DEMO Design Activity in Europe: Progress and Updates

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Power Plant Physics and Technology

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Outline

✓ DEMO in the EU Roadmap

✓ Design Choices under Considerations

✓ Highlights of Technical Achievements

✓ Industry and International Collaborations

✓ Conclusions
DEMO in the EU Fusion Roadmap

- An ambitious roadmap implemented since 2014 by a Consortium (EUROfusion) of 30 Fusion Labs from 26 EU member states (+ Switzerland and Ukraine) and F4E

- 33 Work Packages of different character including:
  - EU ITER physics coordination
  - Experimental campaigns JET & MSTs and PEX upgrade of devices
  - DEMO Concept Design (consisting of 13 WPs)
  - Education and Training and Enabling Research

**Emphasis on:**
- Central role of ITER *initial assumption* FP 2020
- DEMO Concept Design

**EU DEMO Mission requirements**
- DEMO Net electricity (~500 MWe)
- Makes its own fuel (TBR > 1)
- Reliable operation
- Reasonable availability
- Allow extrapolation to a FPP

**High Level Requirements agreed with DEMO External Stakeholders** *(e.g., industry, utilities, grids, safety, licensing, funding bodies)*
Review triggered by:
- **ITER delay**: develop a strategy to minimise impact on mission to realise fusion electricity by ~2050’s
- Underestimate of the “design integration” challenge
- Recommendations to explore a wider DEMO design space

Three phases: (1) a pre-concept design phase to be concluded in 2020; (2) a concept design phase with a CDR in 2027; and (3) an engineering design to follow.
Key Messages

• Contacts made with Gen IV fission and ITER to learn from their experience.

• **Definition of DEMO HLRs** following interaction with external stakeholder group composed of experts from industry, utilities, grids, safety, licensing, etc.

• A **philosophy of integrated design** established with a **traceable decision making process**.

• A **more systems-oriented approach** brought clarity to a number of critical design issues.

• Main **design Integration Risks** that affect Plant architecture identified.

• **Readiness of physics and technology assumptions** of DEMO design points by using systems codes.

• Sensitivities studies to determine impact of uncertainties of underlying physics and engineering/technology assumptions on machine parameters.

• **Design of a first DEMO plant layout** in collaboration with AREVA GmbH to identify major structures needed to contain the plant equipment; to identify needs for improvements.

• Preliminary **safety assessments**, including assessments of radioactive waste.

• **Evaluate multiple design options** for systems and/or technologies with high technical risk or novelty.
**Current DEMO Design Baseline**

**Physics:**
- Single null
- Conventional H-mode
- $H=1.1$ (radiation corrected)
- Based on ITER performance ($Q=10$)
- $P_{sep}/R_0=17$ MW/m (fully detached)
- Pulsed (2 hours)
- “Conservative”, i.e. established physics basis.

**Engineering:**
- 16 LTSC TF Coils, $\text{Nb}_3\text{Sn}$, $\sim 12$ T
- Vertical Maintenance
- EUROFER IVCs
- Starter blanket (20 dpa) + Second blanket (50 dpa) ($\sim 6$-7 FPY total)
- TBR $> 1.1$
- Availability target 30%

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**DEMO1**

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<th>Parameter</th>
<th>Value</th>
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<td>$R_0$</td>
<td>$\sim 9$ m</td>
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<tr>
<td>$A$</td>
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<tr>
<td>$k_{95}$</td>
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<tr>
<td>$B_T$</td>
<td>4.9 T</td>
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<tr>
<td>$\beta_N$</td>
<td>2.6</td>
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<tr>
<td>$H$</td>
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$P_{\text{el,net}} = 500$ MW  
$\tau_{\text{pulse}} = 2$ hr  
$A = 3.1$

**Physics Parameters**

- H-mode access limit
- Divertor limit
- TF coil limits
Evaluate Multiple Design Options

**Breeding Blanket Design Options**

- **Blanket PHTS: He and H$_2$O**
  - He (300-500°C, 80 bar)
  - Issues:
    - High pumping power
    - Large He inventory
    - Large HeX
    - Long piping routing

- **H$_2$O (292-320°C, 150 bar)**

**PCS: Indirect (ESS)/ Direct**

- R&D issues:
  - Increase of wear and tear, corrosion, fatigue and damage risks of shaft, blades, condenser
  - Possible solutions:
    - Auxiliary power sources (Boiler)
    - Motorization of the Electrical Generator

**Flexi-DEMO**

<table>
<thead>
<tr>
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<tr>
<td>$R$ (m)</td>
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<tr>
<td>$P_e$ (MW)</td>
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<td>300</td>
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<td>$q_{SO}/P_0$</td>
<td>4.8/3.3</td>
<td>4.2/2.9</td>
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<tr>
<td>$H$</td>
<td>1</td>
<td>1.2</td>
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Initially operate in a short pulse mode (e.g., 1 hr, but could move to steady-state operation with improvement of physics and CD.

H. Zohm, Nucl. Fus. 57 086002 (2017)
Highlights of Technology Achievements

WPMAG - LTS TF cables

Wind & React

\[ \Delta T_{\text{marg}} > 2K \ @ 82kA, 13T \]
No degradation with e-m cycles
- \( \varepsilon_{\text{eff}} \in [0.55, -0.35] \%
- Higher \( I_c \)
- Less SC strands

React & Wind

\[ \Delta T_{\text{marg}} > 2.0 \ K \varepsilon_{\text{eff}} \approx -0.35\% \]
Low degradation w. e-m cycles
Low AC losses

WPRM – Remote Maintenance

- Precision control of large heavy components that deform significantly under static/dynamic loads
- In-vessel work in the high radiation areas (2kGy/hr) must be minimised and ideally avoided
- Concept designs and tests for proof-of-principle cutting and welding tools developed

Proof of principle tool designs completed
- Fit-up tolerance and filler material methods
- Post weld heat treatment
- Control of weld profile with dual lasers

WPDIV - Technology R&D for HHF PFCs

- Study improvements of ITER technology
- Mock-up fabrication
- HHF testing reached 100 cycles up to 20 MW/m²

WPPR – Remote Maintenace

Multi-Module Segment Blanket Handling

100th cycle

Thin graded Interlayer (W/Cu)

Thermal break

Composite pipe (W/Cu)

WPBB – Blanket Fabrication Technologies

WCLL (EUROFER tubes)

- HIP and EB processes (FW / cooling plates)

2017 Welding Tool Proof of Principle Detailed Design

Initial Industrial Involvement

- Project / Program Management
- Plant Architect Engineering: Systems Engineering and Design Integration
- Cost, risk, safety and RAMI analysis
- Evaluation and selection of design alternatives
- Plant engineering tools, modelling and simulation
- TRL assessment, etc.
- Design for robustness and manufacture of critical components/systems; include design simplification/reduce fabrication costs

- Architect engineering studies support
- Evaluation and selection of design alternatives
- FIIF (Chairman)

- System Engineering Training
- Advisory role on Central Integration Project Team
- FIIF

- Atmostat
- Empresarios Agrupado
- Cosylab
- Assystem
- Saarstahl, Germany
- CSM S.p.A., Rome, Italy
- Plansee
- GRS GmbH

Design for simplification and robustness of critical components such as vacuum vessel; reduce fabrication costs
Ongoing International Collaborations

- **Japan (Broader Approach) IFERC**
  - joint DEMO Design Activities (DDA) to address most critical DEMO design issues
  - investigate feasible DEMO design concepts

- **China as of 2016**
  - DEMO/ CFETR joint design task forces
    - Technical exchange meetings: CFETR and EU-DEMO
    - Systems codes studies
    - Divertor configuration and performance, incl. alternative divertor geometries and potential implementation in CFETR / EU-DEMO / DTT
  - Breeding blanket R&D cooperation:

- **UCLA (DCLL) + Structural Codes**
  - upgrade and use of existing MaPLE facility for combined magneto-hydrodynamic (MHD) thermofluids and fluid-materials interaction experiments

- **Fission Reactor Irradiation Experiment**
  - Collaborations to use non-EU MTRs for high fluence irrad. to close gaps in EUROFER and Cu data base and work towards common MPH and design rule development
Final Remarks

Main Challenges

✓ Integration of design drivers across different systems
✓ High degree of complexity/ system Interdependencies
✓ Design dealing with uncertainties (physics and technology)

- Emphasis should be on design integration risks and engineering/operational challenges arising from power conversion aspects and technology feasibility, safety licensability and RH

- Postponing integration assuming that it restricts innovation and inhibits an attractive DEMO plant, risks developing design solutions that cannot be integrated in practice

- A lot of discussions about making fusion smaller, cheaper, and faster, but there is no magic bullet to solve the integrated design problems
  - Every time you squeeze somewhere, you make problems worse elsewhere...
  - EU-DEMO is current viewed to be the lowest risk option to meet all targets within given timescales (this does not mean it is low risk!)

- This approach represents an important change in the EU fusion laboratory culture
- Involvement of industry and exploitation of international collaborations on a number of critical areas is necessary
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