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Conceptual Design Study of Fusion DEMO Plant at SWIP

K.M. Feng, G.S. Zhang, G.Y. Zheng, Z. Zhao, Z.Q. Li, Z. Chen, T. Yuan, C.H. Pan

Southwestern Institute of Physics, P.O. Box 432, Chengdu 610041, P.R. China
Email: fengkm@swip.ac.cn

ABSTRACT：The development strategy, related R&D activities based on the mapload of Chinese Fusion Power Plant (FPP) program are presented briefly. A conceptual design study of fusion DEMO plant based on the Helium-cooled/Solid Breeder/LAFMs (HCSB) concept has being carried out recently. The design progress, the basic structure outline, as well as the key issue of HCSB-DEMO fusion plant are introduced.

1. Introduction

Although China is a developing country, but their economy growth speed is very quickly. The GDP growth rate has been higher than 7% in last decades. Forecast, the 2020's GDP will be near four times of 2000's. On other hands, China has biggest population in the world, more than 1.3 Billions, and will continue to increase to 1.6 to 2.0 Billions, near the middle of this century. In addition, China has limited energy resources (coal, oil, hydro-power, including uranium resources). The air-pollution problem in China has been already very serious, mainly by coal burning. So that, China specially need to develop nuclear fission energy source in near future. Without doubt, the fusion energy will be a long-term energy source. Great efforts have been devoted to fusion research in the past 50 years, and there is still a long way to go. If large-scale use the nuclear fission energy, several hundreds nuclear power stations should be built in China. Therefore, we need some new technologies for to build more safe, breeder type fusion reactor. Such as, the fusion-fission hybrid reactor or the fusion breeder. On other hands, we should also consider how to dispose so large amount of high-level wastes (HLW) from the nuclear power plants. The fusion-transmutation reactor might be one of considerable tools. A fusion breeder reactor requires a lower level of fusion technology, so under the fuel demand in China, could probably come into the market much earlier than a pure fusion reactor.

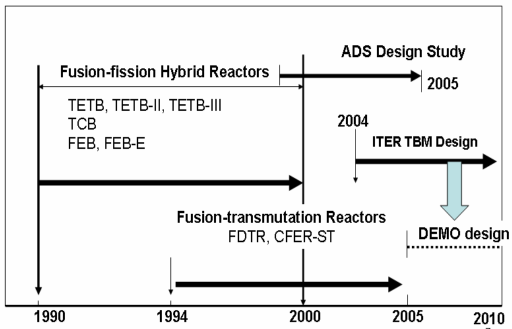

Fig.1. *Design activities of fusion reactor at SWIP*

Based on above consideration, the national program for development of the fusion breeder, its aim is to perform the feasibility of experimental fusion breeder at the early time of the century in China (19986-2000). A series of the conceptual design of experimental fusion breeders have been carried out at SWIP[1. Tokamak Commercial Breeder (TCB); Fusion Experiment Breeder (FEB) [2]; Fusion-Driven Transmutation Reactors (FDTR, CFER-ST)[3-5]; Accelerator-Driven sub-critical System (ADS)[6], etc. al.. The Design activities of fusion reactor at SWIP are shown in Fig.1. A model of fusion experimental breeder (FEB-E) design (1:10) is shown in Fig.2.

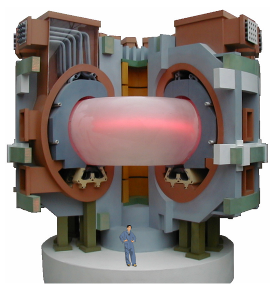

Fig.2. *A model of FEB-E design (1:10)*

2. Definition of DEMO

The DEMO in China is to demonstrate the safety, reliability and environment feasibility of the fusion power plants, meanwhile to demonstrate the prospective economic feasibility of the commercial fusion power plants. Judging from the consideration that there is still a long way to go towards an economically competitive commercial power plant, DEMO in China should be an indispensable step prior to the commercial one. Thus, the power level of DEMO might be several hundred MWe. In addition, China is interested in non-electric applications of fusion energy, such as HLW disposal and hydrogen production. It is expect that these applications will benefit the ultimate development of the fusion power plants. So, DEMO in China should also demonstrate the prospect of these applications.

It was assumed that DEMO is a next step after ITER machine. Therefore, China DEMO studies are the important aspects of long-term national program to evaluate the technology, materials, economics, safety, environment and waste processing for the possible magnetic fusion applications.

The DEMO in China is to demonstrate the safety, reliability and environment feasibility of the fusion power plants, while to demonstrate the prospective economic feasibility of the commercial fusion power plants. Considering that there is still a long way to go towards an economically competitive commercial power plant. DEMO in China should be an indispensable step prior to the commercial one [7].

As one of options, the breeding blanket with ceramic breeders might be basic DEMO concept in the future [8-9]. A conventional type of water/helium cooled divertor targets with reasonable heat load should be considered. The safety and low activation performance should meet the requirement of DEMO power plants.

3. HCSB-DEMO Concept

A conceptual design study of fusion DEMO plant based on the Helium-cooled/Solid Breeder (HCSB) /LAFMs concept has been carried out recently. Relevant calculation and analyses on core plasma, neutronics, thermo-hydraulics and thermo-mechanical have been performed.

3.1. Core plasma

Under different plasma limited conditions, the fusion power, neutron wall loading and burn time in the fusion reactors with different sizes are calculated. In this way, those reactors which fit our requirements are selected, and the POPCON analyses for them also are done. The final parameters simulated by the 1.5-D transport code for inductive operation scenarios. [10-17]

Table 1. *Core plasma parameters of*

parameters		**OP1**	**OP2**	**OP3**
Major radius	R/m	9	8	7.2
Minor radius	a/m	2	2.2	2.1
Aspect ratio	A	4.5	3.6	3.4
Elongation	k	1.7	1.85	1.85
Triangularity	δ	0.33	0.45	0.45
Plasma current	I_p	15.2	15	14.8
TF on axis	B_t	8.23	7.31	6.86
Safety factor	$q_{(95\%)}$	3	4.7	4.6
Average ele density	$<n_e>/10^{20}\cdot m^{-3}$	1.44	1.38	1. 5
Average ele temperature	$<T>$/keV	14.8	15.3	15.4
Average ion temperature	$<T>$/keV	15.3	16.2	15.8
Troyon	β_N	3.2	3.6	4.0
Bootstrap fraction	f	0.528	0.75	0.8
H_H(IPB98y2)	H	1	1.3	1.35
Current drive power	P_{aux}/MW	172	87	74
Fusion power	P_{fus}/MW	2600	2600	2550
Radiation power	P_{rad}/MW	275	255	211
Neutron wall load	P_n/MW•m^{-2}	2.1	2	2.3
Z_{eff}	Z_{eff}	2.08	1.93	1.85
Fusion gain	Q	15	30	35

Table 2. *Design parameters*

HCSB-DEMO	Parameters
Fusion power/electric, (MW)	2550/800MWe
Major radius, (m)	7.2
Minor, (m)	2.1
Elongation, k	1.85
Fusion gain, Q	35
Neutron wall loading, (MW/m^2)	2.3
Surface heating, (MW/m^2)	0.43
Tritium breeding ratio, (TBR)	1.1

Availability, (%)	50-70
Divertor peak load, (MWa/m^2)	8.0(water-cooled)
Plasma operation mode	Steady-state

Three set considerable parameters of plasma core which match with DEMO design objective was given in Table 1. After optimizing, one group plasma parameters for HCSB-DEMO with different plasma limited conditions are given in Table 2. The major parameters of HCSB-DEMO are 2000MW of the fusion power and 2.3 MW/m^2 of the neutron wall loading.

3.2. HCSB-DEMO Concept

The conceptual design of HCSB-DEMO is shown in Fig.3; and the blanket of HCSB-DEMO is designed as modularization structure which are consist of 14 sectors along the poloidal direction, and 4×18 sectors on the toroidal direction, so the total number of blanket modules is about 1008. The radial thickness of inboard blanket and outboard blanket are 630 mm and 800 mm respectively. The single pebble-bed (38% porosity) of lithium orthosilicate is used as breeder material. The binary pebble-bed (20% porosity) of beryllium is used as neutron multiplier material. The pressure and the inlet/outlet temperature of coolant helium in HCSB-DEMO circulation circuit are 8 MPa and 300/500^{0}C, respectively. The cross-section and 3-D view of HCSB-DEMO blanket are shown in Fig.4 and 5. Optimization by changing thickness of breeding zone and enrichment of ceramic lithium-6 has been performed. Main Design Parameters of HCSB-DEMO was shown in Table 4[18-19].

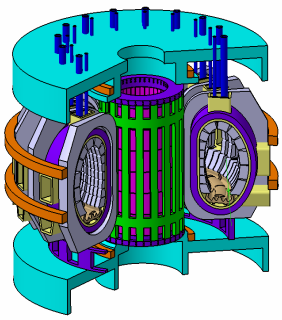

Fig.3 *Conceptual View of HCSB-DEMO*

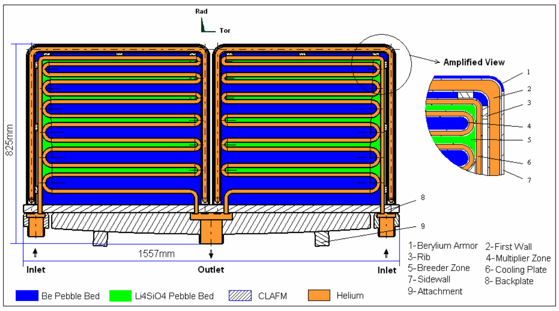

Fig.4. Cross-section of HC-SB DEMO Blanket

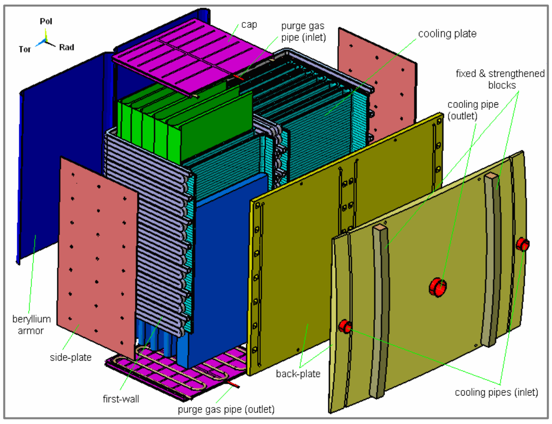

Fig.5. *3-D View of HCSB-DEMO blanket*

3.3 Neutroncs Design

The neutronics calculations are carried out based on 3-D MCNP global code and the parameters of structure design in table 2.

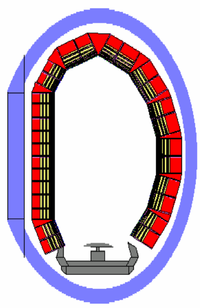

Fig6. *Elevation of HCSB-DEMO MCNP model*

Fig.6 shows the elevation of MCNP three-dimensional model by using in neutronics calculation for HCSB-DEMO. In the MCNP model, the tritium breeding blanket consists of 14 sub-modules in which breeder material is Li_4SiO_4, ^{6}Li enrichment is 80% and neutron multiplier material is beryllium. The ferritic/martensitic steel EUROFER is chosen as reference structural material for the HCSB-DEMO.

3.4. Basic Feature of HCSB-DEMO

(1).Fusion power will be in a range of 2500~3000 MW with an average neutron wall loading of 2.0~3.0 MW/m2;

(2).Have long burning time with inductive operation; Steady-state operation with reverse shear plasma modes;

(3).NBI and RF system for current drive;

(4).Detached or semi-detached divertor operation modes will be adopted; the divertor target loads are decreased by impurity radiation from the main and peripheral plasma;

(5).The Nb3Sn superconductor magnetic system is selected. It includes 18 TF coils, 6 PF coils, central solenoid (CS) and structure elements;

(6).The structure elements combine TF and PF coils and CS into the single structure to withstand the electromagnetic and weight loads.

4. Development Strategy

Chinese DEMO power plant study aims at establishing physics and engineering basis and limitations of the DEMO. Based on the definition of DEMO reactor, the testing objectives for CH DEMO are: to demonstrate the tritium breeding features; to demonstrate heat remove and electricity production in DEMO blanket; to demonstrate the economy for total capital cost and cost of electricity (COE); to demonstrate the safety, environment and fuel management; to demonstrate integration and maintenance. The development objectives for Chinese DEMO are: to continue the domestic plasma research effort using the experiments such as HL-2A (HL-2M) and EAST; to strengthen the domestic fusion reactor research; to cooperate with international effort in DEMO design activities. It is emphasized that the research and development of the fusion experimental reactors in China have already been carried out for more than 15 years under the support of the national Hi-Tech. project. Relevant experiences and technical results will be utilized in the DEMO research and development; In order to assort the domestic DEMO strategy, China will consider participation the IFMIF project and found a uniform agency and national fusion laboratory of domestic nuclear fusion research.

5. Summary

The definition, development strategy, preliminary conceptual design and R&D activities for Chinese DEMO power plant are introduced briefly. Helium-cooled/ Ceramic Breeder/ LAFM concept based on ITER-TBM testing on ITER testing port might be one of options for Chinese DEMO development program.

DEMO is very important one step from ITER to commercial utilization of fusion energy. The DEMO is also one of important ports of Chinese fusion energy development. Relevant R&D on the key techniques based on Chinese DEMO development strategy of fusion power plant will be preformed with the cooperation of domestic and international institutions and companies.

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