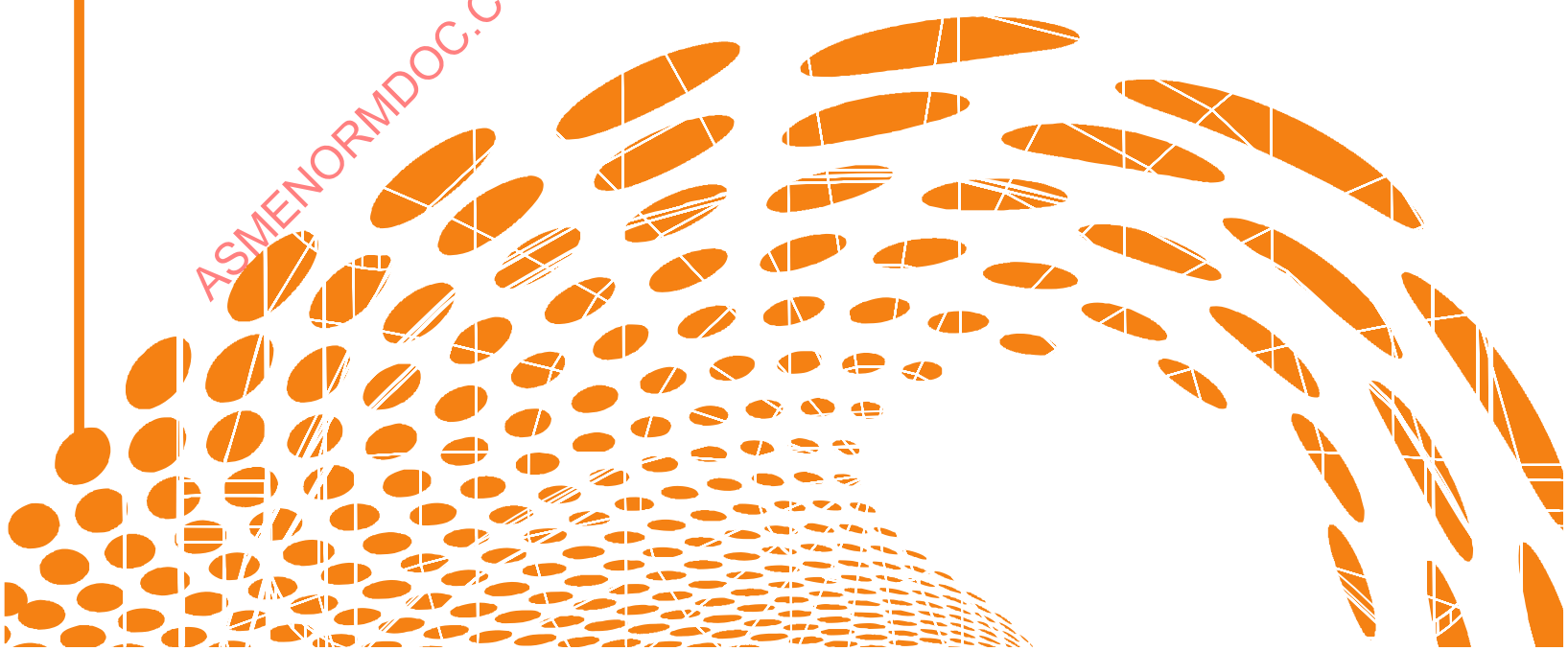
ASME STANDARDS TECHNOLOGY, LLC

STP-NU-067-1

ROADMAP FOR THE DEVELOPMENT OF ASME CODE RULES FOR FUSION ENERGY DEVICES



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ROADMAP FOR THE DEVELOPMENT OF ASME CODE RULES FOR FUSION ENERGY DEVICES

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Summary of Changes

The following changes have been made to the first edition of STP-NU-067.

Foreword

Revised paragraph to simplify the language.

1. Vision Statement and Overview

Clarified the use of this new code rules for next generation fusion facilities.
Explained the role of project teams developing these rules and provided examples of on-going fusion projects.

2. Methodology

Clarified the use of this new code rules for next generation fusion facilities.

2.1 Global Stakeholders

Added new example of National and International Organizations (EURO Fusion and R & D Organizations and Clarified the use of this new stake holder group for next generation fusion facilities.

2.2 A Phased Approach

Clarified a multiple approach.

2.3 Assumption

Clarified approach and assumptions.

3. FED Designs and Information Required

Added new bullets or redefined existing ones in the second paragraph: Types and developmental status of major components; Superconductor Ancillary Systems… and Heat exchangers, Box structures, Bellows, Other Nuclear ancillary structures.

4.1 Research and Development (R&D) Tasks

Organized, Combined and Grouped the various R & D tasks into types of activities.

4.2 Administrative and Technical Tasks

Reorganized paragraph and assigned responsibility for developing a project plan. Introduced the role of the "ASME FE.1-2018 Draft Standard for Trial Use, Rules for Construction of Fusion Energy Devices" and areas of responsibilities.

4.3 Specific Code Rule Development Tasks

Organized the various Tasks into specific categories related to Design, Risk, Industrial and Confinement Structures Rules.

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FOREWORD

This Roadmap provides the guidance for developing construction code rules for Fusion Energy Devices (FED). These code rules are for the design, manufacturing, and construction for the next generation fusion facilities.

The authors acknowledge, with deep appreciation, the activities of ASME staff and volunteers who have provided valuable technical input, advice and assistance with review of, commenting on, and editing of this document.

Established in 1880, the American Society of Mechanical Engineers (ASME) is a professional not-for-profit organization with more than 100,000 members promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit www.asme.org for more information.

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ACRONYMS AND ABBREVIATIONS

ASME	American Society of Mechanical Engineers
ASME ST-LLC	ASME Standards Technology, LLC
BNCS	Board on Nuclear Codes and Standards
BPV	Boiler and Pressure Vessel
DOE	Department of Energy
EURO Fusion	European Fusion Support Organization
EDF	French Utility
FED	Fusion Energy Device
FW	First Wall
HTS	High-Temperature Superconductor
IAEA	International Atomic Energy Agency
ISI	In-Service Inspection
ITER	International Fusion Project (International Thermonuclear Experimental Reactor)
JAEA	Japan Atomic Energy Agency
JSME	Japan Society of Mechanical Engineers
KINS	Korean nuclear regulator
LTS	Low-Temperature Superconductor
O&M	Operation and Maintenance
NDE	Nondestructive Examination
NEI	USA nuclear utilities
PWHT	Post Weld Heat Treatment
QA	Quality Assurance
QME	Qualification of Mechanical Equipment
R&D	Research and Development
RIM, PRA	Reliability and Integrity Management, Probabilistic Risk Assessments
RP	Recommended Practice
SC	Subcommittee
SCD	Subcommittee on Design
SDO	Standards Developing Organization
SI	International System of Units (from the French Le Système International d' Unités)
SWG	Special Working Group
UKAEA	UK Atomic Energy Authority
VV	Vacuum Vessels
WG	Working Group

1. VISION STATEMENT AND OVERVIEW

The ASME Board on Nuclear Codes and Standards approved the development of these rules for construction of fusion-energy-related components for the next generation fusion facilities and these components would include such items as vacuum vessels (vacuum or target chamber), cryostat, in-vessel components, and superconductor structures and their interaction with each other. These rules will be found in Division 4 of Section III entitled "Fusion Energy Devices". The rules contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping.

Current ASME Boiler and Pressure Vessel (BPV) Section III code rules do not specifically address the construction rules for fusion energy devices that are currently under consideration, nor do they support on-going projects, such as ITER (Tokamak Concept) and other fusion concepts such as Inertial Confinement Fusion (primarily laser fusion; an example is the National Ignition Facility), and magneto-inertial confinement concepts.

While it may be feasible to modify the existing Section III rules to meet future fusion needs, it has been recommended that a complete separate set of rules be developed for these new fusion energy devices to cover design, construction and inspection/testing. In addition, it is anticipated that operation and maintenance requirements for these fusion energy devices may also require a new set of rules or major modifications to the existing ASME Operations and Maintenance (OM) Code. It is necessary that these new rules contain the best available methods and technology in each area.

The approach in this Roadmap consists of a compilation of suggestions from subject matter experts, organizations interviewed, as well as the project teams, task groups, and committee deliberations within the Subgroup Fusion Energy Devices of the BPV Committee on Construction of Nuclear Facility Components (III). It is anticipated that some of the tasks identified in this FED Roadmap will be revised or eliminated from consideration and others will be added.

Since the Fusion Energy Devices Code rules will be developed within the BPV III Committee Subgroup Fusion Energy Devices committee structure, there will also be coordination with other impacted groups both inside and outside ASME such as National Laboratories, Fusion User Community, etc. A Fusion Stakeholder Task Group is working on identifying fusion stakeholders and their needs, and developing recommendations and approaches to be incorporated into the Fusion Code rules. This development work will also examine existing rules used for ITER, JET, JT-60, KSTAR, EAST, SST-1 and others for necessary incorporation into these proposed code rules. There are numerous global participants from the US, Japan, Korea, China, UK, Korea, India. There are also other fusion users who are currently involved with this effort. The first edition of these Fusion Code Rules will be the first volume of the Division 4 document published in July 2023 for the ASME BPV Code 2023 edition.

2. METHODOLOGY

The methodology for the development of Fusion Code rules is based on the technical alternatives that are under development at the time and currently being used. The Roadmap is updated as the technical committees reach a consensus on each technical and organizational alternative.

The proposed organization for the various phases will be based on the approved format of the rules (e.g. new Section III, Division 4 book). If the BPV III Standard Committees decides to change the format, the Roadmap will be updated.

2.1 Global Stakeholders

The following stakeholders will be considered in the development of the Fusion Roadmap. The interests of these stakeholders will be considered to the extent practicable.

- Regulatory Community (US NRC, IAEA, KINS, QST, UKAEA-among others)
- Electric Utilities and Associations (EDF, EPRI, NEI, etc.)
- Standards Developing Organizations (ASME, JSME, etc.)
- Designers and Constructors
    - National and International Organizations (US DOE, UK Atomic Energy Authority, EU Fusion for Energy, EURO-Fusion)
    - Consultants
    - Materials suppliers
    - R & D Organizations
- Equipment suppliers
- Service providers.

2.2 Division 4 committee structure

The committee structure of Division 4 is found in Figure 1.

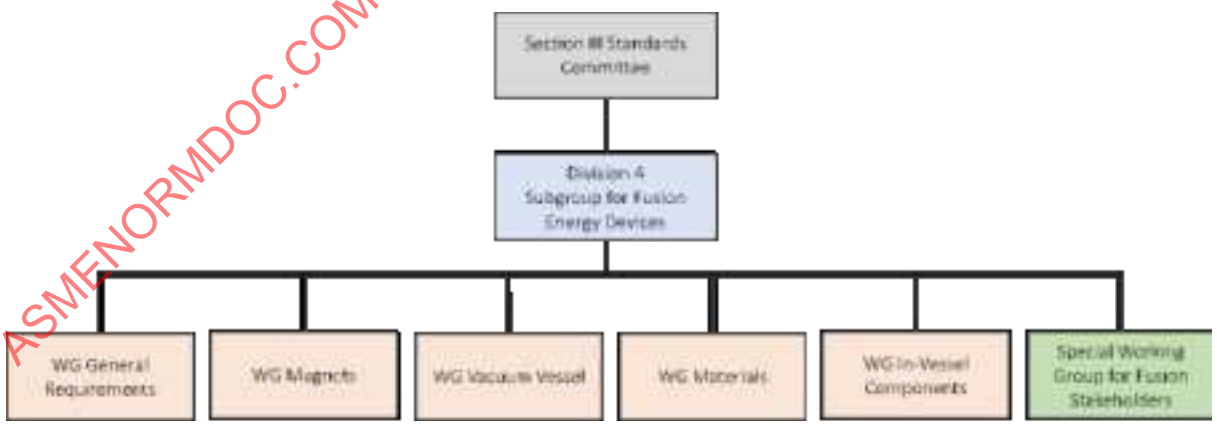

Figure 1: The organization chart of the ASME BPV Section III Division 4 committees, its working groups (WG), and special WGs.

The roles and responsibilities of each Working Group (WG) are as follows:

WG General Requirements

The Working Group on General Requirements shall develop the general requirements rules for the construction of fusion-energy-related components such as magnets, containment vessels (vacuum or target chamber), cryostat and superconductor structures and their interaction with each other. Other related support structures, including metallic and non-metallic materials, containment or confinement structures, fusion-system piping, vessels, valves, pumps, and supports will also be covered. The rules shall contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping and will be closely aligned with the existing General Requirements rules located in Section III.

WG Magnets

The Working Group on Magnets shall develop rules for the construction of fusion-energy-related magnet components such as magnets, superconductor structures and their interaction with each other. Other related support structures, including metallic and non-metallic materials, containment or confinement structures, fusion-system piping, insulation, vessels, valves, pumps, and supports will also be covered. The rules shall contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping.

WG Vacuum Vessel

The Vacuum Vessel Working Group shall develop the code rules for the design and construction of containment vessels (vacuum or target chamber), for fusion devices. The vacuum vessel for ITER will be used as a basis and the main application is for next-generation fusion devices, so-called DEMOs. Other related support structures, including metallic and non-metallic materials, containment or confinement structures, windows and ports, and supports will also be covered. The rules shall contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping.

WG Materials

The Working Group on Materials shall develop rules for the qualification and certification of materials to be used in fusion device construction of fusion-energy-related components. Other related support structures, including metallic and non-metallic materials, containment or confinement structures, and supports will also be covered. The rules shall contain requirements for materials, testing, examination, inspection, and certification.

WG In-vessel Components

The Working Group on In-Vessel Components shall develop rules for the construction of fusion-energy-related In-Vessel Components such as divertors, blankets, in-vessel coils, in-vessel diagnostic devices, in-vessel heating and current drive devices, structures and their interaction with each other. Other related support structures, including metallic and non-metallic materials, containment or confinement structures, and supports will also be covered. The rules shall contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping.

SWG for Fusion Stakeholders

The Special Working Group for Fusion Stakeholders will provide a venue for user needs and development direction, implementation comments and suggested code rule input from within and outside ASME, for the development of rules for the construction of fusion energy devices within Section III, Division 4. The rules constitute the requirements for the construction of Fusion facility components such as pressure vessels, piping, pressure retaining portions of structures as well as pumps, valves, heat transfer system, and support structures and confinement structures. These proposed fusion rules also contain requirements for materials, design, fabrication, testing, examination, inspection, certification and stamping. The special working group shall identify research and development efforts required to support the technical development of the code rules. Interface with BPV XI on Inservice Inspection issues is expected.

2.3 A Phased Approach

A multi phased approach is used to develop the Codes rules. Phase I includes activities related to developing this Roadmap for the new Section III, Division 4 (III-4) book to meet the needs identified by stakeholders worldwide for Fusion facilities that will be designed within the next few decades. It has been assumed in the development of this Roadmap that these needs are in a constant state of development.

Phase II activities will be to develop rules to be issued as the new Section III Division 4 Standard. This new Standard will meet the needs identified by stakeholders worldwide for Fusion Energy Device facilities that will be designed more than a decade from now. As part of this effort a draft standard for trial use by the fusion user community was developed and issued as a digital document. This document is the "ASME FED-1-2018 Draft Standard for Trial Use, Rules for Construction of Fusion Energy Devices." It has been assumed in the development of this Roadmap that these needs include significantly different types of design and operating components than are in commercial fission facilities. Therefore, additional time will be needed for conducting R&D to provide technical data and information for establishing bases for Code rules.

To generate task activities Division 4 will:

- Designate dedicated project teams to draft proposals for each portion of the rules.
- Require and ensure that each project team determines the best available technology for each portion of the rules, incorporating, as appropriate, recent work in other codes and standards as well as the technical literature. It is recognized that this process is well underway in many areas.
- Ensure that close liaison is maintained and coordinated among all project teams and activities to ensure that the new construction and post construction (in-service) rules are complimentary and consistent. Examples include: Ensure that new construction NDE provides the proper baseline for post construction NDE.
- Ensure that fabrication and examination rules are consistent with design rules.
- Roadmap is focused primarily on those tasks that are needed to develop code rules. Tasks that may be needed to demonstrate performance or for specific designs are outside of the scope.

Resource issues were not considered at this time, but further discussions will need to address issues such as sponsors, as well as individuals to draft Code rules as they are identified.

2.4 Assumptions

The FED Roadmap development uses the assumption that the objective is to produce a complete set of Code rules that could be endorsed by regulators and incorporated in regulatory rules, i.e., U.S. Nuclear Regulatory Commission (NRC), among others.

It is anticipated that the format of the new fusion device rules will be generally the same as the current format of Section III but any major changes will be reviewed, considered and addressed because of the differences and functions between a fusion-based facility and a typical fission facility.

3. FED DESIGNS AND INFORMATION REQUIRED

The FED Roadmap covers the currently major fusion device concepts: (1) Magnetic Confinement Fusion (the Tokamak, an example is the ITER international project), (2) Inertial Confinement Fusion, which is primarily laser fusion, e.g., as used by the National Ignition Facility, and (3) Magneto-inertial confinement fusion. There are other fusion design concepts such as Reverse Field Pinch (RFP), Spheromak, Liquid Compression, Solid or Magnetic Compression, Plasma Compression and Laser Projectile Compression to name a few examples.

Types and developmental status of major components that will be needed for fusion will need to be defined, and include:

- Superconducting Magnets, LTS, HTS, Structure and Current-feeders
- Cryogenic Refrigeration, Storage and Distribution Systems
- Containment Vacuum Vessels and/or Target Chambers
- In-vessel components/reactor internals; First Wall, Blanket, Divertor, Shield, Manifolds, Tritium Breeding Blanket
- Superconductor Ancillary Systems; Leads, Busbars, Energy Absorbing Equipment
- Resistors, High Current Switches, and Power Supplies
- Plasma Control Systems
- Balance of Plant Systems such as Tritium, Water-cooling
- Piping, Pumps, Valves
- Cryostat Vacuum Vessel Ports & Thermal Shields
- Cryostat Vent System
- Vacuum Systems
- Heat exchangers
- Box structures
- Bellows
- Other Nuclear ancillary structures

Additionally, Fusion Device Extreme conditions (14 MeV neutrons, heat loads, EM forces/stresses, and Temperature during transients/accidents) and Plasma Configuration Requirements will also need to be specified along with Disruption Mitigation methods.

4. PROPOSED TASK WORK

4.1 Research and Development (R&D) Tasks

The term R&D as used in the Roadmap is intended to include the following categories of tasks:

- Physical tests to develop nuclear-grade material properties and information about the long-term performance of materials in relevant environment including radiation degradation due to neutrons, helium production, ionizing radiation, high magnetic field compatibility etc.
- Development and validation of new design and analysis methods/tools.
- Development of new methods for fabrication and examination, such as NDE and additive manufacturing, HIP process.

Development of drafts of Code rules based on existing methods and data, and the validation of those rules, are not considered to be R&D. However, if a consensus cannot be reached on certain aspects of the rules, it may be necessary to initiate R&D projects to obtain more data or to develop modified or alternative methods.

Also, it should be recognized that it may be necessary to initiate funded projects to develop Code rules in some areas. The project teams responsible for each portion of the rules should make recommendations for consideration by the appropriate groups within the ASME organizational structure.

R&D needs:

General:

- Develop a Component Classification System that can be used to map into classifications of Systems, Structures, and Components (SSCs).
- Preface on the approaches to fusion energy and different safety requirements compared to fission energy.
- Identifying common systems across all fusion energy in order to develop suitable design rules.

Methodology Development

- Develop methodology for design considerations to account for predicted damage mechanisms such as fatigue or creep–fatigue damage.
- Develop Improved Design Methodology for Creep-Fatigue Evaluation by Analysis. This approach should take full advantage of modern analysis methods, such as elastic-plastic finite element analysis with creep strain modeling capability.
- Develop Improved Methodology for Strain Limits based on the results of elastic or simplified inelastic analysis and taking full advantage of modern analysis tools.
- Develop Rules for Design and In-Service Evaluation Using Fracture Mechanics leak-before-break performance.
- Explore the use of Structural Brazes, Magnet Strand and Conductor brazes and other High Temperature Bonding Methods. These types of brazes, diffusion bonding or other joining methods may be needed for components.
- Define Probabilistic methods to be used in PRA applications.
- Develop Methodology for Load Controlled Stress Limits that Require no Stress Classification.