# Conceptual design of mixed pebbles blanket for SlimCS fusion DEMO reactor

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# Considerations of the points for fusion DEMO blanket design

- Main structure material
  - Reduced activation martensitic steel（F82H）
- Blanket structure
  - Simple structure is important from the viewpoint of engineering feasibility.
  - There are no welding points in the forward blanket area, which minimizes the risk of irradiation damage of welding lines.
- Coolant condition
  - The PWR water condition has an advantage that matured technologies in nuclear power plants will be likely to reduce development risks in fusion plant engineering.

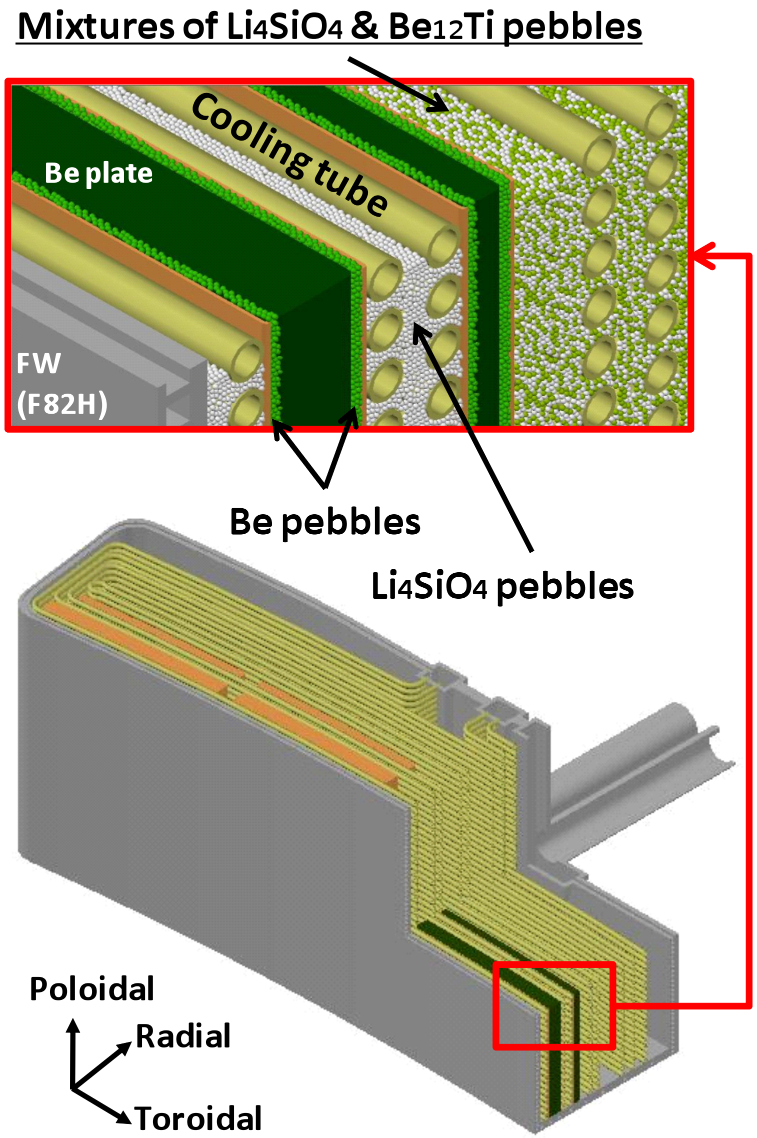
# Introduction



**The multilayered concept has engineering difficulties**

- welding of cooling tubes and the F82H casing for Be-plate, pebbles packing in narrow regions and inspection after fabrication.

- **Simplification of blanket structure is proposed from the view point of mixed breeder blanket.**



# Coolant condition

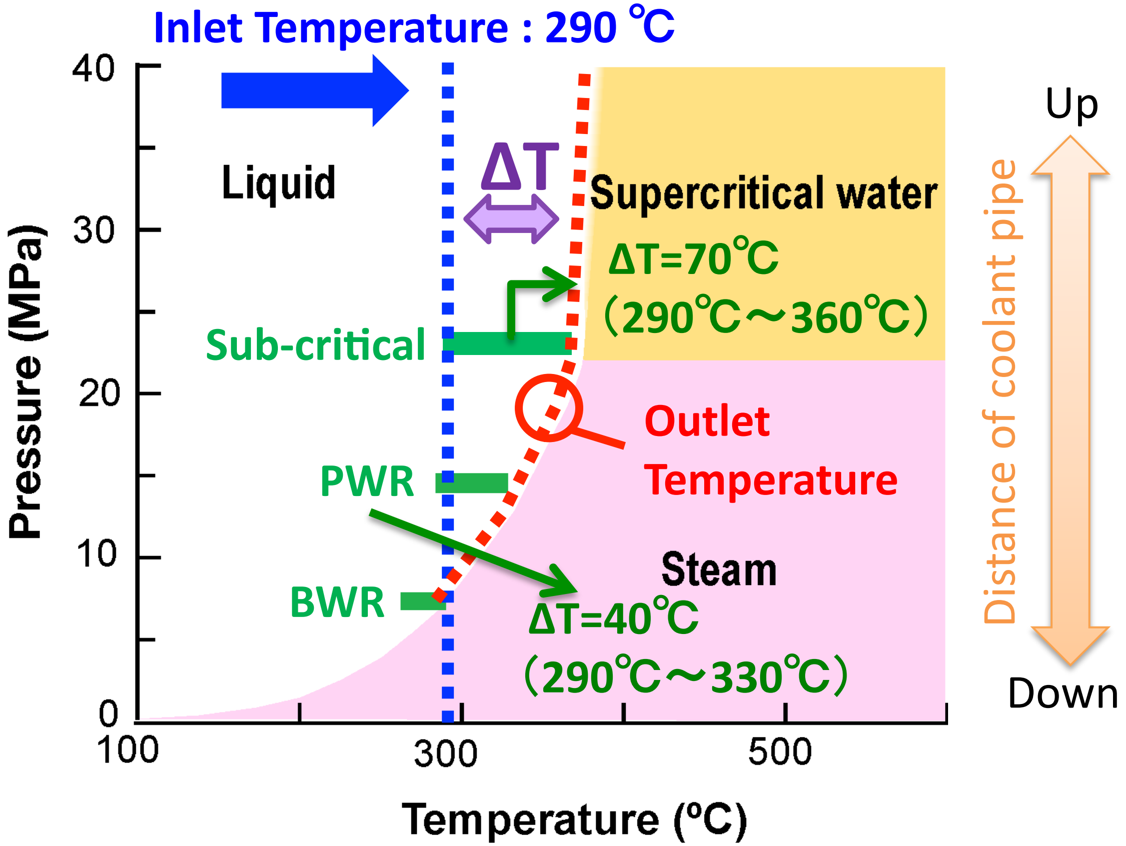


Advantage of the PWR water condition

⇒ Compatibility of F82H with the coolant water condition is well.

**$H_2O_2$ starts to pyrolytically decompose at 240 ℃**

**Inlet Temperature : 290℃**

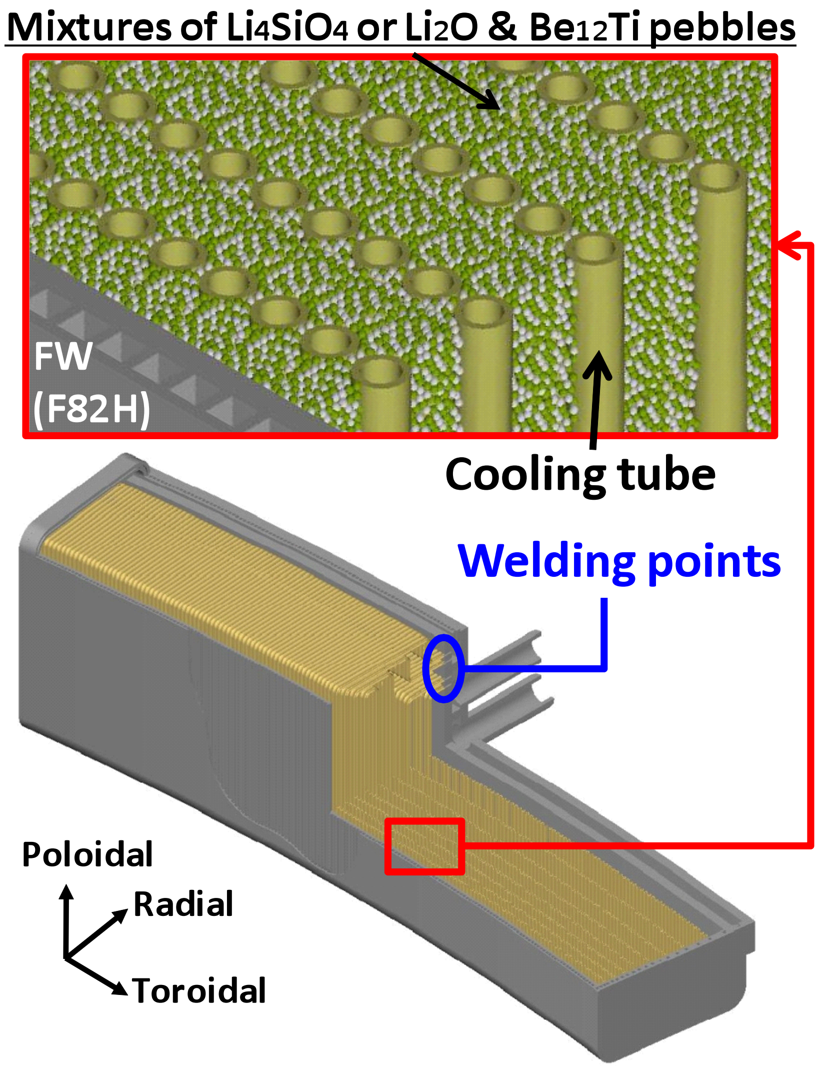



**Problem**

**Coolant plumbing is decreased from all length in blanket.**

# Proposed blanket concept

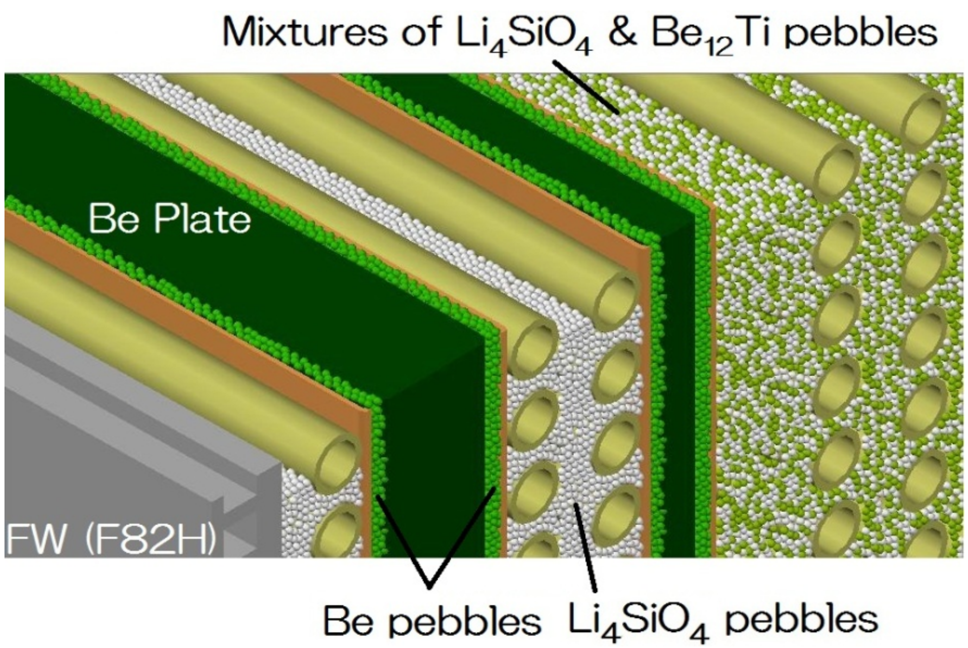





Interior design of the blanket by the water of PWR coolant condition

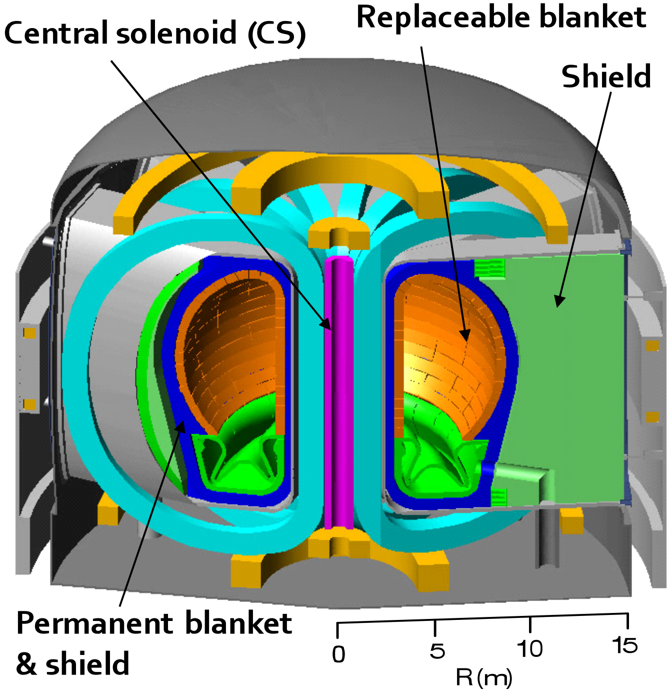
**Mixed pebbles breeder blanket**

**Pebbles of tritium breeding ($Li_4SiO_4$ or $Li_2O$) and neutron multiplication materials ($Be_{12}Ti$) are mixed and these pebbles are filled in blanket.**

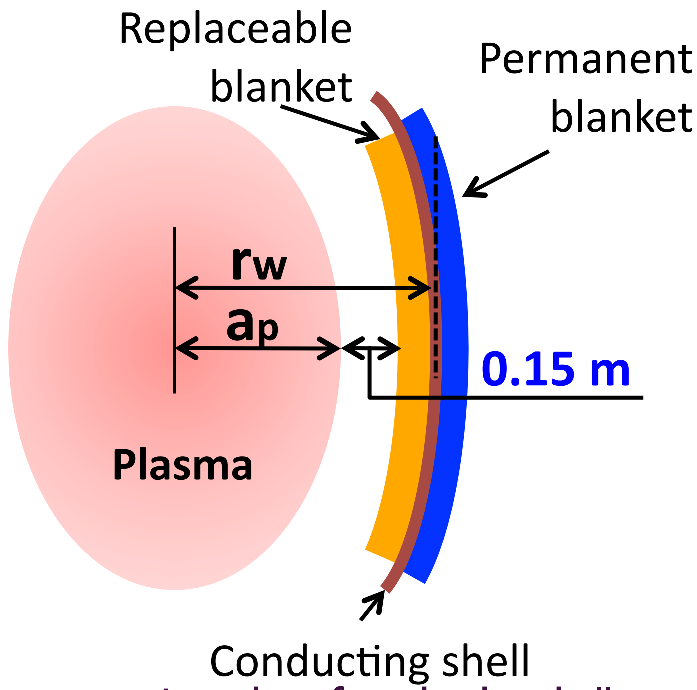


# Calculation conditions

## DEMO Reactor Concept, SlimCS




| | |
|---|---|
| Major radius $R_p$ | 5.5 m |
| Minor radius $a_p$ | 2.1 m |
| Aspect ratio A | 2.6 |
| maximum field $B_{max}$ | 16.4 T |
| Fusion power $P_{fus}$ | 2.95 GW |
| Electric output $P_e$ | 1 GWe |




Location of conducting shell

- The conducting shell need to be located at $r_w/a_p \leq 1.35$ for plasma positional stability and high beta access.
- The gap between the separatrix and the first wall is 0.15 m.

**The thickness of blanket should be <u>0.5 m or less</u> to satisfy $r_w/a_p \leq 1.35$**

# Calculation flow



- **The point of calculation**

  Tokamak fusion reactor has distribution of neutron wall load.

➢ The thickness of each coolant layer in the blanket needs to be adjust the difference of neutron wall load.

→ **Same outlet temperature**

**Calculation parameters**

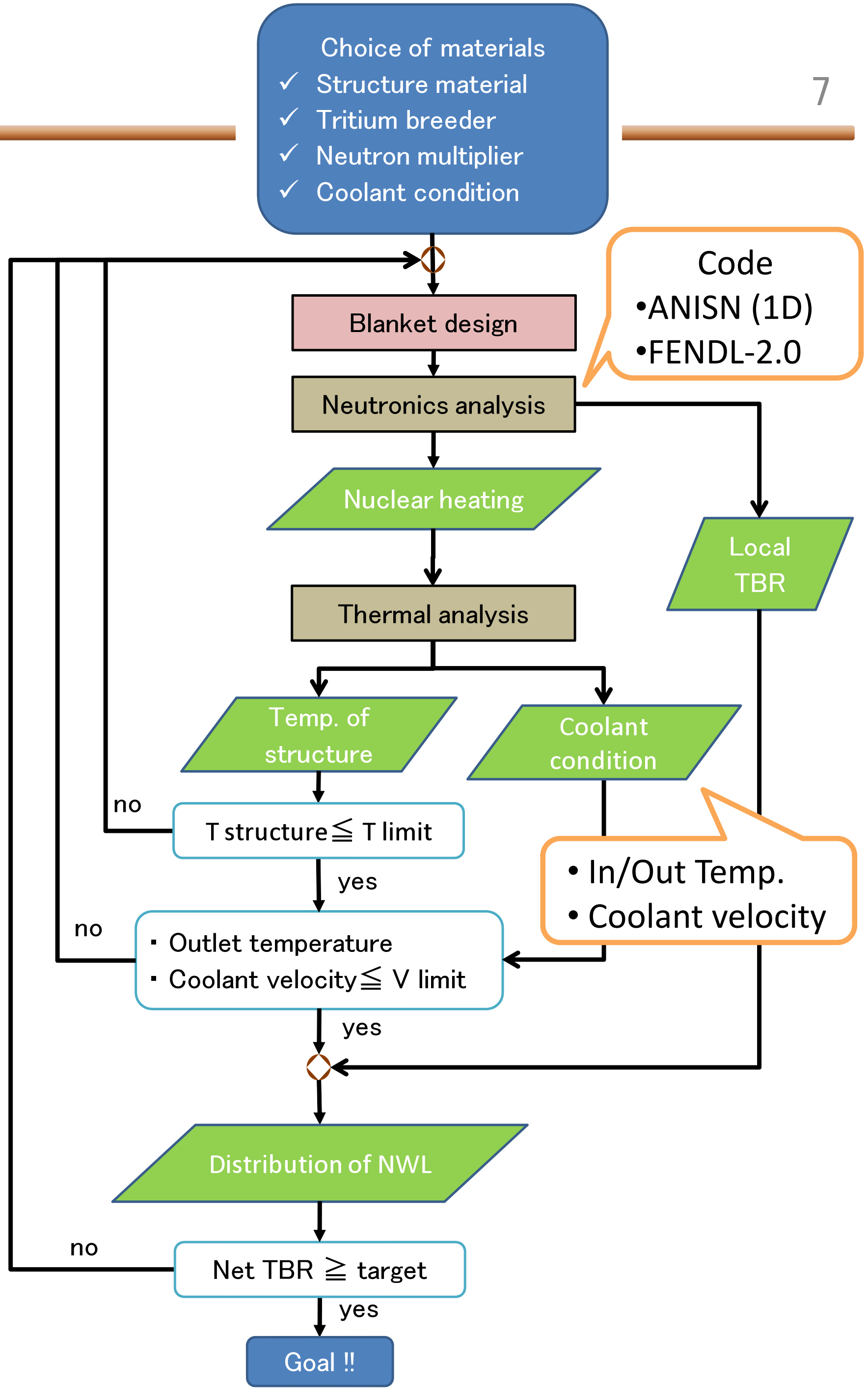
- **Neutron wall load: 1 - 5 MW/m²**
- **Average heat wall load : 0.5 MW/m²**

- **Target of design**

✓ **Net TBR ≧ 1.05**

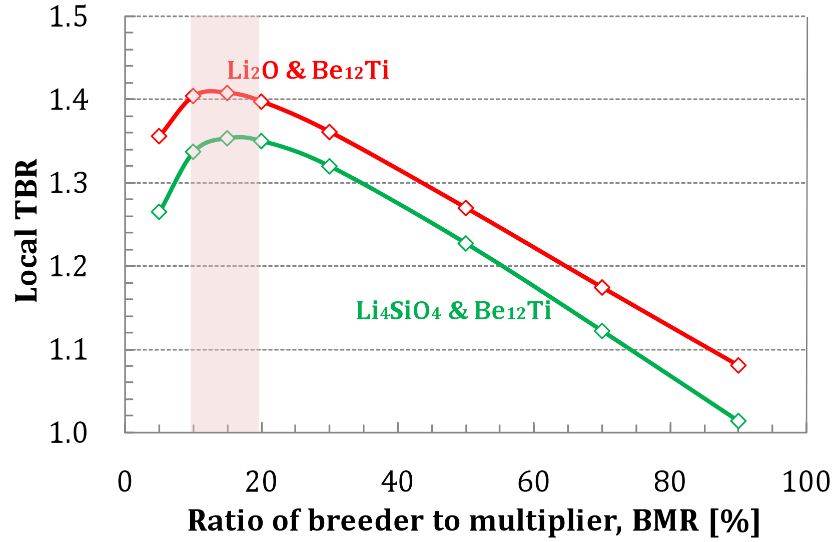
**(Local TBR = 1.38)**

✓ **Blanket thickness ≦ 0.5 m**

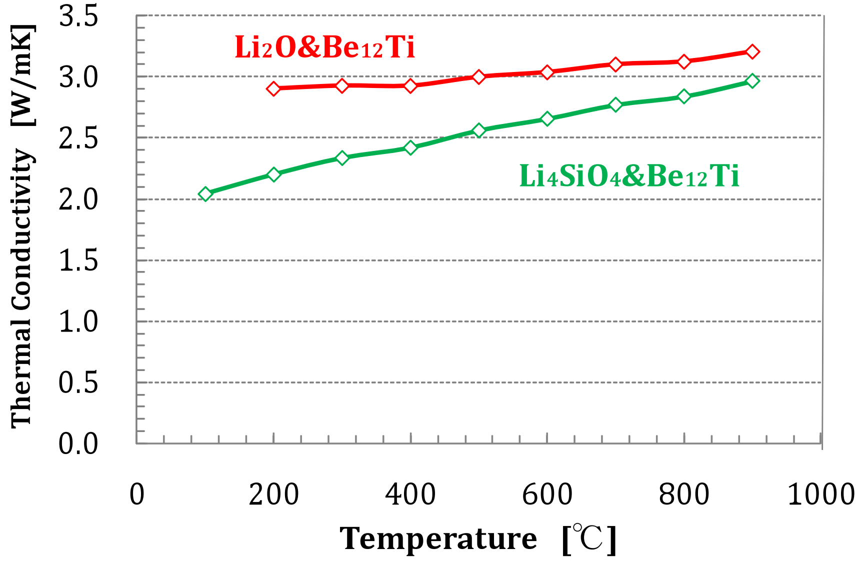


# Mixture ratio






Local TBR with ratio of mixed breeder




Thermal conductivities of breeder and multiplier

- Local TBR becomes a maximum value when BMR is between 10% to 20%.
- BMR is fixed at 15% for both cases.

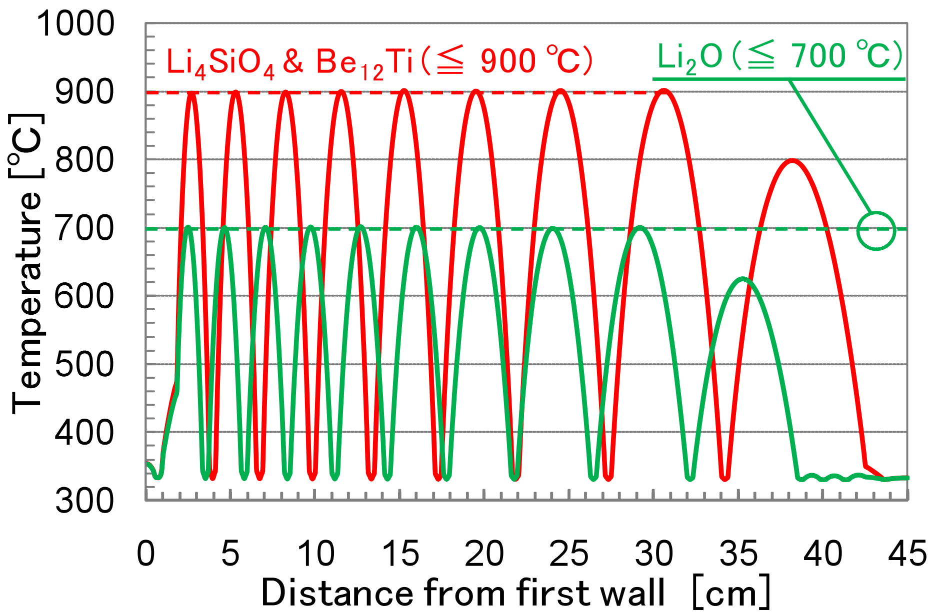
$$BMR = breeder/(breeder + multiplier) \times 100$$

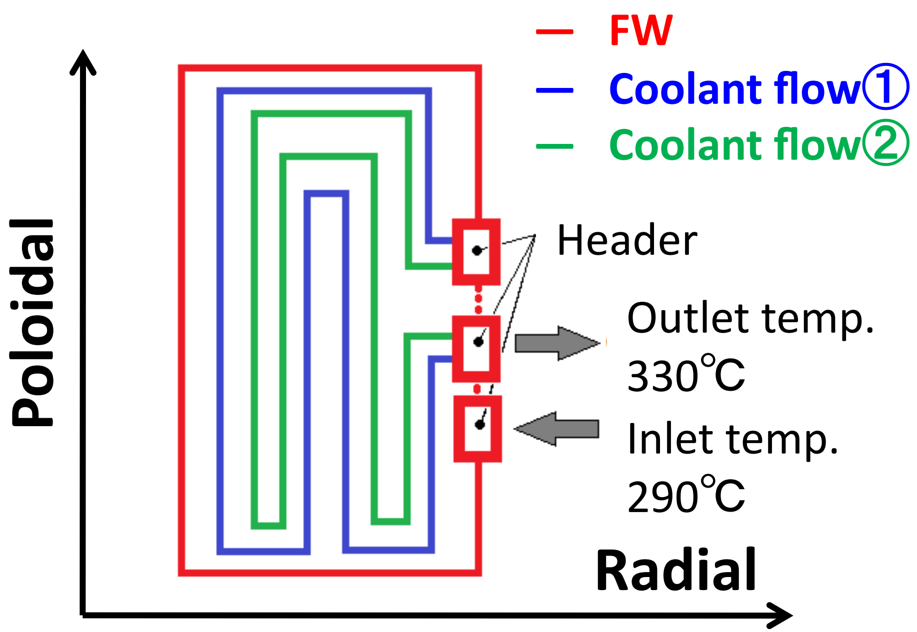
| Packing fraction | Breeder | Multiplier | Gas |
|---|---|---|---|
| Binary | $Li_4SiO_4$ & $Li_2O$ | $Be_{12}Ti$ | He |
| 80% | 12% | 68% | 20% |

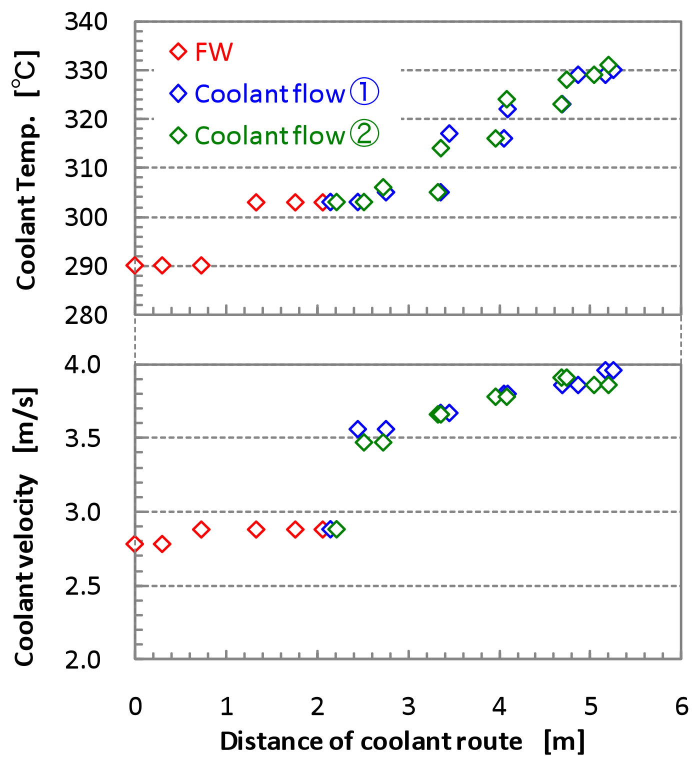
The effective thermal conductivity of the mixed pebbles is defined by the combination of the conductivities of breeder and multiplier pebble beds in accordance with BMR.

# Estimated temperature of structure and outlet coolant

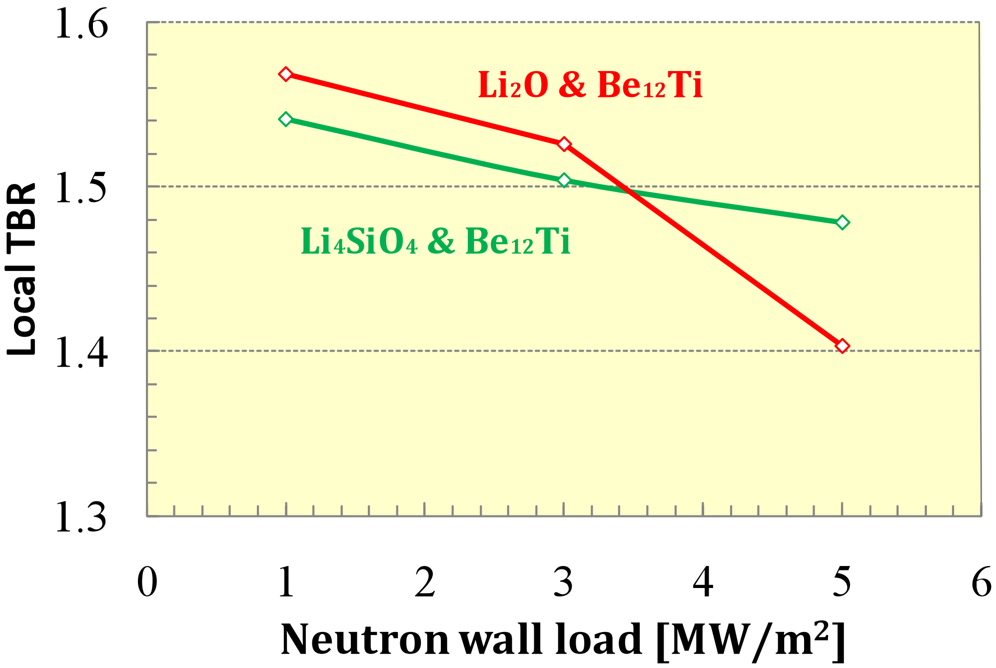
| Coolant conditions | | PWR |
|---|---|---|
| Neutron wall load | MW/m$^2$ | 3 |
| Heat load | MW/m$^2$ | 0.5 |
| Tritium breeding | | $Li_4SiO_4$ or $Li_2O$ |
| Neutron multiplication | | $Be_{12}Ti$ |
| Packing fraction | % | 80 |
| Blanket thickness | cm | 45 |
| Coolant direction | | Poloidal |
| Inlet/Outlet temperature | ℃ | 290/330 |
| Pressure drop | M Pa | 0.14 |



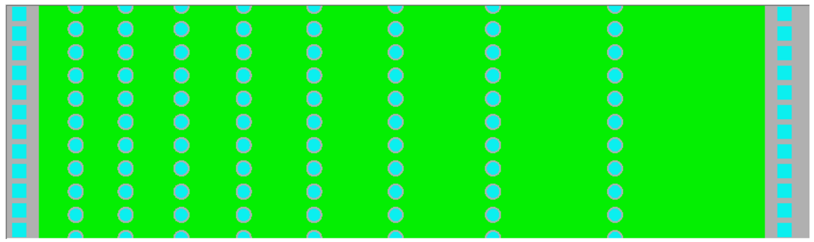



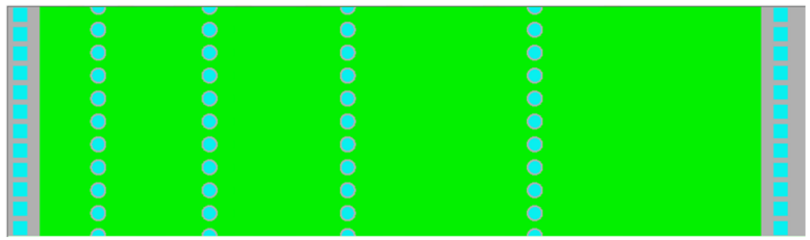
# Dependence of local TBR on neutron wall load 




Cross section of blanket (Pn = 5 MW/m²)



Pn = 1 MW/m²



**TBR improved**

- **With decreasing the NWL from 5 to 1 MW/m², the local TBR is improved because of a reduction of the coolant area in the blanket.**
- **Net TBR need to be calculated by considering the poloidal distribution of neutron wall load.**

# Location of Blanket modules for SlimCS

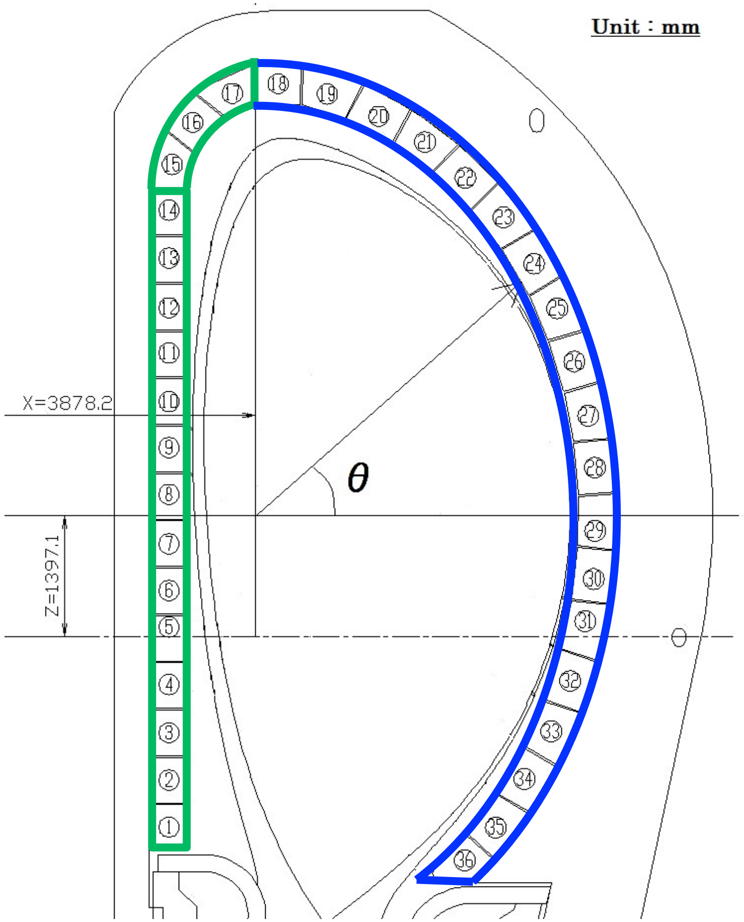


The blanket modules needs to be adjust the difference of outlet temperature.

## → Calculation of neutron wall load for SlimCS

| | IB blanket | OB blanket | Divertor |
|---|---|---|---|
| Surface [m$^2$] | 179 | 489 | 326 |
| Thickness [m] | 0.3 | 0.3 ～ 0.6 | - |
| Coverage [%] | 20.3 | 55.6 | 11.8 |

（12.3 % ：Rims, Ribs and Gap of blanket, and ports）

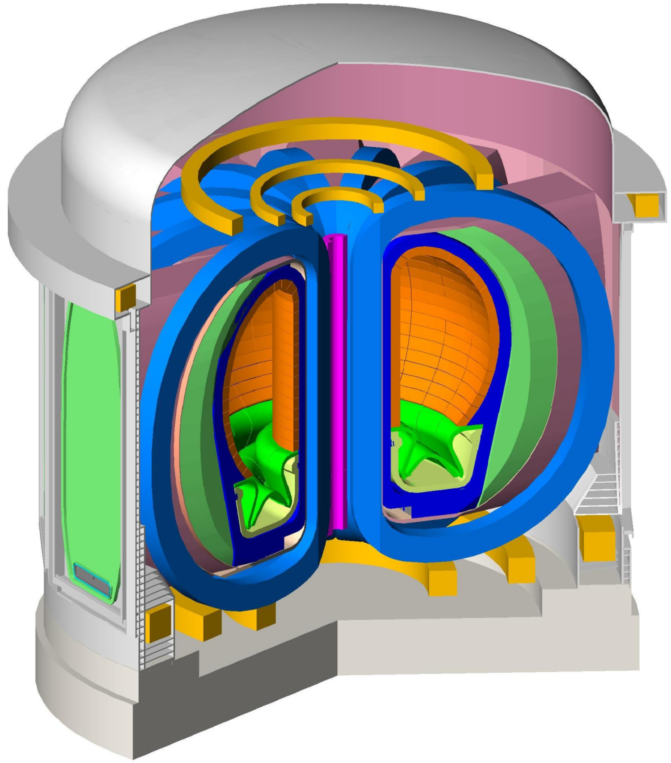


# Calculation of neutron wall load for SlimCS



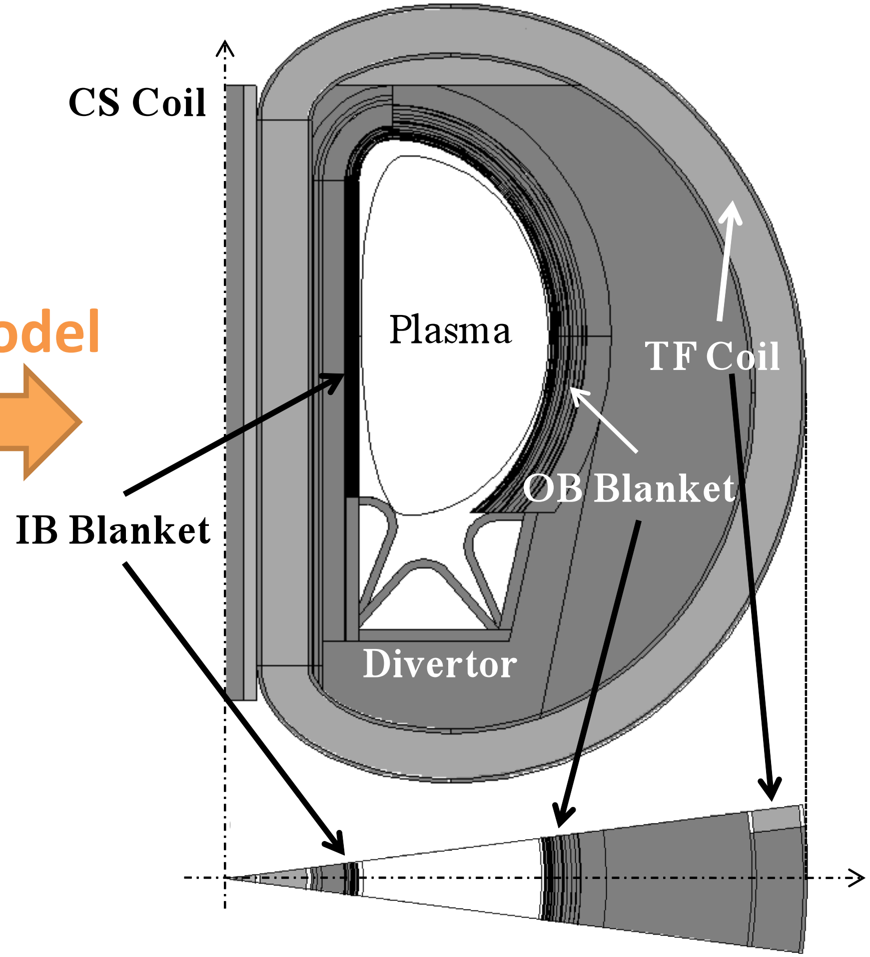
- **3-D calculation code with nuclear library**
  - ✓MCNP-5 with ENDF/B-VII
- **Geometry**
  - ✓15° sector model
  - ✓Reflecting boundaries

> ➢ Neutron source
>
> Volume source for plasma with energy of 14.06 MeV



DEMO fusion reactor concept, SlimCS

3-D model

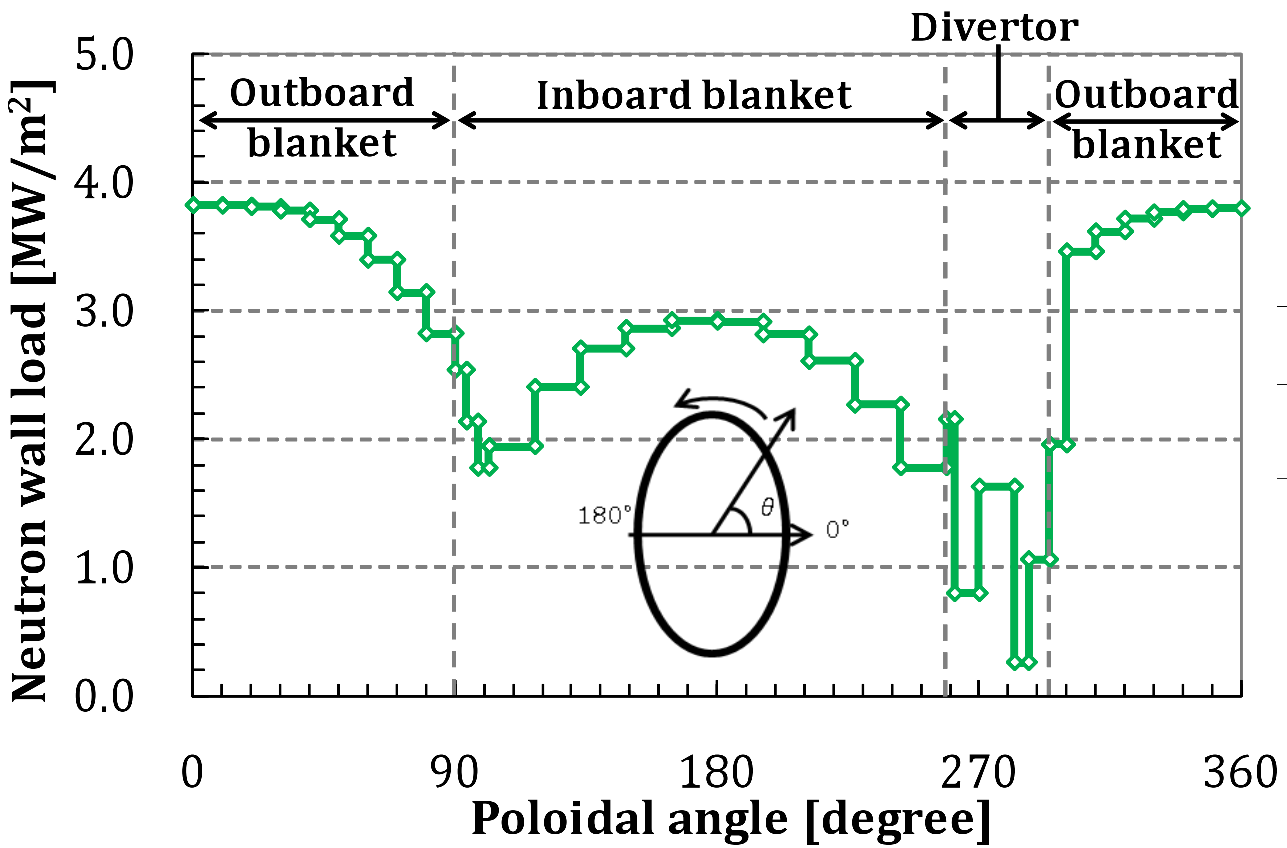


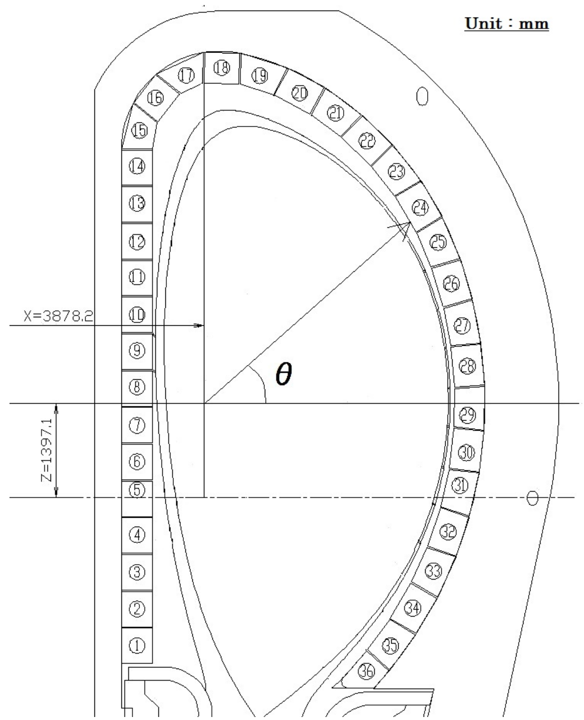

MCNP calculation model for SlimCS

# Distribution of neutron wall load for SlimCS



**$P_{fusion}$ = 2.95 GW**

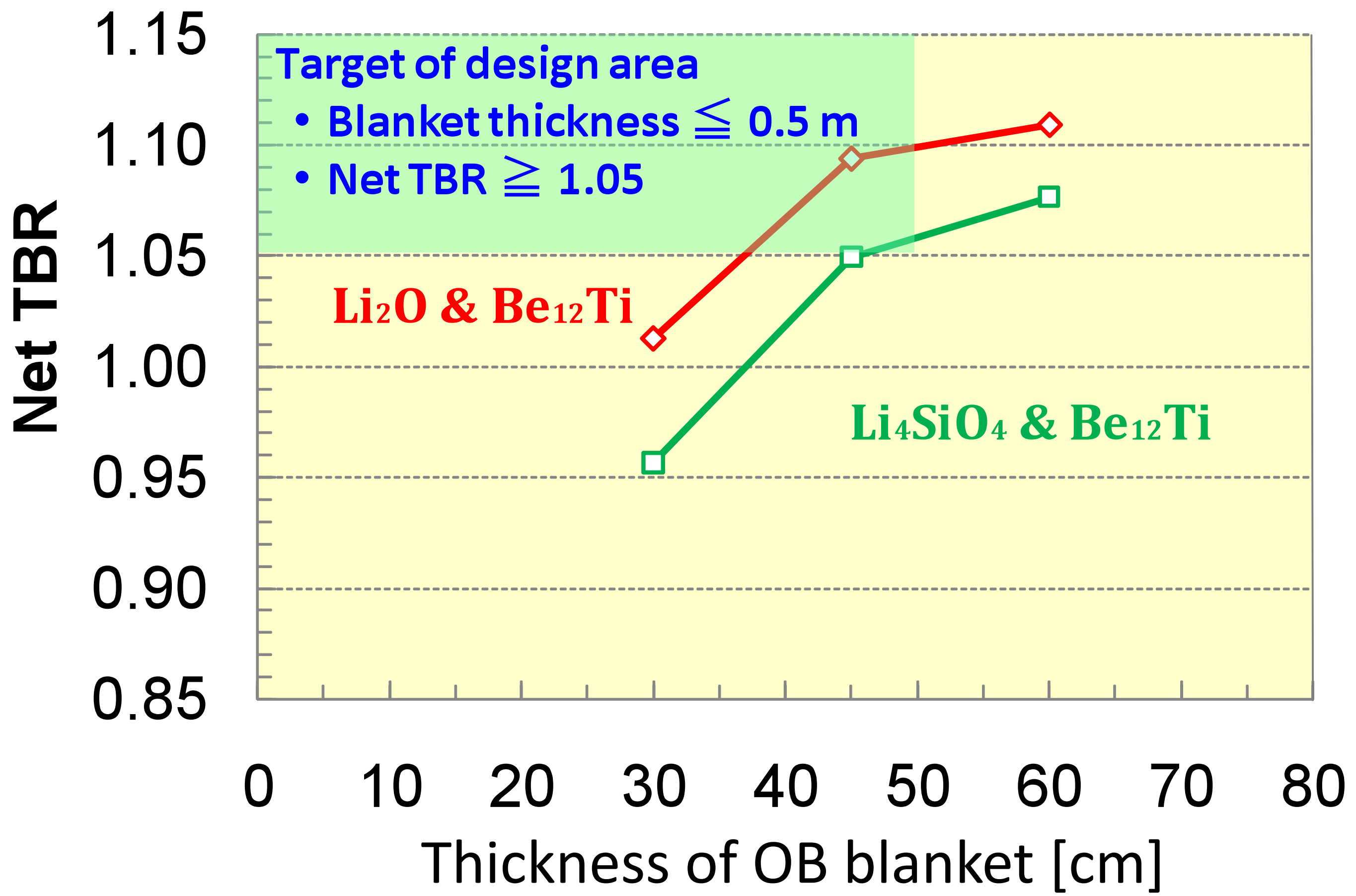



| Neutron wall load | IB blanket [MW/m$^2$] | OB blanket [MW/m$^2$] |
|---|---|---|
| Peak | 2.93 | 3.82 |
| Average | 2.44 | 3.50 |

# Dependence of net TBR on blanket thickness






- $Li_2O$&$Be_{12}Ti$ and $Li_4SiO_4$&$Be_{12}Ti$ attained the target of design area
  - $Li_2O$&$Be_{12}Ti$ : 35 ≦ Blanket thickness ≦ 50 cm
  - $Li_4SiO_4$&$Be_{12}Ti$ : 45 ≦ Blanket thickness ≦ 50 cm

* Satisfies a requirement for conducting shell ($r_w/a_p \leq 1.35$)

# Conclusions



## Conceptual design of mixed pebbles blanket for SlimCS fusion DEMO reactor

- ✓ We are proposed mixed pebbles blanket for fusion DEMO reactor from the view point of engineering fusibility.
- ✓ The blanket modules needs to be adjust the difference of outlet temperature.
- ✓ $Li_4SiO_4$&$Be_{12}Ti$ and $Li_2O$&$Be_{12}Ti$ attained the design target ( Net TBR $\geq$ 1.05).
- ✓ Both cases can satisfy a requirement for location of conducting shell ($r_w/a_p \leq 1.35$)

**Mixed breeder blanket is preferable for the fusion DEMO reactor.**