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Development of the water cooled lithium lead blanket for DEMO

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HIGHLIGHTS

- The WCLL blanket design has been modified to adapt it to the 2012 EFDA DEMO specifications.
- Preliminary CAD design of the equatorial outboard module of the WCLL blanket has been developed for DEMO.
- Finite elements analyses have been carried out in order to assess the module thermal behavior in the straight part of the module.

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ABSTRACT

The water cooled lithium lead (WCLL) blanket, based on near-future technology requiring small extrapolation from present-day knowledge both on physical and technological aspect, is one of the breeding blanket concepts considered as possible candidates for the EU DEMOnstration power plant.

In 2012, the EFDA agency issued new specifications for DEMO: this paper describes the work performed to adapt the WCLL blanket design to those specifications.

Relatively small modules with straight surfaces are attached to a common Back Supporting Structure housing feeding pipes. Each module features reduced activation ferritic-martensitic steel as structural material, liquid Lithium-Lead as breeder, neutron multiplier and carrier. Water at typical Pressurized Water Reactors (PWR) conditions is chosen as coolant.

A preliminary design of the equatorial outboard module has been achieved. Finite elements analyses have been carried out in order to assess the module thermal behavior. Two First Wall (FW) concepts have been proposed, one favoring the thermal efficiency, the other favoring the manufacturability. The Breeding Zone has been designed with C-shaped Double-Walled Tubes in order to minimize the Water/Pb-15.7Li interaction likelihood.

The priorities for further development of the WCLL blanket concept are identified in the paper.

1. Introduction

In 2010 the new Power Plant Physics and Technology (PPPT) department of the European Fusion Development Agreement (EFDA), was established, having as main objective the development of a DEMOnstration fusion reactor whose conceptual design is scheduled for 2020. This reactor shall prove the feasibility of generating electricity with an integrated fusion plant.

In a fusion power plant, the blanket (the first structure surrounding the plasma) is one of the key components since it has to withstand extremely severe operating conditions while insuring tritium self-sufficiency, adequate neutron shielding and coolant temperatures suitable for an efficient power conversion cycle.

Within the EU, several blanket concepts have been considered in the past as possible candidates for DEMOnstration and fusion power plants. In the framework of the Power Plant Conceptual Study (PPCS), five reactor models were considered. Among them, the PPCS model A, featuring a water cooled lithium lead (WCLL) blanket, is based on near-future technology requiring small extrapolation from present-day knowledge both on physical and technological aspect. R&D and design activities of a WCLL concept with lithium lead breeding loop have been launched. The WCLL blanket is indeed considered as one of possible candidates for EU DEMO in present EU fusion roadmap [1].

In 2012, the EFDA agency issued new specifications for DEMO [2], mainly consisting in updated plasma energy source parameters and corresponding new dimensions for the blanket.

This paper describes the work performed to adapt the WCLL blanket concept to the new specifications as well as the continuing work of improving the blanket concept.

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2. Specifications, input data and design criteria

Two options are presently being considered for DEMO: DEMO1, a near-future technology, pulsed, version of DEMO and DEMO2: an "optimistic" steady-state DEMO, based on moderate, foreseeable advances in physics and technology. Both concepts assume a net electrical power output to the grid equal to 500 MW for a total thermal power of ~2.5 GW. The first so-called "starter blanket" will have to withstand up to 20 dpa (~5 years lifetime) and at least 5200 pulses. This work refers to the DEMO1 option, although, at this preliminary stage of the design, issues related to the pulsed plasma mode of operation (mainly the fatigue life of the blanket structures) have not been considered. The main reactor parameters are defined in Ref. [4].

For the design of the blanket, an average neutron wall load (NWL) of 1.27 MW m^{-2} has been assumed [4]. The poloidal distribution of the NWL, as well as the power density profiles in the blanket materials, have been inferred from the PPCS [5] by scaling the results to the ratio of the average NWLs. A constant heat flux (HF) of 0.5MW m^{-2} has been assumed on the plasma-facing wall (First Wall – FW) of the blanket modules.

The selected C&S for the design and manufacturing of the blanket is RCC-MRx 2012 Ed. [6] including a new materials properties group for Eurofer97 [7].

Assumed temperature limits for Eurofer97 are 300 °C and 550 °C. The lower limit is fixed by the embrittlement (shift of the DBTT) of Eurofer97 under irradiation. Indeed, higher minimum temperatures (>350 °C) are recommended for the design of the FW, where irradiation damage is higher. The maximum temperature is fixed by the sharp drop in strength of the material above 550 °C.

To ensure thermal efficiency with the PWR condition (P = 155 bar), and to limit the shift of DBTT of Eurofer97, the normal condition of the WCLL has inlet temperature of water set at 285 °C, and outlet at 325 °C because of the saturation of water at this pressure (Tsat = 343 °C). Thus the cooling pipes have to withstand the pressure of 155 bar for normal condition criteria, while the box has to withstand the same pressure as faulted condition.

3. Blanket conceptual design

The WCLL blanket is constituted of small modules of different sizes made with straight surfaces, attached together along the poloidal direction on a Back Supporting Structure (BSS) and fed with pipes at the rear of the modules. Each module is made of reduced activation ferritic-martensitic steel Eurofer97 [3] as structural material, liquid Lithium-Lead Pb-15.7Li as breeder, neutron multiplier and carrier. Water at typical Pressurized Water Reactors (PWR) conditions, which has high capacity for heat extraction and which is a widely applied technology in nuclear and fossil fired power plants, is chosen as coolant with inlet/outlet temperatures of 285/325 °C and 15.5 MPa pressure. The present WCLL blanket design is based on previous studies performed during the last twenty years. The last reactor concept based on the use of a WCLL blanket is the PPCS model A [8].

The following design options are retained: two walls between the water and the PbLi/and plasma, both walls withstanding the water-coolant pressure. No welds are allowed in front of the plasma, in the front wall. Two independent cooling loops, one for the FW and one for the breeder zone (BZ) to ensure cooling of the blanket in accident events. This choice also allows regulating separately the flow rate in the FW and in the BZ.

3.1. Blanket segmentation

Assuming that the DEMO system will have 16 toroidal field coils [2], then the reactor blanket system can be divided into 16 major sectors of 22.5° each, regarding to the toroidal distribution, formed by 2 inboard and 3 outboard segments. This leads to 48 outboard blanket segments and 32 inboard blanket segments along the toroidal direction.

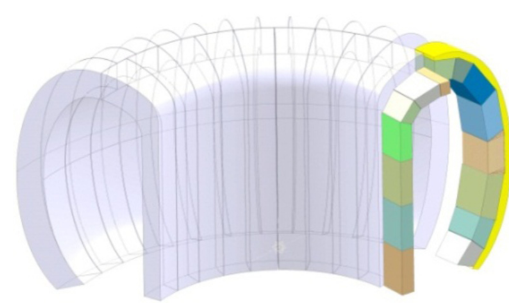

Fig. 1. Blanket segmentation.

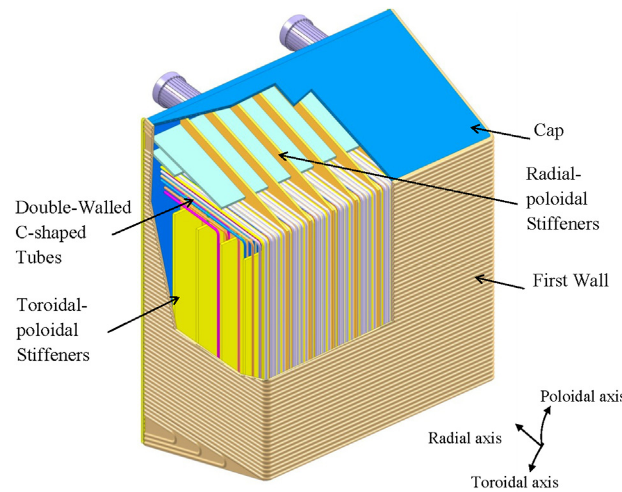

Fig. 2. CAD cutaway of the equatorial outboard module (Without PbLi).

The poloidal segmentation of the blanket is defined as the best compromise between neutronic (limit as much as possible the number of modules in order to reduce gaps and consequently the neutron streaming), electro-magnetic and thermo-mechanical constraint (limiting the size of the modules). The segmentation has been drawn in order to follow as close as possible the plasma shape assuming straight FWs in order to limit manufacturing issues and with a maximum height assumed to be 2 m from previous studies to limit the level of electromagnetic forces on each individual module. Therefore, along the poloidal direction, each outboard segment has 8 modules and each inboard segment has 7 modules (Fig. 1). The segmentation could be revised if neutronic analyses showed that there are enough margins on the values of the Tritium Breeding Ratio (TBR).

3.2. Modules design

The equatorial outboard module has been designed in more detail (Fig. 2). The Eurofer97 module box is reinforced by stiffeners to withstand the disruption-induced forces and the full water-pressure under faulted condition. This orientation allows the PbLi to flow upwards in the module and to insert C-shaped Double-Wall Tubes (DWT) where water flows to remove the heat from the PbLi. The DWT are used to minimize the probability of water/PbLi interaction in order to reduce the probability of leakage within the module. Each wall must withstand the pressure of 155 bar.