PREFACE
SPECIAL ISSUES ON D-^{3}He FUSION

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Although worldwide fusion research currently focuses on the deuterium-tritium (D-T) fuel cycle, a small but vigorous effort has continued on advanced fuels—defined by their production of fewer neutrons per unit power than D-T fuel. Six years ago, *Fusion Technology* (*FT*) published a paper[1] on a large lunar resource of ^{3}He, which revived interest in the advanced D-^{3}He fuel. The advantages of D-^{3}He fuel arise from the fact that its primary fusion products are charged particles, and secondary D-D and D-T reactions produce relatively few neutrons. This leads to remarkable technological advantages for nuclear systems, where neutron damage, activation, and afterheat pose severe problems. These advantages—such as first walls and structures that last the entire reactor lifetime, the ability to use slightly modified conventional steels, greatly reduced radioactivity, much lower radioactive waste volumes, afterheat levels so low that melting is impossible, the potential for direct energy conversion at high efficiency, and elimination of the complicated tritium-breeding blanket—must be balanced against the disadvantages stemming from the almost two orders of magnitude lower fusion power density in the plasma volume compared with D-T fuel.

The papers in the July and the August 1992 issues of *FT* cover a wide range of topics relevant to D-^{3}He fusion. They originate from institutions in the United States, Europe, Japan, the former USSR, and Australia. Many involve multi-institutional or multinational cooperation. The July issue begins with overviews of ^{3}He resources on earth and on the moon and of their relation to fusion power. Subsequent papers discuss various physics and engineering considerations and present reactor studies for the tokamak and the field-reversed configuration (FRC). The August issue includes papers on other magnetic fusion configurations, inertial confinement concepts, applications other than electricity production, and technology studies especially relevant to D-^{3}He reactors.

The July issue also includes a synopsis of the First Wisconsin Symposium on D-^{3}He Fusion held in Madison, Wisconsin, August 21-22, 1990. The second in this series of symposia is planned to be held in Madison in the summer or fall of 1992. Previous issues of *FT* have featured reviews of five earlier workshops on the D-^{3}He FRC concept.[2–6]

Although the attractiveness of the D-^{3}He fuel cycle has long been recognized, the extremely limited terrestrial quantities of ^{3}He stood as a barrier to the development of this concept. Yet, D-^{3}He fusion has emerged recently as a realistic objective. The most important factor has been the discovery of vast ^{3}He resources on the lunar surface. Kulcinski and Schmitt, in their paper "Fusion Power from Lunar Resources," trace this discovery and briefly discuss the economics and technology involved in recovery and transport of this resource to earth.

Wittenberg et al., in "A Review of ^{3}He Resources and Acquisition for Use as Fusion Fuel," examine in detail several aspects of ^{3}He recovery. They first establish the inadequacy of terrestrial resources (including man-made) compared with the fuel needs of a future fusion-based electrical power economy. They determine, by multiple data collection methods, the magnitude of the lunar resource. They also discuss mining strategies, legal regimes, and lunar environmental aspects. Finally, the energy cost of procuring lunar ^{3}He is shown to be strongly competitive with that for fission and fossil fuels.

Until the recent D-T shots in the Joint European Torus (JET), the record for controlled fusion (140 kW in JET) had been held by D-^{3}He fuel. Jacquinot et al., in "D-^{3}He Fusion in the Joint European Torus Tokamak—Experimental Results," give an overview of the experiments and results from these D-^{3}He shots. The JET Team achieved the 140 kW of power during 5- to 7-s sawtooth-free periods using ion cyclotron range of frequency heating of a minority ^{3}He component to ~1 MeV in an 8-keV deuterium majority plasma. Despite the high ^{3}He energy, the plasma behaved as expected, and in particular, anomalous losses were low—an important result in itself.

One of the concerns in the design of a fusion reactor is adequate fusion reactivity to achieve fuel ignition. A unique approach is to polarize both nuclei parallel to the magnetic field, which increases the reaction cross section by ~50% for the D-^{3}He reaction. The effect of partial or complete polarization on the achievement of ignition is examined by Mitarai et al. in "Spin Polarization Effect on Ignition Access Condition for D-T and D-^{3}He Tokamak Fusion Reactors." Using the conventional saddlepoint approach, they determine that the beta and auxiliary heating power requirements to achieve ignition are reduced by as much as a factor of 2 to 3 for complete spin polarization. This paper also discusses environments (e.g., ion cyclotron resonance heating) that might depolarize the nuclei.

A key question in developing D-^{3}He fusion is, "What do we do next?" Emmert and Parker, in "Potential for D-^{3}He Experiments in Next-Generation Tokamaks," address this question for the proposed next generation of tokamaks, the Burning Plasma Experiment (BPX) and the International Thermonuclear Experimental Reactor (ITER). The capabilities of the now-cancelled BPX for D-^{3}He operation were limited. For ITER, however, important D-^{3}He experiments could be performed. Emmert and Parker conclude that even without modification, D-^{3}He in ITER could approach breakeven. Such experiments would supply, for example, useful information on transport, fusion product trajectories, and collective effects.

The tokamak dominates the world's fusion research program. Kulcinski et al., in "Summary of Apollo, A D-^{3}He Tokamak Reactor Design," discuss the tokamak. For any reactor study, decisions among several design options are necessary. For Apollo, these included the first-stability magnetohydrodynamic operating regime; low-activation stainless steel structure; an organic coolant, thermal conversion cycle for bremsstrahlung, transport, and neutron power; and synchrotron radiation conversion using rectennas. The first wall and shield should last the reactor lifetime of 30 full-power years. The radioactive afterheat levels would be so low that a loss-of-coolant accident would not lead to materials damage requiring changeout of the shield modules, and no credible scenario for release of significant amounts of radioactive material would exist.

The high beta, low magnetic field, and suitability for direct energy conversion of the FRC make it a leading candidate for a D-^{3}He reactor. Kernbichler, in "Operational Parameters for D-^{3}He in Field-Reversed Configurations," explores the plasma physics operating space in detail for a steady-state, D-^{3}He FRC reactor and compares it with a D-T FRC reactor. The major difference between ~900-MW(fusion) strawman designs of the same dimensions for the two fuel cycles is that the D-^{3}He design requires an approximately three times higher magnetic field on the coils (7.5 T) and an approximately three times higher midplane current (9.2 MA). Although energy conversion and cost studies were not performed for such devices, the combination of direct energy conversion and reduced shield thickness should more than compensate for the increased magnet cost.

A specific FRC reactor design is presented in "Conceptual Design of the D-^{3}He Reactor Artemis," by Momota et al. This design employs the conventional theta-pinch formation technique, and the FRC is translated from the formation chamber into the fusion burn chamber. It is heated to ignition by neutral beam injection. The internal (poloidal) flux is built up and maintained in steady state by the neutral-beam-driven current. The key technologies involved in such a reactor are discussed. The Artemis design is notable for its compactness and the relatively modest technological advances needed compared with the current state of the art. In addition to the presentation of a point design, sensitivity studies and costing analyses are presented. The estimated cost of electricity is slightly lower than for a light water fission reactor and significantly lower than projected for toroidal fusion concepts.

An alternate approach for an FRC reactor system is proposed by Burtsev et al. in "D-^{3}He–Fueled Fusion Power Plant Based on the Pulsatory Field-Reversed Configuration." The PULSATOR concept employs a unique means for refueling and regenerating the decaying poloidal flux of the FRC in the reaction chamber. Various aspects of such a system are examined, such as the first wall, energy conversion and magnetic systems, and the overall reactor core layout. Finally, an optimization study of a PULSATOR reactor is carried out based on several economic and technical figures of merit. In a related paper, "The PULSATOR Concept as a Possible Technique for Formation of a Field-Reversed Configuration," Burtsev et al. focus on technical aspects of this unique method of forming FRCs.

Compared with the usual theta-pinch approach, the PULSATOR has the advantages of quasi-stationary operation, more effective control, and, in principal, high efficiency. An experimental installation, SAPFIR, which is currently being used to study the PULSATOR technique, is also described.

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