Generation IV, ESNII concepts and associated fuels

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member of ESNII Task Force

Summary

- Introduction to Generation IV
- SNETP and ESNII
- The ESNII concepts
  - Astrid
  - Allegro
  - Alfred
  - Myrrha

Generation IV international Forum (GIF)

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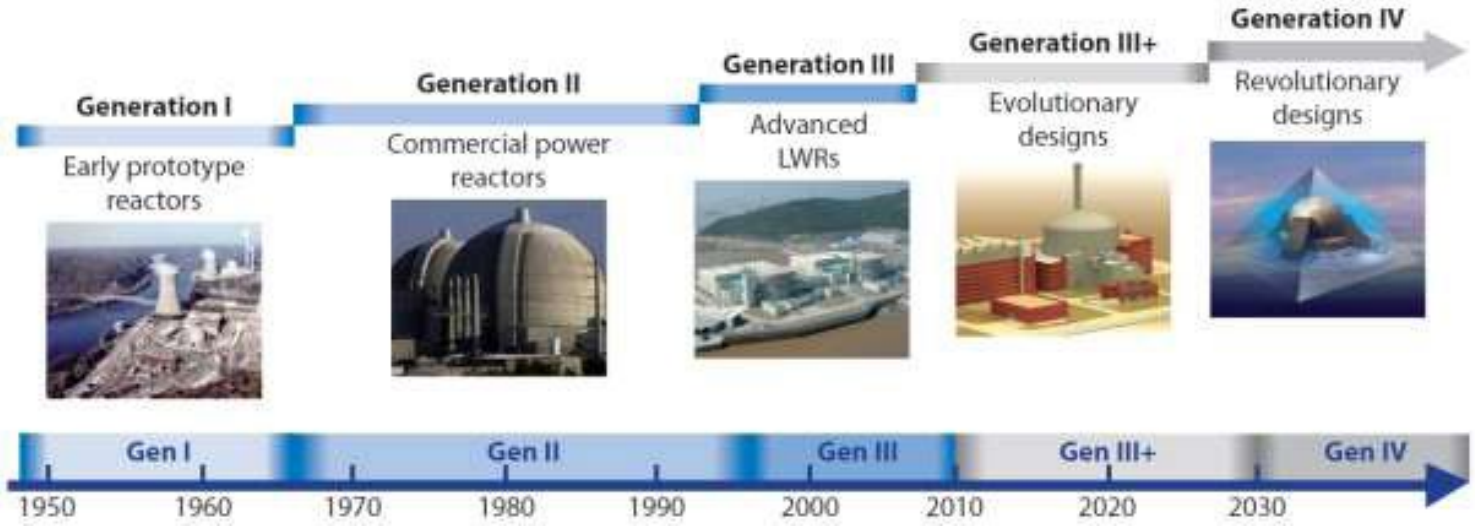
The Generation IV International Forum (GIF) was started in January 2000 by nine countries and established in July 2001. Today, the Generation IV International Forum has 12 members which are signatories of its founding document, the *GIF Charter*.

GIF agreed that nuclear energy is needed to meet future energy needs, and defined in its *Technology Roadmap* four goal areas to advance nuclear energy in its next "fourth" generation:

Sustainability (full use of Uranium resource)
Safety&Reliability (Emergency Planning Zone reduction)
Economic competitiveness (must be competitive)
Proliferation Resistance and Physical Protection (no dual use)



Generation IV international Forum Reactors Technology Evolution

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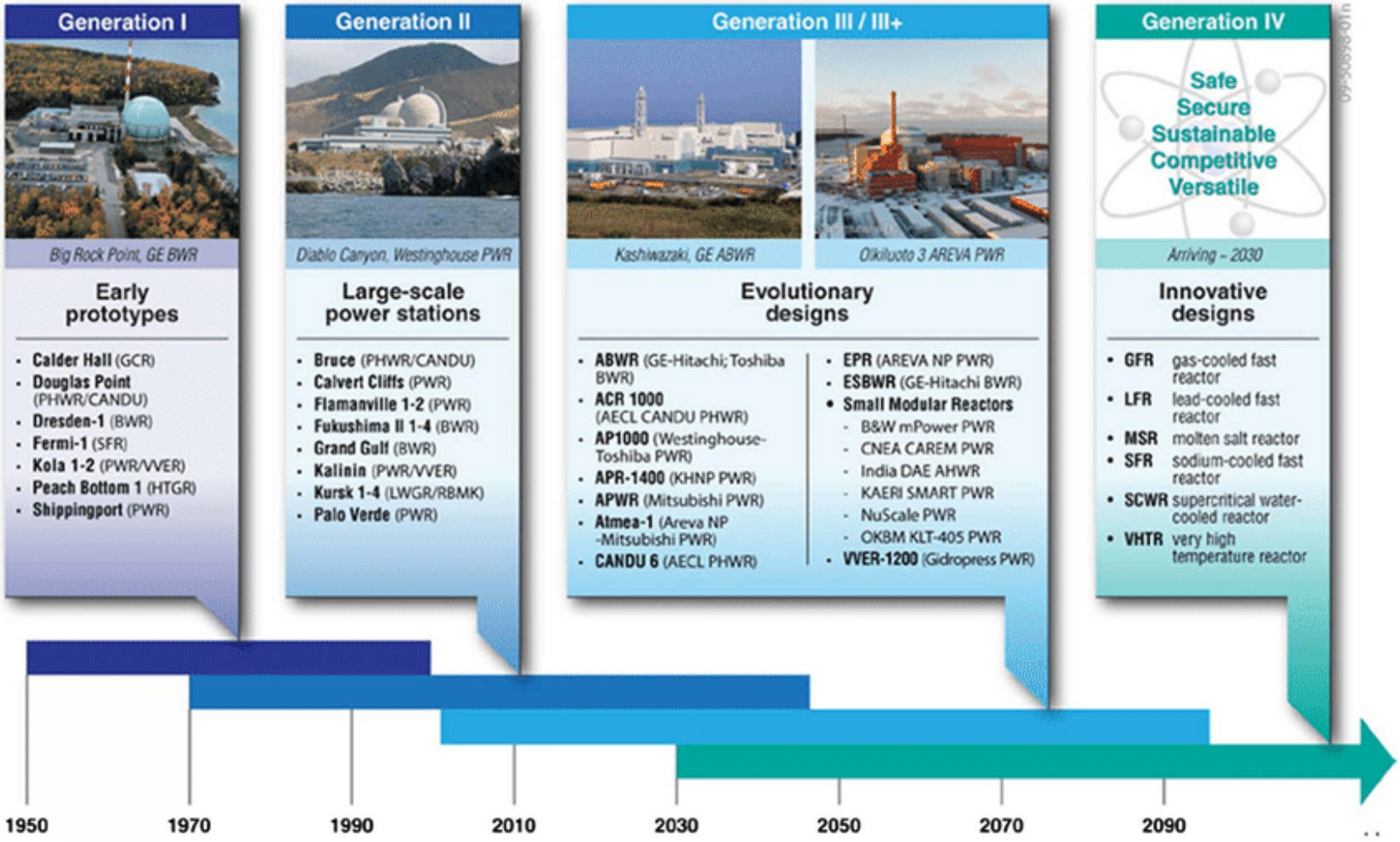

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GIF - Organization Structure

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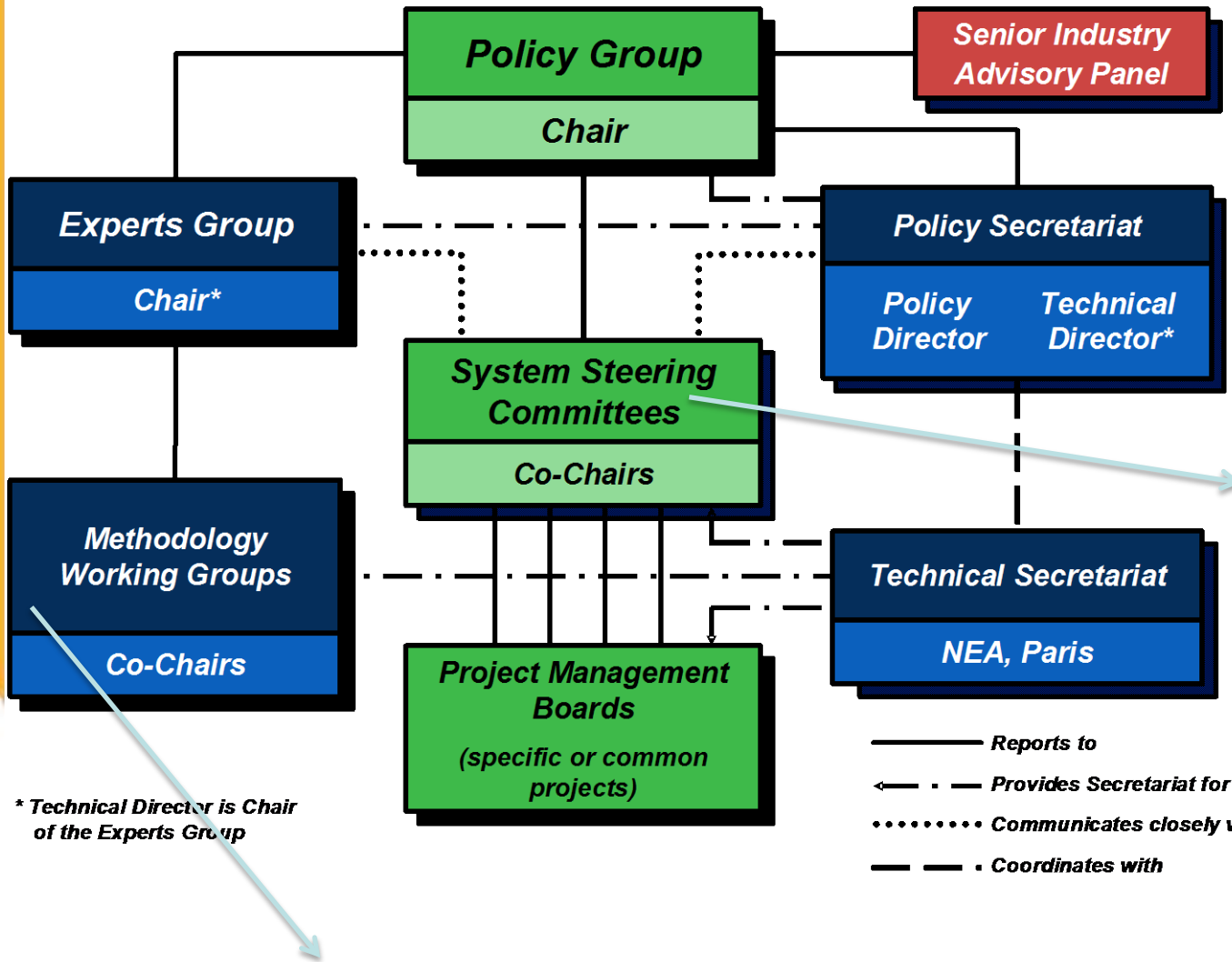

6 System Steering Committee (SSCs)

SFR
LFR
GFR
SCWR
MSR
VHTR

4 MWGs: RSWG, PRPP, EMWG, SWG (one for each goal)

Technology Roadmap Update

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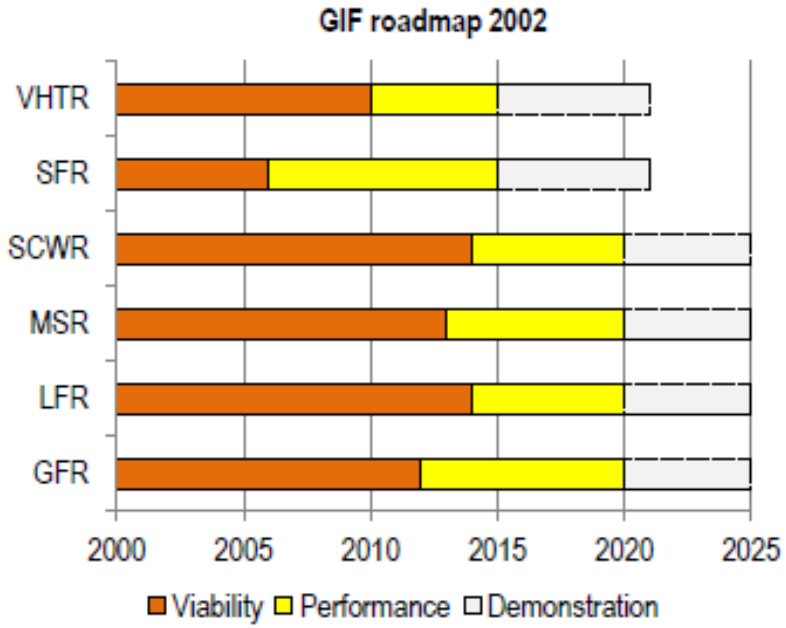
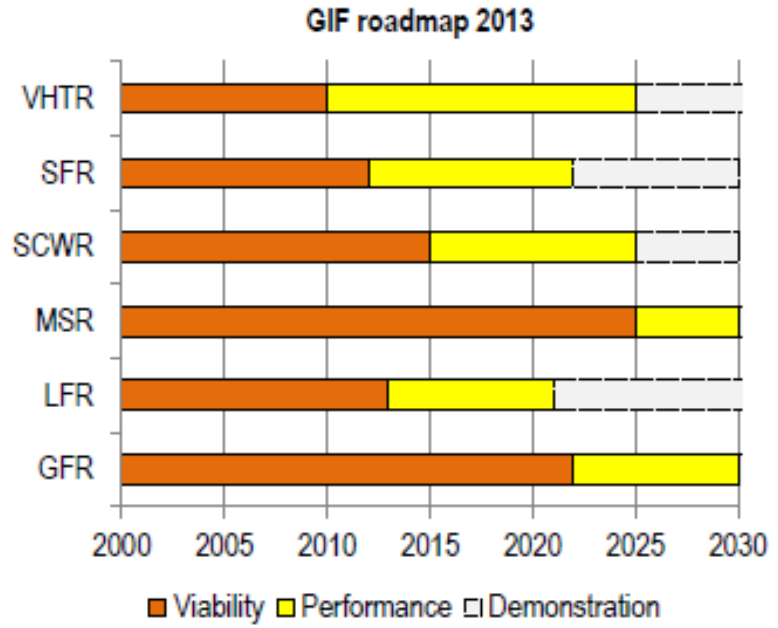
Report available on GIF Web *site* – *public section*
https://www.gen-4.org/gif/jcms/c_60729/technology-roadmap-update-2013

Watch for the 2019 R&D Outlook report … old report at:
https://www.gen-4.org/gif/jcms/c_43526/2009-rd-outlook





Other very interesting reports on GIF website:
Collection of white papers on safety !!! (search for white)
Webinars series 2016-2019 (GIF Education and Training Task Force)

EUROPE

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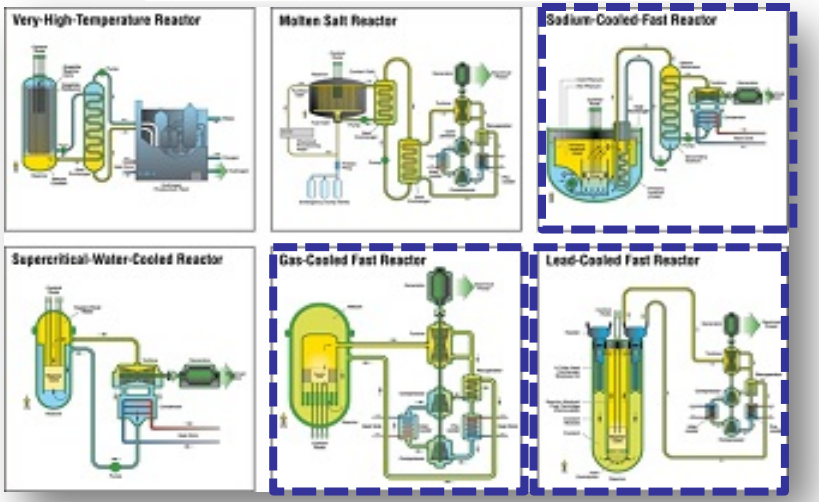
GEN IV International Forum



GEN IV systems included in ESNII

SNETP - Sustainable Nuclear Energy Technology Platform
NUGENIA - NUclear GENeration II&III Association
NC2I - Nuclear Cogeneration Industrial Initiative
ESNII - European Sustainable Nuclear Industrial Iniziative

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EUROPEAN CONTEXT

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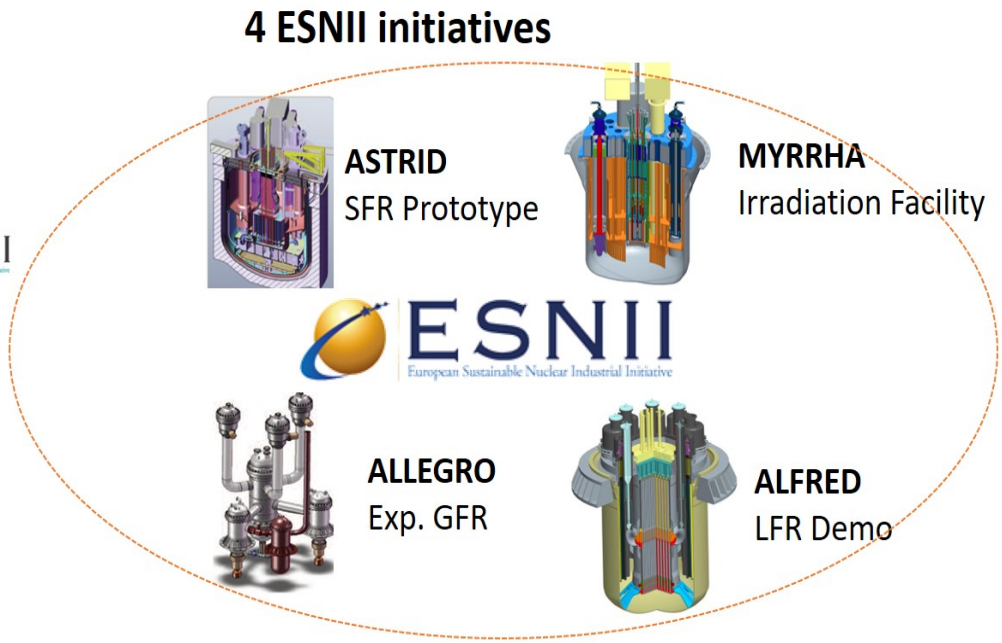

SNETP - Sustainable Nuclear Energy Technology Platform
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ESNII: the actors

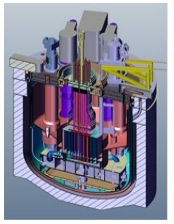
- ESNII is an Instrument for coordinating the implementation of the SNETP pillar on **sustainability of nuclear fission, based on Gen IV fast reactors with closed fuel cycle**

- The **ESNII Task Force**
  - *Memorandum of Understanding* under SNETP umbrella
  - 13 founders in 2010, now about 30 members from Industry, research organisations and Academy

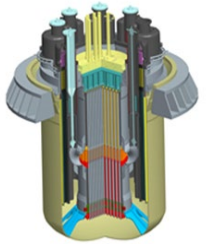
- For manageability, the ESNII Task Force decided to set up a 2-level structure:
  - **Task Force**: all members
  - **Executive Board**: leaders of the ESNII projects

ESNII: the Initiatives

- ESNII activities are based on 4 main initiatives:

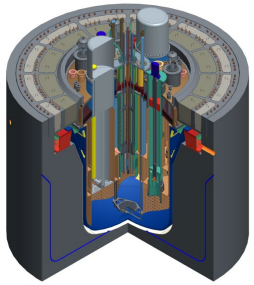


- **ASTRID** - a Sodium cooled FR prototype
- **ALLEGRO** - a Gas cooled FR Experiment

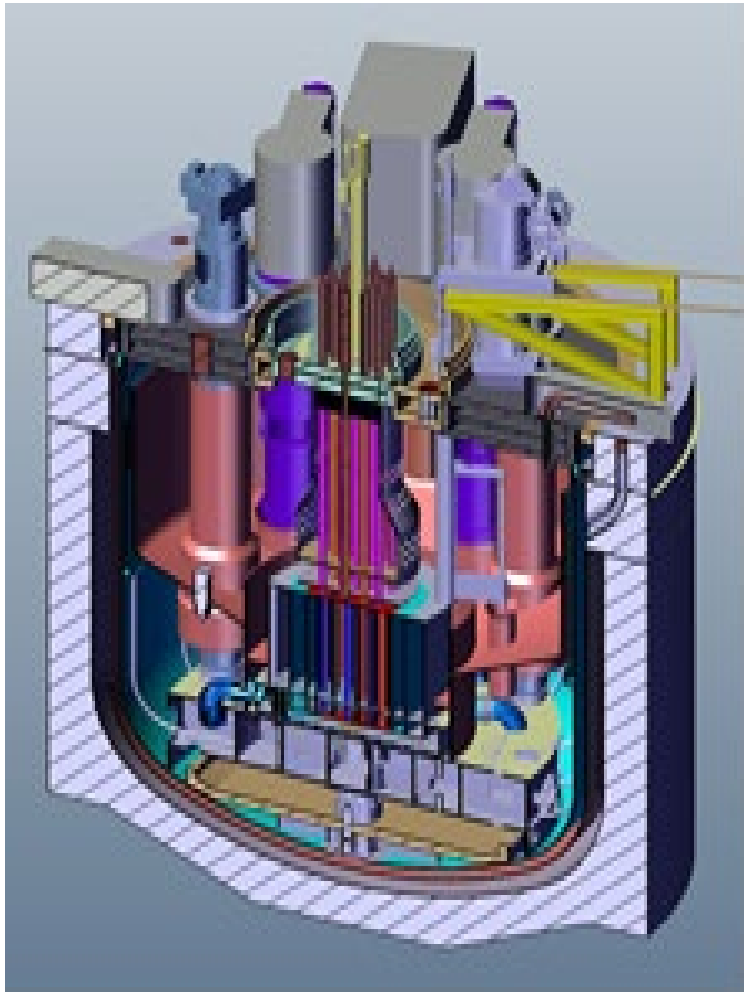


- **ALFRED** - a Lead cooled FR demonstrator

+ **MYRRHA** - An Accelerator Driven System
  - To Demonstrate the ADS concept
  - To Demonstrate transmutation
  - To support ESNII systems
  - multipurpose and flexible irradiation facility



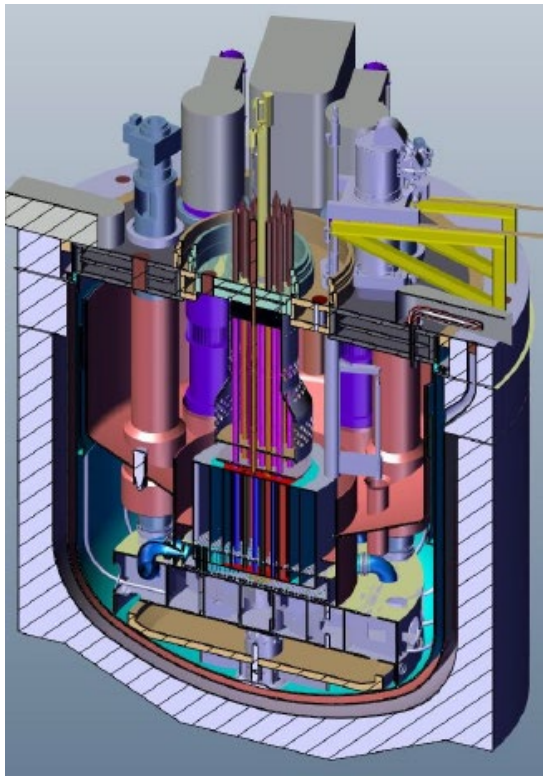
ASTRID



ASTRID

1500 thMW - 600 MWe - Pool type reactor - SFR prototype

- With an intermediate sodium circuit
- CFV core (low sodium void worth)
- **Oxide fuel UO2-PuO2**
- Strategy for severe accidents (internal core catcher…)
- Diversified decay heat removal systems
- Fuel handling in gas, internal storage
- Conical "redan" inner vessel adopted



Preferred lay-out :

3 primary pumps

4 intermediate heat exchangers

4 secondary circuits

5 decay heat removal circuits

Open design option : energy conversion system

ASTRID

Evolution of the context versus before 2010: consensus on the postponement for the commercial deployment of SFR

Update of the Multi-annual Energy Plan

January 2010 — December 2017 — December 2019

ASTRID 600 MWe and associated cycle

- Studies until a level of partial *Basic Design*
- Development of competences and a network of R&D and industrial partnership
- New generation for numerical simulation tools for design and safety studies
- R&D in support
- Investments in experimental facilities for the qualification programs (GISEH, PAPIRUS)

Preparation of a SFR simulation program and cycle including New ASTRID and related fuel cycle (sketch)

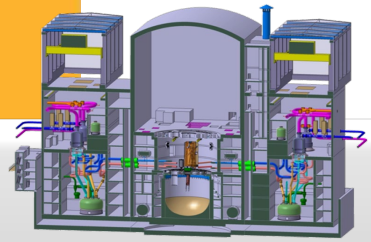
R&D program for the development of SFR and associated cycle

Use of available SFR and MTR in the timeframe (BOR60, MBIR, RJH...)

Demonstration or experimental Reactors

Program performed in the frame of the CEA – French State arrangement (2010-2019), under the umbrella of the French Act of 2006

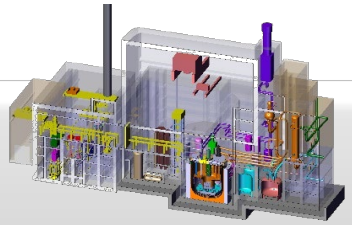
ASTRID



ASTRID 600

Demonstration reactor of 600eMW
Design options and feedback experiences extrapolable to the commercial reactor

New ASTRID



Acquire experimental data and feedback experiences in support to the SFR Development program and associated cycle

Some objectives for the New ASTRID

- Capability to demonstrate fuel performances depending on the different options of management of uranium and actinides (multirecycling, Pu burner, transmutation, high burn-up…)
- Contribution to experimental data acquisition for the validation of simulation tools and their coupling, through specific instrumentation positioning
- Contribution to the qualification of component performances (irradiation effect, integral demonstration), and through the coupling to the electrical network, to the qualification of the selected steam generator
- Demonstration that industrial performances can be reached by SFR (including in service inspection)
- Acquisition of an experimental feedback and an updated safety and normative framework accepted by the safety authorities and contribution to the skill preservation of all the different actors (engineering, supplies chain, R&D, safety authorities…)

ASTRID

- **Industrial players, CEA and the State conducted a review of fast neutrons reactors (FNR) and fuel cycle strategy in 2018. This is now translated into the Multiannual Energy Program (PPE) and in the Strategic Contract for the Nuclear Sector concluded between the State and nuclear industry (CSFN)**
- **The review concluded that the perspective of industrial deployment of Fast Reactors** is more distant. **Yet it has been concluded to keep this option open, requiring to maintain competences, and to progress on technological barriers and further develop know-how.**
- **The strategy for complete closure of nuclear fuel cycle** (meaning complete recycling of recoverable materials) **is maintained** as a long-term sustainability objective.
- **Challenges for achieving full recycling in the long term:**
  - Need to use FNRs,
  - The sodium FNR technology, the most mature, to be consolidated, but interest in evaluating other technologies.
- **Shorter term stakes :**
  - **Management of the decrease in the UOx flow in factories by closing 900 MW reactors and use of MOX fuel in 1300 MW reactors**
  - **Investigation of nuclear fuel multi-recycling in PWR as a possible intermediate step**

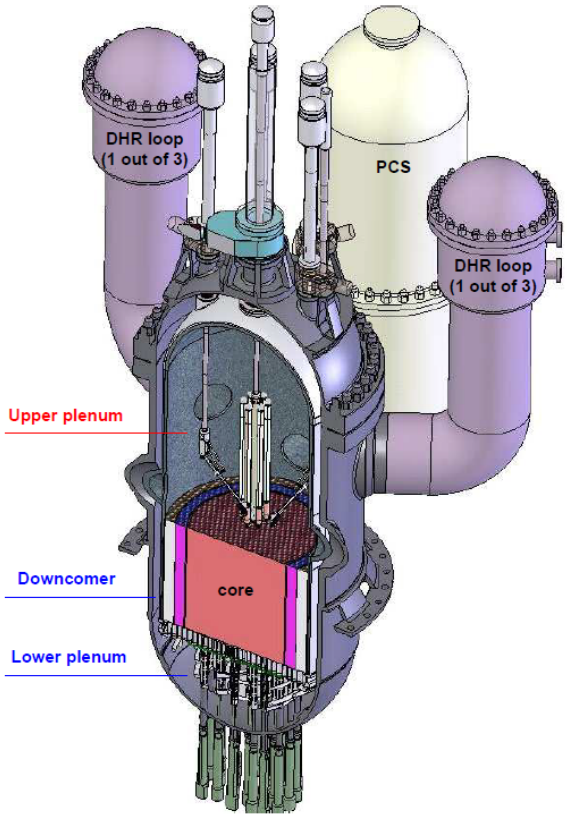
ALLEGRO

ALLEGRO

- **Reference European (GIF) GFR – 2400 MWth**
  - **Excellent theoretical efficiency**
  - **Very ambitious – lots of unresolved issues concerning safety and technology**

- **GFRs:**

+ High temperatures (>850°C)
+ Good neutronic safety
+ Transparent coolant
- Low cooling efficiency of the coolant
- / + Efficient breeder and MA burner



- **Well-known challenges:**
  - LOCA conditions -> minimum pressure in core >> atmospheric pressure
  - Materials (not only) in the core
  - **Fuel Handling – not possible to depressurize the primary circuit**

ALLEGRO

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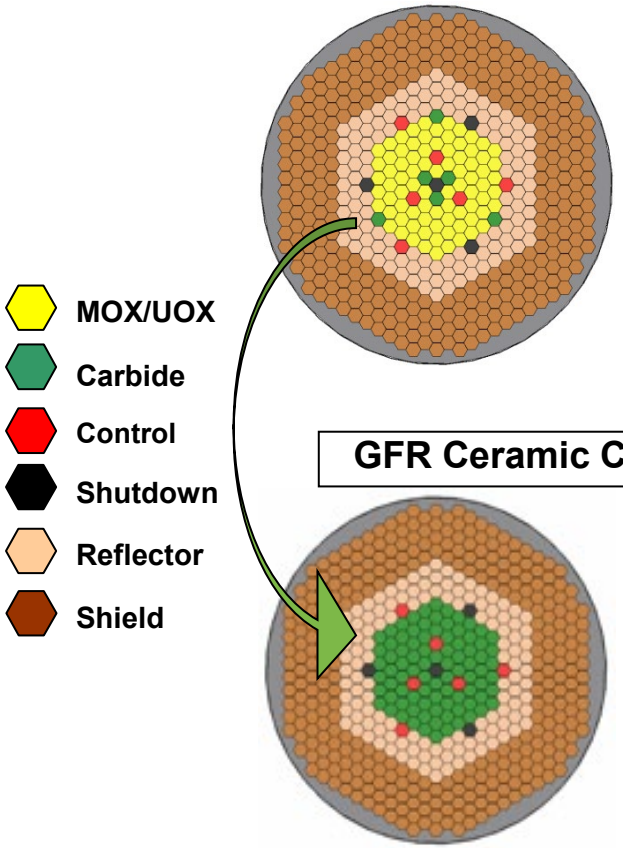
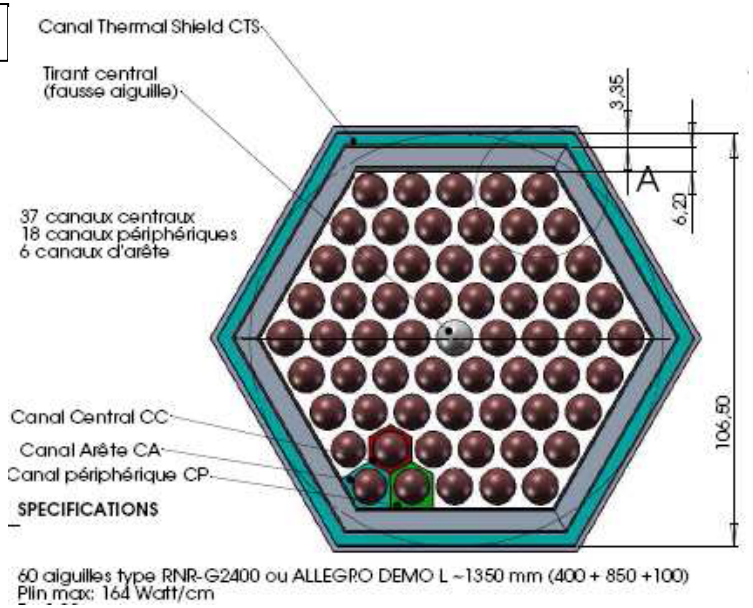
Core

MOX or UOX Core + Exp. Fuel Assemblies



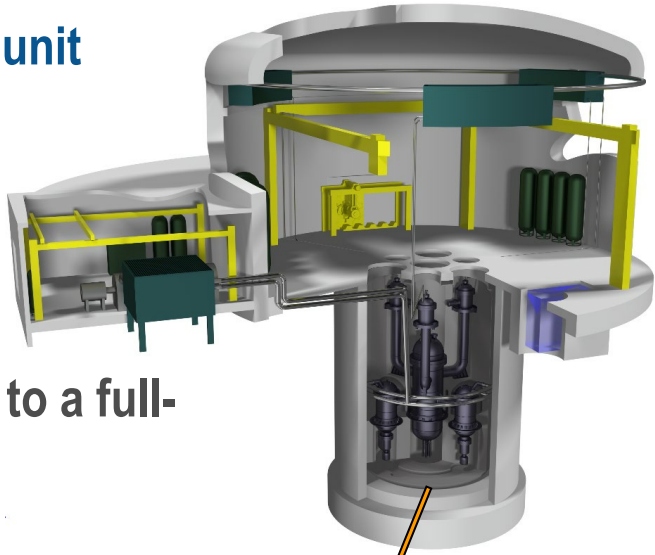
Assembly



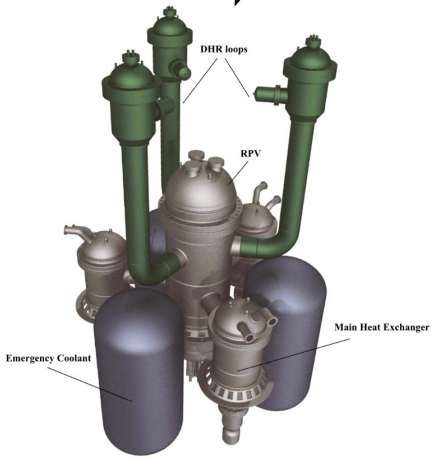
- **ALLEGRO**
  - Small scale (75 MWth) demonstrator of GFR
  - Basis for large scale GFR
- Some safety systems developed for Allegro may not scalable to 2400 MWTh
- Safety systems would be applicable for a reactor with ~ 200-600 MWth
- ALLEGRO could be basis for SMR GFR

ALLEGRO

- **Philosophy of ALLEGRO as a demonstration unit**
  - Three main goals:
    - Core materials (fuel) qualification
    - Technology demonstration
    - Proof of the safety concept
  - Focus on passive safety systems scalable to a full-size unit



ALLEGRO main characteristics	
Nominal Power (thermal)	75 MW
Driver core fuel/cladding	MOX or UO2 / 15-15ti Steel
Experimental fuel/cladding	UPuC / Sic-Sicf
Fuel enrichment	**35% (MOX) / 19.5% (UO2)**
Power density	100 MWth/m3
Primary coolant	He
Primary pressure	7 MPa
Driver core in/out temperature	260°C / 530°C
Experimental fuel in/out T	400°C / 850°C



ALLEGRO

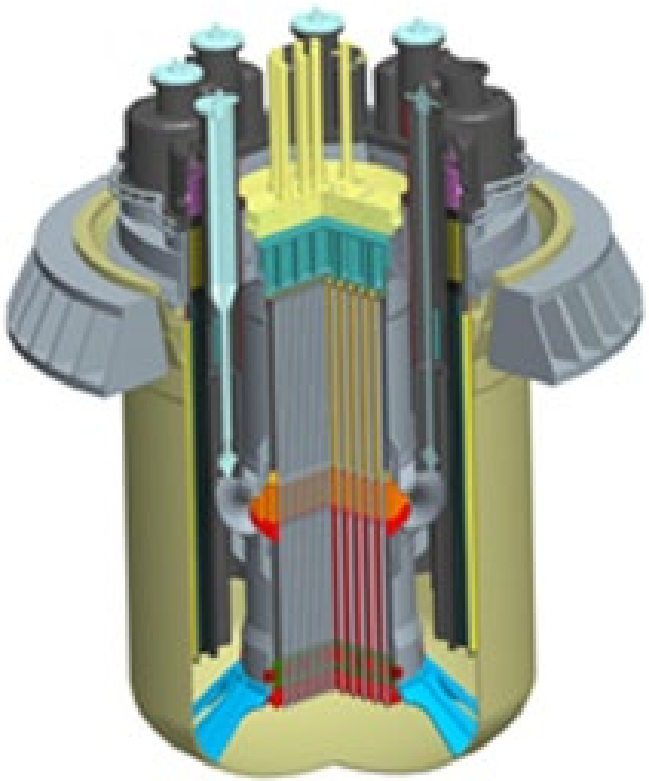
- 2010-2025: CZ-HU-SK- PL- Preparatory phase of ALLEGRO
  - MoU (05/2010): To prepare documents for decision makers (Yes/No)

08/2013: „V4G4 Centre of Excellence“ - Association (legal entity) registered in SK

- VUJE (SK)
- ÚJV Řež (CZ)
- MTA-EK (HU)
- NCBJ (PL)
- CEA (FR), CVŘ (CZ) – associated members

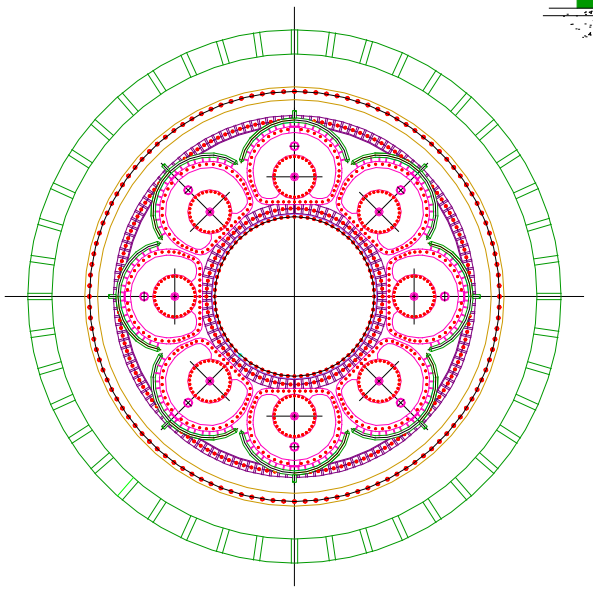
- Content of the ALLEGRO Preparatory phase by V4G4 CoE:
  - **(Pre)conceptual design:** Partially based on work done between 2002-2009
  - **Safety:** Focus on passive systems and meeting Gen IV requirements
  - **R&D and Exp. support:** Thermal-hydraulics, Materials, He technologies,…

ALFRED

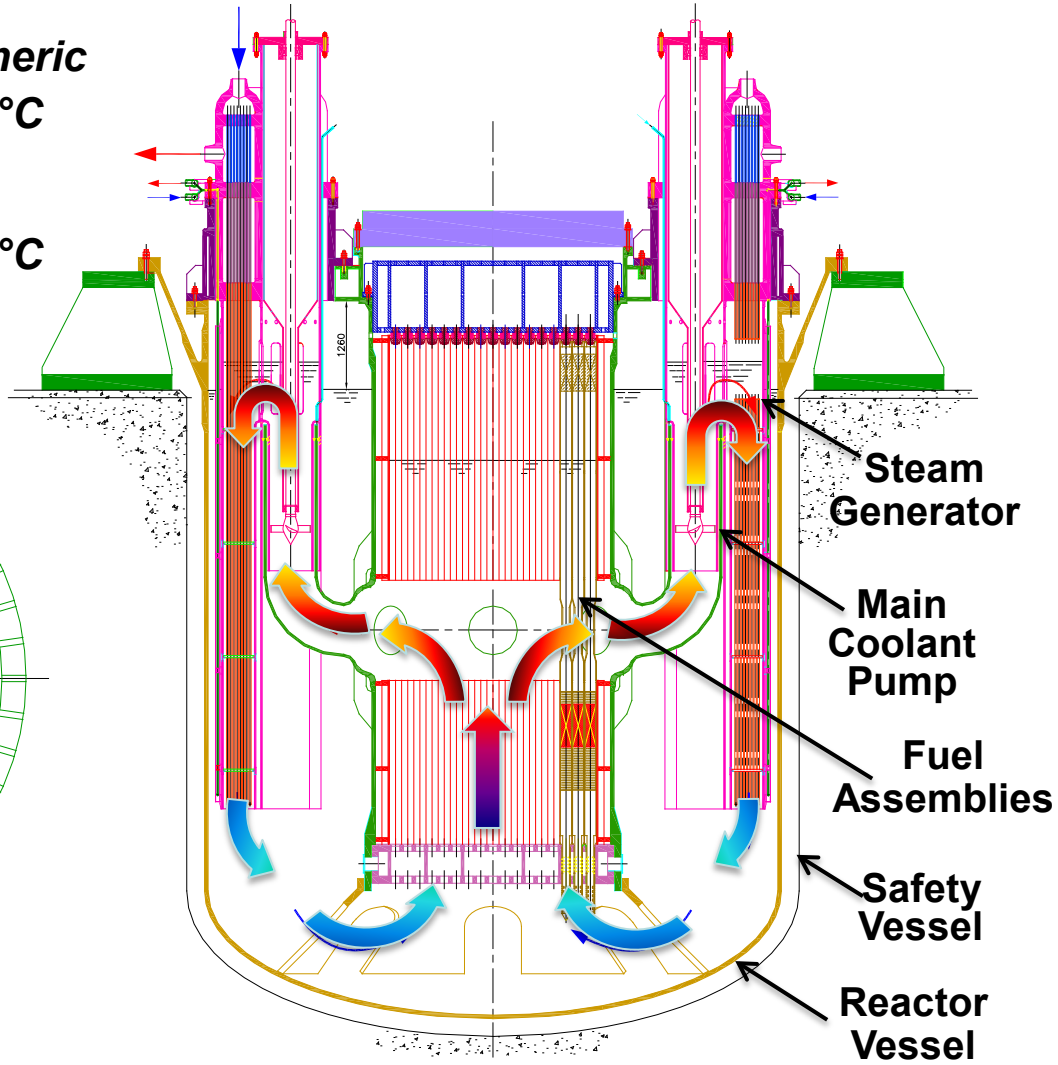


ALFRED

Power:	***300 MWth***
Primary cycle	***Atmospheric***
	400-480 °C
Secondary cycle	***1.8 Mpa***
	335-450 °C



TOP VIEW



ALFRED

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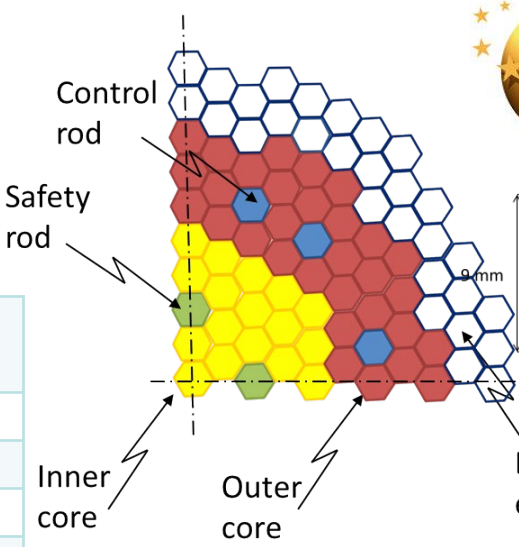
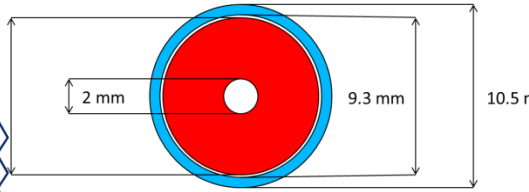
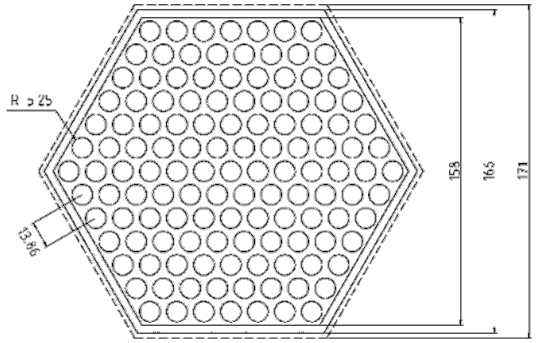
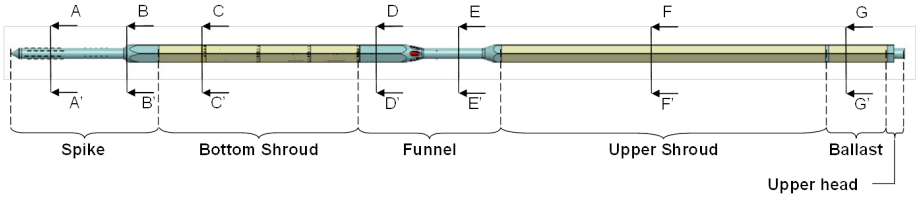
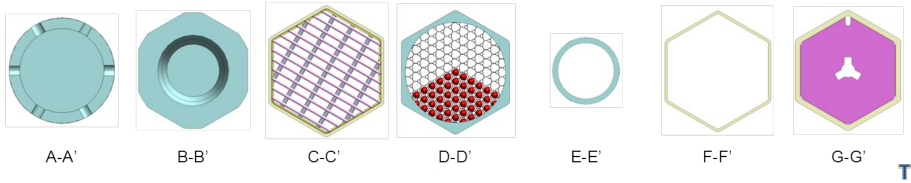
FA	171, hexagonal, wrapped
Inner	57 (21,7 at.%)
Outer	114 (27,8 at.%)
Dummy	108 (ZrO_2-Y_2O_3)
FA lattice	Triangular (127 pins)
Pins p/d	1,32
Cladding	15-15 Ti
Fuel	MOX, 25.77 at% (avg)
Residence	5 years

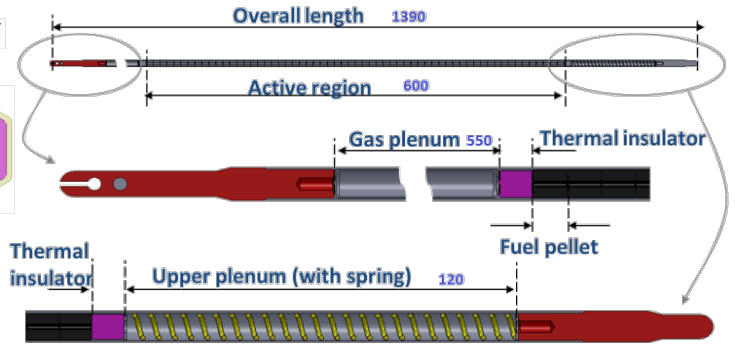












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ALFRED

- **FALCON** Consortium Agreement was established in 2013 to bring LFR technology to industrial maturity
- **FALCON** recently evolved to better cope with European context.
- Main **objectives** are:
  - Firm **commitment** to ALFRED as a Major Project in **Romania**
  - **Finalization** of ALFRED feasibility study
  - Initiation of **construction** of supporting R&D facilities
- **New** members sharing the **objective** of a rapid deployment of an LFR demonstrator, interested in the R&D supporting infrastructure and in the ALFRED industrial outcomes are **welcome** to join.

*__FALCON__ – __F__ostering __AL__fred __CON__struction

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ALFRED

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2014: Government memorandum for the **construction of ALFRED in Romania**

2015: ALFRED included in **Smart Specialization Strategy** of South-Muntenia

2017: ALFRED included in National strategy and Plan for RDI 2015-2020 as a **European project of national interest**

2017: ALFRED in the **National Research Infrastructure Roadmap**

2018: ALFRED **in National Energy and Climate Plans (NECPs); draft submitted to EC**

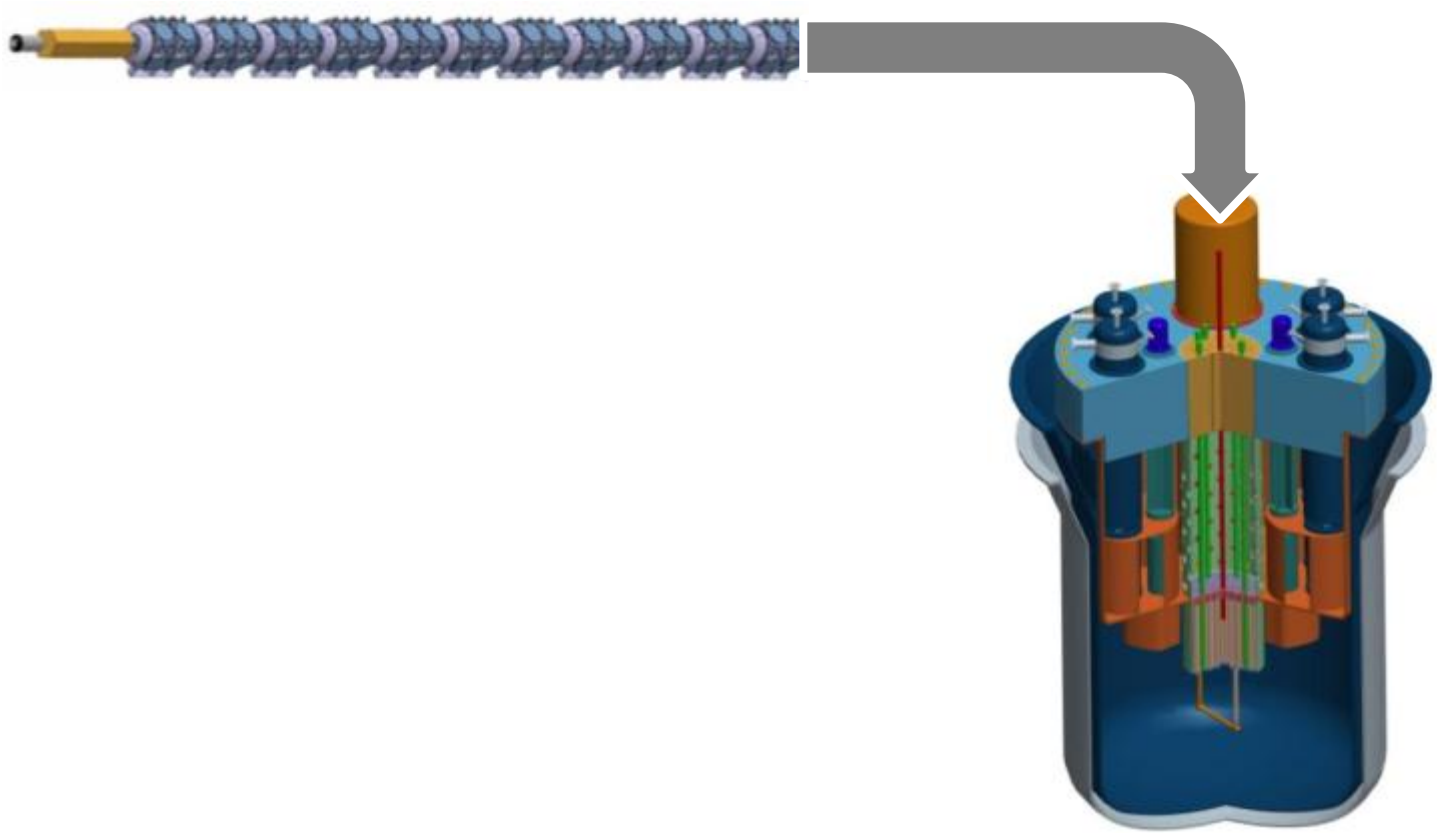
funds		
Past initiatives[1]	R&D	50 M€
Short term availability	R&D[2] RDI Project[3] Minor Project[4]	7,5 M€ up to 2 M€ 20 M€
Planned for the future	Facilities ALFRED	45 M€ 200 M€

[1] Including Italian contribution
[2] Covering a period of 5 years
[3] Currently under proposal
[4] Waiting for award

2018: **Call for support Infrastructure projects:** proposal submitted as World relevant experimental facilities at Mioveni site (**20 M€**)

2019: **RDI project for Generation IV reactor ALFRED** (**2 M€** expected in 2 years)

MYRRHA



MYRRHA

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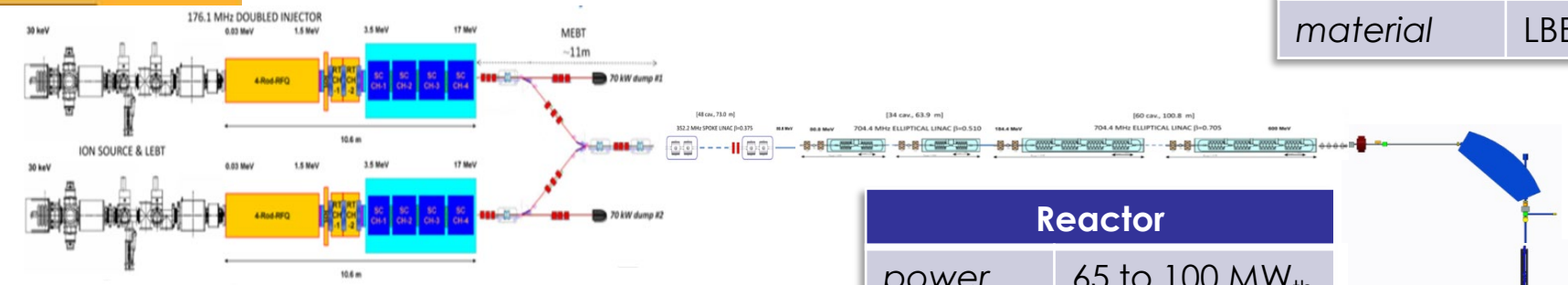
An Accelerator Driven System to:

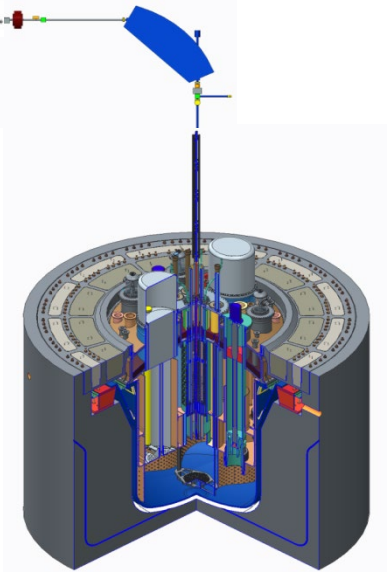
- Demonstrate the ADS concept at pre-industrial scale
  Can operate in critical and sub-critical mode
- Demonstrate transmutation
- Fast neutron source →
  multipurpose and flexible irradiation facility

Target	
main reaction	spallation
output	$2 \cdot 10^{17}$ n/s
material	LBE coolant



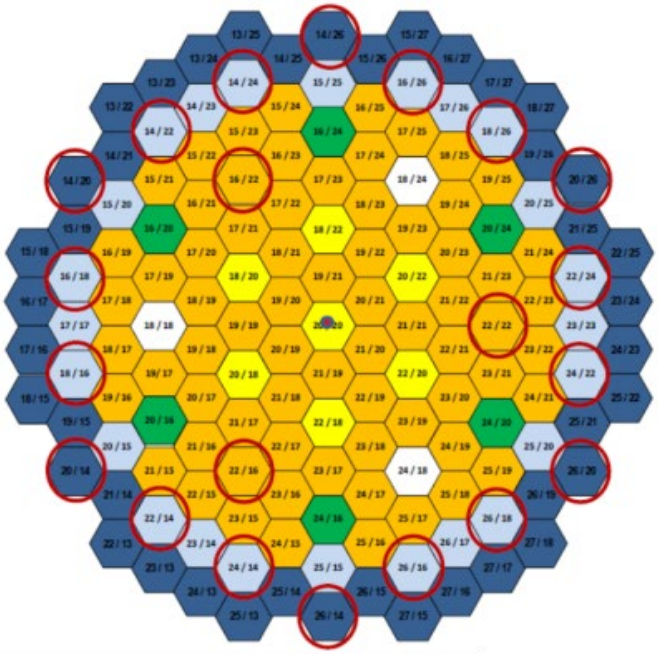
Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA

Reactor	
power	65 to 100 MW_{th}
k_{eff}	0,95
spectrum	fast
coolant	LBE



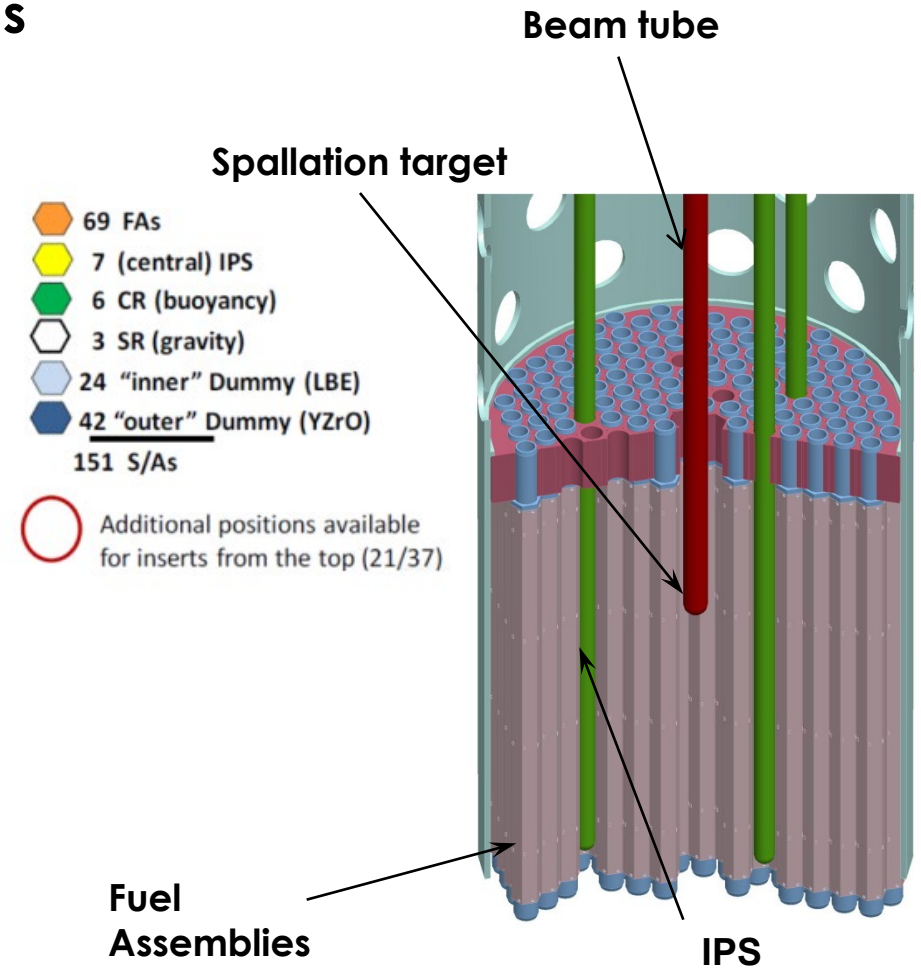
MYRRHA

- 151 positions
- 37 multifunctional plugs



69 FAs
7 (central) IPS
6 CR (buoyancy)
3 SR (gravity)
24 "inner" Dummy (LBE)
42 "outer" Dummy (YZrO)
151 S/As

Additional positions available for inserts from the top (21/37)



Both critical and subcritical configuration:

- Critical: 100 MWth
- Subcritical 65-75 MWth
- MOX driver fuel (~30%)

MYRRHA

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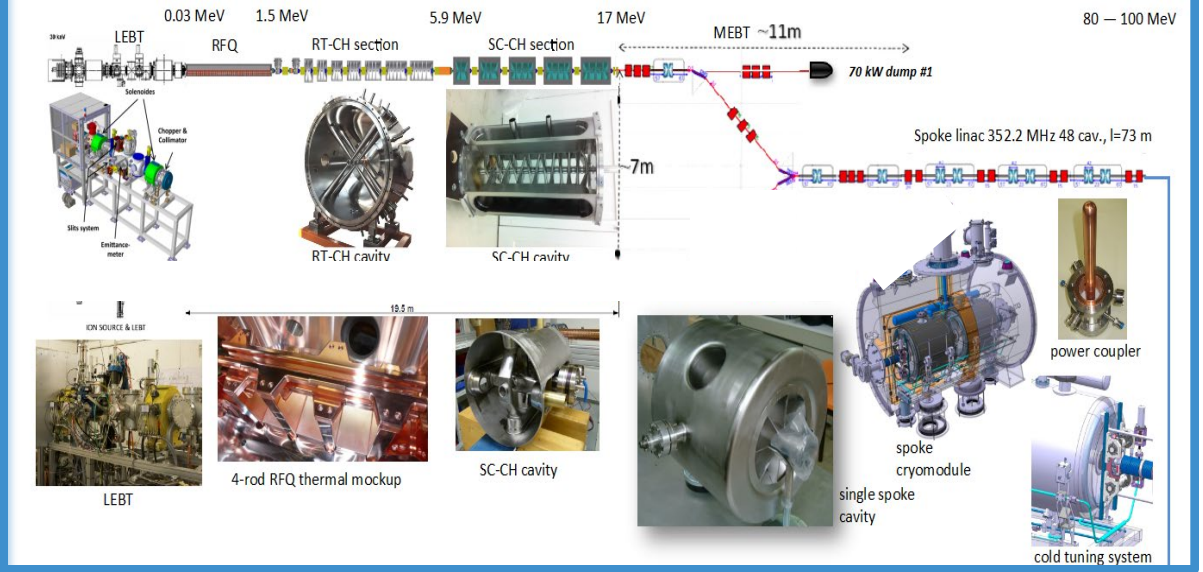
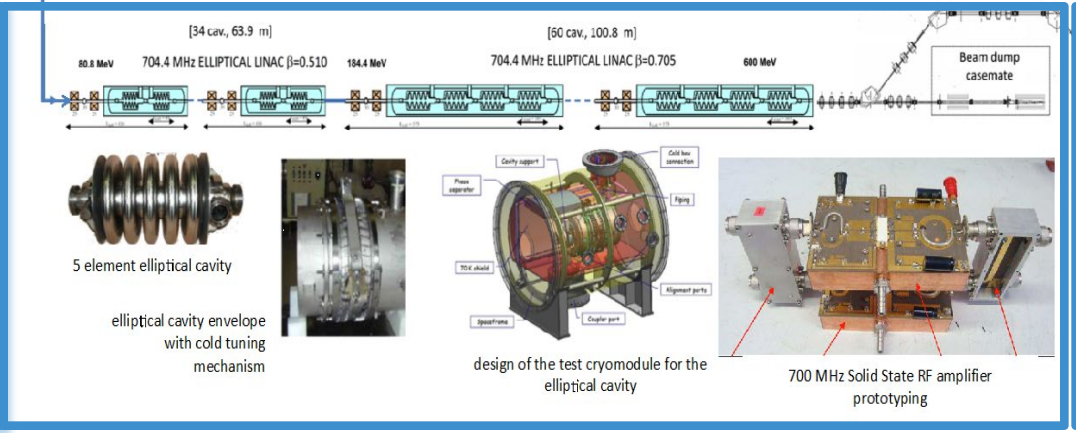
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2026

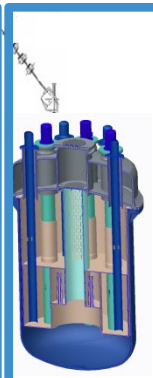
Phase 1 – 100 MeV



Phase 2 – 600 MeV



Phase 3 – Reactor



MYRRHA

Belgian Government decision on September 7, 2018

- Belgium decided to build a new large research infrastructure at Mol : **MYRRHA**
- Belgium allocated 558 M€ for the periode 2019 – 2038:
  - 287 MEUR investment (CapEx) for building MINERVA (Accelerator up 100 MeV + PTF) for 2019 - 2026
  - 115 MEUR for further design, R&D and Licensing for phases 2 (accelerator up to 600 MeV) & 3 (reactor) for 2019-2026.
  - 156 MEUR for OpEx of MINERVA for the periode 2027-2038
- Belgium requests to establish an International non-profit organization (AISBL/IVZW) in charge of the MYRRHA facility for welcoming the international partners
- Belgium continue to mandate Secretary of State for Foreign Trade Mr Pieter De Crem for promoting MYRRHA and negotiating international partnerships

Final considerations

- **Europe centered the efforts on FRs because they have the potential to use a "closed fuel cycle" with a full use of the potential Uranium resource – sustainability**
- **The fuel technology at the basis of European development is the MOX fuel (mainly because of previous developed experience)**
- **The most advanced project within ESNII initiatives is presently the Myrrha project.**