# Progress of the EU Power Plant Conceptual Study (PPCS)

**US/Japan Workshop on Power Plant Studies and Related Advanced Technologies With EU Participation**

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# Outline of Presentation

- ⇨ PPCS Framework & Objectives
- ⇨ Status of PPCS Activities
    - Requirements
    - Design Studies
    - Physics & Basic Parameters
    - Divertors
    - Maintenance
    - Balance of Plant
- ⇨ Conclusions

# PPCS Framework

- PPCS (2000-2002): to establish coherence and priorities within the EU fusion programme
- Stages 1 and 2 between Jan. 2000 and Apr. 2001 (preparatory work)
- Stage 3 effective start in July 2001
  - Four models considered (A, B, C and D)
  - Point design for each model
  - Safety, environmental and economic assessments of each model

# Why a PPCS in Europe?

- ⇨ Technical questions to be answered (raised during discussion on EU ITER site)
  - What is a fusion reactor?
  - How far are we from a fusion reactor?
  - How attractive is a fusion reactor?
  - Is the EU programme really reactor oriented?

2 key references: [1] R. Toschi et al, "How far is a fusion reactor from an experimental reactor", SOFT 21 (2000); [2] K. Lackner et al., "Long-term fusion strategy in Europe", ICFRM 10 (2001).

# Basic Requirements (1/2)

## ⇨ Safety / Environment

- no need for emergency evacuation plan
- no active systems for safe shut-down

## ⇨ Operation

- steady state, >1 GWe, base load
- lifetime 40 yrs. (ext. to 60 yrs.)
- availability 75 ÷ 80 %, only a few unplanned shut-downs/year

(Requirements provided by Industry and Utilities)

# Basic Requirements (2/2)

## ⇨ Economics

- public acceptance could be more important than economics
- economic comparison among equally acceptable energy sources (e.g. including externalities)
- licensing/regulation requirements strongly reduced vs. fission

## ⇨ Construction time ≤ 5 years

(Requirements provided by Industry and Utilities)

# PPCS Design Studies (1/3)

- ⇨ Starting point: ITER, EU long term R&D programme, Safety & Socio-Economic studies
- ⇨ Main Effort: consistency of design
  - Physics assumptions
  - Divertor concepts
  - Maintenance
  - Balance of Plant

# PPCS Design Studies (2/3)

⇨ 2 models with “limited” extrapolations

- Model A: WCLL (water cooled lithium lead)
- Model B: HCPB (helium cooled pebble bed)
- Divertor coolant = blanket coolant
- Normalised gross electric power output of 1.5 GWe (turbogenerators power output less pumping power)

# PPCS Design Studies (3/3)

⇨ 2 more “advanced” models

- Model C: DC (dual coolant: helium and lithium lead)
- Model D: SC (self cooled: lithium lead)
- Divertor coolant = blanket coolant (C: He, D: Li=Pb)
- Normalised gross electric power output (1.5 GWe)

# Physics (1/2)

- ⇨ Assumptions for models A and B: ITER goals achieved, use "ITER physics rules"

  $\Rightarrow$ $n/n_{GW}<1.2$, $H_H<1.2$, $\beta_N<3.5$, first stability

- ⇨ Size driven by the divertor power handling capability (A: 15 MW/m²; B: 10 MW/m²)

- ⇨ Thermal efficiency of power conversion system (A: 31%, B: 40.5%)

# Physics (2/2)

⇨ Goal for models C and D : scenario requiring less re-circulating power for CD without excessive loads on the FW

- High $\beta$ and high confinement
- MHD stabilisation by strong plasma shaping
- High bootstrap current fraction
- Low divertor power loads and low $Z_{eff}$

⇨ divertor loads 10 $MW/m^2$ for C and 5 $MW/m^2$ for D, nuclear loads < 2.5 $MW/m^2$

| | Model A | Model B | Model C | Model D |
|---|---|---|---|---|
| **Basic Parameters** | | | | |
| Major Radius (m) | 9.8 | 8.7 | 7.5 | 6.1 |
| Aspect Ratio | 3.0 | 3.0 | 3.0 | 3.0 |
| Plasma Current (MA) | 33.5 | 28.1 | 20.1 | 14.1 |
| Toroidal Field on axis (t) | 7.3 | 6.9 | 6.4 | 5.6 |
| TF on TF Coil Conductor (T) | 12.9 | 13.1 | 13.6 | 13.4 |
| Elongation (95% and separatrix) | 1.7; 1.9 | 1.7; 1.9 | 1.9; 2.1 | 1.9; 2.1 |
| Triangularity (95 % and separatrix) | 0.27; 0.4 | 0.27; 0.4 | 0.47; 0.7 | 0.47; 0.7 |
| Q | 21 | 15 | 30 | 35 |
| **Physics Parameters** | | | | |
| $H_H$ (IPB98y2) | 1.2 | 1.2 | 1.3 | 1.2 |
| $n/n_G$ | 1.2 | 1.2 | 1.5 | 1.5 |
| $ß_N$(thermal); ß(thermal) | 3.4; 4.8 % | 3.3; 4.6 % | 4.0; 5.0 % | 4.5; 5.6 % |
| Bootstrap Fraction | 0.36 | 0.36 | 0.69 | 0.76 |
| $q_{95}$ | 3 | 3 | 4.5 | 4.5 |
| Zeff | 2.6 | 2.7 | 2.5 | 1.6 |
| **Engineering Parameters** | | | | |
| Fusion Power (GW) | 5.5 | 3.4 | 3.4 | 2.5 |
| $P_{add}$ (MW) | 265 | 234 | 112 | 71 |
| Avge. Neutron Wall Load ($MWm^{-2}$) | 2.3 | 1.8 | 2.2 | 2.4 |
| Max. Divertor Heat Load ($MWm^{-2}$) | 15 | 10 | 10 | 5 |
| Net Reactor Efficiency | 27% | 43% | 44% | 61% |

# Water Cooled Divertor (1/3)

## ⇨ ITER divertor

- Cu pipe armoured by CfC monoblock structure (lower region), W tiles in upper, baffle region
- Water temperature <200ºC

## ⇨ However

- 18% of fusion power goes to the divertor
- If steel instead of Cu, max. heat load <7 MW/m²

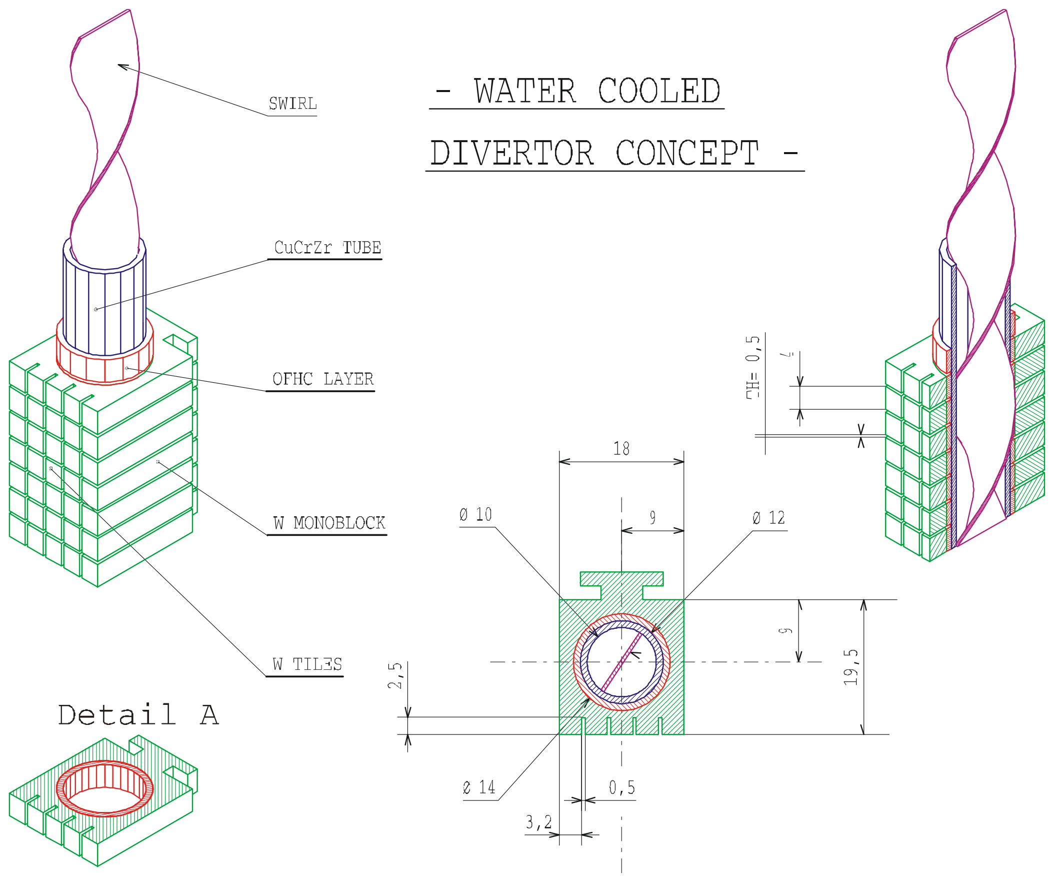
# Water Cooled Divertor (2/3)

⇨ PPCS Model A divertor

- Complete ELM suppression in H-mode
- Maximum heat-load (steady state) 15 MW/m²
- CuCrZr as heat sink, temp. <400ºC, therefore water temp. <170ºC
- W armour (low sputter yield, low tr. retention)
- Main issue: W embrittlement under neutron irradiation below 500ºC

⇨ R&D required to validate concept

# Water Cooled Divertor (3/3)



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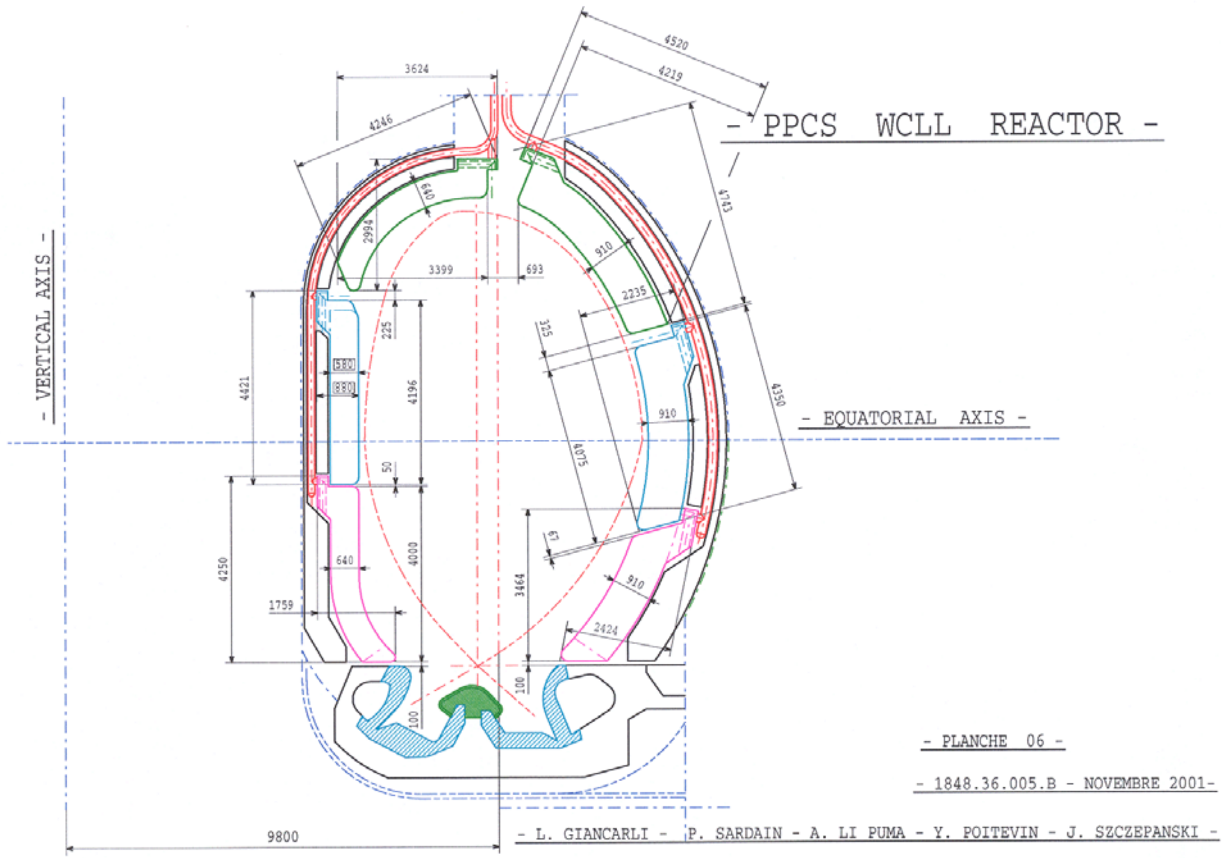
# Cross-section of model A



# Helium Cooled Divertor (1/3)

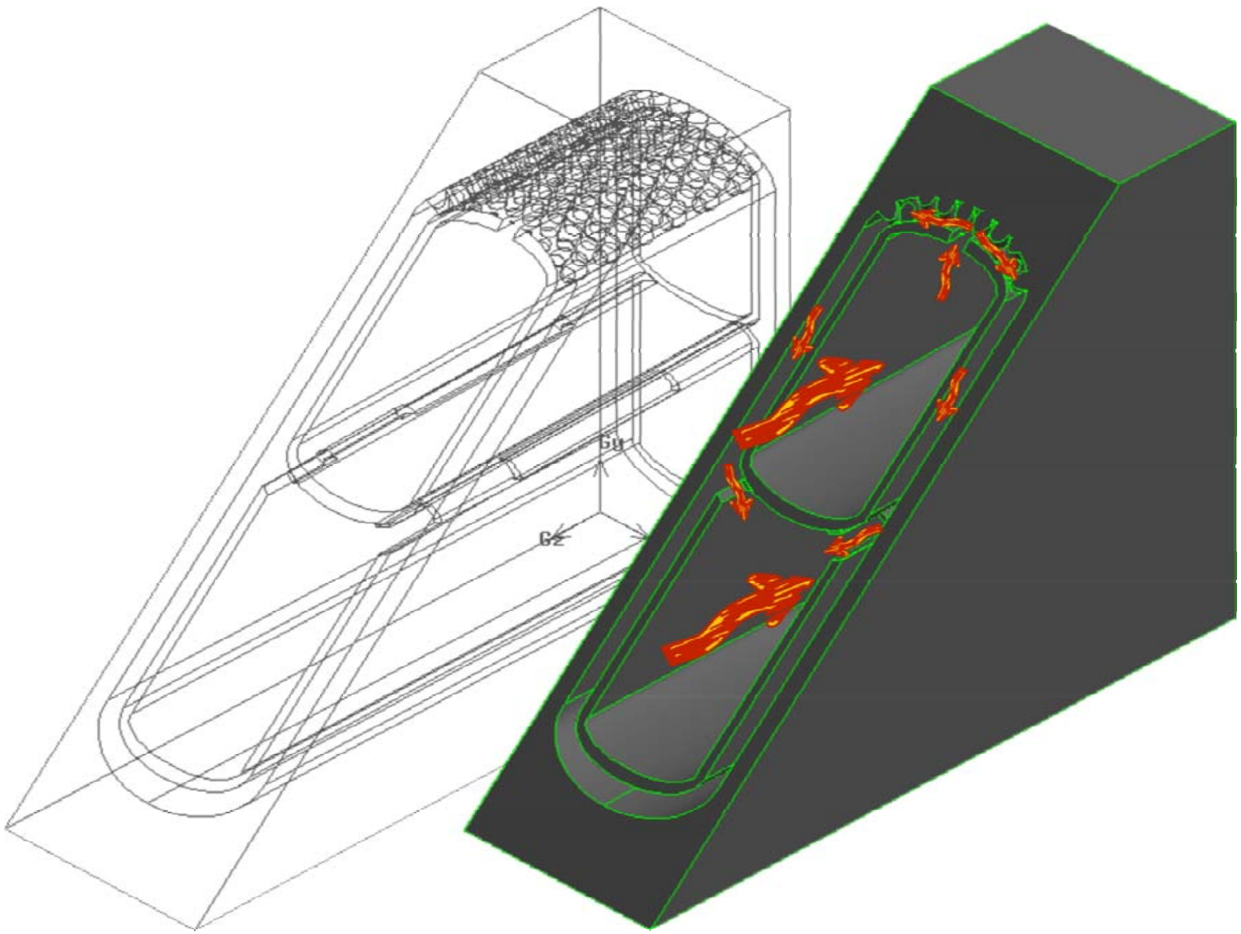
## ⇨ Why a He-cooled divertor?

- No risk of (accidental) Be-water reaction
- High grade heat
- Simplify BoP

## ⇨ Design issue: 10 MW/m²

- W-alloy (Mo alternative) structure and armour
- Very high, local He speed (200 m/s)
- equivalent heat transfer coefficient, i.e. related to the plain channel surface, of 48 $kW/m^2K$

# Helium Cooled Divertor (2/3)



# Helium Cooled Divertor (3/3)

## ⇨ Temperatures

- He inlet temperature: 640°C, temp. gain: 100K.
- Temperature in structure 930°C - 1160°C
- Maximum temp. for 3.5 mm-thick tile: 1530°C

## ⇨ Von Mises Stresses below 400 MPa

## ⇨ Design & R&D required to validate concept

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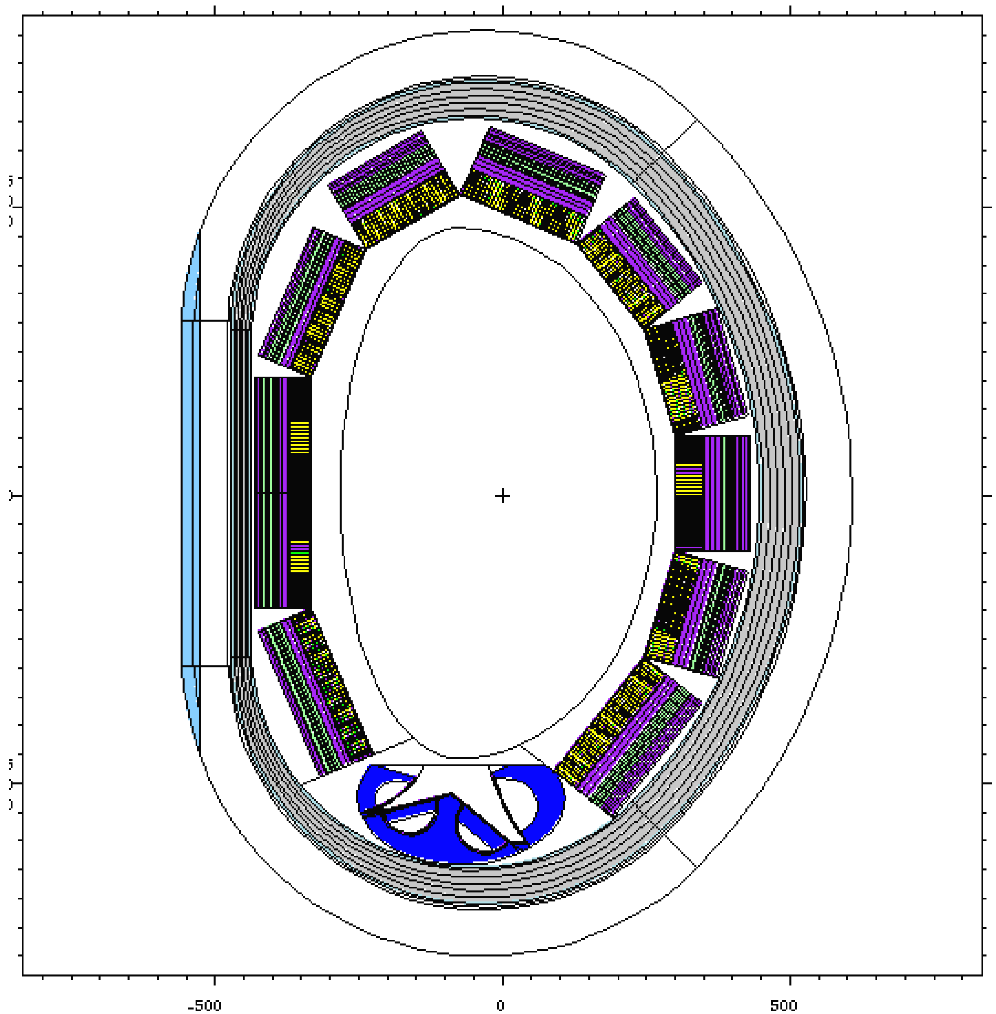
# Cross-section of model B



# Maintenance (1/3)

- ⇨ Two concepts assessed:
  - "Large Modules", i.e. ≈180 modules (ITER 1998: 720, ITER 2001:440)
  - "Large Sectors", as per ARIES-RS
- ⇨ Availability (lifetime: 5 FPY blanket; 2 FPY divertor and sectors)
  - LM $\Rightarrow$ 70/75%, LS $\Rightarrow$ <80%

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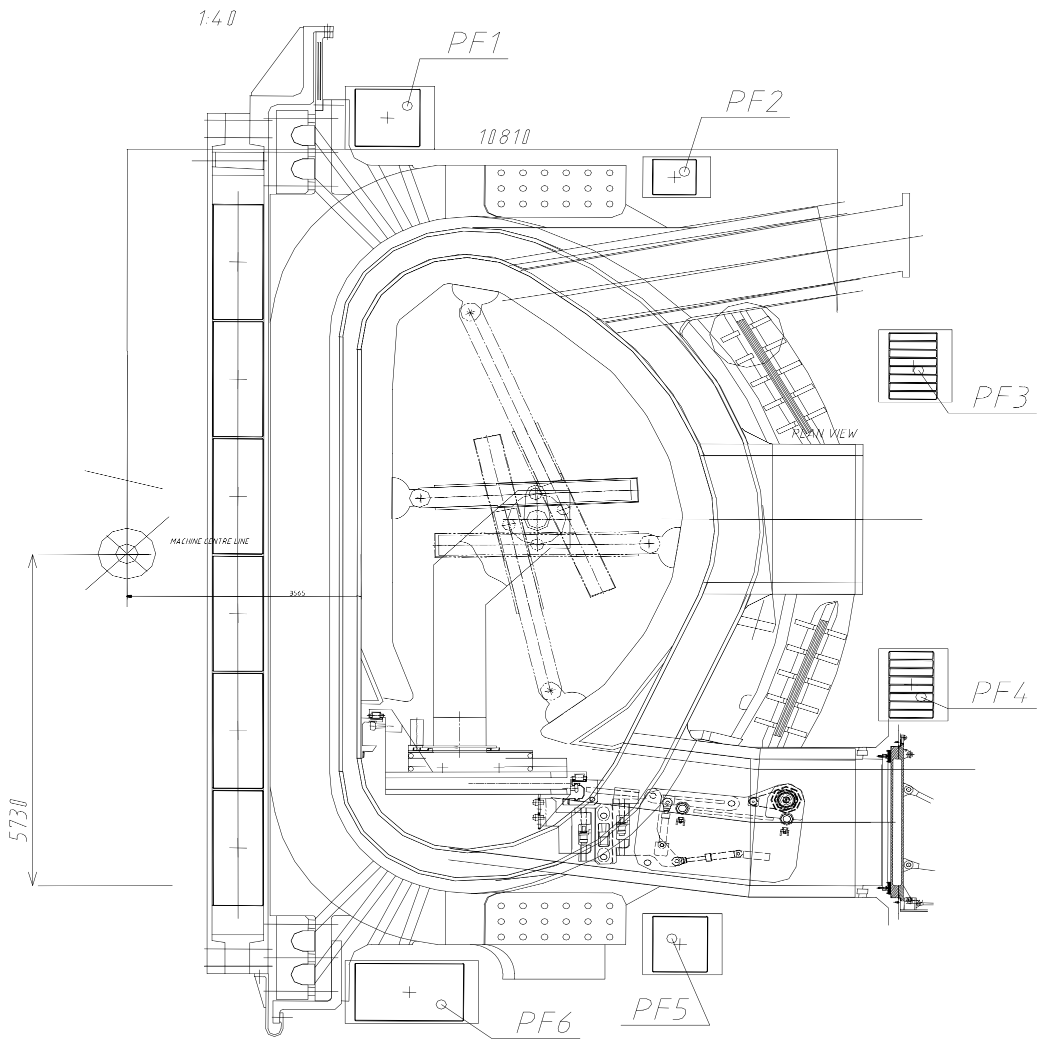
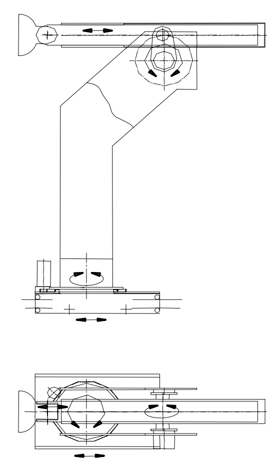
# Maintenance (2/3)

## Large Module Handling



# Maintenance (3/3)

- ⇨ Large Sectors: several engineering issues TBD, >20% higher capital investment
- ⇨ Large Module Handling Concept confirmed as reference for models A and B
- ⇨ For models C and D Large Module or Vertical ”bananas” Segments being considered

# Balance of Plant (1/2)

- BoP: approx. 40% of capital investment, main cause of fission plants unscheduled outages in the 80's
- Model A: blanket cooling water at PWR conditions (divertor water: 170ºC)
- Model B: limited experience; no feasibility issue but "infant" mortality ought to be considered (increase cost and/or reduce availability)

# Balance of Plant (2/2)

## ⇨ Power Conversion

- steam turbine cycle for A, B, possible for C
- direct gas turbine cycle for D, possible for C

## ⇨ Net Reactor Efficiency:

(fusion power)/(electricity to grid)

- A: 27%, B: 43%, C: 44%, D :61%

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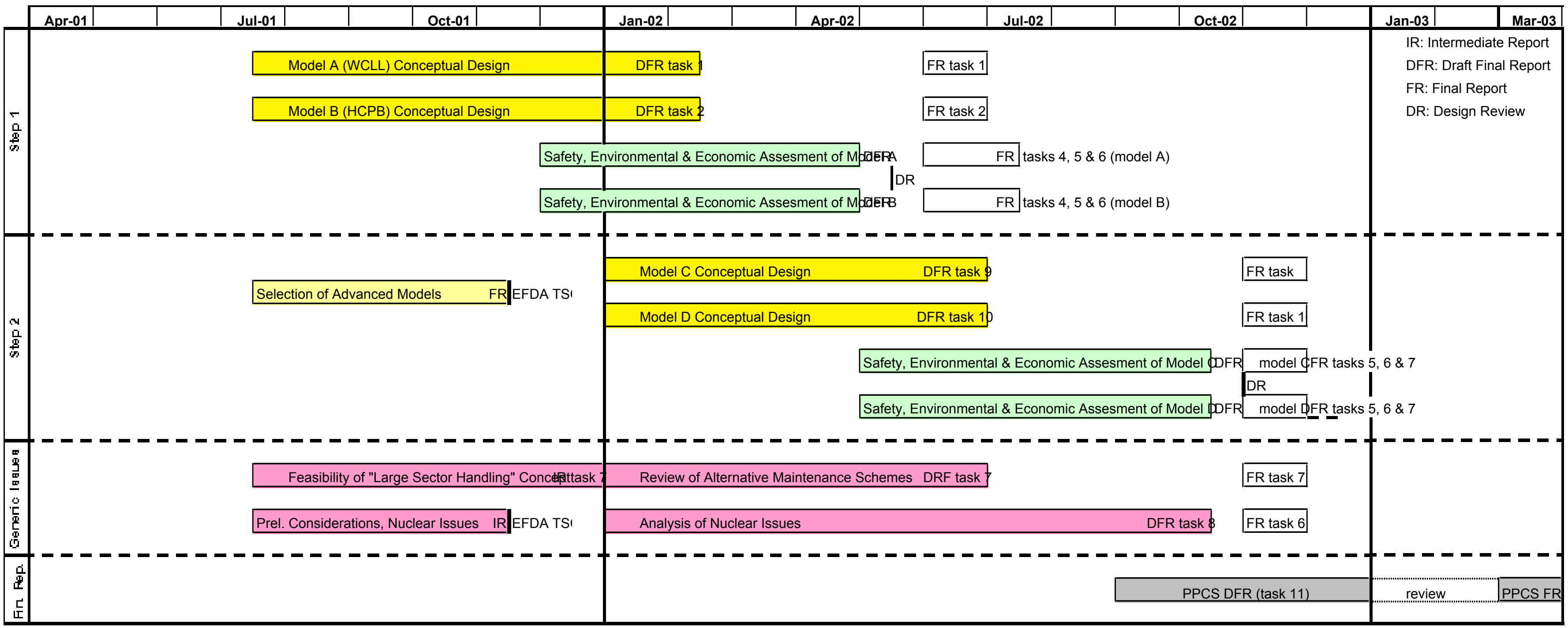
# PPCS St. 3 Original Schedule



# Conclusions (1/2)

- ⇨ Design of conservative models being finalised, assessments in progress
- ⇨ Design of advanced models started
- ⇨ Main emphasis: physics, divertor, maintenance and BoP
- ⇨ PPCS schedule roughly on time (FR in 03.03)

# Conclusions (2/2)

## ⇨ R&D requirements

- Blankets & materials: continue, assess HCLL concept
- Divertor: critical, to be defined and implemented
- Physics: continue work on advanced scenarios
- CD: highly efficient (70%) systems required
- Maintenance: validate “large module” concept

# PPCS Papers at ISFNT-6

- Invited NSD INV. 1 (Parallel Session #5)
  - "The EU Power Plant Conceptual Study" by G. Marbach, I. Cook and D. Maisonnier
- Poster FWC POS. 16 (Poster Session #4)
  - "Optimisation of a Water-Cooled Divertor for the European Power Plant Conceptual Study" by A. Li Puma et al.
- Poster FWC POS. 23 (Poster Session #4)
  - "Gas-cooled High Performance Divertor for a Power Plant" by S. Hermsmeyer and S. Malang