NUCLEAR CHALLENGES AND PROGRESS IN DESIGNING STELLARATOR POWER PLANTS

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ABSTRACT

As an alternate to the mainline magnetic fusion tokamaks, the stellarator concept offers a steady state operation without external driven current, eliminating the risk of plasma isruptions. Over the past 2-3 decades, stellarator power plants have been studied in the U.S., Japan, and Europe to enhance the physics and engineering aspects and optimize the design parameters that are subject to numerous constraints. The earlier 1980's studies delivered large stellarators with an average major radius exceeding 20 m. The most recent development of the compact stellarator concept has led to the construction of the National Compact Stellarator Experiment (NCSX) in the U.S. and the 3 years power plant study of ARIES-CS, a compact stellarator with 7.75 m average major radius, approaching that of tokamaks. The ARIES-CS first wall configuration deviates from the standard practice of uniform toroidal shape in order to achieve compactness. Modeling such a complex geometry for 3-D nuclear analysis was a challenging engineering task. A novel approach based on coupling the CAD model with the MCNP Monte Carlo code was developed to model, for the first time ever, the complex stellarator geometry for nuclear assessments. The most important parameter that determines the stellarator size and cost is the minimum distance between the plasma boundary and mid-coil. Accommodating the breeding blanket and necessary shield to protect the superconducting magnet represented another challenging task. An innovative approach utilizing a non-uniform blanket combined with a highly efficient WC shield for this highly constrained area reduced the radial standoff (and machine size and cost) by 25-30%, which is significant. As stellarators generate more radwaste than tokamaks, managing ARIES-CS active materials during operation and after plant decommissioning was essential for the environmental attractiveness of the machine. The geological disposal option could be replaced with more attractive scenarios, such as recycling (within the nuclear industry) and clearance (or unconditional release to the commercial market). The ARIES-CS bioshield, cryostat, and individual magnet constituents qualify for clearance, representing ~80% of the total waste volume. We developed a recycling approach for the non-clearable, in-vessel components using a combination of conventional and advanced remote handling equipment that can handle high doses of 3000 Sv/h or more. Several additional nuclear-related tasks received considerable attention during the ARIES-CS design process. These include the radial build definition, the well-optimized in-vessel components that satisfy the top-level requirements, the carefully selected nuclear and engineering parameters to produce an economic optimum, and the overarching safety constraints to deliver a safe and reliable power plant. This paper provides a brief historical overview of the progress in designing stellarator power plants and a perspective to the successful integration of the nuclear activity into the final ARIES-CS design.