PREFACE
SPECIAL ISSUE ON STELLARATORS

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This special issue of *Fusion Technology* is devoted to near-term and next-generation stellarators. Recently, there has been an upsurge of interest in these plasma confinement devices, both because of their potential advantages as eventual steady-state fusion reactors and because of the contributions they can make to the broader understanding of toroidal plasma confinement. Significant advances have occurred in recent years in stellarator theory, experimental results, construction techniques, and the reactor concept. New stellarator programs have started in the United States, Japan, Spain, and Australia. Three major new experiments began operation in 1988, three more are in the final design or construction stage, and design studies have started on three large, next-generation devices, one of which is now an approved project. A recent review paper[1] summarized progress in stellarator research during the period 1981 to 1986. This issue looks toward the future.

Like the closely related tokamak and the reversed-field pinch, stellarators are toroidal confinement devices that rely on helical magnetic fields to provide confinement and stability of the plasma. Unlike their cousins, stellarators create these fields with currents flowing only in external conductors, allowing a wider range of magnetic configurations and more external control of the configuration properties. Hence, these devices encompass a wide range of magnetic geometries with very different coil configurations and physics optimization principles. The first paper, "Near-Term Directions in the World Stellarator Program" by J. F. Lyon, briefly discusses the main properties of stellarator configurations and the four main optimization approaches being followed, compares the main device parameters for the major stellarator experiments to each other and to comparable tokamaks, and discusses the main near-term and long-range issues that these devices will address.

The bulk of this issue is devoted to the major experiments that will test the principles of stellarator optimization and provide the main results in stellarator research for the next decade: the Advanced Toroidal Facility (ATF) [Oak Ridge National Laboratory (ORNL)], Wendelstein VII-AS (W VII-AS) [Federal Republic of Germany (FRG)], the Compact Helical System (CHS) (Japan), Heliotron E (Japan), H-1 (Australia), TJ-II (Spain), and Uragan-2M (USSR). The first four are already in operation, and the other three should begin operation in the next few years. The paper "Construction and Initial Operation of the Advanced Toroidal Facility" by J. F. Lyon et al. reviews the physics and engineering design of ATF, describes its assembly and the plasma heating and diagnostic systems, and summarizes results from the initial operation period. The experience to date is compared with the expectations during the design phase, with emphasis on the vacuum vessel construction and the second stability regime. The companion paper "Realization of the Advanced Toroidal Facility Torsatron Magnetic Field" by J. H. Harris et al. reviews the design criteria for the ATF coils, the construction of the segmented helical windings, and verification of the magnetic field configuration. The paper documents the identification of the cause of a field perturbation that produced large islands in the magnetic field structure and describes the modifications that led to a large reduction in the size of these islands.

The paper "Stellarator Wendelstein VII-AS: Physics and Engineering Design" by J. Sapper and H. Renner describes the engineering design and assembly of W VII-AS; the characteristics of its magnetic configuration, modular coils, vacuum vessel, diagnostics, and plasma heating systems; and results from the initial operating period. A companion paper, "Electron Cyclotron Resonance Heating Transmission Line and Launching System for the Wendelstein VII-AS Stellarator" by V. Erckmann and the W VII-AS team, describes the versatile, high-power, 70-GHz electron cyclotron heating (ECH) system used for plasma buildup, heating, and current drive. Adjustable reflectors and a diagnostic array allow variation and measurement of the power deposition profile and the direction of the rays.

The paper "Compact Helical System Physics and Engineering Design" by K. Nishimura et al. summarizes the physics studies [vacuum magnetic configuration, particle orbits, plasma confinement, and magnetohydrodynamic (MHD) equilibrium and stability] that led to CHS, its engineering design (vacuum vessel, helical windings, and poloidal field coils), and its plasma heating systems. Initial results with electron cyclotron and ion cyclotron plasma production and heating are also presented. Recent additions to the mature Heliotron E program, which has been in operation since 1980, are described in the paper "Recent Heliotron E Physics Studies and Engineering Developments" by T. Obiki et al. These additions include experiments on a partial helical divertor, variation of magnetic surfaces, a quasi-optical ECH system, ion cyclotron heating, pellet injection, and new plasma diagnostics.

The paper "H-1 Design and Construction" by S. M. Hamberger et al. describes this medium-size device, its auxiliary systems (power supplies, control, plasma heating, and vacuum system), its magnetic configuration flexibility, and the planned physics program. The paper "TJ-II Project: A Flexible Heliac Stellarator" by C. Alejaldre et al. discusses recent studies on ECH, plasma transport, and MHD stability for TJ-II and engineering features (vacuum vessel and coils) introduced in the final design. The last paper on the near-term experiments, "Uragan-2M: A Torsatron with an Additional Toroidal Field" by V. E. Bykov et al., describes studies that led to selection of the Uragan-2M device parameters; its configuration properties, engineering design features, plasma heating scenarios, and projected performance; and its reactor extrapolation.

The rest of this issue describes studies of large next-generation (≥1995) stellarators designed to demonstrate the attractiveness of the stellarator concept with more reactor-relevant parameters. The devices being studied are the Large Helical Device (LHD) (Japan), Wendelstein VII-X (W VII-X) (FRG), and ATF-II (ORNL). In general, these devices use superconducting coils for long-pulse or steady-state operation, have magnetic fields up to twice those in present stellarator experiments, and have an order of magnitude more plasma volume and heating power. The most developed of these is LHD, described in the paper "The Large Helical Device" by A. Iiyoshi and the LHD design team. This paper discusses the physics issues in the selection of the device parameters, a divertor design study, the plasma heating systems, and the experimental plan for LHD. Beta limits, orbit losses, and divertor geometry enter into the configuration optimization studies. The paper "Physics and Engineering Design for Wendelstein VII-X" by C. Beidler et al. summarizes the various elements of the W VII-X design studies: the optimization principles that led to the choice of the W VII-X magnetic configuration; physics studies of MHD equilibrium and stability, neoclassical transport, the bootstrap current, and the boundary region; the predicted plasma performance; the plasma heating systems; and engineering studies of the modular nonplanar coils (techniques for optimizing the coil geometry, variation of the field, coil design, electromagnetic forces, stress analysis, and mechanical support) and the vacuum vessel. The last paper, "Advanced Toroidal Facility II Studies" by J. F. Lyon et al., discusses the main physics issues for low-aspect-ratio stellarators, optimization approaches based on multiparameter helical windings and on a multiparameter specification of the plasma surface, a particular reference design, performance projections, and optimization of high-current-density, high-field, stable superconducting windings.

The devices described in this issue are those that will have the greatest impact on the evolution of the stellarator confinement concept. In addition, of course, there are a number of smaller facilities that will address basic issues of interest to stellarators. These experiments[2] include L-2 (USSR), Heliotron DR (Japan), IMS (University of Wisconsin, Madison), HBQM (University of Washington, Seattle), Compact Auburn Torsatron (Auburn University, Auburn, Alabama), SHEILA (Australia), SHATLET-M (Japan), and TU-Heliac (Japan). This combination of medium-to-large experiments and small basic experiments in the pursuit of a few complementary approaches offers the best chance for the success of stellarators. If this combined approach is successful, then stellarators offer a fusion reactor option without the main drawbacks of tokamaks, but with many of their advantages. The next decade of stellarator research with the facilities described in this issue will determine whether stellarators will live up to this potential.

The papers in this issue represent a great deal of work on the part of authors, referees, and the editorial staff at *Fusion Technology* and the American Nuclear Society. I wish to thank all those who have contributed to this issue and George Miley for the opportunity to help spread the gospel on stellarators. I hope this issue will serve as a reference on the major new and proposed stellarator experiments. It will be interesting in the years ahead to see how the performance of these devices compares with that outlined here.

REFERENCES

1. B. A. CARRERAS et al., "Progress in Stellarator/Heliotron Research: 1981–1986," *Nucl. Fusion*, **28**, 1613 (1988).

2. See *Proc. 7th Int. Workshop on Stellarators*, Oak Ridge, Tennessee, April 10–14, 1989, International Atomic Energy Agency (1989) for details.