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RF TBMs for ITER tests

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Abstract

Following the DEMO design analysis, two test blanket modules (TBM) were chosen in the RF for the development and testing in ITER: ceramic helium-cooled TBM and lithium self-cooled TBM. In the first one, lithium containing ceramics is used for tritium breeding, helium is used as a coolant and purge gas for tritium extraction, beryllium—as a multiplier. Ferritic steel is a structure material. In the second one lithium is used as tritium breeder and a coolant, and vanadium alloy of V–Cr–Ti system as a structure material.

Conceptual designs of both TBMs and ancillary systems for their tests in ITER, strategy of tests, key R&D issues for both concepts are summarized. An international collaboration in R&D, development and testing of TBMs is of great importance due to shortage of testing space in ITER and due to high cost of the program.

Keywords: Fusion; Blanket; ITER test module; Helium; Ceramics; Lithium

1. Introduction

Fusion development strategy in the RF considers three major steps: an experimental thermonuclear reactor (ITER), a demonstration power reactor (DEMO) and a commercial power reactor (CPR). The major objectives of a DEMO project are to demonstrate:

- an ability to produce heat and electric power at the level of CPR;
- tritium self sufficiency;
- an availability ≥0.6;
- reliability and increased operation safety of all reactor systems during time comparable to operation time of CPR (over 30 years);

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- decreased accident consequences and waste disposal demands with respect to fission reactors.

The design solutions and DEMO systems should be fully adequate for CPR operation, though some extrapolation is possible.

Two blanket concepts developed for the RF DEMO reactor (CHC, ceramic He-cooled and Li self-cooled ones) are planned to be tested in ITER with the aim to demonstrate the integrated performance of "DEMO-like" blanket modules and associated systems in fusion environment and calibrate the design tools for DEMO blankets. These tests should be accompanied with materials testing in dedicated facilities with high neutron fluence.

2. Blanket concepts for DEMO reactor

DEMO reactor studies started in the RF in 1992, first for the pulsed type reactor and later for steady state operation [1–4]. The main technical requirements for these reactors are the following: (1) total electric power around 1.5 GW; (2) the tritium breeding ratio (TBR) $\geq$1.05–1.1; (3) the structural materials should withstand the first wall fluence up to 15–20 MWa/m^2 with the possible replacement of in-vessel components after 5–10 MWa/m^2.

The main characteristics of two DEMO blankets considered for steady state operation are presented in Table 1.

Lithium-cooled blanket concept utilizes Li as a coolant and tritium breeder. Its potential advantages are the following: low pressure operation at high temperature required for effective electricity generation; attractive heat transfer and heat removal characteristics; good tritium breeding capability; outside-of-blanket tritium extraction with low tritium losses; immunity to radiation damage.

V-alloy (type V–4% Cr–4% Ti) is considered as a structural material due to its good compatibility with Li, good mechanical properties at high temperatures, capability to accommodate high heat fluxes and high neutron fluence with low degradation of properties, low decay heat and low activation. Beryllium may be used in some design options as a neutron multiplier and tungsten carbide or titanium carbide as the reflector material.

Li-cooled concept requires some electroinsulating material to be placed on the interface of Li/structure material to decrease induced currents and magnetohydrodynamic pressure drop resulting from the interaction of these currents with the tokamak magnetic fields. Some different concepts of self-healing electroinsulating coatings, based on CaO,

Table 1
Main characteristics of two blanket concepts for the RF DEMO steady state tokamak reactor with 2.44 GW thermonuclear power

Coolant	Lithium	Helium
Breeder	Lithium (50% ^{6}Li)	Lithium orthosilicate (Li_4SiO_4)
Neutron fluence (MWa/m^2)	10–15	10
FW neutron load, average/maximum (MW/m^2)	2.7/4.4	
FW heat flux, average/maximum (MW/m^2)	0.4/0.7	
Blanket radial dimension (m)	0.5	0.5–0.7
Module/section toroidal dimension (m)	1.25–1.45	1.05–1.5
Module/section poloidal dimension (m)	2.9–7.3	0.83
Channel length in poloidal direction (m)	2.9–7.3	–
Coolant temperature, inlet/outlet (°C)	400/600	300/500
Coolant pressure (MPa)	1.2	10
Coolant maximum velocity (m/s)	1.4–2.2	~110
Structure material	V–Cr–Ti	Ferritic steel (10Cr9MoMn)
Structure material maximum temperature (°C)	~690	~550
Multiplier	Be	
Multiplier maximum temperature (°C)	~700	~650
Reflector (shielding) material	WC	–
Reflector material maximum temperature (°C)	350	–
Breeder maximum temperature (°C)	600	~1000
Tritium breeding ratio	~1.09	~1.06