SiC Tokamak Reactor in JAERI

International Town Meeting on SiC/SiC Design and Material Issues for Fusion Systems
Jan.18-19, 2000, Oak Ridge National Laboratory, USA

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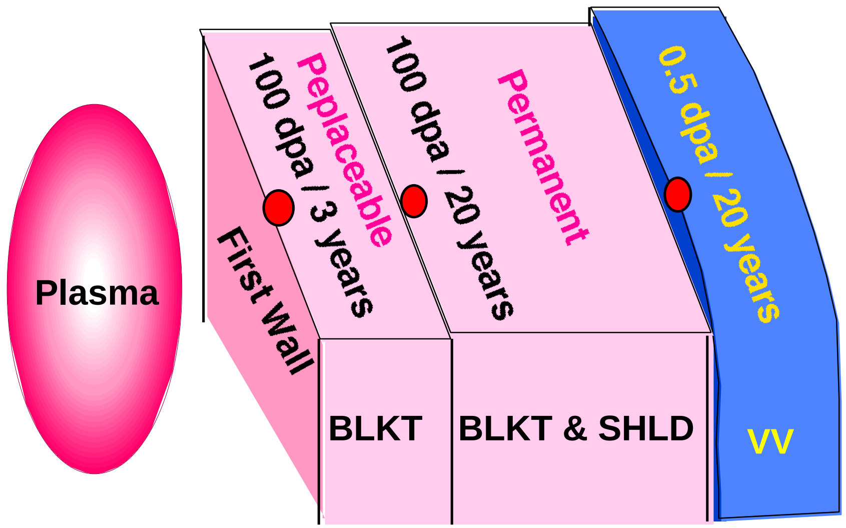
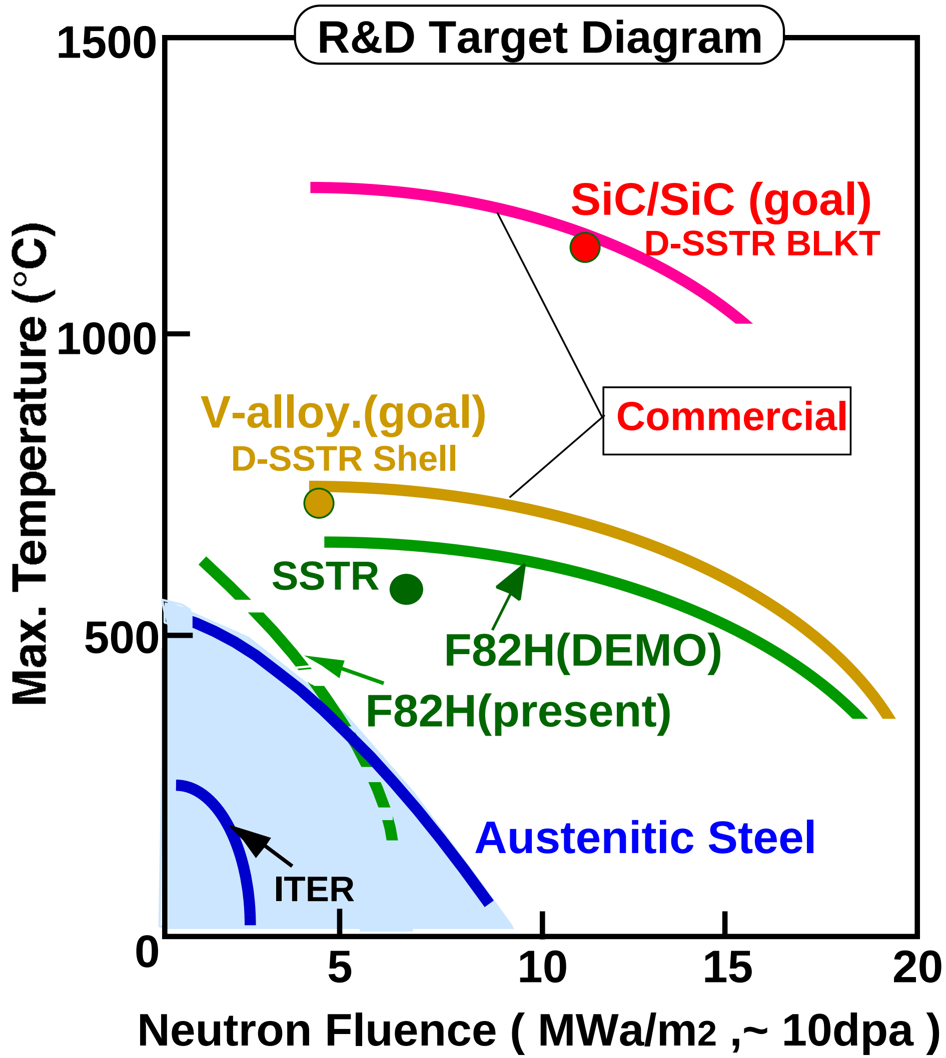
Japan Atomic Energy Research Institute
Naka Fusion Establishment

Fusion Material Development

- LA Ferritic Steel (1st Candi. for DEMO)
- V-alloy (Candi. for Comm.)
- SiC/SiC Comp. (Candi. for Comm.)

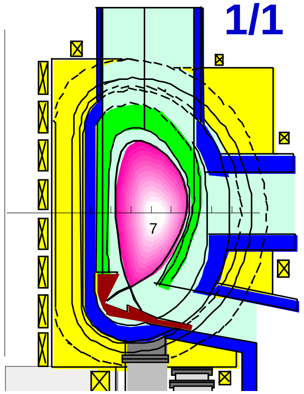
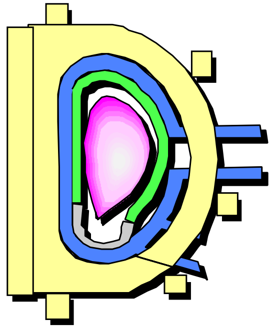
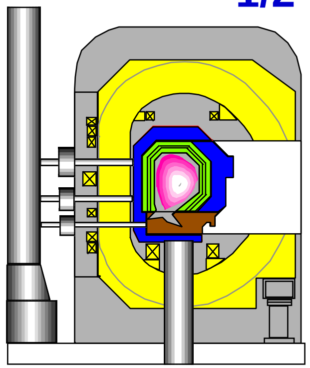
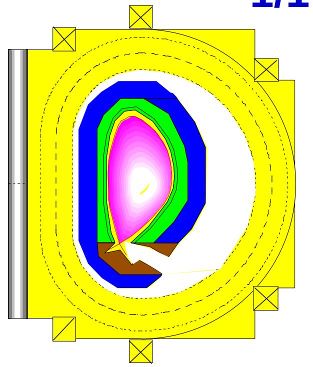


Setup of Power Core Components

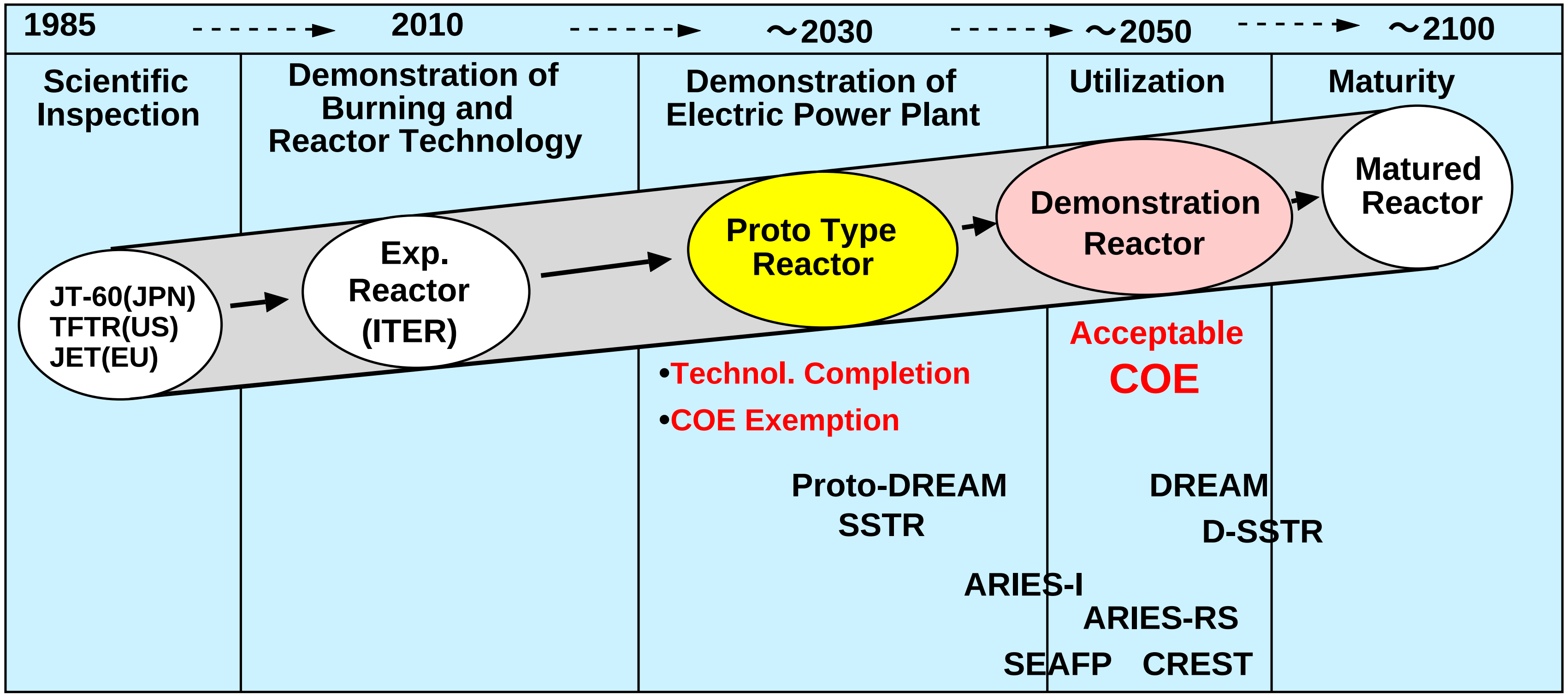


Tokamak Reactor Design in JAERI

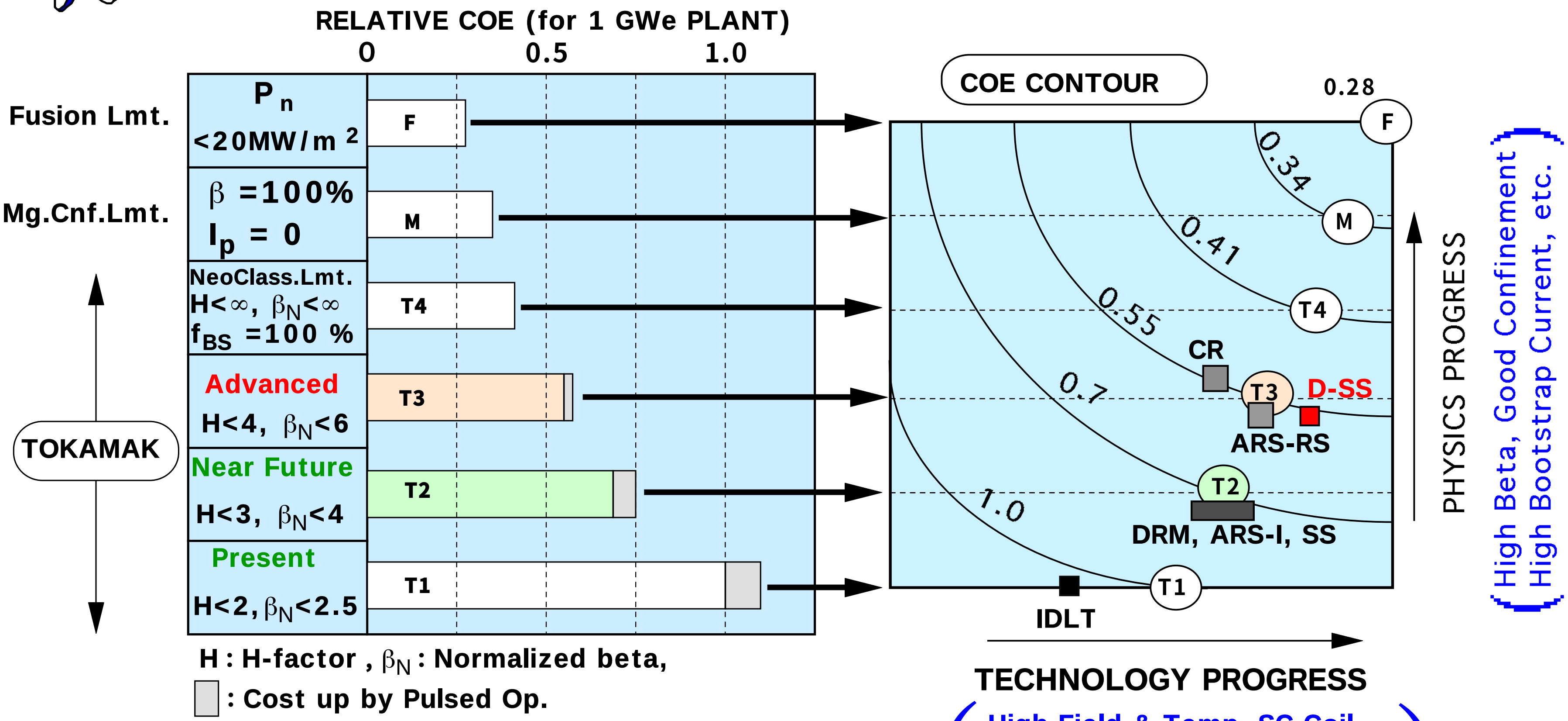
原研 JAERI

	SSTR (1990)	A-SSTR (1996)	DREAM (1996)	D-SSTR (1999)
※ : Remote radiative cooling is fully expected.	1/1 	Needs Pull Sketch 1/1 	1/2 	1/1 
Type	DEMO	Commercial	Commercial	Commercial
Plasma current I_p	12MA	12MA	9.2MA	12MA
Major radius R_p	7m	6m	16m	6.2m
Aspect ratio A	4	4	8	4
Toroidal field B_t	9T	11T	14.5T	11T
Max. neutron load φ_n	5MW/m^2	10MW/m^2	4MW/m^2	8MW/m^2
Blanket heat flux q_w	1MW/m^2	2MW/m^2	0.5MW/m^2	2MW/m^2
Div. heat flux q_{div}	7MW/m^2	4MW/m^2 ※	7MW/m^2	4MW/m^2 ※
Neurton fluence F	7MWa/m^2	14MWa/m^2	10MWa/m^2	12MWa/m^2
Max. coolant temp. T_{max}	550°C	650°C	900°C	900°C
Fusion power P_f	3GW	4.5GW	5.5GW	4.5GW
Current drive P_{CD}	60MW	60MW	50MW	60MW
Blanket Mat.	F82H	F82H	SiC/SiC	SiC/SiC
Coolant	P. Water	P. Water	He	He
Bulk Shield Mat.	F82H	F82H	SiC/SiC,TiH_2	TiH_2

Major Milestones on Road to Fusion Power Reactor



COE DEPENDENCE ON PHYSICS CONSTRAINT FOR D-T FUSION

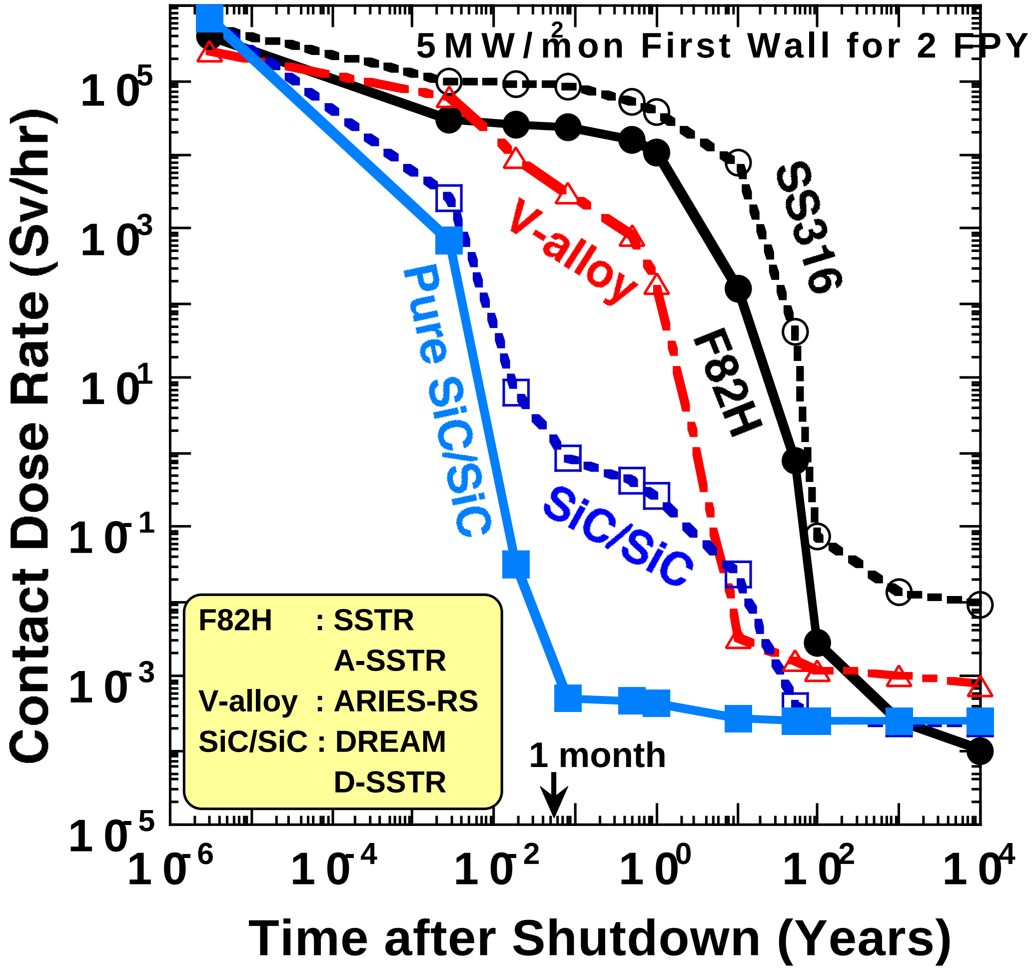


(High Field & Temp. SC Coil,
Advanced material,
Maitenance Tech., etc.)

J.D.Galambos,et al,Nucl.Fusion (1995)
Engineering constraints are common.

Cost Competitiveness of Fusion is not Promising.

Decline Comparison of Activated Materials



D-SSTR

- SiC/SiC Weight of Replaceable Blanket is 125 Ton.
- Every 2 years Replacement and 30 years Life time.

Total Radwaste is 1900 Ton.

After Irradiation of 10MWa/m^2

Induced Activity
10^{18} Bq/ton for SS, F82H
5×10^{15} Bq/ton for SiC/SiC

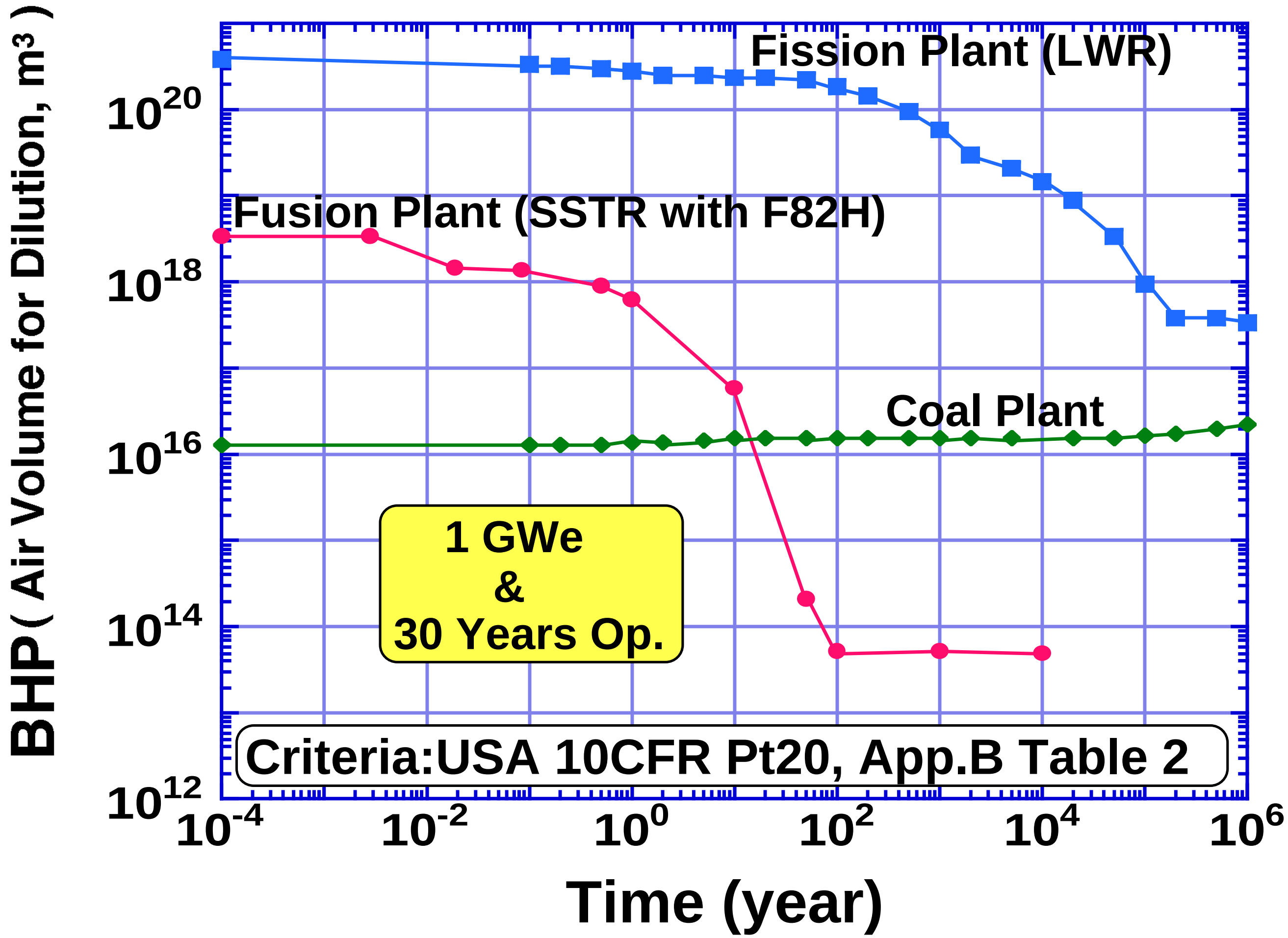
Total Radio Activity

- F82H : 7.5×10^{20} Bq (2.0×10^{10} Ci)
- SiC/SiC : 1.5×10^{18} Bq (4.0×10^{7} Ci)

Dose Rate Rapid Decline of Pure SiC/SiC : < 1mSv/h for 1 month cooling

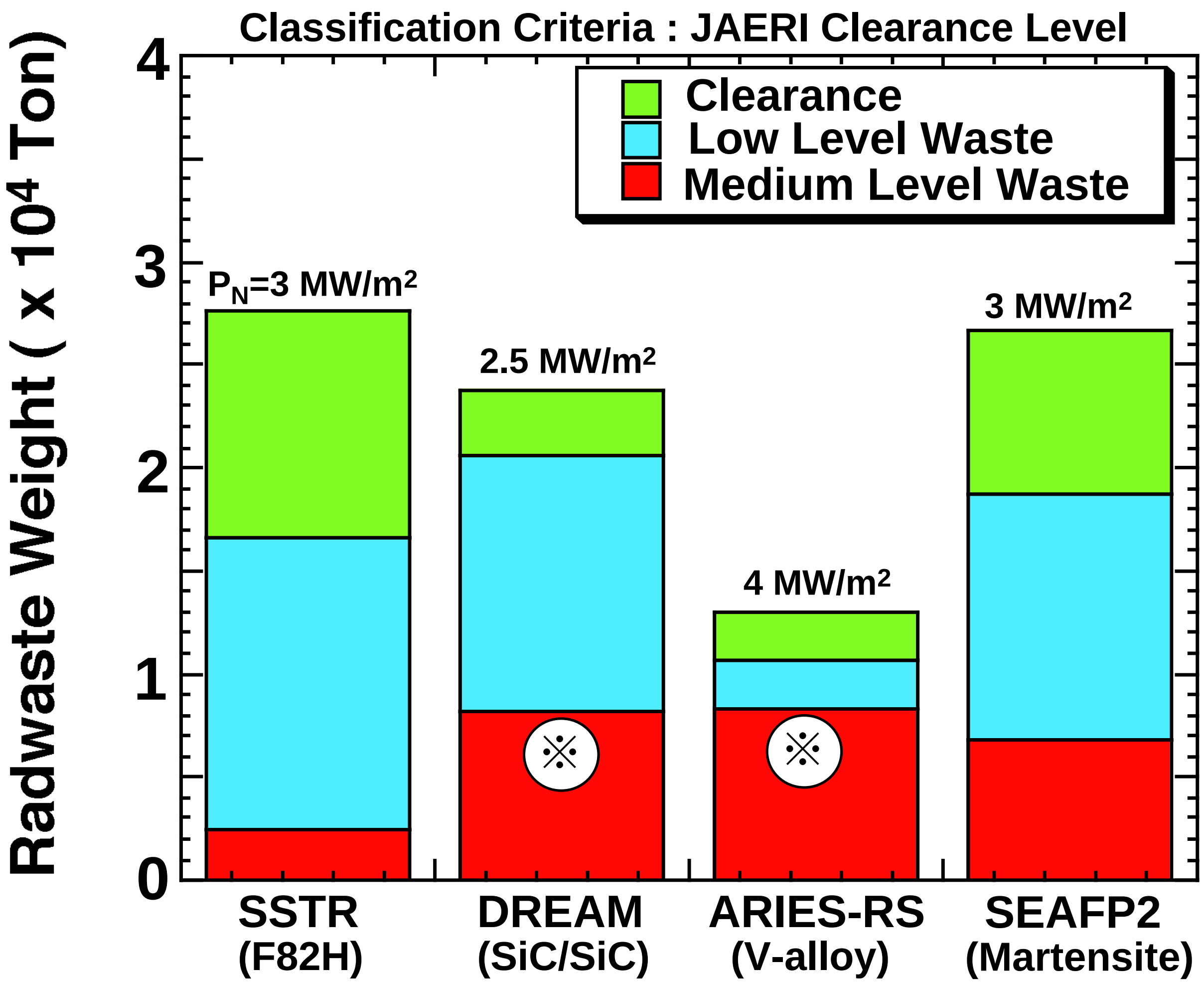
Biological Hazard Potential

(Fission, Fusion and Coal)



Even the F82H fusion plant can catch up with the coal plant within 15 years.
BHP of a SiC/SiC fusion plant may be negligible.

Radwaste Weight of Tokamak Reactor



Medium level waste requires 30 years care before the burial.

※ is derived from impurities,

hence

can be replaced

by .

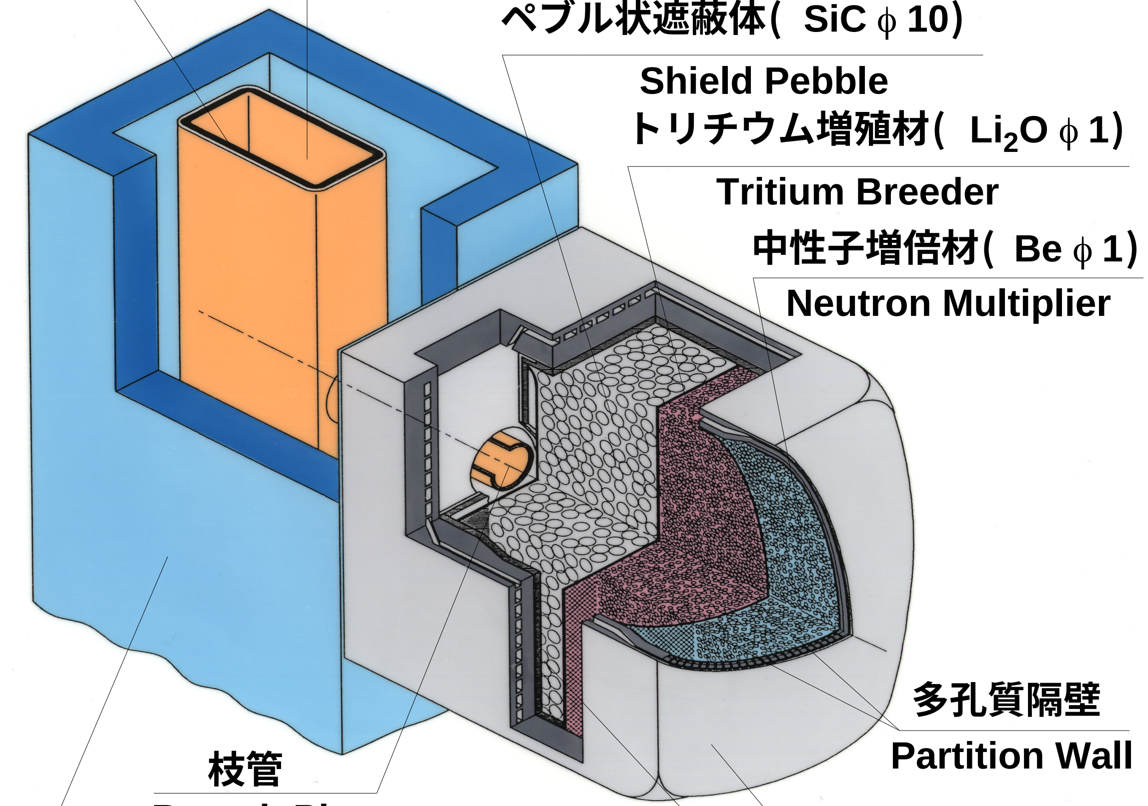
Material Compariaon from Neutronics Viewpoint

Material	Activation Intensity for Maintenance (for replacement)	Neutron Shielding Effectiveness (for thickness)	Radwaste Quantity after Plant Life Time		
			Total	Low Level	Medium Level
SiC/SiC	~10^{-7}	0.2~0.3	1 (2×10^4 Ton)	60 %	40 % (N and Cl)
				100 %※	0 %※
F82H	1 (3×10^4 Sv/h)	~0.7	~0.8	85 %	15 % (Itself)
V-alloy	~10^{-1}	~0.8	~0.65	22 %	78 % (Impurity)
TiH_2	10^{-3}~10^{-4}	1	~0.5	> 90 %	< 10 %

※without impurity(N and Cl)

For power core components, the combination of SiC & TiH2 is preferable.
For conducting material, V-alloy is desirable.

Artist's Conception of DREAM Blanket Module

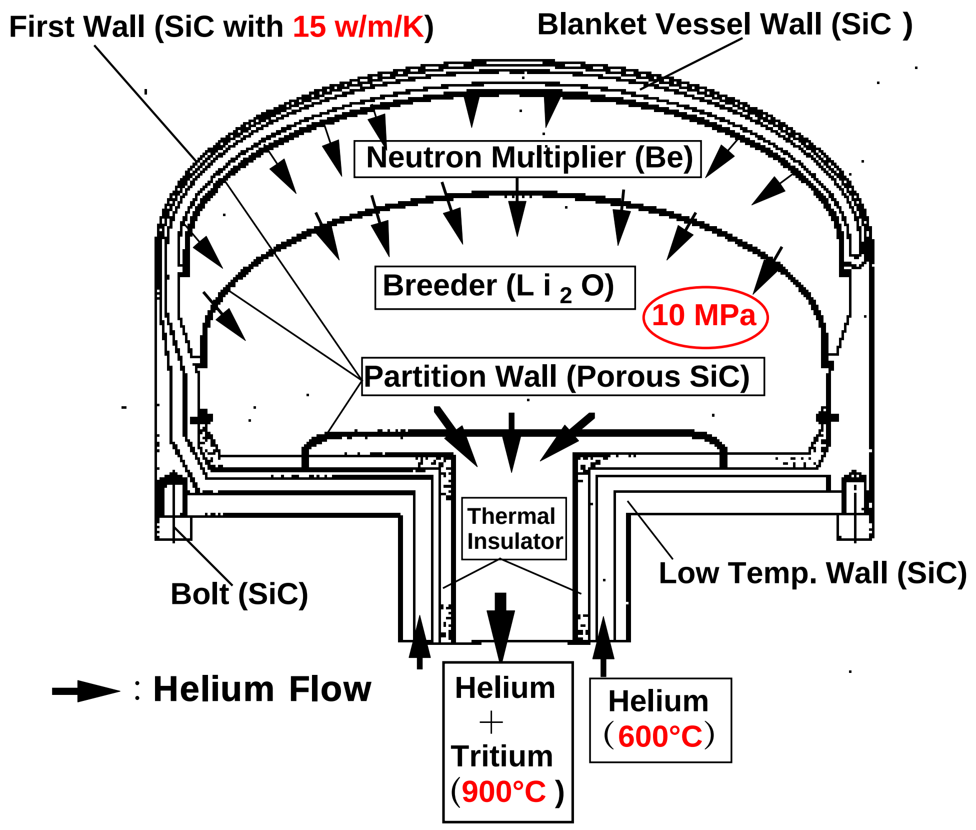


Parameters

Structural Mat.	SiC/SiC Comp.
Therm. Cond.	15W/m/K
Vessel Size	500x500 mm
Coolant	Helium
Coolant Pres.	10 MPa
Coolant Temp.	600/900 ^{o}C
Coolant Vel.	100 m/s
Wall Load	3 MW/m^2

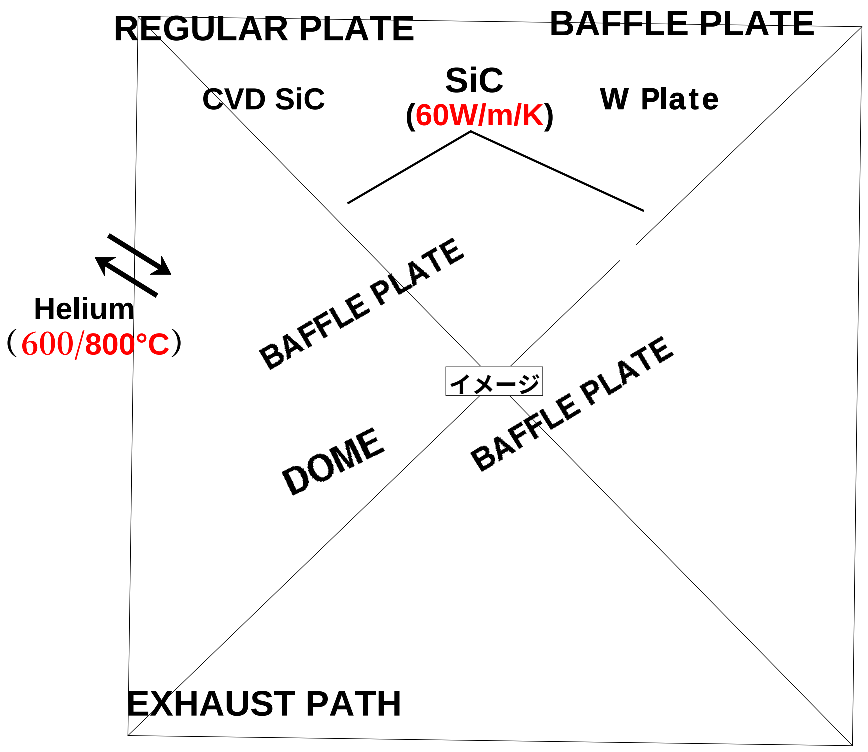
Blanket & Divertor Modules of DREAM

$P_{FW} = 0.5\ MW/m^2$



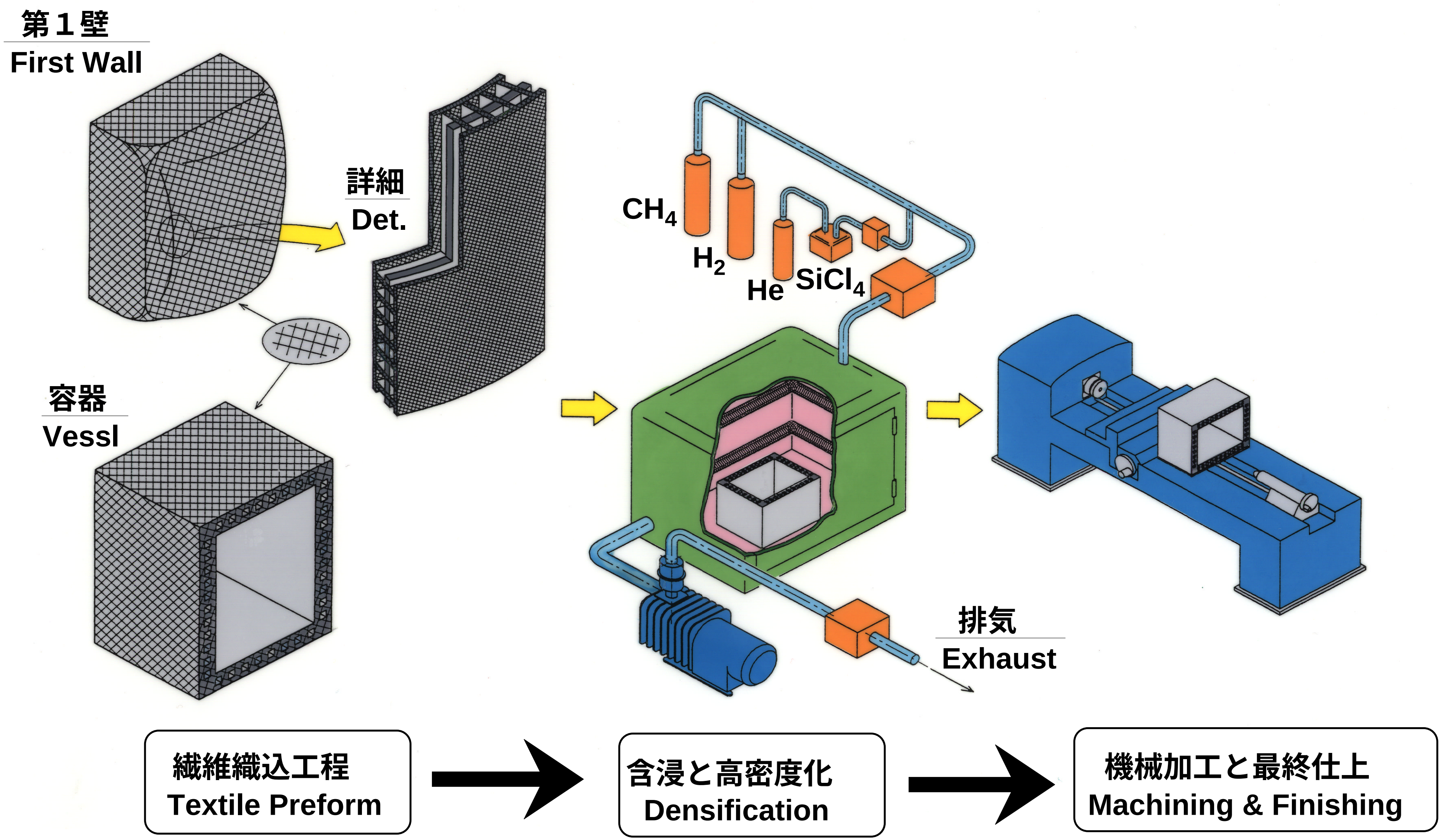
MUSHROOM BLANKET MODULE
(Solution)

$P_{DIV} = 7\ MW/m^2$

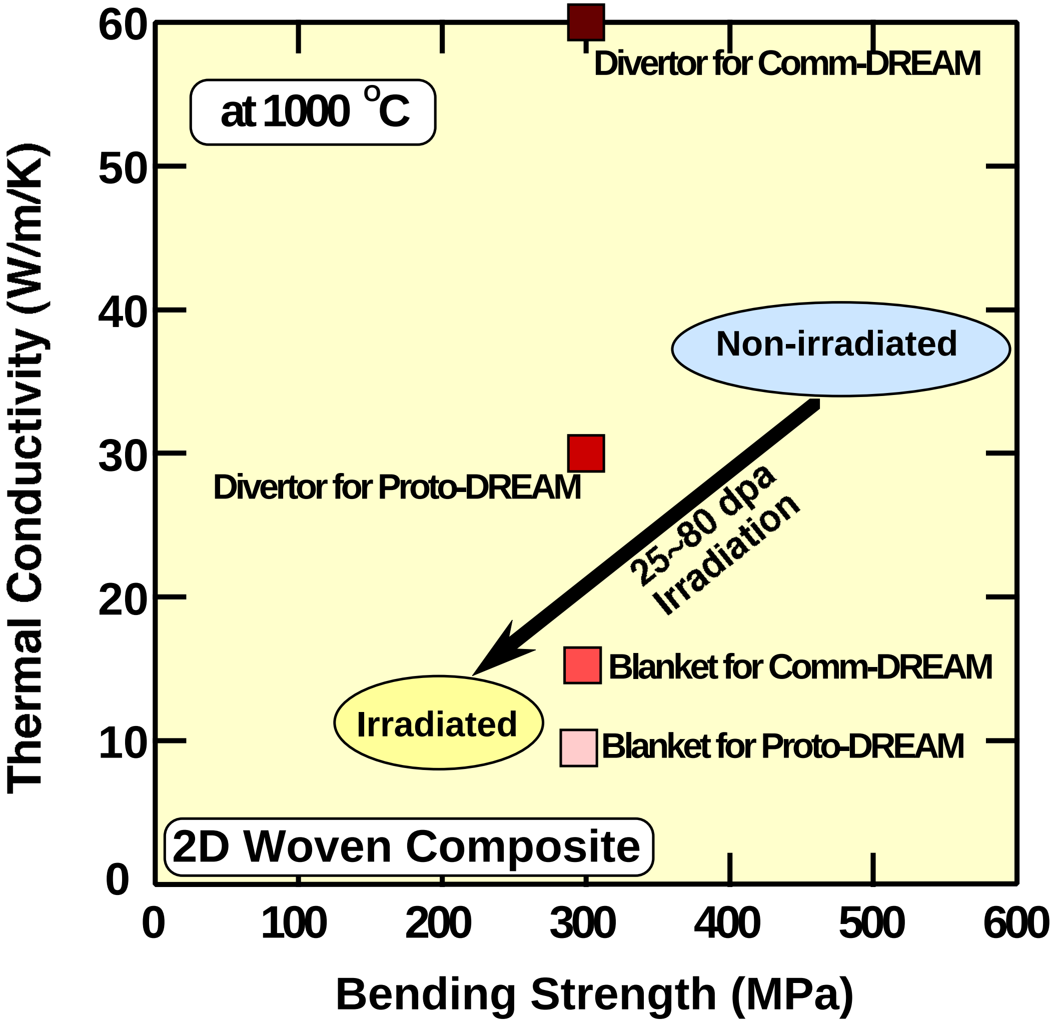


DIVERTOR MODULE
(No Solution)

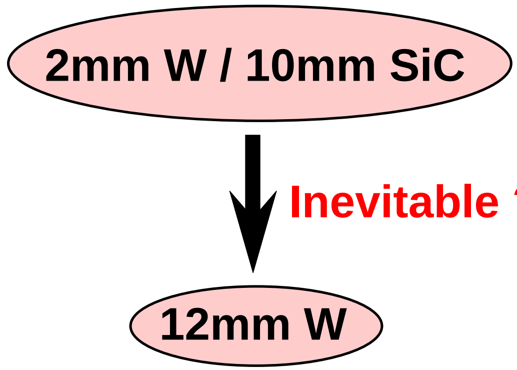
Manufacturing Process of Blanket Module



Neutron Irradiation Degradation of SiC/SiC



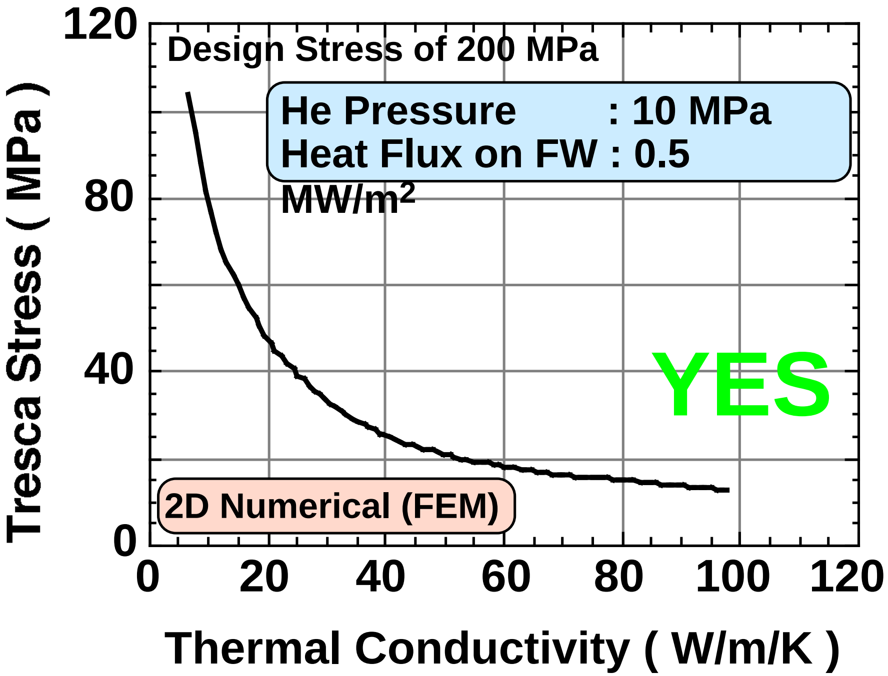
Divertor Plate of Future Reactor Requires Unrealistically high Performance to SiC/SiC Composite.



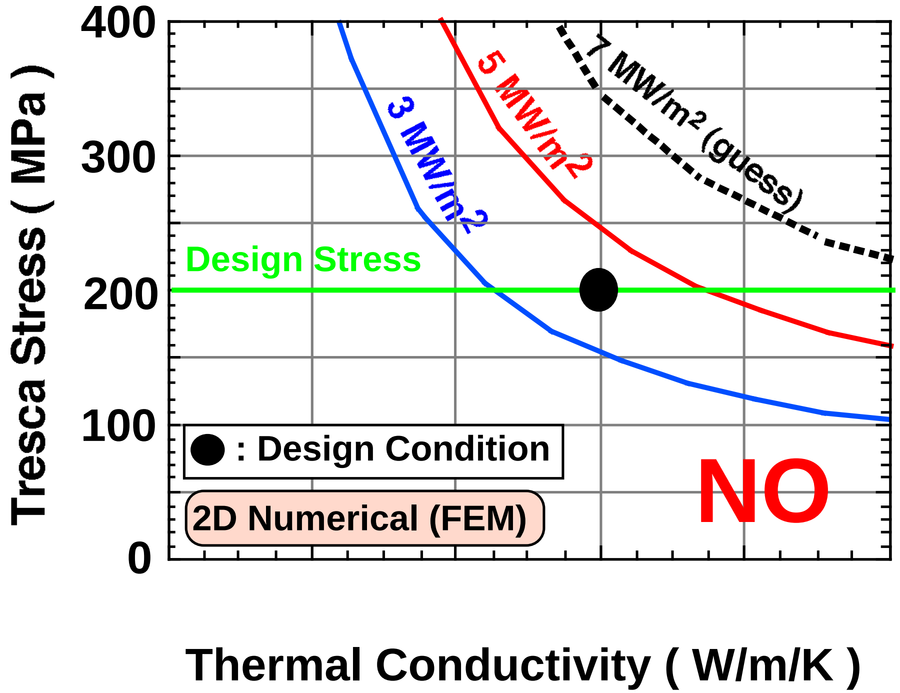
Thermal Stress on SiC/SiC

(High Heat Flux Component)

Blanket First Wall



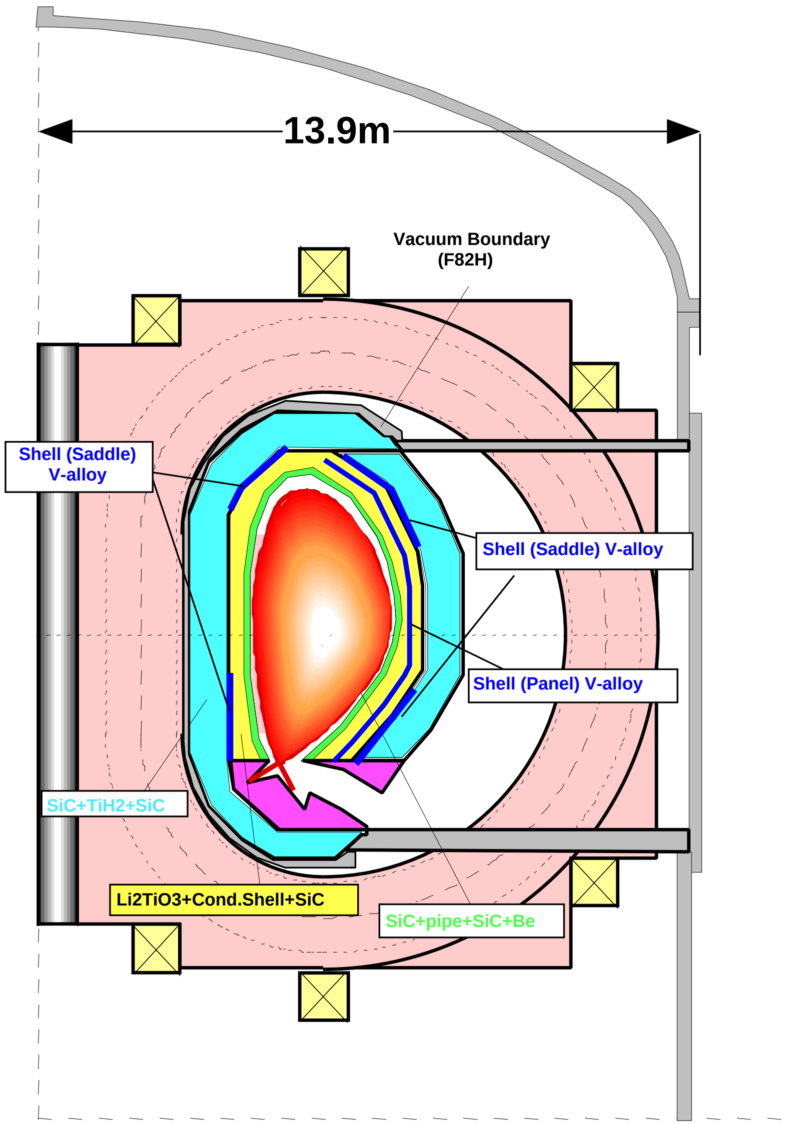
Divertor Plate

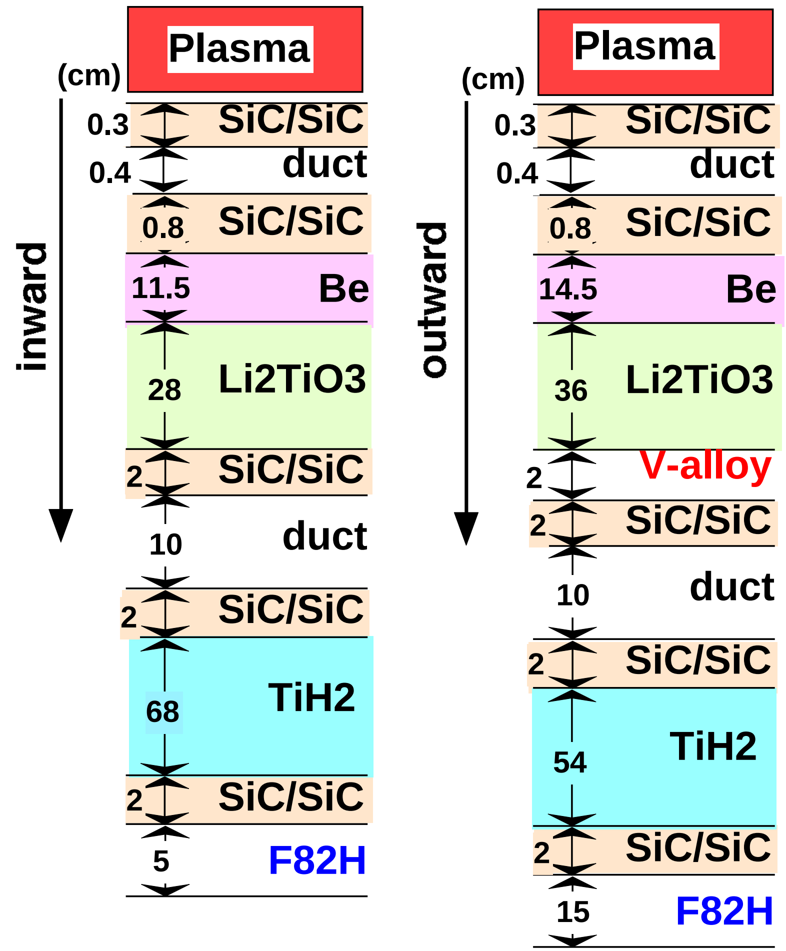


SOLUTION OPTION

- Full W Use for Divertor Plate
- Full Remote Radiative Cooling in Divertor Region
- Development of Excellent SiC/SiC

Radial Build of D-SSTR

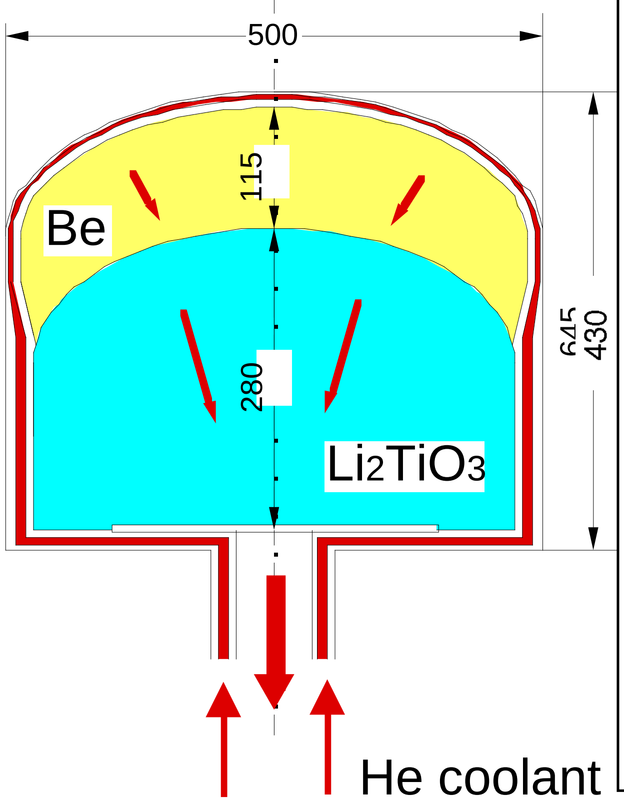




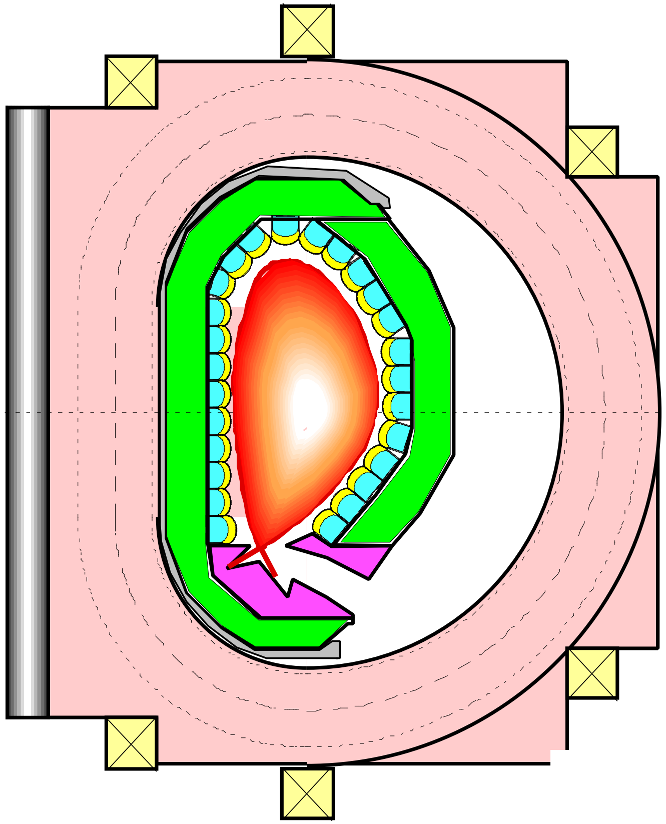
TiH_2 as Bulk Shield

Blanket Module of D-SSTR

Structure Material : SiC/SiC Comp. (Therm. Cond. of 15W/m/K)
Vessel Contents : 1φPebble Be and 1φPebble Li_2TiO_3
Coolant and T Purge Gas : He (10MPa & 600°C_{IN} / 900°C_{OUT})



Small Blanket(221.69kg)	
Be	=0.02875m^3
	=53.59kg
Li_2TiO_3	=0.05509m^3
	=121.6kg
SiC/SiC	=0.01485m^3
	=46.5kg
Large Blanket(301.57kg)	
Be	=0.03625m^3
	=67.57kg
Li_2TiO_3	=0.07509m^3
	=165.7kg
SiC/SiC	=0.02182m^3
	=68.3kg



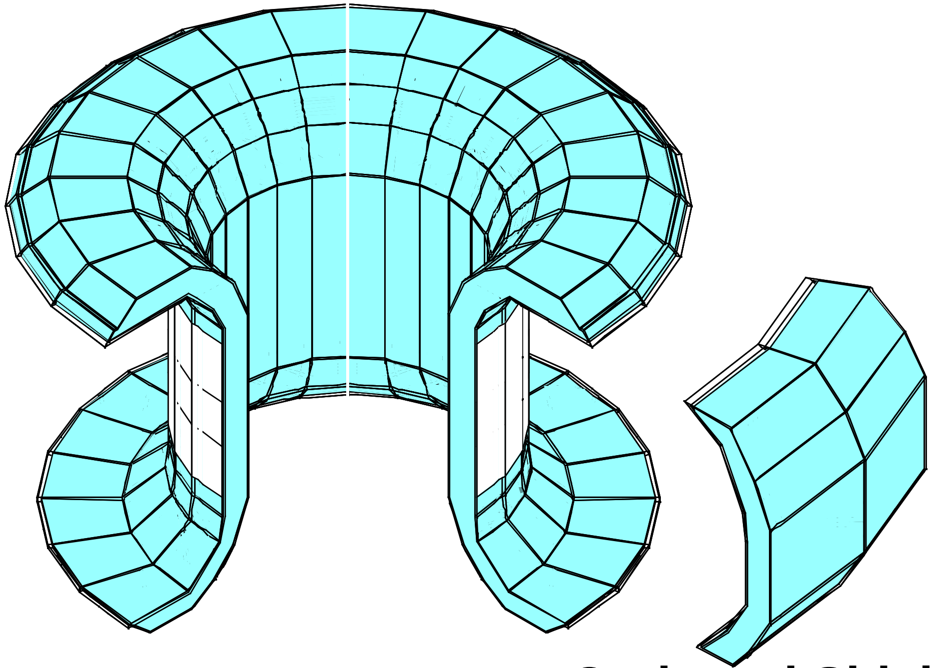
1950 modules S(675),L(1

Bulk Shield Structure Filled with TiH_2

Vessel Material : SiC/SiC Comp.

Inboard Shield
(Permanent & Lifetime Use)

$$\phi_n^{IN} = \begin{cases} 9\times10^{17}\ m^{-2}s^{-1}\ (> 0.1MeV) \\ 2\times10^{16}\ m^{-2}s^{-1}\ (\quad 14MeV) \end{cases}$$



Outboard Shield
(Replaceable but Lifetime Use)

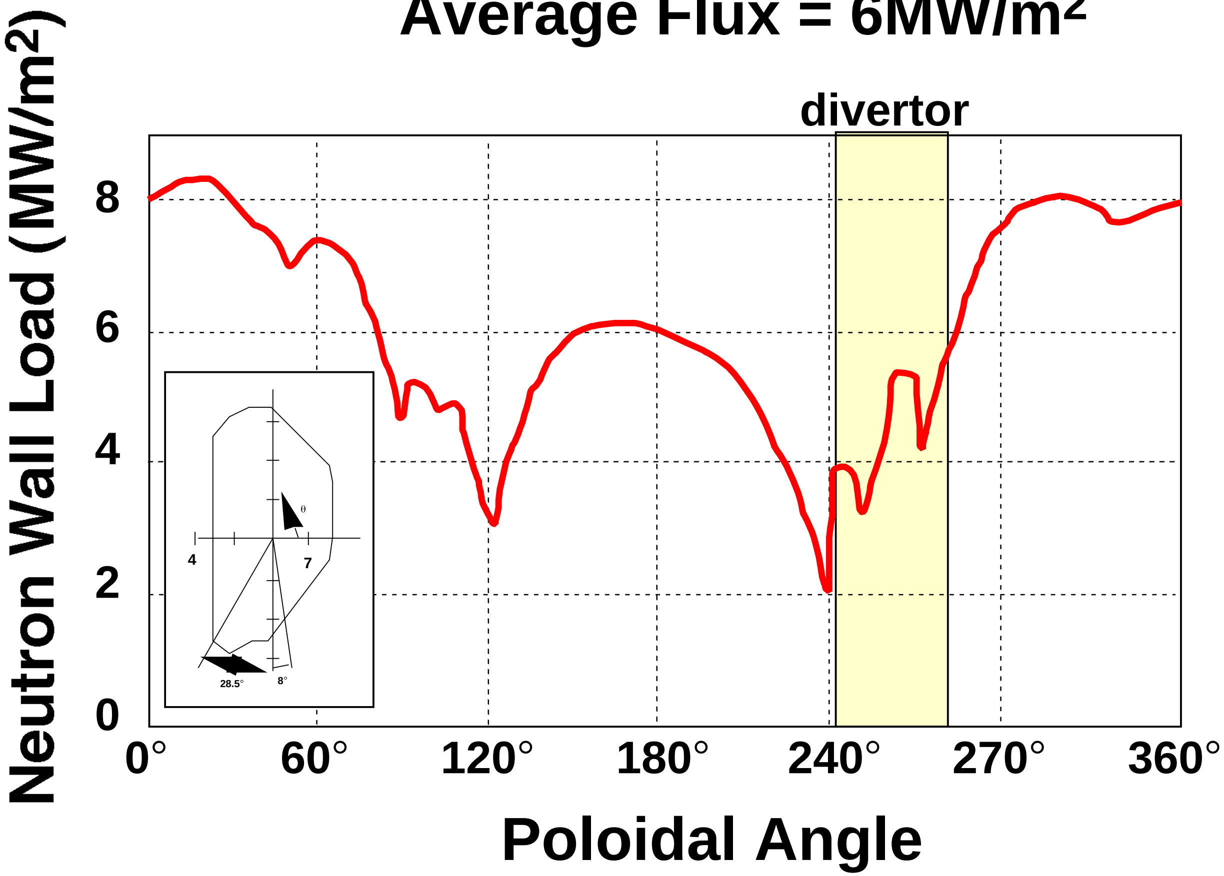
$$= \begin{cases} 5\times10^{17}\ m^{-2}s^{-1}\ (> 0.1MeV) \\ 1\times10^{16}\ m^{-2}s^{-1}\ (\quad 14MeV) \end{cases}$$

Shielding effevtiveness of TiH_2 is more superior than SiC/SiC by several times.

Neutron Wall Load in D-SSTR

D-SSTR : Compact and high power reactor
⇒Very high neutron wall load

Max. Flux = 8MW/m^2
Average Flux = 6MW/m^2



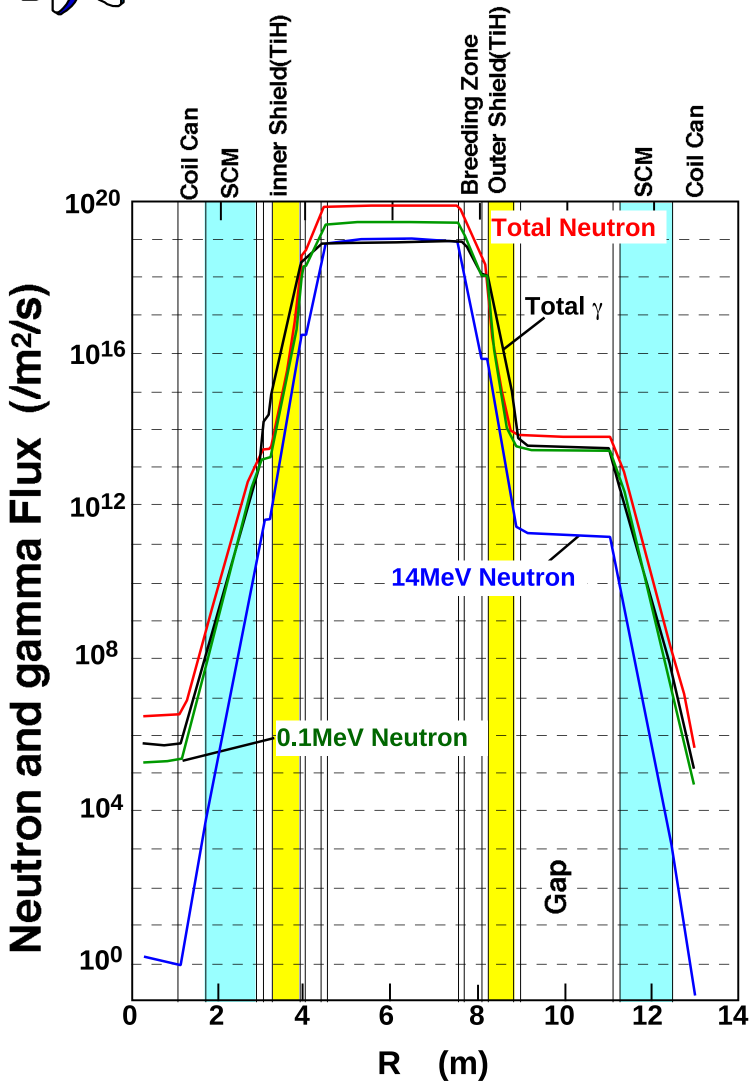
2 years Replacement

75% Availability

Max. Fluence 12MWa/m^2

Radiation Shielding of SiC & TiH_2 Power Core

(D-SSTR Power Core Structure)



TiH_2 for High Shielding Effect

1.35m : from First Wall to SCM

(2.5m for DREAM)

at SCM

Neutron flux (E>0.1MeV)

⇒0.9×10^{13} n/m^2/s(inside)

⇒1.0×10^{13} n/m^2/s(outside)

after 22.5FPY

Neutron fluence (E>0.1MeV)

⇒0.64×10^{22} n/m^2(inside)

⇒0.71×10^{22} n/m^2(outside)

Max. Nuclear Heating

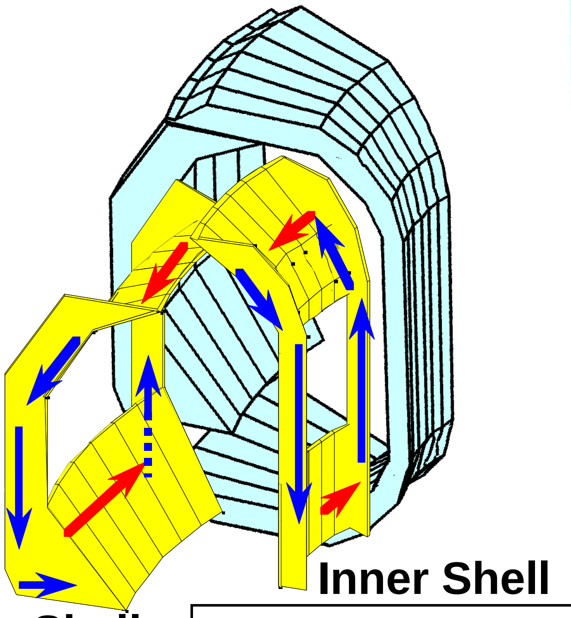
⇒0.06 mW/cm^3(inside)

⇒0.04 mW/cm^3(outside)

Enough Shielding can be expected in compact and high power reactor.

Shell Structure for Vertical Stability

5cm thickness of V-alloy Saddle Loop

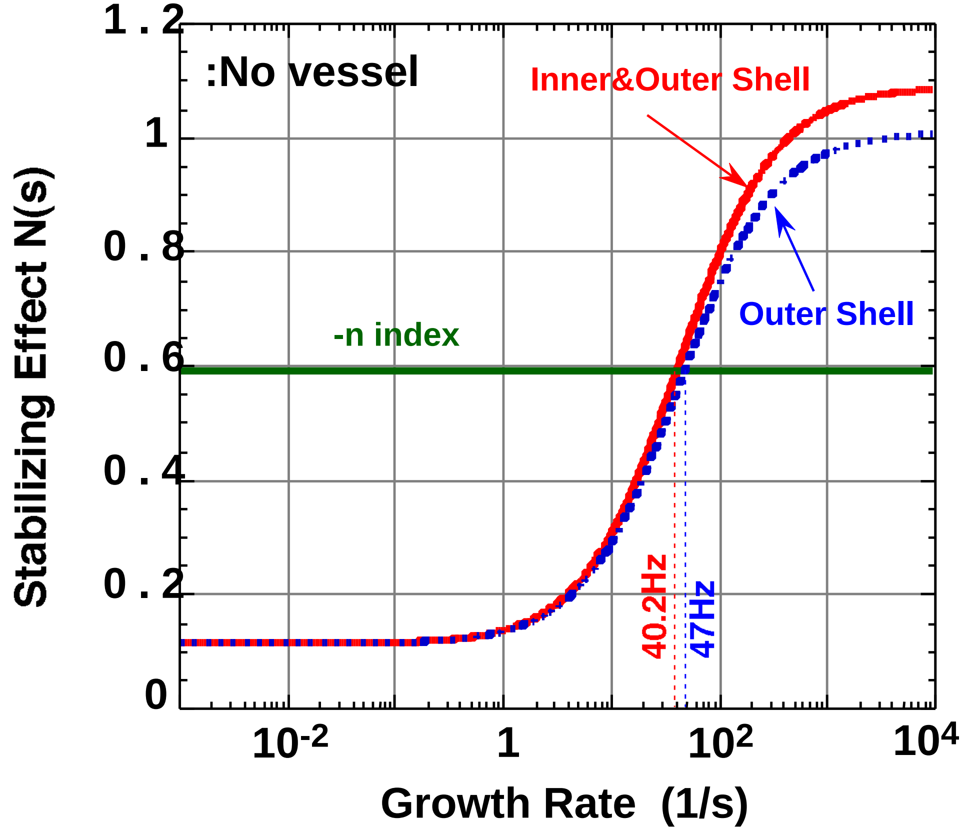


$3\times10^{16} m^{-2}s^{-1}$ (14MeV)
$1.2\times10^{18} m^{-2}s^{-1}$ (>0.1MeV)

$10^{16} m^{-2}s^{-1}$ (14MeV),
$8\times10^{17} m^{-2}s^{-1}$ (>0.1MeV)

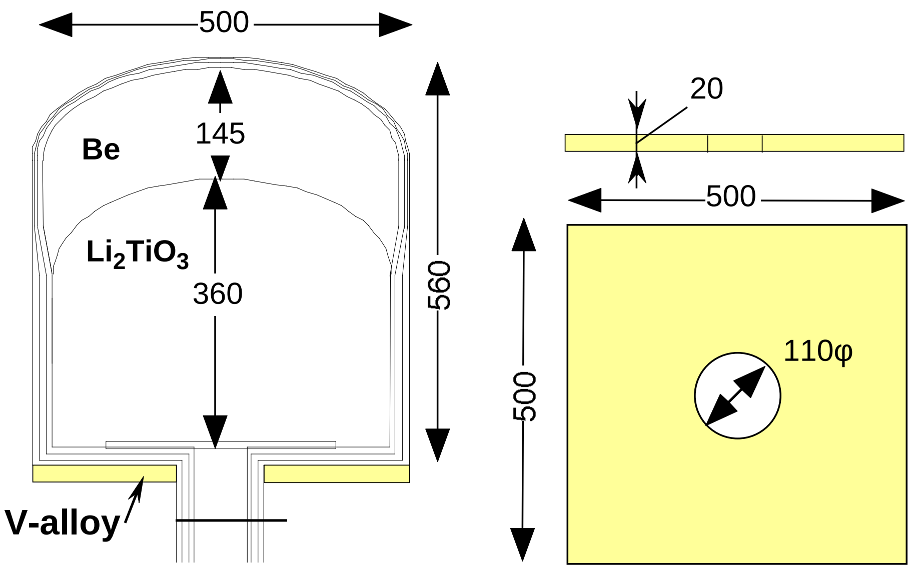
→ Growth rate : 40Hz

: controllable by normal conductors outside vessel

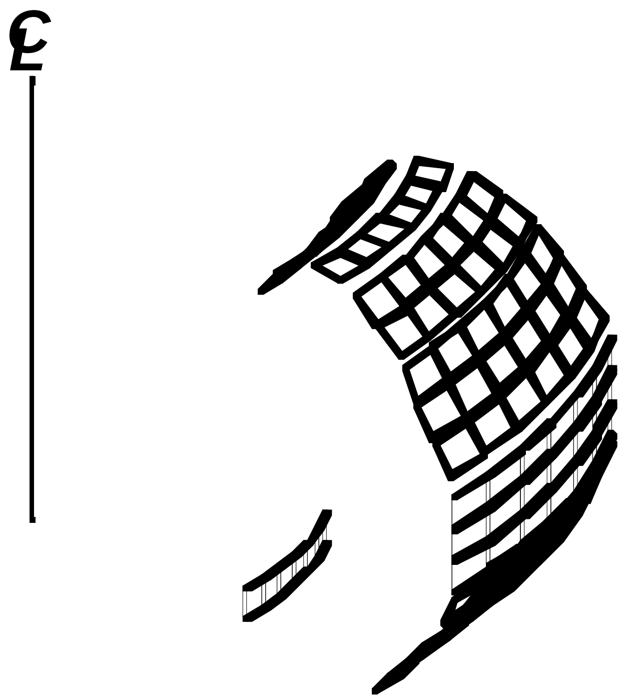


Plasma elongation 1.8 can be accepted.

Shell Structure for High β Stability



Blanket Module
(Larger Module)



V-alloy with 46cm x 46cm x 2cm and Hole for He Gas Coolant

Neutron Flux: 2×10^{16}m^{-2}s^{-1} (14MeV), 1×10^{18}m^{-2}s^{-1} (>0.1MeV)
4×10^{18}m^{-2}s^{-1}(Total)

Summary

Material use optimization for fusion power core components has been attempted in D-SSTR.

- **SiC/SiC for Replaceable Blanket Structure Material**
- **TiH2 for Bulk Shielding material**
- **V-alloy for Conducting Material**
- **W for Divertor Plate**