EUROPEAN COMMISSION

Community Research

ESNII Plus

Preparing ESNII for HORIZON 2020

FP7-Fission-2013
Combination of Collaborative project (CP) and Coordination and Support Actions (CSA)

Grant agreement no: 605172
Start date: 01/09/2013 Duration: 48 Months

Deliverable D212

ESNII

European Sustainable Nuclear Industrial Initiative

Implementation Plan 2016-2018

Document title	ESNII - implementation Plan 2016-2018
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Number of pages	19
Document type	D
Work Package	2
Document number	D212
Issued by	SCK.CEN
Date of completion	14.06.2016
Dissemination level	Public

Summary

Approval

Rev.	Date	Main author	Signature	Approved by	Signature
0	16.06.2016	P. Baeten		A. Vasile	

Distribution list

Name	Organization	Comments
All beneficiaries ESNII Plus		

ESNII

European Sustainable Nuclear
Industrial Initiative

Implementation Plan 2016-2018

A contribution to the EU Low Carbon Energy Policy:

Demonstration Programme for Fast Neutron Reactors

This document has been prepared by the ESNII Executive Board established within the Sustainable Nuclear Energy Technology Platform as a deliverable for the ESNII+ project WP2.

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1. Objectives of this plan

One of the major concerns of society with regard to the implementation of nuclear energy is the high-level nuclear waste. Fast spectrum reactors with closed fuel cycles will allow a significant reduction in high-level nuclear waste radiotoxicity and volume. Fast reactors will also allow an increase in natural resource (uranium) utilisation by a factor of 50 at a minimum. In this way, it is clear that the use of fast reactors with a closed fuel cycle approach will allow more sustainable implementation of nuclear energy.

For the development of these fast reactors within ESNII, it is of paramount importance to excel in safety, reliability, radiological protection and security.

The main objective of ESNII is to maintain European leadership in fast spectrum reactor technologies that will excel in safety and will be able to achieve a more sustainable development of nuclear energy. With respect to the 2010 evaluation of technologies, sodium is still considered to be the reference technology since it has more substantial technological and reactor operations feed-back. The Lead(-bismuth) Fast Reactor technology has significantly extended its technological base and can be considered as the shorter-term alternative technology, whereas the Gas Fast Reactor technology has to be considered as a longer-term alternative option. The main goal of ESNII is to design, license, construct, commission and put into operation before 2025-2030 the Sodium Fast Reactor Prototype reactor called ASTRID and the flexible fast spectrum irradiation facility MYRRHA.

ASTRID will allow Europe to demonstrate its capability to master the mature sodium technology with improved safety characteristics responding to society's concern of having the highest possible level of safety. Therefore, the design of ASTRID focuses on meeting the challenges in terms of industrial performance and availability, improved waste management and resource utilisation and a safety level compatible with WENRA objectives for new nuclear build, whilst at the same time achieving the Generation IV goals. An associated R&D programme will continue to accompany and support the development of ASTRID to increase the lines of defence and robustness of this technology, and allow the goals of the 4th generation to be reached, not only on safety and proliferation resistance, but also on economy and sustainability.

With MYRRHA, Europe will again operate a flexible fast spectrum irradiation facility in support of the technology development (in particular for material, components and fuel irradiation tests) of the three fast reactor systems (SFR, LFR and GFR). Also, MYRRHA will offer a wide range of interesting irradiation conditions for fusion material research. Since MYRRHA will be conceived as an Accelerator Driven System, it will be able to demonstrate the ADS technology, thereby allowing the technical feasibility of one of the key components in the double strata strategy for high-level waste transmutation to be evaluated. An associated R&D programme will accompany and support the development of MYRRHA.

For the financing of the total investment cost of these facilities, it will be of paramount importance to establish the appropriate consortium structure and legal basis, allowing candidate consortium members to identify the added value of the facility for their own interest.

In parallel to the realisation of ASTRID and MYRRHA, activities around the Lead Fast Reactor technology and the Gas Fast Reactor technology should be continued, taking into account their specific needs.

For the development of the Lead-cooled Fast Reactor, and of its demonstrator ALFRED, the main focus will be on design activities typical for a critical power reactor connected to the grid, as well as on R&D activities on the lead coolant. Notably, efforts will be addressed to the demonstration of those safety features permitting the Lead-cooled Fast Reactor to represent a credible case for the ultimate elimination of the need for emergency planning zones that extend beyond the plant’s site boundary. Despite the specific characteristics of lead that differ from lead bismuth, for the R&D program maximum synergy of activities will be sought with the MYRRHA development to optimize resources and planning. These activities will allow the LFR consortium to reach the level of maturity needed to start the licensing phase and then the construction of ALFRED, provided that adequate financial resources are made available.

In addition to the closure of the nuclear fuel cycle in a sustainable manner, the Gas Fast Reactor has the potential to deliver high temperature heat at ~800 °C for process heat, production of hydrogen, synthe tic fuels, etc.. The Helium cooled Fast Reactor is an innovative nuclear system having attractive features: helium is transparent to neutrons and is chemically inert. Its viability is however essentially based on two main challenges. First, the development and qualification of an innovative fuel type that can withstand the irradiation, temperature and pressure conditions put forward for the GFR concept. Secondly, a high intrinsic safety level will need to be demonstrated for this GFR concept. This will imply dedicated design activities followed probably by out-of-pile demonstration experiments. These high priority R&D activities should be embedded into an overall R&D roadmap in support of the development of the Gas Fast Reactor concept. For the development, guidance and implementation of this R&D effort, a GFR centre of excellence will be created. This centre could develop the technical capability to launch the ALLEGRO gas cooled demonstrator.

Based on the ESNII+ WP3, a number of supporting facilities for the different systems and technologies have been identified. The realisation and operation of these supporting facilities, in particular a fast reactor MOX production line, will be of primary importance to reach the aforementioned objectives.

Raising the financial resources to carry out the ESNII projects and to build the different facilities will be a key factor of success. In this respect, international collaboration through GIF and bilateral or multi-lateral frameworks will be sought to optimise resources. In the next years, project financing capabilities may modify the ESNII part of this Strategic Research & Innovation Agenda

This Implementation Plan is focused on the period 2016-2018, with a more accurate description of the R&D tasks and with a deeper integration of national programmes and the EURATOM framework programme.

2. Detailed implementation plan

2.1. ESNII-1: ASTRID

2.1.1. Intro

In the framework of the Investments Program for the Future, launched in 2010, the French government assigned to CEA the design of a Generation IV technological demonstrator ASTRID[1], up to the basic design.

After the conceptual design phase of the project, finalized end 2015, a four years basic design phase is being carried out.

The consistent architecture of ASTRID, defined in the conceptual design phase, is based on a Rankine cycle for the power conversion system.

In parallel, specific studies has been performed in order to increase the technological readiness level of the most innovative components of a gas power conversion system: the sodium-gas exchanger and the turbomachine. At the end of 2015 the TRL of these components are strongly increased. Moreover a first analysis has allowed a preliminary assessing of the possible safety performance for a gas PCS coupled to the ASTRID nuclear island. Nevertheless, no consistent design is available at the end of 2015 with that PCS option.

2.1.2. Implementation plan 2016-2019

The basic design will be deployed on two steps:

- 2016 - 2017
  Confirmation of the design configuration.
  Review of the design options mainly on the secondary loops, reactor layout and safety approach.
  Review of the gas fuel handling system.
  Review of the reactor pit design.
  Cost reduction analysis.
  Identification of key issues on the manufacturability of the innovative components.
  Design of a gas PCS at a conceptual design level that could be comparable to the steam-water PCS design obtained at the end of 2015.
- Integration in the ASTRID layout and BOP of opportunities provided by gas PCS (especially on civil engineering…), and writing of a safety option file for ASTRID with gas PCS option.

At the end of 2017, the reference PCS for ASTRID will be made.

- 2018-2019
  During these 2 last years, the basic design studies will be concluded by a dossier on the technical needs specifications for the systems and components and a plan for the justification of the design options.
  The outcomes of R&D in support to the design and the qualification of the design tools will be included.
  At this step, a first release of the preliminary safety report including the reference PCS and an update of the cost assessment will be done.
  The whole time schedule of the construction till the first criticality will be assessed.
  All along this step, the work plan should be implemented considering the feedback from the interactions with the French Safety Authority and his TSO.

In parallel with the design activities, CEA will continue the investment program on the main experimental facilities, MASURCA refurbishing (core physics), CHEOPS (Sodium technology) and PLINIUS-2 (Severe accidents) to be in position to perform the corresponding confirmation tests from 2020. These facilities will operate in addition to GISEH (Simulant of sodium) and PAPIRUS (Sodium) already used in the previous phase of the project.

At the end of the basic design phase, the outputs attained by CEA and his industrial partners will be:

- The re built of a whole set of technical and scientific competences.

[1] Advanced Sodium Technological Reactor for Industrial Demonstration.

- The refurbishment of existing facilities and the construction of new ones in support to the development of SFRs.
- A new generation of calculation tools for SFRs.
- A design file including specific studies on the manufacturability of key innovative components.
- A re built of the industrial supply chain.

2.1.3. Budget 2016-2019

In 2010, the finance law put into place a multiannual budget for the ASTRID program (Advanced Sodium Technological Reactor for Industrial Demonstration) and an agreement was signed between CEA and the French Government awarding 650 M€ to CEA to conduct the ASTRID R&D and design studies, including the development of associated R&D facilities (see table below).

	Conceptual design phase (2010-2015) M€	Basic design phase (2016-2019) M€
ASTRID demonstration reactor (design studies)	169,0	101,1
Technological platforms for component qualification (refurbishment, building)	152,1	117,1
MASURCA refurbishment	16,1	33,5
Core manufacturing workshop (design studies)	16,3	9,5
Severe accident program in support to ASTRID	12,0	25,0
TOTAL	365,5	286,1

Contributions to R&D in support to ASTRID project are also provided by EC projects, particularly ESNII+ and MATISSE with a budget of about 4.5 M€ over the period 2016-1017, half funded by EC.

2.2. ESNII-2: MYRRHA

2.2.1. Intro

The MYRRHA design as worked out in the FP7 Central Design Team project, served as a starting point for the further design work of the MYRRHA primary system, the accelerator as well as for the design of the auxiliary systems (the latter was conducted in the frame of the FEED contract awarded in November 2013 to an international consortium). This resulted in mid-2014 in an updated MYRRHA primary system design version MYRRHA design Rev. 1.6, further referred to as Rev. 1.6. This version takes into account stringent safety requirement imposed after the Fukushima accident as well as a more advanced design of the primary system based on design mechanical codes after the conceptual stage. Also, in the course of 2014, new results from the supporting R&D programme put into question some design options. Therefore, in 2015, the MYRRHA management team and SCK•CEN conducted on the main design options and the implementation plan of the MYRRHA project.

This reflexion resulted in the following decisions:

- On the MYRRHA Primary System design, it was decided to continue developing the 100 MWth pool-type reactor derived from Rev. 1.6 with one innovative “In-vessel Fuel Handling Machine” (IVFHM) and an innovative Pressurised Heat Exchanger (PHX) system consisting of a double-wall heat exchanger with a monitored gap and to further explore a 100 MW_{th} innovative loop-type primary system with bottom loading and employing conservative technical choices.

- On the MYRRHA Implementation Scenarios, it was decided to implement a phased approach: starting with the 100 MeV accelerator (phase 1) followed by the 100-600 MeV accelerator section (phase 2); the reactor (phase 3) is a separate phase and can be executed in parallel with or after phase 2. This implementation scenario allows the spreading of investment costs over time minimises the risks to obtain the required accelerator reliability and minimises the risk for innovative design options for the reactor.

For this implementation scenario, main emphasis will be on phase 1 with realisation of the 100 MeV accelerator project by 2024. In parallel, activities for phase 2 and phase 3 will be conducted in the period 2016-2024 in order to allow to decide on the construction for phase 2 and phase 3 before 2024. The main activities for the period 2016-2019 for the three phases are summarized below.

2.2.2. Implementation plan 2016-2019

2.2.2.1. Phase 1: the 100 MeV accelerator project

Accelerator design and R&D programme

(i) With regard to the accelerator design activities for the 100 MeV part, a frozen design is existing and main efforts will be dedicated to the realisation of the individual prototypical components through the associated accelerator R&D programme. Presently most of the Accelerator R&D activities at SCK•CEN are included in the WP2 of the H2020 MYRTE project. Indeed, the design and R&D for the MYRRHA accelerator has always relied on a large European collaboration that was usually structured via European Framework Programmes. A strong emphasis is put on the deployment of the first part of the MYRRHA injector (RFQ@UCL project) and its operation with beam. Testing of the first part of the MYRRHA injector (RFQ@UCL) project will be realised by 2019.

However, for this implementation scenario, the design and R&D effort that will be carried out within MYRTE will not be sufficient. Especially, the following additional R&D topics will be addressed in the period 2016-2019.

- Consolidation of the 100 MeV design, especially of its Medium Energy Beam Transport line;
- Design of a test bench for high intensity diagnostics;
- Realisation and testing of a spoke cryomodule prototype housing 2 single spoke cavities;
- Launching of engineering design and fabrication of CH room temperature cavity section 1.5 MeV- 5.9 MeV;
- Design and full implementation of the 100 MeV control system;
- Conceptual design of the full cryogenic system that is compatible with a phased approach;
- Engineering design of the 100 MeV cryogenic system ;

Target design and associated R&D

Although the primary objective of constructing the 100 MeV accelerator is to test the reliability of the first part the MYRRHA accelerator in view of the ADS concept, possible applications for this 100 MeV accelerator were investigated. Two main areas were identified in this respect:

- Fundamental physics;
- Production of innovative radio-isotopes.

Accelerator balance of plant and licensing

Balance of plant activities will be conducted over the period 2016-2018 in order to obtain the accelerator building, the auxiliaries and the integration of the accelerator itself. By end 2018, the lot description for the different lots will be prepared in order to allow to go for construction. The preparation for the licensing process for this class II facility will start in 2016. The preliminary safety assessment report will be prepared in order to have a first advice of the scientific council of FANC by mid 2017.

2.2.2.2. Phase 2: the 600 MeV accelerator project

For the design & prototyping of the 600 MeV accelerator, ESS-activities with regard to double-spoke cavities will be monitored closely. Balance of plant for the 600 MeV part will be limited in the period 2016-2018.

2.2.2.3. Reactor design

Primary system engineering

The primary system activities will focus in 2016 and 2017 on a detailed analysis of 4 critical issues for the confirmation of the 100 MWth pool-type reactor system option:

- Primary heat exchangers with double walled tubes, using an innovative heat transfer design that needs to be further developed and validated experimentally
- An in-vessel fuel handling machine with an additional joint
- A design enabling to transfer the pump moment from the on-the-cover motor up to the impeller which is situated about 8 meter lower in the LBE
- Consequences of the break of the diaphragm will be studied

Based on the outcome of these studies, a global revision and update of the MYRRHA Rev. 1.6 design will be started in 2018.

Reactor supporting R&D programme

The 3 major items that have to be addressed by a specific R&D programme due to the primary system design options are:

- Primary heat exchangers (double-walled)
- In-Vessel Fuel Handling Machine (with additional articulation)
- Primary pumps

It means that during the period 2016-2018, focus is put on executing this specific R&D programme.

For the rest, the impact of the reactor design options on the on-going R&D programme is relatively limited. All the other items in the R&D programme remain valid as being necessary for answering to specific points in the pre-licensing effort. Most of them are also embedded in European Framework Programmes. For the moment there are 5 on-going European Framework Programmes projects that include a technical work programme related to the MYRRHA support R&D. The planned activities in these projects cover the topics material and fuel research, and LBE technology development.

Reactor balance of plant and pre-licensing

Balance of plant activities on the reactor will depend on the progress on the new primary system design.

The pre-licensing phase consists of answering the different focus points and writing the Design Option and Provision File (DOPF). Focus points are items of safety relevance and specific for MYRRHA. However, by end 2016 a preliminary version of Volume 1 (Facility Description), 2 (Safety Approach) and 3 (Design options and provisions) of the DOPF based on MYRRHA primary system design version 1.6 will be submitted to the Belgian safety authorities. This will allow the Belgian safety authorities to give a first official feedback on the licensability of the MYRRHA project and give indications on design options and provisions that will be incorporated into the future work programme.

2.2.3. Budget 2016-2018

During the period 2010-2014, the MYRRHA-project benefitted from a special endownment of 60 M€ from the Belgian Government. The Belgian Government confirmed its support for the MYRRHA-project and allocated 40 M€ for the period 2015-2017. The more detailed expenditures foreseen for the period 2016-2018 are given in the table below.

	2016	2017	2018
	k€	k€	k€
Manage	1.7	1.8	2
Accelerator	4.1	5.3	7
Reactor R&D	4.0	4.6	5
Reactor Design	1.9	3.4	4
Licensing	1.8	2.2	2
Total	**13.5**	**17.3**	**20**

Besides this budget, several Europen Horizon 2020 projects are running in support of the MYRRHA-project.

2.3. ESNII-3: ALFRED

2.3.1. Intro

The ALFRED project deals with the LFR technology development through the design, construction and operation of an LFR demonstrator (ALFRED). ALFRED is an essential step to reach the technology maturity level for the industrial implementation of the European Lead cooled Fast Reactor (ELFR).

The interest on LFR technology is constantly growing also outside of Europe. In 2015 the Republic of Korea joined the GIF (Generation IV International Forum) LFR Steering Committee, chaired by EURATOM. A Cooperation Agreement on LFR technology and Safety was formalized between LEADER Consortium, which initiated the ALFRED design, and ROSATOM-NIKIET, developer of BREST-OD-300 expected to start construction during 2016-17. Canada is showing growing interest in LFR technology applications for remote areas, as proposed by LeadCold, a spin-off from the Royal Institute of Technology (KTH) in Stockholm funded by VINNOVA, through the SEALER project. Recently (end 2015), Westinghouse Electric Company applied for a Grant Agreement from the Department Of Energy, with a proposal based on an LFR concept.

At European level, in 2013 an international Consortium (namely, FALCON - Fostering ALfred CONstruction) was established among Ansaldo Nucleare (IT), ENEA (IT), ICN (IT) and CVR (CZ) to coordinate the organizations interested in the LFR.

FALCON promotion initiatives and coordinated actions were aimed at better clarifying the role of a LFR technology demonstrator, and the main needs for a competitive improvement of the LFR Technology Readiness Level (TRL). In fact, ALFRED is aimed at being designed with elevated margins, to demonstrate in a perspective the safety features of future LFR systems thereby supporting their licensing and operation, and being operated in a phased approach, progressively improving the confidence and technology maturity.

The short-term priorities of ALFRED implementation plan, as supported by FALCON, are here presented.

2.3.2. Implementation plan 2016-2018

The main goals of the next three years work are related to the achievement of the firm commitment to ALFRED as a Major Project in Romania and to the finalization of the feasibility study for the LFR demonstrator ALFRED. Over the period 2016-2018 the activities will be mainly focused on the update of the evidences required to assess the technology meant for use in the reactor, which is needed to complete the basic design of the Advanced LFR European Technology Demonstrator Reactor (ETDR, namely ALFRED) and support as well the site selection and the pre-licensing phase with the Safety Authority.

Priority actions for the LFR Demonstrator (ALFRED)

ALFRED, in the role of LFR ETDR, has the aim to demonstrate the viability of the LFR technology for use in a future commercial power plant, in terms of economic, safe and reliable operation. To realize such goal, projected to a commercial deployment of large LFR systems coping with sustainability goals in 2040s, a general roadmap was developed for ALFRED (Figure 2).

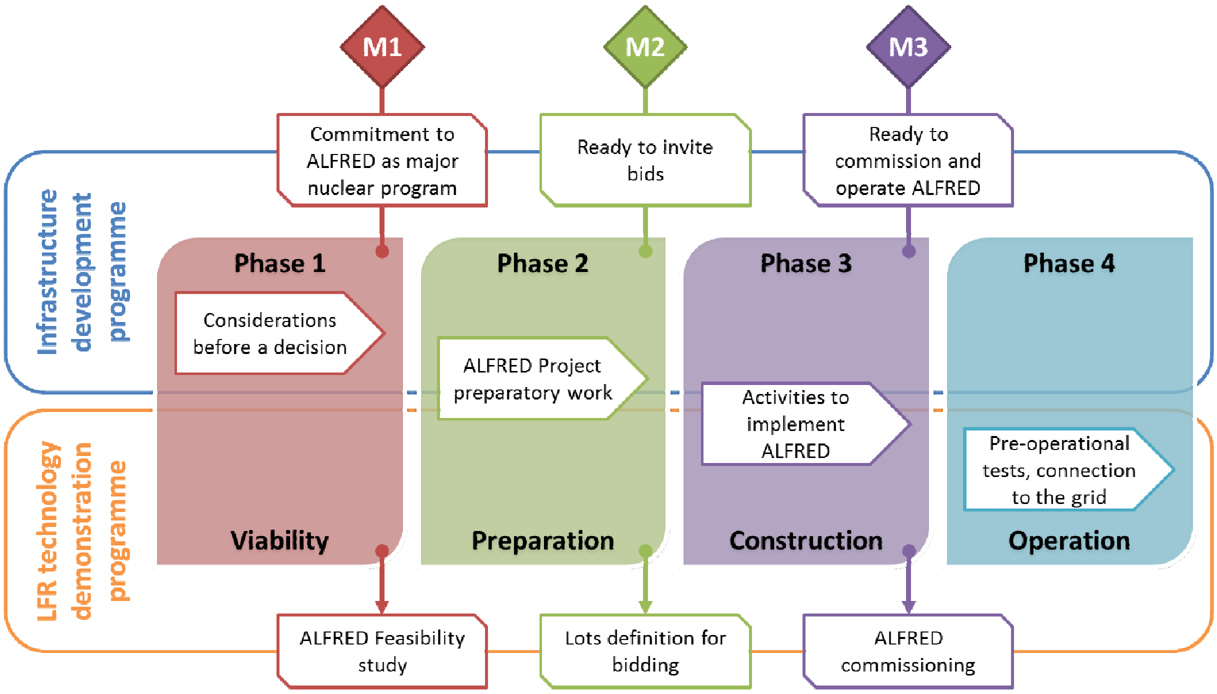

Figure 2: general roadmap of the ALFRED project

The roadmap is based on a phased approach driven by milestones and gate decisions. In particular, the near-term (2016-2018) activities for ALFRED are related to the so-called *Viability Phase* that is aimed at increasing the overall Project maturity, as needed to enter into the subsequent *Preparatory Phase*. The scope of the viability phase is categorized in 5 main areas (governance and management; research, development and qualification; safety and licensing; engineering and design; human resources E&T), intended to systematically tackle all the needs for a smooth execution of the preparatory work for ALFRED construction. The activities will be focused on the following main objectives:

- Preparation of the general frame for the establishment of an International Consortium. The actions are aimed at defining priorities, opening new partnerships, promoting optimal cooperation and joint programming for the implementation of the initiative, through strategic management and governance, financial seeking and technical work.
- Actuate the R&D program through experimental activities focused to the achievement of TRL5 for all technological aspects which are necessary to support the design, including materials, components and main design choices. The three main poles of the R&D program will be Brasimone (IT), Řež (CZ) and Mioveni (RO), where thermal-hydraulic analysis, materials and components testing and qualification will be carried out, in existing infrastructures, as well as in new facilities under design and construction.
- Completion of the Basic Design, implementing all R&D evidences, achieved during the technology assessment that is performed in parallel, through the support of National R&D programs on key topics.
- Finalization of the Site characterization process and related studies being the current reference location identified in the Romanian nuclear site of Mioveni.
- Preliminary dialogues with regulatory body and safety authorities for the definition of a stepwise informed approach to siting and licensing.
- Creation of a Center of Excellence on HLM as key infrastructure supporting education and training of the specific competences required to support the ALFRED project and implementation of human resources education & training programmes by launching open access to the HLM CoE and increasing international participation to ongoing experiments.

The main purpose of the Viability Phase is the reduction of uncertainties in construction and licensing.

Within the past years, the conceptual design of ALFRED has been focused on the identification of the main suitable characteristic and design guidelines for the demonstrator of the LFR technology, aimed at being a scaled down facility sufficiently representative of the industrial size reactor. The choice of components and technologies already available in the short term is of paramount importance, in order to proceed towards the basic design and pre-licensing phase in the near future.

Some R&D activities are already planned and prioritized in support of the next design and licensing steps, through existing national programmes and the ongoing FPs funded by the EC, namely:

- Activities focused on the ALFRED design: optimization of the primary system design (Italian national program); thermal hydraulic experiments to characterize the HLM flow in LFR subassembly, experimental simulation of flow blockage, thermal hydraulic codes validation by access to PHENIX experimental data and CIRCE HLM large pool facility (SESAME EU H2020 project); validation of neutronics codes (Italian national program and FREYA-MYRTE EU FP7-H2020 projects); cross-cutting aspects for enhanced safety through an improved core design, the reduction of uncertainties in fuel properties, protection measures from extreme events and the development of instrumentation and inspection tools (ESNII+ EU FP7 project); qualification of passive DHR providing very high grace time also against freezing (EU H2020 proposal in preparation);
- Activities in support of the ALFRED licensing: engagement of an early dialogue with safety authorities for the pre-licensing phase (Italian national program); preparatory activities for the site characterization (Romanian national program); preparation of LFR Safety Design Criteria as part of GIF activities, ALFRED general design guidelines and general design criteria (Italian national program and ARCADIA EU FP7 project); codes V&V activities (Italian national program); investigation of fuel-coolant interaction and of fission products retention in lead (Italian national program and SEARCH-MYRTE EU FP7-H2020 projects).
- Activities in support of the LFR technology: material testing in HLM environment (Italian national program and MATISSE EU FP7 project); characterization and qualification of coating protections (Italian national program); characterization of austenitic steels for Gen-IV applications and of welding methods in terms of corrosion resistance, long-term ageing, high temperature resistance including mitigation measures (GEMMA EU H2020 proposal); development of the primary pump (Czech national program).

In the frame of the more enlarged R&D roadmap, the short-term action plan will be focused on the following open issues:

- Scaled tests for the LFR Decay Heat Removal System (DHR) to demonstrate feasibility/reliability and validate the computational model;
- Qualification of the innovative design adopted for the Steam Generator;
- Assessment of the Steam Generator Tube Rupture (SGTR) behavior ;
- Coolant chemistry control (through purification systems for large pool);
- Characterization of alumina based coatings and qualification of industrial procedures for coating deposition;
- Complete analysis of FA flow blockage and lead freezing;
- Verification and validation of simulation and modeling tools suitable for LFR design;
- Safety cases and design issues in support of site selection and pre-licensing activities;
- Further investigations on core neutronics and fuel development.

In order to meet the above listed R&D needs, the LFR demonstrator program will rely on the currently available European experimental facilities. In parallel, the International Consortium will evaluate alternative financial instruments (e.g. DG-REGIO Structural Funds) for the design, construction and operation of research facilities to support LFR technology studies (coolant physics-chemistry, corrosion/erosion phenomena, instrumentation/inspection and repair, thermal-hydraulic and heat transfer, structural material characterization in lead under irradiation at high dpa), as well as site selection and pre-licensing activities.

2.3.3. Budget for 2016-2018

The total budget required for the Viability Phase is about 200 M€. Out of these, about 27 M€ are currently ensured through national programs and EURATOM projects (potentially increasing up to 41 M€), dedicated to the development of the LFR and HLM technologies in the 2016-2018 period. Additional 20 M€ are expected in the short-term from European Structural and Investment Funds (ESIF), supporting the development of HLM infrastructures in Romania.

However, the successful implementation of the viability phase is dependent on the firm commitment of ALFRED as a Major Project in Romania, which is expected to lead to a fund injection of the order of 150 M€. A first step was achieved on July 15, 2015, when, as a consequence of the final consultation of Smart Specialization Strategy of Sud-Muntenia region,

«The research, development and innovation activities dedicated to ALFRED are included in High technology Industry […] smart specialization […] of the region»

ALFRED was considered a factor for economic growth, improved innovation, job creation, strengthening of Research Development Innovation poles and creating the career opportunities for young talents.

The following table summarizes all the budget requirements by thematic area considered to date for the ALFRED Viability Phase:

Thematic area	Major Step	Estimated Budget	Funding Sources	Deadline
Governance, Management, Financing	ALFRED as Major Project in Romania	1 M€	National Contributions	2016
Research, Development, Qualification	Open issues addressed	25 M€	EU H2020 projects National Contributions Private Contributions	2018
Saefty, Siting, Licensing	Preliminary siting and licensing	2 M€	National Contributions	2018
Engineering, Procurement, Construction–	Lead Center of Excellence set in Mioveni	140 M€	EU Structural Funds National Contributions Private Contributions	2018
Human Resources, Education, Training	E&T program definition and planning	1 M€	National Contributions EU H2020 projects	2016

The above projected budget for the period 2016-2018 clearly indicates that – at this development stage – the ESIF contribution plays a key role in obtaining significant advances in the short term.

2.4. ESNII-4: ALLEGRO

2.4.1. Intro

The development of the demonstration unit of the GFR technology, the reactor ALLEGRO, has been restarted after establishment of the "V4G4 Centre of Excellence" (V4G4) - association of legal persons from Central European V4 countries[2], in 2013. V4G4 is, at present, in charge of the international representation of the ALLEGRO project and of its technical coordination (design, safety, R&D, …), Slovakia is ready to host the demonstrator. The funding is currently provided by national resources, EURATOM Framework Programmes and EU Structural Funds.

After the initial pre-conceptual design phase by CEA from 2009-2010, V4G4 expects to prepare pre-conceptual design of ALLEGRO by 2020 and the conceptual design by 2025.

The concept by CEA from 2009-2010 has concentrated mainly onto 1) Neutronic analyses of the core 2) Design of the primary circuit and 3) Development of the refractory fuel for GFR. Thermo-hydraulic analyses have confirmed that the concept with stainless steel cladded MOX fuel is coolable in protected transients using active safety systems. However, loss of coolant accidents aggravated with station blackout (as well as most of unprotected transients) leads to core meltdown. Severe accidents in ALLEGRO have not been addressed so far.

The main topics in the next phase of the development shall be concentrated onto 1) Coolability issues in accident conditions using passive safety systems only, 2) Core with uranium oxide fuel enriched to <20% U235, 3) Most urgent R&D issues.

The requirement to investigate the feasibility of UOX core in ALLEGRO was formulated in late 2014. First version of Roadmap of activities in Design & Safety was elaborated in 2015.

2.4.2. Implementation plan 2016-2018

Before the development of the ALLEGRO restarts in full scale by V4G4, the following documents will be finalized:

- Design Specifications & Objectives (Formulation of the mission of the project including the main parameters to be achieved)
- Safety Requirements & Objectives (Formulation of the main safety requirements to be respected by the designers).
- Roadmap for Research & Development (Formulation of the main ALLEGRO-related topics)

The knowledge from the available analyses so far indicates that the power density of cca 100 MW/m^3 assumed by CEA for ALLEGRO with the MOX core does not match the requirement of coolability of the reactor. Lower power densities will be analyzed down to the lower limit of cca 50 MW/m^3 proposed by CEA for GFR. Due to proliferation considerations the use of low enriched UOX instead of MOX is preferable.

The main topics in this development phase to be treated in parallel are the following ones:

1) Coolability of ALLEGRO using passive systems only in protected transients: The reduced power density and/or reduced nominal power improves the coolability in pressurized transients and represents a good input for solving the coolability in depressurized transients. Existing analyses indicate that elevated backpressure in the guard vessel is indispensable to ensure the coolability in LOCA + SBO scenarios. A suitable pressure-resistant design of the guard vessel will be analyzed.
2) Once the acceptable (coolable) nominal power and power density are obtained, the feasibility of the UOX core with U235 < 20% (neutronics, coolability, fuel performance) will be studied.
   The UOX core to be critical will be larger than the MOX core for the same thermal power, which would result in lower power density. Optimization study will be performed.
3) Safety & coolability of ALLEGRO in unprotected transients. The neutronic & thermohydraulic feedback in unprotected transients will be analyzed.

[2] ÚJV Řež, a. s. (Czech republic), VUJE a.s. (Slovak republic), MTA-EK (Hungary), NCBJ (Poland). CEA (France) is expected to become associated member of V4G4. The initial phase of development of ALLEGRO at CEA finished in 2009-2010.

4) Severe accidents mitigation measures in ALLEGRO (to comply with the WENRA requirements): Design of external core catcher inside the guard vessel, feasibility of potential internal core catcher.

Neutronic and thermohydraulic benchmark analyses are underway to assess the capability of computer codes to simulate GFR-related phenomena. Some phenomena are still difficult to simulate by some codes, e.g. the water ingress into the primary helium. Detailed phenomenology of the refractory core behavior in severe accidents is missing and will have to be studied at least qualitatively. Adequate models are missing to date in the severe accident codes.

The GFR-related technologies will be developed in the frame of the supporting R&D program.

Supporting R&D program

Extensive R&D started after 2001 in France at CEA and continued till 2009, when the GFR program in France was reduced. However, the main research challenges for ALLEGRO (and in principle also for GFR2400), remain still valid and are listed below:

- Simultaneous improvement of the robustness and simplification of the decay heat emergency removal (DHR) systems,
- GFR-specific fuel handling technology and guard vessel design resistant to elevated pressure.
- Studies related to the behaviour of both the metal-cladded first core for ALLEGRO and the full refractory core, for both ALLEGRO and GFR in severe accident conditions (core degradation mechanisms and radionuclide transport/retention in a gaseous environment);
- Studies related to turbomachinery in secondary circuit (using suitable gas) aimed at increasing the thermal & mechanical inertia of the system in accident conditions;
- If possible, development of both the refractory fuel based on fuel pins composed of (U, Pu)C pellets in SiCf-SiC based tubes and the first core for ALLEGRO based on MOX (or UOX) fuel in metallic cladding tubes including pin encapsulation and irradiation of assembled pins/rodlets;

Experience feedback and current research related to the HTR and VHTR concepts may yield numerous solutions and benefit to the GFR. This applies principally for:

- development of structural materials suitable for high-temperature operation;
- helium blowers, sealing, purification, thermal barrier & insulation technologies;
- helium valve technology (in particular fast acting isolation valves);
- intermediate gas/gas heat exchanger and possibly also steam generator technology (in particular experience feedback from the VHTR.

2.4.3. Budget for 2016-2018

The total V4G4 budget allocated to the ALLEGRO development including manpower and investments on experimental facilities is around 2 M€ per year for the period 2016-2018:

1. The Slovak national program, ALLEGRO Research Centre was launched in 2014. In the framework of National research project in Slovak Republic, oriented to GFR reactor development, demonstration reactor ALLEGRO CEA 2009 (75 MW_{th}) was re-analysed.

   Its total budget is 0.5 M€ in the period 2016-2018

2. Experimental facility S-ALLEGRO in Czech Republic (DHR-related He loop S, mock-up of ALLEGRO) is under construction. To be commissioned in July 2017.

   Its total budget is cca 3 M€ in the period 2016-2018

3. The Hungarian National Nuclear Program has been launched in 2015 including activities for ALLEGRO safety and core design. The members of the Hungarian ALLEGRO Consortium are the Hungarian Academy of Sciences, the Institute of Nuclear Techniques of TU Budapest (BME NTI) and the NUBIKI Ltd.

   Its total budget is 1.4 M€ in the period 2016-2018

4. EURATOM Project in support

   The H2020 VINCO project (Capacity building in nuclear technologies in Central European V4 countries).

Its total budget is cca 1 M