to improve the natural circulation [4].

RATEN ICN was deeply involved in the LFR research and actively participated in LFR international projects. Romania expressed the availability to host ALFRED demonstrator. An international consortium [5] (entitled FALCON) was built in December 2013 by RATEN ICN, Ansaldo and ENEA considering Romania as the reference option for siting.

The main strategic documents of FALCON (the Roadmap, The Action Plan, the Implementation Plan) are based on a vision of implementation in four phases: Viability, Preparation, Construction, and Operation. Important efforts are planned and are in progress for the building of the Romanian capabilities for LFR development both in terms of infrastructure and human resources.

The present paper is devoted to the progress on the experimental infrastructure aimed to support ALFRED implementation and LFR development, including the SMR option.

2. Identification of needs and gaps

The success of the implementation is strongly dependent on some factors such as the availability of funds, the licensing complexity, the decision-making issues, creation in due time of needed competences.

A support infrastructure is needed for the licensing process in order: (1) to demonstrate the full control of all involved phenomena, (2) to qualify the materials, components, equipment and systems, (3) to validate and verify the computer tools, (4) to support the set-up of the main procedures for the operational stage of the demonstrator, (5) to contribute to the training of the personnel. On the other hand the infrastructure should be characterized by a high sustainability including the period after the starting of the operational phase of ALFRED demonstrator. In this direction a vision to identify valuable solution for the open issues of LFR technology in order to enhance their performances and a synergy with other applicative researches were targeted.

A series of activities supported by FP7-ARCADIA [6] project (2013-2016) and by FALCON consortium were performed for: (1) the mapping of the open issues and of the needs for the implementation of ALFRED demonstrator, (2) mapping of the existing research infrastructures able to be used in the implementation process, (3) identify the gaps, (4) definition of the list of new research infrastructures needed for ALFRED implementation and LFR development. The identification have considered the synergy with two experimental centres - ENEA-Brasimone (Italy), and CVR-Rez (Czech Republic)- and possible cooperation with other European RDI organization such as SCK·CEN-Mol (Belgium) where LBE (Lead Bismuth Eutectic) technology is under development.

Based on the analysis of needs and of the current status, followed by the identification of the gaps, a list of new research infrastructures to be built at RATEN ICN, on Mioveni nuclear platform, was defined. It consists of six experimental facilities and a coordination Hub aimed to integrate the cooperation for an efficient use of the infrastructures at the level of FALCON partners, to manage the open access option, and also to perform scientific management including collaboration with other international partners:

(1) HELENA-2 loop (fuel assembly testing),

(2) ATHENA-2 pool (large equipment testing and thermal hydraulics regimes),

(3) Meltin'pot (fission products aspects),

(4) ChemLab (chemistry laboratory),

(5) HANDS ON (fuel handling testing),

(6) ELF (endurance of the component sand equipment).

This supporting infrastructure together with ALFRED demonstrator was included in the national Roadmap [7] of the large experimental infrastructure of Romania as a pre-condition to open the access to structural funds financing.

3. Research infrastructure for ALFRED

HELENA-2 is a loop type facility, using pure lead as primary working fluid under both forced and natural circulation regimes. It is conceived to test components and equipment from a thermal-hydraulic point of view, in relevant conditions for ALFRED and, in particular, the ALFRED hottest fuel assembly, by means of an ad-hoc mock-up. Flow induced vibration experimental validation is foreseen as well on the ALFRED FA. Testing (including reliability qualification) of absorber devices (e.g., control rods) are also embraced in the purpose.

In Table 1 a synthesis of the objectives and key features of HELENA-2 experimental facility is presented.

ELF is a large scale pool-type facility devoted to the endurance and reliability tests of main components under forced and natural circulation conditions aiming. It consists of a main vessel filled with molten pure lead as working fluid and hosting the core simulator (10 MW), four main steam generators, the decay heat removal system composed by two heat exchangers and two prototypes of the ALFRED vertical pump. The activities planned to be performed in ELF are aimed to: (1) investigate thermal-hydraulic in steady state conditions, (2) demonstrate the long term operation of LFR primary system under active oxygen control, (3) investigate long term effects on coatings and structural materials immersed in pure lead, (4) demonstrate the reliability of components in a relevant scale (e.g. steam generator tube scale 1:1 in length). The experimental facility will be also operated in order to reproduce the transition from forced to natural circulation occurring during a simulated protected loss of heat sink with loss of flow accidental scenario.

Table 1. Key features of HELENA2 experimental facility

Purposes and objectives	**Key features**	**Main requirement**	**Support for licensing**
Thermal-hydraulics: - temperature profile along the pin - maximum clad temperature - sub-channel temperature - local/integral pressure drops - pin coolability under NC conditions	Loop test facility, Forced circulation, Heated test section,	Main building: - dimensions 28x46x30 m Services: - demineralized water	Qualification of: - fuel assemblies, - control rods. - shutdown devices.

Purposes and objectives	Key features	Main requirement	Support for licensing
Fluid-structure interaction: - bundle vibration frequencies and displacements	Hot test section, Oxygen control.	- electric power: approx. 1,6 MW.	
Validation: validate sub-assembly thermal-hydraulic codes.			

In Table 2 a synthesis of the objectives and key features of ELF experimental facility is presented.

Table 2. Key features of ELF experimental facility

Purposes and objectives	Key features	Main requirement	Support for licensing
Thermal-hydraulics: - integral and local flow paths - stratification and thermal striping phenomena - heat transfer among assemblies - temperature field variation and stabilization in simulated accidents. Operation and Maintenance: - demonstrate long term operability of LFR - assess operation procedures. Safety analysis; - system response to simulated accidents. Reliability: - components performances/failure rates; - coolant chemistry control performances. Validation: - validate integral system codes.	Pool test facility; - Forced circulation - Long-run capability - Secondary system coupling - Oxygen control - Coolant chemistry	Services: - demineralized water; - heavy duty crane (30 t). - electric power: approx. 11,5 MW.	Qualification of reactor coolant system arrangement, Performance, reliability and robustness, Assessment of components (e.g. pump, steam generator, coolant chemistry systems) in long run.

Meltin'Pot is a research platform consisting of four experimental systems, operating with pure lead. The goal of the experimental set-up is the investigation on the fuel-coolant interaction, fuel dispersion and relocation in the coolant resulting from a severe accidental scenario, retention of fission products in lead and/or migration in cover gas, retention in lead of Polonium isotopes and influence of a gas/steam trapping on its migration. Meltin'Pot is planned to support the licensing of ALFRED by demonstrating the safety of the reactor in case of core damage accidents with fuel dispersion. In particular, Meltin'Pot will be one of the first experiments in a lead pool environment to investigate the consequences of fuel-coolant interaction and fission/activation products retention by coolant in normal ad off-normal operation.

In Table 3 a synthesis of the objectives and key features of Meltin'Pot experimental facility is presented.

Table 3. Key features of Me;tin'Pot experimental facility

Purposes and objectives	Key features	Main requirement	Support for licensing
Thermal-hydraulics: - fuel dispersion and relocation Chemistry: - fuel-coolant interaction - fission products retention in lead and/or migration in cover gas - activation products (e.g Po) retention in lead - water/steam-lead chemical interaction Validation: - validate chemistry models	Handling capability of hot material, Pool type facility included, Loop type facility included.	Services: - glove box, - hot cell (minimum target 6x6x8), - electrical power: 250 kW.	Demonstration of fuel-coolant interaction Demonstration of fuel dispersion in the coolant Demonstration of fission and activation products retention by coolant

Hands-ON is a pool-type experimental facility, using pure lead, aimed to simulate the fuel handling operations of Sub-Assemblies (S/A) and in particular FAs, absorber assemblies and/or Dummy Assemblies (DAs). The objective is to demonstrate the fuel handling capabilities of the ALFRED machine and to validate a fuel handling procedure. The facility can accommodate mock-ups of all S/As above, having the same sizes of the ALFRED ones. The facility is completed by all the devices necessary to their handling. Hands-ON is planned to support the licensing process of ALFRED by qualifying the fuel handling system and procedures, for both geometrically regular and deformed sub-assemblies.

In Table 4 a synthesis of the objectives and key features of Hands-ON experimental facility is presented.

Table 4. Key features of Hands-ON experimental facility

Purposes and objectives	**Key features**	**Main requirement**	**Support for licensing**
Operation and Maintenance: - demonstrate fuel handling procedures. Reliability: - components' performances/failure rates.	Stand-alone and coupled (to pool) facility.	Main building: - dimensions 15x15x30; - electric power: approx. 250 kW.	Qualification of fuel handling system and procedures

ATHENA is a 3.75 MW large pool type multipurpose facility aimed to investigate at a scale comparable with the real size of ALFRED demonstrator a set of phenomena (corrosion, erosion, stratification of coolant, control, of oxygen, etc), to simulate integral tests, and to test single components in representative scale (i.e. DHRs). The geometrical configuration of ATHENA facility is represented by a large size vessel (4.2 m diameter, 10 m in height). It is able to host and test single and coupled full scale components. In particular, its dimension has been derived considering as main volume demanding test section the full scale Steam Generator coupled with its Primary Pump with reference to the ALFRED design.

In Table 5 a synthesis of the objectives and key features of ATHENA experimental facility is presented.

Table 5. Key features of ATHENA experimental facility

Purposes and objectives	**Key features**	**Main requirement**	**Support for licensing**
Thermal-hydraulics: - operational and accidental regimes, natural circulation capabilities - stratification of lead - erosion of structures - flow blockage - integral and local flow paths - temperature and pressure distribution. Chemistry and materials: - corrosion of structures - behavior of materials and coatings	Large pool (1:43 scale factor vs ALFRED reactor vessel), representative power (1:80 vs ALFRED) Chemistry control Coupled with chemistry laboratory	Vessel dimensions: 4.2 m diameter 10 m height Main building: - dimensions 22x36x23; - electric power: approx.3.75 MW.	Qualification of materials, components, equipment and systems Qualification of coatings Demonstrate the oxygen control in large volume Demonstrate filtration capabilities

Purposes and objectives	Key features	Main requirement	Support for licensing
- lead coolant and cover gas chemistry Safety analysis; - system response to simulated accidental regimes,. Validation: validate integral system codes.	Able to accommodate larger components of ALFRED 9at full scale) Operable in diverse regimes		

ChemLab is a dedicated lead chemistry and cover gas chemistry laboratory directly coupled with ATHENA experimental facility and aimed to provide all analysis line and devices to perform chemical investigations for LFR environment. One of the most important elements in LFR technology is the high control and monitoring of the coolant chemistry (in particular the oxygen concentration in the liquid metal) together with the interaction of the liquid metal with the structural materials and related protection strategies. The investigation of these issues is critical to ensure the operational safety. ChemLab will support the study of these key and basic issues for the operation of the liquid metal pool systems ATHENA and ALFRED. The laboratory is composed of two sections: (1) an experimental section dedicated to experimental tests on oxygen control, solubility, studies of chemical elements and corrosion of structural materials in liquid lead, (2) a metallographic laboratory for the characterization of structural materials in liquid lead and the study of the amount of metals released in liquid lead.

4. The planning and current status

In 2015 the feasibility studies for ATHENA [8] and ChemLab were developed. An update was achieved in 2018 in order to apply for funding in the Operational Programme Competitiveness, Section large Research Infrastructures. The application was developed for the February 2019 call. In 2019 the evaluation procedure was performed and the project devoted to the ATHENA and ChemLab implementation was selected for financing. At the moment (January 2020) the procedure of contracting is expected to be started in the next months.

For HELENA-2, ELF, HandsON, and Meltin'Pot experimental facilities, a vision document was released in November 2019 based on the efforts supported by the national project PRO-ALFRED. Also a vision document was developed for the coordination Hub. In 2020 under PRO-ALFRED [9] framework, the conceptual design for HELENA-2 and ELF was achieved based on the before mentioned feasibility studies.

The conceptual designs for HandsON and Meltin'Pot are planned to be finalized at the end of 2021. The feasibility studies for HandsON, Meltin'Pot, and connection Hub will be developed in accordance with the future calls for projects supporting experimental research infrastructure.

In Table 6, the status of activities and the existing planning for the experimental infrastructure in support for ALFRED demonstrator and the coordination Hub are presented.

Table 6. Status of activities for experimental infrastructure and Hub

Experimental facility	Vision	Conceptual Design	Feasibility Study	Funding Application	Contracting the construction
ATHENA	Yes	Yes	Yes	Yes	In progress
ChemLab	Yes	Yes	Yes	Yes	In progress
HELENA-2	Yes	In progress	2020 Nov	-	-
ELF	Yes	In progress	2020 Nov	-	-
HandsON	Yes	2021	-	-	-
Meltin'Pot	Yes	2021	-	-	-
HUB	Yes	In progress	-	-	-

The total budget to implement ATHENA and ChemLab is around 22 mil. Euro [10], with a component of 20 mil as non-reimbursable European funds. For the other experimental facilities and for the coordination Hub the financing effort are in the estimation phase and will be finished in the feasibility studies. An indicative timeline for the operation is presented in [11]

5. Conclusions

The implementation of ALFRED demonstrator is a crucial step for LFR development towards the commercial stage. An important effort is needed to prepare the licensing process and the dedicated workforce. Taking into consideration the reference site for ALFRED (Mioveni nuclear platform) an important effort was performed for the mapping of the existing capabilities including experimental infrastructures able to contribute to the implementation. Based on the complementarities with the other experimental facilities existing in different international centres a list of experiments was produced and also the gaps and the need for new research infrastructures.

Six experimental facilities are planned to be built at RATEN ICN in order to complete the capabilities for the demonstration, qualification, validation and verification. At the same time the sustainability of the facilities beyond licensing process was considered based especially on the open issues of LFR technology.

The implementation programme was started with 2 experimental facilities (ATHENA and ChemLab) and the contracting for the works is expected to be finalized this year. For the rest of facilities important efforts to produce the documentation (visions, conceptual designs, feasibility studies, and sitting investigations) are in progress in the frame of the national funded project PRO-ALFRED.

The paper presents the main features of the experimental facilities and the current status for the implementation.

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