Technology: basis, gaps, risks and facility needs.

G. Federici (EFDA)

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MFE Roadmapping in the ITER Era

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Technical Challenges on the path to DEMO with potentially large gaps beyond ITER

Physics (see R. Wolf)

Operating scenario:
Long pulse/ Steady-state/ High-Beta

High density operation

Power exhaust and divertor R&D strategy

Abnormal events avoidance/ mitigation

Plasma diagnostics and control

Technology

PFC and Blanket technology including T self-sufficiency

H&CD Systems – Efficiency and Reliability (D. Stork)

Reliability of Core Components & RH for high machine availability

Qualification of resilient structural materials

Safety and licensing

Reactor System Codes
Physics and Technology Assumptions and Guidelines

DEMO Divertor R&D Strategy

- The peak power load on divertor is a key constraint and the power exhaust may ultimately determine the reactor size and choice of the operating scenario.
- Three different approaches could be anticipated for DEMO and impact the definition of a divertor satellite facility:
  - conventional ITER-like divertor; this requires the development of highly radiative regimes and leads to relatively large reactor size;
  - innovative divertor configurations;
  - advanced plasma facing materials (such as liquid metals).
- Final concept selection bears strong impact on the machine design, parameter selection and operation scenario development. → so we need to tackle this early on.
- Until we solve this problem any conceptual design proposal which we are discussing remain questionable.

Mode of operation:pulsed or steady-state DEMO?

- AT (SS mode of operation that relies on high f_{BS}) is attractive but remain very challenging. (Garofalo)
    - Limited disruptivity and power exhaust should be addressed upfront in the scenario development.
    - M. Zarnstorff's talk→ Existing reactor design are not consistent with sustained AT characteristics. Need to iterate designs using more realistic parameters.
- We should retain LP operation and revisit the physics and technology issues.
    - Major engineering issue would be fatigue life. D. Ward's talk.
    - Pulsed DEMO would inevitably be bigger
- **System codes** are used to determine machine parameters
    - Proliferation of designs with significantly different machine parameters.
- **Need to revise the input/assumptions used in the physics and technology models→ generate initial Physics Guidelines for a minimum # of regimes of operation**.
- Benchmark system codes for a number of test cases.
    - EU/ JA collaboration underway in the context of the BA
    - Consider possibility to expand this involving others.

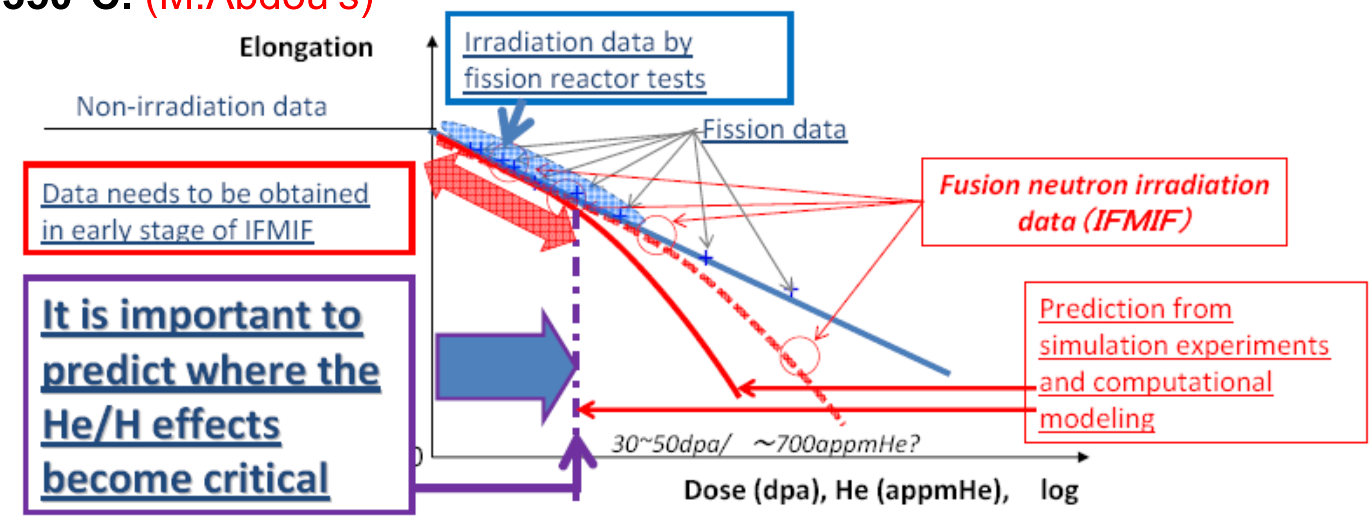
RAFM is the ref. structural material for DEMO and for TBMs in ITER

(→ S. Zinkle, E. Diegele, R. Kurt)

- First wall DEMO "Needed" lifetime dose =12-50 dpa (← M. Abdou's talk)
- FS irradiation data base from fission reactors extends to ~80 dpa, but it generally lacks He (only limited simulation of He in some experiments).
- **Low-dose environment (≤10 dpa, up to 100 appm He)***
  - Sufficient irradiation effects data exists to permit reasonable prediction of performance
- **Intermediate-dose environment (>10 – 60 dpa)**
  - He embrittlement, irradiation creep, volumetric swelling, phase instabilities at >10 dpa
  - Data from fusion-relevant neutron sources and non-nuclear testing facilities still needed.

***Material experts state confidence that FS will work fine up to ~ 300 appm He at irrad. temp. > 350°C.** (M.Abdou's)

H. Tanigawa (JAEA)



Urgent

- review the database (E. Diegele)/ understand implications in a design context
- revisit the DEMO EOL irradiation design requirements → impact testing specs.

Reliability (AMI) of Core Components is a Serious Issue for Fusion Development

See talks: J. Sheffield, M. Abdou, F. Najmabadi, D. Stork, H. Neilson

- Availability should go in from the very beginning. Design must be maintainable and maintainability of design proposal must be demonstrated before we start build.
- RAMI is a complex topic for which the fusion field does not have an R&D program or dedicated experts. What can be learned from the RAMI Programme of ITER?
- Urgent need to define a reliability growth strategy. **Distinct approaches** emerged in this Workshop: **US** (reliability growth based on testing in FNS-type of facilities), **China** (trial and error: build it asap an test it) (←J. Lee).
- Look at what is done in other fields (e.g., nuclear, aerospace). F. Najmabadi advocates adopting a TRL as a basis for assessing development strategy (commonly used in other fields) and provides framework for R&D. Involve industry.
- Licensing and validation of the design must be a necessary consideration throughout the DEMO design development.
  - The validation of the structural components of DEMO requires design criteria.
  - To engage early on with the ASME or other fusion specific design code standards from the outset to drive the evolution of design criteria, as well as to understand data requirements.

Blanket development path to DEMO

- There is a need to reassess the blanket development path to DEMO
  - to study technology readiness and qualification issues for each concept.
  - to determine, in addition to ITER concept testing, any other testing that would be required to qualify blankets for use in DEMO
  - to conduct a gap analysis to determine the risks arising from remaining gaps and the required R&D including necessary test facilities and underlying test programs.
  - RH plays (should play) upfront a strong role in the design (MTTR, MTBF).
  - to determine what the added value of a CTF is.
    - As a strategic risk reduction exercise, the goals of a Components testing programme and the feasibility issues of a **pre-DEMO CTF/ FNS** should be examined.

FNS → Broad scientific scope including PMI effects (M. Peng)

CTF (VNS) → Component validation and endurance testing

Operation/ Construction Staging?

- Include flexibility in the design to accommodate for improvements in plasma performance (J. Sheffield) and design improvements of core components.
- How much credit can we actually take for this? And what can we actually stage?
  - ITER is actually doing this but design frozen from day-1.
  - Keep in mind that we must deal with a nuclear device.
- Much more work is needed to conclude on this.
- Permanent parts and interfaces (mechanical, hydraulic connections), must be designed for the most demanding case.
- Accommodation of sufficient flexibility requires generous design margins (higher costs).
- Compactness of machine (reduce costs) add additional engineering challenges and would mae staging tougher,

Testing Facilities

- Knowledge gaps have been well identified.
- Determine what can be addressed by ITER. Do we have any leverage?
- Reassess capabilities of existing machines to address gaps (e.g., JET W-wall)
- DEMO Divertor satellite is urgent (D. Stork). Define the features of a device that could address any remaining gaps.
  - This facility should be available and operated well before the start of the construction of DEMO, in order to validate fundamental design choices and confirm their performance in a realistic environment.
- 14 MeV n-irradiation facilities
  - IFMIF remains an important facility to investigate radiation damage in matls.
  - Aiming at 30-50 dpa for core components EOL in a GEN-1 DEMO (EU) would relax irradiation testing requirements in contrast to FPP (100-150 dpa).
  - Thus, is IFMIF on the critical path of DEMO, or not? Needs further analysis.
  - Reduce risk/ cost and construction times option IFMIF was proposed (D. Stork)
  - Nevertheless, benefit from a focussed accompanying programme exploiting fission reactors (w. isotope tailoring), i-beams, modelling, exploitation of EVEDA.

Alternative MFE configurations (STE, HEL)

→ C. Beidler, A. Sagara

Develop quantitative metrics on the following engineering aspects.

- Space requirements for blanket / shield/ divertor.
- Coil spacing, bend radius, superconductor type and properties; space requirements etc.
- Diagnostic and heating system port and space requirements.
- Remote handling considerations, including remote maintenance requirements and classification of components, remote handling space needs.
- Costing algorithms for stellarator components.
- In addition, concepts should be identified that make qualitative improvements to reactors.