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Lead Fast Reactor (LFR)

Summary / Objectives:

The Lead-cooled Fast Reactor (LFR) is characterized by a fast neutron spectrum; a liquid coolant with a very high margin to boiling and relatively inert interaction with air or water; and design features that capitalize on these attributes. As with other fast spectrum reactors, the LFR offers fuel cycle options that greatly enhance resource utilization and sustainability. LFR concepts offer great potential in terms of safety, simplification, proliferation resistance and the economic performance. The webinar presents background on fast reactor physics, the historical development and present status of LFR technology and the main characteristics of LFR concepts under current consideration.

Meet the Presenter:

Professor Craig Smith, Research Professor at the Naval Postgraduate School, Monterey, CA, USA, is a nuclear engineer with broad experience in nuclear energy technology, radiation detection and information science. His previous employment includes a career at Lawrence Livermore National Laboratory (LLNL) where he led the Fission Energy and System Safety Program. Beginning in 2004, he served as the LLNL Chair Professor at the Naval Postgraduate School (NPS) in Monterey, CA. After retiring from LLNL, he assumed his current position as Research Professor of Physics at NPS.

Why LFR Technology?

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- As with other Fast Reactors, LFRs offer:
  - Significant advantage in sustainability/uranium utilization – better use of natural resources
  - Potential for dramatic reduction of high level waste if full recycle (closed fuel cycle) is used
- Relative to other fast reactors, LFRs have a unique combination of favorable features:
  - Very high boiling point (1737°C)
  - Benign chemistry (no rapid chemical reaction with water/air)
  - Low vapor pressure
  - Excellent neutronic properties for fast spectrum operation
- These features are inherent in the properties of the lead coolant and can be exploited through proper plant design.

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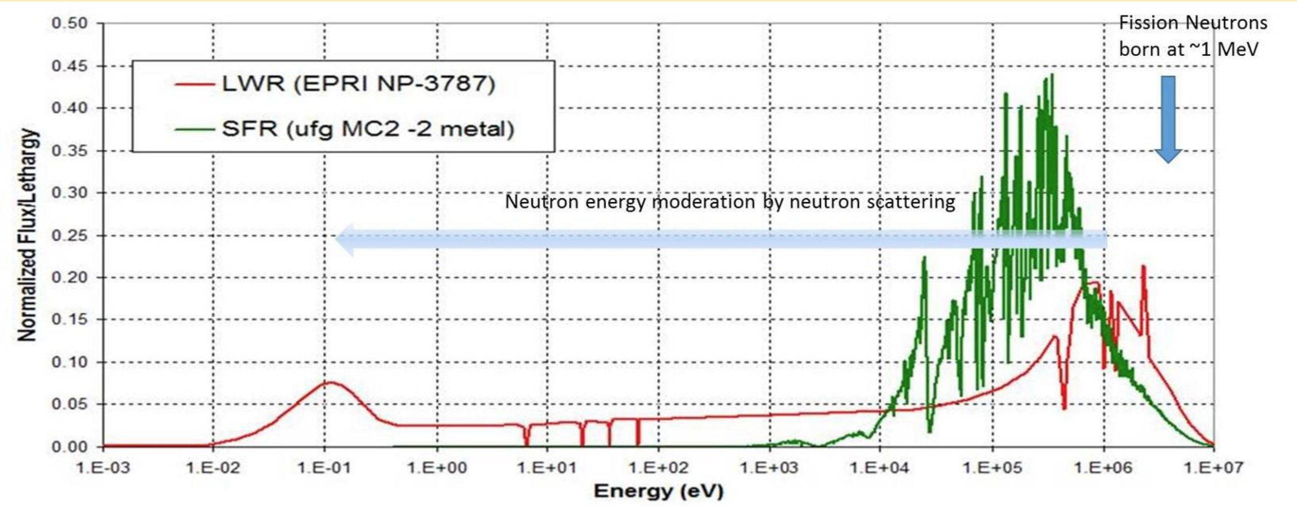
1. **A Recap on Fast Reactor Physics: Comparison of fast (SFR) vs. Thermal (LWR) spectra**

- In thermal reactors such as LWRs, most fissions occur around the ~0.1 eV "thermal" peak.
- In fast reactors such as LFRs or SFRs , neutron energy moderation is avoided fissions occur mainly in "fast" energy range.



2. **Some Chemical and Thermal Characteristics of Liquid Metal Coolants**

- Both of lead-based coolants are practically inert in terms of chemical reactivity with water and air, and this has important and favorable implications for the design, safety, and economic potential of LFRs.

Coolant	Melting Point (°C)	Boiling Point (°C)	Chemical Reactivity (w/Air and Water)
Lead-Bismuth (Pb-Bi, LBE)	125	1670	Practically Inert
Lead (Pb)	327	1737	Practically Inert
Sodium (Na)	98	883	Highly reactive

3. Stored Potential Energy for Different Reactor Coolants

- The very low comparative amount of stored energy in lead-cooled fast reactor coolants is an indication of their enhanced safety potential based on the intrinsic properties of the coolant.

Coolant	Water	Sodium	Lead, LBE
Parameters	P = 16 MPa T = 300 °C	T = 500 °C	T = 500 °C
Maximal potential energy, GJ/m^3, *including:*	~ 21.9	~ 10	~ 1.09
Thermal energy / *including* compression potential energy	~ 0.90 / ~ 0.15	~ 0.6 / None	~ 1.09 / None
Potential chemical energy of interaction	With zirconium ~ 11.4	With water 5.1 With air 9.3	~0
Potential chemical energy of interaction of released hydrogen with air	~ 9.6	~ 4.3	None

4. Recap of Design Parameters of Gen IV Reference LFR Concepts

Within the SRP for LFR, there are reference systems adopted by the committee, and they include, the ELFR (large reactor), BREST-OD-300 (under construction), or SSTAR (transportable, small modular reactor with the supercritical CO2 gas turbine cycle as a secondary cycle).

Parameter	ELFR	BREST-OD-300	SSTAR
Core power (MW_{th})	1500	700	45
Electrical power (MW_e)	600	300	20
Primary system type	Pool	Pool/loop	Pool
Core inlet T (°C)	400	420	420
Core outlet T (°C)	480	535	567
Secondary cycle	Superheated steam	Superheated steam	S-CO_2
Net efficiency (%)	42	43.5	44

5. LFRs Have the Potential to Excel in Safety

To summarize this part of the discussion, lead-cooled fast reactors have the potential to excel in safety for reasons outlined on this slide.

LFRs Have the Potential to Excel in Safety

- The very high boiling point of lead (~1737°C):
  - Allows reactor operation at near atmospheric pressure
  - Eliminates the risk of core voiding due to coolant boiling
- No rapid chemical reactions between lead and either water or air
  - No energetic releases or hydrogen production from chemical reactions
  - Use of water as ultimate heat removal fluid is conceivable, should other heat removal systems fail
- The thermal capacity of lead combined with the large mass of coolant
  - Significant thermal inertia in the event of hypothetical accident initiators.
  - Long grace time (the need for operator's intervention is eliminated or significantly delayed)
- Lead shields gamma radiation and retains iodine and cesium up to 600°C
  - Reduced source term in case of fuel rod failure → enhanced Defense-in-Depth.
- The low neutron moderation of lead allows greater fuel spacing without excessively penalizing neutronic performance:
  - Reduced risk of flow blockage
  - Reduced core pressure drop and simple coolant flow path allow decay heat to be removed through natural circulation

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6. There are challenges to address, and the first is corrosion potential, and this is the one that gets the most attention. Other challenges that need to be considered include the high melting or freezing point of lead, which is 327°C. Another challenge relates to seismic or structural considerations due to the high density and weight of the coolant.

However, There are Challenges to Address

- **Corrosion potential**
  - Operate at temperatures low enough to avoid corrosion (current materials can be used)
  - Use advanced materials for higher temperature operation, to enhance economics
    - Silicon or Aluminum enhanced materials (i.e., Alumina Forming Austenitic (AFA) steels and Silicon enhanced steels)
    - Surface coating with corrosion-protective materials for higher temperature operation (cladding + steam generator)
    - Functionally graded composite materials
  - In any case, methods must be implemented to monitor/control oxygen content to maintain protective oxide coatings and avoid the formation of PbO
- **High melting point (327°C)**
  - Proper engineering to avoid lead freezing
- **Seismic/structural considerations due to heavy coolant**
  - Compact size mitigates this challenge
  - Seismic isolation
- **Opaque, high-temperature coolant**
  - Similar in service inspection issues and solutions as for SFR
  - Accessibility/replaceability of components
  - Newer acoustic methods

These challenges are generally technical in nature and can be overcome through proper engineering and R&D work

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