the tube. Electrochemical oxidation at the fuel electrode converts them to carbon dioxide and water vapor, thereby releasing a flow of electrons to an external circuit. Air is forced past the outside of the tube to provide oxygen and to remove excess heat (which can, in principle, be used to maintain the operating temperature in a coal gasifier). A 120-centimeter tube of this design, containing about 120 cells, would generate more than 80 watts, but the best that Isenberg has obtained so far is a 15-cell unit that generates 8 watts.

The foremost difficulty in constructing such assemblies is applying the components in a thin film that is pinhole and crack free; if fuel leaks through the cell assembly, it will burn in air and destroy the electrodes. The chromium oxide interconnections have also not worked well yet, and may be replaced with other metal oxides.

A commercial fuel cell of this design is obviously some distance in the future, but a Westinghouse contract with the Department of the Interior's Office of Coal Research calls for delivery of two 100-watt units within 2 years to show progress in process and materials development. A 1-kw fuel cell could be produced within 4 years, Isenberg suggests, and a 100-kw prototype power plant within 10 years. Full-scale commercialization of high temperature fuel cells, however, seems certain to be many years beyond introduction of the Pratt & Whitney units.

—THOMAS H. MAUGH II

Fusion: Princeton Tokamak Proves a Principle

One of the smallest machines represents a big advance in the quest for controlled fusion. In order to achieve fusion with a tokamak, which is only one of the many designs being proposed for a "magnetic bottle" to control fusion, it will be necessary to reach higher temperatures and contain the fuel for longer times than ever before. Recent experiments at Princeton University (*1*), with a device called the Adiabatic Toroidal Compressor (ATC) tokamak, were not designed to beat the record for confinement times; hence a major question about the viability of fusion remains unanswered. But the experiments have quite successfully proved the viability of one method of heating the fuel in a tokamak.

With the ATC tokamak the fuel plasma was compressed after it had been made as hot as possible by normal techniques. First a doughnut-shaped plasma with a large radius was heated with the current induced by an external magnet; then the plasma was squeezed to a smaller radius with other magnets (Fig. 1). Compression tripled the temperatures of both deuterium ions and electrons in the plasma. The maximum ion temperature achieved in this way was 6×10^6 °C and the maximum electron temperature was 25×10^6 °C. (For fusion to become a practical source of energy for a power plant, the ion temperature must reach 100×10^6 °C.)

New methods for heating the plasma in a tokamak were necessary because the method by which the plasma discharge is started—ohmic heating—becomes progressively less efficient as the plasma temperature gets higher. The reason is that the effective resistance of the plasma decreases. Compression is not the only new method for heating that is being considered. Proposals to heat the plasma by exciting turbulence (Texas Turbulent Tokamak) and by injecting neutral beams of hydrogen at high velocities (Oak Ridge Tokamak) will be tested soon.

At the same time as the Princeton experiments proved a new method to beat the heating problem, they also debunked a widely believed rule for designing tokamaks. Previous machines had always had a copper shell enclosing the plasma. Many designers were concerned that without such a conductive shell the plasma would not know what shape to assume, but the plasma in the ATC was adequately controlled without any such shell.

The significance of the ATC experiments is that a plasma heated and compressed the same way in a larger device could reach the ignition of fusion. To extract power from a fusion reaction not only must the ion temperature exceed 100×10^6 °C, but also the particle density and the confinement time of the plasma must be large. Specifically, the product of the two must exceed 10^{14} sec/cm^3 (called the Lawson criterion). The ATC experiments did not come as close to meeting the Lawson criterion as other tokamak experiments. Although the electron density (which reached 10^{14} particles per cubic centimeter) slightly exceeded previous records, the confinement time (about 2 msec) was considerably less than that in the larger tokamaks. But confinement time increases rapidly with the size of the machine. According to Harold Furth, of the Plasma Physics Laboratory, Princeton, New Jersey, with a machine five to ten times the linear size of the ATC, operating at somewhat higher magnetic fields, the ion temperature should be high enough for ignition and the confinement time should be long enough to meet the Lawson criterion.

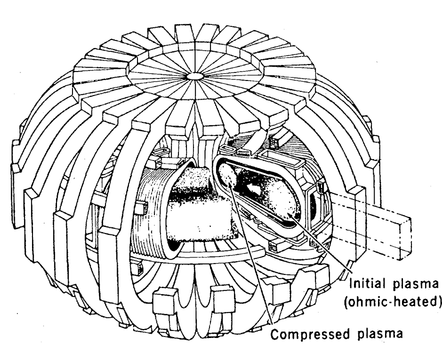

Fig. 1. Compression of a plasma in the ATC tokamak has proved a viable method of heating fusion fuel.

While the results from Princeton indicate that at least one solution is in hand for the problem of heating a tokamak, no one can yet be sure that machines bigger than the tokamaks available today would actually achieve fusion. Instabilities of the plasmas have been the bane of fusion research ever since it began, and theoretical calculations indicate that a new instability—called a trapped particle instability—may appear when scientists explore for the first time the behavior of plasmas under conditions still closer to the Lawson criterion. Results from the ATC don't tip the balance toward optimism for the eventual success of fusion, but they prove that in at least one important way mother nature could have been mischievous, she wasn't.

—WILLIAM D. METZ

References

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