Description

The dipole magnetic field is the magnetic field far from a single, circular current loop. The use of a dipole magnetic field to confine a hot plasma for fusion power generation was first considered by Hasegawa [*Comm. Plasma Physics*, 1987]. In this configuration, a relatively small superconducting ring floats within a large vacuum chamber. The dipole confinement concept is based on the idea of generating pressure profiles having gentle gradients and being stable to all low-frequency magnetic and electrostatic fluctuations. From ideal MHD, marginal stability results when the pressure profile satisfies the adiabaticity condition, $\delta(pV^\gamma) \geq 0$, where V is the flux tube volume and $\gamma = 5/3$. For usual magnetic confinement devices, this constraint can not be satisfied, and MHD stability must be provided by field-line averaging and magnetic shear. In contrast, because of the large dimensions of the dipole plasma on the outer radius of the levitated coil, the pressure profile can scale with radius as rapidly as $R^{-20/3}$ and still remain absolutely MHD stable to beta of order 100%. Because the coil set for a possible dipole fusion power source is very low weight and axisymmetric, operation is inherently steady state, easy to maintain, and potentially of low unit cost. Because the dipole concept permits high beta without magnetic shear, the concept may be appropriate to advanced fusion fuels, such as D-^{3}He. Conceptual reactor studies have supported the possibility of an attractive fusion power source using a levitated dipole.

Status

- The scientific literature for dipole confinement includes space-based observations and theory, laboratory experiments, and fusion theory. This understanding establishes a bridge from the high-beta confinement observed in planetary magnetospheres to the confinement expected in levitated dipoles—where hot plasma will be confined for many collision times. The understanding gained from decades of space plasma research supports the levitated dipoles as a fusion confinement device. Approximately a dozen studies have been published specifically addressing the use of dipole-confined plasmas for energy production or space propulsion. Finally the CTX device at Columbia University has illustrated the stability properties of collisionless energetic electrons confined by a dipole magnetic field.
- The first experiment to investigate the levitated dipole concept is presently under construction at MIT as a joint project between Columbia University and MIT. First plasma is expected in the year 2000.

Current Research and Development

R & D Goals and Challenges

- An essential first step for the understanding of the scientific feasibility of a levitated dipole is a laboratory test of confinement properties of such a device. The Levitated Dipole Experiment (or LDX) has been designed to test the scientific feasibility of levitated dipole confinement at high beta. Construction of the experiment began in July, 1998. A major technical challenge has been met through the collaboration between superconducting magnet technology experts and innovative experiment design: a large current (1.3 MA) must be sustained in a ring having low mass. Another challenge is to complete more detailed modeling of dipole power sources. Limited reactor engineering studies are now underway.

Related Research Activities

The conceptual development of the dipole fusion concept has been inspired by space plasma studies and planetary exploration. Continued exploration of magnetospheric plasmas (for example, the exploration of the Io plasma torus that surrounds Jupiter and the development of physics-based models of space weather) will add to the cross-fertilization of this area of plasma science. Although the dipole plasma confinement concept is a radical departure from the better known toroidal-based magnetic confinement concepts, a scientific investigation of magnetized plasma confinement with high compressibility will add insight to these other more traditional confinement concepts. In the technology area, the development of advanced and high temperature superconductors will aid significantly in the reactor conceptualization of a dipole power source. Experiments to investigate low-density, non-neutral plasma confinement with a levitated dipole device are planned for the University of Tokyo.

Recent Successes

The engineering design of the LDX facility is almost complete. The major fabrication items, including the vacuum chamber and the floating coil are either under construction or awaiting final selection of vendor. Theoretical research supporting the possibility of classical confinement in a dipole confined plasma was recently published.

Budget

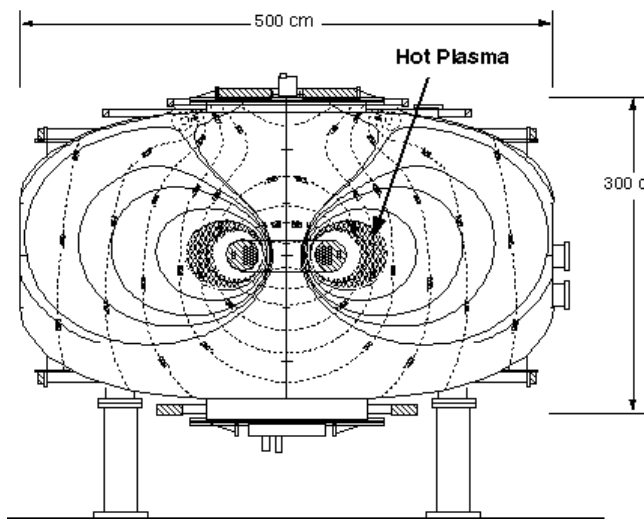
The LDX project budget in FY99 is $1.2M which is divided between Columbia University and MIT.

Anticipated Contributions Relative to Metrics

The levitated dipole confinement concept has the potential to be an attractive fusion power source while at the same time contributing to the understanding of magnetospheric physics. The relative simplicity of the magnetic field structure and the good understanding of plasma confined in planetary magnetospheres indicate that plasmas confined by levitated dipole magnets will have (1) high peak beta (≥ 50%) and volume-averaged engineering beta (≥ 10%), (2) excellent field utilization (≥ 90%), and (3) sufficient confinement to ignite D-^{3}He fuel. Because the plasma equilibrium and magnetic geometry is essentially determined by sustainable current in superconducting magnets, the dipole fusion concept is disruption free and promises to be highly reliable. Since (1) the particle flux to the floating ring is 100% re-cycled, (2) the shear-free magnetic field allows convection of fusion ash without energy confinement degradation, and (3) the outer plasma surface is open, accessible, and naturally-diverted, power and particle handling should be superior to other magnetic confinement concepts. The dipole is best suited for D-^{3}He fusion fuel, and this may lead to a reduction in fusion's adverse impact on the environment.

Near-Term ≤ 5 years

Investigate, for the first time in the laboratory, high-beta plasma having near classical energy confinement scaling for time-scales long compared with particle and energy confinement times. Compare experimental observations with theory. For this purpose, the LDX experiment has been conceived and designed as the lowest cost approach for investigating the key physics issues while simultaneously maintaining high confidence of its technical success. The experimental approach takes two stages. First, multiple frequency ECRH (with frequencies between 6 and 28 GHz) will be used to produce a population of energetic electrons at high $\beta \sim 1$. This technique has been proven effective in magnetic mirror experiments (*e.g.* Constance and Tara). Based on experience generating hot electrons within mirrors and within CTX, the creation and maintenance of high beta plasmas using a few 10's of kW of ECRH power is expected. Secondly, after formation of the high β hot electron plasma, fast deuterium gas puff techniques or the injection of lithium pellets will be used to thermalize the energy stored in the hot electrons and to raise the plasma density. The resulting thermal plasma will provide a test of the MHD limits and of the confinement of a thermal plasma in a levitated dipole.



Mid-Term ~ 20 years

Design and construction of proof-of-principle dipole confinement experiments which operate with plasma parameters resembling those which might be found in fusion power sources. Better understanding of the possibility of practical sources of ^{3}He fuel.

Long-Term > 20 years

Successful operation of a fusion power source and an assessment of the applicability of D-^{3}He dipole fusion for commercial energy and for space-craft power and propulsion.

Proponents and Critics Claims

A dipole power source has the possibility of being steady state with classical confinement and high β. Compared with a tokamak it would not requiring current drive; it is disruption free; and it has a natural divertor. The dipole has a relatively simple magnetic configuration which does not have interlocking coils. On the critical side, the internal floating ring provides a technical challenge. In a reactor embodiment, the large diameter of the outer wall may result in an undesirable small power flux (although a number of design options could ameliorate this problem.) Convective cells could lead to enhanced transport; however, at marginal profiles they may provide a means to fuel and to remove ash. The dipole concept is most compatible with the burning of advanced fuels, such as D-^{3}He.