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

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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
Examples of Different Advanced Reactor Designs Being Developed By Industry

**Fast Reactors**
- GE Hitachi PRISM
- Advanced Reactor Concepts ARC-100

**Gas Reactors**
- X-Energy, Xe-100
- Framatome SC-HTGR

**Molten Salt Reactors**
- Elysium, MCSFR

**Gas Reactors**
- General Atomic EM2 (Gas-cooled Fast Reactor)
- Ultra Safe Nuclear MMR

**Heat Pipe Reactor**
- Westinghouse eVinci
- Kairos Power KP-FHR

**Molten Salt Reactors**
- Terrestrial Energy IMSR
- ThorCon

**Gas Reactors**
- Flibe Energy LFTR (thorium)

**Fast Reactors**
- TerraPower, TWR
- Westinghouse, LFR

**Heat Pipe Reactor**
- TerraPower MCFR

**Molten Salt Reactors**
- Oklo, Aurora
- GE Hitachi PRISM

**Gas Reactors**
- Framatome SC-HTGR

**Molten Salt Reactors**
- Flibe Energy LFTR (thorium)

**Fast Reactors**
- TerraPower & GEH Natrium

**Gas Reactors**
- General Atomic EM2 (Gas-cooled Fast Reactor)

**Molten Salt Reactors**
- Terrestrial Energy IMSR
- ThorCon

**Gas Reactors**
- Westinghouse, TWR

**Molten Salt Reactors**
- Oklo, Aurora
- GE Hitachi PRISM

**Gas Reactors**
- Framatome SC-HTGR

**Heat Pipe Reactor**
- Westinghouse eVinci
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- Terrestrial Energy IMSR
- ThorCon

**Gas Reactors**
- General Atomic EM2 (Gas-cooled Fast Reactor)

**Molten Salt Reactors**
- Oklo, Aurora
- GE Hitachi PRISM

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- Framatome SC-HTGR

**Heat Pipe Reactor**
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**Heat Pipe Reactor**
- Westinghouse eVinci
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?
Addressing the “First Balloon”

- 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

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