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Divertor Design for Modification of JT-60 with Superconducting Coils

JAERI

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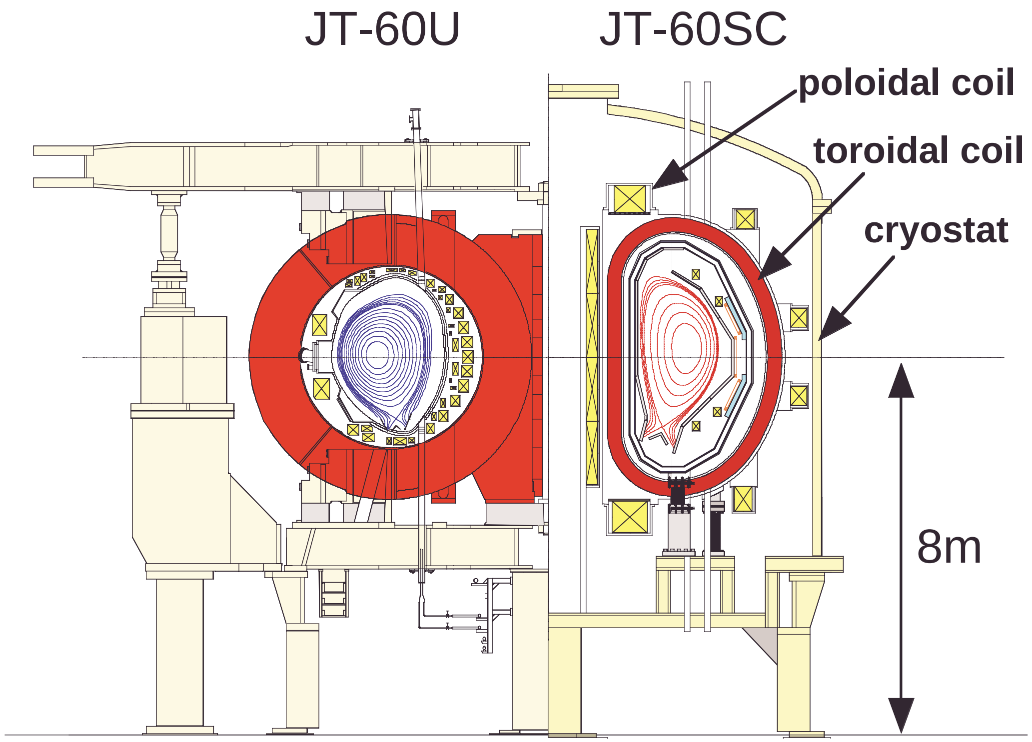
Main Objectives and Parameters of JT-60SC

to establish scientific and engineering bases for attractive DEMO reactor

- sustaining β_N=3.5~5.5 longer than current skin time
- non-inductive full current drive with high bootstrap current fraction
- heat and particle control required for DEMO reactor
- feasibility study of a reduced activation ferritic steel for high β plasma

Existing facility (heating, power source, etc.) will be reused to reduce costs



Main Parameters

pulse width	100s
input power	44MW(10s)
	30MW(30s)
	25.4MW(50s)
	14.7MW(100s)
plasma current	4MA
toroidal field	3.8T
major radius	2.8-3.0m
minor radius	0.7-0.9m
elongation κ_{95}	$\leq$1.9
triangularity δ_{95}	$\leq$0.45

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Divertor research and development

Requirements of DEMO reactor

- **Heat and particle control compatible with high β plasma**

{radiation fraction f_{rad} ≥90%, partial detach, τ_{He}^{*}/τ_{E} ≤5, density control}

- **Low cost and long life-time plasma facing components**

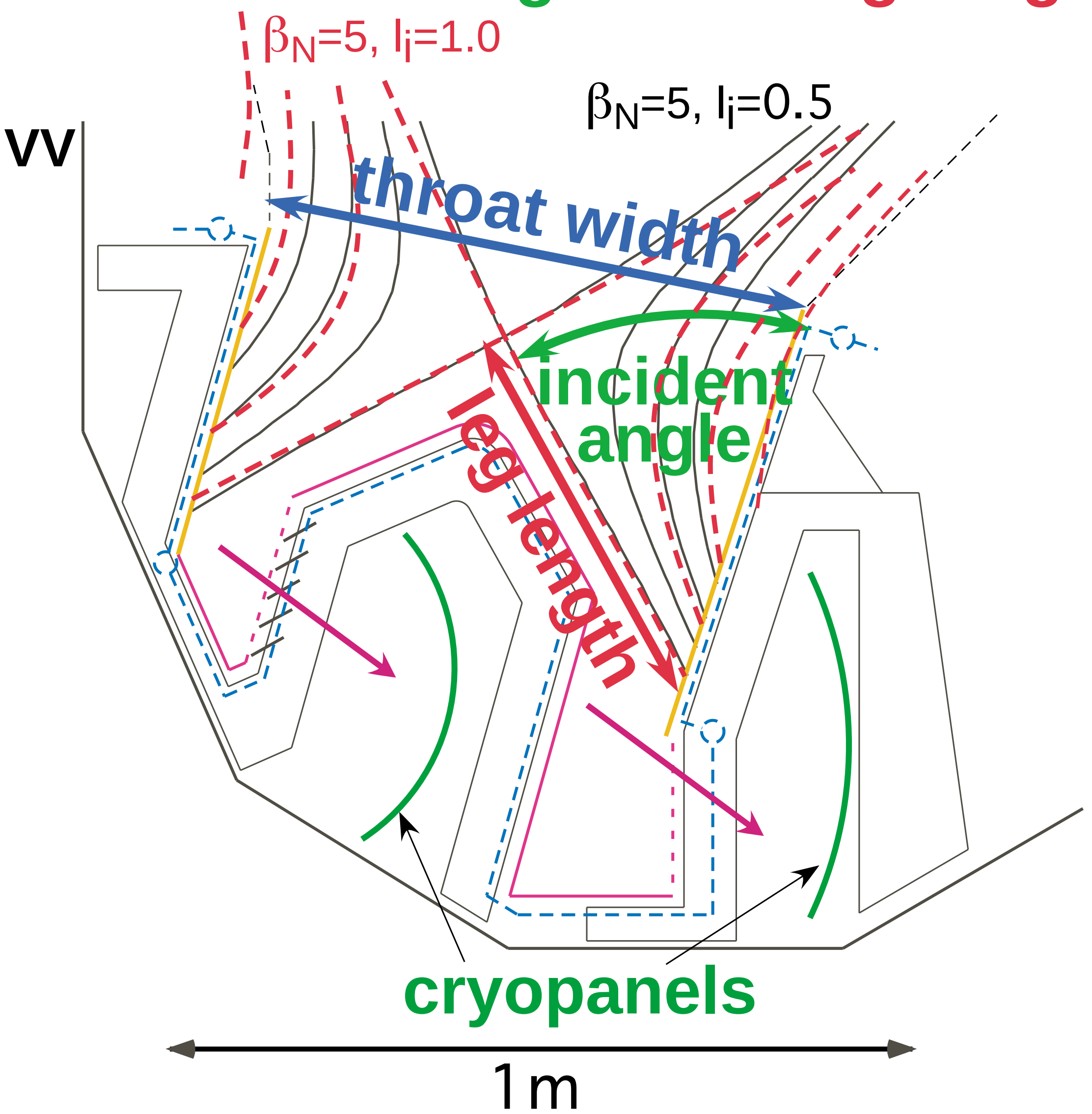
Time Table

	basic phase	advanced phase
Main Objective	compatibility with high β	steady state, integration
β_N	3.5~5.5 (transient)	≥3.5 (steady state)
f_{rad}	≥50~65%	≥80%
Divertor plasma	Exhaust (≥100m³/s)	Geometry (full-closed)
	independent pumping at inner and outer divertor	
PSI, PFC	CFC (10~15MW/m²)	metal (long life-time)
	test of metal by surface station	

Basic parameters of divertor geometry

Steps for design

1st : Throat width
2nd : Incident angle and Leg length



Requirements of baffle throat width

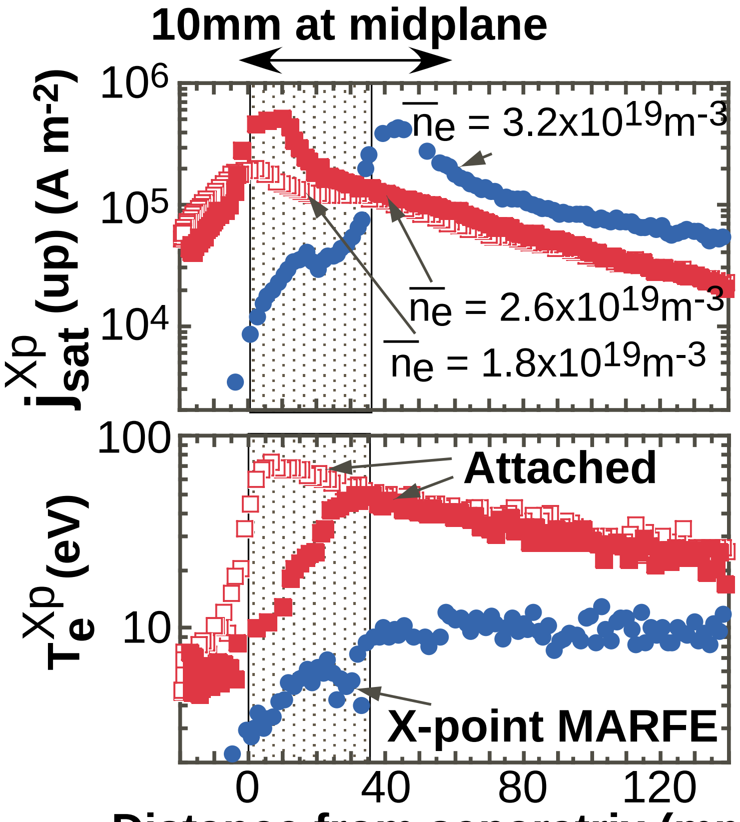
- **Particle flux toward the divertor plate is broadened at X-point MARFE**

flux (∝$nT^{0.5}$) decay length: ~15mm for attach, ~10mm(shift)+~20mm for MARFE

- **Distance from separatrix to SOL flux surface increases with β_N and l_i.**

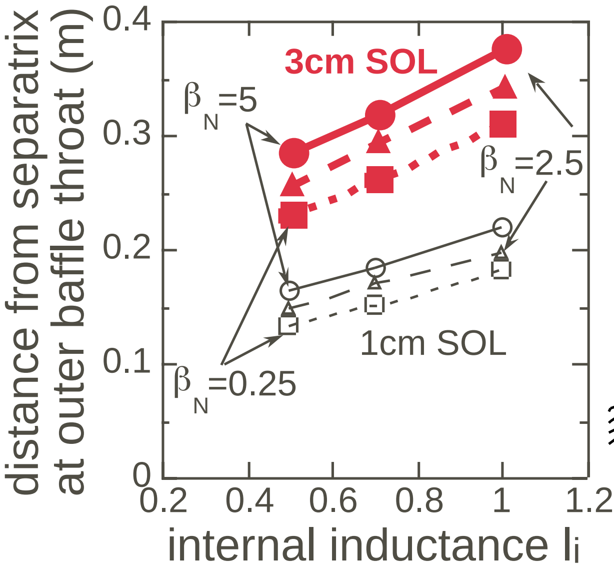
Throat width is opened to 3cm SOL at β_N~5 and l_i=1.0

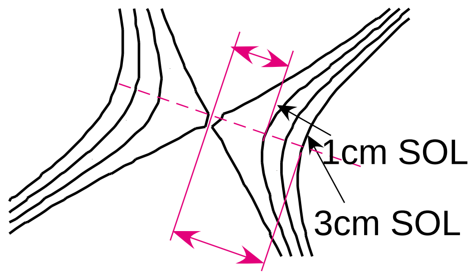
broadening of SOL particle flux



just below the X-point in W-shaped divertor of JT-60U
ref. Nucl. Fus. 39, 1983-1994(1999)

expansion of SOL flux surface



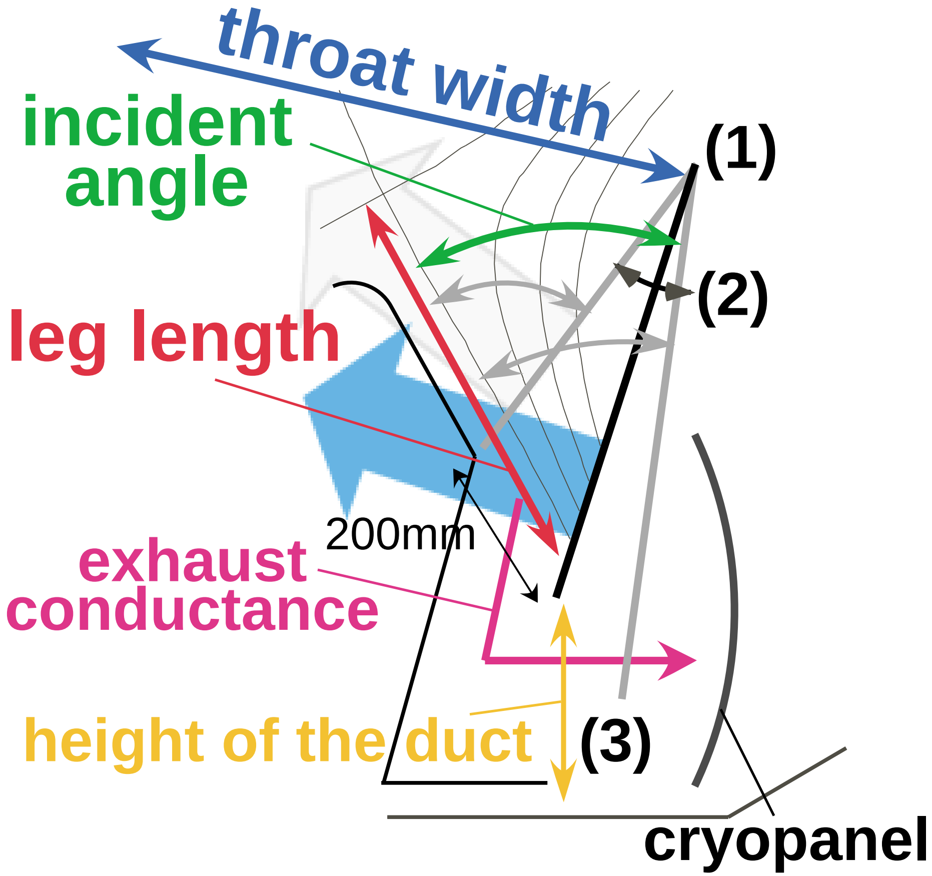


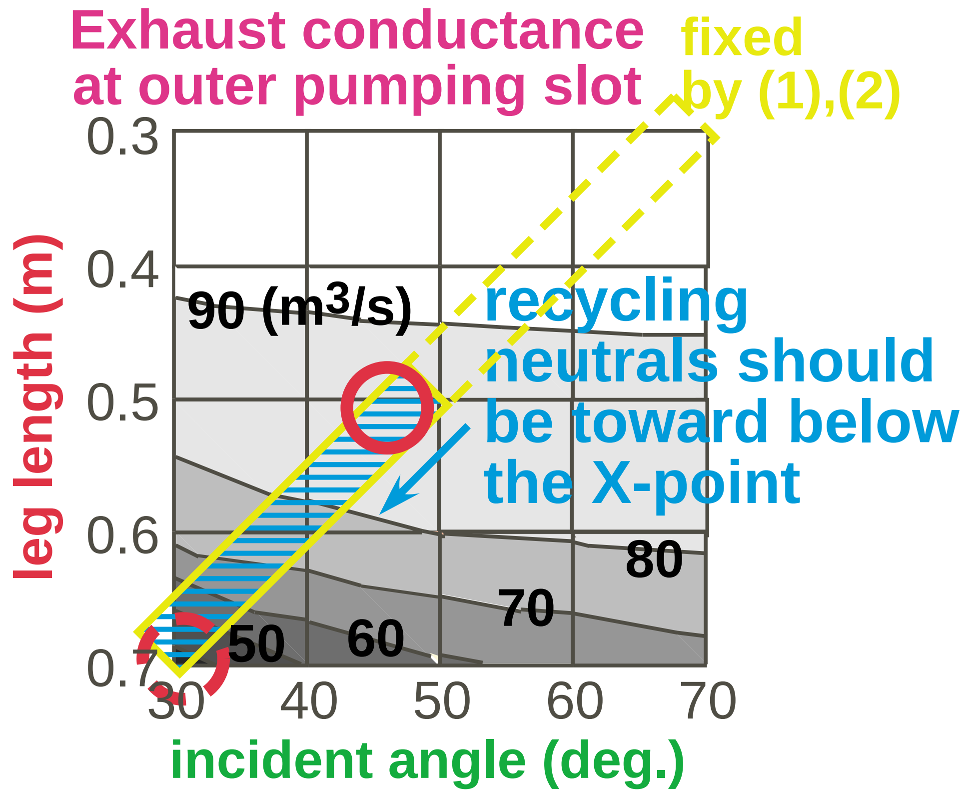
Incident angle and leg length

(1) Top of the divertor plate is fixed by given throat width.
(2) Leg length decreases as incident angle increasing.
(3) Exhaust conductance mainly determined by the height of the duct.

Exhaust conductance decreases from 85m³/s to 35m³/s, when leg length increases 0.5m to 0.7m

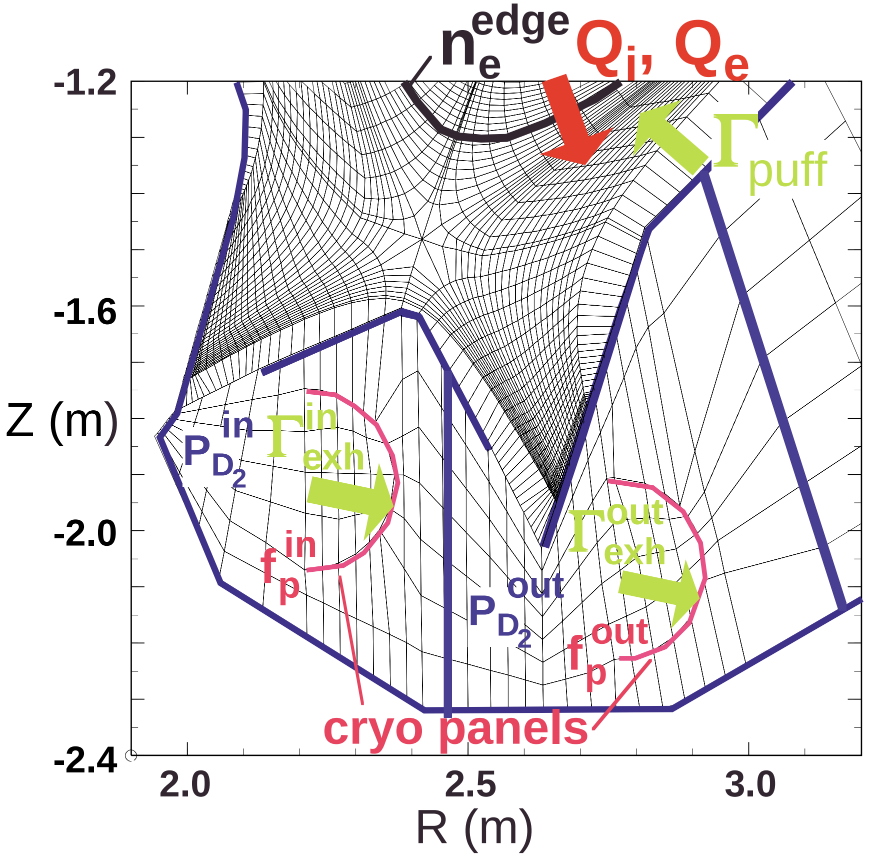
0.5m is selected { ≥ DIII-D (radiative outer leg) >> JT-60U (W-shaped) }





Simulation of detachment control by pumping

- How large pumping speed is required to sustain attachment or partial detachment with avoiding MARFE onset?
- Partially detached outer divertor is simulated, and it changes to attached by increasing exhaust probability at cryopanel.
- Effective pumping speed of cryopanels are evaluated from Γ_{exh} and P_{D2}.

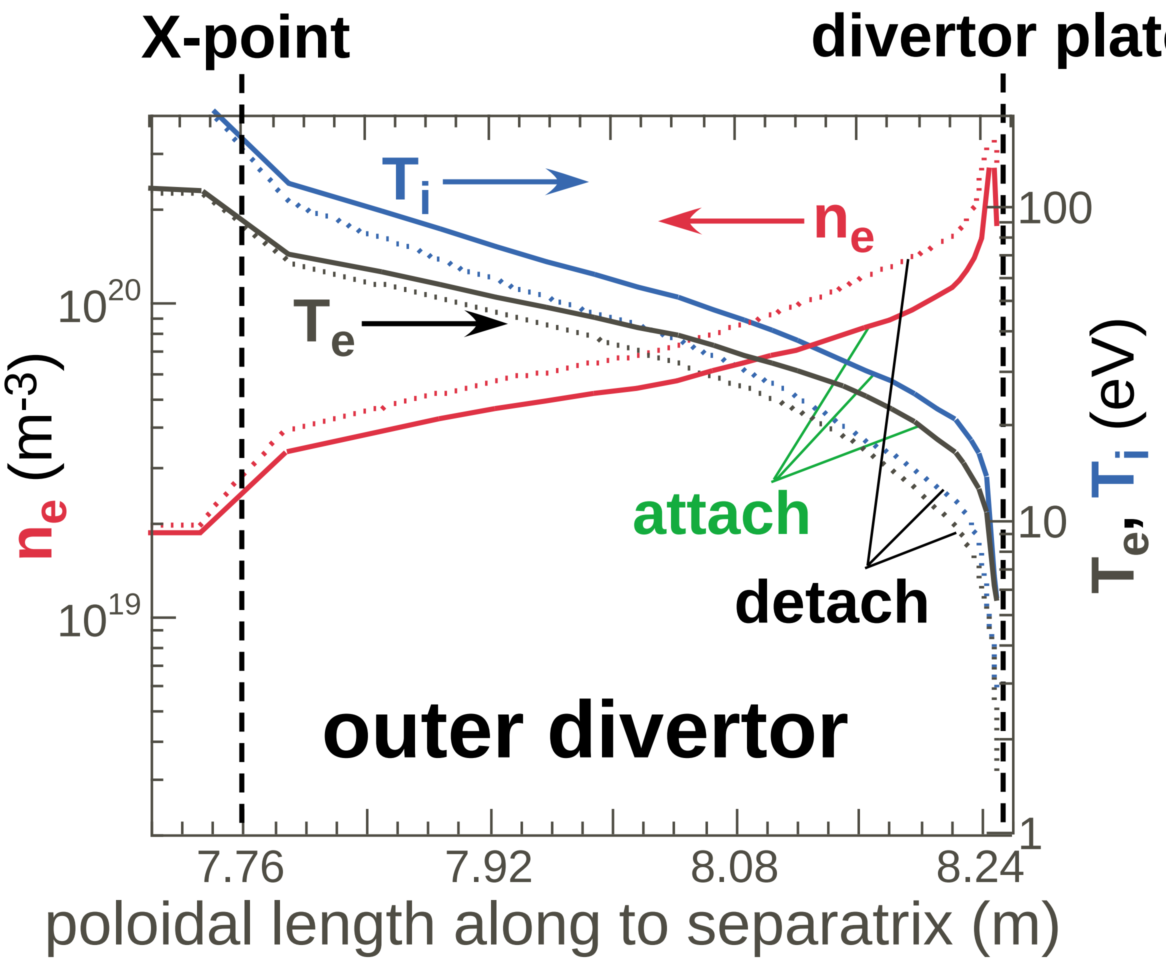


- Divertor fluid code (SOLDOR)
  2D Monte Carlo code for neutral particle (NEUT2D)
- Impurity radiation is calculated by simplified non-corona model with 1.5% of carbon

$n_e^{edge} = 3.2\times10^{19}/m^3$
(corresponds to f_{GW}~0.7 for I_p=1.5MA)
Power flow to SOL : $Q_i = Q_e = 6MW$,
Gas puffing rate : $\Gamma_{puff} = 0.6\times10^{22}/s = 14.8\ Pam^3/s$
f_p : exhaust probability at cryopanels,
Γ_{exh} : exhausted flux, P_{D2} : neutral pressure

Pumping speed for detachment control

- **Pumping speed of outer cryopanel required for the attached condition is evaluated to be 99m³/s. It corresponds to ~42m³/s for pumping slot.**



	detach	attach
f_p^{in}/f_p^{out}	0.04/0.01	0.06/0.03
$P_{D_2}^{out}$ (Pa)	0.27	0.10
Γ_{exh}^{out} (Pam³/s)	5.4	9.9
pumping speed of cryopanel (m³/s)	20	99

Design of power handling

Feasibility for high β plasma research

input power : 30MW/30s ~ 15MW/100s

heat flux density is supposed to be 10~15MW/m^2 at an allowable f_{rad} (50~65%) for high β plasma with input power of 30MW

Design of actively cooled divertor

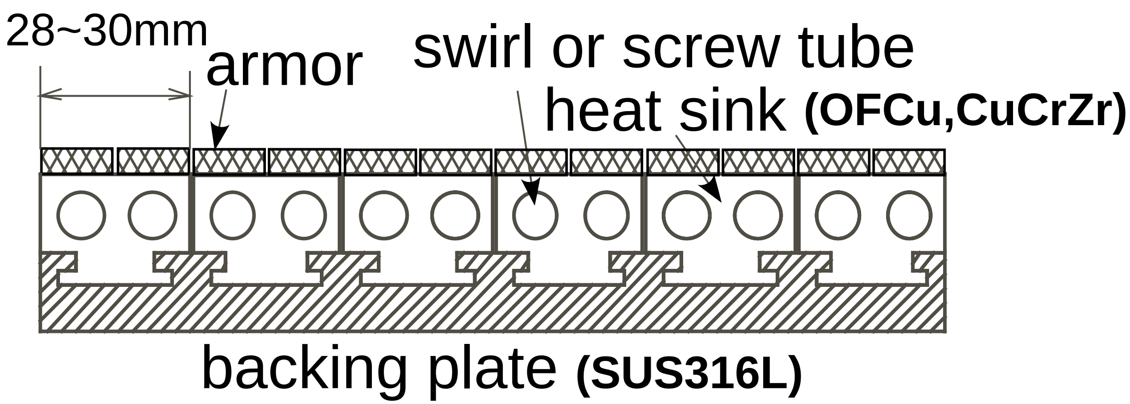
armor material : CFC for basic phase, W alloys for advanced phase

allowable surface temperature for steady heat flux :

~1000°C for CFC, ~700°C for W alloys (with keeping margin for ELMs)

typical thickness of armor : ~10mm for CFC, ≤5mm for W alloys

development : Proto-type CFC target (40 x 40 x t10 mm) has survived for 1400 cyc. at 10MW/m^2.



Summary

- Basic divertor geometry is designed to obtain large exhaust conductance.
- Designed pumping speed (~200m^3/s at cryo panel) is enough to control detachment for outer divertor.
- Heat flux density 10~15MW/m^2 is supposed at outer divertor for the input power of 30MW with radiation fraction of 50~65%.

Future Works

- Divertor geometry will be optimized by more detailed simulation. Effect of the incident angle and the leg length on the detached condition should be simulated.