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

ART Advanced Materials Overview

Joint ART Materials/AMMT Program Review

DOE Headquarters, Germantown, MD

June 5-8, 2023

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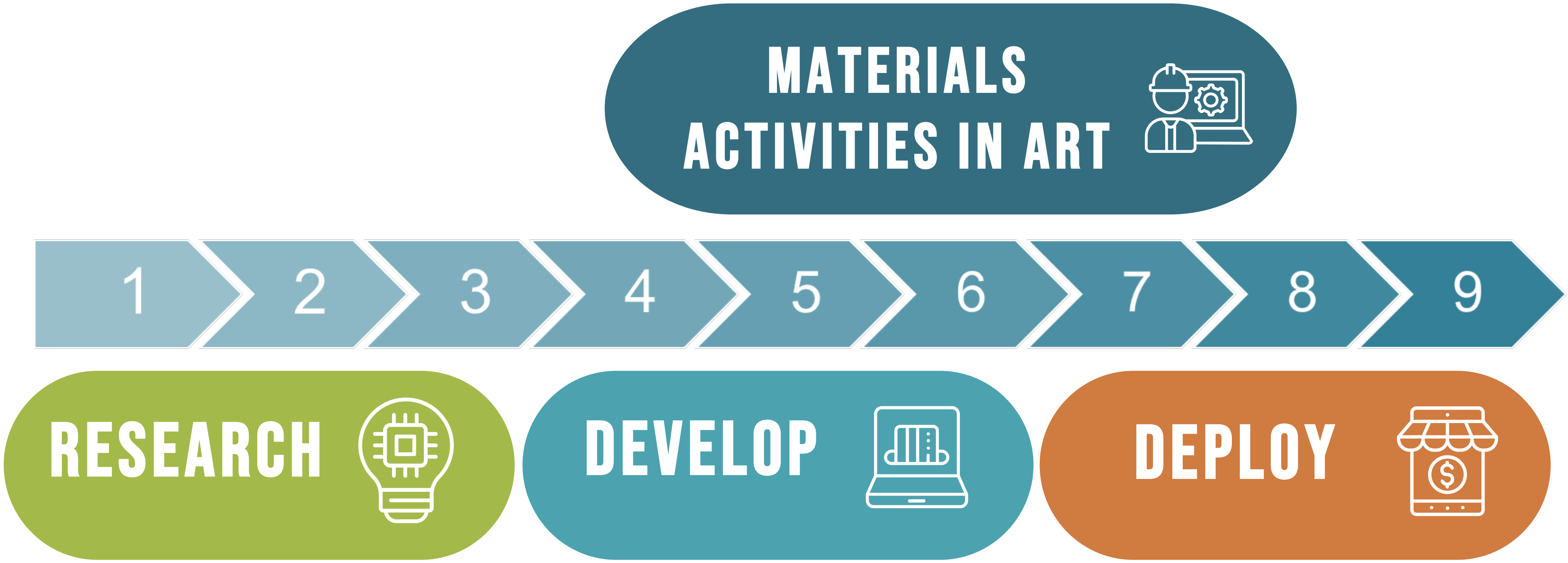
Idaho National Laboratory

Materials Activities in the ART Program



Goal

- The ART advanced materials program focuses on the application of materials and design methods to support advanced reactors deployment in the near and mid-term
    - Covering materials, design, construction, licensing and operations

Metallic Components

Improve High Temperature Design Methodology for Advanced Reactors

Provide Support to Reduce Regulatory Risks for Advanced Reactor Developers

Qualify Next-Gen Construction Materials for Material Insertions in Commercial Advanced Reactors and for FOAK Advanced Reactor Applications for Mid-Term Deployment

Nonmetallic Components

- Provide Support to Reduce Regulatory Risks for Advanced Reactor Developers
- Improve Nonmetallic (Graphite and Ceramic Composite) Design Rules for Core Components

Improve High Temperature Design Methodology for Advanced Reactors – I

- **Develop and implement high temperature design methodology needed for advanced reactor designs into the ASME Code**
  - EPP code cases (completed); EPP + SMT creep-fatigue code case
- **Define and develop modern inelastic models and analysis rules**
  - Universal unified constitutive equations for Division 5, Appendix HBB-Z
- **Extend materials properties and associated design methods (e.g., isochronous stress-strain curves) for very long design lifetimes**

Class A Material	Status
Grade 91	60-year extension completed
304H/316H	60-year extension ongoing, leverage EPRI assistance to locate legacy weldment data and ex-service thermal aging data to support extension
A800H, Grade 22	60-year extension, planned
Alloy 617	20 to 25-year extension, leverage collaboration for long-term data, planned

Improve High Temperature Design Methodology for Advanced Reactors – II

- **Improve and expand ASME Section III, Division 5, Class B design rules to enable more affordable designs with appropriate safety margins**
  - Introduce design-by-analysis rules, time-dependent allowable stresses for varying design lifetimes, rules for cyclic service, more materials (~20) for Class B construction
- **Develop design rules for refractory metals to significantly expand operating temperature envelope**
  - Molybdenum TZM code case
- **Introduce design innovations to advanced reactor systems by leveraging development complimentary to the ART advanced materials program, e.g., incorporating the R&D results into the ASME Code**
  - Cladding code case (R&D through GAIN), planned
  - Compact heat exchanger code case (R&D through NEUP IRP), planned

Provide Support to Reduce Regulatory Risks for Advanced Rx Developers - I

- **Address exceptions and limitations in NRC endorsement of ASME Section III, Division 5, 2017 Edition**
  - Action plan developed
- **Support future NRC endorsement of Code modifications of ASME Section III, Division 5, 2023 Edition and beyond, for improved high temperature reactor design**
- **Support ASME expansions of low temperature Codes to high temperatures for advanced reactor structures, systems and components**
  - Operation and Maintenance (OM) Code
  - Qualification of Active Mechanical Equipment (QME) Code

Provide Support to Reduce Regulatory Risks for Advanced Rx Developers - II

Address issues beyond the construction Code

- **Effects of coolant and materials compatibility**
  - Corrosion testing in molten salts at ORNL, in sodium at ANL, in reactor grade helium at INL (planned)
- **Effects of irradiation**
  - Irradiation campaign for Alloy 709 at ATR or HFIR, planned
- **Long-term plant operations**
  - Develop better performing Alloy 800H weldment to support long-term plant operations

Provide Support to Reduce Regulatory Risks for Advanced Rx Developers - III

Address issues beyond the construction Code

- **Development of new materials surveillance technology to assess the combined effects of temperature and load histories, irradiation, corrosion and aging for materials degradation management**
  - NRC draft Interim Staff Guidance on Material Compatibility for non-LWRs has recommended the consideration of monitoring and surveillance to ensure component integrity in reviewing license applications
  - Collaboration
    - Bilateral with JAEA [sodium coolant] under CNWG, started in mid-2022
    - Formalize collaboration with the Canadian Nuclear Laboratories (CNL) [reactor grade helium] through INL/CNL CRADA under US-Canada Bilateral, planned

Provide Support to Reduce Regulatory Risks for Advanced Rx Developers - IV

Address issues beyond the construction Code

- **Develop material performance assessment procedures in support of ASME Section XI, Division 2, Reliability and Integrity (RIM) Program**
  - Perform high temperature crack growth experiments in air and in reactor grade helium to develop crack growth correlations for inclusion in Section XI high temperature flaw evaluation code case
  - Conduct long-term creep rupture tests on notch specimens to address notch strengthening versus notch weakening mechanisms
- **Coordinate efforts to develop Section XI, Division 2 supplement for MSRs to support RIM**

Qualify Next-Gen Construction Materials

- **Material insertions for commercial deployment of advanced reactor**
  - After near-term reactor demonstration using “off-the-shelf” materials
- **FOAK reactor applications slated for mid-term demonstration**

Qualify Next-Gen Construction Materials - I

- **Qualify and incorporate Alloy 709 into the ASME Code as high temperature construction material for SFR, HTGR and MSR applications**
  - Employ newly developed “staged” code qualification approach
  - Determine mechanisms giving rise to time-dependent properties; predict long-term creep rupture using shorter-term data through modeling and simulation with validation by experiments; effectively increase the time-extrapolation factors for creep rupture (funded by NEAMS)
  - Data package for the first Alloy 709 code case planned for FY24, and code case submittal in FY25

Qualify Next-Gen Construction Materials - II

- **Qualify and incorporate next-gen new materials that can be deployed in more aggressive irradiation and coolant environments into the ASME Code**
  - Refractory metal code case
  - Next-gen new materials being developed by NEUP university projects
- **New guidelines for qualification and incorporation of new materials from advanced fabrication processes that are readily deployable for advanced reactor construction**
  - 316H PM-HIP code case
    - Leverage collaboration with UK Nuclear AMRC and EPRI
- **Guidance for inclusion of AM materials for high temperature reactor applications**
  - Acceptance testing and criteria being developed by NEUP university project
  - Leverage ASME Section III AM working groups

ART Advanced Materials Funding Sources

Metallic

- ART Program
- Regulatory Development Program
- NEAMS Program

Nonmetallic

- TRISO and Graphite Qualification Program

Advanced Materials Portfolio - Metallic

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, GCR, MRP
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
NEAMS	Accelerate A709 qualification with physics-based Mod-Sim & Bayesian model	Initiated in FY23	FR, MSR, GCR, MRP
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 completed; A709 ongoing	FR, MRP
MSR	Effects of molten fluoride & chloride salts on stainless steels & Ni alloys	Ongoing	MSR, MRP

- GCR – Gas-cooled Reactors Campaign
- MSR – Molten Salt Reactors Campaign
- FR – Fast Rectors Campaign
- MRP – Microreactor Program
- NEAMS – Nuclear Energy Advanced Modeling and Simulation

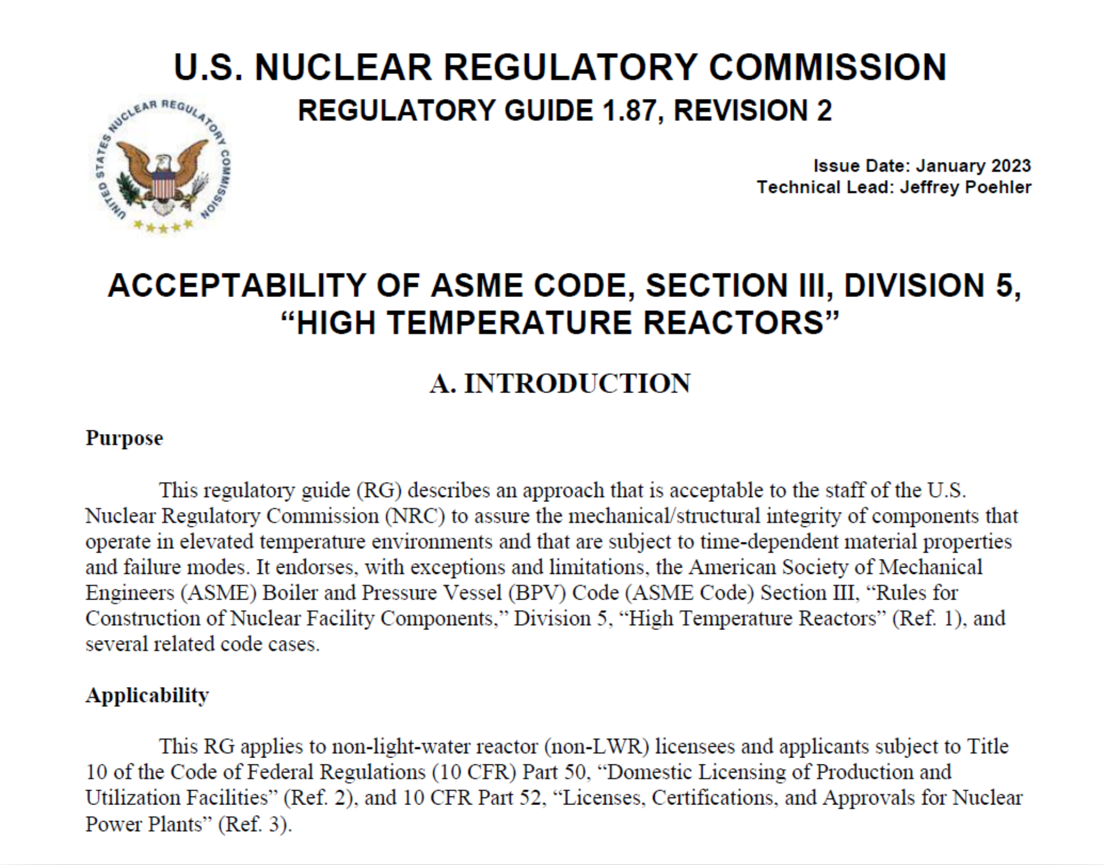
ART Advanced Materials is a Unique Program

- The ART advanced materials program focuses on **the application of materials and design methods to support advanced reactors deployment** in the near and mid-term
  - Covering **materials, design, construction, licensing and operations**

Accomplishment, Recognition and Reportable Incident

NRC Endorsed Section III, Division 5

- Section III, Division 5, 2017 Edition was endorsed by NRC, with exceptions and limitations, via Regulatory Guide 1.87 Revision 2 in Jan 2023
- Congratulations to NRC and its staff for the review effort, ASME Section III volunteers for their effort in establishing and maintaining Division 5, advanced reactor developers for their advocacy, and DOE-NE for supporting Codes and Standards activities
- This is a significant milestone in the reduction of regulatory risk for reactor developers towards the licensing of their advanced reactors



U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE 1.87, REVISION 2

Issue Date: January 2023
Technical Lead: Jeffrey Poehler

ACCEPTABILITY OF ASME CODE, SECTION III, DIVISION 5, "HIGH TEMPERATURE REACTORS"

A. INTRODUCTION

Purpose

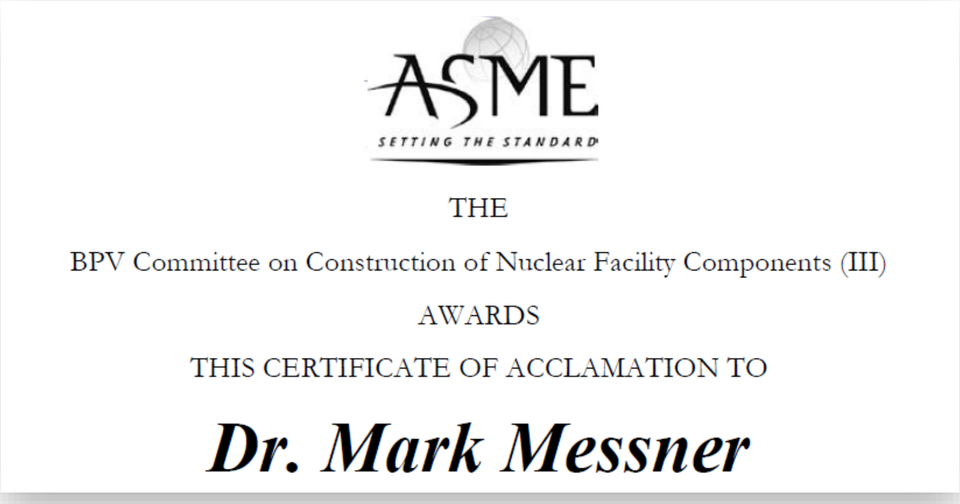
This regulatory guide (RG) describes an approach that is acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) to assure the mechanical/structural integrity of components that operate in elevated temperature environments and that are subject to time-dependent material properties and failure modes. It endorses, with exceptions and limitations, the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code (ASME Code) Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors" (Ref. 1), and several related code cases.

Applicability

This RG applies to non-light-water reactor (non-LWR) licensees and applicants subject to Title 10 of the Code of Federal Regulations (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 2), and 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 3).

ASME Certificate of Acclamation Awarded to Mark Messner

- It is in recognition of Mark's leadership and direct contribution to the development of material models for elevated temperature inelastic analysis and the specific complex model for Grade 91 steel
- The new Section III, Division 5, Nonmandatory Appendix HBB-Z, "Guidance On Constitutive Models For Design By Inelastic Analysis," has accomplished a long standing goal of Division 5 of Section III and has wide application for other BPV sections dealing with elevated temperature components


ASME
SETTING THE STANDARD

THE

BPV Committee on Construction of Nuclear Facility Components (III)

AWARDS

THIS CERTIFICATE OF ACCLAMATION TO

Dr. Mark Messner

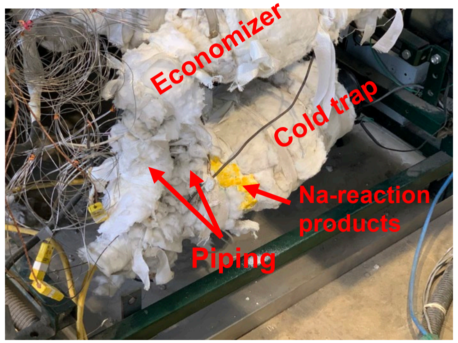
ASME Certificate of Acclamation Awarded to the EPP Team

- A Certificate of Acclamation was awarded to the team, Peter Carter (SES, Inc.), Robert Jetter, Mark Messner (ANL), Sam Sham (INL), and Yanli Wang (ORNL), on the development of three new ASME Section III, Division 5 Code Cases for the evaluation of elevated temperature components
  - N-924 for primary load, N-861-1 for strain limits, and N-862-1 for creep-fatigue

- These three new code cases take advantage of modern computing technology and pseudo-yield stresses to significantly simplify the evaluations
- This development was part of the multi-year Alloy 617 Code Case effort, the success of which would not have been possible without the sustained commitment and support from the ART Program of DOE-NE

Sodium Leak in Materials Test Loop, SMT-2

- **Background**
  - After 24/7 operations for ~10 years, the cold traps in SMT-1 and SMT-2 were replaced recently
- **Sodium leak and current status**
  - During the maintenance work, a sodium leak occurred near the cold trap of SMT-2, leading to smoke and emergency response
  - A VCR fittings on the replaced cold trap was identified as the leak spot
  - Currently, sodium in SMT-2 loop is frozen and kept at room temperature
  - Temperatures in SMT-1 are lowered for a hot standby condition



- **Impact**
  - The cold trap and adjacent components in SMT-2 are damaged, and need to be replaced
  - An improved leak-check mechanism needs to be implemented on both SMT-1 and SMT-2 loops
  - Sodium-exposure experiments in both loops will be delayed

ART Advanced Materials Multi-Laboratory Team

- **ANL**
  - Mark Messner, Xuan Zhang, Yiren Chen, Tianju Chen, Gary Hu
- **INL**
  - Grace Burke, Heramb Mahajan, Mike McMurtrey, Ryann Bass (now at US NRC),Tate Paterson, Mahmut Cinbiz, Xinchang Zhang, Kaelee Novich (Intern from Boise State), Sam Sham
- **ORNL**
  - Yanli Wang, Zhili Feng, Peijun Hou, Bruce Pint, Nidia Gallego
- **SMEs**
  - Richard Wright, Bob Jetter, John Grubb, Isaac Garcia

Day 1

1 Overviews

2 IRP/NEUP

Day 2

3 MSR/MRP

4 Alloy 709

5 HTDM

6 Directions, Reviews and Comments

7 No-host Dinner

Thank you

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