Consideration on Design Window for a DEMO Reactor

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Contents

1) Impact of TF coil design

2) Feasibility on pulsed operation

3) Interrelation between plasma parameters

Acknowledgements: Mr. N. Shinji, Mr. S. Okayama and Dr. R. Hiwatari
This roadmap has been studied and presented by Fusion Energy Forum of Japan in response of Ministry of Education, Culture, Sports, Science and Technology-Japan, which asked the Forum how to develop Tokamak type DEMO reactor as a case study. The related reports are also available from the following Web site (in Japanese): http://www.naka.jaea.go.jp/fusion-energy-forum/
Decision making for SC materials and Max field on coil. (~ 2015)

If we chose a new type of SC coils beyond the ITER design, a lot of issues will appear.

Slim-CS DEMO-CREST

Bmax ~ 16 T Nb3Al
Finding by the roadmap & Working breakdown study

(6) Development of SC coils, if the magnetic field of DEMO exceeds the ITER design parameters (TF: 11.8T, CS: 13T).

- **Nb3Al for SC conductor is a possible candidate** for a higher magnetic field. But, there is no candidate for advanced structure material, over the present JJ1. There is no facility for mass production of Nb3Al. This is another concern.

- If the available SC coil technology is similar to the ITER SC coils, the Japanese DEMO design should be re-design.

- Based on our roadmap, the time limit for our decision on the SC choice is 2015!!
Demonstration Plant: Demo-CREST

Principles for the Demo-CREST Design
1. to demonstrate electric power generation as soon as possible in a plant scale, with moderate plasma performance which will be achieved in the early stage of the ITER operation, and with foreseeable technologies and materials (Demonstration Phase OP1~OP4)
2. to show a possibility of an economical competitiveness with advanced plasma performance and high performance blanket systems, by means of replacing breeding blanket from the basic one to the advanced one (Development Phase OP4, OPRS)

<table>
<thead>
<tr>
<th>R (m) / A</th>
<th>OP1</th>
<th>OP2</th>
<th>OP3</th>
<th>OP4</th>
<th>OPRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.85/ 0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$q_{\text{min}}/q_{95}$</td>
<td>-/5.0</td>
<td>-/5.2</td>
<td>3.6 / 6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_N$</td>
<td>1.9</td>
<td>2.5</td>
<td>3.0</td>
<td>3.4</td>
<td>4.0</td>
</tr>
<tr>
<td>HH</td>
<td>0.96</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>$f_{\text{nGW}}$</td>
<td>0.56</td>
<td>0.73</td>
<td>0.80</td>
<td>1.02</td>
<td>1.31</td>
</tr>
<tr>
<td>$P_b$ (MW)</td>
<td>188</td>
<td>190</td>
<td>185</td>
<td>191</td>
<td>106</td>
</tr>
<tr>
<td>$P_f$ (MW)</td>
<td>1260</td>
<td>1940</td>
<td>2460</td>
<td>2840</td>
<td>2970</td>
</tr>
<tr>
<td>$P_{\text{net}}$ (MWe)</td>
<td>Basic Blanket</td>
<td>30</td>
<td>230</td>
<td>390</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>Advanced Blanket</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>850</td>
</tr>
</tbody>
</table>

Figure: Bird's-eye of Demo-CREST
TF Coil Design

Based on the work by S. Nishio

@ Critical current density
@ Mechanical stress
@ thermal stability
@ Induced voltage

\[ \sigma_\theta \]

Wedge support

\[ R_{\text{out}} \]
\[ R_{\text{in}} \]

\[ \sigma_\theta \]

\[ \text{Insulator} \]
10%

\[ \text{Cooling channel} \]
5%

\[ \text{SuperConductor} \]
2%

\[ \text{Cu stabilizer} \]
8%

75%

Structural material

\[ B_{\text{max}} = 16.1 \ T \]

Casing of an inner region

\[ B_{\text{max}} = 15.4 \ T \]
**Sensitivity on Major radius**

**Nb3Al case**

\[
B_{CS \, \text{max}}
\]

\[\Phi_p(LpIp)/\Phi_{cs} = 70 \sim 80\%\]

**Bmax (T)**

Original design

**Major Radius Rp(m)**

**HH factor**

\[<n>/nGW\]
Sensitivity on Major radius

Nb₃Sn case

**B**<sub>max</sub> (T)

<table>
<thead>
<tr>
<th>Rp (m)</th>
<th>7</th>
<th>7.5</th>
<th>8</th>
<th>8.5</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>&lt;n&gt;/nGW</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>HH factor</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Original design
Feasibility of pulse operation

5 hours operation case
Assist of non-inductive current drive
Correlation between Plasma Performances

Both $f_{n_{GW}}$ and $\beta_N$ have to be increased together so as to increase the net electric power $P_{net}$.

There is no operational point under $HH \leq 0.8$, of course, which is depending on the ristriction $P_{NBI}$.

Existence of inevitable HH value.
Simultaneous achievement of high beta and high confinement

- Beta limit was improved by RWM stabilization, especially in RS plasma with keeping high confinement.
- High $\beta_N$ expected in ITER was achieved with high confinement.
- In WS plasma, high $\beta_N$ with high confinement was obtained without wall stabilization.
- Lower confinement in WS plasma with wall stabilization is attributed to the lack of strong central heating.
Summary

@ Preliminary study has been carried out for design window of a DEMO reactor.

@ The maximum magnetic field strength $B_{\text{max}}$ strongly affect on the machine size and requirement for plasma performance.

@ A pulsed operation regime has been studied. For example, the device with a major radius of $R = 8 \sim 9$ m might be feasible for a few-hours inductive operation with a help of an auxiliary current drive power of $60 \sim 100$ MW.

@ Inter-relationship between various plasma parameters such as HH, $\beta N$ and $\langle n \rangle/n_{GW}$ has been studied. Present experimental data show the strong impact on the design window of the DEMO reactor.
Plasma Performance

Accessible region

Fusion Power: $P_f$

Normalized beta: $b_N$

$b_N^{*HH}=3$

$b_N^{*HH}=5$