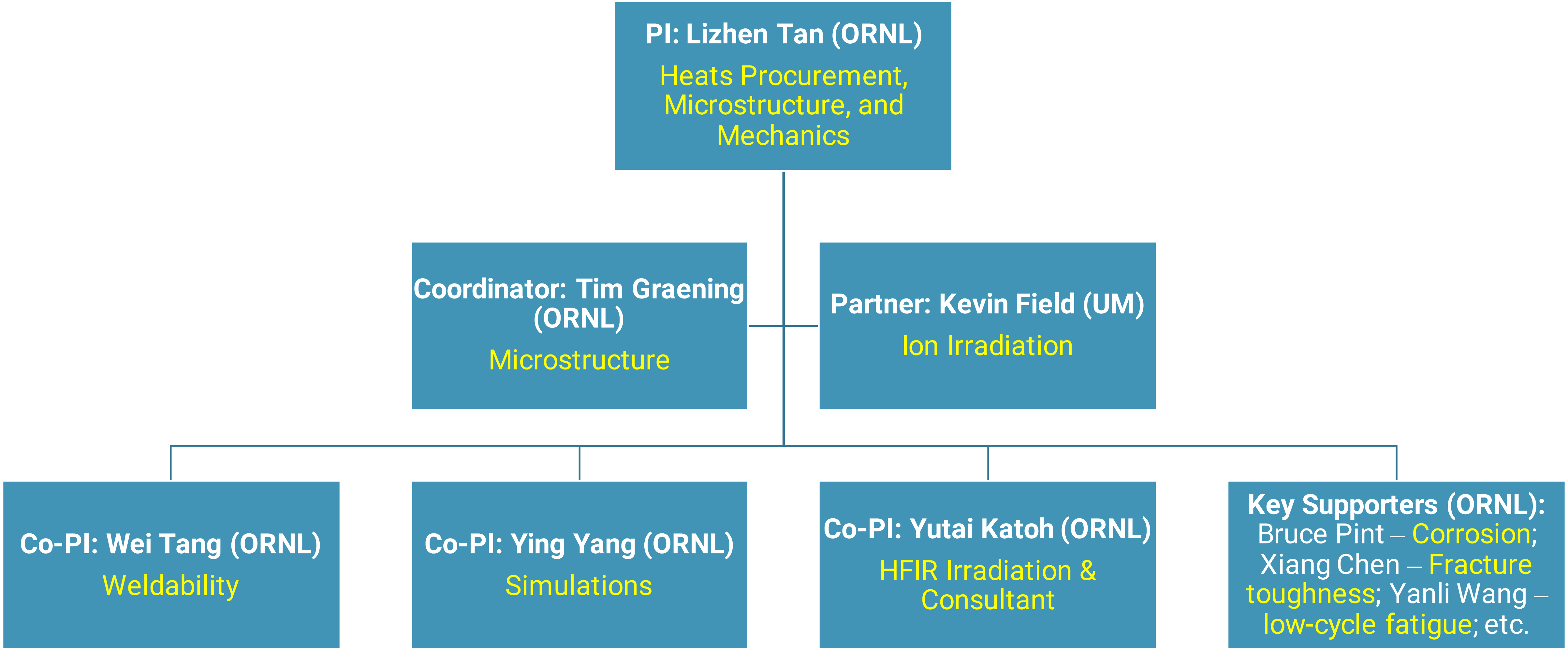
Advance Castable Nanostructured Alloys (CNAs) for First-Wall/Blanket Applications

(project #2288-1517)

GAMOW Kickoff Meeting
January 21–22, 2021

Lizhen Tan, Oak Ridge National Laboratory
Wei Tang, Ying Yang, Yutai Katoh, Oak Ridge National Laboratory
Kevin G. Field, University of Michigan

Team members and roles



PI: Lizhen Tan (ORNL)
Heats Procurement, Microstructure, and Mechanics

Coordinator: Tim Graening (ORNL)
Microstructure

Partner: Kevin Field (UM)
Ion Irradiation

Co-PI: Wei Tang (ORNL)
Weldability

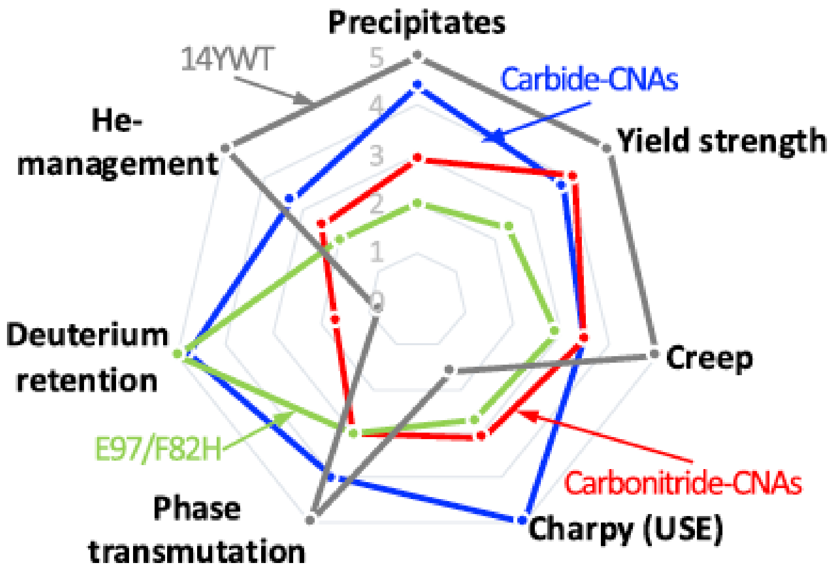
Co-PI: Ying Yang (ORNL)
Simulations

Co-PI: Yutai Katoh (ORNL)
HFIR Irradiation & Consultant

Key Supporters (ORNL):
Bruce Pint – Corrosion; Xiang Chen – Fracture toughness; Yanli Wang – low-cycle fatigue; etc.

The need of advanced reduced-activation ferritic/martensitic (RAFM) steels

- Motivation
  - RAFM steels are critical materials for fusion-energy subsystems such as integrated first-wall and blanket technology.
  - Current RAFM steels are incapable of operating above ~550°C, however, castable nanostructured alloys (CNAs), recently developed at the laboratory scale, can potentially achieve significantly higher temperatures.
- Innovation
  - Laboratory-scale heats of carbonitride- and carbide-CNAs showed various advantages over current RAFM steel Eurofer97 and F82H and oxide-dispersion-strengthened 14YWT examined in seven aspects.
    - **Carbide-CNAs showed the best-balanced properties.**
- Goal
  - Establish a US-RAFM steel based on the carbide-CNAs to demonstrate its industry-scale heats production viability and performance advantages over current RAFM steels.
- Risks
  - Technical: Industry-scale heats impurity and microstructure control
  - Adoption: Cost (material volume) reduction amount



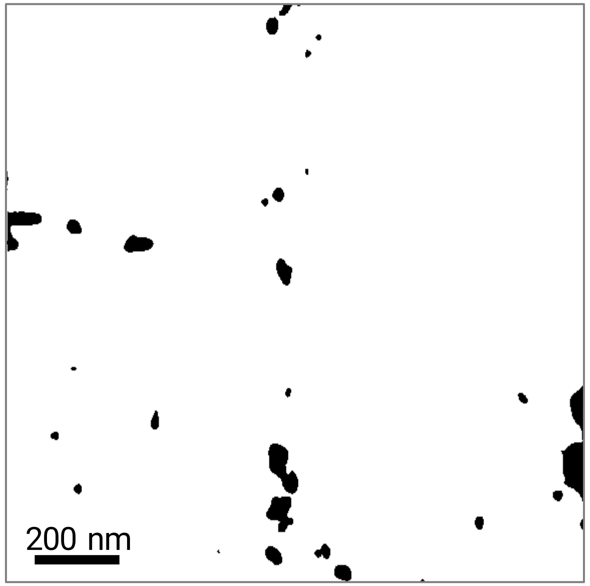
Seven-aspect property comparison indicates the advantages of the laboratory-scale carbide-CNAs over the other steels, in support of its scale up studies. (Scale 0-5 refers to the worst to the best) [L. Tan, et al., JNM 540 (2020) 152376]

Novelty of CNAs in comparison to current RAFM and ODS steels

	Current RAFM steels	CNAs	Oxide-dispersion-strengthened alloys
Manufacturing	Conventional steel making techniques, e.g., VIM, EAF, ESR, etc. (generally inexpensive, possible complex shapes, and isotropic properties)		Mechanical alloying and sintering (generally expensive with small-scale production and anisotropic properties)
Primary features	Lath structures with a low density of MX precipitates (10^{19} m^{-3})	Lath structures with a **high density of MX precipitates** (**10^{21}** m^{-3})	Ferrite or ferrite/TM dual phase with a large span of oxide cluster densities (**10^{21}**–10^{23} m^{-3})

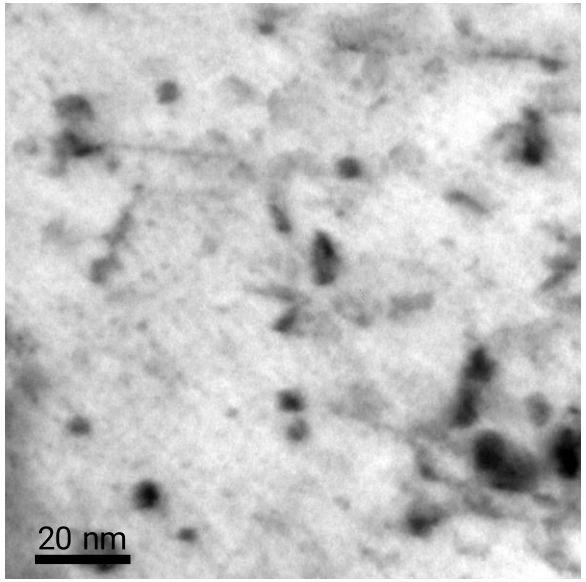
Representative microstructures

Eurofer97

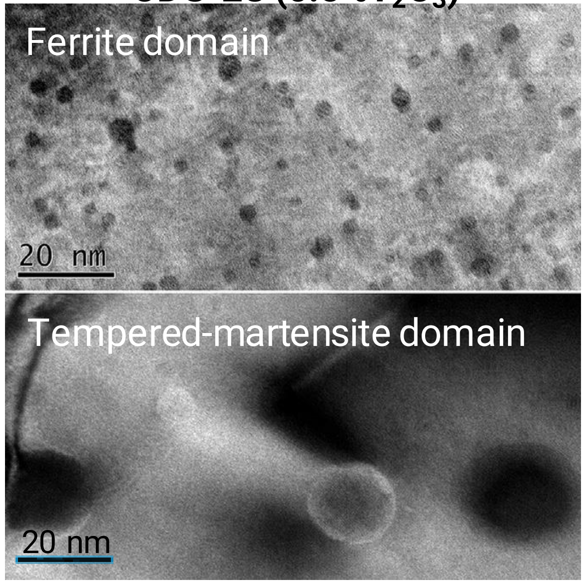


[M. Klimenkov et al. / Progress in Nuclear Energy 57 (2012) 8]

CNA3



ODS-EU (0.5%Y_2O_3)



[D. Brimbal et al. / JNM 465 (2015) 236]

Project milestones and outcomes/impacts

WBS		Title	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
M1	M1.1	Go/No-Go: Refine tasks and milestones (if applicable)	■											
	M1.2	Determine benchmark conditions (referring to Eurofer97/F82H)	■											
M2 Industry-scale heats production	M2.1	Procurement	■											
	M2.2	Evaluate quality of 0.25-ton heats	■	■	■									
	M2.3	Welding wire production (~130 kg)				■	■							
	M2.4	Go/No-Go: Demonstrate manufacturing feasibility (2-5 ton heats)	■	■	■	■	■	■						
M3 Heats property evaluation	M3.1	Weldability (TIG following relevant ASME code for Grade 91)			■	■	■	■						
	M3.2	Mechanical properties (follow relevant ASTM testing standards)			■	■	■	■	■	■	■	■	■	■
	M3.3	Radiation resistance (ion and neutron irradiations and PIE)						■	■	■	■	■	■	■
	M3.4	Coolant compatibility (Li-Pb and Li-Sn exposures)						■	■	■	■	■	■	■
M4 Deliverables	M4.1	Tech-2-market plan		■	■	■	■	■	■	■	■	■	■	■
	M4.2	Presentations				■				■				■
	M4.3	Publications								■				■

- Desired project outcomes
  - CNAs tend to reduce ~1/3 the mass and cost for a fusion reactor, leading to a reduced radioactive waste volume.
  - Increase the Technology Readiness Level (TRL) of CNAs up to TRL5 from the current TRL3. Generate some code qualification credible data, e.g., tensile, fracture toughness, creep, and fatigue, tested using relevant ASTM regular samples and test standards.
  - Maintain US leadership in fusion energy by motivating novel compact fusion system designs and constructions.

T2M and aspirational follow-on plans

- Relevant techno-economic metrics
  - Current RAFM steels Eurofer97 and F82H cost ~$4.6k/ton (raw material cost)
  - CNAs are expected to reduce the total raw material cost by ~1/3 compared with the current RAFM steels
    - CNAs have higher tensile and creep strength to reduce the required material volume/mass
    - CNAs have a slightly lower raw material cost of ~$4.2k/ton
  - The stronger RAFM steel CNAs can increase design safety margins and flexibility, in addition to the reduced material mass/cost, and eventually reduced radioactive waste mass, which will improve some fusion economics.

- Test & deployment plans/aspirations
  - Commercial fusion concept(s) you are enabling: DEMO reactor and ARPA-E BETHE developmental concepts that require advanced RAFM steels for some key component manufacturing
  - Path to testing on fusion-scale experiment: Material Plasma Exposure eXperiment (MPEX)
  - Potential partnerships with private sector: Reactor component design and manufacturing