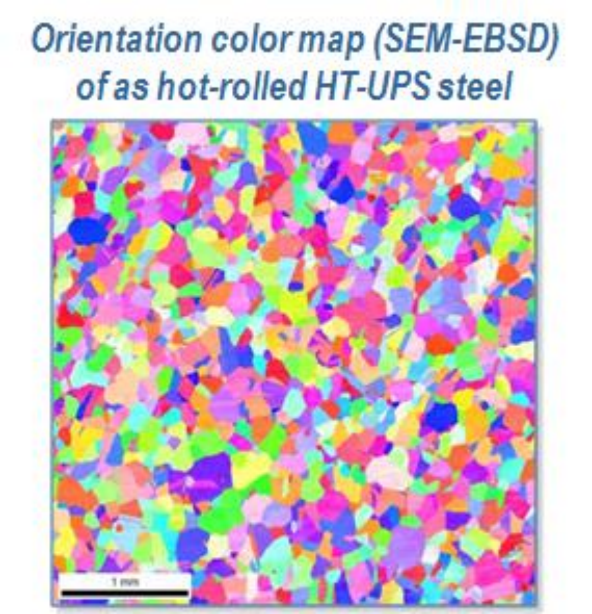
Nuclear Energy University Programs

ARC-3
Advanced Structural Materials

Technical POC – Jeremy Busby

presented by Bob Hill



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Advanced Reactor Concepts

The mission is to develop and refine future reactor concepts that could dramatically improve nuclear energy performance (e.g., sustainability, economics, safety, proliferation resistance)

The strategic approach is to:

- Tackle key R&D needs for promising concepts
  - *Fast reactors for fuel cycle missions*
  - *Fluoride salt cooled thermal reactor for high-temperature missions*
- Develop innovative technology features with potential benefits to many concepts (e.g., energy conversion)
- Utilize international collaborations to leverage and expand R&D investments
  - *Continuation of multi-lateral Generation-IV R&D Projects*
  - *Investment in strategic bilateral or trilateral partnerships*
- Stimulate ideas for transformational reactor concepts

ARC Organizational Structure

Advanced Reactor Concepts (ARC) is part of Reactor Concepts RD&D, with the NE-74 designation

ARC is organized into several technical areas:

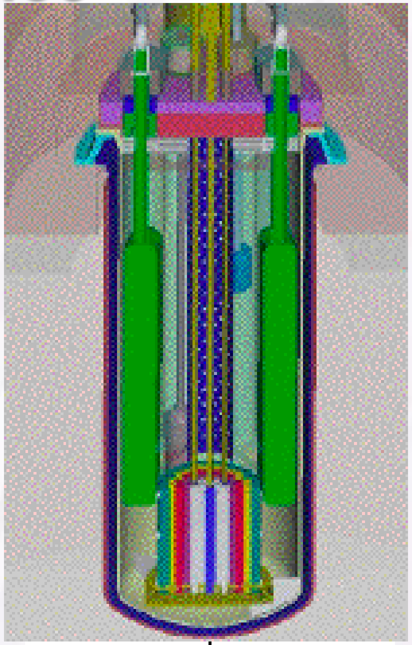
- Management and Integration (*Hill-ANL)*
- Fast Reactor Concepts *(Grandy-ANL)*
- Thermal Reactor Concepts *(Holcomb-ORNL)*
- Energy Conversion Technology *(Rochau-SNL)*
- Nuclear Data *(Hill-INL)*
- Generation-IV International Support *(McFarlane-INL)*
- Transformational Concepts

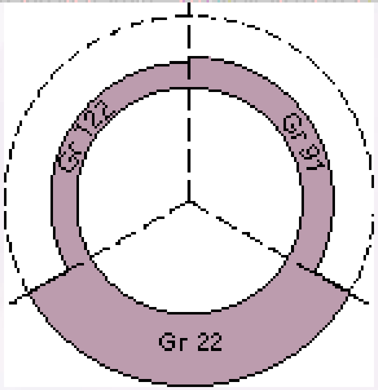
Other DOE-NE R&D initiatives include advanced reactor applications

- Modeling and Simulation *(NE-71)*
- Transmutation Fuels *(NE-FCT)*
- High Temperature Fuels *(NE-73)*

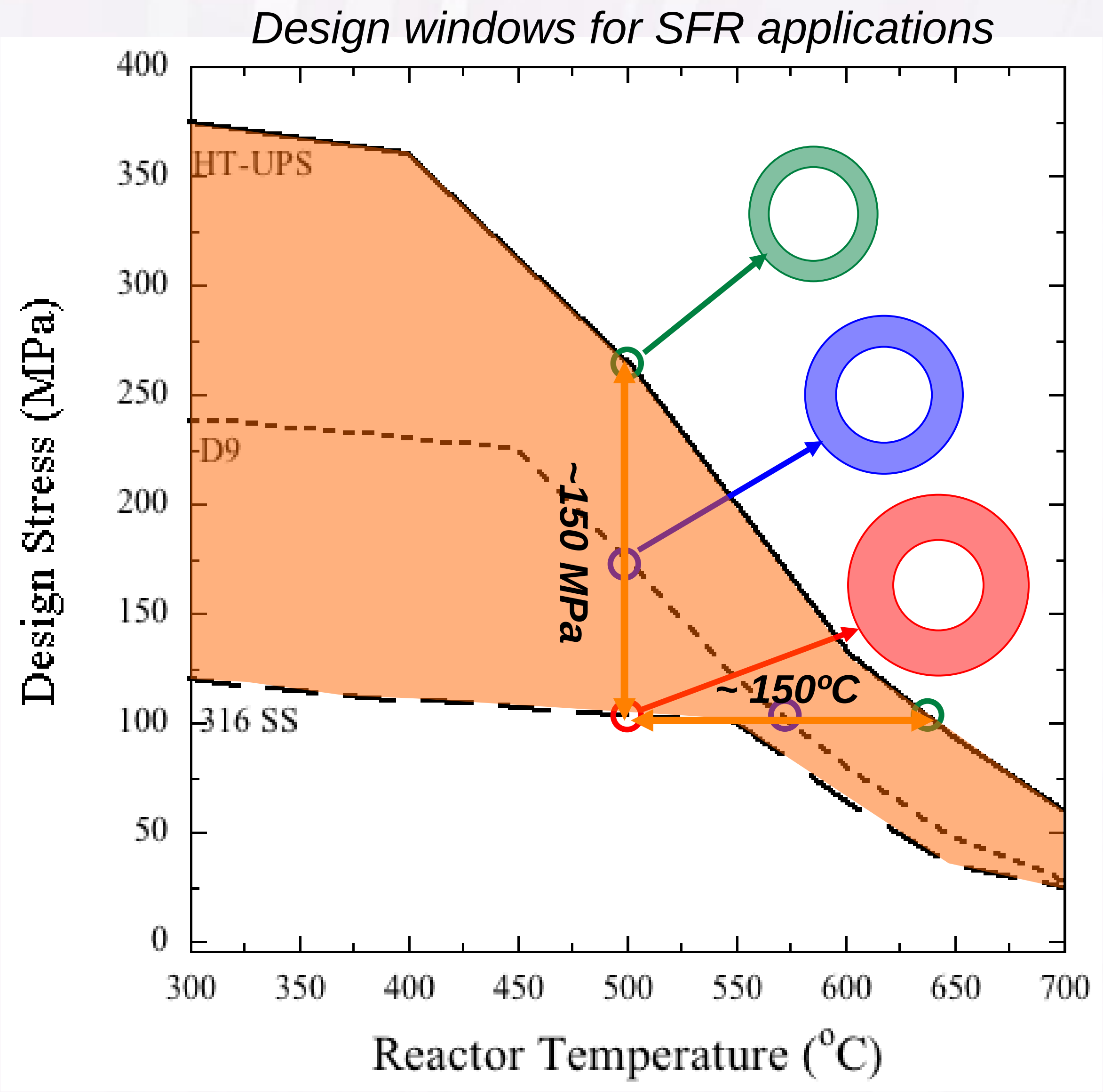
Goal is to provide qualified, advanced structural materials to enable improved reactor performance

- Choosing the right materials can impact key requirements for advanced fast reactor development
  - Economy: reduce capital costs through reduced commodities and simplifications
  - Flexibility: higher material performance allows greater options to designers
  - Safety: higher material performance promotes larger safety margins and more stable performance over longer lives
- For fast reactor R&D, an extensive evaluation of candidate alloys was performed in FY2008.
  - National effort (5 labs, 5 universities)
  - Examined past and other ongoing materials efforts (nuclear, fossil, and space)
- Both austenitic (HT-UPS) and ferritic/martensitic steels (NF616) were chosen for further discussion and development, permitting potential improvement to virtually all structural components
- These alloys offer substantial gains over traditional reactor materials.





Potential Performance Benefits



- **Higher strength for constant temperature:**
  - *Reduced commodities*
  - *Greater safety margins*
  - *Longer lifetimes*
- **Higher temperature for constant stress:**
  - *Improved plant performance*
  - *Greater safety margins in accident scenarios*
- **Combinations of above:**
  - *Greater flexibility*

Estimate of Commodity Reduction for Major SFR Components

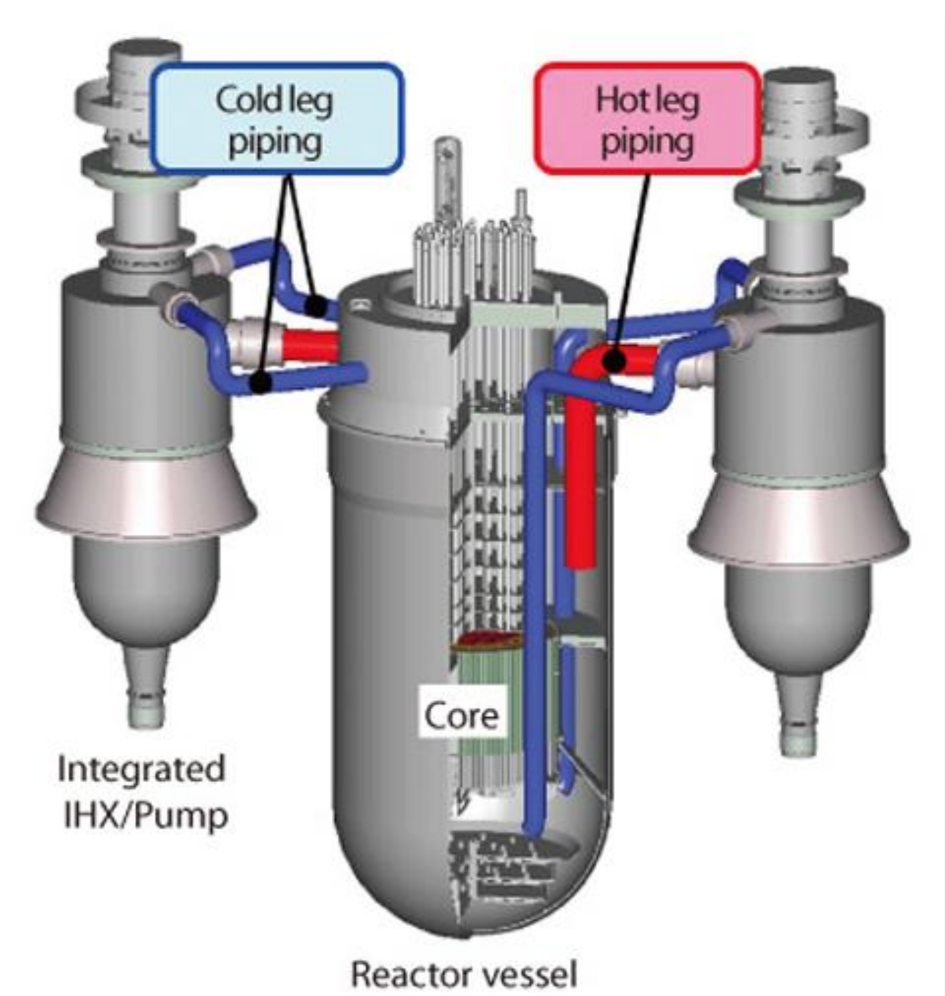
	Traditional Materials	Advanced Materials
Total Mass of Major Components	1,733,894 kg	958,410 kg
Material Savings	N/A	775,484 kg
		44.7%

- The reactor components considered in the analysis were reactor vessel, core support structure, IHX, IHTS piping, and steam generator

★ Impact From The Adoption of Advanced Materials, A. Moisseytsev et al., Argonne National Laboratory Report, ANL-AFCI-263, 2009

Potential for Design Simplifications

- The JSFR utilizes 9Cr steels for piping.
- These steels have improved strength and very low thermal expansion, allowing for larger, shorter piping.
- This allows for only 2 IHX instead of four, leading to millions of dollars in potential cost savings.



Schematic of JSFR

ARC R&D for Advanced Materials

- Advanced Alloy Development:
  - Charged with procurement of alloys, defining and testing material processing, and acquiring basic properties.
- Advanced Alloy Testing:
  - Using the new materials, mechanical testing is performed. This currently includes thermal aging, tensile testing, fracture toughness, impact testing, and creep-fatigue.
- Materials Performance Criteria and Methodology:
  - Licensing needs for advanced materials and resolution of design methodology are key long-term needs for application of advanced materials.
- Environmental Testing (Sodium Compatibility):
  - There is little information on sodium compatibility of selected alloys. Initial assessments are being provided via an FOA collaboration.

Advanced Materials Refinement: Composition and Treatment

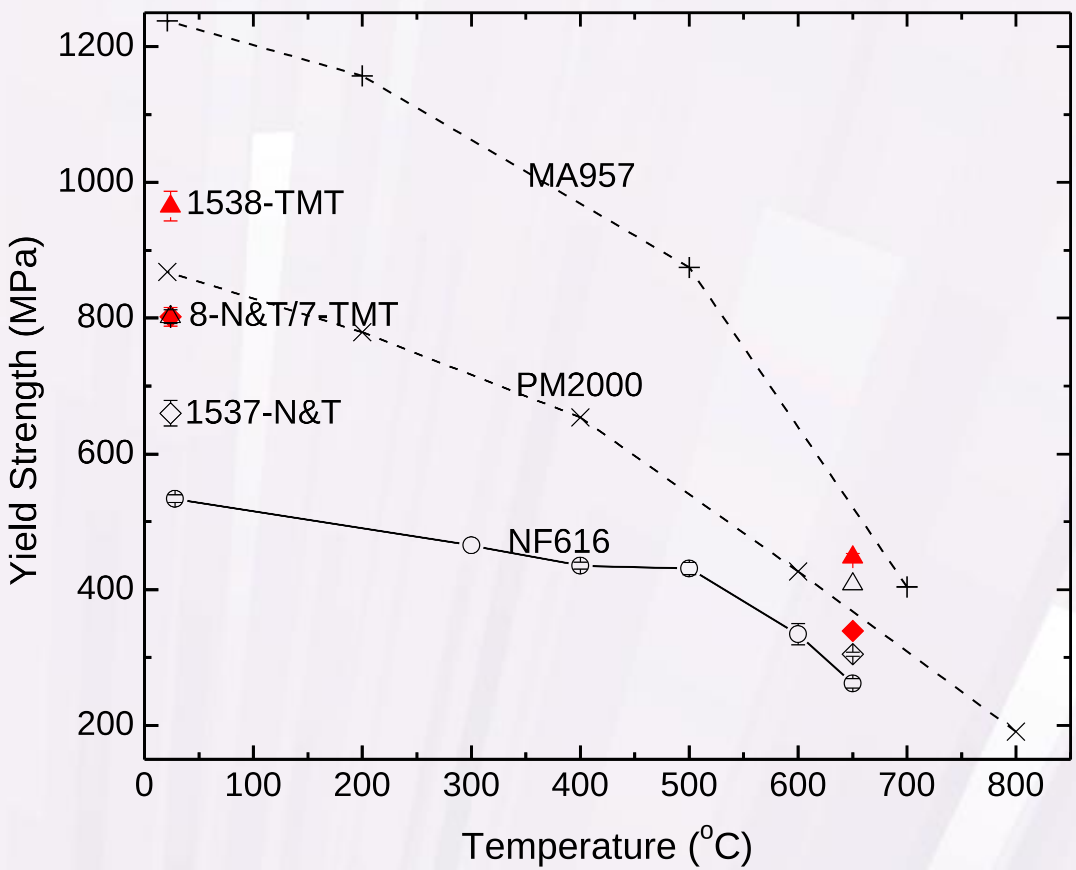
- *A commercial NF616 (Carpenter) and two model alloys were prepared with compositions (wt.%) listed in the following table.*

Alloy	Cr	Mn	Mo	W	Nb	V	Si	Ni	Cu	C	N
NF616	9.0	.45	.45	1.9	.1	-	.2	.2	.05	.1	.02
C3	9.2	.45	.05	2.0	.1	.3	.2	.4	.05	.06	.01
C5	9.3	.05	.05	2.0	.1	.3	.1	.05	1.4	.06	.005

Arc-melted and drop-casted ingots

- *Two TMT treatments, named as TMT1 and TMT2, were applied to the alloys in addition to the conventional normalization and tempering (e.g., 750℃) followed by air cooling, denoted as N&T.*

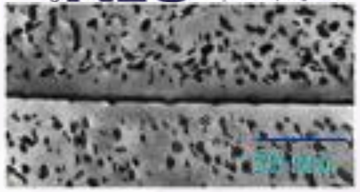
Beneficial Effects of TMT on Strength and Ductility

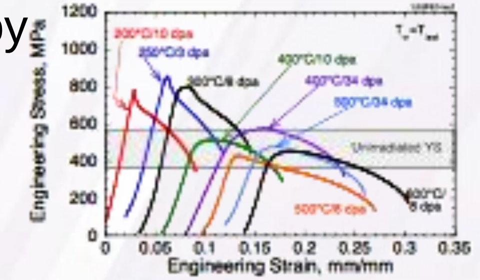


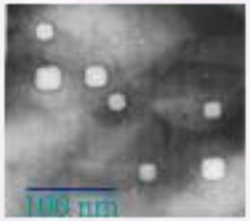
- Compared to the commercial 9Cr F-M steel NF616 and 12Cr-ODS steels
  - All the 4 heats showed higher strength
  - The TMT significantly increased the strength of the 4 heats, which showed comparable (e.g., 1537-TMT) or higher strength (e.g., 1538-TMT) than PM2000 at room temperature and 650°C.

Environmental testing

- Environment effects (thermal, radiation and/or coolant) can have a significant impact on mechanical performance and alloy stability
- Thermal Aging
  - Time at temperature may degrade material properties.
- Irradiation Testing
  - Initial irradiation and PIE on candidate alloys will start in FY09
  - Initial Testing will help prioritize PIE from MATRIX-II
  - Some HT-UPS samples from FFTF/MOTA experiments have also been identified
  - Data interpretation and semi-empirical modeling will guide future tests and needs
- Corrosion in Sodium
  - Corrosion in liquid metals must be evaluated and understood for the candidate alloys
  - The pumped-Na loop at ANL will be utilized in addition to convection-driven loops at ORNL
  - Initial burden-modeling activities will also provide insight into transfer of C, O, and/or N around the reactor loop







Advanced Material Development in FY12

- Advanced Alloy Development: Continued development of optimized conditions, testing, and analysis
- Advanced Alloy Testing: Using the new materials, mechanical testing is performed. This will continue thermal aging, tensile testing, fracture toughness, impact testing, and creep-fatigue.
- Environmental Testing (Sodium-compatibility): Sodium testing will continue at all partners, building upon FOA testing and equipment investments.
- Materials Performance Criteria and Methodology: Key testing needs will be initiated using FY09 report and FY10 progress as basis.

Challenges for Advanced Structural Materials

- Development of robust, inexpensive means for reliable fabrication and joining of advanced materials
- Improved understanding of the microstructure impacts and behavior for advanced materials, including weldments
- Quick, effective test techniques for evaluating long-term impacts of radiation damage, creep, aging, etc.
- Qualified methodology for predicting the long-term performance of materials in reactor conditions

Summary of ARC-3 Research Needs

As identified in the FY-12 workscope description:

- Microstructural stability during lifetime (compatibility, thermal stability, or irradiation)
  - Novel test techniques for long-term performance data
  - Impact of microstructure on long-term structural integrity of weldment
- Predictive capability of microstructure changes (life time model of behavior)
  - Useful models of degradation mechanisms
  - Predictive models for changes in conditions
  - Validation and qualification of long-term properties

ARC-3 NEUP Contacts

The ARC-3 Advanced Structural Materials POCs are:

- Federal – Brian Robinson (DOE)
- Technical – Jeremy Busby (ORNL)

Some key researchers in the ARC Program are:

- ORNL – Busby, Sham
- ANL – Natesan, Li
- INL – Carroll