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Introduction to K-DEMO design activity in National Fusion Research Institute

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1. Introduction

A Korean demonstration power plant (K-DEMO) will be a successor of international thermonuclear experimental reactor (ITER). National Fusion Research Institute (NFRI) has started its pre-conceptual design study since 2012. Since there are large gaps between the current technologies and the required technologies for many components in fusion K-DEMO, the design activity of K-DEMO is very challenging. In this paper, we will introduce K-DEMO design activities, and the technology gaps to be solved to construct K-DEMO.

2. Overall Description of K-DEMO development strategy and requirements

A DEMO should accomplish two important goals [1]: 1) net electricity generation and 2) competitive cost of electricity (COE). K-DEMO would have a two-staged approach for the development of fusion energy. In the first stage, K-DEMO will be regarded as a test facility for a commercial reactor and targeted to demonstrate the net electricity generation. After about 10 years' operation of the first stage K-DEMO, a major upgrade of machine, which involves a replacement of in-vessel components including blankets, divertor system and affected interfacing systems and services, will be followed, then, the second stage K-DEMO operation will be started. Economic feasibility will be demonstrated with a net electricity generation on the order of ~500 MWe and with the planned plant availability over 70%.

The general requirements for K-DEMO are:

K-DEMO has two operation stages, Stage I and Stage II. Though the operation Stage I, K-DEMO is not required to demonstrate the competitiveness in COE, but shall demonstrate the competitiveness in COE in the operation Stage II.

All power core and plant subsystems in K-DEMO plant must be representative of those in the commercial plant. Extrapolation of technologies from K-DEMO to a commercial reactor should be straightforward. Practically all technologies to be used in commercial reactors should be demonstrated in K-DEMO. Also, extrapolation of performance parameters between K-DEMO and commercial reactors should be minimized.

A self-sustainable tritium fuel cycle -shall be demonstrated from the operation Stage I.

K-DEMO shall be operated and maintained with remote handling equipment. This is an absolute prerequisite as the neutron level during operation and radio-activation during maintenance periods will be excessive for human intervention inside the power core building and hot cell bio-shields at all times

For the operation Stage I, K-DEMO is not considered as the final DEMO and served as a test facility for a commercial reactor. Prior to the start of the operation Stage II, K-DEMO will require a major upgrade by replacing the blanket, divertor system and the affected interfacing systems and services. And K-DEMO will be operated as if it is a commercial reactor and needs to achieve an overall plant availability over 70%.

Construction cost for K-DEMO should be minimized.

Table 1. Major parameters of the K-DEMO

Basic Parameter	Option I	Option II	Option III
Major Radius	6.0 m	6.8 m	7.3 m
Minor Radius	1.8 m	2.1 m	2.2 m
Elongation (κ)	2.0		
Magnetic Field (B_o)	7.4 Tesla		
Peak Field	~16 Tesla		
Divertor Type	Double Null (or Single Null)		
Plasma Current	> 10 MA	> 12 MA	> 13 MA
Total Fusion Power	1500~2000 MW	2200~3000 MW	2700~3500 MW
Net Electric Power	130~200 MWe	400~700 MWe	550~900 MWe

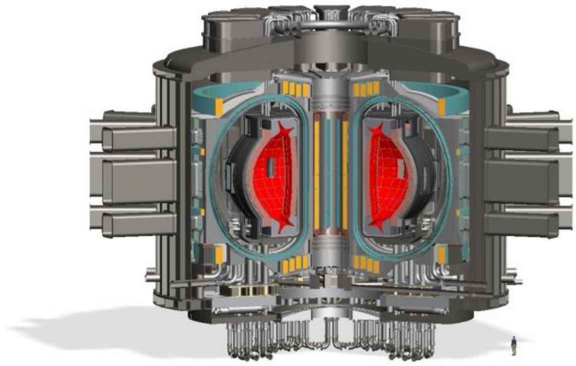

Fig. 1. Cutaway view of a K-DEMO design (option II)

3. Description of K-DEMO tokamak

A top launch high frequency (> 200 GHz) electron cyclotron current drive (ECCD) system is considered as the main candidate for the current profile control and off-axis current drive of K-DEMO. For matching the high frequency ECCD, a high magnetic field is required, and it can be achieved by using high performance Nb3Sn-based superconducting conductor currently being used in accelerator magnet area and the peak magnetic field is approaching to 16 T with the magnetic field at the plasma center above 7 T.

Considering the plasma performance and the peak heat flux in the divertor system, a double-null divertor operation becomes the reference choice of K-DEMO.

A vertical maintenance approach for the in-vessel components is selected because it offers the potential to improve access to plasma components and enhanced integration features between the device and facility. Poloidal field (PF) equilibrium current sizing was found to favor the vertical maintenance approach for the double null plasma, when comparing PF arrangements needed for maintenance (horizontal vs. vertical). Space is available to concurrently serve half of the in-vessel components at any one time.

Blanket modules are toroidally subdivided into 16 inboard sectors and 32 outboard sectors to allow vertical removal of blanket sectors through VV vertical ports located between TF coils. Each blanket unit consists of plasma-facing first wall (FW), layers of breeding parts, tungsten passive stabilizers, shielding and manifolds. A ceramic pebble typed lithium orthosilicate (Li4SiO4) is considered as the primary breeding material with beryllium metatitanate (Be12Ti) as neutron multiplier. Main structural material of blanket system is RAFM. Tungsten FW plate is located at the plasma-facing surface. Borated steel and tungsten carbide are considered as neutron shielding materials to protect VV and superconducting magnets. Centimeters-thick tungsten passive stabilizer plates are located in front of the neutron shield.

In line with the blanket toroidal segmentation for vertical maintenance, upper and lower divertor modules are also subdivided into 32 toroidal modules, respectively. Also, to allow horizontal handling (and then eventual vertical removal) of divertor modules in the presence of outboard blanket modules, bottom and top edges of upper and lower divertor modules are aligned, with keeping clearance, with the top and bottom edges of blanket modules, respectively. Divertor targets consist of water-cooled tungsten mono-block typed HHF (High Heat Flux) units supported by the cooled RAFM structures.

To achieve a global TBR over 1, partial breeding blanket modules are also placed behind divertor structures. The expanded TF and vacuum vessel allows sizing large vertical ports to accommodate the segmented in-vessel sector modules.

A semi-permanent inboard shield forms a strongback for supporting disruption loads, providing shielding for gaps between sectors and an alignment system for plasma facing components. Instead of supporting the internal blanket/shield modules from the vacuum vessel, a lower base platform is included that also serves as a coolant plenum to service the FW/blanket modules.

3. Conclusions

A brief introduction to K-DEMO design activity and the K-DEMO tokamaks was given. There are many technology gaps to be bridged and new technology could help to accelerate the commercialization of power plant based on fusion energy.

REFERENCES

[1] K. Kim, Conceptual Study Report of Korean Fusion Demonstration Tokamak Reactor (K-DEMO), 2014, NFRI