STP-NU-067

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

ASME STANDARDS TECHNOLOGY, LLC

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FOREWORD

This Roadmap has been developed as a guide to the Research & Development (R&D) and Code development tasks that could be considered in developing rules for Fusion Energy Devices (FED). The primary focus of the Roadmap is on the development of a complete set of Code rules for the design and operating conditions that are being proposed for the next generation fusion facilities.

The author acknowledges, 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 135,000 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-LLC	ASME Standards Technology, LLC
BNCS	Board on Nuclear Codes and Standards
BPV	Boiler and Pressure Vessel
DOE	Department of Energy
EFDA	European Fusion Support Organization
EDF	French Utility
FED	Fusion Energy Device
FW	First Wall
IAEA	International Atomic Energy Agency
ISI	In-Service Inspection
ITER	International Fusion Project
JAEA	Japan Atomic Energy Agency
JSME	Japan Society of Mechanical Engineers
KINS	Korean nuclear regulator
O&M	Operation and Maintenance
NDE	Nondestructive Examination
NEI	USA nuclear utilities
PT	Penetrant Testing (dye penetrant)
PWHT	Post Weld Heat Treatment
QA	Quality Assurance
QME	Qualification of Mechanical Equipment
R&D	Research and Development
RP	Recommended Practice
RT	Radiographic Testing
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
UT	Ultrasonic Testing
VV	Vacuum Vessels
WG	Working Group

1 VISION STATEMENT AND OVERVIEW

The ASME Board on Nuclear Codes and Standards approved an effort to develop rules for the construction of fusion-energy-related components such as the vacuum vessel (vacuum or target chamber), cryostat and superconductor structures and their interaction with each other. These rules will be found in a new Division 4 of Section III entitled “Fusion Energy Devices”. The rules shall contain requirements for materials, design, fabrication, testing, examination, inspection, certification, and stamping. The formation of the new Subgroup on Fusion Energy Devices will be responsible for the development of these rules and has begun to develop its membership and future working group support structures.

Current ASME BPVC 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).

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.

As such, this *Roadmap for the Development of ASME Code Rules for Fusion Energy Devices* (FED Roadmap) was developed to outline what should be considered when developing these rules. The approach in this FED Roadmap consists of a compilation of suggestions from subject matter experts and organizations interviewed, as well as that of the author. As the project teams, task groups, and committees deliberate, 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.

The Fusion Energy Device Code rules will be developed by various project teams within the Subgroup Fusion Energy Devices of the BPV Committee on Construction of Nuclear Facility Components (III) and will be coordinated with other impacted groups both inside and outside ASME. A Stakeholder Task Group reporting to the Chairman of the BPV Committee on Construction of Nuclear Facility Components (III) and the Chairman of the Subgroup Fusion Energy Devices has been formed to identify stakeholders and their needs, and develop recommendations and approaches to be incorporated into new FED Code rules.

2 METHODOLOGY

The proposed methodology for the development of FED Code rules is based on the technical alternatives that were under development at the time. The FED Roadmap will be 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 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 should be updated. The final section in this document summarizes the recommended organizational structure for the code development effort.

2.1 Global Stakeholders

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

- Regulatory Community (US NRC, IAEA, KINS, JAEA-etc.)
- Electric Utilities and Associations (EDF, EPRI, NEI, etc.)
- Standards Developing Organizations (ASME, JSME, etc.)
- Designers and Constructors
- National and International Organizations (US DOE, EFDA)
- Consultants
- Materials suppliers
- Equipment suppliers
- Service providers.

2.2 A Phased Approach

A phased approach is being used to develop the FED 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 FED 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 related to developing rules to be incorporated into the new III-4 and to meet the needs identified by stakeholders worldwide for Fusion Energy Device facilities that will be designed more than a decade from now. It has been assumed in the development of the 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.

The philosophy to be used to generate the task activities and organization are:

a) Designate dedicated project teams to draft proposals for each portion of the rules.
b) Require and ensure that each project team determine 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.
c) 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 (e.g., UT vs. RT)

- Ensure that fabrication and examination rules are consistent with design rules.

d) The 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.

2.3 Assumptions

The FED Roadmap was developed using the assumption that the objective was to produce a complete set of Code rules that could be endorsed by regulators and incorporated in regulatory rules (i.e., U.S. NRC).

It is anticipated that the general scope and format of the new fusion device rules will be generally the same as the current scope 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.

The Fusion Energy Device Project Plan development will be based on the assumption that a complete set of new Code rules are needed by regulators for their future adoption.

3 FED DESIGNS AND INFORMATION REQUIRED

The FED Roadmap covers two basic Fusion Device Concepts: (1) Magnetic Confinement Fusion (the Tokamak, an example is the ITER international project), and (2) Inertial Confinement Fusion, which is primarily laser fusion, e.g., as used by the National Ignition Facility.

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

- Superconducting Magnets, Conductor and Structure
- Cryogenic Refrigeration, Storage and Distribution Systems
- Containment Vacuum Vessels and/or Target Chambers
- First Wall, Blanket, Divertor, Shield, Manifolds
- Superconductor Ancillary Systems; Leads, Busbars, Energy Absorbing Equipment Resistors, High Current Switches, and Power Supplies
- Plasma Control Systems
- Balance of Plant Systems
- Piping, Pumps, Valves
- Cryostat Vacuum Vessel Ports & Thermal Shields
- Cryostat Vent System
- Vacuum Systems

Additionally, Fusion Device Extreme conditions (heat loads, EM forces/stresses, and Temperature during transients/accidents) and Plasma Configuration Requirements will also need to be specified.

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 material properties and information about the long-term performance of materials in relevant environment including radiation degradation due to neutrons, helium particles, ionizing radiation, etc.
- The development and validation of new design and analysis methods/tools.
- Development of new methods for fabrication and examination (NDE).
- 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.

The following R & D areas to be considered:

- Develop methodology for design considerations such as fatigue or creep–fatigue damage.
- Consider elastic conditions.
- Compile existing creep relaxation data or develop new data as needed
- Develop initial loading and cyclic stress-strain curves for all materials to be used for BPV III-4 construction for the complete temperature range of interest if these data are needed for the analysis methods selected.
- Develop Improved Design Methodology for Creep-Fatigue Evaluation by Analysis. This approach should take full advantage of modern analysis tools, such as elastic-plastic finite element analysis with creep strain capability.
- Develop Methodology for Load Controlled Stress Limits that Do Not Require Stress Classification.
- 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.
- Develop Rules for leak-before-break performance.
- Develop Additional Materials Data and other Analysis needs.
- Consider Probabilistic methods.
- Develop and Validate Remote NDE methods for fresh and recycled materials.
- Develop methodology for continuous monitoring of critical components during operation.
- Develop programs to support the use of carbon, graphite, ceramic and composite materials, refractory metals and alloys.
- Establish an "NDE Database".
- Investigate 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.
- Develop environmental factors for fusion environments.
- Additional R&D programs as defined by the Project Teams working in each area.

4.2 Administrative and Technical Tasks

The following outlines the recommended approach for the administrative and technical tasks for the phased approach:

a) Establish an administrative structure to oversee the various phase tasks
b) Establish physical boundaries of scope
c) Define Code needs for structures requiring standards
d) Develop a Component Classification System
e) Define BNCS, BPV III and BPV XI Direction and establish interface
f) Establish Technical Framework
g) Organization of BPV III-4
h) Develop Common Terminology and Units of Measurement
i) Develop Overall Guidance for III-4

4.3 Specific Code Rule Development Tasks

The following list recommends the specific code rule development tasks that should be conducted:

a) Determine Need to Develop a PRA Standard
b) Develop General Requirements
c) Develop "Design-by-Rule" Requirements
d) Develop Design-by-Analysis Methodology
e) Fatigue Design Rules
f) Develop Elevated Temperature Design Rules
g) Develop Cryogenic Temperature Design Rules
h) Consider / Develop Rules for Probabilistic methods
i) Develop Rules for the Application of Remote NDE Methods
j) Rules for welding and post weld heat treatment (PWHT)
k) Develop rules for NDE for new and post construction
l) Consider the need for Reliability and Integrity Management (RIM)
m) Consider the need for temperature and leak monitoring rules
n) Consider the need for new construction rules for performance testing of pumps, valves and systems
o) Consider the need for new construction rules for rotating machinery
p) Develop rules for pressure/temperature limits and in-service testing
q) Develop design material rules covering carbon, graphite, and ceramic, composite
r) Verify applicability of nuclear QA applications
s) Determine need for BNCS to develop ASME Code rules for confinement structures

5 RECOMMENDED STRUCTURE FOR ASME FED CODE

The following outlines the recommended structure for the ASME FED Code.

I Magnet
- Magnet Coil
- Magnet Conductor
- Magnet Strand
- Superconductor Systems and Auxiliaries

II Plant Systems
- Cryostat
- Cooling Water System
- Cryogenic System Engineering
- Hot Cell & Radwaste Services Integration
- Radwaste Treatment & Storage

III Vacuum Vessel or Target Chamber
- Ports & Thermal Shield
- Cryostat & VV Pressure Suppression System

IV Internal Components
- FW/Blanket
- Divertor
- Shield
- Manifolds

V Assembly & Maintenance
- Machine Assembly & Tooling
- Remote Handling and Radiation-resistant equipment

VI Fuel Cycle Engineering
- Tritium Plant
- Fuelling and Wall Conditioning
- Vacuum Pumping

VII Electrical Engineering Division
- Coil Power Supply & Distribution
- Steady State Electrical Power Network

VIII CODAC -Control Data Access and Communications

IX Plasma Control Systems
- Startup System
- Stabilization System (coils, shells, etc.)
- Ion Cyclotron H & CD
- Electron Cyclotron H & CD
- Neutral Beam

X Diagnostics

- Port Based Systems
- Divertor Systems
- In-Vessel and Distributed Systems
- Diagnostics Engineering & Generic Components

XI Low-Activation Materials

XII Design/Science

- FW, Divertor and Plasma-Wall Interactions
- Transport and Confinement Physics
- Stability and Control
- Integrated Modeling
- Plasma Operations
- System Analysis
- Tritium Breeding and Extraction
- Disruption and Transient Mitigation
- Radioactive Material Management Scheme
- Maintenance Approach

5.1 Industry Involvement

It is important to Develop Stakeholders Group with representatives from affected SDOs, users and regulators. The interested parties should work towards consensus of responsibility for requirements in any areas where standards are needed. The Nuclear Energy Standards Coordination Collaborative (NESCC) and the Nuclear Energy Agency (NEA) are just two organizations that may appropriate resources toward this objective.

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