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# The Role of DEMO in a Fast-Track Development of Fusion Power

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# Background

- Fast track development of fusion is now widely accepted in general terms.
- Very useful for prioritising R & D.
- Needs to be developed in more detail: this paper focusses on DEMO.
- PPCS Models, and variants, used as the targets.

# Essence of the fast track

First stage

- **ITER.**
- **Materials on the same time scale.**

Second stage

- **DEMO. (Final integration and reliability development.) Realistically, there may be several DEMOs, roughly in parallel.**
- **Leading directly to commercial power.**

# Our approach (1)

- **Motives, opportunities and targets (from power plant and economic studies).**
- **Issues, and their resolution by devices.**
- **Prioritisation and focus to speed the programme.**
- **Risks and benefits.**

# Our approach (2)

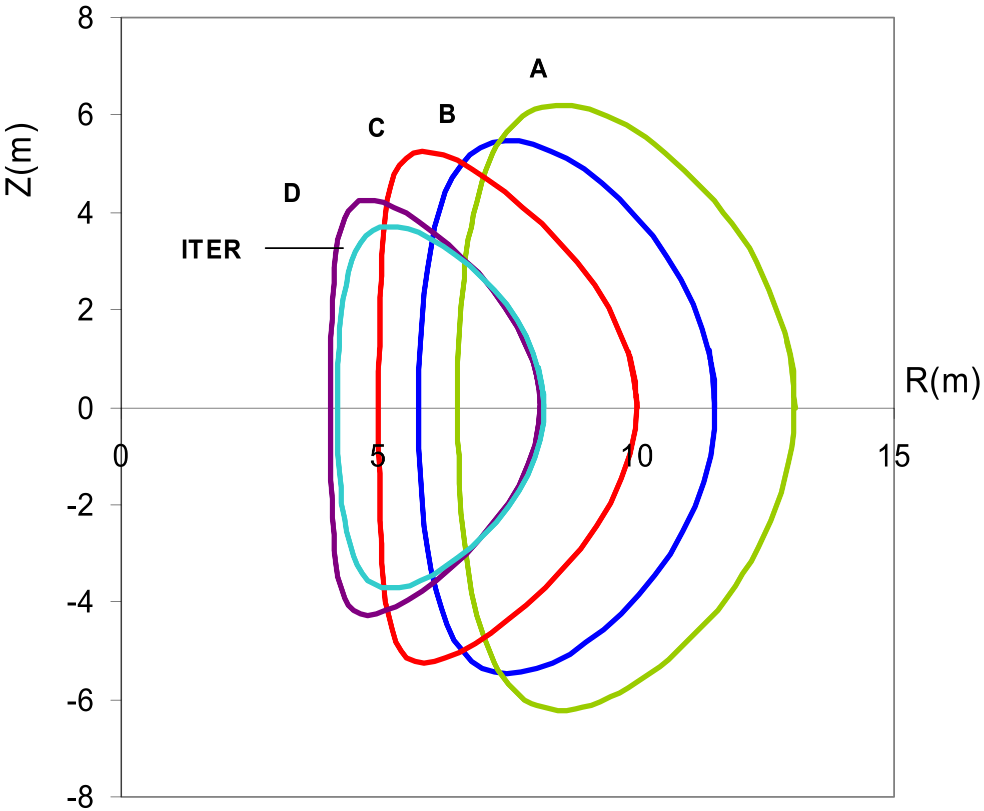
- There has to be a change of culture, to a disciplined project-oriented "industrial" approach to fusion development.

- Compare fusion with the way that fission and flight were developed! There were the equivalents of many DEMOs and many materials test facilities.

# PPCS Models

| PPCS Model | Plasma physics | Structural material | Other blanket materials | Other divertor materials |
|---|---|---|---|---|
| A | Near-term | Eurofer | LiPb/water | W/Cu/water |
| B | Near-term | Eurofer | Li4SiO4/Be/He | W/He |
| C | Intermediate | Eurofer/ODS | LiPb/SiC/He | W/He |
| D | Advanced | SiC/SiC | LiPb | W/SiC/LiPb |

# PPCS Models



# Cost of electricity

| Model | Cost of electricity (Eurocents/kWh) |
|---|---|
| A | 5 – 9 |
| B | 5 – 9 |
| C | 4 – 7 |
| D | 3 - 5 |
| AB | 5 - 9 |
| C* | 4.5 – 8.5 |
| B* | (Marginally worse than B) |

# Model B

- Re-assessment of pumping power has degraded economics.
- But re-optimisation is expected to recover some of this, to a position intermediate between A and B.

# Model AB

- Lithium-lead, but with helium cooling.
- Economics similar to Model A, because:
- Higher blanket temperature, but
- Higher pumping power and lower divertor load.

# Model C*

- **Model C technology, but Model B (near-term) plasma physics.**
- **Economics similar to Model B, because:**
- **Higher blanket temperature and lower pumping power, but**
- **Lower power amplification and thicker neutron shield.**

# Model B*

- Similar to Model B, but with:
- Tungsten carbide shield.
- To decisively remove hydrogen generation in hypothetical accidents.
- Neutronics analysis shows inboard shield <u>may</u> need to be slightly thicker.
- Economics <u>may</u> be slightly worse than Model B.

# First generation targets

- **A, AB, B* and C* (or similar) are all attractive candidates.**
- **Excellent safety and environment.**
- **Acceptably competitive economics.**

# Technical targets: (1) from safety and environmental requirements

- **The main target is to further optimise, and test in IFMIF, reduced activation ferritic-martensitic steel, and/or an oxide-dispersion-strengthened variety.**

- **Tritium inventory control**

# Technical targets: (2) from economic requirements

The variation of direct cost of electricity with the main parameters is well fitted by:

- $$\mathrm{coe} \propto \left(\frac{1}{A}\right)^{0.6} \frac{1}{\eta_{th}^{0.5}} \frac{1}{P_e^{0.4} \beta_N^{0.4} N^{0.3}}$$

where, in descending order of relative importance to economics:

- A is the plant availability, which primarily depends upon the lifetime of the blankets and divertors, before they need to be replaced, and the reliability of all the systems, especially the in-vessel components;
- $\eta_{th}$ is the thermodynamic efficiency, which primarily depends upon the operating temperature and energy multiplication of the blankets;
- $P_e$ the net electrical output of the plant, which can be chosen;
- $\beta_N$ is the normalised plasma pressure;
- N is the ratio of the plasma density to the Greenwald density.

It may be seen that there are no "show-stopping" target minimum values associated with any of these parameters, but they are all potential degraders of economic performance.

# Issues and their resolution

| Issue | Today's expts. | ITER | IFMIF | DEMO* Phase 1 | DEMO* Phase 2 | Power Plant |
|---|---|---|---|---|---|---|
| disruption avoidance | 2 | 3 | | C | R | R |
| steady-state operation | 1 | 3 | | 3 | r | r |
| divertor performance | 2 | 3 | | R | R | R |
| burning plasma Q>10 | | 3 | | R | R | R |
| power plant plasma performance | 1 | 3 | | C | R | R |
| T self-sufficiency | | 1 | | 3 | R | R |
| materials characterisation | | | 3 | R | R | R |
| plasma-facing surface lifetime | 1 | 2 | | 2 | 3 | R |
| FW/blanket/divertor materials lifetime | | 1 | 2 | 2 | 3 | R |
| FW/blanket components lifetime | | 1 | 1 | 1 | 3 | R |
| NB/RF heating systems performance | 1 | 3 | | R | R | R |
| electricity generation at high availability | | | | 1 | 3 | R |
| superconducting machine | 2 | 3 | | R | R | R |
| tritium issues | 1 | 3 | | R | R | R |
| remote handling | 2 | 3 | | R | R | R |

Key:

| | |
|---|---|
| 1 | Will help to resolve the issue |
| 2 | May resolve the issue |
| 3 | Should resolve the issue |
| C | Confirmation of resolution needed |
| r | Solution is desirable |
| R | Solution is a requirement |

* Risks would be reduced and options expanded by operating several alternative DEMO plants in parallel

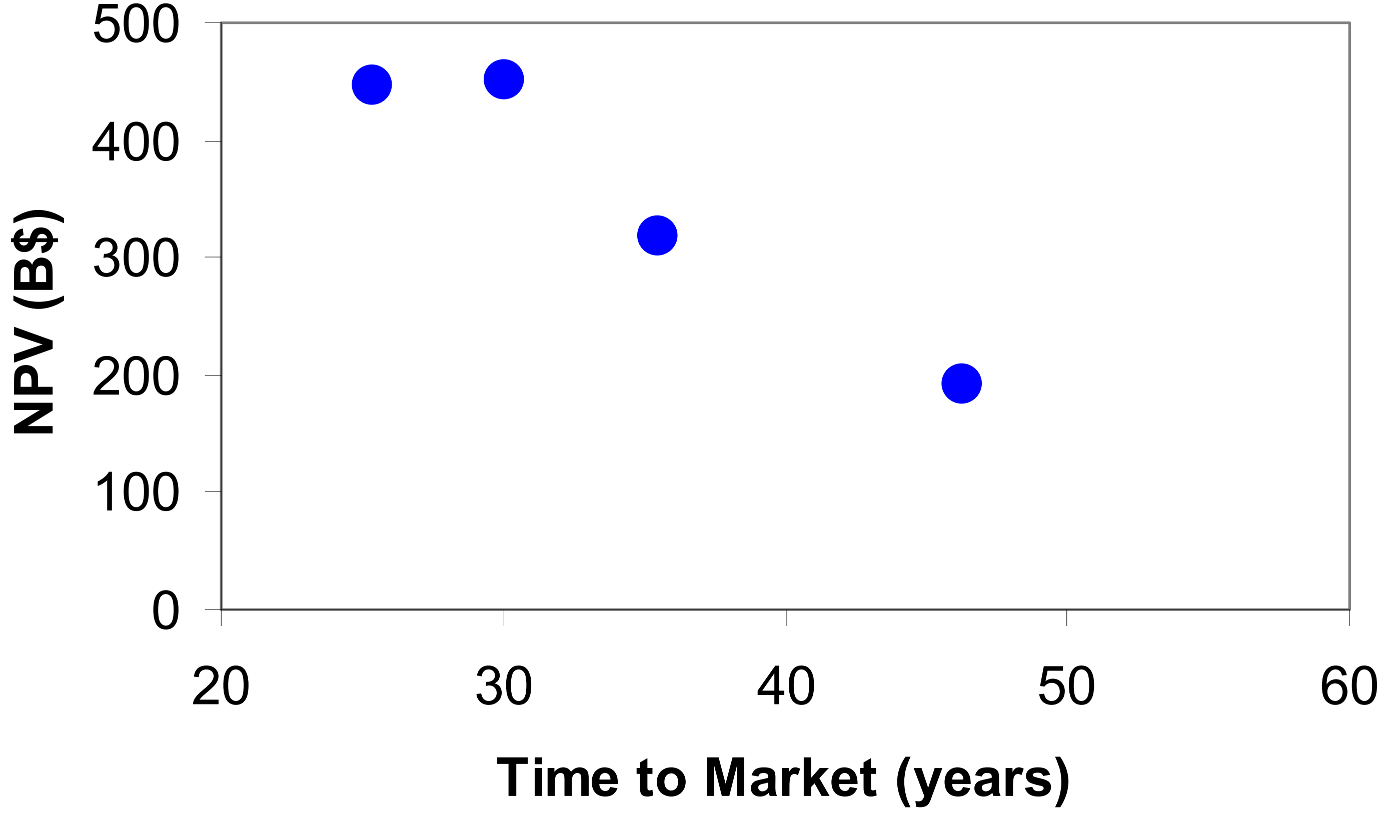
# Risks and Benefits

**The main risks are risks of:**

- **delays, or, if the delay is unacceptable**
- **having to back off to some extent from the economic performance of the first generation of power plants.**

- **Even when discounted for both time delay and probability, the cost of the fusion development programme is much less than the expected benefit.**

# Value of fusion development



# Key assumptions

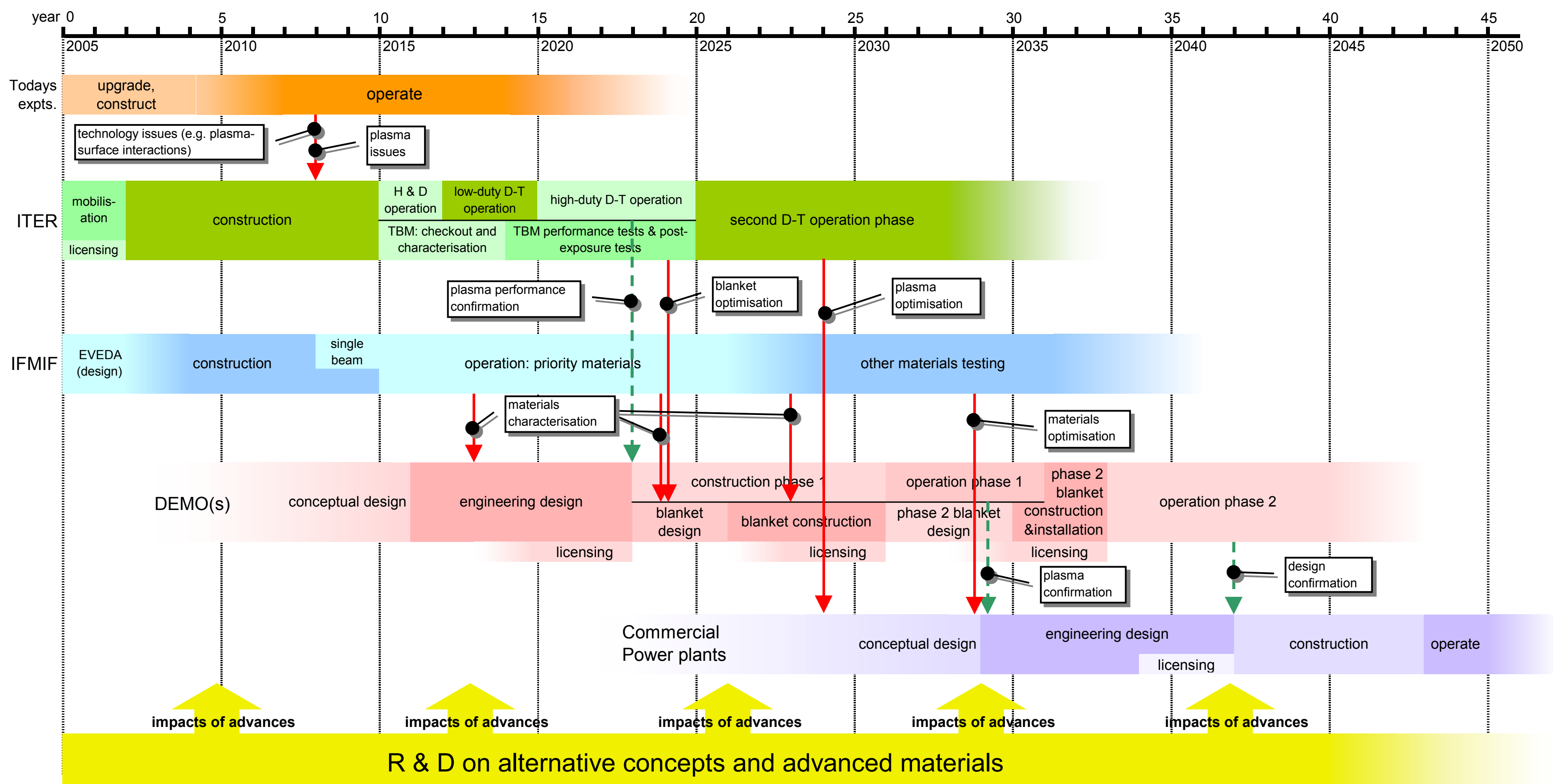
**First stage**

- **ITER**
- **Acceleration of IFMIF design and construction (as EFDA study)**
- **Prioritisation of ITER & IFMIF programmes, in favour of DEMO relevance**

**Second stage**

- **Ex-vessel reliability developed in extended ITER and parallel programme**

# Reference fast track



# Fast track role of DEMO

- Based on ITER-developed physics, but the size of a power plant
- Based on Eurofer or similar
- Based on Models A, AB, B* or C* (or similar)
- First phase similar to power plant EXCEPT reliability and conservative design.
- Second phase builds up reliability.

# Key fast track needs for DEMO

- **Strong top-down prioritisation of ITER physics, ITER TBMs and IFMIF, focussing on near-term, not advanced or peak performance.**
- **Should DEMO (and power plant) be smaller than PPCS? This would reduce extrapolations, but add 20% to the cost of electricity.**
- **How to test helium-cooled divertors, for irradiation-induced creep and swelling?**
- **Several DEMOs are likely – widening and optimising choices. Need to produce tritium in dedicated reactors?**

# Some implications for TBMs

- **There must be a water-cooled lithium-lead TBM.** Model A is completely acceptable, is the nearest term Model, and the only one with a divertor based on ITER's.
- This should be the centrepiece of the TBM programme.
- As there is only room for 6 TBMs, there should be no advanced TBMs.

# Concluding remarks

- Models A, AB, B* or C* are good candidates for attractive fast track DEMOs and first generation power plants.
- The entire cost of the fusion development programme is equal to only a week of spending in the international energy markets.