Analysis of the ARIES-CS Compact Stellarator Power Plant

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The US ARIES group has analyzed different magnetic configurations as potential fusion power plants: different tokamaks, an ST, an RFP and a modular stellarator (SPPS). The latest ARIES study examined compact stellarators, which combine the best features of high-current tokamaks (moderate plasma aspect ratios, good confinement, and high plasma beta $\langle\beta\rangle$) with those of large-aspect-ratio currentless stellarators (steady-state high-plasma-density operation without external current drive or disruptions, stability without a close conducting wall or active feedback systems, and low recirculating power in a fusion power plant).

A stellarator systems/optimization code was used to optimize the ARIES-CS power plant parameters for minimum cost of electricity (CoE) and beta subject to a large number of variable physics, engineering, and in-vessel component constraints. The most important factors determining the size and composition of the fusion power core were the allowable neutron power flux to the wall, the distance needed between the edge of the plasma and the magnetic field coils for the intervening components and gaps, and adequate tritium breeding. The magnetic field and coil parameters were determined by plasma performance and coil pack constraints. The previous ARIES costing approach and algorithms were updated with revised material and component costs.

An NCSX-based compact-stellarator plasma and coil configuration and a LiPb/FS/He blanket and shield concept were used for the reference ARIES-CS power plant with R = 7.75 m, B = 5.7 T, β = 6.4% and a projected CoE = 78 mills/kWhr (in 2004 $). A number of physics assumptions (density and temperature profiles, impurity radiation levels, confinement enhancement, β limits, alpha-particle energy losses, etc.) affected the plasma parameters, but had little effect on the size and cost of the fusion power core. Other parameters (maximum field at the coils, component cost penalties, different blanket and shield approaches, alternative plasma and coil configurations, etc.) had a larger impact. In particular, the use of an advanced LiPb/SiC blanket and shield concept like that adopted in the ARIES-AT tokamak power plant study could reduce the CoE by approximately 17 mills/kWhr.

Optimization was not just a matter of low plasma aspect ratio. More important was having a low plasma-coil-distance aspect ratio and a coil geometry that allowed a tapered blanket/shield concept that can satisfy the breeding requirement. Although the MHH2 plasma and coil configuration has a plasma aspect ratio 58% of the ARIES-CS configuration and a smaller plasma-coil-distance aspect ratio, the inability to use a tapered blanket/shield concept drove the size and CoE for an MHH2 power plant higher than that for even an SNS-based power plant where the plasma aspect ratio was a factor of 2.26 higher and the plasma-coil-distance aspect ratio was higher. Comparisons were also made with some earlier ARIES power plant studies.