# Overview of the JET ITER-like Wall Project

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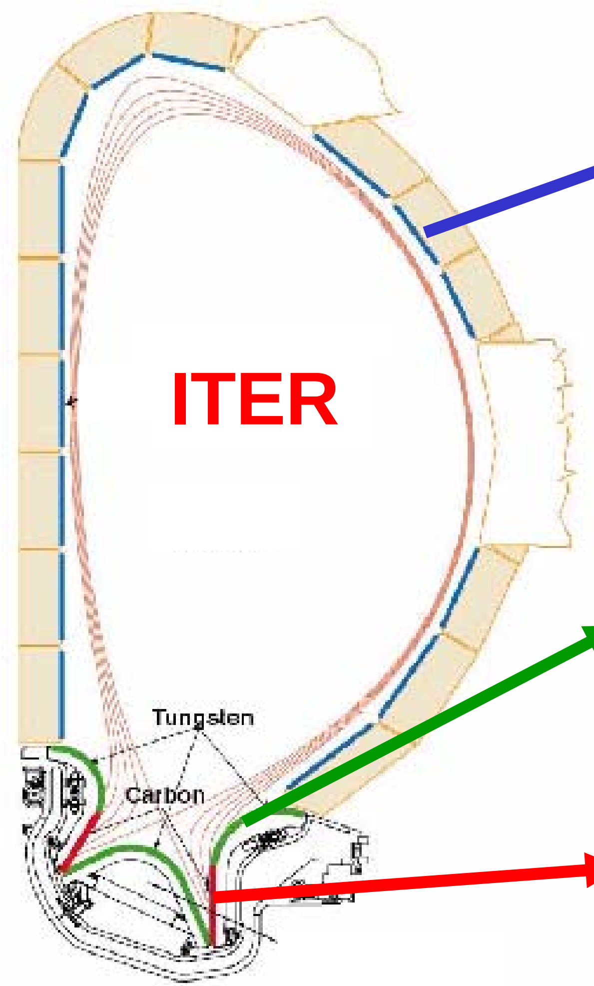
**on behalf of the Project Team**

PFMC-11 Greiswald October 2006

## Outline

1. Introduction
2. Scientific goals
3. R&D overview
4. Material configuration
5. Engineering issues
6. Protection and Control
7. ILW project status

## Rationale for ITER's material configuration




**700m² Be main wall**
- Low Z
- Oxygen getter
- Lower T retention than C

**100m² Tungsten baffles**
- Low erosion at low $T_{e,i}$
- Small T retention

**50 m² Graphite CFC**
- No melting
- Best heat shock resistance

**Main Drives**

Plasma performance & T-retention

Erosion & lifetime

An untested compromise hence JET's ITER-like Wall Project

## PWI is now a main focus for the EU fusion programme

**PWI research programme in EU laboratories: topical oriented**

**Integrated large PWI experiments in tokamaks**

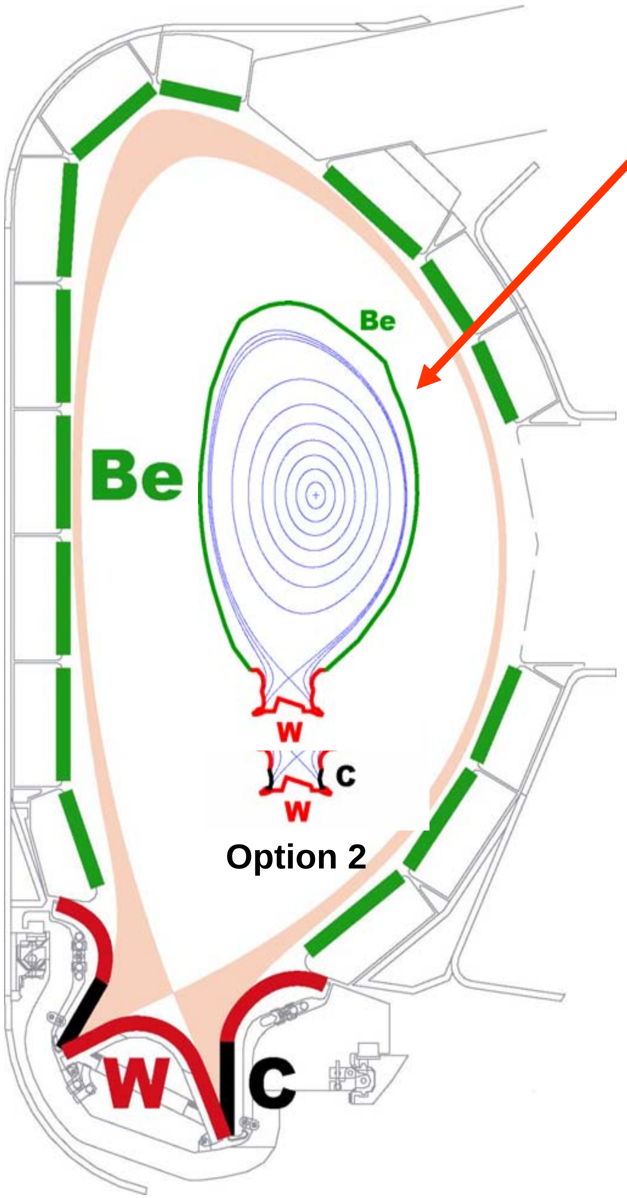
**EU PWI Task Force**

**AUG full W-wall programme**

**JET ITER like Wall Project**

**EFDA technology programme**

**this talk**




## All W divertor & Be wall selected

- Minimises risk of C contamination
- C strike point tiles could come later (option 2)

**JET Machine Parameters**

| | |
|---|---|
| Major radius: | 3.1 m |
| Plasma volume : | 80-100m3 |
| Plasma current: | ≤ 5 MA |
| Magnetic field: | ≤ 4Tesla |
| NBI: | ≤ 35MW + ICRH |
| Pellets for ELM control: | 50Hz |

NBI, ICRH and pellets: EP1+2

Tritium and Beryllium capability

# Scientific Goals

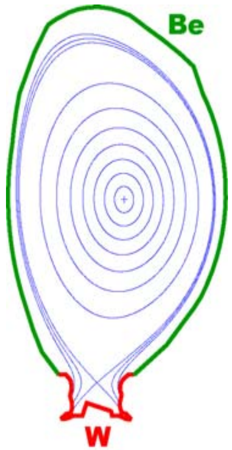
## 1. Operation with a Be main chamber wall

a) Be first wall erosion/migration in all ITER scenarios

b) Be melting behaviour

c) Fuel retention in bulk Be tiles (surface and bulk)

d) Be interaction with oxygen (background, leaks, venting)




## 2. Operation with a full W divertor **(and Be first wall)**

a) Compatibility with ITER-scenarios

c) W-mechanical stability under repetitive power loads

d) Alloying of Be with W and affect on W- erosion

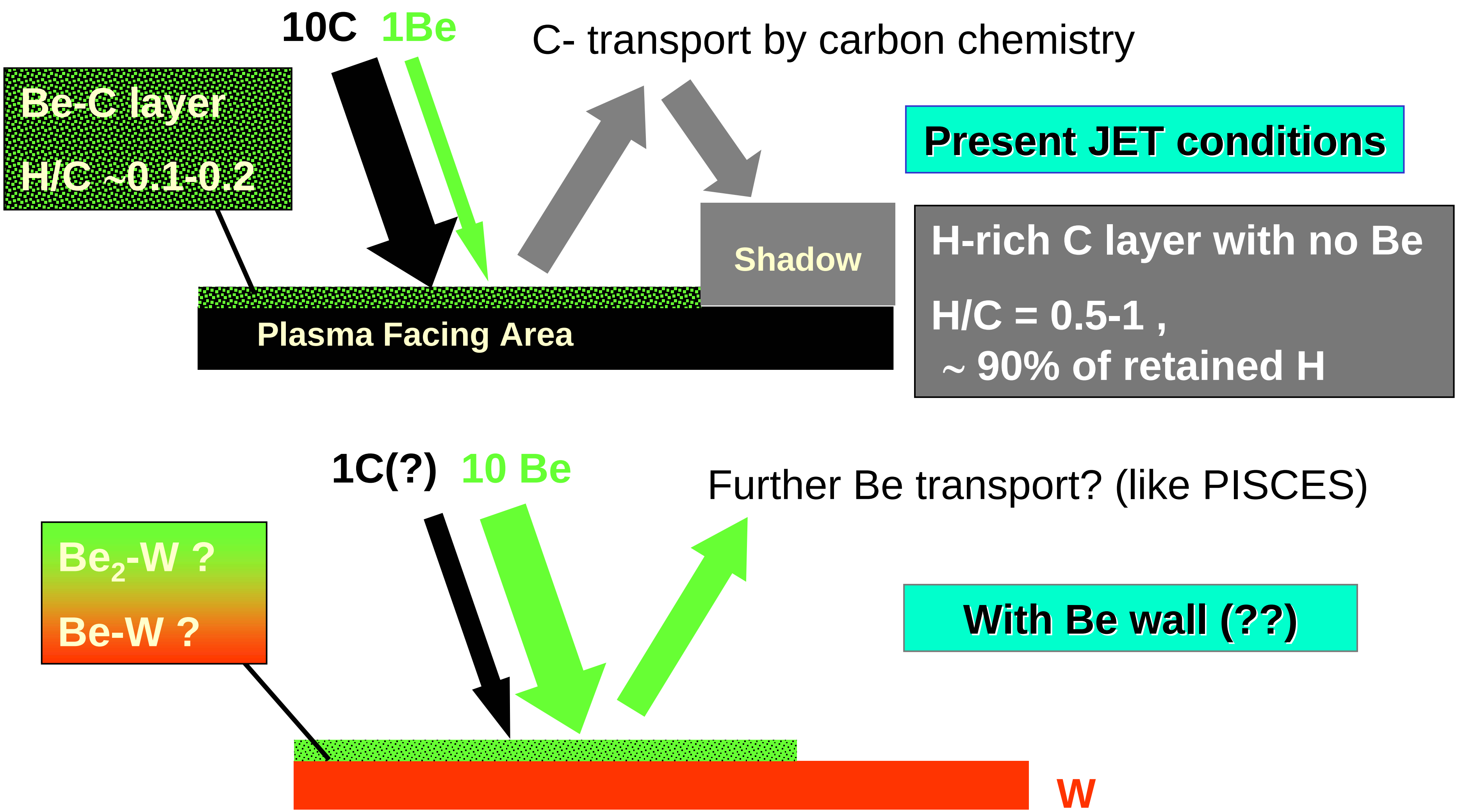
e) W melt layer flow, melt layer loss and stability

(c–e: **Bulk W required**)

f) T-retention

**Need fast shutdowns to remove samples at least once per year**

## Example: Long range transport and T-retention



## W-coating R&D for JET 2D CFC (Details in talk by R.Neu)

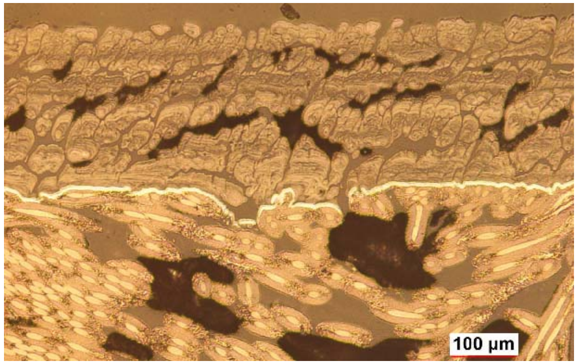
Led by IPP Garching (H.Maier, R.Neu)
14 industrial coatings produced, (CEA, ENEA, IPP, MEdC, TEKES)
CVD (4, 10, 200 μm), PVD (4, 10 μm), VPS (200 μm)

**200μm VPS and 10μm CSMII met test requirements**

**Cautionary note:**

There is tendency focus failure modes but remember that a 3μm marker stripe has survived 80,000s operation in JET over the whole inner divertor and much of the outer divertor – M.Mayer PSI 2006

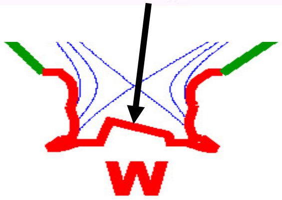
W-Coating Tile 6



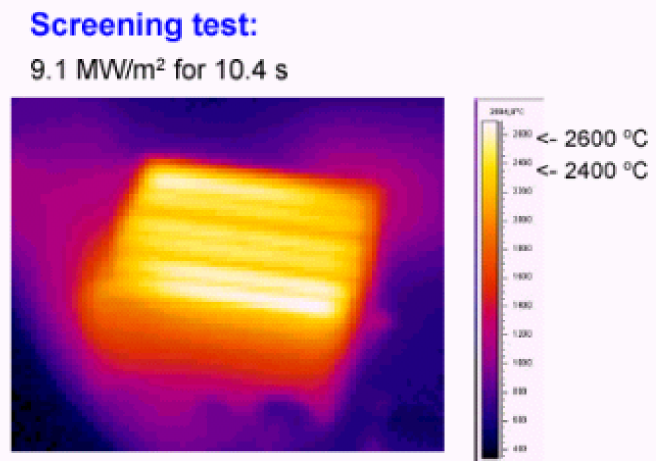
## Bulk W tile 5 R&D (Talk by T.Hirai)

**Bulk lamella concept (FZJ):** 6mm lamellas in 4 poloidal stacks, toroidally isolated, with dedicated contact points to the supporting structure (minimise EM forces)

Prototype




Tests in TEXTOR

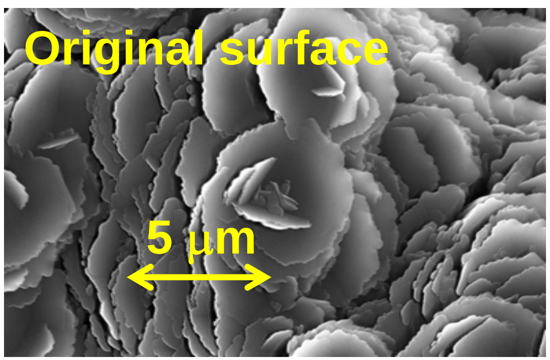


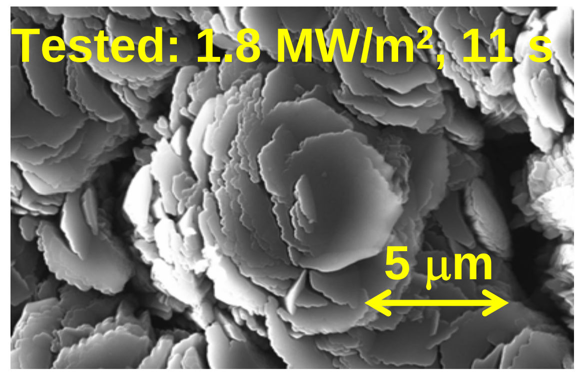

Tests in Judith 1

## Evaporated Beryllium Coatings on Cast Inconel (C.Lungu and T.Hirai)

**Aim: maximum coverage of the wall with low-Z (Be) material**

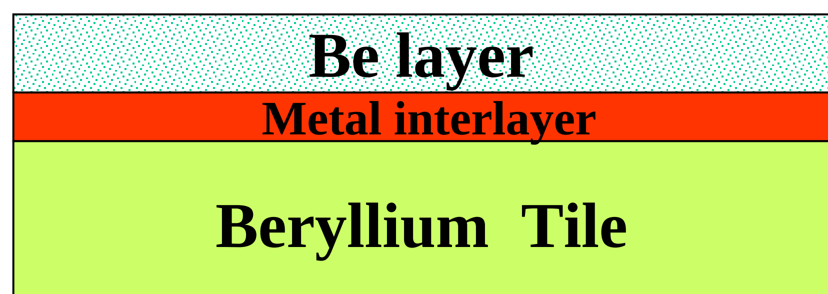
- 8 μm Be coating on Inconel cladding, upper dump plate tile carriers
- Max. heat load in JET: 0.5 MW/m$^2$ in 20 s ⇨ 10 MJ/m$^2$




## Development of Be Erosion Markers (C.Lungu and M.Rubel)

To measure erosion < 10μm





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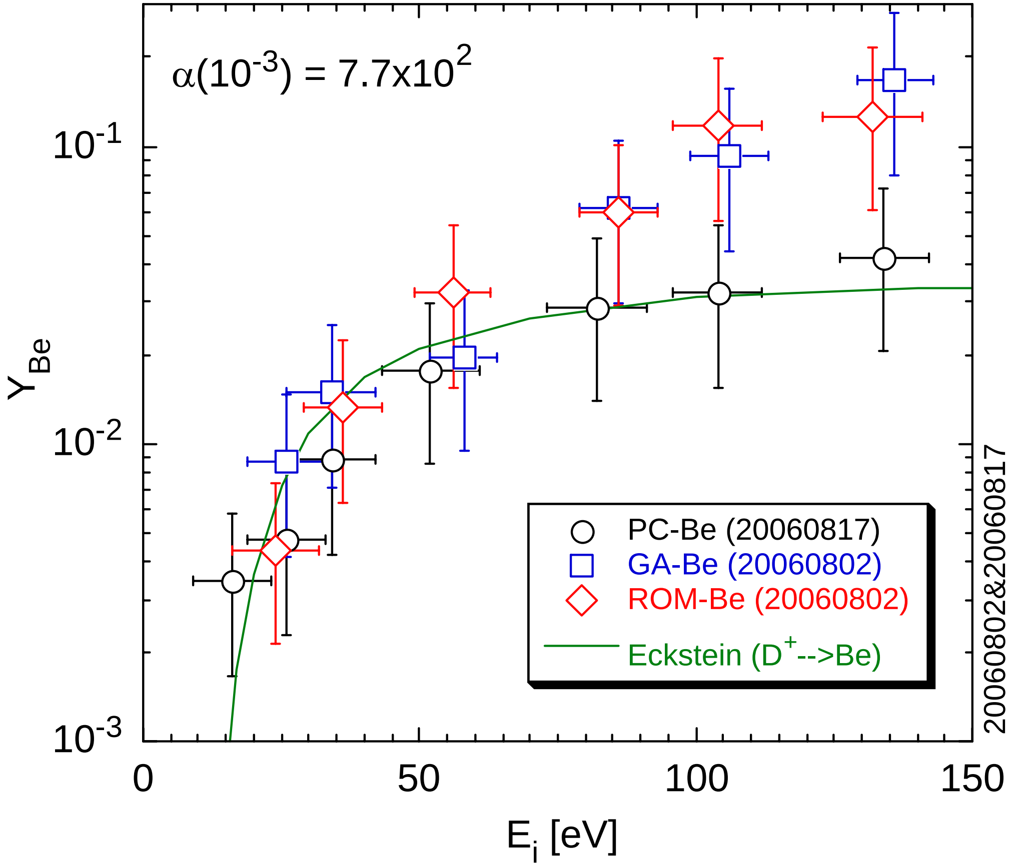
## Sputtering yield for Beryllium Coatings on Cast Inconel

GA-Be & Romanian(ROM)-Be coatings show increased $Y_{Be}$'s at higher $E_{ion}$ compared to Poly Crystalline(PC)-Be.




PC-Be data scaled (α) to Eckstein's value

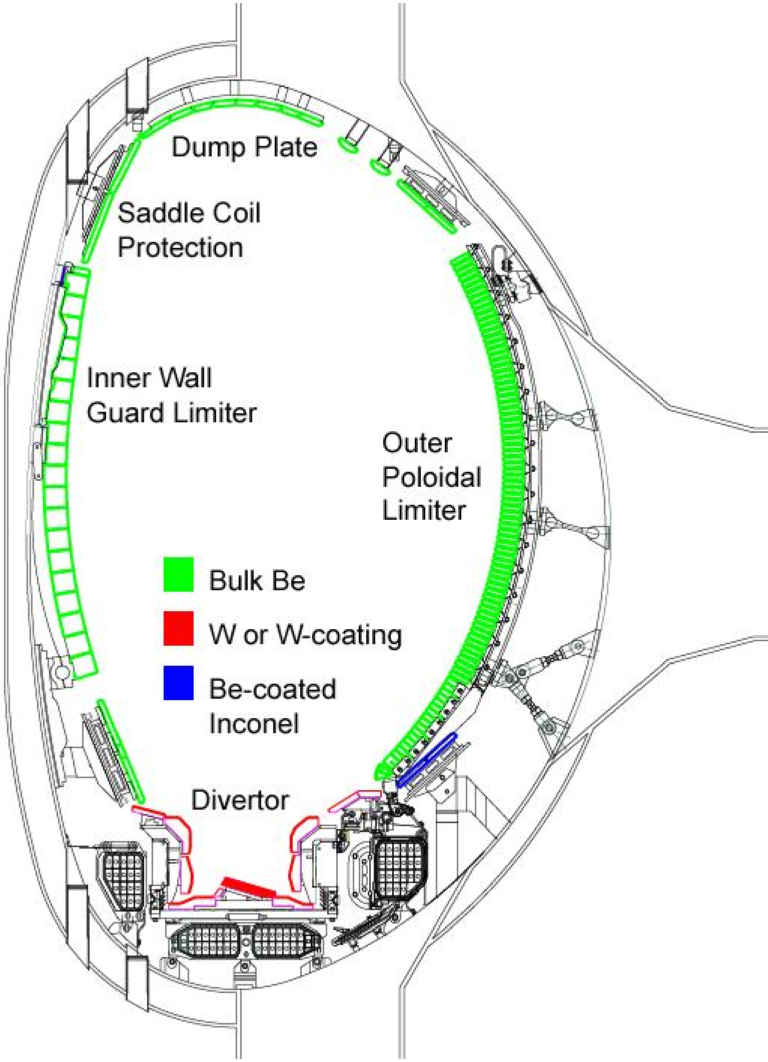
# Material Configuration

## Main Wall

Limiters and primary protection ⇨ bulk Be

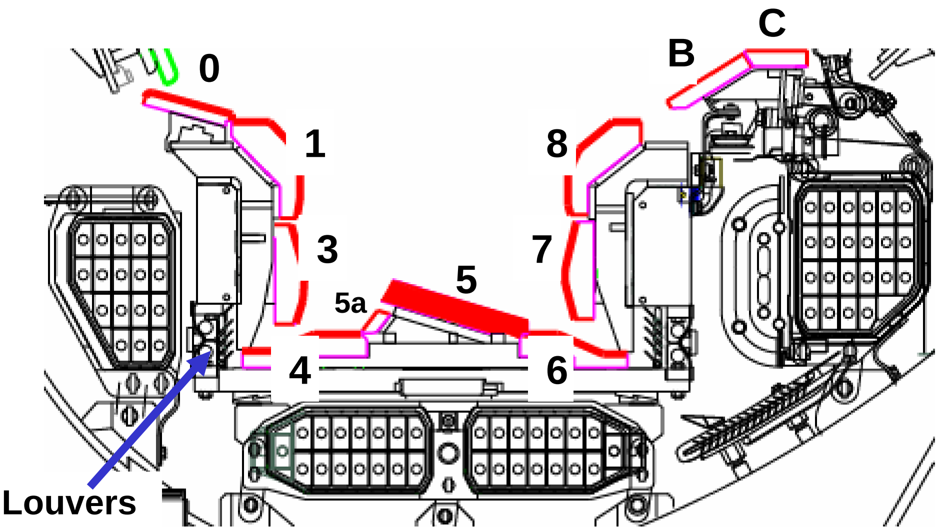
IWGL moved in 3cm from present

W-Coated CFC
Be coated inconel } Recessed ≥ 1cm



# Material Configuration

## Divertor Configuration




**200µm** VPS on CFC
0,1,3,4,6,7,8 – also main chamber lost alpha diagnostics

**10µm** CSMII with Mo interlayer on CFC
5a, B & C – also all main chamber CFC such as shinethrough areas

**Bulk W** inertially cooled
Tile 5 (LBSRP)

# Material Configuration

## NDT of production W coatings

R&D on IR based NDT using lock-in thermography or flashlamps failed to predict coating failures – conclusion is that coatings must be challenged in HHF facility.

**200µm** VPS on CFC

Objective is 100% cyclic high heat flux testing of all production tiles using JUDITH 2 (FZJ) →

**10µm** CSMII with Mo interlayer on CFC

Up to 10% to be tested in GLADIS (IPP)

## Technical Objectives for the Main Wall

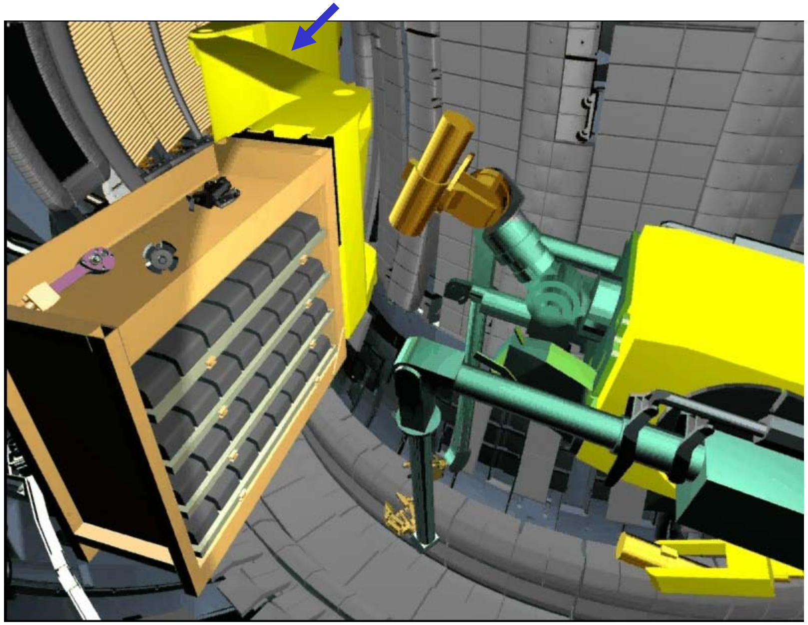
1. Eddy forces consistent with existing supports and JET OIs
2. NBI shinethrough energy handling ≥ $64 MJm^{-2}$ (20s pulse) (i.e. double present - only possible for normal bank)
3. Limiter energy and power handling ≥ current CFC design
4. Low risk of cracking / fragmentation
5. Weight of tile assemblies ≤ 10kg for remote handling
6. Minimum Cost

| | CFC | Be |
|---|---|---|
| **Resistivity** | 10μΩm | 0.08 μΩm |
| **Temperature limit** | ~ 2700°C (ablates) | 1289°C (melts) |

## Shutdown Objectives

- Total shutdown time (excluding unrelated work) ≤ 46 weeks
- Upgrade main boom lifting capability (bulk W divertor) to 100kg

Extension of short boom to increase efficiency



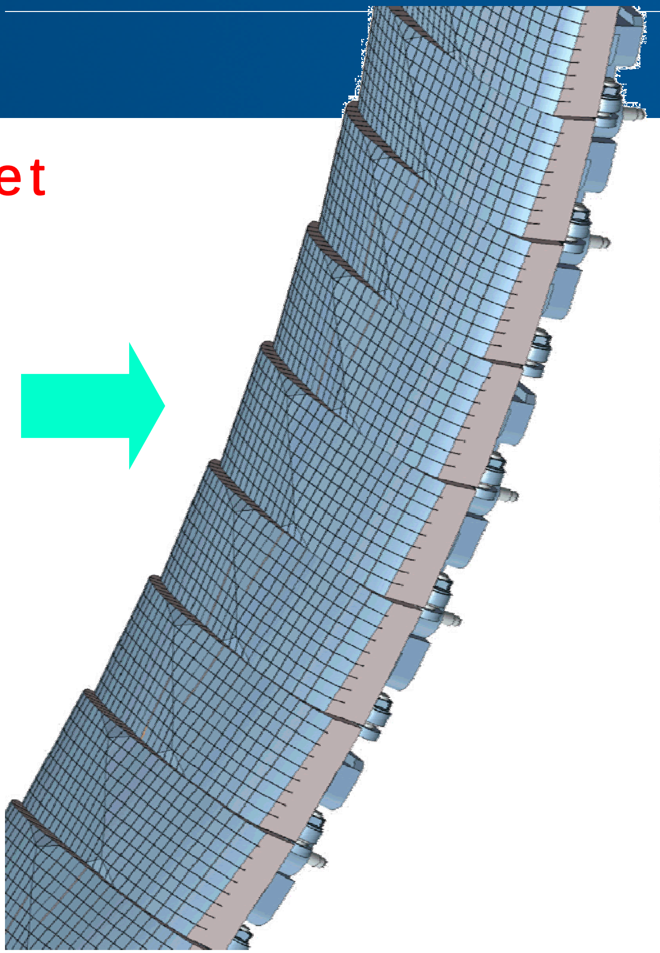
> 4000 tiles to remove & replace

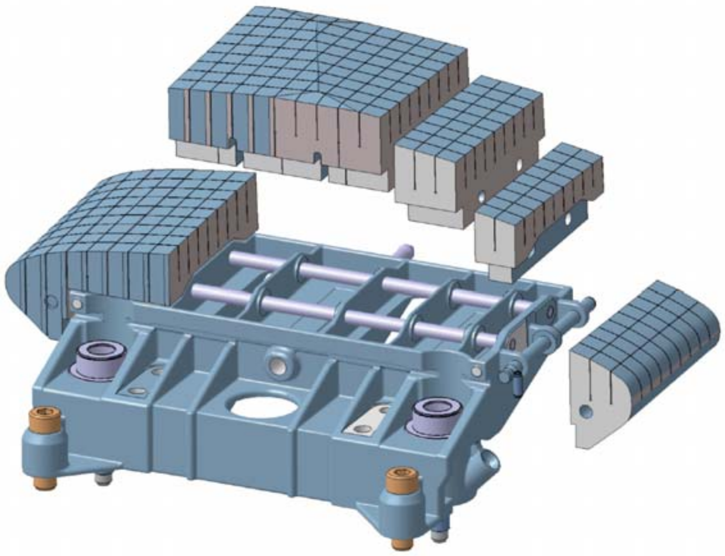
# Engineering issues

## How technical goals have been met

Example: Wide Outer Poloidal Limiter

- ⇨ Eliminate bolt holes (power)
- ⇨ Optimised profile (power)
- ⇨ Large format tiles (power)
- ⇨ Single helicity (power)
- ⇨ Interlocking carriers (tolerance)
- ⇨ S65J HIP Be (mechanical)



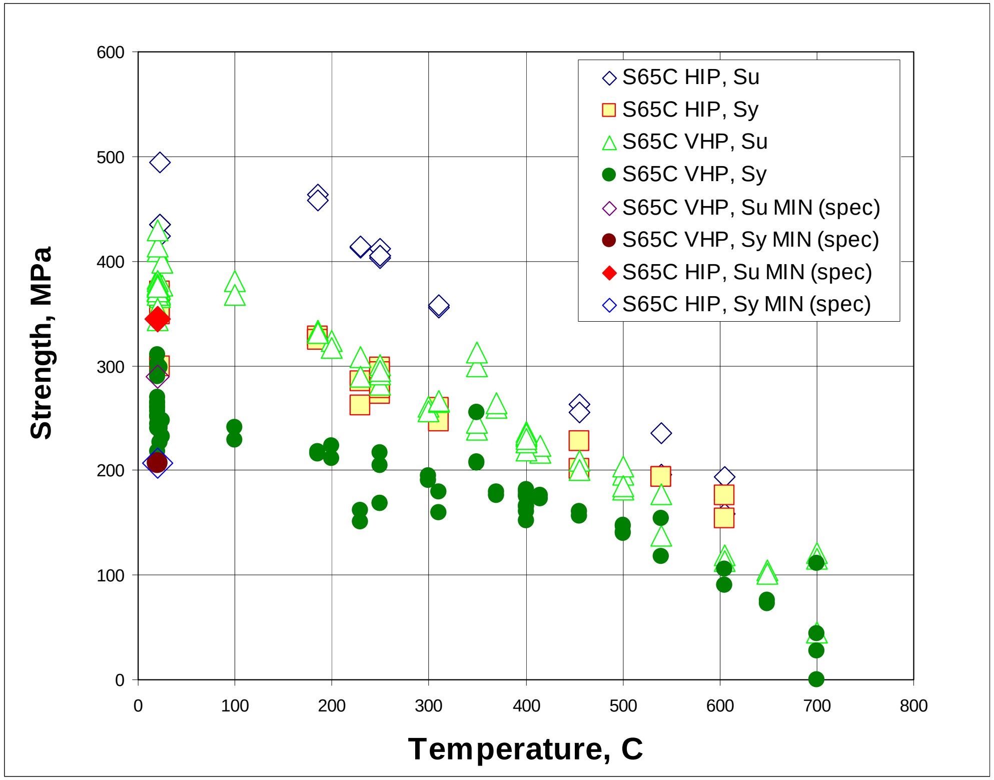


- ⇨ Segmented construction (eddy)
- ⇨ Castellation (thermal fatigue)
- ⇨ Vacuum cast In 625 carriers (strong, high resistivity + low cost)

## Choice of Beryllium Grade

**Brush Wellman S65C VHP is reference material for ITER ILW will use S65J HIP**

- 4 tons of JET S65 Be scrap is being recycled into new S65J HIP blocks for ILW



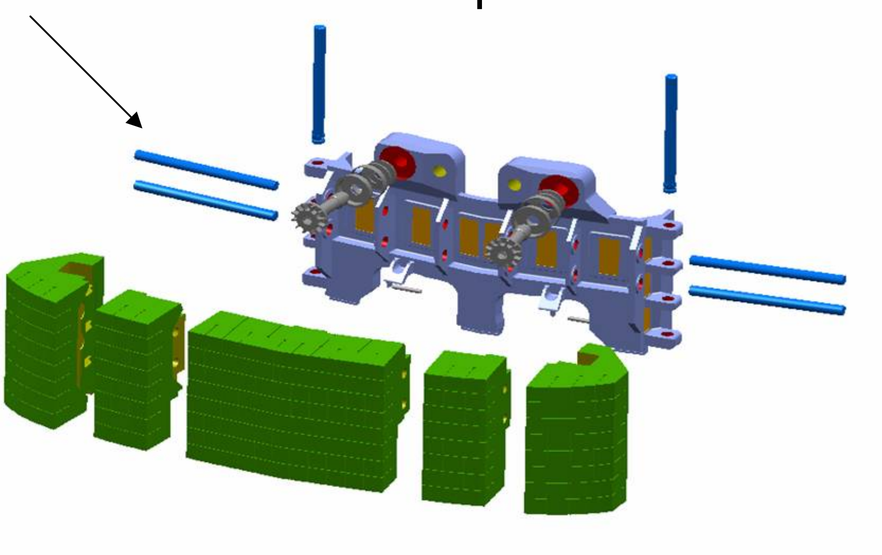
## Structural analysis of tiles

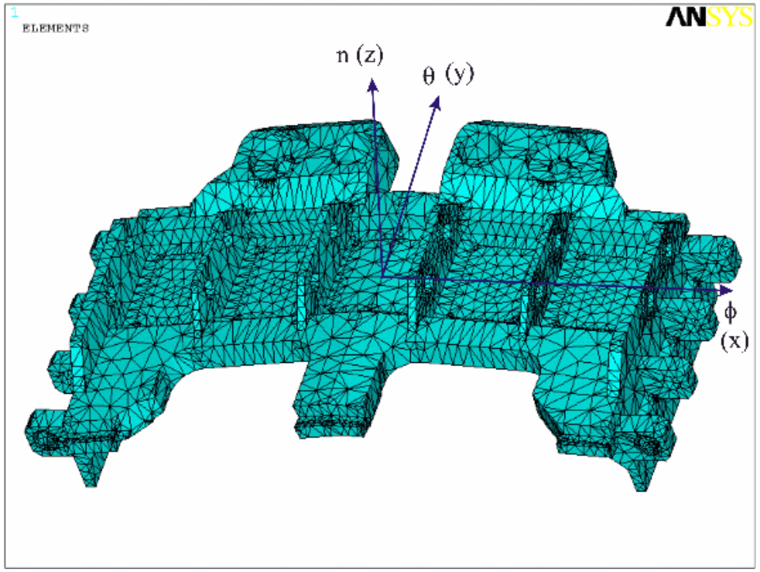
In contrast to CFC tiles forces are dominated by eddy rather than halo current forces

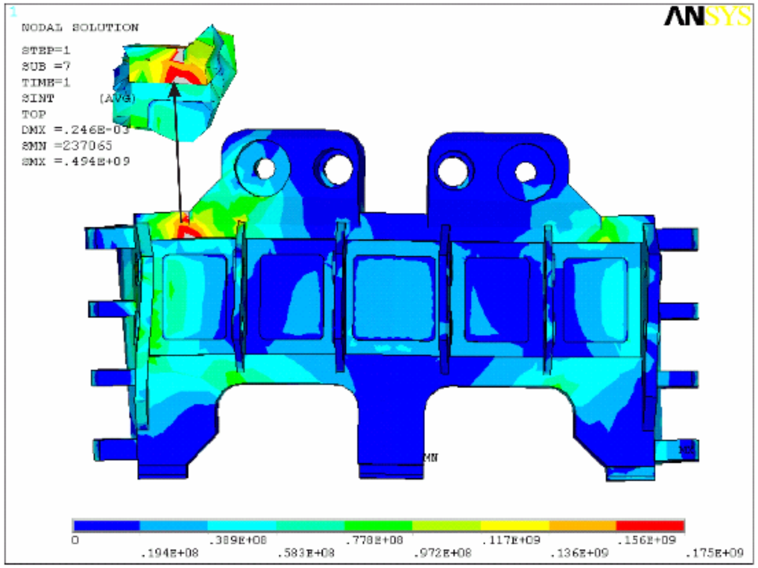
Designed for 6MA, 4T disruptions
dB/dt = 100T/s

**Inner Wall Guard Limiter**

Pins allow thermal expansion of Be



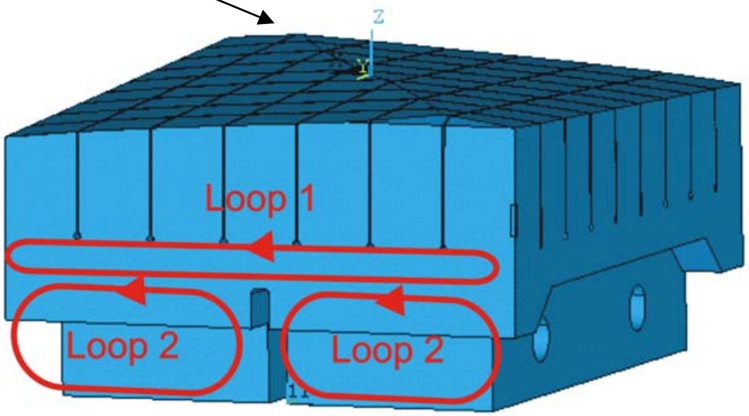


## Limiting Eddy Forces

Central tile block has to be large to cope with ridge

➔ Eddy forces reduced to acceptable level by cuts



## Steps, gaps and field line penetration

**Reference case:**10s pulse, 40mm thick tile (semi-infinite)

Surface melts at 1289°C

Cold start (200°C) heat flux to melt = 6MW/m$^{-2}$
Hot start (400°C) heat flux to melt = 4MW/m$^{-2}$

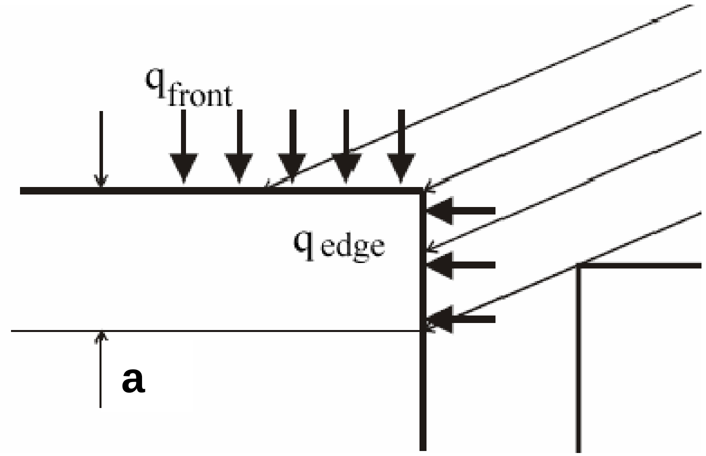
} CFC is 2-3 times better

Castellation depth chosen so root at 2*yield stress when surface melts

**Power to Edges:**

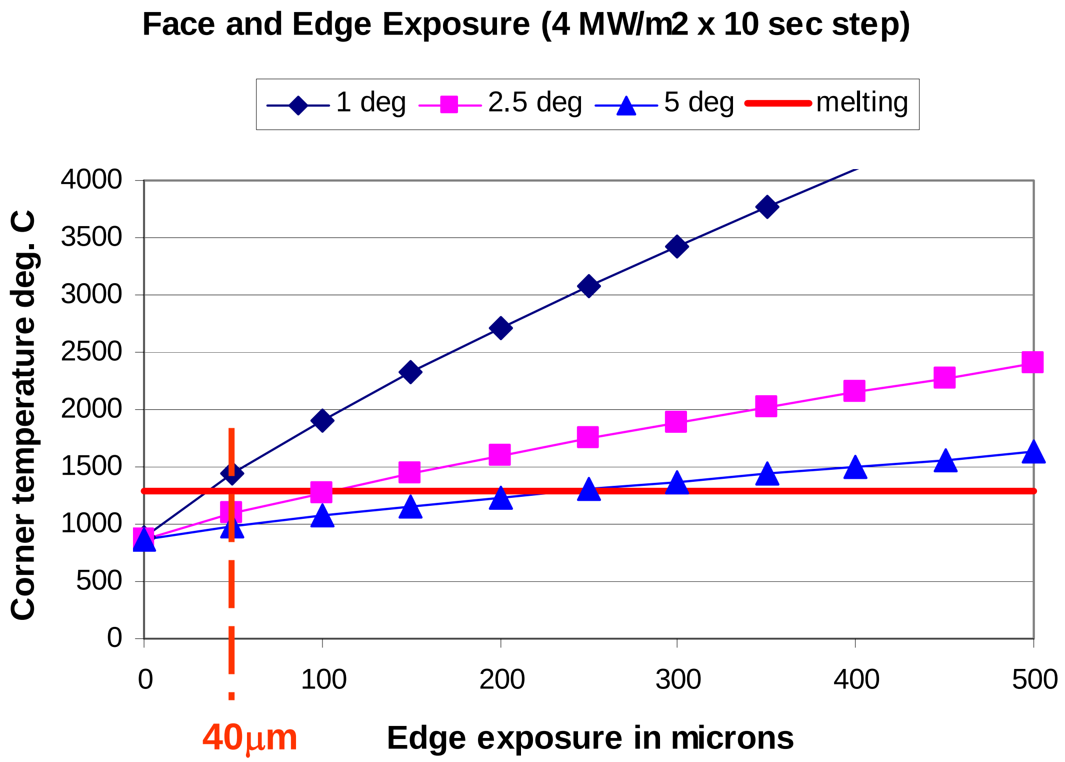
Angle of attack = 1-5°

$q_{edge}$= 45-230MWm$^{-2}$




Edge exposure **a** = step due to tolerance + field line penetration

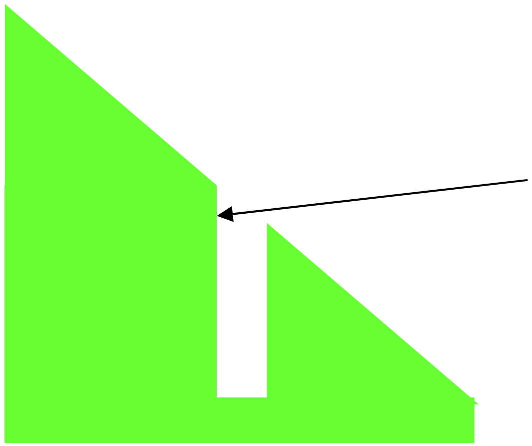
# ILW Design Rule is Edge Exposure < 40μm

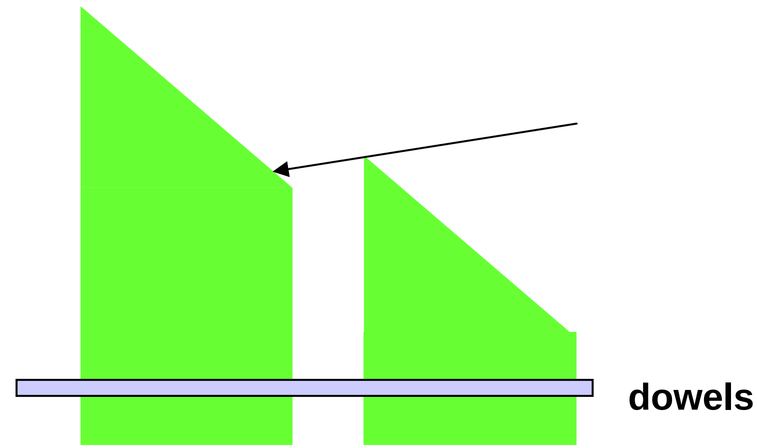



Analysis assumes Sinθ rule for power

Some say this pessimistic ⇨ **Need for validated alternatives**

## Dealing with gaps and steps






**Internal castellations:**
Smallest possible ~ 0.35mm by EDM

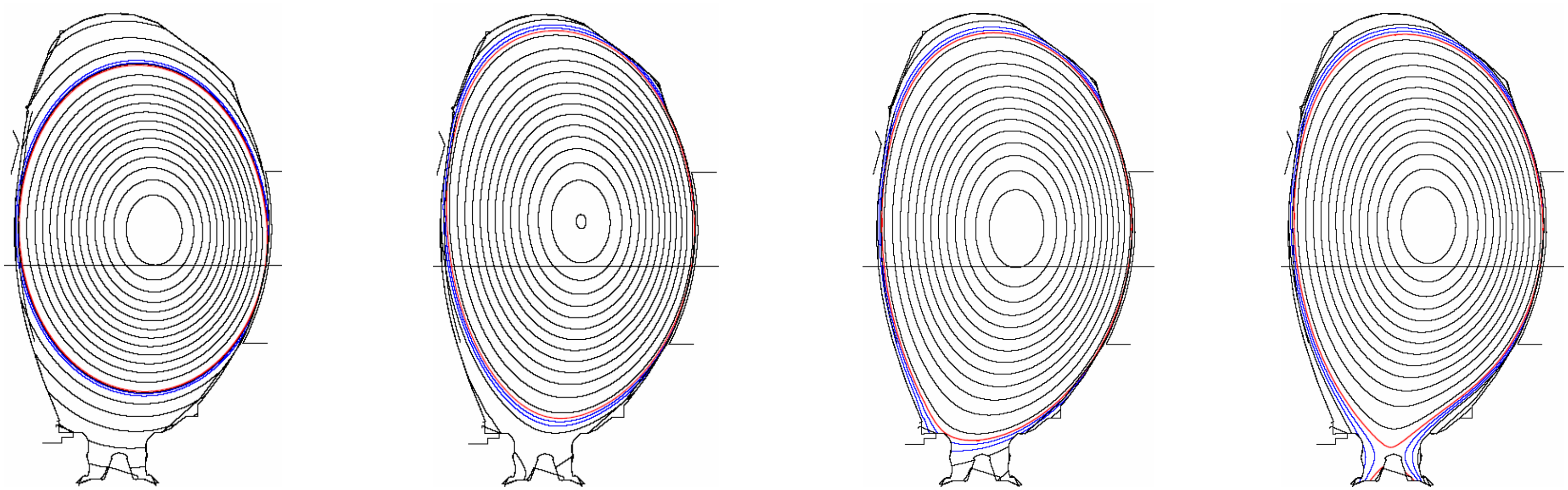
Be is acid etched to remove surface damage, Cu and Zn but we need to maintain the gap tolerance
⇨R&D collaboration with BW

**Slice to slice:**
Shingled

## Operational flexibility

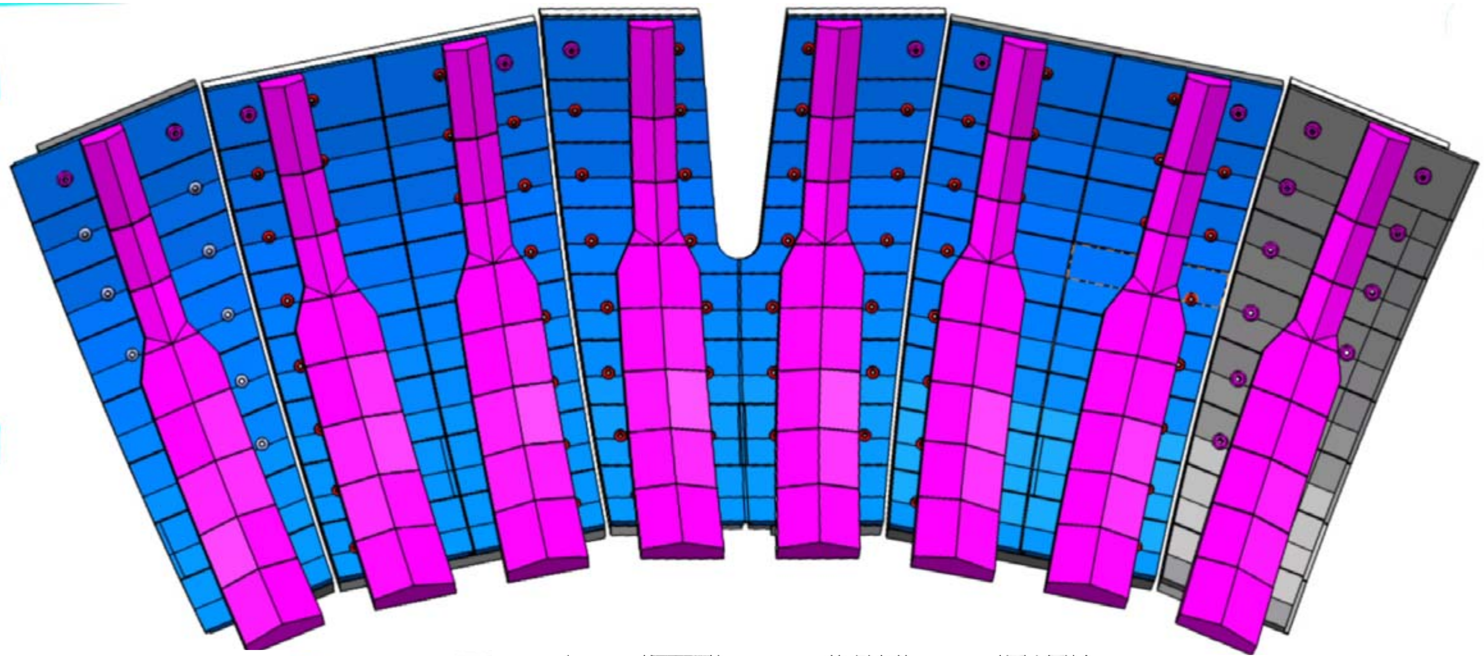
Tile profiles designed (by POG) to handle a wide range of equilibria

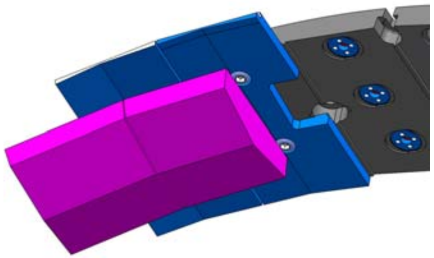
$q_{95} = 2.2\text{-}11.4$ and varying mismatch to limiter curvature

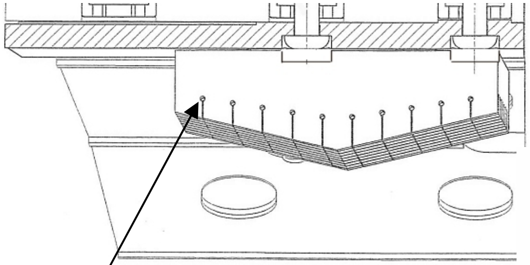


Selection of PROTEUS equilibria for tile shape check by CEA

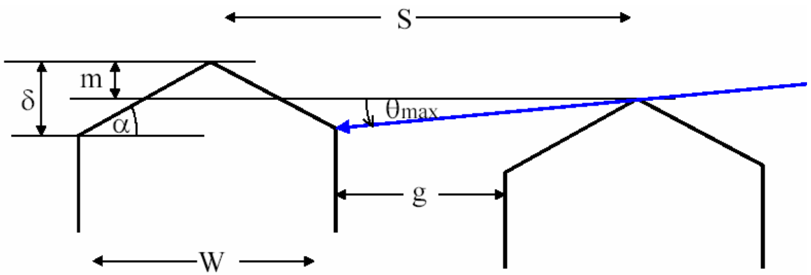
## New upper dump plate configuration







Castellations



## W-coated NBI shinethrough areas (10 $\mu$m)

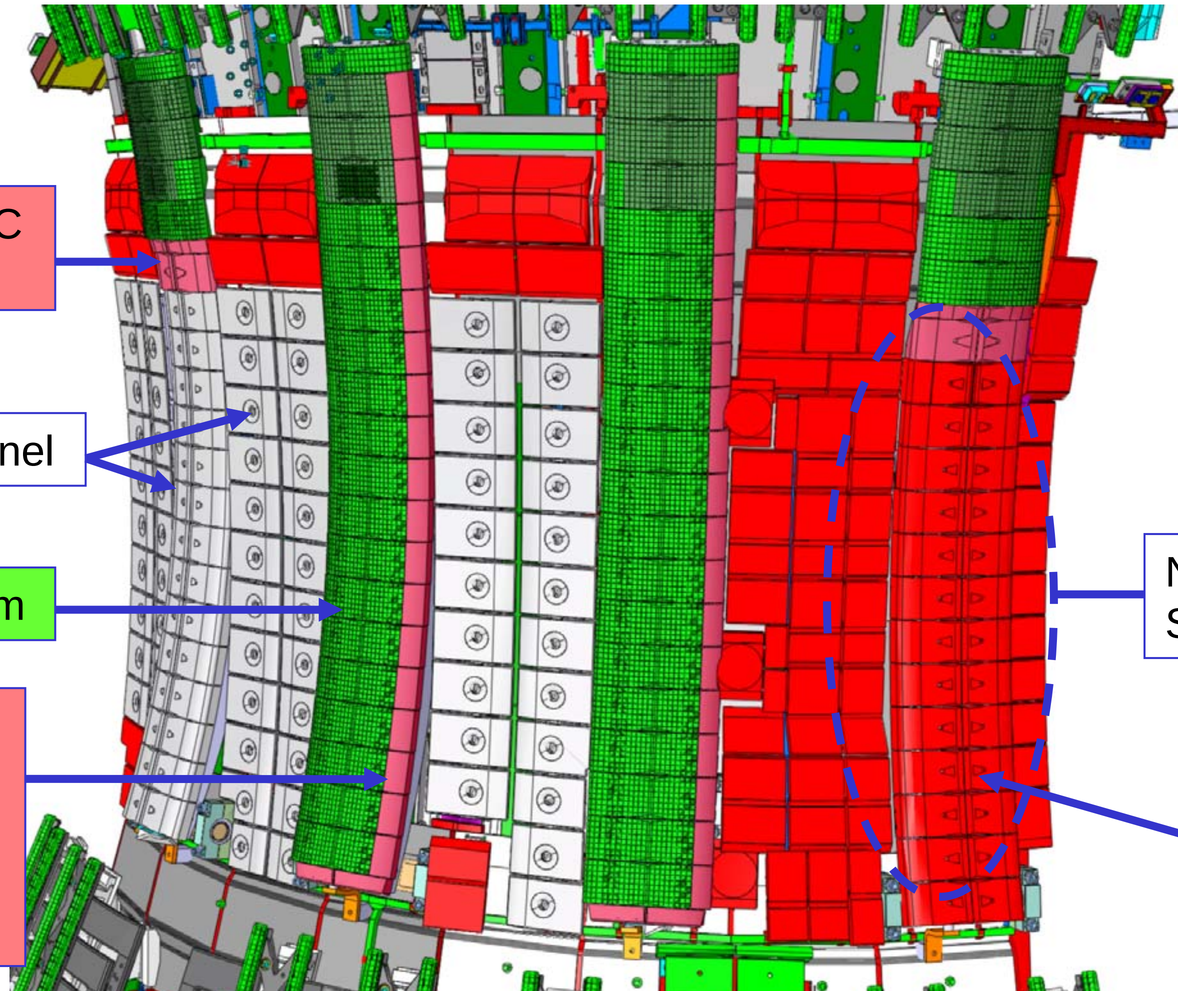
Current drive efficiency $\propto$ NBI ShineThrough power (AT scenarios)

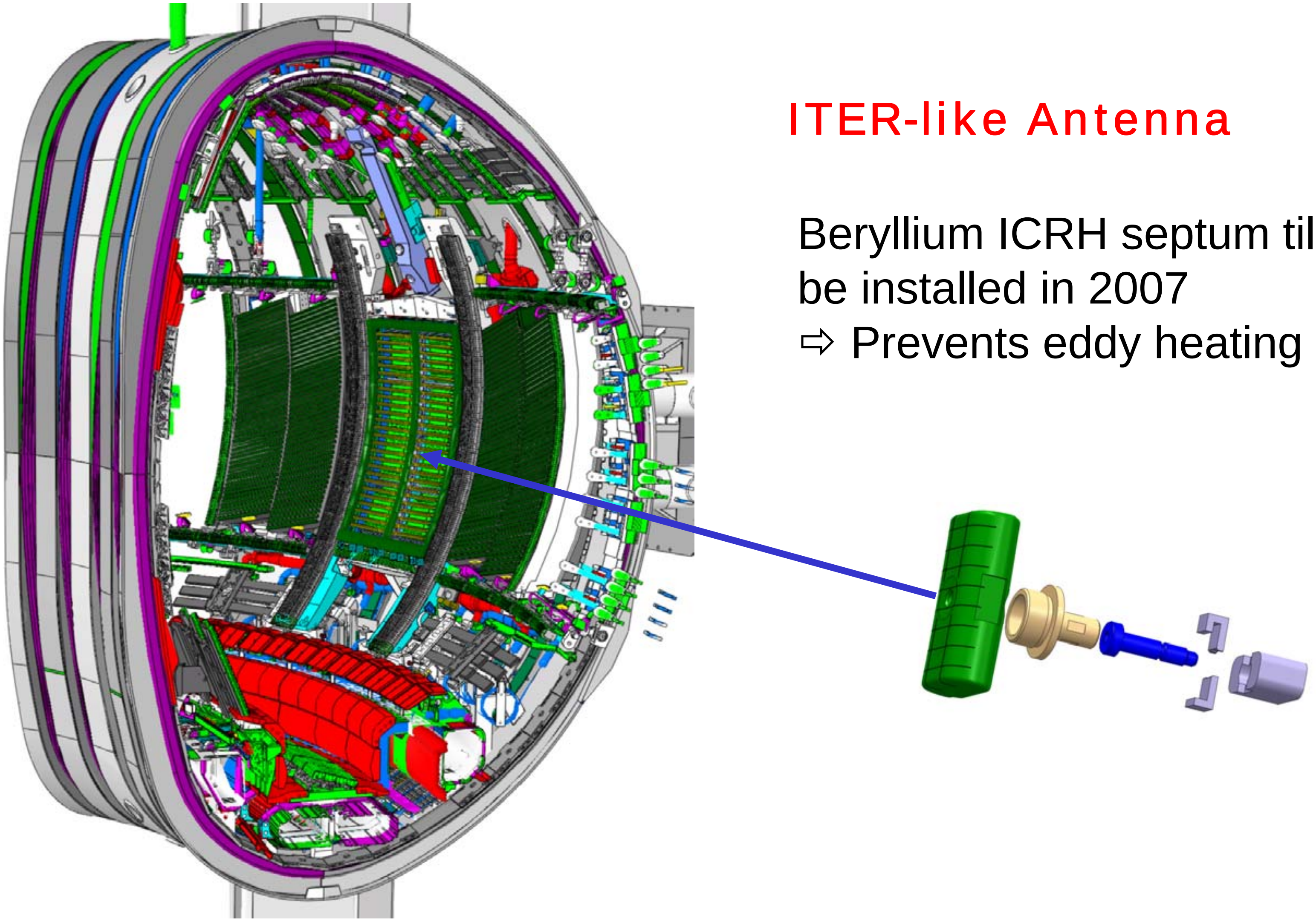
Objective of ILW to double ST energy handling (60MJ/m$^2$)

- Only possible with W-coated CFC on normal bank
- Tangential bank falls short of objective but situation is complex

Coating lifetime due to NBI sputter is OK but W-source may be a problem

# Inner Wall - NBI shinethrough areas





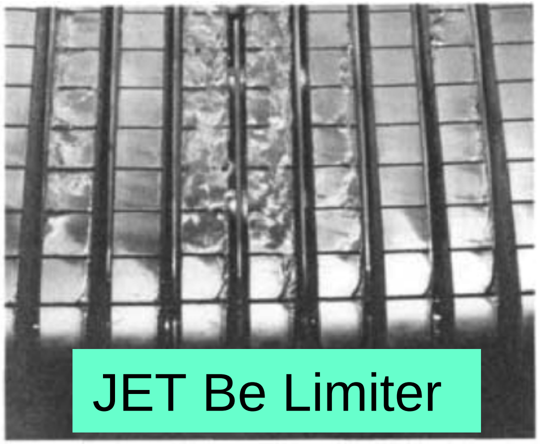
## ITER-like Antenna

Beryllium ICRH septum tiles will be installed in 2007

⇨ Prevents eddy heating by RF

# Outstanding issues for ILW and ITER

## Plasma Control / Machine Protection




CFC PFCs have a benign limit in JET (bloom)

- No longer true with Be wall
- W coatings form droplets when they melt due to surface tension

**Potential for damage from:**

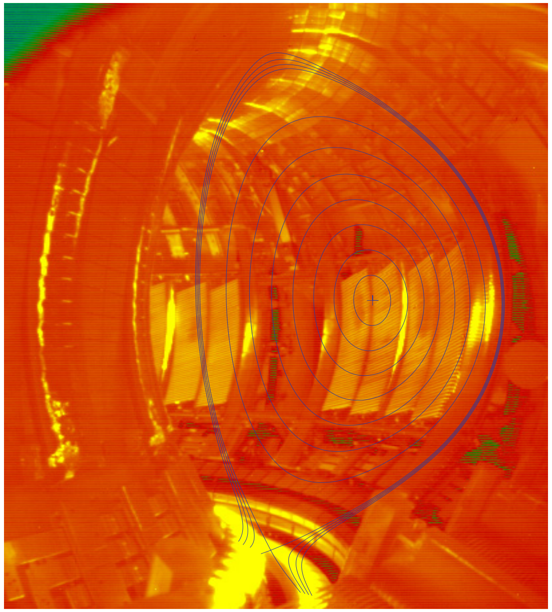
- Steady state plasma power and energy
- NBI shine through
- ICRH and LH generated hot spots
- ELMs and disruptions

**A gentle introduction to what it will be like in ITER**

## Plasma Control / Machine Protection

**To work near the limits we need:**

- Phased programme – build up slowly/carefully
- Calibration of new JET Operating Instructions using new TC array
- Real time control/protection systems



## ILW Project Status

- CFC and Be manufacturing contracts are on schedule
- Tender evaluation completed for all Article 7 contracts
  ⇨ 16 months after official ILW start (20 contracts, >1500 drawings)
- EP2 Shutdown start date now Nov. 2008
  ⇨ Duration ~ 1 year (including NBI etc.)
- Current main foci for ILW Team:
  ⇨ Final design reviews and “For Manufacture Drawings”
  ⇨ Detailed planning with company input of the manufacturing phase

# Contributing Associations

JET Operating Team + EFDA-JET CSU +

UKAEA, United Kingdom

IPP Garching, Germany

FZ Juelich, Germany

Tekes , Finland

VR , Sweden

SCK-MOL, Belgium

ENEA , Italy

CEA , France

Med-C, Romania

**Thanks also to:**
Brush Wellman, USA
PISCES Team, USA