Some Notes on LFR and GIF LFR Safety Design Criteria

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on behalf of
GIF LFR
provisional System Steering Committee
The Lead-cooled Fast Reactor in GIF

GIF LFR provisional System Steering Committee

MoU Signatories

EURATOM

Japan

Republic of Korea

Russian Federation

Observers

People's Republic of China

United States of America
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February 8, 2018
The Lead-cooled Fast Reactor in GIF
Reference systems for the GIF LFR pSSC activities

**SSTAR**
(USA)

Small-sized, battery type reactor with long core life

**BREST-OD-300**
(Russia)

Medium-sized, «pools-in-loop» type reactor + associated fuel cycle

**ELFR**
(Europe)

Large-sized, integral type reactor closing the fuel cycle
The LFR potential

Technological readiness

GIF Roadmap as of 2002  GIF Roadmap 2014 update

- VHTR
- SFR
- SCWR
- MSR
- LFR
- GFR

Viability  Performance  Demonstration
The LFR potential

- **BREST-OD-300** by ROSATOM-NIKIET (Russian Federation)
- **SEALER** by LEADCOLD (Sweden)
- **CLFR** by Westinghouse (USA)
- **LFR-AS-200** by Hydromine Inc. (USA)

Initiatives are also starting in China.
Lead & LBE technology development in Europe

Presently two main projects (with many synergies):

- **MYRRHA (LBE)**
  Flexible irradiation Facility (ADS)

- **ALFRED (LFR)**
  Advanced Fast Reactor European Demonstrator
EU LFR roadmap
Reference documents for LFR-SDC
• **Reference documents**
Development process

Demonstrates that IAEA safety requirements for design (SSR-2/1) are essentially applicable to LFRs, and require only minor modification.

Minimization of the differences between the LFR SDC and the IAEA safety requirements (SSR-2/1) to the extent necessary.
Development process

• Methodology

• The work has been based on the SDC for the Sodium-cooled Fast Reactor (SFR), since the GIF LFR and SFR systems share a number of design solutions and some safety-related phenomenology

• It was also found useful to use the same structure and methodology of the already existing SFR SDC
Development process

• **Criteria**
  • *Applicable as is*
  • *Applicable with interpretation*
    
    No modification is required, but the rationale for the application of the requirement to the design is different than that of the standard light water reactor
  
  • **Application with modification**
    
    Modification is required to be applicable to the design

• **New criteria**

• **Not applicable**

The primary focus is on pure lead, as reactor coolant, but other lead-based coolant options (especially *lead bismuth eutectic*, LBE) are also considered. Where considerations for LBE coolant differ from those of lead, additional commentary is included as footnote in the LFR SDC.
## The GIF LFR SDC

Summary of development process

<table>
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<th>Applicability</th>
<th>Number</th>
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<tr>
<td>With interpretation</td>
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<td>With modification</td>
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<td>New requirement</td>
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<tr>
<td>Not applicable</td>
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LFR safety issues addressed:

- Corrosion/erosion, opacity and high coolant freezing point of lead (327°C)
- Ruptures of steam generator tubes might lead to over-pressurization of the primary side, sloshing and steam/water entrainment resulting in a positive reactivity insertion
- Loss of core geometry (core compaction) might lead to a positive reactivity insertion and power increase

Criterion 42bis: Plant system performance

The overall plant system shall be designed considering the specific characteristics of the reactor coolant and, in general, of the fast reactor system. This includes coolant inherent characteristics, such as its freezing and boiling point, volumetric heat capacity, degree of opacity, chemical reactivity in contact with air and water, as well as corrosion and erosion effects, and the reactor neutronic characteristics, such as its susceptibility to reactivity variations due to coolant heat-up and voiding as well as due to the loss of core geometry. Coolant-specific requirements, including the impurity and toxicity limits, need to be considered in the design as well.
LFR safety issues addressed:

- Operation at relatively high temperatures compared to an LWR and in high fast neutron fluence conditions
- Molten lead is corrosive and oxidizes without oxygen concentration control
- Metallic impurities produced by corrosion can be transported in the primary system and form blockages
- Molten lead might erode structural materials
- Large quantities of primary coolant in pool LFRs may lead to complex flow patterns and interactions with structures

Criterion 47: Design of reactor coolant systems

6.15bis: The components of the reactor coolant systems shall be designed with due account taken of creep properties, thermal fatigue, fast neutron fluence, coolant-induced environmental effects, and other ageing effects, as well as its compatibility with lead, and with thermal stress and dynamic load on structures used under low pressure and high temperature conditions.
LFR safety issues addressed:

- High freezing point (327°C) with a potential for coolant solidification
- Mechanical stresses might be exerted on structures during unfreezing if a proper melting sequence is not applied

Criterion 76bis: Coolant Heating Systems

Heating systems shall be provided for primary coolant as necessary to prevent loss of primary coolant circulation by coolant freezing. These heating systems and their controls shall be appropriately designed to assure that the temperature distribution and rate of change of temperature are maintained within the limits.
LFR safety issues addressed:

- LFR reactor core is not in the most reactive configuration; it is possible to have a positive void reactivity in the central area of the reactor core
- Corrosive properties of molten lead could challenge confinement barriers

Criterion 20: Design extension conditions

5.31. The design shall be such that design extension conditions that could lead to significant radioactive releases are practically eliminated. Since a fast reactor core is not in its most reactive configuration under normal operating conditions, the following design features for prevention and mitigation of severe accidents in postulated design extension conditions shall be considered:

a) Additional reactor shutdown measures against failure of active reactor shutdown systems,

b) Mitigation provision to avoid re-criticality leading to large energy release during a core degradation progression,

c) Means for decay heat removal of a degraded core, and

d) Containment function capability to withstand the thermal and mechanical loads generated by severe accident conditions.
Next steps:

Comments to LFR – SDC received from: RSWG (Okano, Ammirabile, Beils) and US (Sienicki).

Report adjourned to SSR2/1 – 2016 version

Next meeting in Petten (JRC) to finalize the report with Luca Ammirabile (RSWG-co-chair) and Beils Stephane April 13, 2018

Issue of the public report asap .... (June?) to proceed with external reviewers.
Thank you for your attention