U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Summary of Contributions to Gain Innovative Materials workshop at ANS (6/15/22)

Stuart Maloy

Nuclear Materials Advisor

Pacific Northwest National Laboratory

- Nuclear Materials Advisor
- Pacific Northwest National Laboratory

Agenda

PT	Topic	Presenter
1:00 p.m.	Welcome, Introductions, Purpose, Agenda	Lori Braase, GAIN
1:15 p.m.	DOE *Tentative New* Program Objectives	Stephen Kung, DOE
1:30 p.m.	Innovative Cladding Materials for Advanced Reactors / Q&A	Stuart Maloy, PNNL
Advanced Nuclear Industry Gaps and Needs (10 Minute Presentations)		Lori Braase, GAIN
2:00 p.m.	Aurora Reactor	Ryan Webster, Oklo
2:15 p.m.	Westinghouse Lead Fast Reactor	Emre Tatli, Westinghouse
2:30 p.m.	Molten Chloride Fast Reactor (MCFR)	Matt Wargon, TerraPower
2:45 p.m.	*Discussion*	Stuart Maloy, PNNL
National Laboratory Capability and Methods (15 Minute Presentations)		
3:00 p.m.	Summary of the "Capability Needs for Irradiated and Radioactive Materials Research Study"	Simon Pimblott, INL/NSUF
3:20 p.m.	Probing Nanoscale Damage Gradients in Irradiated Metals	Siddhartha Pathak, Iowa State
3:40 p.m.	Properties of Advanced ODS Alloys and Routes for Application	TS Byun, ORNL
4:00 p.m.	High Dose Ion Irradiation Testing of Materials	Kevin Field, U of Michigan
4:20 p.m.	Gaps and Needs Discussion	
5:00 p.m.	Identify Path Forward and Actions	Stuart Maloy, PNNL
5:30 p.m.	Adjourn	

Industry Gaps and Needs

General-High Level

- High Level Needs
  - Irradiation testing facility in the US
  - Qualification of materials/alloys in short timeframes
  - Prioritization of immediate needs
  - A new materials program would need to address engineering scalability, engineering application and joining capabilities.

Industry Gaps and Needs

Oklo's Aurora Reactor

- Oklo- sodium cooled fast reactor-R. Webster – Design Parameters
  - Electric capacity – 1-15 Mwe
  - Thermal capacity – 4-50 MWt
  - Temp of usable heat – 500-550C
  - Capacity factor - > 90%
  - Licensed operating life – 20+years
  - Land Usage - < 1 acre

Larger designs also in development

Industry Gaps and Needs

Oklo's Aurora Reactor

- Oklo- sodium cooled fast reactor-R. Webster – cladding and core materials
  - Near term (1-5 years)
    - Core materials from existing alloys (e.g. F/M and Austenitic SS)
    - Challenged by limited supply chain capacity, capability and interest
  - Intermediate term (5-10 years)
    - Existing alloys with FCCI barriers
    - Incremental improvement in existing alloys
    - Commercial availability of new alloys (e.g. refractory-based metal alloys)
    - Challenged by lack of performance data and supply chain development
  - Long term (10 + years)
    - ODS alloys
    - New manufacturing methods
    - Advanced fuel forms
    - Challenged by lack of performance data and limited to no existing supply chain

Industry Gaps and Needs

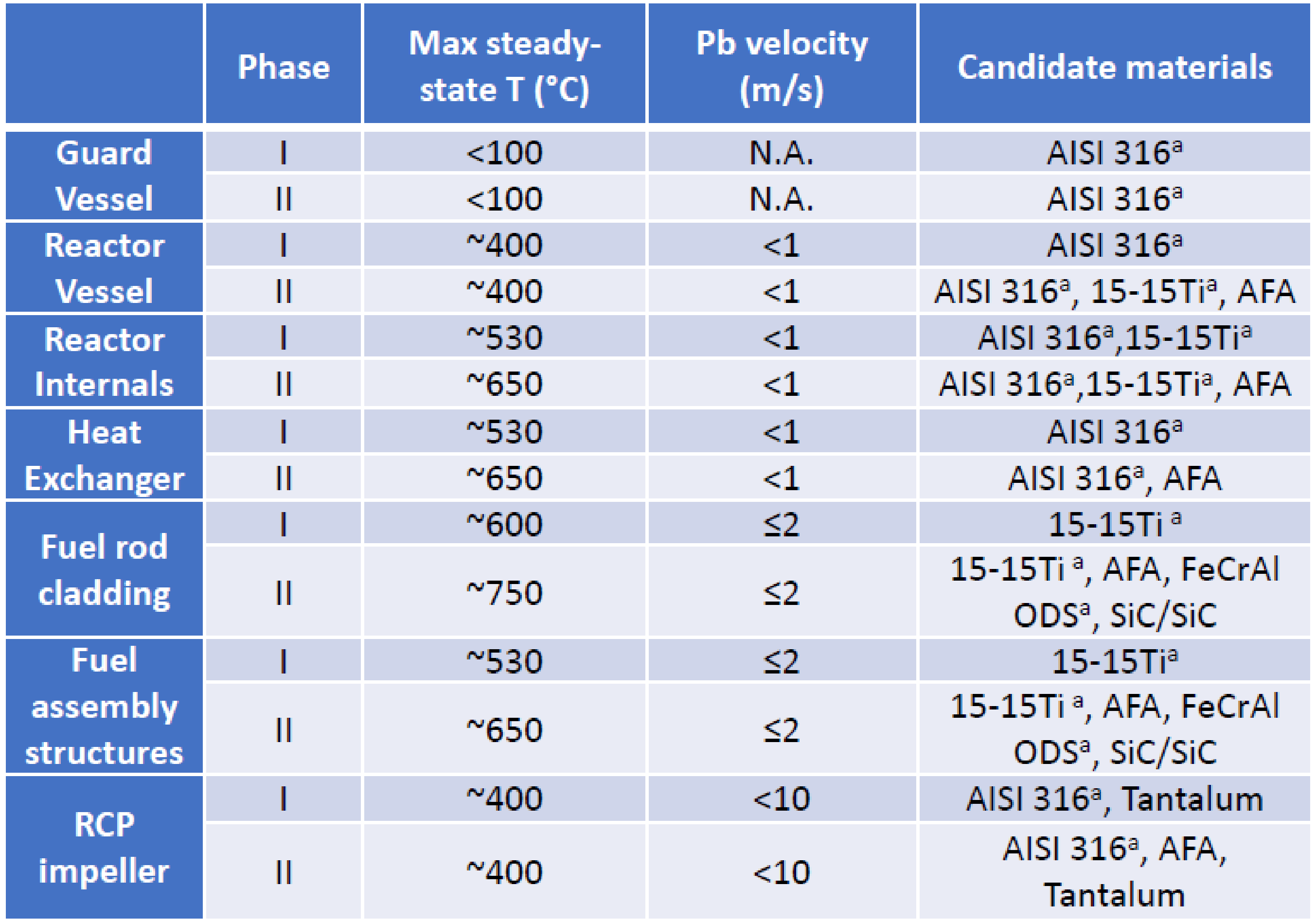
Westinghouse - LFR

- Westinghouse LFR – E. Tatli – Design parameters
  - Reactor power- 450 MWe heat
  - Efficiency - ~47%
  - Primary/secondary coolant – liquid lead/supercritical water
  - 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 yrs; direct-to-cask refueling
  - Operating pressure- 0.1 MPa (primary)/~34 MPa (secondary)
  - Lead coolant min/max temperature – 390C/530C (phase 1); 390C/650C (phase 2)

Industry Gaps and Needs

Westinghouse - LFR

- Westinghouse LFR – E. Tatli – LFR Material Strategy
  - Phase 1 – lower temperature
    - Use existing, qualified materials with corrosion-resistant coating/cladding (e.g. 316L, 15-15Ti)
  - Phase II – higher temperature
    - Qualify new material(s) to allow for greater reliability at high temperatures
      - Alumina-forming austenitics (AFA)
      - FeCrAl ODS, SiC/SiC, tantalum



	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

Industry Gaps and Needs

Terrapower (MCFR)

- Terrapower Molten Chloride Fast Reactor (MCFR) – Cheng Xu, M. Wargon
  - MCFR program focused on materials test for design analysis and also leveraged for NRC licensing and qualification
  - Materials of Interest
    - Alloy 625 grade 2
    - Alloy 617
    - 316H
    - Refractory Alloys
    - Ceramics (SiC, etc)
  - Engineering properties of interest
    - Creep, Fatigue, creep-fatigue, corrosion and erosion -(550-800C)
    - Irradiation effects on mechanical properties and corrosion – (550-800C, 0-100 dpa fast spectrum)

Inconel alloys are preferred materials because of their known high temperature performance, corrosion performance, weldability and ASME code case

University and National Lab Capabilities and Methods

- Capability Needs for Irradiated and Radioactive Material, (S. Pimblott, INL)
- Advanced ODS alloys and routes for application, (TS Byun, ORNL)
- Nanoscale Mechanical Testing (S. Pathak, Iowa State U.)
- High Dose Ion Irradiation (K. Field, U. Michigan)

Innovative Metal Alloys

- Advanced F/M alloys
- Advanced austenitic alloys (e.g. alumina forming austenitics)
- Refractory Metal Alloys
- High Entropy Alloys
- Metallic Glasses

- Novel microstructures (e.g. nanostructured grain size, fine precipitate distribution)
- Novel manufacturing techniques to produce thin walled tubes
- Joining methods for thin walled tubing
- Coatings to prevent FCCI (if needed)

Oxide Dispersion Strengtened Alloys

- ODS ferritic steels (e.g. 14YWT, 12YWT)
- ODS FeCrAl (e.g. MA956, PM2000)
- ODS austenitic alloys

- Processing methods for producing thin-walled tubes
- Processing methods to form a uniform, fine and stable oxide dispersion
- Joining methods for thin-walled tubing that maintain microstructure
- Coating methods to prevent FCCI (if needed)

Ceramics/composites

- SiC/SiC composites
- Other Ceramic/ceramic composites
- Metal matrix composites

- Processing methods to produce thin walled tubing
- Methods to assure tubing his hermetically sealed (e.g. coating methods)
- Joining methods

Innovative Testing and Characterization Methods

- High dose irradiation testing (e.g. ion irradiation)
- Microscale mechanical testing
- In-situ mechanical testing under irradiation
- Novel characterization techniques (e.g. X-ray measurements in situ)