V4G4 Centre of Excellence – ALLEGRO Project

The ALLEGRO Experimental Gas Cooled Fast Reactor Project

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Contents

- Fast reactors
- GFR, V4G4
- Goals, schedule and organisation of the ALLEGRO project
- Technical history in a nutshell
- Main technical challenges
  - Fuel and core design
  - Decay heat removal
  - Further technical isssues
- Conclusions

The presentation is based on a paper with the same title prepared by L. Belovsky, J. Gadó, B. Hatala and A. Vasile at the FR17 Conference, Yekaterinburg, June 2017

Fast reactors

Almost all power reactors in use are based on the fission of ^{235}U below 1 eV (thermal energies). The neutrons emerging from fission have energies between 0.5-10 MeV and then slowed down (generally on H_2O) to thermal energies (< 1eV).

In principle, reactors can be built on using the fast spectrum. In these fast reactors one needs a coolant which does not slow down neutrons (Na, Pb, He). A lot of serious technical obstacles have to be overcome during the development of fast reactors. Sodium cooled fast reactors have been built. At present the main developpers are Russia, India, China and France. Commercial fast reactors are in use only in Russia.

Fast reactors make it possible to close the fuel cycle: to burn the „waste" of thermal and fast reactors and to produce not less fissile materials than burnt in the reactor (based on neutron capture of ^{238}U). However, closure of the fuel cycle assumes the wide use of reprocessing the nuclear „waste".

GFR, V4G4

The main advantages of Gas-cooled Fast Reactors (GFRs) beside the closed fuel cycle are:

- High operating temperature, allowing increased thermal efficiency and high temperature heat for industrial applications
- Low value of the void coefficient
- Helium is a chemically inert and a non-corrosive coolant
- Helium is transparent, facilitating in-service inspection and repair.

The main drawbacks are related to:

- The need to operate under pressurized conditions
- The low cooling efficiency of Helium, in particular in natural convection.

Based on an initiative of CEA, the nuclear research institutes of the Visegrad-4 region decided in 2010 to start joint preparations aiming at the construction and operation of the GFR demonstrator ALLEGRO. They created in 2013 the legal entity, the “V4G4 Centre of Excellence” and launched the ALLEGRO Project – Preparatory Phase in 2015. CEA joined the project in 2017.

Goals of the ALLEGRO project

The viability of the GFR technology shall be demonstrated by constructing and operating the ALLEGRO reactor. ALLEGRO shall be used for

- GFR technology demonstration and
- development and qualification of innovative components & systems, first of all the refractory fuel (UPuC pellets in SiC-SiC_f cladding)

According to the EU nuclear research agenda sodium-, lead-, and gas-cooled fast reactor concepts should be developed parallelly as long as at least one of them reaches the level of industrial maturity.

Project schedule

- *Preparatory phase (2015/2025)*
  - Definition of the basic safety and performance goals, specifications (2015/2017)
  - Pre-conceptual design (2018/2020)
  - Conceptual design (2021/2025)
- *Realization phase (after 2025)*
  - Basic Design
  - Detailed Design
  - Siting and Licensing
  - Construction
  - Operation

Project organisation - 1

The activities of the Preparatory Phase are planned in the Safety and Design Roadmap. The works are financed by national and EU projects, but the financial support is not satisfactory at present.

The works are organized by the Steering Committee and the Project Coordination Team.

Intellectual Property Rights of the design created during the Preparatory Phase will be an important contribution to the capital of the consortium to be created for the Realization Phase.

Project organisation - 2

A preliminary vision has been elaborated on the Realization Phase of the ALLEGRO Project and this vision has to be refined in the coming years. According to this vision a new consortium has to be established for the Realization Phase in a form unknown at present for EU. The consortium should include:

- Representatives of the interested European governments
- The Licensee
- An industrial company (design, documentation, licensing, construction)

The legal aspects of creating such a consortium are still to be elaborated. It seems to be a common issue for any Generation IV reactor in Europe therefore a joint effort is envisaged.

Technical history in a nutshell

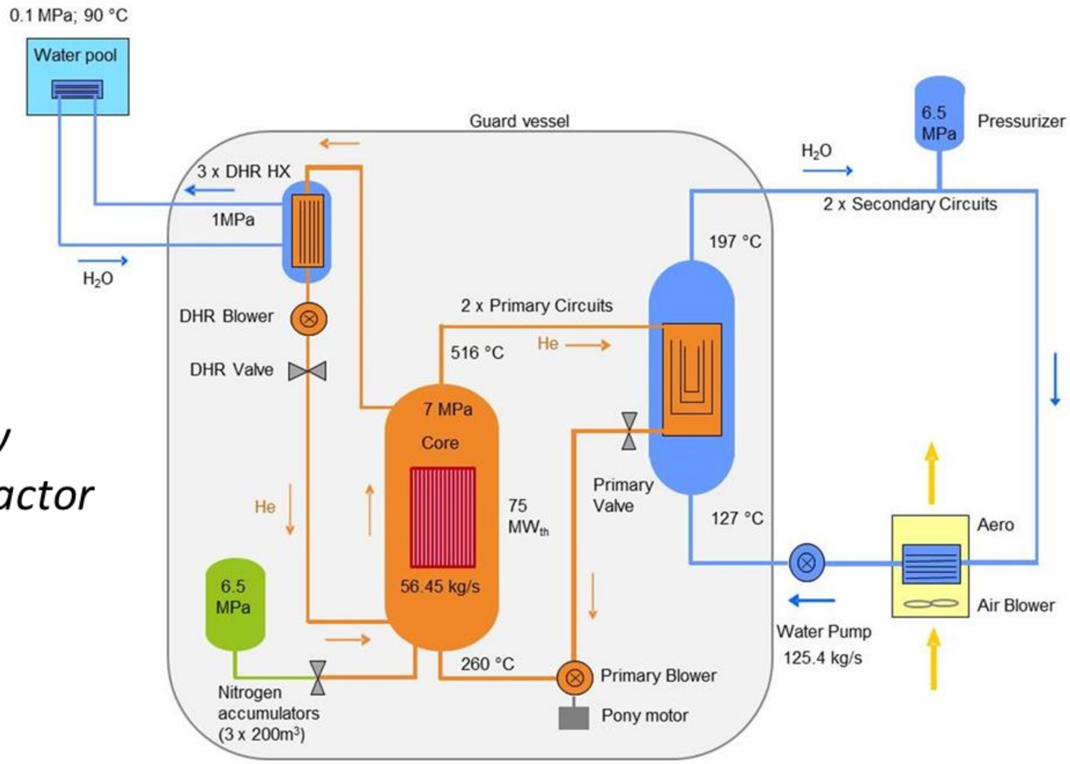
The idea of helium cooled fast reactors goes back to the early days of nuclear energy development. The first realistic concept was elaborated by CEA after 2000. The Experimental Technology Demonstration Reactor (ETDR) from 2008 was characterized by 50 MW thermal power, 560 ºC He first core outlet temperature at 7 MPa, one primary loop and water cooling on the secondary side.

A new concept was presented by CEA in 2009 with the name ALLEGRO. It was characterized with 75 MW thermal power, 530/850 ºC first/refractory core He outlet temperature at 7 MPa, two primary loops and water cooling on the secondary side. This is the reference design (ALLEGRO CEA 2009) for V4G4 CoE. The EURATOM FP7 GoFastR project (2010-2013) further refined this design. In 2011 CEA patented a GFR system with increased safety in accident conditions based on gas turbo-machinery in the secondary circuit mechanical coupled with the primary blowers ensuring decay heat removal during the first more than 12 hours (concept ALLEGRO CEA 2011).

Main technical challenges

As safety of the CEA concept is not satisfactory, a new ALLEGRO V4G4 concept is under elaboration within V4G4 CoE. The main technical challenges of the ALLEGRO reactor are grouped as

- Fuel and core design issues
- Decay heat removal issues
- Further technical isssues



Schematic view of the ALLEGRO reactor

Fuel and core design issues - 1

Gas-cooled Fast Reactors will be fuelled with so-called refractory fuel, most probably UPuC carbide pellets in SiC-SiC_f tubes.

ALLEGRO cannot use this type of fuel from the very beginning since this fuel is not developed and cannot be qualified without irradiations in GFR conditions and the subsequent PIE. The first cores will be built up from stainless steel cladded fast reactor oxide fuel (see the Figures on the next slides). Some core positions will be reserved for the development of the refractory fuels through the irradiation of fragments, rods and sub-assemblies. In these positions an elevated helium outlet temperature (800-850 ºC) is created by reducing the coolant flow rate.

The low melting temperature of stainless steel and the low thermal inertia of the system leads to the need of limited reactor power and power density. The related investigations are in the centre of attention.

Fuel and core design issues - 2

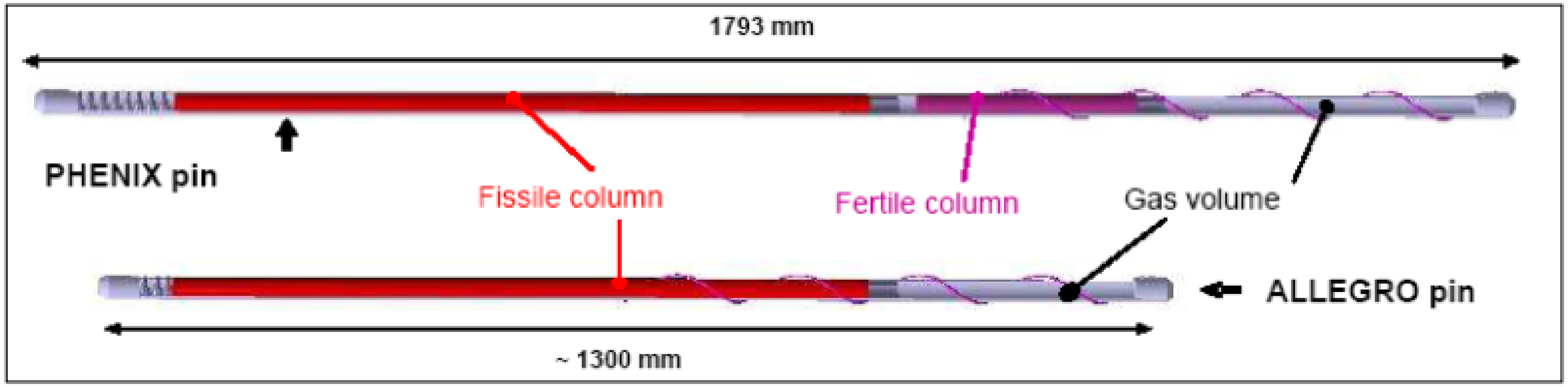


FIG 3. The ALLEGRO fuel pin compared to PHENIX pin [1]

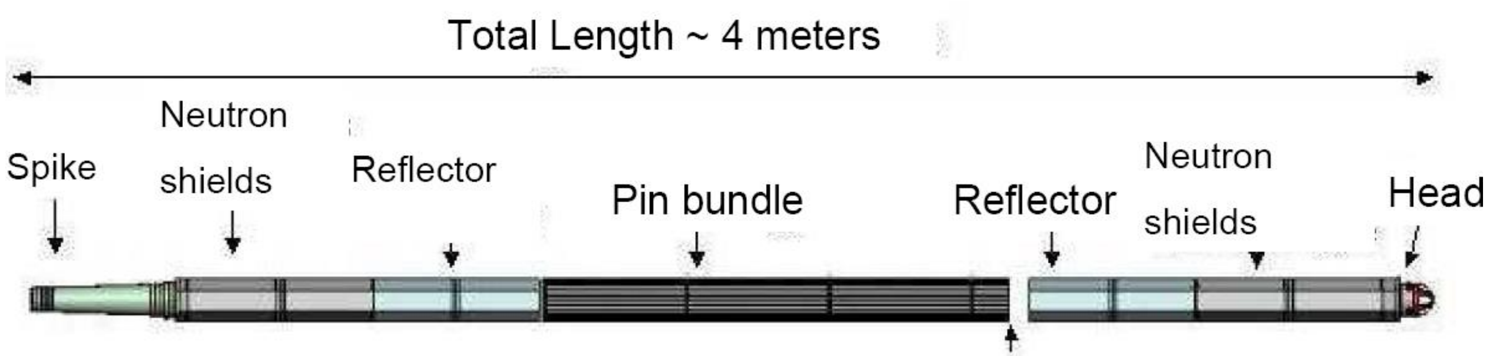
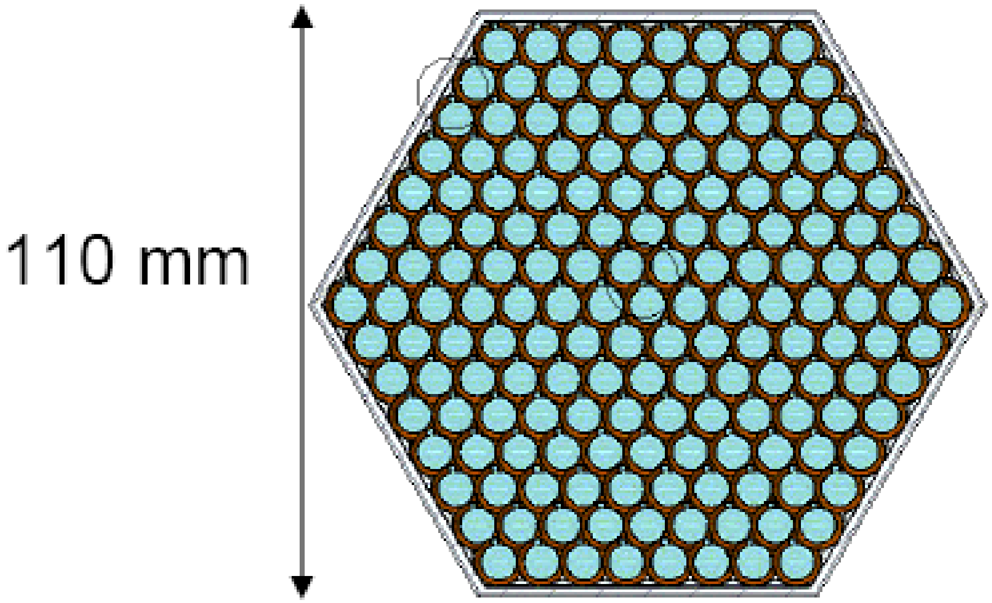


FIG 4. The ALLEGRO fuel pin bundle [1]

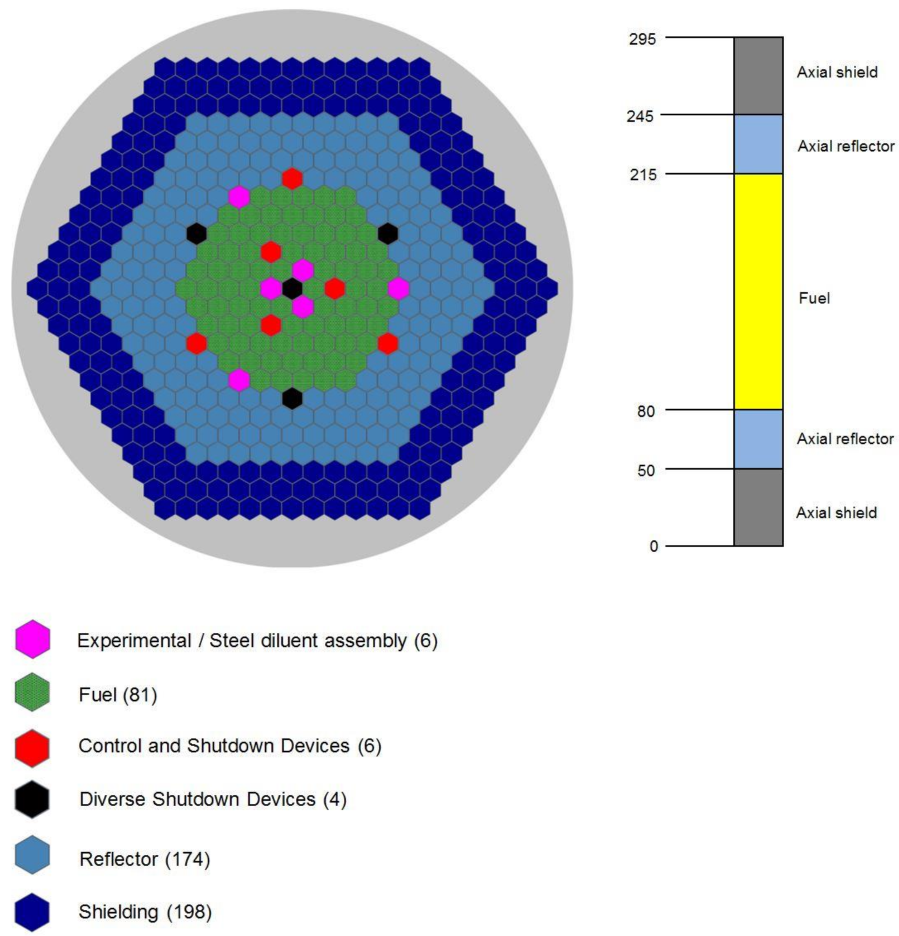
Fuel and core design issues - 3



Fuel pin positions within
the ALLEGRO fuel pin bundle

Fuel and core design issues - 4

First ALLEGRO reactor cores



Fuel and core design issues - 5

The development of UPuC pellets slowed down in the last years. CEA gave it up because of technical difficulties (of chemical nature) and now the main developer is General Atomics in USA. Contact with GA is difficult.

SiC-SiC_f development is also slowed down. Cold working of this composite material is very difficult if it is possible at all. The material is not leak-tight therefore the pellets should be packed into metal capsules. Moreover, pellet clad mechanical interaction has to be avoided while thermal creep and swelling of pellets are too high at high temperatures.

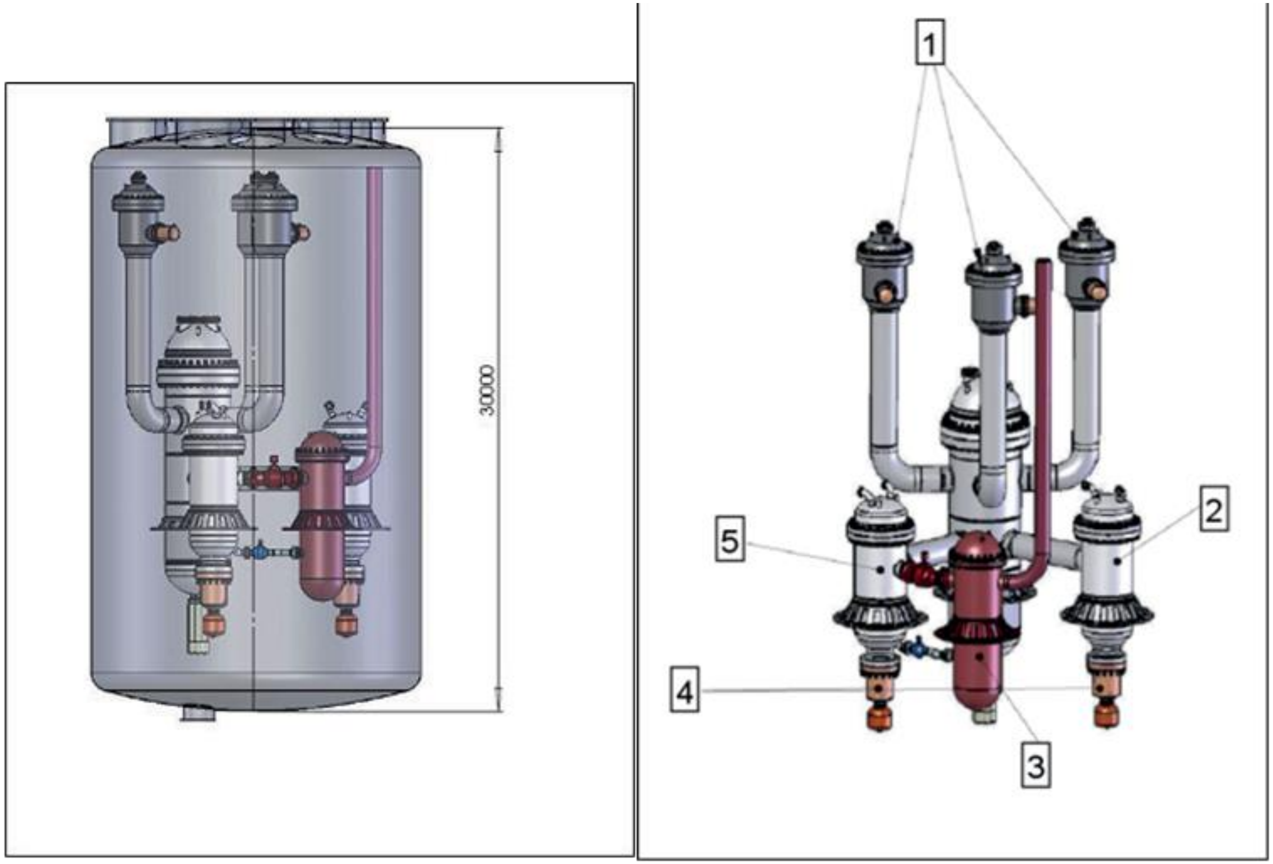
A further problem may emerge if any Generation IV reactor is built in any country not being a nuclear power. The qualification and use of MOX fuel involves several legal and proliferation issues. In order to overcome these potential difficulties, now it is investigated whether using <20% enriched UOX pellets a feasible ALLEGRO core can be designed.

Decay heat removal issues - 1

This is the most important technical issue:

- the limiting reactor power and power density are currently investigated
- LOCA scenarios are to be handled using passive features as
  - gas turbo-machinery in the secondary circuit supplying energy for the primary blower in the first hours after LOCA
  - on the long run the decay heat is to be removed by natural circulation, utilizing nitrogen injection into the primary circuit
  - natural circulation can be promoted by elevated backpressure in the guard vessel
- the potential risk of core bypass in a LOCA scenario must be carefully analysed and has to be minimized by design
- water ingress from a DHR heat exchanger into the primary circuit represents a further challenge, that can be practically eliminated by the isolation of the affected DHR loop if necessary.

Decay heat removal issues - 2



The ALLEGRO reactor arrangement in the close containment:
1 - DHR loops, 2 and 5 - primary loops, 3 - gas-gas heat exchanger, 4 - blower

Further technical isssues

- Important development of Helium technology is still expected.
- The containment system has to be designed from scratch but well-known solutions exist.
- A core catcher system should be built in the containment.
- Fuel handling was designed by CEA as far as the removal of spent fuel from the reactor vessel is concerned, but the strategy of shielding the irradiated fuel transport between the reactor vessel and the spent storage facility is still under development.
- The existing concept of storing spent fuel is under discussion. A temporary wet storage of originally dry fuel elements before storing them in a medium term dry storage facility and a temporary dry storage system are the alternative solutions.
- A system of accident management measures is completely missing at present. A special attention should be devoted to radiation protection.

Conclusions

We are convinced that nuclear energy remains one of the major components of electricity production in the 21st century and fast reactors will play a crucial role in developing the sustainable use of nuclear energy.

The ALLEGRO reactor can fulfil the role of a European GFR technology demonstrator allowing for fast neutron irradiation of ceramic fuel and other perspective reactor materials.

Co-operation with partners (e.g. HTR R&D) seems to be extremely important in order to diminish all technical deficiencies.

THANK YOU FOR YOUR ATTENTION!