1.) Overview on European Blanket Concepts and Integration principles
2.) Large Module Integration
3.) Multi Module Segment (MMS) Integration
4.) New MMS Blanket options

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DEMO = Fusion Reactor PLANT:

Demonstration of all technologies (breeder blankets, He-cooled divertor..), **High Availability**!
HCPB Blanket Design for DEMO (FZK 2003)

- Strong against pressurization
- Orthogonal stiffening grid
- All manifolds behind the breeding zone
- Breeder Units
  - 210 mm x 210 mm
- Helium 80 bars, (300...500°C)
- Structure: Eurofer
- Li$_4$SiO$_4$
- Be

2 m
Design of the HCLL Blanket for DEMO

- Cap
- PbLi loop
- Back Plate - Manifolds
- Grid
- Cooling Plates
- PbLi manifold
- He inlet/oulet
- FW
FZK Dual Coolant

He

PbLi

T
### Blanket Integration Schemes

1.) **Segmented Blanket Maintenance**
- Separate Modules connected to the vacuum vessel (VV) by flexible attachment
- The hot manifold needs flexibility

2.) **Vertical Segment (“banana”)**
- Vertical segments have to be connected to the VV by flexible attachment

3.) **Sector Maintenance**
- Currently not considered in Europe

4.) **MMS Maintenance** *(Op.2.2)* ( “Best from 1. and 2.” )
- Separate Modules connected to a manifold/back plate outside the VV
- Permanent self-supporting shield and manifold connected by bolts
Alternative maintenance scheme: **Vertical Segments**

**Open Issues:**
- Flexible attachment system
- Remote handling of the flexible attachment system
- Thermal stress during transient events
- Fabrication (Eurofer/Austenite)

**EU DEMO 95**
Alternative maintenance scheme: Large Sectors

Currently not considered for DEMO in Europe

Possible issues:

- Building size, layout, logistics, costs
- Disassembly of large parts of permanent reactor equipment (e.g. heating systems NBI, diagnostics) for regular blanket and divertor maintenance
- Divertor maintenance (Divertor lifetime likely only half of blanket lifetime)
- Assembly (mechanical connection between sector elements etc.)
Integration of a modular He-cooled Blanket (FZK)

- He cooled pebble bed blanket (HCPB) 300 … 500°C
- Low temperature shield
- Flexible He pipes
- Water cooled vacuum vessel
- He cooled divertor: 540 … 700°C

MODULAR BLANKET
DIVERTOR CASSETTES
"Transporter" concept for a Fusion Power Plant

- Upper Port: 4 ports for RH of the 54 "Blanket Cassettes"
- Equatorial port: 4 ports for the RH of the equatorial IB and OB Blanket modules
- Lower port: 4 ports for the 54 "Divertor Cassettes"

8m plasma major radius, 1500 MW\textsubscript{el} 20° Sector
permanent components: shield + polodial pipes

~350 modules
~700 pipes, Ø 200 mm

500°C

300°C

Cut-/rewelding zone

In-bore cutting, welding, inspection

RH tool

Shield key

Shield

Pipes

Large Module Concept
Reweldability limit:
1 appm He
- 20 fpy: 0.05 appm
- 40 fpy: 0.025 appm

Reweldability results:
+ sufficient for vacuum vessel
+ sufficient for LTS-MMS
→ NEW effort for large module concept necessary → turn

He production rates in steel (appm/fpy)

3300 MW fusion power

FZK 3D neutronic analysis by U. Fischer, P. Pereslavtsev
New effort to remove neutron streaming issue in large pipes

FZK Shield plate in bend

Hot Shield around bend

A = 2 ... 4 m²

D = 150 ... 200 mm

outlet

inlet
He production rates in steel (appm/fpy)

3300 MW fusion power

Reweldability limit: 1 appm He
- 20 fpy: 0.05 appm
- 40 fpy: 0.025 appm
3-D TIG in-bore welding tool
What is the possible path bending radius for in-bore tools?

\[ r \geq 1.5 \times D_{\text{internal}} \]

Further research for 3D welding torch necessary!

\[ \approx 1.2 \text{ m} \]
shield
key
bend
blanket

in-bore modules

rotating in-bore welding head
Modular axial and lateral wave movements

1.5 mm lateral translation

2 mm axial translation

\[ D_{\text{internal}} = 150 \text{ mm}, \ P_{\text{Op}} = 8 \text{ MPa} \]

Telescope pipes

10 plies x 0.7mm
Large modules: Remote handling

- Blanket segments
- Shield segments
- Vacuum Vessel
- Support
- Ports
- Manipulator
- Rail
- Divertor

FZK
Remote Handling of Large Modules

Precise operation in three axes required

Size of the RH machine strongly depends on the weight of the modules
System operation: element exchange

Lower sections of the ports are used

Step 1: Manipulator gives the blanket to the port transporter

Step 2: Port transporter takes the element out
FZK Integration concepts under investigation

Large modules

- HCPB blanket
- LTS
- He pipes

Multi Module Segments (MMS)

- Each MMS consists of an assembled array of blanket modules and the coolant manifolds
### Multi-Module-Segment (MMS): new maintenance approach

<table>
<thead>
<tr>
<th></th>
<th>Separate modules</th>
<th>Vertical segments</th>
<th>Multi Module Modules (MMS)</th>
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</thead>
<tbody>
<tr>
<td><strong>maintenance time</strong></td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Forces on flex. attachment due to electromagnetic loads</strong></td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td><strong>Reasonable blanket module size for fabrication procedure</strong></td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td><strong>Reduced thermal stresses by segmentation</strong></td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td><strong>Quality Assurance</strong></td>
<td>-</td>
<td>+</td>
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</table>
MMS Options

Option 1.1: Blanket Chain
Option 1.2: LTS-Backplate + hot pipes
Option 2.1: Hot Backplate + LTS
Option 2.2: Supporting Hot Ring Shield
Fusion Core Concept

MULTI MODULE SEGMENTS
with flexible connection between blanket modules and manifold

Self-supporting Hot Ring Shield
with linear bearings at bottom side

Remote handling with Vertical Insertion and rail-based transport machine
MMS concept (2.2)

- Self-supporting hot ring structure
- Detachable mechanical connection
- VV temperature: ~150°C
- Linear bearing
- FZK
- Manifold temperature: ~330°C
- Shield temperature: ~330°C
- Concentric connection
- Blanket temperature 400...550°C

Ring structure to be operated fairly steady-state → intermediate temperature near the helium inlet temperature
Hot ring system
IB element Segmentation: insertion constraint

→ 18 degree IB MMS most reasonable
MMS / PORT configuration

⇒ Helium Pipes can be routed through the vertical ports (inner pipe diameter ~ 550 mm)
⇒ Two … four remote handling ports
**MMS SEGMENTATION**

- 16 coils: 22.5 deg segments
- In-Board MMS 18 deg
- (14x2) Out-Board MMS 11.25 deg at RH port: 7.5 deg, 2X3 OB MMS

- OB MMS 11.25 deg
- IB MMS 18 deg

- 20 elements
- 34 elements
- 54 elements
Torques from EM loads depend on module shape

\[ M_r \propto f \left( \frac{s}{w} \right) V \frac{s^2 w^2}{s^2 + w^2} \]

\[ M_p \propto f \left( \frac{h}{w} \right) V \frac{h^2 w^2}{h^2 + w^2} \]

V = volume of the module,
\( f = \) shape factor

\( M_p \) small for elongated shape
\( M_p \) large for square shape

Optimization for low poloidal torque.

1.) Small size (\( w \times h \))
2.) Elongated shape and long lever against \( M_p \)
→ larger width than height is favorable

Forces on flexible attachment are critical!

CIEMAT
Forces at attachment due to Electromagnetic Forces

A = 4 m²

Vertical module ----->

Which module shape?

TOROIDAL direction of modules for low forces on Flexibles!

Force at shear keys (from rad. Torque)
Force at attachment (from pol. Torque)
Forces at flexible attachment due to Electromagnetic Forces

Assumption for module 1m high x 2 m wide:
- $M_{rad} = 2.5 \text{ MNm}$
- $M_{pol} = 1.5 \text{ MNm}$

Smallest diameter of the attachment
- $> 13 \text{ cm} > 40 \text{ cm}$

- Smaller Blanket sub-modules to be connected to the MMS
- Low forces on flexibles
MMS Blanket sub-modules

Sub-module size:

~ 2 m wide,
~ 1 m high
~ 2 m² front surface
DEMO Reactor
with MMS Blanket
Remote handling Concept

- **Vertical insertion ports** (2 ... 4)
- **Insertion by simple crane-like insertion machine**
- **Toroidal transport by divertor rail based transport machine**
- **Linear positioning system:** MMS is moved towards the shield by use of slides on the transport machine
The inboard MMS is inserted through the vertical port.

The inboard MMS is placed on the support of the transport machine.

The MMS is leant against the shield and carried in toroidal direction.
IB Transport position

Guidance (rolls on the wall)

Gripping

Weight support
IB MMS positioning

Guiding

Lifting

Path ~ 1.1m
OB Transport position

Guidance
(roll against the wall)

Weight support

At least 10 cm clearance anywhere
OB MMS final positioning

Path~1.7m
Below remote handling ports:
last OB MMS element will be connected to the surrounding permanent shield structure from backside

Segmentation at RH ports:
Likely 3 OB MMS per 22.5 segment
Pipe compensation for upper port assembly version 2.2

Total elongation:
1) Vertical about 50mm
2) Radial about 30mm

New strategy:
1.) Hydraulic connection in ports
2.) Compensation outside VV
MMS hydraulic connection pipes are routed through the vertical ports:
Possible approach for new MMS HCPB module shape:

- Filling through openings in top- and bottom plate after heat treatment of the box
- Tapered side walls
- "BU"s with strong L-structure
- Welded consecutively into box frame
NEW alternative breeder unit design

- Flexible for low stress during thermal expansion
- Strong for vibration during filling
- Uniform temperatures in cooling plate cross section
  - low thermal stress
  - reduced risk with plate bulging
  - reduced risk with plate deflection
- One flow direction within and for all cooling plates
  - reduced pressure drop
  - reduced risk with leak between neighbouring cooling channels
- Optimization in terms of plate distance, enrichment etc.
FZK approach for new DCLL (MMS, hot backplate + LTS)

Pb-17Li manifolds

He manifolds

Boxes in toroidal direction → thermal stress during transients reduced

FZK

MMS Op. 2.1
Approach for new MMS DCLL: Flow routing

He flow

Simplified: Pb-17Li routing
FC Inserts

PbLi Flow

Walls with internal He cooling channels

First Walls: internal He cooling channels

Internal SiC/SiC Box with SiC separation plate
Approach for new MMS DCLL: SiC/SiC Box

Parts of the SiC/SiC Box

SiC Box is completed before assembly to the structure
Approach for new MMS DCLL: FC Inserts
SUMMARY, Conclusions

Separate Module Handling seems feasible but maintenance time is likely longer than with MMS.

MMS maintenance very promising, combines advantages.

Self supporting hot ring shield removes the large flexible attachment issue.

Remote handling with vertical insertion + transport machine involves only relatively simple procedures and machines.

Small number of remote handling ports possible.

New version of HCPB blanket to be combined with the MMS.

Alternative DCLL for MMS being investigated.