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

LOREN C. STEINHAUER

STI Optronics, Inc., 2755 Northup Way, Bellevue, Washington 98004-1495

JOHN F. SANTARIUS

University of Wisconsin-Madison, Fusion Technology Institute, 1500 Johnson Drive Madison, Wisconsin 53706

The July and August issues of *Fusion Technology* (*FT*) explore the potential of burning D-^{3}He fuel in fusion reactors. Articles in the July issue discussed the lunar ^{3}He resource, D-^{3}He tokamaks, and D-^{3}He field-reversed configurations (FRCs). The August issue examines other magnetic fusion configurations, inertial confinement concepts, applications other than electricity production, and technology studies especially relevant to D-^{3}He reactors.

The generic advantages of open confinement systems are discussed by Post and Santarius, in "Open Confinement Systems and the D-^{3}He Reaction." Open systems are those in which the field lines of the externally applied magnetic field enter and leave the system at defined ends; included are all mirror configurations, FRCs, spheromaks, and dipoles. Open systems are natural for direct conversion of charged-particle energy, they offer the vastly simpler magnetic geometry of linear systems, and some allow the translation of plasma entities. These and other advantages are discussed. Low Q (fusion energy/input energy) has often been cited as a liability of open systems; an alternative view that emphasizes the advantages of such systems is defended. A unique low-Q "linear collider" reactor system is proposed and discussed. Other applications, e.g., space propulsion, for which open systems have unique applicability are also presented.

A novel and conceptually simple fusion reactor configuration, the dipole, is described by Hasegawa et al., in "A Description of a D-^{3}He Fusion Reactor Based on a Dipole Magnetic Field." Fusion occurs in a region surrounding a single, circular magnet in a configuration that is somewhat analogous to the Van Allen belts. The authors analyze magnetohydrodynamic (MHD) equilibrium and stability and present parameters for a conceptual reactor design. The dipole is predicted to reach very high beta, and the fusion core is fairly compact, with a major radius of ~2.5 m, although this region is surrounded by a large vacuum chamber in order to satisfy equilibrium constraints. The dipole coil must be levitated, but the levitating coils are only of modest magnetic field.

The Dracon, another high-beta, modest-field concept, is explored by Glagolev, in "Estimates of D-^{3}He Dracon Trap-Based Reactor Parameters." The configuration consists of two parallel magnetic mirror sections connected by curvilinear sections called CRELs. The plasma physics and energy balance in the regime of interest for D-^{3}He operation are investigated, and characteristic reactor parameters are given. The Dracon's lower magnetic field and solenoidal coil geometry should reduce its capital cost compared with the tokamak, making it an interesting toroidal alternative.

A unique approach to advanced-fuel fusion is one that combines magnetic and electrostatic confinement. Such an approach is examined by Krall, in "The Polywell®, A Spherically Convergent Ion Focus Concept." This is a novel variation of electrostatic confinement ideas first investigated 25 yr ago. Energetic electrons are injected inward from magnetic cusps arranged around a sphere. This generates an electrostatic potential at the center which confines ions. The advantage of the Polywell is that it offers a high-beta geometry with no complex auxiliary heating or confinement systems. After a discussion of electron and ion orbits and estimates of the ion density, critical physics issues are identified that must be addressed in evaluating the concept. Polywell and related experiments in progress are cited.

Most D-^{3}He fusion research has focused on magnetic confinement concepts, but several papers in this issue explore the possibilities for D-^{3}He fuel in inertial confinement fusion (ICF). Khoda-Bakhsh et al., in "Advanced Fusion Fuel for Inertial Confinement Fusion," examine the burn dynamics of ICF pellets for various fuels, using a volume ignition model. They conclude that the inclusion of deuterium-deuterium (D-D) reactions in the burn dynamics is important for D-^{3}He burn calculations.

As in magnetic confinement fusion, direct energy conversion would increase the efficiency of an inertial confinement fusion reactor. Mima et al., in "Preliminary Studies of Direct Energy Conversion in a D-^{3}He Inertial Confinement Fusion Reactor," propose a direct conversion method for a D-^{3}He ICF reactor that uses pickup coils for inductive energy recovery from a plasma expanding cylindrically. The ICF chamber would be embedded in a low-field (0.3-T) magnetic mirror. The authors analyze the difficult problem of the expansion and coupling to the magnetic field of the high-beta plasma.

The burn characteristics of D-^{3}He ICF pellets with deuterium-tritium (D-T) cores are analyzed by Nakao et al., in "Burn Characteristics of Compressed Fuel Pellets for D-^{3}He Inertial Fusion." A hydrodynamics code that includes neutron and charged-particle transport is used. Approximately 70% of the fusion energy from such pellets would be carried by charged particles, facilitating direct energy conversion. The required ICF driver energy, ~30 MJ, is about five times larger than corresponding D-T driver energies. The authors calculate that using spin-polarized D-^{3}He fuel would reduce the required driver energy by a factor of 2.

A magnetic field for protection of the cavity wall in a D-^{3}He ICF reactor is proposed and analyzed by Nakashima et al., in "Instability Analysis in a Magnetically Protected Cavity of a D-^{3}He Inertial Confinement Fusion Reactor." The authors find that the Rayleigh-Taylor instability should not be a problem for this configuration and that no significant enhancement of plasma diffusion across the field should occur. They conclude that a small magnetic field (~0.6 T) can help protect the cavity wall.

An attractive alternative application for D-^{3}He fusion is the utilization of the energetic fusion products for thrust in a space propulsion system. An example of such is described in "Space Propulsion by Fusion in a Magnetic Dipole," by Teller et al. The particular advantage of fusion propulsion is the considerable reduction of the duration of distant space missions. Some of the discussion is devoted to the specific properties of a dipole system, its magnet, and shield design. In addition, more generic analyses concerning the thruster design are presented. The suitability for fusion propulsion for the various classes of space missions is assessed in terms of propulsion figures of merit.

Other novel applications of D-^{3}He fusion have been proposed. In "Nonenergy Applications for Fusion," Dawson focuses on applications that exploit the unique capabilities of the 14.7-MeV protons produced by the reaction. In particular, they can be used to produce proton-rich isotopes that are of interest for positron emission tomography (PET). PET scans are already in use in diagnostic medicine but have significant diagnostic potential in industrial research, e.g., for tracking lubricant flow in an operating engine or for crack detection. Example positron-producing reactions and the efficiency of positron production are discussed.

One key advantage of the D-^{3}He fuel cycle, the reduced radiation hazard, is addressed by Golovin in "Lowering Radiation Hazards by Using D-^{3}He Reactors." He points out that not only is the induced radioactivity inherently lower than that of D-T reactors for the same materials, but that the reduced radiation damage levels also increase the flexibility in choosing and tailoring materials for reduced activation. Golovin analyzes several elements and structural materials and concludes that D-^{3}He fusion will make it possible to reduce the radiation hazard by up to a million times from fission reactor levels.

The D-^{3}He fuel cycle, although reducing the neutron power fraction by up to two orders of magnitude below D-T neutron power fractions, produces large numbers of 14.7-MeV protons. Khater and Vogelsang, in "Protons as a Potential Source of Radioactivity in D-^{3}He Reactors," question whether the fraction of these protons that escapes from the fusion core and hits the vessel walls at high energy (assumed to be 5% of the total protons) can induce significant radioactivity. They find that both the radioactivity and the afterheat generated in the first wall are only 1 to 10% of the levels generated by the neutrons from D-D and D-T reactions in a D-^{3}He reactor plasma.

The important issue of radioactive waste disposal for D-T, D-^{3}He, and D-D reactors is analyzed by Attaya et al. for four structural materials: PCA, Tenelon, HT-9, and modified HT-9, in "Waste Disposal of Candidate Structural Materials in Fusion Reactors Utilizing Different Fuel Cycles." Detailed calculations show that the low damage rates in D-^{3}He reactors allow the first wall and other structural components for some of these alloys to last the full reactor lifetime. They also show that the low-activation alloys, Tenelon and modified HT-9, will allow near-surface burial for waste disposal. Furthermore, the volume of waste will be greatly reduced below the amount generated by D-T and D-D reactors.

Besides the reduced activation and afterheat associated with the D-^{3}He fuel cycle, an important consideration is that the thickness of the shield required to protect the magnets from radiation damage and heating can be substantially reduced. El-Guebaly, in "Shielding Aspects of D-^{3}He Fusion Power Reactors," provides a very detailed comparison and optimization study of several candidate shield materials and coolants. She finds that the best low-activation shielding materials for D-^{3}He reactors are Tenelon and modified HT-9 and that the shielding effect of organic coolant is slightly less than that of water but the organic coolant can operate at a higher temperature and, therefore, efficiency, so that the balance favors the organic coolant.

Tritium issues for D-^{3}He reactors are explored by Nishikawa, in "Tritium in the Fueling Cycle of a D-^{3}He Fusion Reactor." He examines the particle flow rates and concludes that a 1-GW(electric) D-^{3}He reactor will exhaust ~15 g/day of unburned tritium from D-D reactions. Two options for disposal of this tritium are considered: storage and recycling. Nishikawa concludes that developed technology can safely store the unburned tritium, which would accumulate to ~80 kg after the reactor lifetime of 30 yr. The dynamic and static tritium inventories for D-T, D-^{3}He, and D-D reactors are compared.