Science & Technology

MIT's Alcator C reaches breakeven confinement

by Charles B. Stevens

One of the main goals of the effort to harness the virtually unlimited energy potentials of nuclear fusion was reached this month. On Nov. 7, at the Los Angeles American Physical Society's Plasma Physics Division meeting, Dr. Ronald Parker of the MIT Fusion Center announced that the Alcator C tokamak had approached the confinement parameters needed for energy breakeven in electric power reactors based on magnetic fusion energy. The confinement parameter achieved on Alcator C approached a value of 100 trillion seconds-nuclei per cubic centimeter.

The other major element needed to demonstrate the scientific feasibility of magnetic fusion energy production was attained on the Princeton PLT tokamak in 1978, when it was shown that a stably confined magnetic plasma could be heated to more than 80 million degrees Celius—the temperature needed to ignite nuclear fusion in power reactors. At the same time, MIT was given the go-ahead to build a follow-up to Alcator A with a design which would leapfrog ahead toward demonstrating the full Lawson confinement parameters, the Alcator C. And now Alcator C has achieved the predicted result.

While the Alcator C only reached a temperature of 16 to 17 million degrees, its achievement of the confinement parameter leaves little doubt that the Princeton Tokamak Fusion Test Reactor (TFTR) and the Joint European Tokamak (JET), both of which became operational during the last year, will achieve both the temperature and confinement parameters needed for operation of tokamak magnetic fusion reactors.

How magnetic fusion works

The demonstration of energy breakeven has been the major aim of the effort to harness magnetic fusion for over three decades. In magnetic fusion, hydrogen gas is heated to high temperatures at which it becomes ionized—electrons become separated from the individual hydrogen atoms. This ionized state of matter is called plasma; in the plasma state, matter is quite responsive to electromagnetic forces. To ignite fusion, the heavy isotopes of hydrogen—deuterium and tritium—must be heated to more than 44 million degrees. To efficiently heat and maintain the hydrogen at these temperatures, the hydrogen plasma must be confined in some manner.

Magnetic fields generated by passing electrical currents through metal coils provides one way of confining hot plasma. The tokamak, a doughnut-shaped magnetic bottle, was invented by Andrei Sakharov in the Soviet Union in the early 1950s. It combines the magnetic fields generated by metal coils surrounding the doughnut-shaped plasma column with the field produced by an electrical current flowing through the plasma itself. The combined magnetic field constitutes a magnetic bottle which stably traps the hot plasma. The tokamak plasma current also provides the means to heat the plasma to 10 to 20 million degrees; to reach temperatures needed for operational reactors—about 100 million degrees—means heat sources in addition to current heating must be utilized, such as microwaves and neutral beam heaters.

To attain fusion conditions, energy must be put into the confined plasma. Once the fusion ignition temperature is reached, the rate at which fusion energy is generated is determined by the plasma density, given in terms of fuel ions (nuclei) per cubic centimeters. The condition for net energy generation can therefore be defined in terms of the product of the plasma density and the time during which the "temperature" of the plasma is confined (called the Lawson product, after the English scientist who first stated this condition).

For simple breakeven—the condition in which the energy generator is producing as much energy as that which is necessary to run the generator—a Lawson product of 30 trillion seconds-nuclei per cubic centimeter is needed. But since most fusion reactors are supposed to involve a thermal cycle in which the fusion heat energy is converted to electricity at a 30 percent efficiency—the rate in existing types of electric power plants—the Lawson product needed for "electric" breakeven—three times "simple" breakeven—was projected at 100 trillion seconds-nuclei per cubic centimeter.

Historical background

In the 1950s, theoretical calculations indicated that energy confinement time would increase with increasing plasma temperature. It would also increase with the size of the magnetic bottle—the square of the plasma column's radius. But the original magnetic fusion experiments indicated that the plasma appeared to be quite unstable, and plasma energy confinement times rapidly decreased with increasing temperature. This behavior was termed Bohm diffusion after the American scientist who had sarcastically predicted this result.

In 1965, Soviet scientists reported that their tokamak system was able to beat the Bohm limit by factors of 10.

British scientists made measurements on the Russian experiments and showed that their Soviet colleagues were too conservative and the tokamak was beating Bohm diffusion by factors of 100.

This rapidly led to the adoption of tokamaks in U.S. and other magnetic fusion experiments around the world. Ironically, Soviet scientists continued to explore U.S.-type systems such as the stelarator and demonstrated in the mid-1970s that such systems were as effective as the tokamak in terms of confinement parameters.

The real reason for the poor performance of the original experiments had little to do with actual plasma dynamics. It turns out that non-hydrogen impurities entering the plasma from the vacuum chamber wall were dominating the energy flows. This fact was first demonstrated when the Alcator A in 1975 achieved extremely clean plasmas and showed that the previously projected density limits for tokamaks were pessismistic by more than a factor of 10. In 1975, the MIT Alcator A reached the confinement parameters needed for simple breakeven while attaining record-breaking densities.

This unexpected development led to an entirely new approach to tokamak magnetic fusion. High magnetic fields were utilized to attain high plasma densities. This opened up the prospect of cheap, compact tokamak fusion reactors. A private company called Inesco is in the process of developing prototype fusion power generating systems based on the Alcator approach.

At the Los Angeles meeting, Bruno Coppi, D. Bruce Montgomery, Ronald R. Parker, Leonardo Pieroni, and Robert J. Taylor were given the Excellence in Plasma Physics Award for their original work on the Alcator A.

Alcator C's results

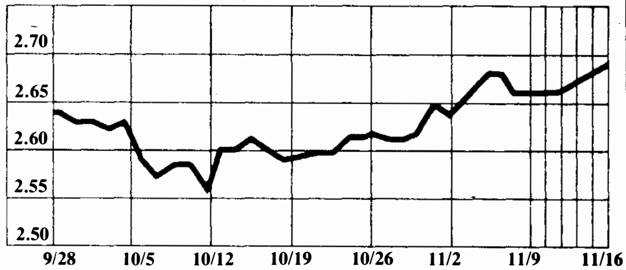
By utilizing pellet injection of hydrogen fuel into the Alcator, higher-density operation was attained. The Alcator C achieved fuel ion densities of 2,000 trillion nuclei per cubic centimeter. With a peak energy confinement time approaching 50 milliseconds (.05 seconds), the Alcator C had essentially reached the goal of the Lawson product for simple breakeven.

Moreover, the recent experiments on the Alcator C and the TFTR indicate that confinement time is a function of the product of the plasma density and the cube of the plasma column radius. This is far better than the most optimistic theoretical projections of the 1950s. Furthermore, experiments on the PLT, the PDX, and the German ASDEX tokamaks indicate that confinement can indeed improve with increasing temperature.

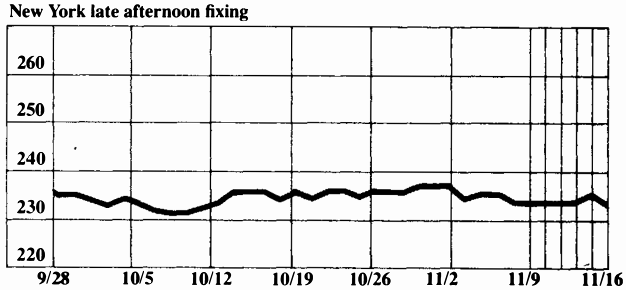
Contrary to earlier expectations, experiments on the Alcator C and PLT show that tokamaks could be made into steady-state devices, despite operating in a pulsed manner. Using microwaves, tokamaks can be kept running for up to a day at a time. It was previously feared that pulsed operation inherent in the tokamak would incur serious economic and engineering drawbacks in power plant design.

Currency Rates

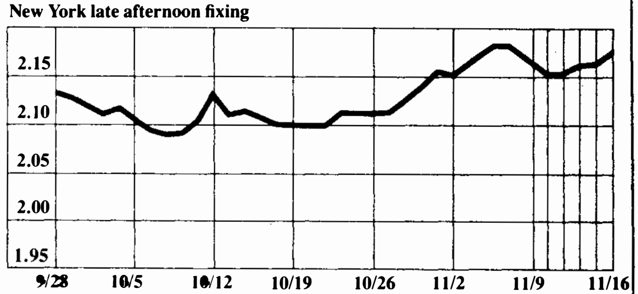
The dollar in deutschemarks
New York late afternoon fixing



The dollar in yen
New York late afternoon fixing



The dollar in Swiss francs
New York late afternoon fixing



The British pound in dollars
New York late afternoon fixing