OPTIMIZATION OF SPHERICAL TOKAMAKS AS POWER PLANTS – THE ARIES-ST STUDY*

Farrokh Najmabadi
and the ARIES Team†

Department of Electrical and Computer Engineering
and Fusion Energy Research Program
University of California, San Diego, La Jolla, CA, U.S.A.

There is substantial interest in spherical tokamak concept because of recent experimental achievements and theoretical predictions. At low plasma aspect ratio (< 2), plasma β becomes large enough and the required toroidal field becomes small enough that resistive toroidal-field (TF) coils with manageable Joule losses are possible. This eliminates the need for a thick, inboard shield for cryogenic TF coils. As such, spherical tokamak concept may lead to small ignition and fusion development devices. Several critical issues and constraints, however, arise for a spherical tokamak power plant: (1) high recirculating power (both Joule losses and the current-drive power), (2) Operation of the inboard leg of the TF coils (center-post) in high-fluence environment.

The ARIES-ST study is a national U.S. effort to evaluate and optimize spherical tokamak concept as a fusion power plant. The 1000-MWe ARIES-ST design has an aspect ratio of 1.6, a major radius of 3.2 m, a plasma elongation (κ_{95}) of 3.4, and a triangularity of 0.64. This configuration attains a β of ~50% with almost perfect alignment of bootstrap and equilibrium current-density profiles. The plasma current is 31 MA, the on-axis toroidal field is 2 T, and the peak field at the TF coil is 7.6 T. Center-post design is a critical element. Single-turn TF coils are preferred because of higher packing fraction and reduced shield requirement (no insulation). A 20-cm inboard shield is also utilized. It reduces the Joule losses in the center-post because of reduced nuclear heating and associated cooling requirements. This shield also results in improved waste disposal characteristics, reduced irradiation damage (and increased resistively due to transmutation), capturing the large nuclear heating as sensible heat, and additional lifetime. The high-recirculating power fraction in ARIES-ST requires a high-performance blanket design. The reference ARIES-ST blanket uses advanced ferritic steels as structural material with helium as coolant and LiPb as both a coolant and a tritium breeder. SiC inserts are used in order to achieve a high LiPb outlet temperature (700 C). The 12-MPa helium coolant exits the blanket at 500 C and is superheated by the LiPb coolant. Through this technique, a thermal conversion efficiency of about 45% has been obtained. Neutronics analysis indicate that ARIES-ST TBR is 1.1. Unique geometry of spherical tokamak allows for a single-piece maintenance scheme in which the entire blanket system is replaced as a unit.

*Institutions involved in the Starlite study, in addition to UC San Diego, are Argonne National Laboratory, Boeing, General Atomics, Massachusetts Institute of Technology, Princeton Plasma Physics Laboratory, Rensselaer Polytechnic Institute, and the University of Wisconsin-Madison.

†Work performed under the auspices of U.S. DOE.