DEMO Design Activity in Europe: Progress and Updates

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Power Plant Physics and Technology

POWER PLANT PHYSICS & TECHNOLOGY DEPARTMENT

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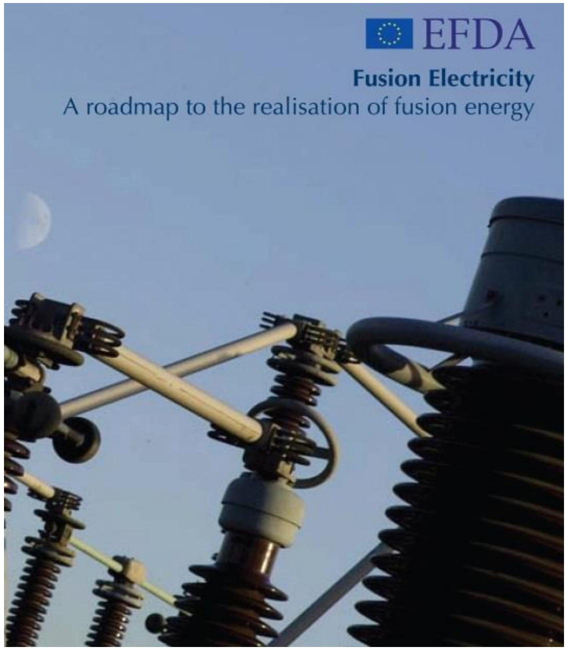
Outline

- ✓ 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**

High Level Requirements agreed with DEMO External Stakeholders (e.g., industry, utilities, grids, safety, licensing, funding bodies)

EU DEMO Mission requirements

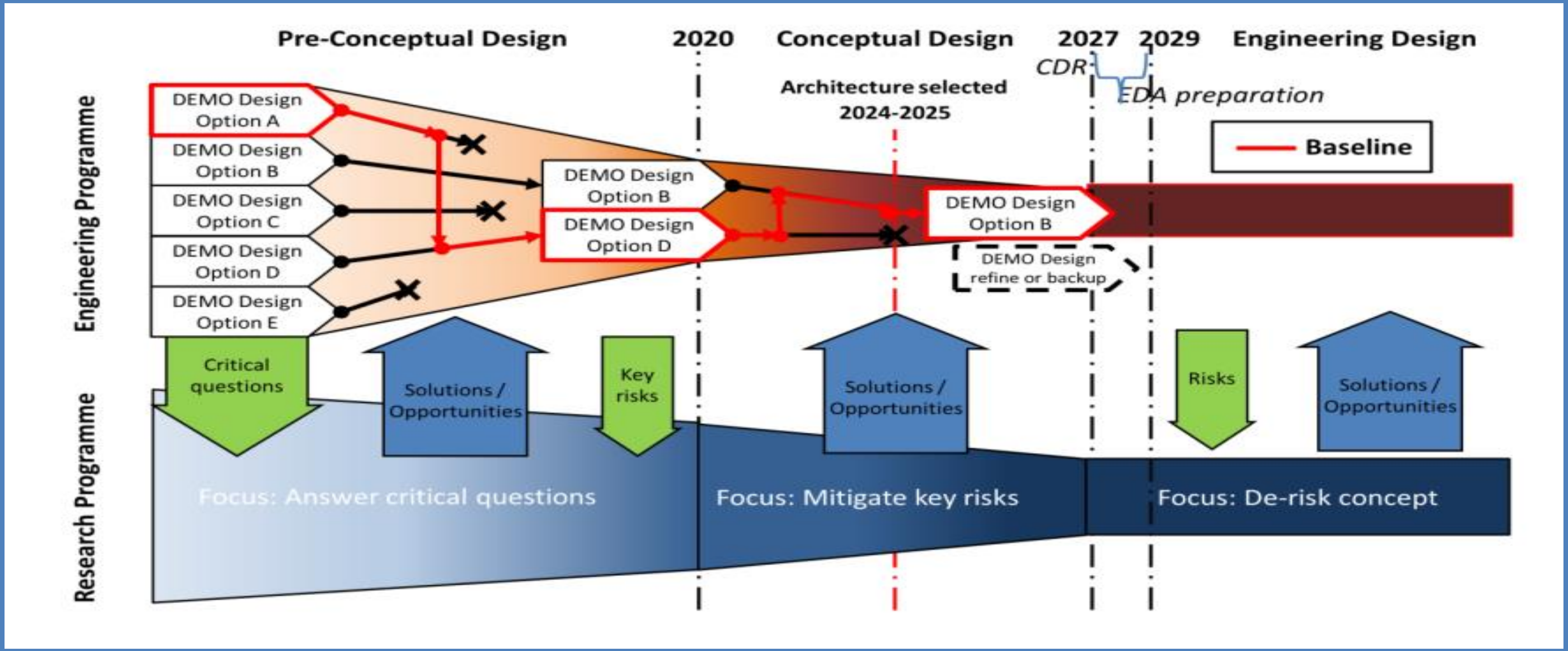
- DEMO Net electricity (~500 MWe)
- Makes its own fuel (TBR > 1)
- Reliable operation
- Reasonable availability
- Allow extrapolation to a FPP

DEMO in the EU Fusion Roadmap (cont'd)

Revision 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.



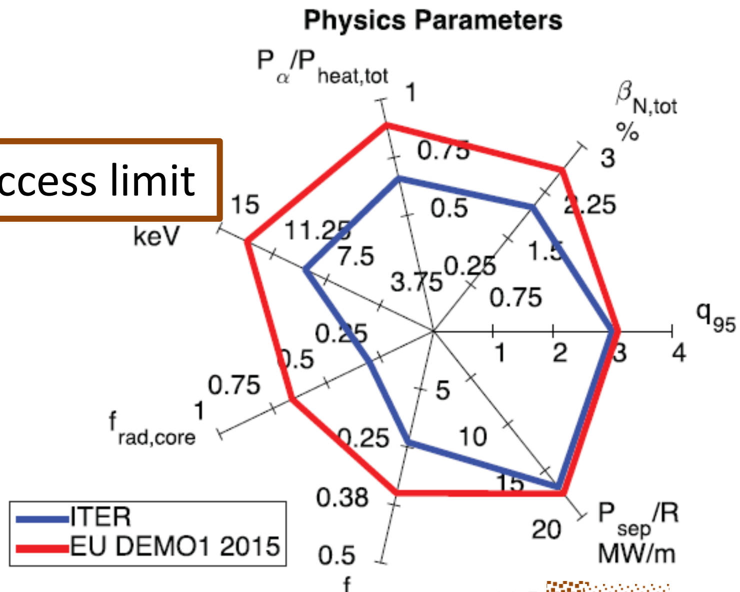
Key Messages

- 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.

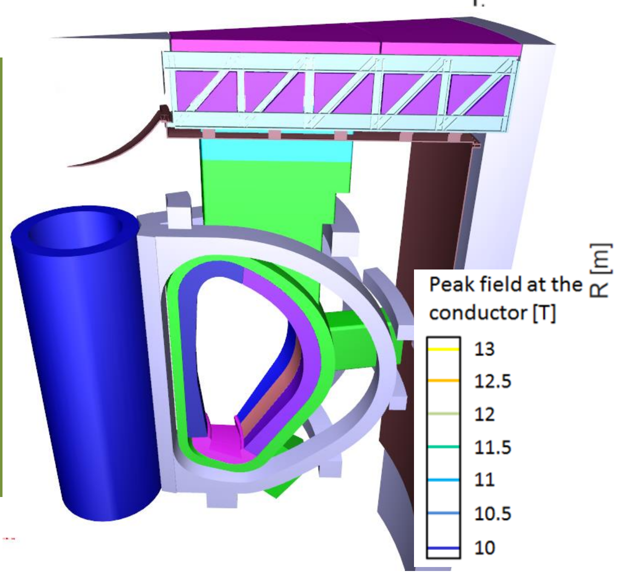
H-mode access limit

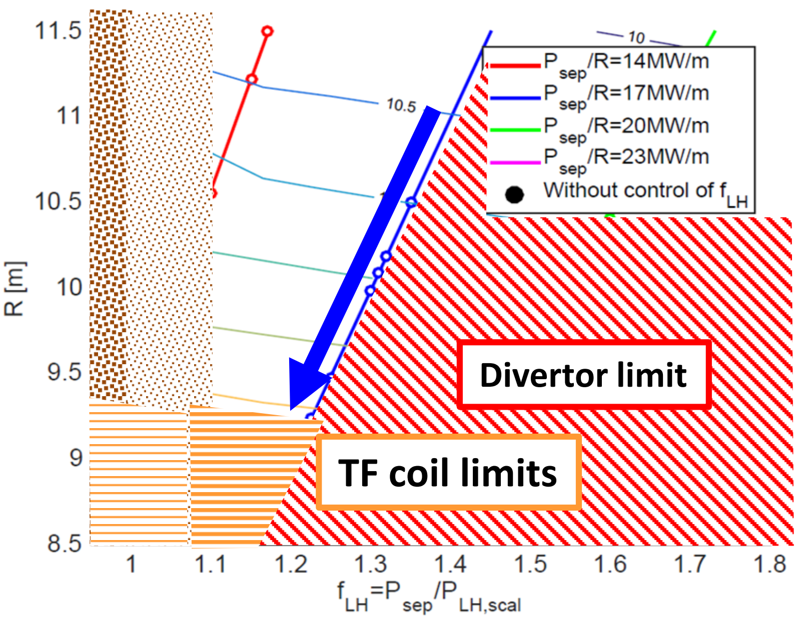


	DEMO1
R_o	~9 m
A	3.1
k_{95}	1.65
B_T	4.9 T
β_N	2.6
H	1.1

$P_{el,net}$ = 500 MW
τ_{pulse} = 2 hr
A = 3.1

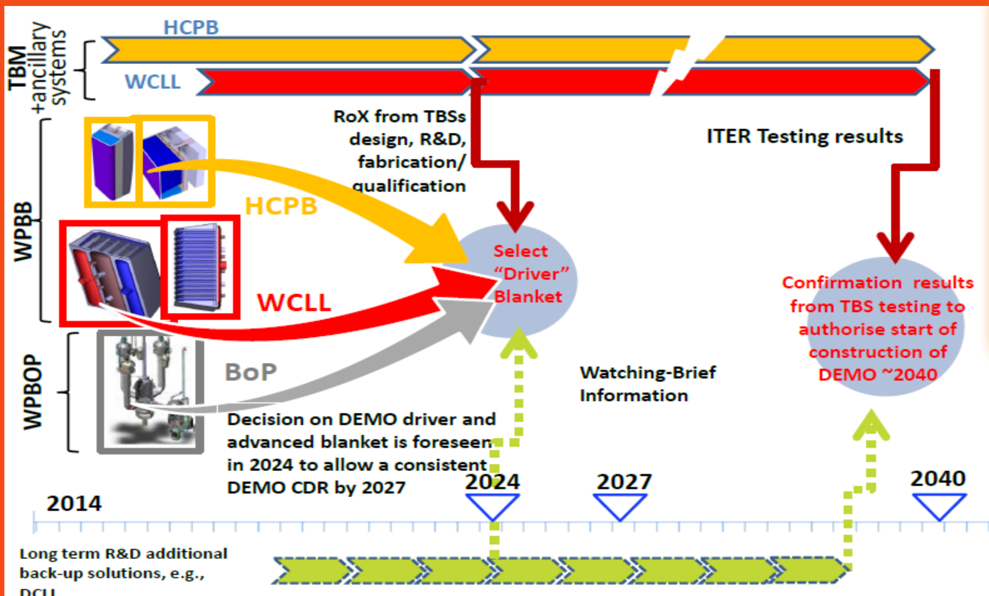
Engineering:
- 16 LTSC TF Coils, Nb_3Sn, ~12 T
- Vertical Maintenance
- EUROFER IVCs
- Starter blanket (20 dpa) + Second blanket (50 dpa) (~6-7 FPY total)
- TBR > 1.1
- Availability target 30%



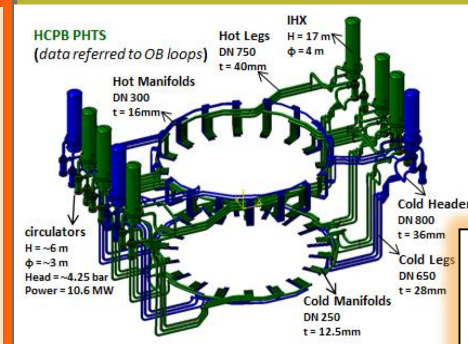


Evaluate Multiple Design Options

Breeding Blanket Design Options



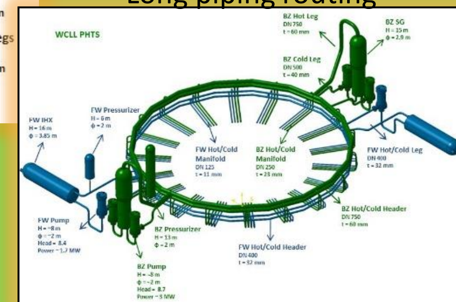
Blanket PHTS: He and H_2O



He (300-500ºC, 80 bar

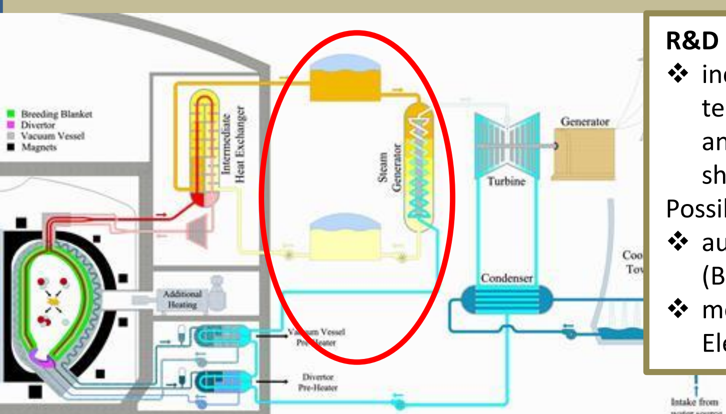
Issues

- High pumping Power
- Large He inventory
- Large HeX
- Long piping routing



H_2O (292-320ºC, 150 bar

PCS: Indirect (ESS)/ Direct



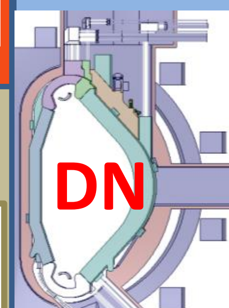
R&D issues :

- 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

Alternative Div Configurations

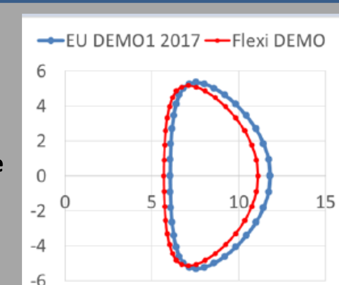


- Effects on TBR, n-shielding
- Remote handling
- Effects of increased radiation from X-point

Flexi-DEMO

	Lower OP	Upper OP
R (m)	< 8.4	< 8.4
P_{el} (MW)	300	300
τ(hr)	1	St. State
q_{95}/β_N	4.8/3.3	4.2/2.9
H	1	1.2

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

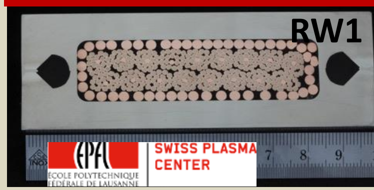
Wind & React

ΔT_{marg} >2K @ 82kA,13T

NO degradation with e-m cycles

❖ $\varepsilon_{eff} \in [-0.55, -0.35]\%$
❖ Higher I_c
❖ Less SC strands

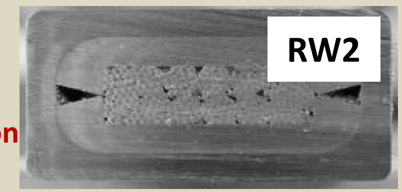
React & Wind



ΔT_{marg} >2.0 K $\varepsilon_{eff} \cong -0.35\%$

Low degradation w. e-m cycles

Low AC losses



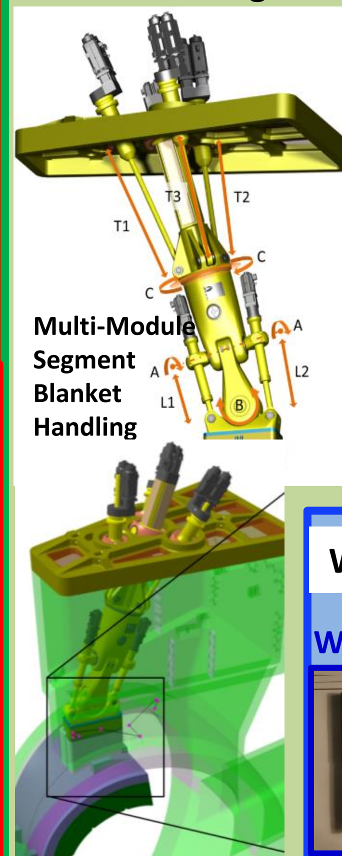
Moderate degradation w. e-m cycles

Very low AC losses

ΔT_{marg} >1.5 K $\varepsilon_{eff} \cong -0.40\%$

WPRM – Remote Maintenace

- 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



Multi-Module Segment Blanket Handling

Proof of principle tool designs completed

- Fit-up tolerance and filler material methods
- Post weld heat treatment
- Control of weld profile with dual lasers

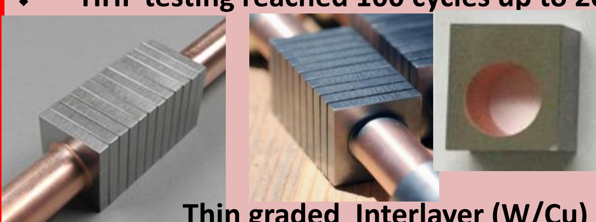
Keelan Keogh et al. (CCFE) to appear in Fus. Eng. Des.

In-bore weld achieved

2017 Welding Tool Proof of Principle Detailed Design

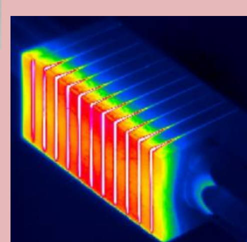
WPDIV - Technology R&D for HHF PFCs

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



Thin graded Interlayer (W/Cu)

100th cycle



Composite pipe (W_f/Cu)

Thermal break

WPBB – Blanket Fabrication Technologies

WCLL (EUROFER tubes)

HIP and EB processes (FW / cooling plates

Spark erosion and bending (FW)

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

AIRBUS

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

ANSALDO NUCLEARE
Ansaldo Energia Group

Kraftanlagen Gruppe

Fortum

SIEMENS

- Design studies BOP/PCS
- Design amelioration of turbines for pulsed loads
- FIIF

EUROfusion

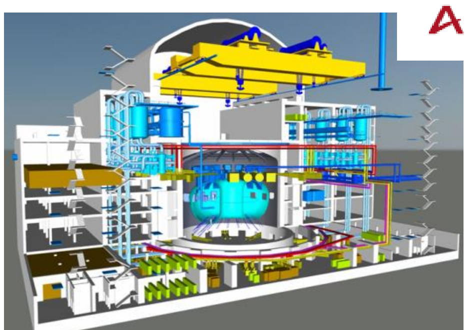
FIIF

Fusion Industry Innovation Forum

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

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

AREVA



MAN

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

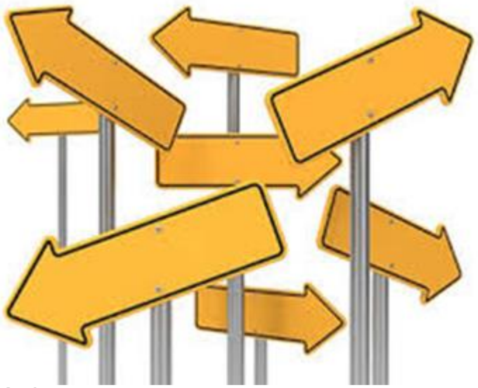
Final Remarks

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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