ALFRED

The EUROPEAN Lead Fast Reactor Demonstrator

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GENERATION IV INTERNATIONAL FORUM (GIF)

SNE-TP and ESNII

The LEADER Project

ALFRED
EVOLUTION, GOALS and the SIX Generation IV International Forum (GIF) Reactor Concepts

**SIX REACTOR CONCEPTS**

- Sodium-Cooled Fast Reactor System (SFR)
- Lead-Cooled Fast Reactor System (LFR)
- Gas-Cooled Fast Reactor System (GFR)
- Supercritical Water Reactor Systems (SCWR)
- Very-High-Temperature Reactor System (VHTR)
- Molten Salt Reactor System (MSR)

**GEN IV - GOALS**

**SUSTAINABILITY:**
effective fuel utilization; reduce the long-term waste

**ECONOMICS:**
cost advantage
Limited financial risk

**SAFETY AND RELIABILITY:**
excel in safety and reliability; no need for offsite emergency response

**NON PROLIFERATION & PHYSICAL PROTECTION:**
be very unattractive route for diversion or theft of weaponsusable materials, and provide increased physical protection against acts of terrorism
European Nuclear research-oriented organisations and nuclear industry stakeholders (35 at the launch, today 97 members) launched in 2007 the Sustainable Nuclear Energy Technology Platform (SNETP)

- SNETP to integrate and develop R&D capabilities
  - to maintain the safety and competitiveness
  - to develop a new generation of sustainable reactors
  - to develop new industrial applications of nuclear power

- SNETP trough the European Sustainable Nuclear Industrial Initiative (ESNII) places a high priority on the development of Gen IV Fast Neutron Reactors (FNRs): SFR, LFR, GFR
The ESNII Roadmap

EUROPE FOCUS: FRs

Strategy:

- a first track along with Europe’s prior experience, the Sodium Fast Reactor (SFR)

- two alternative fast neutron reactor technologies: Lead cooled Fast Reactor (LFR) Gas cooled Fast Reactor (GFR)

The Road Map includes Myrrha, an ADS Pb-Bi cooled facility used as a technology pilot plant and as EU irradiation facility.
Why Lead? - an example of Closed Fuel Cycle

- LFR can be operated as adiabatic:
  - Waste only FP, feed only $U_{\text{nat}}$
  - Pu vector slowly evolves cycle by cycle
- MA content increases and its composition drift in the time
- LFR is fully sustainable and proliferation resistant (since the start up)
- Pu and MA are constant in quantities and vectors
- Safety - main feedback and kinetic parameters vs max MA content - OK
Why Lead? Some advantages...

- **Lead does not react with water or air**
  - Possibility to eliminate the intermediate loop; SGU installed inside the Reactor Vessel
  - Need R&D on effects of water-lead interaction in case of SGTR accident
  - Less stringent requirements on reactor leak tightness

- **Lead has very high boiling point**
  - Reduced core voiding risk (Lead boiling point is 1745°C)

- **Lead has a higher density than the oxide fuel**
  - No need for core catcher to face core melt (molten clad and fuel float)
  - No risk of re-criticality in case of core melt

- **Lead is a low moderating medium and has low absorption cross-section.**
  - No need to have a very compact Fuel Assemblies (FA can have fuel rods spaced large apart; Core pressure loss drastically reduced in spite of the higher density of lead resulting in lower pumping power and higher natural circulation capability)

- **Lead is compatible with existing clad material 15-15/Ti and T91**
  - Operation over long irradiation period and under Oxygen control up to 500°C
  - More margins with surface coating up to 550-600°C

*LEAD COOLANT  PASSIVE SAFETY*
LEADER Project: the MAIN GOALS

Conceptual Design for Lead Cooled Fast Reactor Systems

Conceptual design of an Industrial size LFR configuration → ELFR 600 MWe
Conceptual design of a small size LFR demonstrator → ALFRED 120 MWe

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

LEADER Project Work Packages:

WP1 (SCK CEN): Reference Design Objectives and Specification
WP2 (ENEA): Core design
WP3 (Ansaldo): Conceptual design
WP4 (EA): Operation, instrumentation, control/protection systems
WP5 (KIT-G): Safety and transient analysis
WP6 (KIT-G): Lead Technology
WP7 (KTH): Education and Training
Looking to the past experience, it is clear that the development of a new technology has to follow different steps. For the LFR:

- 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 - 600 MWe

+ ELECTRA - Education & Training Facility for LFR (KTH - Sweden)
• ALFRED will be connected to the electrical grid. Power close to 120 MWe (300 MWth)

• The LFR Demonstrator design should be based as much as possible on available technology to speed up the construction time.

• Design solution (especially for Safety and Decay Heat Removal function) should be characterized by very robust and reliable choices to smooth as much as possible the licensing process. (new technology to be deployed)

Decay Heat Removal System based on **passive technology** to reach the expected high Safety level.

DHRs based on **Active actuation and Passive operation**
ALFRED - Core Configuration

Control/shutdown system adapted from CDT-MYRRHA:

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

FAs – conceptual scheme
FAs – extended to cover gas, above liquid lead
FAs – weighted down by ballast

- 171 Fuel Assemblies
- 4 Safety Rods
- 12 Control Rods
- 108 Dummy Element
Upper core support plate

Box structure as lower grid but more stiff. It has the function to hold down the FAs during the reactor operation.
A series of preloaded disk springs presses each FA on its lower housing

Lower core support plate

Box structure with two horizontal perforated plates connected by vertical plates. Plates holes are the housing of FAs feet. The plates distance assures the verticality of FAs
ALFRED - Inner Vessel

- Upper grid
- Cylinder
- Pin
- Lower grid

Main Vessel

Inner Vessel

Inner Vessel assembly
• Bayonet vertical tube with **external safety tube** and **internal insulating layer**

• Internal insulating layer (delimited by the **Slave tube**)

• **Gap** between the outermost and the outer bayonet tube filled with pressurized helium to permit **continuous monitoring** of the tube bundle integrity (leak detection)

• High thermal conductivities particles in the gap to increase the heat exchange capability

• In case of tube leak this arrangement guarantees an early detection so that adequate measures can be taken to prevent direct contact between water and lead.
ALFRED - Steam Generator Performances

SGs Tubes, forged plates and shells made of X10CrMoVNb9-1, RCC-MRx code (T91 steel)

Steam Generator Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removed Power [MW]</td>
<td>37.5</td>
</tr>
<tr>
<td>Core outlet Lead Temperature [°C]</td>
<td>480.0</td>
</tr>
<tr>
<td>Core inlet Lead Temperature [°C]</td>
<td>400.0</td>
</tr>
<tr>
<td>Feedwater Temperature [°C]</td>
<td>335.0</td>
</tr>
<tr>
<td>Steam Plenum Temperature [°C]</td>
<td>450.1</td>
</tr>
<tr>
<td>SG steam/water side global ∆p [bar]</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Steam Generator Thermal Cycle
Decay Heat Removal Systems

- Several systems for the decay heat removal function have been conceived and designed for ALFRED
  - **One non safety-grade** system, the secondary system, used for the normal decay heat removal following the reactor shutdown
  - **Two independent, 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 connected to four out of eight SGs

- **DHR N2:**
  - Other four Isolation Condenser to the other four SGs have been added
    - Consider that, each SG is continuously monitored, ALFRED is a demonstrator and a redundancy of **266%** is maintained

- **DHR Systems features:**
  - **Independence** obtained by means of two different systems with nothing in common
  - **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
In 1992 Ansaldo Nucleare designed the so called “Isolation Condenser” as part of the cooperation for the development of the SBWR design.

Recently GE used the component developed by Ansaldo for the ESBWR design.

The Isolation Condenser has been already tested in Italy by SIET (ENEA) at full scale SBWR conditions.
• 8 Independent loops
• DHR N1 4 loops
• DHR N2 the other 4 loops
• Each Isolation Condenser loop is comprehensive of:
  – One heat exchanger (Isolation Condenser), constituted by a vertical tube bundle with an upper and lower header
  – One water pool, where the isolation condenser is immersed (the amount of water contained in the pool is sufficient to guarantee 3 days of operation)
  – One condensate isolation valve (function will be performed by at least two parallel valves)
ALFRED - Isolation Condenser Heat Exchanger

- Upper and lower spherical header diameter 560 mm
- Tube diameter 38.1 mm
- Number of tubes 16
- Average tube length 2 m
- Material Inconel 600
4 Loops in operation – primary pumps on (Maximum performances – investigating minimum time to lead freezing) 
Lead temperature always < nominal 
Time to freeze ~ 4 hours

3 Loops in operation – primary pumps off (Minimum performances – investigating maximum cladding temperature) 
Lead Peak Temperature ~ 500°C 
Time to freeze > 8 hours
**Steam Cycle Efficiency (%)**

44.68

**Generator output (MWe)**

134

**SG Mass Flow (kg/s)**

192.7

**SG Pressure outlet (bar)**

182

**SG Pressure inlet (bar)**

188

**SG Temperature outlet (°C)**

450

*Steam Cycle net efficiency Close to 41 %*
### ALFRED Design

<table>
<thead>
<tr>
<th>Primary Coolant</th>
<th>Pure Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary System</td>
<td>Pool type, Compact</td>
</tr>
<tr>
<td>Primary Coolant Circulation: Normal operation</td>
<td>Forced</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
</tr>
<tr>
<td>Allowed maximum Lead velocity (m/s)</td>
<td>2</td>
</tr>
<tr>
<td>Core Inlet Temperature (°C)</td>
<td>400</td>
</tr>
<tr>
<td>Steam Generator Inlet Temperature (°C)</td>
<td>480</td>
</tr>
<tr>
<td>Secondary Coolant Cycle</td>
<td>Water-Superheated Steam</td>
</tr>
<tr>
<td>Feed-water Temperature (°C)</td>
<td>335</td>
</tr>
<tr>
<td>Steam Pressure (MPa)</td>
<td>18</td>
</tr>
<tr>
<td>Secondary system efficiency (%)</td>
<td>~ 41</td>
</tr>
<tr>
<td>Reactor vessel</td>
<td>Austenitic SS, Hung</td>
</tr>
<tr>
<td>Safety Vessel</td>
<td>Anchored to reactor pit</td>
</tr>
<tr>
<td>Inner Vessel (Core Barrel)</td>
<td>Cylindrical, Integral with the core support grid, Removable</td>
</tr>
<tr>
<td>Primary pumps</td>
<td>Mechanical in the hot collector, Removable</td>
</tr>
</tbody>
</table>
## ALFRED Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Power (MWe)</strong></td>
<td>~120 MWe (300 MWth)</td>
</tr>
<tr>
<td><strong>Fuel Clad Material</strong></td>
<td>15-15Ti (coated)</td>
</tr>
<tr>
<td><strong>Fuel type</strong></td>
<td>MOX (max Pu enrich. 30%)</td>
</tr>
<tr>
<td><strong>Max discharged burnup (MWd/kg-HM)</strong></td>
<td>90÷100</td>
</tr>
<tr>
<td><strong>Steam generators</strong></td>
<td>Double wall Bayonet tubes, Integrated in the reactor vessel</td>
</tr>
<tr>
<td><strong>DHR System</strong></td>
<td>2 Passive DHRs (actively actuated, Passively operated) based on ISOLATION CONDENSER concept</td>
</tr>
<tr>
<td><strong>Fuel Assembly</strong></td>
<td>Closed (with wrapper), Hexagonal, Weighted down when primary pumps are off, Forced in position by springs when primary pumps on</td>
</tr>
<tr>
<td><strong>Max Clad Temp. Normal Operation °C</strong></td>
<td>550</td>
</tr>
<tr>
<td><strong>Maximum core pressure drop (MPa)</strong></td>
<td>0.1 (30 min grace time for ULOF)</td>
</tr>
<tr>
<td><strong>Control/Shutdown System</strong></td>
<td>2 diverse and redundant systems derived from CDT</td>
</tr>
<tr>
<td><strong>1st System for Shutdown</strong></td>
<td>Buoyancy Absorbers Rods: control/shutdown system passively inserted by buoyancy from bottom of core</td>
</tr>
<tr>
<td><strong>2nd System for Shutdown</strong></td>
<td>Pneumatic Inserted Absorber Rods: shutdown system passively inserted by pneumatic (by depressurization) from the top of core</td>
</tr>
<tr>
<td><strong>Refuelling System</strong></td>
<td>No refuelling machine inside the Reactor Vessel</td>
</tr>
<tr>
<td><strong>Seismic Dumping Devices</strong></td>
<td>2D isolator below reactor building</td>
</tr>
</tbody>
</table>
• **GUINEVERE** is operating critical condition achieved in February 2011 sub-critical coupling with accelerator achieved in November 2011

• **FEED contract for Myrrha** – Offers under preparation

• **MYRRHA** International **Consortium** under construction

• **Experimental work on-going**, spread over EU research Labs

• An **MOU between Romania/Italy Organizations** has been signed February 2012 to define the steps and rules to be followed to form an **international consortium** for ALFRED Design and Construction

The reference location of ALFRED is Romania
Thank you for your kind attention