The Westinghouse Lead Fast Reactor

Design overview and update on development activities

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About Westinghouse

Approximately 9,000 Employees

Comprised of 6 Business Units

AMERICAS OPERATING PLANT SERVICES
EMEA OPERATING PLANT SERVICES
ASIA OPERATING PLANT SERVICES
ENERGY SYSTEMS
ENVIRONMENTAL SERVICES
PARTS

More Than 70 Facilities

Our Technology Generates Nearly 50% Of the World’s Nuclear Power
Westinghouse Lead Fast Reactor
Mission and development status

A forward-thinking concept designed to:

• Achieve a step-change in economic competitiveness
• Achieve versatility in applications, beyond electricity
• Accommodate transition to closed fuel cycle, if/when needed

Developed leveraging Westinghouse’s demonstrated experience in commercializing nuclear power plants globally

Selected international collaborations to best complement capabilities

Development status:

• Near completion of conceptual design
• Demonstration of key systems, components and materials starting in 2022
• Pre-licensing engagement ongoing with UK Regulators
Westinghouse LFR’s key attributes:

- Competitiveness and enhanced passive safety **together**
- Flexible electricity through adoption of energy storage system
- Enhanced siteability, with no need for vicinity of water bodies
- Fuel cycle flexibility typical of fast reactors
- Staged approach to development, starting with lower temperature to accelerate technology demonstration

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Reactor power</td>
<td>~450 MWe Net</td>
</tr>
<tr>
<td>Efficiency</td>
<td>~47%</td>
</tr>
<tr>
<td>Primary / secondary coolant</td>
<td>Liquid lead / Supercritical water</td>
</tr>
<tr>
<td>Neutron spectrum</td>
<td>Fast</td>
</tr>
<tr>
<td>Configuration</td>
<td>Independent unit for single (450 MWe) or two-unit (900 MWe) site</td>
</tr>
<tr>
<td>Ultimate heat sink</td>
<td>Atmosphere. No water bodies needed</td>
</tr>
<tr>
<td>Load following</td>
<td>Yes, through thermal energy storage system</td>
</tr>
<tr>
<td>Reference fuel cycle</td>
<td>Open (but capable to support closed cycle)</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Oxide (Phase 1); Uranium Nitride (Phase 2)</td>
</tr>
<tr>
<td>Cycle length and refueling scheme</td>
<td>8-15 years; direct-to-cask refueling</td>
</tr>
<tr>
<td>Operating pressure, MPa</td>
<td>0.1 (primary) / ~34 (secondary)</td>
</tr>
<tr>
<td>Lead coolant min/max temperature, °C</td>
<td>390 / 530 (Phase 1); 390 / 650 (Phase 2)</td>
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Emergency Passive Heat Removal System (PHRS)

➢ RVACS-type, with heat removal through reactor vessel walls
➢ Fully passive, no I&C support, no need for actuation
  • Pool of water surrounding the Guard Vessel, with constant water level for 7 days
  • Transition to natural circulation of air once water is depleted
  • Performance triggered by radiative heat transfer between RV-GV → kicks in only when really needed
  • Compliant with IAEA Passive Safety Category B goal
➢ Performance analyzed using SAS4A-GOTHIC coupling, supported by higher-fidelity CFD simulations
  • See companion paper presented at FR22 (D. Wise et al., Passive heat removal system analysis for the Westinghouse LFR)

Full-height test facility simulating PHRS being built in the UK. Testing to start in summer 2022
LFR development activities

- Westinghouse performs most design and analysis activities
  - Reactor Coolant System design and analysis
  - Core and fuel cycle design and analysis
  - Safety analysis
  - Balance of Plant design and analysis
  - Plant layout
  - Refueling
  - O&M
  - Cost analysis

- Collaborations are pursued to most effectively complement capabilities

- Intensive testing campaign to be started in summer 2022 in the UK, in collaboration with 9 international partners
  - Eight state-of-the-art test facilities being erected in the UK
  - Leveraging £10M award in 2021-2022 from the UK Government
LFR Testing Program in the United Kingdom

Supported by the UK Government

Eight LFR test rigs being erected at:

• Westinghouse – Springfields, UK
• Ansaldo Nuclear – Wolverhampton, UK
• Jacobs – Warrington, UK
• University of Bangor, UK
• Fuel development at National Nuclear Laboratory and Univ. of Manchester, UK

...to demonstrate key materials, components, systems and phenomena of the Westinghouse LFR

Start of testing: Summer 2022
**Westinghouse LFR test rigs in the UK (2022 startup)**

| Test rig                                                | Location                        | Mission                                                        | Test rig footprint (LxWxH) (m) | Operating fluid(s) | Lead inventory (kg) | Operating fluid temp (°C) | Operating fluid velocity in test section (m/s) |
|---------------------------------------------------------|---------------------------------|                                                               |                               |                   |                   |                          |                                             |
| High-temperature flowing lead corrosion rig             | Westinghouse-Springfields, UK   | Materials corrosion tests in flowing lead                     | 7.5 x 2.3 x 2.3               | Liquid lead       | 4500               | Up to 800               | Up to 3                          |
| Lead freezing rig                                       |                                 | Test lead freezing Test under-lead viewing technology         | 5.8 x 2.3 x 2.3               | Liquid lead       | 1760               | Up to 600               | 0 (stagnant)                     |
| Heat exchanger failure rig (also known as supercritical H₂O-to-liquid lead interaction rig) |                                 | Assess phenomena associated with interaction between high-pressure supercritical water and liquid lead | 4.8 x 2.3 x 2.3               | Liquid lead, supercr. water | 1300               | Pb – 415, Water – 415 | Pb -0 (stagnant); Water – Up to 370 m/s |
| Versatile Loop Facility for component testing          | Ansaldo Nuclear – Wolverhampton, UK | Demonstration and performance assessment of LFR’s key components (e.g. fuel bundle and primary heat exchanger mockups) | 10 x 10 x 10                  | Liquid lead       | 3500               | 390 – 530 (Phase 2) 390 – 650 (beyond Phase 2) | Up to 3 (bundle) 0.4 –0.6 (piping) |
| Passive Heat Removal Facility                          |                                 | Demonstration and performance assessment of LFR’s Passive Heat Removal System at relevant scale | 8 x 9 x 23                    | Water, steam, air | N.A.               | Up to 250               | Up to 3 (steam or air)             |
| Stagnant lead corrosion rig                            | Jacobs – Warrington, UK         | Materials corrosion tests in stagnant lead                    | 2 x 2 x 1.5                   | Liquid lead       | 114                | Up to 800               | 0 (stagnant)                     |
| Materials’ mechanical property characterization rig     |                                 | Measurement of potential effect of liquid lead on mechanical properties of materials | 0.5 x 0.5 x 2.2               | Liquid lead       | 6 kg/capsule       | Up to 800               | 0 (stagnant)                     |
| High-velocity flowing lead corrosion/erosion rig       | University of Bangor, UK        | Materials corrosion/erosion tests in high-velocity liquid lead | 5.9 x 2.4 x 2.3               | Liquid lead       | 2700               | Up to 450 (flow test) Up to 600 (stagnant) | Up to 6 (samples) Up to 12 (relative velocity at impeller blade) |
Westinghouse LFR: a global program

Global collaborations
Conclusions

• Westinghouse is continuing development of LFR as its Next Generation of high-capacity nuclear power plants
• Primary mission is economic competitiveness even in the most challenging global markets, combined with versatility in applications
• A significant testing program is starting in the UK, which will act as springboard toward reactor demonstration
• Collaborations are being pursued to best complement capabilities and accelerate development further
Backup slides
Core Design and Fuel Cycle

Core design

- Relatively low core power density compared to conventional fast reactors (approx half of a PWR)
- 325 fuel bundles with 3 enrichment zones
- Longer active length than typical FRs
- Grid spacer-supported hexagonal array
- Fuel:
  - Oxide fuel with steel cladding (near-term)
  - Nitride fuel with advanced cladding (longer-term)
  - MOX and metal fuel also considered
- Top- and bottom-inserted control rods

Refueling and fuel cycle

- Long fuel cycle (8-15 years)
- Refueling scheme: direct to cask, with no assembly shuffling. No spent fuel pool
- Reference fuel cycle: open. However, closed cycle solutions are also investigated to ensure capability to accommodate it
Primary heat exchangers

- Hybrid diffusion-bonded microchannel HX technology selected to achieve primary system compactness and diminish significance of heat exchanger rupture:
  - 4-6 times higher power density than conventional shell-and-tube HXs
  - No welds in the main body
  - Secondary headers located outside of the RV
  - Ultra-resistant to pressure differentials → reduced likelihood for ruptures
  - In-vessel leaks limited to microchannel size → reduced consequences of rupture

- Technology already commercially available in the oil/gas industry

- Customized configuration
  - Smaller channels on secondary side and larger channels on primary side

- Code case being developed in ASME Section III, Div. 5

To be tested in prototypical conditions in lead-based test rigs in the UK. Testing to start in summer 2022.