Fusion Reactor Engineering I

Special section :

How to design fusion reactor core

Practice to make a simple system code

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Introduction

✓ **Worldwide research status of fusion reactor & demo**

	R/a	β_N	B_T	f_{GW}	I_p	f_{BS}	H98	Q, PCD
ITER (2011)	6.2/2.0m	2.75	5.3T	0.85	8MA	62.5%	1.5	3.36, 73MW IC, NB, EC
PPCS (2007)	7.5/2.5m	3	6T	1.2	19MA	55%	1.1	17.2, 173MW NB, EC
ARIES (2006)	5.2/1.3m	5.4	5.86T	0.9	12.8MA	89%	1.45	50, 41MW IC, LH
CHINA (2008)	6/2m	5	5.93T	1.2	15MA	69%	1.45	31, 80MW NB, LH, EC, IC
JAPAN (2005)	5.5/2.1m	4.3	6.0T	0.98	16.7MA	77%	1.3	50, 60MW NB, EC
K-DEMO	6.8/2.1m	~4	7.5	~1.0	~12MA	~60%, ~90%	~1.5	~15, 100MW ~50, 50MW

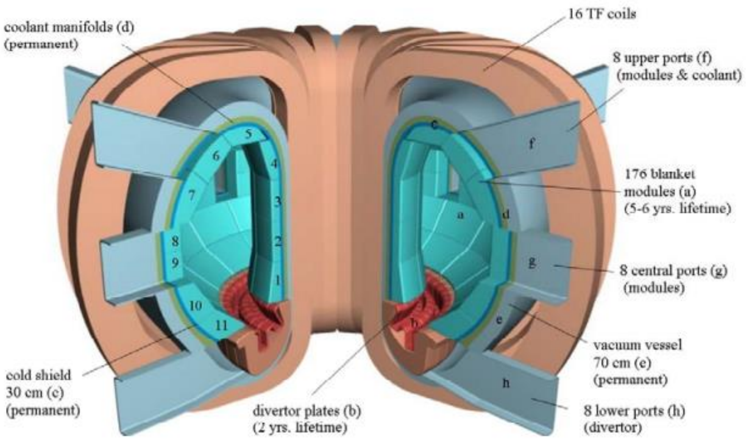
- ITER를 State of the art 라고 가정. ITER보다 조금 가혹한 조건은 주황색 많이 가혹한 조건은 붉은색, 보수적인 조건은 녹색 표기함.

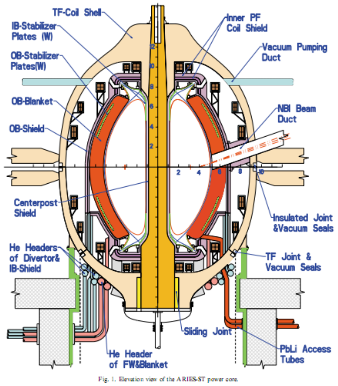
the tokamak configurations have developed a more credible basis compared to older studies.

Introduction

- **Research motivation for fusion reactor in this moment**

- **To identify the impact on the resulting design**
- **To provide the guidance to critical research needs Incorporating updated physics understanding, and using more sophisticated engineering and physics analysis,**





[2] F. Najmabadi , Fusion Engineering and Design 65 (2003) 143-164

[1] D. Maisonnier et al, Power plant conceptual studies in Europe, Nucl, Fusion 47(2007) 1524-1532

System Code

- **System Code – It is a code which Calculate physics parameters of Tokamak with theoretical and empirical formulas.**

<Role of System Code>

Design of new experiment machine

Tokamak Reactor System Analysis

Design and performance research of Commercial Reactor

System Code

- Solve simultaneous equations for n variables (Physical parameters or device parameters)
- Usually, the number of variables exceeds the number of equations.

Need optimization constraints
to obtain a solution for particular plasma state

Constraints	Variables
Beta relation	Electron temperature
Beta limit	Beta
Density limit	Electron density
Power balance	Heating ,current drive power, and radiation
Aux. power = CD power + Heating power	Heating power
Radial build	Major radius, TF-plasma Gap

Conceptual design K-DEMO fusion core

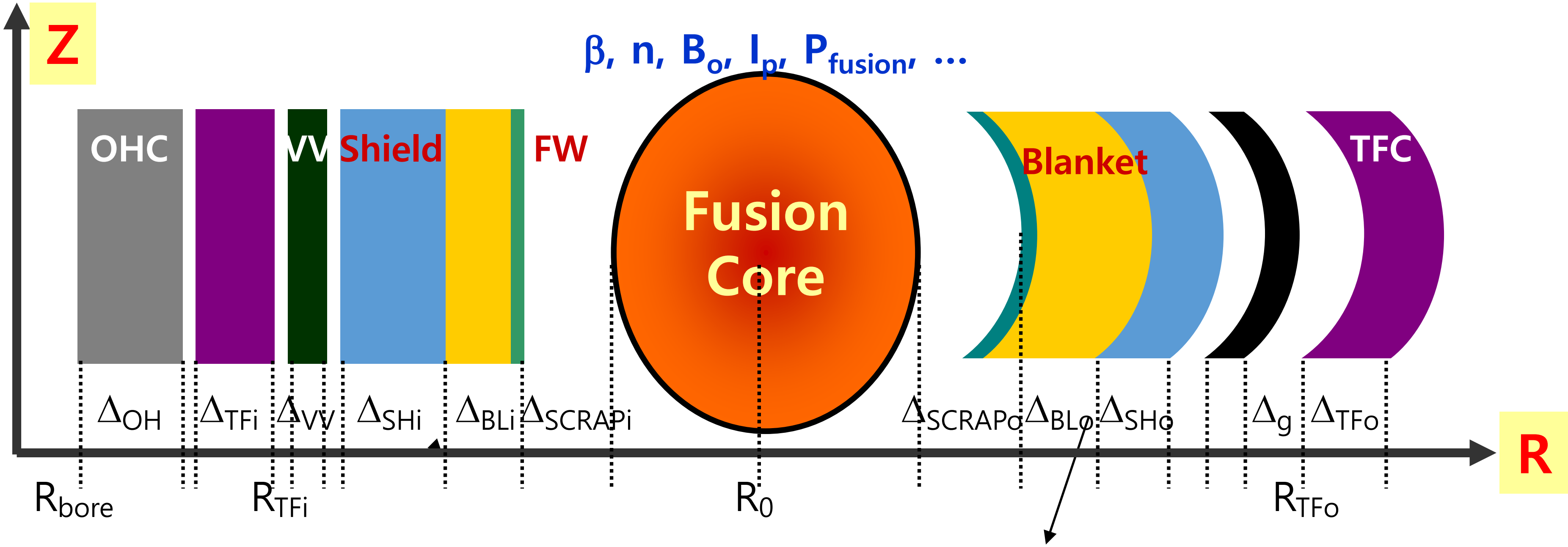
Step 1

Check basic parameters

K-DEMO geometrical factors (R,a, B_T) is from magnet analysis.

In other case : must start from radial build

$$R_0 \geq R_{CS} + \Delta_{TF} + \Delta_{VV1} + \Delta_{S1} + \Delta_{blk1} + a_0$$



Conceptual design K-DEMO fusion core

Step 2 : determine basic stability boundary according to aspect ratio

Plasma elongation is from Menard formula.

$$\kappa = 1.46155 + 4.13281\varepsilon - 2.57812\varepsilon^2 + 1.41016\varepsilon^3$$

Normalized beta is from Lin-Liu.

$$\beta_{N\max}(A) = \frac{-0.7748 + 1.2869\kappa - 0.2921\kappa^2 + 0.0197\kappa^3}{\tanh((1.8524 + 0.2319\kappa)/A^{0.6163}))A^{0.5523}/10}$$

$$\beta_T = \frac{I_P A \beta_N}{R_0 B_T} \qquad \beta_P = \frac{2\beta_T q_{cyl}^2 A^2}{(1+\kappa^2)}$$

Safety factor is from Wong $q_{a,\min} = 1.21 + 1.3A - 0.25A^2$

Plasma Current $$I_p = \frac{5a^2 B_0}{R_0 q_a}\frac{(1+\kappa^2)}{2}$$

Conceptual design K-DEMO fusion core

Step 3 : calculate fusion power

Greenwald Density $n_G = \frac{I_P}{\pi a^2}$

Temperature is from average pressure(betaN) $P = nT$ $T_{avg} = \left(\frac{\beta_N I_P B_T}{2\mu_0 a} \right)$

Reaction rate(another ppt)

Fusion power

$$P_F = 0.25\, n_D n_T < \sigma v >_{DT} E_{fus}$$

Conceptual design K-DEMO fusion core

Step 4 : calculate auxiliary power

assume current drive power is the only external heating power.

- Neutral Beam Injection Energy

  assume that parobolic-like deposition profile with tangential injection at R_0

  beam distance $$L_b = [(R_0 + a)^2 - R_0{}^2]^{1/2}$$

  $$E_b = 100 < n_{e-20} > L_b$$

- Current Drive Efficiency

  from Start and Cordey fitting result

  $$\gamma_{CD} = E_b{}^{0.5327}(-8.47*10^{-4} + 1.852*10^{-3}T_{avg} - 5.307*10^{-5}T_{avg})$$

- Current Drive Power

  current to be driven is [plasma current*(1-bootstrap fraction)]

  therefore $$P_{CD} = \frac{n_e R_0 I_P (1 - f_{BS})}{10^{20}\gamma_{CD}}$$

Conceptual design K-DEMO fusion core

Step 5 : Solving power balance to check confinement

$$P_{Tot} = \frac{W}{\tau_E} = P_{fus} + P_{rad} = P_{OH} + P_{\alpha} + P_{CD}$$

$$P_{rad} = P_{brem.} + P_{sync}$$

$$\tau_E = H\tau_E^{IPB98(y,2)}$$

$$= H\,0.0562 I_P^{0.93} B_0^{0.15} (P_{con} vol)^{-0.69} \bar{n}_{19}^{0.41} M^{0.19} R_0^{1.97} (\frac{a}{R_0})^{0.58} \kappa^{0.78}$$

Radiation power

$$P_{rad} \approx P_{brem} = 4.8 \times 10^{-43} Z_{eff} {n_e}^2 \sqrt{T} a^2 R_0 \kappa \ \times peaking\ factor$$

assume Z_eff = 1.4 peaking factor = 2

Conceptual design K-DEMO fusion core

Evaluate your core design comparing with current technology

Q

H factor

Normalized beta