Fuel Cladding Materials for the Westinghouse Lead Fast Reactor

Emre Tatli, Mike Ickes, Catou Cmar, Arash Parsi, Paolo Ferroni

June 2022

GAIN Innovative Materials Research Workshop

ANS Annual Meeting 2022

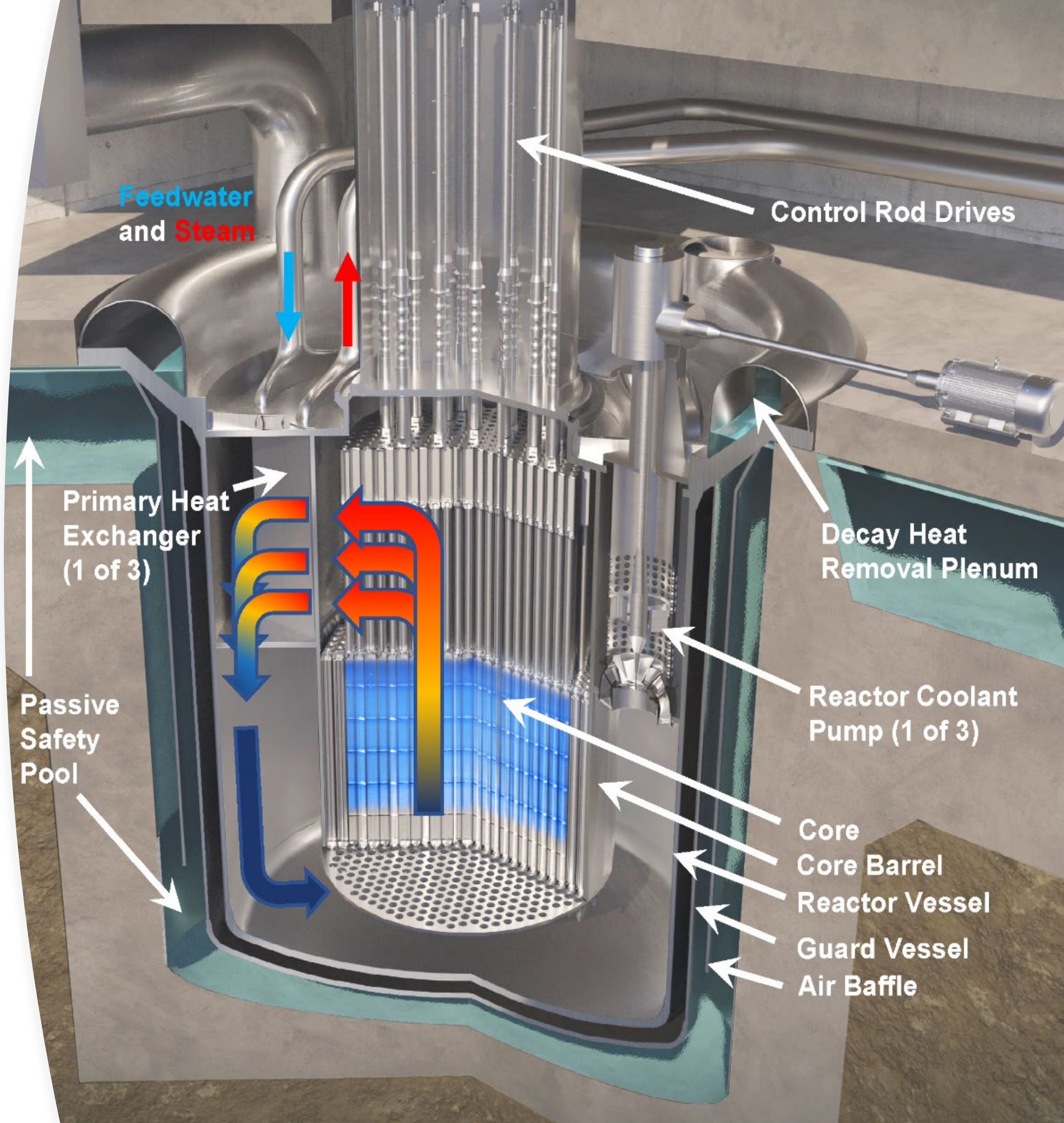
© 2022 Westinghouse Electric Company LLC. All Rights Reserved.

Westinghouse LFR's key characteristics

- Pool-type, passively safe, modular construction
- Primary mission: economic competitiveness and versatility in global markets
- Two-phase approach to deployment:
  - Demonstrator (Phase I)
  - Higher-performance commercial unit (Phase II)

  Difference in phases is primarily moving to higher lead temperatures

Reactor power	~450 MWe Net
Efficiency	~47%
Primary / secondary coolant	Liquid lead / Supercritical water
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)



Westinghouse LFR Materials Strategy

- **Phase I – Lower temperature**
  - Intend to use existing, qualified materials with corrosion-resistant coating/cladding
- **Phase II – Higher temperature**
  - Intend to qualify new material(s) to allow for greater reliability at high temperature
    - Alumina-forming Austenitic (AFA) stainless steel is of special interest as a structural material
    - Interest also in fuel cladding materials that will allow higher burnup, higher temperature operation

	Phase	Max steady-state T (°C)	Pb velocity (m/s)	Candidate materials
Guard Vessel	I	<100	N.A.	AISI 316[a]
	II	<100	N.A.	AISI 316[a]
Reactor Vessel	I	~400	<1	AISI 316[a]
	II	~400	<1	AISI 316[a], 15-15Ti[a], AFA
Reactor Internals	I	~530	<1	AISI 316[a],15-15Ti[a]
	II	~650	<1	AISI 316[a],15-15Ti[a], AFA
Heat Exchanger	I	~530	<1	AISI 316[a]
	II	~650	<1	AISI 316[a], AFA
Fuel rod cladding	I	~600	≤2	15-15Ti [a]
	II	~750	≤2	15-15Ti [a], AFA, FeCrAl ODS[a], SiC/SiC
Fuel assembly structures	I	~530	≤2	15-15Ti[a]
	II	~650	≤2	15-15Ti [a], AFA, FeCrAl ODS[a], SiC/SiC
RCP impeller	I	~400	<10	AISI 316[a], Tantalum
	II	~400	<10	AISI 316[a], AFA, Tantalum

a – Indicates coated/clad with an alumina-forming material, such as FeCrAl

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

Westinghouse LFR Fuel Cladding Material Strategy

- 15-15Ti is a 15Cr-15Ni stainless steel with a titanium addition for stabilization
- D9, DIN 1.4970, AIM1 are examples of some grades that have been used as fuel cladding
- DIN 1.4970 is targeted as the demonstrator fuel cladding material due to existing property data and positive operating experience
- At demonstration reactor temperatures (<550°C), in liquid lead with optimal oxygen control, this material could perform reliably without a corrosion-resistant coating
  - To improve margin and relax oxygen control requirements, a coating for corrosion protection is prescribed
    - Plan to leverage Westinghouse experience coating fuel rod cladding tubes gained during Accident Tolerant Fuel development and other related R&D
- Strain due to creep, void swelling are anticipated to be life limiting

Qualification of this material concept for LFR is underway with planned liquid lead erosion/corrosion and combined effects tests

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

Westinghouse LFR Fuel Cladding Material Strategy

- For the higher-temperature follow on units, where operation to 650°C is projected, more advanced materials are under consideration to enable higher burnup (>100 dpa) and eliminate the need for coating

  - Oxide-dispersion strengthened (ODS) FeCrAl alloys have inherent liquid lead corrosion resistance and the potential for high creep strength
    - Some have also demonstrated extreme void swelling resistance

  - Alumina-forming austenitic stainless steels have improved creep strength and corrosion and oxidation resistance relative to 300-series steels
    - No irradiation data exists at this time

  - Ceramic composite materials, like silicon carbide composites, are also non-reactive with lead and have shown promising high temperature strength and void swelling resistance
    - There is further synergy with other Westinghouse programs, such as ATF, in this area

Some development and testing of such materials is presently being pursued

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

LFR Testing Program in the United Kingdom

Supported by the UK Government

Eight LFR test rigs being erected in the UK:

- Westinghouse (3)
- Ansaldo Nuclear (2)
- Jacobs (2)
- University of Bangor (1)
- Fuel development at National Nuclear Laboratory and Univ. of Manchester

...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

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

FRAZER-NASH CONSULTANCY

Westinghouse

Jacobs

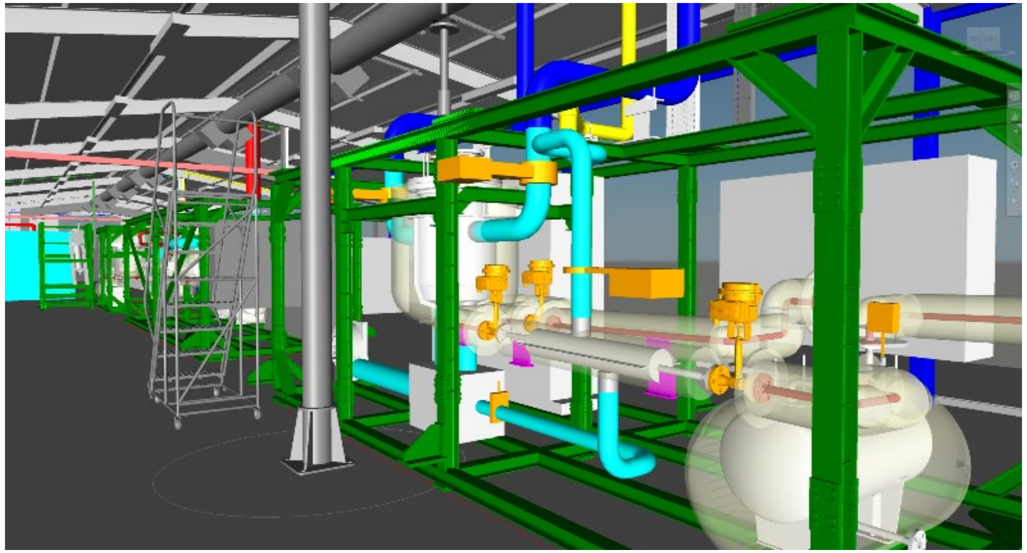
NATIONAL NUCLEAR LABORATORY

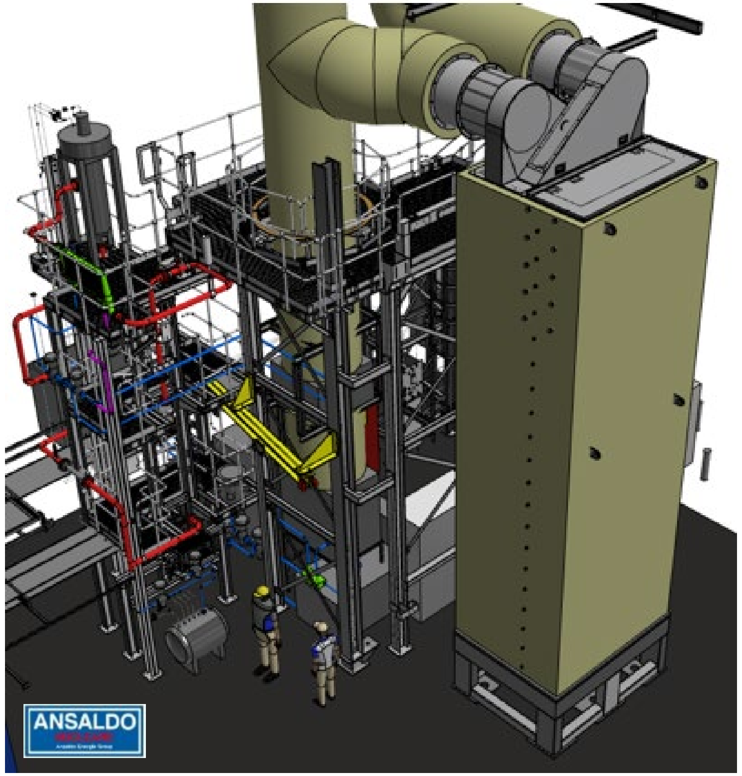
NUCLEAR AMRC

PRIFYSGOL BANGOR UNIVERSITY

MANCHESTER 1824

VPE





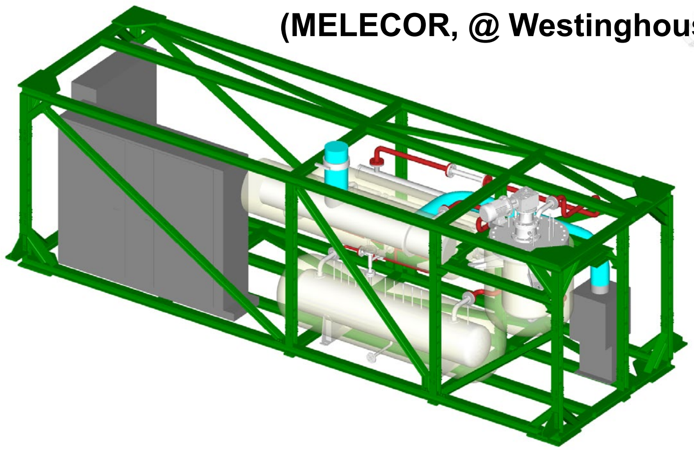
Westinghouse

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

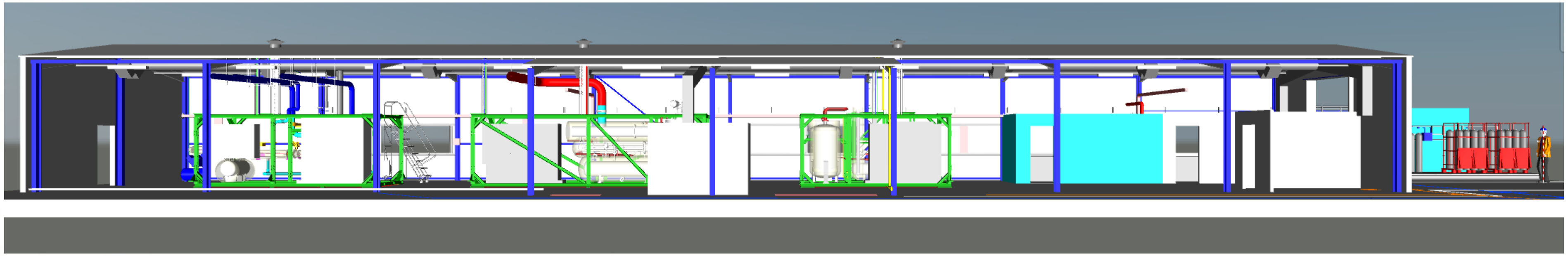
Westinghouse LFR-supporting Materials Testing Capabilities

- In the United Kingdom:
  - Purpose-built facilities for testing materials in oxygen-controlled static and flowing liquid lead at temperatures up to 800°C
  - Purpose-built facility for high-velocity erosion testing in oxygen-controlled liquid lead
  - Creep test stands for creep testing in liquid Pb are also being installed
- In the United States:
  - Liquid metal embrittlement and in-Pb creep testing capabilities are constructed or under construction at Westinghouse
  - Multi-purpose test facility to be built at the Univ. of Pittsburgh
  - Work performed at the Univ. of New Mexico, supporting LFR as well as VTR Lead Cartridge

MEtal-LEad CORrosion facility (MELECOR, @ Westinghouse)



Cross-sectional view of Westinghouse building in Springfields, UK, hosting three Pb-based test facilities



Westinghouse

 © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

Westinghouse LFR Fuel Cladding Material Strategy

- Materials have been identified for the components of the Westinghouse LFR
- Fuel cladding carries special challenges due to the potential for high radiation damage levels and high temperatures
- For the demonstrator, FeCrAl coated DIN 1.4970 is the material of choice
- For follow-on commercial units, more advanced materials are being pursued to enhance performance
- Substantial testing infrastructure has been established to allow full qualification of fuel cladding and other materials

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.

Thank you

Please submit any questions to ickesmr@westinghouse.com

Westinghouse

Westinghouse Non-Proprietary Class 3 | © 2022 Westinghouse Electric Company LLC. All Rights Reserved.