

Impact of Advances in Fusion Physics & Technology on the Attractiveness of Tokamak Power Plants

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Conceptual design and analysis of fusion power plants have been carried out since the early days of fusion research to understand the characteristics of potential fusion energy systems. During the past decade, maturity of fusion science and technologies has transformed these conceptual design studies. Through detailed and integrated design and assessment of fusion concepts as power plants, these studies synthesize a wide variety of fusion R&D results, and provide feedback to the fusion community on the scientific problems that carry greatest leverage for fusion energy. As such, they have been increasingly utilized as valuable tools in guiding the research programs and illuminating the fusion development paths.

During the past ten years, the ARIES Team, a national US team involving universities, national laboratories, and industry, has studied a variety of magnetic fusion power plants (tokamaks, stellarators, spherical torus, and RFP) with different degrees of extrapolation in plasma physics and technology from present database.

In this paper, we present the top-level requirements and goals for commercial fusion power plants developed with consultation with US utilities and industry. We will review several ARIES designs and discuss the candidate options for physics operation regime as well engineering design of various components (*e.g.*, choice of structural material, coolant, breeder). For each option, we will discuss (1) the potential to satisfy the requirements and goals, and (2) the feasibility (*e.g.*, critical issues) and credibility (*e.g.*, degree extrapolation required from present data base).

For tokamaks, our results indicate that for the same plasma physics (*e.g.*, first-stability) and technology extrapolation, steady state operation is more attractive than pulsed-tokamak operation. Dramatic improvement over first-stability operation can be obtained through either utilization of high-field magnets (*e.g.*, high-temperature superconductors) or operation in advanced-tokamak modes (*e.g.*, reversed-shear). In particular, if full benefits of reversed-shear operation are realized, as is assumed in ARIES-AT, tokamak power plants will have a cost of electricity competitive with other sources of electricity. Emerging technologies such as advanced Beryllium cycle, high-temperature superconductor, and advanced manufacturing techniques can improve the cost and attractiveness of fusion plants. For blankets, liquid breeder/coolants are the most attractive because most of neutron power is directly deposited in the coolant. This property can be exploited to arrive at a blanket design with a coolant outlet temperature higher than the structure temperature in the radiation zone. The high coolant temperature leads to a high thermal conversion efficiency (as in ARIES-ST and ARIES-AT blankets). The dual-cooled (He and LiPb) ARIES-ST blanket using ferritic steel structural material represents a near-term option for fusion systems and achieves a thermal efficiency of 45%. Development of high-performance SiC composites leads to the high-performance ARIES-AT blanket (SiC composite/LiPb coolant) that achieves 59% thermal conversion efficiency as well as the full potential safety and environmental features of fusion power.