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Session R8M3 - Mini-Conference: Advanced Fuels for Fusion.
MIXED session, Thursday afternoon, November 19
Tulane, Radisson

[R8M3.01] New Horizons for Fusion-Advanced Fuels for the 21st Century

Gerald Kulcinski, John Santarius (University of Wisconsin-Madison)

The advantages and disadvantages of the second generation advanced fusion fuel cycles (D^3He, p^11B, ^3He^3He, etc.) are contrasted to the first generation fuel (DT). Among the advantages, the reduction or elimination of neutrons has the biggest influence on such features as radiation degradation of the first walls, reduction of the amount and level of long lived radioactive waste, and proliferation resistance. Other advantages include direct conversion of ion energy and lack of tritium breeding blankets. Disadvantages include more difficult plasma physics required for ignition and, for the ^3He cycle, acquiring a large source of fuel. Confinement concepts that have high beta characteristics such as FRC’s, spheromaks, ST’s or RFP’s appear to be good candidates for burning the second generation fuels. Inertial electrostatic confinement concepts also are attractive. Tokamaks, stellarators, and inertial fusion devices relying on lasers or ion beams appear to be less amenable to this generation of fuels. It is possible that early second generation fueled devices can make a positive contribution to commercial markets even at Q << 1.

[R8M3.02] Engineering Considerations for Advanced Fuel Operation in Dipole Reactors

L. Bromberg, M. Berte, E. Chaniotakis, J. Kesner (MIT PSFC), D. Garnier, M. Mauel (Columbia University)

Some of the physics and engineering issues of dipole based fusion reactor concepts will be addressed. Fuel options will be discussed, with emphasis on D-^3He. A major advantages of dipole reactors is that it is possible to have low ratios of particle to energy confinement times, minimizing the ash accumulation that severely impacts other fusion concepts using advanced fuels. This is a consequence of the presence of convection cells in multipole configurations. Fuel polarization may be utilized not for neutron suppression, but for directing the 14 MeV neutrons (from parasitic DT reactions) away from the coil and therefore minimizing the shielding and cooling requirements of the coil.

Dipole fusion reactors have coils that are not accessible. Steady state reactors require on-board power generation and refrigeration. Generation and refrigeration option will be reviewed. A novel internal refrigeration design(Ballinger, Bromberg, Chaniotakis, Kesner, Alvey, Berte, Boswell, Bruno, Chung, Miller, Tutt, Yuh, MIT NE Dept course EP22.63 (1998).) will be presented which utilizes components that are presently available.

[R8M3.03] D-^3He Fusion Burn experiments with present day

technologies^1

B. Coppi, L. E. Sugiyama (MIT)

Toroidal experiments featuring high peak plasma densities(n_0 \approx 1--2 \times 10^21m^-3), capable of reaching high peak temperatures (T_0\approx 65keV) where D--^3He plasmas can ignite or approach ignition conditions have been proposed and analyzed [1]--[2]. This kind of experiments have been called ``Candor'' and a typical set of parameters is B_T \approx 13T, R_0 \approx 25m, a\times b \approx 0.92 \times1.7 m^2, I_p\approx 20MA if a safety factor q_* \approx 4 is adopted. We note that the needed high temperatures can be reached by tritium boosting as ICRH heating is applied. The regimes in which reconnecting modes may develop are collisionless and therefore can be expected to be benign. The major forms of energy loss are bremsstrahlung emission and thermal energy transport due to collective modes followed by cyclotron emission. The initial evolution of the plasma current of the discharge plays an important role in the heating to burning regimes and the control of the plasma stability. The more appropriate conditions are those of reversed or nearly-reversed shear. [1] B. Coppi and L. Sugiyama, MIT R. L. E. Report PTP-88/6 (1988) [2] L. E. Sugiyama and B. Coppi, Bull. Am. Phys. Soc. \textbf36, 2671 (1991); \emphibid \textbf37, 1398 (1992); D. Hijirida, B. Coppi, et al., Bull. Am. Phys. Soc. \textbf38, 2052 (1993). ^1Sponsored in part by the USDOE.

[R8M3.04] Colliding Beam Fusion Reactor

Norman Rostoker, Michl Binderbauer (University of California at Irvine), Hendrik Monkhorst (University of Florida, Gainesville)

Conceptual reactor designs are investigated that are based on the Field Reversed Configuration for D-He^3 and p-B^11 reactions. The majority of fuel ions have a sufficiently large orbit size in the FRC so that classical transport(M. W. Binderbauer and N. Rostoker, J. Plasma Phys. \textbf56), 451 (1996). should prevail in the absence of long wavelength instabilities. We consider a first mode of operation wherein the mean azimuthal velocities and temperatures of the two ion species are the same and the azimuthal velocity of the electrons is very small. The distribution functions are thermal in a moving frame of reference. In this mode the energy invested in the ion beams increases the circulating power. The return on this investment is current drive and and avoidance of anomalous transport. In the second mode(N. Rostoker, M. W. Binderbauer and H. J. Monkhorst, Science \textbf278), 1419 (1997). of operation the two ion species have different azimuthal velocities selected to take advantage of the resonance in the fusion cross section. This leads to a larger reactivity and a further increase in circulating power with a net gain in power for sale. Power flow calculations will be presented based on anticipated conversion efficiencies for charged particles and radiation.

[R8M3.05] Effects of Collisional Dissipation on the "Colliding Beam Fusion Reactor "

Martin Lampe, Wallace M. Manheimer (Naval Research Laboratory, Washington, DC 20375-5346)

Rostoker, Binderbauer and Monkhorst have recently proposed a "colliding beam fusion reactor" (CBFR) for use with the p-B11 reaction. We have examined the various dissipative processes resulting from Coulomb collisions, and have concluded that the CBFR equilibrium cannot be sustained for long enough to permit net fusion gain. There are many collisional processes which occur considerably faster than fusion, and result in particle loss, energy loss, or detuning of the resonant energy for the p-B reaction. Pitch-angle scattering of protons off the boron beam, which occurs 100 times faster than fusion, isotropizes the proton beam and results in proton loss. Energy exchange between protons and boron, which is 20 times faster than fusion, detunes the resonance. Proton-proton scattering, which is faster than fusion for all CBFR scenarios, Maxwellianizes the protons and thus detunes the resonance. Ion-electron collisions lead indirectly to a friction between the two ion beams, which is typically fast compared to the fusion process. Results of Fokker-Planck analyses of each process will be shown.

[R8M3.06] Spherically-Convergent, Advanced-Fuel Systems

D. C. Barnes, R. A. Nebel, M. M. Schauer, K. R. Umstadter (Los Alamos National Laboratory)

Combining nonneutral electron confinement with spherical ion convergence

leads to a cm sized reactor volume with high power density.(R. A.

Nebel and D. C. Barnes, Fusion Technol.), to appear (1998);

D. C. Barnes and R. A. Nebel, Phys. of Plasmas 5, 2498 (1998).

This concept is being investigated experimentally,(D. C. Barnes,

T. B. Mitchell, and M. M. Schauer, Phys. Plasmas) 4, 1745 (1997).

and results will be reported. We argue that

D-D operation of such a system offers all the advantages of aneutronic fusion

cycles. In particular, no breeding or large tritium inventory is required, and

material problems seem tractable based on previous LWR experience. In addition

the extremely small unit size leads to a massively modular system which is

easily maintained and repaired, suggesting a very high availability. It may

also be possible to operate such a system with low or aneutronic fuels.

Preliminary work in this direction will be presented.

[R8M3.07] Fundamental Limitations on Advanced-Fuel Fusion

Todd H. Rider (MIT Lincoln Laboratory)

Several fundamental physical limitations which apply to a very broad range of advanced-fuel fusion approaches will be considered. [1,2] Effects to be discussed include bremsstrahlung radiation and particle scattering due to ion-ion, ion-electron, and electron-electron collisions. A variety of advanced fuels will be considered, including D-3He, 3He-3He, p-11B, and p-6Li. Results will be given for fusion plasmas which are substantially out of thermodynamic equilibrium, as well as for plasmas which are close to equilibrium.

[1] T.H. Rider, Ph.D. thesis, MIT (1995). [2] T.H. Rider, Phys. Plasmas 4, 1039 (1997).

[R8M3.08] Aspects of Stability Related to the Colliding Beam Fusion = Reactor

Michl Binderbauer, Norman Rostoker (University of California at Irvine), Hendrik Monkhorst (University of Florida, Gainesville)

Recent experiments with TFTR, D-III-D and JET involving the injection and trapping of low density beams of high energy large orbit ions indicate that large orbit non-adiabatic ions slow down and diffuse classically in the presence of anomalous fluctuations and transport of adiabatic majority particles. Accordingly, we consider conceptual fusion reactors(N.\ Rostoker, M.W.\ Binderbauer and H.J.\ Monkhorst, Science) \textbf278, 1419 (1997). based on classical confinement of fuel ions and fusion products(M.W.\ Binderbauer and N.\ Rostoker, J.\ Plasma Phys.) \textbf56, 451 (1996).. The magnetic confinement geometry of the proposed designs is a Field Reversed Configuration.

A survey of experimental results on instabilities and their characteristics as related to these reactor concepts is presented. Particular focus will be given to long wavelength (as compared to gyro-radius) and low frequency (ømega\ll c/r_o, r_o=3D major radius of annular current ring) instabilities as they are most harmful to such systems. Results of recent analytic calculations regarding the response of these systems to low frequency flute perturbations(M.W.\ Binderbauer, Ph.D.\ thesis, University of California at Irvine, 1996.) of the form \sim e^il\theta-iømega t will be discussed.

[R8M3.09] Spin Polarization of proton and B^11 Beams for the Colliding Beam Fusion Reactor

Hendrik J. Monkhorst (University of Florida, Gainesville), Norman Rostoker, Michl Binderbauer (University of California, Irvine)

The kinematics of the p+B^11 resonant fusion reaction, including angular momentum conservation, shows that it is possible to enhance its cross section by polarizing the spins of p and B^11 (N. Rostoker, M. Binderbauer and H.J.Monkhorst, Science \textbf278), 1419(1997).. The maximum spin enhancement is 60 percents, to be compared with enhancements of 50 percents for d-t and d-He^3 fusion. There may be an additional enhancement for p-B^11 due to the prolate, nonspherical shape of the B^11 nucleus. However, this effect would be probably small. Schemes for nuclear polarization will be explained. These methods will use optical pumping, Stern-Gerlach and/or rf techniques. Results of some polarization kinetics will be reported. The FRC plasma at the heart of the Colliding Beam Fusion Reactor is ideally suited for the use of polarized fuel. It will be shown that depolarization rates are negligible on fusion and diffusion time scales (H. J. Monkhorst, M. W. Binderbauer and N. Rostoker, Conference Proceedings, in the press). This situation is unlike that for tokamaks, for which these rates are unacceptably large (B. Coppi \textitet al),Phys. Fluids, \textbf29, 4060 (1986)..

[R8M3.10] D--^3He burning during minority heating in Ignitor

S. Migliuolo, B. Coppi (Massachusetts Institute of Technology)

We present a scenario [1] in which ion cyclotron resonance heating of a minority concentration of ^3He in a Deuterium plasmas in Ignitor can produce a significant level of (up to 1 MW) power of nearly neutronless D--^3He fusion. The optimal parameters involve relatively low densities, compared to standard D--T ignition cases, n \sim 2--3 10^20 m^-3, somewhat higher central temperatures (T_i(0) \approx 15 keV, T_e(0) \approx 20 keV) and Helium concentrations of 6-8%. In this regime, a substantial tail of energetic Helium ions (with average energy reaching 1 MeV) is produced with an input ICRH power of 18 MW at f = 132 MHz. [1] B. Coppi \emphet al., Fusion Technol. \textbf25, 353 (1994).

[R8M3.11] A Review of Confinement Requirements for Advanced Fuels

William M. Nevins (Lawrence Livermore National Laboratory)

The energy confinement requirements for burning D-3He, D-D, or p-11B are reviewed, with particular attention to the effects of helium ash accumulation. It is concluded that the D-T cycle will lead to the more compact and economic fusion power reactor. The substantially less demanding requirements for ignition in DT will allow ignition or significant fusion gain in a smaller device; while the higher fusion power density allows for a more compact and economic device at fixed fusion power.

[R8M3.12] Nuclear Fusion by Colliding Crystalline Beams of Ions of Boron and Hydrogen

A G Ruggiero (Brookhaven National Laboratory, Upton, New York 11973), J S Machuzak (MIT Plasma Science and Fusion Center, Cambridge, MA 02139)

It has been proposed to produce nuclear fusion power by having two beams of boron and hydrogen ions colliding either in separate or common storage rings at the energy of 675 keV in the center of mass. The storage ring is made of a novel concept, that is the Circular Radio Frequency Quadrupole, which is a regular RFQ completely bent on itself, otherwise similar to a large size electrostatic ion trap. This device provides strong focusing with short focusing periods to enhance the beam particle density, and to raise the space charge limit to beyond what is currently available with conventional storage rings. Eventually, laser cooling is applied to both ion beams to further exceed the space charge limit of the storage device and to freeze each beam in a crystalline configuration, namely a "string", where particles follow each other, equally spaced by about 20 A^o performing only smaller amplitude oscillations. We describe a system capable to produce a useful fusion power of 10 kW with two intersecting storage rings of 2.5 m circumference. With laser cooling this requires storage of 10^9 to 10^10 ions per beam and a transverse cross section of 10 A^o, compatible with the noise level of the laser. The issue of colliding crystalline beams is also being addressed.

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