

MEETING REPORT



SUMMARY OF THE FIRST WISCONSIN SYMPOSIUM ON D-³He FUSION, MADISON, WISCONSIN, AUGUST 21-22, 1990

The Fusion Technology Institute of the University of Wisconsin initiated and sponsored a symposium on D-³He fusion systems, held in Madison, Wisconsin, on August 21-22, 1990. The purpose of the symposium was to bring together a small group (there were 18 invited participants at the meeting) of knowledgeable researchers to discuss the present status of thinking on such systems. While the deuterium-tritium (D-T) fusion fuel cycle, having the largest cross section and the lowest ignition temperature, has received the most attention from the fusion community, there are substantive reasons for considering alternative fuel cycles, especially the D-³He cycle. The cross section for the D-³He reaction is second only to that of the D-T reaction, and more importantly, its large energy release is carried entirely by charged reaction products. Neutron production in a fusion power plant using D-³He fuel is due to parasitic deuterium-deuterium (D-D) reactions. Recent D-³He reactor studies have shown that the power carried by the neutrons is ~3 to 10% of the fusion power when no attempt is made to suppress the parasitic D-D reactions. Insofar as it is possible to suppress these parasitic D-D reactions, the environmentally related problems of tritium inventory and of neutron activation can be further reduced by orders of magnitude compared with D-T systems. In addition, the fact that the fusion energy released is given to charged reaction products makes possible the consideration of fusion power systems using high-efficiency direct converters with no need for thermal conversion.

Standing in the way of realizing the advantages of D-³He are the long-standing issues of fuel supply and the demanding plasma temperature and pressure requirements that are implied. Earlier work in D-³He reactor systems faced the problem of having to breed ³He using the D-D reaction. The recent realization that the moon is a substantial source of ³He has removed the need for ³He breeding and prompted a second look at D-³He reactor systems. The issues of ³He supply and procurement, as well as innovative reactor concepts for burning D-³He in a fusion power system, were pre-

sented at the symposium. In addition, there was some discussion of alternative applications of D-³He fusion. The presentations are discussed in chronological order.

R. F. Post (Lawrence Livermore National Laboratory) gave an historical overview of D-³He fusion research and concluded his talk with a speculative example of how one might minimize the level of parasitic D-D reactions in a fusion power system by employing deuterium and ³He beams in a "linear collider." Choosing 125 keV for the energy of each beam yields a relative energy matching the peak cross section for the D-³He reaction. If high (80 to 90%) direct conversion and injection efficiencies could be achieved, net fusion power might be achieved at a small fractional burnup, and collision-induced heating of the deuterium beam would be minimal, thus largely suppressing parasitic D-D reactions. Such a collider would necessarily be long (kilometres) and would require the development of very high field solenoidal magnets (20 to 50 T) and, most difficult, the development of high-efficiency beam injectors capable of producing centimetre-sized beams at beam densities of ~10¹⁶ cm⁻³ or higher. The purpose of the discussion was simply to illustrate that D-³He fusion systems permit the consideration of magnetic fusion configurations and techniques that are radically different in character (and in capabilities) from the ones that are normally considered for the D-T cycle.

G. L. Kulcinski (University of Wisconsin) discussed the technological advantages of D-³He fusion compared with D-T fusion. These include the greatly reduced neutron production and the resulting greatly reduced radiation damage of the structure, a 30 (full-power)-yr lifetime of the first wall, a greatly reduced tritium inventory, and the possibility of meeting the class A waste disposal standard and of achieving a passively or inherently safe reactor system in an accident. Despite the lower power density in the plasma, the technological advantages of the D-³He fuel cycle lead to estimated costs for D-³He reactors that are competitive with D-T reactors.

H. H. Schmitt (consultant, former U.S. Senator and Apollo astronaut) discussed the lunar resources of ³He and engineering, economic, and legal issues related to recovering the ³He from the moon and transporting it back to earth for use in terrestrial fusion reactors. His conclusion was that lunar ³He mining is technically feasible, and there are no inhibiting legal or liability factors that would prevent the use

of the moon as a source for ^3He . He also concluded that an adequate rate of return on capital investment can be obtained if the ^3He can be sold for \$1000/g, which would add only ~9 mill/kWh to the cost of electricity.

A communication from D. Meade (Princeton Plasma Physics Laboratory) was presented by G. Emmert (University of Wisconsin) because, at the last moment, Meade was unable to attend. Meade's basic point was that the physics issues for D- ^3He fusion in tokamaks are extensions of those for D-T fusion. These issues are increased confinement and beta, improved current-drive efficiency, and improved plasma heating. Second-stability operation may improve the performance for D- ^3He fusion by allowing higher beta and improved energy confinement. Several tokamaks [Princeton Beta Experiment (PBX-M), Versator, Doublet-IIID (DIII-D), and Tokamak Fusion Test Reactor (TFTR)] have approached the second-stability regime. Novel current-drive schemes, such as helicity injection or a large bootstrap current, may make operation with large plasma currents energetically feasible. Present D- ^3He heating experiments [minority heating in the Joint European Torus (JET) and second-harmonic heating in TFTR] are yielding encouraging results and may lead to D- ^3He specific physics experiments utilizing the fast ions from the $^3\text{He}(d,p)^4\text{He}$ reaction in the next 1 to 3 yr.

R. R. Parker (Massachusetts Institute of Technology) presented calculations of the anticipated performance of the Compact Ignition Tokamak (CIT) and the International Thermonuclear Experimental Reactor (ITER) with D- ^3He fuel. In both CIT and ITER, the highest energy multiplication that can be achieved is less than one, even with an energy confinement time up to four times that given by the present L-mode scaling expressions. By raising the magnetic field at the plasma to 10 T and the plasma current to ~30 MA, ignition appears possible with only a modest improvement over present H-mode energy confinement scaling.

G. A. Emmert presented the basic features of D- ^3He tokamak power reactors drawn primarily from the Apollo study. Apollo is a first-stability tokamak with a high magnetic field; the low neutron production in Apollo results in a permanent first wall, class A waste disposal rating, and an inherently safe reactor. Critical physics issues for a first-stability D- ^3He tokamak include the high plasma current because of the potential for structural damage in a plasma disruption, driving the plasma current without needing large amounts of auxiliary power, and the possible need for active techniques to keep the steady-state ash concentration at a reasonable level. For a second-stability reactor, the plasma current and magnetic field are much lower, and the reactor operating point is much less sensitive to ash accumulation. Bootstrap current overdrive and its compensation are critical issues for a second-stability D- ^3He tokamak reactor.

A. Hoffman (Spectra Technology) discussed transport scaling and stability considerations for field-reversed configuration (FRC) D- ^3He reactors. Experimentally, the stability appears better than calculated. A combination of energetic fusion products and energetic injected ions could provide stability for reactor-scale FRCs. The FRCs may be an ideal configuration for D- ^3He fuel because of the high beta, natural divertor, and the kinetic nature of stability.

G. Miley (University of Illinois) reviewed the SAFFIRE and RUBY FRC reactor studies. The SAFFIRE study utilizes a venetian-blind direct converter to convert the energy of the escaping plasma to electricity, pellet injection to sustain the Hill vortex density profile, and a cold plasma blanket to control the ash concentration and shield the plasma from neu-

tral particle in-flow. The RUBY reactor study, from the U.S.-Japan workshop series, utilizes neutral beam injection to generate an Ohkawa current to sustain a steady state and direct energy conversion of the 14.7-MeV protons by radio-frequency traveling waves.

N. Krall (Krall Associates) discussed the Polywell, a spherically convergent ion focus (SCIF) concept. The SCIF utilizes a magnetic cusp field to confine a low-density plasma containing a small excess of high-energy electrons. The resulting electrostatic potential causes ions to oscillate through the center with a large radially directed velocity, producing a dense plasma at the center, and results in fusion in the central core region. Initial estimates indicate that a favorable power balance for a D- ^3He reactor can be achieved with this concept. An experimental program is under way at Directed Technologies.

N. Rostoker (University of California-Irvine) discussed large ion orbit magnetic confinement for D- ^3He fusion applications. In this approach, self-consistent rigid-rotor equilibria with energetic ions eliminate the effects of ion-ion collisions. Possible applications are to FRCs with large angular momentum and toroidal configurations with no toroidal magnetic field.

J. Dawson (University of California-Los Angeles) proposed some alternate applications for the unique products of D- ^3He fusion. The 14.7-MeV protons from the $^3\text{He}(d,p)^4\text{He}$ reaction are useful for producing proton-rich isotopes and for converting the radioactive waste from fission reactors into nonradioactive waste. Proton-rich isotopes are useful as positron emitters for applications in positron emission tomography, to make a positron microscope, and as unique gamma emitters.

J. Santarius (University of Wisconsin) discussed applications of magnetic fusion energy to space development. The $^3\text{He}(d,p)^4\text{He}$ reaction produces only charged particles, which can lead to direct conversion of fusion energy to either thrust or electricity. In addition, it has the highest fuel energy density of any net energy producing fuel, and there are no radioactive materials at launch. Deuterium- ^3He fusion allows a variety of propulsion modes with widely ranging specific impulse. With pure plasma exhaust, a very high specific impulse can be obtained. By injecting mass into the exhaust stream, lower specific impulse with higher thrust can be achieved. This flexibility can be used to reduce the trip times or enhance the payload fraction significantly for interplanetary missions.

S. Dean (Fusion Power Associates) discussed D- ^3He fusion from an industrial perspective. He saw three approaches to D- ^3He fusion. The first maintains D-T as the main approach and carries D- ^3He fusion as a "second-generation" fuel. The second approach optimizes the fusion development path with D- ^3He as the first-generation fuel. The third approach maintains the near-term momentum of the present D-T program concerning physics issues but goes slowly on long-range D-T technology experiments and initiates an intense program on physics approaches to an optimum D- ^3He system. One would then set up a decision point (in the near future) on whether to continue with D-T as the first-generation fuel or switch to D- ^3He . Dean also noted that industry, which has been largely neglected in the fusion program, should be involved in the front-end of the search for a D- ^3He development path.

No conclusions were officially adopted at the symposium, but one could not avoid the general impression that there exist a number of exciting possibilities for achieving the promise

of D-³He fusion. Achieving a credible D-³He reactor using "standard" first-stability tokamak physics cannot be disregarded and offers the advantage of utilizing the extensive data base already developed. The technology advantages of D-³He systems, compared with D-T systems, are substantial, even for first-stability tokamak power reactors. Other magnetic configurations, such as FRCs, offer potential advantages through their higher beta but have a less developed data base at present. Furthermore, there exist more speculative concepts, such as counterstreaming beams, large orbit confinement, and SCIF, that offer even greater potential advantages but await proof-of-principle experiments. Finally, the technical and economic feasibility of lunar ³He mining appears to be at least as promising as the physics of D-³He fusion at the present stage of development. The procurement of ³He fuel appears to be feasible in the early 21st century, which is consistent with the timetable for the development of

fusion, and also opens up new possibilities for the exploration of our solar system.

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