The Status of ITER;
The ITER Design Review

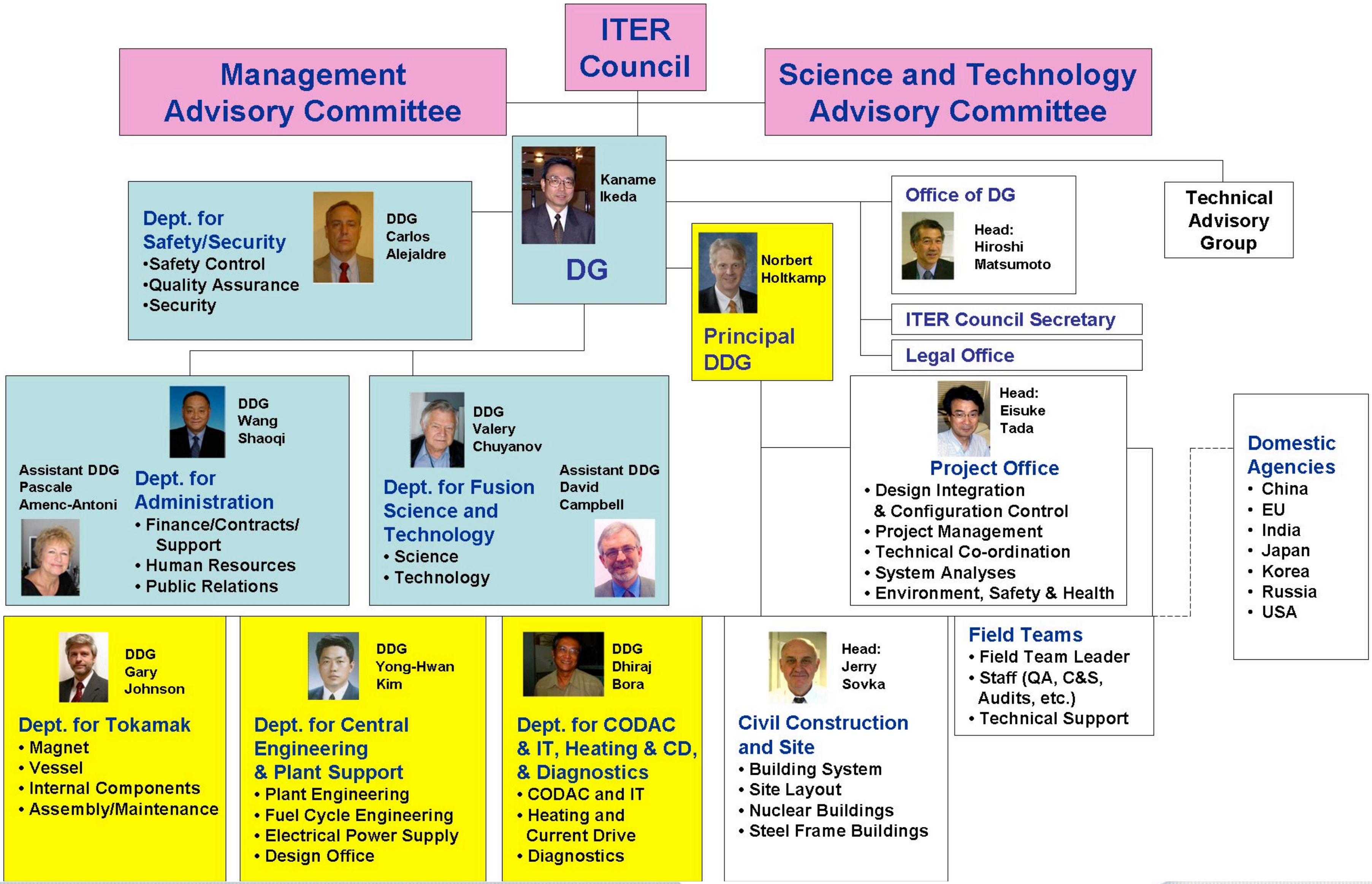
Town Hall Meeting on ITER – APS Conference
Orlando 13th November 2007

ITER Design Review Coordinator
G. Janeschitz

Outline

- ITER Organization and Status
- Scope and Goals of the Design Review
- How was the design review performed
- Some examples of the most important issues and their solutions
- Outlook

Management Structure of the ITER Organization



ITER Agreement, Recruitment and Consultants

- **ITER Agreements entered into force on 24 October, 2007.**

- Headquarters Agreement has been signed between the IO and the state of France on 7 November, 2007.

- **ITER-Organisation Staffing:**
  - As of October 31, the IO has a total of 194 staff
  - **153 professionals**
  - **41 support staff**
  - Around 65 persons on site under service contracts

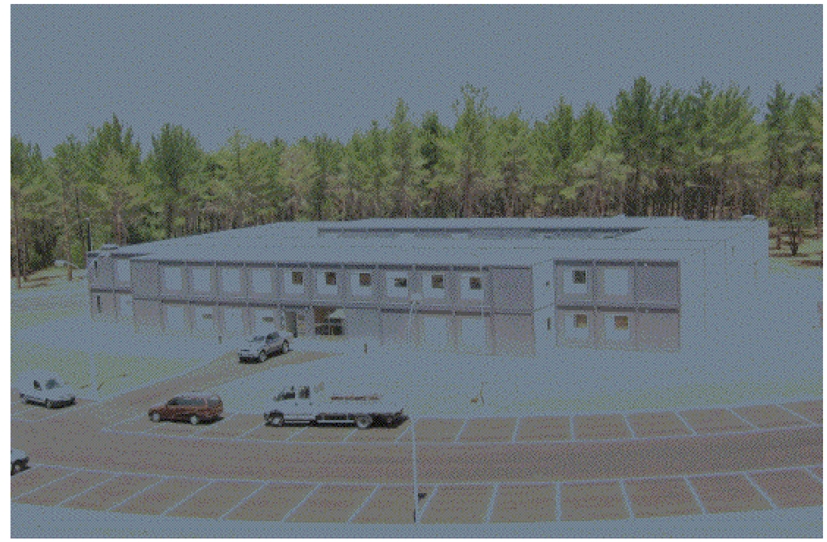
- **Total of about 260 persons at the site in Cadarache**

Temporary ITER Offices

ITER Dungeon

Extension Bureau: completed in March, occupied by 75

Building 507: made available by CEA Fusion, occupied by 38



Building 519: occupied by ~ 150 (designed for 140 – 150)

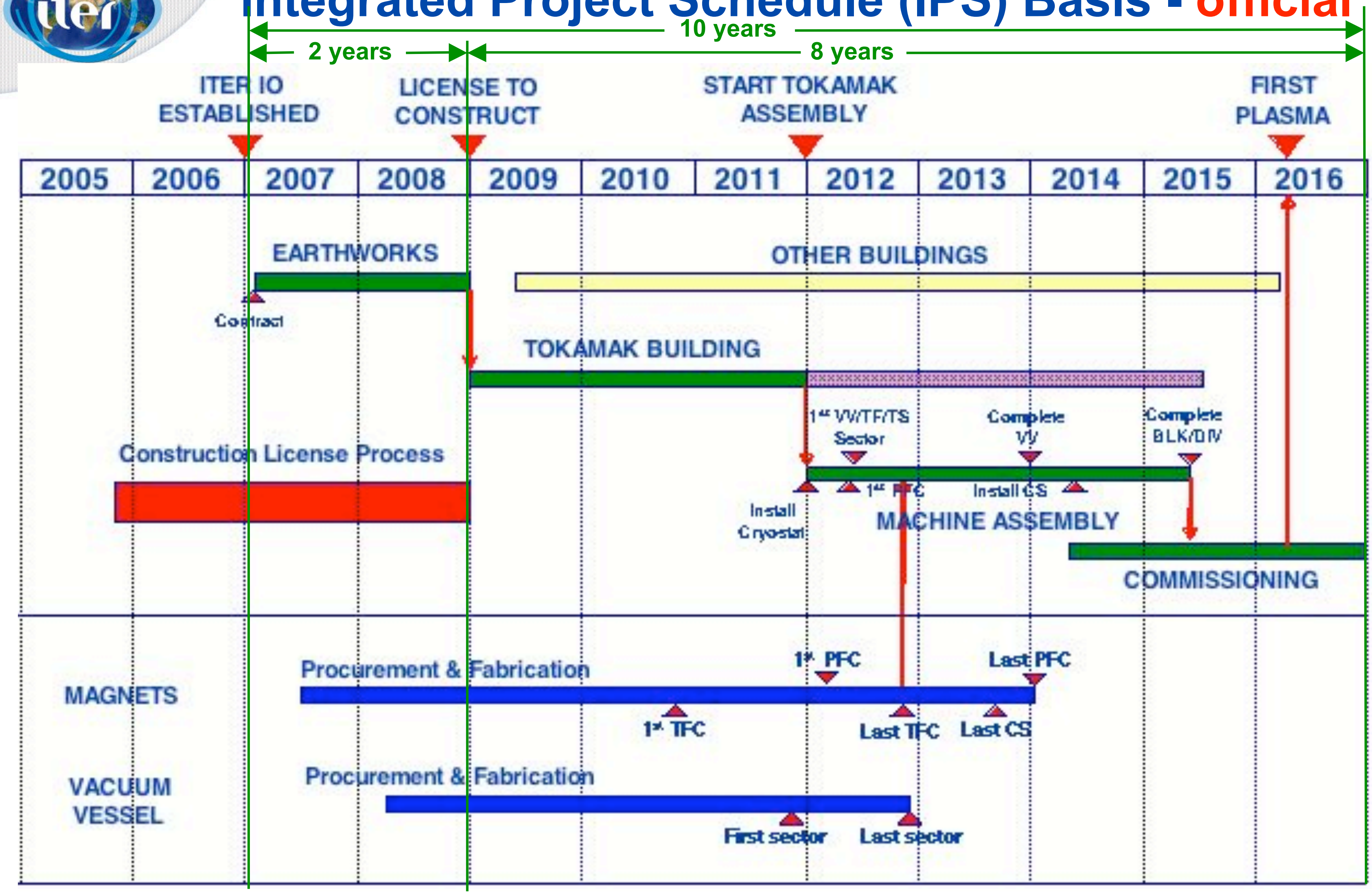
Presently available maximum capacity
150 + 38 + 75 = 263

Roles and Responsibilities for Construction

All domestic agencies will be established latest end of 2007

ITER Organization	Seven Parties
Strong collaboration and know-how transfer between IO and DAs required	
➢ Planning / Design ⟷	➢ Detailing / Designing
➢ Integration / QA / Safety / Licensing / Schedule ⟷	➢ Procuring / QA –exec.
➢ Installation	➢ Delivering
➢ Testing + Commissioning	➢ Supporting installation
➢ Operation	➢ Conformance

Integrated Project Schedule (IPS) Basis - official



Preliminary bottom up schedule suggests up to 3 years delay – work ongoing to bring it as much as possible in line with official schedule

The ITER Design Review

Goals Methodology and Statistics

The Design Review: 2001-2006 History

- 1998 to 2006 (EDA, CDA and ITA) History
  - 1999 to 2000 three options studied (LAM, IAM, HAM)
  - 2000 to 2001 only one year for detailed design of IAM
  - 2001 to 2005 ~ 35 larger design changes recorded but not approved because there was no body to this
  - 200 issues with the design were registered by the ITER team during the above time and not solved until 2006

- **Negotiations were undertaken on the basis of the 2001 design/baseline/cost.**

- **An intermediate baseline (2004) was submitted but never formally accepted, but this intermediate baseline was the basis of the design review which took place this year**

Goals of the Design Review (1)

- **The first goal** for 2007 was to create a new Baseline Design 2007 which
  - confirms or redefines the physics basis and requirements for the project
  - is the basis for the procurement of the long lead items (Vacuum Vessel, Magnets, Buildings),
  - provides input for the Preliminary Safety Report

- For components and systems which are procured at a later date or for issues with lower priority work will continue into the year 2008

Goals of the Design Review (2)

- **The second goal** was to base the ITER design decisions also in detail on a broad basis by involving the worldwide fusion community (physics and engineering)
  - Thus the Fusion community and the parties can take ownership of the project

- **The third goal** was to broaden the knowledge basis into the parties which is essential for a successful procurement of the ITER components in kind
  - A significant part of the technical coaching of industry and of the QA will rest with the Domestic Agencies (DAs)

Design Review was performed by 8 Working Groups ~150 members

WG-1 Design Reqs. & Physics Objectives.
Chair: P.Thomas; IO D.Campbell

WG-2 Safety and Licensing
Chair: J-P Perves; IO J-P.Girard

WG-3 Site and Buildings
Chair: C.Strawbridge; IO J.Sovka

WG-4 Magnets
Chair: M.Huguet; IO N.Mitchell

WG-5 Vacuum Vessel
Chair: Songtao Wu; IO K.Ioki

WG-6 Heating and Current Drive
Chair: J.Jacquinot; IO A.Tanga

WG-7 Tritium Plant
Chair: D.Murdoch; IO M.Glugla

WG-8 In-Vessel Components
Chair: Igor Mazul; IO M.Pick/C.Lowry

The membership consists of the leading experts of the fusion community in each party

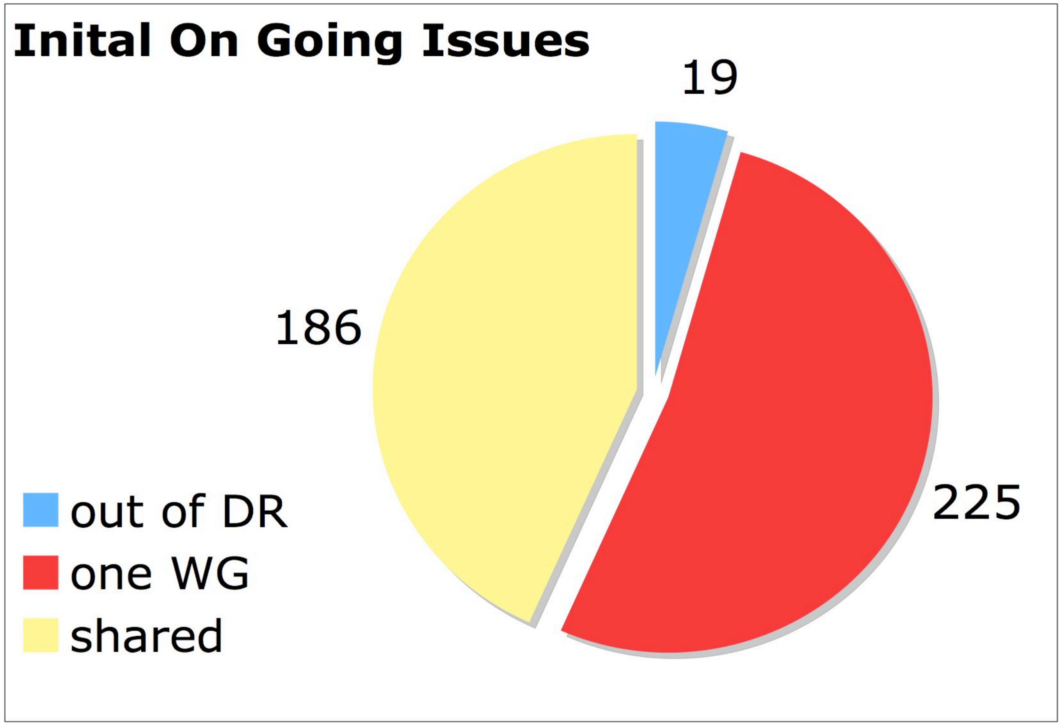
The groups have written manifestos explaining the scope of their work (see ITER technical web)

In order to solve issues work packages have been agreed with the parties based on the work plans established by the design review working groups

=> adding ~ 160 more persons

ITER Issues

(Link: ITER Issues Data Base)



~ 200 issues existed for several years but were for different reasons not solved or rejected

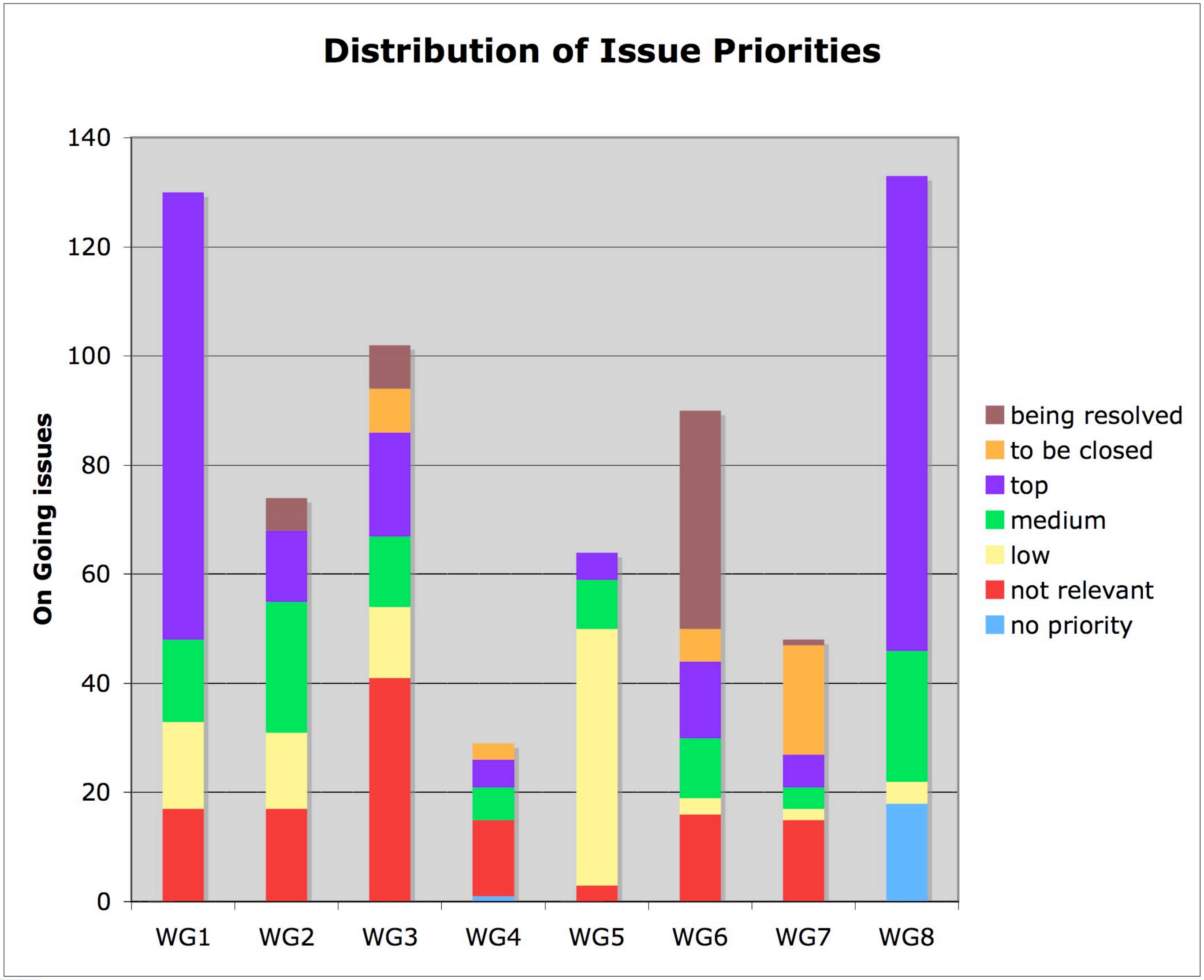
Another ~ 250 were added by the parties last autumn when the design review process started

Thus ~ 450 issue cards existed when the design review working groups were formed in December of 2006 and started their work

186 issues require consideration by more than one group

Issues have been prioritized

Distribution of Issue Priorities



The dark blue issues are the high priority ones

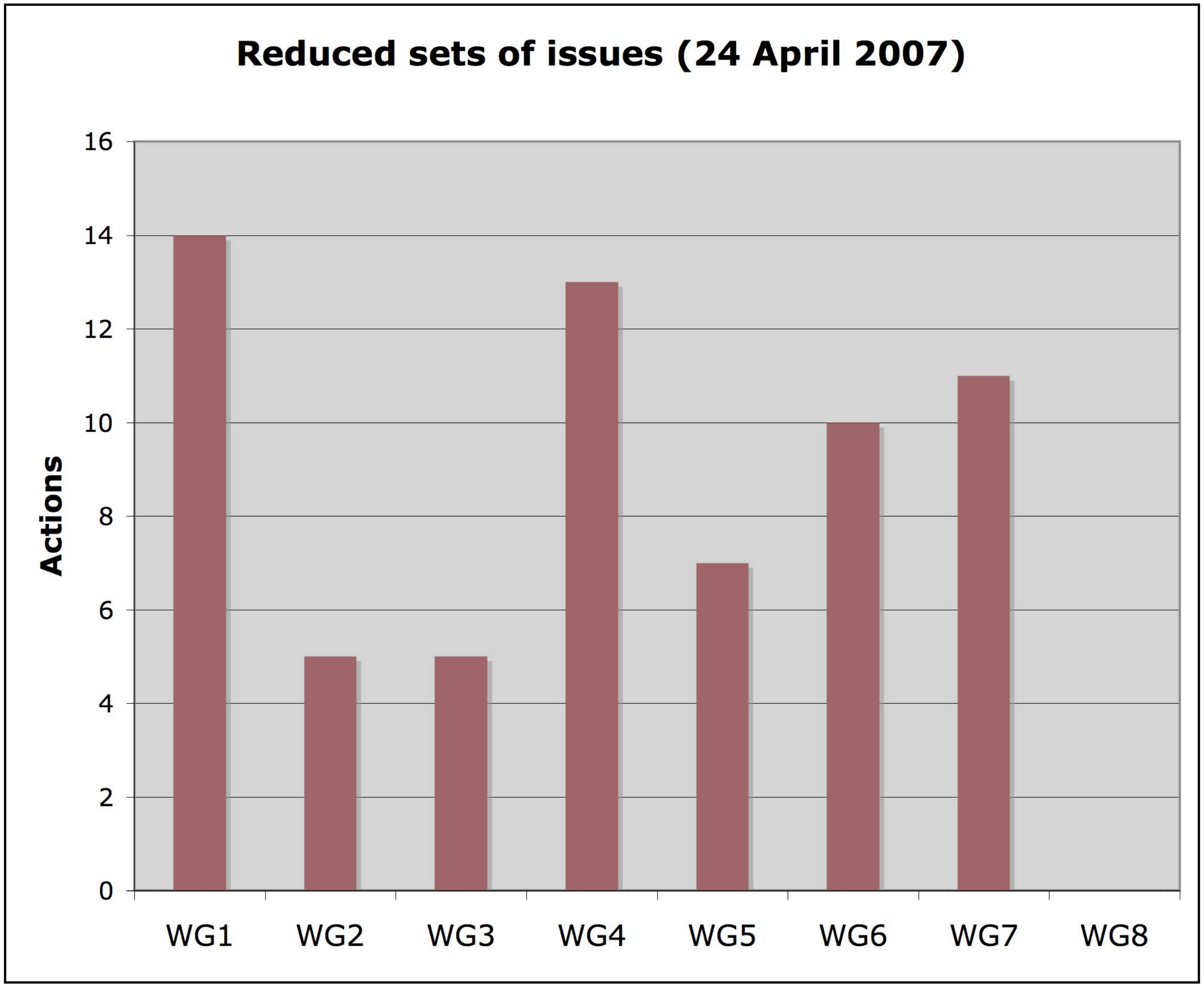
They and the medium priority issues had to be solved until autumn 2007 as a minimum

in order to allow the procurement of the long lead items to go ahead as scheduled

and in order to be able to launch the preliminary safety report in time

We achieved more than that !!

Further Condensation of (High) Priority Issues



The high priority issues, the medium and some low priority issues have been condensed into fewer issue families covering the same range of problems

Thus ~ 80 issue families remained to be tackled

e.g. in Physics ~ 80 issues were condensed into 14

Resources and Interfaces between WGs

Resources:

- The working groups have established work plans with the aim to solve all 80 high priority issue families by September 2007 and to document together with the IO the resulting design in the Baseline 2007 (November)

- **The extra PT resources required for 2007 were 82.4 PMY distributed over the 7 parties**

Interface meetings:

- Approximately every 4 to 5 weeks interface meetings between the DRC, the chairmen, the ITER co-chairmen of the WGs and a few specialists took place either in person or by phone / video conference

- **These meetings have proven to be extremely useful and productive and were essential for a successful progress of the design review process**

Timeline for Implementation of the Baseline

- Two meetings at technical level with Members to discuss DR recommendations followed by TCM (25 and 26)
  - July 16-19 DONE
  - Sept 17-20 DONE

- STAC, TAG, MAC+STAC to discuss officially with the Members
  - STAC: Sept 5-6 DONE
  - TAG: Oct 3-5 DONE
  - MAC+STAC: Nov 5-8 DONE
    - **a few DCRs rejected by IO to be reexamined**
  - CPWG: Nov 8-9 DONE

- Council meeting: Nov 27-28

From Decision making to ITER- Baseline

- DCRs have been mostly adopted for study ("ongoing") at the decision making meetings and thus enter the normal ITER design change process.

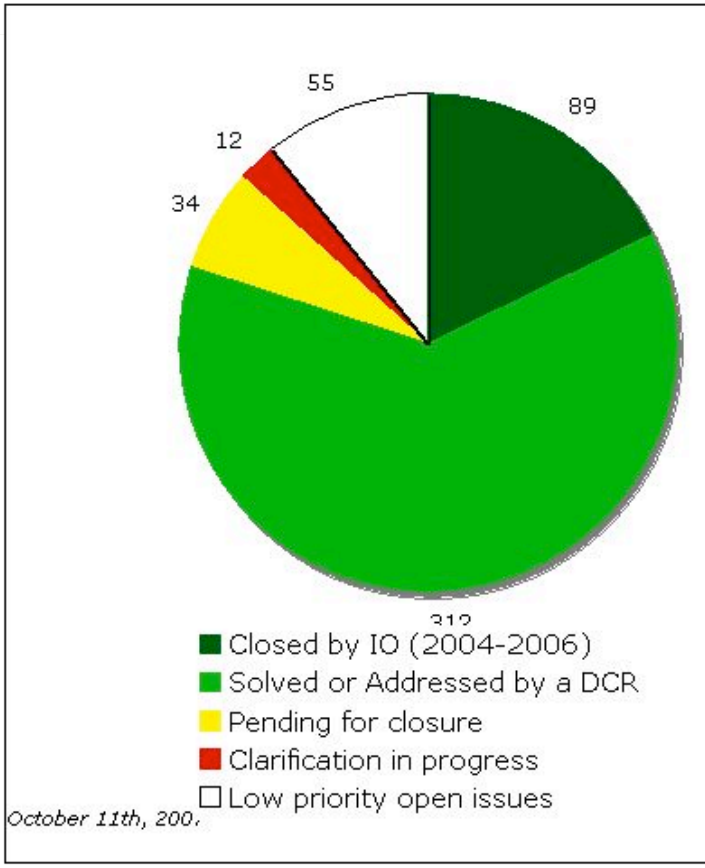
- As soon as a design is mature enough (feasibility demonstrated, requirements fulfilled, it is a significant improvement on the existing design) it will be adopted into the baseline while detailed work will continue

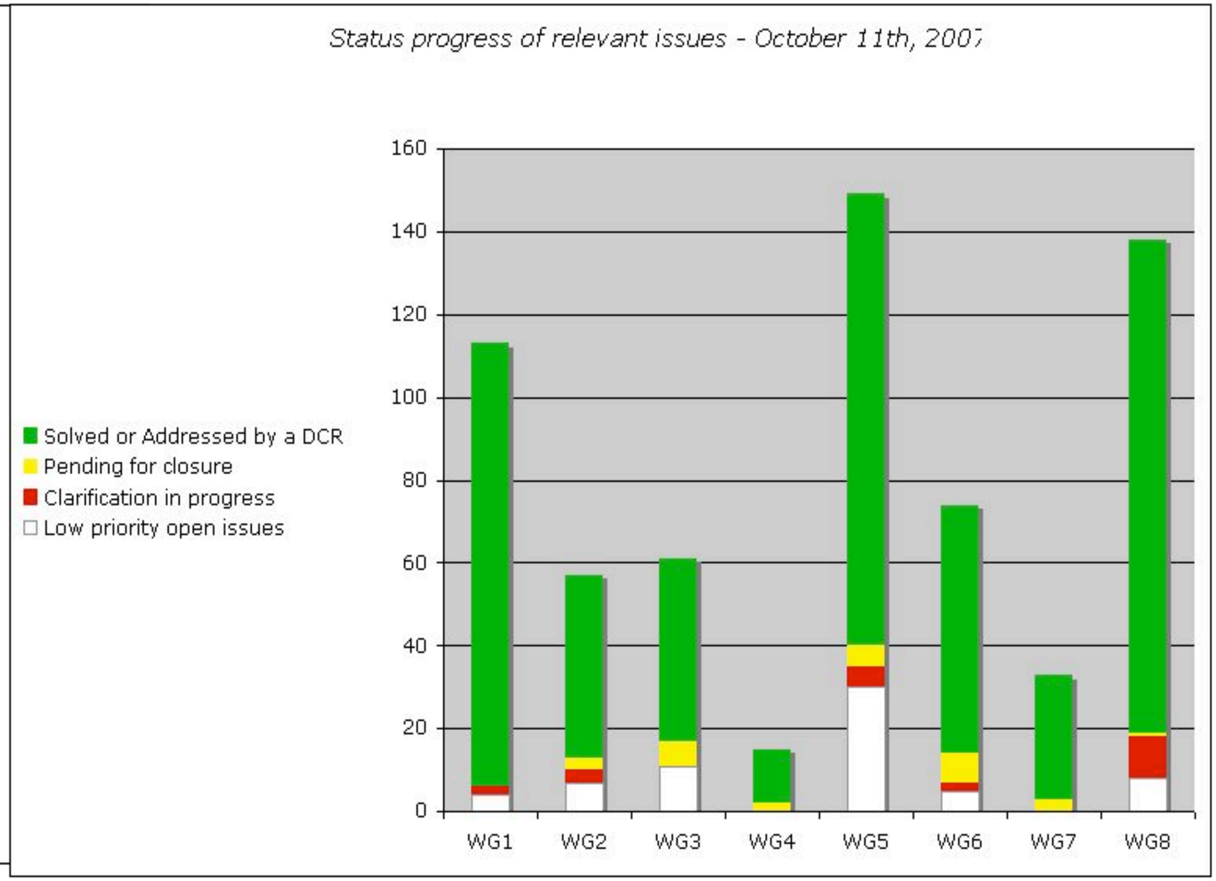
- **All high priority items will thus be part of the new baseline 2007**

  - **All DCRs "ongoing" are cited in the 2007 baseline**

  - **After STAC a few rejected DCRs re-opened for study**

Issues Data Base after the Design Review





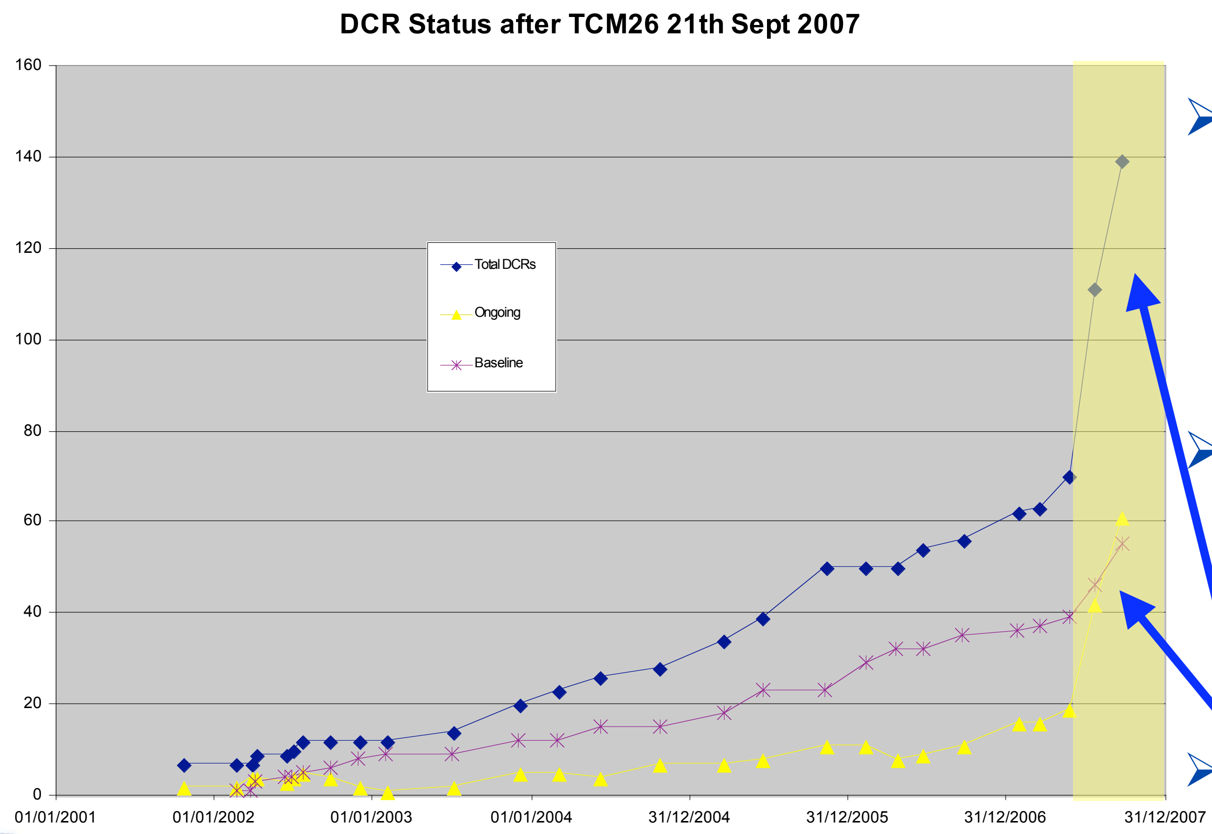
More than 400 Issues have now been closed, dropped or are covered in a DCR

About 67 Issues will still be "ongoing" at the end of 2007, and will be handled during the next years

All important issues are on the way to be solved (including the ones which were contained in a rejected DCR and now have been re-opened by STAC)

Status of DCRs

- The ITER DCR system tracks all baseline design changes from the FDR-2001
- Currently (after TCM-26) it holds 139 DCRs.
  - (4 in "Draft", 61 "Ongoing" (for study), 28 accepted, 27 Completed, 19 Dropped)

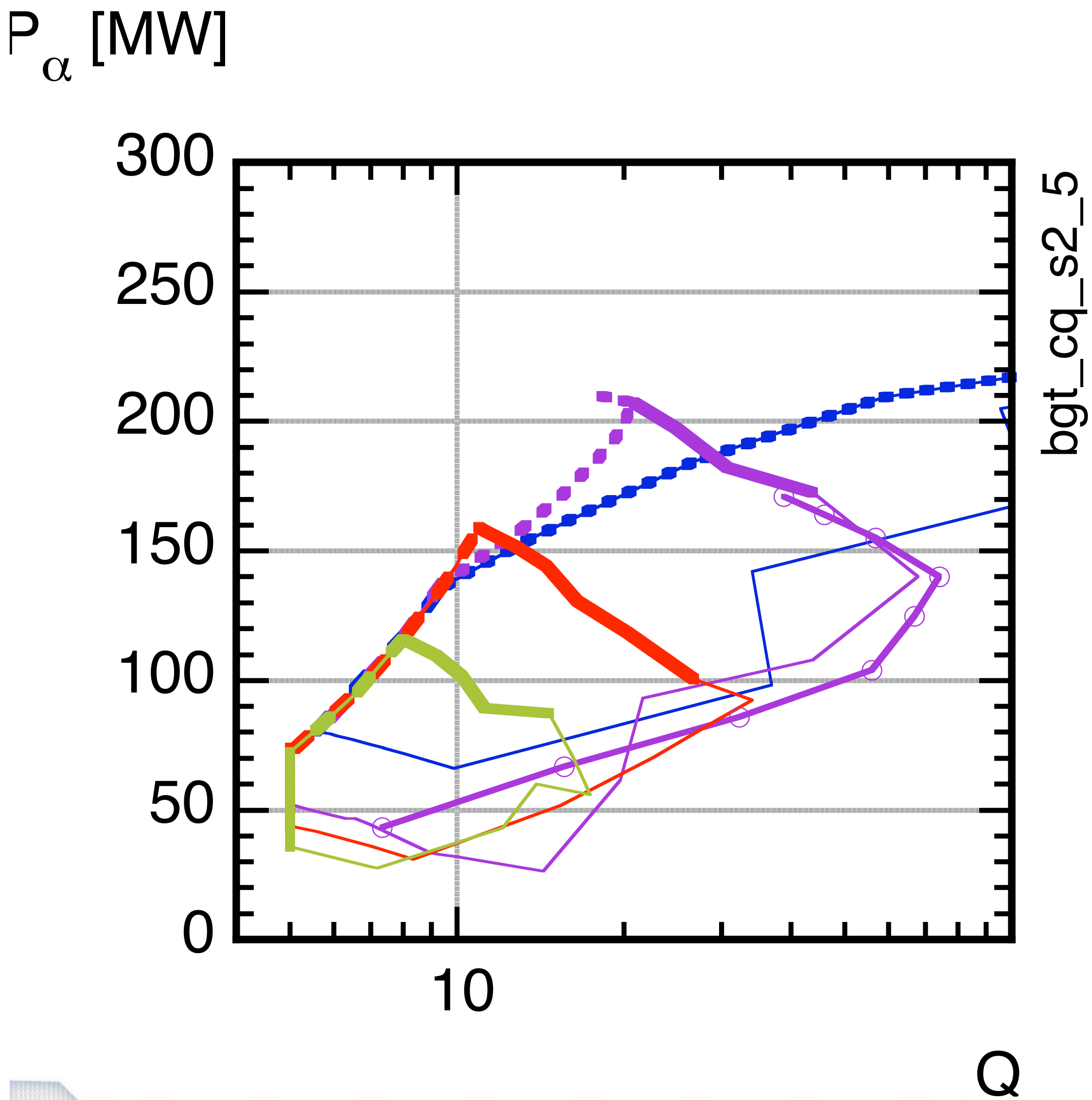


- Completed DCRs will be incorporated in 2007 baseline
- Ongoing DCRs will be cited in the 2007 baseline as "in study"
- Design Review impact

The ITER Design Review Results

- The most important Issues and their Solutions
  - The corresponding DCRs were accepted by IO for study or re-introduced by STAC last week
- All high risk items for ITER are now under study and proper solutions will most likely be implemented

Sensitivity of performance on ITER machine parameters: B_T, elongation, etc



- Operation diagram for ITER calculated with integrated model ICPS
- Core model is MMM – more optimistic than GLF23
- Blue dashed line represents impact of low rotation, purple line full parameters, red 95% B_T or elongation 1.6 instead of 1.7 at 100% B_T, green 90% B_T

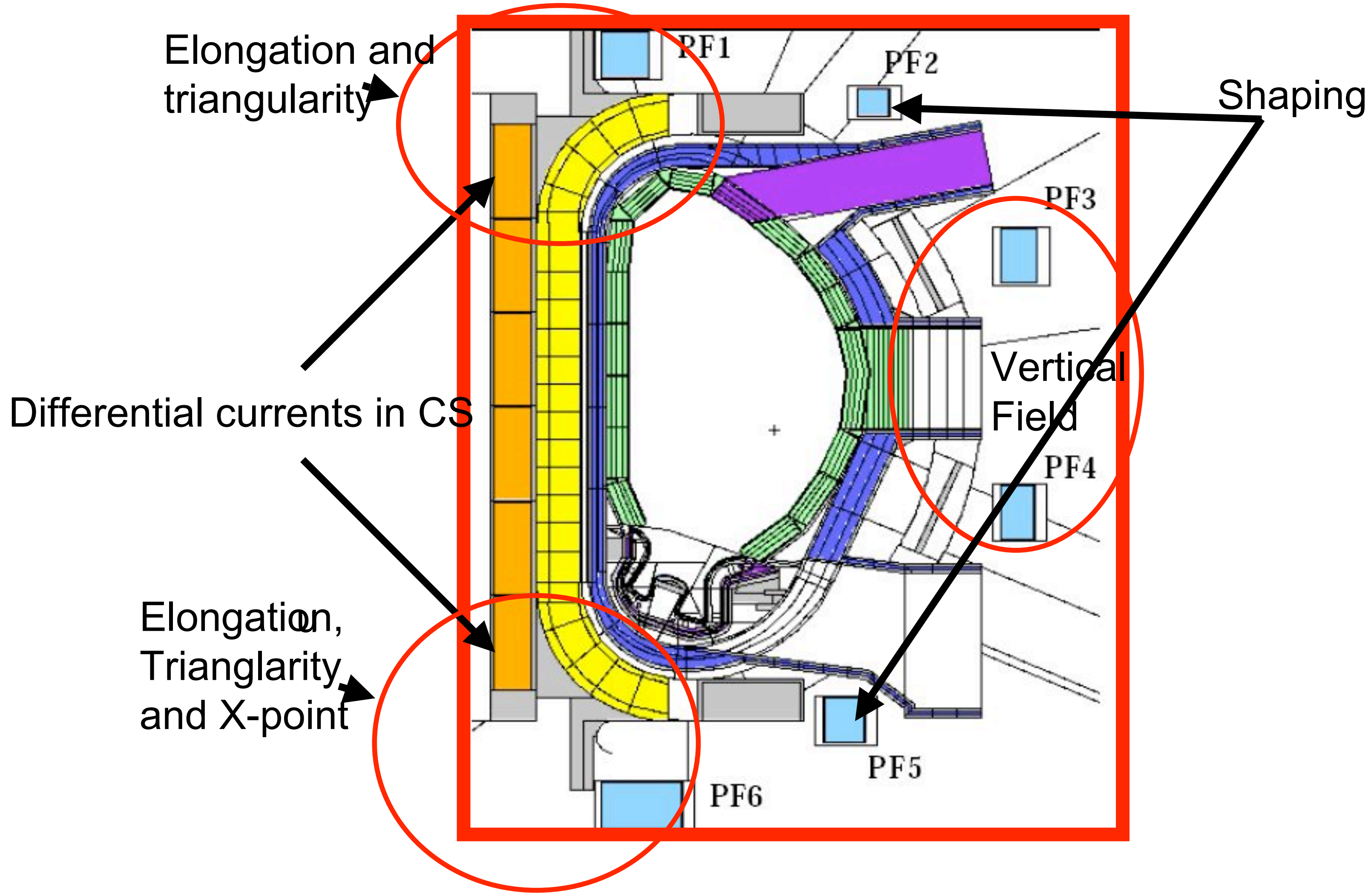
- **To achieve the goals of ITER routine operation at the design parameters (5.3 T; 15 MA) is essential – not standard on todays machines!**

Main Problems in Plasma Control area

- PF system is marginal, in particular for low l_i
  - saturation of some coils in parts of the discharge
  - e.g. early X-point formation difficult, etc
- Vertical Stability is marginal above $l_i = 1$
- CS flux swing is marginal / too low if $l_i > 1$
- ELM control is essential – RMP coil set needed
- Proposals to improve the situation are on the table and were either already accepted for study by the IO or re-introduced by STAC

Shape Control

The ITER PF system



Scenario requirements (minimum l_i)

In the case of PF6 made of NbTi, in 15 MA scenario:

- operation with $l_i < 0.8$ hits the limit on magnetic field on PF6 (5.9 T) and operation with $l_i < 0.75$ hits the limit on current in PF2 (44 kA).
- operation with $l_i < 0.75 - 0.8$ requires more difficult plasma shape feedback control (control of 7 plasma-wall gaps, instead of 6 gaps, without using of PF6 and PF2).

In the case of PF6 made of Nb_3Sn, in 15 MA scenario:

- operation with $l_i < 0.75$ hits the limit on current in PF6 (49 kA) and operation with $l_i < 0.65$ hits the limit on current in PF2 (44 kA).
- operation with $l_i < 0.65 - 0.75$ requires more difficult plasma shape feedback control (control of 7 plasma-wall gaps, instead of 6 gaps, without using of PF6 and PF2).

H.Fujieda

Shape Control - required improvements

- Change conductor in PF6 to **Nb_3Sn, => up to 20% increase of current possible**

- Increase capability of PF2 and PF5 by 10% by adding winding packs

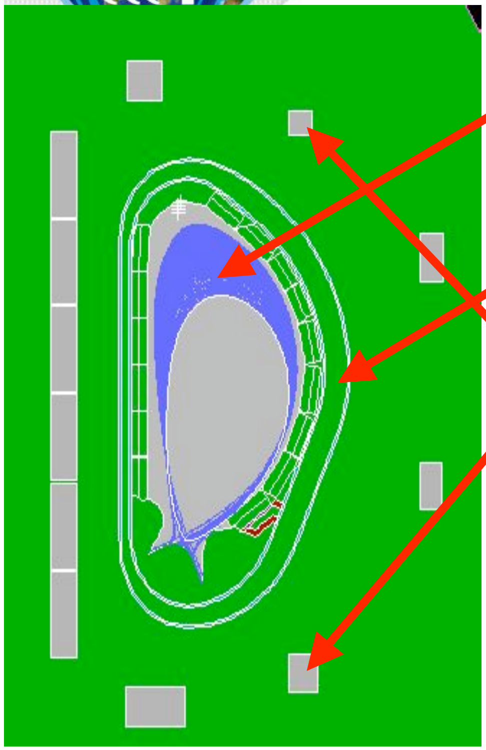
- *The total cost of these changes would amount to ~ 8.4 M€ - estimate of EU team – supported by ITER magnet division*

- *IO did not agree to these changes, wants to sub cool to 3.8 K*

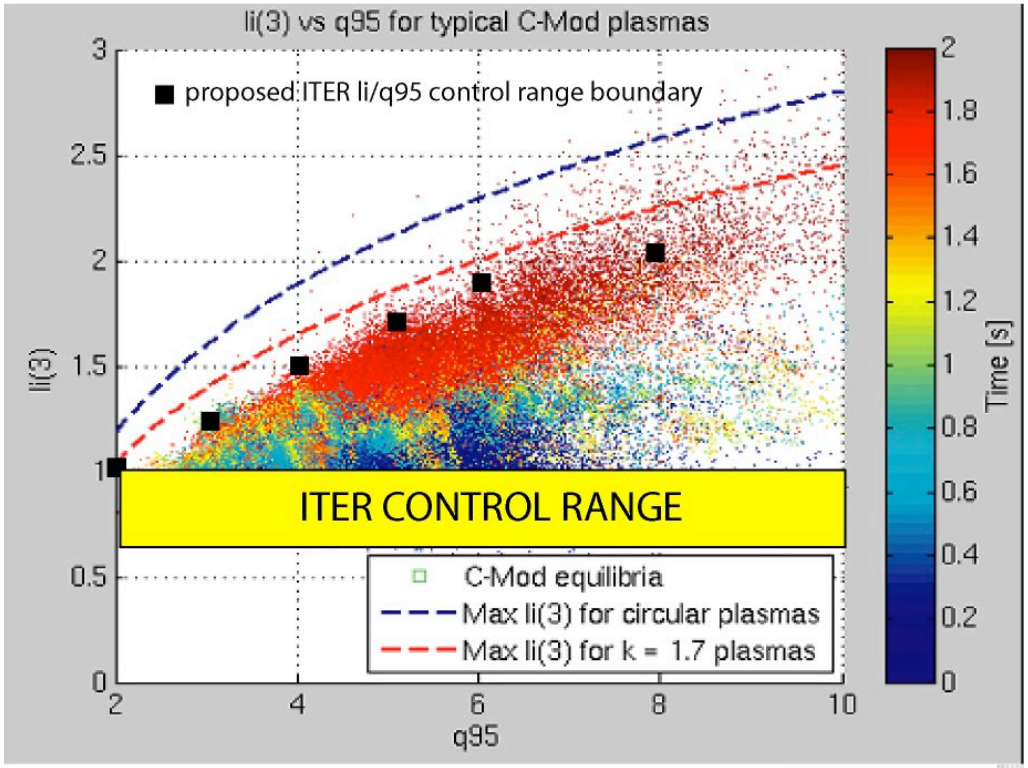
- *However, sub-cooling was foreseen as mitigation of a coil failure*

- **STAC asks for change => study by risk assessment group**

Vertical Stability



- High elongation ~ 1.85 (1.7 in "Big ITER")
- Thick *double-walled* vacuum vessel
- Saturation of P2 and P5 in certain conditions

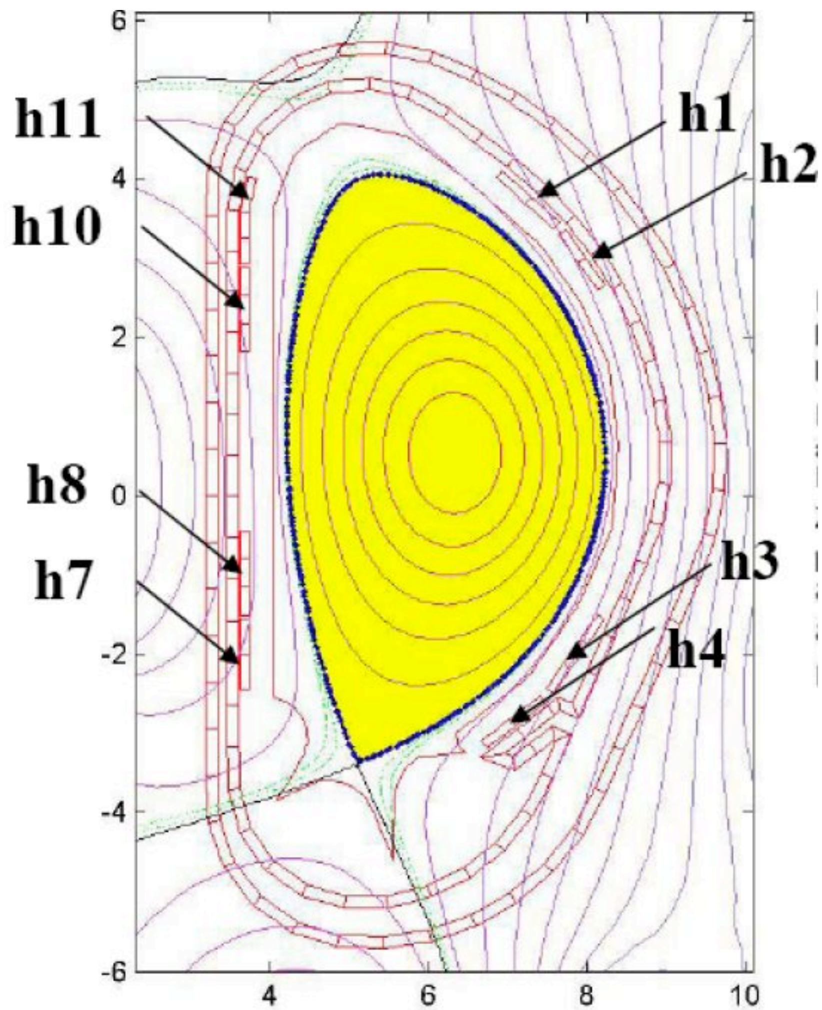


- **The range of *li*(3) between 0.7 and 1.0 has been specified for the design of the ITER PF system**
- **There is a problem with vertical stability in most discharge phases but they are gravest in Ip ramp-up and ramp-down (high l_i)**

Solution: Improve Passive Stabilization

Connection of toroidal rings of blanket modules provides improved passive stability characteristics:

	Stability margin (CREATE)	Stability margin (EFDA)	Growth rate (ms)	M_φ	BAP (mm)
No blanket rings	0.27	0.37	68	3°	20.8
Blanket rings 1 & 5	0.31	0.43	94	9°	31.1
Blanket rings 2 & 4	0.33	0.44	98	11°	33.0
Blanket rings 7 & 11	0.28	0.38	75	7°	25.2
Blanket rings 8 & 10	0.29	0.39	79	9°	26.9
All blanket rings	0.39	0.52	150	22°	52.5



A Portone et al, September 2007

⇒ Studies of possible mechanisms for toroidal coupling of blanket modules

⇒ Analysis of disruption forces

⇒ Analysis of equilibrium/ control implications

⇒Option of increasing voltage in PF coils from 6 to 9kV rejected by IO

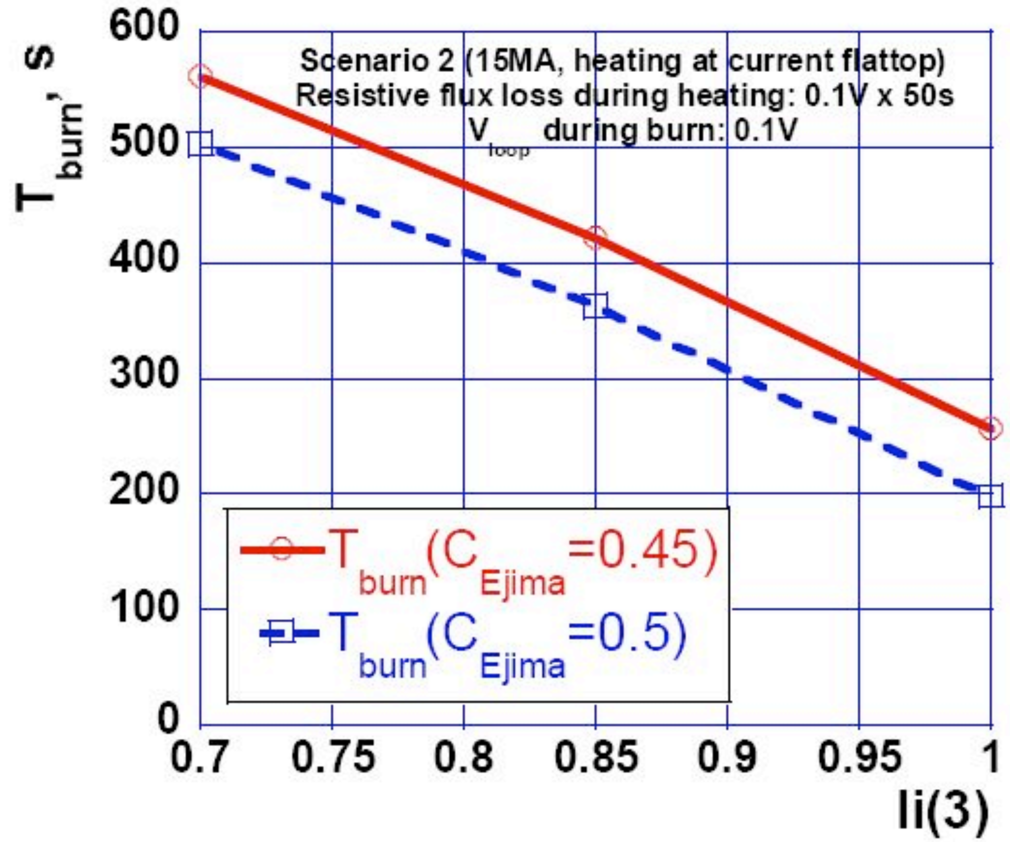
Flux Available for Burn in ITER

At high l_i during current ramp potentially no flux left for flat top

Difficult approach to ITER reference scenario

Possibly mitigation by increasing flux by ferromagnetic insert in the solenoid and by increasing resistivity in VV

Not yet studied by IO



Most likely solution is early X-point formation and possibly to heat the plasma during current rise => PF upgrade

Plasma Control related DCRs

- DCR requiring li-q space experienced in experiments was accepted
- DCRs to add 2nd VS circuit using CS and to increase the VS1 voltage to 9kV were dropped – STAC wants study !
- DCR for extra double-pancake to P2/P5 awaits the "Coil Risk Group" – STAC asks for studying upgrade !
- DCR for Increasing the PF6 capability (NbSn) awaits the "Coil Risk Group" – STAC asks for studying upgrade !
- No DCR for CS flux swing issue – not studied in IO
- **EU party asks for increased flux swing or provide current drive– improve PF6, PF2 & PF5 and keep subcooling as a back-up, in case of failure**

Expected ELMs and the Mitigation Problem

- **Permissible ITER ELMs**
  ~1%
  of the pedestal energy.

- **Expected not mitigated ELMs for ITER low collisionality plasma are**
  ~20%
  of the pedestal energy .

- **ELM Energy Reduction necessary by**
  ~10 to 20 times

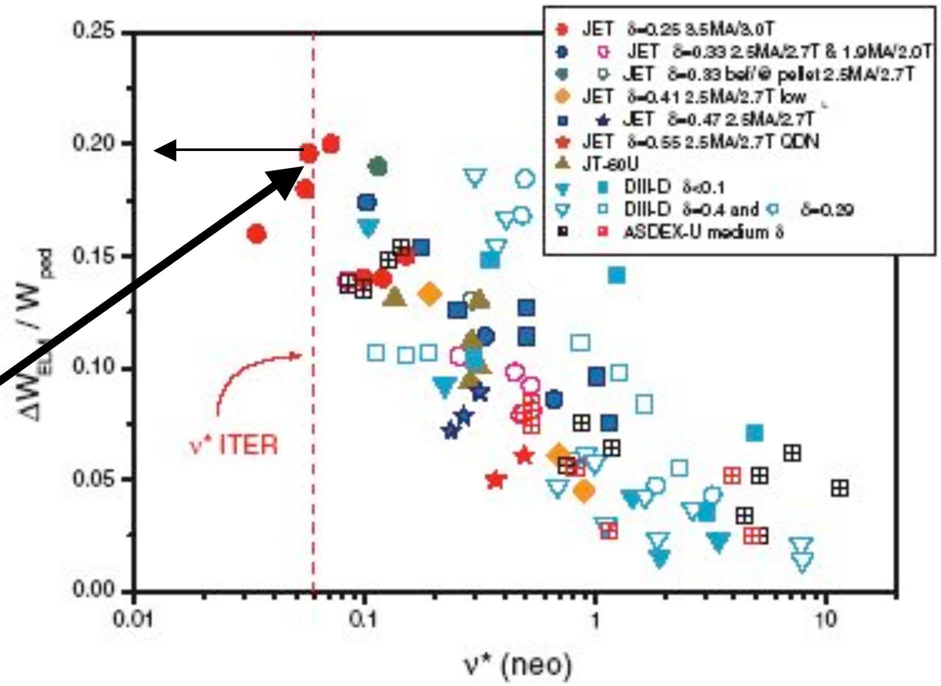
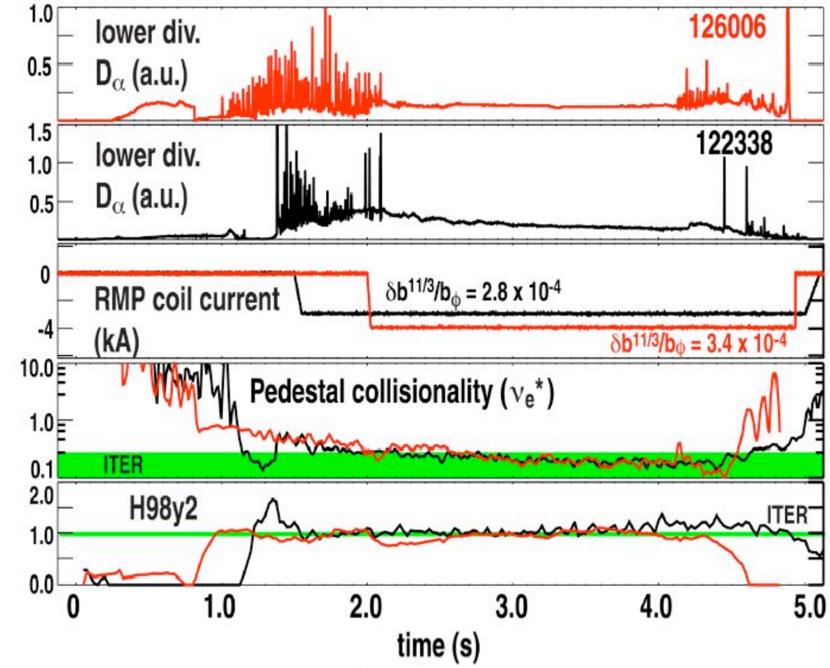
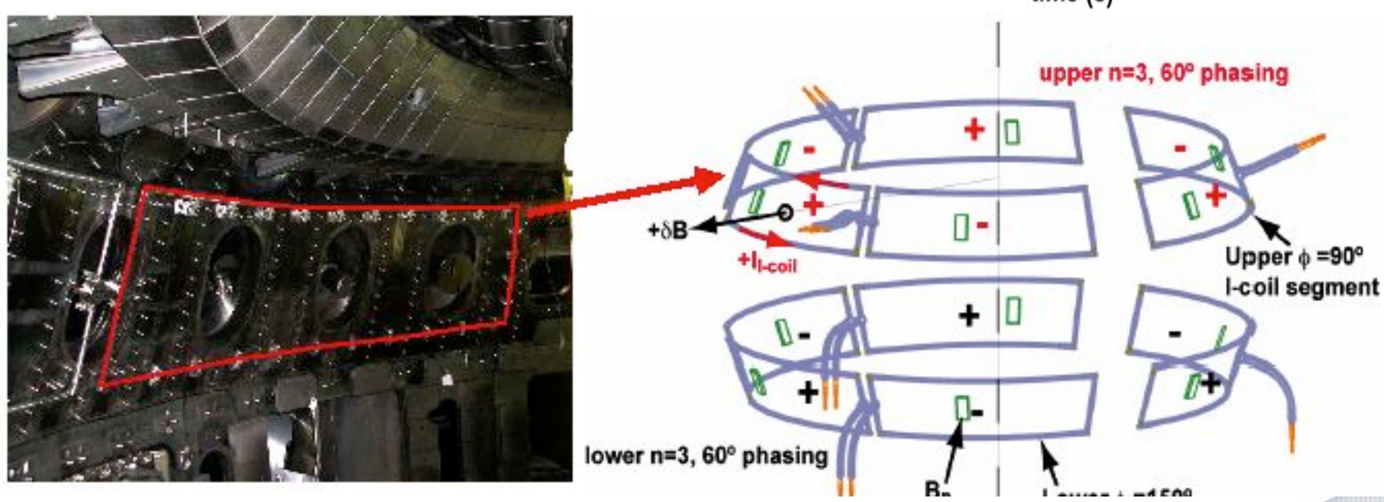


Figure 17. ELM energy normalized to the pedestal energy versus pedestal collisionality. The multi-machine data collected by the ITPA Divertor Group include density scans as well as varying configurations [166].

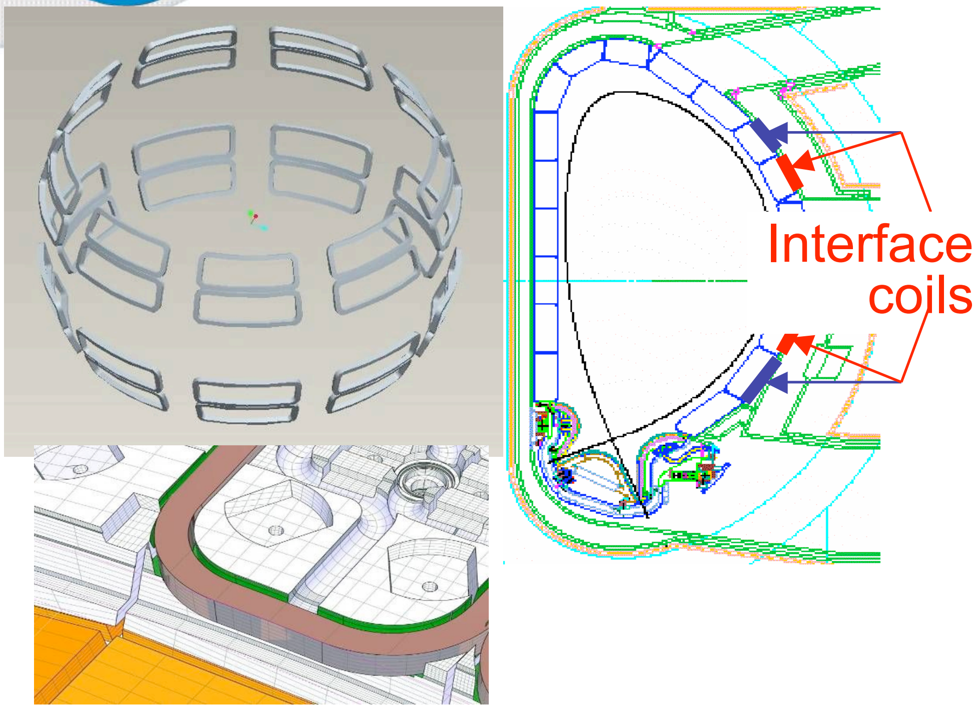
ELM suppression by ergodization

- Ergodization works for D3D (and JET).
- WG-1 has proposed to use a set of 36 Resonant Magnetic Perturbation coils similar to DIII-D

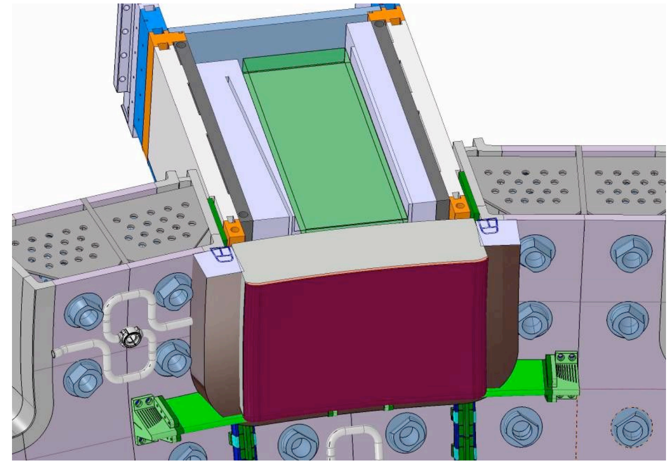




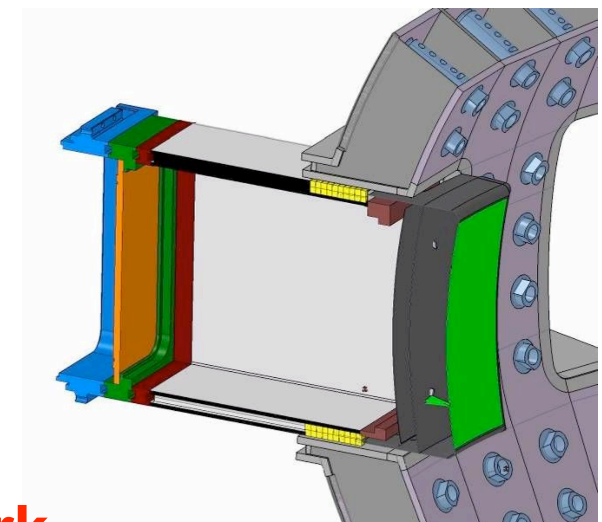
ELM Control Coils options studied



Blanket-Vessel Interface coils



Picture frame coils



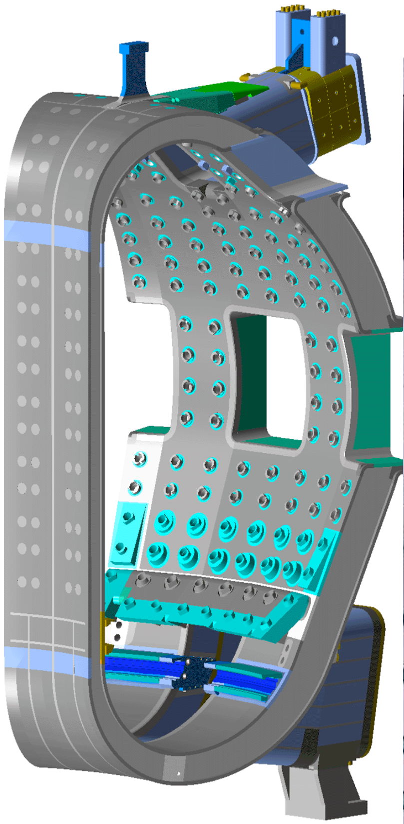
Port-plug coils

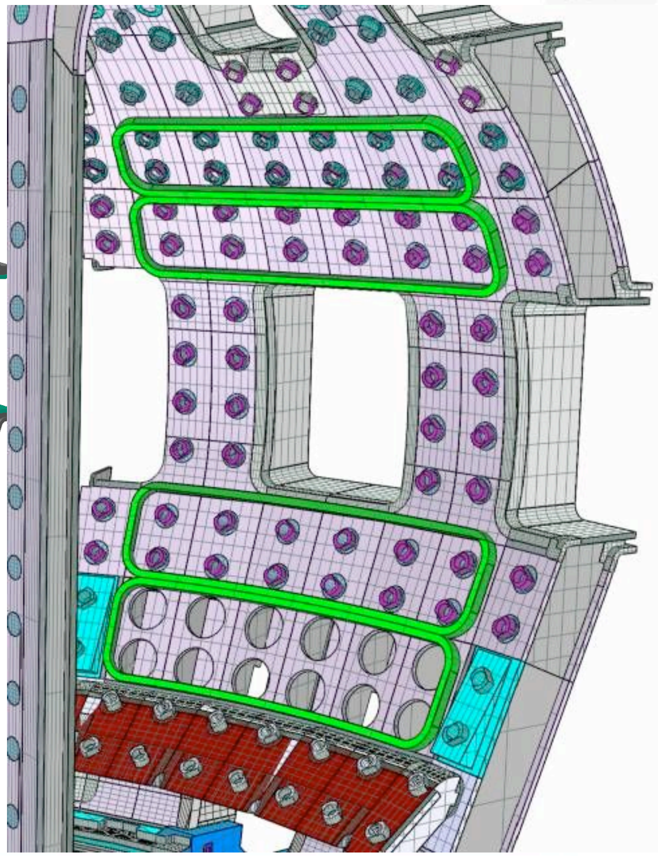
Three concepts studied by WG1and costed by IO

Only 36 coil option will most likely work change location to between VV shells

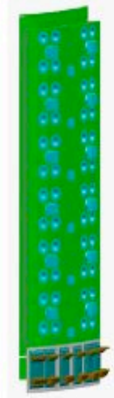
Vacuum Vessel – ELM coils between shells

STAC ask for this study until their next meeting

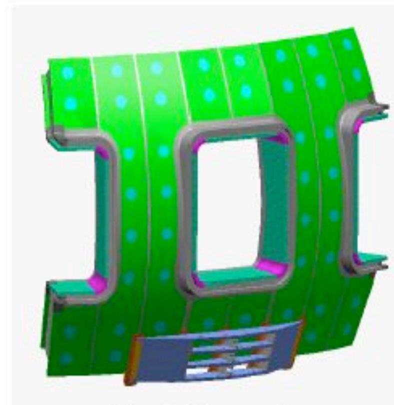




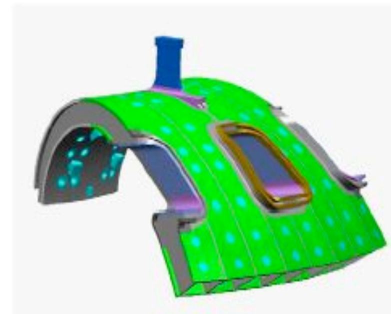
Inboard segment



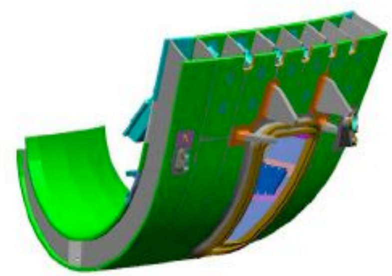
Equatorial segment



Upper segment



Lower segment



A working group (IO, EU, US, KO) will study this option

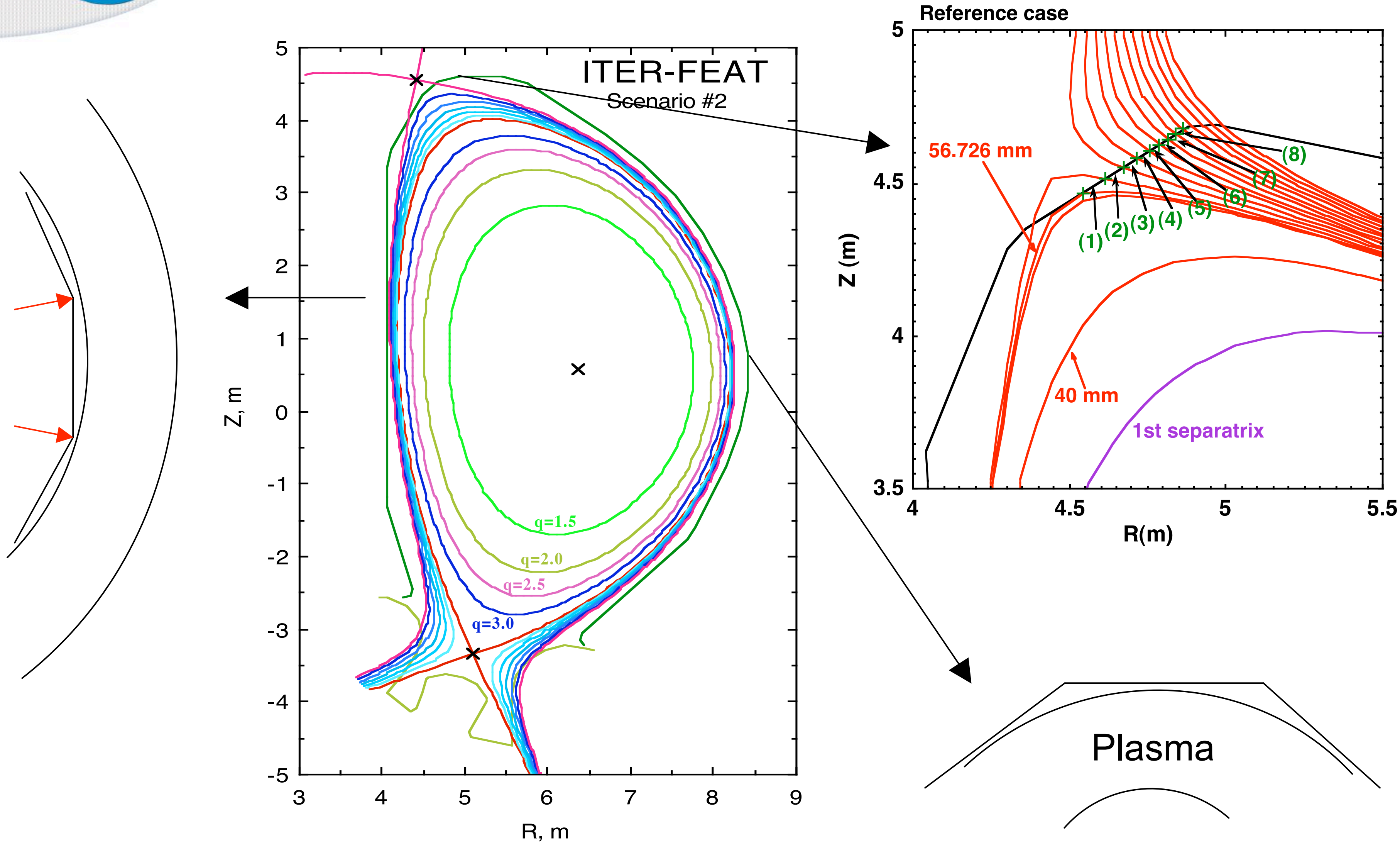
Conceptual design to be available until end of February

Then check schedule – cost- and safety impact

Main Problems in Blanket area

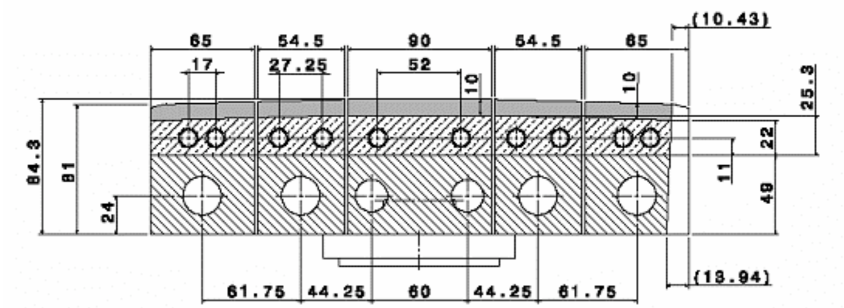
- Update of FW loading conditions require improvements of the FW geometry
  - Hiding leading edges
  - prepare for toroidal peaking factors – increased power loads
  - Possible plasma start up on FW – remove port limiters
- Provide electrical connectors in toroidal direction to improve vertical stability
  - In situ separable FW needed
- Improve RH water connector and review and improve RH approach
- Cooling water manifold is not RH compatible
  - Improve design or integrate the manifold into the blanket modules
- STAC emphasized strongly the RH issue

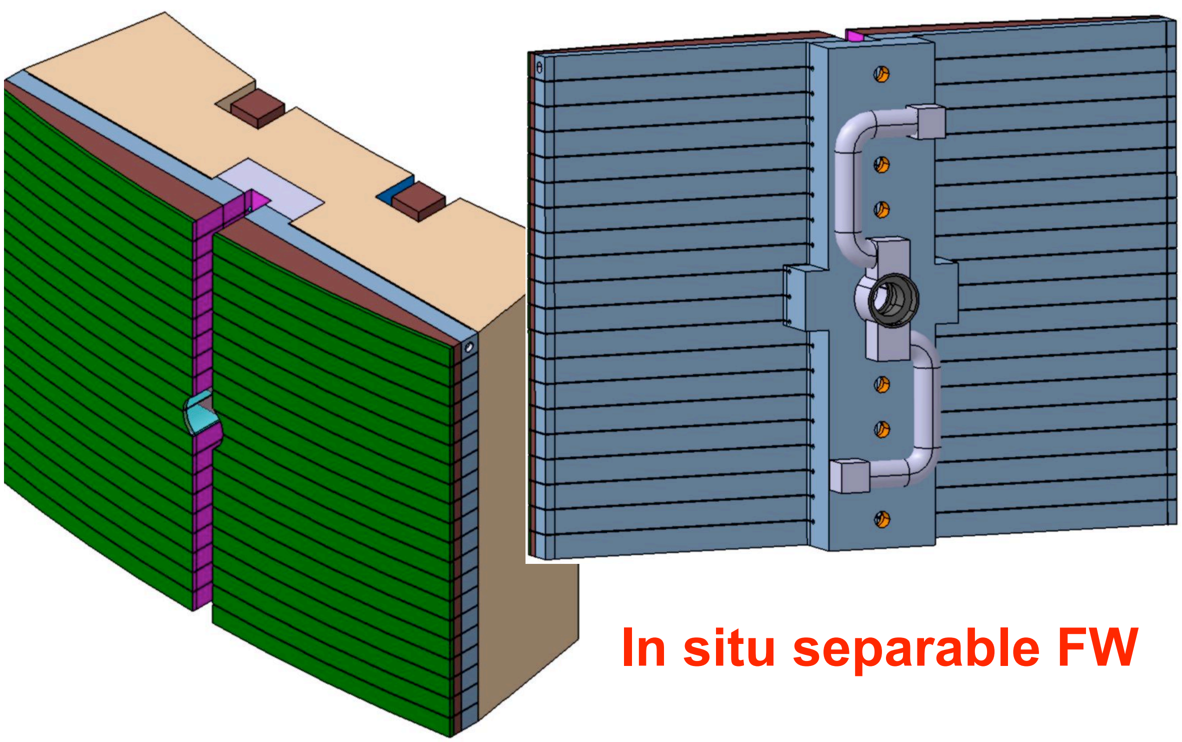
General Concept Differing Geometry around Wall



Detailed shaping of the First Wall to shadow all exposed edges

Inner Wall

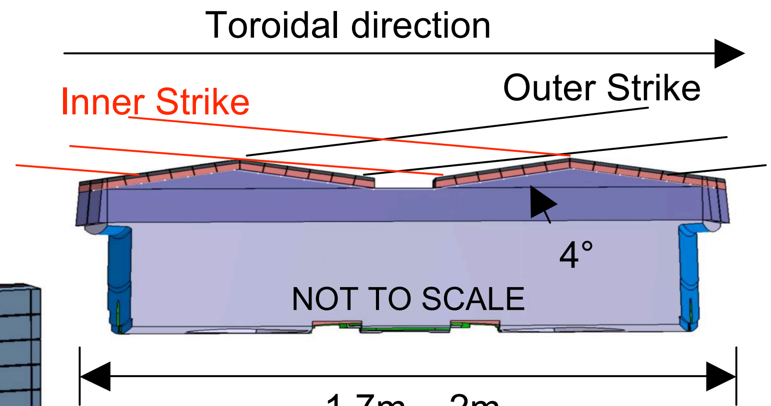




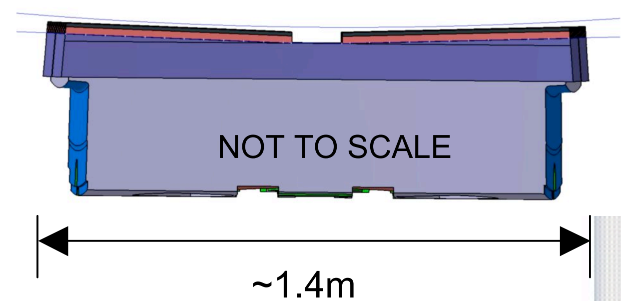
In situ separable FW

Near 2nd X-point

36 of 440 modules



- Bi-directional design
- X-point can move

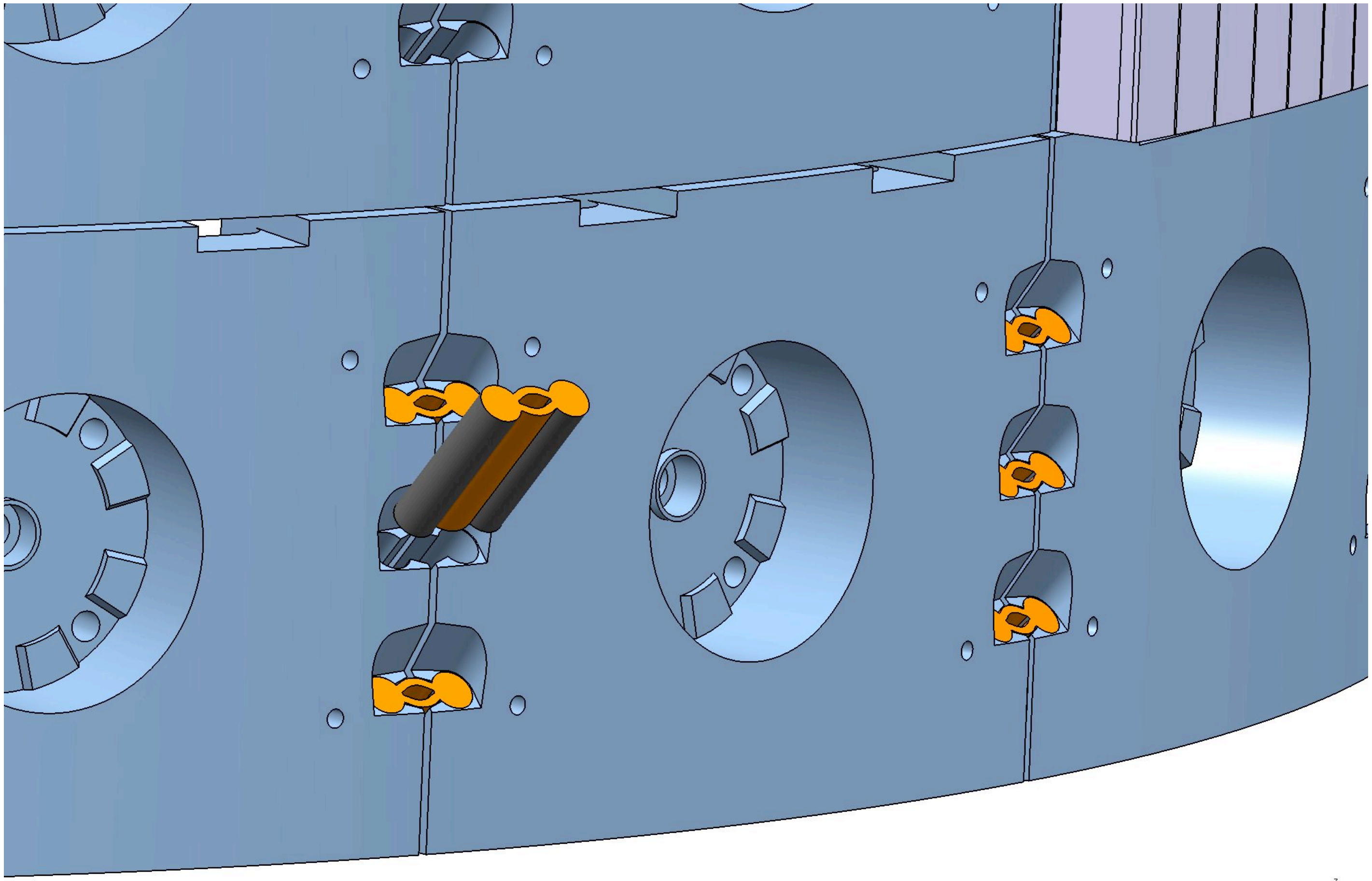


On Outer Wall

260 of 440

Flat surfaces may suffice

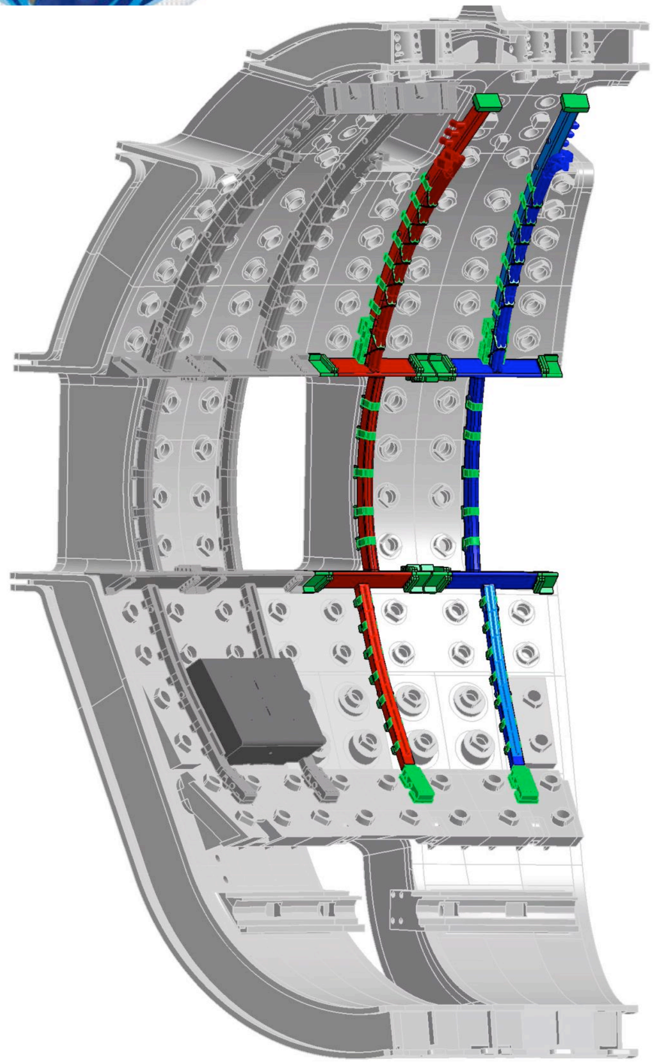
Electrical Straps implementation



CAD view of 3 adjacent strapped shield modules

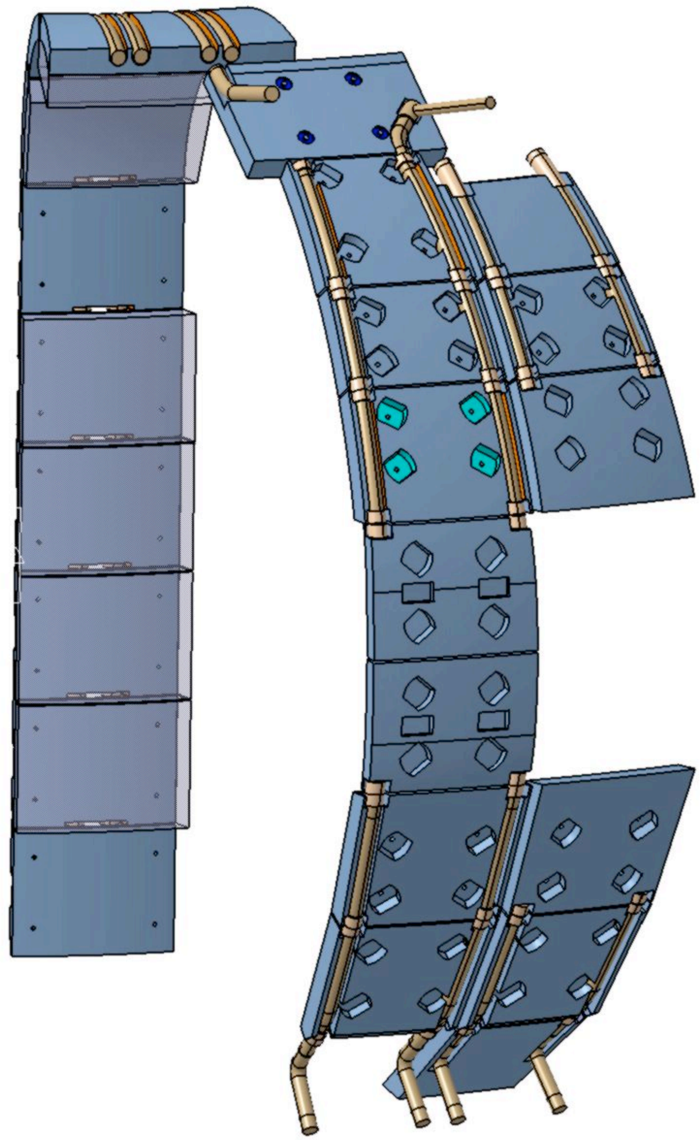
WG 5 – blanket manifold

Alternative concept

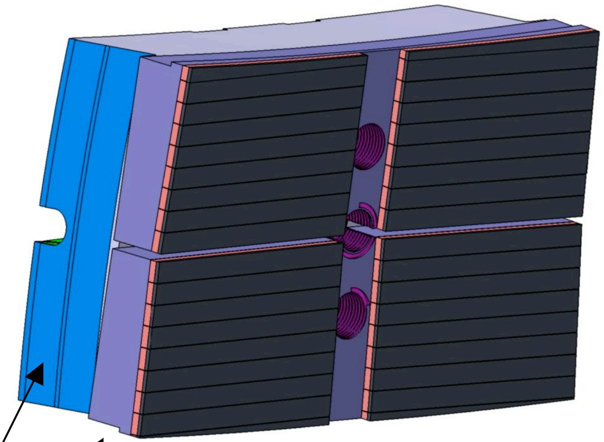


Present reference ITER Blanket Manifold design

Outboard Manifold

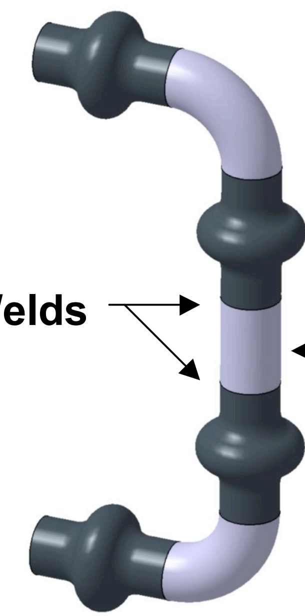


Integrated Blanket Masnifold



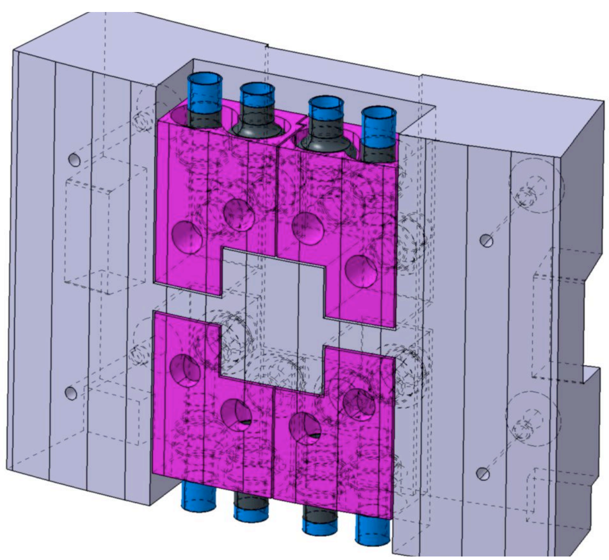
4 Single convolution branching pipe (PH. Rebut) connecting neighbouring shield blocks

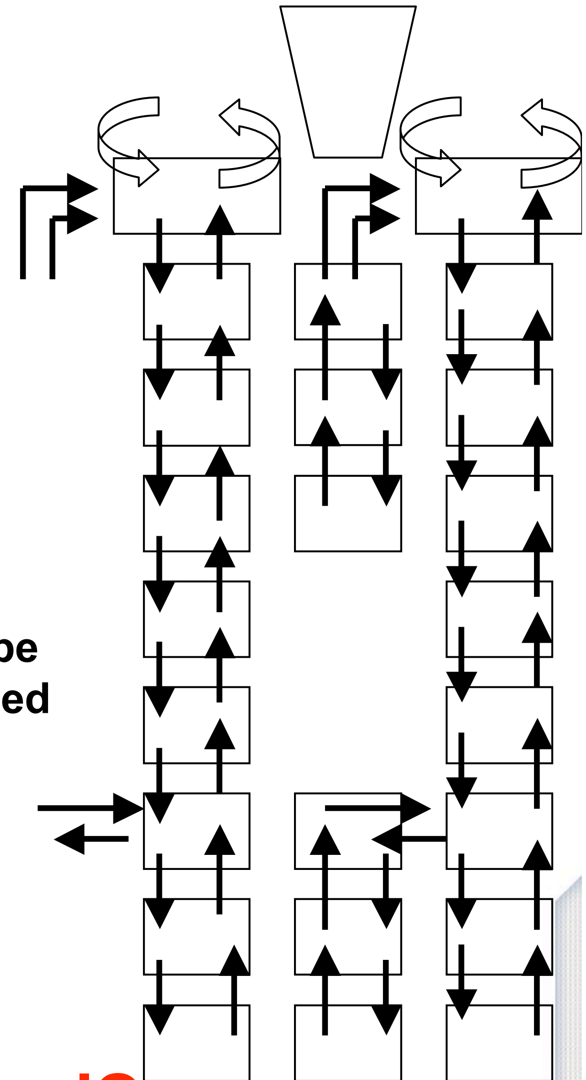
Semi permanent shield block with RH separable First Wall



Welds

Adjust. tube to be welded





Not yet accepted by the IO

Summary of Major Changes

- **Physics**: ELM coils - cost driver, vertical stability, shape control
- **Safety**: No Carbon in the Tritium Phase + Tritium Management
- **Buildings**: Hot cell remains a challenge – potential cost driver; re-optimization of layout and inclusion of Magnetic fields in the building layout.
- **Magnets**: No major changes. PF's may change because of Plasma control. Cold testing is the biggest change and a cost and schedule driver.
- **Vacuum Vessel**: no major changes – blanket manifold integrated with blanket ???
- **H&C drive**: Development of NB asap and decouple RF installation from Assembly hall, consider upgrade of ECRH by 20 MW to allow for possible delay in beams
- **Tritium plant**: Complete redesign and layout but no major cost changes
- **In Vessel Components**: Several adaptations and changes:
  - Blanket attachment and water cooling manifold, electrical connections
  - Use of Tungsten in Tritium phase for divertor
  - Tiling adjustment of first wall in several areas to deal with misalignments and heat loads
  - Use of 18 inward moved columns (~1cm) and eventual no movable limiters
  - **LOTS OF DETAILED DESIGN TO BE DONE**
- **Diagnostics and CODAC** are dealt with separately

Cost and schedule impact of the design review (very preliminary)

- Approximately 80 DCRs are related to the design review process

- **The total cost of the design review related changes will be in the order of 150 M€ +- 50 M€ including the items asked for by STAC**

- Most changes have a small cost impact or non, only a few have a large cost impact
  - (e.g. ELM coils (40 to 55 M€) and magnet cold test (30 to 50 M€)

- **Only a few changes will have a schedule impact**
  - magnet cold test (~ 3 month on TF procurement)
  - ELM coils between VV shells (~ 6 month on VV)

Outlook

- The ITER Project moves rapidly towards reality
  - The team is being built up and starts to be able to fulfil its role (a lot remains to be done)
  - A realistic schedule and cost will emerge towards the middle of 2008
  - A new baseline design for the long lead items is available end of 2007
  - **A decision on scope versus cost and schedule will have to be taken in 2008 by the ITER Council**
- The design review has been very successful and was well supported by the world wide fusion community
  - Decisions on the proposals have been taken in July and September
  - A few complex problems continue to be under investigations
- **We, the fusion community should continue to support the ITER project as much as possible**
  - **Only ITERs success will ensure our all success and that fusion will eventually become a major energy system**