Overview of ASME Boiler & Pressure Vessel Code: Approval of New Materials in Section II and Section III Nuclear Construction Rules

…with an Eye Towards Graphite Construction Rules

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July 2022

Presentation Outline

- Crash course in ASME Boiler & Pressure Vessel Code as it applies to nuclear applications
  - Overall structure and background
- Traditional ASME approach vs. Graphite construction rules
  - Section II rules and design allowables (Mandatory Appendix 5 from Section II)
  - Graphite design data (Mandatory Appendices HHA-II and HHA-III from Section III – Div. 5)
  - Inclusion of environmental effects

Disclaimer

- Information provided is the sole opinion and responsibility of the individuals. It is not supported by ASME, or the committees of ASME, or the participants of the ASME committees, or endorsed by EPRI.

- *References:*
  - *ASME Boiler & Pressure Vessel Code Books*
  - *"High Temperature Reactors: A review of Requirements and Concepts ASME BPV Code, Section III, Division 5", Seminar by Ting-Leun Sham, Bob Jetter, Tim Burchell, Richard Barnes.*

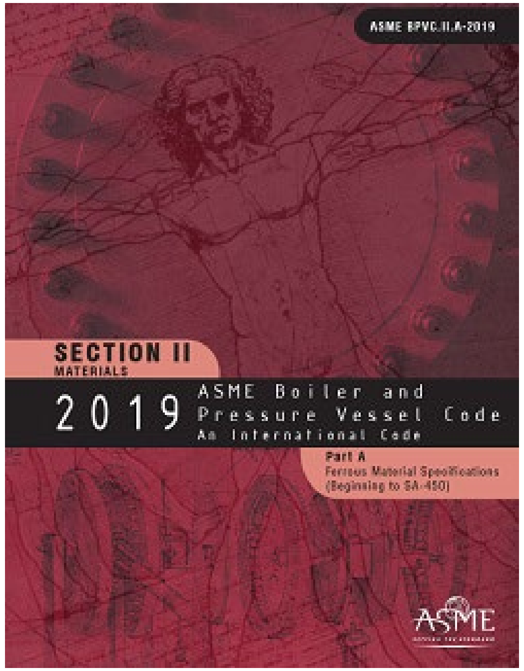
History – ASME Boiler & Pressure Vessel (BPV) Code

- The initial Code, Section I, was developed in 1911 to provide standardization of boilers designs whose failures/explosions were resulting in 50,000 deaths per year in the USA and Canada; at the end of the century 1800's, and early 1900's.
- Primary focus BPV Code was prevention of the **pressure boundary failure**.
- The BPV Code consists of 13 Sections
  - Section I – Power Boilers
  - Section III – construction rules for nuclear facility components
    - Division 1 – requirements for the materials, design, fabrication, examination, testing, inspection, installation, certification, stamping, and overpressure protection of nuclear facility components, typically light water reactors (LWRs).
    - Division 5 – provides construction rules associated with high temperature reactors
      - Subsection HH, Subpart A – Graphite Materials (see next slide for structure)

Classification & ASME Section III

- Classification is a system concept – system classification is based on stated criteria (often referred to as “safety criteria”).
- ASME Section III is a component construction code
  - The component *usually* inherits the classification of the safety in which it is located.
- **Section III does NOT** give guidance on selection of a specific classification
- Guidance is derived from systems safety criteria for specific type of reactor (PWR, BWR, MSR, etc.)
- **The Owner of a nuclear power plant shall be responsible** for applying the system safety criteria to classify the equipment.
- Classification shall be included in the Design Specification

Traditional ASME Structure



- Recall – the primary focus BPV Code is prevention of the **pressure boundary failure**.
- Section III is a component construction code
  - Section III – construction rules for nuclear facility components
    - Requirements for the materials, design, fabrication, examination, testing, inspection, installation, certification, stamping, and overpressure protection of nuclear facility components
- Section II – Materials
  - **MANDATORY APPENDIX 5**
    - GUIDELINES ON THE APPROVAL OF NEW MATERIALS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE

Section II – Mandatory Appendix 5
Policy – Data and Design Values

- Any qualified organization requesting that an ASME BPV Committee approve a "new" material for use in their Code book should be aware that only the ***BPV-II provides the appropriate design values*** for the Construction Codes (BPV I, III, IV, VIII, and XII and B31 Codes).
- The design values are calculated in accordance with the appropriate mandatory Code rules. If the inquirer considers the material to be essentially identical to one that has been approved by the BPV Committee on Materials, the inquirer shall so state in its request, and the BPV Committee on Materials shall evaluate that judgment.
- If the material is not essentially identical to one that has been approved by the BPV Committee on Materials, the inquirer **shall provide all of the data** cited in this Mandatory Appendix.
  - Based on those data, the **BPV-II will provide the appropriate design values.**

Not applicable for Graphite as design values are provided via *Mandatory Appendices of Section III, Division 5 – Subpart A*

Table 3-1
Properties required for materials qualification (adapted from [37])

Property	ASME Code Required	NRC Required	Property	ASME Code Required	NRC Required
Physical			**Time-Dependent**		
Density	Y		Creep	Y	
Poisson's ratio	Y		Creep fatigue (withhold time on fatigue cycles)	Y	
Thermal conductivity	Y		Creep rupture	Y	Per 10CFR50
Thermal diffusivity	Y	Per 10CFR50	Relaxation strength	Y	
Thermal emissivity	N		Isochronous stress-strain	Y	
Thermal expansion	Y		Bi-axial stress rupture	Y	
Specific heat	Y				
Time-Independent			**Environmental Effects**		
Yield strength	Y		Irradiation embrittlement	N	Y
Ultimate strength	Y		Hydrogen embrittlement	N	Y
% elongation	Y		Liquid-metal embrittlement	N	Y
% reduction of area	Y		Irradiation-induced creep	N	Y
Fracture toughness, K_{Ic}	Y	Per 10CFR50	Liquid-metal corrosion	N	Y
Impact toughness, CVN	Y		Stress-corrosion cracking	N	Y
Fatigue curve (S-N)	Y		Yield strength (Irradiated)	N	Y
Low-cycle fatigue (S-N)	Y		Ultimate strength (Irradiated)	N	Y
Fatigue crack growth rate	Y		Fracture toughness (Irradiated)	N	Y

Page 1 of 2: Continued on next slide

Reference:
37. N. R. Brown, M. Serrano De Caro, E. A. Rodriguez, Los Alamos National Laboratory Report LA-UR-12-24358, "Gap Analysis of Material Properties Data for Ferritic/Martensitic HT-9 Steel, August 2012.

Table 3-1
Properties required for materials qualification (adapted from [37])

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Property	ASME Code Required	NRC Required	Property	ASME Code Required	NRC Required
Cyclic stress-strain curve	Y		Impact toughness (Irradiated)	N	Y
Monotonic stress-strain	Y				
Young's modulus	Y				

Note:
This list of properties does not necessarily encompass all material properties required for implementation in an LFR design; for example, neutron absorption behavior is also an important consideration that is not included in this list.

- **ASME Section III typically <u>does not</u> account for Environmental Effects**
  - Owner/Operator has the responsibility to demonstrate to regional regulator that the effects on structural failure modes are accounted for in their specific reactor design

\+ Provides flexibility

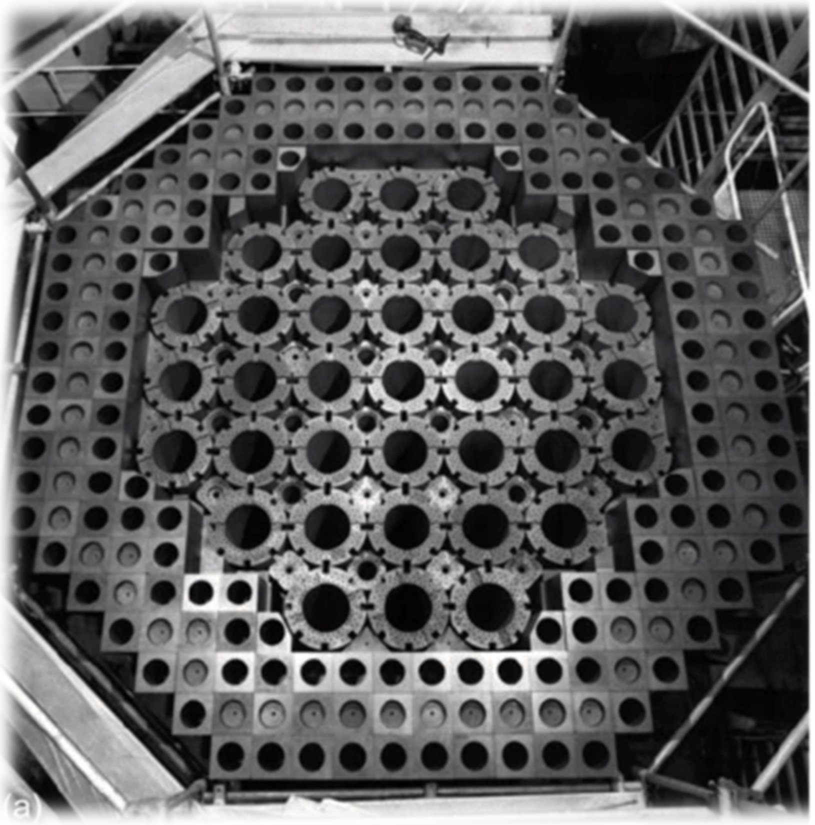
– Reduces standardization

Section III – Important Concepts

- In the pressure retention regime, the code requires a minimum thickness be met. This concept is to prevent plastic collapse (gross failure) and allows the focus to be placed on the mechanisms that cause failure through degradation as a result of operation.
- For the high temperature application, the quantification of minimum thickness has to take into account the loads at temperature and time at temperature. This will be developed further in our presentation.
- For graphite structures the functional requirement to limit deformation from loading to allow the control rods to function correctly, (more than), maintain adequate margin against failure.

How does this relate to Graphite and its construction rules?

- Graphite as a moderator is an integral part of core design and functions as a core support (typically)
  - In addition to control rod alignment/insertion function,
  - The properties and design impact pressure boundary components



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Subsection HH – Nonmetallic Core Support Structures

Section III, Division 5 – Subsection HH, Subpart A Graphite Materials
Section III, Division 5 – Subsection HH, Subpart B Composite Materials

- **Articles under Subsection HH, Subpart A**
- HHA-2000 Materials
- HHA-3000 Design
- HHA-4000 Machining, Examination, and Testing
- HHA-5000 Installation and Examination
- HHA-8000 Nameplates, Stamping and Reports
- Mandatory Appendix HHA-I Graphite Materials Specifications
- Mandatory Appendix HHA-II Requirements for Preparation of a Material Data Sheet
- Mandatory Appendix HHA-III Requirements for Generation of Design Data for Graphite Grades
- Nonmandatory Appendix HHA-A Graphite as a Structural Material
- Nonmandatory Appendix HHA-B Environmental Effects in Graphite
- Nonmandatory Appendix HHA-D Guidance on Defects and Flaws in Graphite

Mandatory Appendix HHA-III

Requirements for Generation of Design Data for Graphite Grades

- The properties data required to qualify a grade for use in this Subpart are defined herein.
- Changes to a graphite grade (specifically the coke or processing route) will require the generation of new design data.
- Properties to be determined
  - As-manufactured Graphite
  - Oxidized Graphite
  - Irradiated Graphite

Recognition that Graphite is Unique and New to ASME Section III


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