International Town Meeting on SiC/SiC Design and Material Issues for Fusion Systems
January 18-19, 2000

Advanced Helium Cooled Pebble Bed Blanket with SiC_f/SiC as structural material

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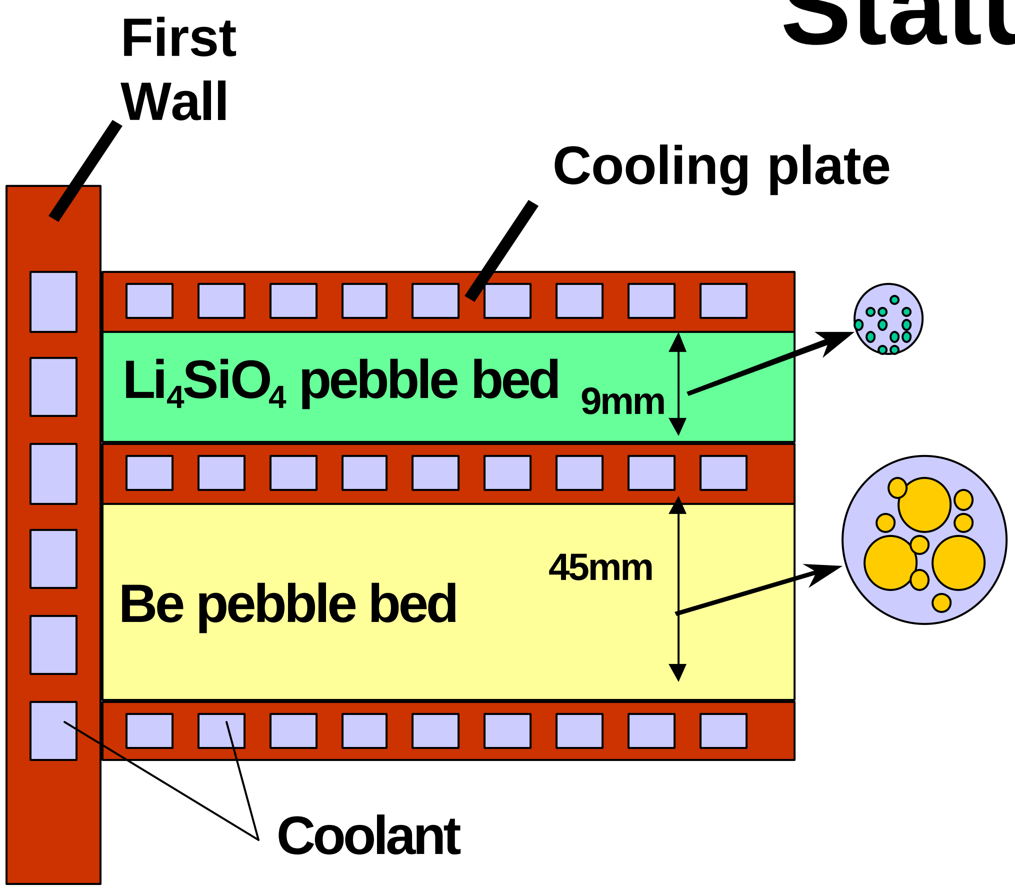
Table of Contents

Introduction

- An European Power Plant study is starting in 2000
- During 1999 a preparatory work has been carried out to select blanket and divertor concepts to be investigated in the study
- FZK carried out a study on an Advanced Helium Cooled concept with SiC_f/SiC as structural material based on the technology of pebble beds (A-HCPB).
- The A-HCPB concept was presented to ISFNT-5, Rome (1999) [L.V. Boccaccini et al.: “Advanced Helium Cooled concept with SiC_f/SiC as structural material “]

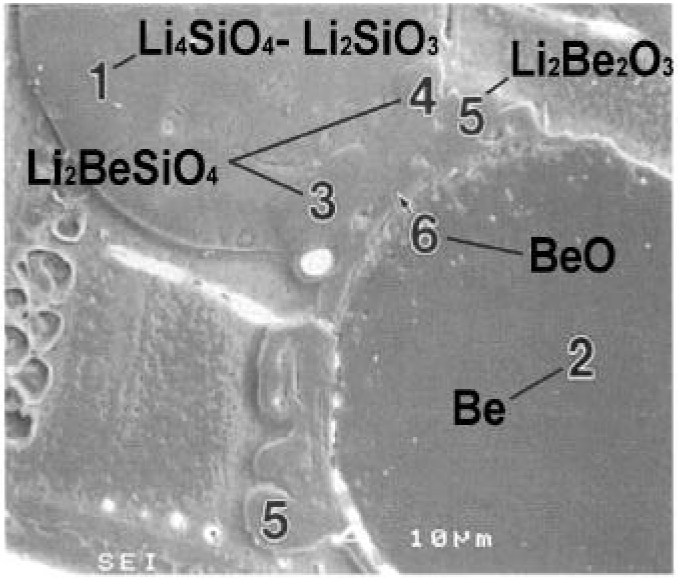
HCPB Blanket Concept for DEMO
Status 1999



Be pebble bed:	binary bed (d_1=1.5-2.3 mm, d_2=0.1-0.2 mm)
Li_4SiO_4 pebble bed:	one size (d=0.25-0.63 mm)
	^{6}Li-enrichment = 40%
Coolant:	He (p=80 bar, T=250 - 450°C)
Purge Flow:	He (p=1 bar, T = 20 - 450°C)
Structural material:	EUROFER

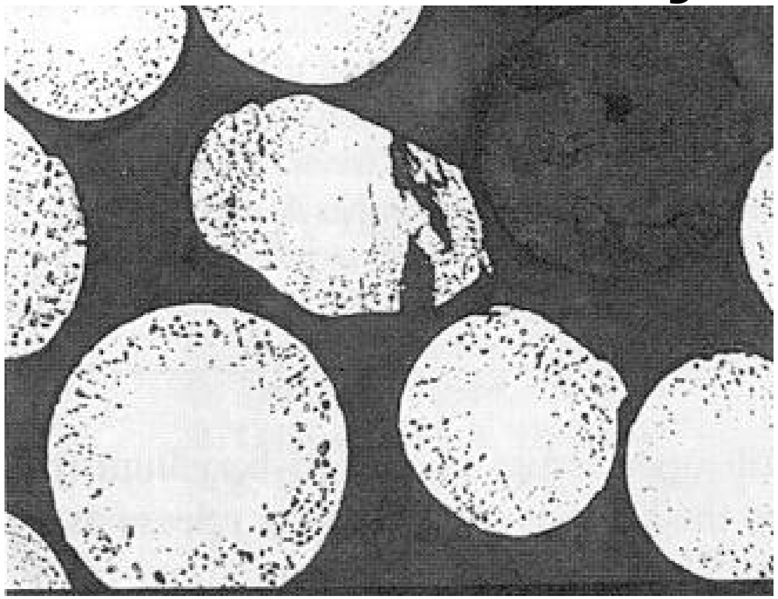
Incompatibility of Li_4SiO_4 and Beryllium in mixed pebble beds

- **Chemical interaction**



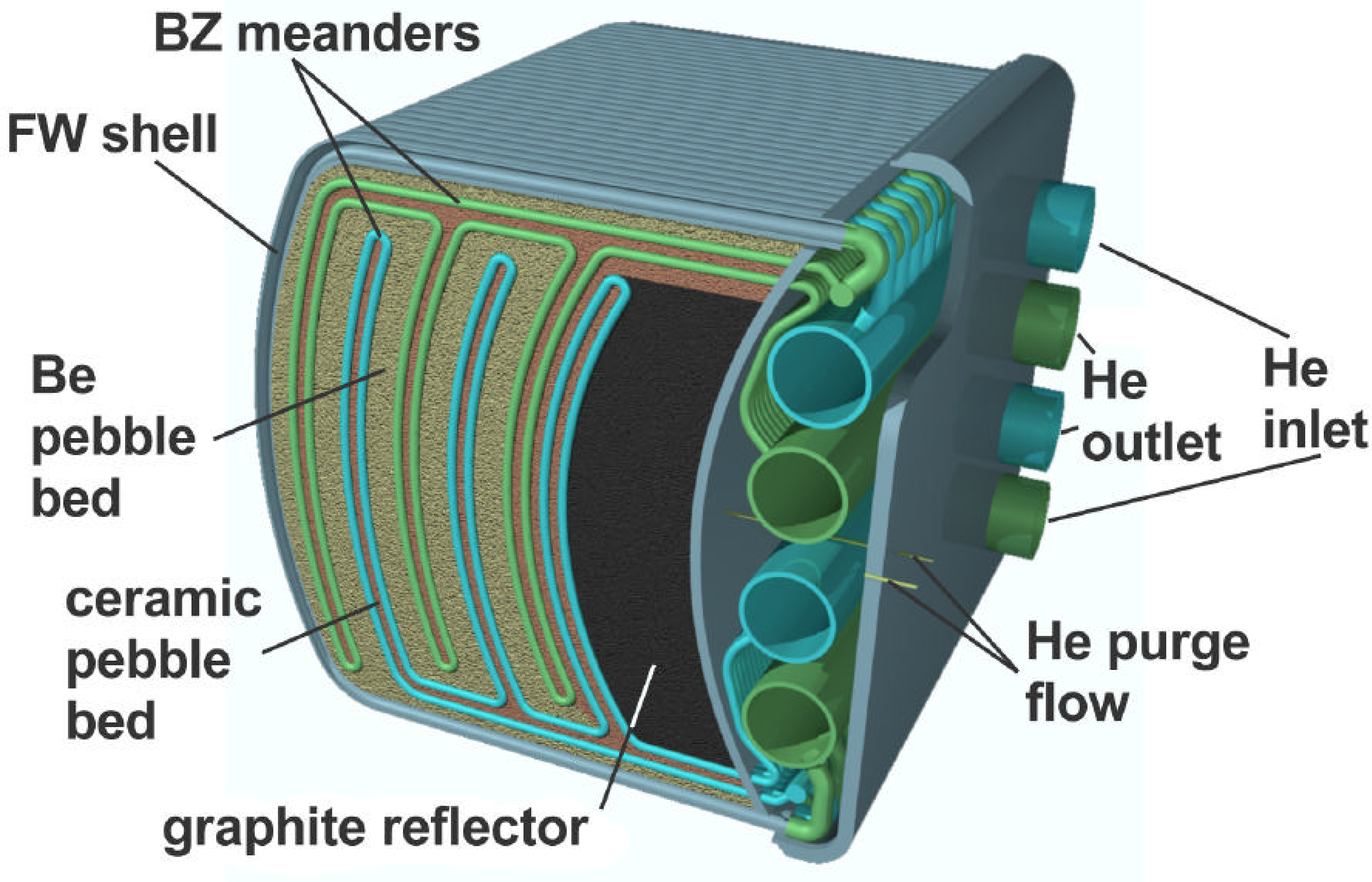
H. Kleykamp, J. of Nucl. Mat. 273 (1999) 171-176

- **Tritium inventory**

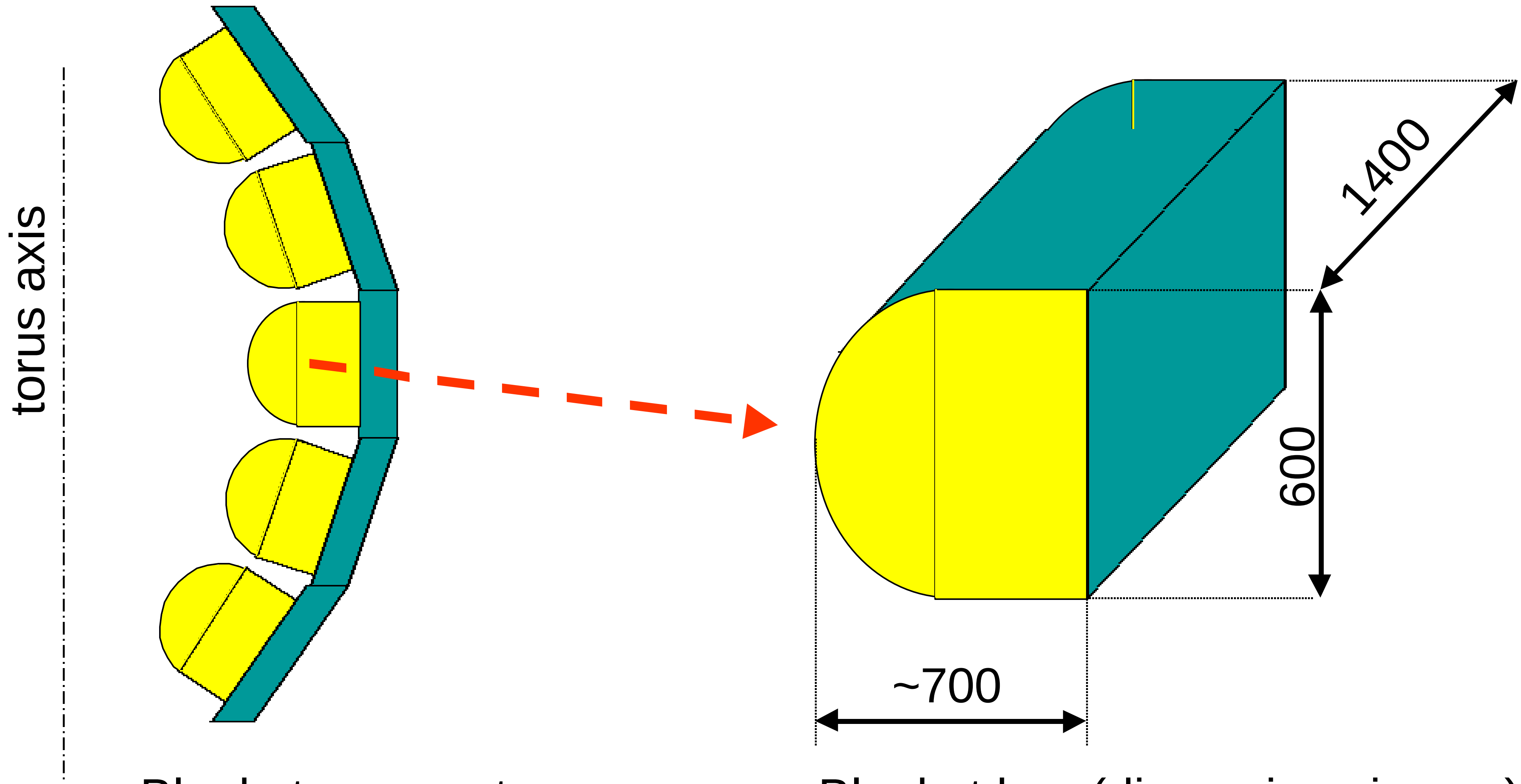


F. Scaffidi-Argentina et al.: J. of Nucl. Mat. 258-263 (1998) 595-600

Advanced HCPB Blanket

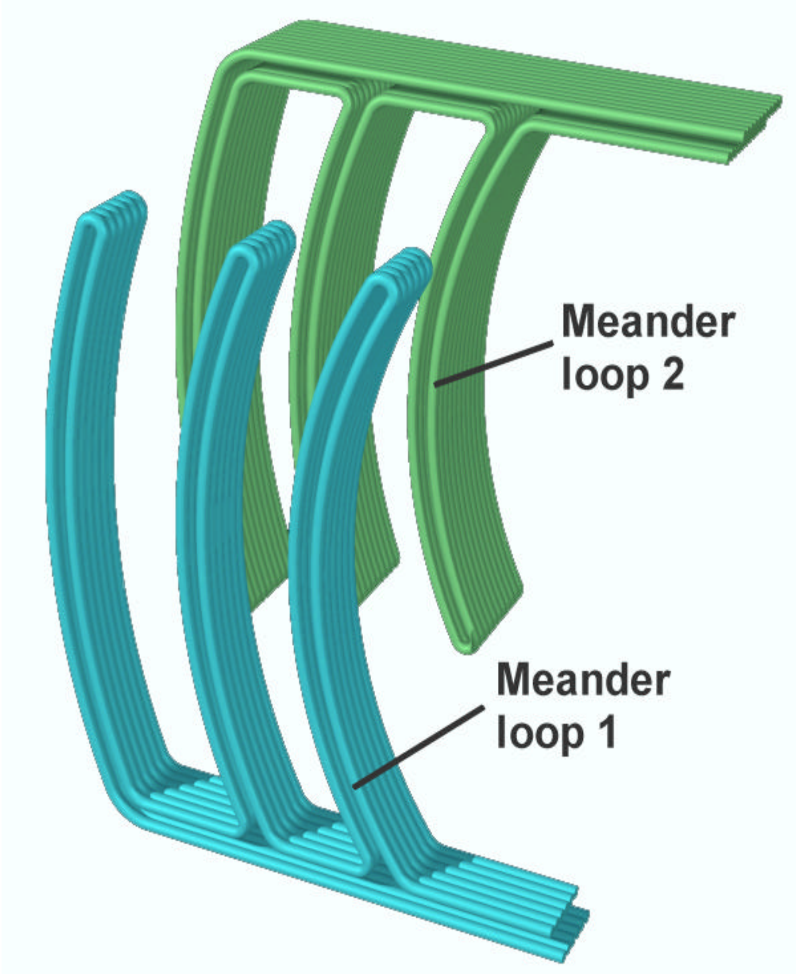


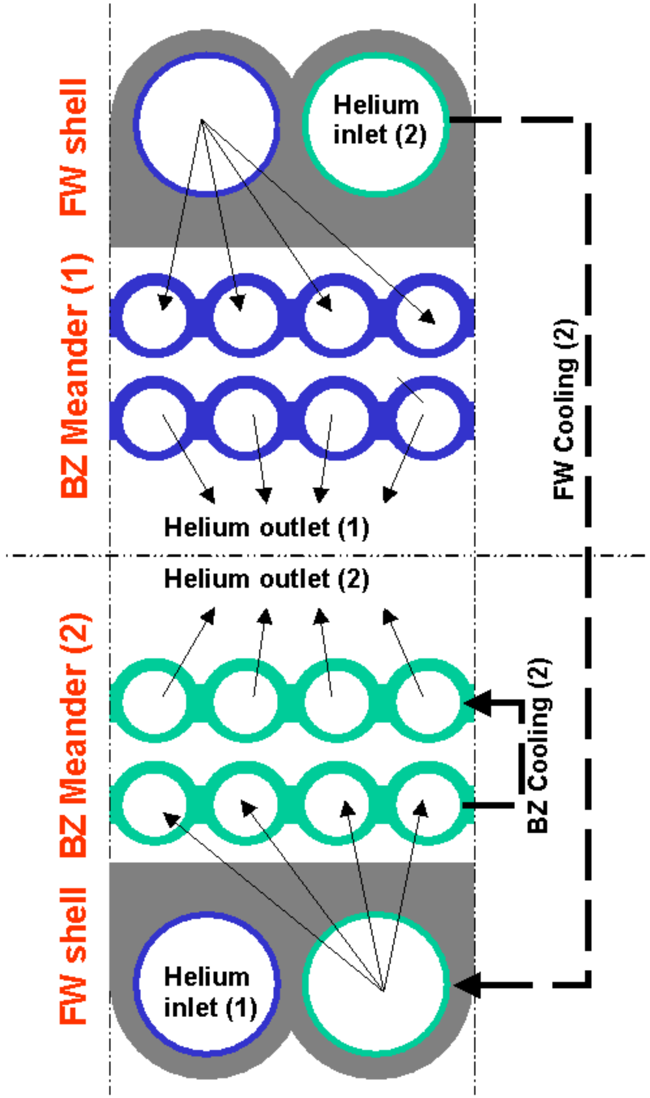
Blanket segment and box



Blanket segment

Blanket box (dimensions in mm)

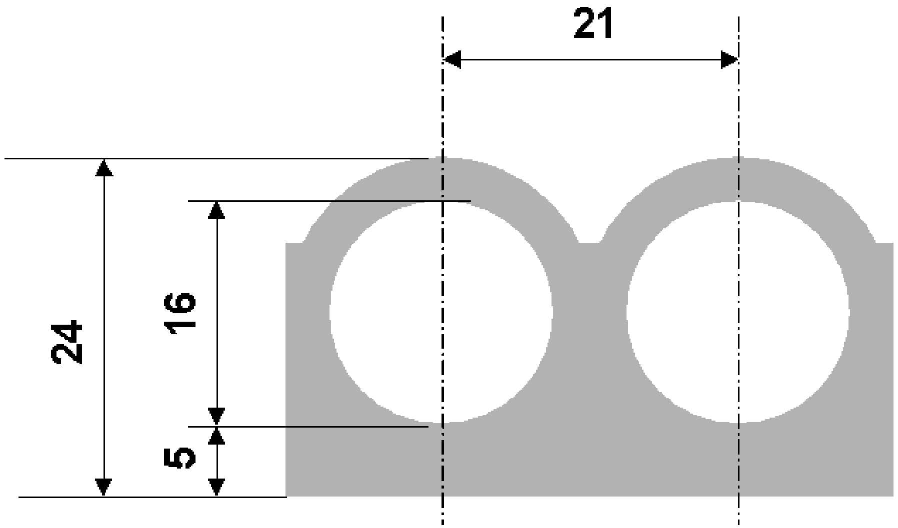




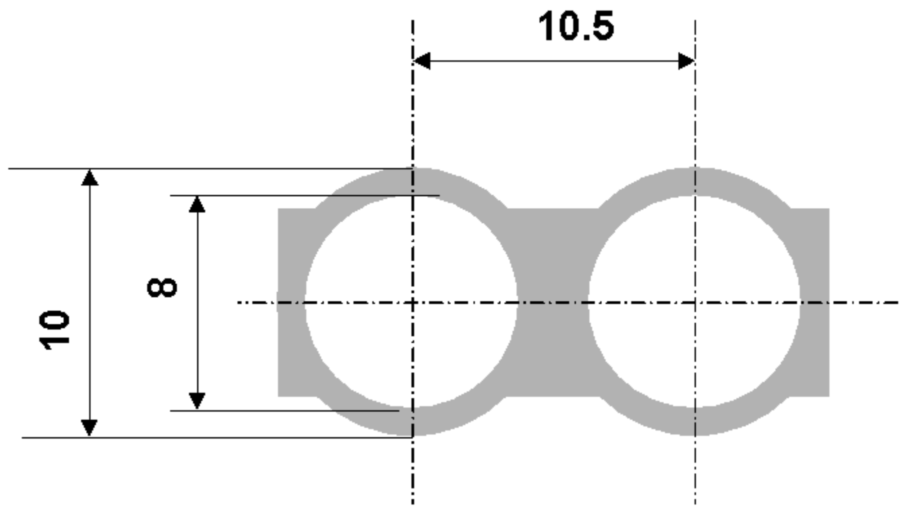
Details of the tubes in form a meander in the BZ

Helium coolant flow schema

Dimensioning of the FW shell and the BZ meanders (in mm)



Section of the FW shell



Section of the BZ meander

Material properties and design limits for Lithium Orthosilicate Pebble Bed

Thermal conductivity (T=500 – 900°C)	1.0 – 1.2 W m^{-1} K^{-1}	M. Dalle Donne et al.: Measurements of the effective thermal conductivity of a Li_4SiO_4 Pebble Bed, ISFNT-5, Rome.
Max. allowable temperature	924°C	U. Fischer et al.: Proceedings of the 20^{th} SOFT (1998), pp.1149-1152
Max. allow. temperature at SiC_f/SiC interface	924°C	H. Keykamp: Chemical reactivity of SiC with Beryllium and ceramic breeder materials, 9^{th} Conf. on Fusion Reactor Materials

Material properties and design limits for Beryllium Binary Pebble Bed

Thermal conductivity (T=500 – 700°C)	25 W m^{-1} K^{-1}	M. Dalle Donne et al.: Experimental investigations on the thermal and mechanical behaviour of a binary beryllium pebble bed, ISFNT-5, Rome.
Max. allowable temperature	700°C	F. Scaffidi-Argentina et al., Beryllium R&D for fusion applications, ISFNT-5, Rome
Max. allow. temperature at SiC_f/SiC interface	700°C	H. Keykamp: Chemical reactivity of SiC with Beryllium and ceramic breeder materials, 9th Conf. on Fusion Reactor Materials

Main plant and blanket design data

Blanket Concept (structural material)	I-HCPB (EUROFER)	A-HCPB (SiC_f/SiC)
Overall plant		
Fusion power [MW]	4500	4500
Neutron power [MW]	3600	3600
Alpha-particle power [MW]	900	900
Energy multiplication	1.41	1.24
Thermal power [MW]	5976	5364
Blanket system		
Neutron power [MW]	3285	3276
Alpha-particle power [MW]	558	558
Tritium breeding ratio	1.11	1.09
Energy multiplication	1.34	1.22
Thermal power [MW]	4960	4555

Main blanket design data (cnt'd)

Blanket Concept (structural material)	I-HCPB (EUROFER)	A-HCPB (SiC_f/SiC)
Blanket surface [m^2]	1187	1187
Average neutron wall load [MW/m^2]	2.8	2.8
Max. neutron wall load [MW/m^2]	3.5	3.5
Average surface heat load [MW/m^2]	0.47	0.47
Max. surface heat load [MW/m^2]	0.61	0.61
Coolant	He	He
- Inlet temperature [°C]	250	350
- Outlet temperature [°C]	500	700
- Pressure [MPa]	8	8
- Mass flow rate [kg/s]	3815	2503
- Pumping power (η = 0.8) [MW]	196	85
Net efficiency of power conversion system	36.5	44.8
Electrical output [MW]	1810	2041

Main blanket design data (cnt'd)

Blanket Concept (structural material)	I-HCPB (EUROFER)	A-HCPB (SiC_f/SiC)
max. Li_4SiO_4 power density [MW/m^3]	49.8	38.1
max. Beryllium power density [MW/m^3]	14	15.5
max. structural material power density [MW/m^3]	29.4	24
max. Li_4SiO_4 temperature [°C]	887	913
max. Beryllium temperature [°C]	564	678
max. structure material temperature [°C]	538	913
eq. thickness of Li_4SiO_4 pebble beds [mm]	59	59
eq. thickness of Beryllium pebble beds [mm]	357	140
eq. thickness of structural material [mm]	87	54
eq. thickness of graphite layer [mm]	-	300

Performance limitations

Max. He outlet temp.	700 °C	Dictated by the max. allowable temperature of Be pebble bed
Max. net electrical efficiency	~45%	Dictated by the max. allowable temperature of Be pebble bed
Max. neutron wall load (peak)	6 MW/m^2	Design with 16 beds and with 300-600°C helium temperatures.
Max. surface heating (peak)	0.7 MW/m^2	Limitation due to the thermal stress parameter of SiC_f/SiC
Lifetime limitations	not known	Probably: • Beryllium: swelling at high temperature • Li_4SiO_4: Li-burnup or dpa damages • SiC_f/SiC: degradation under irradiation.

Performance requirements for structural applications of SiC_f/SiC in the A-HCPB Blanket

Fibre architecture		3D
Operational temperature		400 – 950°C
Strength	ARIES-I [1]:	primary: <140 MPa secondary: <190 MPa
	CEA [2]:	tensile in plane: < 145 MPa compressive in plane: <500 MPa tensile through thickness: <110 MPa shear through thickness: <45 MPa
Elastic modulus		200 GPa
CTE		$4 \cdot 10^{-6}$ °C^{-1}

[1] S. Sharafat and al.: Fusion Eng. and Design 18 (1991), 215-222.

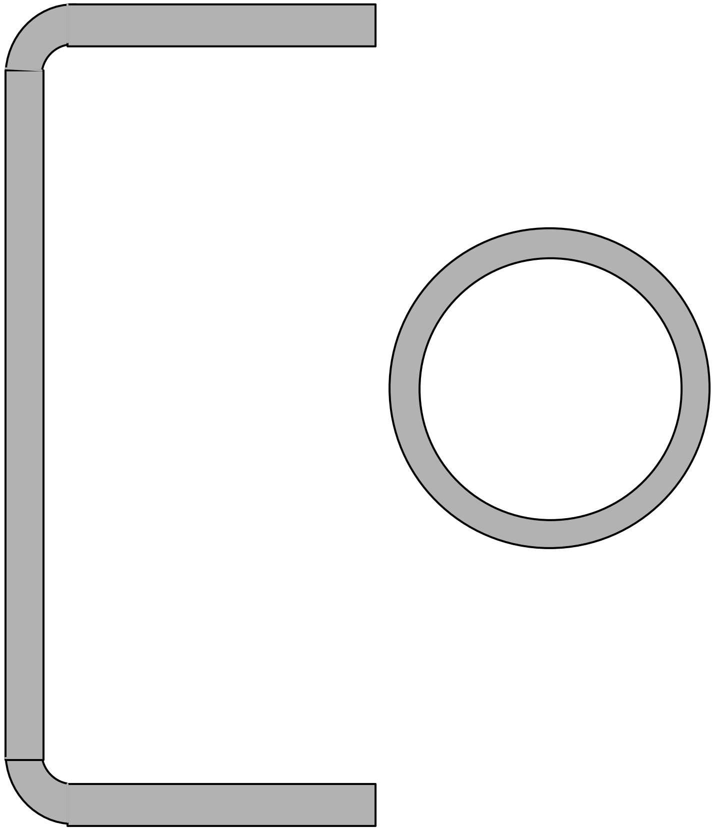
[2] L.Giancarli and al.: CEA report SERMA/LCA/RT/99-2677/A

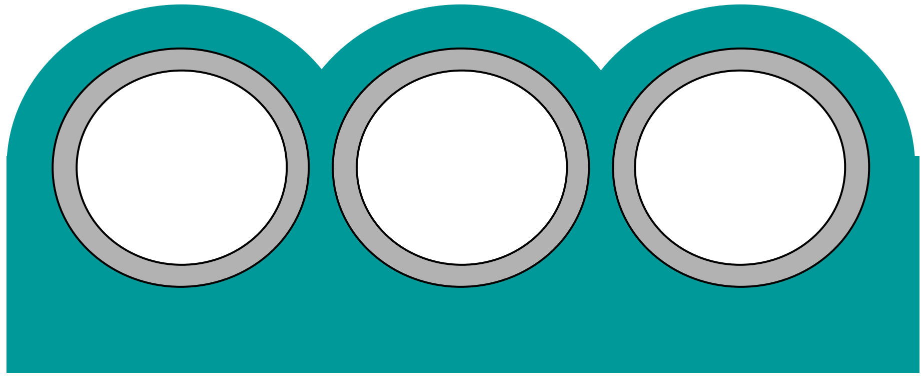
Performance requirements for structural applications of SiC_f/SiC in the A-HCPB Blanket (cnt'd)

Creep rate	NS
Thermal conductivity	15 W m^{-1} K^{-1}
Specific heat	NS
Thermal shock	NS
Density	NS
Chemical compatibility	He (700°C) Li_4SiO_4 (750°C) Be (700°C)
Lifetime	NS
Impurity limits	Dictate by safety (and waste disposal) for all materials
Leak tightness	8 MPa-He (tritium)
Brazing joining-strength	NS
Electrical conditions	NS

NS: not specified

Manufacturing route for the FW shell

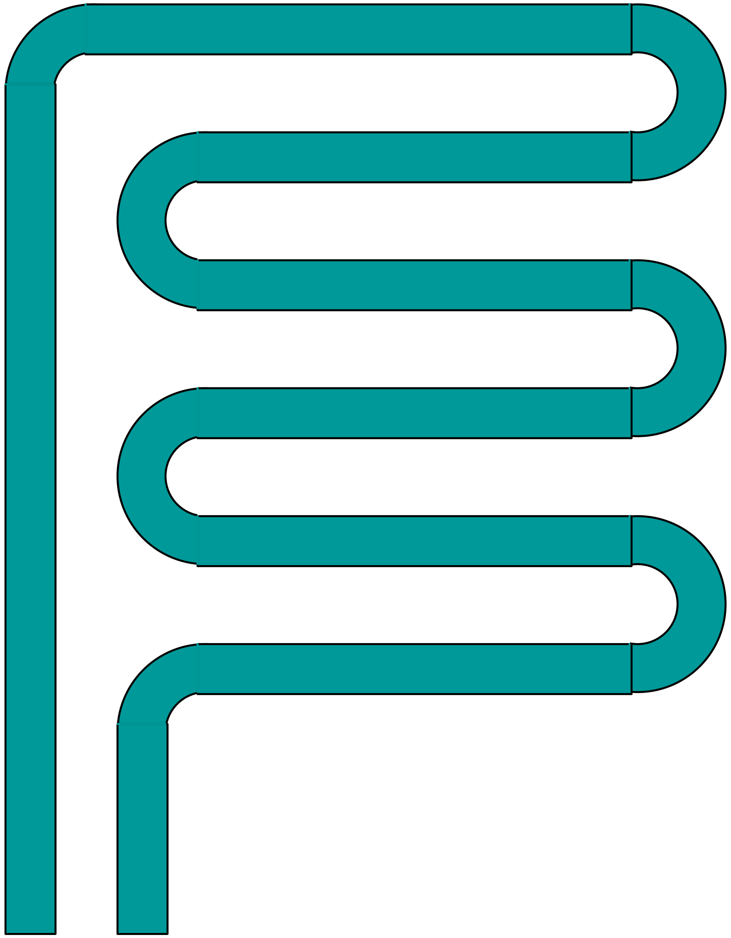


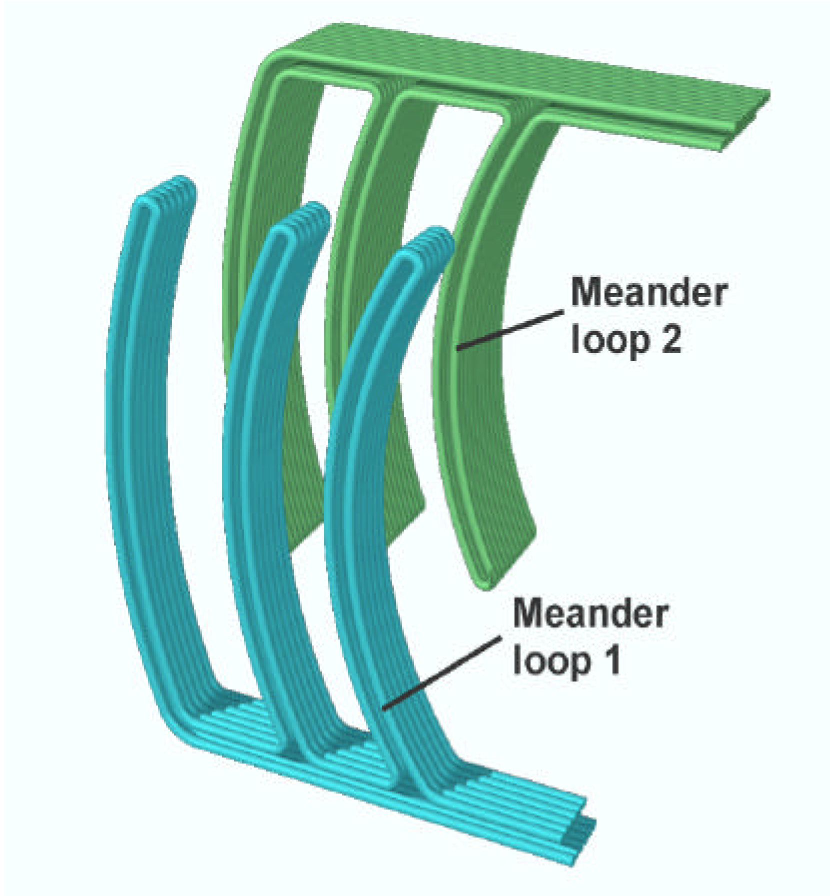


1. Manufacturing of single u-shaped tubes

2. Manufacturing of the shell from the tubes

Manufacturing of the BZ meanders





1. Manufacturing of a single tube in form a meander

2. Manufacturing of the cooling plates

Conclusions

- The investigation for the A-HCPB Concept shows that the use of SiC_f/SiC as structural material allows to increase the efficiency of the fusion power plant
- The proposed design is conceptually very similar to the Improved HCPB concept which use RAFM steel as structural material
- Therefore, the A-HCPB Blanket will be not probably included in the EU power plant study as an independent concept, but will be investigated further on as potential improvement of the I-HCPB concept

Conclusions (cnt'd)

- A set of performance requirements for structural applications of SiC_f/SiC in the A-HCPB Blanket have been identified
- Design specific manufacturing issues have been addressed (FW shell and BZ meanders)
- Overall design goals were to limit high pressure helium in small tubes only, to reduce the number of joints connecting these tubes and to avoid joints in high stress/high neutron flux regions. The resulting design promises to manufacture components with high reliability