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Microstructure Optimization and Novel Processing Development of ODS Steels for Fusion Environments [MONDO-FE]

GAMOW Kickoff Meeting
January 21–22, 2021

Dalong Zhang, Jens Darsell, Glenn Grant, Pacific Northwest National Laboratory
Emma White, Iver Anderson, Ralph Napolitano, Ames Laboratory
Tim Horn, Chris Rock, Djamel Kaoumi, North Carolina State University

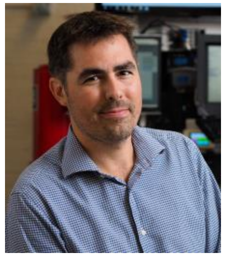
U.S. DEPARTMENT OF ENERGY

Team members and roles

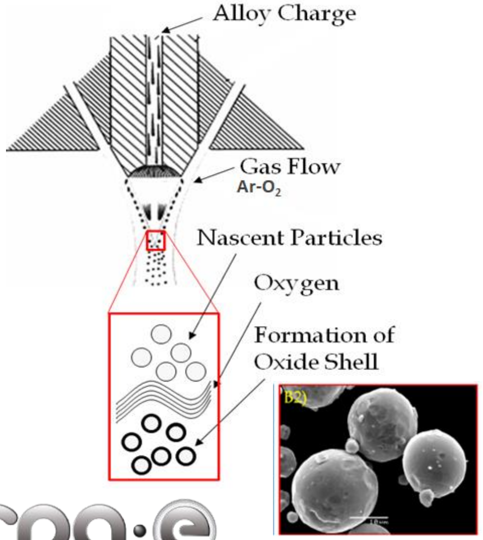


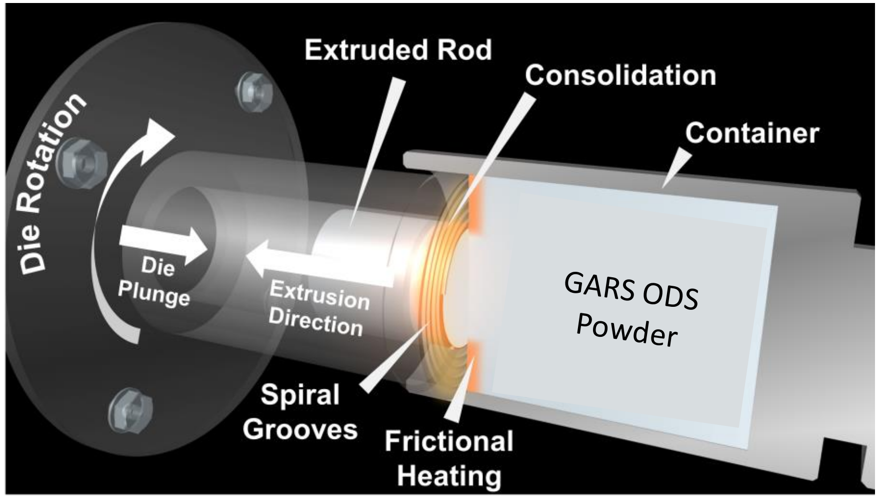


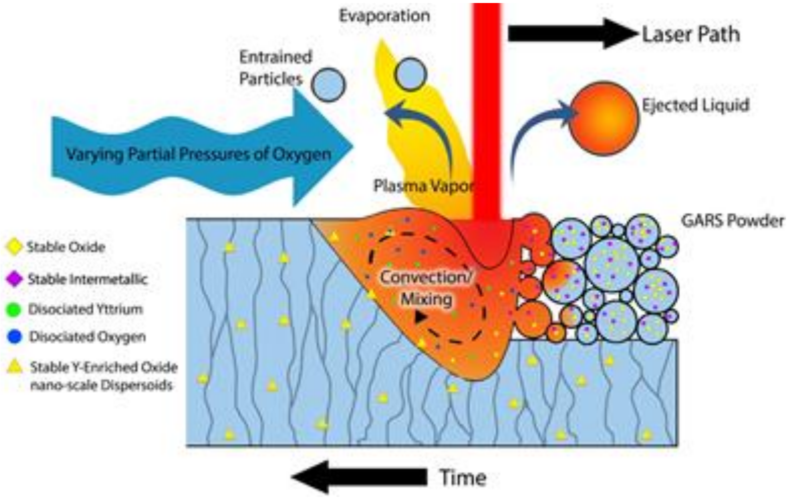




Ames Laboratory	Pacific Northwest National Laboratory	NC State University
Iver Anderson, **Emma White**, **Ralph Napolitano**	**Dalong Zhang (PI)**, **Glenn Grant**, **Jens Darsell**	**Tim Horn**, **Chris Rock**, **Djamel Kaoumi**
Generate ODS precursor via Gas Atomization Reaction Synthesis (GARS)	Fabricate ODS steel rod via Shear Assisted Processing and Extrusion (ShAPE)	Consolidate GARS via Laser-Powder Bed Fusion (L-PBF)







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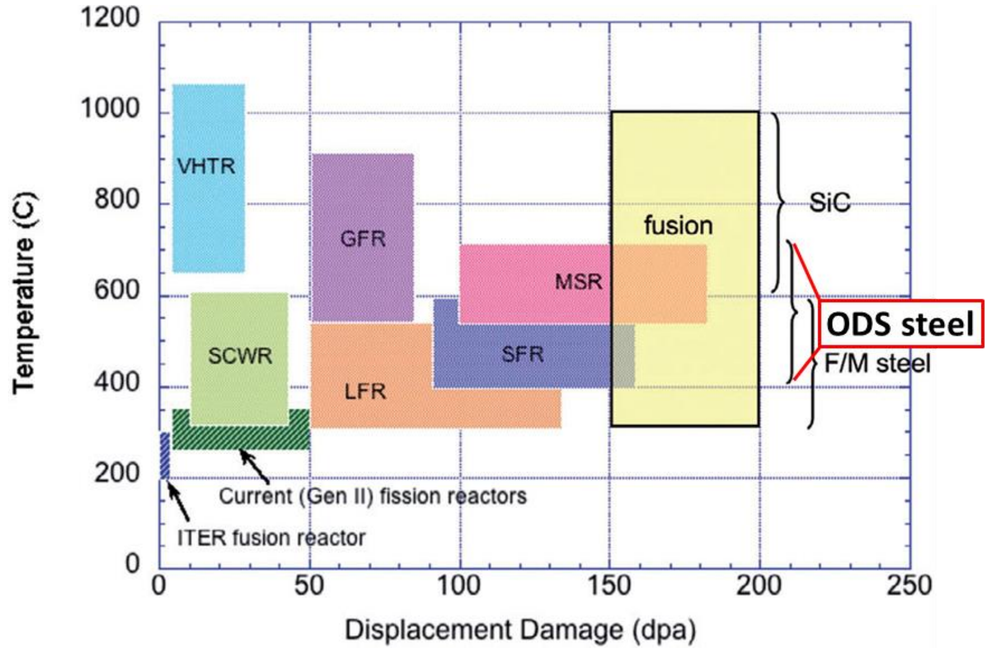
Motivation, innovation, and goals of the project

- ODS steel is almost the perfect material to build a fusion reactor, if only we could make lots of it with uncompromised properties

ARC Reactor designed blanket temperature (Inconel 718 as "first-round" material, not reduced activation)	Thermal conversion efficiency
900 K	~40%
1100 K	~46%
1200 K	~50%

- Game-changing scalable cost-effective ODS ferritic steel fabrication to enable fusion energy reactors



1. S.J. Zinkle, J.T. Busby, Structural materials for fission & fusion energy, Materials Today 12(11) (2009) 12-19.
2. B.N. Sorbom et al. / Fusion Engineering and Design 100 (2015) 378–405

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Moving beyond mechanical alloying

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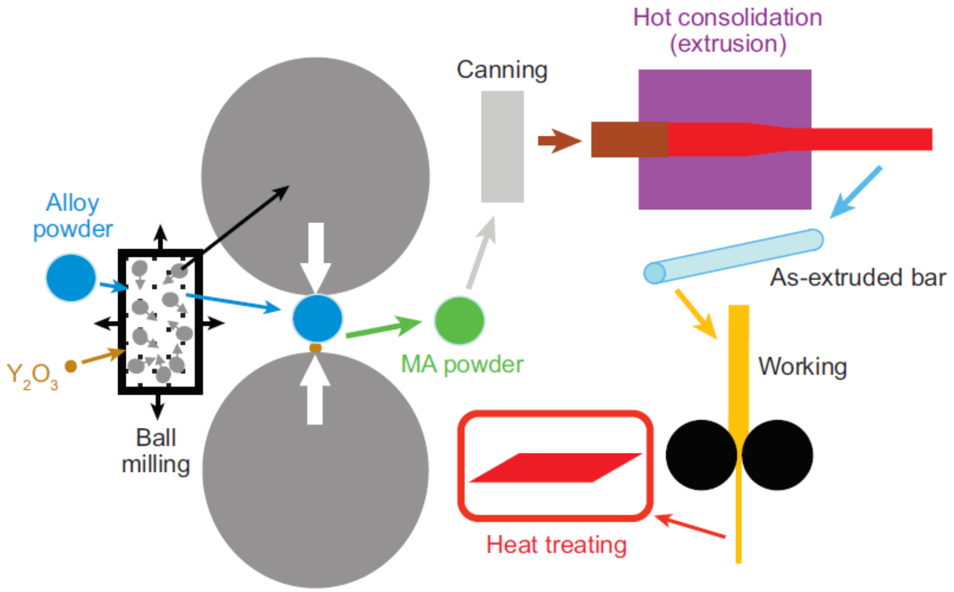

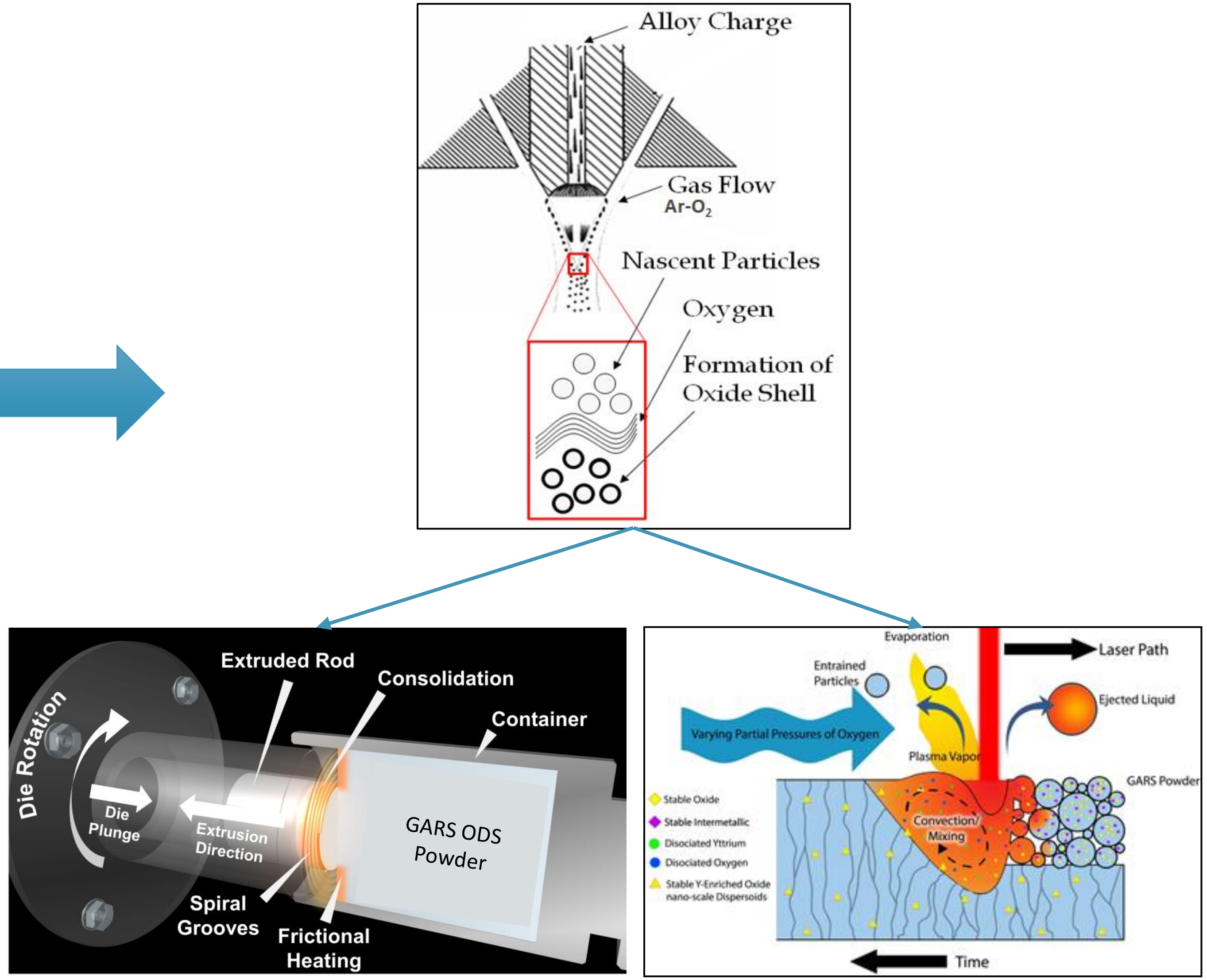

1. G.R. Odette, M.J. Alinger, B.D. Wirth, Recent Developments in Irradiation-Resistant Steels, Annual Review of Materials Research 38(1) (2008) 471-503.

Tasks, milestones, risks, desired project outcomes

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Tasks

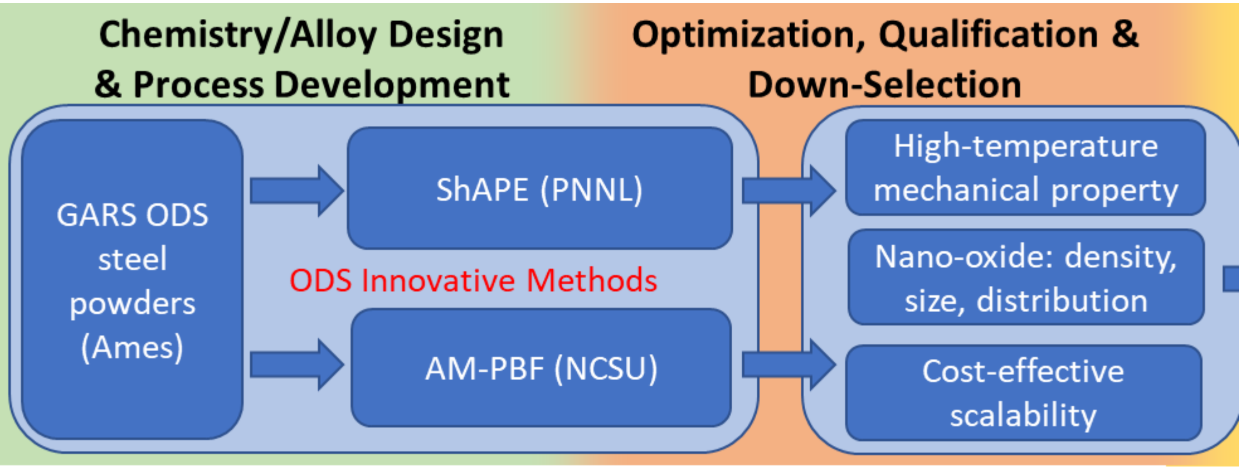
1. Optimize GARS ODS powder synthesis
2. ShAPE process R&D and heat treatment
3. L-PBF within inert and reactive atmosphere
4. HT tensile and creep testing
5. T2M and TT&O

Risks

- Success of fabrication
- Oxide agglomeration

Mitigation

- Alloy design flexibility
- Multiple processing routes



Metric	State of the Art	Proposed
Tensile strength and 100-hour creep rupture strength at 650 °C	MA-based ODS steels Tensile ≥ 400 MPa Creep ≥ 200 MPa	Scalable ODS steels Equivalent or better
Nano-oxides for creep resistance, radiation tolerance, and He management	MA-based ODS steels Density: 10^{22}~10^{23}/m^3 Size ≤ 5 nm	Scalable ODS steel nano-oxides Density: 10^{22}~10^{23}/m^3 Size ≤ 10 nm
Complex parts/components	Simple shapes	L-PBF enabled near-net-shape

Milestones

- ≥ 99% density dia 5 mm × 100 mm rod (ShAPE), 12 mm × 12 mm × 100 mm tensile bar (L-PBF)
- Nano-oxide density
- HT tensile and creep strength

T2M and aspirational follow-on plans

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- Aim to reduce cost by 50%
- Enable higher operating temperature and efficiency

Metric	State of the Art	Proposed
Cost estimate	\$100~200/kg	\$50~100/kg scaled-up
Blanket operating temperature limited by material	< 550 °C based on RAFM steel	≥ 650 °C based on ODS steel
Expected thermal conversion efficiency	~33%	> 40%

- Test & deployment plans/aspirations
  - Promising structural material for various fusion reactor concepts: ARC Reactor, DEMO, etc.
  - Follow-on collaboration for ion or neutron irradiation
    - Preliminary discussion held
  - Planned outreach to fusion industry
    - Establish part and temperature target for specific application
    - Understand industry timing for testing and deployment

1. S. Dewson, B. Thonon, 2003 International Congress on Advances in Nuclear Power Plants (ICAPP 2003), 2003.
2. B.N. Sorbom et al. / Fusion Engineering and Design 100 (2015) 378–405
3. M. Abdou et al. / Fusion Engineering and Design 100 (2015) 2–43