INL/MIS-22-67739-Revision-0

ART Advanced Materials Program Overview

June 2022

Ting-Leung Sham

Changing the World's Energy Future

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ART Advanced Materials Program Overview

Ting-Leung Sham

June 2022

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

ART Advanced Materials Program Overview

Advanced Reactor Technologies Program

Advanced Materials R&D Program Review

June 7 and 8, 2022

Sam Sham

Idaho National Laboratory

DOE OFFICE OF NUCLEAR ENERGY: STRATEGIC VISION

Vision

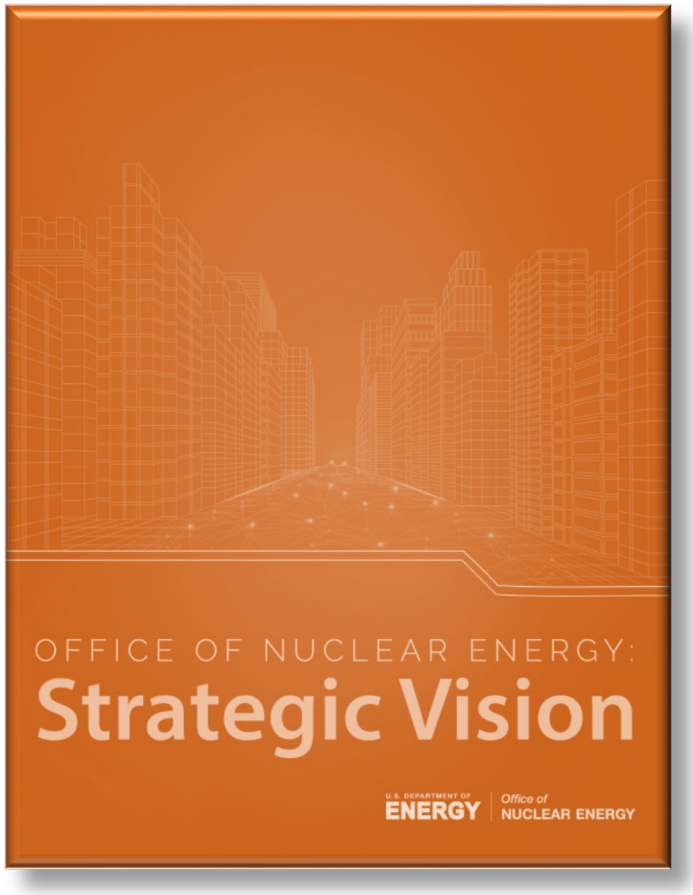
- A thriving U.S. nuclear energy sector delivering clean energy and economic opportunities

Mission

- Advance nuclear energy science and technology to meet U.S. energy, environmental, and economic needs

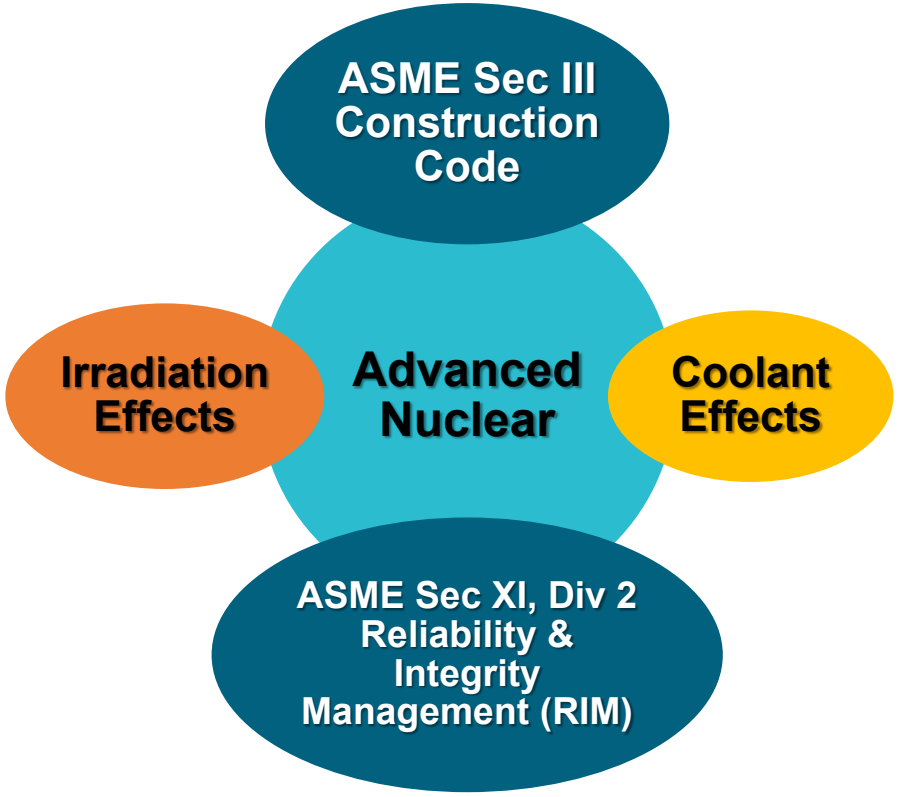
Goals

1. Enable continued operation of existing U.S. nuclear reactors
2. Enable deployment of advanced nuclear reactors
3. Develop advanced nuclear fuel cycles
4. Maintain U.S. leadership in nuclear energy technology
5. Enable a high-performing organization



DESIGN, CONSTRUCTION AND OPERATION CONSIDERATIONS FOR STRUCTURAL MATERIALS

- Advanced reactors under development have diverse designs and operational characteristics
  - Inlet/Outlet Temperatures • Thermal Transients • Coolants • Fuel Types (Prismatic, Pebble, Liquid) • Neutron Spectrum and Dose • Design Lifetimes • Safety Characteristics
- Topics directly related to reactor components construction
  - Metallic: High temperature design methodologies • Alloy qualification • Fabrication & examination
  - Graphite and ceramic composites: Qualification and codification
- Additional topics required for advanced reactor license application and plant operations
  - Corrosion effects
    - Gases (He, N, CO_2), liquid metals, molten salts
  - Irradiation effects
  - Materials degradation management
  - Flaw evaluations



ART ADVANCED MATERIALS

Focus on materials and design methods to support advanced reactors deployment

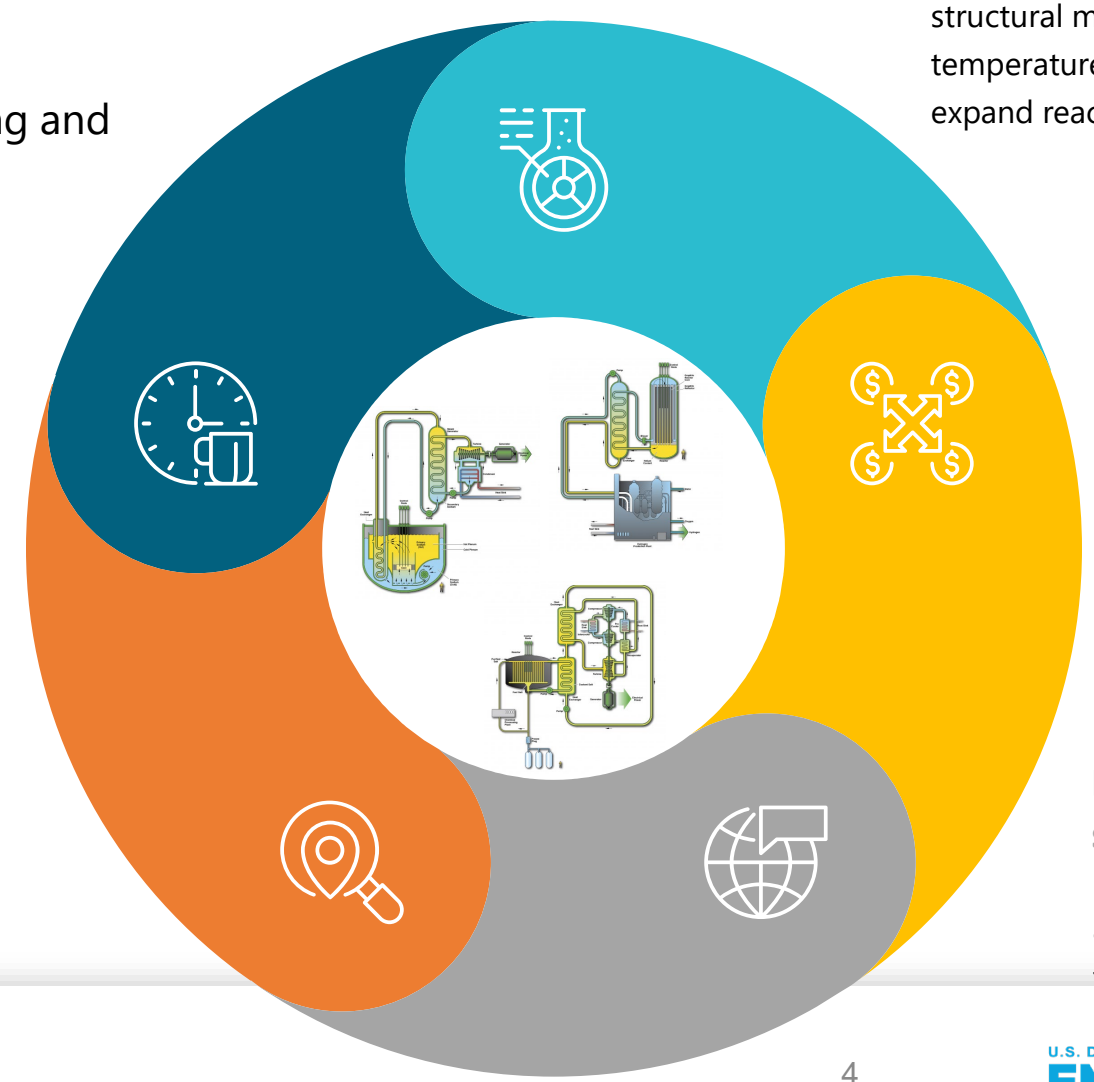
- Design, construction, licensing and operations

High temperature design methodologies

Develop high temperature design methodologies for use of the qualified materials under elevated temperature cyclic service of advanced reactors

Existing qualified materials

Extend qualified lifetimes and usage temperatures of structural materials already approved within the ASME Code for construction of high temperature reactors



Qualify new materials

Qualify additional high performance structural materials for high temperature reactor construction to expand reactor design envelope

NRC licensing

- Understand and predict environmental and irradiation effects relevant to different advanced reactor concepts
- Assess & improve methods to evaluate flaw growth and component lifetime predictions to support plant operations
- Develop in-reactor high temperature structural materials surveillance technology

Innovative materials solutions

Develop material solutions to address highly corrosive working fluids

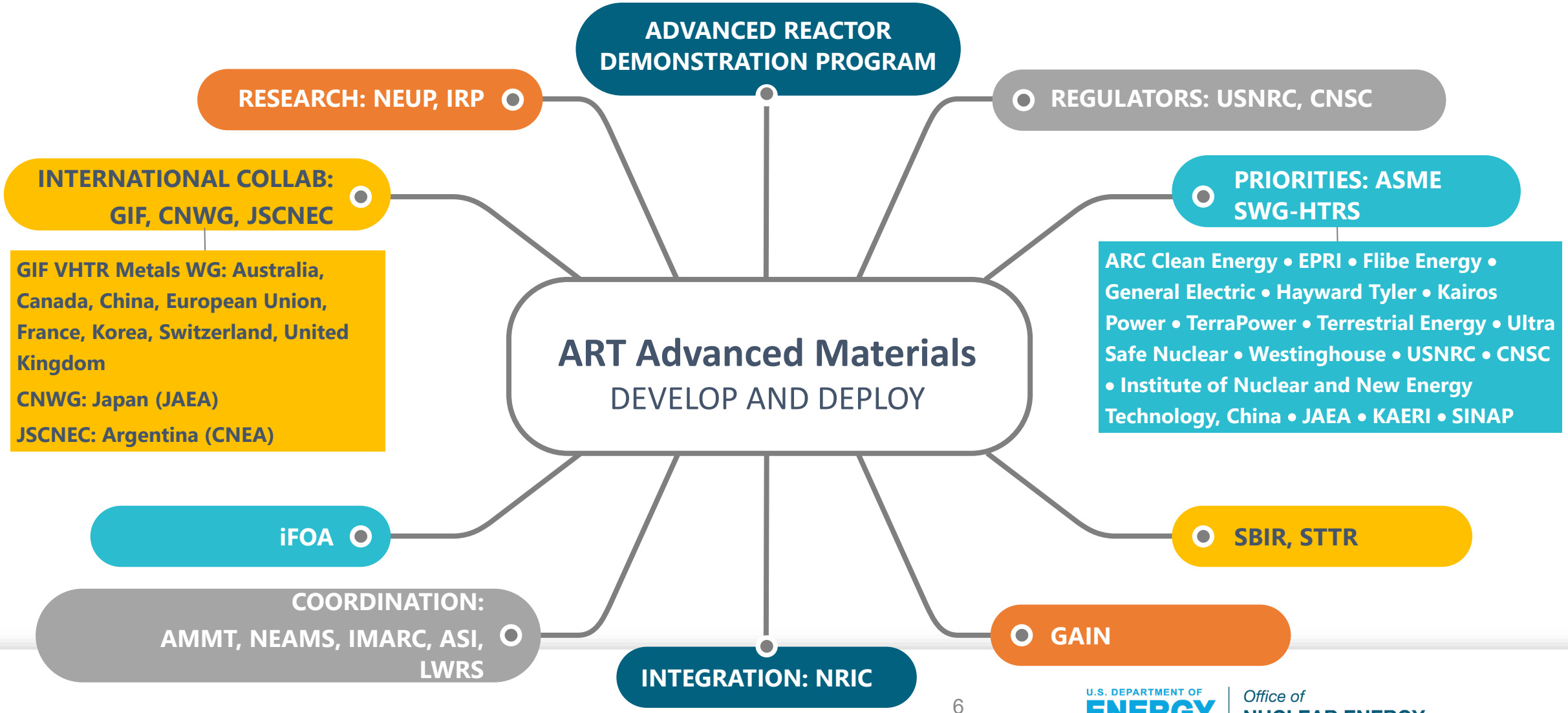
ART ADVANCED MATERIALS PORTFOLIO - METALS

INTEGRATION AND COORDINATION

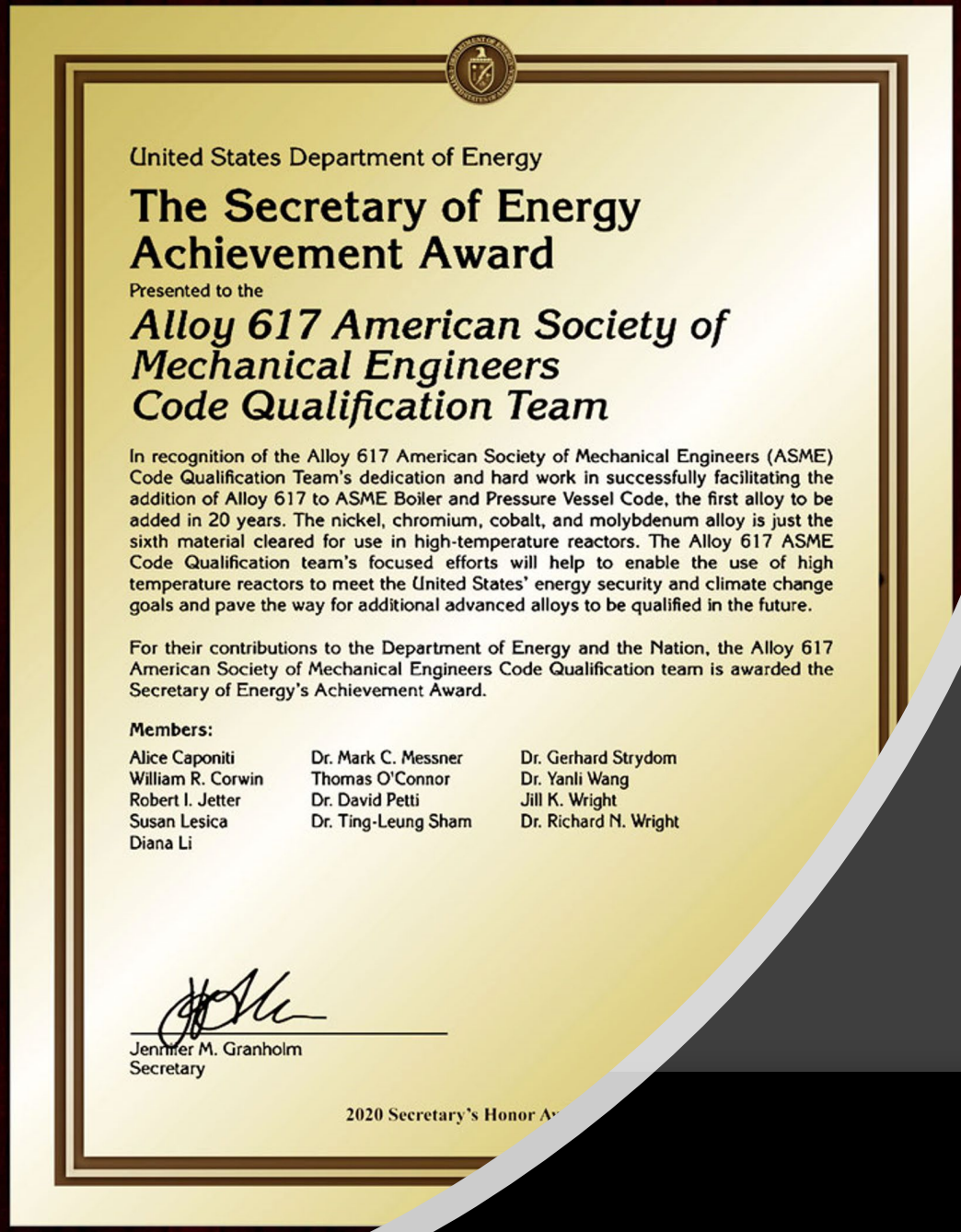
Funding	Topic	Status	Adv Rx Supported
GCR	Design methods improvement & development	Ongoing	GCR, FR, MSR, MRP
GCR	Extension of design lifetime for Class A materials	Ongoing	GCR, FR, MSR, MRP
GCR	Qualification of A617	Completed	GCR, MRP, FR
GCR	Qualification of advanced A800H welds	Ongoing	GCR, MRP
FR	Qualification of A709	Ongoing	FR, MSR, MRP, GCR
MSR	Surveillance test article development	Ongoing	MSR, FR, GCR
MRP	Qualification of PM-HIP components	Ongoing	MRP, MSR, FR, GCR
GCR	GIF VHTR Materials PMB	Ongoing	GCR
Coolant Effects on Metals			
GCR	Impure helium effects on A800H and A617	Completed	GCR, MRP
GCR	Crack growth in impure helium – A617	Ongoing	GCR, MRP
GCR	Impure helium effects on A709	To be initiated	GCR, MRP
FR	Sodium effects on G91, A709	G91 completing; A709 Ongoing	FR, MRP
MSR	Effects of molten fluoride and chloride salts on stainless steels and nickel alloys	Ongoing	MSR, MRP

- GCR – Gas-cooled Reactors Campaign
- FR – Fast Rectors Campaign
- MSR – Molten Salt Reactors Campaign
- MRP – Microreactor Program

INTEGRATION, COORDINATION, COLLABORATION



Since we last met in June 2021 for FY21 ART Advanced Materials Program Review (Virtual) …



United States Department of Energy

The Secretary of Energy Achievement Award

Presented to the

Alloy 617 American Society of Mechanical Engineers Code Qualification Team

In recognition of the Alloy 617 American Society of Mechanical Engineers (ASME) Code Qualification Team's dedication and hard work in successfully facilitating the addition of Alloy 617 to ASME Boiler and Pressure Vessel Code, the first alloy to be added in 20 years. The nickel, chromium, cobalt, and molybdenum alloy is just the sixth material cleared for use in high-temperature reactors. The Alloy 617 ASME Code Qualification team's focused efforts will help to enable the use of high temperature reactors to meet the United States' energy security and climate change goals and pave the way for additional advanced alloys to be qualified in the future.

For their contributions to the Department of Energy and the Nation, the Alloy 617 American Society of Mechanical Engineers Code Qualification team is awarded the Secretary of Energy's Achievement Award.

Members:

Alice Caponiti
William R. Corwin
Robert I. Jetter
Susan Lesica
Diana Li
Dr. Mark C. Messner
Thomas O'Connor
Dr. David Petti
Dr. Ting-Leung Sham
Dr. Gerhard Strydom
Dr. Yanli Wang
Jill K. Wright
Dr. Richard N. Wright

Jennifer M. Granholm
Secretary

2020 Secretary's Honor A

The Secretary of Energy Achievement Award

- This team effort by the multi-lab staff led to the addition of Alloy 617 to the limited materials for advanced high-temperature Class A reactor component construction that are approved by the ASME Boiler and Pressure Vessel Code, Section III, Division 5
- The success of this multi-year endeavor would not have been possible without the sustained commitment and support from the DOE Office of Nuclear Energy, and the dedication and collaboration of the technical staff across the DOE Lab complex

THE ALLOY 617 STORY

WHY DID IT TAKE SO LONG

- Circa 1990 – 2000s, the state of advanced reactors R&D in the U.S. was at its lowest point
- Pursuant to the Energy Policy Act of 2005, the Next Generation Nuclear Plant (NGNP) project was formally established to demonstrate the generation of electricity and/or hydrogen with a high-temperature nuclear energy source
- High temperature structural material(s) to be used up to 950 to 1000C was required to support the NGNP design
- Alloy 617 was down-selected as the high temperature material for ASME Code qualification to reduce regulatory risk
  - Re-acquired high temperature mechanical properties and environmental testing capabilities at the Labs
  - Re-established materials testing technology
  - Re-invented interpretation and analysis of data for developing design parameters for the Code
- ASME design rules were only valid up to 650C and there were no simplified design methods that would allow designers to conduct design evaluations
  - Developed the EPP design methods to close this gap
- Code committees approval workflow for such a complex Code Case was not in place
  - Established a balloting workflow

THE ALLOY 617 STORY

THE SEQUEL

- With the Alloy 617 Code Case successfully Code qualified, the knowledge gained on the testing and design parameters development will allow stakeholders to follow the roadmap to introduce new materials to Division 5 more efficiently. in support of the deployment of “Advanced Nuclear” within the next 10 years
- The Alloy 709 Code qualification effort has benefited significantly from the lessons learned

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ART TEAM TECHNICAL EXCELLENCE

- Awarded to Bipul Barua et al.

  PVPD Conference Award

  For Outstanding Technical Paper from the Codes & Standards Technical Committee at the 2020 ASME Pressure Vessels & Piping Conference, Titled

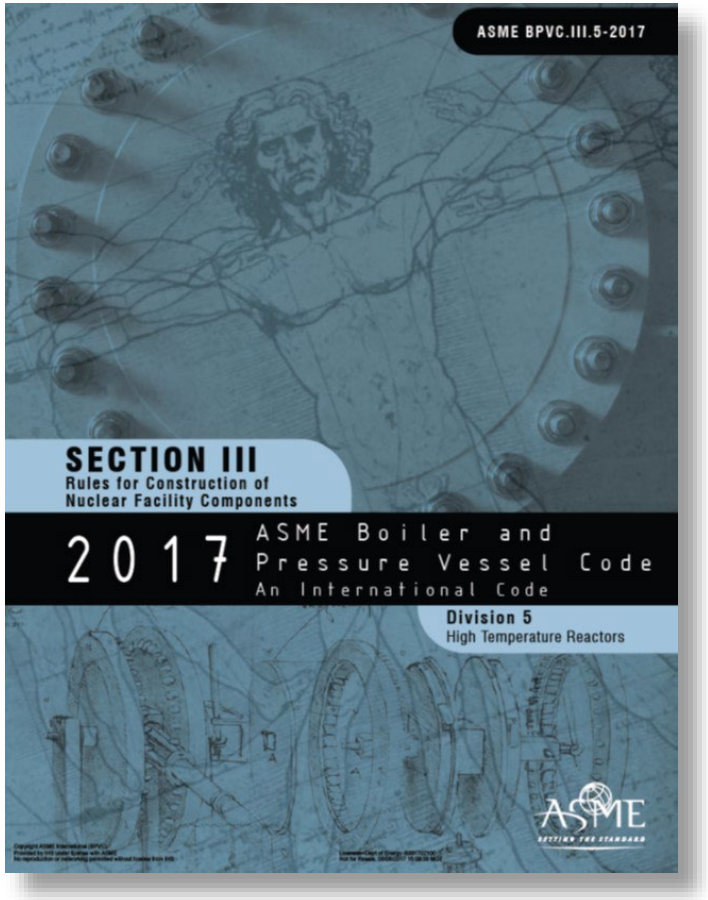
  “Development of Design Method for High Temperature Nuclear Reactor Cladded Components”

  July 2021

NRC ENDORSEMENT OF ASME SECTION III, DIVISION 5

STATUS

- US Nuclear Regulatory Commission (NRC) is currently assessing ASME Section III, Division 5 (2017 Edition) and accompanying Code Cases, including the EPP and Alloy 617 Code Cases, for endorsement
- Endorsement by NRC, with conditions, will be made through the Regulatory Guide 1.87, rev 2, which is scheduled for publication around June 2022



FIRST ASME III, DIVISION 5 CLASS A & B "N" CERTIFICATE HOLDER

- Hayward Tyler, Inc. of Vermont announced on June 2, 2022 that it has been issued the first ASME "N" Certificate of Authorization covering Section III, Division 5 Class A and B vessels, pumps, valves and piping systems

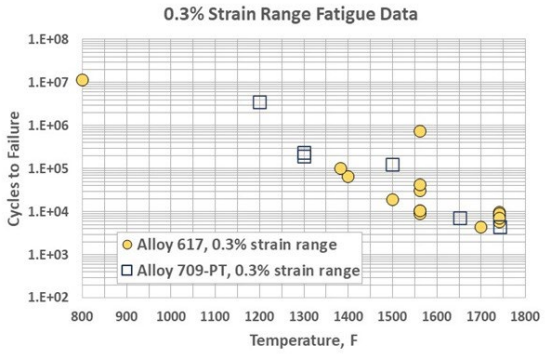
COLLABORATION WITH NEAMS TO ACCELERATE CODE QUALIFICATION OF A709

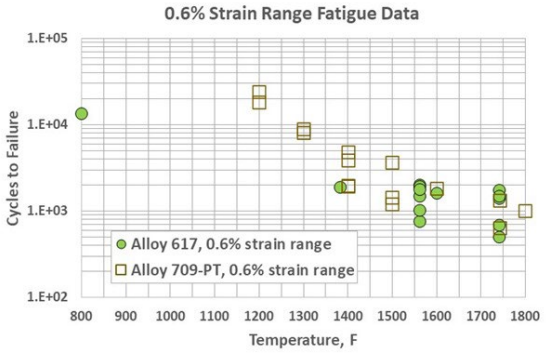
Time from initiation of long-term testing (years)

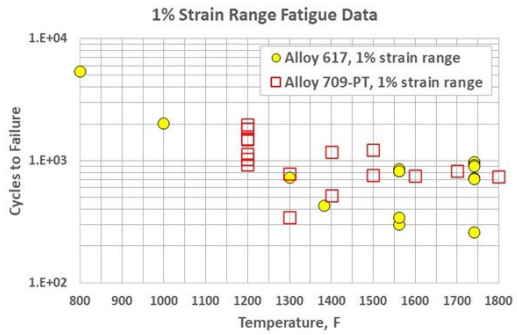
0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10	10.5	11	11.5
Creep tests for 500,000 hr Code Case																						

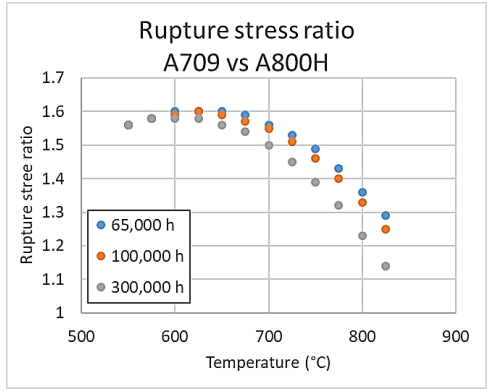
- Currently ASME permits a time-extrapolation factor of 5 on rupture data, hence a 500,000-h design lifetime requires 100,000 hours of creep rupture data
- Argonne has developed a physics-based crystal plasticity Mod-Sim tool together with a Bayesian framework that could predict creep rupture lives of 316H using relatively short-term creep rupture data
- The application of this physics-based Bayesian framework to A709 data will greatly accelerate the qualification timeline for the 500,000-hour code case
- This is a topic where collaboration with the NEAMS Program will have mutual benefits

A709-PT HAS ENHANCED MECHANICAL PROPERTIES





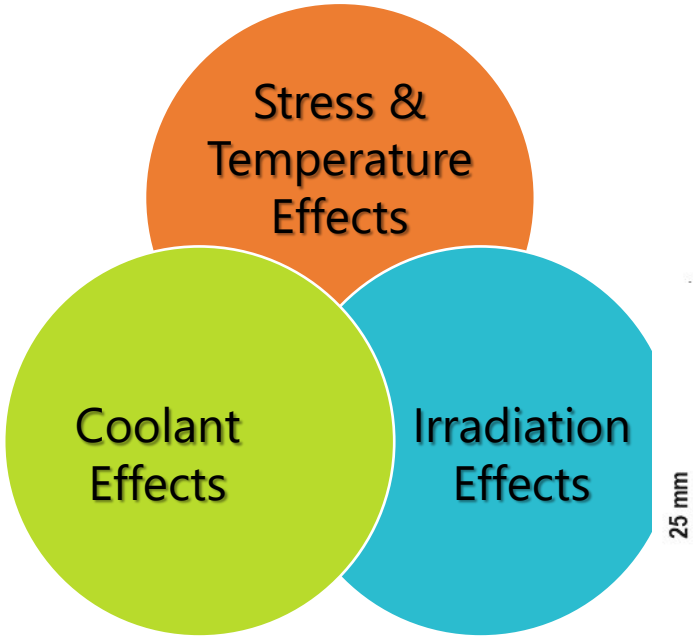


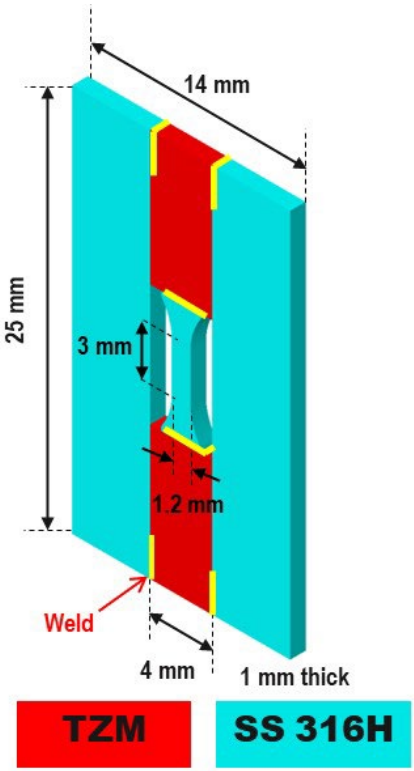


- Fatigue resistance of A709-PT is comparable to A617 at these strain ranges
- Creep strength of A709-PT is higher than A800H
  - Data generated to-date show that A709-PT is a good candidate material for gas-cooled reactor applications, leveraging the code qualification effort that is already underway
  - Need to demonstrate that A709-PT is compatible with reactor grade helium
  - Sufficient Cr in A709-PT to form Cr oxide on component surface for corrosion protection
  - FY23 to initiate a confirmatory corrosion program to establish A709-PT as a gas-cooled reactor construction material, leveraging the helium corrosion loop from the NGNP Program that is in storage

MATERIAL SURVEILLANCE TECHNOLOGY

- Information on materials degradations during advanced reactor operations is limited
- The effects of materials degradations during reactor operations are synergistic, involving:
  - Irradiation, corrosion, elevated temperature exposure and stress (creep-fatigue loading)
- ART MSR is establishing the technology for a surrogate materials surveillance program for the management of materials degradation
  - Would be an important pathway for supporting the timely licensing of advanced reactors
- A bilateral collaboration with JAEA on the development of the materials surveillance technology is being finalized, enabling ART Advanced Materials to leverage additional development effort from Japan
- A parallel WP to establish a regulatory framework for the implementation of a materials degradation management program





AGENDA – DAY 1

Program	Presentation	Presenter
DOE	Introductory Remarks	Alice Caponiti, DOE NE
ART	ART Advanced Materials Program Overview	Sam Sham, INL
FR	A709 Procurement and ASTM Specification Status	Richard Wright, Structural Alloys
FR	A709 Code Case Testing Status	Xuan Zhang, ANL
FR	A709 Weldment Fabrication Status	Zhili Feng, ORNL
FR	Grade 91 Sodium Compatibility	Yiren Chen, ANL
GCR	Graphite R&D Overview	Will Windes, INL
GCR	ASME Division 5 Design Rules	Sam Sham, INL
GCR	Implementation of Inelastic Models in Division 5	Mark Messner, ANL
GCR	Alternative Creep-Fatigue Design Method Using EPP+SMT	Yanli Wang, ORNL
GCR	A617 Notch Effect Testing Status	Ryann Rupp, INL
GCR	A617 Crack Growth Testing Status	Joe Bass, INL
GCR	Development of Improved A800H Weldment	Tate Patterson, INL

AGENDA – DAY 2

Program	Presentation	Presenter
NRC	Readiness for Advanced Reactors Licensing – Materials and Component Performance Research	Raj Iyengar, NRC
NEUP	Multiscale Investigation of SiC/SiC Composite Degradation in Helium Coolant Operating Environment	Xiaodong Li, University of Virginia)
NEUP	Development of Structural Materials Corrosion Resistant Coatings for Liquid Fueled Molten Salts Reactors Applications	Adrien Couet, University of Wisconsin–Madison
NEUP	Advanced Alloy Innovations for Structural Components of Molten Salt Reactors	Kumar Sridharan, University of Wisconsin–Madison
NEUP	Ni-based ODS Alloys for Molten Salt Reactors	Djamel Kaoumi, North Carolina State University
NEUP	Investigation of Novel Nickel-Based Alloys for Molten Chloride Fast Reactor Structural Applications	Vijay Vasudeva, University of North Texas
MRP	Qualification of PM HIP Materials for Elevated-Temperature Nuclear Construction	Ryann Bass, INL
MSR	Salt and Materials Interaction	Rishi Pillai, ORNL
MSR	Graphite Activities Related to Molten Salt Reactors	Nidia Gallego, ORNL
MSR	Surveillance Test Articles Development	Heramb Mahajan, INL
ART	DOE Direction/Review/Comment	DOE, NTDs, Industry, others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