IAEA Technical Meeting on Tritium Breeding Blankets and Associated Neutronics

Topic 2 – Manufacturing, Assembly and Licensing

Introduction

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This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Design and Manufacturing of Fusion SSCs: limitations of existing C&S

- C&S are developed to comply with regulations, but there is **no harmonized regulatory framework** for fusion installations.
- Existing C&S address **SIC components** in fission plants but fusion plants have **different safety challenges** compared to fission.
- **"Mission critical" components** (magnets, IVCs) may not be SIC and exempted from regulation but **must still be designed, manufactured and operated to the highest quality standards (investment protection).**
- **The wide range of operating conditions of fusion SSCs** (operating temperatures from 4K to 2000K, EM loads linked to electrical functionality, strong cyclic operation, effects of 14MeV neutron irradiation, plasma-wall interactions leading to materials degradation, etc.) **are not covered by any single existing industrial code.**

A multi-code approach was selected from the beginning for ITER SSCs, complemented by specific design rules and Technical Specifications

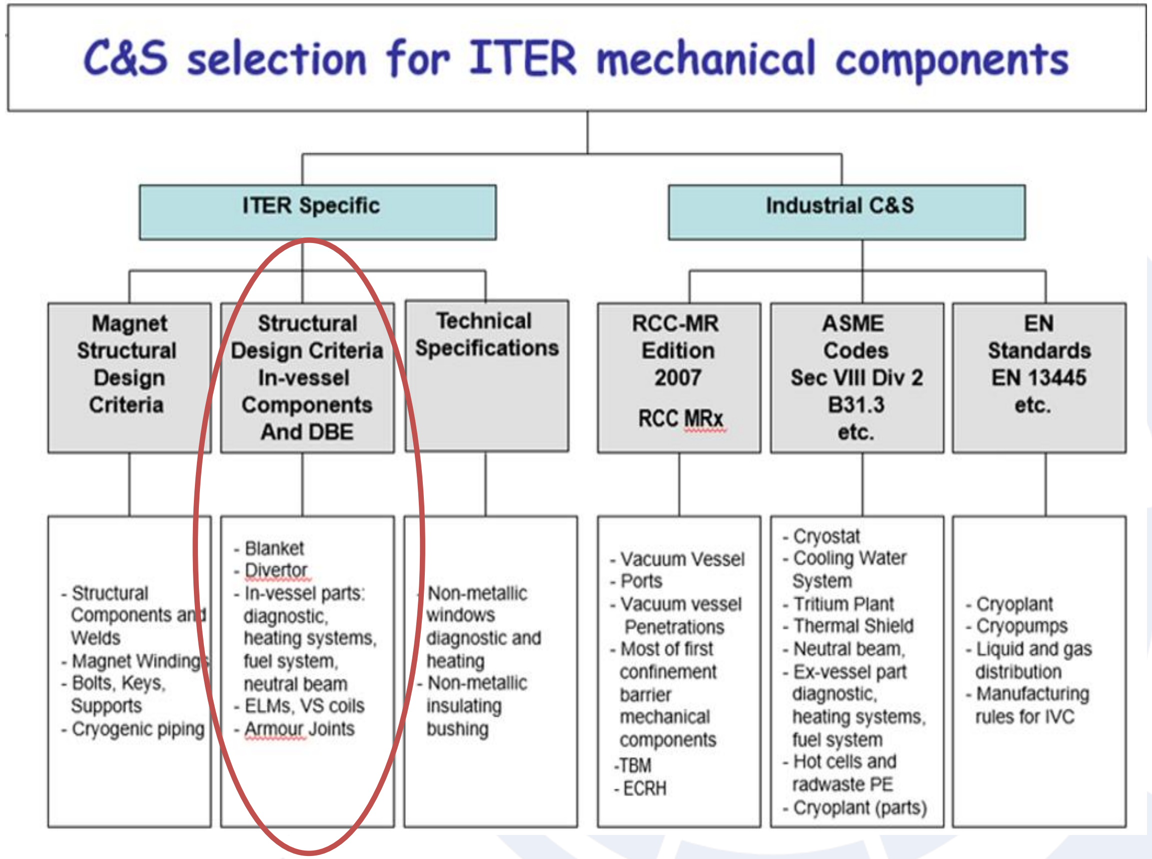
C&S for mechanical components used in the ITER Project

Industrial codes:

- **RCC-MR(x):** for primary confinement barrier (VV) and **SIC/nuclear** components under **ESPN** regulation (TBM).
- **ASME (non-nuclear):** for piping, valves, pumps, vessels and **SIC classified** under the EU **PED/ESP** regulation (CWS).
- **EN standards:** for selected components, as complementary to ASME for **specific EU regulation requirements**.

ITER Specific:

- **SDC-IC:** for IVCs, to take into account **neutron irradiation effects and fusion specific material properties**. Includes **Design By Experiment** for DIV.
- **Magnet-SDC**: for cryogenic temperatures, where **loss of FT and defects acceptability** are the main concern.
- **Technical Specifications:** for non-standard components and **ITER (fusion) specific requirements (Tritium, Vacuum…).**



ITER had to produce additional documentation to complement and justify the coherency and consistency of this multi-code approach

Present status of specific C&S for fusion (In-Vessel) components

- **ASME Sec. III, Div 4: Rules for the construction of Fusion Energy Devices (2023 1rst Ed.)**
  - Initial focus on pressure retaining components, but aims to cover all components in fusion plants.
  - Only generic guidelines, no component-specific detailed rules in the present edition.
  - No design rules for fusion-specific damage modes, no fusion-specific material properties.

- **RCC-MRx: design and construction rules for high temperature, research and fusion reactors (2022 Ed.)**
  - Focus on advanced nuclear installations, limited scope to selected fusion components.
  - Contains specific provisions for fusion components (e.g. Annex 19 - ITER VV).
  - Includes specific design rules for irradiated components and (partial) design data for fusion specific materials.

- **SDC-IC: Structural Design Criteria for In-Vessel Components (2012 Ed.)**
  - Developed for ITER IVCs, mainly based on RCC-MR/MX/MRx with additions from ASME Sec III and VIII.
  - Includes fusion-specific design rules and material data, but limited to the ITER operational domain.
  - Only design rules, no rules for manufacturing and inspection, not a standalone code.
  - **No longer actively developed** (?)

The specific challenges of BB designs and corresponding ITER-TBMs

- **BB designs present specific issues not (or partially) found in other fission & fusion components:**
  - **Specific materials**: RAFM steels, Ceramic Breeders, Be multipliers
  - Use of **non-axisymmetric shell/box structures** with internal stiffeners and limited possibility of NDE inspection.
  - **Specific manufacturing techniques**: Additive Manufacturing, explosion welding, Diffusion Bonding.
  - **Joints between dissimilar materials** that constitute “singularities” not covered by existing C&S.
  - **Missing design rules** to address the additional degradation/failure modes due to 14 MeV neutron irradiation, plasma particles loads, D/T isotope permeation and retention.

- **Regulation requirements (?):** different from other ITER IVCs**, TBMs are classified as PED CAT IV and (for some) ESPN N2 components according to the French regulatory framework.**

RCC-MRx was selected by F4E (EU)as it best met the design requirements of ITER-TBMs. Other ITER parties (JA, KO, CN) have since adopted the same approach.

It was recognized that substantial experimental and theoretical work was still required for TBM design and manufacturing, including design rules, missing material data, assembly and joining techniques, and NDE.

Conclusions: where and what the ITER-TBM program can contribute

- **Identification of SIC and essential safety functions in the different plant states.**
- **Correspondence between ESR and selected C&S (under agreement with safety authorities).**
- **Identification of “mission critical” components and functionalities.**
- **Ensure consistency in design when different C&S are used for interfacing components.**
- **Feedback from design, manufacturing and qualification of components (and later from operation).**

Lack of C&S consequences: increase of costs, delays and risks

The absence of standardization increases costs, delays and risks in multiple ways:

- **Custom Engineering**: without standardized components, each reactor requires bespoke designs.
- **Risk of Overdesign**: to ensure safety, components are often overdesigned, leading to higher costs and inefficiencies.
- **Licensing Delays**: adapting existing fission codes or creating new ones extends project timelines.

Inadequate computational tools result in uncertainties in design, overengineering, delays and inflated costs, ultimately threatening the public acceptance and competitiveness of fusion energy compared to other energy sources