Optimization of Stellarator Reactor Parameters*

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Stellarators have the potential for an attractive, fully ignited reactor. They are inherently steady-state devices without the large driven plasma current of the tokamak and spherical torus approaches. This characteristic reduces both the power needed to sustain the plasma and the risk of damaging disruptions. However, earlier stellarator power plant studies led to large reactor sizes. The German HSR reactor study had an average major radius R = 22 m in the five-field-period (M = 5) embodiment and R = 18 m in the newer M = 4 version. The M = 4 ARIES Stellarator Power Plant Study reactor with R = 14 m was a first step toward a smaller size reactor. The recent development of the compact stellarator concept allows reactors with major radius closer to that of tokamak reactors.

There are a number of factors that determine stellarator reactor size, primary of which is the distance needed between the edge of the plasma and the nonplanar magnetic field coils for the plasma scrapeoff region, the first wall, the blanket and shield, the coil case, and assembly gaps. Stellarator coil configurations with a smaller plasma-coil distance lead to larger reactors and coil configurations with larger plasma-coil distance have more convoluted coils and higher maximum magnetic field Bmax on the coils, which reduces the maximum allowable field on axis, B0. Other considerations in determining the optimum reactor size are the minimum distance between coils, neutron and radiative power flux to the wall, and the beta limit.

Three tools have been developed to optimize the main reactor parameters (R, B0, cost, etc.). A 0-D code allows assessing the compatibility of different constraints for a given power output: plasma-coil spacing, coil-coil spacing, Bmax and coil current density, neutron wall loading, plasma beta value, etc. A 1-D power balance code is used to study the path to ignition and the effect of different plasma and confinement assumptions including density and temperature profiles, impurity density levels and peaking near the outside, confinement scaling, beta limits, alpha particle losses, etc. for a given plasma and coil configuration. A reactor systems/optimization code is used to optimize the reactor parameters for minimum cost of electricity subject to a large number of physics, engineering, materials, and reactor component constraints. Different 1-D transport models including self-consistent electric fields, reactor component models, and costing algorithms are used to test sensitivities to different models and assumptions.

Three different magnetic configurations were analyzed: an M = 3 NCSX-based plasma configuration (NCSX-R) with coils modified to allow a larger plasma-coil spacing, an M = 2 plasma configuration (MHH2) with coils that are closer to the plasma on the outboard side with less toroidal excursion, and a scaled version of the HSR plasma and coil configuration (HSR*). The NCSX-R configuration is compatible with sector maintenance while the MHH2 and HSR* configurations are more suited for maintenance through ports. The reactors have major radii R in the 6-8 m range with an improved blanket and shield concept and an advanced superconducting coil approach. The low recirculating power should make compact stellarator reactors cost competitive with tokamak reactors.

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