San Diego Workshop, 11 September 2003

Results of the European Power Plant Conceptual Study

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on behalf of

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and the PPCS team

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Overall objectives

The PPCS charge was to:

Assist in

- **assessing the status of fusion energy**
- **guiding the future evolution of the fusion programme**

And demonstrate

- **the credibility of the power plant designs**
- **the safety/environmental/economic claims for fusion**
- **the robustness of the analyses and conclusions**

Overall issues

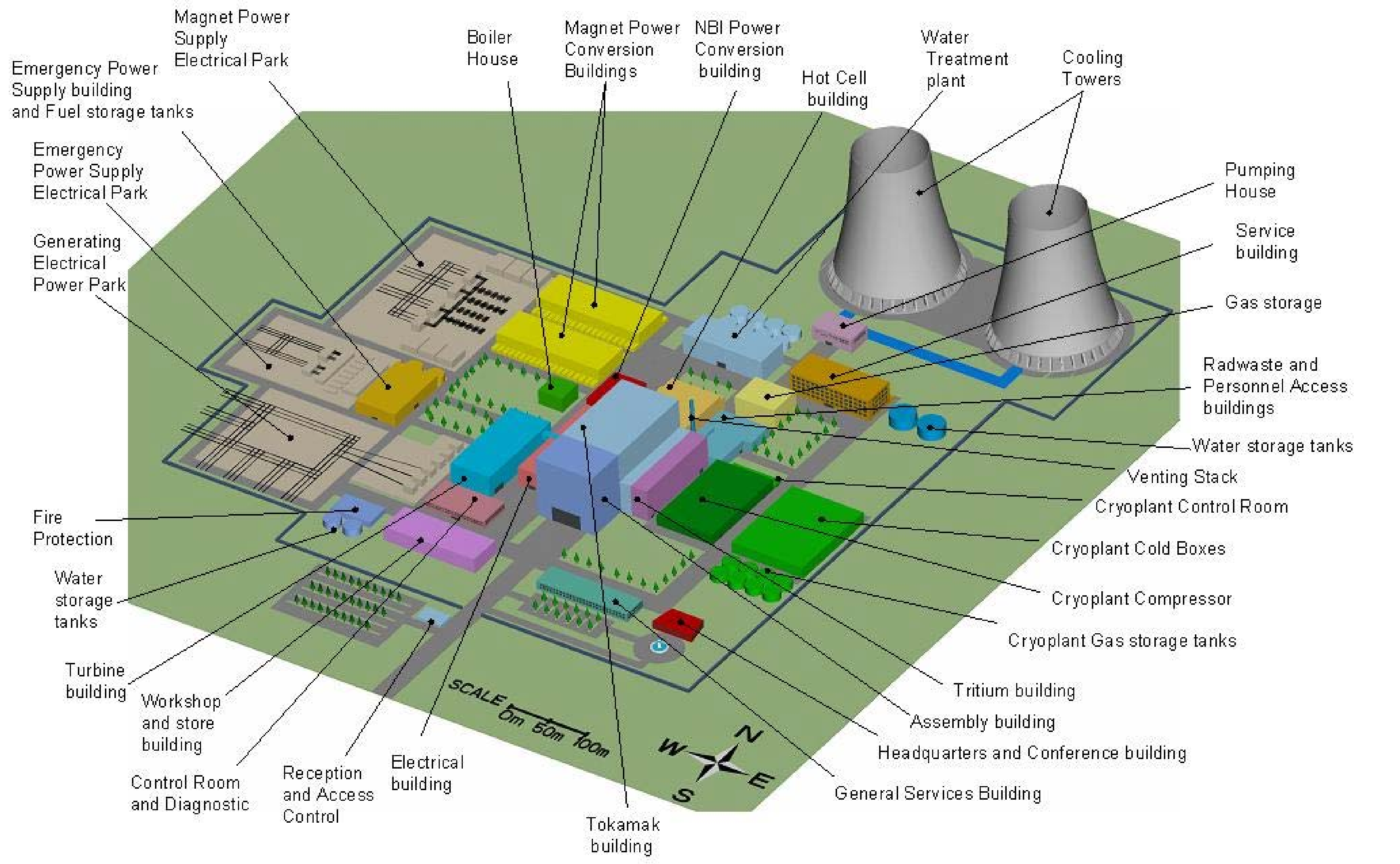
Compared to earlier European studies:

- The designs aim to satisfy economic objectives.
- The plasma physics basis is updated.

So the parameters of the designs differ substantially from those of the earlier studies.

- The need for excellent safety and environmental features has not changed.

General layout



Systems analyses

- Four “Models”, A - D, were studied as examples of a spectrum of possibilities.
- Ranging from near term plasma physics and materials to advanced.
- Systems code varied the parameters of the possible designs, subject to assigned plasma physics and technology rules and limits, to produce economic optimum.

Plasma physics basis

- Based on assessments made by expert panel appointed by European fusion programme.
- Near term Models (A & B): broadly 30% better than the conservative design basis of ITER.
- Models C & D: progressive improvements in performance - especially shaping, stability and divertor protection.

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Materials basis

Model	Divertor	Blanket structure	Blanket other
A	W/Cu/water	RAFM	LiPb/water
B	W/He	RAFM	Li_4SiO_4/Be/He
C	W/He	OST/RAFM	LiPb/SiC/He
D	W/SiC/He	SiC	LiPb

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Key technical innovations

- Concepts for the maintenance scheme, capable of supporting high availability.
- Helium-cooled divertor, permitting high tolerable heat flux of 10 MW/m2 .

Net electrical output

- The **economics of fusion power improves substantially with increase in the net electrical output** from the plant.

- However, **large unit size causes problems with grid integration** and requirement for very high reliability.

- **As a compromise, the net electrical output was chosen to be 1,500 MWe for all the PPCS Models.**

- However, their fusion powers are very different.

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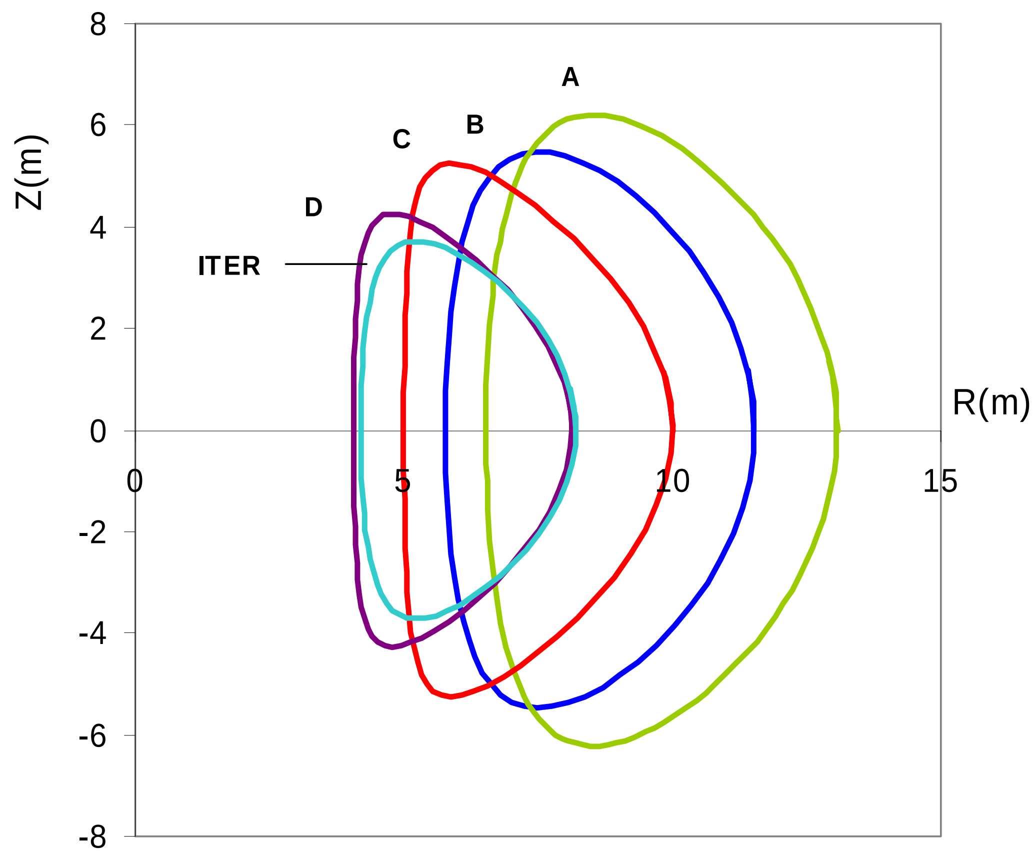
Key issues and dimensions

- **All 1500 MWe net**
- **Fusion power determined by efficiency, energy multiplication and current drive power**
- **So fusion power falls from A to D.**
- **Given the fusion power, plasma size mainly driven by divertor considerations.**
- **So size falls from A to D.**



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Other key parameters

Parameter	Model A	Model B	Model C	Model D
Fusion power (GW)	**5.0**	**3.6**	**3.4**	**2.5**
Q	20	13.5	30	35
Recirculating power fraction	**0.28**	**0.27**	**0.13**	**0.11**
Wall load ($MW/m^{2)}$	2.2	2.0	2.2	2.4
Divertor peak load (MW/m^2)	15	**10**	10	5

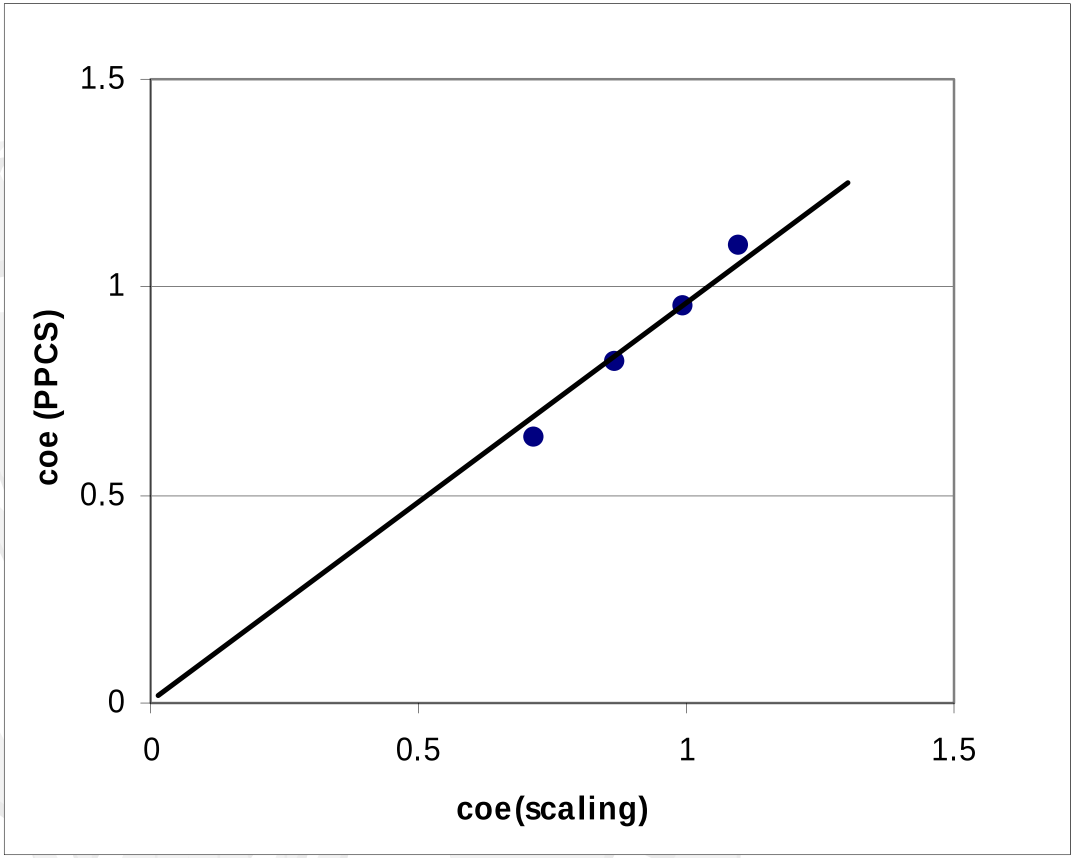
Costs: internal and external

Contributions to the cost of electricity:

- **Internal costs: constructing, fuelling, operating, maintaining, and disposing of, power plants.**
- **External costs: environmental damage, adverse health impacts.**

Internal costs: scaling

- Cost of electricity is well represented by the scaling opposite.
- The figure shows systems code calculations for Models A to D, against the scaling.
- Shows that PPCS Models are good representatives of a much wider class of possible designs.



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

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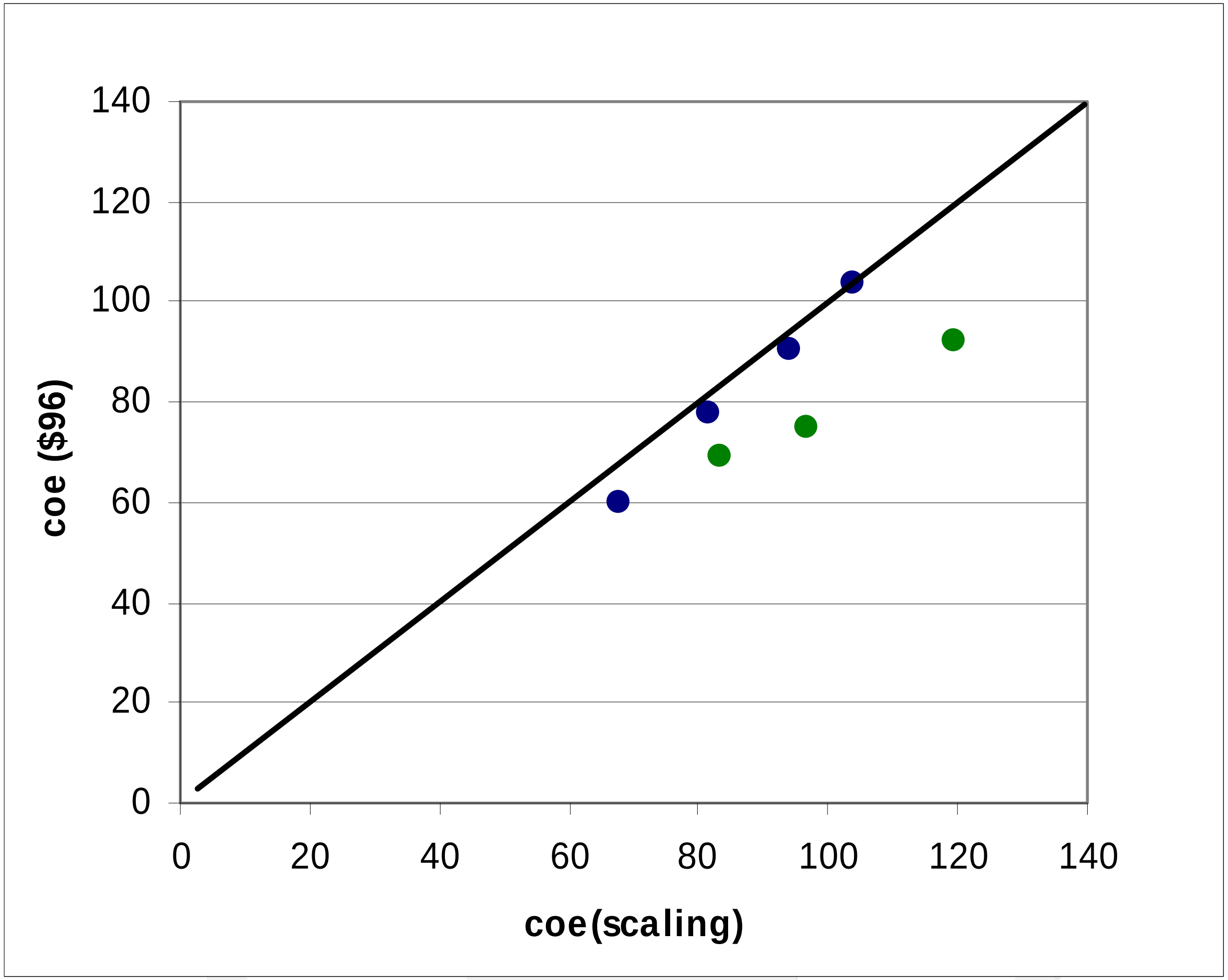
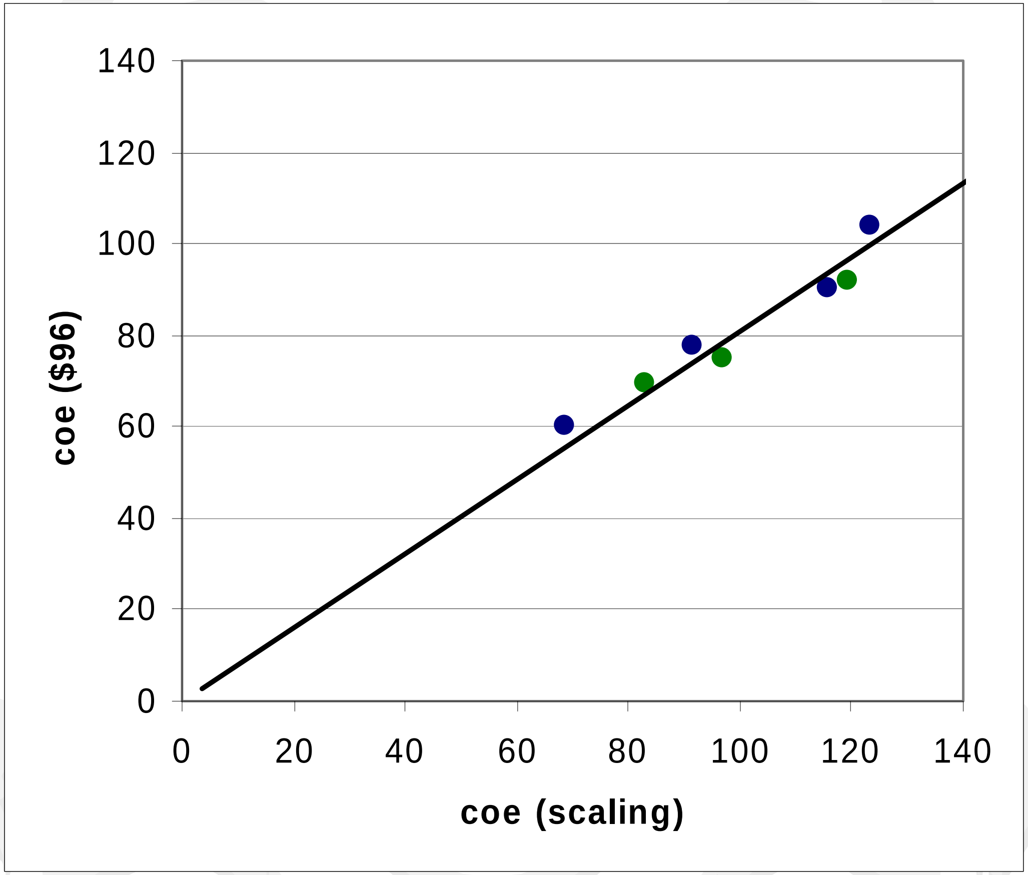
PPCS and ARIES (1,RS,AT) on Same Scaling (1)



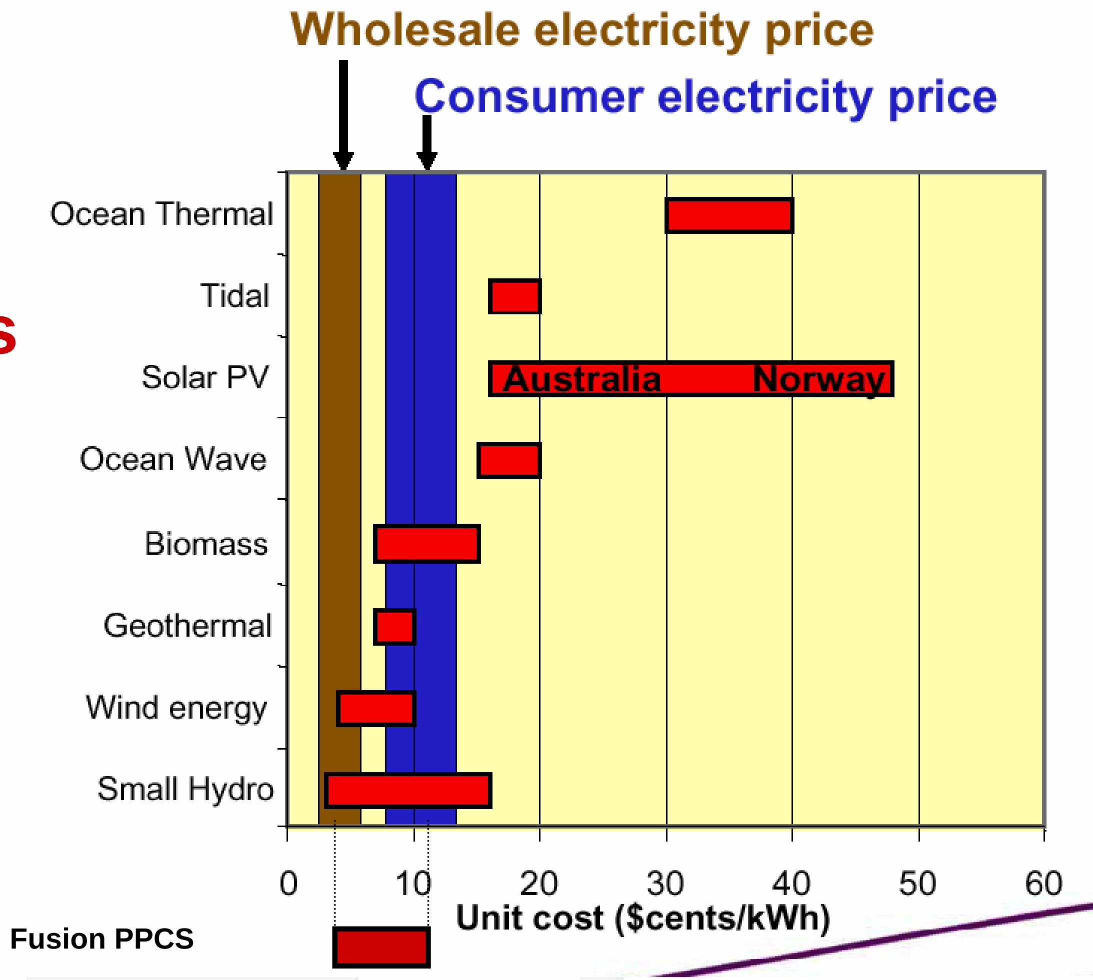
PPCS and ARIES (1,RS,AT) on Same Scaling (2)



PPCS Plants corrected for high dilution
(introduced to protect divertor)

Internal costs: range

- Depending on the Model and learning effects, **PPCS internal cost of electricity ranges from 3 to 12 Eurocents/kWh**.
- Even the near-term Models are acceptably competitive.



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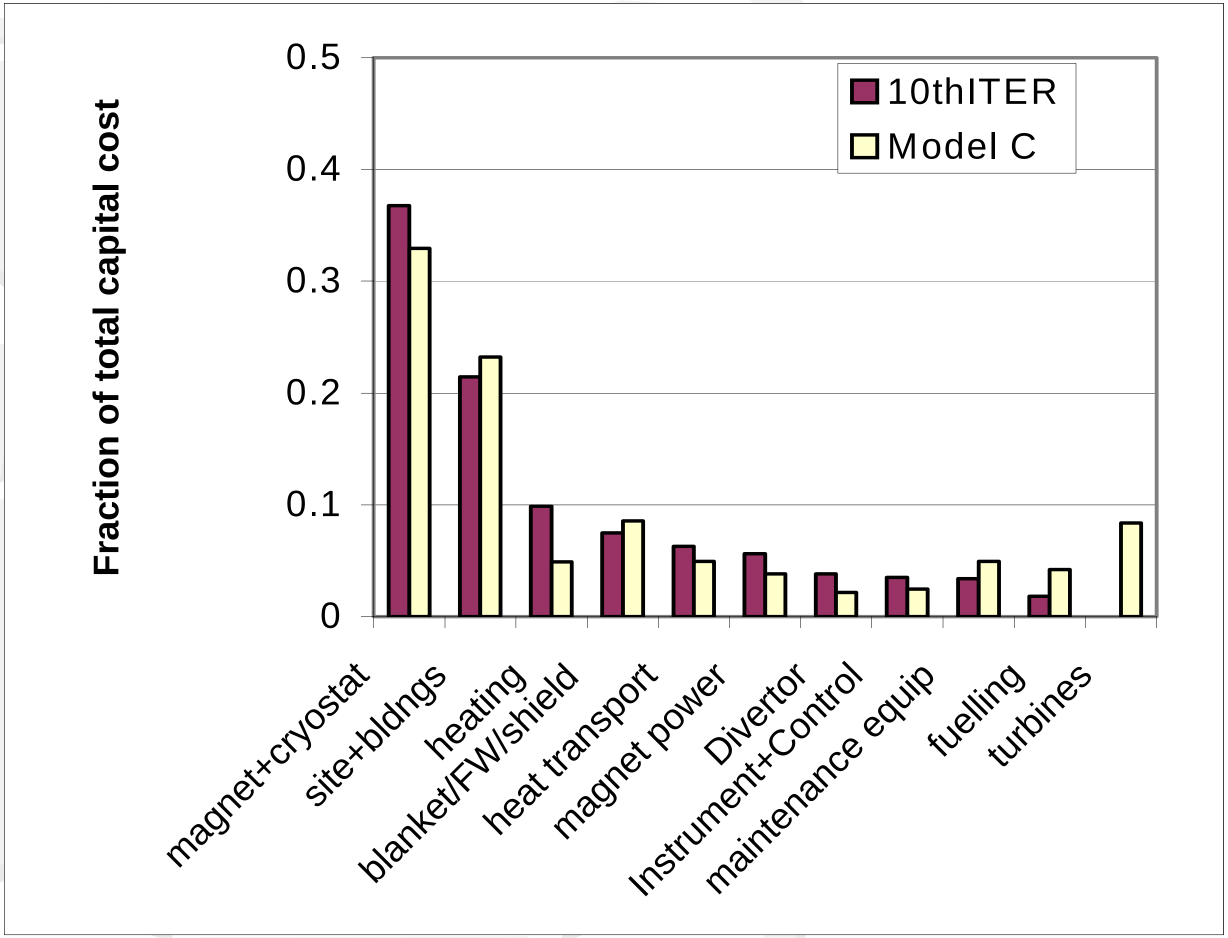
Composition of internal costs

- **Comparison between ITER and Model C fractional capital costs on the same basis.**
- **Good agreement, illustrating robustness of analyses**



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External costs

Model	External cost (Eurocents/kWh)
A	0.25
B	0.10
C	0.06
D	0.06

- These are all small: comparable to wind.
- C & D: dominated by conventional construction accidents.

Safety and environment: key questions

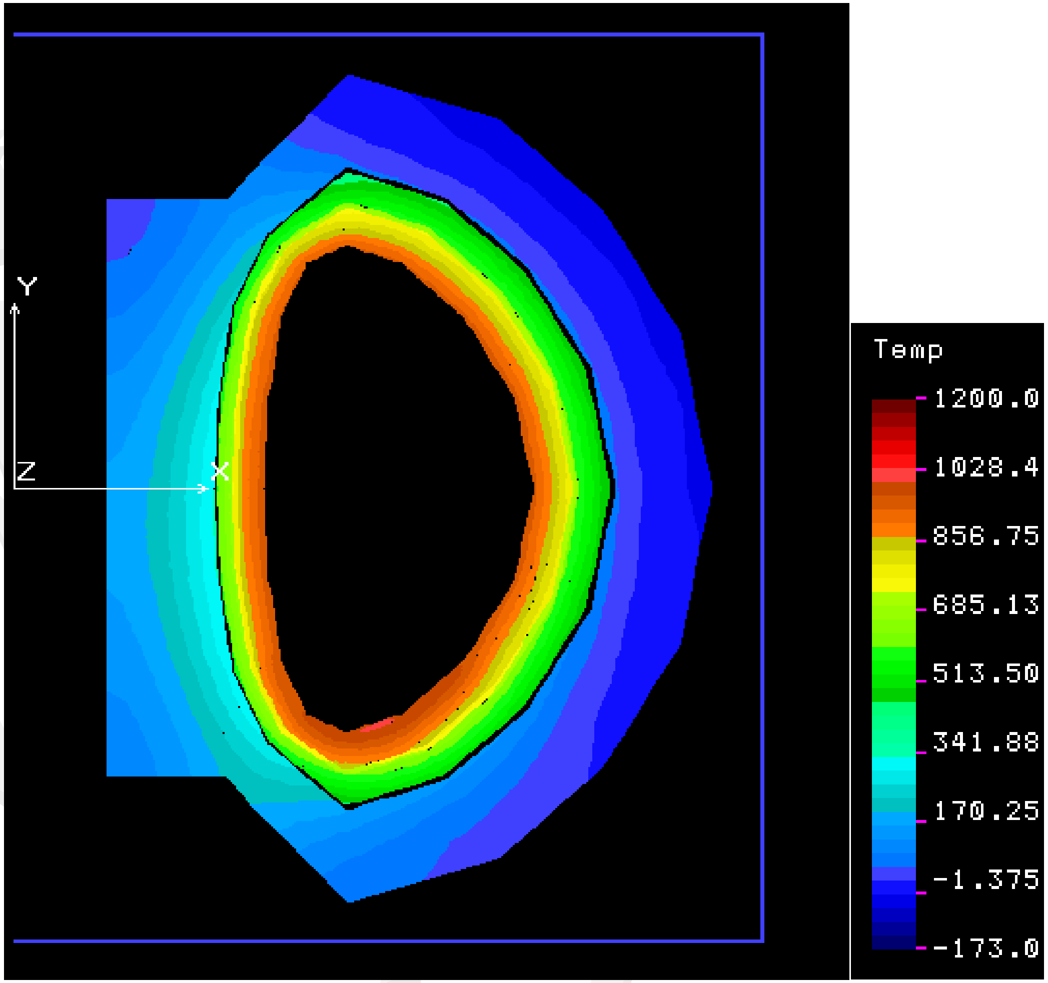
Given that:

- The designs satisfy economic objectives;
- The plasma physics basis is new;
  and so the parameters are substantially different than in earlier European studies:

- Do the good safety and environmental features still hold?

Bounding accident

- **Worst case accident analysis: complete unmitigated loss of cooling; no safety systems operation; conservative modelling.**
- **Temperature transients: example opposite - Model A after ten days.**
- **<u>Maximum temperatures never approach structural degradation.</u>**



Bounding accident: maximum doses

The calculation continues with:

- **Mobilisation; transport within the plant; release and transport in environment; leading to:**

CONSERVATIVELY CALCULATED WORST CASE DOSES FROM WORST CASE ACCIDENTS

MODEL A: 1.2 mSv

MODEL B: 18.1 mSv

- **Comparable with typical annual doses from natural background.**

- **Model C and Model D worst case doses expected to be lower.**

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Detailed accident analyses

- Accident sequence identification studies
- Detailed modelling of selected sequences.
- Shows much lower doses than for the (already low) bounding accident analyses.

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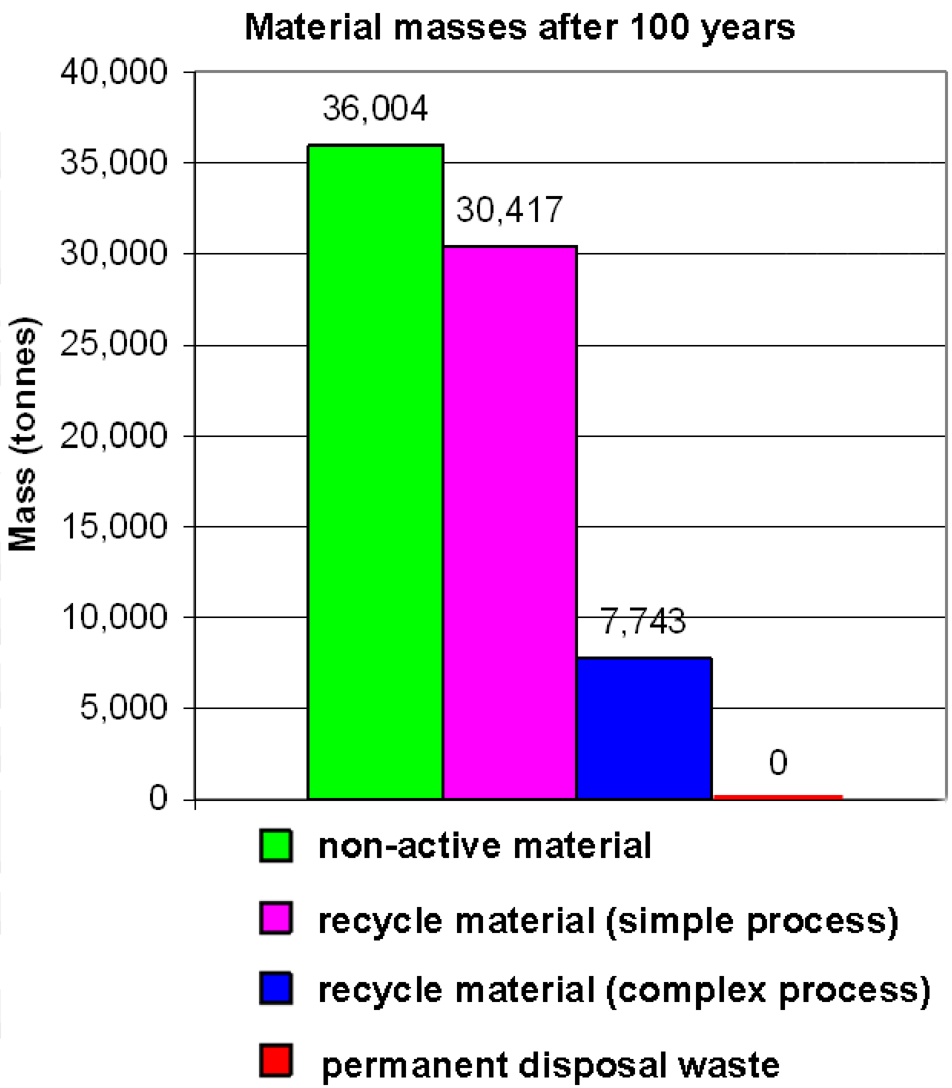
Disposition of activated materials

For ALL the Models:

- **Activation falls rapidly: by a factor 10,000 after a hundred years.**
- **No waste for permanent repository disposal.**
- **No long-term waste burden on future generations.**



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Overall summary

- **Near-term Models have acceptable economics.**

- **All Models have very good safety and environmental impact, and established with greater confidence.**

- **Studies suggest helium-cooled lithium-lead is probably a very promising additional Model, from the safety, environmental and economic viewpoints.**

Conclusions

PPCS shows that:

- **Economically acceptable fusion power plants, with major safety and environmental advantages, are accessible by a "fast-track" development of fusion, through ITER without major materials advances.**

- **There is potential for a more advanced second generation of power plants.**