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第11回GIF-LFR pSSC
(イタリア、ピサ、2012年4月16日）
EU側発表資料　A. Alemberti

EURATOM LFR STATUS

Alessandro Alemberti

11th LFR Prov. SSC Meeting

Grand Hotel Duomo - Via Santa Maria, 94 - Pisa, Italy - April 16th, 2012

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INTRODUCTION

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Two GIF-LFR reference concepts: **ELSY** and **SSTAR**

Following the end of the ELSY project (2006-2010) of the 6th FWP the LEADER project started on April 2010 with the main goal to:

Evolve ELSY Configuration to an improved Conceptual design:

ELFR – European Lead Fast Reactor

Define the configuration of a reduced scale LFR Demonstrator

ALFRED – Advanced Lead Fast Reactor European Demonstrator

EUROPEAN LFR STRATEGY

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The European strategy for LFR development consist of a number of steps:

– Experimental facilities, corrosion tests, materials etc (already in operation)
– GUINEVERE - Zero power facility (started operation in Mol on February 4th - 2011)
– MYRRHA - Technology Pilot Plant (SCK•CEN - Mol) - 100 MWth
– ALFRED - LFR Demonstrator (electrical grid connection) - 300 MWth
– PROLFR - Industrial Prototype - 800/1200 MWth
– **ELFR** - FOAK European LFR (the Reference Concept) - 600 MWe

\+ ELECTRA - LFR Education & Training Facility (KTH - Sweden)

THE **ELFR** (as ELSY evolution) is object of GIF but it is also convenient to have some highlights on ALFRED and MYRRHA (because they are essential steps in the frame of the LFR Road Map)

The LEADER project

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Advanced nuclear systems for increased sustainability
FP7-Fission 2009 2.2.1

Conceptual Design for Lead Cooled Fast Reactor Systems (LEADER)

- 16 European Organization are participating to the project
- Ansaldo Nucleare is the Project Coordinator
- 3 year Project (2010-2013), started 1° of April 2010

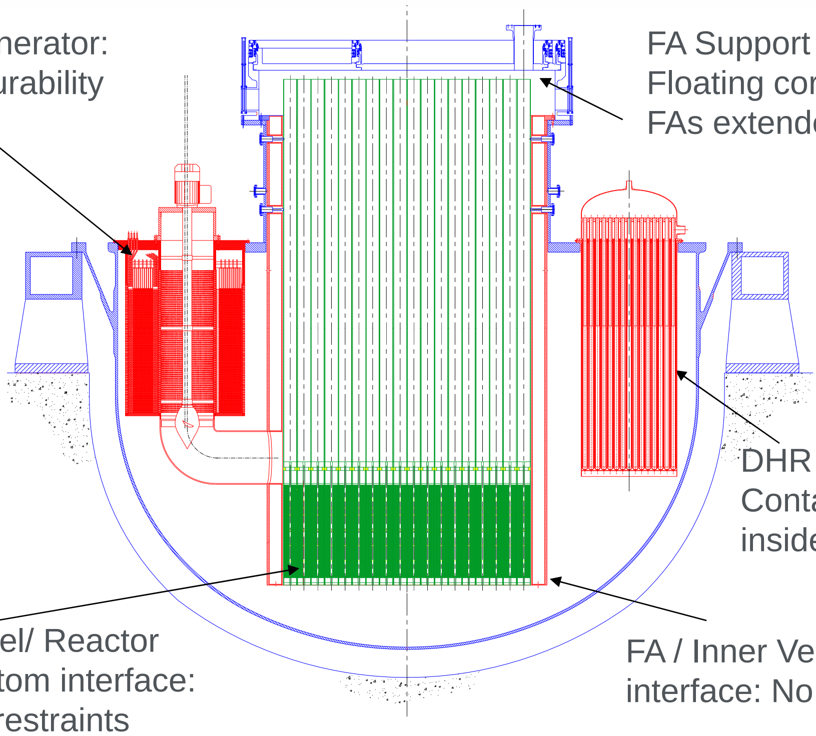
LEADER Objectives

- Deep analysis of the hard points of the ELSY design in order to identify possible improvements with the goal to reach an improved **E**uropean **L**ead **F**ast **R**eactor, **ELFR** configuration
- Definition of a new “frozen” **ELFR** configuration to be used as a reference plant
- Conceptual design of a scaled down facility respect to the reference plant the **A**dvanced **L**ead **F**ast **R**eactor **E**uropean **D**emonstrator - **ALFRED** (300 MWth)

LEADER Project: Status

- Design changes of the ELSY configuration identified
- New “frozen” European Lead Fast Reactor (ELFR) configuration (~600 Mwe) defined and used as a reference for ALFRED
- ALFRED Demonstrator reactor size of 300 MWth (~120 MWe) selected (to be representative with limited cost)
- ALFRED Demonstrator design based on available technology to be able to start construction in the shortest time frame

ELSY - Revisited Critical Issues

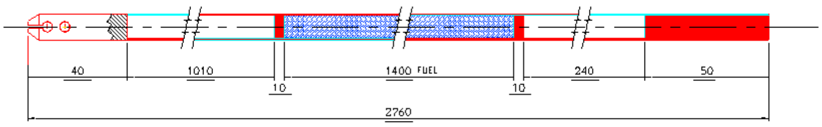


From ELSY to ELFR

STRATEGY: Maintain the good solutions, change the rest

- Spiral SG - specific task in LEADER to address manufacturability issue
- Expected advantage of open FA not verified, back to the wrapped option of ELSY, FA support provided, easy FA continuous monitoring for flow blockage
- Bottom grid introduced, lateral restraint for core and shroud, FAs weighted down by Tungsten ballast
- Need to develop alternative DHRs, ICs maintained.

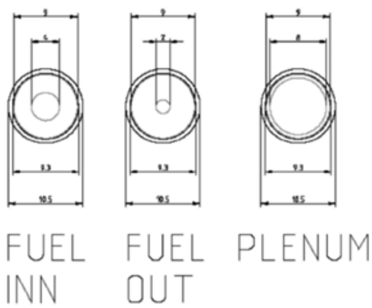
ELFR - Core Configuration

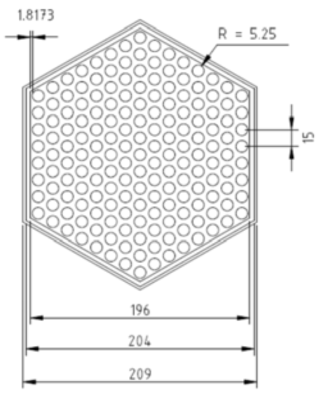


Starting from the ELSY back-up option
Wrapped fuel elements

STRATEGY:
"Adiabatic" core (homogeneous recycling)

power distribution flattened with two zone different hollow pellets diameters





ELFR - Fuel Assembly, blocked with Tungsten ballast, connected to Lower and Top Core Plates

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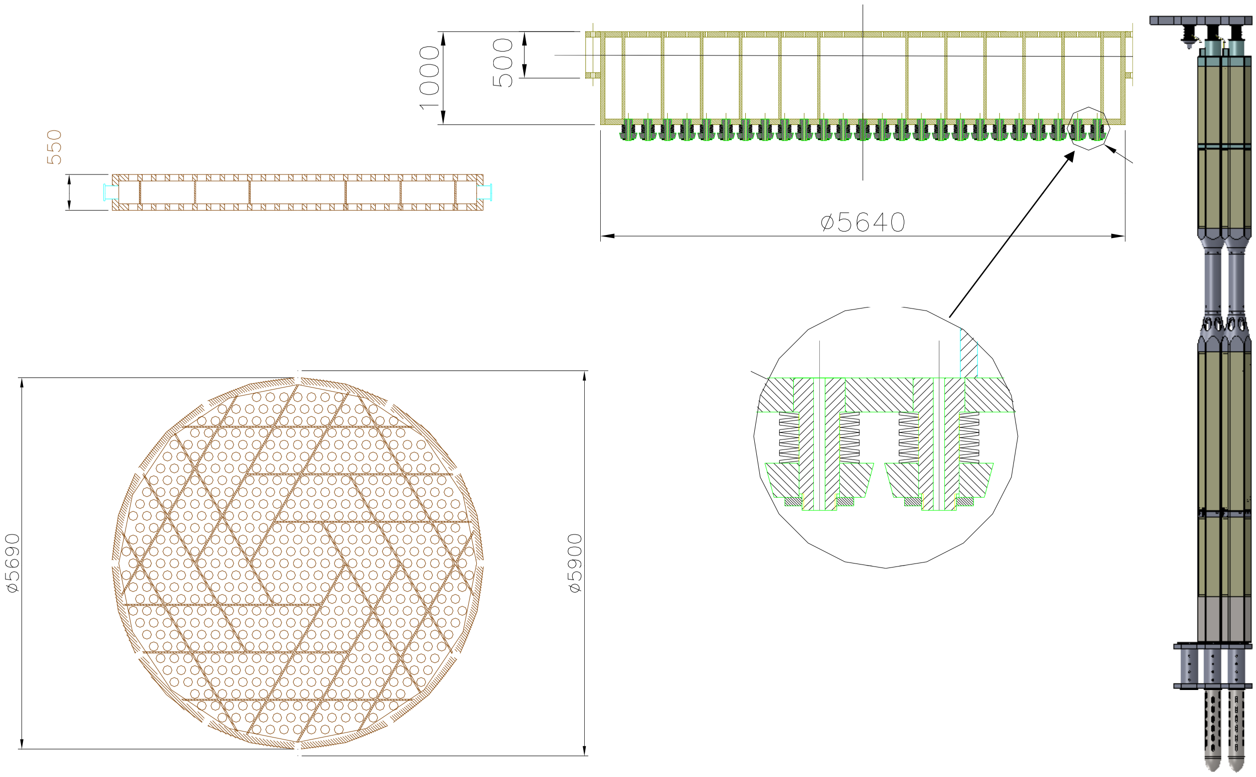

ELFR - Vessel, Inner Vessel

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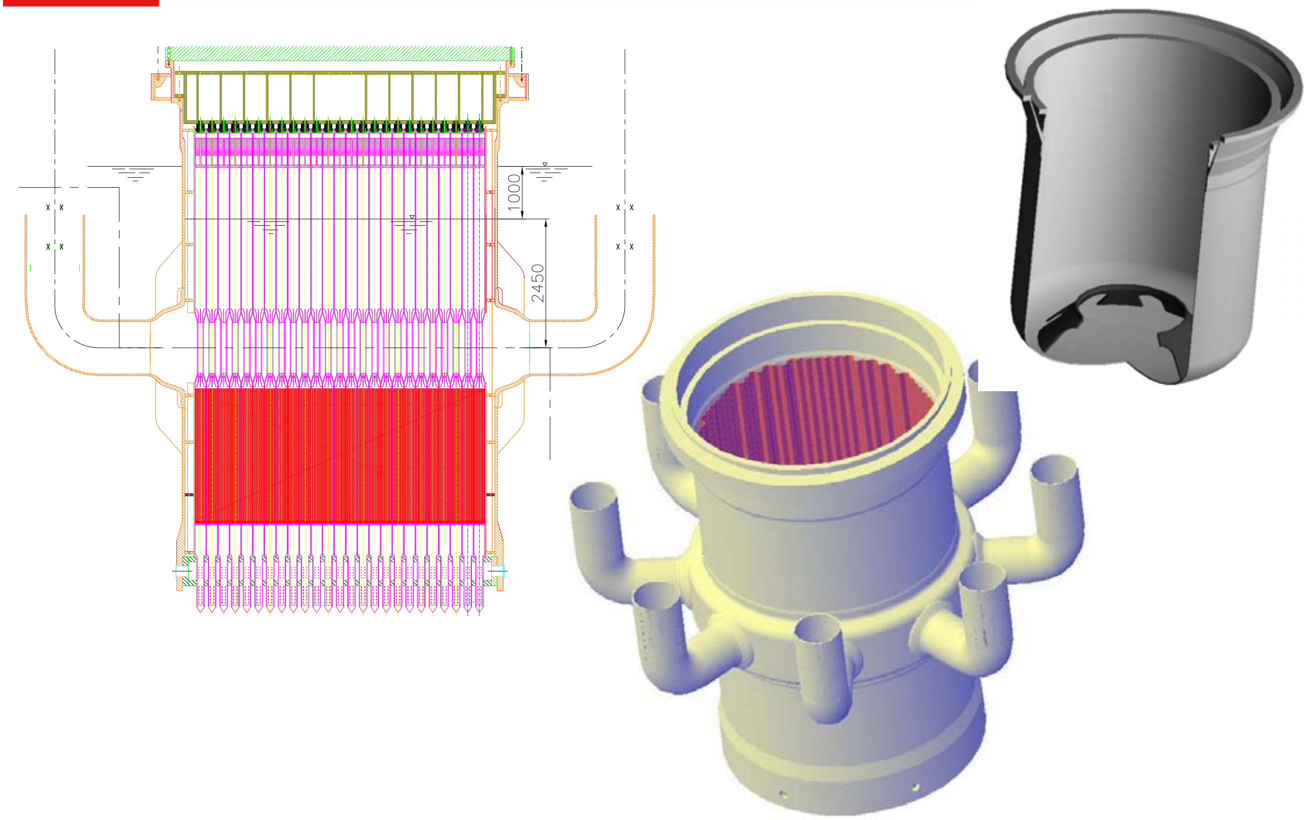

ELFR - Steam Generator and Primary Pump

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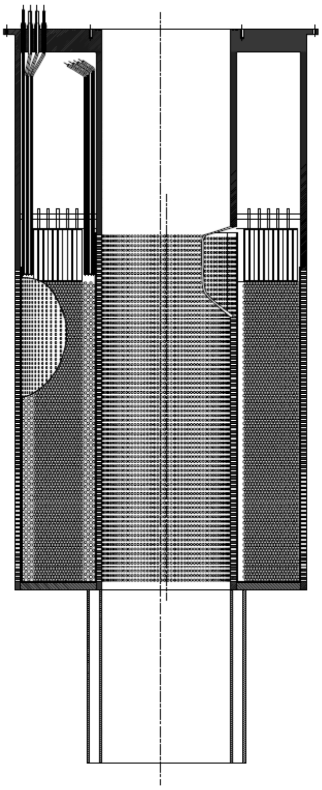
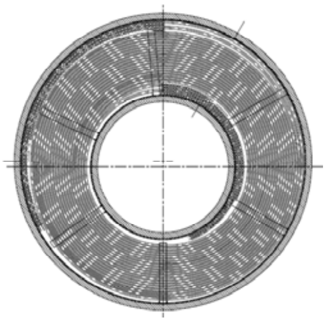


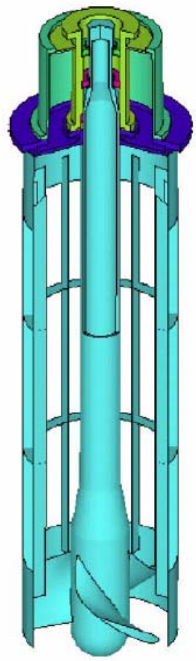


Steam Generator

Power	MW	187.5
Lead Inlet Temperature	°C	480
Lead Outlet temperature	°C	400
Water Inlet Temperature	°C	335
Steam Outlet temperature	°C	471
Steam Outlet Pressure	MPa	18

Pump

Outside impeller diameter, m	**1.1**
Hub diameter, m	**0.43**
Impeller speed, rpm	**140**
Number of vanes	**3**
Vane profile	**NACA 23012**
Suction pipe velocity, m/s	**1.6**
Vanes tip velocity, m/s	**8.7**
Meridian (at impeller entrance and exit) velocity, m/s	**3.1**
Candidate material	**Ti_3SiC_2**



ELFR - Reactor Configuration

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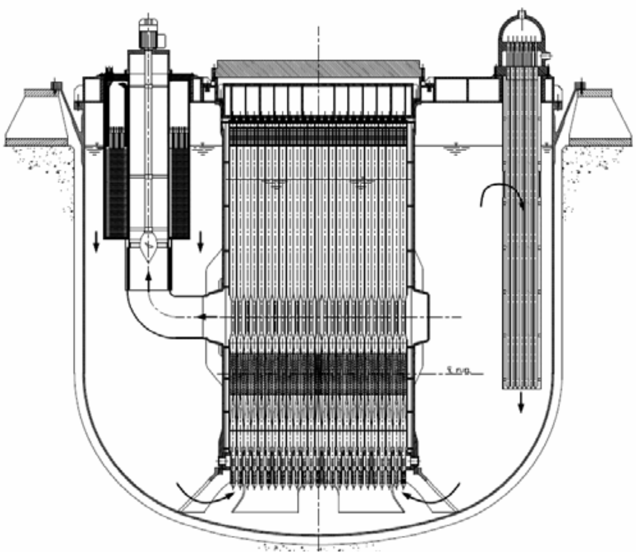
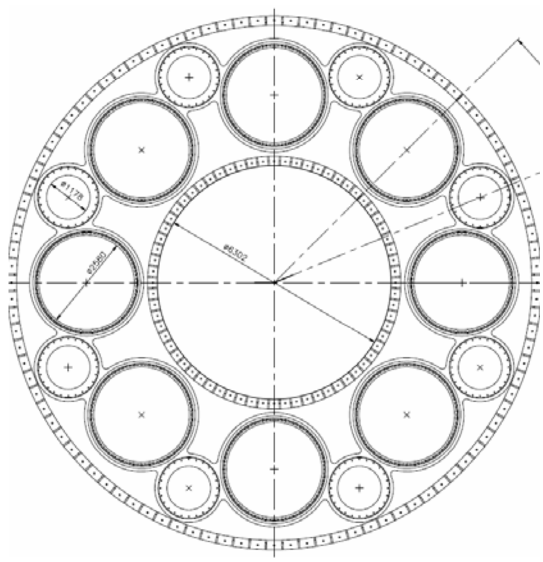


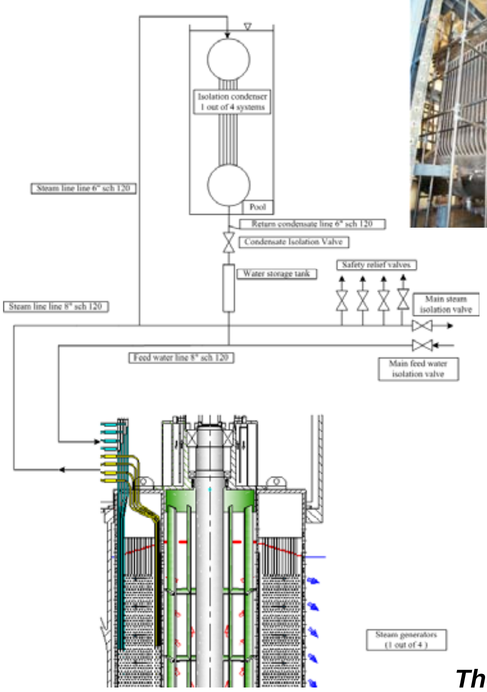


ELFR - Decay Heat Removal Systems

- Several systems for the decay heat removal function have been conceived and proposed for ELFR
  - **One non safety-grade** system, the secondary system, used for the normal decay heat removal following the reactor shutdown
  - **Two independent, diverse**, **passive**, high reliable and **redundant safety-related** Decay Heat Removal systems (DHR N1 and DHR N2): in case of unavailability of the secondary system, the DHR N1 system is called upon and in the unlike event of unavailability of the first two systems the DHR N2 starts to evacuate the DHR
- **DHR N1**: **Isolation Condenser** System (ICS) in the secondary system
- **DHR N2**: **Water Decay Heat Removal** System (WDHRS) in the cold pool
- DHR Systems features:
  - **Independence** obtained by means of two different systems with nothing in common
  - **Diversity** obtained by means of two systems based on different physical principles
  - **Redundancy** is obtained by means of three out of four loops (of each system) sufficient to fulfil the DHR safety function even if a single failure occurs

ELFR - Decay Heat Removal Systems

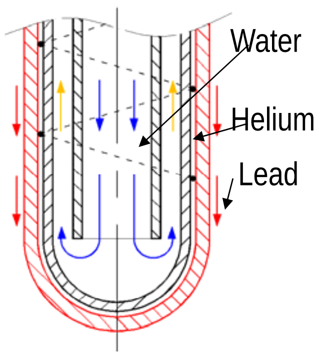
DHR N1 – ICS

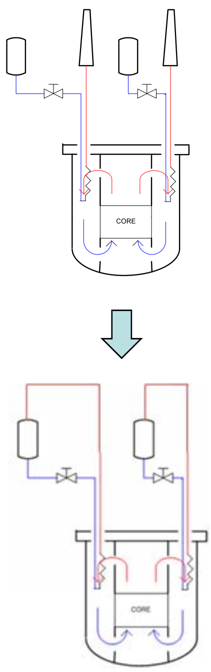


DHR N2 – WDHRS

Close the loop using an HX inside a pool

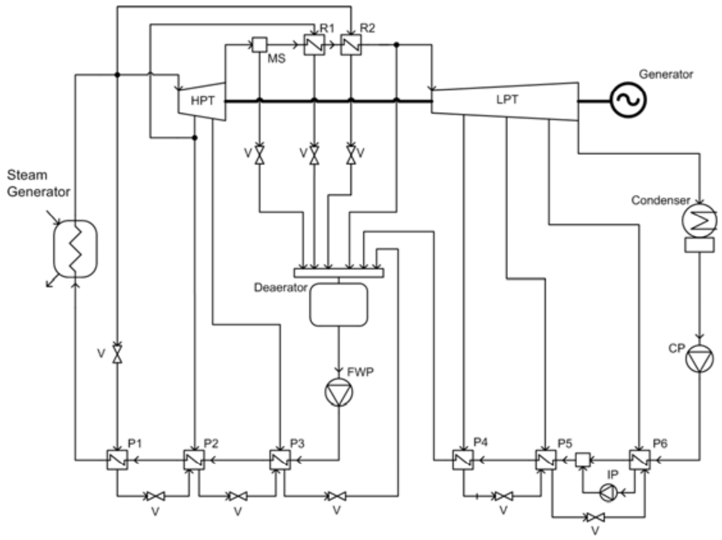
No release outside containment





The two system need further development/improvements

ELFR – Secondary System



Parameters	Value
Water Inlet Temperature (ºC)	335
Steam Outlet Temperature (ºC)	464.5
Water Flow kg/s	114.7 x 8
Water Inlet Pressure (bar)	191
Steam Outlet Pressure (bar)	180
Cycle Results	
Cycle Efficiency (%)	**42.15**
Plant net output (MWe)	623.8

Structural Material to be Used in Molten Lead Environment

Selected candidate materials for nuclear reactor systems using lead or lead-alloy as coolant are:

- Austenitic low-carbon steels (e. g. **AISI 316L**), owing to the available large database, are candidate for components operating at relatively low temperatures and low irradiation flux as is the case of the Reactor Vessel
  - Corrosion rate remains negligible up to 400°C for austenitic low-carbon steels
- Ferritic-martensitic (also the Si-enhanced grade) steels (e.g. **T91**) are candidate materials for components operating at relatively high temperatures and at high irradiation flux as in the case of the Fuel Cladding
  - Corrosion rate remains acceptable for ferritic-martensitic steels up to 500 °C with controlled Oxygen environment
- **15-15/Ti** owing to the available large database, are candidates for fuel cladding operating at relatively low temperature

Structural Material to be Used in Molten Lead Environment

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- One of the provisions adopted in the design to improve the **corrosion** resistance of the selected candidate materials is to maintain a controlled amount of oxygen dissolved in the melt
  - **Oxygen control** systems and strategy in pool type reactor need to be investigated and assessed
- In the high temperature range, the **corrosion** resistance of structural materials can be enhanced by coating
  - **Coating** is of great interest for the fuel cladding or in general for heat exchanger tubes for which protective oxide layer thickness shall be limited so that the heat transfers characteristics are not significantly affected
    - Design approach limits the mean core outlet temperature to less than 500 ° C and protects the construction material of the unavoidably thermally high loaded fuel cladding tubes with coating
    - Qualification program for the use of the coatings is mandatory in order to demonstrate their mechanical stability, adhesion to the substrate etc. under relevant operating conditions
    - Promising coating materials: FeAl alloy; Tantalum; ….

Structural Material to be Used in Molten Lead Environment

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Provisions taken in the design to preserve structural material integrity against **erosion** phenomena impose an upper limit on the coolant **flow velocity**

- ➢ Erosion rate remains acceptable for stainless steels in fluent lead up to velocity of 1 m/s
- ➢ Erosion rate remains acceptable for ferritic-martensitic steels in fluent lead up to velocity of 2 m/s
- ➢ Mechanical pumps are exception where the relative flow velocity cannot be limited below 10 m/s
  - Alternative structural materials, for the pump impeller, resistant to high velocity shall be identified and characterised
  - Promising candidate materials for pumps are Silicon Carbide and Titanium (Ti_3SiC_2) based alloys

Structural Material to be Used in Molten Lead Environment

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- Assessment of lead or lead alloy compatibility with structural materials under typical fast reactors **neutron spectrum** is required
  - The acquired experience with sodium-cooled fast reactors is not transferable to lead and lead alloys, owing to the significant differences in their physical and metallurgical properties
  - Dedicated test plans should provide data, particularly in the higher temperature range, on tensile, creep, creep-fatigue and fracture mechanics and fatigue crack growth of the selected steels in contact with lead
- Design Assumption on dpa Limit
  - Non replaceable structural components (e.g. Reactor Vessel) – Maximum 2 dpa for the whole life
  - “Frequent” Replaceable structural components (e.g. Fuel Rods) – Maximum 100 dpa

ELFR - design options

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Item	Option
Electrical Power (MWe)	600
Primary Coolant	Pure Lead
Primary System	Pool type, Compact
Primary Coolant Circulation: Normal operation/ Emergency conditions	Forced/ Natural
Allowed maximum Lead velocity (m/s)	2
Core Inlet Temperature (°C)	400
Steam Generator Inlet Temperature (°C)	480
Secondary Coolant Cycle	Water-Superheated Steam
Feed-water Temperature (°C)	335
Steam Pressure (MPa)	18
Secondary system efficiency (%)	~ 43
Reactor vessel	Austenitic SS, Hung
Safety Vessel	Anchored to reactor pit
Inner Vessel (Core Barrel)	Cylindrical, Integral with the core support grid, Removable

ELFR - design options

Item	Option
Steam generators	Integrated in the reactor vessel and removable. ELSY Spiral tubes have been exploited. Helical or Bayonet tubes types are alternative options
Primary pumps	Mechanical pumps in the hot collector, Removable
Fuel Assembly	Closed (with wrapper), Hexagonal, Weighed down when primary pumps are off, Forced in position by springs when primary pumps are on
Fuel type	MOX
Maximum discharged burnup, (MWd/kg-HM)	100
Fuel Cycle, (y)	2
Fuel resident time, (y)	5
Fuel Clad Material	T91 (coated)
Maximum Clad Temperature in Normal Operation, (°C)	550
Maximum core pressure drop, (MPa)	0.1

ELFR - design options

Item	Option
Control/Shutdown System	2 diverse and redundant systems of the same concept derived from CDT.
1st System for Shutdown	Pneumatic Inserted Absorber Rods: shutdown system passively inserted by pneumatic (by depressurization) from the top of core. In case of loss of this system, a tungsten ballast will force the absorber down by gravity
2nd System for Control and Shutdown	Buoyancy Absorbers Rods: control/shutdown system passively inserted by buoyancy from the bottom of the core.
Refuelling System	No refuelling machine stored inside the Reactor Vessel
DHR System	2 diverse and redundant systems (actively actuated, passively operated)
DHR1	Alternative solution to ELSY W-DHR should be exploited
DHR2	Isolation Condenser connected to the Steam Generator: 4 units provided on 4 out of 8 SGs
Seismic Dumping Devices	2D isolator below reactor building

ALFRED – Design of the LFR Demonstrator

FROM presentation at the LEADER Kick-off Meeting:

"Being the scope of LEADER the definition of a Demonstration reactor to be realized in the short term we should strongly rely on presently available technology.
As a consequence, while we should try to design a demonstrator as close as possible to the reference industrial size LFR , we must switch (where needed) to proven and available solutions"

Some components of ALFRED will be different from the design proposed for ELFR

- SGs: double wall straight bayonet tubes, continuous monitoring, permits use of SGs tube bundles as part of DHR system, easy coating and/or surface treatment: speed-up to construction

-DHRs: Based mainly on isolation condenser of ELFR

- Core: MOX

In general other solutions as close as possible to ELFR design

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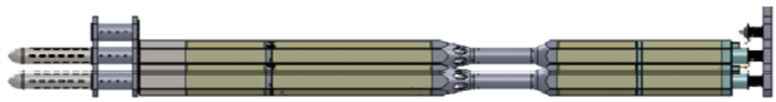
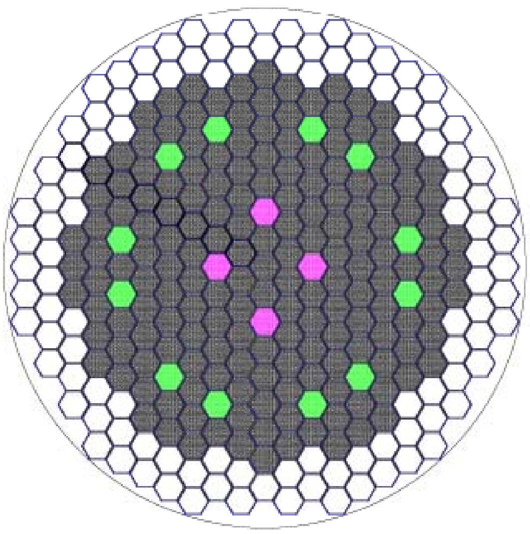
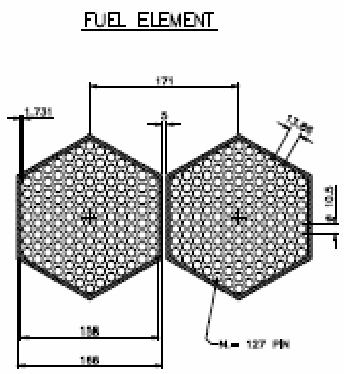
ALFRED - Core Configuration



FAs – Same concept of ELFR



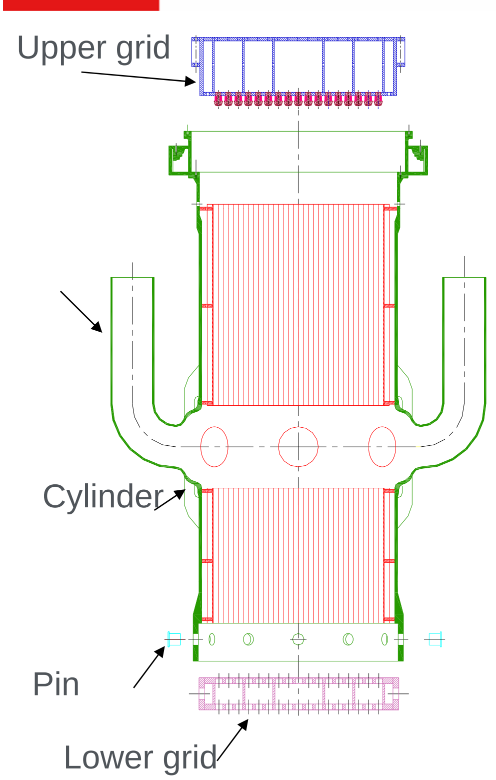
- ***171 Fuel Assembly***
- ***4 Safety Rods***
- ***12 Control Rods***
- ***108 Dummy Element***

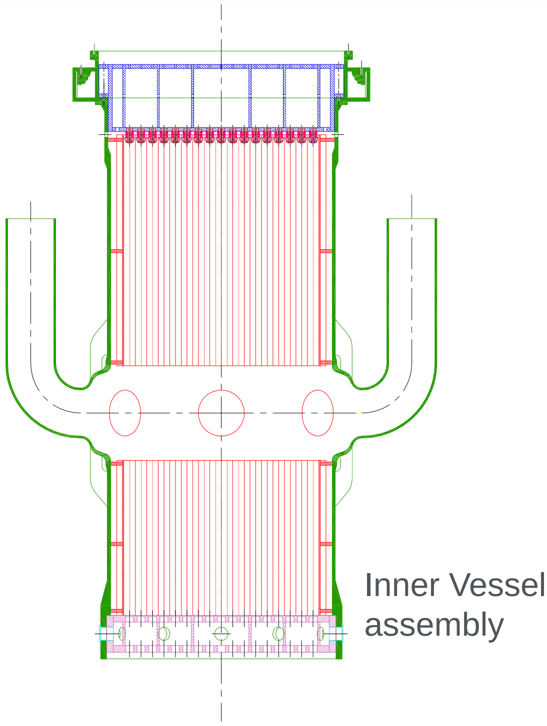


Control/shutdown system adapted from CDT-MYRRHA:

- **2 diverse, independent and redundant shutdown systems**
- **1° System for Control and Shutdown - Buoyancy Absorbers Rods passively inserted by buoyancy from the bottom of the core**
- **2° Shutdown System - Pneumatic Inserted Absorber Rods passively inserted by pneumatic from the top of core**

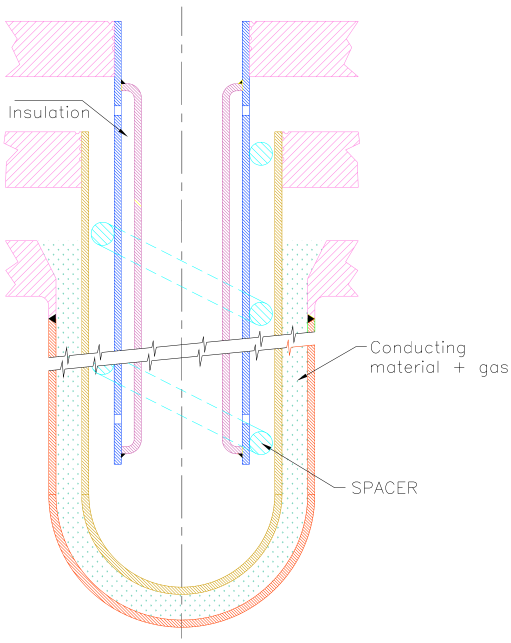
ALFRED - Inner Vessel





ALFRED - Steam Generator Bayonet Tube Concept

- Bayonet vertical tube with **external safety tube** and **internal insulating layer**
- The internal insulating layer (delimited by the **Slave tube**) has been introduced to ensure the production of superheated dry steam
- The **gap** between the outermost and the outer bayonet tube is filled with pressurized helium to permit **continuous monitoring** of the tube bundle integrity
- High thermal conductivities particles in the gap to enhance the heat exchange capability
- In case of tube leak this arrangement guarantees that primary lead does not interact with the secondary water



ALFRED - Reactor Block Configuration

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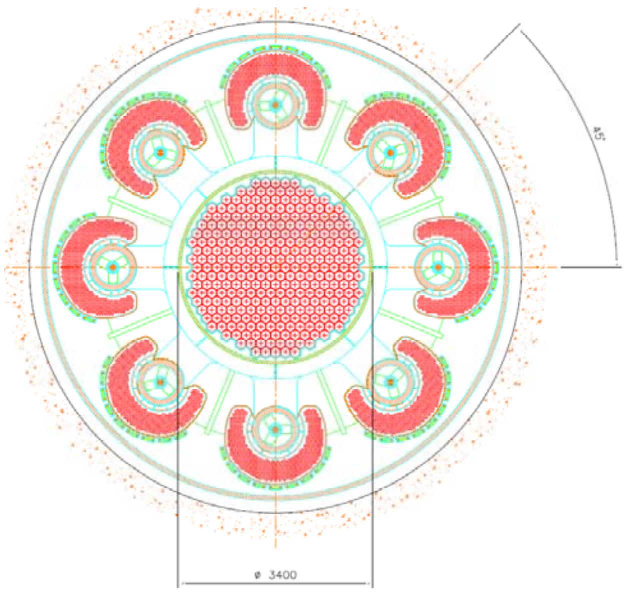

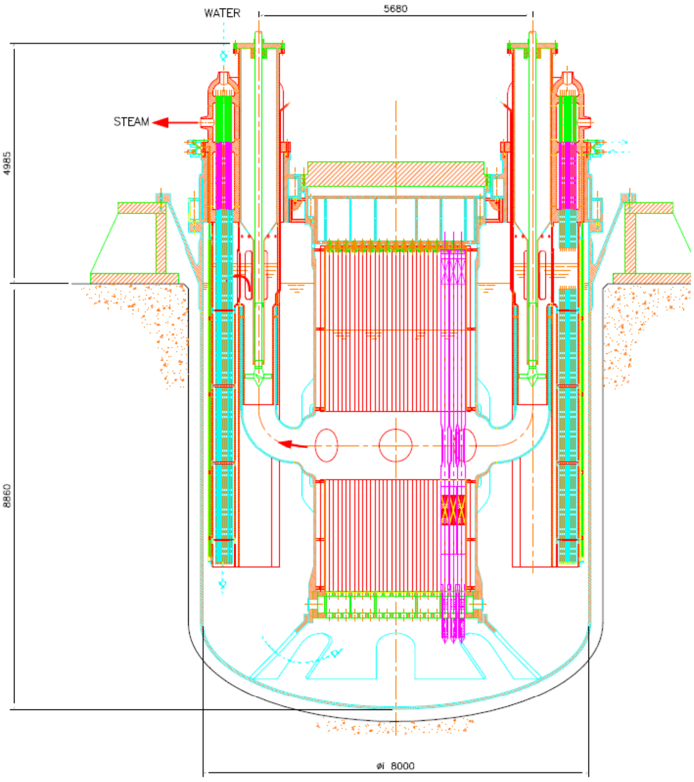

ALFRED and ELFR Design Options (Differences)

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Items	ALFRED Option	ELFR Option
Electrical Power (MWe)	~120 MWe (300 MWth)	600 MWe (1500 MWth)
Fuel Clad Material	15-15Ti (coated)	15-15Ti or T91 (coated)
Fuel type	MOX (max Pu enrich. 30%)	MOX for first load MAs bearing fuel .....
Max discharged burnup (MWd/kg-HM)	90÷100	100
Steam generators	Bayonet type with double walls, Integrated in the reactor vessel, Removable	Spiral type or alternate solution, Integrated in the reactor vessel, Removable
DHR System	2 diverse and redundant systems (actively actuated, Passively operated)	2 diverse and redundant systems (actively actuated, Passively operated)
DHR1	Isolation Condenser connected to Steam Generators: 4 units provided on 4 out of 8 SGs	Isolation Condenser connected to Steam Generator: 4 units provided on 4 out of 8 SGs
DHR2	Duplication of DHR1 260% total power removal	Alternate solution to ELSY W-DHR under investigation

Just some words on Guinevere and MYRRHA

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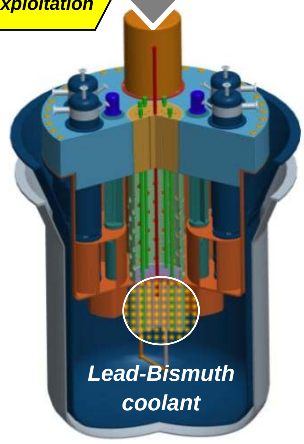
MYRRHA project schedule

Accelerator
(600 MeV - 4 mA proton)

Reactor
Subcritical mode - 65 to 100 MWth

2010-2014 Front End Engineering Design	*2015 Tendering & Procurement*	*2016-2018 Construction of components & civil engineering*	*2019 On site assembly*	*2020-2022 Commissioning*	*2023 Progressive start-up*	*2024- Full exploitation*



MYRRHA (estimated cost - 960 M€)
Accelerator Driven System – ETPP of LFR Technology

FP7 CDT project (Myrrha design) ends March 2012
Front End Engineering Design contract to be awarded by the end of 2012
FEED Pre-selection of 3 consortiums (out of 6) completed in 2011
SCK•CEN entered pre-licensing phase with the Belgian Safety Authorities

GUINEVERE
The Zero-Power facility – solid Lead – critical and sub-critical operation

Nuclear data, nuclear instrumentation, Keff measurements, code validation
Criticality reached in February 2011
Subcritical coupling performed in October 2011

MYRRHA Multipurpose Flexible Irradiation Facility

GUINEVERE and MYRRHA
the first two steps of the EU Road Map for the development of LFR technology

EU Important facts for LFR

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- **GUINEVERE** is operating
- **FEED contract for Myrrha** – Offers under preparation
- **MYRRHA** International **Consortium** under construction
- **Experimental work on-going**, spread over EU research Labs
- An **<u>MOU between Romania/Italy Organizations</u>** has been signed February 2012 to define the steps and rules to be followed to form an **international consortium** for ALFRED Design and Construction
  <u>The reference location of ALFRED is Romania</u>
- **Strong synergies** have been identified between **SFR-LFR** technologies (HeliMNet meeting – Aix en Provence – October 2011)