Test Strategy for European HCPB Test Blanket Modules in ITER

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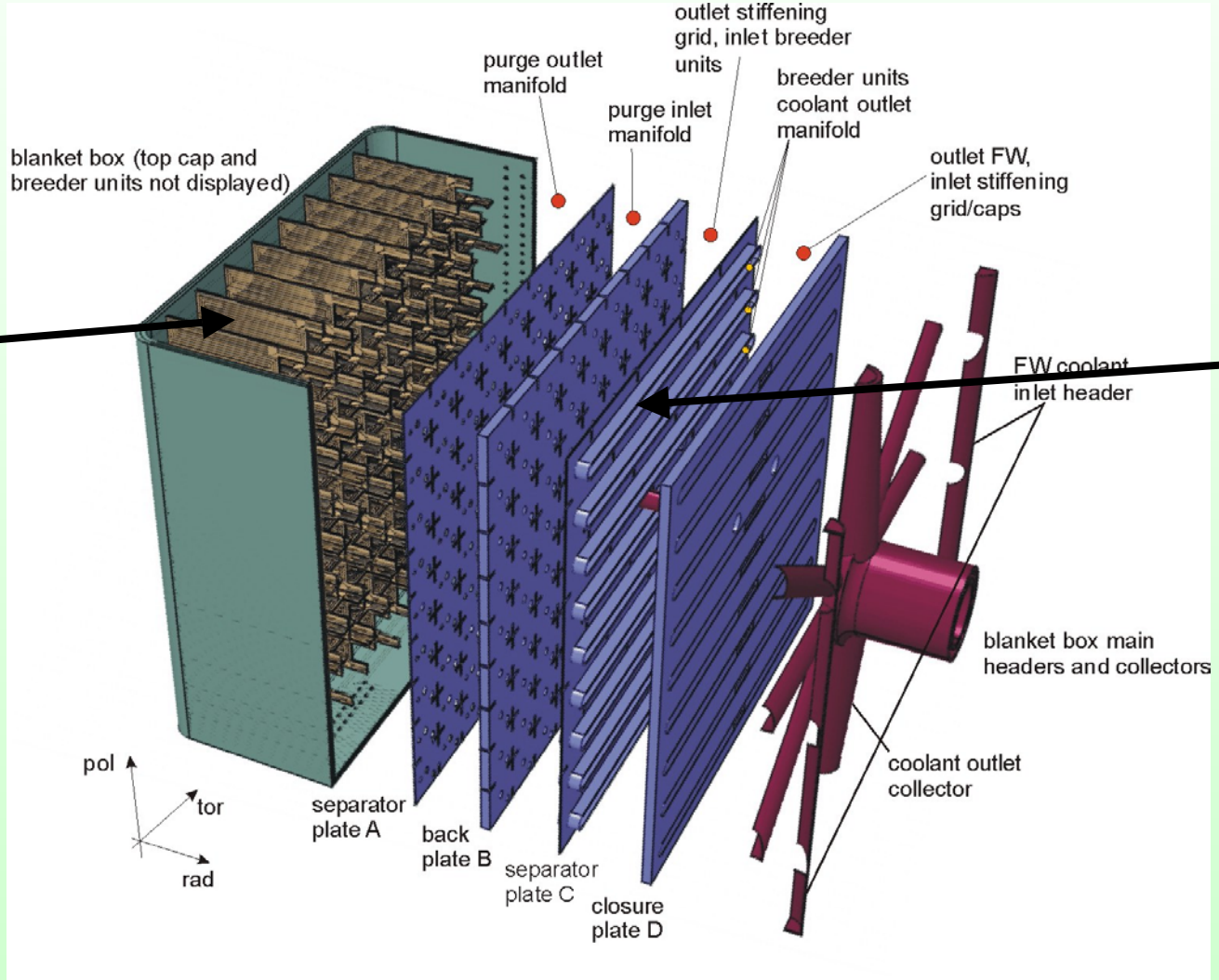
Outline

1. Introduction
2. HCPB TBM design
3. Mock-up test programme for TBM qualification
4. Testing in ITER
5. Conclusions

1. Introduction

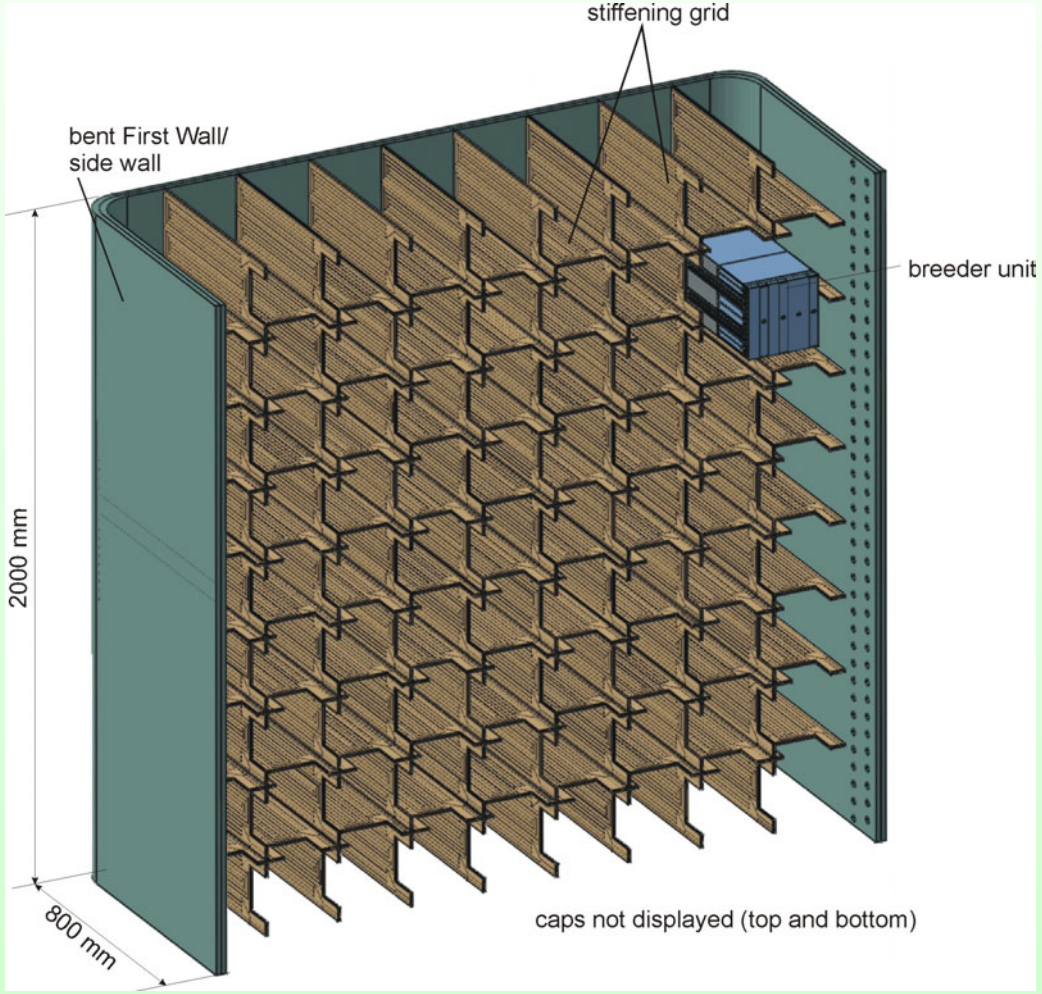
HCPB DEMO Blanket Concept

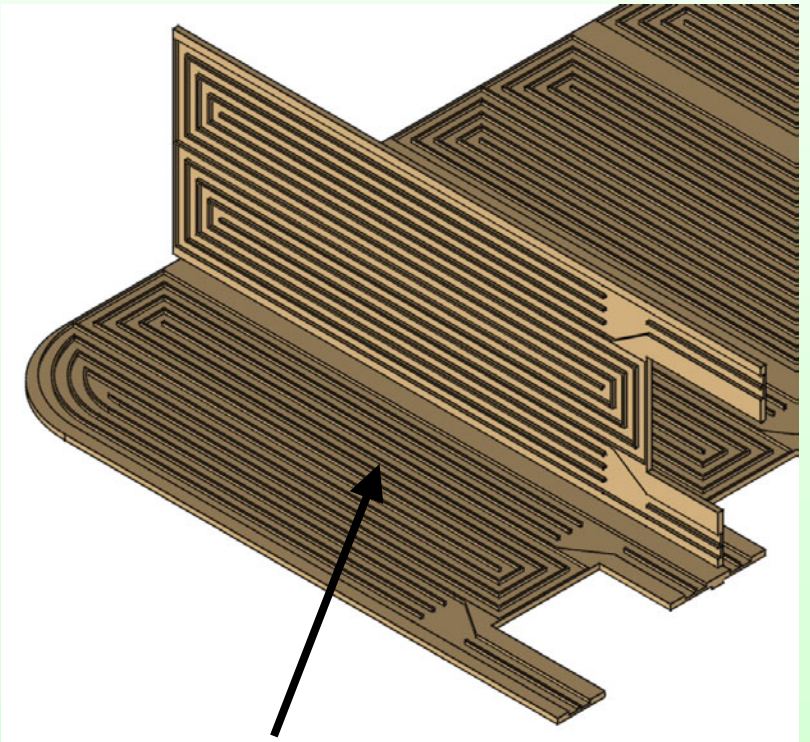
Breeding zone



Manifolds

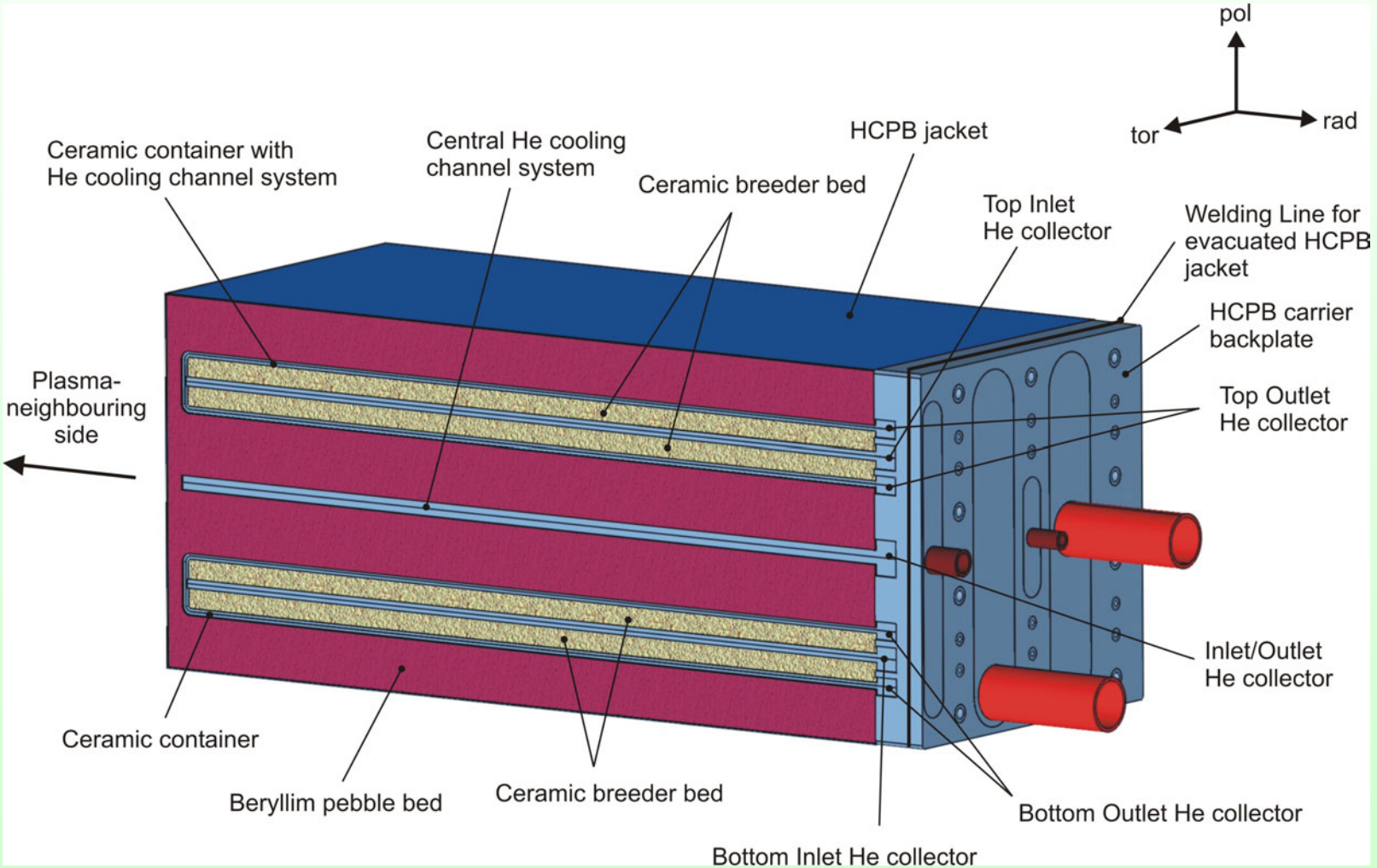
Grid system with Breeder Units



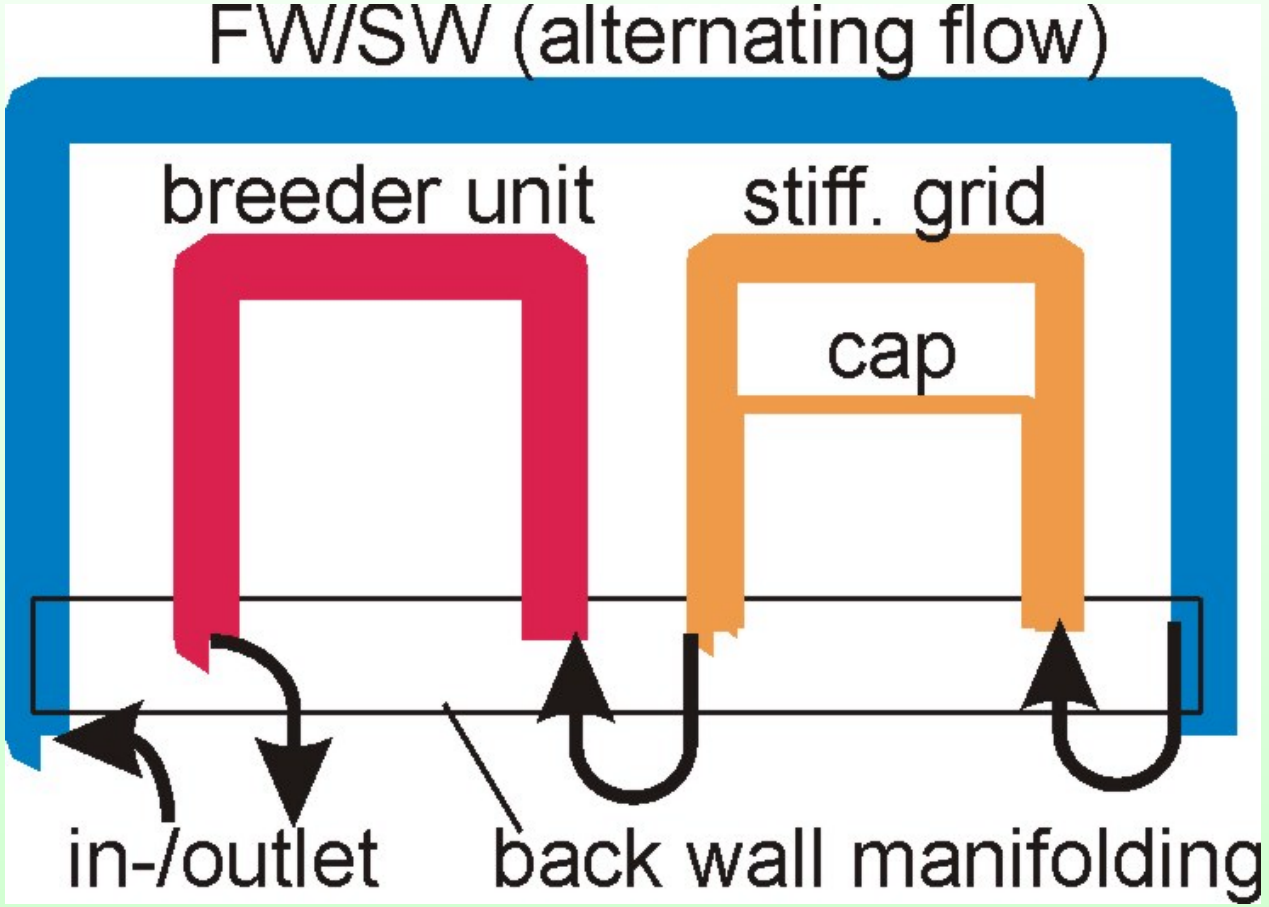


Steel structures have imbedded cooling channels

Breeder Unit for the HCPB Blanket

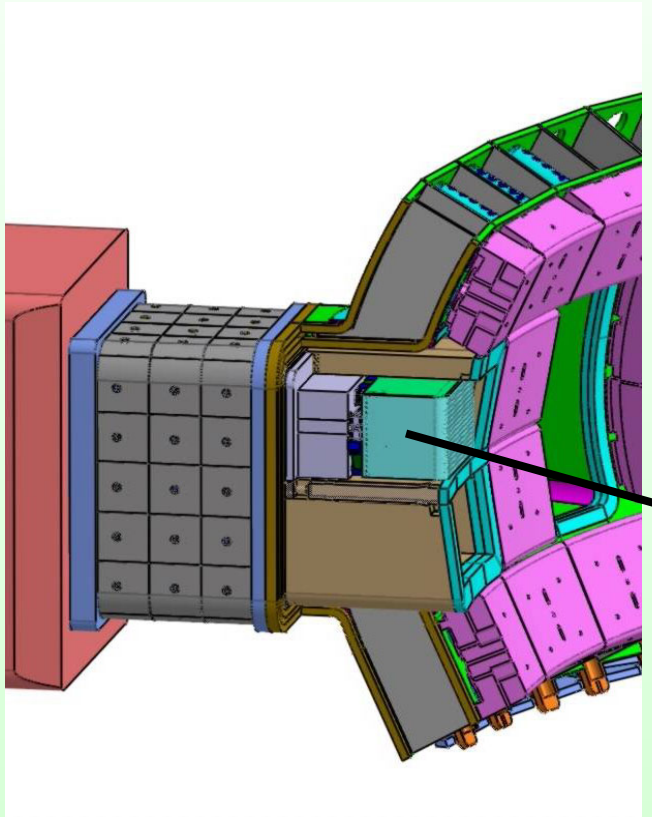


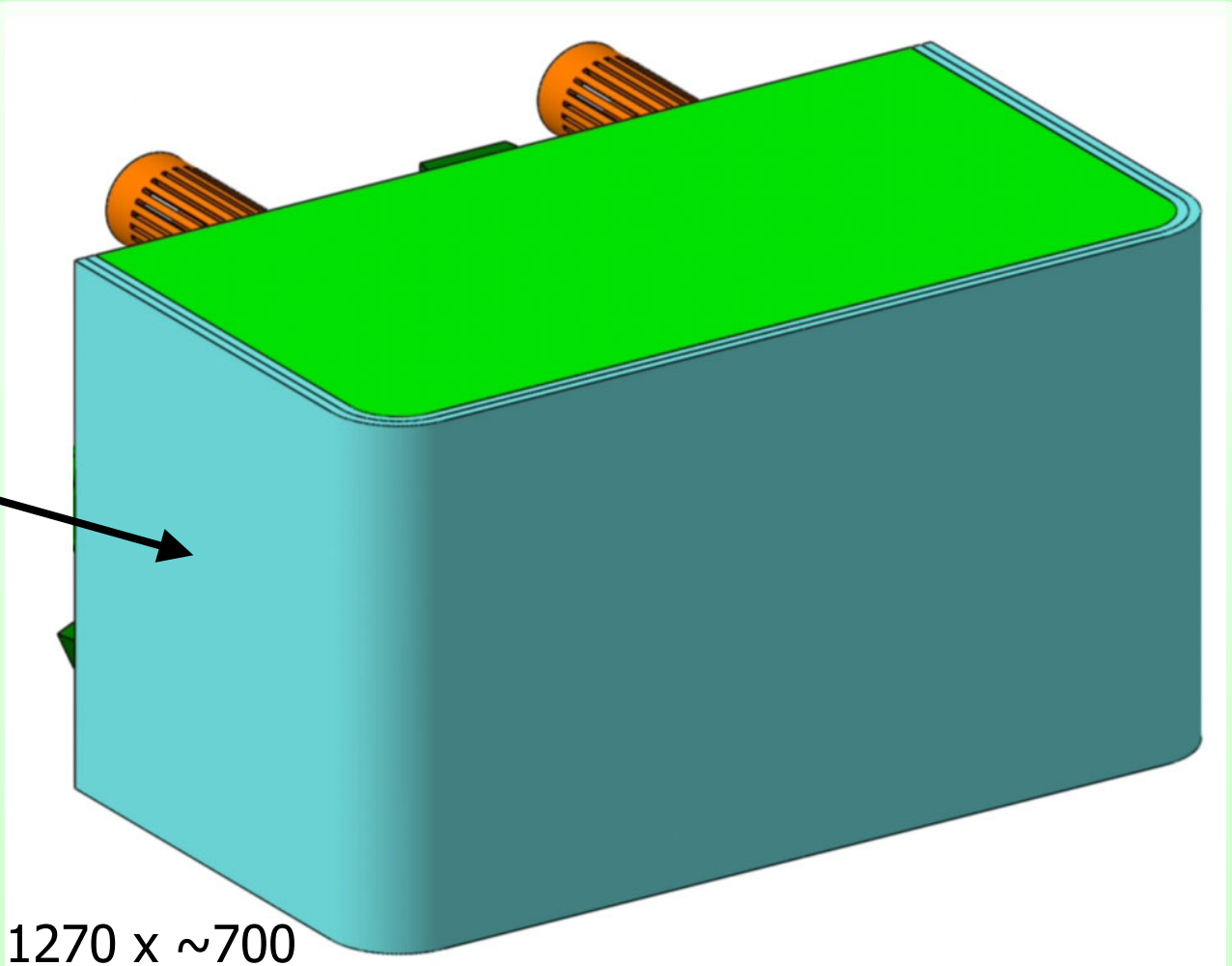
DEMO HCPB coolant flow scheme



2. HCPB TBM Design

HCPB Test Blanket Module

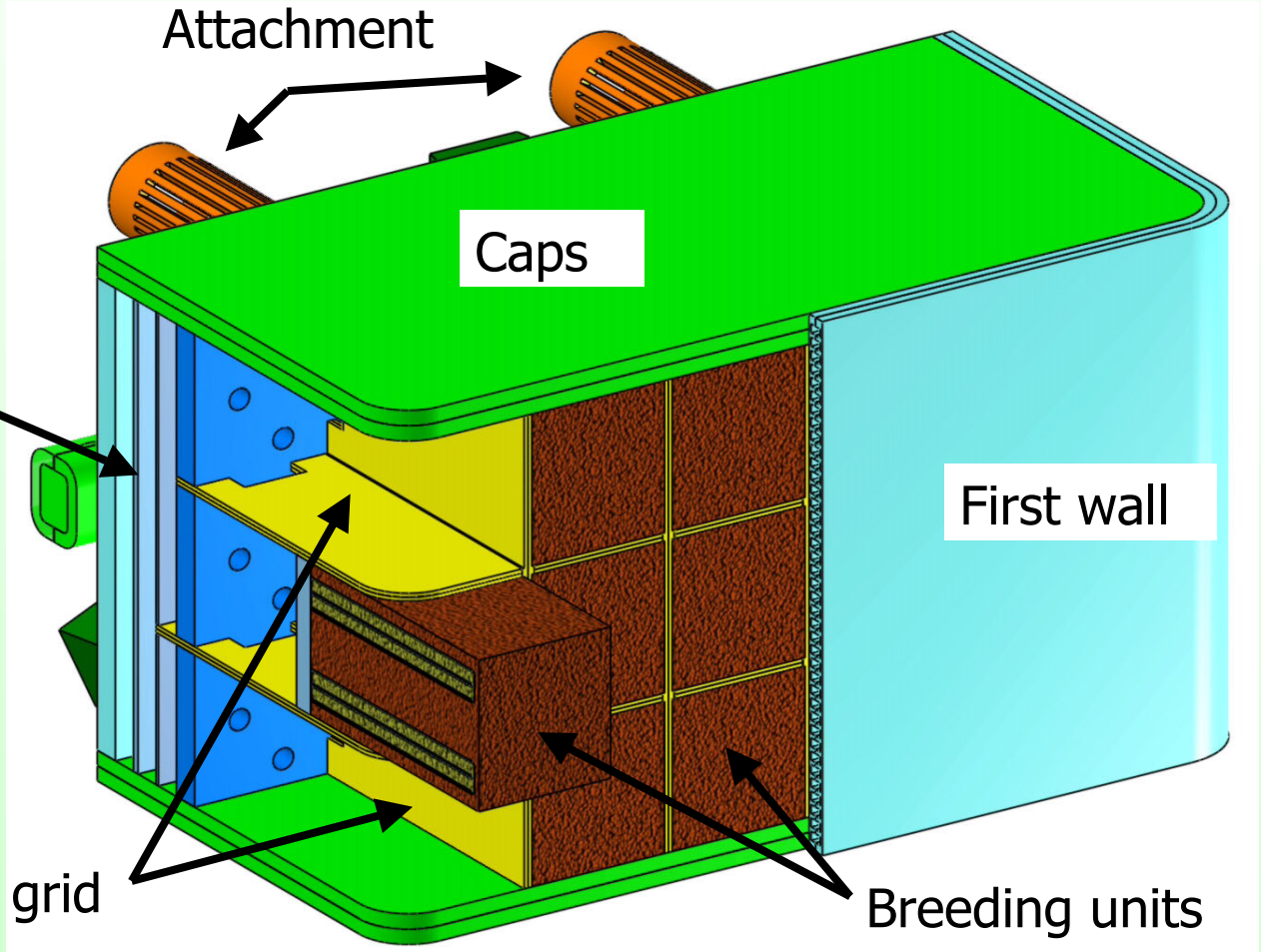




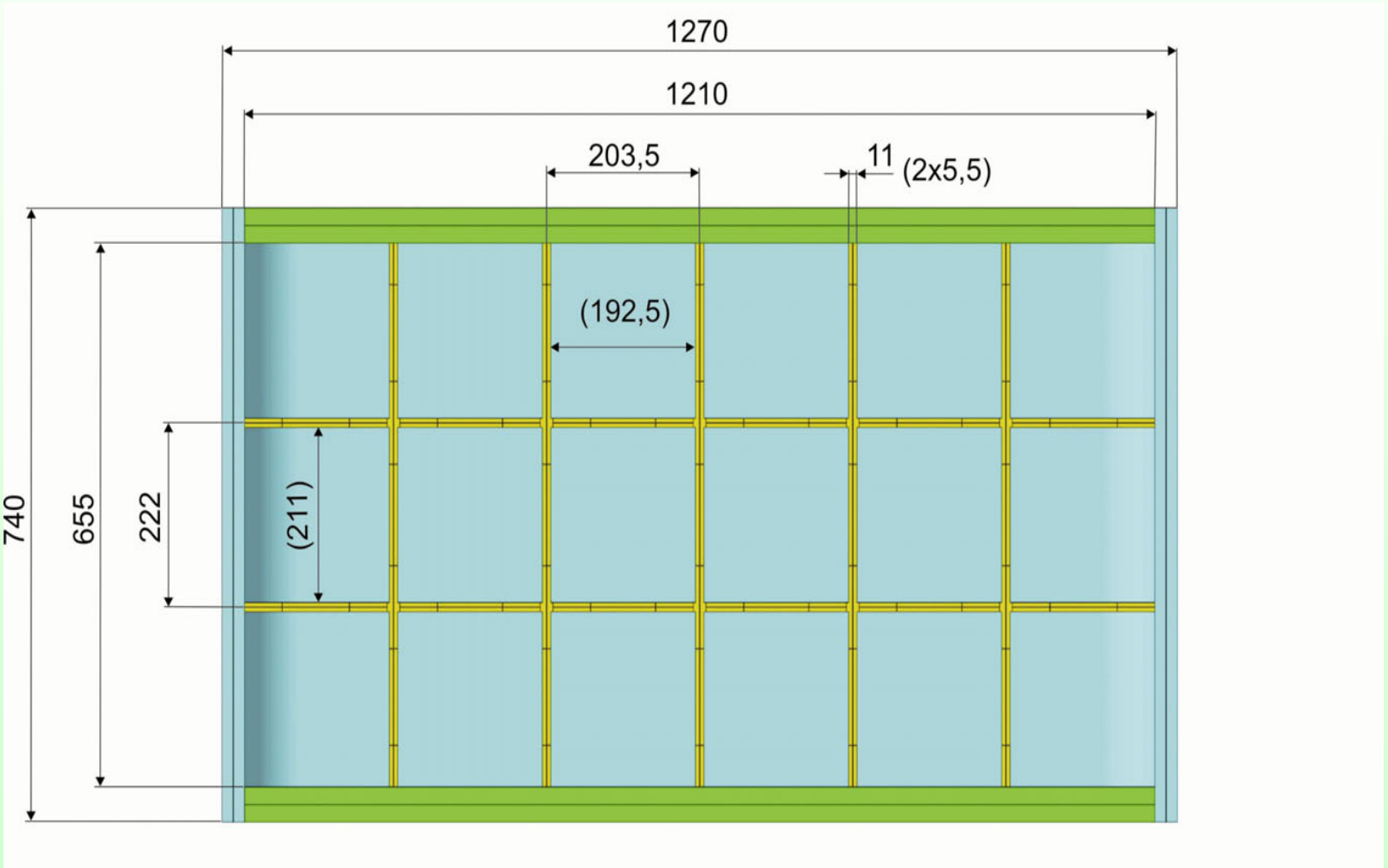
Orientation: horizontal

Dimensions (in mm): 740 x 1270 x ~700

HCPB TBM Design 2003



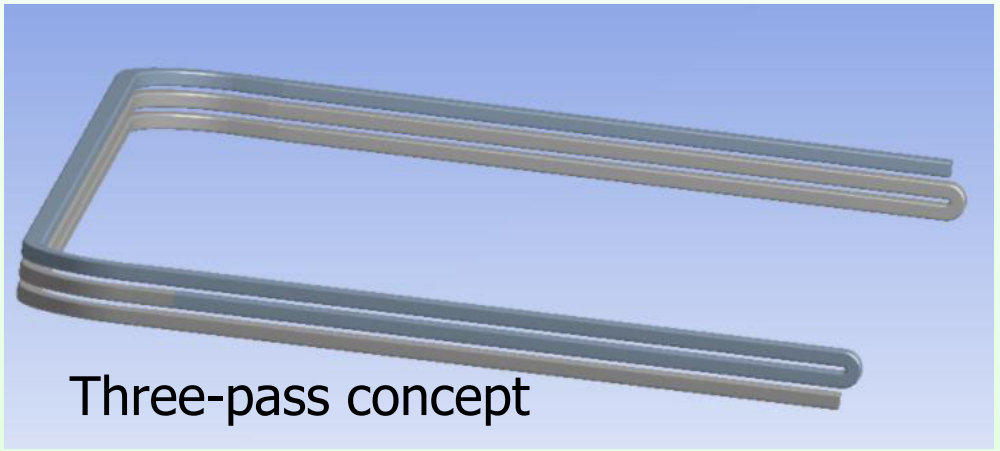
Modular design (18 Breeder Units)

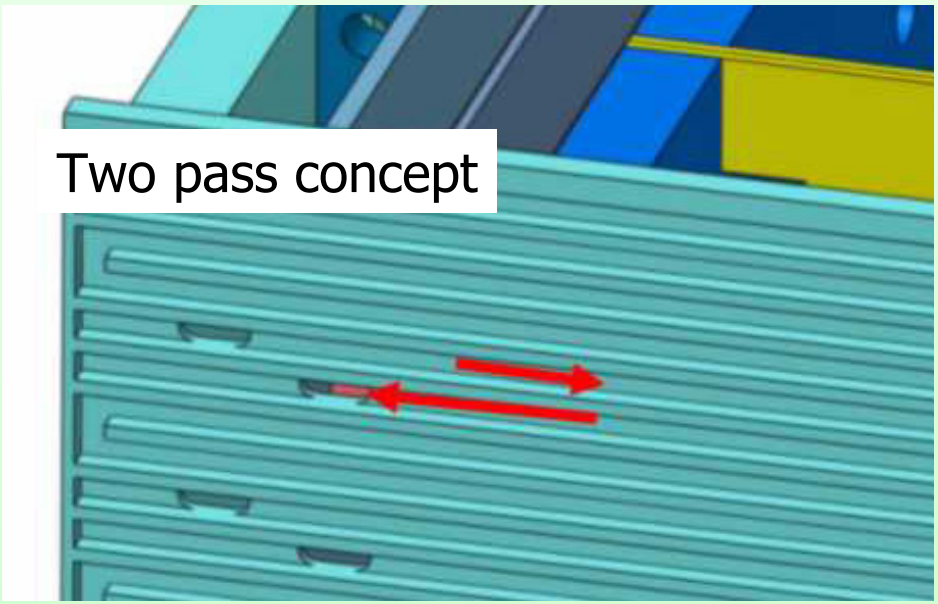


First Wall Lay-out

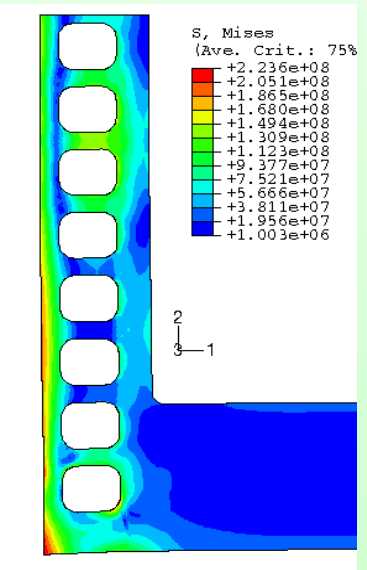
He velocity ~ 80 m/s

Max heat flux : 0.5 MW/m^2





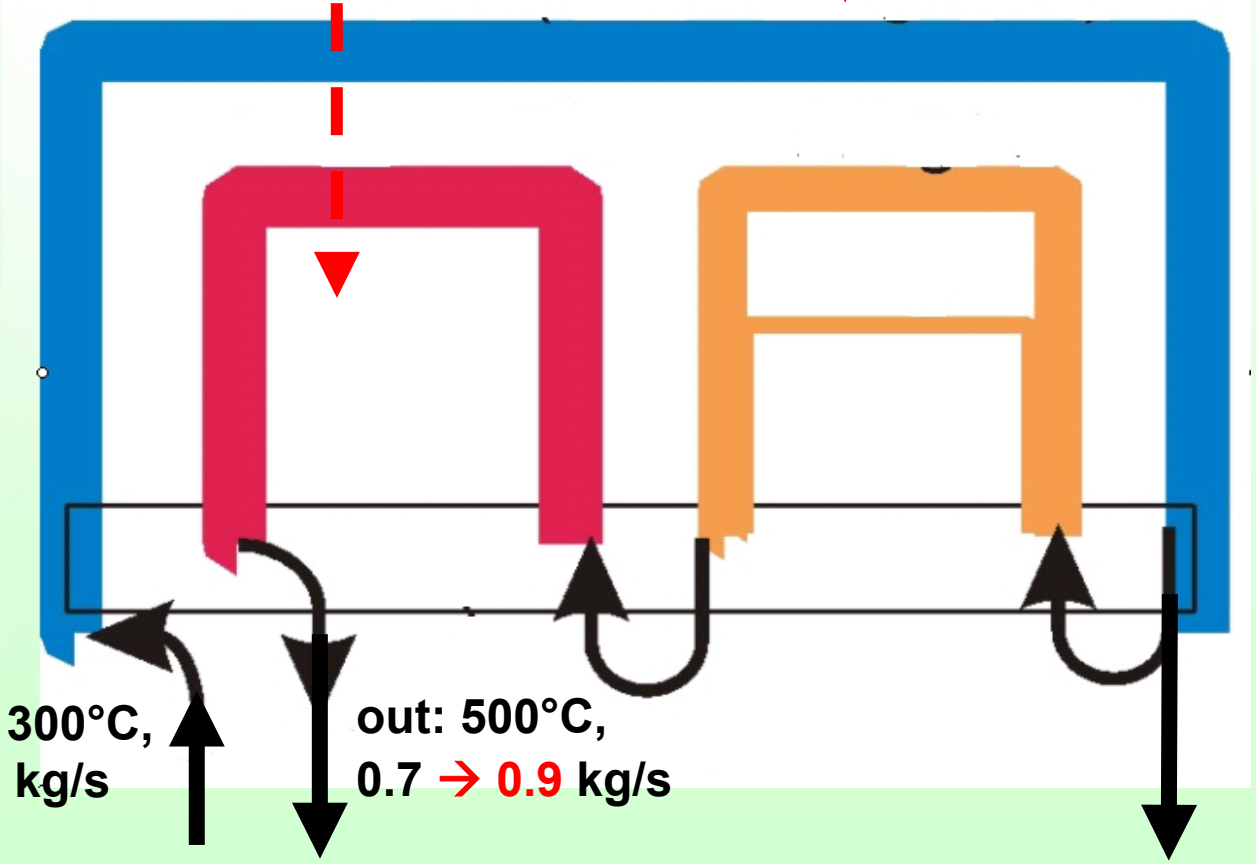
Stress analysis for 3-pass concept indicates an acceptable stress level



He coolant flow through the TBM

Neutron wall load 0.78 MW/m²

Surface heat flux 0.25 MW/m² → 0.5 MW/m²

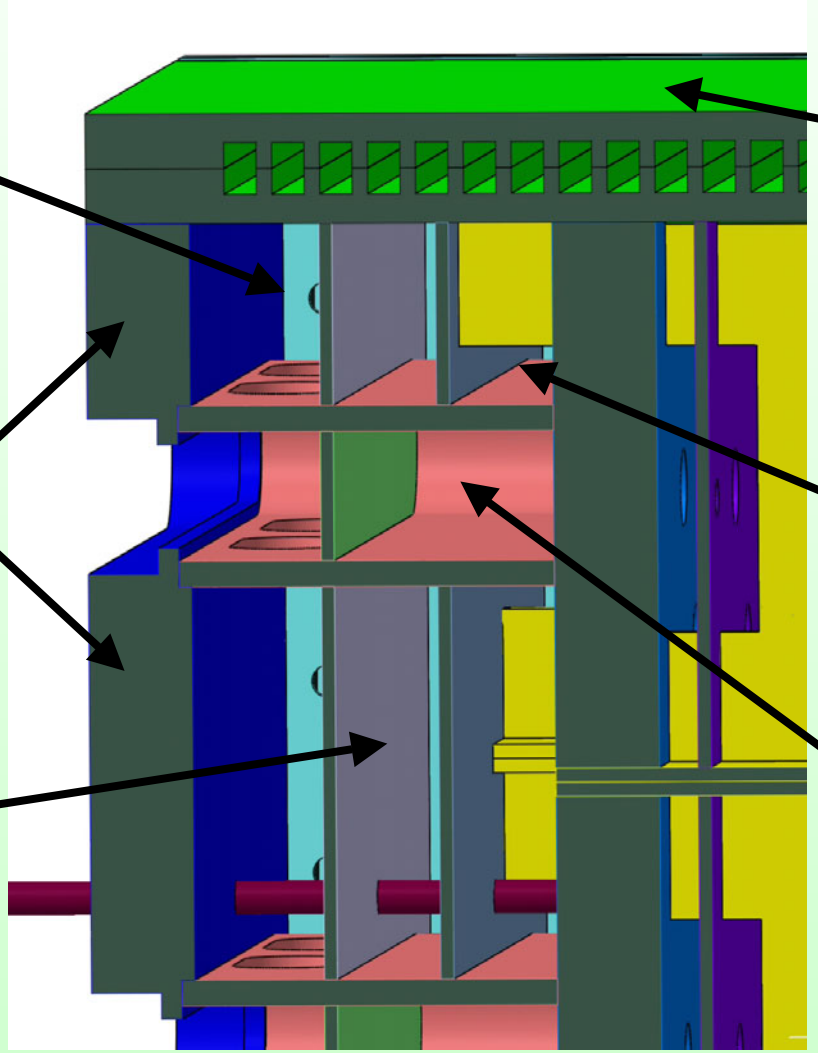


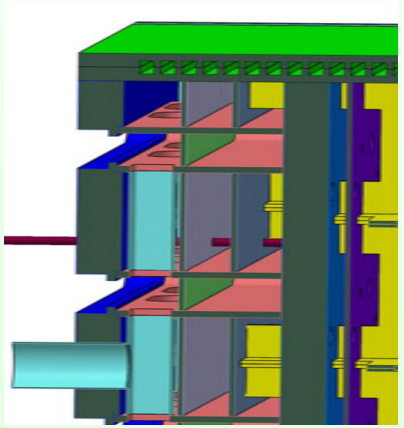
in: 300°C, 1.3 kg/s

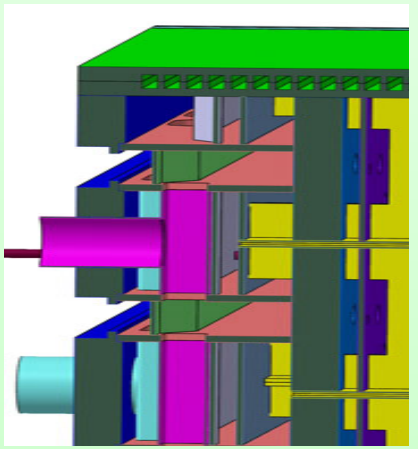
out: 500°C, 0.7 → 0.9 kg/s

by-pass: 360°C →395 °C 0.6 → 0.4 kg/s

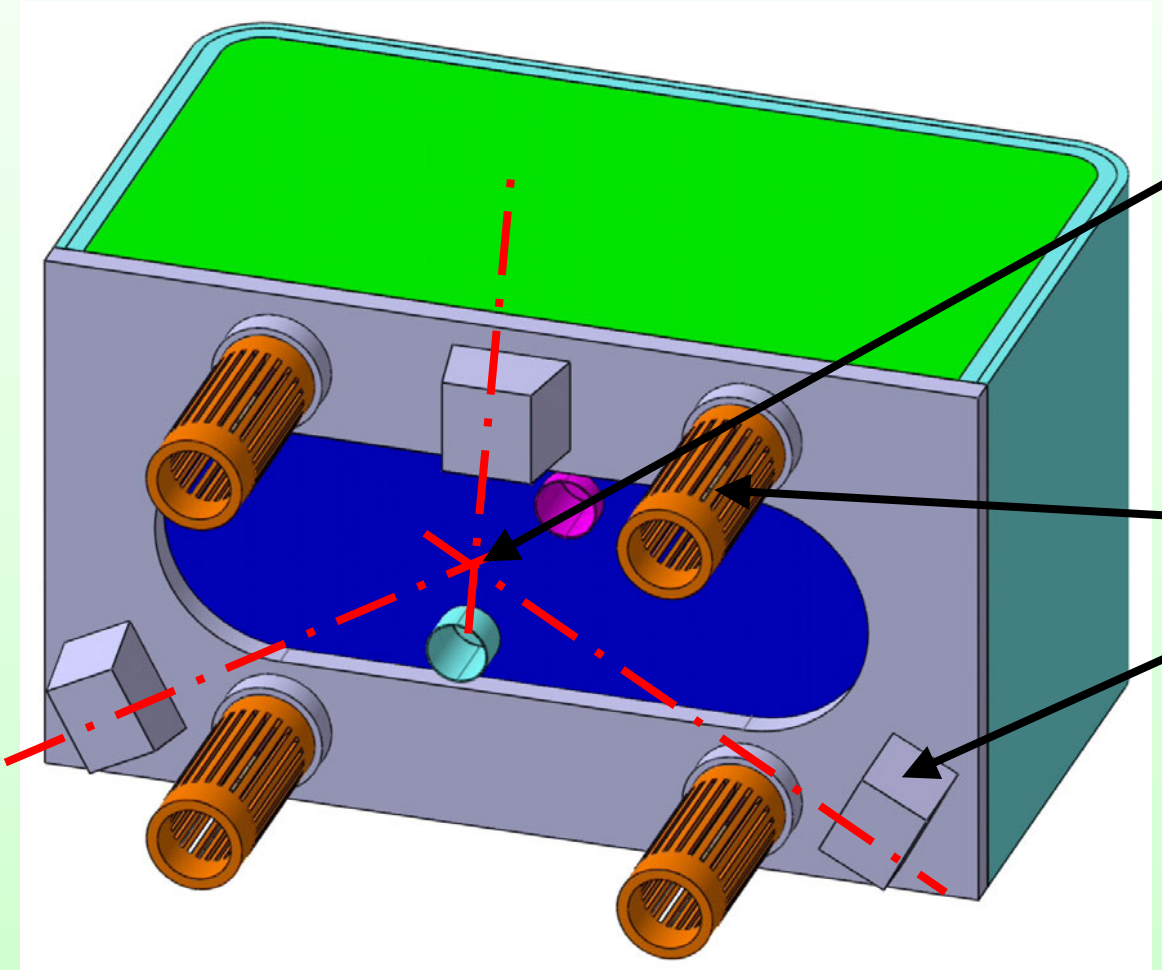
Back plate & Helium coolant manifolds







Mechanical Attachment



Note that the hydraulic connections shown in the drawing are strongly simplified.

3. TBM Qualification Programme

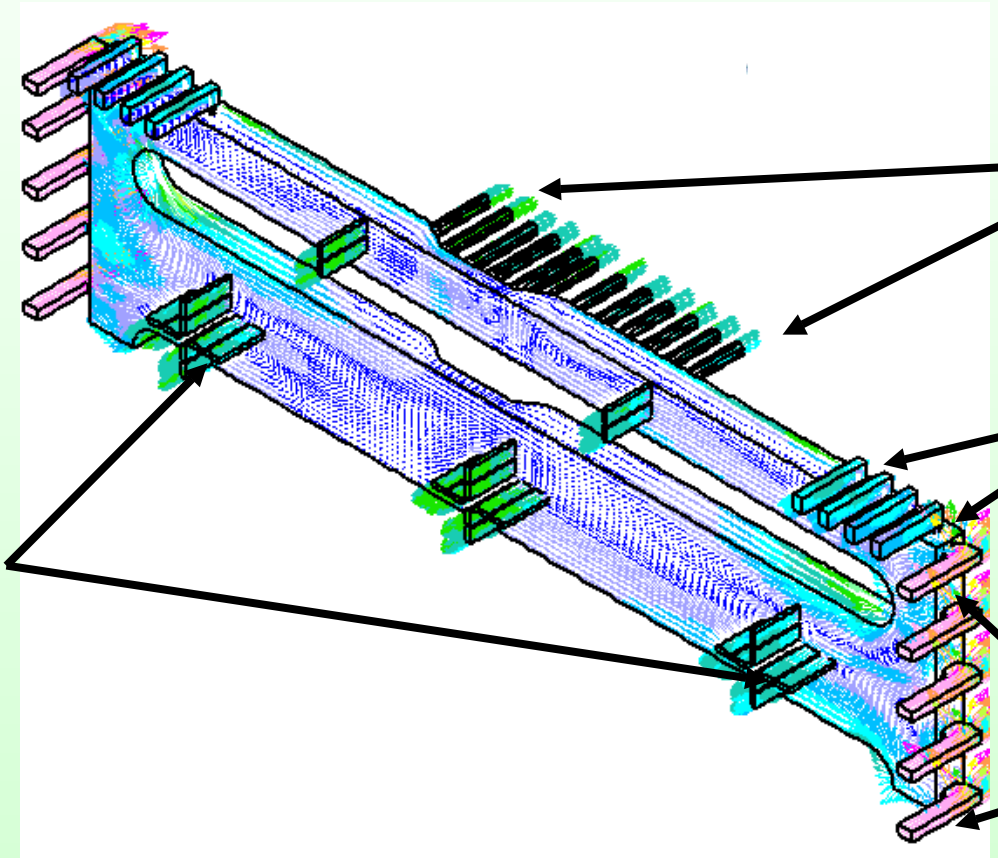
Programme

1) Sub-component tests
   - Manifold flow distribution
   - FW Testing (pressure loss and heat transfer)
   - BU Testing (development of 1:1 ceramic/Be units)
   - Six-cell experiment on box qualification

2) Integral tests (functional tests)
   - 1:3 integral tests
   - 1:1 integral tests

3) Commissioning tests
   - Component commissioning
   - System commissioning

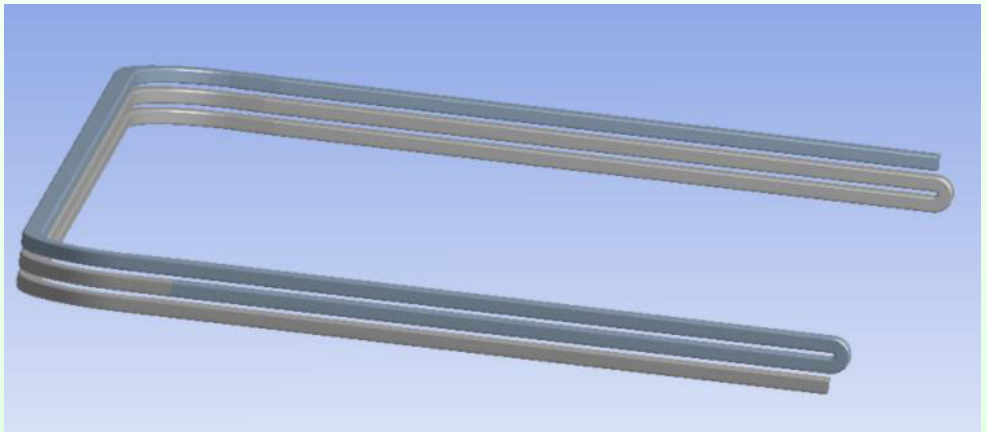
Helium coolant tests for manifold 2 (MF2)

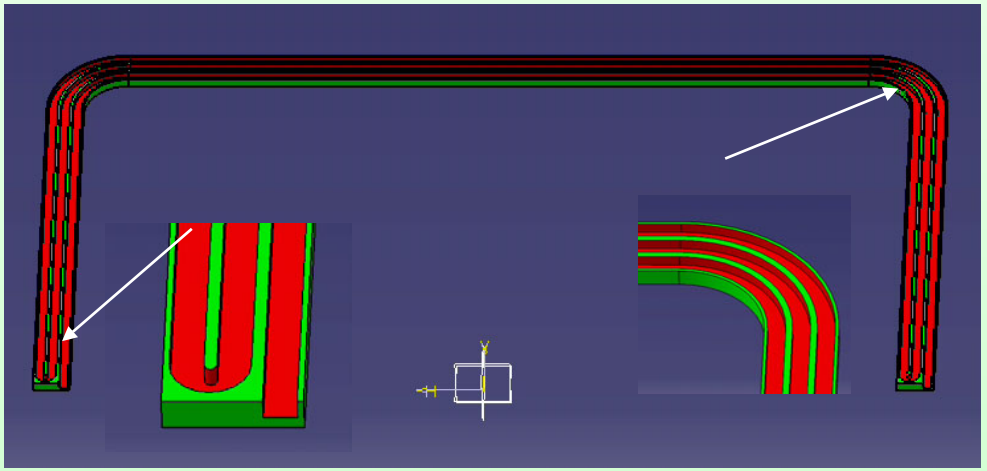


Correct Partitioning of coolant flow
homogeneous supply of grid and cap are investigated

FW cooling tests

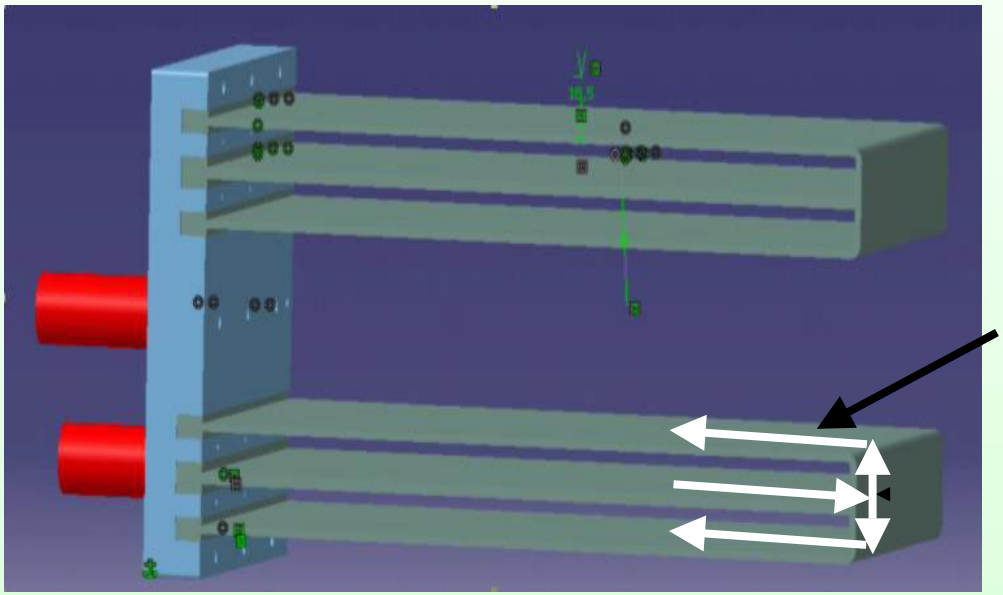
Typical FW coolant channel with 3d bends





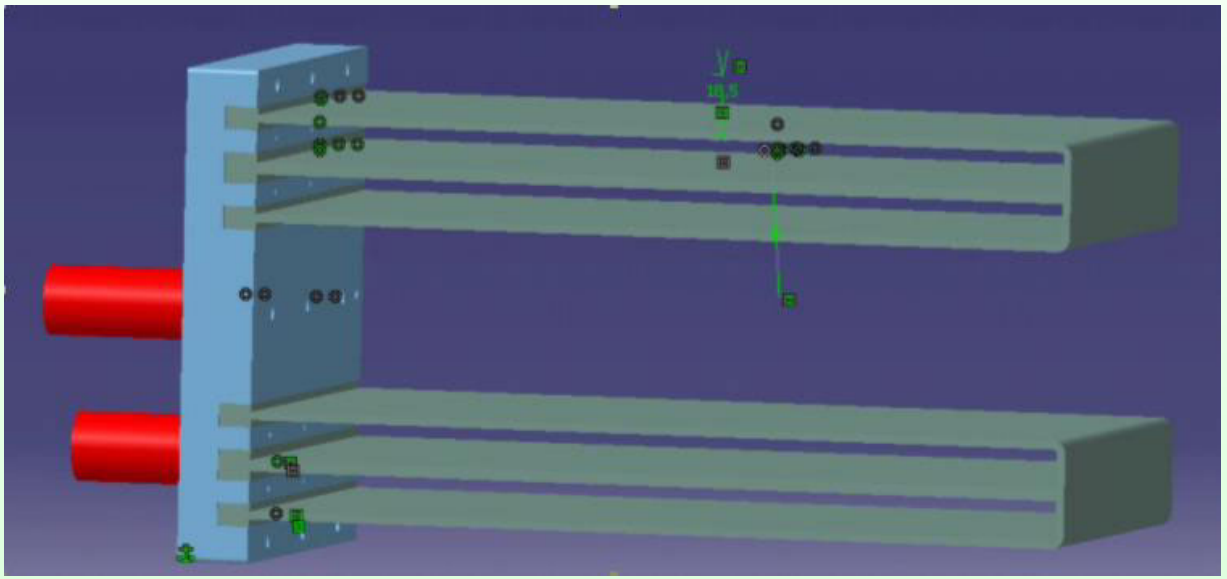
Test to investigate HTC and friction losses in typical geometry for He flow at Re number above 2.2e+5 with bends in 2d

Breeding units functional tests



Start with investigation of mass flow in the 40/80 channels of the „W" container walls up to the functional test of the complete unit, i.e. thermo mechanic of pebble bed, Hydrogen (T) permeation

Breeding units fabrication tests



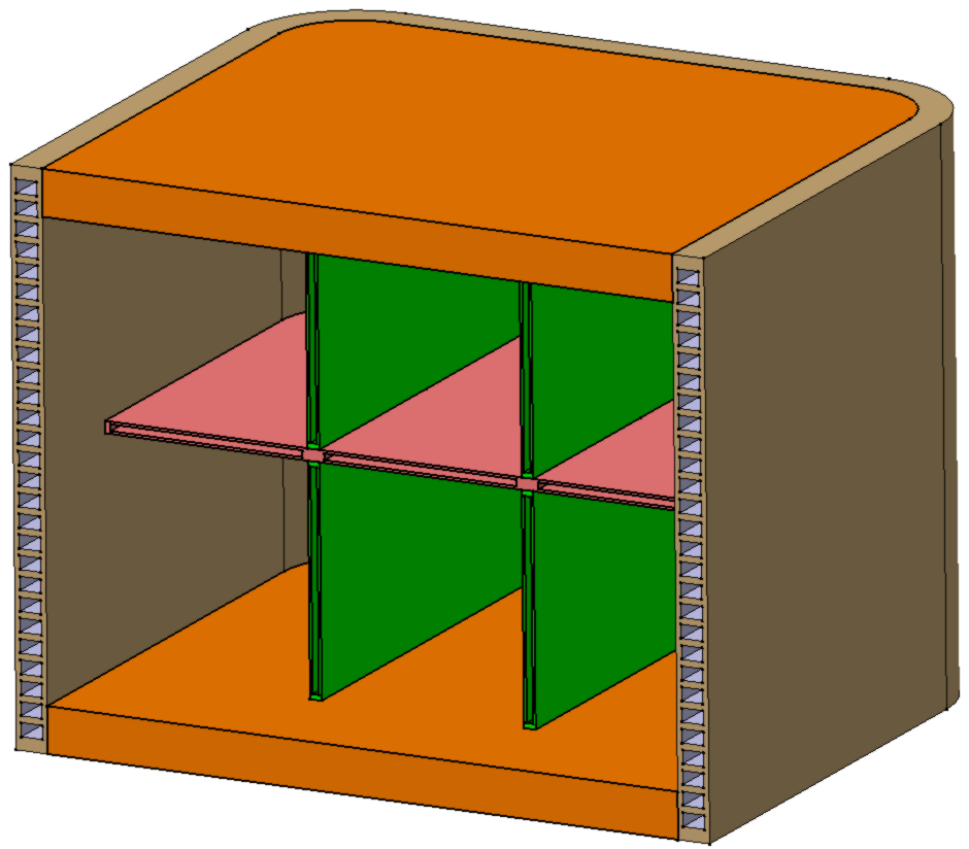
Criteria:

- Dimensions
- Deformations
- Weld quality
- Weld mechanical properties

Techniques:

- Hot Isostatic Pressing (HIP)
- TIG welding
- EB beam welding

TBM fabrication test : 6 cell TBM Box



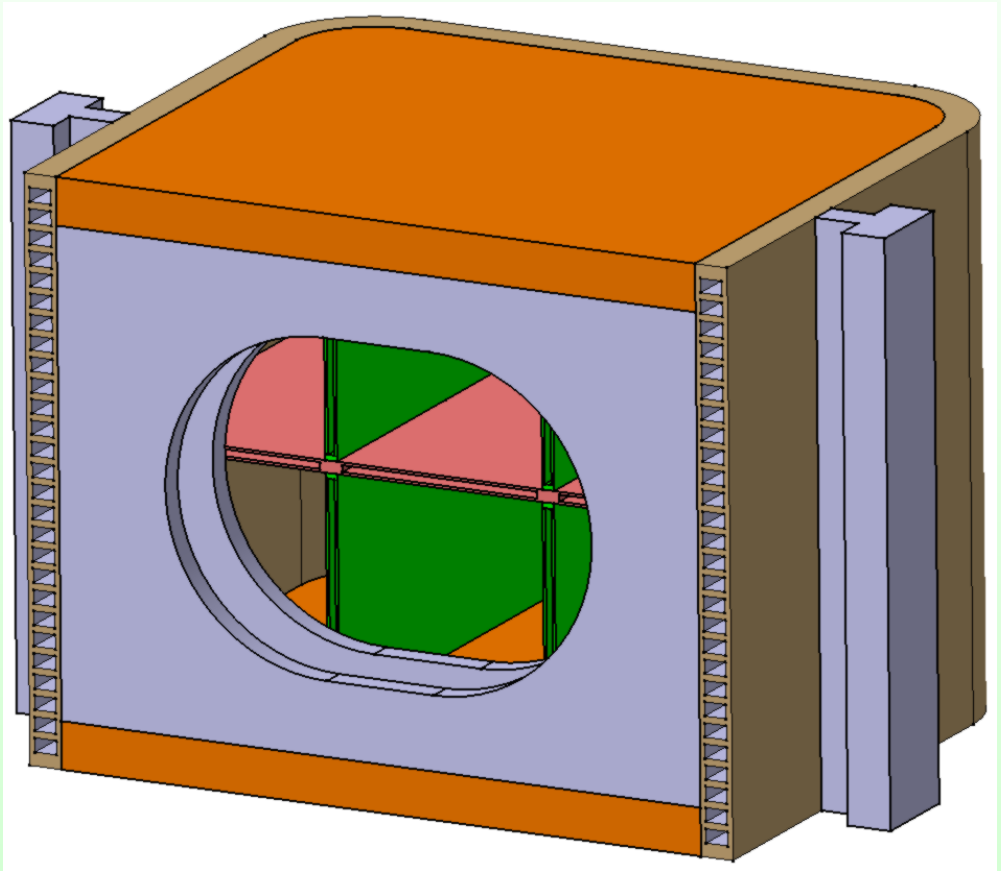
Techniques:

- Hot isostatic pressing
- TIG welding
- EB beam welding
- Bending of FW

Criteria:

- Dimensions
- Deformations
- Weld quality
- Weld Mechanical properties

Functional test for prototypical 1:3 mock-up

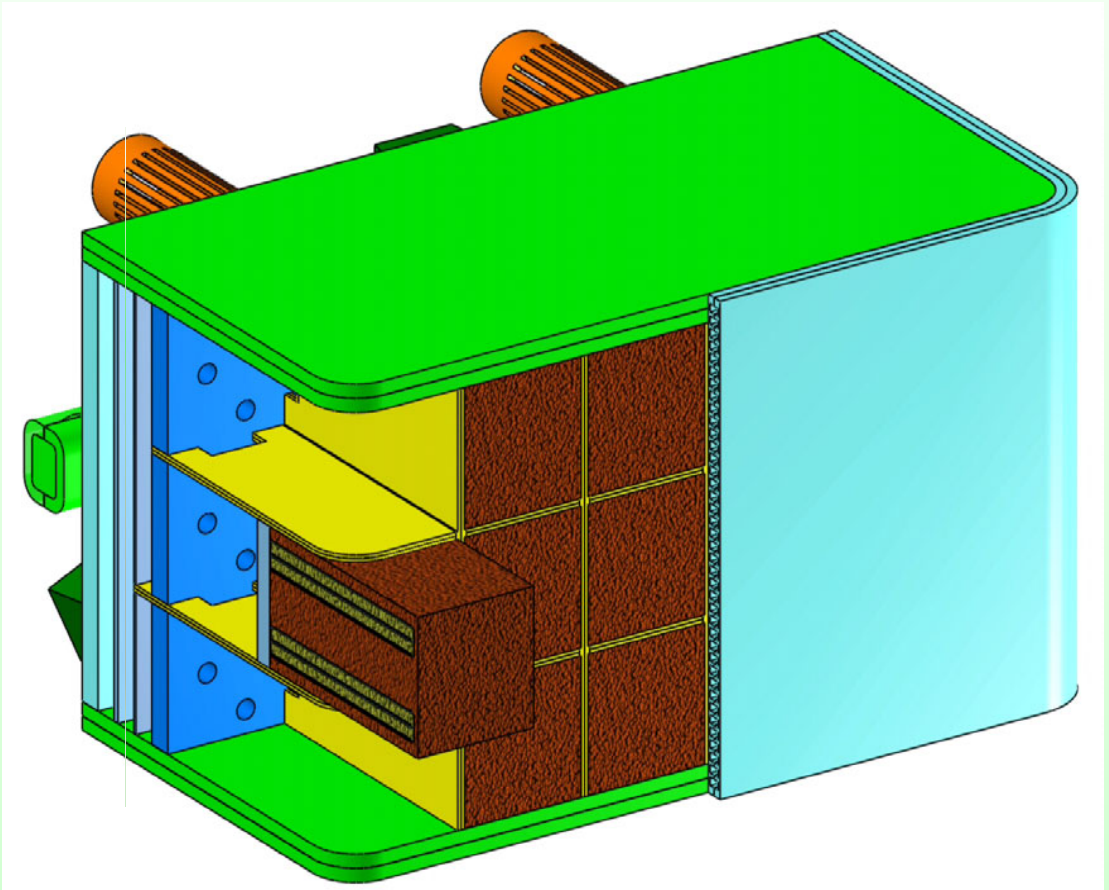


Investigation of

- FW cooling
- Stresses
- Deformations

Check with predictions

Functional test for prototypical 1:1 mock-up



Investigation of

- FW cooling
- Manifolds
- Total friction loss

- Stresses
- Deformations

- Steady state and transient

- Operational and upset conditions

- Check with predictions

Envelop He requirements for HCPB TBM sub-components testing/qualification

Test	Mock-up size	He flow [kg/s]	P, ΔP [MPa]	T He in/out [°C]	Power supply [kW]
Separate tests of FW, HETRA	up to 1:1 but only 3 channels	0.05–0.22	8, < 0.1	20-300 / 20-500	300
test of the box in the “six cell mock-up”	1/3 (2x3 cells)	max 0.4	8, <0.2	300/400	FW : 170 BZ : tbd
BU tests	1 unit at 1:1 size	0.05	8, < 0.1	300-400 / 550	30 – 50

Envelop He requirements for HCPB TBM functional testing of prototypical mock-ups

Test	Mock-up size	He flow [kg/s]	P, Δ P [Mpa]	T He in/out [°C]	Power supply [kW]
1) Functional testing of 1:3 TBM prototypical mock-up	1/3 (2x3 cells)	max 0.4	8, <0.3	300/500	FW : 170 BZ : 240
2) Functional testing of 1:1 TBM prototypical mock-up	1/1	max 1.6	8, < 0.3	300/500	FW: 500 BZ: 700

Envelop He-facility requirements for HCPB TBM commissioning for ITER

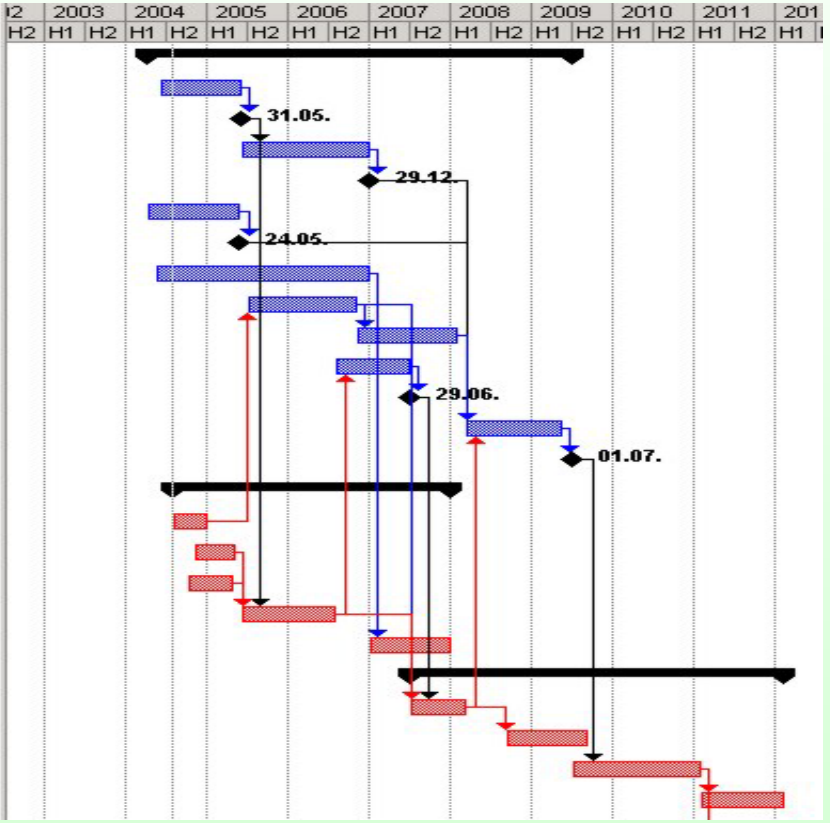
Test	Mock-up size	He flow [kg/s]	P, ΔP [MPa]	T He in/out [°C]	Power supply [kW]
TBM system commissioning tests	Full scale component	tbd	8 nom. + 20% tbd	300-500 > 500 is TBD	FW: 500

Typical Helium facility for mock-up testing

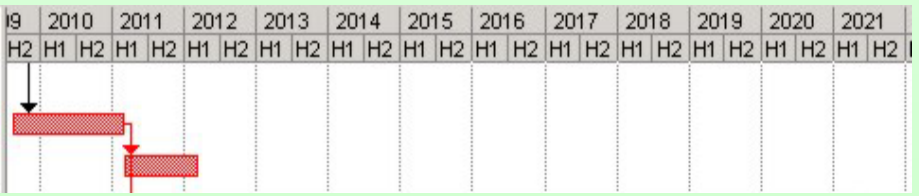
	HEBLO FZK	HE-FUS3 ENEA	HELOKA (planned)
Nominal pressure [MPa]	8	8	8
Mass flow [Kg/s]	0.175 0.33 max	0.05 - 0.35	1.7
Heating/Cooling [MW]	0.115	0.280	1.3
Max. He temp. [°C]	500	500	500
Header/pressure drops [MPa]	0.15	0.5	0.5
Scaling	1:8 small	1:4 medium	1:1 large

Planning Schedule

	Nom de la tâche
1	**Qualification of basic fab. technologies**
2	Fabrication FW mock-up 1/3
3	*FW Mock-up 1/3 fabricated*
4	Fabrication FW mock-up 1/1
5	*FW Mock-up 1/1 fabricated*
6	Fabrication Grid mock-up
7	*Grid Mock-up fabricated*
8	Fabrication BU units (1/1)
9	Manifold fabrication (1/3)
10	Manifold fabrication (1/1)
11	Fabrication of a 1/3 mock-up
12	*1/3 mock-up fabricated*
13	Fab 1/1 TBM prototype
14	*1:1 mock-up fabricated*
15	**Subcomponent Testing**
16	Manifolds Thermohydralic test (with air)
17	FW thermohydraulic tests (small scale)
18	Grid Plate thermo-hydraulic tests (small scale)
19	FW-Grid mock-up tests (HE-FUS3)
20	Tests of BU
21	**Integral testing**
22	1st Test 1/3 TBM proto mock-up (EBBTF)
23	2nd Test 1/3 TBM proto mock-up (EBBTF)
24	1st test 1/1 TBM proto mock-up (HELOKA)
25	2st test 1/1 TBM proto mock-up (HELOKA)



	Nom de la tâche
23	2nd Test 1/3 TBM proto mock-up (EBBTF)
24	1st test 1/1 TBM proto mock-up (HELOKA)
25	2st test 1/1 TBM proto mock-up (HELOKA)



4. Testing in ITER

Test blanket modules planned for ITER

1. Electro magnetic module (EM)
   ⇒ to investigate electro magnetic behavior during disruptions
2. Neutron and Tritium module (NT)
   ⇒ to investigate neutron spectra in a BU, Tritium production
3. Thermo mechanic module (TM)
   ⇒ to investigate behavior of pebble beds
4. Plant integration module (PI)
   ⇒ to investigate module behavior during long pulses and Tritium recovery

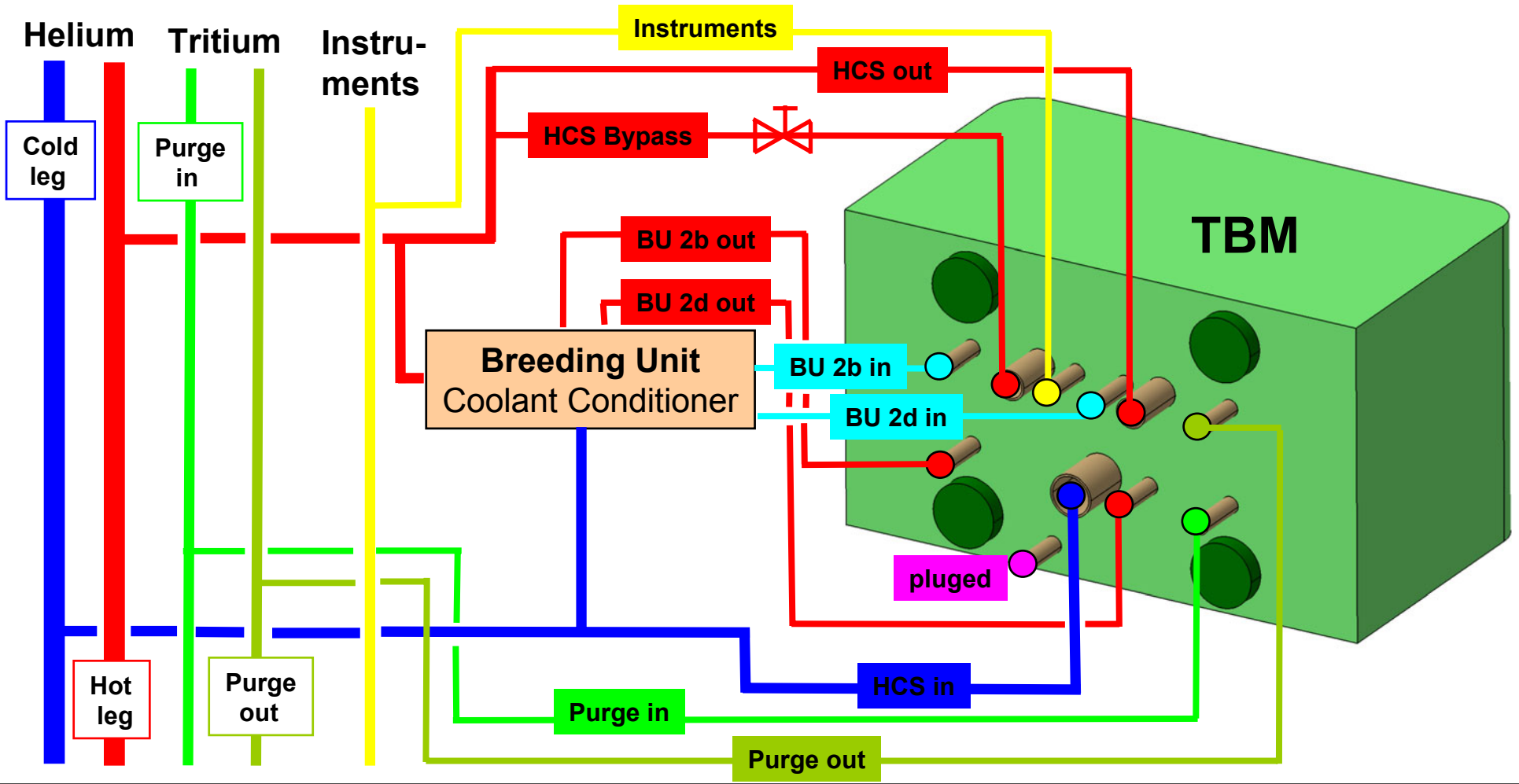
Time schedule of TBM tests in ITER

Operational year	**-2**	**-1**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
ITER Master schedule	**first plasma**		**H-H**			**D-D**	**Low duty D-T**			**High duty D-T**			**Refurbishm.**	
stand. burn pulse No. / year						**1**	**750**	**1000**	**1500**	**2500**	**3000**	**3000**		
1) EM –TBM														
fabrication and qualification														
operation in ITER														
post test examination														
2) NT –TBM														
fabrication and qualification														
stand-by														
operation in ITER														
post test examination														
3) TM -TBM														
fabrication and qualification														
stand-by														
operation in ITER														
post test examination														
4) PI – TBM														
fabrication and qualification														
stand-by														
operation in ITER														
post test examination														

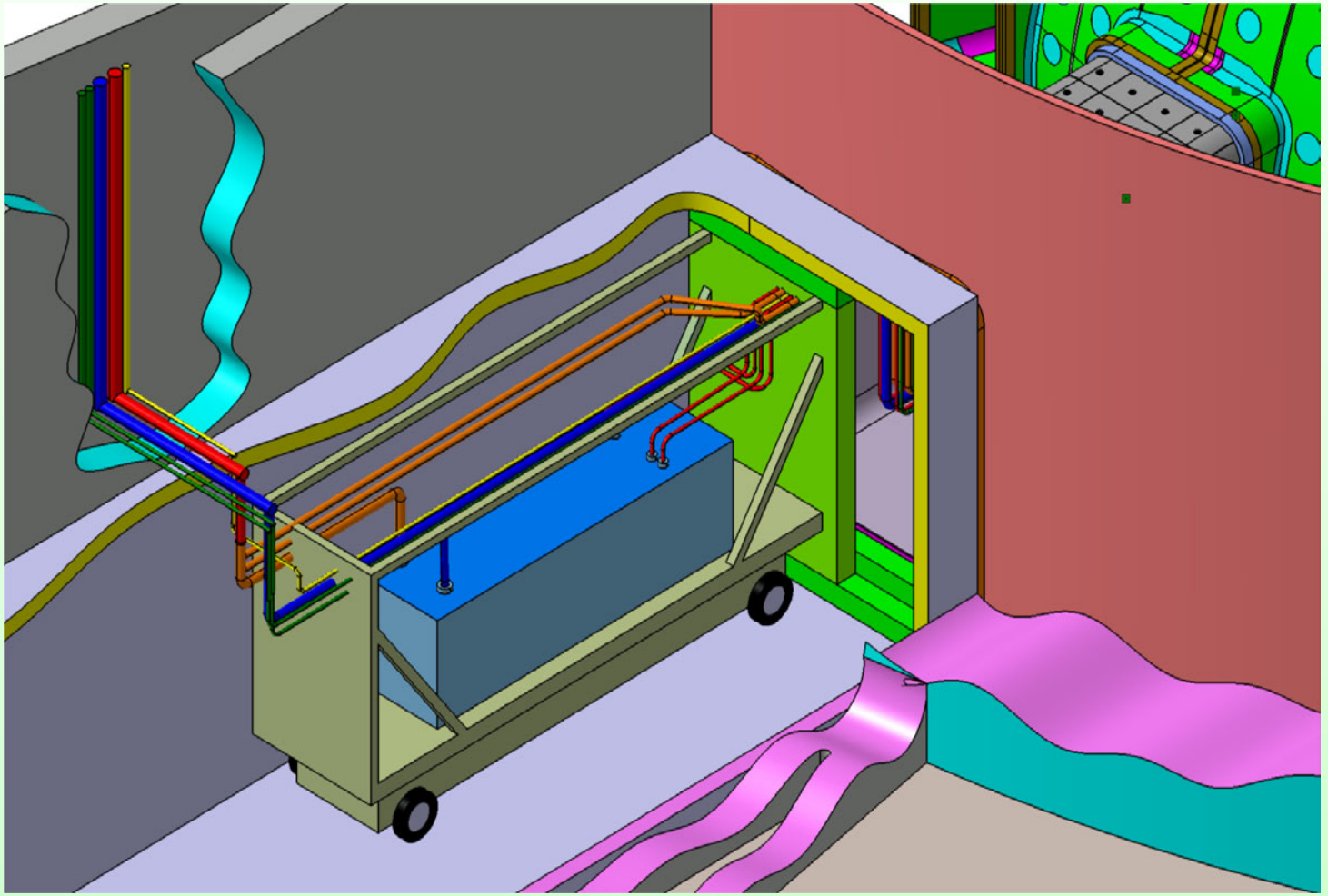
Flexibility of BU tests

- Modularity of BU's allows for testing of various types of BU concepts
  - For achievement of peak temperatures in ceramic and Beryllium different BU designs are needed.
  - There is also the possibility to supply one or two individual BU's with their own coolant, to allow other ITER partners to share

Integration pipes for TM-TBM in port cell



Coolant conditioning for individual BU tests



5. Conclusions

- TBM design replicates a relevant portion of the HCPB DEMO blanket module and leads to DEMO relevant data

- To minimize disturbance of ITER by TBM tests, an extensive qualification programme is needed prior to TBM installation in ITER in terms of
  - Testing of fabrication technologies
  - Tests of sub-component performances
  - Out-of-pile integral tests from in 1:3 to 1:1
  - Commissioning tests

- Modularity of Breeding Units allows for some BU individual temperature control and other BU design testing