The Westinghouse Lead Fast Reactor

Design overview and update on development activities

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Westinghouse Electric Company LLC

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About **Westinghouse**

Approximately
9,000
Employees

Locations in
19
Countries

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

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Westinghouse Lead Fast Reactor
Mission and development status

A forward-thinking concept designed to:

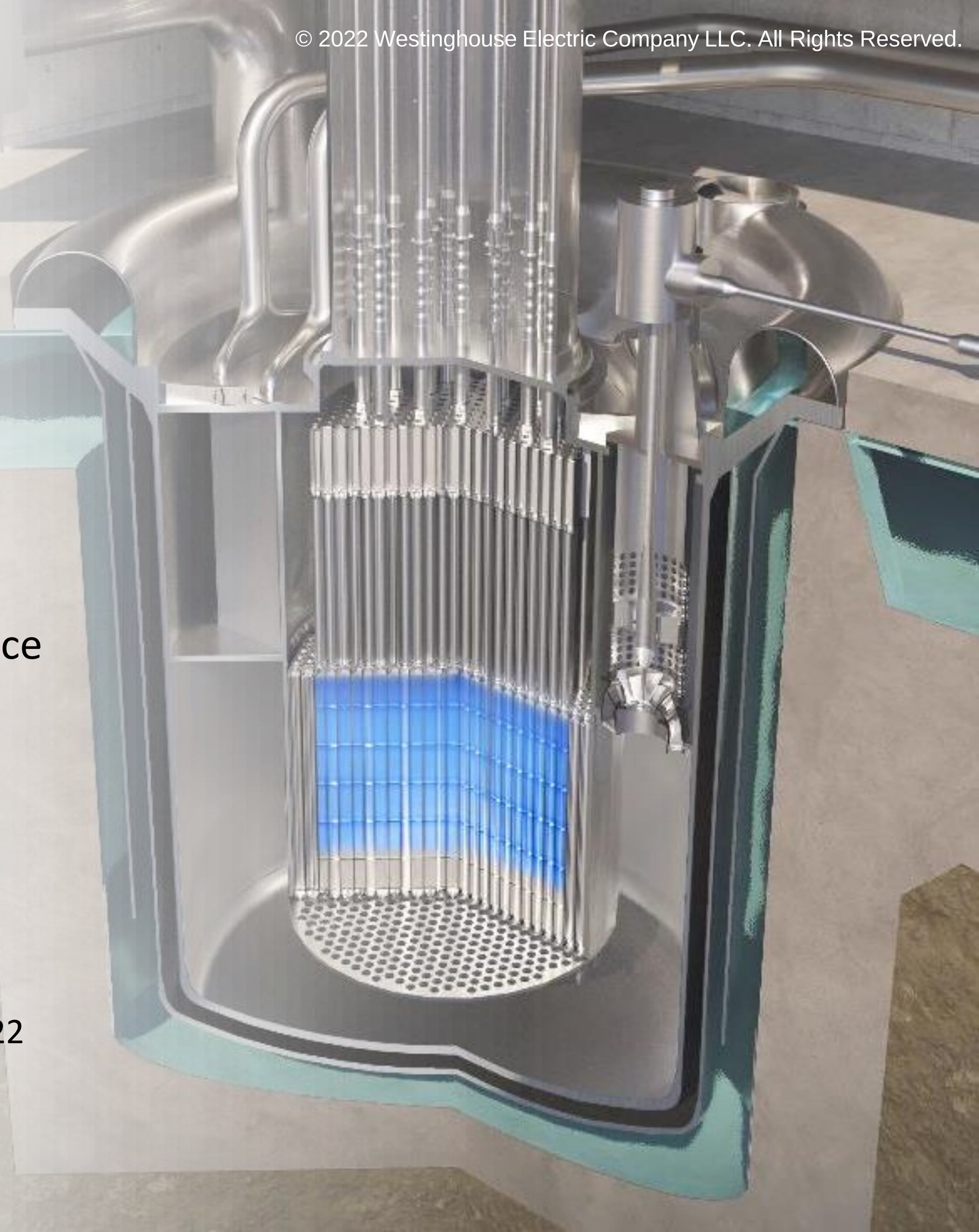
- Achieve a step-change in economic competitiveness
- Achieve versatility in applications, beyond electricity
- Accommodate transition to closed fuel cycle, if/when needed

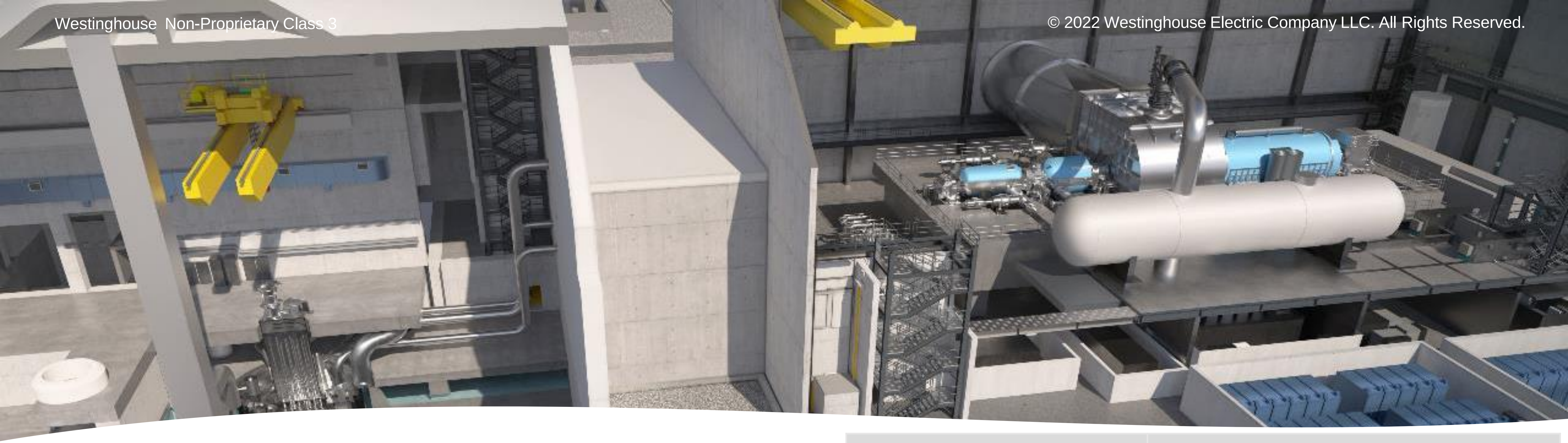
Developed leveraging Westinghouse's demonstrated experience in commercializing nuclear power plants globally

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





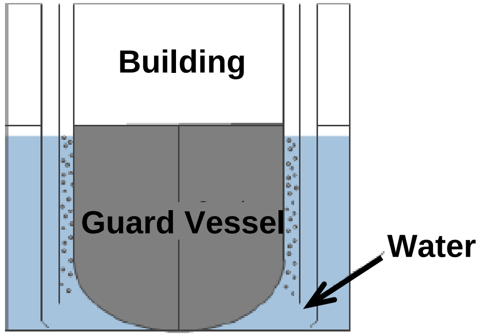
Westinghouse LFR’s key attributes:

- 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

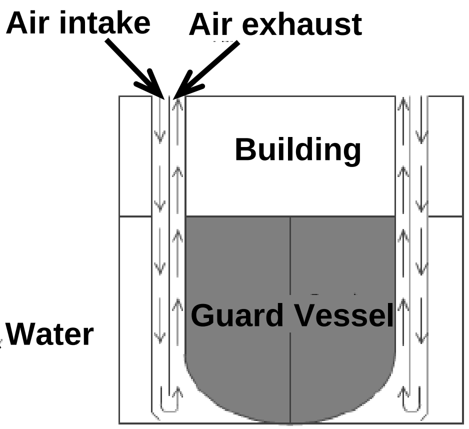
Reactor power	**~450 MWe Net**
Efficiency	**~47%**
Primary / secondary coolant	**Liquid lead / Supercritical water**
Neutron spectrum	**Fast**
Configuration	**Independent unit for single (450 MWe) or two-unit (900 MWe) site**
Ultimate heat sink	**Atmosphere. No water bodies needed**
Load following	**Yes,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

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



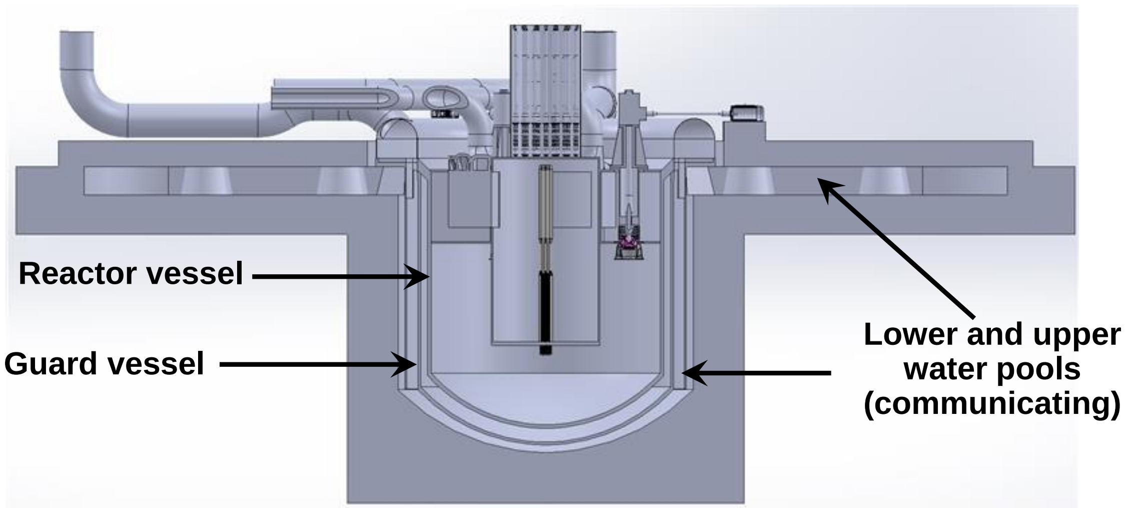
Water-cooling mode (notional)



Air-cooling mode (notional)

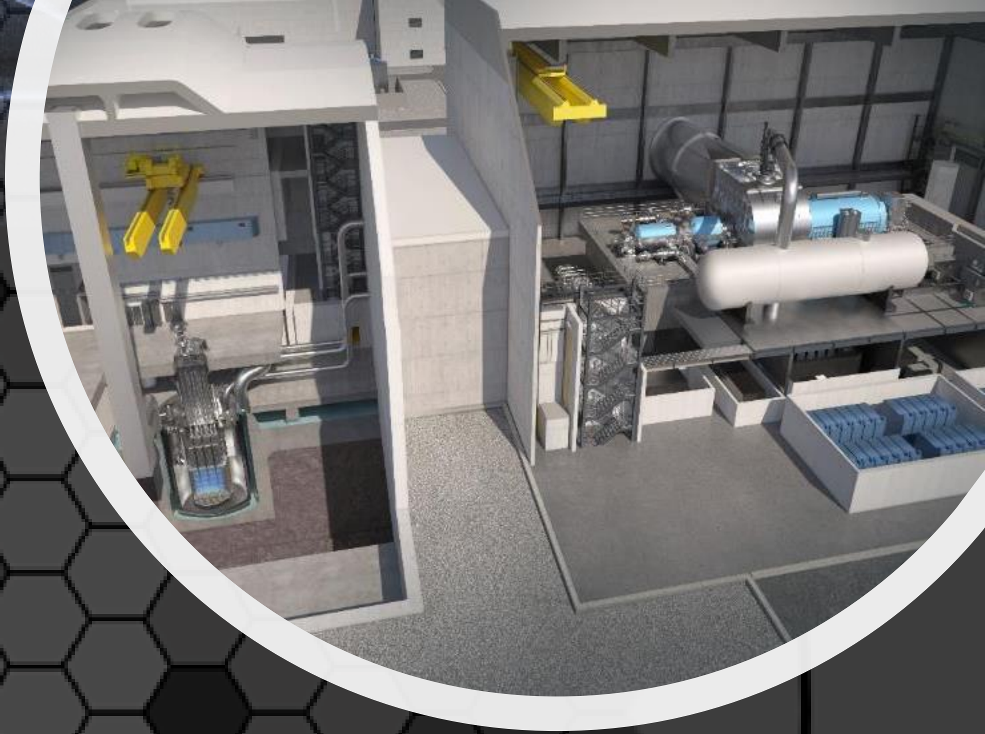
- **Performance analyzed using SAS4A-GOTHIC coupling, supported by higher-fidelity CFD simulations**
  - See companion paper presented at FR22 (D. Wise et al., Passive heat removal system analysis for the Westinghouse LFR)

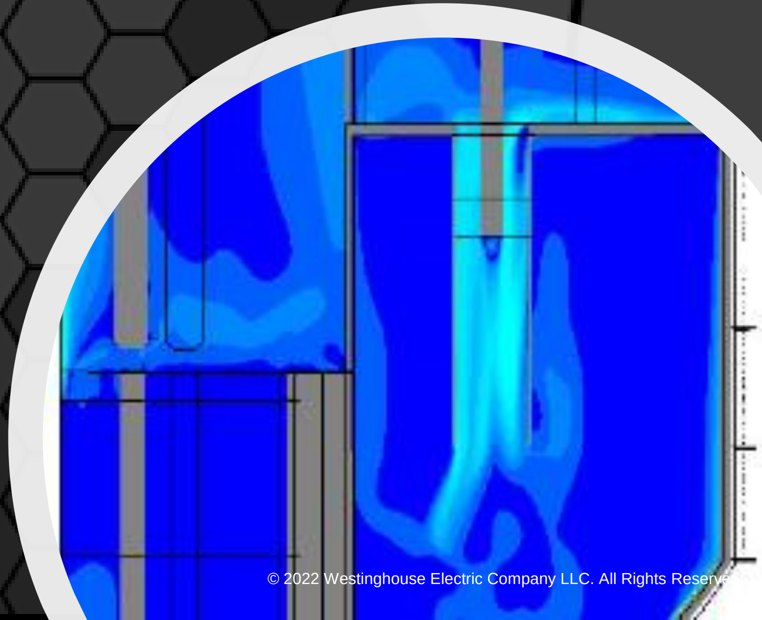
Full-height test facility simulating PHRS being built in the UK. Testing to start in summer 2022



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

Department for Business, Energy & Industrial Strategy

ANSALDO NUCLEARE Ansaldo Energia Group

ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development

FRAZER-NASH CONSULTANCY

Westinghouse

Jacobs

NATIONAL NUCLEAR LABORATORY

NUCLEAR AMRC

PRIFYSGOL BANGOR UNIVERSITY

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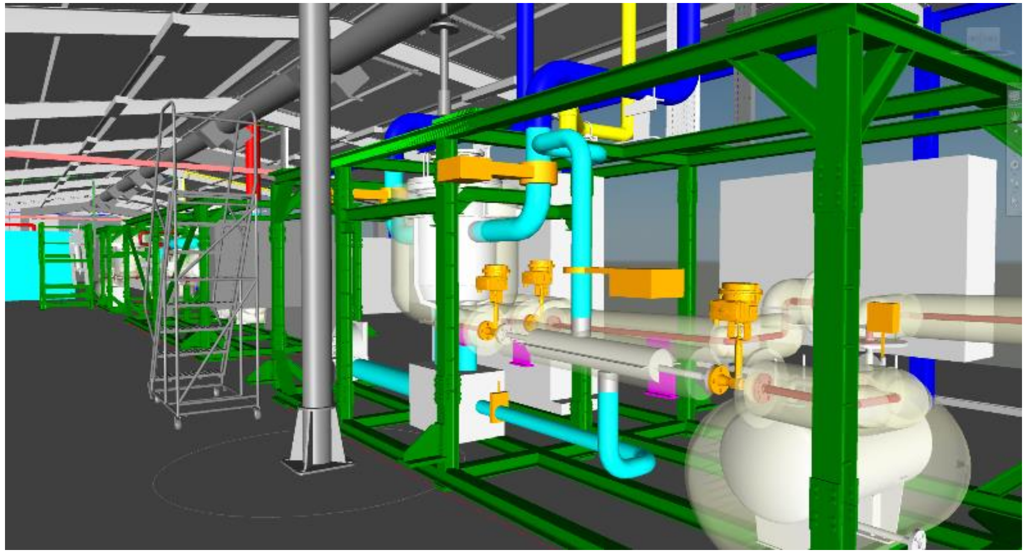

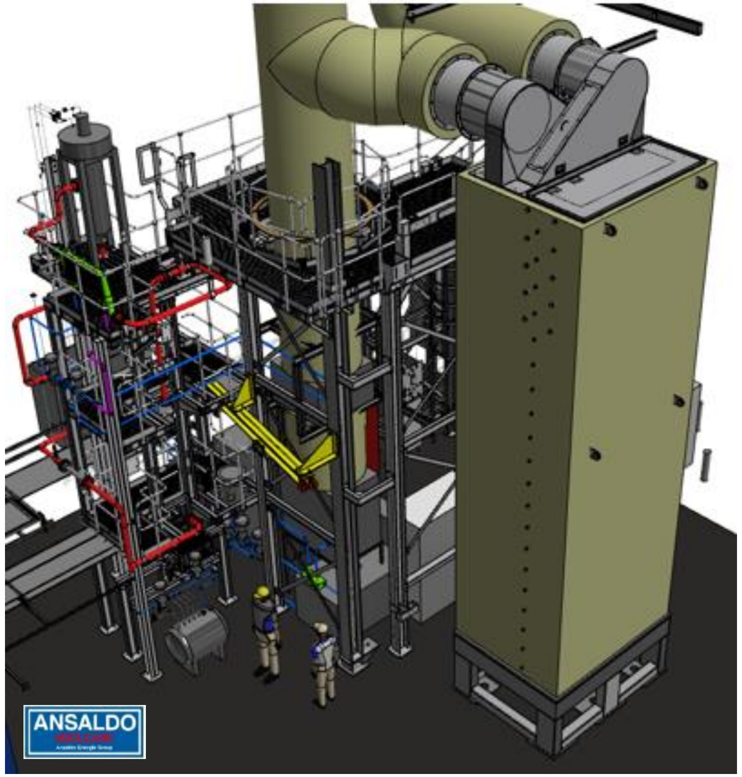

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Westinghouse LFR test rigs in the UK (2022 startup)

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 2.3x 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 2.3x 2.3	Liquid lead	1760	Up to 600	0 (stagnant)
Heat exchanger failure rig (also known as supercritical H_2O-to-liquid lead interaction rig)		Assess phenomena associated with interaction between high-pressure supercritical water and liquid lead	4.8 x 2.3x 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 0.5x 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 2.4x 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

Westinghouse Sweden

Westinghouse US

Westinghouse Mangiarotti (Italy)

Westinghouse UK

Global collaborations

Argonne NATIONAL LABORATORY

ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development

FAUSKE & ASSOCIATES, LLC

ANSALDO NUCLEARE Ansaldo Energia Group

Department for Business, Energy & Industrial Strategy

Los Alamos NATIONAL LABORATORY EST. 1943

Westinghouse

OAK RIDGE National Laboratory

NATIONAL NUCLEAR LABORATORY

PRIFYSGOL BANGOR UNIVERSITY

PennState

BYU

VPE VACUUM PROCESS ENGINEERING

INL Idaho National Laboratory

NUCLEAR AMRC

Jacobs

FRAZER-NASH CONSULTANCY

ECHOGEN power systems

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

MANCHESTER 1824

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

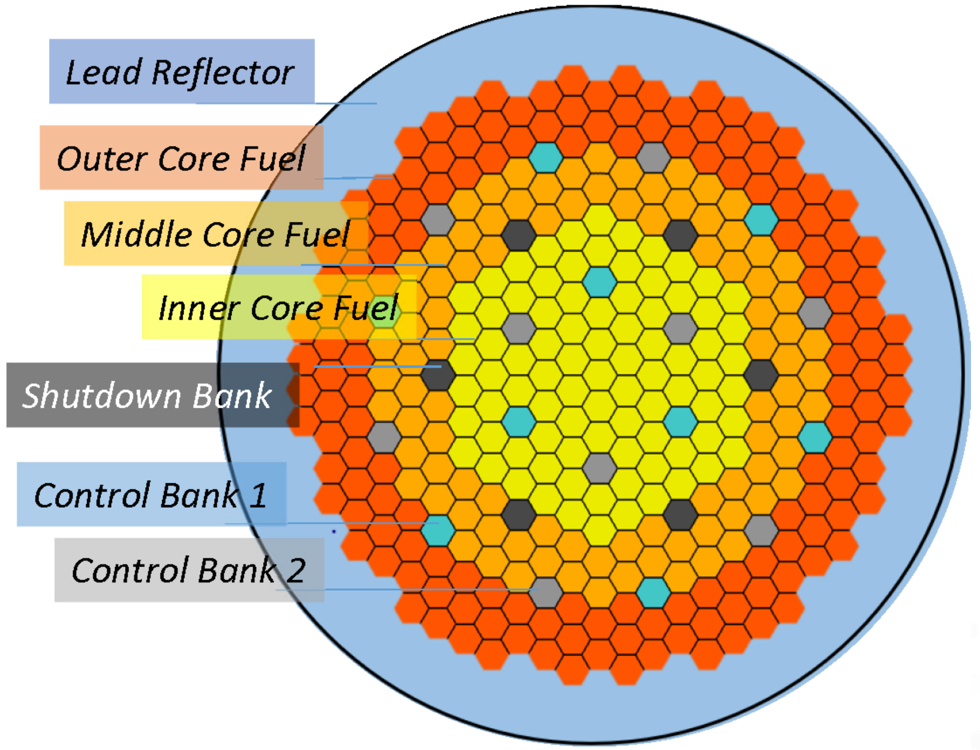
AP1000® plant operating in China

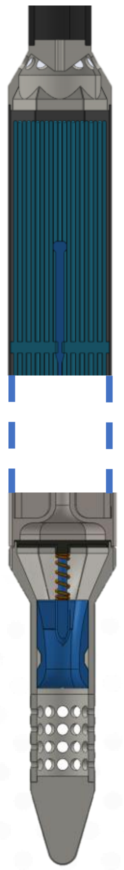
Westinghouse LFR rendering

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



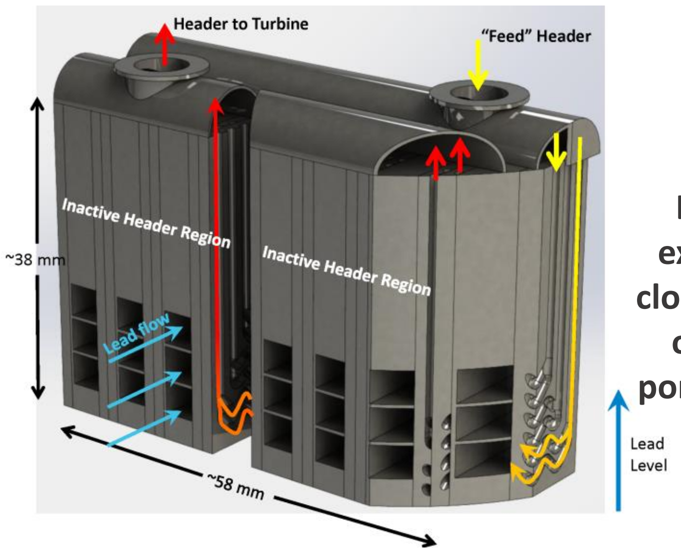


- **Refueling and fuel cycle**
  - Long fuel cycle (8-15 years)
  - Refueling scheme: direct to cask, with no assembly shuffling. No spent fuel pool
  - Reference fuel cycle: open. However, closed cycle solutions are also investigated to ensure capability to accommodate it

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**

Representative structure of diffusion-bonded microchannel heat exchangers (courtesy: VPE)



LFR heat exchanger: close-up view on upper portion of HX

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