APP-DSR15-411-01
Rev. 3
September 2016

Project ALLEGRO - Preparatory Phase

# ALLEGRO Design Specifications & Objectives

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V4 G4
Centre Of Excellence

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## Revisions

| Rev. | Date | Author / company | Changes |
|---|---|---|---|
| 0 | 2015/07/01 | L. Bělovský, UJV | First version of the report. |
| 1 | 2015/10/07 | L. Bělovský, UJV | Format: Cover page, Revisions. |
| 2 | 2016/05/03 | L. Bělovský, UJV | Revision by PCT3, May 2016 |
| 3 | 2016/09/07 | L. Bělovský, UJV | Revision by PCT4, September 2016 |
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# Abstract

This document contains the basic goals, objectives, requirements and parameters (often called mission of the project or basis of design) for the development of the GFR demonstrator ALLEGRO.

The core of the document formulates at the first place the mission of the project (design objectives) including the philosophy adopted for the design of the demonstrator (core configurations). In parallel, certain requirements onto the design are formulated. The relations of the design of ALLEGRO to that of the large commercial GFR are also verbally expressed, which is aimed at minimization of potential future misunderstandings. The desired target values of the main integral parameters such as helium outlet average temperature, neutronic target values or expected lifetime are also summarized in this document.

It is expected that this document will be later extended by a similar information (mission, basis of design) on each individual system (subsystem, structure, component, …). This will help reaching coherency throughout the design of the whole ALLEGRO and simplify the formulation of work for designers of the individual systems in ALLEGRO.

# Table of contents

## List of abbreviations

| | |
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| DHR | Decay Heat Removal |
| GFR | Gas-cooled Fast Reactor |
| MOX | Mixed Oxide Fuel |
| MWt | Megawatt thermal |
| VHTR | Very High Temperature Reactor |

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# Introduction

This document contains the results of the primary decision-making process in form of objectives, requirements, and target values of main reactor parameters aimed at meeting the project goals. Such a document is often called „Basis of design" in the industry. It represents the basic input for both the designer of the whole system and designers of the individual subsystems, structures and components.

Before the project starts, a set of primary objectives, requirements & target values must be carefully formulated by the owner of the project (V4G4 Centre of Excellence in this case), because it represents the initial fixed point for the design process. It is expected to remain unchanged throughout the project or being subject of small adjustments only, if possible. This set of data based on [ 1] and reflecting the wishes of the project owner is summarized in Chapter 2.

The basis of design, i.e. the objectives, requirements & target values for the individual systems, subsystems, structures & components (further called items) will be derived during the design process with the aim to meet the objectives of the demonstrator. The current version of this document does not yet contain list of these items. It will be added (step by step) in the subsequent revisions of this document, because the items are interdependent.[1] The objectives, requirements & target values for each item will be structured using approximately the following scheme:

- Objective of the item (description of its function)
- Important requirements & assumptions (cooperation with other systems, media, space, in service inspection & repair requirements, …)
- Main parameters & target values

It is important to make efforts in the following revisions to provide a complete set of input information on each item for the designer. In the early phase of the design process the parameters of each item will be estimated only. More precise values will be provided during the design process.

[1] For example the characteristics (type, concentration, …) of impurities in the primary helium cannot be known before the materials and conditions within the primary circuit are specified. Or the guard vessel cannot be designed before the (approximate) size & layout of the equipment inside GV is known.

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# Objectives & requirements of the reactor ALLEGRO

This chapter summarizes the objectives of the reactor ALLEGRO in relation to the target commercial-scale GFR [ 2]. The design objectives, requirements, design philosophy and main target parameters are grouped in individual chapters. Details on testing the high-temperature refractory fuel in ALLEGRO using a (provisional) driver core is summarized in chapter 2.5.2.

## 2.1. Design objectives

The ALLEGRO experimental reactor, with a thermal power in the range around 75 MWt, is a necessary step towards a large-scale GFR prototype, as no GFR has ever been built.

The three main goals for the ALLEGRO reactor are the following ones:

**A) Test the innovative refractory fuel**

1) ALLEGRO will be the test bed to **develop the innovative refractory, high-power density fuel** [2] that is required for a commercial-scale high-temperature GFR. This fuel development will be carried out in prototypic coolant at representative temperature & pressure and with simmilar neutron spectrum & peak flux.
2) ALLEGRO shall propose a capability to irradiate the innovative fuel elements in the prototypic conditions (close to large-scale GFR). Special irradiating positions are to be implemented in the ALLEGRO core for this purpose. The special core design - starting from the first cycle must take into account the presence of these special positions for refractory fuel subassemblies.
3) The reactor shall be capable to deliver a sufficient conditions to sucessfully qualify the refractory fuel in a reasonable time scale.

[2] The **refractory fuel** to be irradiated in ALLEGRO special positions in the core requires a specific dense fuel element that can withstand very high temperature transients, due to the lack of thermal inertia of the gas cooled systems. Ceramic or refractory metal clad should be selected, developed and qualified. Such a program requires material properties measurements, selection of different materials, their arrangement and their interaction, **out-of and in-pile tests up to qualification**, demonstration tests.

**B) Test GFR-specific technologies**

The major issue is to **demonstrate** and **qualify**, at a **pilot scale**, the following key GFR-specific technologies such as:

1) Reactor control & operation.

- 2) The key safety systems and components important to safety, respecting the general IAEA standards. Their design should be applicable in scalable way to the large-scale GFR. It concerns:The reactivity control system
- A robust Decay Heat Removal (DHR) systems enabling to cool down the core whatever the situation.

3) Fuel handling, transfer and storage devices.

4) Core instrumentation and measurements.

5) Other technologies, similar to VHTR, but GFR-specific (control and management of the helium quality, guard vessel atmosphere management, thermal insulation barriers, cross-duct pipes, seals for reactor tightness, blowers, heat exchangers etc.).

**C) Provide pilot test capacity of high temperature components or heat processes**

An additional dedicated test loop with significant thermal power shall be implemented in the primary or secondary circuit for providing high potential heat for testing of industrial applications.

In addition, in the framework of development of ALLEGRO the GFR Safety Framework will be established through the definition of the GFR Safety design criteria.

## 2.2. Core configurations

The philosophy of testing the innovative refractory fuel consists of three core configurations with different fuel technologies and two successive temperature modes of operation:

**A) First (driver) core without refractory test subassemblies**

A starting oxide core with existing or close to existing technology (e.g. MOX or UOX pin-type subassembly with metallic cladding) ready for the irradiation of a few experimental sub-assemblies in the later stage, to qualify one or several GFR subassemblies in the stage of concepts. Due to the metallic cladding, the core must be operated at lower helium outlet temperature compared to the GFR target temperature. The first core consists of fuel, control & shutdown subassemblies and dummy (steel) subassemblies at the experimental positions, surrounded by reflector & shielding subassemblies.

**B) Intermediate core containing some refractory test subassemblies**

First core containing several refractory fuel subassemblies. The outlet temperature of these subassemblies must be increased as close as possible to the refractory core values, achieved e.g. by reducing the flow rate at the fuel subassembly inlet. Since both the oxide core and the refractory core are assumed to rely on the same core supporting structures and control rod drive mechanisms, both cores will have the same fuel subassembly dimensions with the same control rods locations.

**C) Final refractory core**

After the preliminary phase (first & intermediate core), a full refractory core, representative of the GFR, will be implemented for a full-scale industrial demonstration in a GFR prototype

ALLEGRO. The irradiation conditions should be as close as possible to those of the GFR. That concerns the fuel and clad temperatures, the primary pressure and the core design.

The two temperature modes of operation are the following ones:

- Mode 1: Core outlet temperature is limited by the driver core (cores A and B)
- Mode 2: Core outlet temperature is limited by the refractory core (core C)

## 2.3. Design requirements

The following requirements should be respected in the design:

A) The reactor shall be designed for accommodating the parameters (high temperatures) of the ultimate refractory core (temperature mode 2). The number of components to be replaced due to the upgrade from mode 1 to mode 2 shall be minimized.

B) No fertile blankets.

C) The principle of operation of the key safety systems should be based on physical laws (passive systems), whenever possible.

D) The generation of electricity as well as the maximization of the thermal efficiency are not the primary objectives of ALLEGRO but the generation of electricity and/or heat should be considered, if reasonably achievable. Selling electricity and/or heat will at least partially cover operational costs and/or potential loans.

E) The maintenance and repair of individual primary circuit components must be as much feasible and easy as possible.

## 2.4. Required design similarities with a large-scale GFR

The GFR2400 [ 2] by CEA[3] is taken as reference for the reactor ALLEGRO. The similarity concerns both the core parameters and the system design up to the boundary between the secondary and tertiary circuit:

**A) Core parameters**

1) Clad and fuel temperatures of the refractory fuel subassemblies tested in ALLEGRO shall be as close as possible to those of the large-scale GFR.

2) Fast flux in the refractory subassemblies and dose/burnup values shall be close to the reference values for the large-scale GFR

**B) System design**

The number and symmetry of the primary circuit loops as well the shape and materials of the guard vessel in ALLEGRO are not limited by the corresponding design of these structures in the large-scale GFR.

## 2.5. Target values and characteristics

This chapter summarizes other requirements onto the reactor ALLEGRO.

[3] Even if reduced power levels are presently being considered (GIF/GFR/Conceptual Design and Safety or EM2 GA project)

### 2.5.1. System requirements

A) Number of circuits: **No limitation**

B) Number of primary loops: **No limitation**

C) Symmetry of the primary circuit layout inside the guard vessel: **No limitation**

D) Coolant of the secondary circuits: **No limitation**

E) Shape and material of the guard vessel: **No limitation**

F) Reactor design life-time without replacing main components: **min. 40 years**

### 2.5.2. Core design & fuel cycle requirements

A) ALLEGRO fast neutron flux and the ratio dose/burn-up values are targeted within a range of 30 % of the large-scale GFR. The minimum targeted values are:

- Max fast flux (E > 0.1 MeV): $\mathbf{8 \cdot 10^{14}}$ n/cm$^2$/s
- Neutron dose: **15** dpa SiC for **365** FPED

B) The average helium outlet temperature from the refractory core (before mixing with the bypass) shall be at least ~**800** ºC.

C) The time needed to reach typical refractory fuel burnup should be not more than approximately eight full-power equivalent years.

D) Helium void effect shall be minimized.

E) The overall temperature reactivity feedback coefficient must be < 0.

F) Refractory fuel design must facilitate reprocessing.

G) LEU (Low Enriched Uranium, U235 < **20**%) shall be used in case of UOX driver core.

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# References

[ 1] Ch. Poette et al.: ALLEGRO Preliminary Viability Report. Report CEA, CEA/DEN/CAD /DER/SESI/LCSI/NT DO 12, 02/12/09 (2009).

[ 2] Ch. Poette: Contribution to the Gen IV GFR viability report. FP7 GoFastR-DEL-1.1-16 (2012).