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Advanced power core system for the ARIES-AT power plant

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Abstract

The ARIES-AT power core was evolved with the overall objective of achieving high performance while maintaining attractive safety features, credible maintenance and fabrication processes, and reasonable design margins as a rough indication of reliability. The blanket and divertor designs are based on Pb-17Li as coolant and breeder, and low-activation SiC_f/SiC as structural material. Flowing Pb-17Li in series through the divertor and blanket is appealing since it simplifies the coolant routing and minimize the number of cooling systems. However, Pb-17Li provides marginal heat transfer performance in particular in the presence of MHD effects and the divertor design had to be adapted to accommodate the peak design heat flux of 5 MW/m^2. The blanket flow scheme enables operating Pb-17Li at a high outlet temperature (about 1100 °C) for high power cycle efficiency while maintaining SiC_f/SiC at a substantially lower temperature consistent with allowable limits. Waste minimization and additional cost savings are achieved by radially subdividing the blanket into two zones: a replaceable first zone and a life of plant second zone. Maintenance methods have been investigated which allow for end-of-life replacement of individual components. This paper summarizes the results of the design study of the ARIES-AT power core focusing on the blanket and divertor and including a discussion of the key parameters influencing the design, such as the SiC_f/SiC properties and the MHD effects, and a description of the design configuration, analysis results and reference operating parameters.

Keywords: Advanced tokamak; Power plant studies; Power core system; Blanket and divertor design; Power cycle

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1. Introduction

The ARIES-AT power plant was evolved to assess and highlight the benefit of advanced technologies and of new physics understanding and modeling capabili-

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ties on the performance of advanced tokamak power plants [1]. The design builds on over a decade of experience and effort by the ARIES team in advanced power plant design (e.g. [2,3,4]) and reflects the overall benefit from high-β operation, high temperature superconducting magnet, high power cycle efficiency, and lower-cost advanced manufacturing techniques. Fig. 1 shows the ARIES-AT power core and Table 1 summarizes the typical geometry and power parameters of the device, emerging from the parametric system studies [1].

The ARIES-AT power core have been developed with the overall objective of achieving high performance while maintaining attractive safety features, credible maintenance and fabrication processes, and reasonable design margins as an indication of reliability. The design utilizes Pb-17Li as breeder and coolant and low-activation SiC_f/SiC composite as structural material. The Pb-17Li operating temperature is optimized to provide high power cycle efficiency while maintaining the SiC_f/SiC temperature under reasonable limits.

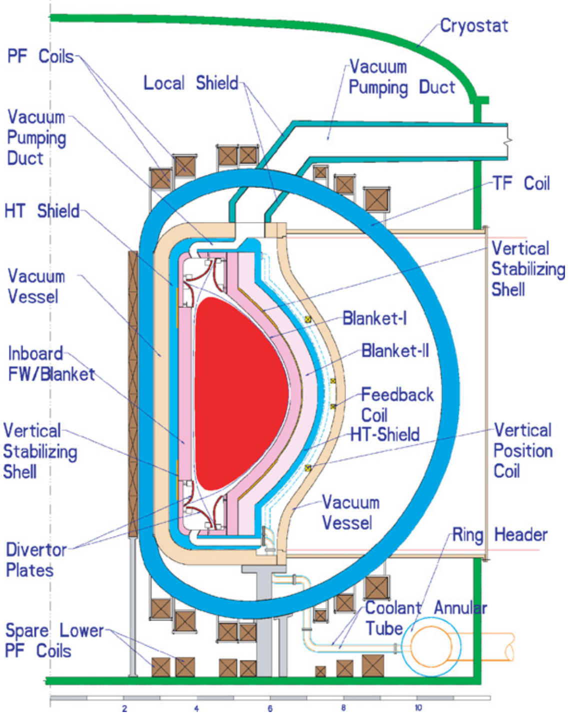

Fig. 1. ARIES-AT power core (radial dimension in m).

Table 1
Typical ARIES-AT machine and power parameters

Machine geometry	
Major radius	5.2 m
Minor radius	1.3 m
Outboard FW location at midplane	6.5 m
Outboard FW location at lower/upper end	4.9 m
Inboard FW location	3.9 m
On-axis magnetic field	5.9 T
Toroidal magnetic field at inboard FW	7.9 T
Toroidal magnetic field at outboard FW	4.7 T
Toroidal magnetic field at divertor (outer/inner)	7/7.9 T
Power parameters	
Fusion power[a]	1719 MW
Neutron power	1375 MW
Alpha power	344 MW
Current drive power	25 MW
Transport power to the divertor	256 MW
Blanket multiplication factor	1.1
Maximum thermal power	1897 MW
Average neutron wall load	3.2 MW/m^2
Outboard maximum wall load	4.8 MW/m^2
Inboard maximum wall load	3.1 MW/m^2

[a] In the course of design optimization, slightly different design parameters were used for various calculations, and in the case of very small differences, the calculations were not redone to save time and effort. For example, the neutronics calculations were performed for a fusion power of 1755 MW, whereas a fusion power of 1719 MW is assumed here. However, the neutron wall load values are consistent under the assumptions of slightly different first wall surface areas.

2. Power cycle

The Brayton cycle offers the best near-term possibility of power conversion with high efficiency and is chosen to maximize the potential gain from high temperature operation of the Pb-17Li which after exiting the blanket is routed through a heat exchanger with the cycle He as secondary fluid [5]. The Brayton cycle considered is shown in Fig. 2. It includes three-stage compression with two intercoolers and a high efficiency recuperator. Its main parameters are set under the assumption of state of the art components and/or with modest and reasonable extrapolation and are as follows:

- lowest He temperature in the cycle (heat sink) = 35 °C;
- turbine efficiency = 93%;
- compressor efficiency = 90%;
- recuperator effectiveness = 96%;