Status of GIF-LFR Activities

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Seminar : Activities for Lead-cooled Fast Reactors (LFR) in Generation IV International Forum (GIF)

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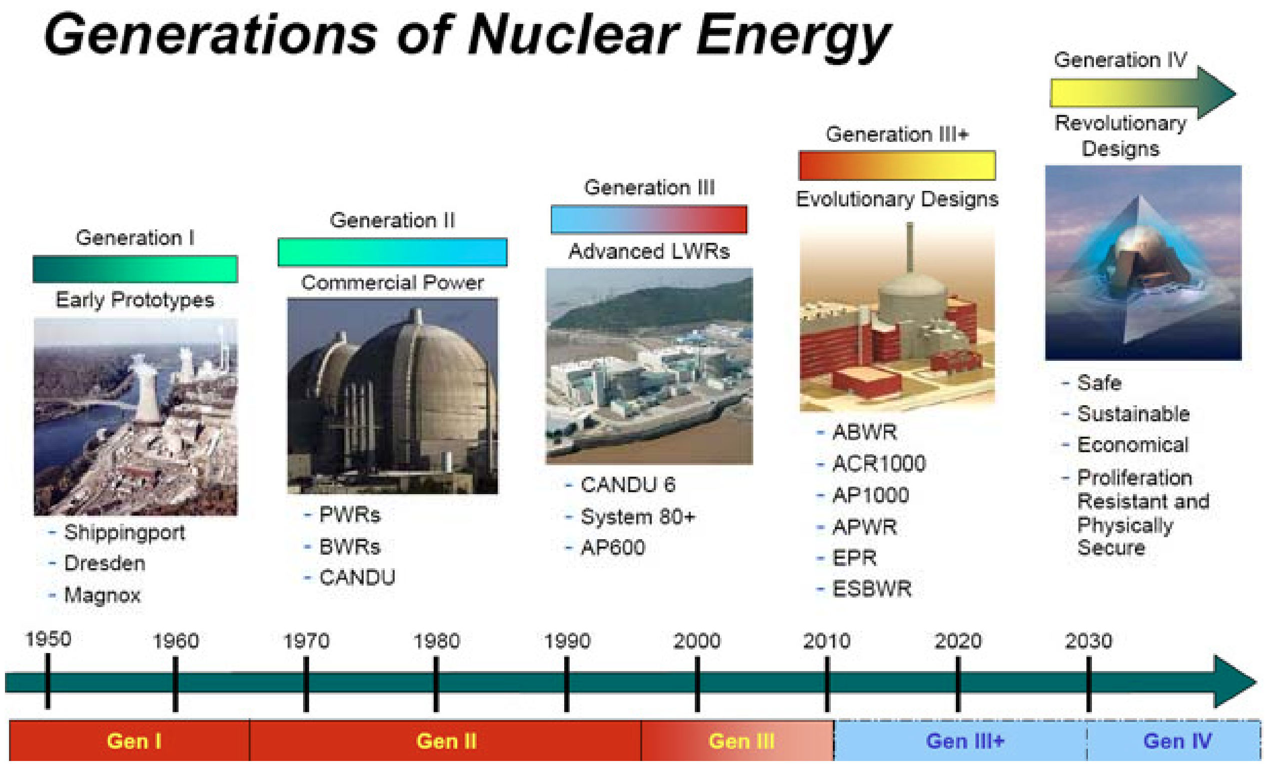
Overview of Presentation

- Few words on GIF
- Overview and historical backdrop of LFR development
- The present status of GIF-LFR-PSSC
- Summary of three reference LFR systems
- Advantages and challenges facing LFR development
- Some considerations in light of the Fukushima event

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 weapons-usable materials, and provide increased physical protection against acts of terrorism

Overview of LFR Technology

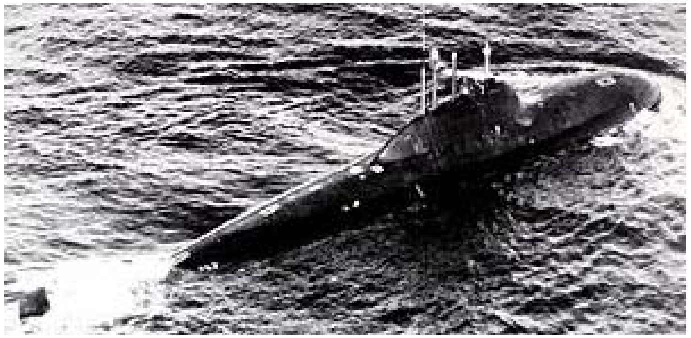
- The LFR is a reactor technology characterized by a fast neutron spectrum; a liquid coolant with a very high margin to boiling and benign interaction with air or water; and design features that capitalize on these features.
- LFR concepts offer substantial potential in terms of safety, simplification, proliferation resistance and the resulting economic performance. Key is the potential for benign end state to severe accidents.
- However, certain drawbacks must be overcome, including the need for coolant chemical (oxygen) control, prevention of corrosion by materials selection and design features, seismic/structural issues and in-service inspection (ISI).

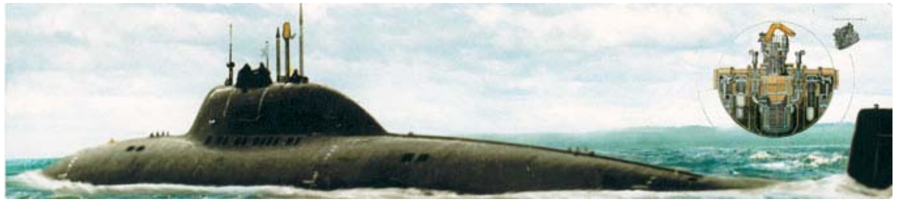
Today we summarize international activities and current status of LFR development

Lead as a primary coolant: some safety and design simplification considerations

- No exothermic reaction between lead and water or air ➔ elimination of intermediate circuit ➔reduced footprint, complexity and overall cost.
- High boiling point of lead (1749°C) ➔ eliminates risk of core voiding due to coolant boiling.
- High density of lead ➔fuel dispersion instead of compaction in case of core destruction.
- High heat of vaporization of lead ➔ low primary system pressure ➔ reduced reactor vessel thickness.
- High thermal capacity ➔ significant grace time in case of loss-of- heat-sink.
- Lead retains iodine and cesium at temperatures up to 600°C ➔ reduces source term in case of volatile fission products release.
- Lead density ➔ shields gamma-rays effectively.
- High thermal exchange ➔ some components (e.g., Steam Generators) can have innovative and compact design and can be placed in the hot leg allowing a simple flow path design.
- Low moderation of lead ➔ greater spacing between fuel pins ➔ low core pressure drop and reduced risk of flow blockage.
- Simple coolant flow path and low core pressure drop ➔ natural convection cooling in the primary system for shutdown heat removal

International Activities in LFR R/D





Russia - Mid 1960's to present

- 4 reactors (73MWt) in prototype submarines
- 7 “Alpha Class” subs (155 MWt)
  + 1 replaced reactor
- 15 reactors total, including 3 on shore reactors
- ~80 reactor-years experience
- Accelerator Driven Subcritical (ADS) reactors
- Reactor systems (BREST; SVBR), GIF MOU

Europe - 2000 to present

- ADS efforts (EFIT, MYRRHA)
- Numerous experimental initiatives using Lead and Pb-Bi
- European Lead-cooled Fast Reactor ELFR, LEADER, ALFRED and MYRRHA, GIF MOU

Asia - 2000 to present

- Toshiba concept of a Pb-Bi cooled 4-S reactor
- Korean and Japanese LFR design work (CANDLE, 4S, PEACER, BORIS)
- GIF MOU (Japan)

U.S. Programs - 1997 to present

- LANL, ANL and UNLV – Lead corrosion and thermal-hydraulics testing
- UC-B Encapsulated Nuclear Heat Source (ENHS) and related studies
- Small, Secure Transportable Autonomous Reactor (STAR-SSTAR)
- MIT - alloy studies to mitigate corrosion; GenIV Energy, SUPERSTAR; E-SSTAR

LFR Compliance with Generation IV Goals

Generation IV Goal Areas	Goals for Generation IV Energy Systems	Goals Achievable via: Ineherent features of lead	Goals Achievable via: Specific Engineered Solutions
Sustainability	Resource utilization	• Low moderating medium. • Low neutron absorption • Core with fast neutron spectrum also with large coolant fraction	• Conversion ratio close to 1 (without radial blanket)
	Waste minimization and management		• Flexibility in fuel loading, homogeneous dilution of MA in the fuel
Economics	Life cycle cost	• Does not react with water • Does not burn in air • Very low vapour pressure • Not expensive	• Reactor pool configuration • No intermediate loops • Compact primary system • Simple internals design • high efficiency
	Risk to capital (Investment protection)		• Small reactor size and/or • in-vessel replaceable components

LFR Compliance with Generation IV Goals

Generation IV Goal Areas	Goals for Generation IV Energy Systems	Goals Achievable via: Ineherent features of lead	Goals Achievable via: Specific Engineered Solutions
Safety and Reliability	Operation excel in safety and reliability	• very high boiling point • low vapor pressure • high **γ** shielding capability • fuel compatibility and fission product retention	• Atmospheric pressure primary • Low coolant ΔT between core inlet and outlet.
	Low likelihood and degree of core damage	• good heat transfer • high specific heat • high expansion coefficient	• Large fuel pin pitch • High Natural circulation • DHR coolers in the cold collector • negative reactivity feedback
	No need for offsite emergency response	• Density close to that of fuel (reduced risk of re-criticality accidents) • fission products retention	• Requirements on fuel porosity
Proliferation Resistance and Physical Protection	Unattractive route for diversion of weapon-usable material		• Small system, sealed, long-life core and/or • Fuels with MA increase Proliferation Resistance

Current Status with regard to LFR PSSC

- Provisional System Steering Committee (PSSC) was formed in 2005
  - Members included EU, US, Japan and Korea
  - Prepared initial draft LFR System Research Plan (LFR-SRP)
  - Systems included a large central station design (ELSY) and a small transportable system (SSTAR)
- <u>In 2010, an MOU was signed between EU and Japan</u> causing a reformulation of the PSSC
- <u>In 2011, the Russian Federation added its signature to the MOU</u>
- In April, 2012, the reformulated PSSC met in Pisa and began the process of revising the LFR-SRP
  - Members are signatories of the MOU: EU, Japan and Russia
  - US invited to participate as observer
- The new PSSC envisions various updates to the central station and small reactor thrusts while adding a mid-size LFR (e.g., the BREST-300) as a new thrust in the SRP

Current Activities of the LFR-PSSC

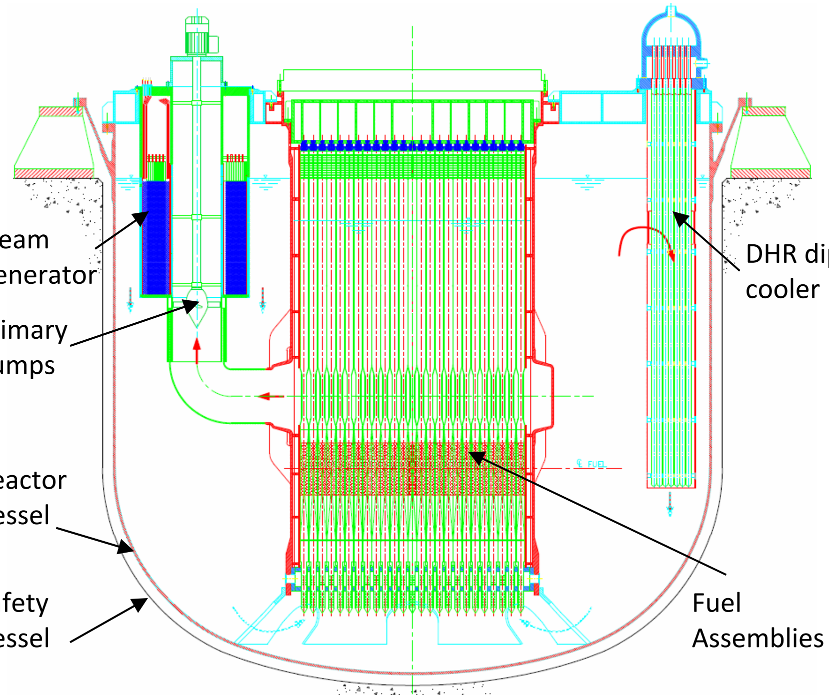
- The new PSSC met in Pisa, Italy in April, 2012
  - Representatives present from EU, Japan and Russian Federation
  - Additional participants from US and OECD/NEA
  - Actions included:
    - ✓Decision to expand the initiative to three thrusts (large, medium and small LFRs)
    - ✓Agreement to prepare PSSC position paper describing the basic advantages and remaining research challenges of the LFR
    - ✓Invitation to US representative to continue in observer status
    - ✓Initiation of a significant revision to the SRP to be completed in 2012

- <u>Working meeting of the PSSC on November, 7-9 2012 in Tokyo, Japan</u>

- System designs representing the three thrusts are the following:
  - The European Lead-cooled Fast Reactor (ELFR) for the large, central station plant
  - The BREST-OD-300 for the medium size plant
  - The Small Secure Transportable Autonomous Reactor (SSTAR) for the small system

The European Lead-cooled Fast Reactor ELFR

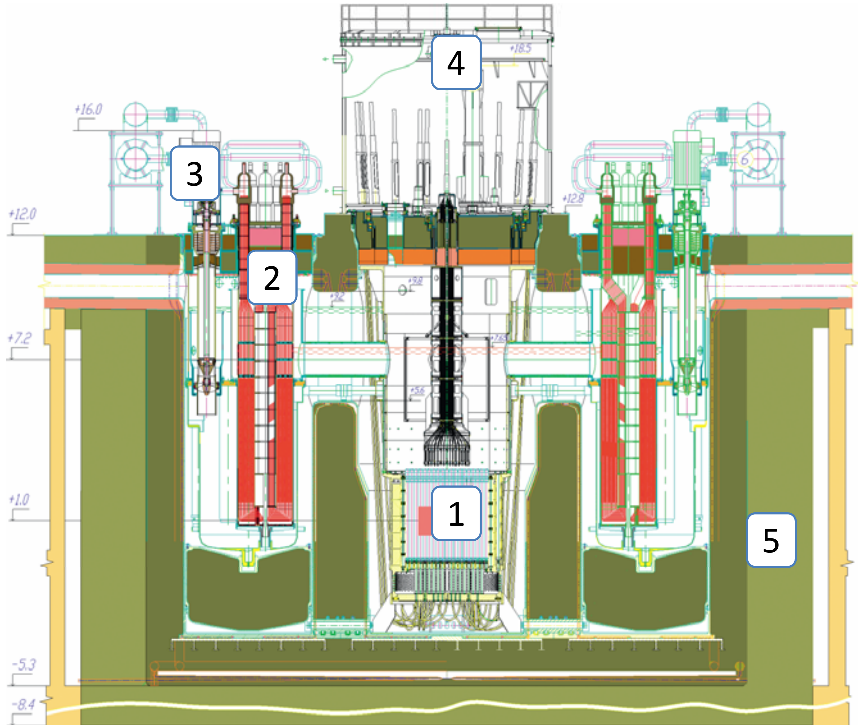
- Power: 1500 MW(th), 600 MW(e)
- Core diameter, 4.5 m
- Core height, 1.4 m
- Core fuel MOX (first load)
- Coolant temp., 400/480°C
- Maximum cladding temp., 550°C
- Efficiency: ~42%
- Core breeding ratio (CBR) ~ 1



Key technical attributes include FA extension to cover gas
DHRs: Secondary side isolation condensers + dip coolers

The BREST-OD-300 Russian Lead-cooled Reactor

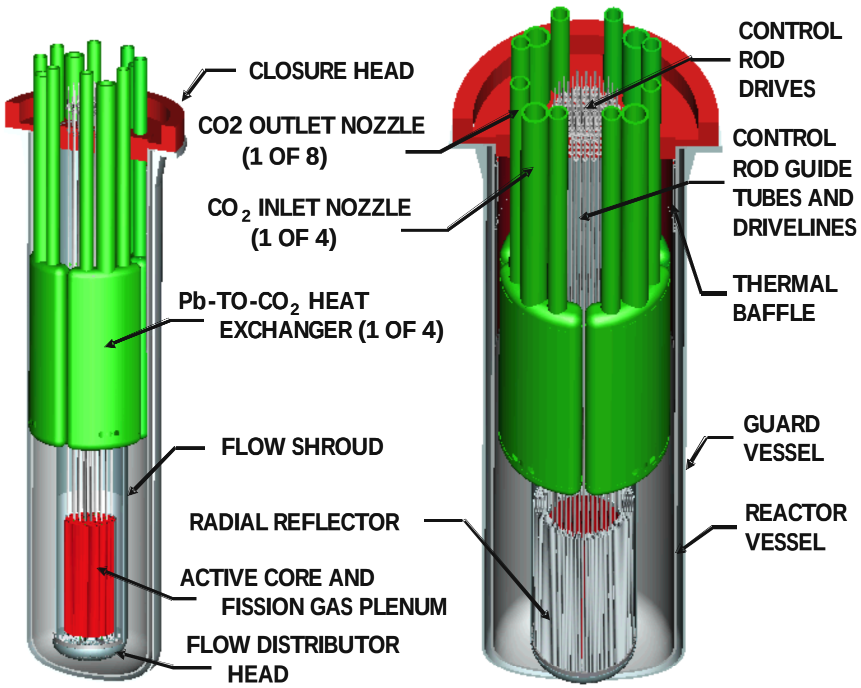
- Power: 700 MW(th), 300 MW(e)
- Core diameter, 2.6 m
- Core height, 1.1 m
- Core fuel UN + PuN
- Coolant temp., 420/540°C
- Maximum cladding temp., 650°C
- Efficiency: 42%
- Core breeding ratio (CBR) ~ 1



1 Core, 2 steam generator, 3 Pump, 4 refueling machine, 5 Reactor Vault

Key technical attributes include concrete Reactor Vault, fuel reprocessing in dedicated building integrated with the plant

The Small Secure Transportable Autonomous Reactor (SSTAR)



SSTAR is a small natural circulation fast reactor of 20 MWe/45 MWt, that can be scaled up to 180 MWe/400 MWt.

The compact active core is removed by the supplier as a single cassette and replaced by a fresh core.

Key technical attributes include the use of lead (Pb) as coolant and a long-life sealed core in a small, modular system.

Research challenges remain

Research challenges remain due to: the high melting point of lead; its opacity; coolant mass; and potential for corrosion when the coolant is in contact with structural steels.

- The high melting temperature of lead (327 °C) requires that the primary coolant system be maintained at temperatures to prevent the solidification of the lead coolant. This presents design as well as engineering challenges during the operation and maintenance.
- The opacity of lead, in combination with its high melting temperature, presents challenges related to inspection and monitoring of reactor in-core components as well as fuel handling.
- The high density and corresponding high mass of lead require careful consideration of structural and seismic design.
- Significant challenges result from the phenomenon of lead corrosion of structural steels at high temperatures and flow rates. These phenomena require careful material selection and component and system monitoring during plant operations.

LFR and EXTREME NATURAL EVENTS

Response to earthquakes enhanced ➔ adoption of seismic isolation

Decay Heat Removal Systems independent, redundant and diverse

DHR systems completely passive. Only actuation (through valve alignment) is active, using local stored energy ➔

**the Station Blackout does not present a concern;
any initiating event is managed without AC power**

Even in case of Station Blackout without DHR systems available, safety analyses demonstrated that fuel and cladding temperatures do not represent a concern

Complete core melt is practically impossible due to favorable intrinsic lead characteristics: high thermal inertia, very high boiling point, higher density with respect to oxide fuel with enhancement of the fuel dispersion in contrast to fuel compaction.

In the very unlikely event of an extreme Fukushima-like scenario (or beyond) leading to the loss of all heat sinks (both DHR and secondary systems), the heat can still be extracted injecting water in the reactor cavity between the reactor and safety vessels, while in case of reactor vessel breach the decay heat can still be removed by the same system that cools the concrete of cavity walls.

Some final comments

- Lead-cooled systems offer great promise in terms of fast reactor plant simplification and economic performance
- The Russian experience demonstrates that the LFR can be produced and operated on a relatively large scale
- Some important areas for R&D include:
  - Completion of designs
  - Testing of special materials for use in lead environment
  - Fuel studies including recycle
  - Special studies (seismic; sloshing; LBE dust/slag formation)
  - Evaluation of long term radioactive residues from fuel and system activation
  - Technology pilot plant/Demo activities
- In the post-Fukushima era, the unique safety potential of the LFR should be recognized