ic variable that alters the concentration range over which the two networks can exist together.

For this interpretation to be correct, it is necessary to show that gold actually is associated with the phase transformation. If the gold is present in higher concentrations at the grain boundaries than in the crystalline regions and if the concentration in the <100> network were higher than that in the <110> network, that would suggest gold is at least related to the transition. The Cornell researchers verified that this was indeed the case by means of two techniques. Rutherford back scattering, which is an ion scattering technique that yields the concentration of gold with depth, showed that the gold was concentrated in the vicinity of the plane of the grain boundary. And energy-dispersive x-ray spectrometry in a high-resolution electron microscope demonstrated that the gold concentration was several times higher in the regions of the grain boundary described by the <100> network. ■

ARTHUR L. ROBINSON

ADDITIONAL READING

K. E. Sickafus and S. L. Sass, "Grain boundary structural transformations induced by solute segregation," *Acta Metall.*, in press.

Tokamak Sets Records In Temperature and Confinement

In an uncommonly successful series of experiments this year, researchers at the Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor (TFTR) have set two new records for a magnetically confined plasma: a temperature of 200×10^6 K, and a confinement parameter of 1.5×10^{14} seconds per cubic centimeter. These milestones in turn put the TFTR scientists within striking distance of energy breakeven, in which the plasma produces as much fusion energy as is required to heat it up.

"What these experiments show is that physics is not the restriction," says Dale M. Meade, head of the laboratory's experimental division.

The breakeven experiments themselves, which were originally scheduled for this year and which will require the installation of special remote-handling equipment to deal with radioactive tritium fuel, have been delayed until late 1989 by funding constraints in the Department of Energy. In the meantime, as Meade suggests, the TFTR scientists have been exploring the basic plasma physics questions using nonradioactive deuterium.

In April, for example, the researchers achieved their record confinement parameter by first establishing a relatively low-density plasma in the tokamak, and then injecting high-velocity pellets of frozen deuterium using an injector developed at the Oak Ridge National Laboratory. As the pellets evaporated they deposited a high density of deuterium ions in the center of the plasma. Measurements of the resulting Lawson parameter—defined as the product of the particle density times the confinement time of the plasma—showed 1.5×10^{14} seconds per cubic centimeter, or nearly twice that of the previous record achieved by the Alcator C tokamak at the Massachusetts Institute of Technology in 1983. This value of the Lawson parameter is only about a factor of two below that needed for energy breakeven.

The Lawson number is a measure of the efficiency of plasma confinement, and is one of the two key parameters that determine whether or not a fusion reaction will produce net positive energy. The other is plasma temperature. This June, in another series of experiments, the TFTR scientists pushed toward their record temperature using a combination of powerful auxiliary heating and enhanced energy confinement.

The heating was accomplished by the well-established technique of neutral beam injection, in which the plasma is bombarded with intense beams of electrically neutral deuterium atoms. The TFTR has four such injectors, developed by the Lawrence Berkeley and Lawrence Livermore National Laboratories. Together they have a full-power rating of 27 megawatts, although for these experiments they were only used at half power.

The confinement scheme grew out of a recognition in the early 1980's that high-powered plasma heating can actually cause a deterioration in confinement. It turns out that good confinement at high temperatures requires a density profile that is sharply peaked in the center. However, when the plasma is heated to very high temperatures, ions tend to diffuse outward from the center and build up near the chamber walls, thus creating a relatively flat density distribution. The trick is to get rid of those ions.

In many fusion reactors, including all those being designed for the future, this is easy enough: magnetic "divertors" strip the ions away from the walls harmlessly. But TFTR was designed before the phenomenon was fully understood, and it has no divertors. Thus, the TFTR researchers have had to rely on ingenuity. It happens that the walls of the chamber are lined with graphite tiles. The researchers thus spent several weeks conditioning the graphite, hitting it with plasma pulse after plasma pulse so as to drive out all the absorbed gasses; their idea was that clean graphite would absorb the errant deuterium ions rather than letting them build up. And that is exactly what happened: in a series of test runs beginning 12 June, the scientists were able to reach temperatures of 200×10^6 K at a Lawson parameter of 10^{13}. This is well in excess of the minimum temperature needed for breakeven, although the Lawson parameter in this case is about a factor of 20 too low. The previous record of 80×10^6 K was set in 1980 at the Princeton Large Torus.

These same experiments also showed some preliminary evidence for the so-called bootstrap current. First predicted theoretically in 1971, this current is supposed to arise spontaneously in hot, high-density tokamak plasmas, and to flow in such a way as to sustain the confining magnetic field with a minimum of input from external transformers. If real, it will be a key to making fusion reactors that can produce a steady level of power instead of pulsing on and off as present-day tokamaks do.

Meanwhile, the obvious next step for the TFTR team is to combine pellet injection with high-intensity heating techniques so as to advance the Lawson parameter and the temperature simultaneously. In addition to heating the plasma by neutral beam injection, the researchers also plan to use a technique known as radio-frequency heating. In any case, by next year the current schedule calls for the demonstration of conditions in the deuterium plasma equivalent to breakeven in a tritium plasma. ■

M. MITCHELL WALDROP