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Overview of ASME Section III, Division 5, High Temperature Reactors

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Changing the World's Energy Future

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Idaho National Laboratory

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ASME Section III, Division 5, High Temperature Reactors

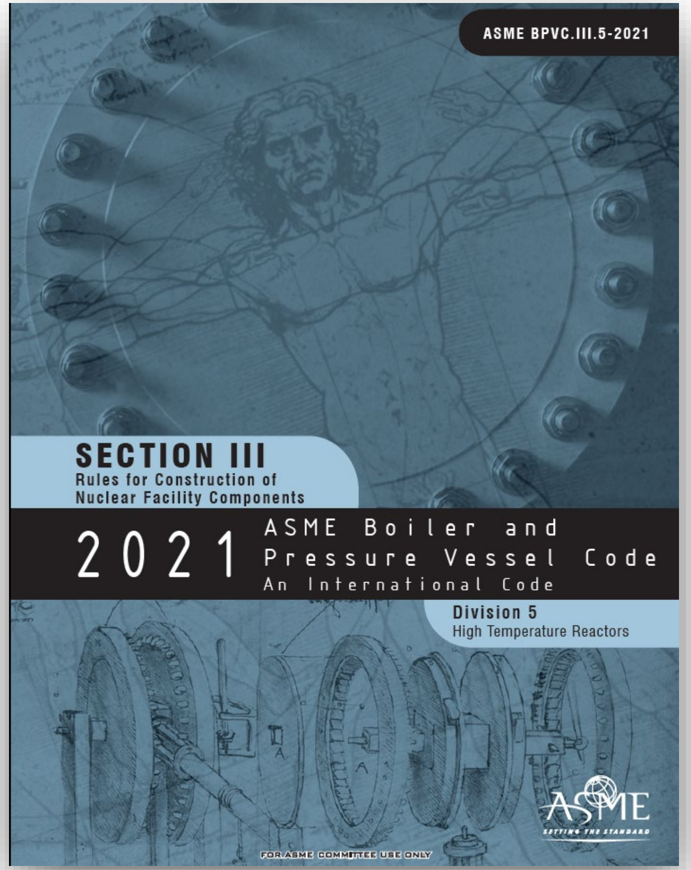
High Temperature Materials

Conference for advanced Reactor Deployment
Annenberg Presidential Conference Center
College Station, TX, USA
February 22–23, 2023

Idaho National Laboratory

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
    - 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)



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).

Section III, Division 5, 2017 Edition was Endorsed by NRC, with Exceptions and Limitations, via Regulatory Guide 1.87 Revision 2, Jan 2023

Section III, Division 5 is 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

Regulatory Guide 1.87 revision 2, Jan 2023		
Classification Method	Component Classification	
Traditional	Quality Group A	Quality Group B
Risk-informed (10 CFR 50.69)	RISC-1	RISC-1
Risk-Informed (RG 1.233)	SR	SR
	SR Qualify Design Standards	
Components		
Pressure Vessels, Piping, Pumps, Valves, Atmospheric Storage Tanks, Storage Tanks (0-15 psig)	ASME Code, Section III, Division 5, Class A	ASME Code, Section III, Division 5, Class B
Metallic Core Support Structures	ASME Code, Section III, Division 5, Subsection HG	NA
Nonmetallic Core Support Structures	ASME Code, Section III, Division 5, Subsection HH	NA

Division 5 Construction Rules for High Temperature Metallic Components – A Long History of Development

1963	Code Case 1331, design rules for nuclear components initiated.
Early 1970s	Code Cases 1592, 1593, 1594, 1595 and 1596, covering materials and design, fabrication and installation, examination, testing, and overpressure protection.
1975	NRC endorsed Code Case series 1592-1596 in RG 1.87 for HTGR, LMR, GFR.
Late 1970s	Code Case series 1592-1596 converted to Code Case N-47. Used by Clinch River Breeder Reactor project, with additional DOE requirements.
…	Continued improvements of N-47.
1995	Subsumed N-47 into a new Section III, Division 1, Subsection NH.
2011	Consolidated Subsection NH and other nuclear Code Cases, and added construction rules for graphite core components, into a new Section III, Division 5 construction rules for high temperature reactors.

Division 5 High Temperature Materials – Environmental Effects

- Effects of coolant and irradiation on structural failure modes are different from one reactor design to another even for the same structural material
- Division 5 cannot cover these effects for all reactor types, and for all different design characteristics for the same reactor type, viz. molten salt reactor
- Approach is for Owner/Operator to have the responsibility to demonstrate to regional jurisdiction authority 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.
- Essentially, 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, etc.
  - Conduct surrogate materials surveillance

Division 5 Class A Material Code Cases

Current Class A Materials

- Type 304 and 316 stainless steels
- Alloy 800H
- Grade 91 (9Cr-1Mo-V)
- 2¼Cr-1Mo (solution annealed)
- Alloy 617
- SA 508 Grade 3 and SA 533B reactor pressure vessel steels (for short term, elevated temperature excursions)

New Material Code Cases

- Lessons-learned from Alloy 617 Code Case effort have streamlined the balloting workflow for Class A material code cases
- After requester submitted material design parameters and supporting data package to ASME, Division 5 could turn around a material code case in about three Code Week cycles (less than a year)
- Data requirements for new materials are described in Division 5, "Nonmandatory Appendix HBB-Y, Guidelines For Design Data Needs For New Materials"

Division 5 High Priority Items (Metallic) - Making Progress

- Developed new Elastic, Perfectly Plastic (EPP) design evaluation methods (Completed)
- Extend allowable stresses and design parameters of Class A materials to support 60-year design lifetime (In progress)
- Qualify a new Class A alloy – Alloy 709, advanced austenitic stainless steel (In progress)
- Develop Division 5 code case for PM-HIP (Powder Metallurgy – Hot Isostatic Pressing) 316H stainless steel (In progress)
- Revamp Class B design rules and incorporate more materials (In progress)

Completed Development of Elastic, Perfectly Plastic (EPP) Design Analysis Methods

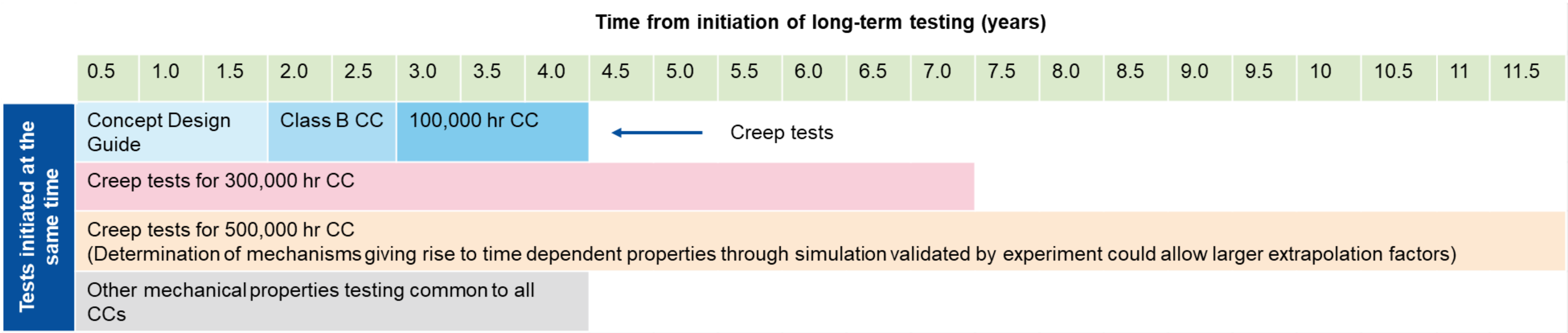
- Use different allowable stresses as pseudo yield stress in EPP finite element analysis to determine different bounding characteristics for different failure modes
- Intended as simplified "screening" tools in place of elastic analysis methods
- No stress classification
- Applicable for any geometry or loading
- Applicable over full temperature range
- Accounts for redundant load paths
- Simpler to implement
- Based on finite element results at integration points, no linearization

EPP Design Check	Code Cases	Materials
Primary Load	N-924	304H, 316H, A800H, Grade 91, Grade 22, Alloy 617
Strain Limits	N-861, N-898	304H, 316H, A800H, Grade 91, Grade 22, Alloy 617
Creep-fatigue	N-862, N-898	304H, 316H, A800H, Grade 91, Grade 22, Alloy 617

Extension of Allowable Stresses and Design Parameters to Support 60-Year Design Life

Class A Material	Time Dependent Allowable Stress	Minimum Expected Stress-to-Rupture	Thermal Aging Factor	Stress Rupture Factor (Weldment)	Isochronous Stress-Strain Curves
Type 304 Stainless Steel	Completed	Completed	Ongoing	Ongoing	Ongoing
Type 316 Stainless Steel	Completed	Completed	Ongoing	Ongoing	Ongoing
Alloy 800H	Ongoing	Completed	TBD	Ongoing	Ongoing
Grade 91	Completed	Completed	Completed	Completed	Completed
2¼Cr-1Mo	TBD	TBD	TBD	TBD	TBD

“Staged” Approach for Material Code Cases to Support Advanced Reactor Projects – Alloy 709 Case Study



A three/four-year testing program, without resource constraints, would have sufficient time to generate data package to support:

- Conceptual design (first 2 years)
  - Conceptual Design Guide for 500,000-hour lifetime
- Preliminary design
  - 100,000-hour Class A code case (3 to 4 years)
  - Class B material code case (first 2 to 3 years)

Additional creep data only at 7-year mark from start:
- Final design
  - 300,000-hour Class A code case

Additional creep data only at 12-year mark from start:
- Nth-of-a-kind
  - 500,000-hour Class A code case

Advanced Manufacturing: Division 5 Code Case for Powder Metallurgy Hot Isostatic Pressing (PM-HIP) 316H Stainless Steel

- PM-HIP is a mature advanced manufacturing method that is used by many non-nuclear industries to fabricate structural components
- PM-HIP attributes are also attractive for fabricating reactor components
  - Particularly timely for microreactors
- Target Division 5, 316H PM-HIP elevated temperature code case by 2025 to support Section III Strategic Priorities
- R&D and testing are currently being conducted through INL, EPRI and UK Nuclear Advanced Manufacturing Research Centre (AMRC) collaborative effort

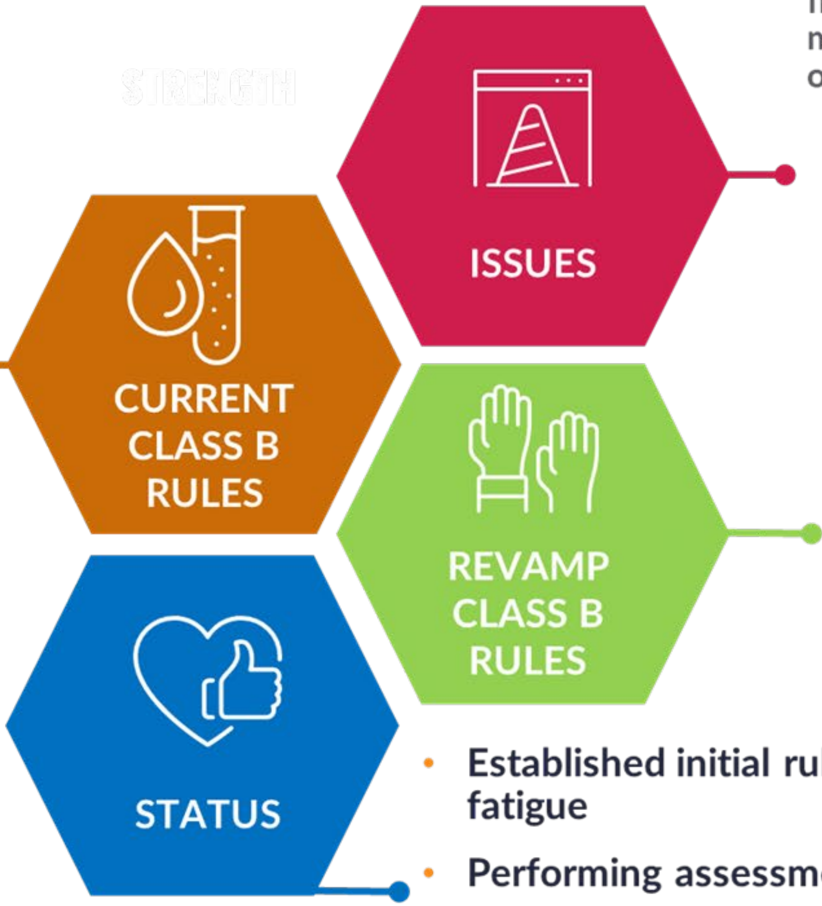
LWR reactor head – Courtesy EPRI

316L PM-HIP component for ASME Section III Code Case N-834

Kyffin, W., Gandy, D., Burdett, B. (2020)

Revamp Division 5 Class B Design Rules – Code Case by 2025

- Are extension of construction rules of Section III, Division 1, Class 2 vessel, pump, valve and piping designs to elevated temperature service
- Similar to commercial rules (Section I and Section VIII, Division 1)
- Based on the design-by-rule approach
- Allowable stresses based on extrapolated 100,000-hour creep rupture properties
- Cyclic loading in creep regime (i.e., creep-fatigue interaction) not considered
  - Except for piping, but very conservative rules



- These rules do not provide the design flexibility and are not adequate to address many design and operational characteristics of new high temperature reactors
  - Different design lifetimes, e.g., 7, 20 or 60 years
  - Thermal cycles
  - Limited permissible Class B materials

- Incorporate time-dependent allowable stresses and design lifetime concept
- Introduce simplified design-by-analysis approach to address primary load, strain limits and creep-fatigue
- Expand the permissible Class B materials list

- Established initial rules for primary load, strain limits and creep-fatigue
- Performing assessment of the new rules using sample problems
- Considering data requirements for Class B

Revamp Division 5 Class B Design Rules – Code Case by 2025

Materials Identified for Incorporation into the New Class B Code Case		
Creep data in Section III, Division 5	**Creep Data in Section II (non-nuclear)**	**None of the above**
• 304H, 316H, Alloy 800H, Grade 22 (solution annealed), Grade 91, Alloy 617	• 316L, 316Ti, Ti-mod 304 (TP321), 304N, 316N • Alloy 690, Hastelloy X, Alloy 625, Hastelloy N, Haynes 230, Haynes 242, Haynes 282, Inconel 740H • Grade 92, Grade 22 (N&T)	• Alloy 709 • XM-19 (NITRONIC 50) • Haynes 244 • HT-9 • 15-15-Ti

- Cyclic loading in creep regime (i.e., creep-fatigue interaction) not considered
  - Except for piping, but very conservative rules

- Expand the permissible Class B materials list

- Established initial rules for primary load, strain limits and creep-fatigue
- Performing assessment of the new rules using sample problems
- Considering data requirements for Class B

Concluding Remarks

- Section III, Division 5 stands ready to support near-term deployment of advanced reactors
- We are making a lot of progress:
  - Improving design rules
  - Extending design lifetimes
  - Adding more materials
  - Adding advanced component fabrication method

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