EUROfusion

9th DEMO and Fusion Plants Workshop

Amori, Japan, 10–13 June 2025

European Strategy for Fusion: Work in Progress

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on behalf of:
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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.

Main Achievements in design and technology

Source: G. Federici, EUROfusion PM

- Significant resources have been devoted, in Europe, to DEMO design and R&D during the last 10 years.
- A major milestone was the DEMO G1 Gate held in 2020
- Important lesson learned

A more systems-oriented approach and integrated design that drives technology R&D priorities	**Rationalization of blanket design and R&D and change EU TBM/TBS options (+ WCLL)**	**Early attention to industrial feasibility, costs, nuclear safety and licensing**	**A technology maturation plan by embedding ITER / F4E and industry experience**	**Feasibility assessment of a 14 MeV plasma-based VNS to contribute to the qualification of critical fusion reactor systems**
Embed more industry and expand international collaboration to fill critical gaps	**Refocus the physics R&D for DEMO (ELMs-free plasma scenario, low disruptivity, power exhaust etc.)**	**Training of young engineers in critical areas to overcome lack of skills**	**Implement a process to assess/ validate progress through Gate Reviews**	**Knowledge management transfer and in particular ITER lesson learned**

…..and more

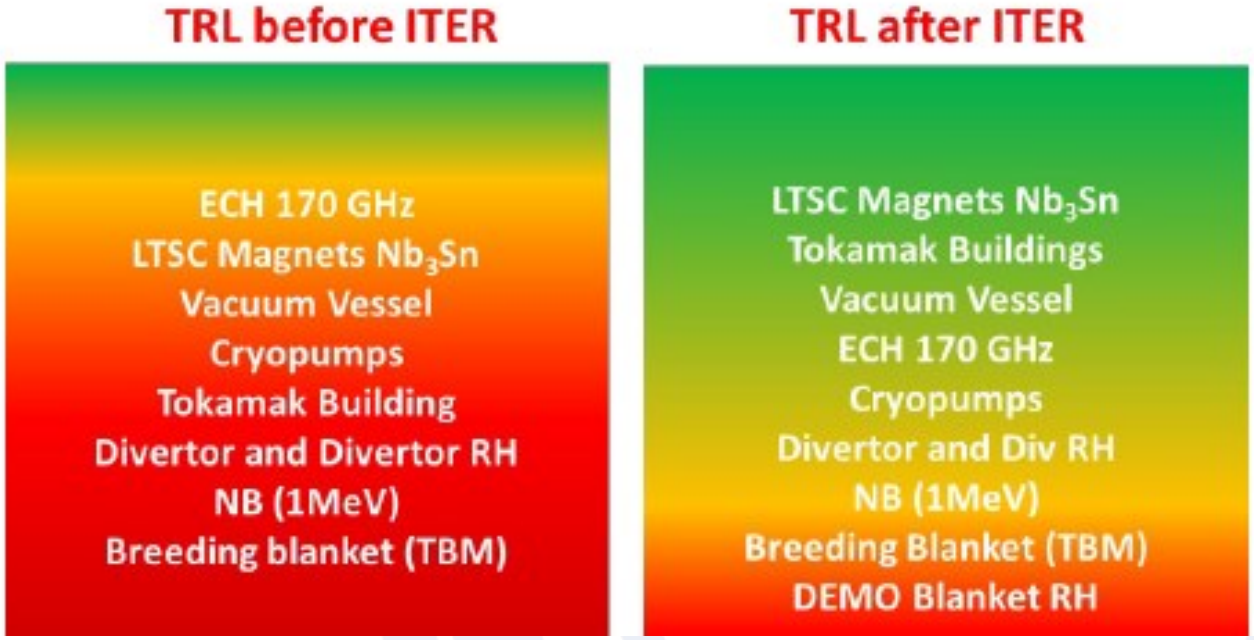
ITER mission is fundamental

Source: G. Federici, EUROfusion PM

ITER remains a crucial machine for validation of physics and part of technology for next steps

- Designing and constructing ITER **necessitated extensive R&D programmes** characterized by wide-ranging, long-term international collaborations **and major innovations**.

- **Return of Experience:** the time for the introduction and qualification of new materials, technologies, or manufacturing processes is a decades-long effort, without assurance of success. ***The devil is in the details.***



- **There are still major technology gaps beyond ITER**
- **Low TRLs of DEMO enabling technologies for systems (i.e., breeding blanket, materials, RH) even after ITER**
- The role of ITER in de-risking DEMO in the area of breeding blanket and RH is questionable and risk mitigation options must be developed.

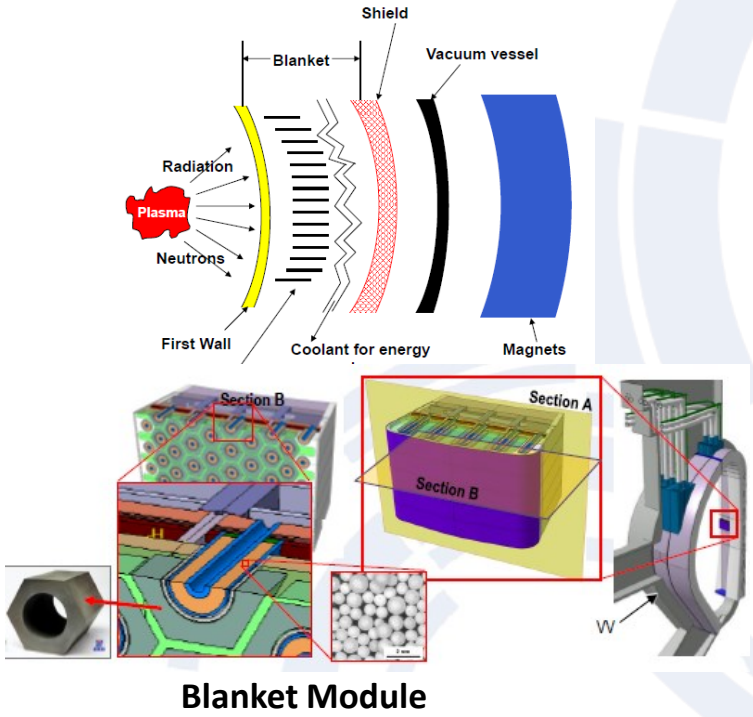
Main remaining technical challenges

Source: G. Federici, EUROfusion PM

1. Tritium Breeding and Fuel Cycle - mainly Blanket
2. Power Exhaust Management – Divertor ← DTT and ITER
3. Remote Maintenance - mainly Blanket
4. n-hardened Materials - (mainly Blanket)
5. Heat Extraction and conversion - Blanket
6. Advanced magnets (HTS)

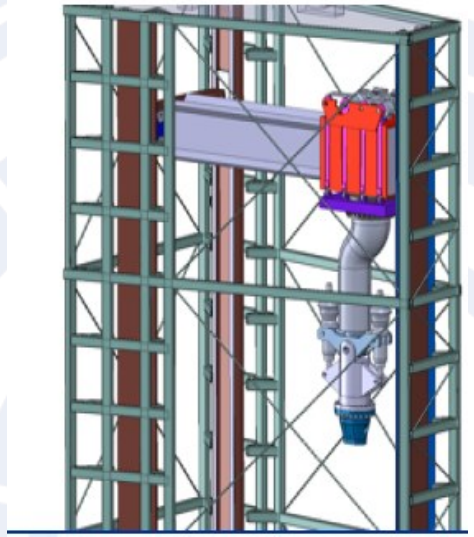
Breeding blanket

- ✓ **Tritium Consumption in Fusion Systems is huge**
  55.8 kg per 1000 MW fusion power per year
- ✓ DEMO requires a self-sufficient BB from day-1.
- ✓ No BB has ever been built or tested.
- ✓ Most of the concepts explored to date suffer from feasibility issues, supply chain, manufacturability, cost and reliability.
- ✓ ITER TBM is important but not sufficient.
- ✓ EUROfusion is addressing feasible ways to fill the technology gaps and qualify key nuclear technologies for DEMO outside of ITER



Blanket Module

Remote Handling



- ✓ Huge impact on plant layout and availability
- ✓ Minimise IVC work in the high radiation areas (2kGy/hr)
- ✓ Service Joining Technology R&D is urgently needed.
- ✓ Feasibility and performance concerns -> R&D
- ✓ A dedicated breeding blanket handling facility co-funded by EUROfusion is being built in SDU (Denmark)

Existing and new facilities and expertise in the Fusion Labs are essential to execute the required R&D. Europe, and other international players are investing the most in these areas. Start-ups are extending investments)

Current Roadmap: **Lessons learned**

Source: G. Federici, EUROfusion PM

The current EU fusion roadmap is articulated around the sequential development of 3 main devices: **JET, ITER, and DEMO** supported by a strong R&D programme

1. Still large plasma physics uncertainties that heavily constrain the design space and affect performance and operation of future devices. **ITER Mission is fundamental.**

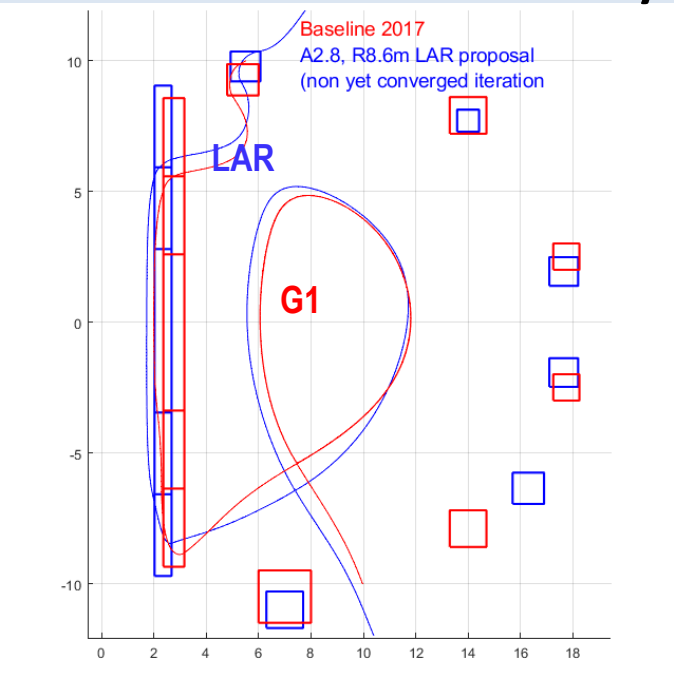
2. Two distinct, successive phases of operation: **DEMO phase 1** (20 dpa), **a qualification phase** to qualify technologies and processes in a fusion nuclear environment, and **DEMO phase 2** (50 dpa), **a nuclear operation phase** to demonstrate the feasibility of fusion as a source of energy

3. Tritium fuel consumption in fusion is huge. **55.8 kg per 1000 MW fusion power per year.** This tritium will not be available from external sources, which means that **must breed effectively (TBR>1) from day-1 during qualification phase**. This introduces a high failure risk.

4. To qualify components and processes, DEMO will have to operate with a relatively high availability already during phase 1. However, because none of the DEMO components will have previously been qualified in a representative fusion nuclear environment, this introduces a high failure risk.

DEMO LAR (Phase-2) ← Design Activities → VNS (Phase-1)

Work underway baseline LAR



P_{fus}=1.6 GW, P_{el}=0.35 GW
TBR>1 - 110 kg-T/ FPY
Pulse duration=2 hr
R= 8.6 m, a = 3.1 m
B_o=4.3 T, B_{leg}=10.3 T
I_p=20 MA
NWL= 1 MW/m^2,
n-Fluence = 20+(50) dpa

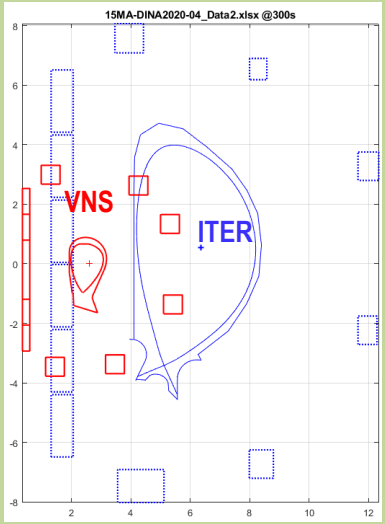
High field: for DEMO, no advantage going to higher B

- **advantage offset by larger size of mechanical structures**
- **HTSC is still considered a promising technology for use in DEMO CS**

Allowing lower, difference in size (plasma volume) is not pronounced

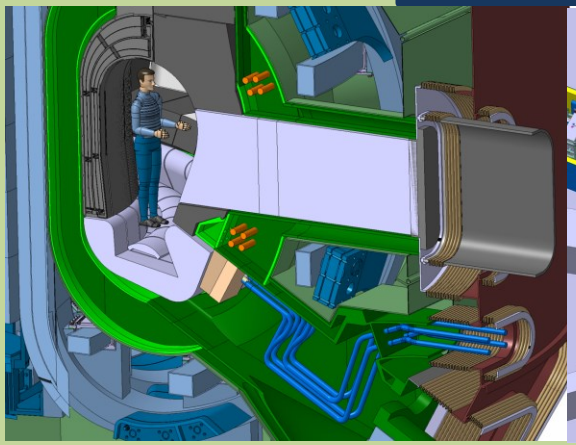
- **But lower A has a much-reduced reattachment heat flux**
- **the magnet technology is proven and readily available**

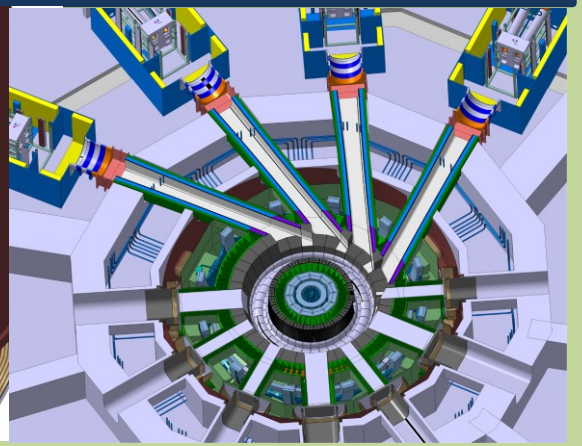
Feasibility Study (several common technologies with DEMO)



VNS design and engineering features are driven by the nuclear testing requirements

- **Beam-target driven mode with Q≤1**
- **Minimize T supply requirement (< 1-2 kg-T per FPY) and capital cost**
- **Small size: R_0-2.5 m**
- **Steady-state**
- **Peak - NWL:~0.5 MW/m^2**
- **testing surface 10-30 m^2**
- **neutron fluence: > 20-50 dpa**



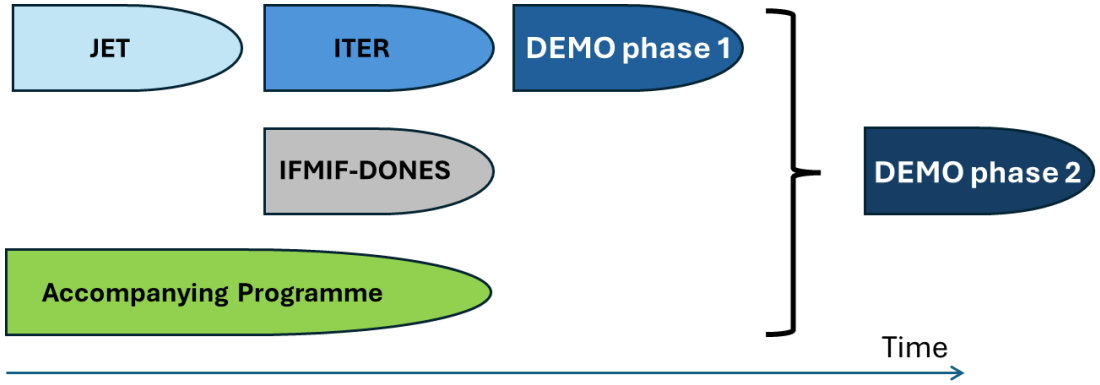


Ongoing revision of the EU Fusion Roadmap

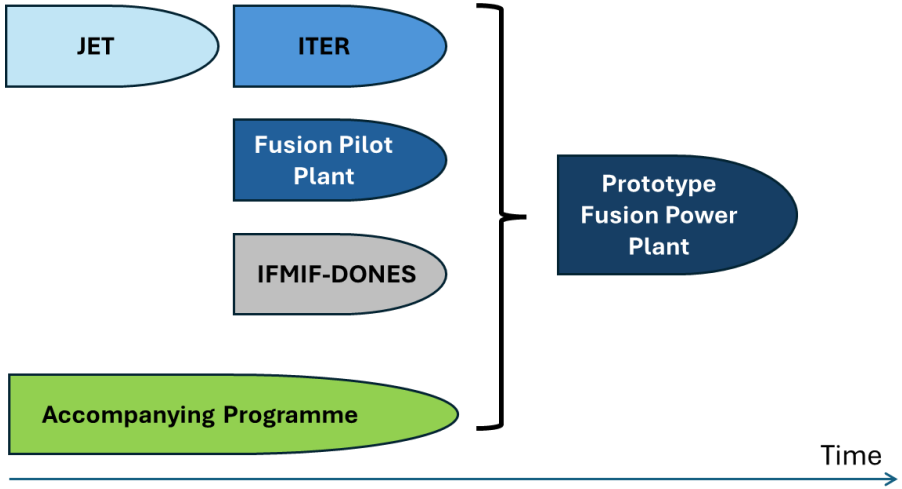
Source: G. Federici, EUROfusion PM

1. Strategic indications emerging from the Fusion Expert Group
2. Assessment of independent international experts
3. A WG established by the GA to explore options to reorient and accelerate the EU Fusion development strategy

Original fusion roadmap



Accelerating fusion technology development with a Pilot Plant



- **Confirm the attractiveness of the VNS** and explore further improvements and /or simplifications
- In parallel: **define acceptable requirements and search for credible designs of a fusion pilot plan**t to be build in parallel to ITER to demonstrate tritium and electricity production

High Level Objectives Fusion Pilot Plant

- Demonstrate electricity and tritium production
- Complement ITER (which is focused on burning plasma physics)
- Complement DONES (focused on large dpa in small material samples or blanket submodules).
- Reduce technological risk by qualifying essential technologies in advance (breeding, reliability).
- Does not require another step to build a prototype fusion power plant

Conclusions

Conclusions

- Europe has a clear, long-term strategy for delivering fusion electricity, structured around **a staged and risk-informed approach**, anchored by **ITER**, **DEMO**, and robust **R&D programs** (*e.g.* DONES, existing technology facilities, fission reactors, etc.).
- System code development, integrated design approaches, and industry engagement are guiding current design and technology efforts.
- Qualification of fusion nuclear technologies (e.g. **breeding blanket**, **materials**, **maintenance**) is a critical bottleneck requiring new facilities beyond ITER.
- The **Volumetric Neutron Source (VNS)** is under assessment as a **potentially attractive solution** to close the fusion nuclear qualification gap and must be **confirmed as viable**.
- In parallel, the feasibility of **alternative pathways** leading to a **fusion pilot plant**, to accelerate demonstration of electricity and tritium production is being explored.
- These initiatives aim to reduce technological risk and enable flexibility in the fusion roadmap, adapting to evolving data from ITER and R&D.