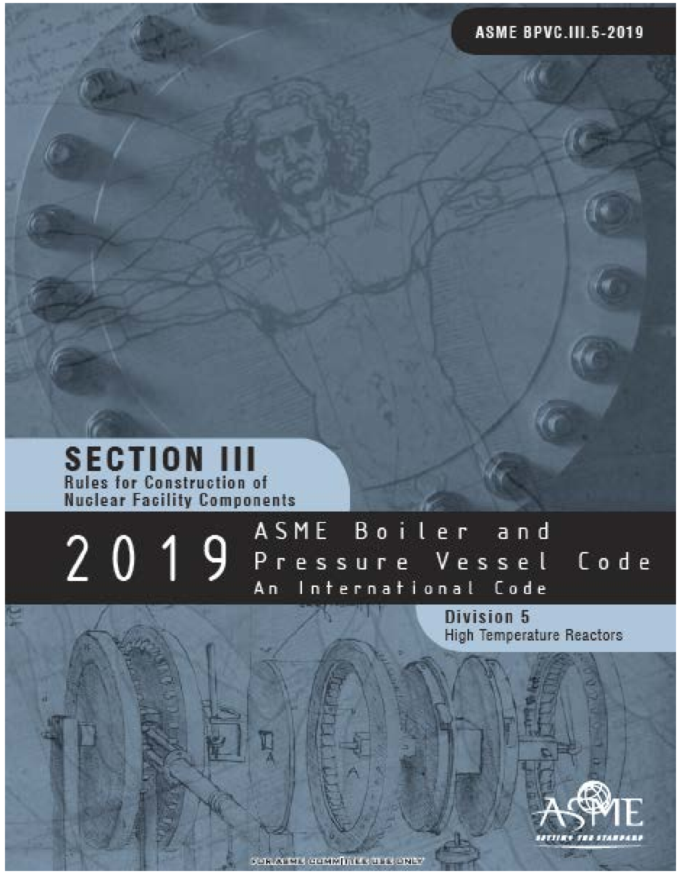
Section III, Division 5 Overview

ASME BPV III Division 5 Workshop
on High Temperature Reactors
November 8 & 9, 2020 • Virtual Meetings

Sam Sham
Chair, Subgroup High Temperature Reactors

ASME Section III, Rules for Construction of Nuclear Facility Components - Division 5, High Temperature Reactors

- ASME Section III Division 5 Scope
  - Division 5 rules govern the construction of vessels, piping, pumps, valves, supports, core support structures and nonmetallic core components for use in high temperature reactor systems and their supporting systems
    - o Construction, as used here, is an all-inclusive term that includes material, design, fabrication, installation, examination, testing, overpressure protection, inspection, stamping, and certification
- High temperature reactors include
  - Gas-cooled reactors (HTGR, VHTR, GFR)
  - Liquid metal reactors (SFR, LFR)
  - Molten salt reactors, liquid fuel (MSR) or solid fuel (FHR)



Section III, Division 5 Organization

Class	Subsection	Subpart	Subsection ID	Title	Scope
General Requirements					
Class A, B, & SM	HA	A	HAA	Metallic Materials	Metallic
Class SN		B	HAB	Graphite and Composite Materials	Nonmetallic
Class A Metallic Pressure Boundary Components					
Class A	HB	A	HBA	Low Temperature Service	Metallic
Class A		B	HBB	Elevated Temperature Service	Metallic
Class B Metallic Pressure Boundary Components					
Class B	HC	A	HCA	Low Temperature Service	Metallic
Class B		B	HCB	Elevated Temperature Service	Metallic
Class A and Class B Metallic Supports					
Class A & B	HF	A	HFA	Low Temperature Service	Metallic
Class SM Metallic Core Support Structures					
Class SM	HG	A	HGA	Low Temperature Service	Metallic
Class SM		B	HGB	Elevated Temperature Service	Metallic
Class SN Nonmetallic Core Components					
Class SN	HH	A	HHA	Graphite Materials	Graphite
Class SN		B	HHB	Composite Materials	Composite

Division 5 - A Component Code

- Division 5 is organized by Code Classes:
  - Class A, Class B, Class SM for metallic components
  - Class SN for non-metallic components
- Division 5 recognizes the different levels of importance associated with the function of each component as related to the safe operation of the advanced reactor plant
- The Code Classes allow a choice of rules that provide **a reasonable assurance of structural integrity and quality** commensurate with the relative importance **assigned** to the individual components of the advanced reactor plant

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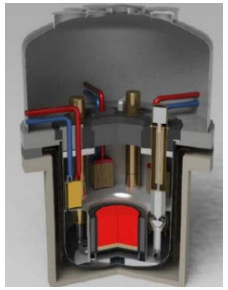
Examples of Different Advanced Reactor Designs Being Developed By Industry

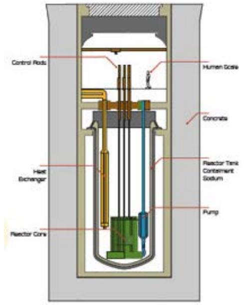
Fast Reactors

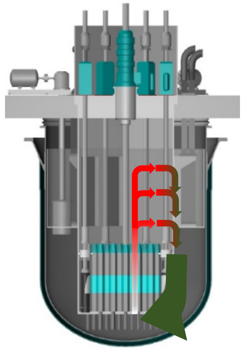
GE Hitachi PRISM

TerraPower, TWR



Advanced Reactor Concepts, ARC-100



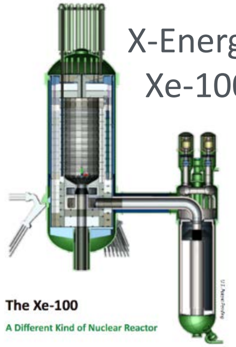


Westinghouse, LFR

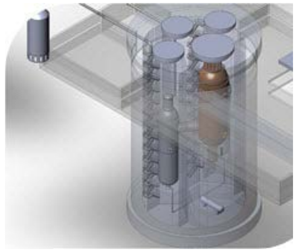
TerraPower & GEH Natrium

Oklo, Aurora

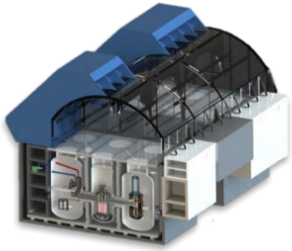
Gas Reactors



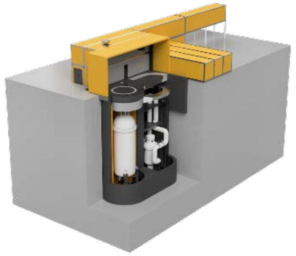
X-Energy, Xe-100



Framatome SC-HTGR

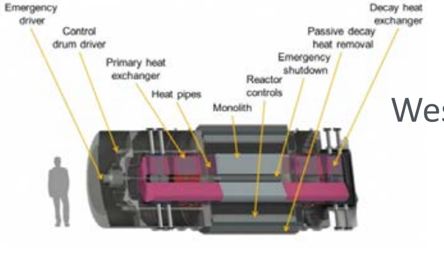


General Atomic EM2 (Gas-cooled Fast Reactor)



Ultra Safe Nuclear MMR

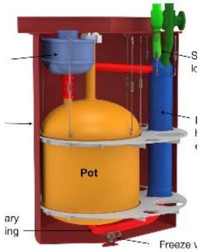
Heat Pipe Reactor



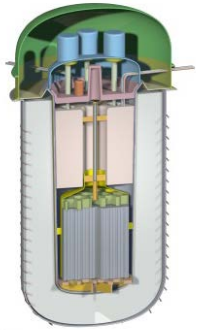
Westinghouse eVinci

Molten Salt Reactors

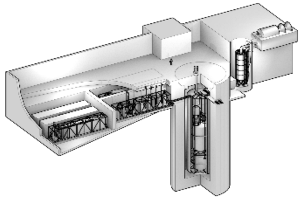
Elysium, MCSFR



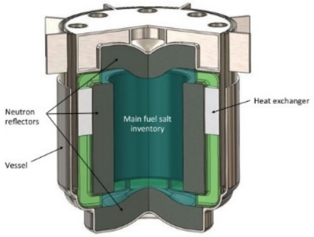
ThorCon



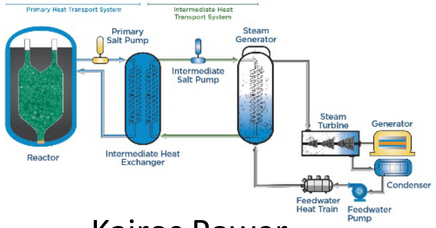
Terrestrial Energy IMSR



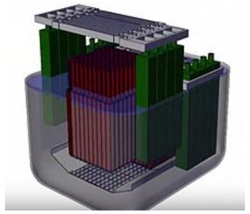
Flibe Energy LFTR (thorium)



TerraPower MCFR



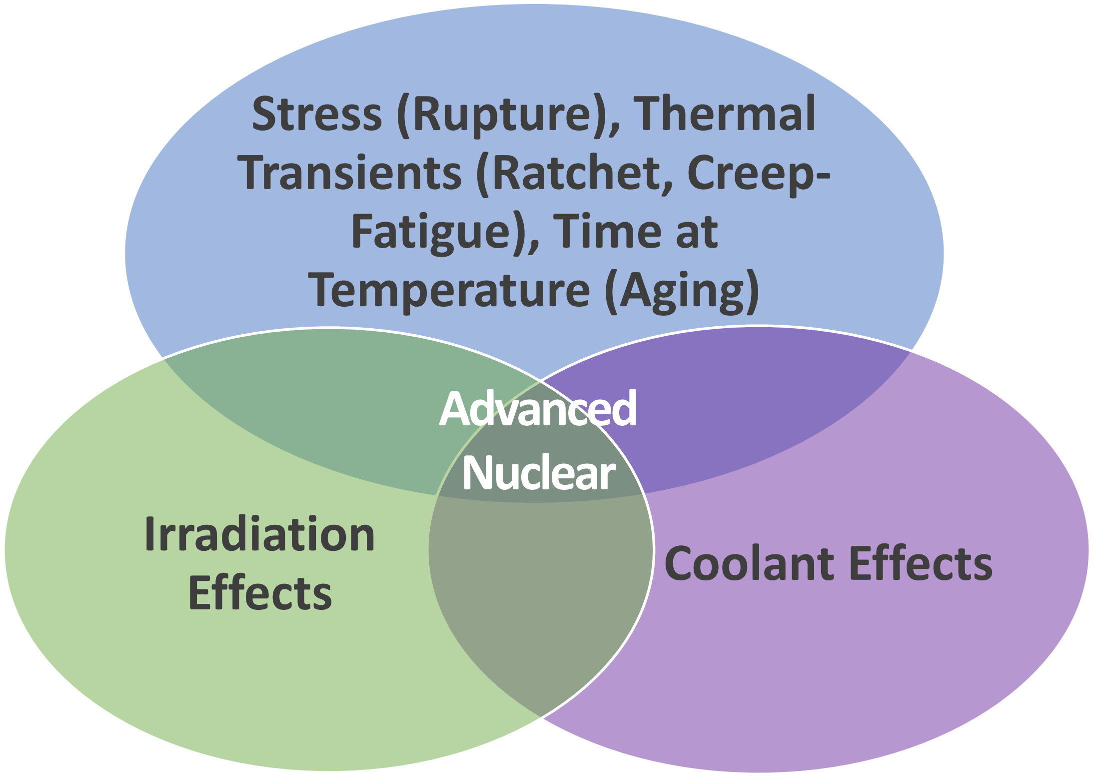
Kairos Power KP-FHR



Moltex Energy, SSR

Advanced Reactors Under Development Have Drastically Different Characteristics

- Inlet/outlet temperatures
- Thermal transients
- Coolants
- Solid fuel vs liquid fuel
- Neutron spectrum and dose
- Design lifetimes
- Safety characteristics



What is the Division 5 approach to cover these effects for all different advanced reactor types?

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Addressing the "First Balloon"

Stress (Rupture), Thermal Transients (Ratchet, Creep-Fatigue), Time at Temperature (Aging)

- Focus on structural failure modes under elevated temperature cyclic service, rather than reactor types
- Develop acceptance criteria and attendant high temperature design methodologies (HTDM) to guard against the identified structural failure modes
  - Essentially cross-cutting different reactor types

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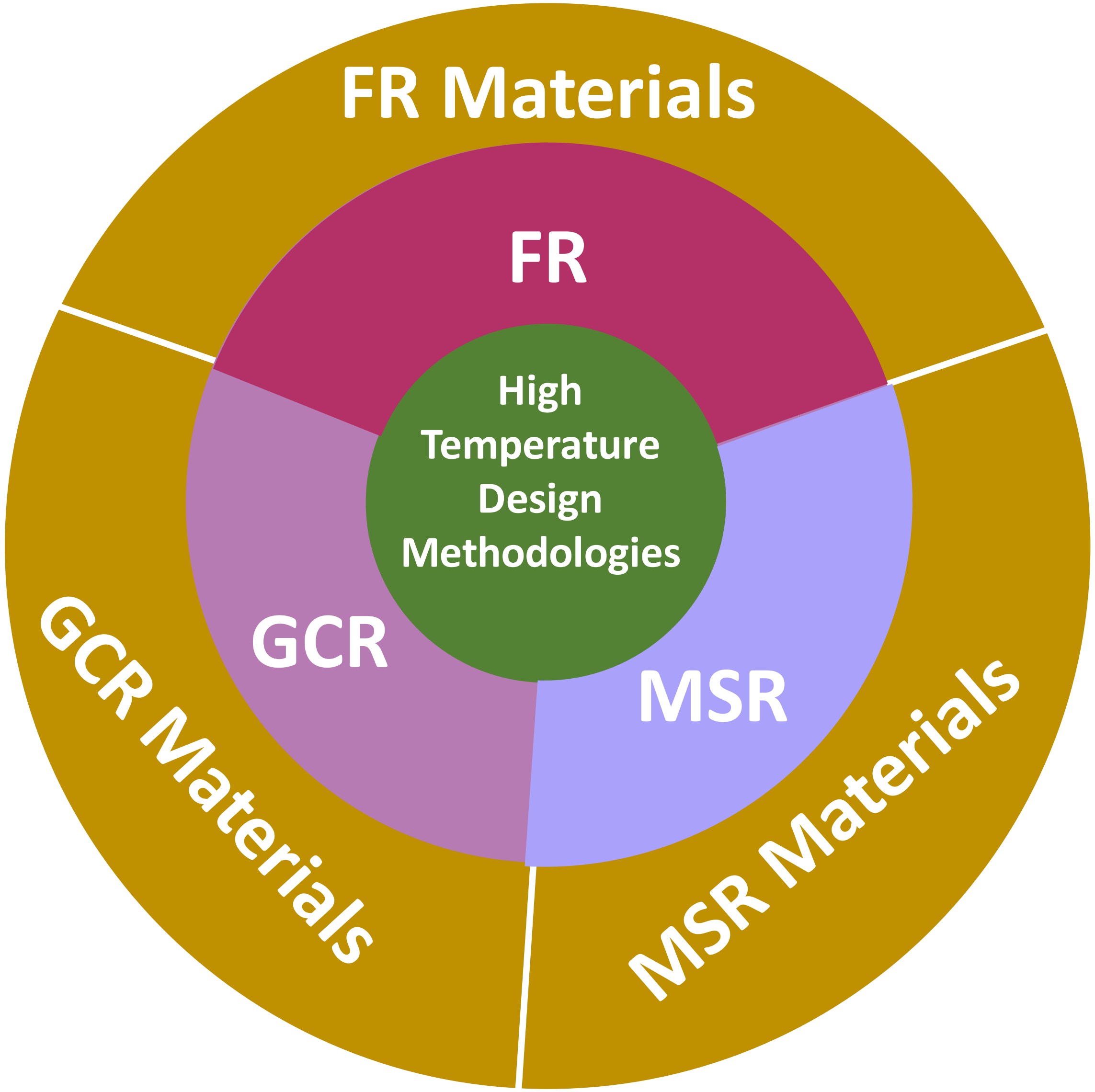
Materials Data Requirements



- Design parameters that are required by the HTDM would drive the materials data requirements
- FRs, GCRs and MSRs have different coolants, neutron irradiation environments and operating conditions (temperature, pressure, and transients)
- Different structural materials are needed to meet different requirements of FRs, GCRs and MSRs

Addressing the “Other Two Balloons”

- Effects of coolant and irradiation on structural failure modes are different from one reactor design to another even for the same structural material
- It is very challenging to cover these effects for all reactor types, and all different design characteristics for the same reactor type, viz. molten salt reactor
- The Division 5 approach is for Owner/Operator to have the responsibility to demonstrate to regional regulator that these effects on structural failure modes are accounted for in their specific reactor design
  - Irradiation dose, dose rate, embrittlement, corrosion due to coolant, coolant chemistry and chemistry control, mass transfer leading to strength reduction or loss of ductility, etc.
- These provisos are specifically called out in the General Requirements subsection of Division 5
- In essence, these materials degradation effects are outside the scope of Section III, Division 5, and have to be addressed by Owner/Operator for their specific reactor design
  - Generate data for specific coolant and irradiation environment in test reactors, demonstration reactors
  - Conduct surrogate materials surveillance

Graphite and Composite Design Rules

- Division 5 is the only nuclear construction code that provides design rules for graphite and composite components
- Design rules are based on probabilistic approach because that is the failure behavior of these structural materials
- An overview of the Division 5 graphite and composite construction rules will be given in the afternoon by William Windes

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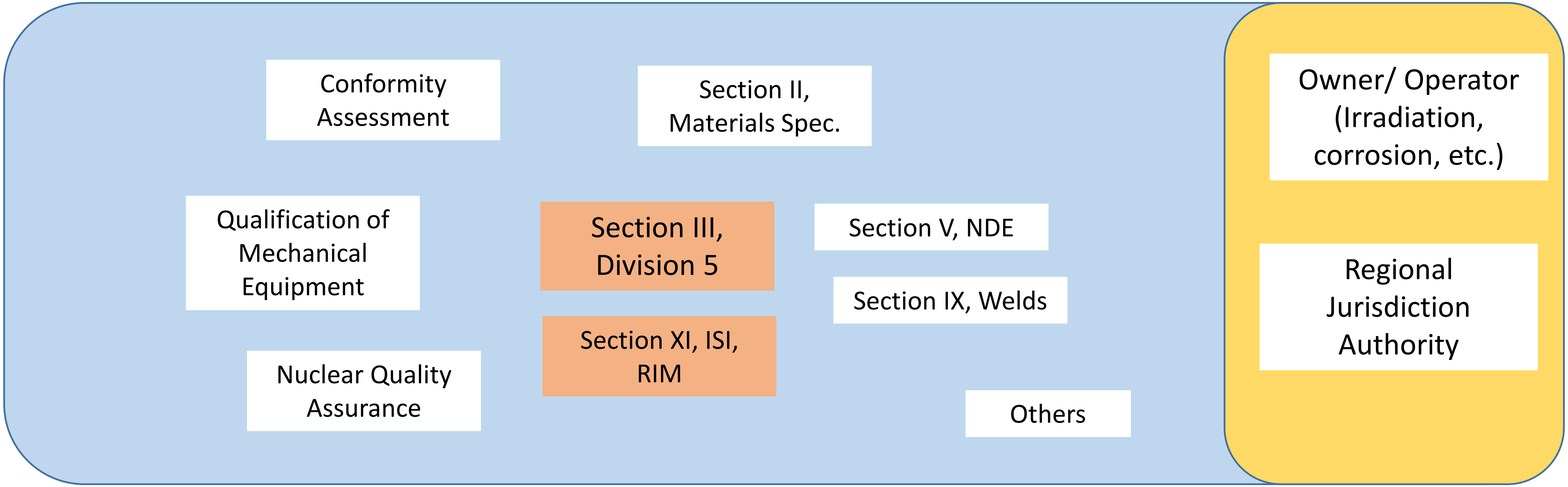
Advances in Metallic Design Rules – Since Division 1, Subsection NH

- Design rules based on elastic analysis results (Subsection NH)
  - Screening tools to provide conservative bounds (sometimes very conservative) to guard against failure modes
    - Require stress classification (engineering judgment)
    - Require linearization
    - Rules for strain limits and creep-fatigue not applicable for very high temperatures (deformation is viscoplastic)
- New design technology – Elastic, Perfectly Plastic (EPP) methods
  - Intended as screening tools in place of elastic analysis methods
  - No stress classification
  - Applicable over full temperature range
  - Accounts for redundant load paths
  - Well adapted to modern finite element technology

Reasonable Assurance of Structural Integrity

- Division 5 is not just on "design analysis," it is a Construction Code
- All Subsections (except General Requirements) have, in addition to Design, sections on:
  - Material, Fabrication, Installation, Examination, Testing, Overpressure Protection, Inspection, Stamping, And Certification (heavily referencing appropriate Division 1 Subsection(s))



Major Division 5 Initiatives For Metallic Components Under Development

- Constitutive models to support inelastic analysis method (2023 Code Edition)
  - New Appendix HBB-Z on guidance on constitutive model development being balloted
    - Included Grade 91 viscoplastic model with material parameters covering the entire use temperature range
    - 316H viscoplastic model to be introduced in 2021, followed by Alloy 617
- Design rules for Class A diffusion bonded compact heat exchanger
  - R&D through DOE Integrated Research Project – University of Wisconsin, Madison
  - Code Case for ASME consideration in 2021 (MPR lead)
- Design rules for Class A cladded structural components
  - R&D through DOE GAIN voucher to Kairos Power
  - Code Case for ASME consideration in 2021
- Alloy 709 Code Case (new Class A material to replace 316H)
  - R&D through DOE Labs (ANL, INL, ORNL)
  - 760C, 100,000-hour Code Case, ~2024

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Other Division 5 Initiatives For Metallic Components

- Extension of design parameters of existing Class A materials to support long design lifetime, when possible
- Increase temperature coverage of design parameters (fatigue curves, stress rupture factors for welds) to support other advanced reactor designs, when possible
- Identify and qualify better welds to expand design envelop, when possible
  - Alloy 82 and Alloy A welds have low stress rupture factors for Alloy 800H base metal

Major Division 5 Initiatives For Nonmetallic Components Under Development

- Inclusion of irradiation and oxidation data in the graphite code
- Inclusion of carbon/carbon composites in Subsection HH, Subpart B

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Today's Program on High Level Overview of Division 5

- Division 5 Historical Perspective and Comment Resolution – Bob Jetter
- Division 5 Design Methods for Metallic Components – Mark Messner
- Division 5 Materials (Metallic) – Richard Wright
- Division 5 Design & Materials (Nonmetallic) – William Windes

Thank You