Status of
Lead-cooled Fast Reactor Activities

Alessandro Alemberti

EURATOM / Ansaldo Nucleare

on behalf of
GIF LFR
provisional System Steering Committee
LFR-pSSC Main activities

- LFR-pSSC Virtual meeting on April 21\textsuperscript{st} 2020
- LFR-MoU signature of China at Weihai meeting
- LFR – pSSC nomination

LFR – pSSC welcome a new member

Ms. Yuliya KUZINA, deputy general director at nuclear power department in the State Scientific Centre of the Russian Federation, Institute for Physics and Power Engineering (IPPE, Obninsk).

Yuliya, nominated substitute member by Rosatom, will work in collaboration with the pSSC member Andrei Moiseev (NIKIET).
LFR-pSSC Main activities

- **LFR System Safety Assessment report**
  Following EG comments at Weihai meeting a final version developed by LFR-pSSC and RSWG has been sent on May 18th 2020 to TD for EG approval.

- **LFR Safety Design Criteria (SDC):**
  New revision of LFR-pSSC transmitted to RSWG members in February 2020 for final approval of transmission to EG. Report discussion is included in the agenda of next virtual meeting of RSWG (end of June).

- **Status of LFR PRPP White Paper**
  Rev.3 discussed at BNL PRPP-WG Annual Meeting (November 2019)
  Rev.3 modified by PRPP and distributed to pSSC members (February 2020)
  Discussed at LFR-pSSC meeting in May.
  LFR pSSC agreed on a general endorsement of PRPP White Paper text.
  New version under preparation by PRPP to be distributed to LFR-pSSC members by end of May for final review.
Status of LFR R&D activities
in MoU Countries/Entities
Main activities focused on: ALFRED and MYRRHA

- Running Euratom-US I-NERI PROJECT
  Title: Small Modular Lead-cooled Fast Reactors in regional energy markets: safety, security, and economic assessment

- ESNII evaluating the launch of an “industrial” project able to provide for Europe the production of MoX fuel for the two demonstrators MYRRHA and ALFRED.

- SNETP: publication of new Strategic Research and Innovation Agenda (2020) new road-map:

  Projects awarded from the 2019-2020 call

  PUMMA - Plutonium Management for More Agility Grant: 3.8M€ - Federate the European community on MOX fuel
  Study Plutonium management in 4th generation reactors

  PATRICIA - Grant: 6.5 M€ - Joint proposal between the Partitioning and Transmuter development communities

  Orient-NM - Establishing a European Joint Programme for Nuclear Materials
  Grant: 1.1 M€ - Coordinated Support Action – Vision Paper etc.
• Falcon working on new design configuration to define main components and systems.

• Falcon working on feasibility study for Major Project

• Contacts with CNCAN (Romanian safety authority) to provide a seminar (3 days) on technical and safety aspects of ALFRED

• Euratom 2019 PIACE project: passive safety freezing prevention in LFRs, started June 2019
  Project running, facility commissioning now expected for September 2020
National status of LFR development in Japan

- Theoretical study for LFR
  - Numerical analysis of neutron balance in LFR
    - Comprehensive analysis of neutron balance for fast reactors with lead and lead-bismuth coolant is in progress.
  - The analysis is to show the capability of conversion and transmutation in the core during burnup quantitatively.
  - Current results show the lead and lead-bismuth have excellent neutron balance in the use of metallic fuel and N-15 enriched nitride fuel.

\[
\text{Neutron balance} = \int_0^{Bu} \bar{\nu} \left[ 1 - \frac{1}{k_\infty(1 - L)} \right] dBu
\]
Current status of BREST-OD-300 development

**Research activity**
- Preliminary stages (technical proposal, conceptual design)
- Preliminary research and solutions

**Development activity**
- Specification
- Engineering design (final solutions)
- Mockup tests
- Technology development
- Verification of software tools
- Working design documentation, operational documentation, pilot model
- Preliminary acceptance tests
- Development of federal rules, regulations and standards (if necessary)

**Correction of documentation**

We are here TRL 5 (6)

Readiness for serial production or manufacturing of pilot product (elements of the BREST-OD-300 reactor)

NIKIET working to obtain Construction license
Republic of Korea

Micro Nuclear Energy Verification Arena (MINERVA)

Organizations: UNIST, USN, KHU, Moojin Ltd, KAIST, SNU, KINGS

MINERVA - 2019 ~ 2022 Korea National Research Foundation
## MicroURANUS: LBE-cooled Pool-type Design

### MicroURANUS 1.0 Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal/Electric power</td>
<td>MW</td>
<td>60/20</td>
</tr>
<tr>
<td>Target cycle length</td>
<td>EFPY(^a)</td>
<td>30(^b)</td>
</tr>
<tr>
<td>Assembly concept</td>
<td>-</td>
<td>Hexagonal</td>
</tr>
<tr>
<td>Fuel material</td>
<td>-</td>
<td>U-10Zr/UO(_2)</td>
</tr>
<tr>
<td>- Smear density(U-10Zr/UO(_2))</td>
<td>%TD(^c)</td>
<td>75/90</td>
</tr>
<tr>
<td>- Maximum (^{235})U enrichment</td>
<td>w/o</td>
<td>19.75</td>
</tr>
<tr>
<td>Cladding material</td>
<td>-</td>
<td>SS316L</td>
</tr>
<tr>
<td>Coolant</td>
<td>-</td>
<td>LBE</td>
</tr>
<tr>
<td>- Inlet/Outlet temperature</td>
<td>°C</td>
<td>250/350</td>
</tr>
<tr>
<td>- Maximum coolant velocity</td>
<td>m/s</td>
<td>2.0 (~0.5(^d))</td>
</tr>
<tr>
<td>- Pressure</td>
<td>MPa</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\(^a\)Effective Full Power Year  
\(^b\)75% capacity(=40 operation years)  
\(^c\)Theoretical Density  
\(^d\)Best estimate for MicroUranus 1.0
Westinghouse’s Lead Fast Reactor

- 950 MWt (~450 MWe) reactor, to be developed starting with a lower-power prototype unit for technology demonstration
- Hybrid, micro-channel type heat exchangers to reduce vessel size/weight
- Thermal energy storage system to provide load-following with minimum variations in core thermal power
- Supercritical CO$_2$ power conversion system with air as the ultimate heat sink
- Oxide fuel and lead T<550°C for prototype unit. Advanced fuel and higher temperatures sought past demonstration phase

Other initiatives already presented by Hydromine and Columbia Basin Consulting Group (CBCG) on-going
### United States of America

#### Westinghouse Key collaborations

<table>
<thead>
<tr>
<th>Area</th>
<th>Collaboration</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modeling and simulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argonne National Laboratory (USA): development of safety analysis tools and validation</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>ENEA (Italy): core design support</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Frazer Nash Consulting (UK): support in modeling and simulation</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>University of Manchester (UK): support in modeling and simulation</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Material testing in static and flowing lead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENEA (Italy): material corrosion testing</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>University of New Mexico (USA): forced convection Pb loop for corrosion testing</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>University of New Mexico and Brigham Young University (USA): fission gas retention in Pb</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Oak Ridge National Laboratory (USA): natural convection Pb loop for corrosion testing</td>
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<tr>
<td></td>
<td>University of Pittsburgh (USA): versatile Pb facility for instrumentation and erosion testing</td>
<td>✓</td>
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<tr>
<td></td>
<td>Westinghouse (USA): mechanical property testing in Pb (Liquid Metal Embrittlement)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Westinghouse (UK): Pb freezing facility</td>
<td>✓</td>
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<tr>
<td></td>
<td>Jacobs (UK): material corrosion and mechanical property testing in Pb</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Bangor University (UK): RCP impeller material testing</td>
<td>✓</td>
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<tr>
<td><strong>Fuel development and fuel system testing in liquid lead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Westinghouse (Global): fuel development</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>National Nuclear Laboratory (UK): fuel development</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Various universities (USA): fuel-Pb and fuel-cladding compatibility tests</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Versatile Test Reactor (USA): development of cartridge for material/fuel irradiation testing in Pb</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Component development and testing (reduced scale)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>University of Pittsburgh (USA): versatile Pb facility for instrumentation and erosion testing</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Vacuum Process Engineering (USA): heat exchanger design</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Echogen (USA): design of sCO₂ balance of plant</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Nuclear AMRC and Univ. of Cambridge (UK): advanced manufacture of components</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Westinghouse (UK): testing of heat exchanger rupture</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Component testing (prototypical or near-to-prototypical scale)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ansaldo Nuclear Ltd (UK): fuel bundle, heat exchangers, pump, DHR system</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>National Thermal-Hydraulic Facility (UK): integral effect tests</td>
<td>✓</td>
</tr>
</tbody>
</table>
China’s Accession to GIF LFR pSSC

18 October 2019 at 48th GIF PG meeting, Weihai, China

INEST was appointed as Chinese representative of LFR program in the GIF by Ministry of Science and Technology (MOST) of China
Domestic Coordination Meeting of GIF LFR

- **Data:** 21\(^{st}\) Dec. 2019
- **Host:** INEST
- **Participants:** MOST, CAS, CGN, CNNC, SPIC, XJTU, USTC, ...
- **Content:**
  - LFR related information has been shared
  - The domestic LFR joint working group was proposed
Small LFR Projects
Supported by National Five-Year Plan

- China is making the 14th five-year plan for 2021-2025
- Minister of Science and Technology (MOST) and National Energy Administration will provide SMR development projects in the 14th five-year plan
- LFR is one of the most attractive choices for the SMR plan

CLEAR-M10
Other LFR Activities in China

✓ USTC (University of Science and Technology of China)
  • Small LFR design, T-H and power conversion system research

✓ CGN
  • CLFR reactor conceptual design and related research

✓ CNNC
  • Core neutronics characteristics test

✓ SPIC
  • 100MWe BLESS reactor conceptual design

✓ Other universities and institutes
  • Fundamental LFR technologies R&D, like T-H analysis, safety analysis and materials test
Thank you for your kind attention!

26th GIF-LFR-pSSC April 21st Virtual meeting

(From left: Yuliya, Sunyoung, Alessandro, Craig, Toru, Il Soon, Kamil, Guido (PRPP invited representative), Yican and Ming)